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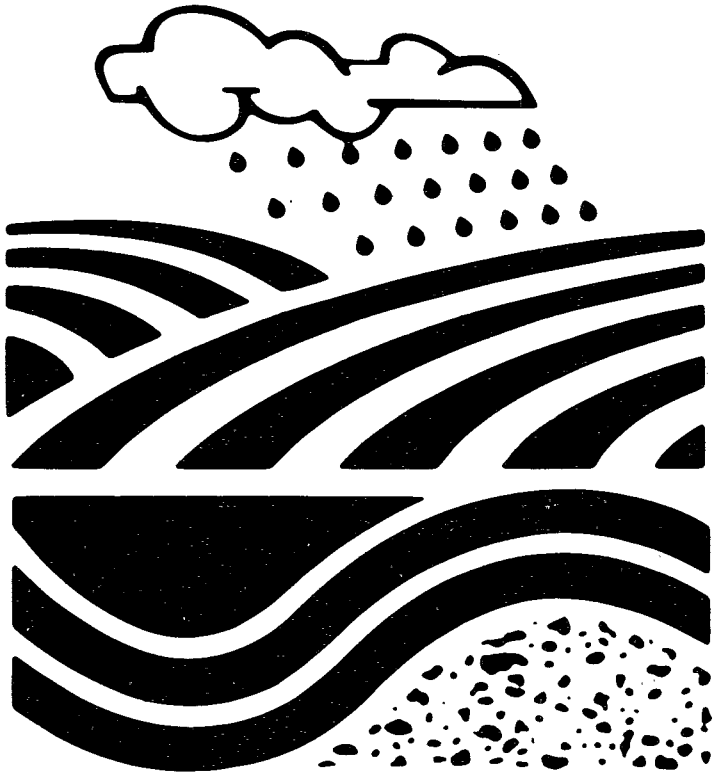
The National Rural Clean Water Program Symposium

10 Years of Controlling Agricultural Nonpoint Source Pollution: The RCWP Experience



EPA/625/R-92/006
August 1992

PROCEEDINGS

The National RCWP Symposium

10 Years of Controlling Agricultural Nonpoint Source Pollution: The RCWP Experience

September 13 – 17, 1992 • Orlando, Florida

Hosted by the

The South Florida Water Management District

in cooperation with

U.S. Environmental Protection Agency

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Foreword

The lessons learned from a 10-year experiment in controlling nonpoint source pollution are recorded in this proceedings of the 1992 National Rural Clean Water Program (RCWP) Symposium.

The symposium itself was designed to present the results of the RCWP experience to Federal, State, and local project managers, landowners, and others interested in solutions to nonpoint source pollution.

In the interest of providing guidance for State nonpoint source programs and local watershed projects, the symposium addressed both successes and obstacles experienced by the RCWP. The results presented in this proceedings have been peer reviewed.

Symposium organizers recognize the enormous contribution of the reviewers of these papers, among them scientists from the U.S. Environmental Protection Agency's Office of Research and Development. Their expertise, and the time they gave to this project, assured the technical quality of the papers presented at the symposium and published in this volume.

Others also deserve our gratitude:

- The National Steering Committee, for its vision and guidance of this program to accurately present the RCWP experience, and
- The Florida Symposium Planning Committee, for translating the vision into reality and the RCWP experience into a training ground for the rest of the country.

That, of course, is the mission of the symposium and this proceedings — to build on the foundation of the Rural Clean Water Program a blueprint for controlling agricultural nonpoint source pollution in this Nation.

The symposium sponsors salute those who worked with the 21 project sites over the past decade and join with them in presenting the fruits of the Rural Clean Water Program as lessons to be used by all who strive to meet the challenge of controlling nonpoint source pollution.

The Rural Clean Water Program

- **Lake Tholocco, Alabama** — *Coffee and Dale Counties*
- **Appoquinimink River, Delaware** — *New Castle County*
- **Taylor Creek-Nubbin Slough Basin and Kissimmee River, Florida** —*Glades, Highlands, Martin, Okeechobee, Counties*
- **Rock Creek, Idaho** — *Twin Falls County*
- **Highland Silver Lake, Illinois** — *Madison County*
- **Prairie Rose Lake, Iowa** — *Shelby County*
- **Upper Wakarusa River, Kansas** — *Osage, Shawnee, Wabaunsee Counties*
- **Bayou Bonne Idee, Louisiana** — *Morehouse Parish*
- **Double Pipe Creek, Maryland** — *Carroll County*
- **Westport River Watershed, Massachusetts** — *Bristol County*
- **Saline Valley, Michigan** — *Washtenaw County*
- **Garvin Brook, Minnesota** — *Winona County*
- **Long Pine Creek, Nebraska** — *Brown, Rock Counties*
- **Tillamook Bay, Oregon** — *Tillamook County*
- **Conestoga Headwaters, Pennsylvania** — *Lancaster County*
- **Oakwood Lakes-Poinsett, South Dakota** — *Brookings, Hamlin, Kingsbury, Counties*
- **Reelfoot Lake, Tennessee/Kentucky** — *Lake, Fulton, Obion Counties*
- **Snake Creek Project, Utah** — *Wasatch County*
- **St. Albans Bay, Vermont** — *Franklin County*
- **Nansemond-Chuckatuck, Virginia** — *City of Suffolk and Isle of Wright County*
- **Lower Manitowoc River Watershed, Wisconsin** — *Brown, Calumet, Manitowoc, Counties*

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The Evolution of the RCWP Water Quality Monitoring Networks in the Taylor Creek/Nubbin Slough and Lower Kissimmee River Basins

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ABSTRACT

The South Florida Water Management District has supported two Rural Clean Water Program water quality monitoring projects located in watersheds north of Lake Okeechobee. This region is primarily agricultural with dairy and beef operations. In 1978, a monitoring network was designed to evaluate water quality in the headwaters of Taylor Creek. At the inception of the Rural Clean Water Program in 1980, the monitoring network incorporated the entire Taylor Creek/Nubbin Slough drainage basin. In 1987, the Lower Kissimmee River basin monitoring network was included in the program; data collection in this basin has been ongoing since 1986. The major objectives have been to evaluate the effectiveness of best management practices in reducing nonpoint source nutrient inputs to Lake Okeechobee and monitor water quality as these changes occur in land use. Throughout the Rural Clean Water Program, network design has changed for sample frequency, collection for analysis of chemical parameters, and intensity of monitoring on individual farms.

All water in southern Florida flows through an intricate network of hydrologically and ecologically connected marshlands, constructed canals. streams, sloughs, rivers, and lakes. The heart of this ecosystem is Lake Okeechobee, the wellspring of water from the Kissimmee River and other northern tributaries to the environmentally unique Florida Everglades.

Lake Okeechobee is a vast body of water covering an area of approximately 1,890 square kilometers, making it the second largest freshwater lake within the contiguous United States. Located in south central Florida, the lake is a vital resource to all inhabitants of the region. For five surrounding cities, it is a potable water supply and for municipalities along Florida's southeast Atlantic coast, it is a source of aquifer recharge to abate salt water intrusion. In the agricultural area south of Lake Okeechobee, farmers use lake water to irrigate crops, such as sugar cane, rice, and winter vegetables. A highly productive biological ecosystem, Lake Okeechobee contains large populations of plants and animals and provides habitat to endangered species such as the Everglade, or snail, kite (S. Fla. Water Manage. Distr. 1989). The lake is also a sportsman's paradise for fishing and hunting, and it supports a lucrative commercial fishing industry.

Though the eutrophic state of Lake Okeechobee (Federico et al. 1981) has made it a flourishing,

productive resource, the lake is in danger of becoming hypereutrophic because of increased nutrient input, primarily phosphorus from agricultural activities in areas north of the lake (Flaig and Ritter, 1989). Two watersheds identified as making the most significant nutrient contributions to the lake are the Taylor Creek/Nubbin Slough and Lower Kissimmee River basins. The Taylor Creek/Nubbin Slough basin contributes 5 percent of the average annual flow to the lake and approximately 28 percent of the lake's average annual phosphorus load, while the Lower Kissimmee River contributes 31 percent of the average annual flow and approximately 20 percent of the average annual phosphorus load to the lake (Federico et al. 1981). Land uses in this region are primarily agricultural: beef and dairy operations with additional improved pastures; sod, vegetable, and citrus farms. Highly dense populations of animals present the major source of the phosphorus input problem.

Several programs aimed at reducing the elevated levels of phosphorus entering Lake Okeechobee have been instituted through the cumulative efforts of various local, State, and Federal agencies. The Rural Clean Water Program (RCWP) was developed in 1980 to assist landowners in the design, cost-share, and implementation of agricultural best management practices (BMPs) (Okeechobee RCWP Local Coor. Comm. 1981). Since the early 1970s, the South Florida Water Management District has been monitoring the quality of water in the Taylor Creek/Nubbin Slough and Lower Kissimmee River basins.

Network Beginnings—Early Investigations and Research (1955-78)

The Taylor Creek/Nubbin Slough basin first existed in nature as two distinct hydrologic areas. Taylor Creek originally included a basin of 36,248 hectares and flowed through the city of Okeechobee into Lake Okeechobee. Major tributaries discharging into Taylor Creek include Otter Creek, Northwest Taylor Creek, Little Bimini, Williamson Ditch, and Wolf Creek as shown in Figure 1. From 1962 through 1968, improved channels, spillways, and

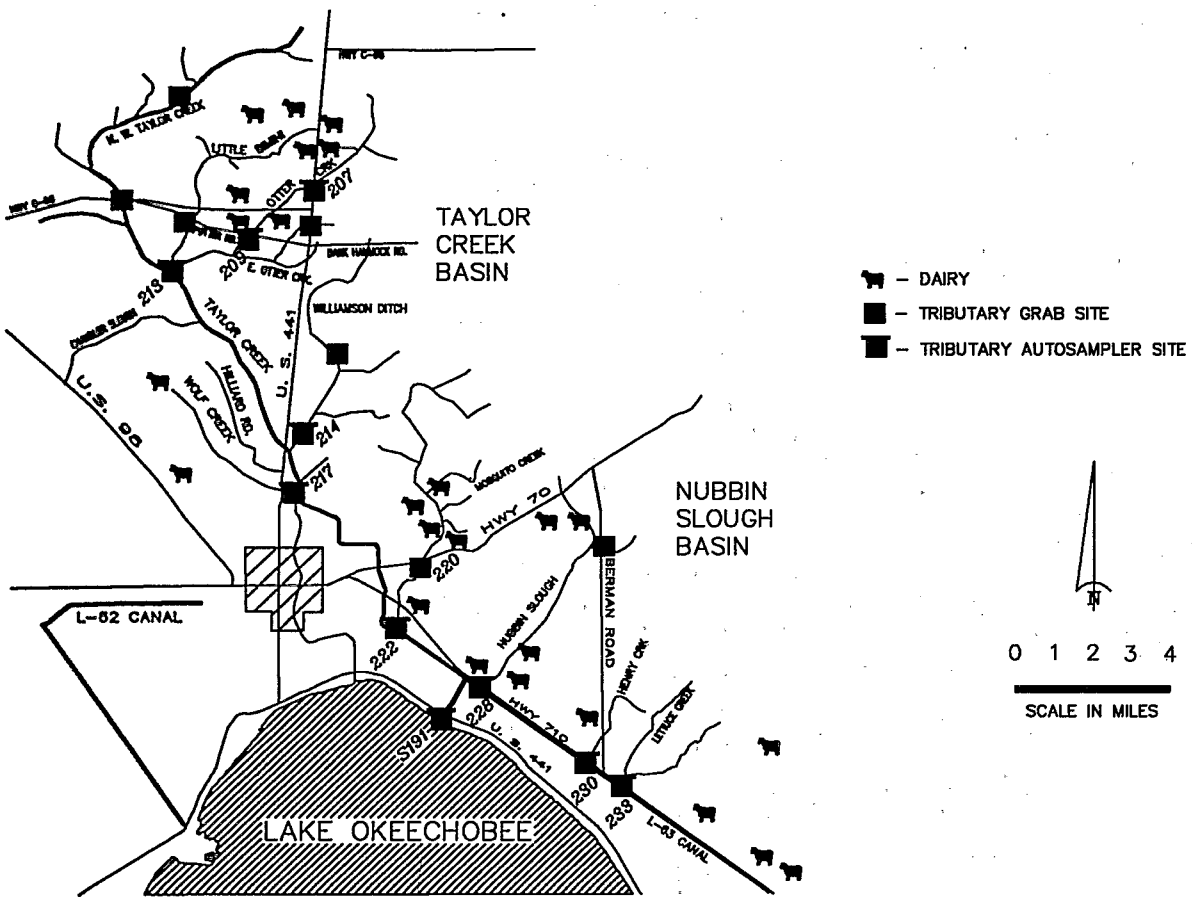

Figure 1.—Taylor Creek/Nubbin Slough basin near Lake Okeechobee, Florida.

water control structures were constructed in the upper Taylor Creek watershed to alleviate flooding (Knisel et al. 1985). Discharge from the watershed was diverted in 1973 into the L-63 interceptor canal, which also collects discharge from Mosquito Creek, Nubbin Slough, Henry Creek, and Lettuce Creek. These improvements increased the drainage area to 48,800 hectares. The entire combined hydrologic watershed, called the Taylor Creek/Nubbin Slough basin, drains into the north end of Lake Okeechobee through control structure S191 (Fig. 1).

A long-term hydrologic study extending from 1955 to 1975 was initiated in the upper Taylor Creek basin through the cooperative efforts of various Federal and State agencies (Yates et al. 1982). The objective of this research effort was to monitor the hydrologic behavior of the watershed before, during, and after channelization and other flood control improvements in the 1960s and observe resulting effects upon groundwater elevations, streamflow duration, water yield, and storm runoff.

The U.S. Department of Agriculture Agricultural Research Service (ARS) installed seven weight-recording rainfall gages to measure daily rainfall (Table 1 lists the sites). In 1959, groundwater wells were installed at each rain station and equipped with analog stage recorders.

As environmental concerns for Lake Okeechobee increased in the early 1970s, ARS expanded the study with a water quality survey to identify sources of nutrient pollution to the upper Taylor Creek watershed. The objectives of the survey were to assess the water quality of phreatic and open channel flows in tributaries of the watershed, estimate nutrient loads, and determine relationships of water quality and nutrient loads to watershed hydrology and land use practices—which were primarily dairy, beef, and citrus operations (Allen et al. 1976). The survey consisted of 15 sampling locations of which 12 were collected from open channels in the Taylor Creek watershed and 3 from groundwater wells. During part of the 1972 wet season (April through July), samples were collected biweekly (Knisel et al. 1985). Dry season sampling occurred monthly until January 1973, when the survey was temporarily discontinued. In March 1974, the ARS reinstated an abbreviated version (which extended through 1975) of the original open channel streamflow water quality survey in the Taylor Creek watershed (Stewart et al. 1978).

The research found that channel improvements and water level control structures promoted more rapid recession of stormwater discharges, but had only negligible effects on groundwater recharge and drainage (Yates et al. 1982). Data obtained from both water quality surveys indicated that overland transport of nutrients had occurred as nitrate-nitrogen and orthophosphorus concentrations were lower in groundwater wells than in open channels. The most substantial concentrations of orthophosphorus (up to 3.26 mg/L) originated in the Otter Creek watershed, where intensive dairy operations drained into the tributary.

Taylor Creek and the upper portion of the S191 basin, Mosquito Creek, became the focus of study in 1975 when the South Florida Water Management District initiated a research project to investigate relationships between water quality and land use (Federico, 1977). The study's goals were to document water quality in four subbasins of the Taylor Creek/Nubbin Slough basin and determine the temporal variation and land use effects on water quality.

The following four subbasins were selected for the study based on the diversity of land use practices: Mosquito Creek, Williamson East Lateral, Otter Creek, and Northwest Taylor Creek. Water quality monitoring stations were located at each outflow of the four subbasins. The regime consisted of four sample-collection runs during part of the 1975 wet season (July through September). For each run, an ISCO automatic sampler collected surface water samples every three hours for three days.

Otter Creek and Mosquito Creek showed elevated concentrations of total nitrogen (up to 6.97 mg/L) and total phosphorus (up to 2.97 mg/L) as a result of runoff from major dairy operations existing in the two watersheds. Samples from the Williamson

Table 1.—Agricultural Research Service rainfall and groundwater stations in the Upper Taylor Creek Basin.

STATION NAME	RAIN STATION NUMBER	GROUNDWATER STATION NUMBER	LOCATION
Well Line B	8500	8510	Taylor Creek at R Bar Ranch
Bassett	8502	8512	Bassett Ranch off Hwy. 68
Judson	8504	8514	Wilson Rucks Dairy off Hwy. 441 N
Opal	8507	8517	Williamson Cattle Company
Williams	8501		McArthur Dairy calf barn
Raulerson	8503		Raulerson house on Potter Rd.
Mobley	8506		Lawrence Road off Hwy. 441 N

East Lateral Ditch exhibited extremely high chloride and sodium concentrations resulting from a citrus operation that was irrigating with water from an artesian well. The results indicated that land use was a significant influence on water quality. In particular, dairy operations appeared to be significant sources of nitrogen and phosphorus (Federico, 1977).

Taylor Creek Headwaters Project (1978-81)

Results of early investigations prompted the 1976 Florida Legislature to create the Coordinating Council on the Restoration of the Kissimmee River Valley and Taylor Creek/Nubbin Slough Basin. Representatives of various State and Federal agencies were selected by the coordinating council to make up a technical advisory committee. Recognizing that agricultural operations should use management practices to reduce nutrient runoff, the technical advisory committee established the Taylor Creek Headwaters Project in 1978 (Allen et al. 1982). The project prioritized the Otter Creek subwatershed and allocated approximately $300,000 to provide landowners 100 percent funding to implement BMPs, which included

- fencing cows out of streambeds,
- constructing supplemental watering facilities, shade structures, and cattle crossings over waterways, and
- establishing vegetative filter strips for nutrient uptake and detention areas to hold storm runoff.

The Taylor Creek Headwaters Project established a water quality monitoring network designed to evaluate the effectiveness of BMPs at reducing nutrient runoff in the basin. The primary objective of the network was to determine baseline water quality and nutrient loads in the area. A comprehensive database was established to provide pre-BMP construction concentration data.

The initial monitoring was conducted by Agricultural Research Service in November 1977 with 16 sampling locations that had been monitored since 1972 as part of the original open channel streamflow water quality survey (Allen et al. 1976). ARS collected hydrologic data and biweekly water quality samples, and analyses for chemical and physical parameters were performed by the South Florida Water Management District's branch laboratory in Okeechobee. The technical advisory committee conducted an investigative grab sampling tour on June 7, 1979, at 59 locations in the project area to pinpoint the most significant contributors of nutrient inputs and provide justification for the design of a long-term water quality monitoring program. As a result, new sites were added to the network, increasing the number of biweekly sampling sites to 28. Two additional sites were included in 1980. Two automatic samplers collected samples daily at upstream and downstream locations on Otter Creek (Sites 207 and 209, respectively, of Fig. 1).

In January 1981, the South Florida Water Management District accepted responsibility for all Taylor Creek Headwaters project management (Ritter and Allen, 1982) and relieved ARS of all water quality and hydrologic data collection in October 1981. Table 2 provides a comprehensive list of all sample stations monitored throughout the Taylor Creek/Nubbin Slough basin. Sample sites designated with the Taylor Creek Headwaters station code (TCHW) were monitored under the project, and monitoring continued at the ARS stations located in the lower Taylor Creek/Nubbin Slough basin. These sites represented water quality resulting from various land uses, including runoff from dairy operations, beef cattle pastures, and hayfields.

Samples were collected biweekly at each station and analyzed within one week. Samples were filtered through a fiberglass prefilter and a polycarbonate membrane and analyzed for nitrate, nitrite, ammonia, and orthophosphorus. Unfiltered samples were analyzed for total Kjeldahl nitrogen, total phosphorus, pH, specific conductivity, turbidity, and color. Samples of lagoon water were also analyzed for calcium, manganese, sodium, and potassium.

The period of the Taylor Creek Headwaters Project (1978 through 1981) represented the pre-BMP implementation phase. BMP effectiveness is documented in detail by Gunsalus, Flaig, and Ritter (1992). Generally, throughout the project, nitrogen and phosphorus concentrations decreased as a result of a decrease in annual rainfall in the area, which helped deplete groundwater levels and dry out many beef and dairy operations' drainage systems. The closing of one dairy operation in the Otter Creek subwatershed resulted in a decrease in total phosphorus concentration at the downstream discharge station (Ritter and Allen, 1982).

RCWP Inception (1981)

In July 1981, the entire Taylor Creek/Nubbin Slough basin (48,800 hectares) (Fig. 1) was selected to participate in the RCWP as one of 21 federally funded programs designed to reduce nonpoint source water pollution problems in predominantly rural watersheds. Total funds ($1.3 millon) for the entire RCWP project were administered by the USDA's Agricul-

Table 2.—Period of record, station code, and location of sampling sites in the Taylor Creek/Nubbin Slough basin.

PERIOD OF RECORD	STATION	LOCATION
01/04/72 to Present	TCHW 01	N.W. Taylor Creek at Hwy. 68
03/19/74 to Present	TCHW 02	Little Bimini at Potter Rd.
01/04/72 to Present	TCHW 03	Otter Creek at S-13B
01/04/72 to 09/11/84	TCHW 04	Otter Creek at Hwy. 68
03/19/74 to 09/03/81	TCHW 05	Otter Creek at Otter Creek Rd.
03/19/74 to Present	TCHW 06	Otter Creek at Potter Rd.
01/04/72 to Present	ARS 07	Williamson Main Ditch
01/04/72 to Present	ARS 08	Williamson East Lateral
01/04/72 to Present	ARS 09	Williamson Ditch at S-7
01/04/72 to 09/03/81	ARS 10	Taylor Creek at Hwy. 441
03/19/74 to 10/01/91	ARS 11	Taylor Creek at Cemetary Rd.
01/04/72 to 09/10/84	ARS 12	Taylor Creek at Well Line B
03/19/74 to Present	ARS 13	Mosquito Creek # Hwy. 710
03/19/74 to Present	ARS 14	Nubbin Slough at Hwy. 710
03/19/74 to Present	ARS 15	Mosquito Creek at Hwy. 70
11/01/77 to 10/25/83	ARS 16	Nubbin Slough at Hwy. 70
11/01/77 to Present	ARS 17	Nubbin Slough at Berman Rd.
09/05/79 to Present	TCHW 18	Taylor Creek at S-2
09/05/79 to Present	TCHW 19	East Otter Creek at Potter Rd.
09/05/79 to Present	TCHW 20	East Otter Creek at Hwy. 441
09/05/79 to 09/03/81	TCHW 21	Little Bimini at Hwy. 68
09/05/79 to 09/24/80	TCHW 22	F & R Dairy Runoff
09/05/79 to 10/01/91	TCHW 23	Wilson Rucks Dairy Runoff
09/05/79 to 09/27/83	TCHW 24	Remsberg North Runoff
09/05/79 to 01/01/90	TCHW 25	McArthur #1 2nd Stage Lagoon
09/05/79 to 08/09/88	TCHW 26	Otter Creek at McArthur Farms
09/05/79 to 10/01/91	TCHW 27	McArthur Hayfield Runoff
09/05/79 to 09/03/81	TCHW 28	Otter Creek Upstream
11/19/80 to 10/25/83	TCHW 29	Gomez Creek at Hwy. 68 West
11/19/80 to 10/25/83	TCHW 30	Gomez Creek at Hwy. 68 East
10/01/81 to Present*	TCHW 31	McArthur Runoff at Otter Creek
10/28/81 to 03/05/86	TCHW 32	McArthur 2nd Stage Lagoon
10/28/81 to 11/29/83	TCHW 33	T. Rucks 2nd Stage Lagoon
10/28/81 to 02/04/87	TCHW 34	SEZ 2nd Stage Lagoon
06/11/81 to Present	ARS 39	Henry Creek at Hwy. 710
06/11/81 to Present	ARS 40	Lettuce Creek at Hwy. 710
03/01/76 to 09/31/81	TCHW 508	Otter Creek at Potter Rd.
03/01/76 to 09/31/81	TCHW 509	Otter Creek at Hwy. 441

*TCHW 31: No samples collected between 09/11/83 and 08/09/88

tural Stabilization and Conservation Service (Okeechobee RCWP Local Coor. Comm. 1981). The major goal of the Taylor Creek/Nubbin Slough RCWP project was to achieve a 50 percent reduction in phosphorus concentrations entering Lake Okeechobee from the Taylor Creek/Nubbin Slough basin by 1992 through implementation of agricultural BMPs (Okeechobee RCWP Local Coor. Comm. 1982). The RCWP provided participating landowners with 75 percent of the cost of BMP implementation, up to $50,000 maximum. Landowners in the Taylor Creek Headwaters Project area continued to receive 100 percent of the funding for best management practices implemented under that project in addition to the RCWP funds.

Each RCWP project had to establish a water quality monitoring and evaluation element to provide continuous feedback and documentation of water quality changes resulting from land treatment practices (Spooner et al. 1991). As the Taylor Creek/Nubbin Slough project was not slated for additional funding from the RCWP for water quality monitoring, the South Florida Water Management District stepped forward to provide a comprehensive monitoring and evaluation program. The South Florida Water Management District took responsibility for establishing and funding the program (as specified in the approved monitoring and evaluation plan) by enlarging the Taylor Creek Headwaters Project monitoring network (already in operation) to include the entire Taylor Creek/Nubbin Slough basin. A sound database was available to provide background information for the monitoring effort.

The objectives of the RCWP water quality monitoring project were to

- evaluate the effectiveness of agricultural BMPs for reducing phosphorus concentrations in tributaries, basin outlets, and ultimately, Lake Okeechobee,
- identify trends in nutrient concentrations that occurred as a result of land use changes or implementation of BMPs, and
- document the general water quality throughout the nine major tributaries to provide justification for the use of agricultural BMPs to control phosphorus runoff (Spooner et al 1991).

The sampling method and sample locations monitored for the Taylor Creek Headwaters Project continued to be used for the RCWP monitoring network (Okeechobee RCWP Local Coor. Comm. 1982).

The local coordinating committee deleted urban areas of the Taylor Creek/Nubbin Slough from the critical area covered by the Rural Clean Water Program in 1983 and redefined critical area to include all dairy farms, all extensively drained beef cattle farms, and all areas within 0.40 kilometers of streams, ditches, or channels that continually hold water (Okeechobee RCWP Local Coor. Comm. 1983).

In May 1983, seven analog stage recorders were installed to provide accurate calculation of nutrient loads at the outflows of the four major tributaries along the L-63 canal: Mosquito Creek (upstream and downstream), Nubbin Slough, Henry Creek, and Lettuce Creek (upstream and downstream). Water quality sampling continued biweekly through 1986. In summary, the data collected can be categorized into three groups:

- **1978–82:** Pre-BMP background
- **1983–87:** BMP implementation/transition
- **1986– :** Post-BMP Evaluation (completion dates may vary)

Focus on Lower Kissimmee River (1986)

Originally, the Kissimmee River meandered like a snake through a wide, shallow floodplain and naturally filtered its waters across vast marshlands. However, in 1971, the river was channelized to relieve flooding, which created a deep, narrow canal 90 kilometers long (Loftin et al. 1990). Located in western Okeechobee County and eastern Highlands and Glades counties, the Lower Kissimmee River basin covers an area of approximately 90,600 hectares. The basin drains into Lake Okeechobee through control structure S65E and collects discharge from tributaries including Fish Slough, Gore Slough, Ash Slough, Cypress Slough, Chandler Slough, Popash Slough, Yates Marsh, the L-62 canal, and Maple River, as shown in Figure 2. Land use in the basin consists of 91 percent beef cattle operations, 7 percent dairy operations, and 2 percent woodland or urban areas (Stanley and Gunsalus, 1991). The basin became an area of concern as a major contributor of phosphorus and nitrogen to Lake Okeechobee—second only to the Taylor Creek/Nubbin Slough basin (Federico et al. 1981).

In January 1986, the South Florida Water Management District began to monitor the water quality of selected tributaries throughout the Lower Kissimmee River basin under the Kissimmee River Eutrophication Abatement program in response to mandates issued by the Kissimmee River Resource

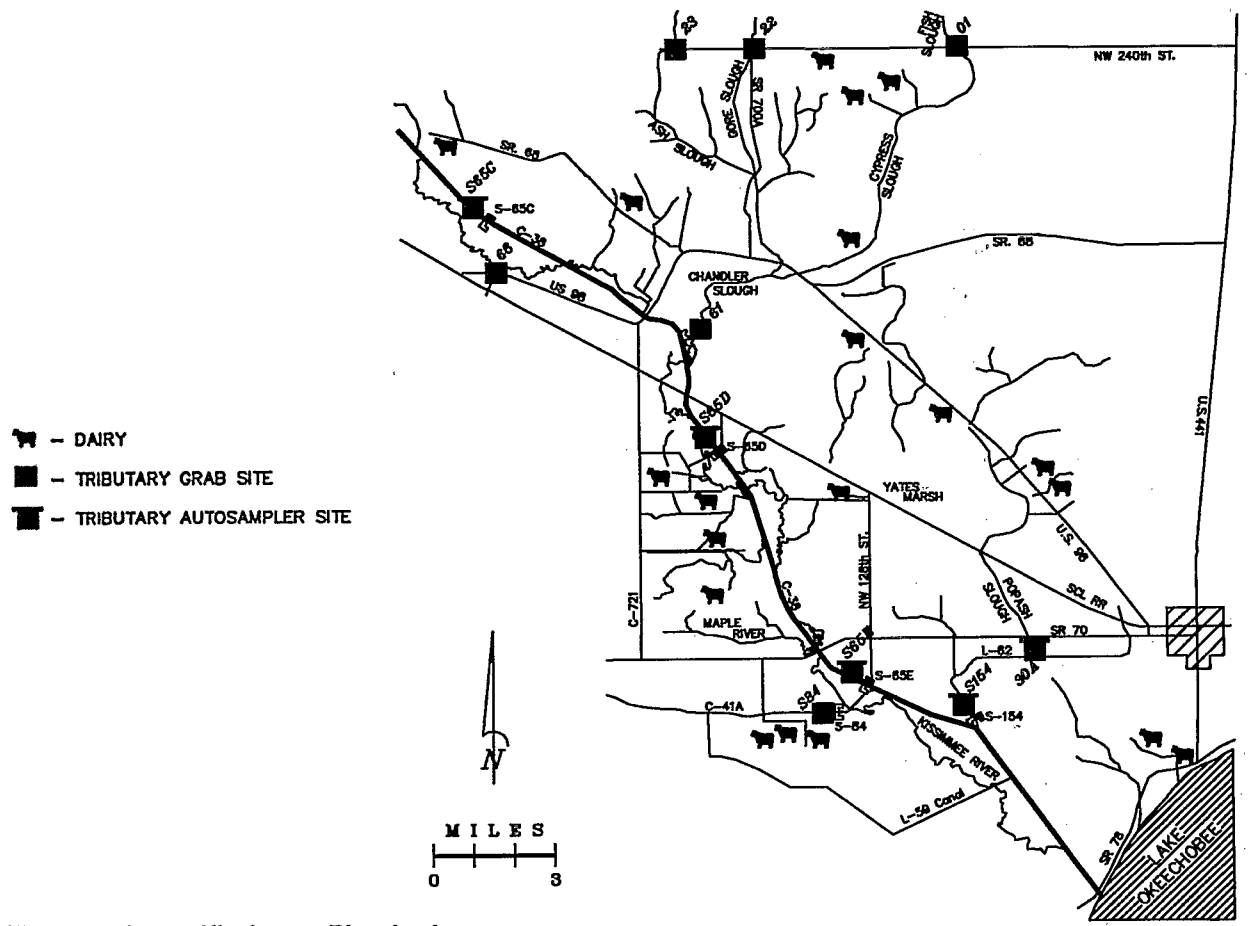

Figure 2.—Lower Kissimmee River basin.

Planning and Management Committee and the Lake Okeechobee Technical Advisory Committee (Germain and Shaw, 1988). The sample site locations are listed in Table 3. Sample frequency gradually increased from monthly sampling intervals to biweekly and then weekly intervals. The initial monitoring efforts in the Lower Kissimmee River basin provided the groundwork for a more intensive, comprehensive network for both the Lower Kissimmee River and Taylor Creek/Nubbin Slough basins.

Table 3.—Kissimmee River Eutrophication Abatement (KREA) Project water quality grab sample stations in the Lower Kissimmee River basin (sampling began 1986).

STATION CODE	LOCATION
KREA 01	Fish Slough at NW 240th Avenue
KREA 02	Chandler Slough at Chandler Road
KREA 03	Ash/Gore at C-700A bridge
KREA 04	Chandler Slough at N bridge on Hwy. 98
KREA 05	Chandler SLough at S bridge on Hwy. 98
KREA 06	Cypress Slough at Lamb Is. Rd. bridge
KREA 07	Larson #1 West on NW 160th Drive
KREA 08	Larson #1 East on NW 160th Drive
KREA 09	Upstream Larson #1 on Old Peavine Tr.
KREA 10	Butler Dairy #1 on Underhill Road
KREA 11	Butler #1 on Underhill House Road
KREA 12	Larson Dairy Road North side
KREA 13	Larson Dairy Road South side
KREA 14	Clemons Ranch pump off Larson Dairy Rd.
KREA 15	Yates Marsh off NW 128th Avenue
KREA 16	Brighton Dairy #1 on NW 56th Street
KREA 17	Yates Marsh at Platts Bluff RR bridge
KREA 18	Yates Marsh at Platts Bluff S RR
KREA 33	Dry Lake Dairy #2 outfall on Hwy. 98
KREA 34	Ferrell Dairy outfall on Hwy. 78
KREA 35	L-59 at C-38 Southwest side
KREA 48	Eagle Bay at Hwy. 78
KREA 50	Pool E Maple River Downstreams
KREA 51	Pool E Maple River Upstream
KREA 52	Pool E East of Maple River
KREA 53	Pool E Yates Marsh E. Brighton Dairy
KREA 54	Pool E Daugherty cutoff
KREA 55	Pool E Larson/Butler 2 runoff
KREA 56	Pool E Yates Marsh
KREA 57	Pool E Butler Dairy runoff
KREA 58	Pool D Butler Dairy runoff
KREA 59	Pool D Chandler Slough Downstream
KREA 60	Pool D Chandler Slough Midpool
KREA 61	Pool D Chandler Slough Upstream
KREA 62	Pool D Larson Dairy #1 runoff
KREA 63	Pool D Larson Dairy #1 East runoff
KREA 64	Pool D Larson Dairy #1 West runoff
KREA 65	Pool D EEEE Fish Camp Downstream
KREA 66	EEEE Fish Camp U.S. at Hwy. 98 N
KREA 67	Pool E Yates Marsh North

During the summer of 1986, a severe algal bloom covered over 120 square miles of Lake Okeechobee. Intense concern for the lake's future grew as highly concentrated nutrient runoff from agricultural operations (primarily dairies) north of the lake was charged with causing the algal bloom. The effectiveness of the Rural Clean Water Program was questioned as conservationists demanded immediate cleanup of the lake (Stanley et al. 1986).

In June 1987, the Florida Department of Environmental Regulation adopted the Dairy Rule requiring all dairies to obtain an operating permit and implement BMPs designed to recycle nutrients on the farm. Concurrent to institution of the Dairy Rule, the Florida legislature enacted the Surface Water Improvement and Management (SWIM) Act, which required the South Florida Water Management District to protect Lake Okeechobee's water quality and reduce its average annual phosphorus inflow load to 397 tons (Flaig and Ritter, 1989). The South Florida Water Management District's SWIM plan established total phosphorus concentration standards for direct inflows to the lake (0.18 mg/L) and for outflows from various land uses including dairies (1.2 mg/L) (S. Fla. Water Manage. Distr. 1989). Dairies, under the regulation of the Dairy Rule, were required to implement waste management systems to try to meet the targeted 1.2 mg/L total phosphorus concentration standard of the SWIM plan.

In 1987, the Lower Kissimmee River basin was included as an RCWP project aimed at reducing nutrient loads entering Lake Okeechobee from the basin (Stanley et al. 1988). The same criteria that had been used to determine the critical area of the Taylor Creek/Nubbin Slough RCWP project were employed for the Lower Kissimmee River project, which considered all dairy farms to be the most critical. At this time, the program objectives of the Taylor Creek/Nubbin Slough RCWP were paralleled to those of the Lower Kissimmee River RCWP to coordinate BMP implementation and water quality monitoring with established Dairy Rule and SWIM plan regulations (Spooner et al. 1991).

A target goal of a 43 percent reduction in phosphorus load to the lake was calculated for the Lower Kissimmee River Rural Clean Water Program based on the 0.18 mg/L inflow concentration standard set forth in the South Florida Water Management District's SWIM plan (Flaig and Ritter, 1989). BMPs implemented in the Lower Kissimmee River basin were similar to those of the Taylor Creek/Nubbin Slough project, with emphasis on intensive waste management systems designed to capture and recycle nutrients to achieve a nutrient mass balance for the farm.

Intensive Dairy Monitoring (1987-89)

From 1987 through 1989, the South Florida Water Management District's original water quality monitoring network in the Taylor Creek/Nubbin Slough and Lower Kissimmee River basins was revolutionized and expanded to provide more intensive on-farm, tributary, and basin monitoring to support the Rural Clean Water Program and respond to monitoring needs to support State regulation. The objectives of the monitoring program were as follows:

1. To provide a detailed assessment of water quality throughout the basins to determine the effectiveness of BMPs at reducing phosphorus concentrations,
2. To predict the movement of phosphorus throughout the basins, quantify, and estimate the effectiveness of BMPs at reducing phosphorus loads entering Lake Okeechobee, and
3. To evaluate the efficiency of specific BMPs.

To meet these objectives, a multifaceted data collection program was implemented to better quantify water quality changes that resulted from land use changes. Table 4 lists all water quality stations. Basin water quality assessment was accomplished with data obtained from weekly grab samples from dairy, beef, and tributary discharge points to provide adequate identification of recent episodic conditions and data for load calculations (Flaig and Ritter, 1988). Sample stations were located at points both upstream and downstream of dairy operations. However, not all discharge outlets could be monitored at some operations because of inaccessible or undefined discharge outlets. Monitoring of multiple discharge points is discussed in detail by Sawka, Ritter, Gunsalus, and Rompot (1992).

Surface water samples were collected by field technicians using established sampling protocol (South Fla. Water Manage. Distr. 1987). Unfiltered samples were analyzed for total phosphorus and total Kjeldahl nitrogen and filtered samples were analyzed for nitrate, nitrite, ammonia, orthophosphorus, chloride, and color. Physical parameters such as temperature, pH, dissolved oxygen, and conductivity were measured by technicians in the field using a Hydrolab multiparameter instrument. Flow conditions were determined by observing the movement of fluorescent dye injected in the stream. The technicians also recorded the extent of aquatic vegetation observed at the sample site.

To better quantify nutrient loads as set forth in the second monitoring objective, American Sigma automatic samplers were employed to collect real time continuous water quality samples at major tributaries, water control structures, and dairies within the basins. The automatic samplers pumped 21 bottles of sample per week, three bottles per day.

Autosamplers were serviced and samples collected weekly. A routine grab sample was also collected from each site at the time of servicing. Analysis of the continuous samples was limited to the number of samples the South Florida Water Management District laboratory could analyze per week (250 per project). To reduce the number of samples submitted to the laboratory, all samples collected by the automatic samplers were screened each week for soluble reactive phosphate at the Okeechobee field office using a Hach DR 2000 spectrophotometer. Seven samples were selected out of the total 21 to best represent the observed trend in soluble reactive phosphorus concentrations for the week. Unfiltered samples were analyzed for total nutrients and filtered samples for dissolved nutrients. The in-house soluble reactive phosphorus screening analysis also provided quick information for evaluating nonroutine grab samples (Sawka et al. 1992).

Several automatic sampler locations were also equipped with environmental monitoring equipment for recording stream stage (upstream and downstream of primary discharge points), velocity, rainfall, pH, conductivity, dissolved oxygen, and oxidation-reduction potential. Environmental data measurements were recorded every 15 minutes through an Easylogger onto a data storage pack, which was removed from the site monthly and transported to the South Florida Water Management District's Data Management Division to be downloaded to the mainframe computer database.

Specific BMPs—such as irrigated sprayfields, seepage areas, watering holes for cows, and fencing of waterways with filter strips—were monitored through weekly grab sampling and continuous automatic sampler collection, where possible, to better identify how they affected water quality.

Shallow groundwater monitoring wells (2 meters) were also installed at the majority of dairies in the Lower Kissimmee River basin to supplement data obtained from the original Agricultural Research Service rain and groundwater stations in the Taylor Creek/Nubbin Slough basin and better understand the rainfall, groundwater, and runoff relationships existing throughout the basins.

For a project of such magnitude, maintaining a high level of quality assurance and control was a key

Table 4.—Taylor Creek/Nubbin Slough and Lower Kissimmee River water quality monitoring station locations, 1988.

EASY LOG DATA CODE	AUTO SAMPLE CODE	GRAB SAMPLE STATION CODE	HISTORIC SAMPLE STATION CODE	LOCATION
TCN2+	TCN2	TCNS 201	TCHW 01	N.W. Taylor Creek at Hwy. 68 bridge
RUC2+	RUC2	TCNS 202	TCNS 202	H&T Rucks #1 at Little Bimini
MCA4+	MCA4	TCNS 203	TCNS 104	McArthur #4 & 5 at Little Bimini
TCLB+	TCLB	TCNS 204	TCHW 02	Little Bimini at Potter Road
MCA2+	MCA2	TCNS 205	TCHW 27	McArthur #1 & 2 hayfield runoff
MCA1+	MCA1	TCNS 206	TCNS 206	McArthur #1 & 2 runoff at Remilu
TCO1+	TCO1	TCNS 207	TCHW 03	Otter Creek at structure S-13b
TCWR+	TCWR	TCNS 208	TCHW 23	Wilson Rucks runoff at Otter Creek
TCO2+	TCO2	TCNS 209	TCHW 06	Otter Creek at S-13 and Potter Road
RUC3+	RUC3	TCNS 210	TCNS 111	H&T Rucks #3 runoff to West Otter Creek
RUC1+	RUC1	TCNS 211	TCHW 19	H&T Rucks #2 runoff, East Otter Creek
TCEO+	TCEO	TCNS 212	TCNS 212	East Otter Creek below Remilu Ranch
TCS2+	TCS2	TCNS 213	TCHW 18	Taylor Creek Headwaters at S-2
TCWD+	TCWD	TCNS 214	ARS 09	Williamson ditch below Boys School
ROFR+	ROFR	TCNS 215	TCNS 215	Rofra Dairy runoff at Dry Lake
SEZO+	SEZO	TCNS 216	OSEZ 01	Sloan Ray Dairy runoff at Wolff Creek
TCWC+	TCWC	TCNS 217	TCNS 217	Wolff Creek off Cemetary Road
LARB+	LARB	TCNS 219	TCNS 219	County ditch above Larson #8 at N.E. 80th
LARC+	LARC	TCNS 220	ARS 15	Mosquito Creek at Hwy. 70
MWHI+	MWHI	TCNS 221	TCNS 221	Murphy White Dairy off Hwy. 710
MOSQ+	MOSQ	TCNS 222	ARS 13	Mosquito Creek below Hwy. 710
DAV2+	DAV2	TCNS 223	TCNS 223	Davie Dairy #2 runoff on farm
NEWP+	NEWP	TCNS 225	TCNS 225	New Palm Dairy runoff
REDT+	REDT	TCNS 227	ARS 14B	Red Top Dairy runoff
NUBB+	NUBB	TCNS 228	ARS 14	Nubbin Slough below Hwy. 710
HENR+	HENR	TCNS 230	ARS 39	Henry Creek below Hwy. 710
UNDE+	UNDE	TCNS 231	TCNS 231	Underhill Dairy runoff
LETT+	LETT	TCNS 233	ARS 40	Lettuce Creek below Hwy. 710
MATT+	MATT	TCNS 235	TCNS 235	Mattson Dairy runoff off Hwy. 710
DAV3+	DAV3	TCNS 241	TCNS 241	Davie Dairy runoff below 1 & 2
		TCNS 242	TCHW 25	McArthur #1 runoff seepage field
		TCNS 243	TCNS 243	West Otter Creek upstream at Hwy. 68
		TCNS 245	ARS 07	Williamson Ditch on Williamson Cattle
		TCNS 246	ARS 08	Williamson East Latteral
		TCNS 248	ARS 11	Taylor Creek at Cemetary Road
		TCNS 249	ARS 17	Nubbin Slough at Berman Road
		TCNS 252	TCNS 252	Tributary runoff above New Palm Dairy
		TCNS 253	New Station	Runoff above Enrico Dairy at Berman Road
		TCNS 255	TCNS 255	Runoff Newcomer Dairy at Nubbin Slough
		TCNS 258	New Station	Enrico Dairy runoff to Henry Creek
		TCNS 259	New Station	Enrico hayfield runoff at Berman Rd.
		TCNS 260	New Station	H.T. Rucks #3 runoff at Potter Rd.
		TCNS 261	New Station	Rofra Dairy runoff
		TCNS 262	New Station	Larson Dairy #7 runoff
		TCNS 263	New Station	Larson Dairy #8 runoff
		TCNS 264	New Station	Murphy White Dairy runoff at Hwy. 710
		KREA 01	KREA 01	Fish Slough at N.W. 240th St.
CHAN+	LKR 04A	KREA 04A	KREA 04A	Chandler Slough at JC Bass East
	LKR 06A	KREA 06A	KREA 06A	Cypress Slough at Watford Ranch
		KREA 07	KREA 07	Larson #1 W on N.W. 160th Dr.
LARW+	LKR 08	KREA 08	KREA 08	Larson Dairy #1 Tributary E at N.W. 160th Dr.
		KREA 09	KREA 09	Larson #1 W UPS on N.W. 203rd Ave.
BUT1+	LKR 10	KREA 10	KREA 10	Butler Dairy #1 Outfall at Underhill Rd.
		KREA 10A	KREA 10A	Butler #1 runoff from east pastures
		KREA 10B	KREA 10B	Butler #1 retention pond
		KREA 16	KREA 16	Brighton #2 N.W. 156th St.
YATE+	LKR 17A	KREA 17A	KREA 17A	Yates Marsh Outfall at Children's Home
		KREA 19	KREA 19	Queen Bee Farms runoff to Maple River
		KREA 20	KREA 20	Sandfly Gully at Hwy. 98
RUCWF+	LKR 21	KREA 21	KREA 21	WF Rucks Dairy Outfall (flume)

Table 4.—Continued.

EASY LOG DATA CODE	AUTO SAMPLE CODE	GRAB SAMPLE STATION CODE	HISTORIC SAMPLE STATION CODE	LOCATION
		KREA 23	KREA 23	Ash Slough at Viking Property weir
		KREA 25	KREA 25	Turkey Slough off U.S. 98
		KREA 28	KREA 28	Popash Slough at SCL RR N
POPS+	LKR 30A	KREA 30A	KREA 30A	Popash Slough at L-62, S-154
		KREA 31	KREA 31	Newcommer heifer runoff at Hwy. 70
	LKR 32B	KREA 32B	LREA 32B	Dry Lake Dairy #1 Outfall to Hwy. 98
FERR+	LKR 34	KREA 34	KREA 34	Ferrell Dairy Outfall at Hwy. 78
WOLF+	LKR 36	KREA 36	KREA 36	Wolff Dairy Outfall
RUCR+	LKR 37	KREA 37	KREA 37	Ralph Rucks Dairy Outfall
WHIT+	LKR 39	KREA 39	KREA 39	White Dairy Outfall to Smith Farms
LAR2F+	LKR 40	KREA 40	KREA 40	Larson Dairy #2 Flume Outfall
BUT2+	LKR 41	KREA 41	KREA 41	Butler Dairy #2 Outfall
		KREA 41A	KREA 41A	Larson 2/Butler 2 Outfall
FLYG+	LKR 42	KREA 42	KREA 42	Flying G Dairy Outfall to Yates Marsh
RUCC+	LKR 43A	KREA 43A	KREA 43A	C&M Rucks Dairy Outfall
	LKR 44	KREA 44	KREA 44	Lamb Island Dairy Outfall
		KREA 44A	KREA 44A	Lamb Island Dairy Outfall east
		KREA 44B	New Station	Lamb Island Dairy outfall at entrance
MICC+	LKR 45	KREA 45	KREA 45	Micco Dairy Outfall
		KREA 45A	New Station	Micco Dairy at Chandler Ranch
		KREA 46A	KREA 46A	Williamson Dairy Outfall
		KREA 46B	New Station	Williamson Dairy Outfall at Hwy. 98
EAGL+	LKR 47	KREA 47	KREA 47	Eagle Island Dairy Outfall
		KREA 49	KREA 49	Dry Lake #1 & #2 outfall at Hwy. 98
		KREA 66	KREA 66	Four E's Fish Camp bridge on Hwy. 98
BASW+	LKR 68	KREA 68	KREA 68	Bass Ranch West Outfall to Ash Slough
DL1+	LKR RI1	KREA IR1	KREA IR1	Dry Lake #2 East Sprayfield
DLI2+	LKR IR2	KREA IR2	KREA IR2	Dry Lake #2 NW Sprayfield
	S154	S154	S154	River Structure S154
	S191	S191	S191	Lake Structure S191
	S65C	S65C	S65C	River Structure S65C
	S65E	S65E	S65E	River Structure S65E
	S84	S84	New Station	River Structure S84

element. Established procedures for sampling protocol were practiced routinely by South Florida Water Management District technicians to ensure that the required precision, accuracy, and reliability of the data were upheld (S. Fla. Water Manage. Distr. 1987). A set of quality assurance samples was submitted weekly along with the routine grab samples, which included the following:

- a duplicate sample,
- a duplicate sample with an added spike of known concentration,
- a replicate sample,
- a blank sample of deionized water, and
- a blank sample spiked with a known concentration standard solution.

Quality assurance samples were submitted for the automatic samplers along with routine samples collected. All samples were transported through a chain of custody protocol from the time the sample was relinquished to the chemistry laboratory to the time of sample disposal following analysis.

Expansion of the monitoring capabilities was well under way for both RCWP projects by the summer of 1988. Throughout the project's development, modifications to the sampling program were made as necessary. The automatic sampler load of 21 bottles of sample collected per week at each sample site was reduced to seven bottles per week at some sites to lessen the soluble reactive phosphorus screening load at the Okeechobee field office before sample submission to the chemistry laboratory. Weekly screening of continuous samples collected at the major tributary and structure inflow sites continued. Other automatic samplers located at dairy sites (particularly in the Taylor Creek/Nubbin Slough basin) were programmed to pump 80 mL every two hours into a single 11-liter bottle to form one weekly composite sample.

To provide greater sample preservation, all samples to be analyzed for total nutrients were acidified with 50 percent sulfuric acid to a pH less than 2.0. All automatic sampler bottles were treated with sulfuric acid before being placed in the field for sample collection.

Monitoring Streamlined (1990)

Faced with increasing economic pressure to implement expensive management options, dairy farmers requested that the State of Florida institute a buy-out program, which began in 1989 (Albers et al. 1991). To date, 18 dairies in the basins have elected to participate in the buy-out program, which paid them approximately $600 per cow and established deed restrictions prohibiting future dairy activity on the property. Water quality monitoring of buy-out dairies continued to document the effects of change in land use.

Through 1990, the Lower Kissimmee River–Taylor Creek/Nubbin Slough water quality monitoring program evolved and became more streamlined to optimize the equipment and human resources available (Ritter, 1991). Monitoring objectives were as follows:

1. To monitor water quality in support of the Florida Department of Environmental Regulation Dairy Rule in accordance with the 1.2 mg/L total phosphorus concentration target standard for dairies,
2. To assess tributary and basin loading and concentration inputs to Lake Okeechobee to compare with the 0.18 mg/L total phosphorus concentration SWIM standard for inflows, and
3. To develop basin and spatial scale models designed to predict changes in loads to Lake Okeechobee as changes in land use occur.

Because of the increased sample load brought on by the automatic sampler program and the labor-intensive maintenance and repair work necessary to keep the continuous sampling equipment in operation, some automatic samplers were either discontinued or the number of samples collected was reduced. The resolution of continuous samples collected as a daily composite (seven bottles per week) was sufficient to observe trends in water quality. Weekly composite samples were discontinued as they did not provide an adequate degree of resolution. Automatic samplers continuously collecting daily composite samples were maintained at the major inflows and tributaries in the two project basins. A higher degree of quality control was established for these remaining automatic sampler sites: intake tubing was changed quarterly, sample volumes calibrated, and the intake strainer cleaned. A PVC intake strainer holder was designed and implemented to keep the intake properly positioned to collect flow in the stream without disturbing bottom sediments.

Of the seven bottles of samples collected each week, three were submitted to the South Florida Water Management District chemistry laboratory in West Palm Beach to be analyzed for total phosphorus and total Kjeldahl nitrogen. Samples were submitted based on changes in the daily stage readings recorded at each site. Intensified quality control maintenance procedures for the Easyloggers were implemented, including cleaning of all probes and staff gages, removing of debris from the site, probe calibrating with standard solutions, and replacing used desiccant.

At times, sample stations were relocated or added to collect the most representative discharge point(s) of the dairy operation as completion of large scale BMP construction altered the hydrology of the property. Grab samples continued to be analyzed for total and particulate nutrients, with physical parameters measured in the field by the technician using a Hydrolab. Hydrolabs are calibrated daily with standard solutions before field use. Each Hydrolab undergoes a quarterly maintenance/overhauling procedure to clean the conductivity probe, replace the dissolved oxygen membrane and reference solution, and replace the pH reference solution.

Current Monitoring Network (1991)

To better facilitate the established water quality monitoring network goals and objectives for the RCWP projects, the South Florida Water Management District modified the network design in October 1991. The network consists of three key components:

1. Dairy monitoring in support of the Florida Department of Environmental Regulation Dairy Rule,
2. Synoptic surveys designed to identify sources of high phosphorus concentrations within the dairy operation, and
3. Tributary monitoring to assess water quality throughout the basins.

Sites were deleted or added to sample all dairy outflows as the construction of BMPs redirected off-site discharge. Some buy-out dairy and subtributary sites were also discontinued.

To provide water quality compliance monitoring in support of the Dairy Rule, grab samples continue to be collected on a biweekly basis from 68 sites representing all active and selected inactive dairy outflows. An unfiltered sample is collected and analyzed for total phosphorus and total Kjeldahl nitrogen.

Results are reported monthly to landowners, State regulatory agencies, and other interested organizations.

A second, innovative component of the network is the implementation of synoptic water quality surveys on dairies (Sawka et al. 1992). The objective of the synoptic surveillance program is to identify the sources of high phosphorus concentrations within the dairy farm operation. A team of two technicians surveys an entire dairy operation during high water conditions and collects grab samples, tracking all flows within the farm. Samples are returned to the Okeechobee facility, where they are screened for soluble reactive phosphorus using the spectrophotometer. The data collected provide a water quality assessment of the farm that is reviewed with the landowner and Florida Department of Environmental Regulation personnel to identify and work toward eliminating problem areas of high phosphorus concentration.

Finally, major tributaries and inflow control structures to Lake Okeechobee are monitored through 21 weekly grab samples and collection of daily composites using automatic samplers at 17 sites (Figs. 1 and 2). Biweekly grab samples are also collected from nine subtributary sites. Weekly grab samples are analyzed for total and dissolved nutrient species; daily composite and biweekly samples are analyzed only for total nutrients. Continuous samples collected from the major outflows of the Lower Kissimmee River–Taylor Creek/Nubbin Slough basins (S191, S65E, and S154) are all screened for soluble reactive phosphate each week at the Okeechobee field office before sample submission to identify any episodic trends that occurred during the seven-day sampling period. Environmental equipment continues in operation at 16 automatic sampler sites. Original Agricultural Research Service rainfall and groundwater stage recorders continue to be monitored. Constant servicing, maintenance, and repair of all equipment are essential to keep the continuous monitoring program functioning.

The present monitoring program succeeds because it has experienced personnel specifically dedicated to each component of the network.

Conclusion

The South Florida Water Management District's exceptional water quality monitoring efforts have been a support for the RCWP. Several years of solid background data in the Taylor Creek/Nubbin Slough watershed provided the foundation for development of a comprehensive evaluation of the pre- and post-BMP implementation. Although it was difficult to evaluate the effectiveness of individual BMPs, future monitoring efforts strategically located on dairy operations should provide valuable information.

The monitoring program has evolved from routine collection of grab samples into a complex level of environmental monitoring technology. Many lessons have been learned throughout the evolution. Thorough servicing and maintenance of a large number of continuous monitoring stations is difficult to sustain because of the considerable investment in resources and the labor-intensive nature of the work. By using a moderate number of automatic samplers, Easyloggers, and other environmental equipment, technicians have time to perform proper field maintenance necessary to provide more reliable data. The importance of maintaining field quality assurance and quality control protocols for precision and accuracy are essential to the success of the program and ensure quality data.

The monitoring program has been well received by landowners, whose concerns over regulatory enforcement prompted participation in the Rural Clean Water Program. Landowners are appreciative of the information produced with the synoptic surveillance component of the current monitoring program to help identify and alleviate trouble spots.

The protection of Lake Okeechobee, the heart of the fragile Kissimmee River–Lake Okeechobee-Everglades ecosystem, is a primary mission for the South Florida Water Management District. Efforts must be ongoing to reduce nonpoint source pollution as agricultural operations and urban development continue to expand in South Florida. Water quality monitoring provides the essential key to understand how modern technology can be used to achieve a more equitable balance with our unique environment.

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Nutrient Loadings and Chlorophyll *a* in the Oakwood Lakes System

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ABSTRACT

The amount of nutrients entering lakes has been shown to be related to productivity when large groups of freshwater lakes are studied. The assumption is often made that this relationship holds true for individual lakes. A project in South Dakota provided an opportunity to examine the relationship between annual nutrient loadings and in-lake water quality. Nutrient, sediment and hydrologic budgets for the Oakwood Lakes were determined in 1987, 1988, and 1989. Chlorophyll *a*, total phosphorus, organic nitrogen, and Secchi disk transparency were measured as indicators of in-lake water quality. Low nutrient input in 1988 (.159 g/m^2 total phosphorus in West Oakwood and .087 g/m^2 total phosphorus in East Oakwood) was associated with high chlorophyll *a* concentrations (330 mg/m^3 peak in West Oakwood and 339 mg/m^3 peak in East Oakwood). High nutrient input to West Oakwood in 1989 (.464 g/m^2 total phosphorus) was associated with much lower chlorophyll *a* concentrations (80 mg/m^3 peak in West Oakwood). Chlorophyll concentrations were intermediate for both lakes in 1987 as were nutrient loads for West Oakwood (.213 g/m^2 total phosphorus). East Oakwood, however, had high phosphorus loadings (.230 mg/m^2) in 1987.

The Oakwood Lakes and Lake Poinsett watersheds in eastern South Dakota (Fig. 1) were accepted into the Rural Clean Water Program (RCWP) in 1981. The project was designed to improve water quality through the implementation of agricultural best management practices (BMPs) based primarily on conservation tillage. In 1982 a comprehensive monitoring and evaluation project was approved to study the water quality impacts of the Oakwood Lakes-Poinsett RCWP. The main focus of the comprehensive monitoring and evaluation was groundwater quality. The Oakwood Lakes System Study (OLSS) was initiated in 1987 to determine if the application of BMPs in agricultural watersheds would affect lake water quality.

Study Area

The Oakwood Lakes are a complex of five small, interconnected, shallow, hypereutrophic lakes in eastern South Dakota. The lakes have a mean depth of 2 m, a maximum depth of approximately 3 m, a combined surface area of 971 ha and a total watershed area of 12,793 ha. The lakes are fed by several intermittent streams that drain a predominantly agricultural watershed estimated to be 50 percent cropland. The lake system has a single outflow from East Oakwood to the Big Sioux River (S.D. Dep. Environ. Nat. Resour. 1985).

Nonbedrock aquifers in eastern South Dakota consist of glacial outwash deposits resulting from the Pleistocene epoch glaciation. Within the project area surficial deposits are of the Wisconsin stage of glaciation, specifically the Cary and Iowan substage till, loess, and outwash (Flint, 1955). The Big Sioux aquifer is the surficial aquifer associated with the Big Sioux River and its tributaries and is of greatest importance in the project area. Seepage meters and monitoring wells indicate that the Oakwood Lakes are hydraulically connected to shallow unconfined and confined aquifers located around the lake system (U.S. Dep. Agric. et al. 1991).

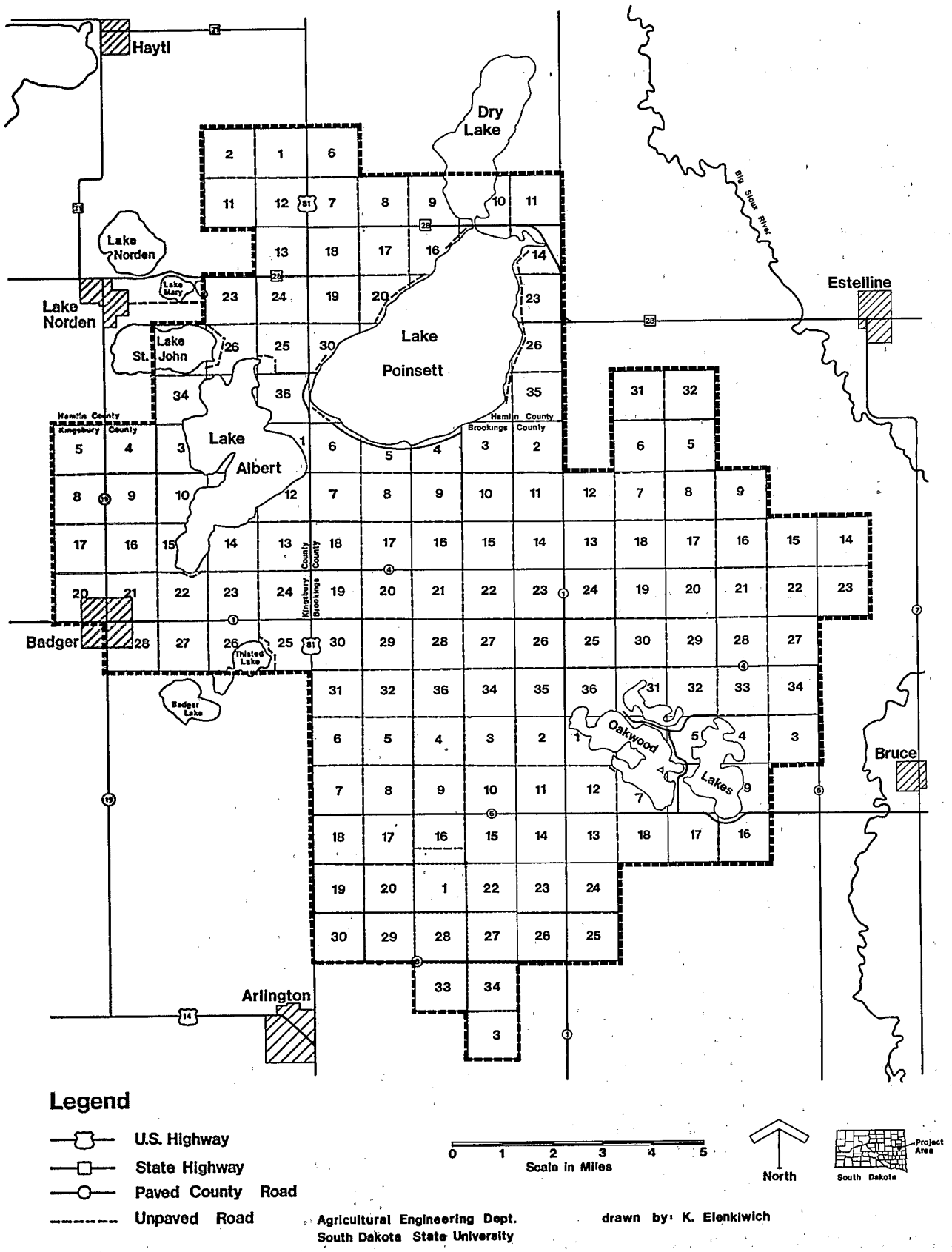

Figure 1.—Oakwood Lakes-Poinsett RCWP project area map.

Monitoring Strategy

Monitoring before and after BMP implementation to determine water quality effects was inappropriate since BMP implementation preceded the OLSS by several years. A strategy was developed that incorporated monitoring of water quality and quantity, biological surveys, land use modeling, and lake modeling to evaluate BMP impacts. The approach relies on the development of nutrient, sediment, and hydrologic budgets for the Oakwood lakes system for comparison to reductions in loadings estimated by watershed models. Predictions of water quality improvements through BMP implementation were based on in-lake water quality parameters.

OLSS monitoring included the direct measurement of surface water and groundwater flux through the lake system. Direct measurement of groundwater flux through the Oakwood Lakes was considered to be an important part of the OLSS monitoring strategy because of the presence of extensive sand and gravel aquifers adjacent to the lakes.

In-lake monitoring was designed to determine the current trophic state and to provide water quality indicators such as chlorophyll *a* that could be regressed against tributary nutrient loadings. Zooplankton and fish populations, nutrient parameters, and weather were monitored to help explain variability in such characteristics as chlorophyll *a*, total phosphorus, and Secchi disk transparency.

Methods

Surface Water

Ten sites were instrumented with 13 stage recorders and stilling wells to monitor surface water movement through the Oakwood Lakes system (Fig. 2). At six tributary sites and the outlet (T-0, 1, 2, 3, 4, 5, 6), simple rating tables were developed by measuring velocities with a flow meter, measuring the cross-sectional area, and calculating discharges for numerous stage heights (Kennedy, 1984). Two stage recorders and more complex equations were used at three sites where water flows between lake basins (IL-1, 2, 3) (Fig. 2). The Manning formula was used when the culverts were flowing partially full (Olson, 1967).

$$Q = 1.49/n\ Rh^{2/3}\ S^{1/2}\ A$$

With the exception of the roughness coefficient (n), the information required to calculate discharge with the formula can be determined from stage records. Channel slope S was represented by slope of the water surface in partially submerged culverts. Wetted cross-sectional area and hydraulic radius were based on stage heights and a survey of the culvert. The roughness coefficient was determined by solving the formula for n, using measured values for Q. For all sites stage records were digitized and converted to discharge with equations derived based on flow measurements taken at known stages.

Loadings were calculated by combining the continuous discharge record for each site with water quality data. Discharge from each site was divided into time intervals determined by the date and time when a sample had been taken. The water quality sample was located at the midpoint of the time interval. This method is patterned after the "trapezoidal rule" proposed by Huber et al. (1979). Frequency of sample collection varied and was determined by hydrologic activity. Tributaries were grab sampled except during storm events when they were sampled by ISCO flow-actuated automatic samplers.

In-lake water quality samples were collected at seven sites (L-1, 2, 3, 4, 5, 6, 7) every two weeks from May through October and monthly from November through April (Fig. 2). Samples were collected with an integrated sampler designed by the project that collected a column of water from the lake surface to within 15 cm of the bottom. The sampler was essentially a 5.08 cm inside-diameter tube that let water in as it was lowered into the lake; the tube was sealed with a rubber stopper set in place by a tripping mechanism when the sampler touched bottom. The sample was poured into a clean plastic bucket to ensure complete mixing of the water column from which subsamples for water quality and chlorophyll *a* analysis were taken. Secchi disk transparencies, dissolved oxygen and temperature profiles, and vertical zooplankton tows were taken at the same time.

Chemical analysis of all samples was conducted by standard U.S. Environmental Protection Agency-approved procedures (U.S. Environ. Prot. Agency, 1983). Parameters are listed in Table 1. In-lake samples were also analyzed for chlorophyll *a*. Chlorophyll *a* samples were filtered through .45 micron glass fiber filters immediately upon arrival in the laboratory. An ethanol extraction procedure (Nusch, 1980) was used with absorbance measured on a Perkin Elmer Model 35 Jr. spectrophotometer.

Groundwater

There were 18 existing monitoring wells (15 on comprehensive monitoring and evaluation field sites) applicable to OLSS project goals. To complete the coverage of the lakes, 26 additional groundwater monitoring wells were installed (Fig. 3). This

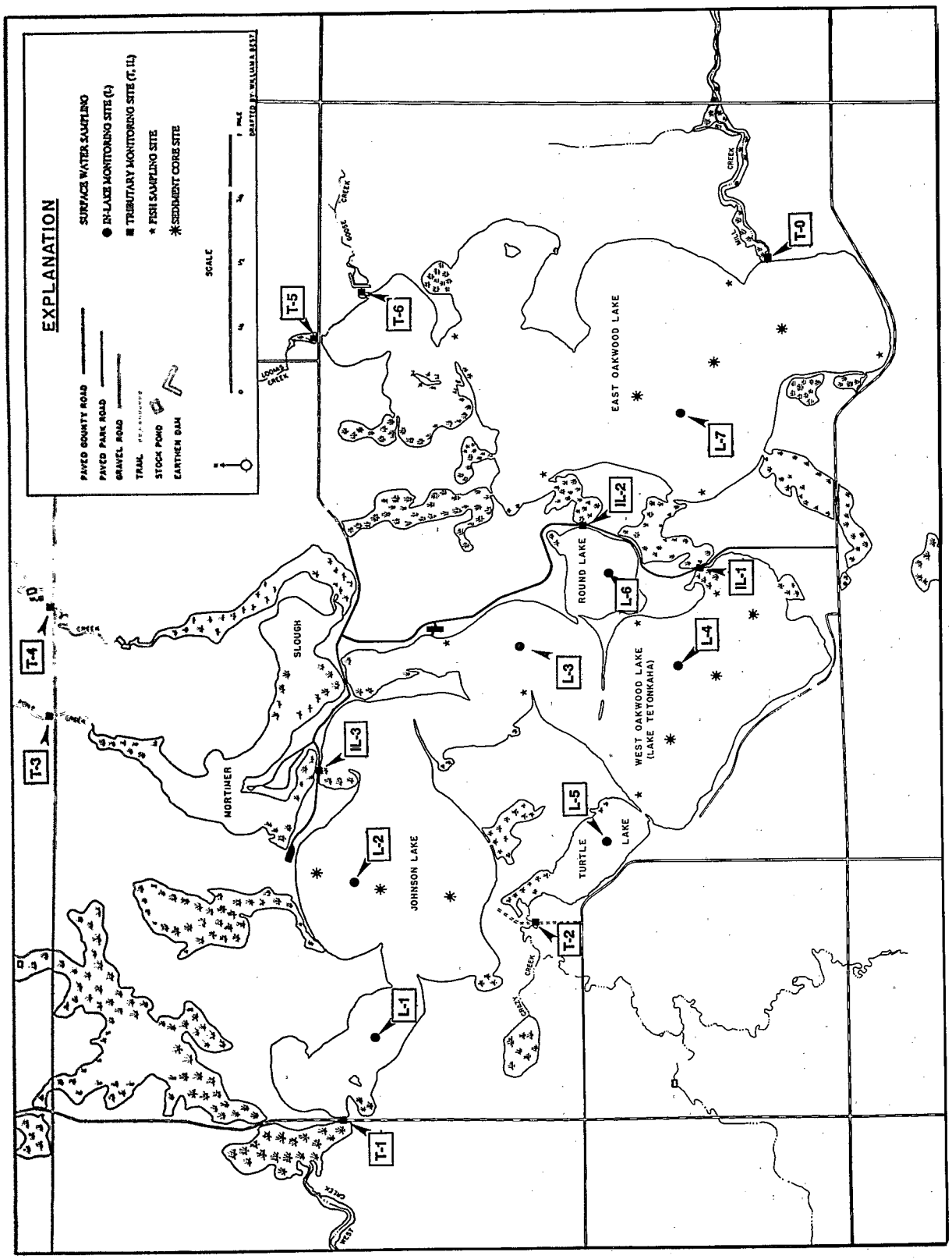

Figure 2.—Map of Oakwood Lakes surface water monitoring sites.

Table 1.—Parameters and methods of analysis used for the Oakwood Lakes System Study.

PARAMETERS	YEAR APPROVED	METHOD NUMBER	PROCEDURE
Soluble reactive PO_4-P	1971	365.2	Colorimetric
Total PO_4-P	1971	365.2	Colorimetric
Nitrate-N	1971	352.1	Colorimetric-brucine
Nitrite-N	1971	354.1	Spectrophotometric
Ammonia-N	1974	350.2	Colorimetric-distillation
TKN	1978	351.3	Colorimetric
Suspended solids	1971	160.2	Gravimetric 103-105° C

brought to 44 the total number of wells available for analysis of flow direction and groundwater chemistries.

Land wells were installed through a hollow stem auger after advancing the auger to the proper depth. At many well locations more than one well was installed (referred to as a well nest) to permit sampling of water quality at different depths. The wells were constructed of 5.08 cm diameter polyvinyl chloride (PVC) pipe coupled to #18 slot well screen. Sand and gravel were allowed to cave in around the well screen during withdrawal of the auger, which after development formed a natural gravel pack. When caving did not occur, pea gravel was installed as a gravel pack. If the borehole penetrated a confining layer, bentonite was placed in the confining layer interval to create a seal between the well screen and upper saturated layers. A bentonite seal was always placed in the top of the borehole around the well.

Single in-lake monitoring wells were installed to determine groundwater chemistries within the lake bottom. In-lake wells were constructed of 2.54 cm diameter PVC pipe with a 15 cm slotted area at the bottom, wrapped with fiberglass cloth (epoxied in place) for a screen. Installation was accomplished by driving a steel tube, with a steel drive point on the end, into the lake bottom to the desired depth. The well was inserted into the tube and the tube was withdrawn, leaving the well and drive point in place. Bentonite and a tripod support were placed around the base of the well, at the lake bottom, to seal the well and to give it strength, and also to protect the bentonite. The support was weighted to the bottom with large cobble-size rocks.

Seepage meters were placed on the lake bottom (Fig. 3) to measure the volume of water that passes through, be it in flux or out (Lee, 1977). They were constructed of the upper or lower portion of a 208 L (55 gallon) metal drum to which a partially filled pliable bag, such as a hospital IV bag, was attached (Cherkauer and McBride, 1988).

Seepage meter readings were taken every two weeks during the open water season if wind conditions permitted. Seepage bags were filled with 110 mL of water and the volume was remeasured within 24 hours or less, so that back pressure bag did not inhibit seepage.

Groundwater monitoring wells were sampled with submersible bladder pumps or bailers depending on the site accessibility, well recharge capability, and weather conditions. Samples were collected every two months. In-lake wells were sampled every two months except when the lake was frozen. Samples were collected from the in-lake monitoring wells with a peristaltic pump. Groundwater samples were analyzed for nitrate, nitrite, organic nitrogen, ammonia nitrogen, total dissolved solids, and total dissolved phosphorus.

The goal of analysis and evaluation of groundwater data was to determine the quantity and quality of groundwater entering and exiting the Oakwood Lakes system. Seepage rates were calculated at every available measuring point. Areas of lake bottom with similar seepage rates for selected time intervals were delineated. The area was multiplied by the seepage rate and the time interval to obtain a volume. Volume was multiplied by a concentration determined by available water quality data from in-lake or land wells to obtain a loading for each area. The loadings were summed to obtain a total loading for the entire lake bottom for the year.

Lake Sediment

A study of phosphorus release from Oakwood Lakes sediment was conducted as part of the OLSS (Price, 1990). As part of the study, 36 sediment cores were obtained from Oakwood Lakes during March 1989 (Fig. 2). Sampling sites were selected based on a nested experimental design of 4 cores within a site, three sites within a basin, and three basins within the lake system. Each lake basin was sampled along a transect which extended from the shallow nearshore area to the deep water area.

Intact sediment cores, approximately 0.91 m long, were collected with a piston-type sediment corer equipped with removable polycarbonate tubes

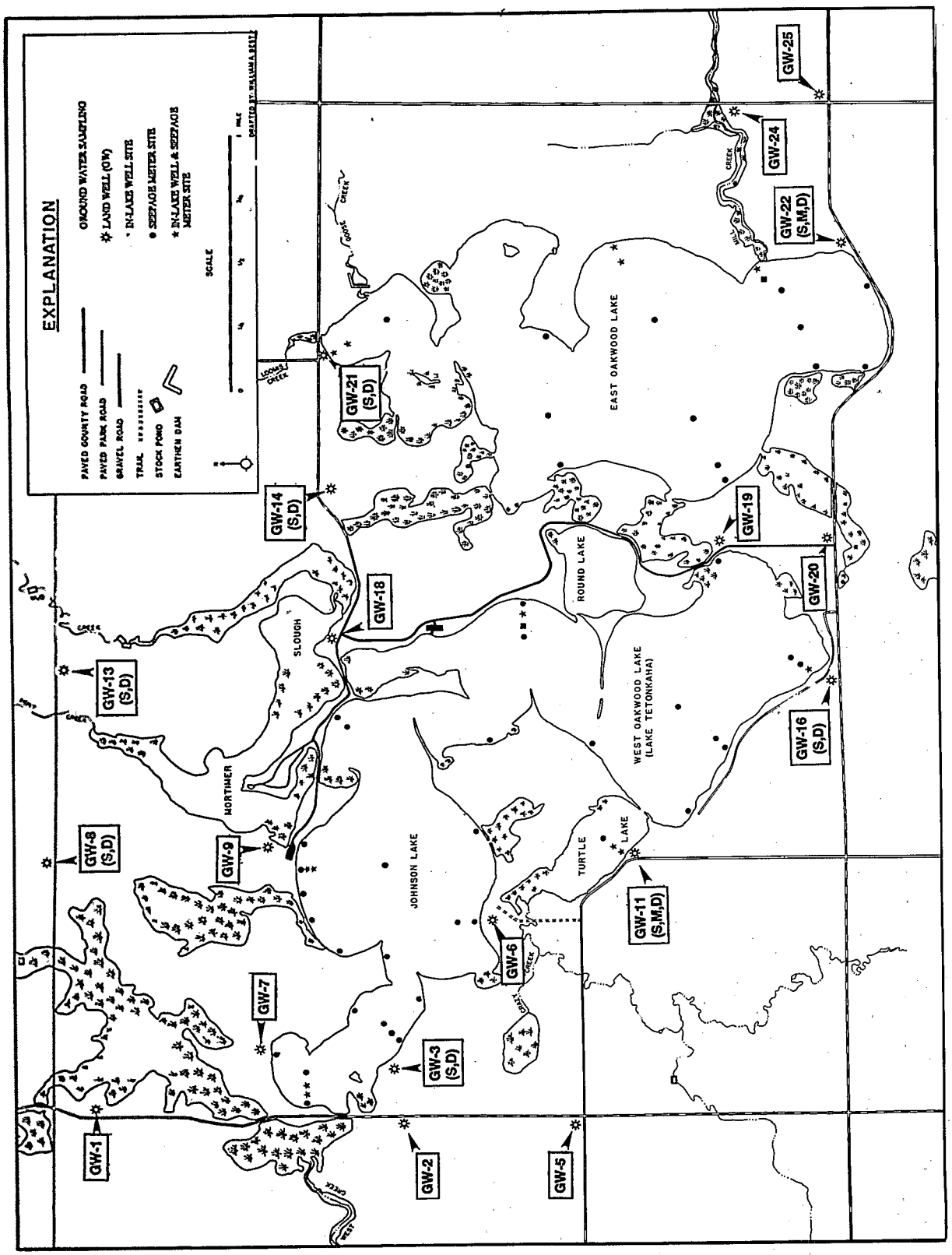

Figure 3.—Map of Oakwood Lakes groundwater monitoring sites.

(4.5 cm o.d. x 1.2 m). Polycarbonate was selected for use because of its resistance to phosphate adsorption (Ryden et al. 1972).

Two cores from each site were chemically analyzed to determine the phosphorus content of the sediment. The cores were extruded from the polycarbonate tubes while held in an upright position to prevent mixing of the sediment layers. Each core was divided into 15.2 cm sections for analysis, except that the sufficial segment was further divided into two 7.6 cm sections to increase resolution of phosphorus content near the sediment water interface. A brief description noting core length, sediment color, sediment texture, and presence of organic matter was logged for each core. The phosphorus content of the sediment was determined by the phosphorus extraction method of Aspila et al. (1976). The remaining two cores from each site were used in an incubation experiment.

To investigate the extent of phosphorus release from the sediment to the overlying water during aerobic and anaerobic conditions, two undisturbed sediment cores from each site were incubated within their original polycarbonate tubes, one under aerobic conditions and one under anaerobic conditions. Compressed air and nitrogen were bubbled in the overlying water to maintain the aerobic and anaerobic systems, respectively.

The overlying water was replaced with low nutrient (< .02 ppm total PO_4-P) groundwater every 2 days during the 32-day incubation period. The replacement water was allowed to settle, decanted and analyzed for total PO_4-P and ortho PO_4-P, before and after incubation. The quantity of phosphorus released from the sediment was determined by mass balance. A well adjacent to East Oakwood Lake was used as a source of replacement water. The incubated cores were sectioned and analyzed to determine the post-incubation phosphorus content of the sediment after termination of the incubation experiment.

Methods of statistical analysis used to evaluate the results of the sediment study included Analysis of Variance (ANOVA) and Least Significant Difference (LSD). Analysis was conducted using SAS Institute, Inc., procedures, including PROC LEAPS and PROC MEANS (SAS Inst. 1985).

Results

Chlorophyll a

Because of their importance in primary production, measurements of photosynthetic pigments have been widely used to quantify phytoplankton-standing crops and to measure in-lake water quality. Chlorophyll *a* is the pigment of choice since it is normally the most common (abundant) pigment in living phytoplankton and has been studied extensively. In this study, chlorophyll *a* was measured primarily to serve as a dependent variable in regression analysis to determine the relationship between tributary loadings and water quality.

Mean chlorophyll *a* concentrations for West Oakwood Lake stations are presented in Figure 4. Data for East Oakwood Lake is presented in Figure 5. Algal biomass as estimated by chlorophyll *a* concentrations were lower in 1987 and 1989 than in 1988. Peak chlorophyll *a* concentrations were observed in late August or early September of all three years.

Trophic State

Carlson (1977) proposed a Trophic State Index that allows lakes to be placed on a scale of 0 to 100 based on their trophic state, with 0 being the least productive. Each change of 10 in the scale represents approximately a doubling of the algal biomass for the index, based on summer chlorophyll *a* levels. Trophic State Indices (TSI) were calculated for total phosphorus, chlorophyll *a*, and Secchi disk transparency from measurements taken at seven in-lake sites in each of the years 1987, 1988, and 1989 (Carlson, 1977). The mean TSIs for six sites in West Oakwood and one site in East Oakwood is presented in Table 2. TSIs of 80-90, indicating hypertrophy, are common during the peak recreational season of July and August. During spring and early summer, much better water quality is often observed.

Seasonal TSI values for West Oakwood Lake stations (mean of 1-6) are plotted in Figure 6. TSI values for East Oakwood Lake (station L-7) are plotted in Figure 7. The values for total phosphorus tend to fluctuate less than for the other parameters. Large fluctuations in chlorophyll *a* TSIs are observed in the spring of each year. Apparently enough phosphorus is available to support a larger amount of algal biomass, as estimated by chlorophyll *a*, than was realized. Carlson (1977) reported a similar phenomenon for several Minnesota lakes that resulted from springtime crashes in the algae population. Many factors can cause low algae populations. In the Oakwood Lakes, light limitation is unlikely because of extended day length and high transparency during periods with low chlorophyll *a* (Figs. 6 and 7). Nutrient limitation is a possibility, but on dates with low chlorophyll *a* and high transparency (May 27, 1987; May 24, 1988; and June 6, 1989) only a few stations show any indication of nutrient limitation (Table 3). On May 24, 1988, at station L-7,

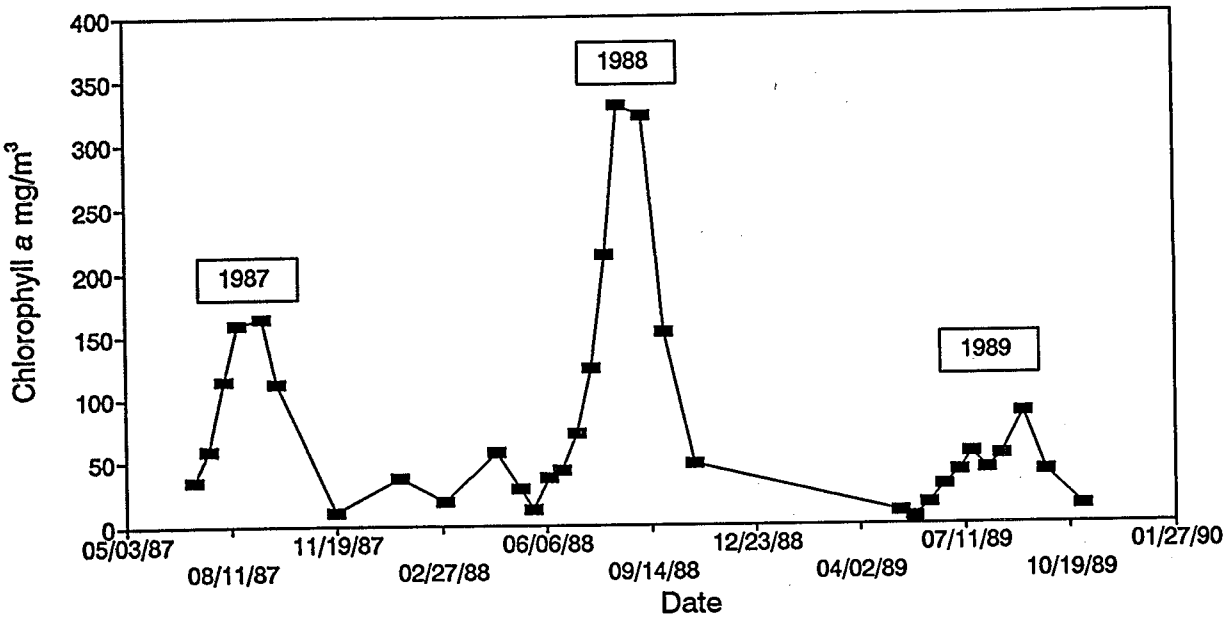

Figure 4.—Chlorophyll *a* concentrations in West Oakwood Lake (mean of six stations) from 1987 through 1989.

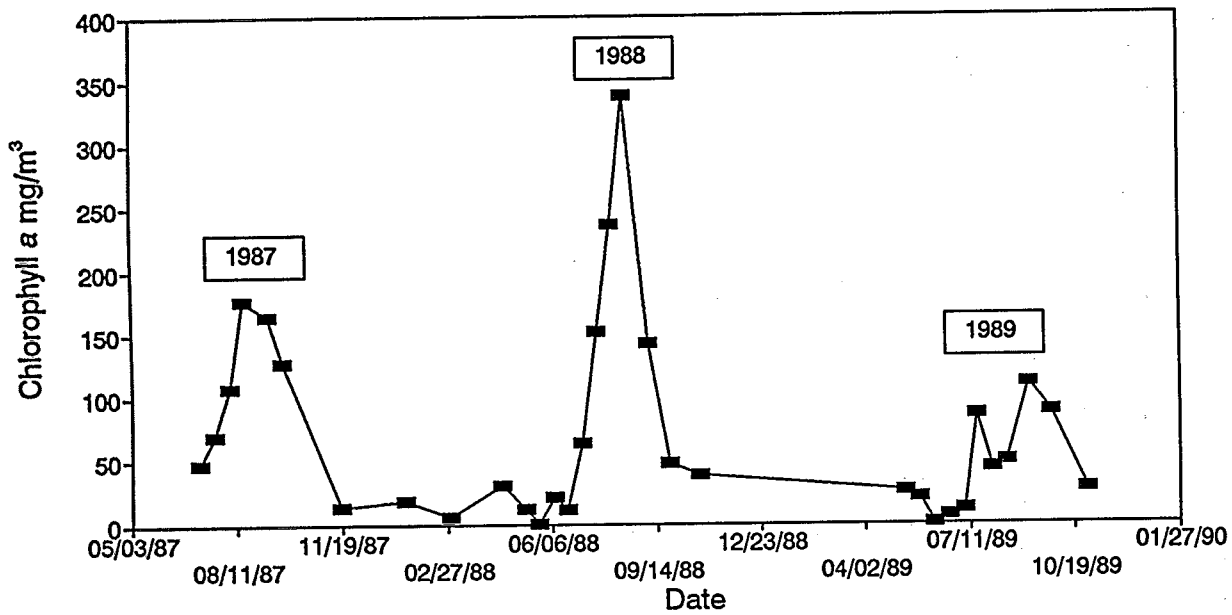

Figure 5.—Chlorophyll *a* concentrations in Eastwood Lake (station L-7) from 1987 through 1989.

during the most transparent period observed, nutrient limitation was not indicated. Temperature change cannot be ruled out as a factor, since the lakes warm rapidly during the spring period. Zooplankton grazing has been associated with high transparency in other lakes in the upper Midwest (Carpenter et al. 1985; Shapiro and Wright, 1984) and may contribute to low TSI values for chlorophyll *a* and transparency in the Oakwood Lakes. Other unknown factors may also contribute to this phenomenon.

In August and September of all three years, TSIs for Secchi disk transparency and chlorophyll *a* exceed the TSI value for phosphorus. Late in the summer, more chlorophyll *a* is present than would be indicated by the amount of total phosphorus present. This indicates that the lake may be phosphorus-limited during this time of the year. The data is consistent with high nitrogen-phosphorus ratios indicating phosphorus limitation late in the year for 1988 and 1989, and to a lesser extent for 1987 (Table 3).

Table 2.—Trophic state indices for East and West Oakwood Lakes.

	EAST OAKWOOD			WEST OAKWOOD		
DATE	TSI (TP)	TSI (SD)	TSI (CHL)	TSI (TP)	TSI (SD)	TSI (CHL)
April 28, 1987	71	65	—	77	72	—
May 14, 1987	69	65	—	79	72	—
May 27, 1987	74	64	—	82	75	—
June 9, 1987	74	67	—	81	76	—
June 23, 1987	76	70	—	78	72	—
July 6, 1987	74	72	77	73	71	74
July 20, 1987	76	73	81	74	75	79
August 4, 1987	81	77	86	80	78	86
August 17, 1987	77	82	90	81	82	89
September 9, 1987	82	85	90	82	86	90
September 23, 1987	82	91	87	82	88	85
April 19, 1988	—	—	—	77	69	79
May 11, 1988	65	70	64	73	74	72
May 24, 1988	66	47	32	73	66	63
June 8, 1988	61	62	70	73	73	74
June 20, 1988	65	60	64	74	72	75
July 5, 1988	66	80	80	70	80	81
July 19, 1988	70	83	89	75	82	86
August 1, 1988	77	89	93	81	90	92
August 15, 1988	81	95	97	84	98	96
September 6, 1988	77	85	88	84	99	96
September 27, 1988	76	80	78	82	91	89
May 10, 1989	71	68	72	70	56	59
May 23, 1989	71	62	69	70	52	53
June 6, 1989	64	49	39	69	56	64
June 21, 1989	70	55	58	71	65	71
July 5, 1989	67	59	63	76	73	75
July 17, 1989	72	69	83	74	72	79
August 1, 1989	76	70	77	75	71	76
August 15, 1989	71	76	78	72	76	78
September 5, 1989	73	79	86	81	86	88
September 26, 1989	75	81	84	68	77	76

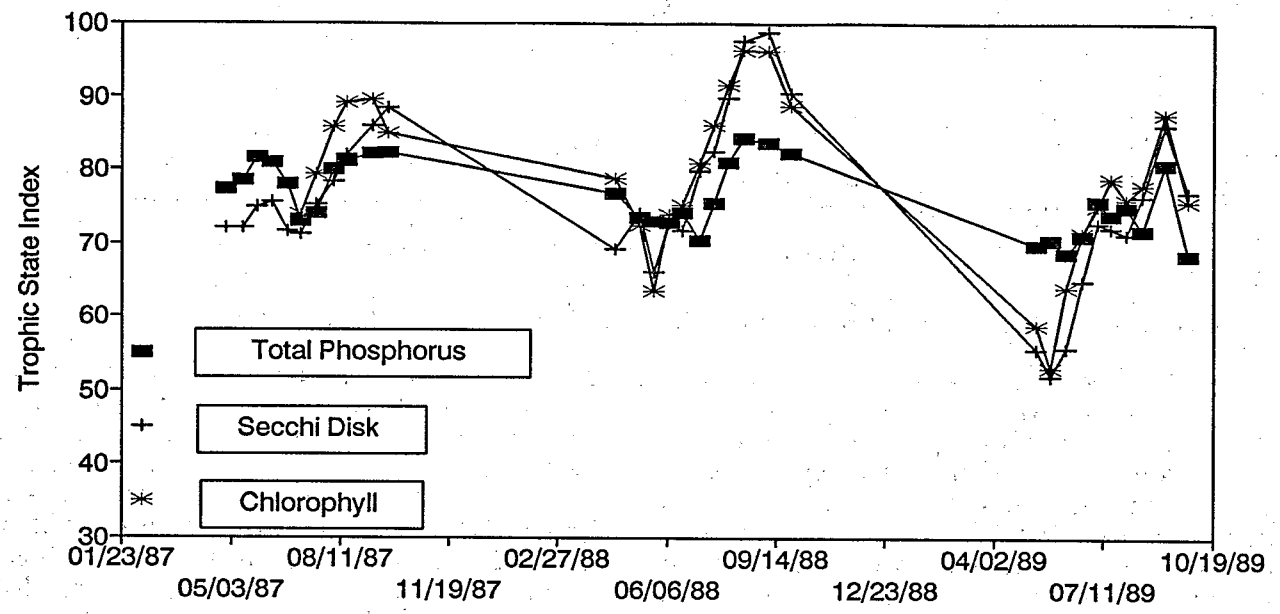

Figure 6.—Trophic state indices for West Oakwood Lake (mean of six stations) from 1987 through 1989.

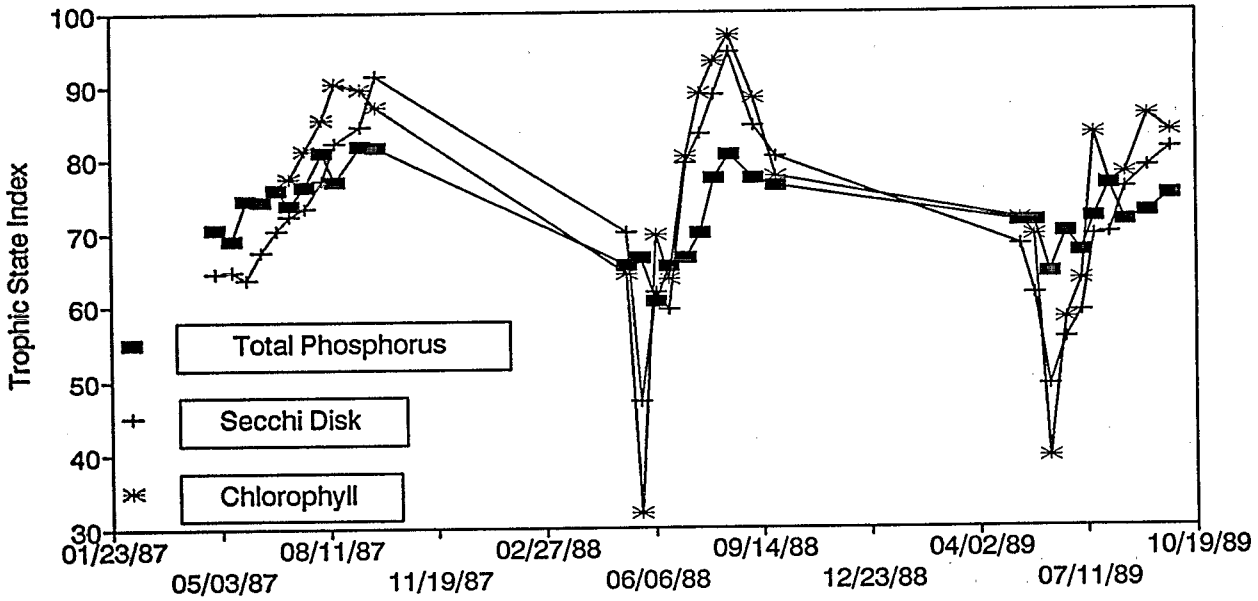

Figure 7.—Trophic state indices for East Oakwood Lake (station L-7) from 1987 through 1989.

Table 3.—Inorganic nitrogen to inorganic phosphorus ratios for Oakwood Lake stations for 1987 to 1989.

DATE	JOHNSON LAKE (L-1)	JOHNSON LAKE (L-2)	W. OAKWOOD LAKE (L-3)	W. OAKWOOD LAKE (L-4)	ROUND LAKE (L-7)	ROUND LAKE (I-6)	E. OAKWOOD LAKE (L-7)
Jan. 22, 1987	6	4	2	3	2	3	2
Apr. 12, 1987	57	22	8	10	6	27	23
Apr. 28, 1987	14	13	21	5	2	8	37
May 14, 1987	3	3	2	1	1	2	6
May 27, 1987			3			7	4
June 9, 1987	2	1	3	4	5	5	4
June 23, 1987	4	3	14	21	4	19	5
July 6, 1987		56	162	206	84	39	276
July 20, 1987		32	21	30		31	18
Aug. 4, 1987			4				
Aug. 17, 1987							
Sept. 9, 1987	20	61	147	255	72	27	135
Sept. 23, 1987	2	3	2	3	3		
Oct. 21, 1987							
Nov. 18, 1987							
Jan. 18, 1988							
Mar. 1, 1988							
Apr. 19, 1988	No data	No data	No data	7	3	No data	3
May 11, 1988	1	1	1	1	5	4	7
May 24, 1988		5	7	3	29		
June 8, 1988	10	8	14	3	2	208	3
June 20, 1988	13	10	13	12	10	44	4
July 5, 1988	22	9	8	14	19	15	10
July 19, 1988	5	4	8	5	8	3	8
Aug. 1, 1988	18	26	16	166	24	13	116
Aug. 15, 1988	37	206	216	41	26	19	
Sept. 6, 1988	15	21		19	21	17	84
Sept. 27, 1988	48	52	254	373	177	152	387
Oct. 25, 1988	188	179	225	217	249		295
May 10, 1989	11	26			106	198	10
May 23, 1989			87		63	8	
June 6, 1989	99			56	149		
June 21, 1989							
July 5, 1989			195	35	139		
July 17, 1989	30	32	90	103	30	50	No data
Aug. 1, 1989	9	15	6	13	7	4	
Aug. 15, 1989	4	4	5	4	4	4	2
Sept. 5, 1989	9	27	19	14	11	21	21
Sept. 26, 1989	38	26	16	39	77	23	17
Oct. 31, 1989	162	115	203	105	59	116	299

Nutrient, Sediment, and Hydraulic Budgets

Data produced by the OLSS monitoring program permitted calculation of the volume of water and the mass of nutrients and suspended sediment entering the Oakwood Lakes system from several tributaries and groundwater in 1987, 1988, and 1989. Tributary contributions of nutrients and sediments to the Oakwood Lakes system are presented in Table 4. Mill Creek (T-0) represents the amount of material exported by the system through the outlet. Water flowing through the outlet to Mill Creek exhibited lower concentrations of nutrients than water flowing into the lakes from the tributaries.

Hydraulic loadings from most tributaries were highest in 1987 and were lower in 1988 and 1989. Loadings for 1987 and 1988 were comprised primarily of snowmelt runoff; in 1989, in addition to snowmelt, three major storm events in June and July resulted in significant runoff in several tributaries. West Creek contributed the most water to the system in all three years of the study.

There was less transfer of water between basins in each successive year of the study. Lake levels were high at the beginning of 1987 due to several preceding wet years, and the large flows between lakes resulted from the lakes draining to normal levels. Below normal precipitation beginning in 1987 caused lake levels to fall below outlet elevations at the beginning of 1988 and 1989. Part of the tributary contribution was needed to fill the basins before outflow could begin in 1988. The culverts at Kimball's Crossing were also partially blocked for most of 1988 and 1989 because of local concern over falling water levels, thus causing less water to flow into East Oakwood Lake from West Oakwood Lake. No water left the system through the outlet in 1989, so 100 percent of the hydraulic, nutrient, and sediment load from surface water was retained, minus the evaporation that occurred from the water surface.

A summation of seepage through of the lake bottom and estimates of loadings for 1987 through 1989 are presented in Table 5. The data for 1988 and 1989 are superior, since no wells and fewer seepage meters were installed in 1987. The groundwater contribution to the Oakwood Lakes system was approximately one-half of the combined tributary and groundwater loadings. The estimates of groundwater flow into the lake are probably not as reliable

Table 4.—Total contribution of water, suspended solids, total phosphorus, and total nitrogen for tributary and interlake sites in 1987, 1988, and 1989, with flow-weighted mean concentrations in parts per million (ppm).

SITE	YEAR	DISCHARGE (m^3)	SUSPENDED SOLIDS		TOTAL PHOSPHORUS		TOTAL NITROGEN	
			LOADING (kg)	MEAN (ppm)	LOADING (kg)	MEAN (ppm)	LOADING (kg)	MEAN (ppm)
Pony Creek (T-3)	1987	164,195	950.4	5.8	96.7	0.59	453.9	2.76
	1988	48,605	746.3	15.4	32.6	0.67	110.6	2.28
	1989	22,806	234.3	10.3	22.4	0.98	66.9	2.94
Mud Creek (T-4)	1987	608,421	8,026.0	13.2	263.1	0.43	2,204.8	3.62
	1988	121	371.9	2.5	71.1	0.48	283.6	1.90
	1989	145,814	1,691.0	11.6	137.6	0.94	823.7	5.65
Mortimer's Crossing (IL-3)	1987	2,714,332	9,684.1	15.3	106.0	0.17	1,197.1	1.89
	1988	1,344,522	3,038.4	26.9	39.5	0.35	495.8	4.40
	1989	24	-366.1	12.4	20.6	0.70	175.4	5.92
West Creek (T-1)	1987	2,714,332	43,301.2	16.0	553.5	0.20	6,893.3	2.54
	1988	1,344,522	33,165.4	24.7	403.1	0.30	3,056.6	2.27
	1989	2,389,397	149,400.9	62.5	1,625.5	0.68	7,766.5	3.25
Crazy Creek (T-2)	1987	1,064,402	41,675.1	39.0	339.4	0.32	3,590.2	3.36
	1988	697,858	10,840.1	15.5	306.4	0.44	1,533.1	2.20
	1989	749,177	4,575.9	6.1	532.8	0.71	2,855.1	3.81
Kimballs Crossing (IL-1)	1987	4,249,942	66,887.4	15.7	517.1	0.12	6,607.5	1.55
	1988	1,078,553	24,994.3	23.2	263.1	0.24	3,231.8	3.00
	1989	744,736	26,985.6	36.2	133.9	0.18	2,037.0	2.74
Round Crossing (IL-2)	1987	1,390,906	24,798.0	17.8	172.3	0.12	2,261.6	1.63
	1988	90,671	2,524.1	27.8	11.6	0.13	230.7	2.54
	1989	5,798	238.5	40.9	0.9	0.15	17.9	3.08
Loomis Creek (T-5)	1987	128,790	2,105.7	16.3	158.6	1.23	676.8	5.26
	1988	23,932	810.9	33.9	45.0	1.88	174.7	7.30
	1989	51,812	6,724.4	129.8	182.7	3.53	529.0	10.21
Goose Creek (T-6)	1987	65,382	1,509.4	23.1	7.8	0.12	192.4	2.94
	1988	19,491	327.6	16.8	4.6	0.24	66.2	3.40
	1989	89,561	2,771.4	31.0	27.0	0.30	359.2	4.01
Mill Creek (T-0)	1987	5,328,618	55,581.3	10.4	427.9	0.08	7,560.9	1.42
	1988	1,686,111	31,041.3	18.4	200.7	0.12	2,859.0	1.70
	1989	0	0.0	0.0	0.0	0.00	0.0	0.00

Table 5.—Groundwater discharge and loadings estimates of total dissolved phosphorus and total dissolved nitrogen to the Oakwood Lakes in 1987–89. Percent of the combined tributary and groundwater loadings that were delivered through groundwater seepage is shown in parentheses.

YEAR	E. OAKWOOD (m^3)	W. OAKWOOD (m^3)	GROUNDWATER DISCHARGE (m^3)		TOTAL PHOSPHORUS LOADING (kg)		TOTAL NITROGEN LOADING (kg)	
1987	1,733,944	1,411,260	3,185,204	(40%)	79.4	(05%)	1,853.3	(12%)
1988	2,139,096	2,050,275	4,189,371	(65%)	102.3	(11%)	2,252.9	(30%)
1989	2,876,800	3,824,200	6,701,020	(66%)	164.4	(06%)	3,717.9	(23%)

as those calculated for the tributaries, but a substantial portion of the hydraulic budget of the Oakwood Lakes is contributed by groundwater.

Phosphorus Budget

All basins had a net gain of total PO_4-P during the three years of the study. The basins were most efficient at trapping total PO_4-P in 1989, with ranges from 87 percent to 100 percent. The lake system as a whole trapped 70 percent, 80 percent and 100 percent of the total PO_4-P that was contributed by six monitored tributaries in 1987, 1988, and 1989, respectively. The Oakwood Lakes system operated as a phosphorus sink, even though a net loss of water occurred in West Oakwood Lake during 1987 and in East Oakwood Lake during 1988.

The total PO_4-P load to the lake system carried by six monitored tributaries was 1,419 kg in 1987, 993 kg in 1988, and 2,528 kg in 1989. To estimate the water quality effect on the lake, loading per square meter of lake surface was calculated. This represented an annual tributary total PO_4-P load to the Oakwood Lake system of 0.16 g/m^2/year in 1987, 0.11 g/m^2/year in 1988, and 0.28 g/m^2/year in 1989. West Oakwood Lake received a tributary total PO_4-P load equal to 0.21 g/m^2/year in 1987, 0.16 g/m^2/year in 1988, and 0.46 g/m^2/year in 1989. East Oakwood Lake received a tributary total PO_4-P load equal to 0.230 g/m^2/year in 1987, 0.012 g/m^2/year in 1988, and 0.093 g/m^2/year in 1989 (Fig. 8). Vollenweider (1968) would consider this a dangerous load (i.e., one that would cause rapid eutrophication) for lakes much deeper than the Oakwood Lakes (permissible load varies directly with a lake's mean depth). A total PO_4-P loading of 0.13 g/m^2/year for a lake of 5 m mean depth is considered dangerous. In relation to this standard, West Oakwood Lake (maximum depth = 3.5 m) received excessive tributary total PO_4-P loads in 1987 and 1989, and East Oakwood Lake (maximum depth = 3.2 m) received an excessive load in 1987.

Nitrogen Budget

Unlike phosphorus, nitrogen may undergo denitrification and be lost to the system as it is returned to the atmosphere. Nitrogen may also be added to the

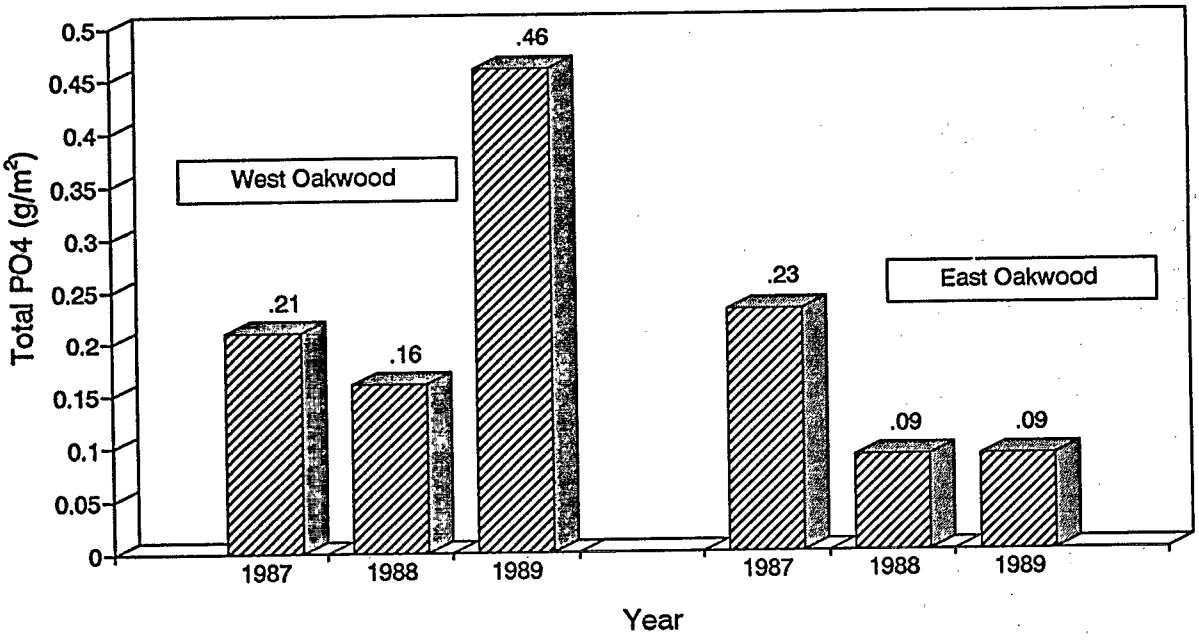

Figure 8.—Tributary phosphorus loadings to the Oakwood Lakes in 1987, 1988, and 1989.

system through nitrogen fixation by several species of blue-green algae. No attempt was made to account for nitrogen lost to denitrification or gained by nitrogen fixation.

Large differences in total nitrogen as N loading between years was observed for most tributaries (Table 4). The smallest contributions occurred during 1988 for all tributaries, except Pony Creek, which had a smaller contribution in 1989. Highest contributions of total nitrogen as N for most tributaries occurred in 1987. The large load of total nitrogen as N carried by West Creek in 1989 was due primarily to the July 11 storm.

All basins retained nitrogen in 1988 except Mortimer's Slough, which had a net loss of 102 kg of total nitrogen as N. Although the lake system was operating as a nitrogen sink, nitrogen was trapped less efficiently than phosphorus by the lake system. The lake system as a whole trapped 46 percent of the tributary load in 1987, 44 percent in 1988 and 100 percent in 1989. An accumulation of nitrogen over time will occur if this condition persists, unless denitrification exceeds nitrogen fixation or nitrogen is lost through sedimentation.

The largest tributaries (Mud Creek, West Creek, and Crazy Creek) contributed the largest amounts of total nitrogen in all three years. The total nitrogen as N load to the lake system carried by six monitored tributaries was 14,016 kg in 1987, 5,095 kg in 1988, and 12,400 kg in 1989. This represents an annual tributary total nitrogen as N load to the Oakwood Lake system of 1.57 g/m^2/year in 1987, 0.57 g/m^2/year in 1988, and 1.39 g/m^2/year in 1989. West Oakwood Lake received a total nitrogen as N load of 2.8 g/m^2/year in 1987, 1.4 g/m^2/year in 1988, and 2.8 g/m^2/year in 1989. East Oakwood Lake received a tributary total nitrogen as N load of 3.0 g/m^2/year in 1987, 1.3 g/m^2/year in 1988, and 1.2 g/m^2/year in 1989 (Fig. 9). As with phosphorus, this represents a load that would lead to rapid eutrophication for lakes as shallow as the Oakwood Lakes (Vollenweider, 1968).

Groundwater contributions of total phosphorus to the phosphorus budget are insignificant when compared to tributary contributions. Groundwater contributed 5 percent, 11 percent, and 6 percent of the combined tributary and groundwater phosphorus loadings in 1987, 1988, and 1989, respectively (Table 5).

Groundwater contributions to the nitrogen budget are larger relative to phosphorus loads. Groundwater nitrogen comprised 12 percent, 30 percent, and 23 percent of the combined tributary and groundwater total nitrogen loads in 1987, 1988, and 1989, respectively (Table 5).

Lake Sediment Study

At the time of the lake sediment sampling, the dissolved oxygen concentration in all lakes decreased with water depth to < 1 ppm, 15 cm from the sediment surface. The low dissolved oxygen concentrations near the lake bottom may have allowed a release of phosphorus from the sediment to the water column prior to the collection of the sediment cores. If so, the amount of phosphorus per gram of

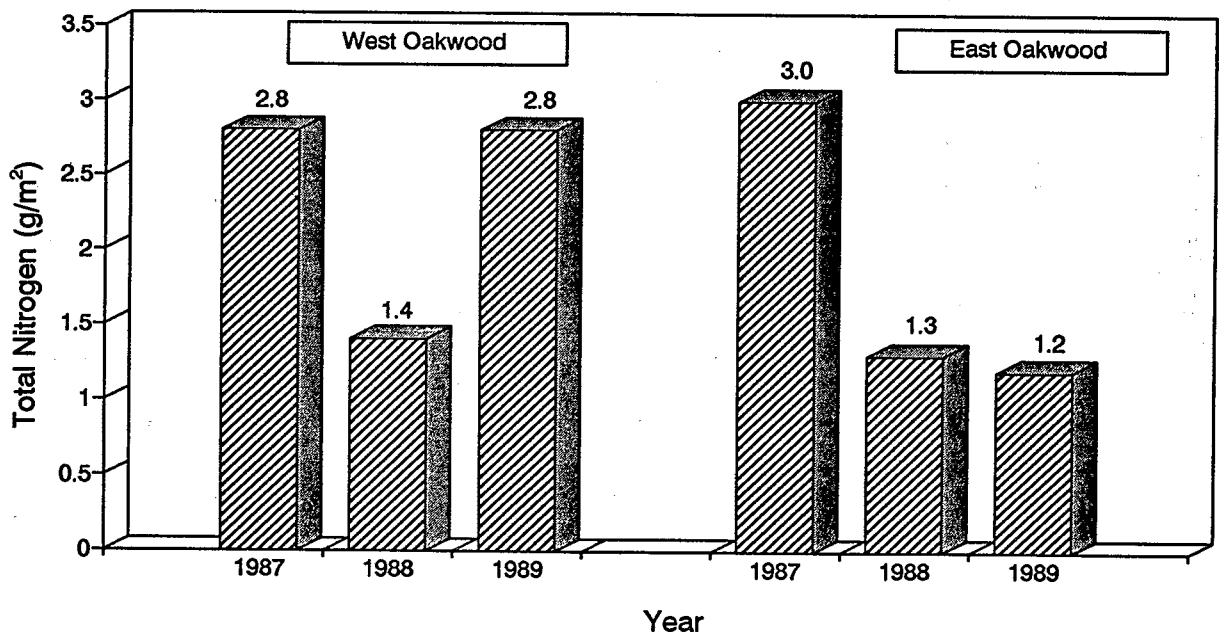

Figure 9.—Tributary nitrogen loadings to the Oakwood Lakes in 1987, 1988, and 1989.

sediment, and subsequently, the quantity available for release to the overlying water under anaerobic conditions, may have been underestimated by this study.

The overlying water of all anaerobically incubated cores experienced a net gain of total PO_4-P, indicating phosphorus was released from the sediment (Fig. 10). A smaller net gain of total PO_4-P occurred in the water of the aerobically incubated cores. Two cores from West Oakwood Lake experienced a net loss of total PO_4-P in the overlying water, which indicates that the sediment had removed phosphorus from the water column of these cores, resulting in the negative aerobic treatment mean.

The LSD analysis of the treatment means shows that the anaerobically incubated cores released significantly more total PO_4-P (0.305 g/m^2) than the aerobically incubated cores (0.080 g/m^2). Based on a muck-type sediment surface area of 7.12×10^6 m^2 (85 percent of the lake bottom), the potential sediment phosphorus load to the Oakwood Lakes system is 2,041 kg total PO_4-P during anaerobic conditions, and 468 kg total PO_4-P during aerobic conditions. These figures are based on the total available phosphorus that was released during the 32-day incubation period, although most was released in the first 3 days (Price, 1990). ANOVA indicated that the release of total PO_4-P varied significantly between lakes for both aerobic and anaerobic incubation at the 0.03 significance level.

A comparison of the observed tributary phosphorus load and the calculated potential sediment phosphorus load to West Oakwood Lake and East Oakwood Lake is presented in Figure 11. The sediment load during anaerobic conditions was equal to or greater than the tributary loadings of phosphorus in East Oakwood Lake and, during 1987 and 1988, for West Oakwood Lake. During aerobic conditions the sediment load of phosphorus was substantially less than the tributary loads for both years.

Discussion

When large numbers of lakes worldwide have been studied, it has been shown that the amount of nutrients entering a lake is directly related to productivity within the lake (Schindler, 1978). The assumption was made at the beginning of this study that this relationship would hold true for the Oakwood Lakes. It was assumed that determining the mathematical nature of the relationship between tributary loadings and productivity in the lake would allow estimates of water quality improvement that could be attributed to reductions in loadings through BMP implementations.

To develop a useful mathematical model, it was desirable that differences in both tributary loadings and in-lake water quality be observed in the three years of study. Indeed, this was the case for both West and East Oakwood Lakes. Tributary phos-

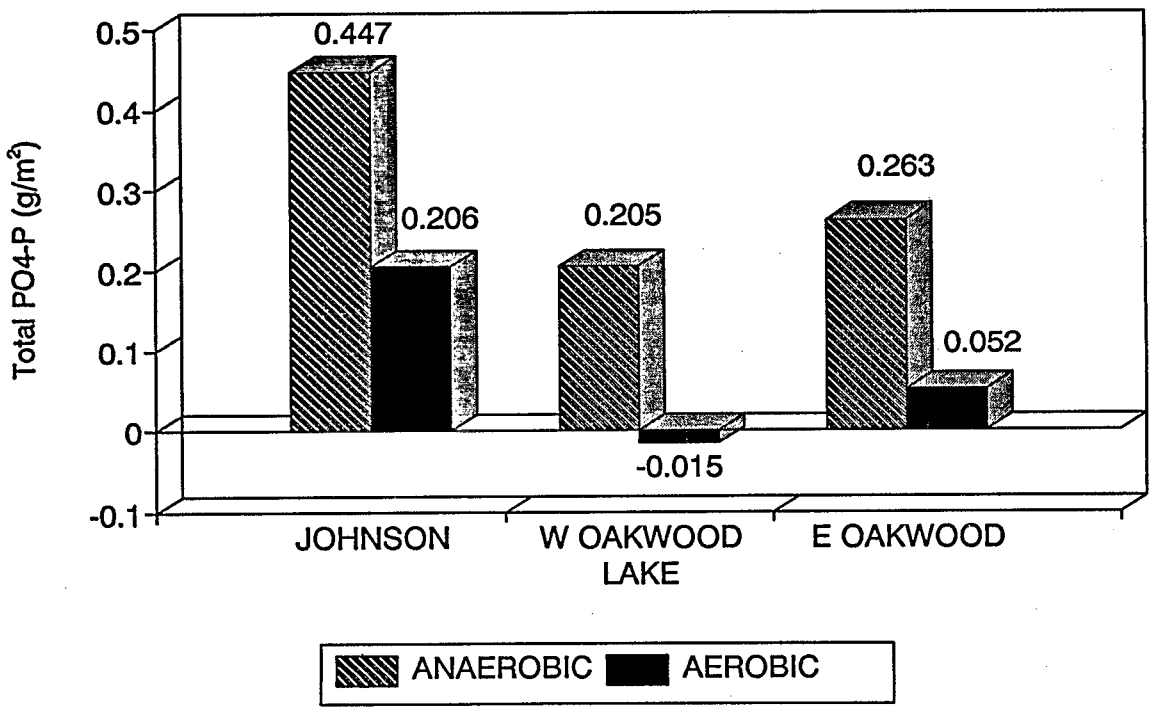

Figure 10.—Flux of phosphorus between sediment cores and overlying water.

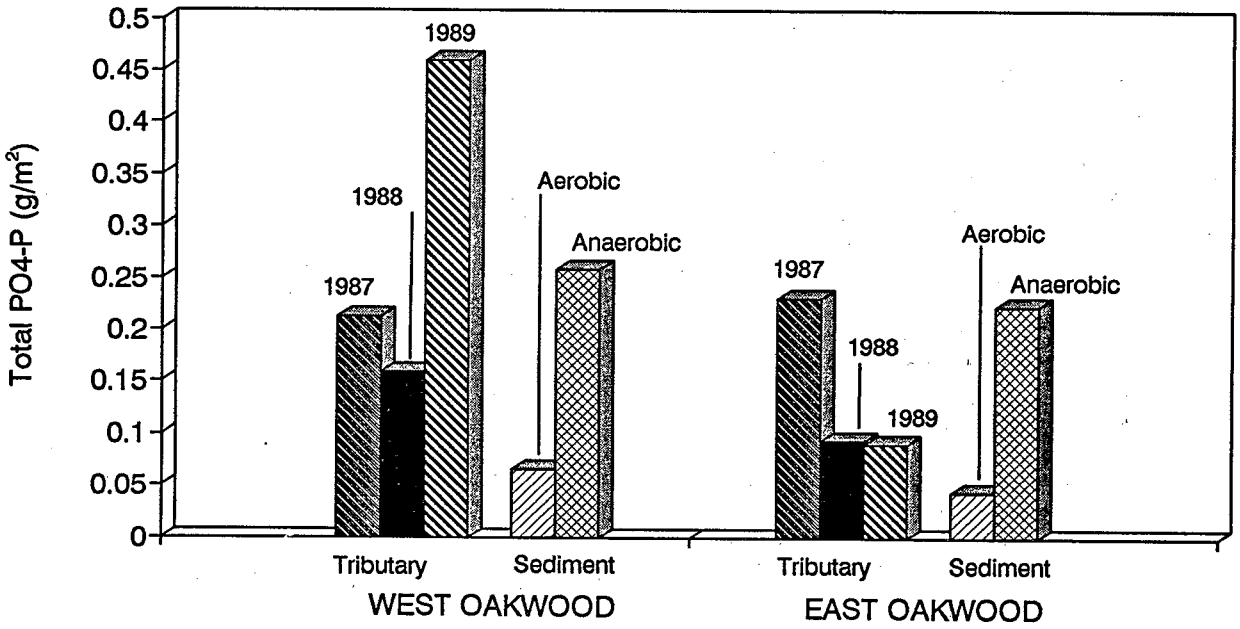

Figure 11.—Comparison of observed tributary loadings and calculated potential sediment phosphorus loadings.

phorus loadings in 1989 were nearly three times higher than in 1988 for West Oakwood Lake (Fig. 8). East Oakwood Lake received its highest tributary phosphorus loadings in 1987. Phosphorus loadings in 1988 and 1989 were much lower. A similar pattern was observed for tributary nitrogen loads (Fig. 9).

Simple linear regression was used to determine the relationship between annual tributary phosphorus loadings and mean summer chlorophyll *a*. The predictive model that resulted for West Oakwood yielded an R^2 of 0.71, with a negative slope (Fig. 12). Taken at face value, this would indicate that if loadings increased to over 0.65 g/m^2 of phosphorus over the surface area of West Oakwood, algae in the lake would be eliminated.

The predictive model for East Oakwood indicated no relationship between phosphorus loadings and algae populations (Fig. 13). In fact, there appears to be no relationship between annual phosphorus loadings and water quality in either of the Oakwood Lakes. This holds true when tributary nitrogen loading is regressed against chlorophyll *a*. Adding groundwater loadings does not improve the predictive equations.

During periods in 1987 and 1988, when tributary loadings had ended completely, large increases of phosphorus were observed in the water column. This was especially true for West Oakwood Lake in July and August of 1987 and 1988 (Fig. 14). The large increase in in-lake phosphorus concentrations suggest that internal loading of sediment phosphorus may be the primary source of phosphorus during periods when there are no tributary inputs, indicating a substantial release of phosphorus from the lake sediments. Although the pulse of phosphorus is short-lived and phosphorus returns to the sediment with the fall decline in the algae population, it occurs during the peak of the recreation season.

The sediments represent the historical nutrient and sediment loads to the Oakwood Lakes. The lakes have the ability to support large algae blooms in years when tributary loadings are quite low. Apparently water quality in the lake is more a function of sediment phosphorus release than annual tributary loadings.

The primary objective of the OLSS was to determine if BMPs were likely to have an impact on water quality in the Oakwood Lakes. BMPs have not yet reduced nutrient loadings to acceptable levels or restored desirable water quality to the Oakwood lakes. Large reductions in tributary may be needed to have any impact on water quality in the Oakwood Lakes. The sediments are laden with nutrients and the trapping efficiency of the lake system is very high. Without inactivation or removal of the sediment-stored phosphorus, the lakes are likely to remain self-sufficient in phosphorus.

Recommendations

Findings of the Oakwood study may prove useful to nonpoint source projects in the planning stage or just underway. New projects should recognize that if their goal is to improve water quality in lakes with

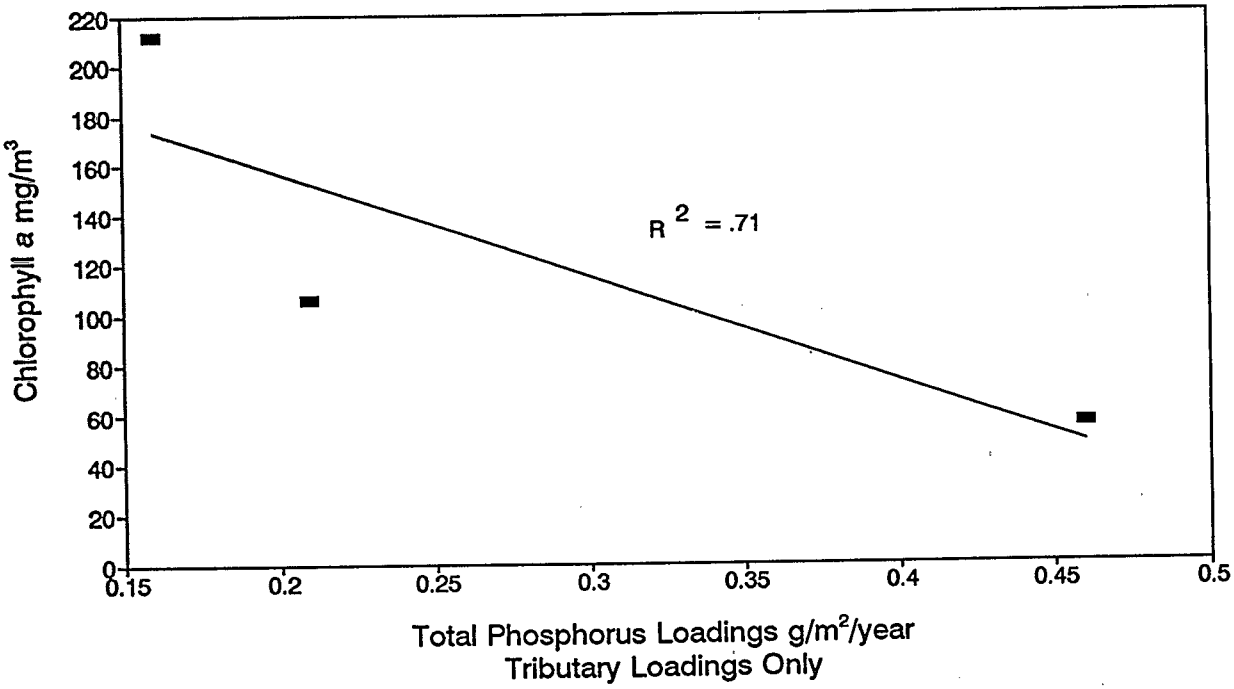

Figure 12.—Linear regression of tributary phosphorus loadings versus in-lake chlorophyll *a* for West Oakwood Lake.

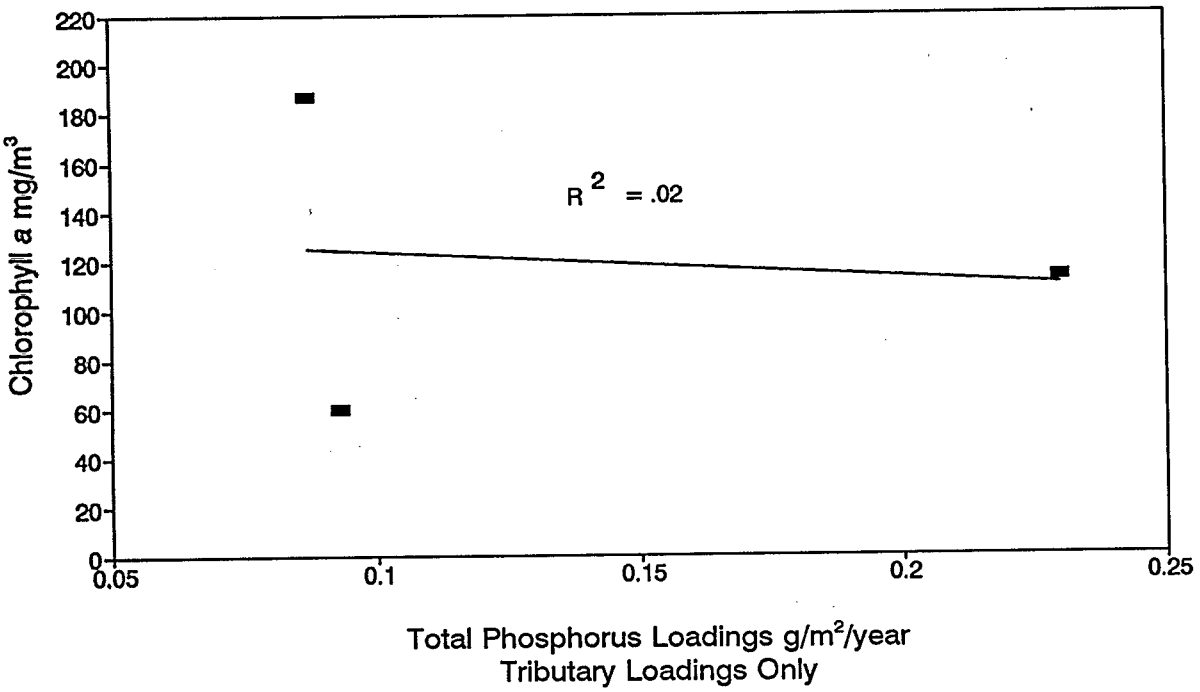

Figure 13.—Linear regression of tributary phosphorus loadings versus in-lake chlorophyll *a* for East Oakwood Lake.

algae blooms, internal sources of nutrients may prevent them from reaching this objective through watershed treatment alone. This likelihood may seem obvious to experienced limnologists, but it does not seem to be widely considered when new nonpoint source projects are selected. The assumption is often made that reducing nutrient loadings from the watershed will automatically result in improved in-lake water quality. This may not be true for lakes similar to the Oakwood Lakes. The danger is that if large numbers of nonpoint source projects fail to improve water quality through watershed treatment, public support for such projects may decline. Therefore, internal nutrient loadings should be considered when new nonpoint source projects are selected for funding; lakes that are thought to have

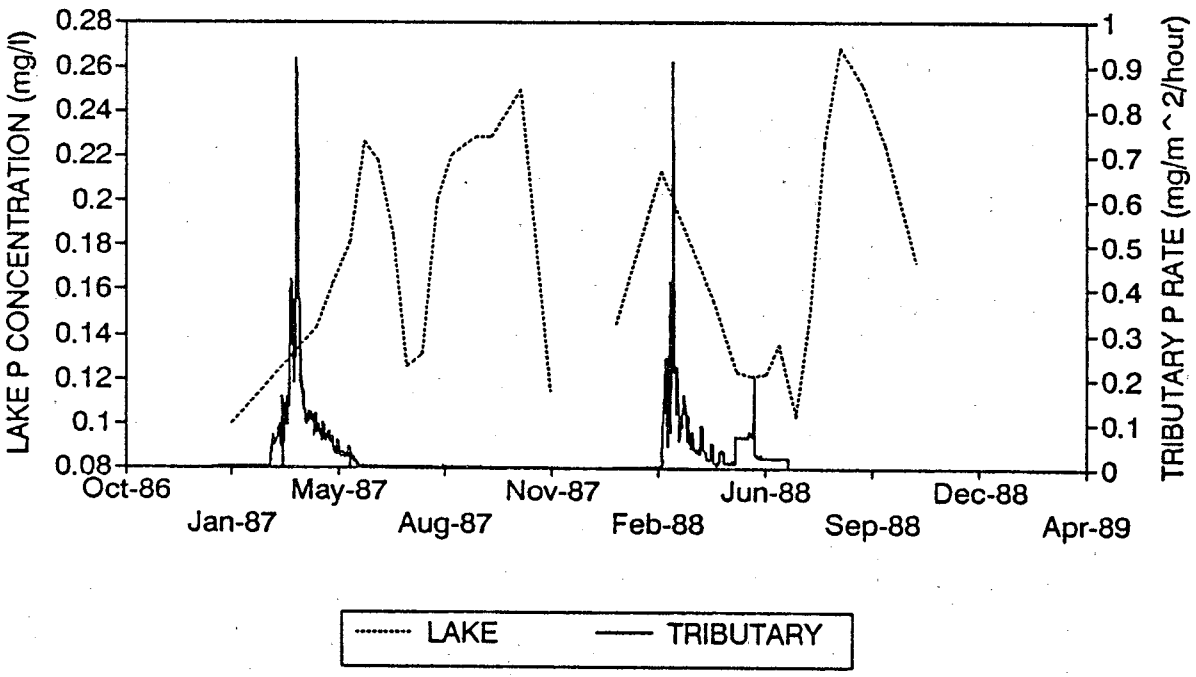

Figure 14.—A plot of in-lake phosphorus concentrations and tributary phosphorus loadings for West Oakwood Lake during 1987 and 1988.

considerable internal loadings should be given a low priority to receive funding for watershed treatment, if this is the only treatment planned.

Lake projects that include a component that is likely to reduce or control the effects of internal loadings, or that target lakes that have minimal internal loadings and show a good relationship between tributary loadings and water quality, should be given a high priority for funding to control nonpoint source pollution. Projects of this nature are more likely to succeed and contribute to the body of evidence that nonpoint source pollution control is worth the investment.

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Nitrate and Pesticide Occurrence in Shallow Groundwater During the Oakwood Lakes-Poinsett RCWP Project

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ABSTRACT

From 1984 through 1990, shallow groundwater was monitored at six farmed fields and one unfarmed site in eastern South Dakota as part of the Oakwood Lakes-Poinsett Rural Clean Water Program comprehensive monitoring and evaluation project. The implementation of best management practices (BMPs) began concurrently with the initiation of monitoring sites with BMPs, sites without BMPs, and an unfarmed site. Groundwater samples, collected at varying frequencies from project monitoring wells, were analyzed for nitrate and pesticides (herbicides and insecticides). Nitrate concentrations above the U.S. Environmental Protection Agency's maximum contaminant level of 10 ppm were found in 15 percent of the groundwater samples. Based on crops grown, the dominant controls on nitrate concentrations in the groundwater appear to be precipitation and infiltration, denitrification, and fertilizer applications. Tillage practices did not appear to affect nitrate concentrations in groundwater. Pesticides were detected in 11 percent of the groundwater samples. Lasso (alachlor), 2,4-D, and Banvel (dicamba) were the most frequently detected pesticides. Although each field site exhibited detectable pesticide concentrations in the groundwater, concentrated leaching of pesticides resulting in sustained groundwater contamination did not appear to be a problem in the RCWP project area. Several recommendations for future land treatment and water quality projects in areas of vulnerable groundwater resources were developed based on the study results.

The Oakwood Lakes-Poinsett Rural Clean Water Program (RCWP) project was part of a U.S. Department of Agriculture experimental program aimed at protecting and improving water quality in areas with identified water quality problems. The Oakwood Lakes-Poinsett project area is located in the glacial lakes region of east-central South Dakota (Fig. 1). Dryland, row-crop agriculture is the predominant land use, and corn and soybeans are the major crops produced, with alfalfa and small grains less prevalent. Commercial fertilizers and pesticides, primarily herbicides, are commonly used in the project area with application rates varying from no application to 100 pounds of fertilizer per acre (averaging 40 pounds per acre) and pesticides applied according to label recommendations (U.S. Dep. Agric. et al. 1991).

The glaciated Oakwood Lakes-Poinsett area is characterized by numerous lakes, wetlands, and shallow sand and gravel aquifers. Nearly level to severely undulating topography occurred in collapsed glacial drift, which consists of deposits of

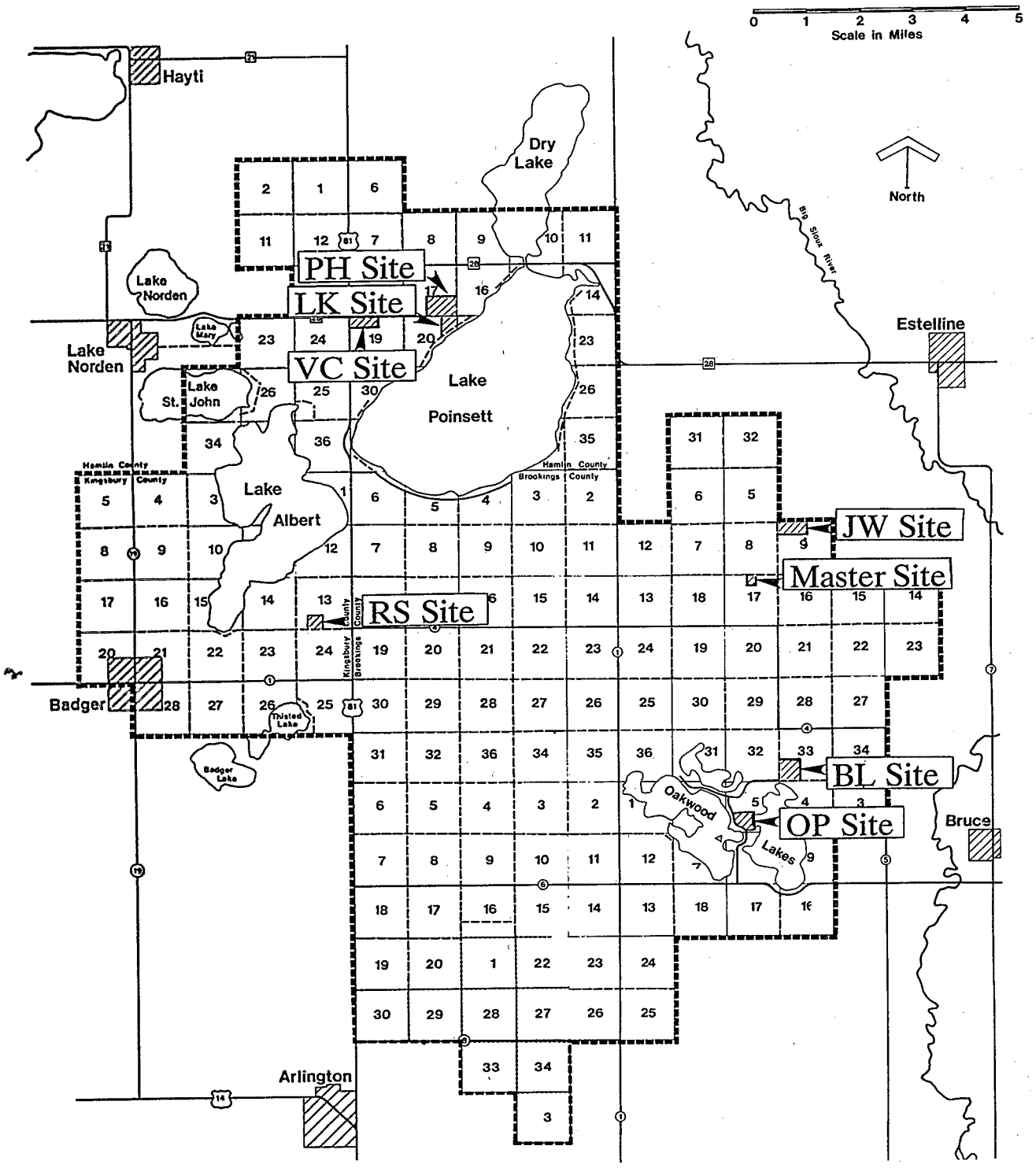

Figure 1.—Groundwater monitoring field sites and master site location.

sand, gravel, and silty-clay till. The major soil associations are deep silty, loamy, well-drained soils (U.S. Dep. Agric. et al. 1991). The average annual precipitation in the project area is approximately 22 inches; actual annual precipitation levels for the study years are given in Table 1.

Water quality problems identified in the project area were (1) excess nutrients in the tributaries and lakes and (2) evidence of excess nitrate concentrations in the Big Sioux aquifer. The Big Sioux aquifer is a surficial sand and gravel aquifer ranging from 5 to 80 feet in saturated thickness, with coarse-

Table 1.—Annual precipitation of project area.

YEAR	AMOUNT (IN INCHES)
1982	27.67
1983	22.20
1984	31.35
1985	28.98
1986	27.00
1987	19.92
1988	17.92
1989	16.06
1990	24.47

textured overlying soil (S.D. Dep. Water Nat. Resour. 1984).

The goals of the 10-year Oakwood Lakes-Poinsett RCWP project, implemented from 1981 through 1991, were to improve and protect groundwater and surface water by reducing nonpoint source pollution from total nitrogen, pesticides, water and sediment-borne contaminants, and animal waste. Among best management practices (BMPs), conservation tillage and fertilizer and pesticide management were emphasized, with a secondary emphasis on animal waste management systems. Fertilizer management included annual soil testing in the spring so that fertility recommendations could be based on residual soil nutrients and yield goals. Pesticide management consisted of weed and pest scouting so that recommendations for chemical use could be based on treating infested areas only. Conservation tillage, defined as 30 percent residue at planting before crop emergence, was typically achieved by not using moldboard plowing.

The goal of the comprehensive monitoring and evaluation portion of the project was to monitor and evaluate the effects on groundwater and surface water from the implementation of agricultural BMPs. Specifically, monitoring was conducted to determine if the BMPs recommended to prevent surface water pollution would change the amount of nitrogen and pesticide input to the groundwater.

Monitoring Strategy

The groundwater monitoring approach was site-specific because the project area (106,000 acres) was too large to monitor as a single unit and the probability of detecting land-use-affected-changes in water quality was increased. The seven monitoring sites, called field sites, ranged from 10 to 80 acres in size. Six sites were farmed fields, and one site (OP site) had not been farmed since the early 1970s. Conservation tillage, fertilizer management, and pesticide management BMPs were implemented on five of the farmed sites; the sixth site (JW site) was a control site without these BMPs. An additional farmed site (VC site) reverted to conventional tillage (moldboard plow) from conservation tillage in 1987. Locations of the field sites are shown in Figure 1.

Agricultural chemical inputs (in the form of fertilizers and pesticides) and tillage practices were documented for each field site. Also, field site operators were interviewed to collect historical land use patterns. In general, the BL, LK, and VC sites were planted in corn, small grain, and soybeans; corn and small grain were grown at the JW site; soybeans and wheat were rotated at the PH site; and corn and soybeans were rotated at the RS site (U.S. Dep. Agric. et al. 1991).

Groundwater monitoring began at field sites in 1984 and continued through 1990. The groundwater was monitored at 60 locations with 114 monitoring wells installed with a hollow flight auger drill rig and constructed of 2-inch polyvinyl chloride (PVC) casing with 3-foot or 5-foot, 0.018-inch commercial slot PVC screens. Well depths ranged from 7 to 66 feet and averaged 20 feet. All casing sections were joined with threaded couplers. The monitoring design included well nests and wells placed across the field sites to identify each site's water quality and hydrogeology.

Groundwater sampling was conducted at all field sites at a frequency described in Table 2. Quarterly and bimonthly samples were analyzed for nitrate, nitrite, total Kjeldahl nitrogen, ammonia, total dissolved solids, pH, electrical conductivity, and dissolved oxygen. In addition, monthly and biweekly sample analyses included a gas chromatograph scan for the pesticides listed in Table 3.

Table 2.—Sampling frequency for field site groundwater sampling.

WELLS	FREQUENCY	TIME FRAME
All wells	Quarterly	1984 to Aug. 1989
All wells	Every two months	Aug. 1989 to Dec. 1990
Wells for pesticide analysis	Monthly	1984 to Dec. 1990
Wells for pesticide analysis	Every two weeks	June/July 1989 June/July 1990

Table 3.—Pesticides tested with scan.

Ambien (chloramben)	Atrazine
Banvel (dicamba)	Bladex (cyanazine)
Counter (terbufos)	Dual (metolachlor)
Dyfonate (fonofos)	Endrin
Ramrod (propachlor)	Lindane
Tordon (picloram)	Parathion
Treflan (trifluralin)	Sencor (metribuzine)
Toxaphene	Thimet (phorate)
Methoxychlor	2,4-D
Prowl (pendimethalin)	Lasso (alachlor)
Dursban (chlorpyrifos)	

Table 4.—Geozone abbreviations and definitions.

ABBREVIATION	DEFINITION
WTLT15	Weathered till (brown color) or silty clay (reworked till) with the screened interval of the well at a depth b.g.s. of less than or equal to 15 ft. (19 wells)
WTGT15	Weathered till or transition zone (greenish brown zone interpreted as a transition zone between the weathered and unweathered till) with the screened interval at a depth b.g.s. of greater than 15 ft. (11 wells)
UT	Unweathered till (gray color). (7 wells)
SC	Silty clay aquitard located between an upper and a lower aquifier system. (2 wells)
SS-A	Alternating layers of thinly bedded fine sand and silt. (4 wells)
SGLT5LT10	Sand and gravel with less than or equal to 5 ft of overlying soil material, with the screened interval less than or equal to 10 ft below the water table. (30 wells)
SGLT5GT10	Sand and gravel with less than or equal to 5 ft of overlying soil material, with the screened interval less than or equal to 10 ft below the water table. (15 wells)
SG5-15LT10	Sand and gravel with less than or equal to 5 ft and less than or equal to 15 ft (4.6 m) of overlying soil material, with the screened interval less than or equal to 10 ft below the water table. (2 wells)
SG5-15GT10	Sand and gravel with less than or equal to 5 ft and less than or equal to 15 ft (4.6 m) of overlying soil material, with the screened interval less than or equal to 10 ft below the water table. (3 wells)
SGGT15	Sand and gravel with greater than 15 ft of overlying soil material. (5 wells)
SG-UA	Sand and gravel located under and aquitard as the lower unit of a two-aquifier system. (16 wells)

Note: Overlying soil material refers to all silt- and clay-rich sediments overlying a sand and gravel layer. It includes silt and/or clay loams and, in some cases, glacial till.

Note: While it may appear that the SGGT15 and SG-UA may both apply to a monitoring well, SG-UA specifies an aquitard between two sand and gravel units that both have some portion of their saturated thickness. SGGT15 only implies that there is 15 feet of burden above the mentioned sand and gravel unit. If there is an upper sand unit, it was not saturated.

To reduce scatter in the water quality data, a classification method was developed to identify the well screen's location in relation to the geology that was sampled. Table 4 lists the geozones, the number of monitoring wells in each geozone, and the abbreviation used. Depth at which the well was screened is expressed in two ways: (1) depth below ground surface (depth b.g.s.) for wells screened in glacial till; and (2) depth below the water table (depth b.w.t.) for wells screened in sand and gravel.

Figure 2 illustrates the geozone abbreviations displayed on a diagrammatic cross section. The schematic cross section is not specific for a single site but represents a general composite of the stratigraphic sequences found throughout the project area. The water table in the diagram is not intended to suggest flow directions, only the typical relative position of the water table within the geozones.

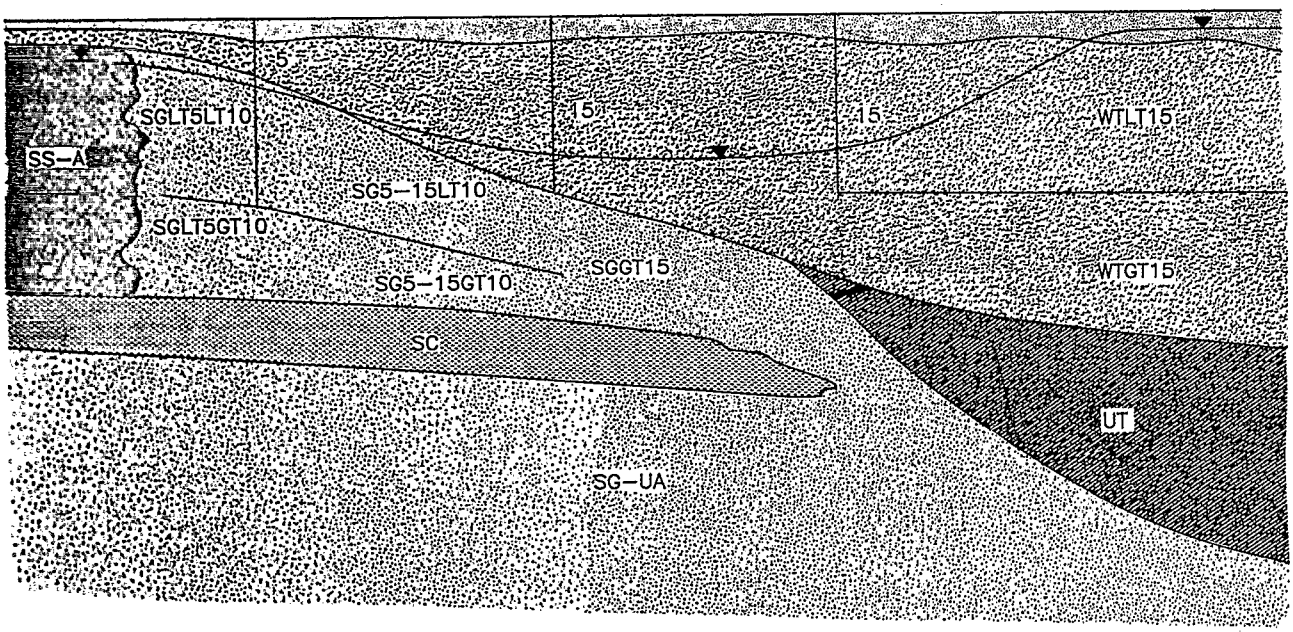

Figure 2.—Schematic cross section illustrating the geozones for Oakwoods Lake-Poinsett RCWP project.

Well placement and distribution within the geozones were targeted toward shallower depths. Most monitoring wells penetrated saturated conditions at 10 feet or less below the ground surface. Monitoring wells predominantly monitored sand and gravel outwash at the PH, LK, JW, and VC sites and till at the RS and BL sites. The OP site was characterized by areas of till and outwash deposits.

To help interpret field site data, an agricultural chemical leaching study was conducted at the master site (Fig. 1). Water, nutrient, and pesticide movement through the soil profile was monitored on plots of no-till and moldboard plow tillages with corn and oats in rotation. Fertilizer and pesticide inputs were strictly controlled.

Nitrate Occurrence

A total of 3,092 groundwater samples were collected from the monitoring wells between January 1984 and December 1990 for analysis of nitrate as nitrogen (NO_3-N). All field sites exhibited groundwater samples with NO_3-N concentrations greater than 10 parts per million (ppm), which is the U.S. Environmental Protection Agency's (EPA's) maximum contaminant level for NO_3-N in drinking water, in at least one well. Less than 15 percent of all nitrate detections, however, were in concentrations greater than 10 ppm.

Table 5 lists the statistical NO_3-N data for each geozone. Wells with the highest median NO_3-N concentrations were monitoring the shallow geozones: alternating sand and silt layers (SS-A), shallow sand and gravel (SGLT5LT10), silty clay (SC), and shallow till (WTLT15). Median NO_3-N concentrations are reported because testing indicated that the NO_3-N data were not normally distributed (SAS Inst., 1985; Crawford, 1984). It is important to note that the silty clay geozone, which had the highest median NO_3-N concentration, appeared hydraulically similar to the shallow till and that the median NO_3-N concentration is based on samples collected from only two wells. The median NO_3-N concentrations from the deep geozones were 2 to 20 times lower than those from the shallow geozones.

NO_3-N concentrations from the 3,092 samples from 106 monitoring wells were plotted versus depth of sample point below the water table (Fig. 3). With few exceptions, NO_3-N concentrations above 5 ppm were not detected at depths greater than 20 feet below the water table, and NO_3-N concentrations greater than 0.2 ppm were not observed at depths greater than 30 feet below the water table. The plot also illustrates that NO_3-N concentrations exceeded 50 ppm only twice.

Commercial fertilizer has been used in the project area for over 20 years; therefore, nitrate has had sufficient time to migrate to depths greater than 20 feet below the water table (S.D. Dep. Environ. Nat. Resour. 1989), based on vertical hydraulic gradients and hydraulic conductivities measured at the field sites. NO_3-N concentrations of up to 75 ppm in the groundwater also illustrate the amount of nitrogen that is available to migrate to the groundwater. It appears that the nitrate has not traveled to greater depths because of denitrification, the process by which biological organisms transform nitrate or nitrite to gaseous nitrogen by using the oxygen present in the nitrate for metabolism.

Denitrification has been shown to occur in shallow sand, groundwater environments (Trudell et al. 1986) similar to the glacial aquifers in eastern South Dakota. Denitrification has been shown to take place in low oxygen environments even though it is an anaerobic process (Focht and Verstraete, 1977). During the RCWP study period, the dissolved oxygen concentration in the groundwater decreased with depth below the water table in a manner similar to the NO_3-N concentrations.

BMPs were implemented on the field sites before monitoring, so an experiment designed to

Table 5.—Geozone statistical data.

GEZONE	NUMBER OF WELLS	N-SPECIES	MINIMUM	MAXIMUM	MEDIAN	NUMBER OF SAMPLES	MEAN
SS-A	4	NO_3-N	0.02	26.20	5.25	147	6.78
SG5-15GT10	30	NO_3-N	0.00	4.05	0.65	57	0.92
SGLT5LT10	15	NO_3-N	0.00	75.25	4.32	869	6.97
SGGT15	2	NO_3-N	0.00	4.07	0.03	730	0.24
SG-UA	3	NO_3-N	0.00	34.91	0.14	433	4.64
SGLT5GT10	5	NO_3-N	0.00	28.54	0.29	427	3.29
SC	2	NO_3-N	1.60	23.50	7.18	43	10.08
SG5-15LT10	16	NO_3-N	0.00	0.20	0.05	64	0.05
WTLT15	19	NO_3-N	0.00	54.75	7.03	504	9.96
WTGT15	11	NO_3-N	0.08	28.00	2.20	338	6.32
UT	7	NO_3-N	0.02	15.26	0.37	185	0.56

Note: Concentrations are in parts per million (ppm) of water, which is equivalent to milligrams per liter (mg/L).

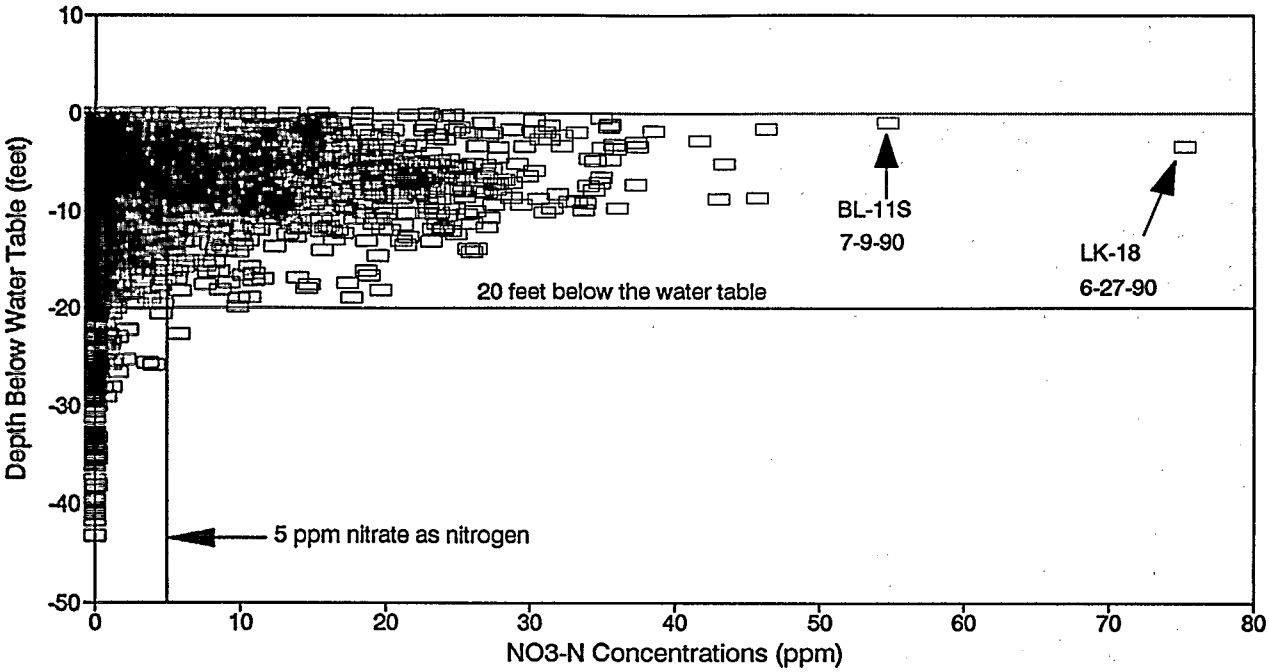

Figure 3.—NO_3-N (ppm) versus depth below water table: all sites.

compare before and after BMPs was not possible. To distinguish effects that could be attributed to BMPs, evaluation of the differences in water quality resulting from BMP implementation was conducted by making comparisons between fields with BMPs, fields without BMPs, and the unfarmed field site. Using the Wilcoxan Rank Sum testing (SAS Inst. 1985), significantly lower median NO_3-N concentrations were found at the unfarmed site than at the farmed sites (S.D. Dep. Environ. Nat. Resour. 1989).

No significant differences in median NO_3-N concentrations were found between field sites with conventional tillage and conservation tillage (S.D. Dep. Environ. Nat. Resour. 1989). Differences in tillage practices did not appear to affect groundwater quality, either positively or adversely, during the study period at the field sites. However, the vadose zone monitoring at the master site measured a faster rate of movement of rainwater from the soil surface to the groundwater for the no-till tillage plots than for the moldboard plow plots. Higher quantities of water and NO_3-N were delivered to the 6-foot depth under no-till plots (U.S. Dep. Agric. et al. 1991).

Median nitrate concentrations were plotted by year for each site (Fig. 4). The plots in Figure 4 illustrate several occurrences at the field sites. First, the plots indicate the median NO_3-N concentrations decreased in 1988 and 1989 and increased slightly in 1990. Second, the median NO_3-N concentrations increased between 1984 and 1987 at five sites. Above normal precipitation from 1984 through 1987, below normal precipitation during 1988 and 1989, and a return to above normal precipitation levels in 1990, correlate with decreases and increases in NO_3-N concentrations during this period with three exceptions:

- an increase in NO_3-N concentrations occurred at the OP site in 1988 and 1989 following a field-controlled burn of the vegetation at the site;
- a decrease in the concentrations at the JW site appears biased by the installation of additional monitoring wells at the site with lower concentrations of NO_3-N; and
- a high median NO_3-N concentration of 7 ppm at the RS site in 1984 follows corn production at the site with the highest recorded fertilizer application rate of 100 pounds per acre in 1983.

Nitrogen applied to the land surface reaches the groundwater through precipitation and groundwater recharge events; therefore, it follows that less NO_3-N reaches the groundwater during periods of low precipitation. It appears that nitrogen applied to the land surface that is not used in crop uptake during periods of low precipitation remains in the soil profile until it is available for transport during increased rainfall periods.

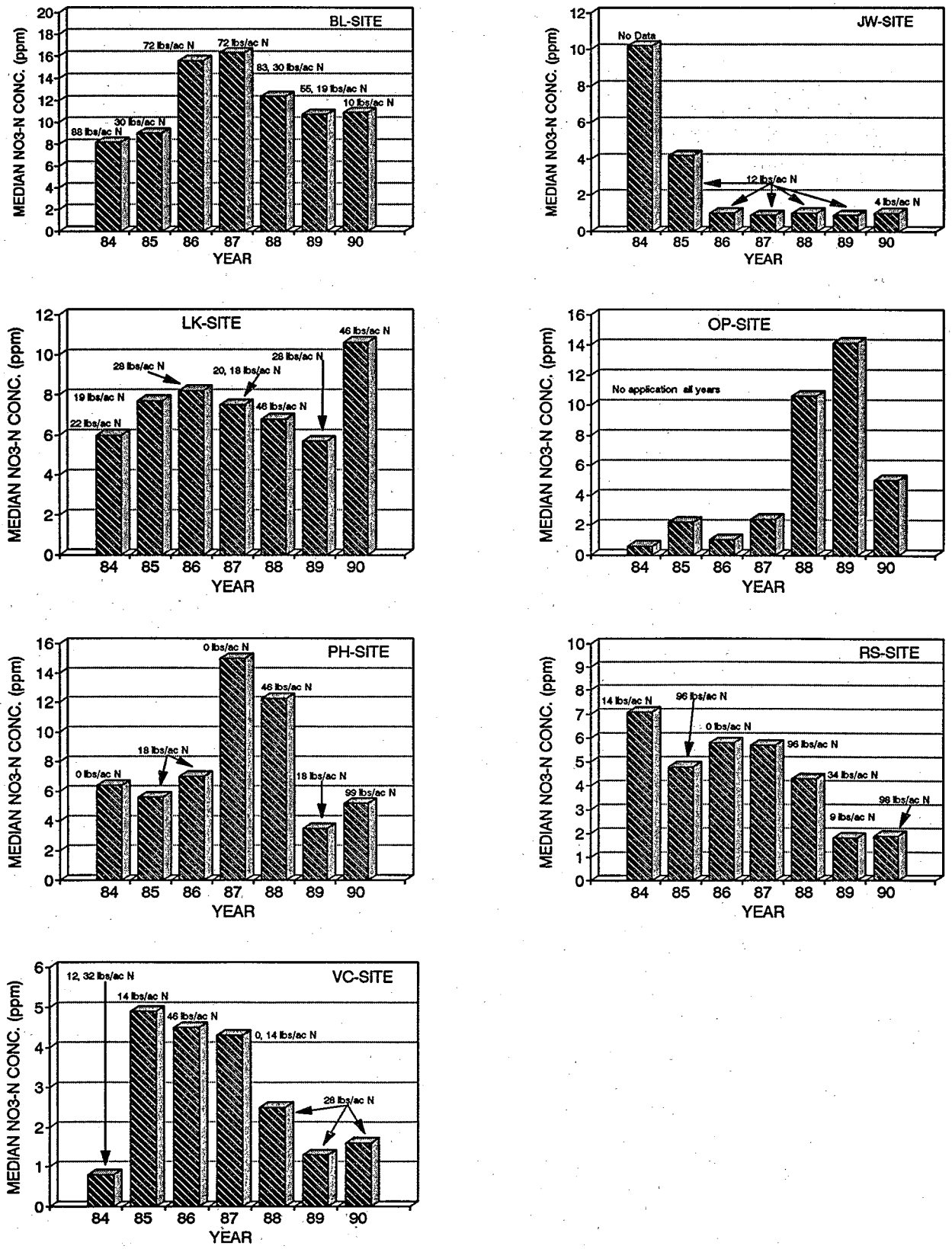

Figure 4.—Median NO_3-N concentrations and nitrogen applications for seven field sites.

The 1990 precipitation measurements, individual monitoring well hydrographs, and NO_3-N concentrations were evaluated to determine the effect of precipitation on NO_3-N concentrations. Several major storm events occurred between May 1 and July 31, 1990, with a total of over 12 inches of rain received in the area. During these major precipitation events, the NO_3-N concentrations in most of the wells studied decreased initially within days of the storm event because of the dilution effects of the recharge. NO_3-N concentrations then began to increase gradually and approach the prestorm event levels. For example, at the PH site, the NO_3-N concentration decreased from 9 ppm in May to 4 ppm in July, which was followed by an increase to over 6 ppm by the end of August.

The VC field site was chosen for further analysis of groundwater NO_3-N concentrations because the site changed from a conservation tillage site to a conventionally tilled site (moldboard plow used every year) in 1987. Seven wells were sampled at the field site; three of the shallowest wells were sampled monthly. All monitoring wells were screened in the shallow sand and gravel geozones between 12 and 30 feet below the land surface.

The site was planted to corn in 1988 and divided into two areas planted to corn and soybeans in 1989 and 1990. Twenty-eight pounds of nitrogen fertilizer were applied per acre of corn; soybeans were not fertilized. Two monitoring wells were located in the area of corn production in 1988 and then planted to soybeans in 1989 and 1990. In one well, NO_3-N concentrations decreased from a high of 0.1 ppm in May 1988 to a low of 0.01 ppm in August 1989 to nondetectable in June 1990. In the second well, NO_3-N concentrations decreased from 15.65 ppm in August 1988 to 0.36 ppm in August 1989 and June 1990. These changes appeared to be related to the change in cropping patterns — corn in 1988 and soybeans in 1989 and 1990. The up-gradient monitoring well at the site indicated no groundwater quality influence from off-site activities. The lack of fertilizer inputs to the soybeans during 1989 and 1990 appears to be the major factor contributing to the decrease in NO_3-N concentrations in the monitoring wells. It appears that the change in BMPs had not affected the median NO_3-N concentrations at this site, and the dominant control appears to be the amount of fertilizer applied to the fields.

Pesticide Occurrence

The pesticide groundwater sampling program was initiated in May 1984 and continued through December 1990. The term pesticide in the study included both herbicides and insecticides.

The frequency of groundwater sampling for pesticides increased each year in the study from quarterly sampling in 1984 to a monthly or biweekly groundwater sampling program thereafter. The number of groundwater samples collected for pesticides over the study period are presented in Table 6. The pesticide sampling program consisted of 1,628 samples collected from 73 wells. Detectable pesticide concentrations occurred in 11.3 percent of the samples (184 of 1,628 samples had detections; in 26 samples, more than one pesticide was detected). As the program progressed, the frequency of groundwater sampling and the number of detections increased. However, the data suggest that the number of detections per sample collected remained consistent during the RCWP sampling period.

Table 6.—Number of groundwater samples collected for pesticide analysis.

YEAR	SAMPLES COLLECTED
1984	55
1985	125
1986	161
1987	219
1988	277
1989	305
1990	486
Total	1,628

Groundwater samples were collected from wells ranging in depth from 8.5 to 65.5 feet. The average depth of wells in which pesticides were detected was 17.7 feet. Figure 5 presents the sampling frequency of the geozones, and Figure 6 depicts the frequency of geozones when pesticides were detected. The shallow sand and gravel geozone (SGLT5LT10) was sampled most frequently, and the geozone with the most frequent pesticide detections was the shallow till (WTLT15).

The majority of pesticide detections in the groundwater sampling program were represented by a single detection of a single pesticide. During subsequent sampling, the pesticide was not detected. This type of "hit-and-miss" detection of pesticides appears to be common for groundwater monitoring at agricultural sites (S.D. Dep. Environ. Nat. Resour. 1992). Commonly, the pesticide detected was applied to the field more than one year before sampling and was accompanied by the detection of a pesticide with no application history to the field.

Because of sporadic, irregular detection of pesticides, long-term or continued trends of pesticides leaching to groundwater with BMPs were difficult to ascertain. However, distinct pesticide leaching events were clearly evident at all sites based on one

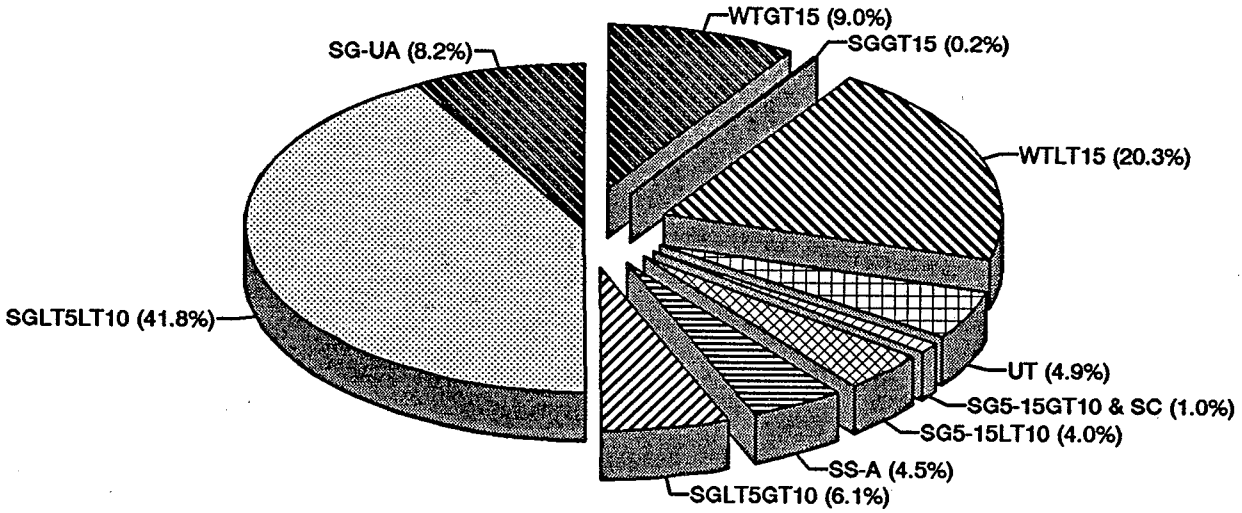

Figure 5.—Percentage of pesticide samples collected by geozone.

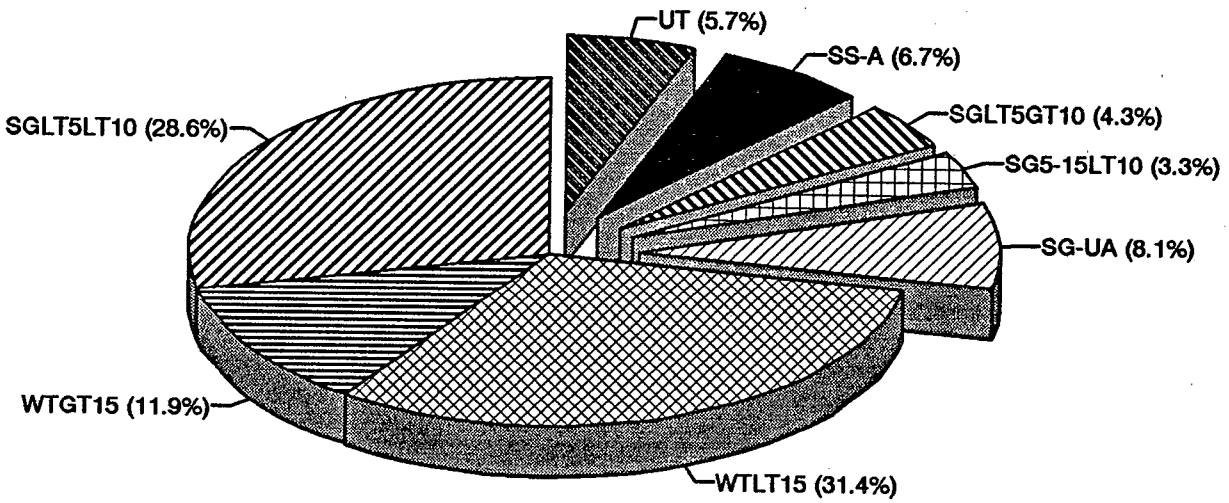

Figure 6.—Percentage of pesticide detections by geozone.

or more wells detecting one or more pesticides during a single groundwater sampling event. For example, at the RS site on July 10, 1990, samples from three shallow wells contained a range of Banvel (dicamba) from 0.04 to 0.83 parts per billion (ppb), and samples from two deep wells contained the same chemical at a range of 0.02 to 0.09 ppb. Banvel (dicamba) was applied to the field approximately one month before sampling, and a major precipitation event occurred between its application and sampling.

The pesticides applied to the field sites are presented in Table 7. Lasso (alachlor) was the most commonly detected pesticide, followed by 2,4-D, Banvel (dicamba), and Sencor (metribuzin) (Fig. 7). The detection of pesticides was primarily seasonal in nature, because most detections clustered in the late spring and summer months (Fig. 8). A variable in the detection of pesticides in groundwater appears to be the timing of pesticide application in relation to the occurrence, duration, and intensity of precipitation events. Undoubtedly, the topsoil and unsaturated zone play the most important roles in the storage of pesticide residues. The timing, release, and transport of pesticides to the groundwater occur as the soil moisture is replenished, and entrained pesticides migrate through unsaturated flow to the water table.

Table 7.—Pesticides used on field sites.

Banvel (dicamba)	Roundup (glyphosate)
Basagran	Ramrod (propachlor)
Furadan (carbofuran)	Sencor (metribuzin)
Lasso (alachlor)	Treflan (trifluralin)
MCPA	2,4-D
Classic (chlorimuron)	Dual (metolachlor)

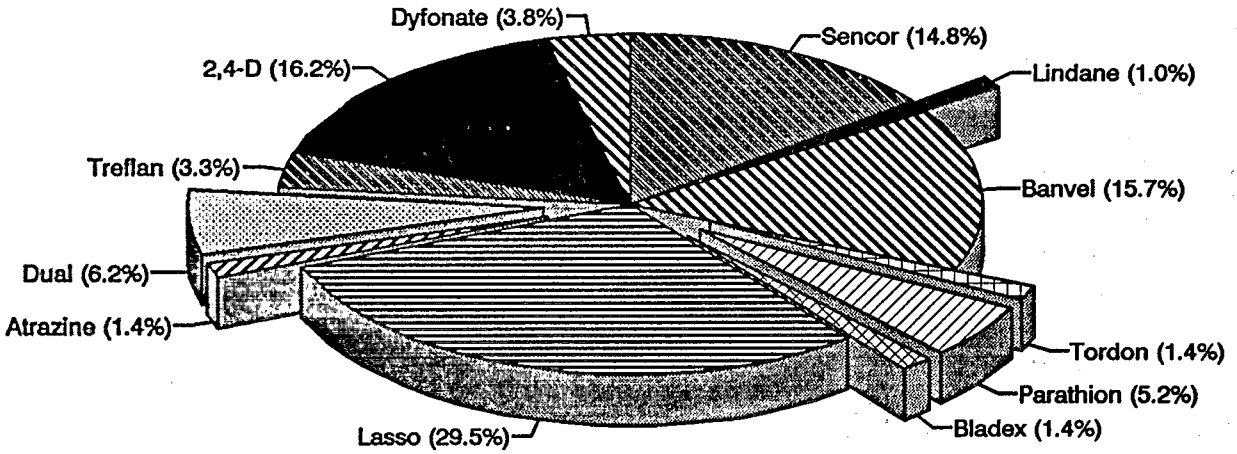

Figure 7.—Percent of total pesticide detections.

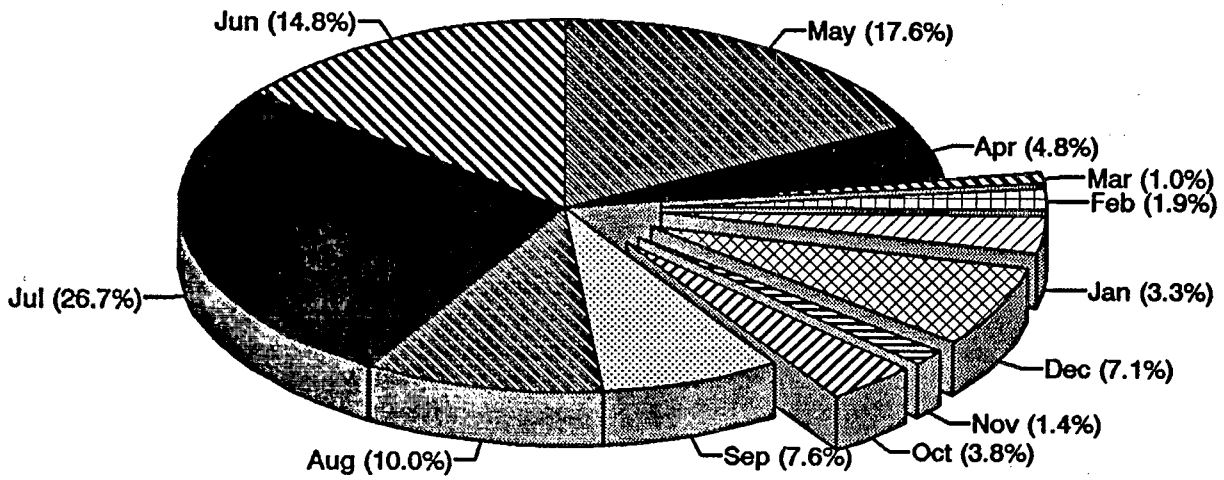

Figure 8.—Months when pesticides were detected.

Three pesticides correlated positively with application on field sites and the subsequent detection of the pesticide in groundwater (Table 8). These pesticides were Lasso (alachlor), 2,4-D, and Banvel (dicamba). These three compounds accounted for more than 61 percent of the pesticides detected. The frequent detection of pesticides that have no history of use at the site on which they were detected (parathion and Sencor) account for greater than 20 percent of detections. These detections could be a result of improper reporting of applications by the operators, atmospheric transport of chemicals, contaminated application equipment, pesticides in groundwater or surface water that flows into or onto the site; or they may result from the extended time span during which the chemicals were entrained in the unsaturated zone.

Overall, concentrations of pesticides detected during the Oakwood Lakes-Poinsett RCWP study were extremely low (Fig. 9). Continual leaching of pesticides resulting in sustained groundwater contamination does not appear to be a problem at any field sites in the Oakwood Lakes-Poinsett RCWP project area. Therefore, BMPs for pesticides applied at label rates did not create a long-term negative effect on groundwater quality in this study area.

Conclusions and Recommendations

NO_3-N was found in excess of 10 ppm in at least one monitoring well at each field site, but in total, 15 percent of the samples exceeded EPA's maximum contaminant level for NO_3-N in drinking water. With few exceptions, NO_3-N concentrations greater than 5 ppm were not found at depths greater than 20 feet below the water table. Nitrate concentrations in the groundwater were affected by infiltration events and crop rotations that included crops requiring higher

Table 8.—Pesticide applications and detection.

	BL site		JW site		PH/LK site		RS site		VC site		OP site	
	A	D	A	D	A	D	A	D	A	D	A	D
Ambien												
Atrazine		X	X					X				
Banvel	X	X	X	X	X	X	X	X	X	X		X
Basagran*	X						X					
Bladex		X		X		X						
Classic*	X											
Counter												
Dual		X				X		X	X	X		X
Dyfonate	X			X		X						X
Eradicane					X							
Furadan							X					
Lasso	X	X		X		X	X	X		X		X
MCPA*	X				X		X		X			
Ramrod	X		X				X					
Roundup*			X									
Sencor		X		X				X				X
Sutan												
Thimet												
Tordon		X									X	X
Treflan	X			X	X	X		X				X
endrin												
lindane		X										
methoxychlor												
parathion				X		X		X		X		
toxaphene												
2,4-D	X	X	X	X		X	X	X			X	X

A - Pesticide applied at site

D - Pesticide detected at site

* - Pesticides not included in analytical scan

nitrogen application. The three apparent dominant controls on NO_3-N concentrations in the groundwater were

- the amount of nitrogen applied to the land surface,
- the volume of infiltration, and
- denitrification in the aquifer.

Projectwide, the pesticide sampling program resulted in 11.3 percent of the groundwater samples with detectable concentrations of pesticides. Lasso (alachlor), 2,4-D, and Banvel (dicamba) were the most frequently used chemicals on the field sites and were the most frequently detected chemicals in the groundwater. Several chemicals were detected in the groundwater samples from field sites with no history of application at the sites. Most detections of pesticides were one time occurrences with no detections of the same chemical in the same well in subsequent sampling events. The application of a chemical and the subsequent detection of the chemical in the groundwater were commonly separated by up to a year's time. This data clearly indicated that pesticide residues may remain in the soil profile for an extended period, tied up in the soil matrix and released during infiltration events rather than

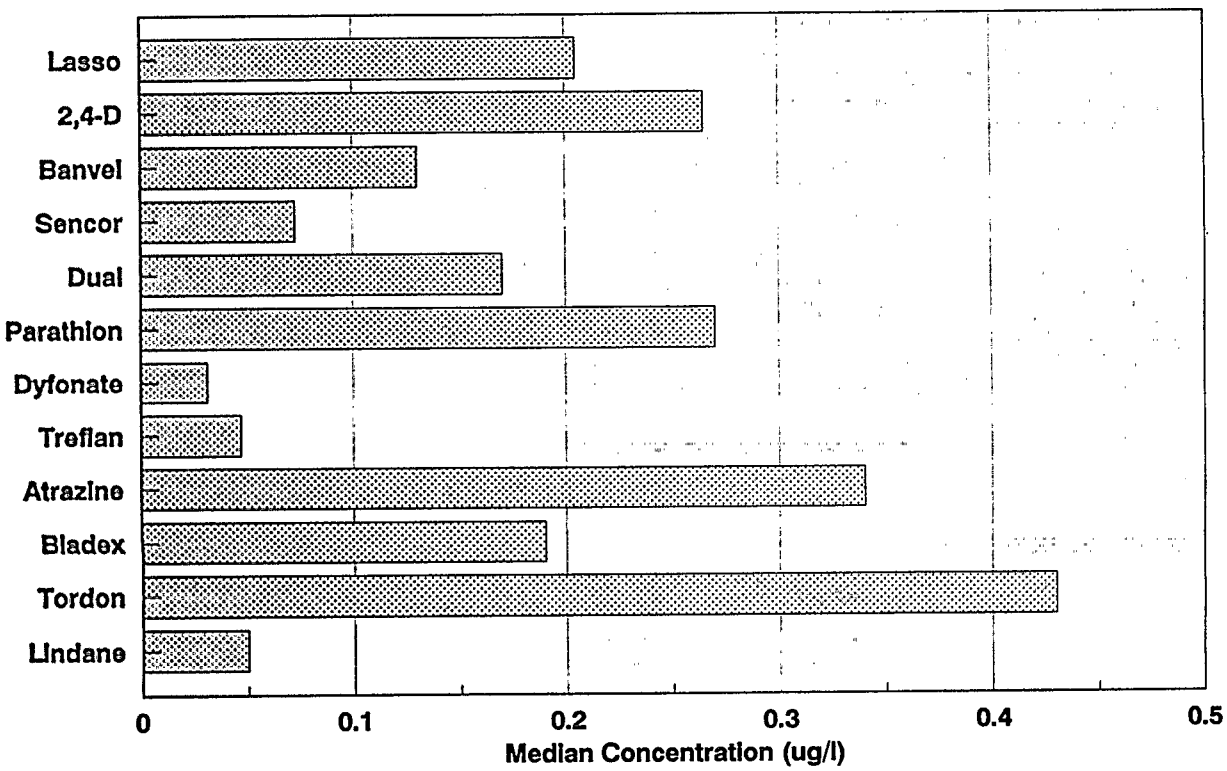

Figure 9.—Median pesticide concentrations: all sites.

moving to the groundwater shortly after application. Although some detections of Atrazine and Lasso (alachlor) were in concentrations at or above EPA's maximum contaminant levels or health advisories, overall pesticide concentrations were extremely low.

No significant differences in groundwater quality were found between field sites with conservation tillage practices and field sites with conventional tillage; however, at research plots in the study area, vadose zone monitoring measured differences in the rate of water movement and quantities of water and NO_3-N to the 6-foot depth between no-till plots and moldboard plow plots. NO_3-N concentrations were significantly higher at the farmed field sites than at the unfarmed site.

Water quality monitoring began concurrently with BMP implementation. Therefore, it was difficult to establish a positive correlation between BMPs and water quality impacts. It is evident, however, that after groundwater monitoring began, the overall change in groundwater quality attributable to agricultural chemicals was negligible. It appears that label rate pesticide application does not have a sustained long-term negative effect on groundwater quality.

For future land treatment and water quality projects and in areas defined as vulnerable areas for groundwater quality, the following are recommended:

1. Fertilizer management practices must address timing, rate, and method of application to minimize the amount of nitrogen available to leach by maximizing the amount of fertilizer uptake by the crop.

2. Crop rotations that include crops requiring low to no nitrogen should be used.

3. Pesticide management, especially in areas of vulnerable water supplies, should be used, based on the detection of several pesticides in the groundwater after application to the land surface.

4. Water supply wells should be constructed so that the screened portion of the well does not produce water from the upper portion of the water-bearing materials where high NO_3-N concentrations can occur.

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Water Quality Trends in the St. Albans Bay, Vermont, Watershed Following RCWP Land Treatment

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ABSTRACT

The St. Albans Bay Rural Clean Water Program project sought to improve water quality in eutrophic St. Albans Bay and its tributaries by implementing improved management practices to control nonpoint sources of pollution from dairy agriculture. The goal of comprehensive monitoring and evaluation was to evaluate water quality changes in the bay and its tributaries resulting from the land treatment program. Despite a significant reduction in point source phosphorus load, St. Albans Bay water quality did not improve significantly, probably because of internal phosphorus loading. Sediment concentration and export decreased significantly in most tributaries. Phosphorus concentrations increased in most monitored streams, but export did not change significantly. Nitrogen concentrations and export increased across the watershed. Indicator bacteria counts in all monitored streams, however, declined by 50 to 70 percent, suggesting that the land treatment program did affect water quality. Because these bacteria are not readily stored in the environment, their rapid decline may represent the leading edge of greater water quality improvements to come as current nutrient losses from agricultural land decline and nutrients historically accumulated in the system are gradually flushed out.

St. Albans Bay on Lake Champlain in Vermont has been subjected to increasing rates of eutrophication because of excessive phosphorus loads from both point and nonpoint sources. The primary goal of the St. Albans Bay Rural Clean Water Program (RCWP) project was to improve water quality and restore beneficial uses in the bay and its tributaries by implementing a program of agricultural best management practices (BMPs) to control nonpoint sources of pollution. Begun in 1980 and completed in 1991, the St. Albans Bay RCWP project was one of five nationwide to include comprehensive monitoring and evaluation (CM&E) to assess water quality changes in response to land treatment.

The effectiveness of watershed land treatment programs in improving water quality has not been well documented (Braden and Uchtmann, 1985). Few of the early watershed agricultural nonpoint source control programs were able to document water quality improvements following intensive implementation of BMPs (Harbridge House, Inc., 1983). This lack of response has been attributed to the incremental process of land treatment, short duration of monitoring, and difficulty in controlling for natural and cultural variability (Morrison and Lake, 1981; Persson et al. 1983). Recently, however, improvements in water quality have been reported in some agricultural nonpoint source projects. Under the RCWP, projects in Idaho, Florida, and elsewhere

have begun to show water quality changes following land treatment (Soil Conserv. Serv. et al. 1991; Flaig and Ritter, 1989; Natl. Water Qual. Eval. Proj. 1988). This paper presents the principal findings of the CM&E effort in the St. Albans Bay Watershed RCWP project.

Study Area

The St. Albans Bay watershed is located in northwestern Vermont 40 km north of Burlington and drains 13,000 ha of agricultural, forested, and urban land into St. Albans Bay of Lake Champlain. The 700 ha bay is 4.2 km long and 2.2 km wide. Mean depth is 8 m, maximum depth is 12 m. Four major tributaries drain the watershed into St. Albans Bay (Fig. 1):

- Jewett Brook (median flow = 0.03 m^3/sec);
- Stevens Brook (median flow = 0.16 m^3/sec);
- Rugg Brook (median flow = 0.19 m^3/sec); and
- Mill River (median flow = 0.46 m^3/sec).

The city of St. Albans tertiary wastewater treatment plant discharges about 91 m^3/sec to Stevens Brook wetland at the head of the bay.

The St. Albans Bay watershed is primarily in the Champlain Lowlands, an area of generally low relief between Lake Champlain and the foothills of the Green Mountains. Watershed soils formed on glacial till or lacustrine deposits and include loams (51 percent) (half of which are poorly drained); silts and clays (27 percent); rock outcrop (15 percent); and sands (7 percent). The climate is cool and humid, with pronounced seasonal variations. Mean annual temperature is 7.3°C, and the growing season averages 150 days. Mean annual precipitation is 845 mm, with a minimum average monthly precipitation in February of 44 mm and a maximum average monthly rainfall in August of 100 mm. Average annual snowfall is 1,550 mm.

Sixty-five percent of the land in the watershed is devoted to agriculture, about 20 percent is forested, and 10 percent is urban and residential. Of the 102 farms in the watershed, dairy farms predominate and average 134 ha, with a mean herd size in 1991 of 110 animal units, up from 95 animal units in 1980. Corn for silage is the principal cultivated crop, with land in corn ranging from 1,336 to 1,821 ha or about 10 to 15 percent of the total watershed. Substantially more agricultural land is devoted to hay: 3,845 to 4,452 ha or about 30 to 35 percent of the watershed. Some cropland in the watershed has been in continuous corn cultivation; a three-year corn/five-year hay rotation is the prevalent practice. Both manure and commercial fertilizer are commonly applied to corn cropland; hayland is generally manured twice a year, immediately following haying.

Recreation, aesthetics, and other beneficial uses of St. Albans Bay have been impaired by eutrophication for many years. The most serious nonpoint source water quality problems associated with agriculture in the St. Albans Bay watershed have been nutrients (principally phosphorus) from runoff of animal and milkhouse waste and sediment from cropland erosion. Improper manure management — year-round spreading because of lack of waste storage — and inadequate milkhouse waste and barnyard runoff management were thought to be the principal contributors to water quality problems. Improper fertilizer management — failure to balance manure and fertilizer nutrient applications with soil and crop needs — was also thought to be a significant contributor to excessive nutrient loading. Erosion of cropland soil and streambanks also contributed to the decline in water quality.

Methods

Water Quality Monitoring

Four levels of water quality monitoring were conducted to document water quality changes in St. Albans Bay and its tributaries:

- **Level 1,** bay sampling,
- **Level 2,** tributary trend monitoring,
- **Level 3,** an edge-of-field BMP study, and
- **Level 4,** randomized grab sampling.

The design and specific methods of these and other elements of the CM&E program, including biological and land use monitoring, have been discussed in detail elsewhere (Clausen, 1985; Vt. RCWP Coord. Comm. 1991; Meals, 1992). Only Level 1 and 2 monitoring will be discussed in this paper.

■ **Level 1.** St. Albans Bay was monitored by four Level 1 stations sampled 20 times each year (Fig. 1). Grab samples were collected at Stations 11 (outer bay), 12 (inner bay), and 14 (off-bridge) at a 0.5 m depth and 1.0 m from the bottom using a Kemmerer sampler. Samples were analyzed for turbidity, total suspended and volatile suspended solids, total and soluble reactive phosphorus, total Kjeldahl and ammonia nitrogen, and chlorophyll *a*. *In situ* measurements were made of temperature, dissolved oxygen, pH, conductivity, and Secchi disk trans- parency. Surface samples collected at Station 13, located just offshore of the former public beach, were analyzed for

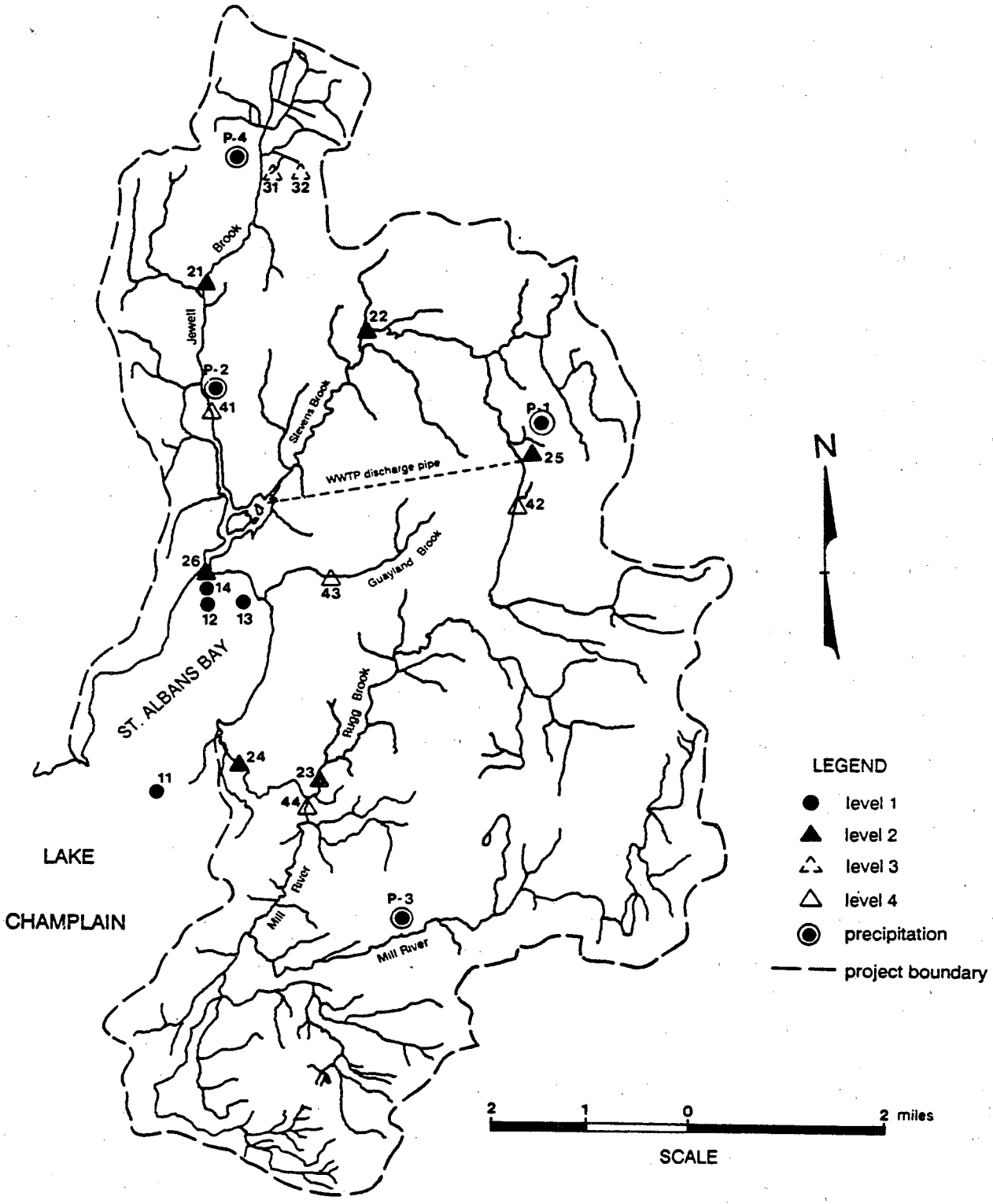


Figure 1.—Map of St. Albans Bay watershed, showing location of monitoring stations.

fecal coliform and fecal streptococcus bacteria. Additional biological monitoring in the bay included annual macrophyte surveys by aerial photography as well as algal enumerations at Stations 11, 12, and 14.

■ **Level 2.** Level 2 tributary trend monitoring was designed to determine long-term patterns of concentration, streamflow, and load in the four major tributaries to St. Albans Bay and from the St. Albans

city wastewater treatment plant. The subwatersheds monitored by these trend stations comprised 72 percent of the entire St. Albans Bay watershed. A fifth station monitored sediment and nutrient loads from the wastewater treatment plant, the major point source in the watershed.

At each of the five Level 2 stations, samples were collected automatically at eight-hour intervals using refrigerated ISCO samplers and combined into two 48-hour and one 72-hour composite samples each week for analysis. During some stormflow periods, individual samples were analyzed discretely. This sampling/compositing schedule was dictated by budgetary restrictions and because the use of previously ungaged stations precluded flow-proportional sampling. It should be recognized that this program probably tended to underestimate export rates by over-sampling low-flow periods and under-sampling high-flow periods. However, the importance of consistency in sampling schedules for long-term trend monitoring outweighed the benefits of changing to a flow-proportional sampling schedule after stage-discharge ratings were developed.

All Level 2 samples were analyzed for turbidity, total suspended and volatile suspended solids, total and soluble reactive phosphorus, and total Kjeldahl, ammonia, and nitrite+nitrate nitrogen. Weekly grab samples were analyzed for pH, conductivity, and fecal coliform and fecal streptococcus bacteria, while *in situ* measurements were made of temperature and dissolved oxygen at the time of grab sampling.

Stream stage was recorded continuously at each Level 2 station using ISCO bubbler-type stage recorders and discharge was calculated from site-specific stage-discharge ratings. Three standard 20-cm weighing bucket gages were used to measure watershed precipitation.

Data Analysis

The lack of preproject water quality data, the concurrent start-up of both monitoring and land treatment, and the incremental implementation of BMPs made straightforward before/after comparisons impossible. Since no appropriate control watershed was available, paired-watershed analysis was also impractical. Therefore, evaluation of changes in water quality were based on the detection of trends over time.

Some adjustments to these data were necessary to satisfy statistical assumptions. To reduce autocorrelation problems, concentration, streamflow, and mass data were typically aggregated to monthly mean values for trend analysis. Neither original data nor these monthly means followed a normal distribution; all parametric statistical analyses were performed on log(base 10) transformed data. All means reported for parametric tests are antilogs of these log means (geometric means). While some small bias was introduced by back-transforming these means, it should be noted that parametric trend tests, such as regression and analysis of variance (ANOVA), were conducted and interpreted in log space, not on retransformed data. Thus, the influence of retransformation bias on the conclusions of trend analysis was probably minimal.

For some analyses, monitoring data were divided into approximate pre-BMP and post-BMP periods, based on the progress of implementation. Although the gradual application of land treatment did not provide an absolute before/after break, it was useful to approximate such a division. Project Years 1982–85 (covering 9/1982 through 8/1986) were considered pre-BMP because active contracting and implementation took place during this period. By August 1986, all critical acres were under contract, over 75 percent of animal waste systems had been installed, and more than 80 percent of goals for animal units, nitrogen, and phosphorus under BMP had been achieved. Thus, Project Years 1986–89 (covering 9/1986 through 8/1990) were designated post-BMP.

To fully explore the data, a variety of trend analysis techniques were used: simple linear regression against time, t-test of pre- and post-BMP periods, ANOVA, comparison of pre- and post-BMP flow and concentration relationships, analysis of covariance (ANCOVA), and nonparametric tests such as Mann-Whitney and seasonal Kendall. Using numerous trend tests was somewhat cumbersome but necessary because of the complexity of the data set, which made reliance on a single technique unwise. Some tests, such as time regression, were used only as screening tools because the high number of observations tended to inflate the apparent significance of the regression. The ANCOVA technique was employed to test for trends in concentration data while controlling for streamflow variation but proved inappropriate for export data. Some tests were applicable to data sets with particular characteristics, such as seasonality (e.g., seasonal Kendall). Different trend tests were also required to assess monotonic or step trends. Furthermore, the application of several different trend tests provided some additional confidence in the interpretation of results: a trend confirmed by all analyses was judged more meaningful than one indicated by only one test. Different approaches did not disagree on the direction of change but on magnitude and statistical significance. Statistical significance of trend test results was evaluated at $P \leq 0.10$.

Results

Land Treatment

Of the 102 farms in the St. Albans Bay watershed, 61 signed RCWP contracts. Land treatment in the watershed achieved 98 percent of goals for critical acre treatment and 95 percent of goals for critical source treatment. The most widely used BMPs were animal waste management (BMP 2) and cropland protection (BMP 8), which were included in 93 percent and 92 percent of all contracts, respectively. Other widely applied BMPs included permanent vegetative cover (BMP 1), stream protection system (BMP 10), permanent vegetative cover on critical areas (BMP 11), and fertilizer management (BMP 15). Overall, 64 manure storage systems, 61 barnyard runoff control systems, and 43 milkhouse waste treatment systems were installed and 3,760 ha of conservation cropping systems were implemented. After implementation was complete, 79 percent of watershed animal units were under BMP, representing 133 tons of manure phosphorus and 664 tons of manure nitrogen under proper waste management.

St. Albans Wastewater Treatment Plant

The quality of effluent from the city of St. Albans wastewater treatment plant improved dramatically following a 1987 upgrade of the plant to tertiary treatment. The main result of the upgrade was a major decrease in sediment and nutrient concentration and export and a decrease in bacteria counts in plant effluent. Mean effluent total phosphorus levels, for example, dropped from over 5 mg/L to 0.50 mg/L after the upgrade, and monthly effluent total phosphorus load dropped 85 percent from 984 kg/month to 147 kg/month. The distribution of nitrogen species in effluent shifted from predominantly total Kjeldahl nitrogen and ammonia nitrogen to substantial proportions of nitrite-nitrate nitrogen because of increased nitrification. Despite significant increases in nitrite+nitrate concentration and load, effluent total nitrogen concentration and load decreased nearly 35 percent after the upgrade.

One additional effect of the treatment plant upgrade was improvement in plant operations, which eliminated periodic overflows of untreated wastewater to Stevens Brook. These discharges had strongly influenced water quality observed at Stevens Brook Station 22, and improvements in Stevens Brook water quality were likely a result of their elimination.

Tributary Streams

Year-to-year variation in watershed precipitation and tributary discharge was significant but without a consistent pattern. Above-average precipitation and high streamflows occurred in project years 1983, 1985, and 1989; successive years of below-average precipitation and low streamflows characterized most of the second half of the monitoring period (1986–88).

Sediment and nutrient concentrations, which varied between watersheds and between years throughout the project, were influenced by differences in weather, runoff, and streamflow. Water quality data over the monitoring period are summarized in Table 1. The Jewett Brook watershed (Station 21), with the highest proportion of land in agriculture and the highest level of agricultural activity in the St. Albans Bay watershed, consistently exhibited the highest concentrations of suspended solids, phosphorus, and nitrogen and bacteria counts over the monitoring period (Meals, 1992).

Sediment and nutrient export from the tributary watersheds varied strongly with season and with streamflow. Most annual export occurred during spring snowmelt, midwinter thaws, or summer storm events. Total annual sediment and nutrient export across the monitored tributaries to St. Albans Bay is summarized in Figure 2. During the final year of monitoring, nonpoint sources contributed an estimated 99 percent of the suspended solids, 93 percent of the phosphorus, and 85 percent of the nitrogen loading to St. Albans Bay.

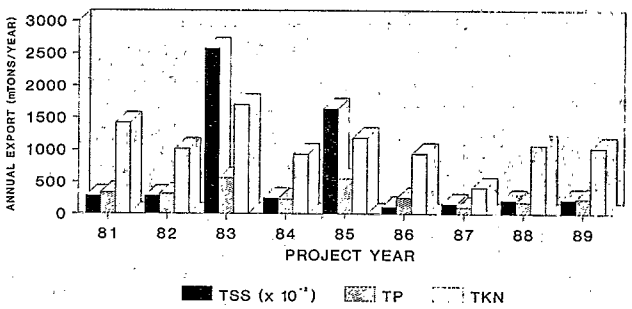


Figure 2.—Plot of total annual sediment and nutrient export from monitored tributaries, St. Albans Bay watershed, project years 1981 to 1989. Values plotted represent sum of measured export from the monitored subwatersheds plus the point source contribution. Values do not represent total load to St. Albans Bay because exports from ungaged portions of the watershed are not included.

Areal nutrient loading rates from the monitored tributary watersheds differed among the watersheds, and these rates were generally higher than average values cited for other agricultural water-

Table 1.—Range in annual mean[1] water quality, Level 2 monitoring stations, St. Albans Bay watershed.

	JEWETT BR. (STA. 21)	STEVENS BR. (STA. 22)	RUGG BR. (STA. 23)	MILL R. (STA. 24)	WWTP (STA. 25)
[TSS] (mg/L)	14.6–24.9	11.1–35.2	5.6–16.1	5.9–14.6	5.6–102.8
[VSS] (mg/L)	4.0–7.0	2.7–6.4	1.6–2.9	1.9–2.8	3.5–78.9
[TP] (mg/L)	0.68–1.04	0.15–0.30	0.10–0.15	0.08–0.17	0.35–5.89
[SRP] (mg/L)	0.33–0.61	0.07–0.24	0.02–0.06	0.02–0.06	0.08–3.87
[TKN] (mg/L)	2.0–3.7	0.8–1.0	0.6–0.9	0.6–0.9	2.7–20.0
[NH_3-N] (mg/L)	0.5–0.9	0.1–0.2	0.1–0.2	0.1–0.2	1.3–10.9
[NO_2+NO_3-N] (mg/L)	0.2–1.3	0.4–0.9	0.2–0.4	0.2–0.5	0.1–6.4
FC(#/100 mL)	230–1,600	180–1,200	110–330	60–230	1–700,000
FS(#/100 mL)	50–450	50–340	30–230	20–140	<1–190,000
Q(m^3/sec)	0.01–0.09	0.11–0.28	0.14–0.41	0.26–0.98	0.06–0.14
TSS (kg/mo)	790–10,000	5,600–26,000	4,200–64,000	9,600–150,000	1,800–15,200
VSS (kg/mo)	260–1,700	1,300–3,300	780–2,700	1,800–7,900	970–12,500
TP (kg/mo)	30–190	75–340	60–240	110–400	100–1,300
SRP (kg/mo)	20–120	24–110	10–60	30–160	20–900
TKN (kg/mo)	90–760	250–760	230–950	480–2,000	800–4,000
NH_3-N (kg/mo)	30–130	40–180	40–130	90–300	400–2,400
NO_2+NO_3-N (kg/mo)	40–250	150–620	100–570	210–1,250	10–2,120

[1]geometric mean (anti-log of log mean)

TSS = total suspended solids; VSS = volatile suspended solids; TP = total phosphorus; SRP = soluble reactive phosphorus; TKN = total Kjeldahl nitrogen; NH_3-N = ammonia nitrogen; NO_2+NO_3-N = nitrite+nitrate nitrogen; FC = fecal coliform; FS = fecal streptococcus; Q = streamflow.

sheds in the United States (Table 2). The Jewett Brook watershed tended to exhibit the highest areal nutrient export rates in the St. Albans Bay watershed, rates that were higher than those observed in similar agricultural watersheds in Vermont (Meals, 1990). The Stevens Brook watershed generally showed the lowest nutrient export rates.

Water quality trends in tributaries to St. Albans Bay were evaluated using regression, pre- and post-t-test, ANOVA, ANCOVA, and nonparametric tests such as the seasonal Kendall and Mann-Whitney. Monthly mean streamflow, mean concentration of measured parameters, and monthly sediment and nutrient export values were used as the basic data set. The results of trend analysis are reported in detail in the project's final report (Vt. RCWP Coord. Comm. 1991); tributary trends are summarized in Table 3.

Although tributary stream discharge varied from year to year, there were no strong, consistent trends observed that would drive overall trends in water quality across the St. Albans Bay watershed. Stream discharge did, however, tend to be slightly lower in the post-BMP period, compared to pre-BMP.

Turbidity and both concentration and export of suspended solids declined in all tributaries except Jewett Brook. According to the seasonal Kendall test, total suspended solids concentrations declined by 4.1 mg/L/year in Stevens Brook, 1.1 mg/L/year in Rugg Brook, and 1.4 mg/L/year in Mill River. Declines in volatile suspended solids concentration were estimated at 0.2 to 0.3 mg/L/year. Mean suspended solids levels in Jewett Brook, however, showed a significant 10 to 15 percent increase between pre-BMP (15.3 mg/L) and post-BMP (17.1 mg/L) periods, even when differences in flow were controlled.

Sediment export from the Stevens Brook watershed dropped from a pre-BMP average of 25,000 kg/month to a post-BMP average of 8,274

Table 2.—Range of areal export observed in St. Albans Bay watersheds, 1982–90.

	JEWETT BR.	STEVENS BR.	RUGG BR.	MILL R.	LaPLATTE R. WATERSHEDS (VT)[1]	U.S. WATERSHEDS[2]	GREAT LAKES WATERSHEDS[3]
	kg/ha/yr						
TSS	7–54	104–552	174–1,927	156–4,025	11–696	—	3–5,600
TP	1.1–6.4	1.1–2.8	1.3–6.1	0.8–6.2	0.2–2.5	0.1–0.3	0.1–9.1
SRP	0.6–4.0	0.2–0.9	0.3–2.4	0.2–1.2	0.1–1.2	0.09–0.13	0.1–0.6
TKN	3.3–24	3.9–7.6	4.4–16	2.6–15	1.4–20	5.2–9.8	0.6–4.2

[1] Meals, 1990
[2] Omernik, 1976, 1977
[3] Pollut. from Land Use Act. Ref. Group, 1978
TSS = total suspended solids; TP = total phosphorus; SRP = soluble reactive phosphorus; TKN = total Kjeldahl nitrogen.

Table 3.—Trends in St. Albans Bay tributary water quality, 1982–90.

	CONCENTRATION									
	TRB	TSS	VSS	TP	SRP	TKN	NH_3-N	NO_2+NO_3-N	FC	FS
Jewett Br.	▽	△	△	△	●	△	△	△	▼	▼
Stevens Br.	▽	▼	▼	▼	▼	●	▽	●	▼	▼
Rugg Br.	▽	▼	▼	▲	▲	▲	▲	▲	▼	▼
Mill R.	▽	▼	▽	▲	▲	▲	△	▲	▼	▼
WWTP	▼	▼	▼	▼	▼	▼	▼	▲	▼	▼

	MASS							
	Q	TSS	VSS	TP	SRP	TKN	NH_3-N	NO_2+NO_3-N
Jewett Br.	●	▽	●	●	●	●	●	●
Stevens Br.	●	▼	▽	▼	▼	▽	▼	▽
Rugg Br.	●	●	●	●	●	▲	▲	▲
Mill R.	●	▽	▽	●	●	●	●	▲
WWTP	▲	▼	▼	▼	▼	▼	▼	▲

● = No significant trend

△▽ = Increasing or decreasing trend by some but not all statistical tests ($P \leq 0.10$)

▲▼ = Increasing or decreasing trend by all statistical tests ($P \leq 0.10$)

TRB = turbidity; TSS = total suspended solids; VSS = volatile suspended solids; TP = total phosphorus; SRP = soluble reactive phosphorus; TKN = total Kjeldahl nitrogen; NH_3-N = ammonia nitrogen; NO_2+NO_3-N = nitrite+nitrate nitrogen; FC = fecal coliform; FS = fecal streptococcus; Q = streamflow.

kg/month, a decline of 67 percent. Sediment export from the Mill River watershed declined 59 percent from an average of 37,000 kg/month pre-BMP to an average of 15,000 kg/month post-BMP. Total suspended solids export from the Jewett Brook watershed dropped 60 percent from an average 33,000 kg/month to 13,350 kg/month in the post-BMP project period, according to the seasonal Kendall test.

Phosphorus concentrations increased significantly over the monitoring period in Jewett Brook, Rugg Brook, and Mill River but declined in Stevens Brook. In Jewett Brook, the mean post-BMP total phosphorus concentration of 0.67 mg/L was 13 percent higher than the pre-BMP mean of 0.76 mg/L. In Rugg Brook and Mill River, total phosphorus concentrations increased by an estimated 0.010 mg/L/year and soluble reactive phosphorus levels increased by 0.006 mg/L/year. These increases were still significant when concentrations were adjusted for differences in streamflow using ANCOVA. In contrast, total phosphorus and soluble reactive phosphorus concentrations in Stevens Brook both declined by 0.018 mg/L/year. Few significant trends in phosphorus export from the monitored watersheds occurred during the study period. In Stevens Brook, total phosphorus and soluble reactive phosphorus export declined by 40 percent and 55 percent, respectively, in the second half of the project, but no other significant trends were observed.

Concentrations of all forms of nitrogen generally increased over the entire St. Albans Bay watershed during the monitoring period, although fewer statistically significant trends were observed than for phosphorus because of high variability in observed nitrogen levels. Most significant changes in nitrogen concentration seemed to occur in Rugg Brook and in Mill River. Concentrations of total Kjeldahl and nitrite-nitrate nitrogen in Mill River, for example, increased by an average of 0.04 mg/L/year and 0.05 mg/L/year, respectively. In Rugg Brook, ammonia and nitrite-nitrate nitrogen levels increased by about 0.01 mg/L/year and 0.03 mg/L/year, respectively. These increases became most apparent around 1987–88, corresponding to similar areawide increases in nitrogen levels observed in other Vermont watersheds (Meals, 1990) and the Great Lakes region (Richards, 1991). The explanation for this phenomenon is unclear. Significant increases in nitrogen concentrations did not occur in Stevens Brook, where a 13 percent decline in average post-BMP NH_3-N levels was observed.

Changes in nitrogen export across the St. Albans Bay watershed followed a pattern similar to changes in nitrogen concentrations. No significant trends in nitrogen export from the Jewett Brook watershed were documented. Nitrogen export from the Stevens Brook watershed tended to decline; in the latter half of the project, export of total Kjeldahl nitrogen, ammonia, and nitrite-nitrate nitrogen declined by 30 percent, 46 percent, and 32 percent, respectively. As with concentration, nitrogen export from the Rugg Brook and Mill River watersheds tended to increase. Monthly export of all forms of nitrogen from Rugg Brook increased significantly in the later project years: total Kjeldahl nitrogen +90 percent, ammonia nitrogen +160 percent, and nitrite-nitrate nitrogen +100 percent. The Mill River watershed showed an estimated 110 percent increase in

monthly nitrite-nitrate nitrogen export; however, no trends in total Kjeldahl nitrogen or ammonia nitrogen export were observed.

Fecal coliform (FC) and fecal streptococcus (FS) bacteria counts declined significantly across all the monitored St. Albans Bay tributaries. Declines in FC counts were greatest in Jewett and Stevens brooks, where mean monthly counts decreased by an average 130 to 140 per year. Monthly FC counts in Rugg Brook and Mill River decreased by about 15 to 30 per year. Mean post-BMP FC counts dropped by 50 to 70 percent compared to pre-BMP counts in each of the monitored streams.

Fecal streptococcus (FS) counts also declined significantly across all the monitored tributaries. Again, the declines were greatest in Jewett and Stevens brooks — drops of 30 to 50 per year — compared to 8 to 16 per year in Rugg Brook and Mill River. The decrease in post-BMP FS counts was even greater that the decline in FC: mean post-BMP counts dropped 60 to 70 percent at all of the tributary stations. The decline in indicator bacteria counts is illustrated in Figure 3. These declines are comparable to those observed following land treatment in other Vermont agricultural watersheds (Meals, 1989). The decline in FC and FS counts is the strongest and clearest water quality trend observed in the CM&E project.

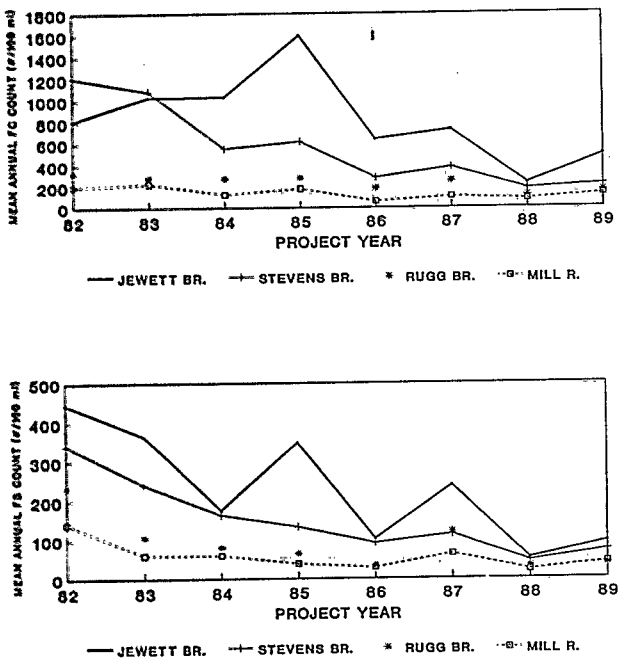


Figure 3.—Plots of mean annual indicator bacteria counts in monitored tributaries, St. Albans Bay watershed, project years 1982 to 1989. Top: fecal coliform bacteria; bottom: fecal streptococcus bacteria.

St. Albans Bay

A water quality gradient typically existed from the north end of the bay (Station 14) to the outer bay (Station 11) for conductivity, Secchi disk transparency, turbidity, suspended solids, phosphorus, nitrogen, and chlorophyll *a* levels. Concentrations tended to be highest at the inner end of the bay, where inflow from Jewett and Stevens brooks dominates, and lowest at the outer bay. Water quality was poorer in the inner region of the bay, which is close to the influence of point and nonpoint sources of sediment and nutrients.

Water quality in St. Albans Bay was variable throughout the monitoring period. Annual mean values for total phosphorus, chlorophyll *a*, and Secchi disk transparency for the three main bay stations are plotted in Figure 4. In the outer bay, median annual total phosphorus concentrations ranged from 20 to 52 µg/L, median chlorophyll *a* levels were 4 to 19 µg/L, and median Secchi disk transparency was 2.7 to 4.3 m. These values were consistent with mesotrophic conditions characteristic of the northeast area of Lake Champlain.

In the inner bay, however, annual median total phosphorus levels were 54 to 76 µg/L, median chlorophyll *a* ranged from 6 to 20 µg/L, and median Secchi disk values were just 1.1 to 1.5 m, all suggestive of eutrophic conditions. At Station 14, just offshore of the Jewett–Stevens Brook inflow at Black Bridge, water quality was even further into the eutrophic range: annual median values were total phosphorus, 66 to 104 µg/L; chlorophyll *a*, 7 to 26 µg/L; and Secchi disk transparency, 0.9 to 1.2 m. Although some year-to-year differences in St. Albans Bay water quality were significant, few consistent patterns were observed during the study.

Water quality trends in St. Albans Bay are discussed in detail in the project's final report (Vt. RCWP Coord. Comm. 1991); trends are summarized in Table 4. Turbidity and suspended solids concentrations generally decreased in inner St. Albans Bay but were unchanged in the outer region of the bay. Phosphorus concentrations increased at both the outer and inner bay stations but decreased significantly at Station 14. Seasonal Kendall tests suggested increases in outer bay total phosphorus and soluble reactive phosphorus concentrations of 6 µg/L/year and 1 µg/L/year, respectively. Similar analysis suggested a decline of 3 µg/L/year in total phosphorus concentrations at the off-bridge station. Fewer significant changes were observed for nitrogen. Concentrations of both total Kjeldahl nitrogen and NH_3-N increased at the outer bay station but did not change significantly in the inner bay.

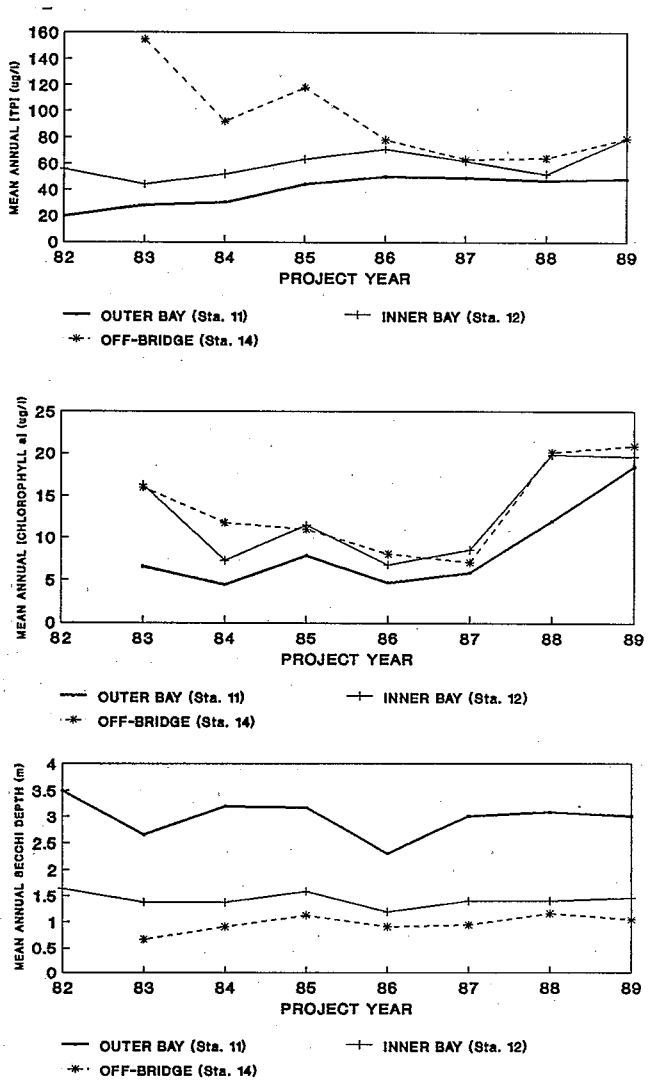


Figure 4.—Plots of mean annual concentrations of phosphorus (top), chlorophyll *a* (middle), and Secchi disk transparency (bottom) in St. Albans Bay, project years 1981 to 1989.

Ammonia levels declined significantly at the off-bridge station.

Chlorophyll *a* concentrations increased by about 2 to 3 µg/L/year at St. Albans Bay stations over the monitoring period. Secchi disk transparency tended to be lower at the inner and outer bay stations in the post-BMP period; no trends in transparency were observed at Station 14.

No statistically significant trends were detected in bacteria counts at the Beach Station (Station 13), principally because of the high variability in the observed counts. However, frequency of fecal coliform counts in excess of the Vermont water quality standard (200 per 100 mL) dropped to near zero during the last three years of the project and median fecal streptococcus counts were at or below detection level for the last two project years. Both patterns suggest declines in indicator bacteria counts near the beach.

Data on algae populations indicated significant declines in algal abundance (cells/L) throughout the bay, but total algal biomass (g/L) tended to increase significantly over the study period. Blue-green algae biomass did not change significantly over the project. Annually, the proportion of blue-green algae in the bay was less than 10 percent; however, during the summer, blue-greens dominated algae in the bay.

Annual macrophyte surveys of the entire bay did not reveal major changes that could be attributed to land treatments. A decline in overall density and extent of macrophytes was noted in 1989 and 1990, particularly for *Myriophyllum spicatum*, the predominant exotic species. However, declines could have resulted from decreases in water clarity caused by increasing algal populations, elevated lake levels from above-normal precipitation in 1990, or predation by an aquatic caterpillar *Acentria acentropus* and other organisms recently discovered to feed and reproduce specifically on *M. spicatum* throughout Vermont (Creed and Sheldon, 1991).

Table 4.—Trends in St. Albans Bay water quality, 1981–90.

Station	TRB	TSS	VSS	TP	SRP	TKN	NH_3-N	CHLα	S.D.
Off-Bridge (14)	▽	▼	●	▼	▽	●	▽	▲	●
Inner Bay (12)	▽	▽	△	△	●	●	●	▲	▽
Outer Bay (11)	●	●	●	▲	▲	▲	▲	▲	▽

● = No significant trend

△▽ = Increasing or decreasing trend by some but not all statistical tests ($P \leq 0.10$)

▲▼ = Increasing or decreasing trend by all statistical tests ($P \leq 0.10$)

TRB = turbidity; TSS = total suspended solids; VSS = volatile suspended solids; TP = total phosphorus; SRP = soluble reactive phosphorus; TKN = total Kjeldahl nitrogen; NH_3-N = ammonia nitrogen; CHL *a* = chlorophyll *a*; S.D. = Secchi disk.

In summary, since the beginning of the RCWP project, St. Albans Bay water quality improved only very slightly in the innermost portion of the bay but declined elsewhere. Nutrient concentrations and algal production generally increased in most of the bay, and water transparency decreased. Only in the innermost bay (Station 14) and at the beach (Station 13) did water quality remain stable or show

slight improvement in terms of slightly decreased nutrient levels and lower bacteria counts.

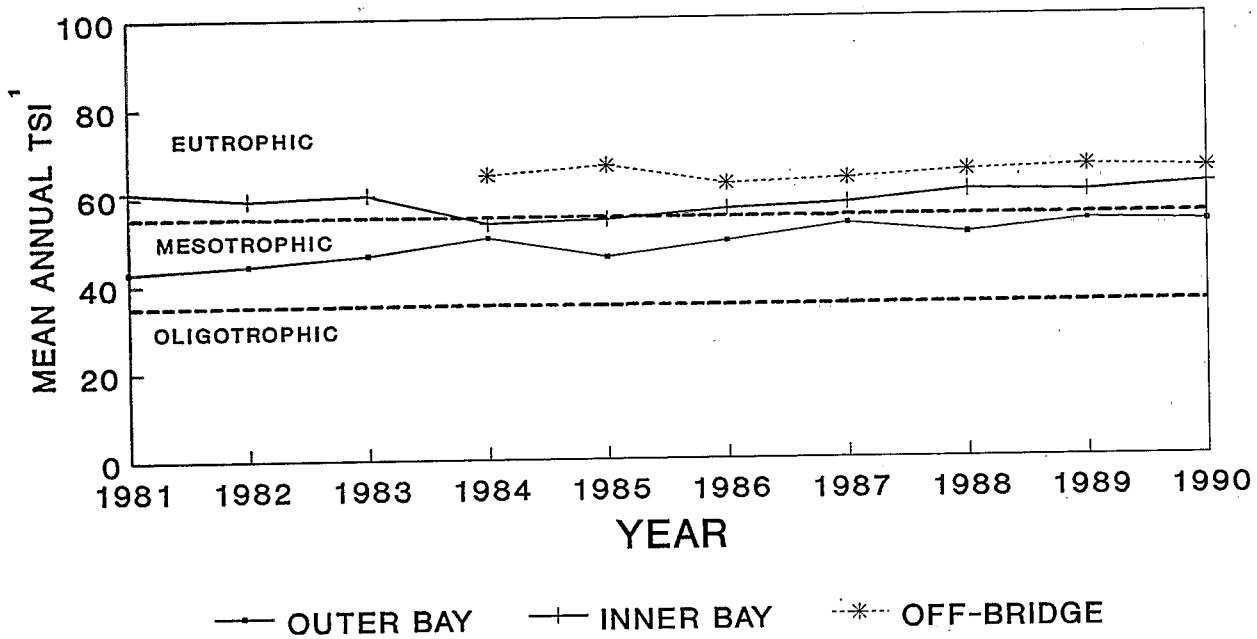
Water quality in St. Albans Bay was tracked using the Trophic State Index (TSI) (Carlson, 1977) as an aggregate measure of condition. Carlson's TSI considers values of total phosphorus, chlorophyll *a*, and Secchi disk and may range from 0 (oligotrophic) to 100 (hypereutrophic). Mean annual TSI values for St. Albans Bay from 1981 to 1990 are plotted in Figure 5; they suggest a trend from mesotrophic to eutrophic conditions. TSI values observed during peak summer algae production were in the eutrophic range. Individual TSI values recorded during peak summer algal growth have been as high as 84, 78, and 63 for Stations 14, 12, and 11, respectively. TSI values at Station 14 have stabilized in recent years, but most of St. Albans Bay remains in the mesoeutrophic range.

Conclusions

Despite dramatic reduction in phosphorus load from the wastewater treatment plant, St. Albans Bay water quality did not improve significantly over the RCWP project period. Recent modeling analysis of St. Albans Bay response to phosphorus loading using a mass-balance model calibrated and verified with CM&E data predicted that substantial summer phosphorus reductions in the bay should have resulted from the treatment plant upgrade (Smeltzer, 1991). The continued high phosphorus levels observed in the bay contradict model predictions and suggest the existence of some other source(s) of phosphorus for St. Albans Bay.

High phosphorus levels in St. Albans Bay sediments have been documented (Corliss and Hunt, 1973) and the potential for internal phosphorus loading in the bay has been established by early studies conducted for the CM&E program (Ackerly, 1983; Drake and Ackerly, 1983; Fowler, 1984; Fowler et al. 1984). Sediment resuspension and chemical release under both anaerobic and aerobic conditions are all possible mechanisms for internal phosphorus loading in the bay. Based on these findings and on modeling results, Smeltzer (1991) suggested that a net flux of phosphorus from the sediments to the water column is supporting continued high algal production in St. Albans Bay. Since phosphorus is being continually removed from the bay by flushing to the main lake, this internal load should persist only as long as phosphorus can be remobilized from the sediments. Thus, after some lag time, St. Albans Bay should respond to the reduced point source phosphorus load.

Unfortunately, no comparable decreases in nonpoint source phosphorus loads from St. Albans Bay tributaries were observed during the RCWP period; the dramatic in-stream water quality improvements



[1]Carlson's Trophic State Index

Figure 5.—Plot of mean annual Trophic State Index values in St. Albans Bay, 1981 to 1990. The dashed horizontal lines represent the areas of transition between trophic state categories.

anticipated when the St. Albans Bay Watershed RCWP project began were not realized. While sediment concentrations and export from most of the monitored tributaries declined, phosphorus concentrations in the streams increased and loads were essentially unchanged. Increases in phosphorus concentrations may have been the result of higher runoff and streamflows in the last years of the project.

Nitrogen concentrations and export generally increased across the watershed. Only in Stevens Brook were reductions in nutrient concentrations and loads noted and these improvements were directly attributable to the wastewater treatment plant upgrade that eliminated discharges of untreated wastewater to the stream upstream of the monitoring station. However, the lack of general improvement in tributary water quality is somewhat puzzling because the effectiveness of many of the BMPs applied has been documented at the edge-of-field scale (Meals, 1990; Vt. RCWP Coord. Comm. 1991).

Several reasons can be advanced for the lack of strong water quality response to the land treatment program. The nature, timing, or level of land treatments may have been inadequate to change water quality above background variability. Some practices, such as riparian zone management or livestock exclusion, were not applied in the project. Furthermore, despite the relatively high level of farmer participation in the RCWP, loads from a few nonparticipating farms may have overwhelmed upland treatment effects. For example, winter manure spreading continued to occur on many noncontract farms, and evidence shows that manure application rates actually increased in some riparian areas during the project (Schlagel, 1992).

The lag time in the system between application of land treatment and improvements in water quality may exceed the monitoring period (Clausen et al. 1992). Just as St. Albans Bay sediments appear to be serving as a reservoir for continued phosphorus supply, so too may watershed soils that have been farmed and fertilized for decades be acting as a continuing nutrient reservoir — despite recent changes in inputs and/or management. Significant supplies of phosphorus may also remain in stream sediments.

The dramatic 50 to 70 percent decline in indicator bacteria counts in all monitored streams is encouraging and argues that the land treatment program did affect water quality. Relationships between some land use and agricultural management changes and observed bacteria levels in streams have been suggested (Meals, 1992). Declines in fecal coliform and fecal streptococcus counts would be expected to result from improvements in animal waste management. Manure storage alone can reduce bacteria levels in manure (Patni et al. 1985). Reduction of daily spreading and increases in incorporation of applied manure should tend to reduce the quantity of bacteria that is transported in runoff from the soil surface. Finally, diversion of barnyard runoff into manure storage structures or otherwise away from surface waters may have diminished a potent source of these bacteria.

It is important to note that, unlike phosphorus, fecal coliform and fecal streptococcus bacteria are not readily stored in the environment. Decreases in their numbers in watershed streams suggest a decreased rate in supply to surface waters. Their rapid decline may represent the leading edge of greater water quality improvements to come as nutrient losses from agricultural land also decline and nutrients accumulated historically in the system are gradually flushed out.

ACKNOWLEDGMENTS: The St. Albans Bay Watershed RCWP Comprehensive Monitoring and Evaluation Program received financial support from the U.S. Department of Agriculture's Agricultural Stabilization and Conservation Service and the University of Vermont. Assistance from the Soil Conservation Service was critical to the success of the program. The cooperation and assistance of the Franklin County Natural Resources Conservation District, the Vermont Cooperative Extension Service, and the Vermont Department of Environmental Conservation is gratefully acknowledged. Finally, the hard work and dedication of Dr. John Clausen, who guided the Comprehensive Monitoring and Evaluation Program for most of its course, are also acknowledged.

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Understanding the Groundwater System: The Garvin Brook Experience

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ABSTRACT

A 15 well monitoring network was established in 1981 to create baseline data and track groundwater quality changes in the Garvin Brook watershed resulting from Rural Clean Water Program (RCWP) best management practices (BMPs). Later, researchers discovered that most of the 15 wells yield water that entered the ground over 30 years ago and will not reflect current land management practices for decades or centuries. Water monitoring and hydrogeologic investigation led to additional discoveries: (1) nitrate contamination of groundwater was a significant problem in the Garvin Brook area and (2) the actual recharge area for major aquifiers in the original project area extends five miles beyond the Garvin Brook surface watershed boundary. Consequently, mid-course adjustments were made to the project, including increased emphasis on groundwater protection BMPs, expansion of the project area to include all of the groundwater recharge area, and increased monitoring of wells yielding recent water. Trend analysis of data collected between 1983 and 1990 shows decreasing nitrate concentrations in high nitrate domestic wells. Vadose zone modeling results, however, indicate that it will take several decades before the benefits from nitrogen management BMPs are fully realized. The value of conducting a diagnostic study before BMP implementation became increasingly apparent during the Garvin Brook RCWP project.

Garvin Brook watershed in Winona County, Minnesota, is one of 21 Rural Clean Water Program (RCWP) project sites throughout the United States established to evaluate the social, economic, and technical aspects of controlling nonpoint source pollution. The Garvin Brook RCWP, one of three RCWP projects with a major focus on improving groundwater quality, began in 1981 by providing financial and technical assistance to farmers implementing best management practices (BMPs) to prevent nonpoint source pollution of streams and groundwater.

The original emphasis of the project was to protect and monitor streams in the Garvin Brook watershed. However, groundwater protection and monitoring became increasingly important throughout the early 1980s. The shift in emphasis from surface water to groundwater was prompted in part by the discovery that nearly one-fourth of 80 sampled wells in the Garvin Brook watershed contained nitrate-nitrogen in excess of 10 mg/L.

This report provides an overview of hydrogeological and groundwater quality findings in the Garvin Brook RCWP project and resulting adjustments in project direction and monitoring strategy. Methods to evaluate the program's effects on groundwater nitrate concentrations are also discussed.

Background

Project Area Description

The Garvin Brook RCWP area was limited to the 30,720-acre Garvin Brook watershed until 1985 when it was expanded to include 15,800 additional acres, a major groundwater recharge area for wells in the Garvin Brook watershed (Fig. 1). Garvin Brook watershed and the groundwater recharge area, which, combined, make up the Garvin Brook RCWP area, are often referred to in this report as two separate and distinct areas.

Garvin Brook watershed is 58 percent cropland, with nearly 40 percent of all cropland in corn production in any given year; other crops include soybean, barley, oats, other small grain, and hay. Nearly 25 percent of land in the watershed is forested and the other 17 percent is mostly pasture and urban. Most of the farms in the watershed are dairy operations, which together use over 60 feedlots. The additional groundwater recharge area is 85 percent cropland, with 60 percent in corn production. Land uses on the remaining 15 percent are primarily pasture, woodland, urban, roads, and railroads. Average annual precipitation is 31 inches, with about 75 percent falling from April to September.

Garvin Brook watershed is characterized by relatively narrow flat-topped ridges, steeply sloping valley sides, and deep, relatively broad valleys. The relief ranges from 400 to 600 feet. The groundwater recharge area is characterized by broad ridges (one to two miles wide) with narrow drainageways throughout, narrow valleys (25 to 75 feet wide), and total relief less than 200 feet. Ridge soils consist of 3 to 30 feet of silt loam soils underlain by thin localized deposits of till and outwash. These unconsolidated deposits overlie carbonate bedrock. Narrow terraces and floodplains, primarily consisting of silt loam soils 5 to 20 feet thick over sand or cobbly material, characterize the valleys. Below the soil and glacial deposits is a sequence of Paleozoic units characterized by Mossler and Book (1984) and depicted in

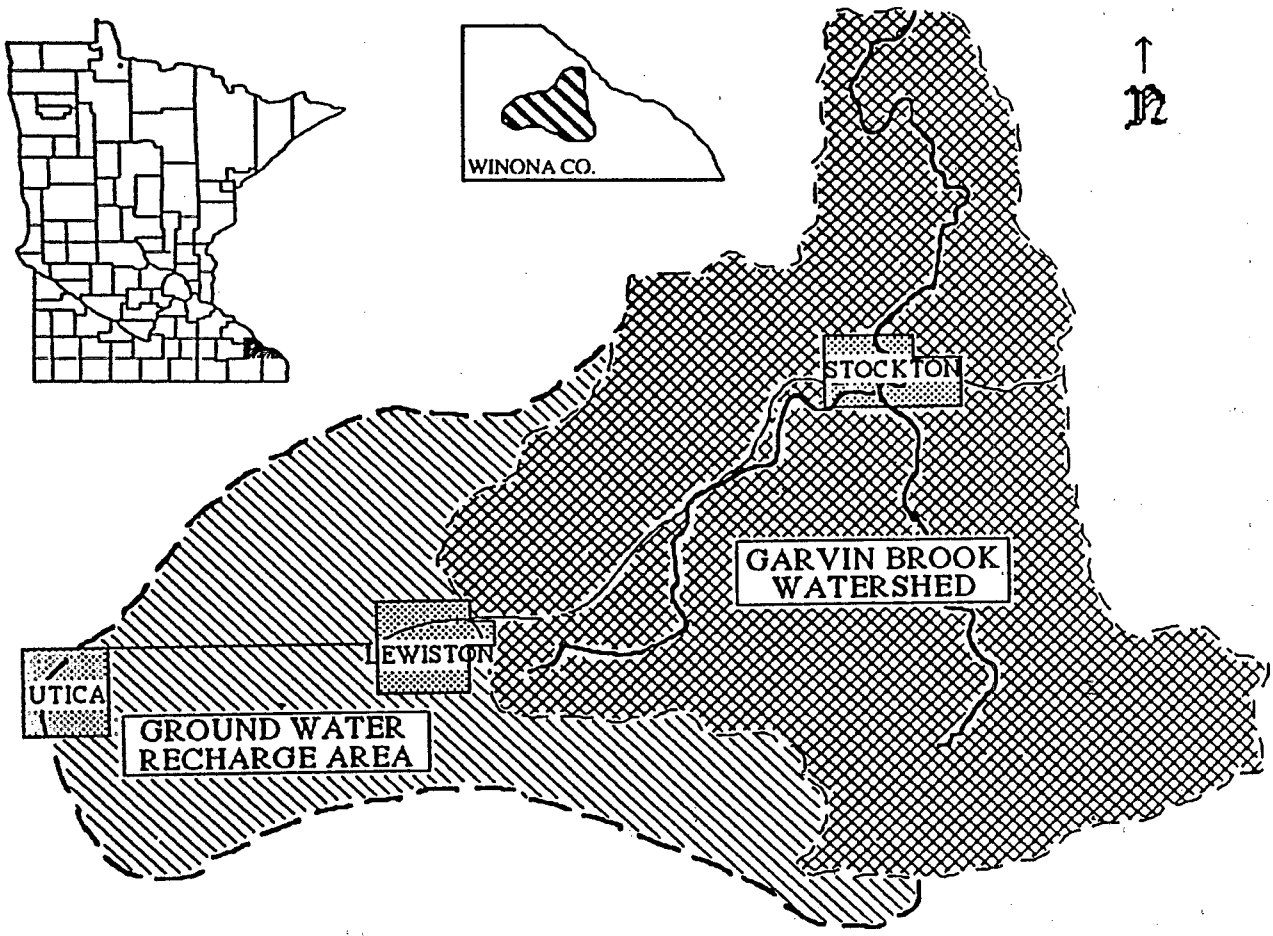

Figure 1.—Map showing location of Garvin Brook Watershed and the adjacent groundwater recharge area. Together, these two areas comprise the Garvin Brook RCWP project area.

Figure 2. Five formations supply virtually all drinking water to residents within the project area.

The first bedrock formation encountered below the glacial deposits in ridge areas is the Prairie du Chien group, consisting of the Shakopee Formation and Oneota Dolomite. The carbonate bedrock of the Shakopee and Oneota is slowly being dissolved by mildly acidic water, producing solution-enlarged frac-

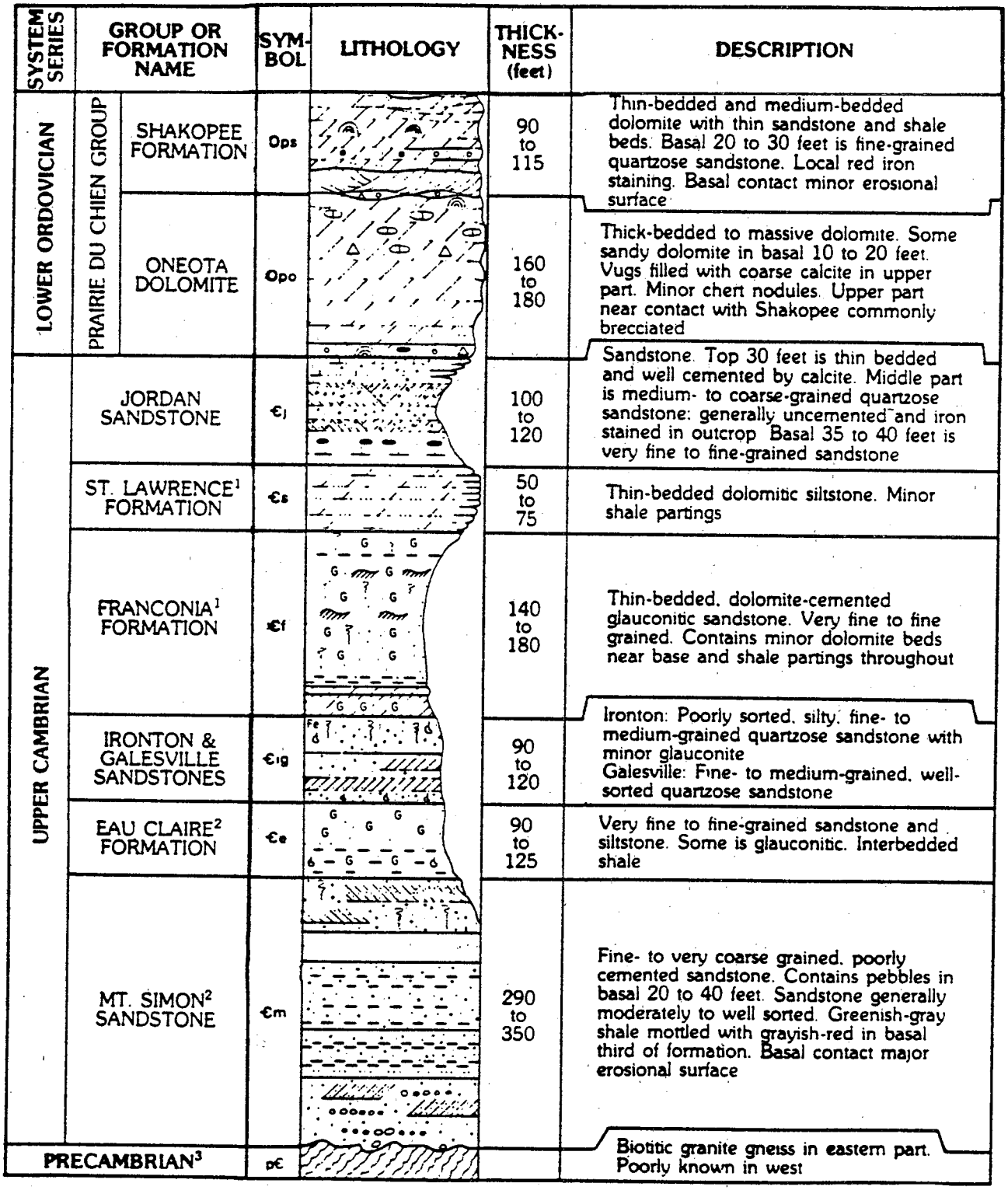

Figure 2.—Stratigraphic sequence of Paleozoic bedrock in the Garvin Brook project area (from Mossler and Book, 1984).

tures and sinkholes. The resulting karst terrain renders the groundwater system highly susceptible to contamination. Many wells in the ridges are developed in the Prairie du Chien group.

Underlying the Oneota Dolomite is the Jordan Sandstone, which supplies drinking water to many domestic wells throughout the project area. Many wells are open in both the Prairie du Chien group and Jordan Sandstone area and therefore draw water from both formations. The Prairie du Chien-Jordan aquifer is unconfined in the project area and is largely absent along the valleys of Garvin Brook and Stockton Valley Creek. Depths from land surface to the water table generally range from 75 to 250 feet in the ridges to less than 50 feet in the valleys.

Stratigraphically below the confining St. Lawrence Formation, the Franconia Formation is thin-bedded dolomite-cemented glauconitic sandstone that is hydraulically connected to the Ironton and Galesville sandstones. The Franconia-Ironton-Galesville aquifer supplies water to a few wells on the ridges and many wells in the valleys. The Eau Claire Formation acts as a confining unit between the Franconia-Ironton-Galesville aquifer and the Mount Simon Sandstone. The Mount Simon Sandstone is confined except near Minnesota City, at the mouth of Garvin Brook, and serves several wells in that area.

BMPs Implemented

Over 1.7 million dollars of Federal cost-share money has been contracted with farmers for implementation of BMPs in the Garvin Brook Project area since 1981. The primary BMPs implemented in the project area for groundwater protection were pesticide management, fertilizer management, sinkhole treatment, and animal waste management systems. Pesticide management, which includes the application of pesticides at the rate, time, and method recommended by Cooperative Extension and the proper disposal of empty containers, was implemented on approximately one-third of the cropland receiving pesticides in the project area.

Fertilizer management was implemented on about 40 percent of all corn cropland in the project area. This BMP includes split-application of nitrogen fertilizer at a rate based on realistic yield goals and proper crediting for previous crops and manure application. A 1989 survey of farmers implementing fertilizer management under the RCWP indicated an average 20 percent reduction in nitrogen fertilizer use. Twenty-eight of 90 sinkholes located in the project area have been treated since 1985, and 15 animal waste management systems have been constructed through the RCWP.

Early Findings

Original Groundwater Monitoring for RCWP (1981 to 1982)

The Minnesota Pollution Control Agency began sampling groundwater in Garvin Brook watershed in June 1981. The initial objective was to establish baseline water quality in the major aquifers so that groundwater quality changes resulting from RCWP BMPs could be monitored. Fifteen wells and three springs were chosen for quarterly sampling. The Prairie du Chien aquifer (an upper carbonate aquifer) and the underlying Jordan Sandstone were each represented by two wells; two of the three springs were also from the Jordan Sandstone. The other 11 wells and 1 spring produced water from older bedrock formations.

The 15 wells and 3 springs were sampled for nitrate, major ions, metals, and four different pesticides. Nitrate-nitrogen was found at concentrations exceeding the drinking water standard in both Prairie du Chien wells (280 and 291 feet deep). At one of the Prairie du Chien wells, the pesticide, alachlor, was detected on one occasion. All other wells had nitrate-nitrogen concentrations less than 2 mg/L and no pesticide detections; many had nitrate-nitrogen levels less than 0.01 mg/L. These results are described in more detail in Wall et al. (1989).

During the early 1980s, the RCWP project focused on surface water and, consequently, few hydrogeologic studies were conducted. Little effort was made to understand flow systems, recharge area boundaries, variability in geologic sensitivity, and groundwater residence times.

Groundwater Findings (1983 to 1985)

■ **Groundwater Flow Directions and Recharge Areas.** A geologic atlas for Winona County was developed during 1983 and 1984 by the Minnesota Geological Survey (1984). One of the maps developed for the atlas was a potentiometric contour map (Kanivetsky, 1984) that showed general groundwater flow directions (Fig. 3). It was evident from the potentiometric map that the groundwater and surface watershed had different boundaries. The boundary for the area supplying groundwater to Garvin Brook watershed was found to extend about five miles west of the surface watershed. The geologic atlas enabled delineation of the entire groundwater recharge area providing water for Garvin Brook watershed, and it described and mapped geologic sensitivity, bedrock and surficial geology,

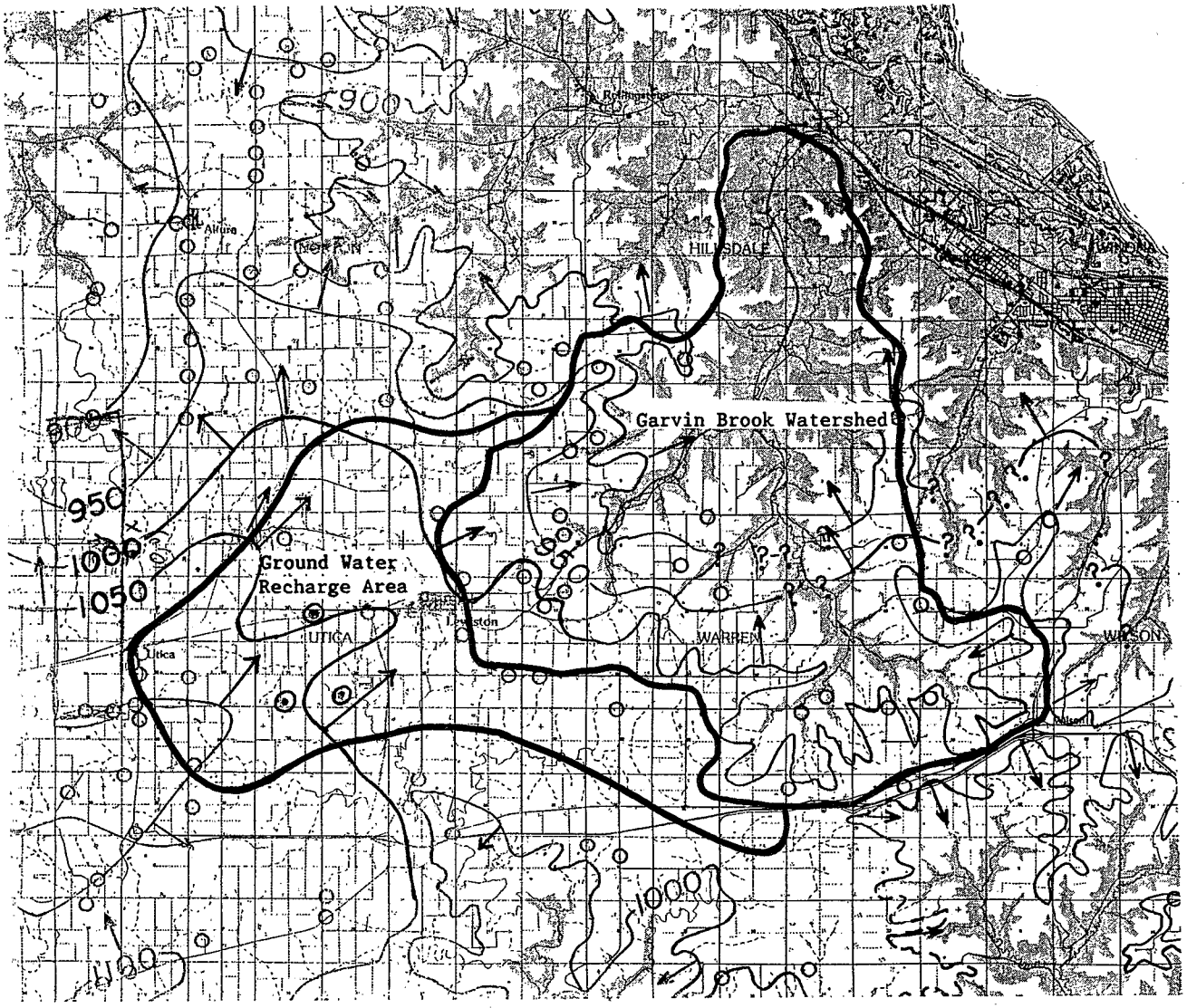

Figure 3.—Potentiometric map for the Prairie du Chien-Jordan aquifer in central Winona County (from Kanivetsky, 1984). Water level monitoring locations are designated by circles. Boundaries for Garvin Brook Watershed and the additional groundwater recharge area are depicted.

and sinkhole development, all useful information for the Garvin Brook RCWP.

■ **Nitrate Analyses in Domestic Wells.** In 1983, Winona County Cooperative Extension, working in conjunction with the Minnesota Department of Agriculture, began annual sampling of domestic wells for nitrate. The original purpose of this sampling was to raise the awareness of people in the Garvin Brook watershed regarding current and potential water quality problems. Of the 80 wells selected to uniformly cover Garvin Brook watershed, many were older, with no construction records. According to 1983 to 1985 sampling results, 21 to 24 percent of the wells exceeded the 10 mg/L drinking water standard for nitrate-nitrogen, and approximately half of all wells sampled had nitrate-nitrogen concentrations exceeding 3 mg/L. Nitrate-nitrogen concentrations above 3 mg/L generally reflect human impacts in southeastern Minnesota groundwater. These results indicated a fairly widespread nitrate problem in Garvin Brook watershed.

Mid-course Adjustments to the Garvin Brook RCWP

In response to the geologic and groundwater nitrate findings, several programmatic changes were made to the RCWP project. The project area was expanded during 1985 to include the additional groundwater

recharge area for Garvin Brook watershed, increasing it from 30,720 to 46,520 acres.

The groundwater recharge area included numerous sinkholes and more intensive row crop agriculture. The critical area for BMP implementation was redefined to include areas where susceptibility to groundwater contamination was classified as "High" in the geologic atlas, which included 94 percent of the groundwater recharge area.

The Garvin Brook RCWP also switched emphasis from surface water protection BMPs to those that protected groundwater. Sinkhole treatment, which became more commonly implemented, usually consisted of cleaning out sinkhole debris, grouting and sealing the holes with clay and plastic liners, and filling them with soil. Diversions and berms were constructed around some sinkholes. To contract in the RCWP, farmers had to implement fertilizer and pesticide management BMPs.

Groundwater monitoring also intensified during the mid-1980s. The annual nitrate sampling program expanded into the groundwater recharge area and included an additional 80 wells (160 total). The Minnesota Pollution Control Agency and State Department of Agriculture began sampling wells for pesticides, focusing on water quality in the Prairie du Chien-Jordan aquifer. Results during 1985 and 1986 showed that 54 percent of sampled wells in the groundwater recharge area and 21 percent in the Garvin Brook watershed had nitrate-nitrogen levels that exceeded 10 mg/L. Higher nitrate concentrations observed in the groundwater recharge area as compared to Garvin Brook watershed were probably related to a greater number of wells in the groundwater recharge area drawing water from the unconfined karst Prairie du Chien group and land use differences.

Ten of the high nitrate wells in the groundwater recharge area were initially (1985) tested for pesticides: six had detection levels of atrazine, alachlor, or both. The range of atrazine concentration in four wells was 0.79 micrograms per liter (µg/L) to 5.57 µg/L, and alachlor concentrations ranged between 0.04 and 1.23 µg/L.

By 1988, groundwater monitoring had increased to include

- 22 wells sampled quarterly for pesticides,
- 12 wells sampled for nitrate every five weeks,
- major ion chemistry performed quarterly,
- 160 wells sampled annually for nitrate, and
- lysimeters installed to better track the water quality effects from specific land uses and management.

Evaluating Changes in Groundwater Quality

In addition to groundwater monitoring, vadose zone monitoring and modeling helped evaluate changes in water quality resulting from RCWP BMPs. Groundwater age dating near the project area proved to be an important tool for interpreting water quality results.

Understanding Groundwater Residence Times

When analyzing groundwater for changes resulting from land use alterations, it is important to understand the age or residence time. Groundwater age dating near the project area reported by Alexander et al. (1987) and Alexander and Alexander (1987) determined that the older bedrock aquifiers (such as Franconia-Ironton-Galesville, Mt. Simon-Hinckley), which were sampled as part of the original (1981) RCWP monitoring network, contain mostly water that predates modern agriculture.

Further age dating work by the Minnesota Pollution Control Agency in the Garvin Brook Area showed that several Jordan Formation wells also draw water that entered the ground before 1953. These results were based on enriched tritium analyses in wells of known construction. Tritium is a radioactive isotope that is released into the atmosphere during nuclear testing. Atmospheric tritium concentrations increased considerably during the mid-1950s. Well water with nondetectable tritium concentrations (< 0.8 tritium units [TU]) entered the ground before 1953; water with > 0.8 TU contains at least some post-1953 water; water with > 17 TU contains all or mostly post-1953 water. Five of 24 Jordan Formation wells sampled for tritium had pre-1953 water. All eight Prairie du Chien wells sampled for tritium contained water with a larger fraction of post-1953 water (see Fig. 4).

The nitrate-nitrogen concentrations in the pre-1953 water were < 0.04 mg/L in four wells, and 1.1 mg/L in the fifth well (Table 1). These results are very consistent with other nitrate/tritium relationships developed in Minnesota (Minn. Pollut. Control Agency and Minn. Dep. Agric. 1991). Wells with elevated nitrate in Minnesota (e.g., > 3 mg/L) supply water that has at least some recent (post-1953) component. Many wells in the Garvin Brook area with elevated nitrate probably reflect land use activities after 1953 but before 1981, when the RCWP began. Therefore, in this study, project evaluators had to sample and analyze trend data from numerous wells with elevated nitrate to obtain an understanding of

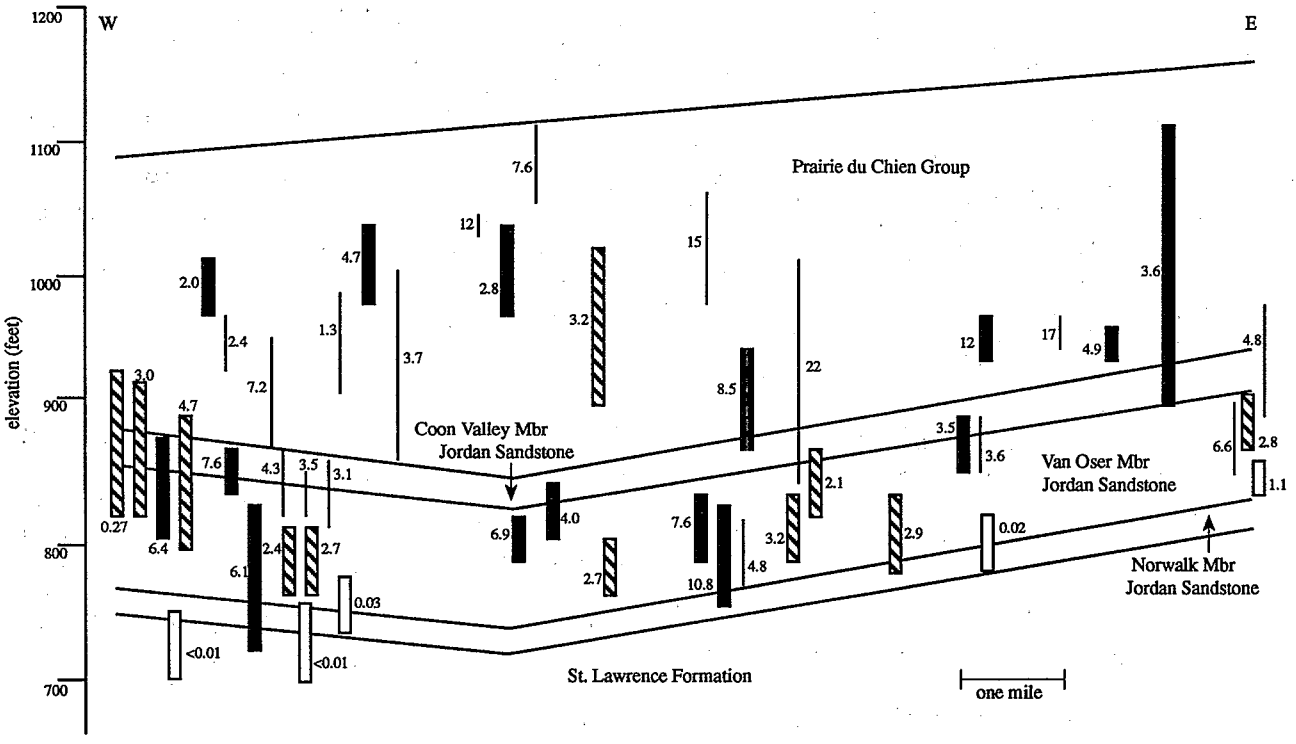

Figure 4.—Conceptualized cross section showing the position of open boreholes in relation to bedrock straitigraphy. Nitrate-nitrogen concentrations are shown for each of the 47 wells sampled in west central Winona County during 1990-91. Residence times are indicated for 31 wells.

Table 1.—Tritium (TU) and nitrate-nitrogen (NO_3-N) results in west central Winona County wells. All wells were constructed after 1960 and have associated well logs indicating the aquifer from which water is withdrawn (JDN = Jordan, PDC = Prairie du Chien). Median nitrate concentrations are significantly different ($p < 0.01$) among the three groupings.

PRE-1953 WATER			MIXED WATER			ALL OR MOSTLY POST-1953 WATER		
AQUIF.	TRITIUM	NO_3-N	AQUIF.	TRITIUM	NO_3-N	AQUIF.	TRITIUM	NO_3-N
JDN	< 0.8	< 0.01	JDN	0.9	3.2	PDC	17.3	3.6
JDN	< 0.8	< 0.01	JDN	1.3	2.9	JDN	18.8	6.6
JDN	< 0.8	0.02	JDN	1.3	2.7	PDC	19.9	4.7
JDN	< 0.8	0.03	JDN	1.6	0.3	JDN	21.3	4.0
JDN	< 0.8	1.1	JDN	2.1	2.7	PDC	25.6	1.6
			JDN	2.7	0.3	JDN	27.0	3.5
			JDN	4.2	2.1	JDN	28.0	6.4
			JDN	8.2	2.8	JDN	28.3	10.8
			PDC	8.2	3.2	PDC	29.4	2.8
			JDN	9.7	4.6	PDC	30.0	12.0
			JDN	10.4	2.4	PDC	33.0	8.5
			JDN	11.7	3.0	PDC	40.0	2.0
						JDN	40.0	7.6
						JDN	42.5	7.6
						JDN	42.5	6.9
Mean NO_3-N = 0.22 mg/L			Mean NO_3-N = 2.5 mg/L			Mean NO_3-N = 5.9 mg/L		
Median NO_3-N = 0.02 mg/L			Median NO_3-N = 2.8 mg/L			Median NO_3-N = 6.4 mg/L		

groundwater quality changes resulting from the post-1982 implemented RCWP BMPs.

Vadose Zone Monitoring

Complex hydrogeologic conditions of the karst bedrock made it difficult to use domestic (bedrock) wells when associating groundwater quality with specific land uses. To more directly link land use and water quality and better understand potential groundwater quality improvements from the RCWP, soil water samplers were installed at depths between 2 and 22 feet during 1988 and 1989. The primary objectives for installing the soil water samplers were to

- determine nitrate and pesticide concentrations moving past the rooting zone in cornfields that had been under RCWP contract for two to four years, and
- evaluate nitrate and pesticide contributions from agricultural fields, sinkholes, grassland, woodland, and catchment ponds to better characterize the major sources and pathways of groundwater contamination.

Twenty-nine soil water samplers were installed at 15 sites and sampled two to eight times. Four different types of soil water samplers were used, including stainless steel pressure vacuum lysimeters, BAT™ monitoring systems, glass block percolate lysimeters, and wick percolate lysimeters. Water samples were analyzed for pesticides, nitrates, and major ion water chemistry. For more information on lysimeter construction, locations, timing of sampling, and specific results, refer to Wall et al. (1989), Wall et al. (1990), and SCS et al. (1991).

Nitrate-nitrogen concentrations at four- to five-foot depths below three RCWP cornfield sites ranged between 20 and 50 mg/L, as compared to 0 to 7 mg/L below nearby grassland (3 lysimeters in Conservation Reserve Program set-aside land) and two forested sites. Since no pre-BMP implementation monitoring was conducted at the cornfield sites, researchers did not know whether there had been an increase or decrease in vadose zone nitrate concentrations. However, given the relatively high concentrations, either more stringent measures were needed to reduce nitrate leaching or more time was needed to observe the full benefits from implemented nitrogen management BMPs.

Nitrate concentrations in sinkholes were quite variable. Sinkholes surrounded by fertilized/manured fields had high nitrate levels (20 to 100 mg/L) and those surrounded by urban land or grassland had low levels (< 10 mg/L). Pesticide concentrations in one sinkhole (which were much higher than pesticide leachate concentrations in cornfields and in other sinkholes) received runoff from the city of Lewiston. The maximum pesticide concentrations found in this 2.5 feet deep sinkhole lysimeter were atrazine 24.7 ppb, metolachlor 7.1 ppb, alachlor 12.3 ppb, and cyanazine 27 ppb.

Subsequent monitoring of runoff water from Lewiston also showed elevated pesticide concentrations. Comprehensive inspections of four commercial pesticide applicator facilities in that city by the Minnesota Department of Agriculture showed very high pesticide residues in the facilities' soil. Eight pesticides with concentrations over 1,000 ppb were found in soil samples. The herbicides alachlor, atrazine, cyanazine, metolachlor, and EPTC in soil samples were each found at concentrations greater than 70,000 ppb in at least one sample. EPTC — at over a million ppb — had the highest concentration of any pesticide in soil samples at the facilities. Both on-site leaching at the facilities and runoff into the sinkhole were likely avenues of pesticide contamination to groundwater near Lewiston.

The only wells with pesticide concentrations known to exceed drinking water standards in the Garvin Brook RCWP were located near Lewiston. Pesticide point sources were probably the cause of excessive pesticide concentrations in groundwater and should be considered in future groundwater protection efforts.

Modeling Lag Times for Groundwater Response

The vadose zone component of the subsurface water and solute transport (SWAST) model (Nieber and Lopez-Bakovic, 1989) was used to attempt to answer the following question: once nitrate concentrations are reduced in the upper soil zone through nitrogen management BMPs, how long will low nitrate water take to move through the unsaturated zone into the carbonate aquifer? An answer to this question helps define the lag time between nitrogen fertilizer BMP implementation and decreases in groundwater nitrate concentrations.

The SWAST model, which was applied at three representative sites in the groundwater recharge area, calculates major components of water flow through the soil matrix but does not incorporate preferential flow through soil cracks, root channels, or worm holes. It was assumed for this study that much of the nitrate within the soil will not move out of the system by preferential flow but through the soil matrix. Given this assumption, we would not expect to achieve maximum water quality benefits from nitrogen management BMPs until the soil matrix

nitrate moves through the soil profile and out of the groundwater system.

The modeling was performed on a daily step basis starting April 1, 1985, the beginning of nitrogen management BMP implementation on many farms in the Garvin Brook area. Soils in this region are usually frozen and infiltration is minimal between November 16 and March 31. The depth of peak concentration movement through the soil profile was determined for the periods 1985 to 1991 and 1985 to 2001. The following assumptions were made:

- Soil moisture levels were at field capacity each spring.
- Ninety-five-day corn was planted each year on May 10.
- Each soil textural zone represents a homogenous medium.
- Denitrification did not affect the depth of maximum nitrate level movement.
- No deep percolation occurred between November 15 and April 1.

The primary inputs to the model include soil properties and climatic conditions. The thicknesses of soil layers at the three sites are shown on Figure 5. Saturated hydraulic conductivities (Ks) were determined using the relationships between soil texture and conductivity devised by McCuen et al. (1981). Two simulations were conducted for each profile: one using the mean Ks for each soil texture determined by McCuen et al. and one using a Ks value three standard deviations above the mean. Actual temperature and precipitation data for 1985 to 1991 were input into a climate generator, Cligen (Arlen Nicks, Agricultural Research Service, Ada, OK), which then computed other climatic variables needed for that period. Cligen was used to randomly generate all climatic data for 1992 to 2001.

Modeling outputs included annual records of evapotranspiration and deep percolation. Evapotranspiration ranged from 40 to 50 cm/year and deep percolation ranged from 0 to 18 cm/year, reasonable values for the area modeled. The final depths of peak concentration movement through the soil profile for the 7 and 17 year runs are shown in Figure 5. For the 17-year simulations at all three sites and for both conductivity values, the depth of peak concentration migration ranged from 5.9 to 8.9 feet. This small range, despite large differences in Ks, reflects the influence of evapotranspiration in maintaining soil moisture levels below field capacity, thereby greatly reducing the effective hydraulic conductivity. The predicted depths of peak concentration movement

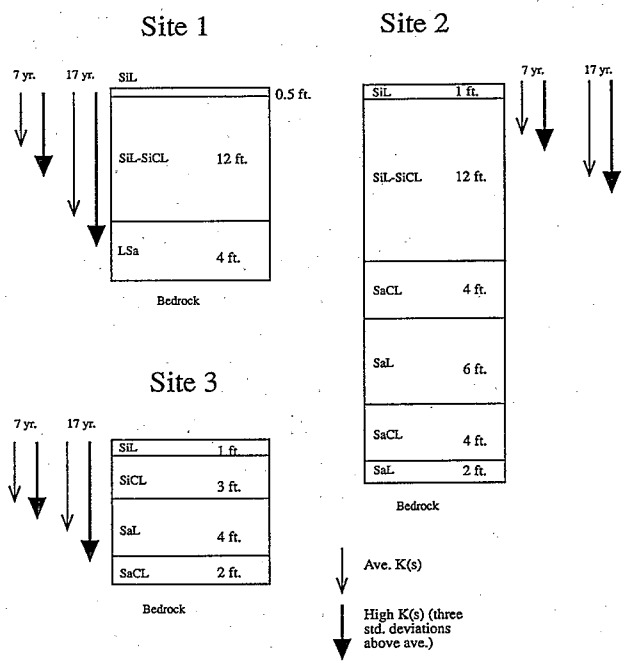

Figure 5.—Predicted depth of peak nitrate movement through the soil matrix at three Garvin Brook RCWP sites. Four runs of SWAST were conducted for each profile varying the length of time (1985-91 and 1985-2001) and the saturated hydraulic conductivity (average and high values for the soil's textural classes).

for the 1985 to 2001 simulations using the higher conductivity value were 23, 54, and 74 percent of the soil profile thickness at the three sites. Thus, for the portion of nitrate that does not move with preferential flow, residence times to bedrock are estimated to range from 15 years to 60 years for most Garvin Brook area soils.

After percolating water reaches the bedrock, there will be a lag in the time it takes to move through 50 to 150 feet of carbonate materials to the water table. Given the great amount of fracturing and solution channel development in the karstic bedrock, water movement through these materials is believed to be very fast. However, water movement into bedrock microfractures may have much longer residence times.

Groundwater Nitrate Trend Results

Time trend analysis was conducted on data produced from annual nitrate sampling of numerous wells in the Garvin Brook watershed and the groundwater recharge area. Sampling was conducted by Winona County Cooperative Extension and chemical analyses performed at the Minnesota Department of Agriculture's laboratory. Well sampling occurred each year between late May and early

Table 2.—Results of Kendall's tau test of correlation between nitrate and time. Statistics were conducted on data obtained from annual sampling in Garvin Brook Watershed and the groundwater recharge area between 1983 and 1990.

AREA	NITRATE RANGE	# OF WELLS	STATISTIC	# NO TREND	# INCREASING	# DECREASING
Garvin Brook Watershed	3–10 mg/L	35	$p < 0.05$	27 (77%)	4 (11.5%)	4 (11.5%)
Garvin Brook Watershed	3–10 mg/L	35	$p < 0.10$	24 (69%)	6 (17%)	5 (14%)
Groundwater recharge area	3–10 mg/L	25	$p < 0.05$	22 (88%)	3 (12%)	0 (0%)
Groundwater recharge area	3–10 mg/L	25	$p < 0.10$	20 (80%)	4 (16%)	1 (4%)
Garvin Brook Watershed	> 10 mg/L	16	$p < 0.05$	10 (62.5%)	0 (0%)	6 (37.5%)
Garvin Brook Watershed	> 10 mg/L	16	$p < 0.10$	8 (50%)	0 (0%)	8 (50%)
Groundwater recharge area	> 10 mg/L	35	$p < 0.05$	30 (86%)	0 (0%)	5 (14%)
Groundwater recharge area	> 10 mg/L	35	$p < 0.10$	27 (77%)	0 (0%)	8 (23%)

July and took about two weeks. During the first three years of testing, wells chosen for trend analysis had average nitrate-nitrogen levels that exceeded 3 mg/L and were sampled for a minimum of five continuous years. Wells with low nitrate (< 3 mg/L) during the first three years of sampling were not analyzed for trends because low nitrate water had been shown to represent water that had entered the ground before 1953.

Fifty-one wells in Garvin Brook watershed met the selection criteria: eighty-eight percent were sampled each year between 1983 and 1990; the remaining 12 percent were sampled from 1985 to 1990. Sixty wells in the groundwater recharge area met the data selection criteria. Eighty-three percent were sampled each year from 1985 to 1990, nine wells (15 percent) were sampled from 1986 to 1990, and one well (2 percent) was sampled from 1983 to 1990.

Kendall's tau test, which is a nonparametric test of correlation, was used to measure the direction and statistical significance of observed trends. Statistical analysis results are shown in Table 2 and Figure 6. Two measures of statistical significance are noted in Table 2: $p < 0.05$ and $p < 0.10$. Significance levels of $p < 0.05$ or $p < 0.10$ indicate that there is less than a 5 or 10 percent probability, respectively, of obtaining a slope as different from zero as the observed slope if in fact there is no relationship between parameter value and time. Significance levels of $p < 0.05$ and $p < 0.10$ are commonly used in scientific work to allow reasonable certainty that a relationship between parameter and time really exists. Trend results for Garvin Brook watershed and the groundwater recharge area were similar. In both areas, trend analysis results differed greatly when comparing wells that had nitrate-nitrogen between 3 and 10 mg/L and those with greater than 10 mg/L during the first three years of testing. Seventy-three percent or 44 wells with nitrate-nitrogen between 3 and 10 mg/L had no significant trend ($p < 0.10$); 17 percent or 10 wells had statistically significant increasing trends; and 10 percent or six wells had sig-

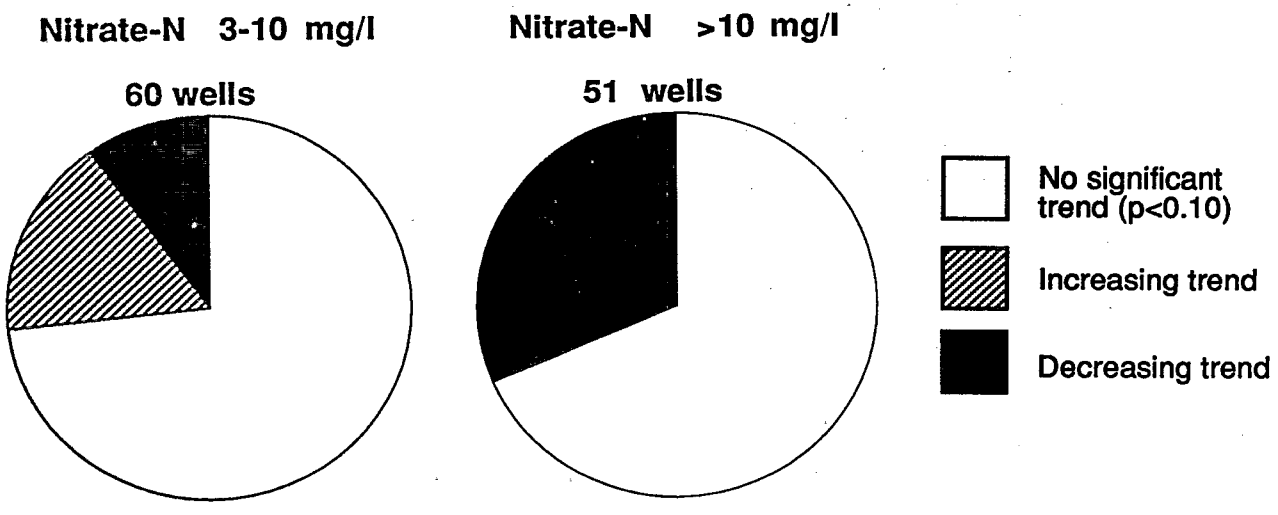

Figure 6.—Nitrate-nitrogen concentration trends from wells sampled annually (late May to early July) in Garvin Brook Watershed and the groundwater recharge area for five to eight years (between 1983 and 1990). Kendall's tau test of correlation was used to determine the significance and direction of trends for the two categories of wells.

nificant decreasing trends. However, when considering only wells that had over 10 mg/L during the first three years of sampling, the only statistically significant trends were decreasing trends ($p < 0.10$). Sixty-nine percent of 51 high nitrate wells had no significant trend and 31 percent had a decreasing trend.

The major differences in trends between mid-range and high-nitrate wells could be related to groundwater residence times. High nitrate-nitrogen wells (> 10 mg/L) tend to be very sensitive to surface contamination, have short residence times, and are likely to be more directly affected by local nitrogen sources. Therefore, the water quality in these wells may reflect more recent land use changes and climatic conditions. Conversely, wells with nitrate-nitrogen between 3 and 10 mg/L tend to be somewhat less sensitive to surface contamination and may be less responsive to recent land use and climatic conditions compared to the high nitrate wells.

It is unknown whether the observed decreases in the high-nitrate wells are related to BMPs, climatic conditions, or a combination of many factors. There were two extended periods of precipitation extremes during the project duration. From 1981 to 1984, total precipitation was 13.2 inches greater than normal. Between 1987 and 1989, total precipitation was 12.0 inches less than normal. It is possible that during the dry period between 1987 and 1989, nitrate concentrations decreased as a result of decreased recharge into the aquifer simultaneous with denitrification and/or mixing of lower and higher nitrate waters within the aquifer. Vadose zone modeling and monitoring results suggested that the full benefits of nitrogen management BMPs have not yet been realized. However, it is possible that nitrate movement into the aquifer through preferential flow paths was reduced by sinkhole treatment projects, sealing abandoned wells, and nitrogen fertilizer management BMPs. Continued monitoring of these wells over the next 10 to 15 years should help to determine whether the trends are more likely the result of climatic variability or implemented BMPs.

Conclusions

The Garvin Brook RCWP project maintained enough flexibility to allow for programmatic adjustments throughout its duration. Groundwater monitoring and hydrogeologic analysis prompted the adjustments, which included expansion of the project area to include all of the groundwater recharge area for Garvin Brook watershed and a shift in emphasis from surface water to groundwater protection BMPs and monitoring.

In future similar studies, a diagnostic study should be conducted before developing implementation plans and installing expensive BMPs. If time and resources allow, the diagnostic study should determine

- pollutants of greatest concern in surface and groundwaters,
- specific land uses and areas responsible for the water quality degradation,
- baseline water quality before land use changes,
- groundwater recharge area boundaries, groundwater residence times, and other hydrogeologic characteristics,
- the flow system and pollutant pathway—especially as they relate to surface and groundwater interactions, and
- temporal and spatial variability of water quality within the aquifer.

A long-term water quality monitoring strategy and information protocol should be developed at the very beginning of a project. The strategy and protocol should consider

- monitoring before, during, and after BMP implementation,
- how to assess attainment of water quality goals,
- monitoring overall resource response,
- focused monitoring to assess the effect of specific BMPs,
- documentation of assumptions and working hypotheses so others can follow the decision-making process,
- clearly defining who needs the monitoring information, and
- how best to communicate monitoring activities to the target audience.

Vadose zone monitoring and modeling results suggest that major nitrate loading reductions into the carbonate aquifer are not yet realized in the Garvin Brook area. Modeling results indicated that the complete water quality benefits from fertilizer management BMPs will not be observed until after the year 2000.

Residence time analyses showed that many wells in the project area withdraw water that entered

the ground before 1953. Water in these wells had very low nitrate; most of the recent water wells had elevated nitrate. Therefore, to better understand the data from the RCWP, many high nitrate wells were analyzed. Trend analysis of high nitrate-nitrogen (> 10 mg/L) wells indicates generally decreasing nitrate concentrations between 1983 and 1990. Trend results were much more variable for wells with nitrate-nitrogen in the 3 to 10 mg/L range. It is not known whether the decreasing concentrations in high nitrate wells are the result of implemented BMPs, climatic conditions, or a combination of many factors. Another 10 to 15 years of water quality monitoring will probably be needed to determine trends associated with BMP implementation. Vadose zone monitoring should be considered in future studies to determine the effect of BMPs within a shorter time frame.

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Keeping Bacteria Out of the Bay — The Tillamook Experience

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ABSTRACT

Bacterial pollution in shellfishing areas is not uncommon along the coasts of the United States. Elevated bacterial numbers and the potential for disease have forced several fishing areas to close and implicated point and nonpoint sources of surface water contamination. Tillamook Bay, along the Oregon coast, presents an ideal location to study these problems. An important shellfishing industry is located in the bay, surrounded by a large dairy industry. High bacterial counts have forced the bay to close for harvesting on numerous occasions. The efforts of the Rural Clean Water Program (RCWP) have reduced bacterial pollution in the bay, but the challenge continues.

This paper summarizes the Tillamook Bay Rural Clean Water Program (RCWP) project. It includes a general literature review on water quality problems in shellfishing areas; a description of the location, climate, and hydrology of the Tillamook basin; some history on the development of the water quality problem in the basin; and the process used to develop farm plans and motivate dairy farmers in the drainage basin to implement best management practices (BMPs) for achieving acceptable water quality. The results and impacts of 10 years' efforts to keep bacteria out of the bay will also be discussed.

Literature Review

The problem of fecal pollution in estuarine areas can be defined by two questions: (a) where do the bacteria come from; and (b) how can their numbers be reduced so that natural shellfish resource areas will not diminish. Much research has been conducted to determine the sources of fecal contamination in rivers and estuaries. Runoff from pastures and other agricultural land has been implicated as a major bacteriological source by many researchers (Carney et al. 1975; Doran and Linn, 1979; Dudley and Karr, 1979; Faust and Goff, 1978; Feachem, 1974). McDonald and Kay (1981) hypothesized that bacteria collect on the surface between rainfalls and are flushed by runoff into rivers and streams. Recreational areas without sanitary waste facilities also increase the levels of fecal bacteria in adjacent streams (Varness et al. 1978).

Bacterial pollution of estuaries and oyster beds can be caused by urban area flooding (Mackowiak et al. 1976), marinas and pleasure boats (Mack and

D'Itri, 1973), upstream activities (Sayler et al. 1975), and duck production areas (Davis et al. 1966; Gates, 1963). A serious problem was encountered in the Newport River in North Carolina; all shellfish beds in the river showed unacceptable levels of bacteria generated from wildlife, sewage treatment plants, agricultural runoff, and faulty septic systems (Ga. Environ. Prot. Agency, 1972).

The Tillamook area provided a good setting to conduct a water quality study for several reasons:

- it is a small, enclosed river basin;
- it is not predominantly urbanized and contains within its boundaries many bacterial sources;
- it has a seasonally distributed, high annual rainfall (2,337 mm), which increases bacterial pollution in the bay through runoff;
- its bay is shallow enough to allow interaction between freshwater inflows and tidal flushing; and
- its basin contains five different watersheds with multiple activities and varying influence in water quality.

Area Description

The Tillamook watershed is located on Oregon's northwest coast, approximately 116 km west of Portland (Fig. 1). The city of Tillamook has a population of 4,000 and is the largest city in the county. Tillamook Bay is approximately 16 km long and 5 km wide, with a surface area of roughly 46 km^2 at high tide. Surrounding the bay to the southeast is an area of tidal floodplains and river terraces. The floodplain is created by the Tillamook, Wilson, Trask, and Kilchis rivers at their entrance to the bay. The fifth river, the Miami, joins the bay along a narrow floodplain much nearer the mouth of the bay. Floodplains in the basin are used for urban development and agriculture, predominantly dairy farming. Steep forested uplands surround the entire bay, floodplain, and river terraces. The local cheese plant uses 30 per-

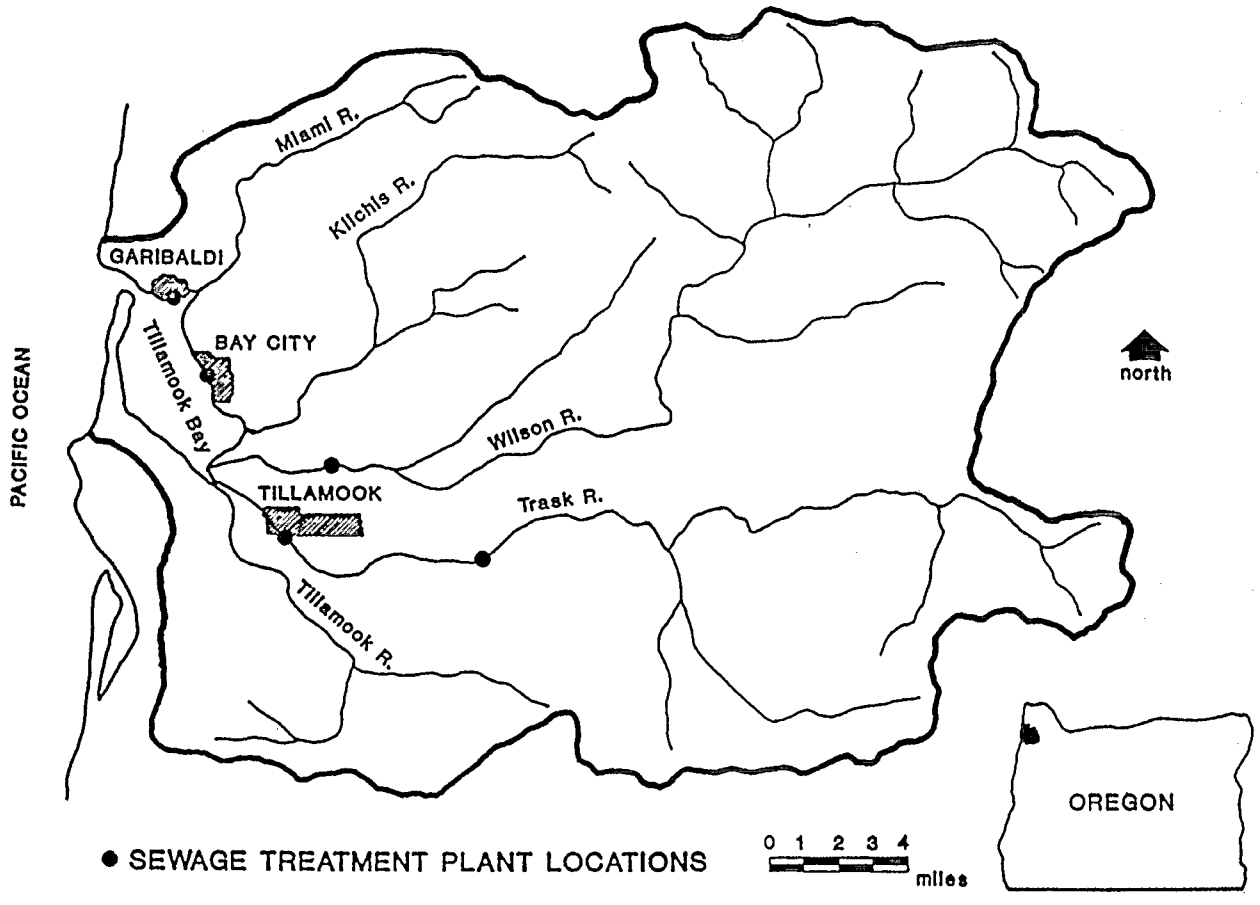

Figure 1.—Location of Tillamook Bay in Oregon and the river systems that flow into the bay.

cent of the milk produced in Oregon. As a result, over 210 dairies with 28,000 cow-units are based in the county; over 16,000 cow-units are located in the Tillamook drainage basin.

Climate and Hydrology

The Tillamook area climate is dominated by a strong marine influence from the Pacific Ocean. This influence leads to wet winters and dry summers, with a comparatively narrow range of seasonal temperatures. Frequent intense winter storms account for major rainfall in the area, which averages from 3.8 km on forested uplands to 2.3 m annually in the city of Tillamook. Freezing temperatures infrequently occur near the bay, and average temperatures range from 5°C in January to 15°C in July.

River discharge into the bay varies considerably by season. Average summer flows of the five rivers total approximately 0.5 m^3/sec. Average winter flows total 28 m^3/sec. The estimated 50-year flood would produce a combined average flow of 85 m^3/sec (Jackson and Glendening, 1982).

Building Solutions

Oregon has been a leader in using interagency cooperation to achieve a variety of major conservation goals. The Conservation Resource Management (CRM) process is the organizational structure that involves all Federal, State, and local agencies, coordinates their efforts, and provides local landowners with information and assistance to solve conservation problems in their communities. We learned in the Tillamook project that interagency sharing is not enough; the landowner is the key to a successful project and cannot be left out of the planning process.

In the early part of this project, dairy farmers in the Tillamook Bay drainage basin were not aware they were the major cause of pollution in the bay. They had been using advice from the Soil Conservation Service (SCS) and the Cooperative Extension Service (CES) in their manure-handling efforts for years. They had confined the manure to large stacks outside the barns so that it could be spread in the spring when the threat of flooding had passed. Some farmers had even constructed small underground liquid manure tanks with Agricultural Stabilization and Conservation Service (ASCS) cost-sharing funds to hold and then spread their liquid waste on nearby fields. However, monitoring by the Oregon Department of Environmental Quality (DEQ) and the U.S. Food and Drug Administration (FDA) showed that coliform levels in the bay were sometimes above safe levels for commercial shellfish production for interstate commerce. Bay closings were frequent, unpredictable, and of great concern among oyster growers.

Water Quality History

The first indication of bacterial contamination problems were identified in routine monitoring of the bay from 1969 to 1971. During heavy rains, water quality dropped below acceptable levels and resulted in threats of FDA intervention. Additional studies from 1972 to 1974 and again in 1976 and 1977 documented an extensive problem. A threat from FDA to close the bay led to the formation of several task forces on the State and local levels to address the problem.

Funding under a Clean Water Act, section 208 grant directed resources to solve the problems in Tillamook Bay. Comprehensive monitoring was initiated in 1979 and 1980 to identify the sources and extent of the bacterial problem.

Weather conditions were evaluated to determine if and how hydrologic extremes in the bay and drainage basin influence bacterial levels. The results showed that coliform standards were exceeded in the bay and tributaries during intense storms. The Oregon DEQ developed a list of possible sources of fecal pollution, including failing septic systems, recreational areas, forested areas, animal (dairy) wastes, and malfunctioning sewage treatment plants. By relating the land use with the sampling locations and results, the major fecal pollution sources were identified as

- management of dairy manures,
- hydraulically overloaded sewage treatment plants, and
- failing on-site domestic waste systems.

Agency Activity and Cooperation

The DEQ and the Tillamook County Health Department began to address problems from the failing septic tanks and overloaded sewage treatment plants; CES, SCS, and ASCS began work on reducing the bacteria pollution from the dairy manure management systems.

CES, SCS, DEQ, and the local Soil and Water Conservation District (SWCD) cooperated in an educational effort to convince the dairy community

it was a major part of the bay's water quality problem and to demonstrate, discuss, and explain management practices that reduce or eliminate bacterial pollution from existing manure management systems. SCS and ASCS offered options of technical assistance and cost-share programs that would help finance control measures. In 1981, the area was selected to participate in the RCWP, which provided additional financial support for the technical, educational, and cost-share portions of the facilities improvement program for individual dairy farms. The SCS field office added staff to accelerate the planning, design, construction, and inspection of agricultural waste facilities.

As the RCWP project began, dairy farmers in the Tillamook Soil and Water Conservation District and the county ASCS committee were convinced that the time had come for dairy farmers to adopt new practices. Many of these practices were directed to reduce runoff of manure and contaminated water into the hundreds of drainage ditches, small streams, and tributaries flowing into the five major rivers that empty into Tillamook Bay. At first, the task appeared impossible, especially when dairy farmers learned that their original practice of storing manure for 30 days was no longer adequate.

Through a highly effective information program by all agencies, many hours of personal contacts by leaders in the dairy community, and strong support from the local Tillamook County Creamery Association, the RCWP project began. Within the first year, over 90 percent of the 120 dairy operations in the basin agreed to participate in the project. A rating system was developed to rank and identify those operations that should receive assistance first. A computer program was written to calculate the fate and movement of bacteria through the various dairy operations and manure management practices (Moore et al. 1981). Input data (site-specific for soil type, farm size, number of animals, and manure collection type) were used to help the county ASCS committee and the SWCD board rank operations to allow treatment of the worst cases first and to evaluate the BMPs that could best achieve the largest reduction in bacterial movement and losses.

One task was to develop a list of appropriate BMPs. In one BMP, for example, large above-ground tanks (up to 80 feet in diameter and 12 feet high) were designed by SCS. Special foundations were often required in boggy lowlands near the bay. A roofing BMP was developed to divert clean water from contaminated areas; the roof covered the cattle walkways and open concrete slabs, where cows wait to enter the milking parlor. It proved more economical to divert clean water with roofing than to collect, store, and handle large volumes of contaminated water. A BMP for gutters, downspouts, and underground drains was also necessary to move clean water away from barnyard areas. "Speed bump" curbing was designed for the edges of concrete holding areas to contain polluted water, yet allow access of equipment and livestock. Drain tile systems were designed and installed to lower the water table so that animal waste could be applied on pastures during predicted dry periods.

A challenge faced by the Extension Service and SCS technicians was how to teach new and improved manure management methods to dairy farmers. One major BMP that deals with manure storage management takes advantage of "windows" in the weather or spreading opportunities to apply manure. This approach allows greater use of manure as a fertilizer and encourages using less commercial fertilizer.

This project was the first time that BMPs were developed to reduce the movement and water quality impact of bacteria from a manure management system. While many BMPs relate to physical and chemical contaminants, few had been applied to address bacterial movement. The major thrust in research has been to identify the sources of bacteria, with far less emphasis on source control. However, any solution to the problem must consider not only how to determine when shellfish harvesting in an affected area has become a public health hazard but also how we can reduce the magnitude of the bacterial source.

Project Results

In the past 10 years, 105 operations within the Tillamook Basin have participated in the RCWP project and agricultural conservation programs. Today, 80 percent of the initial construction projects have been completed. Several key dairies are still completing major BMPs that will affect runoff quality.

The project's cost figures are important and can be presented in several ways. The following items provide some summary statements about initial, operating, and per ton of manure costs for the total project: (1) $107.88 was spent per 1,000-pound animal unit for implementation of BMPs; (2) $13.42 was the average annual operating cost for manure management systems per animal unit; and (3) it cost an average of $1.07 to handle a ton of manure. These average annual implementation costs are equivalent to the cost of a loan amortized over the life of each BMP. They do not include the annual operation and maintenance costs of the manure management systems. Approximately $8,500,000 will be spent to im-

prove facilities by the end of the project. Of this amount, $4,540,278 are RCWP cost-share funds administered through ASCS.

In addition to improving the bay's water quality and creating a positive sense of community pride, the expenditures have been a boost to the local economy. Many good things unrelated to water quality have resulted from efforts to address the water quality problem. The successes of this project have caught the attention of dairy farmers throughout the United States, especially those living in coastal areas where high rainfall complicates waste handling. Numerous tours for dairy farmers and technicians of all agencies have been held in the Tillamook Bay Drainage Basin, and this activity continues today. In Oregon, the lessons learned from this project are now being used in special water quality projects along the further reaches of the Oregon coast and in the State's other dairy areas.

Water Quality Today

Although much positive improvement has occurred, the water quality problem has not been solved. Monitoring continues in the bay, but the bay is still closed occasionally during major storms because of high levels of fecal coliform. Some facilities are yet to be constructed, and some poor management practices have been observed. The problems identified in this watershed were extensive and will require a continuing effort to reach success.

Unfortunately, the monitoring strategy was changed during the project and further handicapped by inadequate background and limited data. A sampling strategy should be established and followed throughout the project's life. At a minimum, the parameter set must include data on fecal coliform bacteria, bay salinity, river flow, and rainfall. Statistically valid trends have not been successfully established using the current data.

All data were entered into EPA's STORET system. Data dumps from STORET were imported into spreadsheets for some analysis and into a statistical software package for nonparametric analysis. Data points represent discrete grab samples collected on a given day. For evaluating trends, data were parsed to monthly or quarterly values. In some cases, data from multiple sites were pooled. Frequency histograms were also developed. Trends were estimated using the seasonal Kendall test (a nonparametric trend indicator) and, in some cases, ordinary least squares regression (a parametric technique). The ordinary least squares regression was used for comparison because it is a well-known test. It is not an optimal test for the data set, however, because it assumes a normal distribution of optional data.

Wilson River is the largest river flowing into Tillamook Bay (as seen in Fig. 1). One of the sampling stations is near town, just before it enters the bay. Figure 2, a plot log of fecal coliform vs. time that shows the trend but no significant difference, is included to give the reader a sense of the variation and direction of water quality changes. Careful, ongoing tracking of water quality trends will, however,

- allow better documentation of the water quality improvements;
- make it possible to take timely enforcement actions;
- identify systems that require maintenance, enlargement, or management changes; and
- help refine manure management techniques.

Indications exist that water quality improvements have occurred in Tillamook Bay and its tributaries. Upstream-downstream sampling can identify farm locations but, to date, not enough data have been collected to evaluate post-project BMP installations. It is important to continue the current monitoring efforts so that future threats to Tillamook Bay's water quality can be quickly identified.

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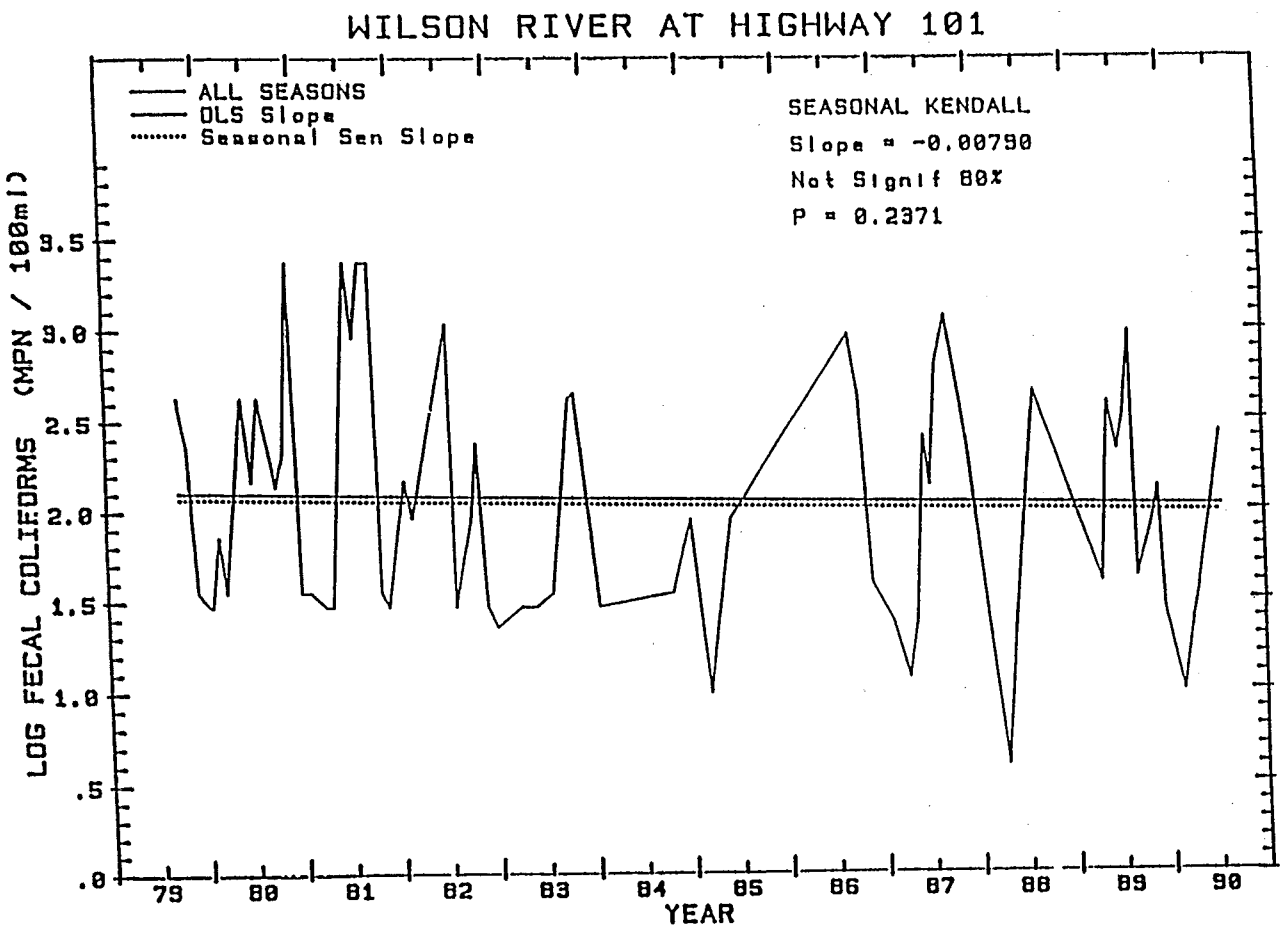

Figure 2.—Plot of changes in fecal coliform counts against time in Wilson River, the major river entering Tillamook Bay.

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A Tracking Index for Nonpoint Source Implementation Projects

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ABSTRACT

One of the challenges of the Rural Clean Water Program (RCWP) is how to appropriately report program success and summarize the findings of 21 different projects. Measures of success often address best management practice implementation, institutional achievements, public involvement, modeling projections, and economics. Water quality and the protection and restoration of beneficial uses, however, constitute the bottom line for RCWP projects. A nonpoint source index (NPI) is proposed to help identify water quality status in projects before and after BMP implementation. The NPI ranges from 0 to 100 and is based on measures of use attainment, water quality conditions, and level of land management. The NPI score is calculated as the sum of the scores for each of four subindices that address these measures. By tracking NPI scores over time, trends in land management and water quality can be assessed and reported. Analysis of the scores for any of the subindices can shed some light regarding further nonpoint source treatment needs. Applications of the NPI to select RCWP projects are presented. This index should be useful to the general public, managers, and the scientific community.

Simple and clear reporting of progress made in improving or protecting water quality and designated beneficial uses of waters for watershed implementation projects has generally been difficult to achieve for water quality professionals. Problems stem from the variety of information typically generated by a watershed project to the variety of ways in which such information can be evaluated, to lack of consensus regarding the most meaningful ways to report the information.

Traditionally, projects have reported water quality monitoring and implementation data to document the progress made in meeting water quality objectives. Recently, more emphasis has been placed

on documenting the relationship of pollution control implementation to water quality (Hopkins and Clausen, 1985; Meals, 1991), but few have documented such relationships with statistical confidence (Spooner et al. 1990).

Statistical analyses of water quality data can be interpreted by the relatively small number of water quality experts across the Nation, but most program managers, decisionmakers, and the general public often find little reward in reviewing such information. The problem is not so much that the information is abstract or complex, which it often is, but that the presentation of the information does little to make it more palpable.

Similar problems have been faced in the past. For example, a new method of reporting the trophic status of lakes was developed to provide better communication with the general public about the current and potential status of lakes (Carlson, 1977). Carlson developed a trophic state index (TSI) with a range of 0 to 100 that could be calculated as a single index using a range of measured parameters as input. Other indices have been developed to address the biological status of streams (Karr, 1981) and the status of habitat (U.S. Environ. Prot. Agency, 1989).

This paper presents an index for summarizing water quality status in projects before and after implementation of best management practices (BMPs). The nonpoint source index (NPI) ranges from 0 to 100 and is based on measures of use attainment, water quality conditions, and level of land management. The NPI score is calculated as the sum of the scores for each of four subindices that address these measures. By tracking the NPI scores over time, trends in land management and water quality can be assessed and reported. Analysis of the scores for any subindex can shed some light regarding further nonpoint source treatment needs. This index is a tool for presenting data; it does not reduce data needs.

Development of the Index

The NPI is intended to provide a clear and meaningful measure of a watershed's status with respect to identified water quality problems. It is intended to help identify water quality status in watershed projects before and after BMP implementation. The NPI is not intended to be used to compare different watersheds, but users may wish to develop standardized scoring schemes that allow for such comparisons.

Index parameters were selected that can be measured at a reasonable cost. Unlike more focused indices, such as the TSI (Carlson, 1977) and the index of biological integrity (IBI) (Karr, 1981), the NPI uses interpreted data rather than raw data. For example, where the TSI uses Secchi disk, chlorophyll *a*, or total phosphorus data, the NPI uses measures such as beneficial use support status and the fraction of sample values meeting certain numeric criteria. Given the variety of designated beneficial uses for waters (e.g., drinking, fishing, wildlife, industrial) and the variety of chemical, physical, and habitat parameters that can be monitored, it is impossible to provide a generalized watershed index using raw data that faithfully represents the range of information generated by any given project. It is, however, possible to specify the process by which projects can analyze raw data to provide interpreted data as input parameters for the NPI.

The NPI

The NPI ranges from a score of 0 to 100, with higher scores indicating better water quality and greater pollution control in the watershed. The scores are structured to represent extremes that will not be exceeded by any given watershed. The NPI is a mathematical combination of two separate but related water quality subindices with two separate but related land management subindices.

Each subindex is assigned a weight of 25 percent of the NPI score. As with other similar tools (U.S. Environ. Prot. Agency, 1990b), considerable subjectivity occurs in the selection and assignment of weights to subindices and input parameters for the NPI. We recommend that users establish appropriate weights based on local priorities or conditions; these weights should be set at the beginning of a watershed project and not changed thereafter. Equations must be adjusted accordingly if user-assigned weights are applied.

The overall NPI score is calculated as follows:

$$NPI = (0.25U) + (0.25W) + (0.25E) + (0.25C) \quad (1)$$

Where:

U = Beneficial Use Support Status Subindex
W = Water Quality Data Subindex
E = Extent of Critical Area Treatment Subindex
C = Pollution Control Expected from Treatment Applied Subindex.

NPI scores can be calculated annually, monthly, daily, or at any other interval supported by the data. Data used in the NPI must be summarized for the same time interval for which the NPI is calculated. For example, to calculate annual NPI scores, monthly water quality data would have to be reduced to annual values.

Since the NPI indicates the state of a watershed with respect to specific water quality problems or threats, users may wish to establish more than one NPI score for any given watershed. For example, users may wish to establish NPI indices for eutrophication ($NPI_{Eutrophication}$) and bacterial contamination ($NPI_{Bacterial}$) in the same watershed to track progress in preventing both problems. An overall NPI score for the watershed could then be calculated as the arithmetic mean of the eutrophication and bacterial scores.

Water Quality Subindices

Two subindices are provided for rating water quality status: (1) an assessment of beneficial use support status, and (2) an analysis of water quality data. While not directly related in many cases because of the general lack of water quality criteria for nonpoint source pollutants and impacts, the two water quality subindices are, in theory at least, correlated.

■ **Beneficial Use Support Status (U).** Beneficial use support status is generally reported in four categories (U.S. Environ. Prot. Agency, 1991a):

1. fully supporting uses,
2. fully supporting uses but threatened,
3. partially supporting uses, and
4. not supporting uses.

The U.S. Environmental Protection Agency (EPA) (U.S. Environ. Prot. Agency, 1991a) provides guidance to States on making use support decisions based on biological data, evaluative (non-water quality) data, chemical data, and other indicators such as fishing restrictions. EPA also provides guidelines for determining use support status for multiple-use waterbodies. This paper generally incorporates EPA's procedures for use support determinations, with the exception of multiple-use waterbodies, in which a different approach is taken for the NPI.

The scoring for use support status (U) ranges from 0 to 100 and is based on the four categories developed by EPA. It is assumed that appropriate criteria and analyses are performed to assess use support status.

NPI users first select the beneficial uses and waterbodies within the watershed that are to be tracked. It is recommended that users focus on those uses intended to benefit from the watershed project. Next, a subscore is determined for each designated use on each receiving waterbody being tracked. A subscore for each waterbody is then calculated as the arithmetic mean of the beneficial use subscores for the waterbody. The overall score for U is calculated as the arithmetic mean of the subscores for the waterbodies.

For example, a project may plan to control bacterial contamination to restore or protect the following uses and water bodies:

- drinking water and swimming uses on the rivers,
- shellfishing in the estuary, and
- well water supplies.

The U score for this project is derived by calculating the subscore for the river as the arithmetic mean of support status for the two uses, i.e., $U_{River} = [U_{Drink} + U_{Swim}]/2$, and then calculating U as the arithmetic mean of support status for the three waterbodies, i.e., $U = [U_{River} + U_{Estuary} + U_{Ground}]/3$.

For waterbodies with only one designated use, full use support is assigned a score of 80, full use support but threatened is assigned a score of 70, partial use support is assigned a score of 50, and no support is assigned a score of 20 (Table 1). Waters of pristine conditions are assigned a score of 100. In the above example, we might assume that swimming was threatened and drinking water fully supported in the rivers, shellfishing was not supported, and drinking from wells was threatened. The beneficial use support status score (U) would then be 55, i.e., $U = [(70+80)/2 + 20 + 70]/3$. The generalized equation for use support status is:

$$u=\left(\sum_{1}^{n} U_j\right)/n \qquad (2)$$

The score for use support status on waterbody "j" (U_j) is calculated as the arithmetic mean of the scores for the beneficial uses on the waterbody. The overall score for U is calculated as the mean of the scores for the n water bodies.

■ **Water Quality Data (W).** An assumption made in the NPI is that all properly collected water quality data are equal. This assumption is loosely based on the principles of meta-analysis (Mann, 1990). In meta-analysis, similar information is combined for

Table 1.—Use support scores for single-use waters.

USE SUPPORT STATUS	SCORE
Pristine waters	100
Full support	80
Full support but threatened	70
Partial support	50
Not supported	20
Not supported and no chance for support	0

Note: Users may wish to assign intermediate scores based on intermediate conditions.

statistical analyses using techniques such as the Mantzel-Haenszel-Peto method. With respect to the NPI, biological, chemical, and physical data are considered to provide equivalent information regarding water quality status in any given waterbody.

It is recommended that NPI users select the key parameters most related to beneficial uses and most responsive to pollution control implementation. For example, in the previous project (see Beneficial Use Support Status), fecal coliform could have been used as the parameter for calculating the score of the water quality data (W) subindex. If streams in the watershed were affected by sediment, then total suspended solids, total sediment, or a benthic macroinvertebrate index would also be appropriate.

For all water quality data, the NPI scores are determined by comparing observed values versus benchmark values. The benchmark values are water quality criteria values for many parameters, but for a number of biological and habitat parameters, the benchmark will be the maximum potential attainment level (maximum potential) score. Maximum potential scores should be determined by calibration of biological indices through reference site monitoring (U.S. Environ. Prot. Agency, 1991b). If data are lacking, best professional judgment can be used to establish these scores. Each monitored parameter should be scored against the same benchmark value throughout the course of any given study. For closed-end indices, the maximum potential score is the highest value that can be scored (e.g., 60 for the IBI; Karr, 1981), but for open-end indices, such as the index of well being (Iwb) (Gammon, 1980), judgment must be made regarding the highest possible score achievable in the watershed (U.S. Environ. Prot. Agency, 1991b).

When using water quality criteria, W is calculated as the percentage of samples or observations that meet the criteria. Since NPI analyses are exploratory, the minimum number of samples or observations needed can be based on professional judgment rather than rigorous statistical analysis. When using maximum potential scores for biological or habitat parameters, W is the sample value as a percentage of the maximum potential score (i.e., 100*[sample value/maximum potential score]). If more than one biological or habitat sampling is done, the arithmetic mean of the sampling scores should be reported as the score for W. The range of scores for W is 0 to 100.

Although criteria and maximum potential scores are not necessarily equivalent, both can be used to develop W scores because both are used to represent water quality status with respect to a meaningful goal for the watershed. The scale (i.e., 0 to 100 percent) for each approach provides similar information, yet a 50 percent score against criteria is not likely to be equivalent to a 50 percent score against maximum potential. This discrepancy results from several factors, including the fact that criteria are not typically set to represent the maximum potential but to establish what is necessary to support designated uses. In some cases, however, the designated uses may be established with "maximum potential" in mind.

Three scenarios generally exist for the use of benchmark values, and all can be addressed with the NPI. Most typically, samples with measured values less than or equal to the criterion are judged as meeting the criterion (e.g., nitrate levels of 10 mg/L or less). Some criteria are such that measured sample values within a specified range (e.g., dissolved oxygen concentrations of 6 to 8 mg/L) are judged to meet the criterion. Higher scores often indicate better conditions for biological and habitat parameters (e.g., IBI; Karr et al. 1986).

For example, if the water quality criterion for nitrate is 10 mg/L, the percentage of groundwater samples or observations not exceeding 10 mg/L would be reported as the score for that parameter. NPI users may choose to compare flow-adjusted (or otherwise adjusted) data values against criteria to account for some of the natural variability that affects water quality data. This comparison would, of course, change the interpretation of scores.

If more than one parameter is tracked per waterbody, W is calculated as the average score for all parameters for the waterbody. For example, the monitoring program in a watershed where a lake is eutrophic and the streams are impacted by sediment may track total phosphorus (criterion=0.010 mg/L; < or = meets criterion) in the lake, chlorophyll *a* (state criterion=25 mg/L; < or = meets criterion) in the streams, and the IBI (maximum possible value=60) in the streams. (Streams are lumped as one waterbody in this example because they are very similar.) The lake subscore (W_{Lake}) is simply the percentage of samples that are less than or equal to 0.010 mg/L, and the subscore for the streams is the arithmetic mean of the chlorophyll *a* ($W_{Stream\text{-}Chl\alpha}$) and IBI ($W_{Stream\text{-}IBI}$) subscores. The chlorophyll *a* score is calculated as the percentage of samples that are less than or equal to 25 mg/L, and the IBI score is calculated as 100 times the arithmetic mean of sample values, divided by 60.

If more than one representative monitoring station exists for a waterbody, subscores should be calculated for each monitoring station before calculating W for the waterbody as the arithmetic mean of monitoring station subscores. It is best, however, to

analyze only those stations that best represent conditions in the waterbody.

Individual station scores for each waterbody are calculated as the arithmetic mean of parameter scores for the station. Parameter scores are determined as either the percentage of parameter values at the station that meets the criterion *or* as the arithmetic mean of the biological or habitat parameter values expressed as a percentage of the maximum potential attainment value.

The generalized equation for water quality data is

$$W=(\sum_{1}^{p} W_k)/p \qquad (3)$$

In equation 3, the score of W is the arithmetic mean of the p waterbody scores, where W_k is the score for waterbody "k," calculated as the arithmetic mean of the station scores on the waterbody.

Implementation Subindices

Two implementation subindices are used in the NPI: (1) a measure of the extent of implementation in the critical area (E), and (2) a measure of the level of pollution control expected from the practices or measures implemented (C). The two implementation subindices are related in theory, but not necessarily in practice. For example, no predictable relationship exists between the percentage of critical area treated and the level of pollution control achieved in the critical area. However, the overall level of pollution control obtainable through any given treatment technology is a function of the extent to which the technology is applied.

Users are advised to track implementation as it relates to beneficial uses and pollutants or problems of concern in the watershed. The intent is to track implementation information that relates to the information tracked for the water quality subindices.

Point sources are factored into each implementation subindex as necessary. For the purposes of the NPI, point sources consist of wastewater treatment plants, direct industrial discharges, permitted animal operations, and combined sewer overflows. The NPI does not consider background contributions as pollution sources, and it does not have a capability for including unknown sources.

■ **Extent of Critical Area Treatment (E).** For nonpoint sources, the delineation and treatment of critical areas is central to the cost-effective control of the major pollutant sources affecting beneficial uses in a watershed (Humenik et al. 1987; U.S. Environ. Prot. Agency, 1990a,b). Targeting procedures (U.S. Environ. Prot. Agency, 1990b) and modeling (Davenport, 1984) are two tools often used to delineate critical areas and project the benefits of pollution control efforts.

The score for the extent of treatment in the critical area (E) is calculated as the percentage of critical area under treatment, ranging from 0 to 100. For a nonpoint source project to be successful, most implementation should occur within the critical area. A key assumption is that the critical area has been adequately identified based on critical area delineation criteria (e.g., percentage of pollutant loads from the critical area) that are linked to specific beneficial uses, pollutants, and problems of concern in the watershed. An essential step in establishing critical areas is to assess all *potential* pollutant sources or problems of concern. NPI users should consider for inclusion within the critical area any well-managed land uses or activities that would be a source of pollutants or problems if they were not well-managed.

Treatment is defined for the NPI as the application of a management or structural measure to control specific nonpoint source pollutants or problems of concern identified in the watershed. For example, stormwater detention basins can be used to treat a watershed in which sediment is the pollutant of concern. In cases where phosphorus loading is a problem, both nutrient management and sediment control would typically be needed to achieve treatment on cropland. Clearly, judgments must be made regarding what constitutes treatment versus no treatment. Generally, if no effort has been made to control the pollutants or impacts causing the problems, then treatment has not occurred. The level of pollution control provided through treatment is reflected in subscore C.

In many cases, point sources will also contribute to water quality problems in the watershed. Because they generally discharge directly to receiving waters, significant point sources should be considered when delineating critical areas. Point sources are generally considered treated when they have at least primary treatment. Livestock operations with no-discharge permits are considered treated.

The percentage of critical units under treatment can be calculated in several ways, but in all cases NPI users must be careful to count only treatment that addresses the pollutants or problems of concern in the watershed. For cropland watersheds, the percentage could be calculated based on acreage treated. For animal operations, the percentage could be determined as the percentage of animal units under treatment. For urban areas, the percentage treated could be calculated as the percentage of the

drainage area served by stormwater treatment devices.

If multiple sources are present, a weighted average of the percentage treated for each source should be calculated with the weighting factor based on the proportion of the potential pollution generated by or potential problems caused by each source in the critical area. For example: if 30 percent of irrigated cropland in the critical area is treated ($E_{Irrigate}$ =30) and 20 percent of the problem (e.g., suspended solids) from the critical area is potentially caused by irrigated land; livestock operations have the potential to cause 15 percent of the problem from the critical area and 10 percent is treated ($E_{Livestock}$ =10); point sources potentially contribute 35 percent of the problem from the critical area and 100 percent are treated (E_{Point} =100), and nonirrigated cropland has the potential to cause 30 percent of the problem from the critical area and 55 percent is treated ($E_{Nonirrigated}$ =55); then, the overall $E_{Suspended\ solids}$ for the watershed would be 59 (i.e., E = [30*0.20]+[10*0.15]+[100*0.35]+[55*0.30]).

■ **Pollution Control Expected From Treatment Applied (C).** The level of pollution control expected from treatment applied (C) in the critical area is another key factor in achieving an adequate level of nonpoint source control. Tables 2 and 3 provide examples of nonpoint source controls and their effectiveness. Table 4 provides examples of the range of technology used to treat point sources. Effectiveness ranges from 0 to 100 percent and is measured with respect to on-site, or source, control. Effectiveness estimates do not incorporate off-site delivery. Users will need to assign effectiveness values based on local data and best professional judgment. For many control practices, users will have to establish a maximum storm size (e.g., 24-hour, 25-year storm) for which effectiveness values apply.

To be meaningful, the C score must reflect the level of control of the pollutants or problems of concern in the watershed. For example, a technology that removes 80 percent of suspended solids and 15 percent of total nitrogen would receive a C score of 15 in a watershed in which nitrogen was the major concern, but it would receive a score of 80 if suspended solids were the pollutant of concern.

Most land treatment takes the form of systems of practices rather than individual practices. Overall system effectiveness, therefore, is the most appropriate parameter to apply in calculating C scores. For example, a conservation tillage system may include conservation tillage, grassed waterways, and filter strips. The combined effectiveness of these practices (i.e., the system) in keeping pollutants on

Table 2.—Examples of nonpoint source treatment effectiveness: agriculture.

TREATMENT	EFFECTIVENESS* (POLLUTANT)
Animal waste systems[1]	0 to 37 (Dissolved P)
	11 to 82 (Nitrate)
	24 to 78 (Total P)
	31 to 83 (Total N)
	37 to 100 (Fecal coliform)
Filter strips[1] (confined livestock application)	0 to 35 (Dissolved P)
	0 to 15 (Nitrate)
	5 to 52 (Total P)
	8 to 29 (Total N)
	11 to 71 (Sediment)
Conservation tillage[1] (for manure applied to cropland)	–40 to 51 (Dissolved P)
	–230 to 29 (Nitrate)
	–144 to 89 (Total P)
	36 to 82 (Total N)
	39 to 97 (Sediment)
Nutrient management[2] (for manure applied to cropland)	0 to 73 (Dissolved P)
	10 to 41 (Nitrate)
	5 to 73 (Total P)
	0 to 55 (Total N)
Filter strips[1] (for manure applied to cropland)	–21 to 35 (Dissolved P)
	0 to 29 (Nitrate)
	15 to 57 (Total P)
	0 to 39 (Total N)
	7 to 45 (Sediment)
Terrace systems[1] (for manure applied to cropland)	–14 to 61 (Dissolved P)
	–52 to 24 (Nitrate)
	18 to 75 (Total P)
	10 to 61 (Total N)
	29 to 64 (Total sediment)
Buried pipe systems[2] (irrigation)	75 to 95 (Sediment)
Sediment basins[2] (irrigation)	75 to 95 (Sediment)

[1]Robillard, 1992
[2]U.S. Dep. Agric. 1991
*Percent reduction in load vs. control or no treatment

Table 3.—Examples of nonpoint source treatment effectiveness: urban.

TREATMENT	EFFECTIVENESS* (POLLUTANT)
Wet ponds[1]	12 to 91 (Total P)
	6 to 85 (Total N)
	8 to 95 (Total Pb)
	13 to 96 (Total Zn)
Seeding to establish vegetation on disturbed construction site[2]	50 to 100 (TSS)
Sediment basin for construction sites[2]	55 to 100 (TSS)
Conventional septic system[2]	54 to 83 (TSS)
	30 to 60 (BOD)
	0 to 58 (Total N)
	0 to 95 (Total P)
Recirculating sand filter[2] (on-site disposal system)	70 to 98 (TSS)
	75 to 98 (BOD)
	1 to 94 (Total N)
	70 to 90 (Total P)

[1]Schueler et al. 1991
[2]U.S. Environ. Prot. Agency, 1992
*Percent reduction in load vs. control or no treatment

Table 4.—Examples of point source treatment effectiveness.

TREATMENT	EFFECTIVENESS* (POLLUTANT)	
No discharge	100	(N)
Breakpoint chlorination	80 to 95	(N)
Reverse osmosis	80 to 90	(N)
Denitrification	70 to 95	(N)
Land application-irrigation	60 to 90	(N)
Ammonia stripping	50 to 90	(N)
Oxidation ponds	20 to 90	(N)
Filtration	20 to 40	(N)
Secondary treatment	10 to 30	(N)
Primary treatment	5 to 10	(N)
Primary sedimentation tanks	50 to 70	(TSS)
	25 to 40	(BOD_5)
	25 to 75	(Bacteria)
Primary sedimentation tanks	80 to 90	(TSS)
with chemical precipitation	70 to 80	(BOD_5)
	80 to 90	(Bacteria)
Alum addition	Up to 95	(P)
Activated sludge process	85 to 90	(BOD)
No treatment	0	

*Percent removal
Source: Metcalf and Eddy, 1979

site should be used to calculate C for the land area treated by the system.

The C score for a farm or other subarea that has multiple land uses (e.g., cropland and confined livestock) would be calculated as the arithmetic mean of the weighted land use subscores. Land use subscores would be weighted on the basis of their relative potential contribution of the pollutant or problem of concern. Clearly, the relative potential contribution of any nonpoint source must be determined on the basis of best professional judgment. We recommend that conventional tillage with excessive nutrient applications be considered the worst-case scenario for assessing potential contributions of nutrients and sediment from cropland. For livestock, one might assume for the worst-case that all animal waste would leave the site.

For example, a dairy farm that includes both cropland and livestock may be treated to keep 80 percent of cropland-generated phosphorus on site and 90 percent of livestock-generated phosphorus on site. If cropland has the potential (i.e., conservation tillage, excessive nutrient applications) to contribute 85 percent of the total phosphorus from the dairy, and livestock facilities have the potential (i.e., all animal waste leaves site) to contribute 15 percent of the total phosphorus from the dairy, the C score for the dairy would be 81.5 (C = [80*0.85]+[90*.15]). In summary, 81.5 percent of the phosphorus is kept from leaving the dairy.

Watersheds with multiple sources in the critical area can be addressed by calculating a C score for each source category (e.g., dairies, suburban residential, and forestry) and then calculating a weighted average score for the critical area. For example, the above dairy could be one of 20 in the critical area. The C score for dairies ($C_{Dairies}$) would be the arithmetic mean of the weighted scores (based on relative, potential contribution of pollutant or problem of concern) for the 20 dairies. The overall C score for the critical area would be calculated as the arithmetic mean of the weighted C scores for all source categories in the critical area. The weighting factor for each source category would be based on the proportion of the critical area pollutants or problems potentially contributed by that source.

As an example, assume that the above dairy is in a watershed that has four sources with the following potential contributions of phosphorus: (1) dairies in the critical area potentially contribute 30 percent of the phosphorus from the critical area, (2) a wastewater treatment plant potentially contributes 55 percent of the phosphorus, (3) cropland may contribute 10 percent of the phosphorus, and (4) urban runoff may contribute 5 percent. The 20 dairies are treated to remove an overall average of 85 percent of the phosphorus ($C_{Dairy=85}$), the wastewater treatment plant has secondary treatment ($C_{WWTP=90}$), the cropland is generally under conservation tillage and nutrient management ($C_{Crop=65}$), and the urban runoff is not treated ($C_{Urban=0}$). Then, the overall C score is

$$C = (.30)(85) + (.55)(90) + (.10)(65) + (.05)(0) = 81.5.$$

If more than one pollutant or problem must be tracked the C score is calculated as the arithmetic mean of the pollutant scores. For example, if total suspended solids were tracked (C score = 50.5) in addition to phosphorus (C score = 81.5), the overall C score would be 66 ([50.5+81.5]/2).

Testing

We tested the NPI using data from the Rock Creek Rural Clean Water Program (RCWP) project in Idaho and using data from the St. Albans Bay RCWP project in Vermont.

Rock Creek RCWP, Idaho

The Rock Creek, Idaho, RCWP project, located in south central Idaho, covered 18,321 hectares (45,000 acres) in an 80,352-hectare (198,400-acre) watershed (Fig. 1). About 350 farms in the project area produce dry beans, dry peas, sugar beets, corn, small grain, alfalfa, and livestock. Annual rainfall is low (21.6 cm/year) and irrigation is required for crop produc-

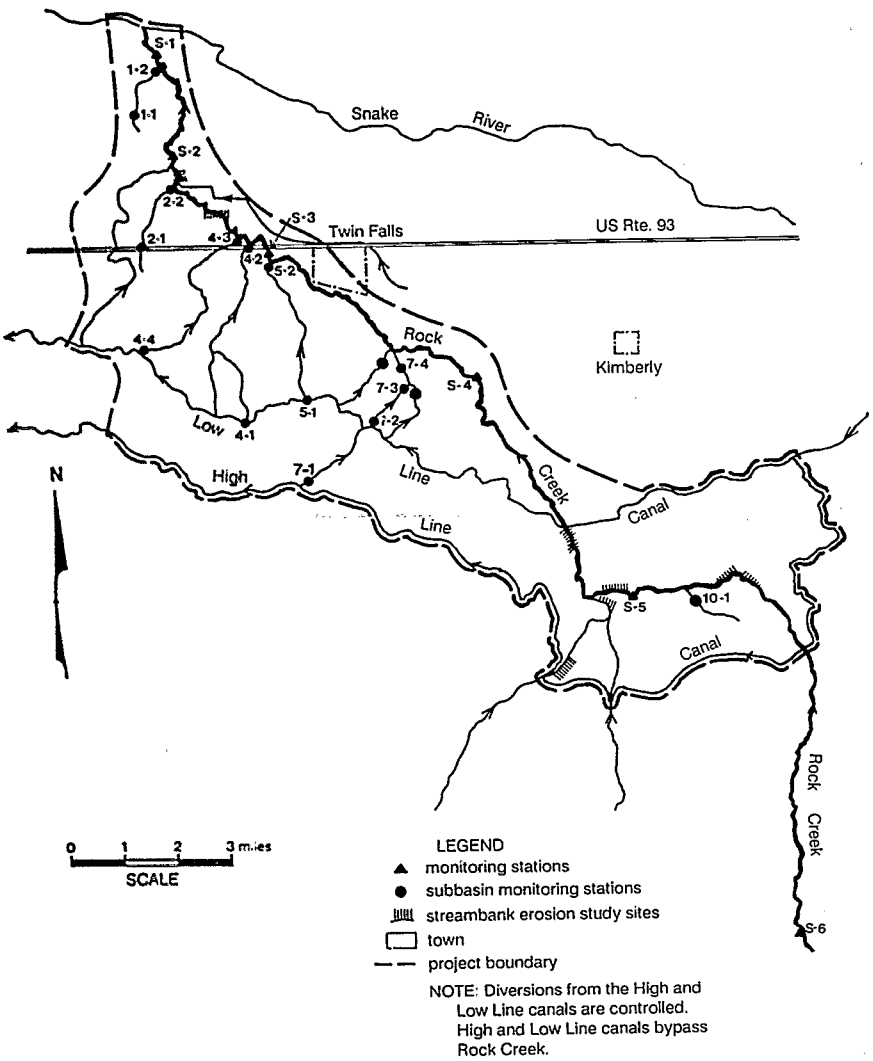

Figure 1.—Project map for the Rock Creek, Idaho, RCWP project.

tion. Irrigation water is diverted from the Snake River into main canals and delivered to the farms through a network of canals, laterals, and drains (ditches). Irrigation return flows eventually empty into Rock Creek, which discharges in the Snake River.

Rock Creek has poor water quality that impairs the beneficial uses of contact recreation and fishing. In addition, Rock Creek delivers a disproportionate load of sediment to the Snake River. Major sources of nonpoint source pollution in the area are sediment and associated pollutants (i.e., phosphorus and nitrogen) from irrigation return flows. Streambank erosion in the upper reaches of Rock Creek is also a major problem.

The nonpoint source management strategy is to reduce the amount of sediment, sediment-related pollutants, and animal waste discharging into Rock Creek from agricultural lands. All irrigated cropland and animal pro-duction facilities are included in the critical area, which comprises 11,470 hectares (28,159 acres). The primary implementation objectives are to control field erosion and prevent sediment from leaving fields. BMPs include conservation tillage, sediment retention structures, irrigation water management, vegetative filter strips, cover crops, and animal waste management.

Water quality monitoring objectives include (1) documenting beneficial use improvements by monitoring in-stream habitats, benthic macroinvertebrate, and fish populations; and (2) recording changes in concentrations of sediment and nutrients attributable to BMP implementation. Monitoring stations are located on Rock Creek and at downstream and upstream pairs in the subwatersheds, with the downstream stations representing outlets from the subwatersheds to Rock Creek.

Grab samples for chemical and physical parameters are taken biweekly during the irrigation season at the Rock Creek stations; the subwatersheds are sampled biweekly at the beginning and end of the irrigation season and weekly during the middle of the season. Monthly grab samples are taken in Rock Creek during the nonirrigation season. Fish populations have been measured in 1981, 1985, 1987, 1988, and 1989. Macroinvertebrate surveys are performed quarterly. Habitat Evaluation Procedures analyses were completed in 1981, 1984, and 1988.

The suspended sediment concentrations from the downstream Rock Creek monitoring station (S-2) were used for the NPI case study (Fig. 1). This station should reflect the cumulative nonpoint source impacts from the project area.

■ **Beneficial Use Support Status (U).** The U scores were calculated based on Water Quality Index (WQI) values. WQI values were calculated by the "WQI" program in EPA's STORET database, which compares the measured chemical and physical

values with recommended "fishable and swimmable" criteria. The project's 10-year report contained WQI values and associated use support ratings (U.S. Dep. Agric. 1991). In contrast to the U scores, a low WQI indicates good quality waters. The U scores were calculated based on an interpolation between the WQI values and use support ratings and the status and scores found in Table 1.

■ **Water Quality Data (W).** The W scores reflect the percent of samples that met the proposed standard of 100 mg/L suspended sediment in Rock Creek (U.S. Dep. Agric. 1991).

■ **Extent of Critical Area Treatment (E).** The extent of critical area treatment was obtained from the 10-year report and from annual project reports for 1982 to 1990.

■ **Pollution Control Expected From Treatment Applied (C).** The level of sediment control expected from treatment applied was estimated with sediment removal efficiencies determined by the project (U.S. Dep. Agric. 1991). The project reported a 70 percent decrease in the sediment load delivered to Rock Creek from the project area.

■ **NPI.** Scores for each subindex and the NPI for 1982 through 1990 for the downstream Rock Creek station are given in Table 5 and Figure 2. Although the project has documented improvements in the biology and habitat of Rock Creek, the improvement is far short of results predicted from suspended sediment measurements. Future analysis of the NPI using available biological and habitat data should reflect this discrepancy.

Table 5.—NPI and subindex annual scores for the downstream Rock Creek water quality monitoring stations (S-2), Rock Creek, Idaho, RCWP project.

YEAR	NPI SCORE	BENEFICIAL USE (U)	WATER QUALITY (W)	CRITICAL AREA TREATMENT (E)	POLLUTION CONTROL (C)
1982	14.9	30	7	10	12
1983	33.4	39	53	22	19
1984	32.2	35	27	30	37
1985	36.9	43	44	32	28
1986	45.5	47	59	35	41
1987	47.1	45	59	42	42
1988	64.0	53	87	46	70
1989	58.9	50	79	60	46
1990	64.1	54	92	75	35

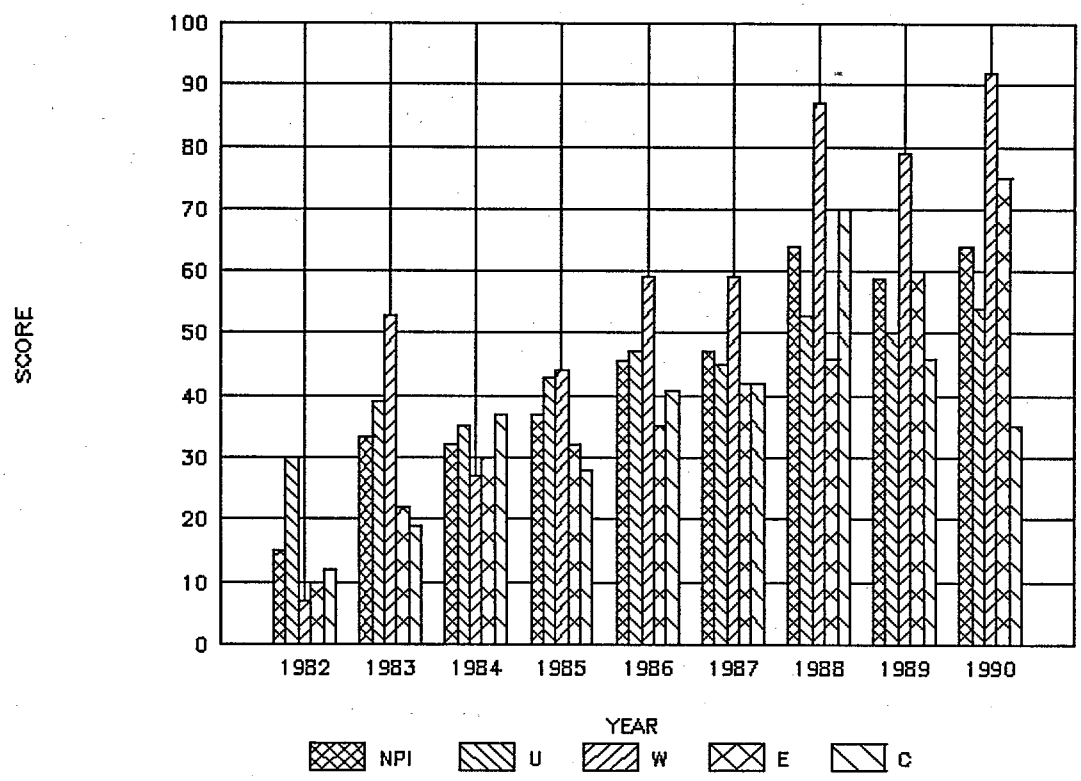

Figure 2.—NPI scores for Rock Creek, Idaho (sediment).

St. Albans Bay RCWP, Vermont

A complete description of the St. Albans Bay RCWP is given in Meals (1992). The impaired use was contact recreation in St. Albans Bay, which could not be used for swimming because of elevated fecal coliform counts.

■ **Beneficial Use Support Status (U).** Before implementing watershed BMPs, St. Albans Bay partially supported use for contact recreation (U_{Rec}=50). Following BMP implementation and upgrading of the wastewater treatment plant, use for recreation has been fully supported (U_{Rec}=80).

■ **Water Quality Data (W).** For this paper, only the bacteria data from the Vermont RCWP will be discussed. Table 6 summarizes the frequency in which the fecal coliform bacteria criterion of 200/100 mL was exceeded in each stream tributary to St. Albans Bay during pre- and post-BMP time periods. Overall, the percentage of bacteria violations dropped from 54 percent during the pre-BMP period (W=46) to 42 percent (W=58) during the post-BMP period. The study showed an average 58 percent decline in fecal coliform bacteria concentrations across the watershed.

Table 6.—Percentage of samples exceeding the fecal coliform criterion of 200/100 mL for streams tributary to St. Albans Bay, Vermont.

PERIOD	JEWETT BROOK	STEVENS BROOK	RUGGS BROOK	MILL RIVER
Pre-BMP	62	74	49	32
Post-BMP	61	49	34	22

■ **Extent of Critical Area Treatment (E).** Critical areas were defined as those lands receiving animal wastes. Initially, no critical areas were being treated (E=0). After the fifth year of the 10-year project and thereafter, 74 percent of the critical areas were treated (E=74). The project's goal was to treat 75 percent of the critical areas (79 percent of the animal units in the watershed were being managed by BMPs).

■ **Pollution Control Expected From Treatment Applied (C).** Animal waste management systems are expected to reduce fecal coliform loads by at least 37 percent (C=37).

■ **NPI.** Below are the NPI calculations for bacteria during the pre-BMP condition versus the post-BMP condition.

$$NPI_{Pre}=(0.25X50)+(0.25X46)+(0.25X0)+(0.25X0)=24 \quad (4)$$

$$NPI_{Post}=(0.25X80)+(0.25X58)+(0.25X74)+(0.25X37)=62 \quad (5)$$

This analysis indicates that the NPI for bacteria increased as a result of the project (Fig. 3). The NPI scores for phosphorus are given below. The threshold used for phosphorus was 0.05 mg/L.

$$NPI_{Pre}=(0.25X20)+(0.25X30)+(0.25X0)+(0.25X0)=12.5 \quad (6)$$

$$NPI_{Post}=(0.25X20)+(0.25X25)+(0.25X74)+(0.25X24)=35.6 \quad (7)$$

Although the NPI indicates a higher phosphorus index following BMP implementation, no improvement in phosphorus concentrations occurred in St. Albans Bay. However, as indicated in Clausen et al. (1992), the level of implementation should result in water quality improvements after a new field phosphorus equilibrium has been reached.

Conclusions

Results from two case studies indicate that the NPI can be a useful tool to help identify water quality status in projects before and after BMP implementation. In both cases, the NPI provides a convenient summary of land treatment and water quality parameters that can be easily interpreted by the scientific community, managers, and the general public.

The test results also show that the subindex scores can be used to explain trends in the overall NPI scores. For example, the Idaho analysis indicates that suspended sediment data are inadequate as the sole predictor of use support status in the watershed. The Vermont analysis illustrates the vastly different response times for bacteria and phosphorus.

The NPI does not reduce data collection needs, but it may help drive project participants toward more thorough data collection and a greater understanding of the relationships among identified problems, pollutants of concern, and implementation plans.

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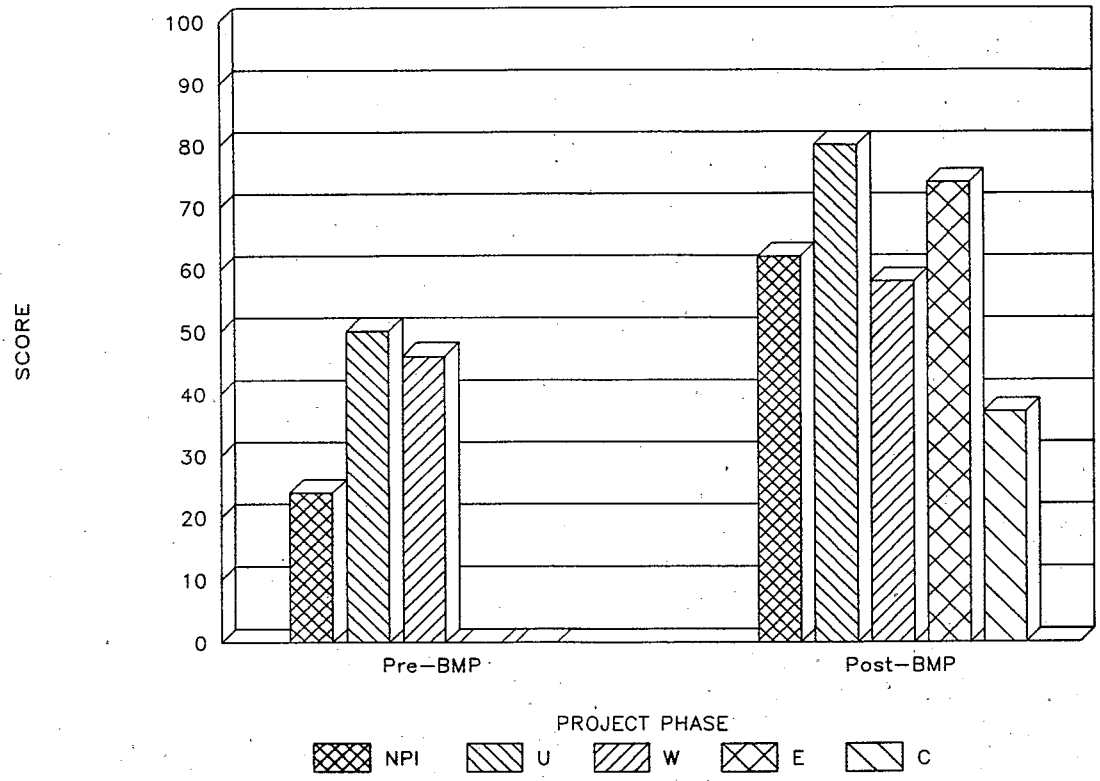

Figure 3.—NPI scores for St. Albans Bay, Vermont (bacteria).

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The Effects of Temporal and Spatial Variability on Monitoring Agricultural Nonpoint Source Pollution

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ABSTRACT

The Saline Valley Rural Clean Water Program project was one of 21 projects developed to evaluate methods of controlling agricultural nonpoint source pollution. Control programs were designed around voluntary implementation of best management practices, and water quality trends were monitored at eight stream stations from July 1981 to December 1989, using a fixed, weekly sampling design. An additional monitoring program was established within the Macon Creek subbasin (Station 9) in June 1988 to quantify temporal and spatial variability in pollutant loads. Macon Creek was monitored daily for seven days following any storm of more than half an inch of rain. Five stations were added upstream from existing Station 9 to examine spatial variation in loading rates throughout the subbasin. This study describes these storm monitoring results and discusses their implication to the Saline project's monitoring data.

Saline Valley was one of 21 projects within the U.S. Department of Agriculture's Rural Clean Water Program (RCWP) designed to evaluate methods for controlling agricultural nonpoint source pollution. For meaningful results from a water quality management perspective, it is necessary to quantify the effectiveness of best management practices (BMPs) in reducing pollutant loadings associated with agricultural production. Most projects found it difficult to establish these relationships for treatment applied at the watershed level.

Measuring effectiveness was complicated because a wide variety of BMPs were adopted gradually over large areas of land and because the RCWP relied on voluntary participation, which greatly limited control over the timing, amounts, and placement of these practices. The lack of treatment control, the spatial scales involved, and the inherent variability of meteorological processes posed significant problems for the water quality monitoring programs.

Limited funding and human resources severely restricted the Saline Valley project's ability to address patterns of temporal and spatial variability. The two most significant problems were the lack of continuous discharge records and the inability to monitor individual storm events in detail. The purpose of this project was to quantify patterns of temporal and spatial variability within the watershed by monitoring individual storms daily and increasing the number of stations along the stream. These data were then used to help evaluate and interpret the monitoring data. Data presented in this discussion

predominately focus on results from Subbasin 9, where all of the additional monitoring took place (Fig. 1.).

Materials and Methods

Temporal Variability

Temporal variability in pollutant loading was assessed on annual and daily time scales. Loading data collected under the project's weekly sampling scheme were tabulated and analyzed graphically through cumulative loading distributions to examine annual variability. Daily variability was assessed by monitoring individual storm events; however, only rainstorms producing greater than 0.5 inches a day were sampled. Following a storm, Macon Creek transect stations were monitored daily for seven days or until discharge returned to baseline conditions. A total of eight storms were monitored between 1988 and 1989.

Storm monitoring results were used to quantify potential errors in the project's loading estimates. Errors in the project's weekly loading estimates were calculated from the difference between summing the seven consecutive daily measurements versus extrapolating a single sampling event over a week. Errors were calculated for each of the seven days following a storm to represent all possible intervals between the storm and sampling day of a fixed schedule.

Results from storm monitoring were also used to evaluate errors in annual loading estimates. A daily precipitation record, obtained from the Saline wastewater treatment plant, was used in conjunction with average loading values observed for storms to estimate annual loads. These computed loading values were then compared against the project's loading estimates.

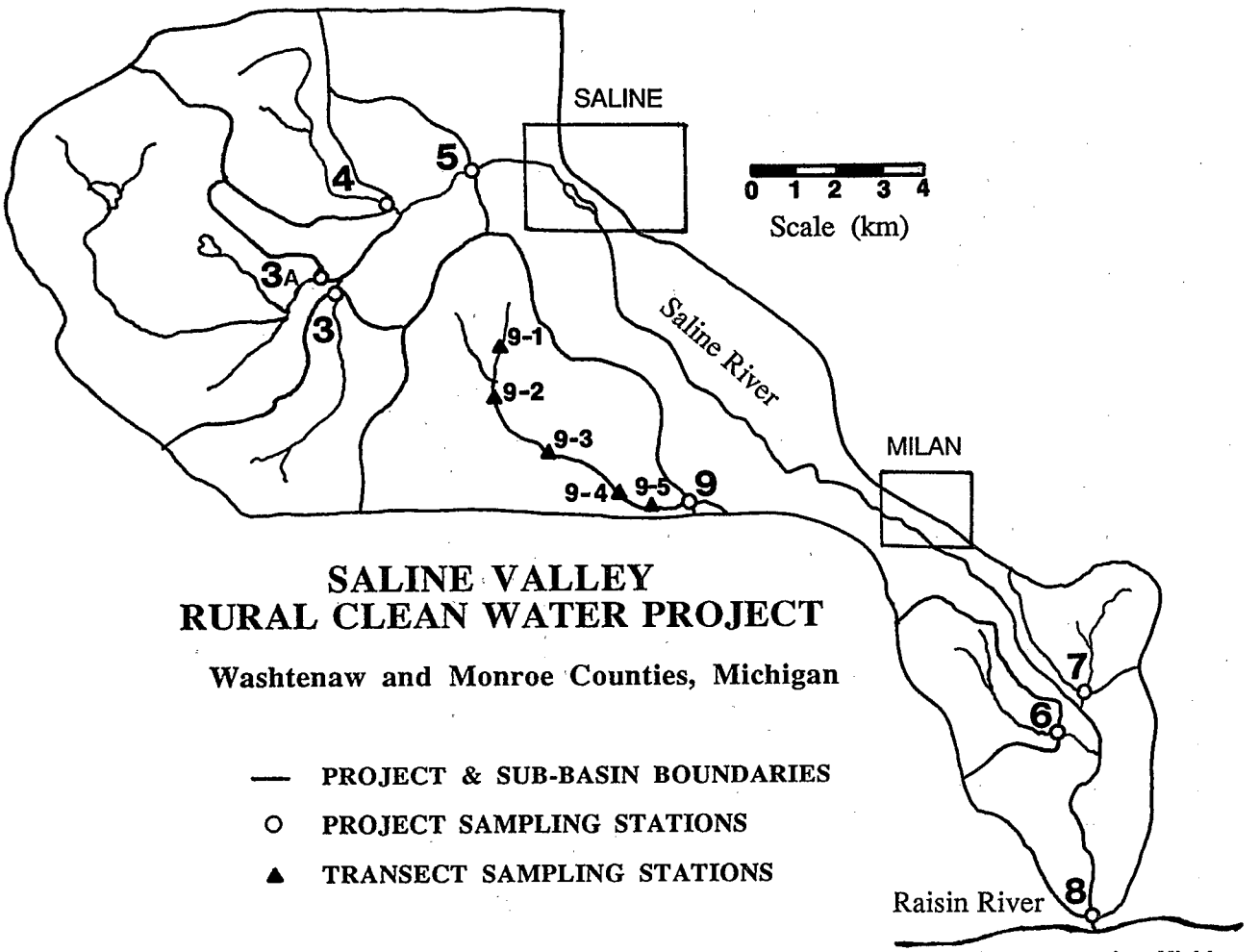

Figure 1.—Saline Valley Rural Clean Water Project study area located in Washtenaw and Monroe counties, Michigan. Project stations were located at (3) Saline–Bridgewater Drain, (4) Bauer Drain, (6) Bear Creek, (7) Wanty Drain, and (9) Macon Creek. Stations 3A, 5, and 8 were located on the Saline River. Transect Stations 9-1 to 9-5 were added along Macon Creek to examine patterns in spatial variability.

Spatial Variability

Spatial variability was examined over both watershed and subbasin scales. Variability within the project's watershed was evaluated by comparing patterns in concentration, loading, and export rates among the stations. Variability at the subbasin level was examined by creating a longitudinal transect along Macon Creek within Subbasin 9 (Fig. 1). Five additional stations were added upstream of existing Station 9, ranging from 0.8 to 2.9 kilometers apart. Transect stations were established in September 1988 and sampled during routine project sampling and storm events until the project's termination in December 1989.

Results

Temporal Variability in Pollutant Loading

The project's annual loading data for Station 9 revealed extreme variability in both magnitude and timing. Annual loads for suspended solids, total phosphorus (total-P), soluble phosphorus (soluble-P), and nitrate (NO_3) varied by 14-, 5-, 7-, and 3-fold, respectively, over the course of the study (Table 1). Cumulative loading distributions for total phosphorus revealed that loading rates were highly variable within a given year as well as among years (Fig. 2). If loading rates were uniform throughout the year, distributions would plot as straight lines. Distributions were highly nonlinear and indicated that annual loads were dominated by a storm events. Summing the three highest weekly loading estimates from the project's data indicated that, on average, 76, 56, 51, and 50 percent of annual loads for suspended solids, total-P, soluble-P, and nitrate, respectively, occurred in only 8 percent of the time within 28 days of the year.

Table 1.—Annual loads for suspended solids (SS), total phosphorus (TP), soluble phosphorus (Sol-P), and nitrate (NO_3) at Station 9 for 1983 through 1989.

	ANNUAL LOAD (mtons)			
YEAR	SS	TP	SOL-P	NO_3
1983	248	0.49	0.15	15.8
1984	101	0.34	0.15	13.6
1985	79	0.27	0.09	18.6
1986	256	0.85	0.26	19.8
1987	43	0.20	0.07	15.3
1988	604	1.13	0.49	44.4
1989	342	0.71	0.29	34.1

Daily monitoring of individual storm events revealed that the majority of loading occurred within the first 48 hours of a storm and returned to baseline conditions within three days (Table 2). This response was fairly consistent for all storms monitored, which ranged from 0.5 to 2.5 inches per day of precipitation. The percentage of the week's load, which occurred on Day One after a storm, was always greater for particulate parameters than for dissolved nutrients or discharge levels. On average, 40, 85, 71, 65, and 55 percent of the week's total load for discharge, suspended solids, total-P, soluble-P, and nitrate, respectively, occurred on this first day (Table 2). This pattern reflects a "first flush" effect, where material that has accumulated on the ground is washed off by overland runoff during the first part of a storm. Nitrate showed the smallest loading spike because its concentrations tended to peak one or two days after the storm when overland runoff ceased and the majority of input to the stream was derived from seepage through the soil.

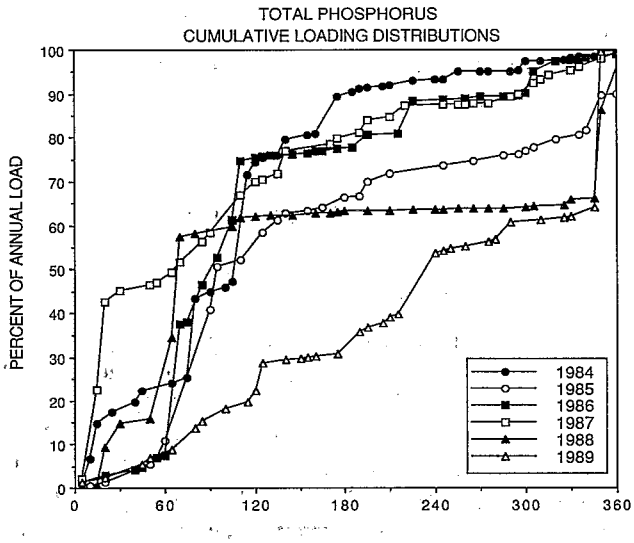

Figure 2.—Total phosphorus cumulative loading distributions at Station 9 for years 1984 through 1989.

Table 2.—Percent of weekly discharge (DIS), suspended solids (SS), total phosphorus (TP), soluble phosphorus (Sol-P), and nitrate (NO_3) loads occurring over seven days following a storm.

# DAYS AFTER STORM	PERCENT OF WEEKLY LOAD				
	DIS	SS	TP	SOL-P	NO_3
1	40	85	71	65	55
2	20	9	15	14	15
3	13	2	5	10	10
4	9	1	3	5	8
5	7	1	3	3	7
6	6	1	2	2	3
7	5	1	1	1	2

Results from daily sampling were used to calculate loading errors produced under the project's fixed weekly sampling schedule. Errors in weekly

loading estimates varied as a function of the duration between the storm event and sampling (Table 3). If sampling occurred during the first 24 hours after the storm, weekly loads were overestimated by an average of 505, 405, 365, and 295 percent for suspended solids, total-P, soluble-P, and nitrate, respectively. Errors were greater for particulate species because a larger percentage of their weekly load occurred on Day One after storms. Conversely, when sampling occurred five or more days after the storm, weekly loads were underestimated by approximately 93 percent for suspended solids, 79 percent for total and soluble phosphorus, and 50 percent for nitrate.

Table 3.—Percent loading error for suspended solids (SS), total phosphorus (TP), soluble phosphorus (Sol-P), and nitrate (NO_3) based on extrapolating a single sampling event over seven days versus sampling daily for seven days.

# DAYS AFTER STORM	PERCENT ERROR IN WEEKLY LOAD			
	SS	TP	SOL-P	NO_3
1	505	405	365	295
2	-36	+/-	+/-	+/-
3	-86	-64	-29	-29
4	-93	-79	-64	-43
5	-93	-79	-79	-50
6	-93	-86	-86	-79
7	-93	-93	-93	-86

The implications of this sampling bias were used to evaluate the project's annual loading estimates. Average loading values from storm monitoring were substituted for existing project estimates when more than 0.5 inches of rainfall occurred. Average weekly loading values following storms were 50,000, 60, 15, and 1,700 kilograms for suspended solids, total-P, soluble-P, and nitrate respectively. On average, rainfall of 0.5 or greater occurred 25 days per year in the project area. Adjusted loads indicated that only 3, 13, 20, and 17 percent, respectively, of the annual loads occurred from outside these storms. More importantly, adjusted loads indicated the project measured only 19, 34, 47, and 46 percent of the annual loads for suspended solids, total-P, soluble-P, and nitrate respectively (Table 4).

Table 4.—Project's loading estimate (observed) versus adjusted loading estimate based on storm monitoring results (predicted) for suspended solids, total and soluble phosphorus, and nitrates at Station 9.

MEAN ANNUAL LOAD	SUSP. SOLIDS (mton)	TOTAL-P (kg)	SOL-P (kg)	NITRATE (mton)
Observed:	240	590	220	24
Predicted:	1,295	1,725	470	52
Percent observed:	19%	34%	47%	46%

Spatial Variability in Pollutant Loading

Areal normalized export rates revealed large differences in loadings patterns among the project's subbasins (Table 5). Rates varied the most for suspended solids (eightfold) and least for soluble-P (twofold). Differences among basins were specific to individual parameters. For example, in Subbasin 7, suspended solid export was nearly sixfold less than in Subbasin 3 but nitrate export was nearly sixfold greater (Table 5).

Table 5.—Export rates for runoff, suspended solids, total and soluble phosphorus, and nitrate calculated as annual mean load divided by watershed size.

STATION	AREA (ha)	RUNOFF (cm)	EXPORT RATE (kg/ha/yr)			
			SS	TP	SOL-P	NO_3
3	1,610	20	193	0.29	0.07	8.0
4	1,980	19	183	0.28	0.08	26.7
5	11,780	33	267	0.38	0.09	12.0
6	1,000	30	33	0.26	0.11	19.4
7	780	61	31	0.26	0.06	44.5
8	31,200	28	106	0.50*	0.21	10.2
9	3,940	10	61	0.15	0.06	6.0

*After subtracting known point source contributions.

Regression of annual mean total-P concentration versus annual mean discharge also indicated that subbasins responded differently (Fig. 3). Subbasin streams exhibited similar phosphorus concentrations during years with lower mean discharge; however, as mean discharge increased, concentrations varied greatly, as indicated by the different slopes. Station 9 showed the greatest increase in phosphorus concentration whereas Station 5 showed only a minimal response. Variations in response could have resulted from differences in the physical characteristics of the basins and in current land use activities that would affect source amounts and transport efficiencies.

To examine spatial variability at the subbasin level, a longitudinal transect was created along Macon Creek (Fig. 1). Concentration patterns were examined to evaluate whether individual farm sites were having a disproportionately large effect on pollutant loads and survey changes that occur during transport. Differences among transect stations were examined statistically using a nonparametric Kruskhal-Wallace test (Table 6). Data were stratified according to low-flow and stormflow conditions. Concentration patterns were quite similar throughout the transect under both conditions. Surprisingly, more significant differences occurred for total-P, soluble-P, and ammonia concentrations under low-flow versus stormflow conditions. These results imply that internal cycling during transport affected

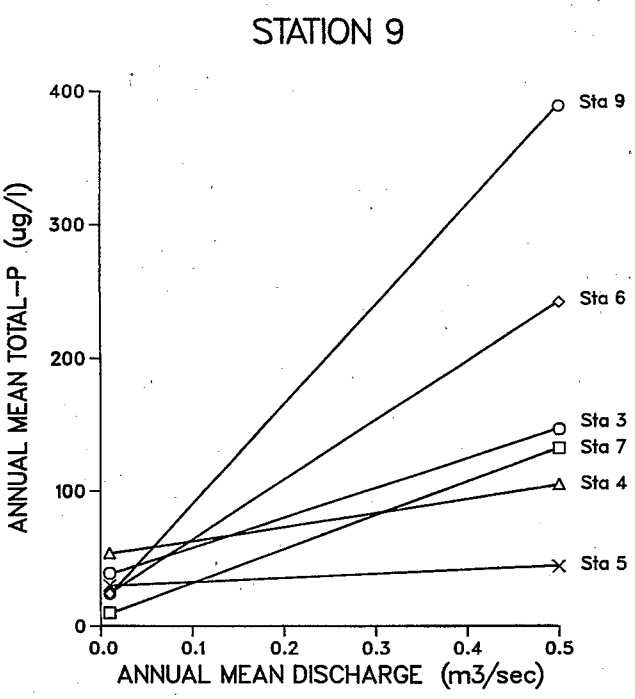

Figure 3.—Annual mean total phosphorus concentration plotted against annual mean discharge for each subbasin within the Saline Valley watershed. Regressions were based on means from 1982 through 1989 and were all significant at the 0.05 level.

concentration patterns more than differences in input from runoff. Presumably the slower velocities and less turbid water during low-flow conditions allowed sufficient time for biogeochemical processes to alter concentration patterns. Under stormflow conditions, only nitrate and chloride showed consistent differences between stations. These results are interesting because inputs for both these parameters tended to be dominated by subsurface flows.

Discussion

Temporal Variability

Temporal variability in loading rates over daily and annual scales were examined to evaluate the reliability of the project's monitoring design. Cumulative load distributions revealed that a significant portion of the annual load occurred in only a few sampling intervals. Specifically, over 75 percent of the suspended solids and 50 percent of the total and soluble phosphorus annual loads were received in 8 percent of the time.

The significance of a few individual storms to annual loads has also been observed in previous studies (Taylor et al. 1971; Johnson et al. 1976) and

Table 6.—Kruskal-Wallace test for concentration differences among Macon Creek transect stations during stormflow and baseline conditions (N=58 and 61 respectively) (Alpha < 0.1 reported as NS).

PARAMETER	STORMFLOW					BASELINE				
	STA:	9-3	9-4	9-5	9	STA:	9-3	9-4	9-5	9
	9-2	NS	NS	NS	NS	9-2	.09	.01	.06	NS
TOTAL-P	9-3		NS	NS	NS	9-3		NS	.00	NS
	9-4			NS	NS	9-4			.00	.02
	9-5				NS	9-5				NS
	STA:	9-3	9-4	9-5	9	STA:	9-3	9-4	9-5	9
	9-2	NS	.08	NS	NS	9-2	NS	NS	NS	NS
SOLUBLE-P	9-3		NS	NS	NS	9-3		NS	.03	NS
	9-4			NS	NS	9-4			.00	.03
	9-5				NS	9-5				NS
	STA:	9-3	9-4	9-5	9	STA:	9-3	9-4	9-5	9
	9-2	.00	.00	.00	.00	9-2	.00	.00	.00	.00
NITRATE-N	9-3		.07	.01	.00	9-3		NS	.00	.01
	9-4			NS	.04	9-4			.00	NS
	9-5				NS	9-5				NS
	STA:	9-3	9-4	9-5	9	STA:	9-3	9-4	9-5	9
	9-2	NS	.08	NS	NS	9-2	.00	.01	NS	NS
AMMONIA-N	9-3		NS	NS	NS	9-3		NS	.03	NS
	9-4			NS	NS	9-4			.01	.02
	9-5				NS	9-5				NS
	STA:	9-3	9-4	9-5	9	STA:	9-3	9-4	9-5	9
	9-2	NS	NS	NS	NS	9-2	NS	NS	NS	NS
SILICA	9-3		NS	NS	NS	9-3		NS	NS	NS
	9-4			NS	NS	9-4			NS	NS
	9-5				NS	9-5				NS
	STA:	9-3	9-4	9-5	9	STA:	9-3	9-4	9-5	9
	9-2	NS	NS	.05	.00	9-2	NS	NS	NS	.02
CHLORIDE	9-3		NS	NS	.00	9-3		NS	NS	.03
	9-4			NS	.02	9-4			NS	.02
	9-5				.07	9-5				.01

appears quite characteristic of nonpoint source pollution. The magnitude of loads following storms is great because the effect of increased discharge is multiplied by that of increased concentration. The magnitude and duration of increased concentration appears to be a function of the amount of pollutant that has accumulated in the watershed and the rate at which it is washed off. Daily monitoring data of storm runoff indicated that loading spikes typically lasted only a few days. Spikes were always greatest for particulate species, reflecting the effect of increased erosion from overland runoff and probably the increased carrying capacity of the stream during higher velocities. Dissolved nutrient concentrations remained elevated for several days after the storm ended, presumably because of subsurface inputs, and consequently, daily loading rates decreased more slowly.

The importance of these few large storms to total annual loads implies that BMPs must be designed to handle runoff conditions that develop under intense storms. If BMPs are not effective against these major events, they may reduce only an insignificant portion of the annual loads.

During each study year, annual loads were dominated by a few events. The timing and frequency of these loading spikes were, however, highly variable among years. These results imply that errors in loading estimates using a fixed sampling schedule would be inconsistent between years. Inconsistent errors will compound the problem of high variability resulting from meteorological conditions and could invalidate a monitoring program's conclusions about BMP effectiveness.

Monitoring data from individual storm events revealed that the project's annual loading estimates were extremely inaccurate and could not be used to assess the effects of the land treatment program. The magnitude of variability revealed by this study strongly suggests a mandate for continuous discharge meas- urements and event-based sampling to accurately evaluate nonpoint pollution loading. In addition, the effects of varying amounts of discharge must be removed from annual loading or concentration trends to provide a sensitive measure of land treatment effectiveness. In an earlier analysis of the project's data, changes in empirical regressions of concentration versus discharge were examined to evaluate whether BMPs reduced pollutant export (Johengen et al. 1989). No significant effects were found, and it was concluded that there was insufficient coverage of BMPs. Present results also suggest that sampling biases could have affected concentration and discharge regressions, greatly reducing their sensitivity.

Comparisons between storm event sampling and fixed weekly sampling indicated that the fixed schedule produced extreme errors in loading estimates because the fixed schedule assumed that loading rates were constant over the entire duration between sampling intervals. Daily monitoring indicated loading spikes lasted only a few days; therefore, loads were overestimated if sampling occurred within one or two days after the storm and underestimated if more than two days passed before sampling. This timing also meant that the weekly sampling schedule would often miss the loading from a storm completely. The final result was that the project's annual loading estimates were only 19 to 47 percent of calculated loads accounting for storms.

Stevens and Smith (1978) found that even with load rating curves and continuous discharge measurements, an eight-day fixed sampling schedule underestimated nitrate loading by 18 percent and overestimated particulate-P loading by 43 percent. Errors are produced even when using rating curves because concentration values are predicted from relationships with discharge, and the fixed schedule tends to oversample more common low-flow conditions. Johnson (1979) suggested that, in the absence of automated samplers that can sample on a flow-proportioned schedule, a varying frequency schedule should be used that samples all stages of flow. Sharpley et al. (1976) reported that sampling intervals for some streams should be as short as 60 minutes during peak flow to produce loading estimates with less than a 15 percent error. Resources were not available in this study to examine loading patterns at such time scales.

Spatial Variability

The RCWP was unique because it attempted to establish relationships between land treatment practices applied at the watershed level and resulting changes in the water quality of receiving waterbodies. Few projects, however, addressed the issue of spatial variability within their watersheds. Several projects concurred that sampling within the subbasin helped in examining the relationship between land treatment and water quality (Natl. Water Qual. Eval. Proj. 1989). Results were not, however, discussed in terms of the variability in response among subbasins or the implications for site-specific effects.

This study revealed extreme variability in pollutant export rates among subbasins; differences were specific to the individual parameters. Systematic differences in concentration and loading patterns among subbasins can occur as a result of their

size, topography, soil type, land use, and drainage efficiency (Baker, 1985). These findings imply that individual subbasins may respond quite differently to the applied land treatment, and BMP effectiveness should be assessed at the subbasin scale. Monitoring at the subbasin level also establishes stations closer to the sites of BMP implementation and can reduce the influence from nonparticipating areas or other sources of pollution.

Transect stations established within Subbasin 9 revealed that internal cycling within the stream can also affect concentration patterns. These results also imply the need to monitor water quality trends as close to the site of land treatment as possible. Although transect stations did not reveal many significant differences in pollutant inputs during storms, they did catch occasional spikes that were orders of magnitude different. These site-specific results could help target critical areas within the subbasin.

Variations in loading rates among basins could be used to focus attention on those areas that may have the greatest effect on water quality. Targeting critical areas was expounded as the best way to maximize cost-effectiveness (Natl. Water Qual. Eval. Proj. 1989). One difficulty with this approach is that extensive mon- itoring must take place before the land treatment program can be initiated. However, although this degree of initial monitoring could ultimately make BMPs more cost effective, it may be difficult to convince managers to invest in this approach.

Conclusions

Temporal and spatial variability in pollutant loadings were extremely high throughout the study. Cumulative loading distributions indicated that a few storms can produce over 50 percent of the total annual pollutant load. Loading spikes typically lasted only a few days; therefore, their impact was often missed because the project mandated weekly sampling. Loading adjustments based on a daily precipitation record indicated that the project estimated only 20 of the suspended solids load and 50 percent of the total and soluble phosphorus load. Storm monitoring results suggest that a continuous discharge record and flow-proportional sampling are necessary to establish accurate loading estimates for nonpoint source pollution. Without this detailed record, evaluating long-term trends would be impossible, given the extreme temporal variability.

Differences in concentration and loading patterns among the project's stations revealed a high degree of spatial variability within the watershed. For transect stations established along Macon Creek, variability was greater during low-flow versus stormflow conditions. Results suggest that monitoring at the subbasin level would help target critical areas and improve chances of detecting water quality changes resulting from land treatment application.

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Effects of Pipe-Outlet Terracing on Runoff Water Quantity and Quality at an Agricultural Field Site, Conestoga River Headwaters, Pennsylvania

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ABSTRACT

Terracing effects on runoff were investigated between 1983 and 1989 at a 22.1-acre agricultural site in Lancaster County, Pennsylvania, as part of the Rural Clean Water Program. The site, underlain by carbonate rock, was primarily corn and alfalfa fields with a median slope of 6 percent. Average annual runoff was 11 percent of 44 inches of precipitation. Runoff quantity, suspended sediment, nutrient, and precipitation data were collected for 21 months before, and 58 months following, pipe-outlet terrace construction. Data were analyzed using graphic, regression, covariate, cluster, and Mann-Whitney techniques.

Terracing changed runoff characteristics. Storm characteristics were similar throughout the study period; however, after terracing, storms producing less than 0.4 inches of precipitation rarely produced runoff. Total storm discharge as a function of precipitation did not change significantly throughout the range of runoff-producing storms after terracing. Multiple discharge peaks that appeared on hydrographs before terracing did not occur after terracing. Then hydrographs reflected the stepwise draining of each terrace through the pipe outlet.

After an initial two-year period of terrace stabilization, suspended sediment yield in runoff decreased significantly as a function of runoff. This result was expected because terracing decreased runoff energy and because terrace ponding allowed time for sediment redeposition.

Nitrate plus nitrite yields increased proportionally throughout the range of runoff during the postterracing period relative to the preterracing period. After terracing, increased nitrate concentrations were found in runoff, possibly from a combination of increased soil contact time and increased nitrification caused by wetter soils.

No significant change was found in total nitrogen, ammonium plus organic nitrogen, or total phosphorus yields relative to runoff before and after terracing. Limited data suggest that fine sediment particles (less than 0.62 micrometers in diameter), which continued to be discharged from the site, transported most of the phosphorus.

The U.S. Geological Survey (USGS), in cooperation with the Pennsylvania Department of Environmental Resources, conducted a study to determine the effects of agricultural best management practices (BMPs) on surface and groundwater quality. The study involved water-quality monitoring in the Conestoga River headwaters area over a 10-year period (1982 to 1991) on three scales: regional, small watershed, and field. A detailed description of the overall study can be found in Chichester (1988). This project was one of five comprehensive monitoring and evaluation projects in the Rural Clean Water Program (RCWP).

This report documents the effects of terracing on surface water quantity and quality at Field Site 1. Climatological and agricultural activity data are compared to surface water quantity and quality data collected before and after implementation of terracing.

The pre-BMP period (January 1983 through September 1984) is Period 1. Data from the study's post-BMP phase are grouped into three time periods: October 1984 through September 1986 is Period 2, October 1986 through September 1988 is Period 3, and October 1988 through September 1989 is Period 4. Period 3 is the most comparable to Period 1 in terms of annual precipitation and nutrient applications to the field. In addition, by October 1986, the terraces were well established (settled) and cropping patterns were stable. Therefore, data from Period 3 and Period 1 are compared in this report to discuss changes related to terracing.

All species of nitrogen or phosphorus are expressed in their elemental forms. For example, whether discussing ammonium or nitrate concentrations or loads, all values are expressed as nitrogen. The term ammonium refers to the ammonium ion plus free ammonia. A water year is the 12-month period beginning October 1 and ending September 30; it is designated by the calendar year in which it ends.

Study Area Description

Location and Description

Field Site 1 is located in the Conestoga headwaters basin, between Churchtown and Goodville, Lancaster County, Pennsylvania (Fig. 1). The 22.1-acre site, underlain by carbonate rock, is conventionally tilled cropland, planted primarily in corn and alfalfa. Soils at the site are classified as Duffield and Hagerstown silt loams. The soils, formed in residuum of weathered carbonate rocks, are up to 60 inches deep and moderately to well drained. The site has an overall slope of about 6 percent.

Best Management Practices

The BMPs implemented at Field Site 1 were terracing and nutrient management. Six pipe-outlet terraces, designed to accommodate a 5-inch, 24-hour storm, were constructed between October 19, 1984, and November 16, 1984. (The four lower terraces were rebuilt in May 1985 shortly after runoff from a thunderstorm on May 21, 1985, overflowed the terraces and created severe gully formation.) Terrace construction changed the site's topography and increased the surface drainage area from 22.1 to 23.1 acres (Fig. 2). The terraces were graded so that each terrace sloped gently downgradient toward the field's center. The terraces trapped runoff creating ponds that drained through a pipe outlet. During the post-BMP period, surface runoff was water leaving the upper 90 percent of the site through the pipe-outlet system plus runoff from the unterraced lower 10 percent of the site. Under extreme storm conditions, runoff breached the terrace structures. In contrast, surface runoff during the pre-BMP period was unimpeded by structural devices and created large feeder gullies throughout the site and massive receiving gullies in the lower one-third of the site.

The nutrient-management plan for the site was developed in November 1984. The plan was based on nitrogen only and, as a result, recommended an excess of phosphorus when manure was used to satisfy the crops' nitrogen needs. The nutrient management plan recommended an annual nitrogen application rate of 350 to 375 pounds per acre of nitrogen within 5 to 7 days of cornfield plowing (less than a 15 percent reduction from that applied during the pre-BMP period). In addition, the plan recommended an average application rate of 100 pounds per acre of nitrogen for newly seeded alfalfa fields (with no application recommended on established alfalfa).

Nutrient management recommendations were followed within 25 percent in the 1985, 1986, and 1988 crop years, with adjustment to applications for rapid incorporation of a substantial portion of the manure for 1986 and 1988. However, the planned applications were exceeded by about 2.5 times in the 1987 and 1989 crop years. Nutrient management also recommended that the timing of nutrient applications be changed from daily spread to the time the crops could most readily use these nutrients. Flexibility in the timing of nutrient applications was made possible by constructing a facility to store manure for 6 months.

Sampling Network and Data Analysis

Precipitation was collected at the site in a 13-inch funnel mounted above a plastic receiving pipe; precipitation quantity in the pipe was recorded every 5 minutes with an Analog Digital Recorder (ADR) (Fig. 2). Runoff was channeled through a 9-inch Parshall™ flume located beside the gaging station (Fig. 2). Stage was recorded continuously with a Stevens™ graphic recorder and an ADR. Runoff samples were collected with a float or stage-triggered PS-69 automatic sampler modified with a refrigeration unit. Perforated intakes for the samples were positioned in the flume's center. Each time a sample was collected, a mark was automatically made on the graphic recorder to identify the stage associated with the sample. Nutrient samples were preserved with mercuric chloride and stored at

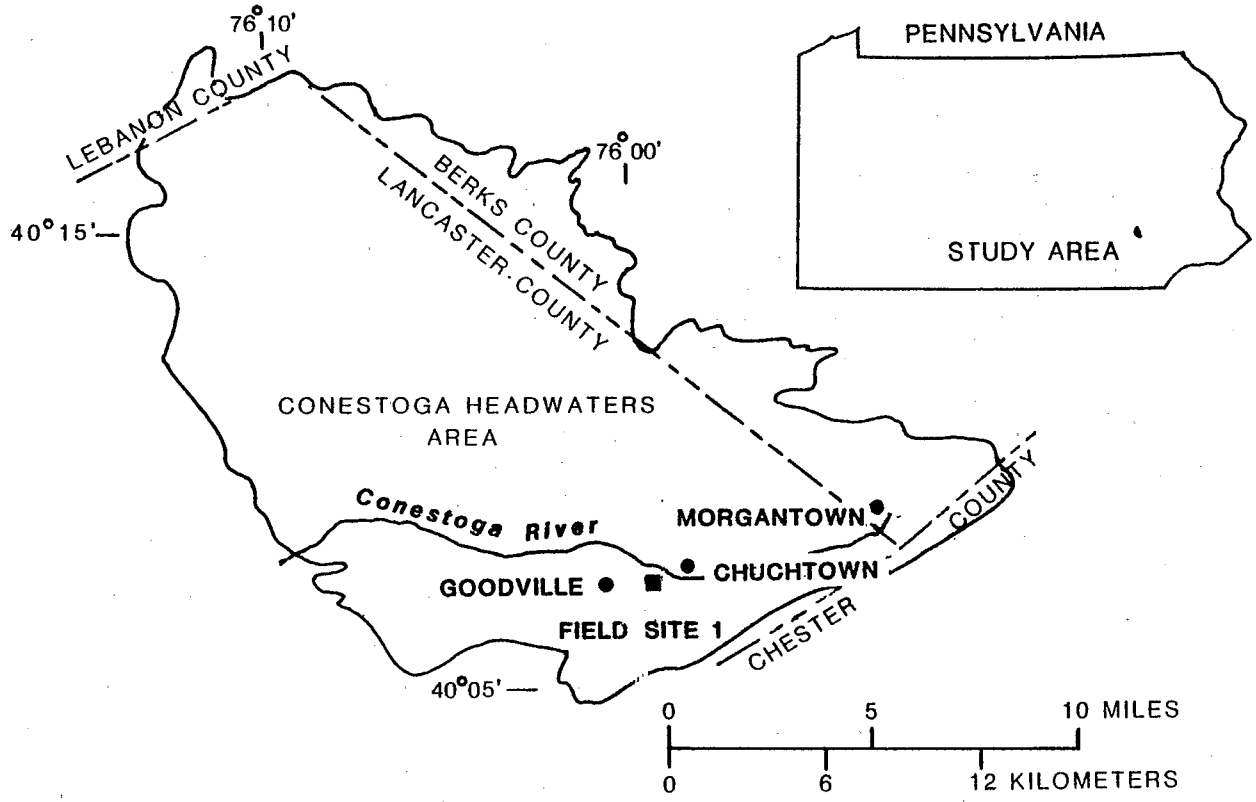

Figure 1.—Conestoga headwaters study area and Field Site 1 location.

about 4°C from time of collection until time of analysis.

Detailed information on methods of data collection and sample and data analysis is presented in Chichester (1988). A summary of the data collection network is given in Table 1, and data collection sites are shown in Figure 2.

Water quality data collected during this study, published in U.S. Geological Survey Water Resources Data Reports PA-83-2 to PA-89-2 (U.S. Geo. Surv., 1984-90), are stored in the USGS WATSTORE and U.S. Environmental Protection Agency (EPA) STORET databases. The data were catalogued by the USGS using the local identification numbers used in this report. All agricultural activity and soil data are on file in the USGS office in Lemoyne, Pennsylvania.

Statistical procedures were used for summarizing data, making statistically supported inferences about the data, and defining explanatory relations between various data. Statistical inferences were based on results of hypothesis testing at the 95 percent confidence interval except where noted. The null hypothesis was always that no significant change occurred from Period 1 to Period 3. Summary statistics, linear regression, analysis of covariance, cluster analysis, and Mann-Whitney testing were run on software from P-STAT, Inc. (1989).

To estimate annual load, suspended sediment and nutrient loads for unsampled runoff events were estimated by using regression equations derived

Table 1.—Data collection network at Field Site 1.

MEDIUM	NUMBER OF LOCATIONS	DATA COLLECTION FREQUENCY	ADNALYSES PERFORMED OR DATA COLLECTED
Precipitation	1	5-minute intervals during storms; 7 times during study period	Volume
Agricultural activities	Entire site	Biweekly	Nutrient concentration
Manure	Varied	At selected major applications	Nutrient application timing and rates; planting, plowing, and harvesting locations and dates
Soil	Varied	Spring, summer, fall	Nutrient concentration
Runoff	1	All runoff events Most runoff events	Volume Suspended sediment and nutrient concentration

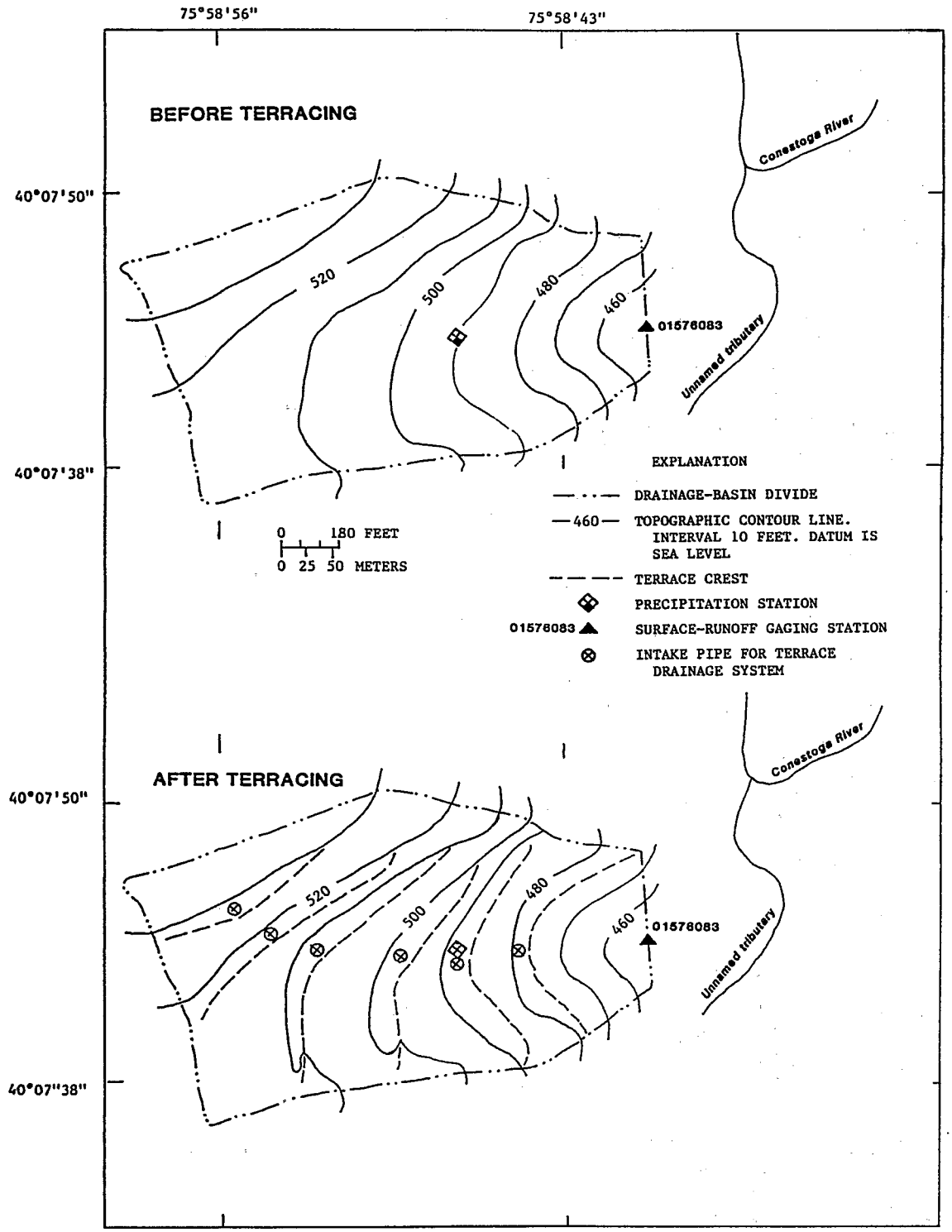

Figure 2.—Field Site 1 topography and surface: runoff, groundwater, and precipitation sampling locations before and after terracing.

from log-transformed loads as a function of log-transformed total runoff from sampled runoff events. Regression analyses were performed separately for data from the growing season (May through October) and the nongrowing season (November through April) to make calculations on the basis of runoff occurring during similar field conditions. For the 79 months of study, 19 percent of the suspended sediment load, 21 percent of the total nitrogen load, and 22 percent of the total-phosphorus load were es-

timated. Data for estimated and sampled individual runoff events were summed to calculate annual loads.

Climate

Annual precipitation at Field Site 1 ranged from 35.6 inches during the 1986 water year to 59.8 inches during the 1984 water year (Table 2). Table 2 shows that Period 3 was the most comparable period to Period 1 for total rainfall; total precipitation at Field Site 1 was slightly below normal during the 1983 and 1988 water years, and annual precipitation substantially exceeded the normal average during the 1984 and 1987 water years.

During the pre-BMP Period 1 (1983-84 water years), 169 storms occurred. The median storm precipitation was 0.29 inch, the median storm duration was 2.8 hours, and the median maximum 15- and 30-minute intensities were 0.08 and 0.13 inch, respectively. Nineteen storms in the period produced a total precipitation of 1.0 inch or greater, and four storms produced 2.0 inches or greater. During Period 3 (1987-88 water years), 148 storms occurred. The median total storm precipitation was 0.33 inch, the median storm duration was 3.4 hours, and the median maximum 15- and 30-minute intensities were 0.07 and 0.10 inch, respectively. Twenty-four storms produced 1.0 inch or more of precipitation, and six storms produced 2.0 inches or more of precipitation. Thus, on the basis of this qualitative assessment, Periods 1 and 3 were climatologically similar.

Agricultural Activities

Year-to-year crop acreages and summer cropping patterns for the 1983-89 crop years ("crop year" is defined as the interval of time beginning immediately after the harvest of 1-year's corn crop at the site and ending with the harvest of the next corn crop) are shown in Figure 3. A substantial shift in cropping occurred at the site during the study period. Period 3 was the study period most representative of the terracing BMP because terraces were settled by October 1986, and the planned cropping pattern was established.

Annual totals of nitrogen and phosphorus applications were tabulated by crop year rather than by water year to determine with the greatest possible accuracy the amount of applied nutrients available to a season's crop.

Dairy cattle manure was the primary source of nutrients applied to the site, comprising about 95 and 85 percent of the total nitrogen and phosphorus applications, respectively. Commercial fertilizer and nitrogen from precipitation made up the remainder. Manure applications were concentrated on the corn acreage, whereas the alfalfa and soybean acreage received relatively small applications (Table 3).

Period 3 was the post-BMP period most comparable to Period 1 with respect to crops and nutrient applications to the site (Fig. 3 and Table 3). During both periods, an average of 65 percent of the site was planted in corn. The corn planting and harvesting times were about the same in Periods 3 and 1. A

Table 2.—Annual precipitation at Field Site 1 and the 30-year mean from a nearby raingage at Morgantown, PA.

		PRECIPITATION IN INCHES	
PERIOD	DATES	ANNUAL PRECIPITATION FIELD SITE 1	30-YEAR MEAN MORGANTOWN[1] (1951-80)
1	Jan 1. to Sept. 30, 1983	31.4	31.9
	Oct. 1, 1983 to Sept. 30, 1984	59.8	41.5
2	Oct. 1, 1984 to Sept. 30, 1985	41.7	41.5
	Oct. 1, 1985 to Sept. 30, 1986	35.6	41.5
3	Oct. 1, 1986 to Sept. 30, 1987	46.2	41.5
	Oct. 1, 1987 to Sept. 30, 1988	41.3	41.5
4	Oct. 1, 1988 to Sept. 30, 1989	45.0	41.5

[1]Data from the National Oceanic and Atmospheric Administration (1985).

Table 3.—Annual nutrient applications to Field Site 1 by crop (all values in pounds per acre).

		CORN		ALFALFA	
PERIOD	CROP YEAR	NITROGEN	PHOSPHORUS	NITROGEN	PHOSPHORUS
1	1983	150	33	0	0
1	1984	640	170	31	8
2	1985	230	61	9	15
2	1986	290	72	7	12
3	1987	690	130	24	0
3	1988	300	80	0	0
4	1989	540	160	290	84

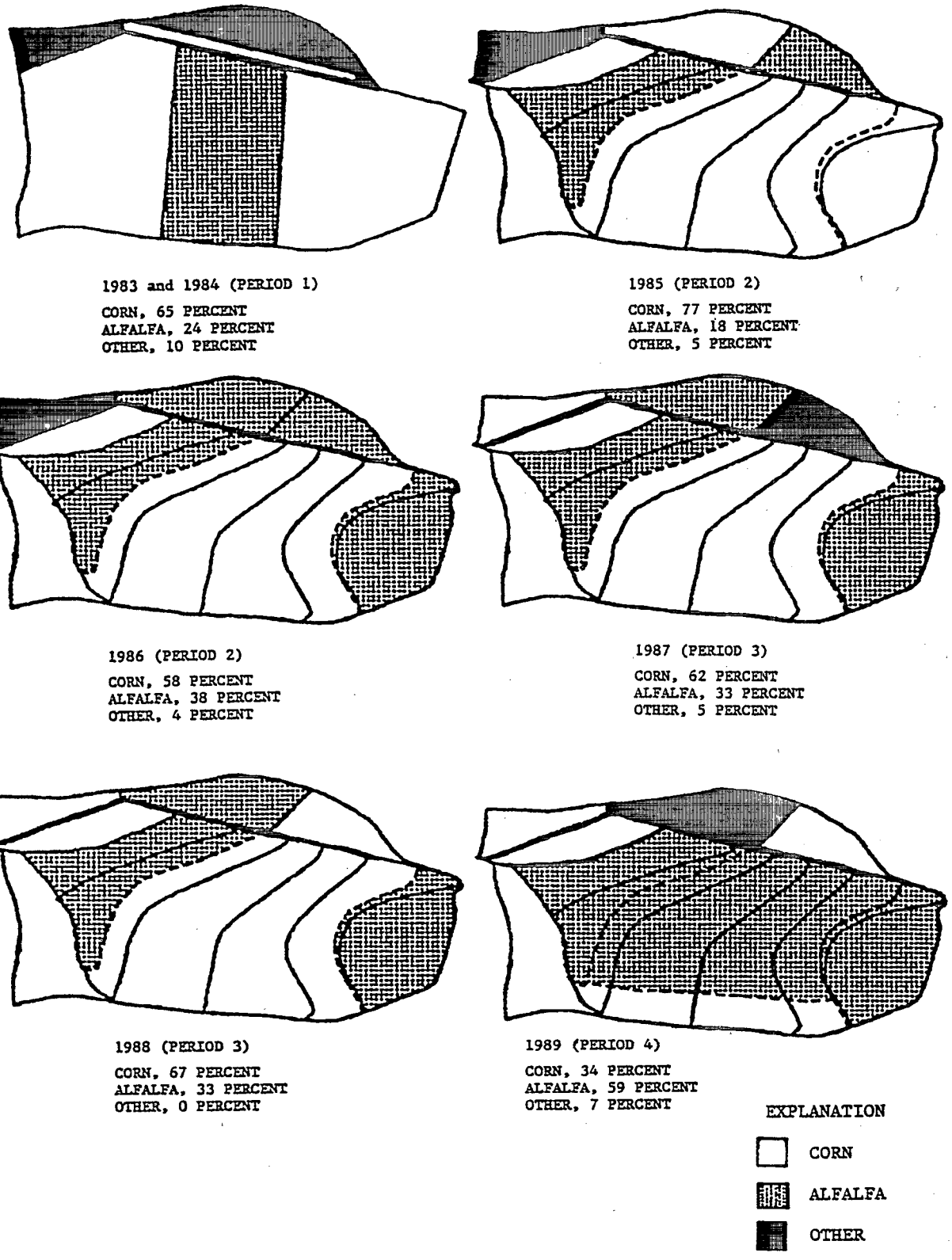

Figure 3.—Cropping patterns at Field Site 1 for the 1983-89 crop years.

winter cover crop was planted during both years of the pre-BMP period, but little winter cover crop was planted during the post-BMP period. The average annual applications for the site were about 320 pounds per acre nitrogen and 82 pounds per acre phosphorus during Period 3, and 270 pounds per acre nitrogen and 70 pounds per acre phosphorus during Period 1.

Effects of Terracing on Surface Runoff

Quantity

Surface runoff during the pre-BMP period was unimpeded by structural devices and created small feeder gullies and larger receiving gullies over much of the area planted in corn (Fig. 3). A massive gully was created in the lower cornfield. In contrast, most surface runoff during the post-BMP period, after installation of the terraces, discharged through the pipe-outlet system. Twice, under extreme storm conditions, runoff breached the terrace structures. Measurable runoff from Field Site 1 during Periods 1 (21 months), 2 (24 months), 3 (24 months), and 4 (10 months), was recorded 97, 58, 52, and 29 times, respectively. As shown in Figure 4, runoff during the post-BMP periods occurred only when storms were larger and generally of longer durations and higher intensities than storms during the pre-BMP period. These changes were a result of terrace construction, which changed runoff characteristics.

The change in runoff character was most evident in the change in the shape of runoff hydrographs for the different periods (Fig. 5). During Period 1, before terracing, the hydrograph had numerous peaks of different sizes caused by varying intensities of rainfall. Surface runoff from different parts of the field could also be distinguished on the hydrograph. The most downgradient part of the field peaked first, followed by subsequent peaks from the upgradient cornfield. After terracing, water retention in the terraces and steady drainage through the pipe outlets resulted in a stepwise decline in stage as the terraces drained, regardless of precipitation intensity. During summer 1985, the initial hydrograph peak (Fig. 5) was associated with runoff from the corn field downgradient from the first terrace and with initial outflow from the terraces. During Period 3, when the field downgradient from the first terrace was established in alfalfa, the initial runoff peaks generally did not occur.

For Periods 1, 2, 3, and 4, respectively, 9.8, 15, 13, and 3.9 percent of the total precipitation was discharged from the site as runoff (Table 4). For the pre-BMP period, the runoff varied from 3 percent of precipitation for the 9-month study period in 1983 (January through September), to 13 percent for the 1984 water year. The distribution of rainfall probably accounted for the low runoff during 1983. Many small and moderate rainfalls occurred during the spring when the winter crop cover was high, and many small rainfalls occurred in the early summer on recently plowed, loose soil. Annual variation was much less during Periods 2 and 3.

Multiple regression analyses of data from the pre-BMP period (unpublished report on file, USGS office, Lemoyne, Pennsylvania), which were used to determine explanatory variables, suggested that total runoff was primarily controlled by total precipitation and antecedent soil moisture (based on total precipitation for 30 days before a runoff event). Regression analyses also suggested that crop cover on corn acreage reduced total runoff. Analysis of the pre-BMP data also showed that nearly all rainfall ran off when the soil was frozen. Results from multiple regression analysis of the post-BMP data show that the total runoff after terracing was controlled by the same factors — total precipitation and antecedent soil moisture — as was total runoff before terracing. After terracing, the measured mean and maximum storm discharges at the gage were controlled by the pipe-outlet dynamics in addition to the climatological

Table 4.—Annual runoff, suspended sediment, and nutrient yields in runoff from Field Site 1.

PERIOD	WATER YEAR	TOTAL RUNOFF (ft^3/acre)	PERCENT OF TOTAL PRECIPITATION IN RUNOFF	SUSPENDED SEDIMENT YIELD (tons/acre)	TOTAL NITROGEN YIELD (lb/acre)	AMMONIA + ORGANIC NITROGEN YIELD (% of total n)	NITRATE + ORGANIC NITROGEN YIELD (% of total N)	TOTAL PHOSPHORUS YIELD (lb/acre)
1	1983[1]	3,734	3.3	0.70	1.8	91	9	1.0
1	1984	28,568	13.2	111.00	12.0	92	8	7.0
2	1985	24,317	16.1	3.40	8.0	68	32	3.1
2	1986	17,859	13.8	.83	6.3	68	32	2.9
3	1987	18,851	11.2	.54	4.6	61	39	4.0
3	1988	21,788	14.5	1.00	9.3	64	36	3.8
4	1989[2]	5,692	3.9	.28	3.4	78	22	1.3

[1]January through September 1983.
[2]October 1988 through July 1989.

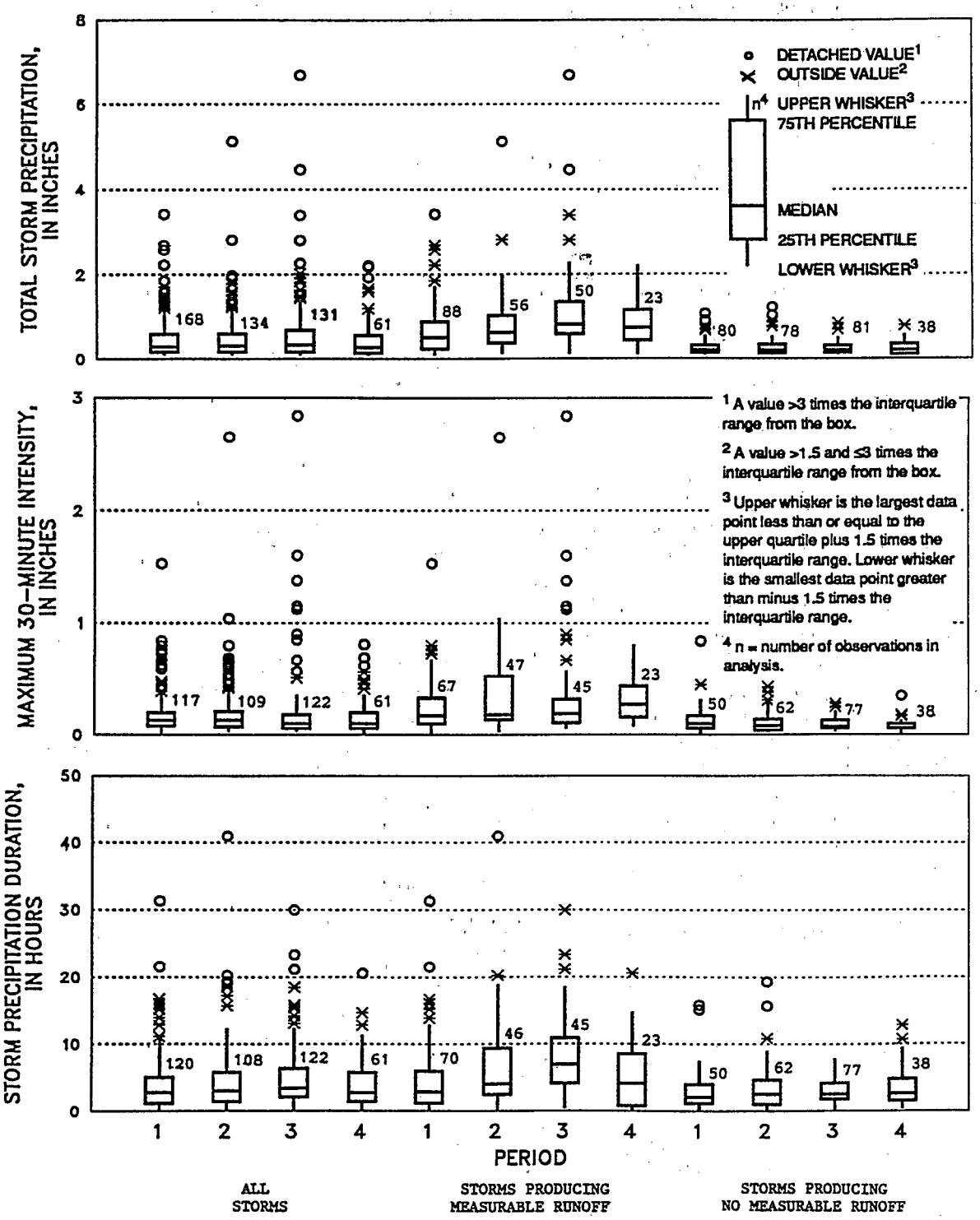

Figure 4.—Total storm precipitation, maximum 30-minute intensity within each storm, and storm duration for all storms, storms producing runoff, and storms that did not produce runoff during Periods 1 (January 1983 through September 1984), 2 (October 1984 through September 1986), 3 (October 1986 through September 1988), and 4 (October 1988 through July 1989).

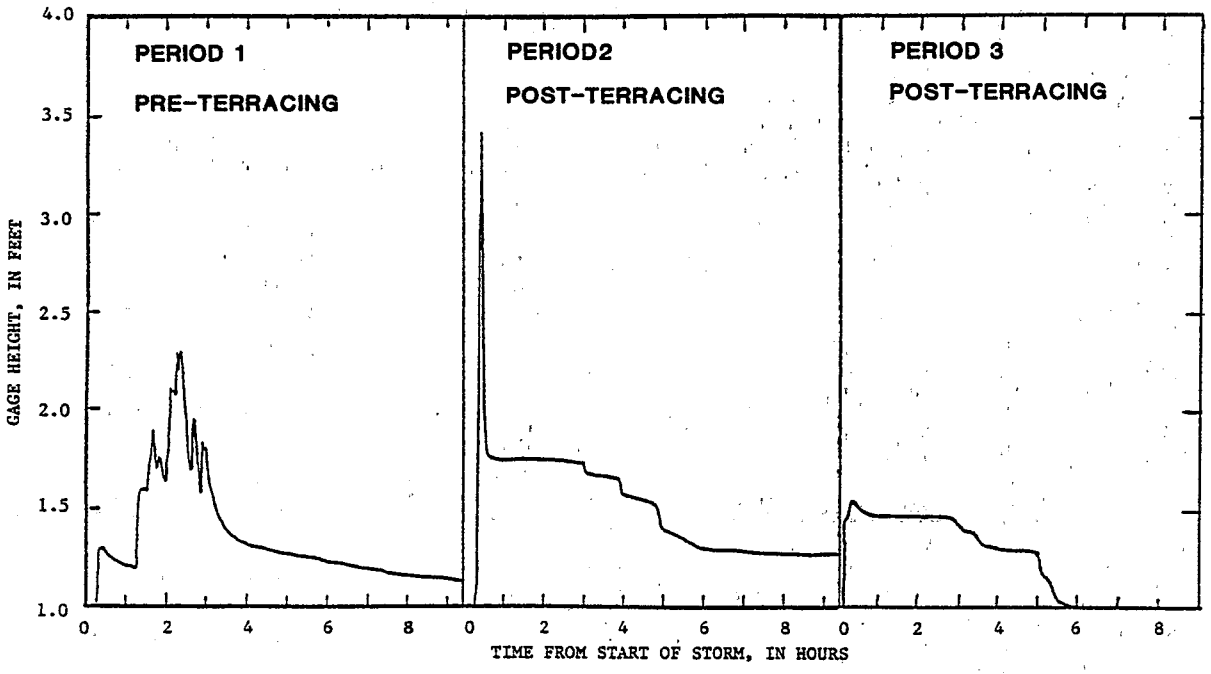

Figure 5.—Hydrographs of runoff for a storm from Period 1 (June 24, 1984), Period 2 (July 31, 1985), and Period 3 (July 26, 1988) with similar amounts of rainfall (0.65 to 0.80 inches) and similar soil conditions.

factors such as precipitation quantity and intensity, and antecedent soil moisture that affected mean and maximum discharge before terracing.

Analysis of covariance was used to determine significant differences in regression relations between total runoff and precipitation for Periods 1 and 3 for all storms that produced runoff (except those that produced runoff on frozen ground). Runoff as a function of precipitation was not significantly different in Period 3 and Period 1 (Fig. 6 and Table 5). Figure 6 also shows that small amounts of precipitation (less than 0.40 inch) rarely produced runoff during Period 3.

Because small storms rarely produced runoff during Period 3, regression and covariate analyses compared pre- and post-BMP storms that produced different amounts of runoff and precipitation. Therefore, cluster analysis was used to compare similar type storms to verify the results of covariate analysis.

Pre-BMP data analysis indicated that total runoff was affected by total storm precipitation, antecedent soil-moisture conditions, precipitation duration,

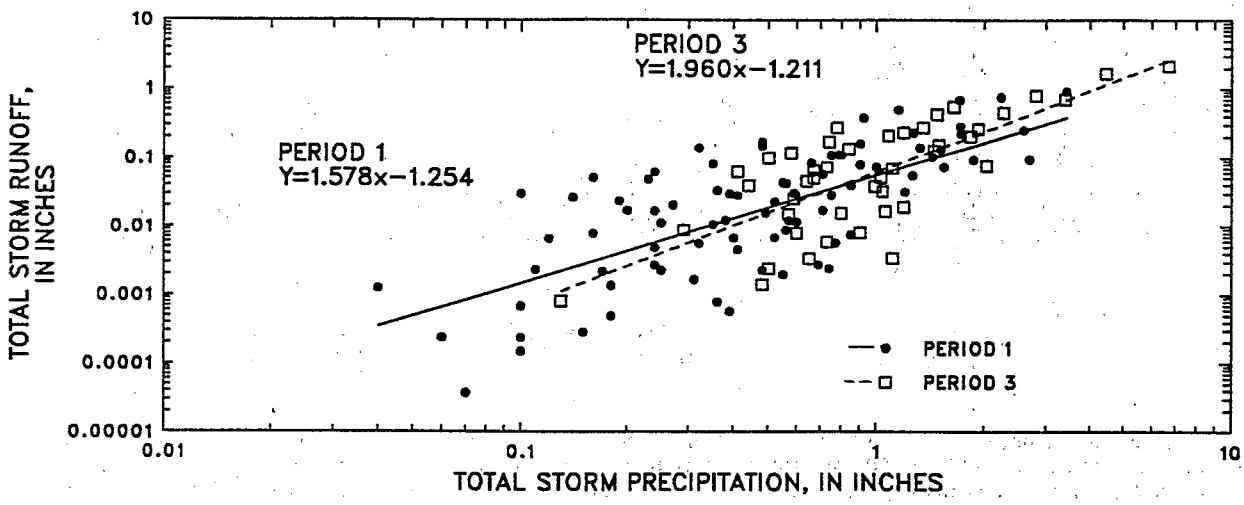

Figure 6.—Total storm runoff as a function of total precipitation for all storms except storms on frozen ground for Periods 1 (January 1983 through September 1984) and 3 (October 1986 through September 1988). (Regression statistics are listed in Table 5.)

Table 5.—Regression statistics for the log of total storm runoff (in inches) as a function of the log of storm precipitation (in inches) for all storms in each period, except those occurring on frozen ground. (< denotes less than.)

PERIOD[1]	DEGREES OF FREEDOM	INTER-CEPT	COEFFICIENT OF THE LOG OF TOTAL PRECIPITATION	T-STATISTIC	P-VALUE	COEFFICIENT OF DETERMINATION (ADJUSTED R^2)[2]	STANDARD ERROR		
							LOG UNITS	PERCENT[3]	
								PLUS	MINUS
1	84	–1.254	1.578	8.47	<0.001	0.46	0.70	401	80
3	43	–1.211	1.960	7.41	<0.001	0.46	.54	247	71

[1]Period 1, January 1983 through September 1984; Period 3, October 1986 through September 1988.
[2]Coefficient of determination (R^2) adjusted for degrees of freedom.
[3]Calculated as described by G.D. Tasker, U.S. Geological Survey (written comm. 1978).

precipitation intensity, and crop cover. Therefore, these characteristics were used to define eight clusters for storms occurring during the entire 79-month study period. Five clusters included all but seven storms. A characterization of the clusters is given in Table 6, and data from five clusters are shown in Figure 7. (For the cluster analysis, a factor from one to four was used to categorize crop cover: 1 is less than 15 percent, 2 is 15 to 49 percent, 3 is 50 to 85 percent, and 4 is greater than 85 percent.) Data from storms that produced runoff on frozen ground were eliminated from the data set, and runoff was set at zero when no runoff was measured for a storm.

Table 7 summarizes changes that were detected for four clusters by using the Mann-Whitney test to determine differences in medians between Periods 1 and 3 for all storms and for storms producing runoff. Cluster 3 was not included because an insufficient number of storms occurred for comparison in Period 3. Clusters 2, 4, and 5 were not included because they included too few storms.

Table 6.—General storm characteristics by cluster and percent of total precipitation by period and cluster (all storms on frozen ground were excluded from the data set before clustering).

CLUSTER	CHARACTERISTICS	PERIOD	NUMBER OF STORMS	PERCENT OF TOTAL PRECIPITATION
1	Summer showers on moist soil with crop cover	1	31	11
		2	26	10
		3	21	10
		4	16	11
2	Three large storms in Dec. 1983, Sept. 1985, and June 1987, with 3.4 to 5.1 inches of rain	1	1	3.8
		2	1	6.6
		3	1	3.9
		4	0	0
3	Typical spring and fall all-day storms generally with 0.2 to 0.6 inches of precipitation on soil with little crop coverage	1	22	9.4
		2	2	.3
		3	2	1.7
		4	10	13
4	One large Sept. 1987 storm with 6.7 inches of rain	1	0	0
		2	0	0
		3	1	7.7
		4	0	0
5	Three large summer storms, one in May 1985 and two in July 1988, with 2.8 to 4.5 inches or rain	1	0	0
		2	1	3.6
		3	2	8.3
		4	0	0
6	Thunderstorms occurring predominantly in the summer on soil with crop cover	1	18	18
		2	20	27
		3	10	14
		4	4	15
7	Very small storms throughout the year on dry soil; most storms occurring on soil with little crop cover	1	67	22
		2	63	21
		3	73	24
		4	25	16
8	Typical spring and fall all-day storms generally with 0.8 to 1.6 inches of precipitation on soil with little crop cover	1	15	21
		2	11	7
		3	12	16
		4	26	9

Table 7.—Mann-Whitney test results comparing within clusters (Table 7 and Fig. 7) total storm runoff and mean storm suspended sediment and nutrient concentrations between Period 1 (1983-84) and Period 3 (1987-88); storms on frozen ground excluded. ↑ = statistically significant increase; ↓ = statistically significant decrease; ↔ = no statistically different change; (90) = significant at the 90 percent confidence interval; (95) = significant at the 95 percent interval; n = number of storms; mg/L = milligrams per liter; ft^3/s = cubic foot per second; ft^3/acre = cubic foot per acre; and lb/acre = pound per acre.

		CLUSTER 1	CLUSTER 6	CLUSTER 7	CLUSTER 8
		PERIOD 1/PERIOD 3	PERIOD 1/PERIOD 3	PERIOD 1/PERIOD 3	PERIOD 1/PERIOD 3
ALL STORMS[1]					
Total storm runoff (ft^3/acre)	Change	↓(90)	↔	↓(95)	↔
	median	85/0	54/400	0/0	205/260
	n	31/21	18/10	67/73	15/12
STORMS THAT PRODUCED RUNOFF					
Total storm runoff (ft^3/acre)	Change	↑(90)	↔	↔	↔
	median	120/240	102/740	24/80	260/260
	n	21/7	13/9	26/10	13/12
Mean suspended sediment concentrations (mg/L)	Change	↔	↓(95)	↓(95)	↓(95)
	median	2,870/2,030	9,040/1,850	3,530/725	1,930/470
	n	19/7	9/8	22/6	7/10
Mean total phosphorus concentration (mg/L as P)	Change	↔	↔	↔	↔
	median	2.6/2.7	4.1/3.4	3.1/3.4	3.1/4.3
	n	12/7	8/7	17/3	6/7
Mean total nitrogen concentration (mg/L as N)	Change	↑(90)	↔	↔	↑(90)
	median	3.4/6.1	5.4/6.2	5.2/7.4	4.1/7.2
	n	12/7	8/7	17/3	6/7
Mean ammonia + organic nitrogen concentration (mg/L as N)	Change	↔	↔	↔	↔
	median	2.7/4.2	4.6/4.2	4.1/4.2	3.6/4.8
	n	12/7	8/7	17/3	6/7
Mean nitrate + nitrite concentration (mg/L as N)	Change	↑(95)	↑(95)	↑(95)	↑(95)
	median	.56/1.7	.54/1.8	.59/4.1	.43/3.0
	n	12/7	8/7	17/3	6/7

[1]Total and mean discharge set equal to zero if no measurable runoff occurred.

The test results in Table 7 show for clusters 1 and 7 (clusters containing small storms), fewer storms producing runoff occurred during Period 3 than during Period 1. Terracing (which changed the surface slopes) decreased runoff velocities, increased water-soil contact time, and increased surface storage. These factors promoted evaporation and soil wetting and delayed the onset of runoff, which was particularly apparent during small storms. Nearly all storms in Clusters 6 and 8, which produced about five times more precipitation than storms in Clusters 1 and 7, produced runoff during all periods. The total storm discharge for storms in Clusters 6 and 8 did not change from Period 1 to Period 3.

In summary, data analysis shows that after terracing, storms that produced less than 0.4 inch of precipitation rarely produced runoff; therefore, in effect, terracing increased the threshold at which runoff occurred. The terrace BMP had no significant effect on runoff quantity during larger storms and no overall effect on runoff quantity.

Quality

Annual suspended sediment and nutrient yields transported by runoff from Field Site 1 are shown in Table 4. The 1984 annual suspended sediment yield exceeded the erosion rate (T) of 4 tons per acre per year recommended for the site by the U.S. Soil Conservation Service. The suspended sediment yield was substantially less than T for all years after terrace installation and after one year of stabilization (Table 4). Annual yields of total nitrogen and phosphorus for the post-BMP period were within the range of yields for the pre-BMP period. However, during the pre-BMP period (Period 1), less than 10 percent of the annual total nitrogen yield was nitrate plus nitrite, and more than 90 percent was ammonium plus organic nitrogen. During post-BMP Periods 2 and 3, 32 to 37 percent of the annual total nitrogen yield was nitrate plus nitrite (Table 4).

Pre-BMP data indicate that storm runoff on frozen ground responded differently from runoff during other storms. Generally, mean concentrations

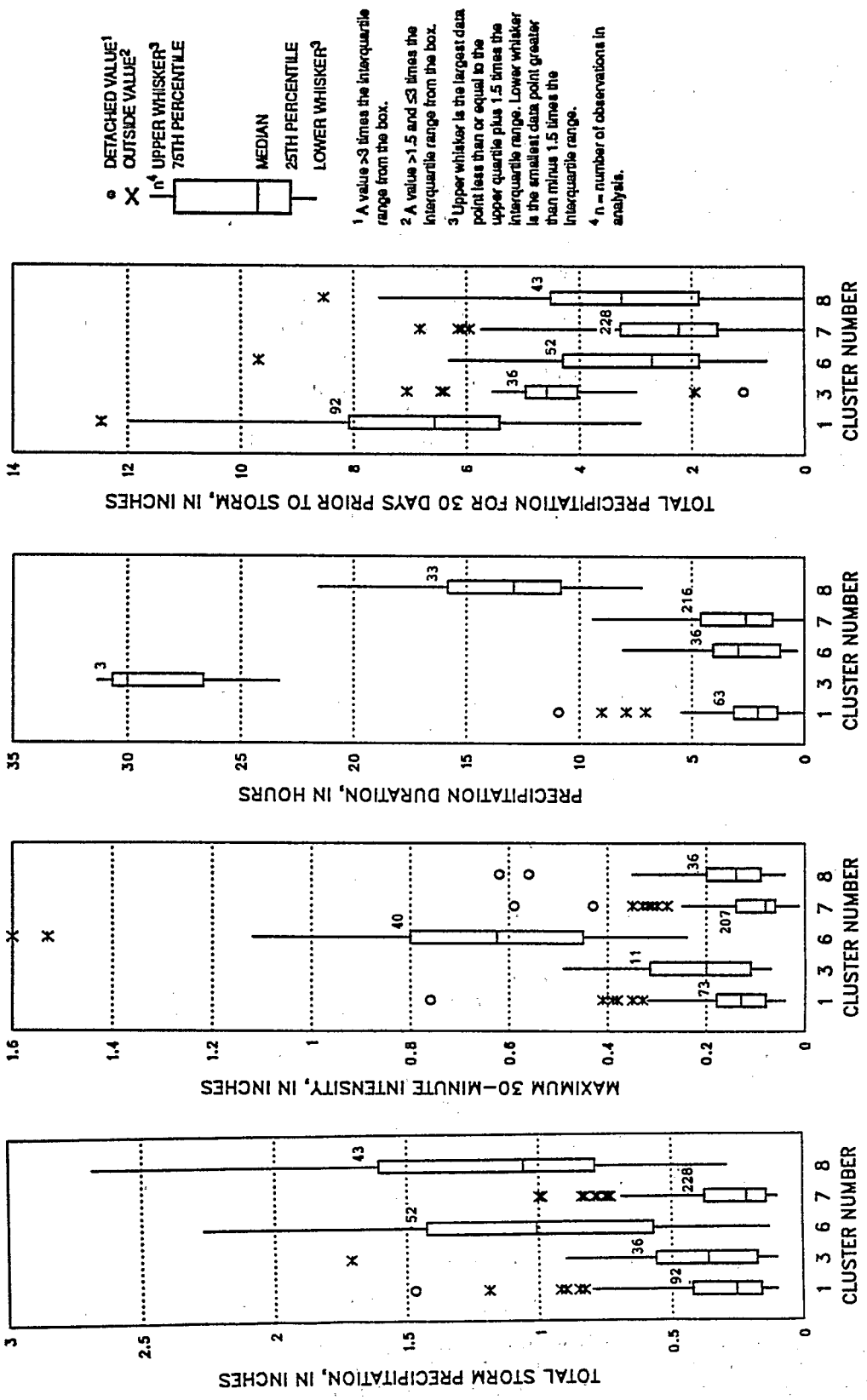

Figure 7.—Distribution of precipitation data for storms within clusters described in Table 7.

and loads of suspended sediment in runoff were relatively low; total nitrogen concentrations and loads were relatively high when the ground was frozen compared to runoff from all other storms. Therefore, all storms (except those that produced runoff on frozen ground) were used for data analysis.

Graphic and regression analyses of the total constituent yields as a function of total storm runoff were used to investigate the relation between yields and runoff and differences in the relation between pre-BMP and post-BMP periods over the range of runoff (Figs. 8 and 9 and Table 8). Suspended sediment yields as a function of runoff were lower during Period 3 than during Period 1, that is, after terraces had stabilized for two years and after the field downslope from the first terrace was stabilized with alfalfa (Fig. 8). This result was expected and was the primary reason for installing the terraces at the site and establishing the lower alfalfa field. Analysis of covariance showed statistically significant changes in the intercept and slope of the regression lines of suspended sediment yield as a function of runoff from Period 1 to Period 3: ($F = 18.10$) > ($F\alpha = .025, 2, 96 = 3.83$). Graphic analysis shows that moderate storms carried about the same amount of sediment relative to total storm runoff during Period 1 and Period 3, but large storms carried much less sediment relative to runoff during Period 3 than during Period 1 (Fig. 8, Table 8).

Analysis of covariance indicated that proportionally more nitrate was carried in runoff during Period 3 than during Period 1: ($F = 21.99$) > ($F\alpha = .025, 2, 73 = 3.89$). No significant changes were detected between Period 1 and Period 3 with respect to total phosphorus, total nitrogen, or ammonium + organic nitrogen yields as a function of total storm runoff (Figs. 8 and 9, Table 8).

To better understand the effects of terracing on runoff quality, mean storm concentration and yield data for suspended sediment and nutrients were compared within the clusters (Fig. 7 and Table 6).

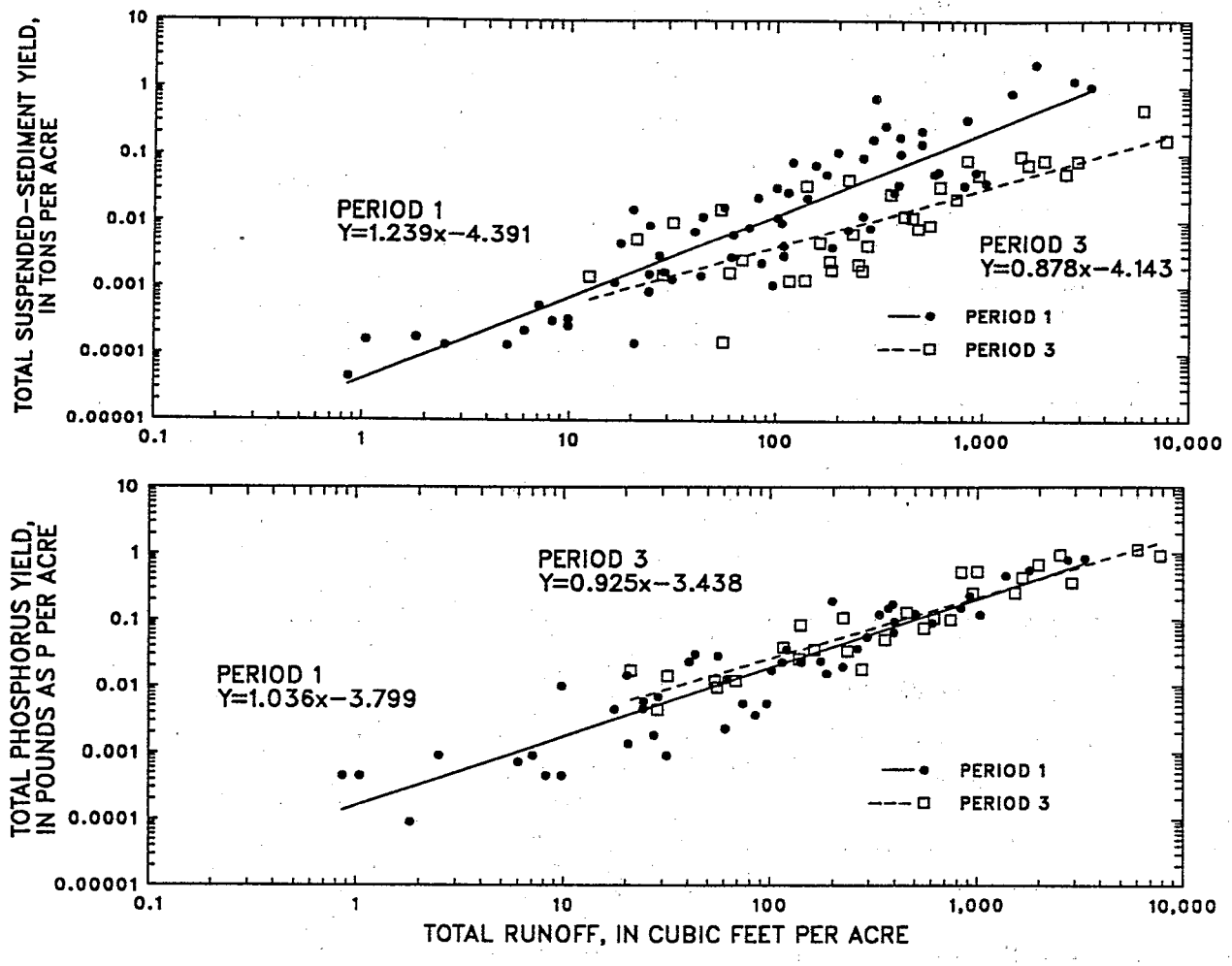

Figure 8.—Total suspended sediment (top) and total phosphorus (bottom) yield in runoff as a function of total discharge for all storms, except storms on frozen ground, for Periods 1 (January 1983 through September 1984) and 3 (October 1986 through September 1988). (Regression statistics are listed in Table 8.)

Table 8.—Regression statistics for the log of suspended sediment yield (in tons per acre) and the log of total nutrient yield (in pounds as N or P per acre) as a function of the log of total runoff (in cubic feet per acre) for all storms occurring during Periods 1 and 3, except for runoff from storms on frozen ground. < = less than.

PERIOD[1]	DEPENDENT VARIABLE	DEGREES OF FREEDOM	INTERCEPT	REGRESSION COEFFICIENT	T-STATISTIC	P-VALUE	COEFFICIENT OF DETERMINATION (ADJUSTED R^2)[2]	STANDARD ERROR OF ESTIMATES		
								LOG UNITS	IN PERCENT[3]	
									PLUS	MINUS
1	Suspended sediment	65	–4.391	1.239	15.47	<.001	0.82	0.495	213	68
3	Suspended sediment	34	–4.143	.878	7.13	<.001	.60	.491	210	68
1	Total nitrogen	49	–3.379	.942	16.85	<.001	.85	.341	119	54
3	Total nitrogen	27	–3.063	.866	12.21	<.001	.85	.259	82	45
1	Total ammonium plus organic nitrogen	49	–3.470	.948	15.77	<.001	.83	.367	133	57
3	Total ammonium plus organic nitrogen	27	–3.295	.876	11.60	<.001	.83	.276	89	47
1	Total nitrate plus nitrite	49	–4.528	1.006	14.23	<.001	.80	.431	170	63
3	Total nitrate plus nitrite	27	–3.553	.869	10.59	<.001	.80	.300	100	50
1	Total phosphorus	49	–3.799	1.036	16.65	<.001	.85	.379	139	58
3	Total phosphorus	27	–3.438	.925	12.90	<.001	.86	.262	83	45

[1]Period 1, January 1983 through September 1984; Period 3, October 1986 through September 1988.
[2]R^2 adjusted for degrees of freedom to allow more valid comparison between seasons.
[3]Calculated as described by G.D. Tasker (written comm. 1978).

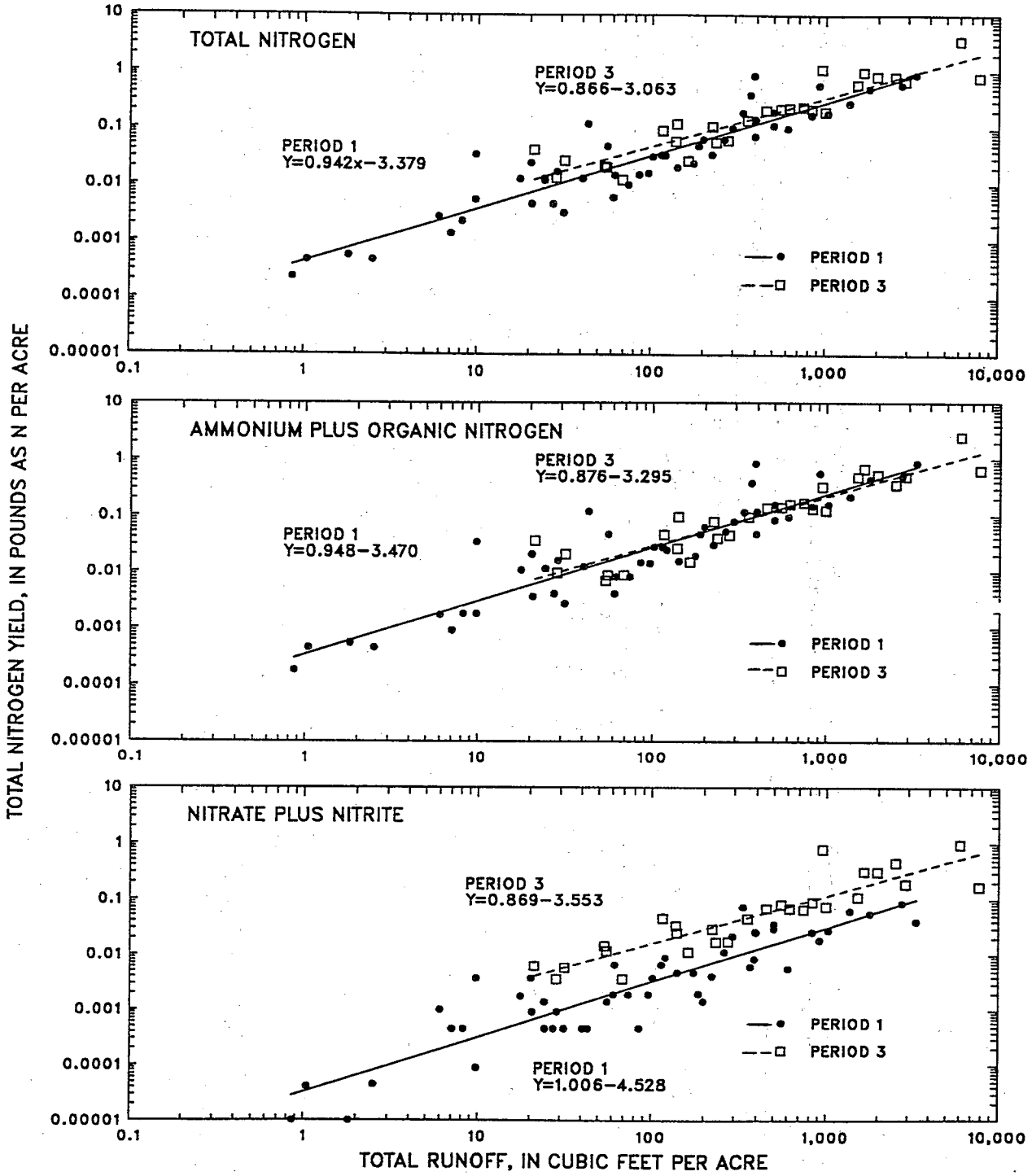

Figure 9.—Total nitrogen (top), total ammonium plus organic nitrogen (middle), and total nitrate plus nitrite (bottom) yield in runoff as a function of total discharge for all storms, except storms on frozen ground, for Periods 1 (January 1983 through September 1984) and 3 (October 1986 through September 1988). (Regression statistics are listed in Table 8.)

For storms in clusters 6, 7, and 8, mean storm suspended sediment concentrations in runoff decreased from Period 1 to Period 3 (Table 7). The terraces reduced runoff energy and thus its ability to transport sediment. Pooling in terraces allowed time for deposition of suspended material before the runoff discharged through the pipe outlet. For storms in Cluster 1, which contained the smallest storms, no significant change was detected in suspended sediment concentrations from Period 1 to

Period 3 using the Mann-Whitney test. The distribution of the data may bias the statistical analysis within cluster 1 because no runoff was produced by the small storms in this cluster during Period 3. Graphic examination of the data within Cluster 1 shows that suspended sediment yields per unit of discharge were generally larger during Period 1 than during Period 3.

No change in mean storm total phosphorus concentrations in runoff was detected from Period 1 to Period 3 (Table 7). Total phosphorus concentrations did not decrease proportionately with suspended sediment concentrations throughout most storm groupings (Table 7). It is believed, on the basis of observation and other limited particle size analysis, that most of the fine sediment particles (less than 0.62 micrometers in diameter) continued to be discharged from the site after terracing and that most phosphorus is sorbed to and transported with fine-grained particles (Sharpley et al. 1981).

Particle size analysis of instantaneous suspended sediment samples showed that a significantly larger percentage of the sediment in runoff was silt and clay (sediment finer than 0.62 micrometers in diameter) after terracing than before terracing. A median of 96 percent of the sediment in runoff from 44 samples collected during the 1986-88 water years was silt and clay, whereas a median of 86 percent of the sediment in runoff from 175 samples collected during the 1983-84 water years was silt and clay.

Limited phosphorus concentration data on instantaneous runoff samples shows that a median of 90 percent of the total phosphorus in runoff was suspended before terracing (125 samples), and 82 percent of the total phosphorus was suspended after terracing (12 samples). The Mann-Whitney test detected no change in the total and suspended phosphorus concentrations from the pre-BMP to post-BMP periods, but the dissolved phosphorus concentrations increased significantly. The small number of samples weakens any conclusions from the data analysis, but it is possible that small increases in dissolved phosphorus concentrations in runoff offset any decreases in suspended phosphorus concentrations.

Within each cluster, the mean storm nitrate plus nitrite concentrations in runoff increased significantly (changes were 3- to 7-fold) from Period 1 to Period 3 (Table 7). Therefore, regardless of storm type, nitrate transport by runoff increased after terracing. During storms when no runoff was produced after terrace construction, overall soil moisture may have increased, allowing increased nitrification and, therefore, increased amounts of nitrate available for transport by runoff. During all storms after terracing, the soil wetting area probably increased from an increase in sheet runoff and a reduction in gully runoff. Thus, the increased contact time and possibly increased contact area of the runoff with the nutrient-rich soils allowed for an increase in the conversion to and dissolution of nitrate. During many storms, runoff pooled in the terraces — a process that also increased nitrification and the solution of nitrate.

Table 7 shows that the mean values of the storm total nitrogen concentrations in runoff during Period 3 for each cluster were greater than or equal to the mean values of the storm total nitrogen concentrations in runoff during Period 1. However, a significant increase in mean storm total nitrogen concentrations in runoff was only detected from Period 1 to Period 3 for storms in Clusters 1 and 8. The distribution of data within Cluster 1 may bias this statistical analysis. The increase in mean storm total nitrogen concentrations for Cluster 8 storms resulted primarily from the large increases in nitrate concentrations.

No changes within clusters were found in mean storm ammonium plus organic nitrogen concentrations in runoff between Periods 1 and 3. The mean storm ammonium plus organic nitrogen concentrations in runoff were much more variable than the mean storm nitrate plus nitrite concentrations in runoff. Therefore, significant changes occurred in the nitrate plus nitrite concentrations without corresponding significant changes in total nitrogen concentrations. Figure 10 shows the change in monthly mean storm nitrate plus nitrite concentrations in runoff for storms that were sampled following the installation of terraces in October 1984.

The monthly mean storm total nitrogen concentrations in runoff apparently responds to nitrogen applications at the site (Fig. 10). However, because of varying lag times between applications and runoff and lack of nitrogen data for every runoff event, no statistical relation between land-surface applications and monthly mean storm total nitrogen concentrations in runoff could be established.

Conclusions

Terracing of a 22.1-acre agricultural field site underlain by carbonate rock was effective in reducing suspended sediment losses from the site but ineffective in reducing nitrogen or phosphorus losses from the site. Nutrient management, a planned BMP at the site, did not result in reduced applications of nutrients to the site.

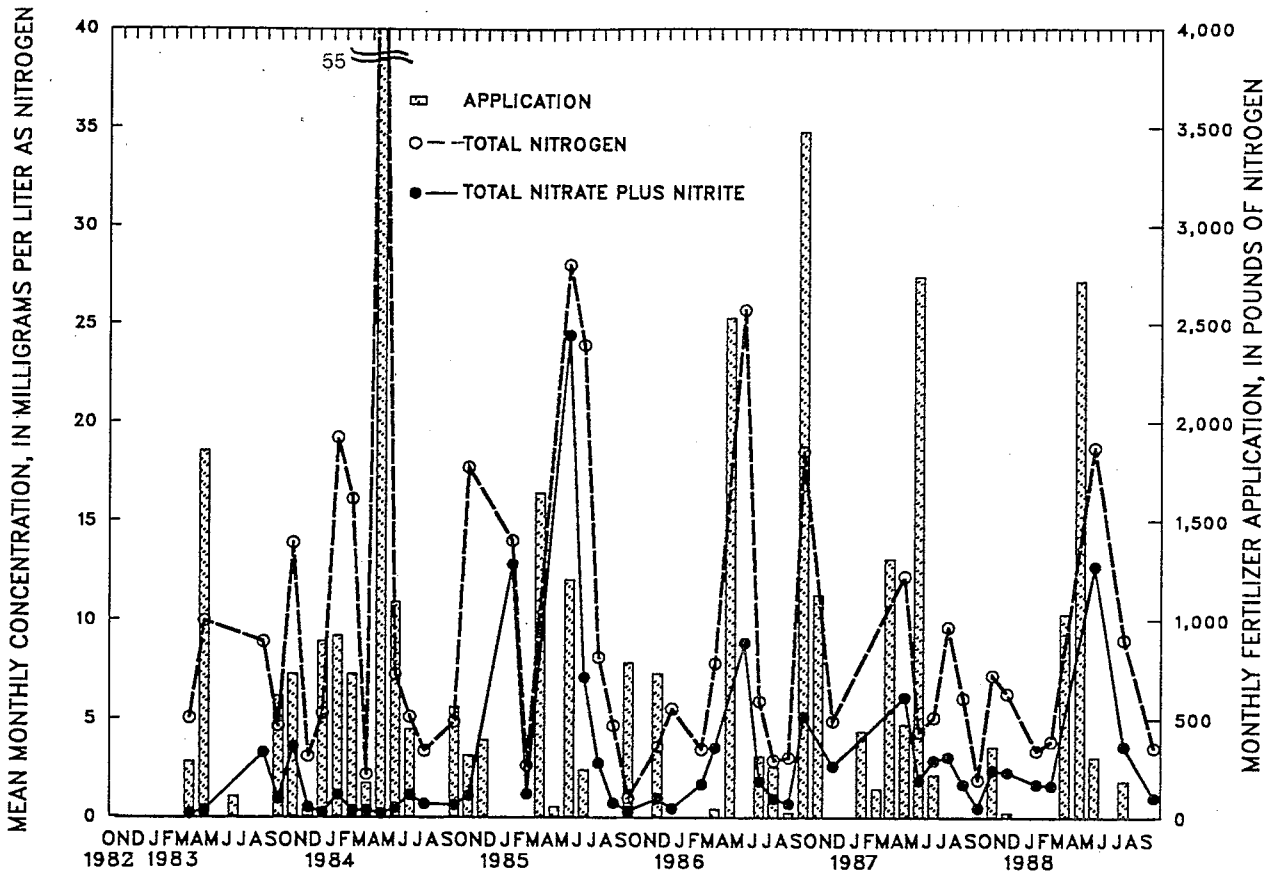

Figure 10.—Mean monthly water-weighted total nitrogen and total nitrate plus nitrite concentrations in runoff from sampled storms, and total monthly nitrogen application to Field Site 1.

Terracing did change runoff characteristics. However, terracing did not cause a change in the relation of runoff quantity to precipitation, although small storms (generally less than 0.4 inch) did not produce runoff after terracing.

Suspended sediment yields as a function of runoff were significantly reduced after a period of stabilization following terrace construction and establishment of crop changes planned as part of the terracing BMP. Reductions in the suspended sediment yields were larger during storms with larger amounts of runoff.

Total phosphorus yields as a function of runoff did not change significantly after terracing. Limited data suggest that fine sediment particles, with which most of the phosphorus is associated, continued to be transported from the site.

Although nitrate plus nitrite yields as a function of runoff increased significantly after terracing, total nitrogen loads did not change significantly. Total nitrate plus nitrite yields made up 35 percent of the total nitrogen load after terracing, compared to 10 percent of the load before terracing.

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Effects of Nutrient Management on Nitrogen Flux through a Karst Aquifer, Conestoga River Headwaters Basin, Pennsylvania

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ABSTRACT

The implementation of nutrient management at a 55-acre farm near Ephrata, Pennsylvania, substantially reduced applications of nitrogen to cropped fields, nitrate concentrations in groundwater, and nitrogen loads in groundwater discharge from the site. After implementation of a nutrient-management plan in October 1986, decreases in applications of nitrogen to farm fields ranged from 39 to 67 percent. By 1990, decreases in nitrate concentrations in measured shallow groundwater at the site ranged from 8 to 32 percent, based on Wilcoxon median tests. Changes in nitrogen applications to areas contributing water to five wells were correlated (by Spearman rank-sum correlations) with changes in nitrate concentrations of groundwater samples. The correlation analyses indicated that the transport time of nitrogen fertilizer from the land surface to the water table was approximately 4 to 19 months. Annual loads of nitrogen added to and removed from the site were estimated for 1985 through 1990. Nitrogen was added from manure, commercial fertilizer, precipitation, and groundwater inflow; these sources averaged 93, 4, 2, and 1 percent of the nitrogen added to the site, respectively. Nitrogen was removed in harvested crops by groundwater outflow, volatilization, and surface runoff; these losses averaged 38, 38, 24, and less than 1 percent of the nitrogen removed from the site, respectively. Nitrogen loads in groundwater discharge were estimated to have been approximately 300 and 200 pounds of nitrogen per million gallons of discharge, respectively, before and after implementation of nutrient management.

From 1985 through 1990, the effects of managing agricultural nutrients on nitrogen flux in a karst aquifer were studied by the U.S. Geological Survey (USGS) in cooperation with the Pennsylvania Department of Environmental Resources. The study was part of the U.S. Department of Agriculture's Conestoga Headwaters Rural Clean Water Program (RCWP) comprehensive monitoring and evaluation project (Chichester, 1988).

Elevated nitrate concentrations in groundwater within and surrounding the Conestoga Headwaters River Basin were documented by Hall (1934), Meisler and Becher (1966, 1971), and Poth (1977). In 1979, Pennsylvania developed an agricultural 208 plan (required under section 208 of the 1972 Federal Water Pollution Control Act) that designated the Conestoga Headwaters as the top priority watershed in the State for water quality studies (Schueller, 1983). The objective of the Field Site 2 part of the

Conestoga Headwaters RCWP project was to determine the effects of reduced applications of manure and fertilizer under nutrient management (an agricultural best management practice [BMP]) on groundwater quality at an agricultural field site.

This paper presents statistical comparisons of pre- and postnutrient-management nitrate concentrations in groundwater, correlations of changes in nitrogen applications to changes in concentrations of nitrate in groundwater, and estimations of annual nitrogen additions and removals at the site. Reduced loads of nitrogen in groundwater discharge that occurred as the result of reduced nitrogen applications to farm fields are also discussed.

Data on agricultural activity, precipitation, water table altitude, and groundwater quality were collected at the site during a prenutrient-management period (water years 1985-86) and a postnutrient-management period (water years 1987-90). A water year is the 12-month period that begins October 1 and ends September 30; it is designated by the calendar year in which it ends. Elevations and altitudes are described in reference to the National Geodetic Vertical Datum of 1929.

Site Description

Field Site 2, located near Ephrata, Pennsylvania (Figs. 1 and 2), is used for intensive animal and crop production. The monitored site was 55 acres, with approximately 47.5 acres in crops and the remaining 7.5 used for farm buildings, animal confinement facilities, and a residence. The site, underlain by karstic limestone and dolomite, is located within the Conestoga Valley section of the Piedmont physiographic province (Meisler and Becher, 1971). Soils at the site are classified as Hagerstown silt loams and silty clay loams (*Typic hapludulfs*) (Fox and Piekielek, 1983; U.S. Dep. Agric. 1985). A clay hardpan, where present, may retard the downward movement of solutes. The depth from land surface to bedrock ranges from 5.5 to 28 ft, and the depth to the water table has a similar but noncoincident range of 5 to 30 ft below the land surface.

A recording precipitation gage was installed at Field Site 2 in October 1984. Annual precipitation for the study period (1985-90) is shown in Table 1. The 30-year average precipitation (1951-80) for Field Site 2 was 43.5 inches, based on records from the National Oceanic and Atmospheric Administration (NOAA) precipitation station at Ephrata, Pennsylvania (Natl. Oceanic Atmos. Admin. 1982). Table 1 shows a comparison of annual precipitation measured at Field Site 2, long-term annual average precipitation from the Ephrata NOAA station, and percent of measured precipitation deviation from long-term average annual precipitation. Surface runoff of precipitation occurred briefly during periods of large or unusually intense rainstorms, periods of rain on frozen ground, and periods of rapid snowmelt.

Thirteen wells were drilled to depths ranging from 40 to 350 ft to characterize the hydrogeology of the site and to serve as monitoring wells for collect-

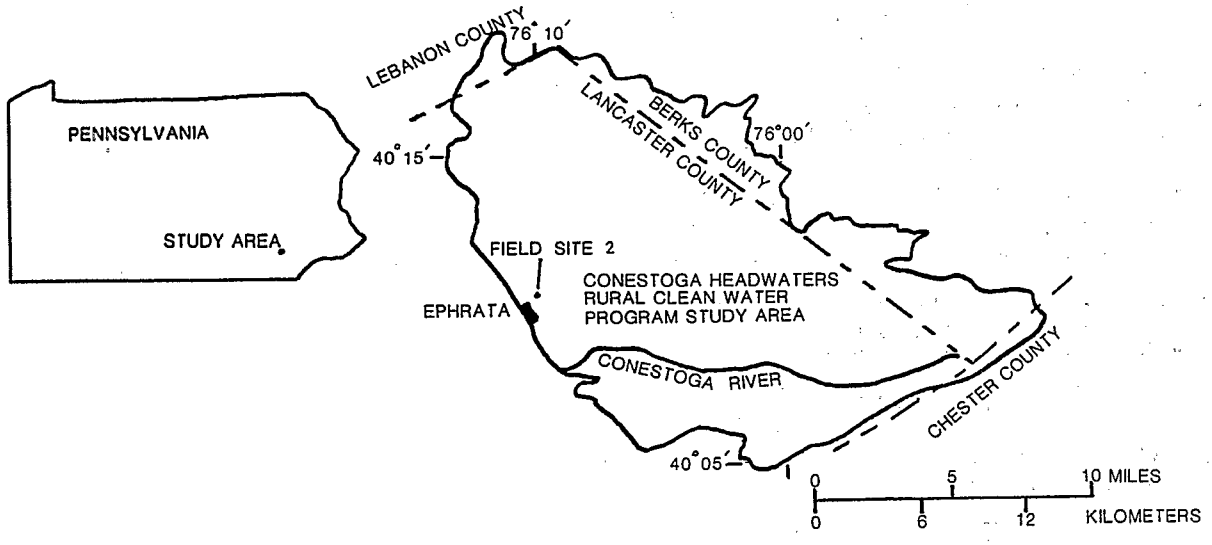

Figure 1.—Location of the Conestoga Headwaters Rural Clean Water Program project study area and Field Site 2 near Ephrata, Pennsylvania.

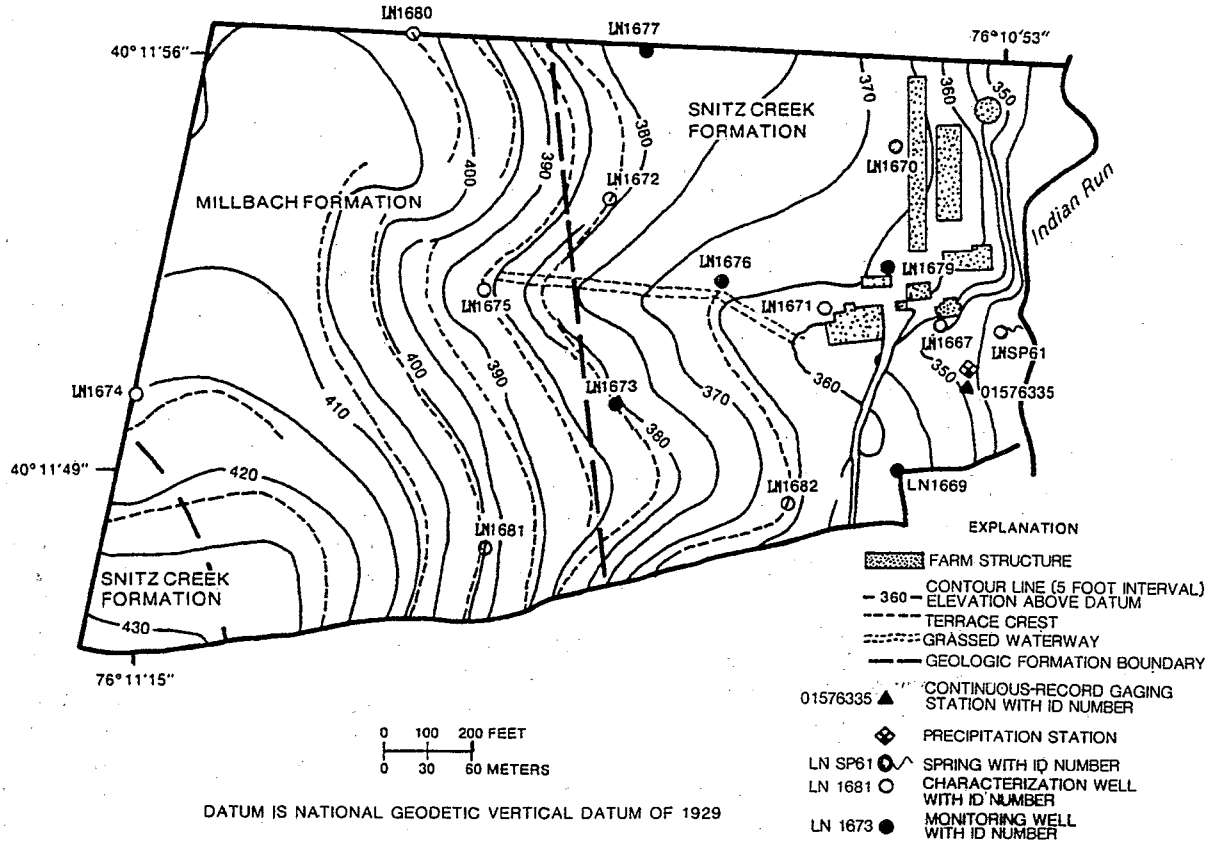

Figure 2.—Data collection locations and geologic units (from Chichester, 1988).

ing water quality data. These wells were drilled using air-rotary techniques, cased to bedrock with 6-inch steel casing, and finished as open holes in the carbonate bedrock. The wells were then grouted with cement and sealed with bentonite clay caps at the land surface (Chichester, 1988). An existing hand-dug well (LN 1667) and a spring were also used for site characterization. Eleven wells had specific capacities less than or equal to 1 (gal/min)/ft (gallons per minute per foot of water-level drawdown) and three wells had specific capacities of 1 to 20 (gal/min)/ft. Five wells with the largest specific capacity were selected as monitoring wells for the collection of water quality data. Figure 3 shows a water table map contoured on the basis of median water levels from the period 1985-86. Figure 4 shows generalized cross sections A-A' and B-B' on Figure 3.

Contributing areas were estimated for the five monitoring wells at the site to relate groundwater quality to the land-surface nitrogen applications (Fig. 5). The contributing area to a well is the area of diversion of groundwater to a well and surface areas that provide recharge to the aquifer within the area of diversion (Morrissey, 1987). The contributing areas to wells at the site were arbitrarily defined by using the following methods and assumptions (processes discussed by Bouwer, 1978; Memon and Prohic, 1989; and Hickey, 1984). First, a

Table 1.—Comparison of annual precipitation at Field Site 2, long-term average for Ephrata, Pennsylvania, and percent deviation from long-term average.

PERIOD	PRECIPITATION IN INCHES	LONG-TERM AVERAGE[1]	PERCENT DEVIATION FROM LONG-TERM AVERAGES
October 1984–September 1985	35.8	43.5	-18
October 1985–September 1986	38.8	43.5	-11
October 1986–September 1987	45.0	43.5	+03
October 1987–September 1988	40.4	43.5	-07
October 1988–September 1989	46.6	43.5	+07
October 1989–September 1990	43.6	43.5	+00

[1]Long-term average precipitation based on 30 years (1951-80) of record from the National Oceanic and Atmospheric Administration weather station at Ephrata, Pennsylvania.

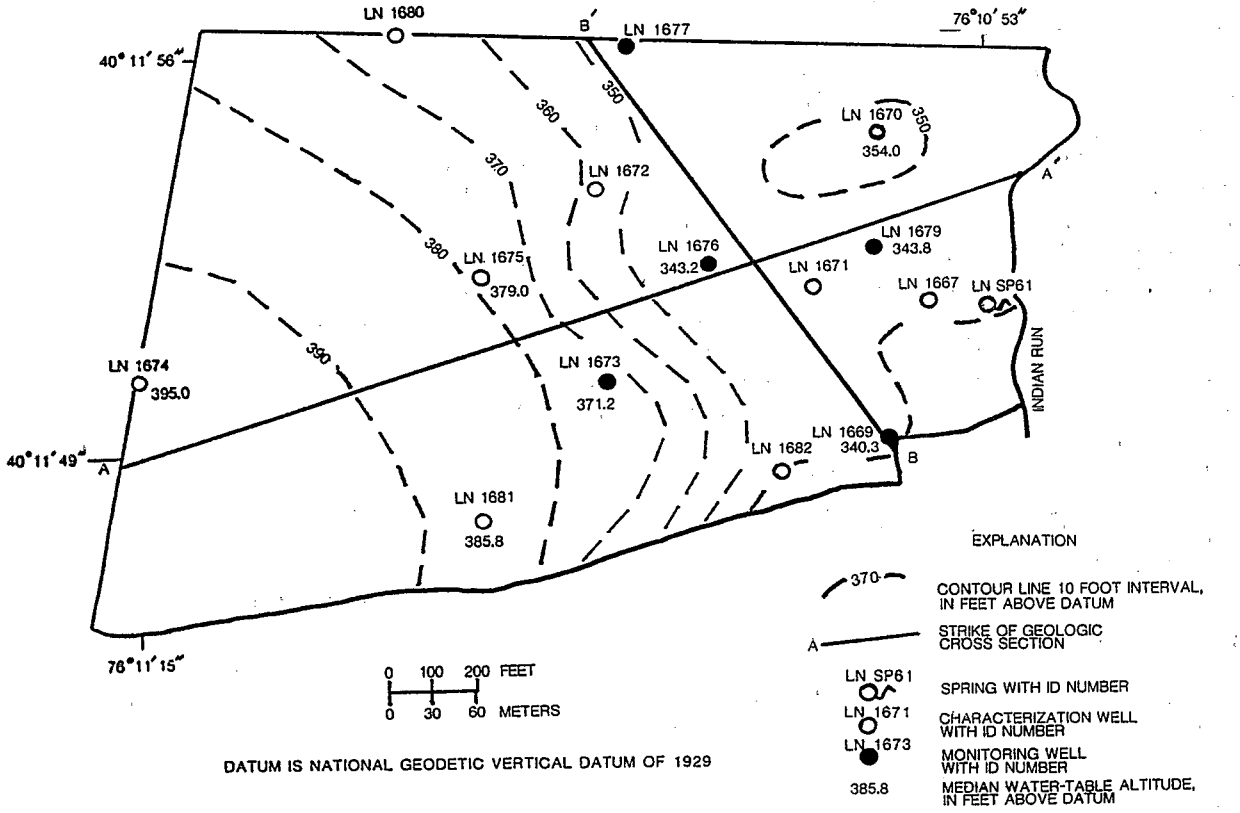

Figure 3.—Estimated water table altitude map (cross sections A-A' and B-B' are illustrated in Fig. 4).

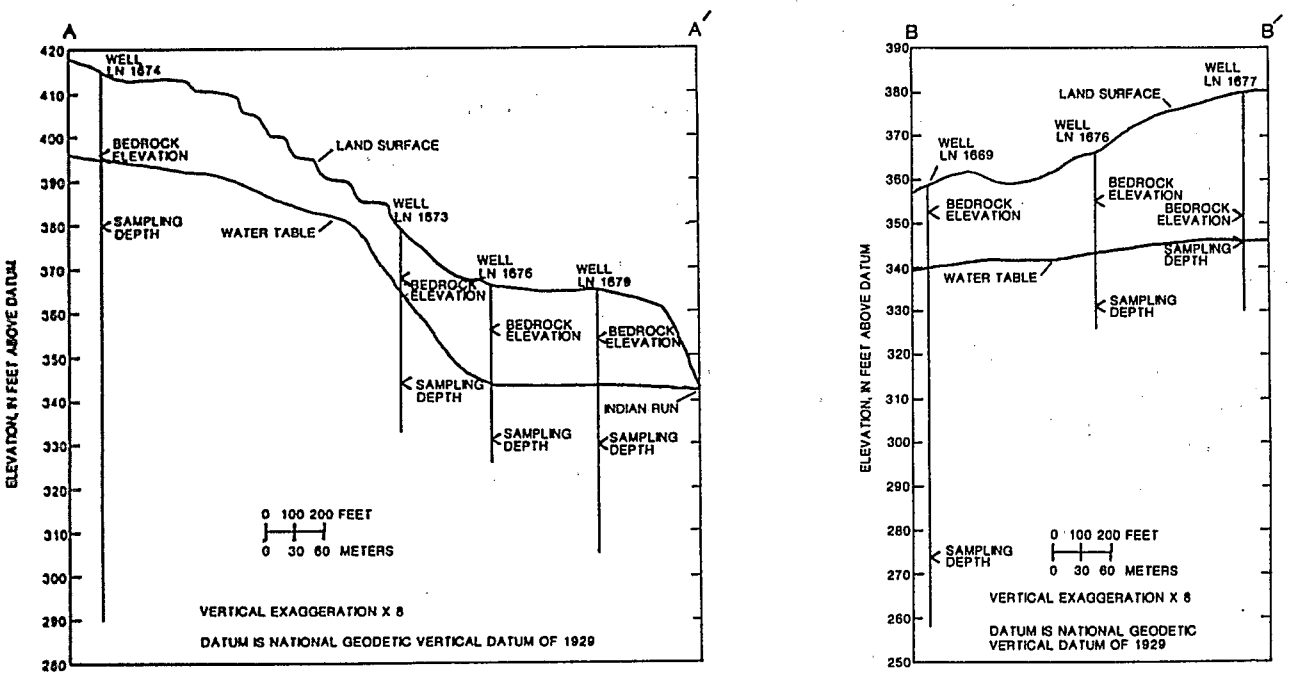

Figure 4.—Generalized cross sections A-A' and B-B' from Figure 3.

groundwater-flow path was located upgradient from each well, taking into account the water table configuration. Flow lines, which are perpendicular to the water table gradient, were then expanded into wedge-shaped contributing areas by using an arbitrary 2:1 (roughly 25°) ratio of longitudinal flow distance to distance of lateral spreading. True flow-to-dispersion ratios of this aquifer are unknown. Some dispersion undoubtedly occurs as solutes infiltrate vertically through the unsaturated zone, and additional dispersion (anisotropic) occurs during flow through the aquifer. Therefore, applications of manure and commercial fertilizer made upgradient and close to the well could have contributed more nitrogen to well water than if the applications were made farther upgradient. Contributing areas were limited to approximately 1,000 ft upgradient from each well instead of to the entire area contributing recharge water to the well, thereby defining a land area where nitrogen applications had a maximum effect on groundwater quality.

Agricultural Activities

Agricultural activity data, including times of planting and harvest, tillage information, and areas and times of applications of manure and commercial fertilizer, were collected monthly from the farmer. Approximately 100 steers, 1,500 swine (three groups — 500 at a time), and 110,000 chickens (five groups — 22,000 at a time) are raised at the site each year. Crops were fertilized using both manure and commercial fertilizer. The manure was of three types: hog manure from gestation and finishing operations, steer manure and bedding mixture from a feedlot, and poultry manure from a poultry house. The steer manure mix and the poultry manure were applied by surface spreading. The gestating and finishing hog manure was injected into the soil 8 to 10 inches below the surface, unless the soil was frozen. In the case of frozen soil, all manures were surface spread. The commercial fertilizers applied were ammonium sulfate, broadcast before planting, and a nitrogen liquid coapplied with preemergent pesticides. Before implementing nutrient management at the site, all animal wastes were applied to the 47.5 cropped acres, which supplied about twice the amount of manure-nitrogen needed for crop fertilization (Table 2).

A nutrient-management plan (Graves, 1986a,b) was implemented at the site in October 1986. Under nutrient management, quantities of nitrogen applied

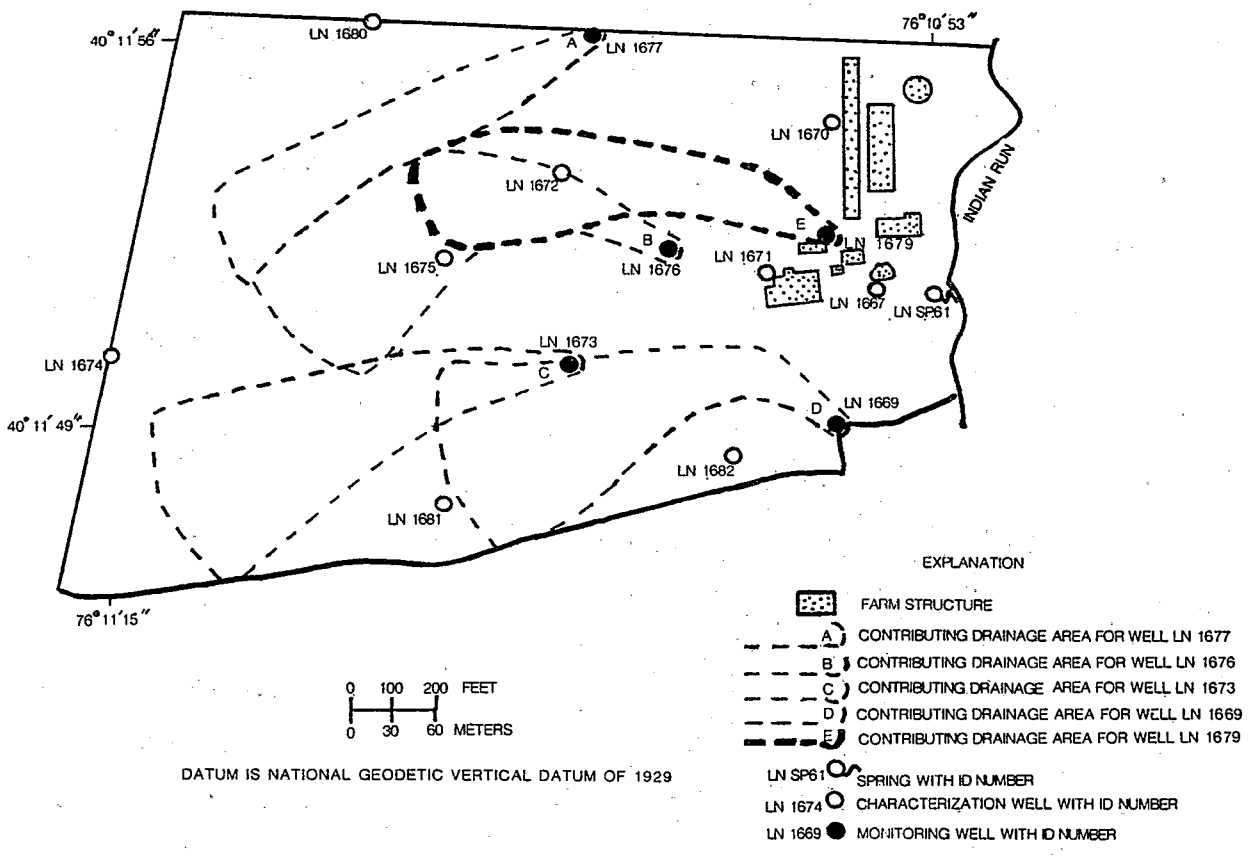

Figure 5.—Estimated contributing areas for five wells at the field site.

Table 2.—Nitrogen in manure and commercial fertilizer applied in the contributing areas of five wells (in pounds of nitrogen per acre per year).

PRE- OR POSTNUTRIENT MANAGEMENT	WATER YEAR	WELL				
		LN 1669[1]	LN 1673[2]	LN 1676[3]	LN 1677[4]	LN 1679[5]
Pre-	1985	580	670	570	550	830
Pre-	1986	390	490	440	470	430
Post-	1987	160	200	180	290	290
Post-	1988	130	160	150	310	290
Post-	1989	230	360	150	310	270
Post-	1990	120	380	180	340	160

[1]Contributing area for LN 1669 = 5.6 acres.
[2]Contributing area for LN 1673 = 5.6 acres.
[3]Contributing area for LN 1676 = 5.5 acres.
[4]Contributing area for LN 1677 = 3.4 acres.

to cropped land are determined by crop-nutrient needs rather than manure-disposal needs. Nutrient-management plans for the site were based on crop yield goals, manure application methods, soil nitrogen concentrations, nitrogen analyses of manure samples collected at the site, and past manure-application practices. Nutrient-management implementation resulted in the export of about 33 percent of the animal manure generated at the site. The reductions in nitrogen applications that occurred from water years 1986 to 1987 resulted from the implementation of nutrient-management planning (Table 2). In water years 1988 and 1989, for example, under nutrient management the farmer was permitted to apply either 5 tons of poultry manure per acre, supplying approximately 280 pounds of nitrogen per acre; 9,000 gallons of liquid hog manure, supplying approximately 410 pounds of nitrogen per acre; or 20 tons of steer manure, supplying approximately 340 pounds of nitrogen per acre.

Planting and harvesting were scheduled according to growth requirements of the crops and weather conditions. Corn, the primary crop, was usually planted during the last two weeks in April and harvested from mid- to late-September. Tobacco, which requires a shorter, warmer season, was transplanted from starting beds to the field in mid-June and harvested in mid- to late-August. During 1985 and 1986, a winter cover crop of rye was broadcast seeded after corn harvesting and covered primarily the pipe-drained terraces. The rye was not harvested but was sprayed with herbicide before planting corn. In 1987, a winter cover crop of sudan grass was planted on 5.5 acres of the site. Beginning in 1988, fruit and vegetables, in addition to sweet corn, were cultivated. In 1989 and 1990, more acreage was planted in fruit and vegetables than in tobacco. Table 3 lists crop acreage for the years 1985 through 1990.

Table 3.—Annual crop acreage at Field Site 2.

YEAR	GROWING SEASON	CROP TYPE	ACREAGE
1985	Summer	Corn	43.5
	Summer	Tobacco	4.0
	Winter (1984-85)	Rye	22.5
1986	Summer	Corn	43.5
	Summer	Tobacco	4.0
	Winter (1985-86)	Rye	25.0
1987	Summer	Corn	42.0
	Summer	Tobacco	5.5
	Winter (1986-87)	Sudan grass	5.5
1988	Summer	Corn	39.5
	Summer	Tobacco	5.0
	Summer	Fruit and vegetables	2.5
1989	Summer	Corn	35.0
	Summer	Tobacco	2.5
	Summer	Fruit and vegetables	10.0
1990	Summer	Corn	37.0
	Summer	Tobacco	4.0
	Summer	Fruit and vegetables	6.5

Concentrations of Nitrate in Groundwater

Groundwater samples, collected monthly near the water table, were analyzed (Chichester, 1988) to determine long-term changes in nitrate concentration caused by implementing nutrient management. Nitrate concentrations in groundwater appeared to be unrelated to either depth to the water table or sampling depth below the water table for four wells. An exception was well LN 1669, which was sampled approximately 50 ft deeper below the water table than the other wells (Table 4). Nitrate concentrations were less in water samples from LN 1669 than in water samples from the other wells, and water from this well may have represented groundwater quality of a deeper zone in the aquifer than the water from other wells (Fig. 6c).

Neither changes in quantity or timing of precipitation nor changes in other climatic factors within the variation that occurred during the study period had a major effect on nitrate concentrations in groundwater (Fig. 6a to c). Although the wells at the

Table 4.—Average depth to water table, sampling depth, lag time, significance of Wilcoxon-Mann-Whitney test, number of samples, prenutrient management and postnutrient management nitrate concentrations, percent change in median nitrate concentrations, and percent change in nitrogen applications to contributing areas at five wells (mg/L = milligrams per liter).

WELL	AVG. DEPTH TO WATER (IN FT) FROM LAND SURFACE	AVG. SAMPLING DEPTH (IN FT) BELOW WATER TABLE SURFACE	WILCOXON-MANN-WHITNEY TEST, SIGNIFICANT TO PRE- TO POST- INCREASE (+) OR DECREASE (-)?	# SAMPLES (PRE-; POST-NUTRIENT MANAGE-MENT)	PRENUTRIENT MANAGEMENT MEDIAN NITRATE CON-CENTRATION (mg/L)	POSTNUTRIENT MANAGEMENT MEDIAN NITRATE CON-CENTRATION (mg/L)	CHANGE FROM PRE- TO POST- PERIOD IN MEDIAN NITRATE CON-CENTRATION (%)	CHANGE FROM PRE- TO POST- PERIOD IN APPLICA-TIONS (%)
LN 1669	18	66	Yes (+)	15; 35	11	12	+8	-67
LN 1973	10	23	Yes (-)	15; 35	53	37	-30	-53
LN 1676	24	10	Yes (-)	11; 25	82	56	-32	-67
LN 1677	30	3	Yes (-)	10; 33	26	23	-12	-39
LN 1679	20	13	Yes (-)	5; 35	24	22	-8	-60

site are a maximum of only 1,150 ft apart, and climatic influences (including precipitation) are virtually identical across this site, nitrate concentrations in groundwater samples from the five wells demonstrated no climate-induced long- or short-term trend or any consistent seasonal variation. For example, a period of increased recharge occurred during the late spring and summer of 1989 (Fig. 6a and b). During this period, nitrate concentrations in groundwater samples collected at wells LN 1673 and LN 1676 were increasing, concentrations in samples collected at wells LN 1677 and LN 1679 were decreasing, and concentrations in samples collected at well LN 1669 were remaining relatively constant (Fig. 6c). Most variations in nitrate concentrations in groundwater at each well are explained by amounts and timing of nitrogen applied in the contributing area of each well.

Three techniques were used to investigate the effects of nitrogen applications on water quality. First, median nitrate concentrations in groundwater from the five monitoring wells (before and after implementation of nutrient management) were compared. Second, changes in amounts of nitrogen fertilizer applied to the five well-contributing areas were statistically correlated with changes in nitrate concentrations of groundwater. Third, estimates of the quantities of nitrogen added to and removed from the site for each year of the study were compared to determine whether nitrogen loading to groundwater decreased as the result of decreased applications of nitrogen under nutrient management.

Comparison of Prenutrient and Postnutrient Management Nitrate Concentrations in Groundwater

Median nitrate concentrations in groundwater samples collected during the pre- and postnutrient-management periods were tested for significant differences by use of the Wilcoxon-Mann-Whitney test (Iman and Conover, 1983). The results of this test (Table 4) indicate that statistically significant decreases (at $\alpha = 0.05$) occurred in nitrate concentrations at four of the five wells. The largest post-nutrient-management reductions in median nitrate concentration occurred at wells in which pre-nutrient-management groundwater contained the largest nitrate concentrations. The median nitrate concentration at well LN 1669 increased 1 mg/L after the implementation of nutrient management. Test results indicate that nutrient management reduced nitrate concentrations in groundwater at four of five monitoring wells.

Correlations of Changes in Nitrogen Applications to Changes of Nitrate Concentrations in Groundwater

Cross-correlation functions (Wilkinson, 1987) were used to select the most significant lag times for lagged correlations between nitrogen applied to land areas contributing to the wells and nitrate concentrations in groundwater. For example, the series of monthly nitrogen applications estimated from an application curve on Figure 7 can be correlated with the series of monthly nitrate concentrations estimated from the corresponding concentration curve with lag times of 1 month, 2 months, and so on up to 20 months. When several adjacent lag times were significant — for example, lag times for well LN 1676—lags from 2 to 9 months were statistically significant — the lag time with the strongest correlation was reported. Rho and p on Figure 8 are reported from Spearman-ranked correlations (P-STAT, 1986) by using the most significant correlation indicated in the cross-correlation procedure for each well data set.

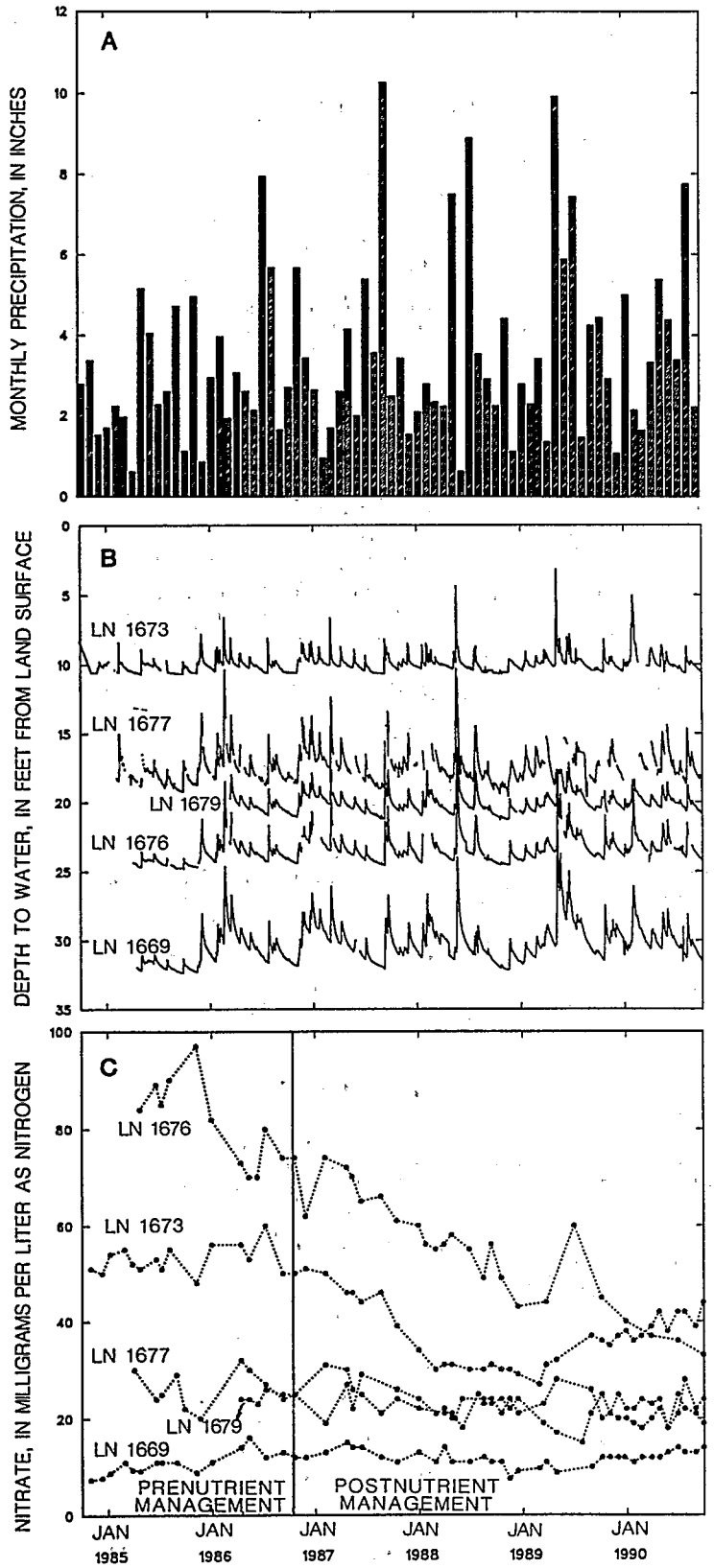

Figure 6.—Monthly precipitation (A), depth to water from land surface (B), and nitrate concentrations (C) in groundwater samples.

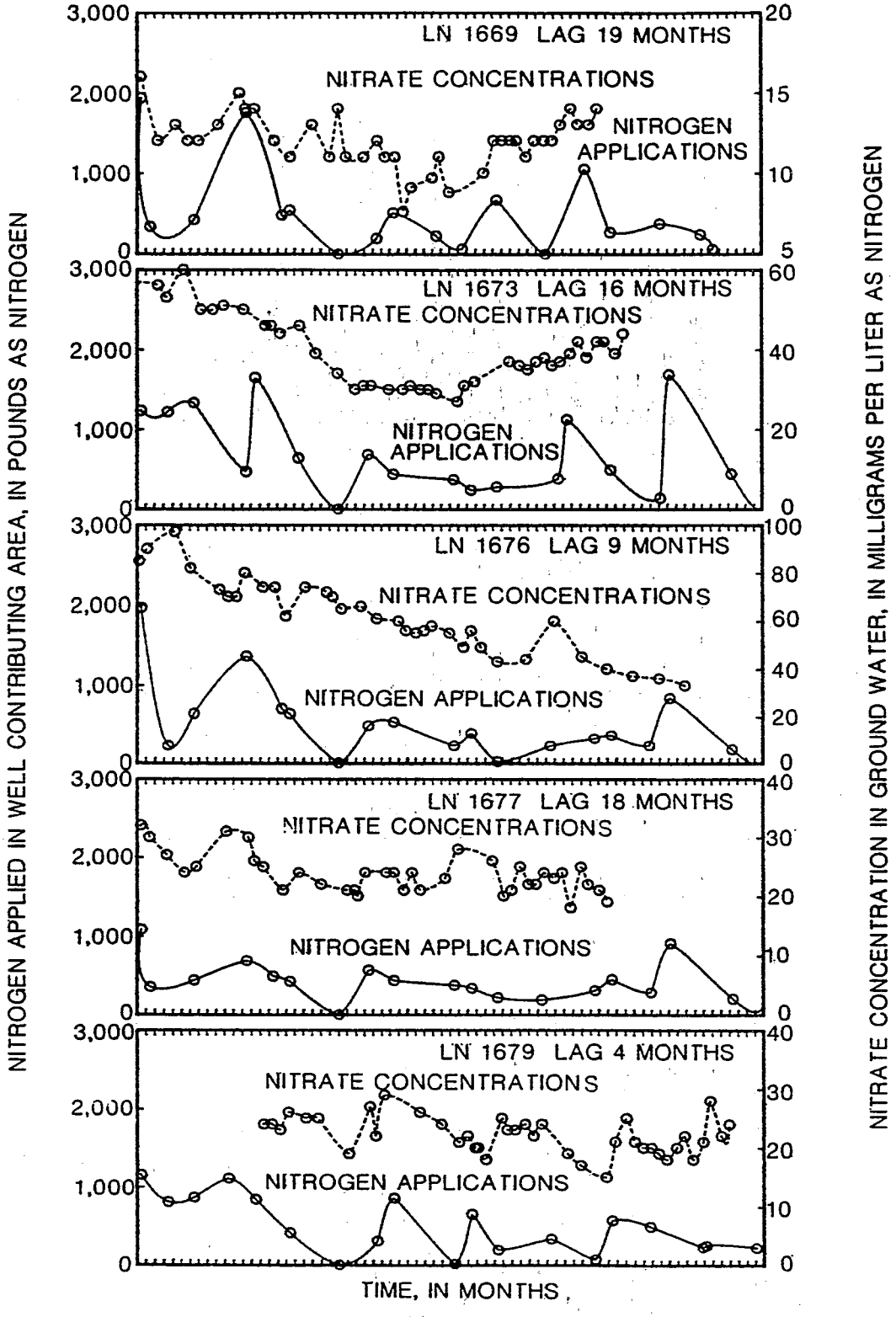

Figure 7.—Groundwater nitrate concentration data and applied nitrogen data for wells LN1669, LN 1673, LN 1676, LN 1677, and LN 1679. Note: To illustrate correlations, nitrogen applications have been moved to the right to match resultant nitrate concentrations; to get real-time relations, move the application curves to the left by the indicated time lag for each well.

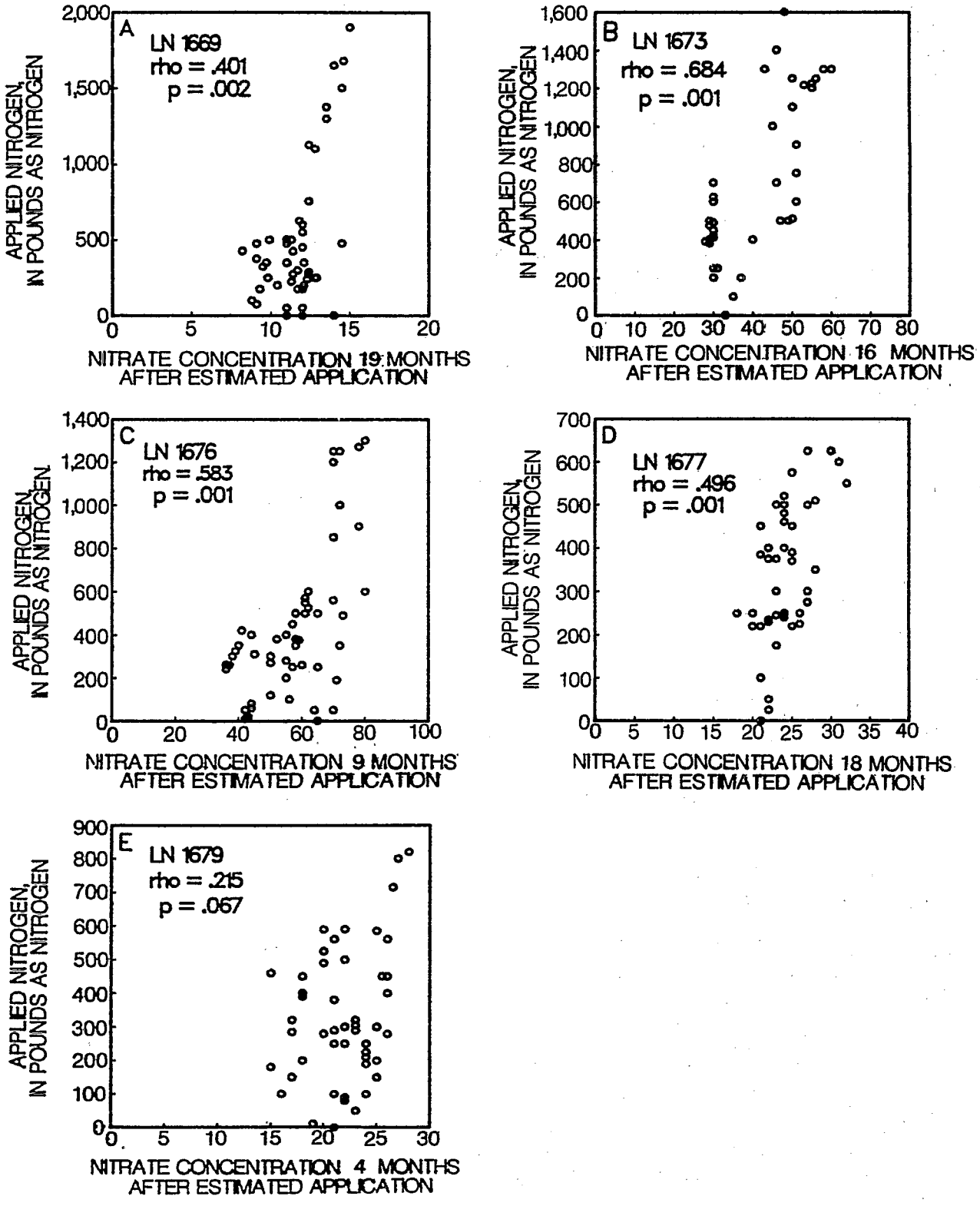

Figure 8.—Plots of groundwater nitrate concentrations and applied nitrogen and results of Spearman rank correlation testing using data from wells LN 1669, LN 1673, LN 1676, LN 1677, and LN 1679.

Figures 7 and 8 show the effects of changes in loads of applied nitrogen on changes in nitrate concentrations in groundwater at the five monitoring wells. Each point on the nitrogen-application graphs of Figure 7 represents the sum of 4 months of applications made to the contributing area of each well. The points are plotted on the day of the maximum application in each 4-month period and are, therefore, unequally spaced.

Statistically significant correlations (Spearman rank correlations, $\alpha = 0.10$ [P-STAT, 1986]) exist between the timing and amount of applied nitrogen and changes in groundwater nitrate sample concentrations adjusted for lag time (Fig. 8). The statistically significant, cause-effect relations between changes in the amounts of applied nitrogen and changes in groundwater nitrate concentrations indicate that a significant amount of the nitrogen in manure and fertilizer becomes available for leaching and is transported with recharge to the groundwater system within 4 to 19 months following application. Therefore, any substantial reduction or increase in quantities of applied nitrogen would be expected to produce a similar reduction or increase of nitrate concentrations in groundwater samples collected at the five monitoring wells.

Lag times required for applied nitrogen to leach to groundwater at each of the wells range from about 4 months upgradient of well LN 1679 to about 19 months upgradient of well LN 1669, probably because of differences in the hydraulic conductivity of the unsaturated zone, soil-moisture content, clay contents of the unsaturated zone, and the depth to the water table upgradient of each well.

Annual Additions and Removals of Nitrogen

Additions and removals of nitrogen at the site were calculated for each year of the study (Table 5). Potential errors caused by assumptions made in the calculation of loads may greatly affect the numbers reported in Table 5.

Loads of nitrogen in manure were calculated by using application data supplied by the farmer and laboratory analysis of manure samples collected at the site. Loads of nitrogen entering the site in precipitation were calculated by using rainfall volumes estimated on the basis of precipitation data collected at the site and estimated concentrations of nitrogen in precipitation samples for the Ephrata, Pennsylvania, area (Lynch, 1990).

Amounts of commercial fertilizer applied to the site were reported by the farmer. In spring 1989, Pennsylvania State University announced that the "quick" nitrogen soil test would be made available on a limited basis to the public. This test measures the amount of soluble nitrate-nitrogen available in the soil and was designed to be used at side-dress time (early June) to determine if additional nitrogen was necessary for optimum corn yield. Pennsylvania State recommended that the test be used on fields that had recently received manure or following a legume crop. Recommended nitrogen side-dressing rates were based on soil nitrate test results and corn yield goals. For example, a soil test level of 20 ppm of nitrate nitrogen would result in a recommended side-dressing rate of 25 pounds/acre for a yield goal of 100 bushels/acre, but the recommended rate for a yield goal of 200 bushels/acre should be 100 pounds/acre.

The owner of Field Site 2 requested that the "quick" nitrogen soil test be used on his farm. The test showed that some fields had nitrate levels below 25 ppm. These fields were side dressed with urea-ammonium-nitrate on June 26, 1989, at the recommended rate (either 50 or 75 pounds of actual nitrogen per acre). Approximately 29 acres of the field site planted in field corn had additional nitrogen applied, which accounts for the use of commercial fertilizer during the nutrient management period (Table 5).

Quantities of nitrogen removed from the site in crops were calculated from estimated crop yields, crop nitrogen-content information (Anderson, 1989) and discussions presented in Knott (1962). Loads of nitrogen in surface water were calculated by using discharge-weighted mean-storm concentrations for each storm multiplied by gaged discharge. Volatilization of nitrogen was estimated as a percentage of the nitrogen applied: 40 percent for surface-spread manures and 20 percent for injected manures (on the basis of information in Graves [1986b]), and a 15 percent value for commercial fertilizers (Pionke and Urban, 1985). Denitrification losses from soil and groundwater are unknown; however, large concentrations of dissolved oxygen in groundwater may indicate that losses are small because denitrification is an anaerobic process. For example, water from wells LN 1669, LN 1673, LN 1676, LN 1677, and LN 1679 was sampled for dissolved oxygen concentration during May 1986; dissolved oxygen concentrations ranged from 5.7 to 10.5 mg/L.

Approximately 99 percent of the nitrogen leaving the site in water was discharged through the groundwater system. More than 90 percent of this nitrogen was in the form of dissolved nitrate.

A groundwater-flow model of the hillslope on which the site is situated was constructed to help es-

Table 5.—Estimated additions and removals of nitrogen (numbers are in pounds as nitrogen).

	ESTIMATED NITROGEN ADDITIONS TO SITE				ESTIMATED NITROGEN REMOVALS FROM SITE			
WATER YEAR	NITROGEN IN MANURE FERTILIZER	NITROGEN IN COMMERICAL FERTILIZER	NITROGEN IN PRECIPITATION	NITROGEN IN GROUNDWATER INFLOW	NITROGEN CONSUMED BY CROPS	SURFACE WATER LOADS OF NITROGEN	VOLATILIZATION	GROUNDWATER LOADS OF NITROGEN
1985[1]	25,500	1,000	290	90	8,500	120	7,300	5,100
1986[1]	18,500[2]	500	300	180	8,700	50	4,600	10,800
1987	11,500	0	390	190	6,900	20	4,400	10,500
1988	13,500	0	320	170	6,500	160	4,700	7,100
1989	17,200	1,600	330	190	7,400	90[3]	5,500	7,700
1990	16,700	1,700	340	160	8,100	90[3]	4,600	6,400
Average 1985-90	17,150	800	330	160	7,700	90	5,180	7,930
% annual additions or removals	93	4	2	1	38	<1	24	38

[1]1985 and 1986 were prenutrient management.
[2]1986 manure applications were unusually small because of less manure disposal resulting from an outbreak of avian influenza.
[3]Estimated as average of surface runoff loads calculated for years 1985-88.

timate the volumes of groundwater inflow and outflow across site boundaries needed for groundwater nitrogen load calculations. The hillslope was simulated as a two-dimensional, steady-state flow system in the x-y plane by using the finite-difference model of McDonald and Harbaugh (1988). Figure 9 shows the finite-difference grid, aquifer properties, and boundary conditions used in the model. Transmissivities were based on the site water table gradients (Fig. 3) in conjunction with Darcy's Law (Driscoll, 1986).

The water budget computed by the model (Table 6) is based on the long-term average recharge from precipitation of 19.1 in/yr (inches per year), estimated to be 44 percent of the long-term precipitation of 43.5 in/yr recorded at the Ephrata, Pennsylvania, NOAA station (Natl. Oceanic Atmos. Admin. 1982). Groundwater inflow during 1985-90 was estimated to be 16 percent of total inflow of water to the site as indicated by modeling simulations.

Nitrogen in groundwater inflow was calculated from volumes of flow estimated by groundwater flow-model simulations multiplied by the average nitrogen concentrations in two water samples collected at well LN 1674, located on the western boundary of the site.

The quantity of groundwater discharged annually across each site boundary was computed by multiplying the total annual discharge from the site by the percentage of annual flow estimated to cross each site boundary as indicated by output from the groundwater model. Annual discharge across each site boundary was then apportioned among months by using water level hydrograph rises for each month divided by the total annual water level rise to obtain the fraction of annual discharge in each month.

Having thus obtained quantities of groundwater discharge crossing each site boundary during each month of the study, monthly water samples from wells located in different parts of the site were chosen to characterize the nitrogen concentrations of the groundwater discharges from each part of the site. Water samples from well LN 1677 were chosen to characterize the nitrogen concentrations of water discharged across the northern site boundary, water samples from wells LN 1676 and LN 1679 were chosen to characterize the nitrogen concentrations of water discharged across the eastern site boundary, and water samples from wells LN 1673 and LN 1669 were chosen to characterize the nitrogen concentration of water discharged across the southern site boundary. Estimated groundwater discharges across site boundaries were multiplied by nitrate concentrations in groundwater samples from the northern, eastern, and southern areas to obtain loads of nitrogen in groundwater discharge.

The estimated loads in groundwater averaged 7,950 lb of nitrogen per year in the 1985-86 prenutrient-management period and 7,925 lb per year in the postnutrient-management period. Because loads were calculated by multiplying groundwater discharge by groundwater nitrate concentrations, average annual loads appear to be unchanged because annual groundwater discharge averaged about 6 inches more during the postnutrient-management period than in the prenutrient-management period. However, annual nitrogen loads normalized for discharge (Table 7) in-

Table 6.—Simulated steady-state groundwater budget for the site.

	CUBIC FEET PER SECOND	INCHES PER YEAR	PERCENT OF TOTAL INFLOW
Groundwater Inflow			
Recharge from precipitation	0.119	19.1	84
Flow across western boundary	0.023	3.7	16
Total	0.142	22.8	100
Groundwater Outflow			
Flow across eastern boundary	0.023	3.7	16
Flow across northern boundary	0.033	5.4	24
Flow across southern boundary	0.084	13.7	60
Total	0.140	22.8	100

Table 7.—Loads of nitrogen per inch and per million gallons of groundwater discharge, 1985 to 1990 (loads of nitrogen are in pounds).

YEAR	PERIOD	NITROGEN LOAD IN GROUNDWATER (IN LBS. PER INCH OF GROUNDWATER DISCHARGE)	NITROGEN LOAD IN GROUNDWATER (IN LBS. OF NITROGEN PER MILLION GALLONS OF GROUNDWATER DISCHARGE)
1985	Prenutrient management	421	294
1986	Prenutrient management	450	314
1987	Transition year	408	285
1988	Postnutrient management	306	214
1989	Postnutrient management	298	208
1990	Postnutrient management	304	212

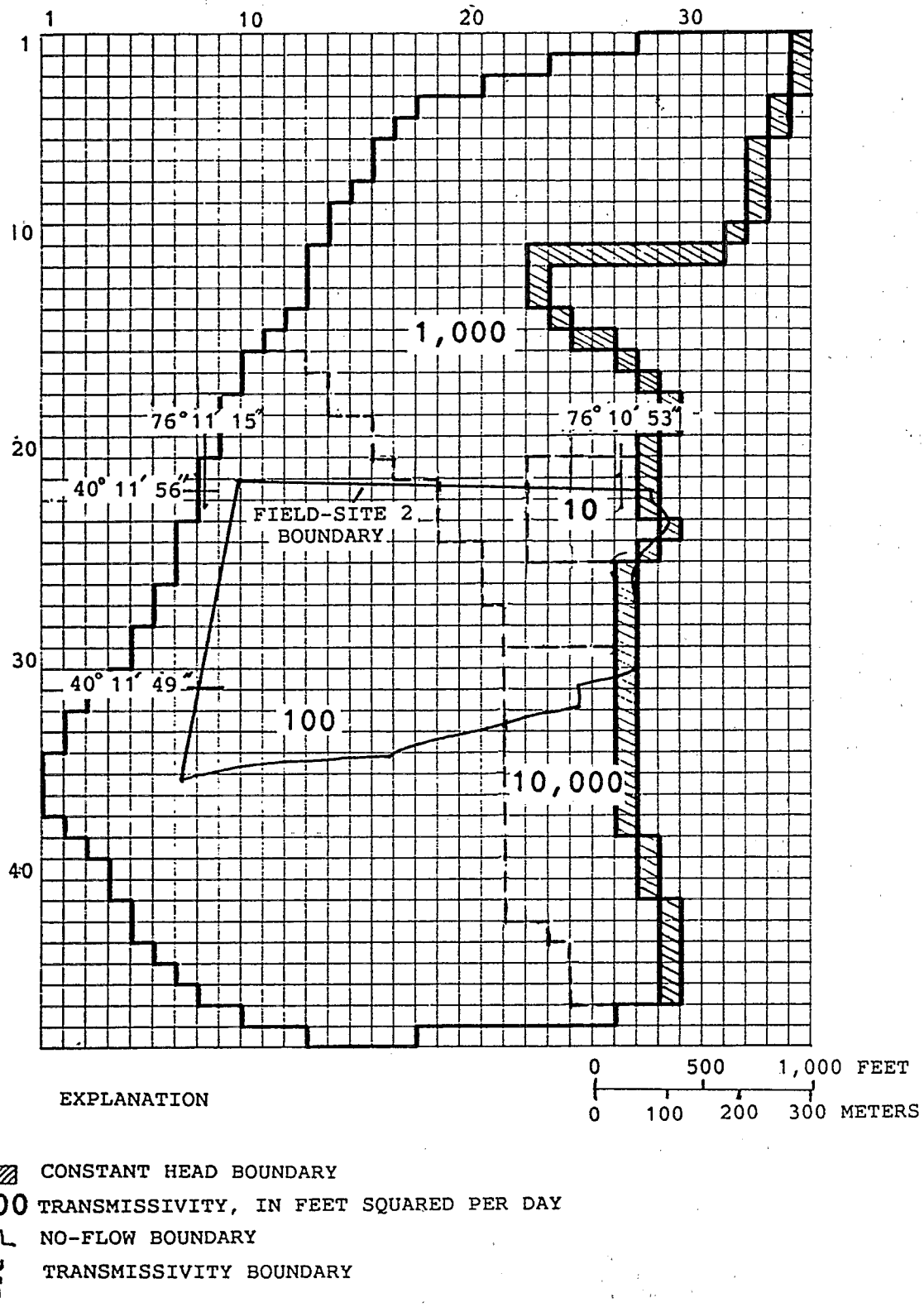

Figure 9.—Finite-difference grid, hydrologic boundaries, and aquifer properties used in the groundwater flow model.

dicate that nitrogen discharge in groundwater decreased. Reduced nitrogen applications to the land surface under nutrient management caused the decrease in nitrogen that discharged in groundwater.

The reduced loads of nitrogen in groundwater that occurred as the result of nutrient management are further illustrated in Figure 10. For example, a monthly groundwater discharge of 4 in contained about 1,750 lb of nitrogen in the prenutrient-management period, but only about 1,200 lb of nitrogen during the postnutrient-management period. Dilution was not responsible for the load reductions. No consistent relation was found between nitrate concentrations in groundwater and the volumes of recharge. Nitrate concentrations in groundwater increased during some recharge events and decreased during others at this site (Hall, 1992) and at a similar site in Lancaster County, Pennsylvania (Gerhart, 1986).

By entering the monthly groundwater discharge (MGWD) values from the postnutrient-management period into regression equation (1) in Figure 10, loads of nitrogen that would have been discharged from the site if nutrient management had not been implemented can be estimated for the period 1988-90. Subtracting the actual 1988-90 loads from the estimated 1988-90 loads, it was determined that a reduction of about 11,000 lb of nitrogen in groundwater discharge was achieved as the result of nutrient management during the period 1988-90.

Conclusions

The implementation of a nutrient management plan in 1987 was effective in reducing concentrations of nitrate in groundwater at a 55-acre farm site near Ephrata, Pennsylvania. Under nutrient management, applications of nitrogen to the site decreased approximately 33 percent. Statistically significant decreases in median nitrate concentrations in groundwater ranged from 8 to 32 percent at four out of five monitoring wells. The largest decreases in nitrate concentration occurred at wells in which prenutrient-management nitrate concentrations in groundwater were the largest.

Correlations between changes in loading of applied nitrogen fertilizers (primarily manure) and changes in nitrate concentrations in groundwater at five wells were statistically significant. Changes in nitrate concentrations in groundwater occurred about 4 to 19 months after changes in applications of nitrogen fertilizer.

Additions and removals of nitrogen loads from the site were estimated for the period 1985-90. Nitrogen entered the site in manure, commercial fertilizers, precipitation, and groundwater inflow; these sources averaged 93, 4, 2, and 1 percent of the nitrogen that entered the site, respectively. Nitrogen was lost from the site in harvested crops, groundwater outflow, volatilization, and surface runoff; these losses averaged 38, 38, 24, and less

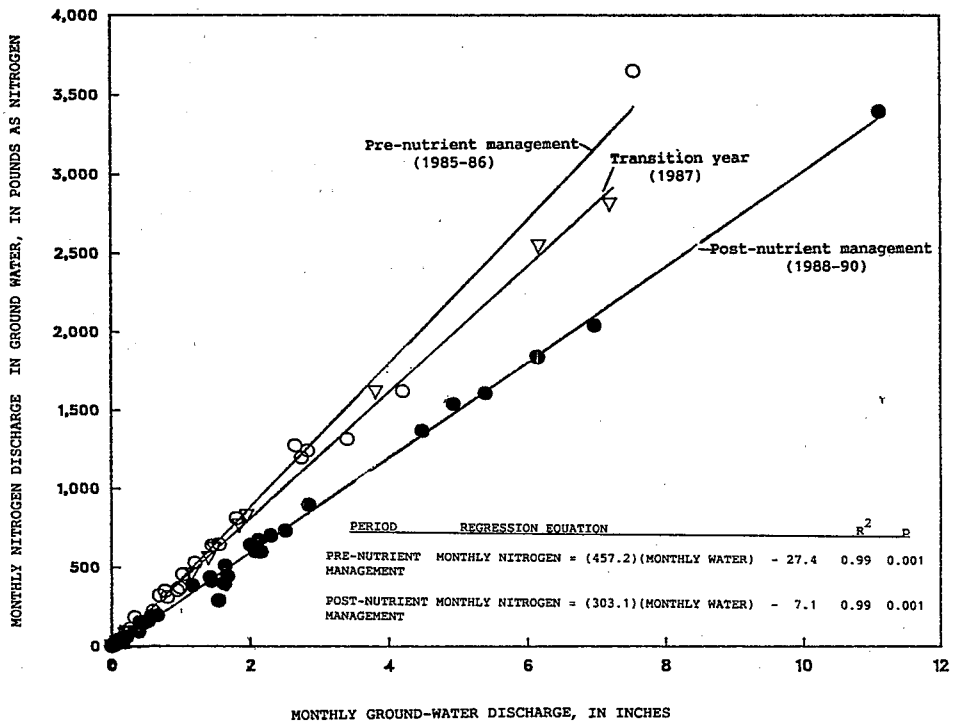

Figure 10.—Relation between monthly groundwater discharge and nitrogen discharge.

than 1 percent of the nitrogen removed from the site, respectively.

Virtually all nitrogen leaving the site that was not removed in harvested crops or lost to the atmosphere by volatilization discharged with the groundwater. Nutrient management substantially reduced nitrogen loads in groundwater discharge. Nitrogen loads in groundwater discharge were estimated to have been approximately 300 and 200 pounds of nitrogen per million gallons of discharge, respectively, before and after implementation of nutrient management.

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Relating Land Use and Water Quality in the St. Albans Bay Watershed, Vermont

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ABSTRACT

The St. Albans Bay Rural Clean Water Program comprehensive monitoring and evaluation program assessed water quality changes in response to land treatment. Evaluation of response to treatment must be based not only on detection of water quality trends but also on linking such trends to observed changes in land use or management. To this end, the St. Albans Bay watershed monitoring and evaluation program included intensive tracking of annual land use and agricultural management activities and related them to observed water quality using correlation and linear regression. Major variables considered included animal management, cropping patterns, and manure management. Bacteria counts in streams increased with higher animal density but declined with increasing percentage of animals under BMP waste management, while lower bacteria counts occurred with greater use of manure from storage. Although data from another watershed had previously suggested that lower stream nutrient levels would be associated with higher proportions of watershed animals under BMP, no such relationship was observed in the St. Albans Bay watershed, perhaps because a sufficiently high level of treatment was not achieved. Future efforts to document land use/water quality relationships should include improved experimental design, better tracking of changing land use and agricultural management, and more powerful statistical analysis.

St. Albans Bay on Lake Champlain in Vermont has been subject to increasing rates of eutrophication as a result of excessive phosphorus loads from both point and nonpoint sources. The primary goal of the St. Albans Bay Rural Clean Water Program (RCWP) project was to improve water quality and restore beneficial uses in St. Albans Bay and its tributaries through a program of agricultural best management practices (BMPs) to control nonpoint sources of pollution.

Initiated in 1980 and completed in 1991, the St. Albans Bay RCWP project was one of only five projects nationwide to include comprehensive monitoring and evaluation to evaluate the water quality impacts of land treatment. The goal of this program was to assess water quality changes in the bay and its tributaries in response to land treatment. The results of the program have been presented in detail by the Vermont RCWP Coordinating Committee (1991) and Meals (1992).

Evaluation of water quality response to land treatment must be based not only on detection of water quality trends but also on linking such trends to observed changes in land use or management. To this end, the St. Albans Bay watershed comprehensive monitoring and evaluation program included intensive tracking of land use and agricultural management activities. This paper discusses the ap-

proach taken to relate land use to water quality and presents some results of the analysis. Annual patterns of agricultural activity were related to observed water quality by using correlation and linear regression to clarify the effects of treatment.

Study Area

The St. Albans Bay watershed is located in northwestern Vermont 40 km north of Burlington (Fig. 1) and drains 13,000 ha of agricultural, forested, and urban land into St. Albans Bay of Lake Champlain. The 700-ha bay is 4.2 km long and 2.2 km wide and is oriented on a southwest-northeast axis, opening to the southwest. Mean depth is 8 m; maximum depth is 12 m.

Four major tributaries drain the watershed into St. Albans Bay: Jewett Brook, Stevens Brook, Rugg Brook, and Mill River (Fig. 1). The city of St. Albans tertiary wastewater treatment plant discharges about 91 m^3/sec to Stevens Brook wetland at the head of the bay.

The St. Albans Bay watershed is located primarily in the Champlain Lowlands, an area of generally low relief between Lake Champlain and the foothills of the Green Mountains. Watershed soils formed on glacial till or lacustrine deposits and include loams (51 percent) (half of which are poorly drained), silts and clays (27 percent), rock outcrop (15 percent), and sands (7 percent).

The climate of the St. Albans Bay watershed is cool and humid, with pronounced seasonal variations. Mean annual temperature is 7.3°C; the growing season averages 150 days. Mean annual precipitation is 845 mm, with a minimum average monthly precipitation in February of 44 mm and a maximum average monthly rainfall in August of 100 mm. Average annual snowfall is 1,550 mm.

Agriculture is the dominant land use in the watershed (65 percent); about 20 percent of the watershed is forested, 10 percent is in urban/residential use, and 5 percent consists of roads and surface water. Of the 102 farms in the watershed, most are dairy operations, with a few fruit and vegetable or horse farms. Dairy farms average 134 ha in size, with an average herd size in 1991 of 110 animal units, up from 95 in 1980. (One animal unit is equivalent to a 405 kg dairy animal.) Corn for silage is the principal cultivated crop: from 1980–90, land area in corn ranged from 1,336 to 1,821 ha or about 10 to 15 percent of total watershed area. Substantially larger agricultural land area is devoted to hay, from 3,845 to 4,452 ha or about 30 to 35 percent of watershed area.

Some cropland in the watershed has been in continuous corn, but a three-year corn/five-year hay rotation is the prevalent practice. Both manure and commercial fertilizer are commonly applied to corn cropland; hayland generally receives manure twice a year immediately following hay cuts, which typically occur in early June and in mid-July.

Recreation, aesthetics, and other beneficial uses of St. Albans Bay have been impaired by eutrophication for many years. The most serious nonpoint source water quality problems associated with agriculture in the St. Albans Bay watershed have been nutrients (principally phosphorus) from runoff of animal and milkhouse waste and sediment from cropland erosion. Improper manure management (e.g., year-round spreading because of inadequate waste storage) and inadequate milkhouse waste and barn- yard runoff management were believed to be the principal contributors to water quality problems. Improper fertilizer management — failure to balance manure/fertilizer nutrient applications with soil/crop needs — was also thought to be a significant contributor to excessive nutrient loading. Cropland soil and streambank erosion were also important contributors to water quality problems.

Methods

Water Quality Monitoring

To document overall water quality changes in St. Albans Bay and its tributaries, water quality monitoring was conducted on several geographic scales:

- **Level 1:** bay sampling
- **Level 2:** tributary trend monitoring
- **Level 3:** edge-of-field BMP study
- **Level 4:** randomized grab sampling

The design and specific methods of the comprehensive monitoring and evaluation program, including bay monitoring, edge-of-field studies, and biological monitoring, have been discussed in detail elsewhere (Clausen, 1985; Vt. RCWP Coor. Comm. 1991; Meals, 1992). Discussions presented in this paper are based exclusively on tributary monitoring data (Level 2).

Intensive tributary trend monitoring was designed to determine long-term patterns of streamflow as well as pollutant concentrations and loads in the four major drainages to St. Albans Bay and from the St. Albans city wastewater treatment plant (Fig. 1). The subwatersheds monitored by these trend stations comprised 72 percent of the entire St. Albans Bay watershed. A fifth station

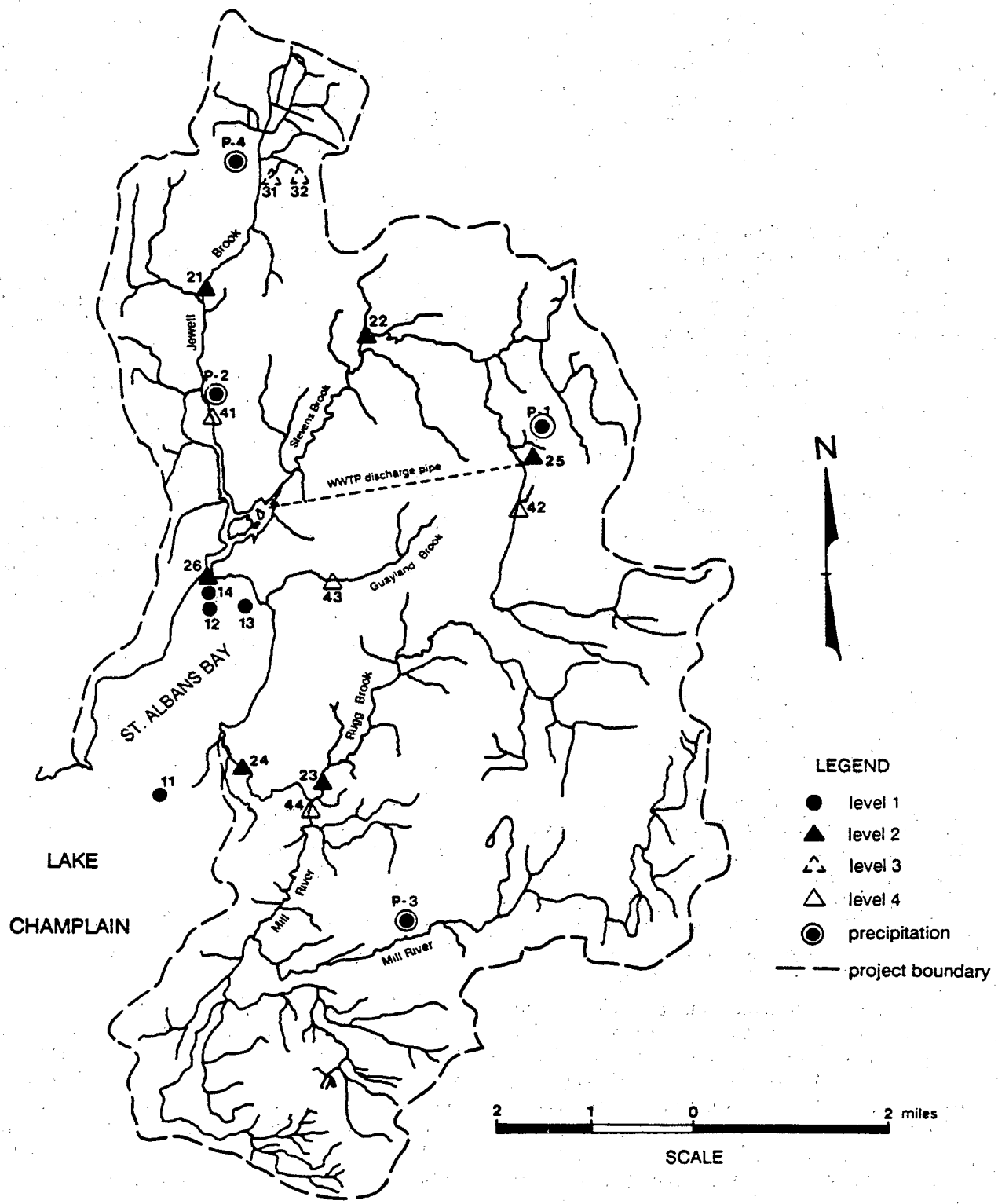


Figure 1.—Map of St. Albans Bay watershed showing location of monitoring stations.

monitored suspended solids and nutrient loads from the wastewater treatment plant, the major point source in the watershed.

At each of the five tributary stations, samples were collected automatically at eight-hour intervals using refrigerated ISCO Model 1680R samplers and

combined weekly into two 48-hour and one 72-hour composite sample(s) for analysis. During some stormflow periods, individual samples were analyzed discretely. All samples were analyzed for turbidity, total and volatile suspended solids, total and soluble reactive phosphorus, and total Kjeldahl, ammonia, and nitrite+nitrate nitrogen by accepted methods (U.S. Environ. Prot. Agency, 1983; Standard Methods, 1985). Weekly grab samples were collected at each station and analyzed for pH, conductance, and fecal coliform and fecal streptococcus bacteria, while *in situ* measurements were made of temperature and dissolved oxygen at the time of grab sampling.

Stream stage was recorded continuously at each station using ISCO Model 1870 bubbler-type stage recorders and discharge was calculated from site-specific stage-discharge ratings. Three standard Belfort 20-cm weighing bucket rain gages were used to measure watershed precipitation.

Land Use Monitoring

Basic land treatment implementation data were collected and maintained by the U.S. Department of Agriculture (USDA) Agricultural Stabilization and Conservation Service, including number of participating farms, critical acres treated, and number or area of BMPs completed. However, far more detailed land use information was needed to complement the water quality database. The comprehensive monitoring and evaluation program therefore included intensive tracking of land use and agricultural management activities, which was conducted as a cooperative venture among land treatment and water quality monitoring agencies.

As a first step, baseline information was collected on all farms (both contract and noncontract) in the watershed from 1982 to 1983. These data included:

- **Livestock:** type and number
- **Manure management:** type, capacity, schedules
- **Land use:** location and crop type, by field
- **Fertilizer:** type, amount, fields, schedule
- **Milkhouse:** type, effluent disposal
- **Barnyard:** size, use, paving
- **Pesticides:** type, amount, fields, schedule
- **Drainage:** type, location.

For long-term land use monitoring, detailed information was collected from each watershed farmer (regardless of contract status) on amount, date, and location of manure and fertilizer applications and cropland activity over each calendar year. The goal was to identify not only *what* activities took place and *where* but also *when* these activities, such as manure spreading, occurred.

Information was recorded in a checkbook-style logbook distributed to each farmer (Fig. 2). Each logbook included an individual farm map derived from the farm conservation plan or from aerial photographs, with each field identified by number. Farmers were asked to maintain records of activities by field throughout the year, and this information was collected during biannual (later annual) interviews. USDA Soil Conservation Service personnel distributed logbooks and collected information from contract farms, while comprehensive monitoring and evaluation staff did the same for noncontract farms.

A. MANURE APPLICATION: Name: _____

DATE	FIELD I.D. (see map)	AMOUNT APPLIED (full spreader load)	DATE INCORPORATED	COMMENTS 1
Example 4/23/83	3b	2½	4/23	-Evenly spread except wet spot on NE corner -planted corn 4/28 -etc.

B. OTHER FERTILIZER APPLICATION
(including commercial fertilizer, lime, sewage sludge and whey)

DATE	FIELD I.D.	FORMULATION	AMOUNT APPLIED/AC	HOW APPLIED	COMMENTS 13
Example 5/23/83	21 (or all corn fields)	10-20-10	250 lbs/Ac.	planter	disced in 5/23/83

C. CROPLAND ACTIVITIES

DATE	FIELD I.D.	ROTATION C or H	ACTIVITY	COMMENTS 25
Example 6/23/83	21	C	seed or plow or harvest or herbicide/pesticide	Bladex _____ 5 lb/acre

Figure 2.—Example of manure/fertilizer logbook, St. Albans Bay RCWP.

Once collected, land use and agricultural management data were managed and analyzed in the ARC/INFO geographic information system (GIS). In addition to basic data layers, such as soils, water courses, and farm location, annual "snapshots" of

land use, cropping patterns, and manure application were routinely mapped in the GIS.

Data Analysis

Relationships between land use and water quality on a fine time scale are typically confounded by weather and season and their influence on specific farming activities. Furthermore, the timing of land use and farm management activities was not determined as precisely as the timing of streamflow or pollutant loads. Therefore, analysis focused on annual patterns of land use and water quality.

Although some detail was lost by using only annual values, this simplified approach had the advantages of paralleling annual cropping cycles and rotations. The approach was also necessary because, despite intensive data collection efforts, the precision of much of the land use data varied widely among farmers reporting. Some farmers, for example, reported manure application data by exact day and number of spreader loads; others, however, reported spreading "some manure every week over the summer." Aggregating data to an annual basis was the only workable solution to such differences in data precision. Furthermore, some land treatment data, such as completion of structures, were typically reported annually.

The following land use/agricultural activity variables were hypothesized to affect water quality:

- Animal population (animal units: AU)
- Animal density (AU/ha)
- Animals under BMP (% of total AU)
- Land in corn (ha and % of watershed)
- Land in pasture (ha and % of watershed)
- Land receiving manure (ha and % of watershed)
- Land receiving manure from storage (% of manured area)
- Land receiving manure with incorporation (% of manured area)
- Cornland where manure incorporated (% of manured cornland)
- Manure applied (tons and tons/ha)
- Manure quantity from storage (% of manure applied)
- Manure quantity incorporated (% of manure applied)
- Barnyard runoff control (# of systems)
- Milkhouse waste management (# of systems)
- Erosion control (ha and % of watershed).

Animal population and density, for example, determine the amount of animal waste available as a pollutant source. The percent of animals under BMP is an aggregate measure of the proportion of improved waste management practiced, including proper storage, application, timing, and incorporation into the soil. Specific BMPs, such as barnyard runoff control and milkhouse waste management, reduce the volume of contaminated runoff and divert runoff away from surface waters.

Annual water quality values were used for compatibility with the annual land use data. As with the latter data, aggregating water quality data to annual values helped reduce some of the same confounding interactions between weather, season, streamflow, water quality, and agriculture. The water quality and flow data used in this analysis were annual means (antilogs of means of log-transformed data). Only concentrations were considered to avoid the influence of variations in annual stream discharge on mass export.

Relationships between flow and pollutant concentrations generally were not statistically significant at this level of data aggregation (Vt. RCWP Coor. Comm. 1991). However, hydrologic variables, such as precipitation and streamflow, were also included as independent variables in the correlation analysis to assess the significance of their effect on observed annual water quality.

Correlation and simple linear regression were used to analyze land use/water quality relationships. Correlations were evaluated separately in each of the four monitored subwatersheds. Unique characteristics of some of the monitored watersheds (e.g., extremely high animal populations in the Jewett Brook watershed and occasional point source discharges to Stevens Brook) prevented combining all watershed data into a single analysis. Significant correlations were examined further using simple linear regression to determine strength and direction of the relationship.

It was not possible to control rigorously for hydrologic variation in this analysis because of the few degrees of freedom (n=8-9). However, correlations between annual water quality values and hydrologic variables (such as mean annual streamflow, total annual discharge, and total annual precipitation) were tested and generally found to be weak and inconsistent. In the few cases where correlation between a water quality and a hydrologic variable was statistically significant, relationships between land use and that water quality variable were

considered meaningful only if the strength of the correlation exceeded the strength of correlation with the hydrologic variable.

Results

Water Quality

Water quality data and trends over time in the St. Albans Bay watershed have been presented and discussed in detail elsewhere (Vt. RCWP Coor. Comm. 1991) and in these proceedings (Meals, 1992), and the reader is directed to these sources for further information.

Land Use and Agricultural Activity

The monitoring program was highly effective in tracking annual patterns of agricultural land use in the St. Albans Bay watershed. Agricultural land use in each of the monitored subwatersheds in 1990 is shown in Table 1. The Jewett Brook watershed had the highest proportion of agricultural land (86 percent) and the highest proportion of land in corn (32 percent) among the monitored subwatersheds. Agricultural land comprised 45 to 55 percent of the other subwatersheds and less than 10 percent of the land in these subwatersheds was planted in corn.

Overall land use patterns in the St. Albans Bay Watershed were relatively stable during the RCWP project. Total agricultural land area in the watershed declined by just 364 ha (3 percent) from 1983 through 1990. Forest land increased by 200 ha (7 percent) and urban land added 133 ha (10 percent).

The mix of agricultural land uses remained reasonably constant within the St. Albans Bay watershed from 1983 through 1986, with about 12 percent of agricultural land in corn, 40 percent in hay, and 23 percent in pasture (Fig. 3). After 1987, cornland area increased, while areas of both hayland and pastureland declined. This trend in land use coincided with the Dairy Termination Program and a general downturn in the dairy economy. One result of the Dairy Termination Program was a trend toward increases in herd size. The increase in cornland may reflect an effort by farmers to produce additional feed to support these larger herds.

Total watershed animal populations remained relatively constant over the study period (9,900 to 10,000 animal units), with a slight change associated with the Dairy Termination Program (Fig. 4). The effect of that program and other livestock sales beginning in 1986 can be seen in the downturn in animal units in Figure 4. Minimum animal population in the St. Albans Bay watershed occurred in 1987; after 1987, animal numbers rebounded as average herd size increased. The highest animal population was recorded in 1990, the final project year.

The monitored subwatersheds generally were similar with regard to changing animal numbers. In most parts of the St. Albans Bay watershed, animal densities were fairly low and comparable to values elsewhere in Vermont, about 0.5 to 0.7 animal units/ha. In the Jewett Brook watershed, however, animal densities were more than double this level, 1.2 to 1.6 animal units/ha.

The estimated quantity of manure applied by farmers in the St. Albans Bay watershed from 1983 through 1990 is shown in Figure 5. Manure quantity was probably underestimated in 1983, the first year of land use monitoring. The quantity of manure reportedly applied in the watershed appeared to be reasonably constant from 1984–90 (122,000 to 151,000 tons/year); year-to-year differences reflected small changes in animal populations, varying duration of pasturing, or reduced spreading in wet years with carryover to the following years.

The proportion of the total mass of manure applied each year that came from storage increased through the project (Fig. 5). The percent from storage may have been overestimated because of under-reporting by non-BMP daily-spreaders; however, there is no doubt that manure application from storage tended to increase over the project period. The prevalence of manure application from storage and an observed increase in manure incorporation on cornland indicated improved manure management following RCWP land treatment.

Field-by-field data on land receiving manure were collected and compiled into an annual "snap-

Table 1.—Agricultural land use in monitored watersheds, St. Albans Bay RCWP, 1990.

LAND USE	JEWETT BR.	STEVENS BR.	RUGG BR.	MILL R.
	HECTARES (%)			
Corn	450 (32%)	209 (9%)	48 (3%)	380 (6%)
Hay	557 (40%)	532 (22%)	523 (34%)	1,712 (29%)
Pasture	175 (13%)	324 (13%)	227 (15%)	1,020 (18%)
Farmstead	10 (<0.1%)	10 (<0.1%)	7 (<0.1%)	40 (1%)
Ag. use unknown	1 (<0.1%)	15 (1%)	0 (0%)	26 (<.0.5%)
Forest	169 (12%)	511 (21%)	339 (22%)	1,804 (31%)
Non-ag.	22 (2%)	825 (34%)	404 (26%)	828 (14%)
TOTAL	1,384	2,426	1,548	5,810

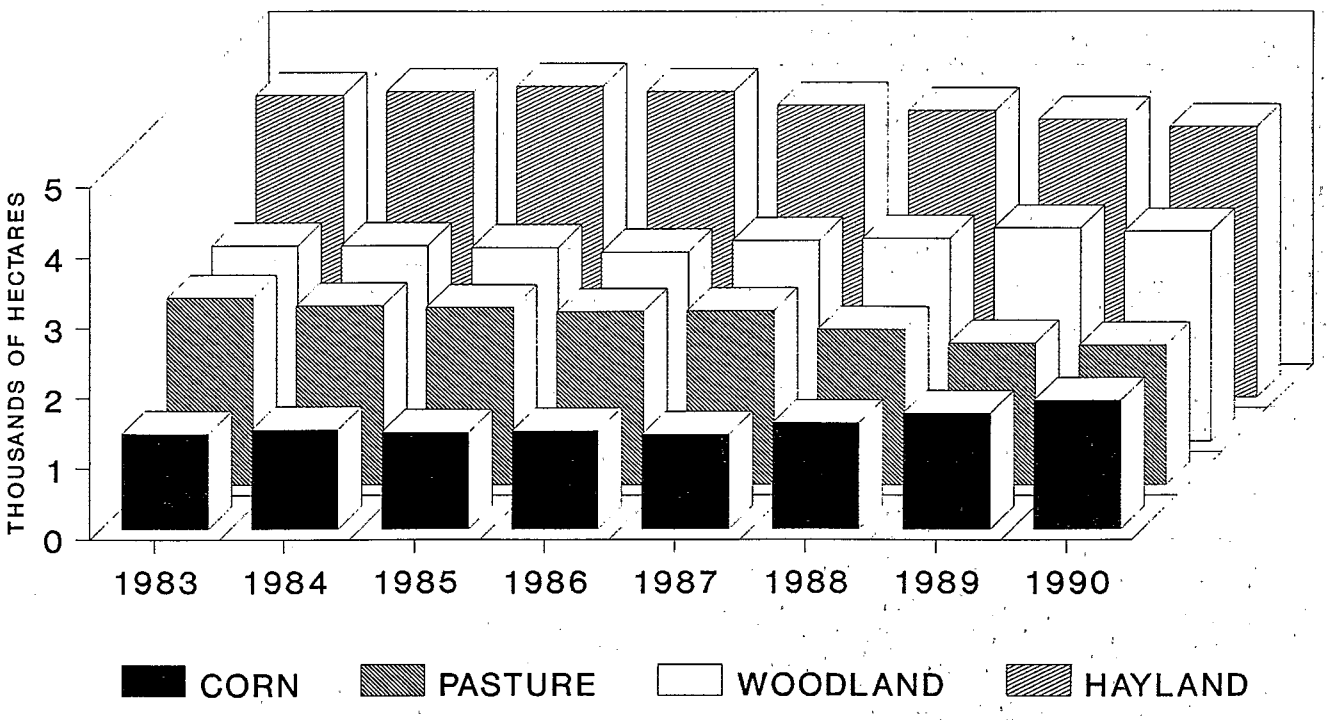
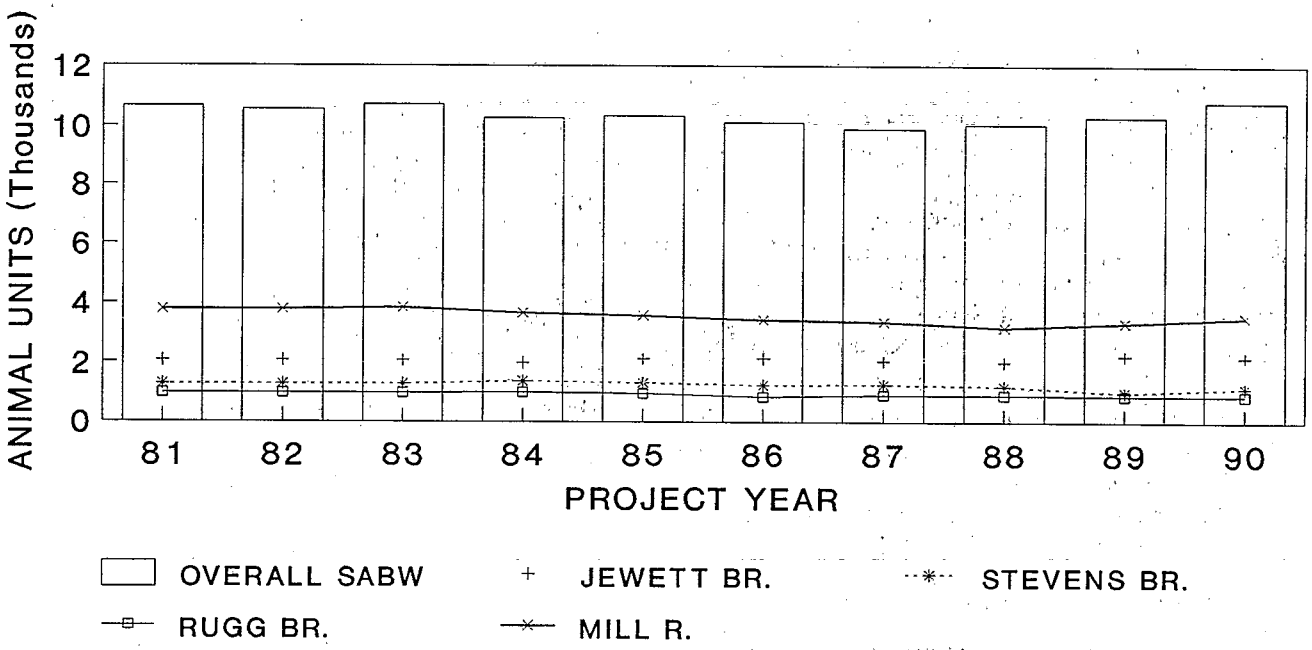


Figure 3.—Plot of agricultural land use, St. Albans Bay watershed, 1983–90.



Animal unit=405 kg dairy equivalent

Figure 4.—Plot of animal populations, St. Albans Bay watershed, 1981–90.

shot" of manure application through use of a GIS; the 1990 data are mapped in Figure 6. In general, some 2,400 to 2,800 hectares of land received manure annually between 1983 and 1990. Over time, the area of land receiving manure did not vary dramatically across the St. Albans Bay watershed or within most of the monitored subwatersheds. A substantially greater proportion of the Jewett Brook subwater-

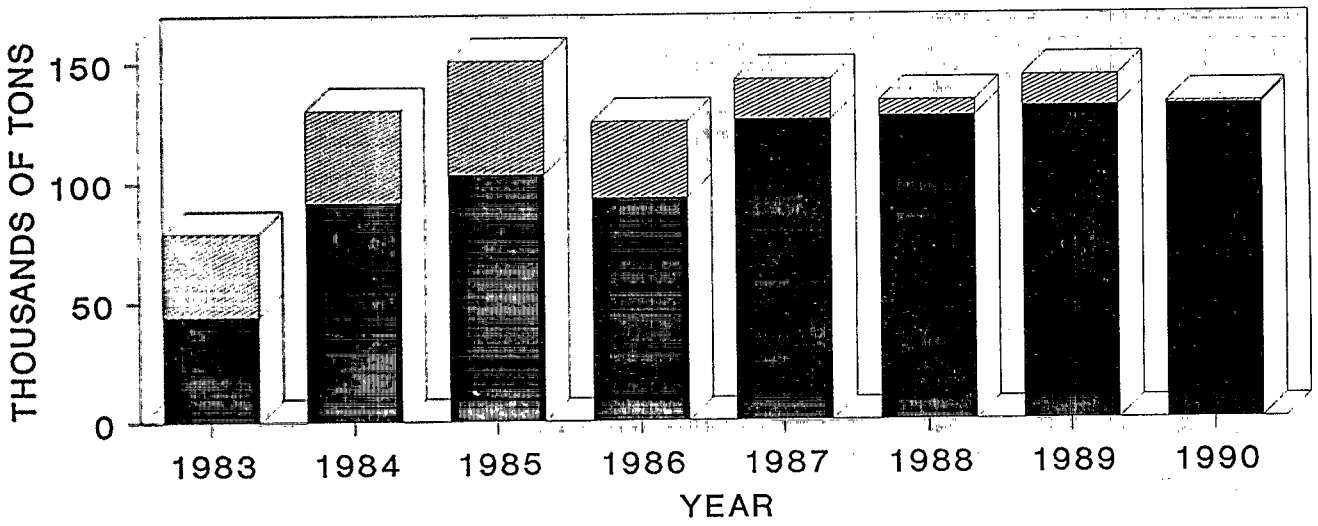


Figure 5.—Plot of annual quantity of manure applied in St. Albans Bay watershed, 1983–90.

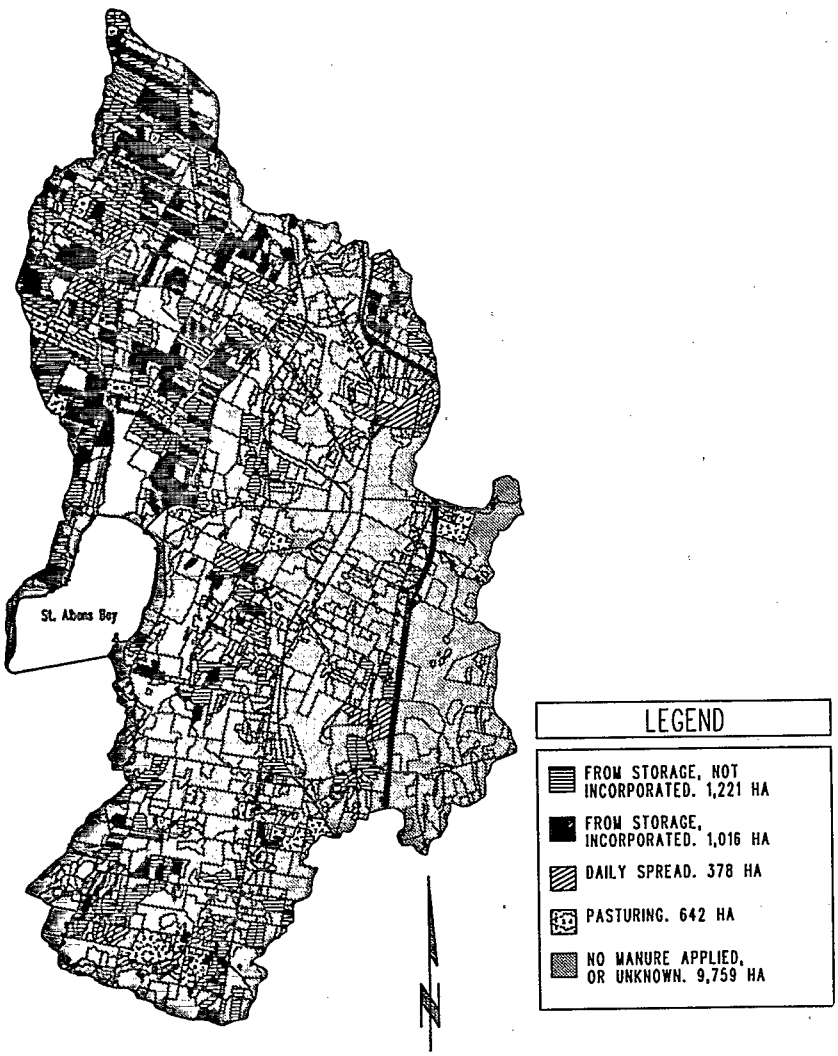


Figure 6.—Map of land receiving manure in St. Albans Bay watershed, 1990.

shed received manure (30 to 50 percent) than did the other subwatersheds (<20 percent).

Land Use and Water Quality

■ **Animal Populations.** Neither total watershed animal population nor animal density appeared to exert a significant or consistent influence on in-stream sediment or nutrient concentrations. Sediment and nitrogen concentrations were not significantly correlated with animal numbers or density. Positive correlations between phosphorus levels and animal density were observed in some watersheds and negative relationships between these same variables in other watersheds.

However, in each of the monitored streams, both fecal coliform (FC) and fecal streptococcus (FS) bacteria counts were significantly correlated with animal density:

CORRELATION COEFFICIENTS (r)
ANIMAL DENSITY (Animal units/ha)

	JEWETT BR.	STEVENS BR.	RUGG BR.	MILL R.
FC	–0.69**	0.60*	0.56*	0.81**
FS	–0.73**	0.75**	0.78**	0.77**

**P ≤ 0.05; * P ≤ 0.10

In Stevens Brook, Rugg Brook, and Mill River, higher bacteria counts were associated with high animal densities, which might be expected since animal waste is a major source of bacteria. In Jewett Brook, however, lower bacteria counts appeared to be associated with higher animal populations.

■ **Animals Under BMP.** The percent of watershed animals under BMP was expected to be an important factor in stream nutrient concentrations in the St. Albans Bay watershed as it had been in the nearby LaPlatte River watershed project (Meals, 1990). However, in the St. Albans Bay watershed, such relationships were not observed.

CORRELATION COEFFICIENTS (r)
ANIMAL UNITS UNDER BMP (%)

	JEWETT BR.	STEVENS BR.	RUGG BR.	BILL R.
TP	0.45	–0.86**	0.78**	0.74**
SRP	0.22	–0.92**	0.66**	0.68**
TKN	0.06	–0.16	0.18	0.17
NH_3-N	0.31	–0.33	0.41	0.25
NO_2+NO_3-N	0.26	–0.27	0.31	0.51

** P ≤ 0.05; * P ≤ 0.10; TP = total phosphorus; SRP = soluble reactive phosphorus; TKN = total Kjeldahl nitrogen; NH_3-N = ammonia nitrogen; NO_2+NO_3-N = nitrite+nitrate nitrogen.

The negative correlations observed in Stevens Brook probably reflect changes in water quality resulting from the wastewater treatment plant upgrade, rather than changes in nonpoint source contributions (Meals, 1992). Unlike the pattern observed in the LaPlatte River watershed where phosphorus and nitrogen concentrations were negatively correlated with animal units under BMP and only cases where animal units under BMP exceeded 85 percent were considered (Meals, 1990), positive correlations were observed in Rugg Brook and Mill River when all cases were considered (as shown previously) as well as when early years of low implementation were excluded (r=+0.45 to +0.75).

The lack of apparent response in nutrient levels to improvements in animal waste management may relate to the threshold concept. In the LaPlatte River watershed where 100 percent of animals came under BMP waste management in some subwatersheds, response did not seem to occur until more than 85 to 90 percent of watershed animals were under BMP, although exact threshold levels were not established (Meals, 1990). In the St. Albans Bay RCWP monitored subwatersheds, however, maximum levels of treatment achieved were considerably lower: 61 to 83 percent of animal units under BMP. Thus, the level of treatment with regard to animals under BMP waste management in the St. Albans Bay watershed may not have been sufficient to generate a response in stream nutrient levels—at least on an annual basis.

The level of animals under BMP, however, appeared sufficient to affect bacteria levels (Fig. 7). In each of the monitored subwatersheds, decreasing fecal coliform and fecal streptococcus counts were clearly associated with increasing proportions of watershed animals under BMP:

CORRELATION COEFFICIENTS (r)
ANIMAL UNITS UNDER BMP (%) (AUBMP)

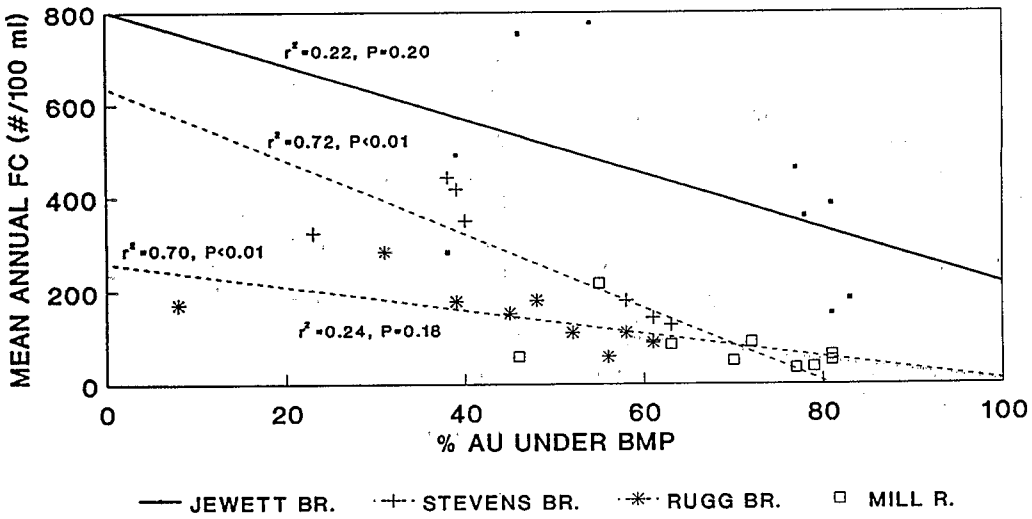
	JEWETT BR.	STEVENS BR.	RUGG BR.	MILL R.
FC	–0.47	–0.85**	–0.84**	–0.49
FS	–0.85**	–0.94**	–0.84**	–0.78**

** P ≤ 0.05; * P ≤ 0.10; FC = fecal coliform; FS = fecal streptococcus

The significant regression relationships were:

- **Jewett Brook:**
  logFS= -1.68(logAUBMP)+4.96 r^2=0.72 P<0.01
- **Stevens Brook:**
  logFC= -1.74(logAUBMP)+5.27 r^2=0.72 P<0.01
  logFS= -1.69(logAUBMP)+4.60 r^2=0.89 P<0.01
- **Rugg Brook:**
  logFC= -0.96(logAUBMP)+3.70 r^2=0.70 P<0.01
  logFS= -1.44(logAUBMP)+3.92 r^2=0.70 P<0.01
- **Mill River:**
  logFS= -2.47(logAUBMP)+5.92 r^2=0.61 P=0.01

■ **Manure Management.** Few significant relationships were observed between water quality and



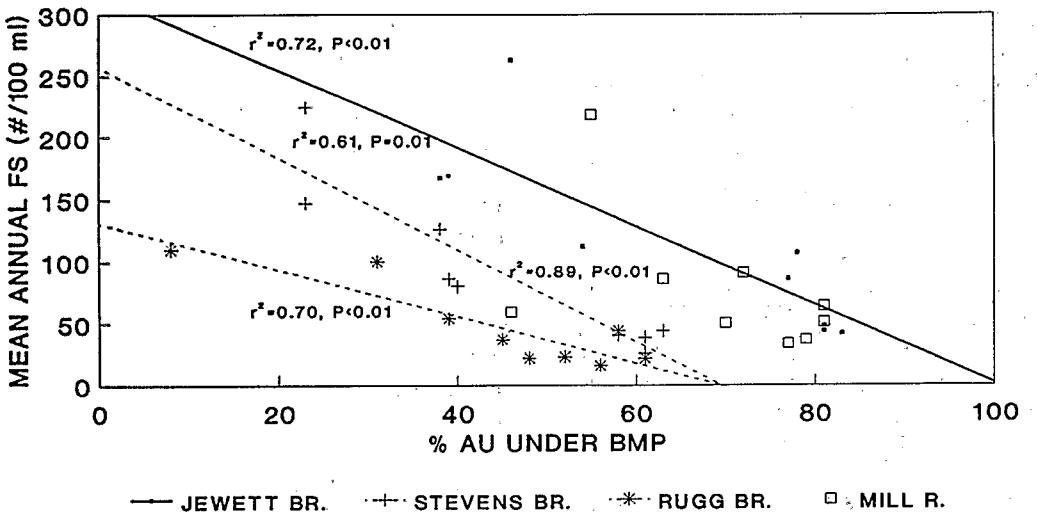


Figure 7.—Plots of indicator bacteria counts vs. percent of watershed animals under BMP waste management in monitored subwatersheds, St. Albans Bay watershed.

either manure quantity or manured area. Use of manure storage assessed by either area or quantity of application did not appear to exert a significant influence on stream nutrient levels.

Manure storage did appear to have a major effect on stream bacteria counts. In most of the monitored subwatersheds, significant negative correlations were observed between percent of manured area from storage and both fecal coliform and fecal streptococcus counts as well as between percent of manure quantity applied from storage and bacteria counts. Significantly lower bacteria counts in streams occurred with greater use of manure from storage.

CORRELATION COEFFICIENTS (r)
MANURE FROM STORAGE (% of total applied)

	JEWETT BR.	STEVENS BR.	RUGG BR.	MILL R.
FC	–0.73**	–0.78**	–0.89**	–0.59*
FS	–0.64*	–0.64*	–0.70**	–0.43

** P ≤ 0.05; * P ≤ 0.10; FC = fecal coliform; FS = fecal streptococcus

AREA RECEIVING MANURE FROM STORAGE
(% of manured area)

	JEWETT BR.	STEVENS BR.	RUGG BR.	MILL R.
FC	–0.82**	–0.30	–0.97**	–0.74**
FS	–0.79**	–0.24	–0.84**	–0.70**

** P ≤ 0.05; * P ≤ 0.10; FC = fecal coliform; FS = fecal streptococcus

This pattern may be a result of rapid die-off of bacteria in stored manure. Reports in the literature suggest that, by itself, storage of manure may reduce levels of fecal coliform and fecal streptococcus in the manure by more than 99 percent (Patni et al. 1985). Furthermore, improved manure management associated with storage (e.g., proper timing, control of application rates) may have further reduced opportunities for transport and delivery of bacteria to streams.

No significant relationships were found between water quality and soil incorporation of applied manure, either on an areal or quantity basis. The strong association between the extent of manure incorporation and cropping patterns (manure can only be incorporated on plowed cropland, for example) may have obscured any meaningful relationships.

■ **Cropping.** Associations between water quality and cropping patterns, such as land in corn and pasture, were generally weak, inconsistent, and confounded by relationships with other variables. In Jewett Brook, for example, lower bacteria counts seemed to be associated with greater land in corn. However, since increases in cornland were also associated with increases in animals under BMP, the decline in bacteria counts could have been a response to greater BMP waste management.

■ **Specific BMPs.** Variables focusing on implementation of specific BMPs, such as barnyard runoff or erosion control, were of little use in explaining observed water quality. Implementation of such practices was progressive and irreversible, remaining constant after implementation goals were achieved. Consequently, there was not enough variation in these measurements to be useful as explanatory variables. The cumulative progress of implementation of all of these practices closely paralleled other changes in agricultural management, such as animal units under BMP. Thus, even when correlations were found between higher numbers of barnyard systems installed and lower bacteria levels on streams, for example, concurrent increases in animals under BMP waste management were likely an important contributor to the observed relationship.

■ **Riparian Land Use.** It was hypothesized that agricultural activities close to surface waters might influence water quality more than upland activities. To test this hypothesis, land use and manure application data within a 50 m corridor along either side of Jewett Brook and its tributaries were explored for significant correlation with observed water quality. Use of GIS facilitated the determination of riparian land use.

Land use for corn, hay, or pasture within 50 m of Jewett Brook seemed to have a significant influence on streamwater quality, possibly because of manure management practices. In particular, concentrations of some forms of nitrogen tended to be lower when more riparian land was in hay or pasture but higher when more riparian area was in corn:

CORRELATION COEFFICIENTS (r)
JEWETT BROOK RIPARIAN LAND USE (ha)

	CORN	PASTURE	HAY
TKN	0.26	0.5[redacted]	–0.90**
NH_3-N	0.85**	–0.18	–0.82**
NO_2+NO_3-N	0.74**	–0.[redacted]	0.21

** P ≤ 0.05; * P ≤ 0.10; TKN = total Kjeldahl nitrogen; NH_3-N = ammonia nitrogen; NO_2+NO_3-N = nitrite+nitrate nitrogen

This relationship makes some sense because manure applications on pastureland tend to be lower (i.e., by cows only) and, more importantly, more pastureland implied less cornland where manure and/or fertilizer would be more likely to be applied regularly. Positive correlations were, in fact, observed between riparian land in corn and both total quantity of manure applied and area receiving manure. Similarly, there were negative correlations between both manure variables and land in pasture or hay. Data from nutrient management studies in the St. Albans Bay watershed confirmed that manure nutrient application to corn was nearly twice that to hay and tended to be in excess of crop need (Vt. RCWP Coor. Comm. 1991).

Bacteria counts in Jewett Brook also appeared to be correlated with agricultural activities close to the stream. Mean fecal coliform and fecal streptococcus counts showed significant negative correlations with land in corn within the stream corridor:

CORRELATION COEFFICIENTS (r)
JEWETT BROOK RIPARIAN LAND USE (ha)

	CORN	PASTURE	HAY
FC	–0.78**	0.30	0.64*
FS	–0.86**	0.48	0.43

** P ≤ 0.05; * P ≤ 0.10; FC = fecal coliform; FS = fecal streptococcus

Lower bacteria counts were associated with greater cornland area adjacent to the stream. This apparently anomalous relationship may be explained by manure management practices. Within the stream corridor, cornland area was significantly associated not only with manure quantity but also with manure storage and incorporation—more manure was applied to cornland than to hayland or pasture, but more of that manure was from storage and more was incorporated. The influence of manure storage on stream bacteria counts has already been suggested. Thus, the declines in bacteria counts that were associated with increased cornland near Jewett Brook may have been the result of improved manure management. In addition, decreased bacteria counts may have resulted from the decreased likelihood of direct deposition of manure by grazing cattle when more riparian land was in corn.

Discussion

Evaluation of land use/water quality relationships in the St. Albans Bay watershed was not a simple or straightforward task, nor were results unequivocal. Changing land use and agricultural management activities did not appear to have significant effects on stream nutrient concentrations. This may not be surprising because no significant reductions in phosphorus and nitrogen levels in tributaries to St. Albans Bay were observed (Meals, 1992).

The strongest results were noted for levels of indicator bacteria in the streams. Bacteria counts in streams seemed to be related to animal density — higher bacteria counts were associated with higher watershed animal populations. Bacteria counts appeared to decline with increasing percentage of watershed animals under BMP waste management. Significantly lower bacteria counts in streams tended to occur with greater use of manure from storage.

Both in-stream nitrogen concentrations and bacteria counts appeared to be significantly related to riparian land use. Lower nitrogen levels seemed to be associated with more riparian land in pasture or hay. Greater riparian land in corn tended to yield higher nitrogen concentrations but lower bacteria counts.

On a whole watershed basis, few meaningful relationships were found between cropping patterns or manure management and water quality. Use of data on the progress of implementation of specific BMPs was of little value.

The unique behavior of water quality in the Jewett Brook watershed deserves note. Compared to the other monitored subwatersheds, the Jewett Brook watershed had a higher proportion of its land in agriculture (86 percent), a higher proportion of its land cultivated for corn (32 percent), the highest animal density (1.2 to 1.6 animal units/ha), and the highest proportion of land receiving manure (30 to 50 percent). Jewett Brook consistently demonstrated the highest phosphorus and nitrogen concentrations and areal loads as well as the highest bacteria counts among the monitored subwatersheds (Meals, 1992).

Some relationships between water quality and land use in the Jewett Brook watershed were also distinct from those observed elsewhere in the St. Albans Bay watershed. In Jewett Brook, for example, lower bacteria counts were associated with higher animal densities, while the opposite was true in the other monitored subwatersheds. The explanation for this contrary behavior may be twofold. First, the Jewett Brook watershed had the greatest proportion of land where manure can be incorporated (corn) and the lowest proportion of area in pasture where manure cannot be collected and managed, thus possibly reducing the availability of bacteria for transport in surface runoff. Second, the proportion of animals under BMP increased along with animal numbers in the Jewett Brook watershed, which had the highest proportion of animals under BMP among all the monitored subwatersheds. It is possible that manure was managed better in the Jewett Brook watershed, despite higher animal numbers.

It must be noted that the simple analysis of annual values reported here was not able to control effectively for climatic and hydrologic variation nor was it able to sort out clearly the competing and confounding effects of multiple changes in land use and agricultural management. For example, while the percent of animal units under BMP waste management was proposed as an explanatory variable for changes in bacteria counts, other aspects of the land treatment program, such as control of barnyard runoff, may have contributed to the change in bacteria counts. The number of animals under BMP was advanced as a likely factor because reasonable mechanisms can be proposed to support such a relationship; i.e., bacteria die-off in storage and soil incorporation.

Thus, the land use/water quality relationships discussed here should be taken as observations and suggestions, not indications of cause and effect. The primary lesson learned in attempting to sort out such relationships in the St. Albans Bay RCWP project was that there is a long way to go before land use/land treatment and water quality can be clearly linked on a watershed scale. Numerous issues must be addressed along the way.

■ **Improved experimental design** is needed to document land treatment/water quality relationships

at the cause-and-effect level. Improved design would include

- targeting land treatment so the most serious problems are treated first;
- accounting for hydrologic variability by using a control watershed where no treatment occurs;
- monitoring other critical influences on in-stream water quality, such as hydrologic pathways, soil interactions, and pollutant transport mechanisms; and
- allowing greater manipulation and control of management activity to influence system response.

■ **Better data are needed** concerning land use and changing agricultural management activities. Even though the monitoring program conducted for this comprehensive monitoring and evaluation effort was very ambitious and more successful than anticipated, the accuracy and precision of the land use management data collected were still far less than that of the water quality data. Methods must be developed to obtain more accurate land use and management data.

■ During the course of this long-term monitoring program, land treatment contracts expired and continued adherence to implemented practices was not adequately measured. Furthermore, livestock numbers, the composition of livestock populations, and the distribution of animals among contract and noncontract farms varied and may have had a significant impact on the effective level of treatment in different watersheds. **Such changes may have important water quality implications and must be tracked throughout the monitoring period,** not just during the active implementation phase of the project.

■ Simple counts of BMPs implemented are of extremely limited usefulness; **detailed information on farm practices and changing patterns of land use and management is essential.** For example, better information on timing of manure application might have allowed analysis on a finer time scale than one year, thereby permitting more sophisticated statistical analysis of land use/water quality relationships. Future land use monitoring and land treatment tracking efforts must strive to improve data accuracy and precision. Without an improved database, efforts to link land treatment with water quality will be limited to the simple, suggestive results discussed here.

■ Finally, **improvements in experimental design and data quality** would allow more sophisticated statistical analysis. Use of annual values, even with the relatively long monitoring period, provided insufficient degrees of freedom for multivariate models. Multiple or stepwise regression, cluster analysis, or other multivariate techniques might be more effective in sorting out the importance of numerous influences on water quality.

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Spatial and Temporal Change in Animal Waste Application in the Jewett Brook Watershed, Vermont: 1983–1990

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ABSTRACT

The Jewett Brook watershed is part of the St. Albans Bay watershed, located on Lake Champlain in northwestern Vermont. In 1980, funds were made available under the Rural Clean Water Program to develop and implement strategies to reduce agricultural nonpoint source pollution in the St. Albans Bay by using agricultural best management practices (BMPs). However, implementing BMPs in the Jewett Brook watershed did not significantly improve water quality over the 10-year monitoring period (Vt. RCWP Coor. Comm. 1991), possibly because significant changes in the spatial pattern of animal waste application also occurred during the monitoring period. If these changes did occur, they may have obscured the benefits of the agricultural BMPs. A geographic information system-based nonparametric statistical method was used to investigate this hypothesis. It found that the annual manure application rate increased on 13 percent of the land in the Jewett Brook watershed that received manure during the project period, while the application rate decreased on 4 percent of the manured land ($P \leq 0.10$). Within 100 meters of Jewett Brook, the annual application rate increased on 18.2 percent of the manured land and decreased on 3 percent of the manured land ($P \leq 0.10$). These changes in manure application rates may help explain the lack of improvement in surface water quality during the project period.

The St. Albans Bay watershed is located 40 km north of Burlington in northern Vermont. The watershed drains 13,000 hectares of agricultural, forested, and urban land into St. Albans Bay of Lake Champlain. The Jewett Brook watershed, a largely agricultural subwatershed located at the north end of the St. Albans Bay watershed, represents slightly less than 11 percent of the total watershed area. St. Albans Bay has been experiencing accelerated eutrophication because of nutrient inputs from point and nonpoint sources. Agricultural nonpoint sources of phosphorus (primarily from dairy farming) account for 93 percent of the total phosphorus reaching St. Albans Bay (Vt. RCWP Coor. Comm. 1991). Spring runoff from farm fields where manure had been spread during the winter was believed to be the most significant source of nonpoint source pollution in the St. Albans Bay watershed.

Under the Federal Water Pollution Control Act of 1980, funds were made available to design and implement the St. Albans Bay Rural Clean Water Program (RCWP) project. The St. Albans Bay RCWP project provided funding to farmers to implement a series of agricultural best management practices (BMPs), including installing animal waste management systems or containment structures that allow farmers to store manure until needed, giving the

farmer an alternative to spreading manure during winter months. Animal waste management systems were the most costly BMP implemented in the St. Albans Bay watershed, accounting for 77 percent of Federal cost-sharing funds (Vt. RCWP Coor. Comm. 1991).

The St. Albans Bay RCWP project also included comprehensive monitoring and evaluation—an intensive land use and water quality monitoring program conducted by the University of Vermont's Water Resources Research Center from 1981 through 1990. The results of the 10-year comprehensive monitoring and evaluation program suggest that implementation of recommended agricultural management practices in the Jewett Brook watershed did not significantly improve water quality over the monitoring period (Vt. RCWP Coor. Comm. 1991).

The land use monitoring portion of the comprehensive monitoring and evaluation program gathered data on manure application rate, source, and application method, as well as time and location of application. If significant changes in the spatial pattern of animal waste application occurred over the monitoring period, these changes would have enhanced or offset the benefits of recommended agricultural BMPs. To investigate this possibility, a raster geographic information system database containing the location, time, and quantity of manure application was generated. A nonparametric test for trend in manure application rate over time was then calculated on a per-pixel basis. The result of this statistical operation was a geographic information system coverage representing the spatial distribution of the statistical significance of trend in manure application rate over time (Schlagel, 1992).

Study Area

The Jewett Brook watershed is an area of 1,384 hectares at the north end of the St. Albans Bay watershed. Twenty-one farms and approximately 2,000 animal units are located within the Jewett Brook watershed. (One animal unit is equivalent to one 1,000-pound dairy cow for estimation of manure production [Vt. RCWP Coor. Comm. 1991].) The Jewett Brook watershed is the most agricultural of the St. Albans Bay watersheds, with approximately 85 percent of its land in agricultural use. It also has more land planted in corn and a greater density of farm animals than other subwatersheds (Vt. RCWP Coor. Comm. 1991). The Jewett Brook watershed also had the highest areal phosphorus and nitrogen loadings to St. Albans Bay (Vt. RCWP Coor. Comm. 1991).

Within the Jewett Brook watershed, 80 percent of the land was identified as critical for inclusion in the St. Albans Bay RCWP project. Critical areas were defined as "all land used for animal waste disposal as well as all cropland and farmsteads" (Vt. RCWP Coor. Comm. 1991). Sixteen farms comprising 2,126 critical acres (860 hectares) participated in the RCWP project, while five farms representing 594 critical acres (240 hectares) did not participate. During the project period, most agricultural land in the watershed remained agricultural with hay, corn, and pasture being the dominant land uses (Table 1). The intensity of agricultural practice appeared to increase between 1983 and 1990, planted corn acreage increased from 21 to 33 percent of the land in the watershed. Herd size varied from 1,963 animal units in 1984 to 2,166 animal units in 1990.

Methods

Water Quality

Comprehensive water quality monitoring in the Jewett Brook watershed was conducted from 1981 through 1990. The monitoring program goals were to

- **document changes** in water quality resulting from the implementation of BMPs, and
- **evaluate trends** in water quality in the watershed during the St. Albans Bay RCWP.

The water quality monitoring program methodology has been described in detail elsewhere (Vt. RCWP Coor. Comm. 1991; Meals, 1992a).

Table 1.—Agricultural land use in the Jewett Brook watershed, 1983 to 1990.

LAND USE	1983	1984	1985	1986	1987	1988	1989	1990
	hectares (percent)							
Corn	291 (21)	325 (23)	378 (27)	378 (27)	405 (29)	421 (30)	407 (29)	450 (32)
Hay	662 (48)	625 (45)	581 (42)	647 (47)	558 (40)	548 (40)	607 (44)	557 (40)
Pasture	195 (14)	193 (14)	194 (14)	148 (11)	205 (15)	184 (13)	140 (10)	175 (13)
Woodland	203 (15)	203 (15)	195 (14)	176 (13)	180 (13)	196 (14)	187 (13)	169 (12)
Other*	34 (2)	38 (3)	35 (3)	36 (3)	36 (3)	36 (3)	44 (3)	33 (2)

*Other includes farmsteads, nonagricultural land, and agricultural land—use unknown

Animal Waste Management

Intensive agricultural land use monitoring of the Jewett Brook watershed began in 1983. Farmers in the watershed served as primary source of data for the monitoring program. Maps of each farm within the watershed were prepared from 1:5,000 orthophotographs and digitized. All farmers within the watershed, including those who chose not to participate in the RCWP, were given checkbook-sized logbooks containing a map of their farm (with each field numbered). Here they were asked to record the date, field, amount of manure and fertilizer applied, planting and harvesting dates, and other information about cropping activities. These data were gathered from farmers semiannually, along with data on the use of each field for that period (e.g., corn, hay, or pasture). Information on the type and number of animals present on the farm as well as subdivision of land, field boundary, and field ownership changes were recorded during periodic interviews.

Farmer participation in the land use monitoring program was far greater than expected, but the use of the field logs and the quality of the data collected varied from farm to farm. Roughly one-third of the farmers kept very accurate records, one-third kept some information, and one-third did not record data but were willing to try to reconstruct their activities when interviewed (Vt. RCWP Coor. Comm. 1991). Results of each farm interview (including the relative quality of the data obtained) were coded and added to a geographic information system database. This data collection procedure was repeated for each of the eight years that data were collected. The ARC/INFO geographic information system (Environ. Systems Res. Inst. 1990) was used initially to store and analyze the land use data.

The manure application date, location, and quantity for each calendar year were aggregated into four quarterly totals (January to March, April to June, July to September, October to December) and an annual total. The data were then converted from a vector to a raster data format and transferred to the Idrisi geographic information system (Eastman, 1990), with each pixel representing 256 square meters. The Mann-Kendall trend statistic was then calculated for each pixel location using the overlay operations of Idrisi. The Mann-Kendall test is a nonparametric test for zero slope of the linear regression of time-ordered data versus time (Gilbert, 1987).

The presence of statistically significant trends was examined in each quarterly and the one annual coverage at the $P \leq 0.20$ and $P \leq 0.10$ significance levels. The consideration of the $P \leq 0.20$ probability level was deemed important for this data set because of the small sample size (n=8 years). Figure 1 is a map that represents results of the Mann-Kendall trend calculations for annual manure application data.

Results

Water Quality

Trend analysis of water quality data was conducted using a variety of nonparametric tests, including the seasonal Kendall and the seasonal Mann-Whitney. Based on the results of these analyses, no significant trends were apparent in either surface water phosphorus concentration or the mass of phosphorus exported from the Jewett Brook watershed. In addition, strong trends were not present in total or volatile suspended solids concentration (or export) or nitrogen export, although nitrogen concentrations did tend to increase. Fecal coliform and fecal streptococcus bacteria counts decreased more than 50 percent over the project period. Water quality results are discussed in detail elsewhere (Vt. RCWP Coor. Comm. 1991; Meals, 1992a; Meals, 1992b).

Animal Waste Management

Over the eight-year monitoring period, the first quarter manure application rate significantly decreased on 9 hectares at the $P \leq 0.10$ level. No trend was present on 221 hectares, and no significant increase in application rate occurred on any watershed land at $P \leq 0.10$ (Table 2). The limited area on which

Table 2.—Quarterly and annual trends: manure application rate.

DIRECTION OF TREND & STATISTICAL SIGNIFICANCE	ANNUAL	Q1	Q2	Q3	Q4
	hectares				
Downward trend P≤0.10	41	9	19	11	16
Downward trend P≤0.20	80	26	48	26	34
No trend P≤0.10	826	221	720	64	566
No trend P≤0.20	621	200	571	570	516
Upward trend P≤0.10	129	0	138	6	2
Upward trend P≤0.20	294	5	258	68	34
Nonmanured area	389	1,153	507	720	799

Q1 = January through March; Q2 = April through June; Q3 = July through September; Q4 = October through December

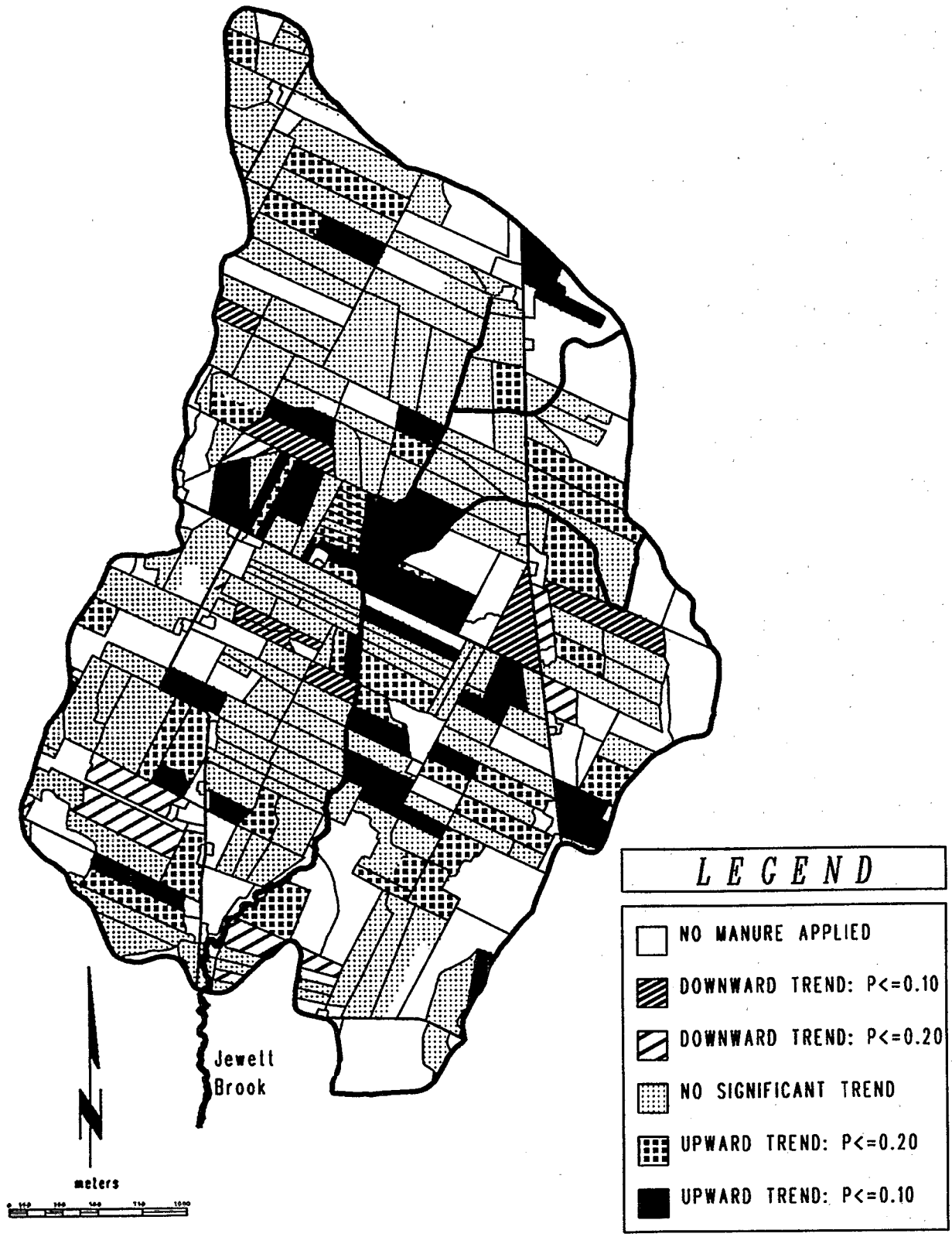

Figure 1.—Jewett Brook watershed 1983-90: trend in annual manure application rates.

manure was applied during the first quarter and the limited area with significant decreases in application rate probably reflects the widespread implementation of the animal waste management BMP in the watershed before the beginning of detailed land use monitoring. Most farmers were already properly managing manure by 1983, and the first quarter data indicate that farmers were generally reporting compliance with BMPs over the project period. The 221 hectares that had manure applied (but for which there was no significant trend) probably reflect manure spreading by farmers who chose not to participate in the project, the late implementation of BMPs on some farms, and occasional early spring spreading of manure.

During the monitoring period, most manure was spread during the second quarter in the early spring before planting. The second quarter also saw the greatest area with increases in manure application rates during the project period. Statistically significant increases in application rate occurred on 138 hectares or 15.8 percent of the manured land at $P \leq 0.10$ (Tables 2 and 3). Significant decreases in application rates occurred on 19 hectares or 2.1 percent of the manured land at $P \leq 0.10$. The increase in manure application rates on these fields is probably associated with an overall increase in reported manure application and an increase in corn acreage in the watershed from 1983 to 1990.

Data for the third and fourth quarters reflect similar patterns. Increases or decreases in manure application rate statistically significant at $P \leq 0.10$ were found on very little watershed land (Tables 2 and 3); however, at the $P \leq 0.20$ significance level, changes were more evident. At the $P \leq 0.20$ level, a significant increase occurred on 10.2 percent of the manured land in the watershed during the third quarter and 5.9 percent of the manured land during the fourth quarter.

The pattern of manure application reflected in the annual totals appears similar to the second quarter data, largely because the total annual manure application is dominated by the second quarter.

The initial trend analysis in manure application rate deliberately ignored farm and field designations and boundaries because they varied over the project's course. Nonetheless, it is useful to consider the farm as a unit when examining the location of significant trends in application rate. To do this, the coverage containing the annual Mann-Kendall result was intersected with the 1990 land use coverage to identify those farms responsible for trends in manure application rates. This analysis revealed that one farm was responsible for an increase in manure application rate on 38 hectares (or 29 percent of all acres) with a significant increase in annual application rate at $P \leq 0.10$. This farm is located in the watershed's center at the junction of the two branches of Jewett Brook. A review of the field logs for this farm revealed that herd size and manure application increased consistently over the project period.

It is also useful to consider the location of trend with respect to the watershed's physical features that may be associated with nonpoint source pollution. For example, changes in agricultural practice occurring within 50 meters of Jewett Brook were more highly correlated with changes in surface water quality than changes in agricultural practice at more remote locations (Vt. RCWP Coor. Comm. 1991; Meals, 1992b). It is clear from a visual inspection of Figure 1 that the largest concentration of fields with statistically significant increases in annual application rate are located adjacent to Jewett Brook.

Geographic information system buffer operations were used to identify the area in six different distance classes from the main course of Jewett Brook (shown as a heavy line in Fig. 1). Table 4 contains a breakdown of the trend in application rate versus distance to Jewett Brook. Within 50 meters and 100 meters of the stream course, annual manure application rate significantly increased on 19.7 and 18.2 percent of the land respectively, as compared to 13 percent of the land throughout the watershed at $P \leq 0.10$. Significant decreases ($P \leq 0.10$) occurred on 2.4 and 3.0 percent of the land within 50 and 100 meters of the stream course as compared to 4.0 percent watershed-wide.

Table 3.—Temporal trend in manure application rate on manured land.

DIRECTION OF TREND & STATISTICAL SIGNIFICANCE	ANNUAL	Q1	Q2	Q3	Q4
	percent				
Downward trend $P \leq 0.10$	4.0	4.1	2.1	1.7	2.8
Downward trend $P \leq 0.20$	8.0	11.1	5.5	3.8	5.8
No trend $P \leq 0.10$	83.0	95.9	82.1	97.5	96.8
No trend $P \leq 0.20$	62.4	86.8	65.1	85.9	88.3
Upward trend $P \leq 0.10$	13.0	0.0	15.8	0.8	0.4
Upward trend $P \leq 0.20$	29.6	2.1	29.4	10.2	5.9

Q1 = January through March; Q2 = April through June; Q3 = July through September; Q4 = October through December

Table 4.—Temporal trend in manure application rate versus distance to Jewett Brook.

DIRECTION OF TREND & STATISTICAL SIGNIFICANCE	DISTANCE (METERS)						
	50	100	200	300	400	500	WS*
	percent						
Downward trend P≤0.10	2.4	3.0	3.9	4.3	4.2	4.8	4.0
Downward trend P≤0.20	3.8	4.7	5.7	6.0	6.2	7.0	8.0
No trend P≤0.10	77.9	78.8	80.3	80.6	80.2	79.7	83.0
No trend P≤0.20	60.5	59.5	58.1	58.7	58.2	58.9	62.4
Upward trend P≤0.10	19.7	18.2	15.8	15.0	15.6	15.5	13.0
Upward trend P≤0.20	35.7	35.9	36.2	35.3	35.6	34.1	29.6

*WS = watershed total

Discussion

This project investigated the possibility that changes in the spatial pattern of manure application occurring during the St. Albans Bay RCWP project in some way offset the benefits of improved agricultural management. For the first, third, and fourth quarters of the year, relatively little change occurred in the pattern of manure application from 1983 to 1990. The pattern for the second quarter and the annual aggregate data reflected increases in annual manure application rate on one farm and several fields on other farms from 1983 to 1990. Twenty-nine percent of the land with significant increases in application rate was associated with one farm. Despite a sample size of only eight years, these increases were statistically significant at P≤0.10.

Farm fields with increases in manure application rate tended to be located adjacent to Jewett Brook. Statistically significant increases in annual manure application rates over the study period occurred on 20 percent of the land within 50 meters of Jewett Brook that received manure during the study period, compared with decreases on just 2 percent of the riparian land. Watershed-wide application rates increased on 13 percent of the land receiving manure and decreased on just 4 percent. Increases in manure application rates, particularly on riparian land, demonstrate that, despite widespread implementation of BMPs, agricultural practices in the Jewett Brook watershed are—to some extent—working against improvements in water quality.

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Water Quality and Land Treatment in the Rock Creek, Idaho, Rural Clean Water Program

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ABSTRACT

Because of point and nonpoint pollution sources, Rock Creek has long been recognized as one of the most severely degraded streams in Idaho. By the late 1970s, most point source pollutants had been eliminated; however, nonpoint sources remained a problem. Rock Creek water quality is affected by sediment and associated pollutants from irrigation return flows and feedlot runoff. Rock Creek was one of only five national Rural Clean Water Program (RCWP) projects to receive additional funding for land treatment and water quality monitoring and evaluation. Goals of the Rock Creek RCWP project included reducing the amount of sediment, sediment-related pollutants, and animal waste entering Rock Creek by implementing best management practices (BMPs). Landowners were contracted to implement BMPs with the length of the contract varying from three to ten years (depending on the practice contracted). Nonparametric trend analysis has shown significant reductions in pollutant loadings and concentrations in lower Rock Creek resulting from BMP implementation. As part of this evaluation an extensive water quality and land treatment database for subbasins has been constructed. This data will be used to compare water quality with various land use/land treatment practices implemented over the 10 years of the project.

The Rural Clean Water Program (RCWP) is designed to control agricultural nonpoint source pollution in rural watersheds and ultimately improve water quality (Yankey et al. 1991). Rock Creek, Idaho, is one of 21 RCWP projects in the United States and one of only five with a comprehensive monitoring and evaluation component.

RCWP projects involve both land treatment and water quality monitoring. Landowners were contracted to implement best management practices (BMPs), for three to ten years, depending on the practice being implemented. Most RCWP contracts began in 1980 or 1981, and ended in 1986, but the implementation of some BMPs continued through 1992.

This paper describes the Rock Creek RCWP's water quality results and the process of linking land treatment and water quality data. Changes in water quality result from changes in the environment. Therefore, correctly implemented BMPs are expected to have a positive effect on water quality. Linking land treatment to water quality is a complex process. This paper summarizes the techniques being used to make this connection in the Rock Creek RCWP's postevaluation phase.

Project Background

Rock Creek, located in Twin Falls County, Idaho, had long been recognized as one of the most severely degraded streams in the State because of point and nonpoint source pollution. For years, the creek had been used by sugar, meat, and dairy processing plants, stockyards, and feedlots for waste disposal and septic tank overflow. In 1960, the Idaho Depart-

ment of Health and Welfare (IDHW) Division of Environmental Quality (DEQ) identified serious public health problems in Rock Creek (Idaho Dep. Health, 1960). As a result of the National Pollution Discharge Elimination System program, most direct discharges into the creek had been eliminated by 1980 (Yankey et al. 1991). Nevertheless, Rock Creek was still carrying heavy loads of sediment and agricultural pollutants, which entered the stream primarily through irrigation return flows as evidenced by comparing water quality tests made during the irrigation and nonirrigation seasons (Yankey et al. 1991). Irrigation return flows were the largest contributor to the impairment of Rock Creek's beneficial uses—namely, cold water biota, salmonid spawning, and recreation.

Because of continuing water quality problems, the Idaho Agricultural Pollution Abatement Plan listed Rock Creek as a top priority stream in 1979 (Idaho Dep. Health Welfare, 1979a). Subsequently, the Snake River and Twin Falls Soil Conservation Districts received a Section 208 grant to develop a detailed water pollution abatement plan for Rock Creek (Idaho Dep. Health Welfare, 1979a). In 1980, Rock Creek became one of 21 RCWP projects in the United States. Goals of the project included implementing BMPs to reduce the amount of sediment, sediment-related pollutants, and animal waste entering Rock Creek.

Study Area

Rock Creek is located in Cassia and Twin Falls Counties in south-central Idaho within the Snake River Basin/High Desert Ecoregion. Its headwaters are in the Sawtooth National Forest in western Cassia County. Rock Creek flows northwest approximately 67.6 km (42 miles) through Twin Falls County to the Snake River confluence north of the city of Twin Falls. About 25 miles of Rock Creek were involved in the project area (Fig. 1).

Soils in the lower watershed are generally thin, light-colored, medium-textured surface soils and very strong calcareous, silty subsoils. These highly productive but highly erosive soils vary in total depth (from 2.5 to 212 cm) and are underlain by fractured basalt. Soils lie on gently sloping plains, with slopes averaging between 1 and 2 percent (Yankey et al. 1991).

The climate is semiarid with moderately cold winters (mean low of -3°C in January) and warm summers (mean high of 23°C in July). Annual precipitation averages about 23 cm (9 inches). Except in unusual years, precipitation runoff appears to be a minor factor in the annual sediment loading to the stream. The area has a 120-day frost-free growing season (Yankey et al. 1991).

Rock Creek was historically fed by snowmelt in the higher watershed and characterized by high spring flows and low summer and fall streamflows. Developing the area for irrigated agriculture has greatly changed this historical flow pattern. Rock Creek now follows an altered-flow regime. Irrigation return flows and recent hydroelectric developments have greatly increased summer streamflows. Maximum streamflows now occur in spring and fall.

The Rock Creek watershed covers a total of 490,046 ha (198,400 acres) of which 128,211 ha are irrigated pasture and cropland containing 69,552 ha that are designated critical areas. Approximately 350 farm units lie within the watershed. Basic crops are dry beans, dry peas, sugar beets, corn, small grains, potatoes, alfalfa, and pasture. Because of low annual precipitation, all crops are irrigated. Irrigation water is diverted from the Snake River at Milner Dam to individual farms through a network of canals and laterals owned by the Twin Falls Canal Company. Water is available to the farm tract at a constant flow from about April 15 through October 15.

Methods

Land Treatment and Land Use

Information, including data on participants, was entered annually into the land treatment database. The Rock Creek RCWP project's original goal was to contract 75 percent of the critical acres. A critical acre was defined as land lying on a steep slope, rented land, intensively cropped land, or land without any irrigation improvements.

The Rock Creek RCWP project watershed was divided into 10 subbasins, and each subbasin varied in total area as well as percent of critical area (Table 1). In addition, the percent of critical area contracted in each subbasin ranged from a low of 62 percent to a high of 100 percent in subbasins 3 and 10, respectively (Table 1). The overall project goal of 75 percent of the critical area contracted was achieved (74.7 percent, Table 1).

The U.S. Department of Agriculture (USDA) Soil Conservation Service (SCS) is the lead agency maintaining the land treatment database. Information was collected and stored on all Rock Creek RCWP project contracts by farm fields. Information for each contracted field included type of BMP installed, year installed, last year operated and estimated benefited area of the BMP. The benefited areas and dominance of BMPs will be discussed in

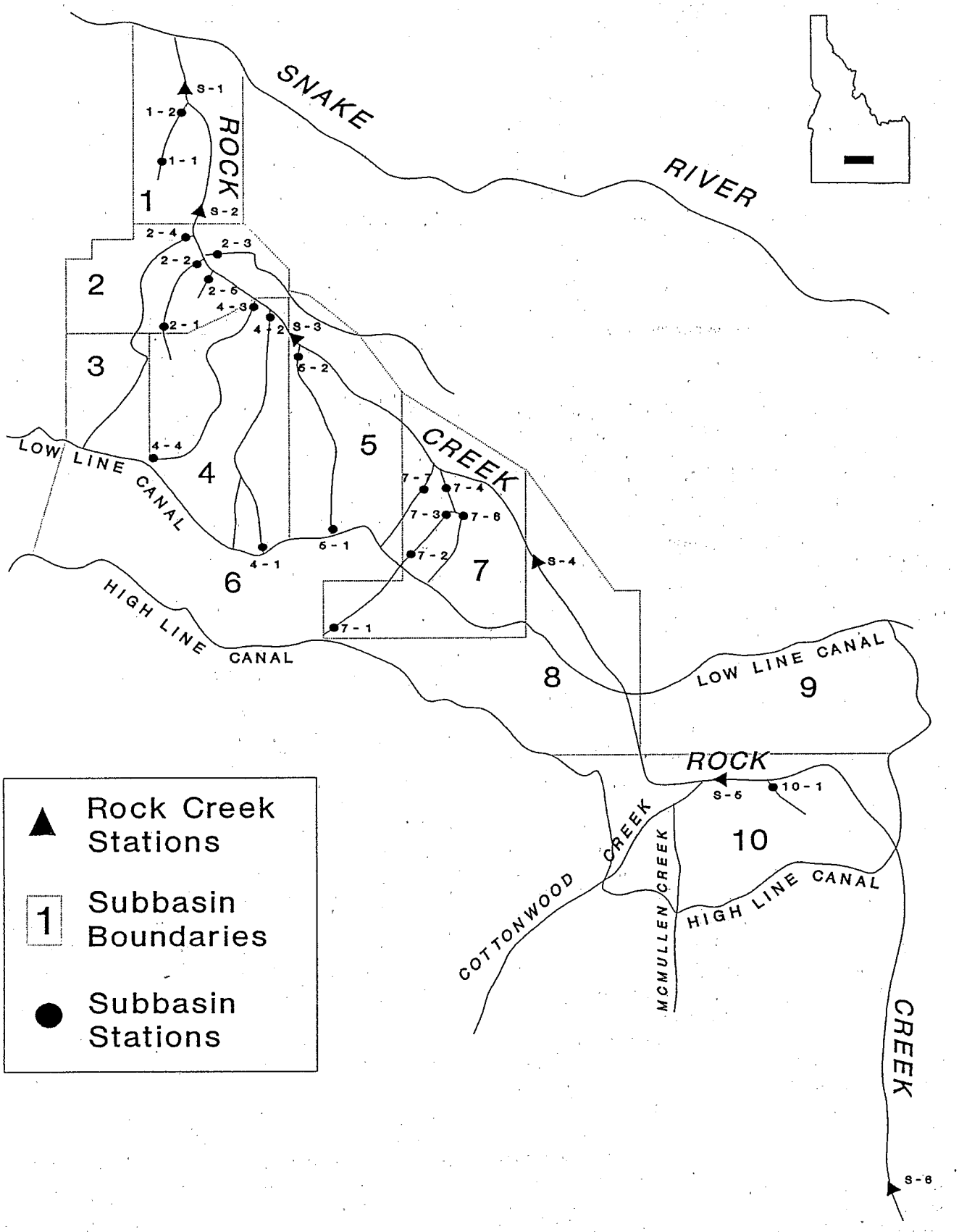

Figure 1.—Map of the Rock Creek RCWP project study area.

Table 1.—Summary of total hectares and critical areas in the Rock Creek RCWP project (Yankey et al. 1991).

SUBBASIN	TOTAL AREA (ha)	TOTAL CRITICAL AREA (ha)	PERCENT CRITICAL AREA	CRITICAL AREA CONTRACTED (ha)	PERCENT CRITICAL AREA CONTRACTED
1	6,002.1	4,199.0	70.0	3,786.5	90.2
2	8,126.3	7,805.2	96.0	4,026.1	51.6
3	5,335.2	4,643.6	87.0	2,889.9	62.2
4	10,781.5	9,282.2	86.1	6,547.9	70.5
5	7,854.6	2,835.5	36.1	1,793.2	63.2
6	12,337.6	11,492.9	93.2	9,324.2	81.1
7	16,598.3	12,609.3	76.0	8,422.7	66.8
8	15,906.7	8,113.9	51.0	7,360.6	90.7
9	11,305.1	5,320.4	47.1	4,391.6	82.5
10	17,490.0	3,250.5	18.6	3,250.5	100.0
TOTAL	111,737.4	69,552.4	62.2	51,793.2	74.7

the linkage of water quality to land use/land treatment portion of this paper.

SCS also maintained a land use database by field on the contracted farms. Information included field size and crop type by year throughout the length of the contract. The USDA Agricultural Stabilization and Conservation Service (ASCS) has provided farm unit cropping information for the noncontracted years and nonparticipants. This information is used in conjunction with crop and field slope to determine an erosion index for each subbasin (Carter, 1984).

Water Quality Data

The Rock Creek RCWP project's water quality data were collected and the database maintained on STORET by DEQ. Rock Creek had six monitoring locations and monitoring stations that were placed on irrigation drains to track changes in sediment load and associated pollutants as close to their sources and the BMPs as possible (Fig. 1). Some stations measured the source of water to the subbasins (7-1, 5-1, 4-1, 4-4, 2-1, and 1-1); some stations measured the input of the subbasins to Rock Creek (10-1, 7-7, 7-4, 5-2, 4-2, 4-3, 2-5, 2-4, 2-3, 2-2, and 1-2); and other stations were key intermediate sites (7-2, 7-3, and 7-6). Subbasin stations were usually sampled weekly; Rock Creek station was sampled biweekly during the irrigation season. Water quality parameters of interest included

- total suspended sediment,
- volatile suspended sediment,
- total phosphorus,
- orthophosphate,
- total nitrogen,
- fecal coliform bacteria, and
- flow.

Data Analysis

Spooner et al. (1985) described three experimental designs that can be used to document water quality improvements from agricultural nonpoint source control programs. The three experimental designs are

- time trend analyses,
- above and below analyses, and
- the paired watershed design.

Time Trend Analyses

Water quality information has been collected over the Rock Creek RCWP project's entire 10 years. The project is, therefore, perfect for a time trend analysis, which simply involves monitoring a site or sites over an extended period to determine any changes in water quality.

The disadvantage of this analysis is that sensitivity is low unless related variables are measured so that water quality improvements can be attributed to land treatment measurements. The Rock Creek project did measure related variables, including flow and precipitation. Even though this area has been in a drought situation for the last six years, water uses have not changed; therefore, changes in water quality reflect changes in land treatment or land use.

The null hypotheses that can be tested using this design for the Rock Creek RCWP project are

- H_{01}: the concentrations, loads, or levels of measured variables have not changed over time with the level of BMP implementation; and
- H_{02}: seasonal mean (or median) concentrations, loads, or levels of

measured variables have not changed over time.

The first null hypothesis (H_{O1}) will be tested by regression analysis of the concentration, load, or level of the variable versus the BMP implementation level. H_{O2} has been tested using a seasonal Kendall with WQHYDRO, a software package developed by Eric Aroner to analyze water quality information (Aroner, 1991).

Upstream-Downstream Design

This analysis involves sampling a flowing system over time, above and below a potential impact. This approach allows one to account for upstream inputs to the monitoring site of interest. The Rock Creek RCWP project had many upstream-downstream paired sites in its original monitoring design (Fig. 1). Station S-6 in Rock Creek is above most agricultural nonpoint sources entering Rock Creek; station S-4 is above the majority of the irrigation return flows; and station S-2 is just below the highest concentration of irrigation return flows. Subbasin station pairs set up for this design include 1-1 vs. 1-2; 2-1 vs. 2-2; 4-4 vs. 4-3; 4-1 vs. 4-2; 5-1 vs. 5-2; 7-1 vs. 7-2; and 7-2 vs. 7-3 or 7-6.

The appropriate null hypothesis to test with this design in the Rock Creek RCWP is

- **H_O:** The difference between upstream and downstream pollutant concentrations, loads, or levels have not changed over time as BMPs were implemented.

The information needed to test this hypothesis includes paired concentrations and loadings above and below the potential nonpoint source over time for both pre- and post-BMP periods. This design also assumes that sampling is timed so that the same parcel of water is sampled at the above and below sites. This assumption may have been missing in the Rock Creek study because of sampling regime.

To test this hypothesis, the differences between paired samples must first be determined. Then, the same tests used in the trend analyses can be used with this data set. In cases in which not all the water originates within the project area, this experimental design allows trends to be established with more certainty than the before and after design because of the corrections for incoming irrigation water from the Snake River.

Paired Watershed Design

This design is the most complex, has the most stringent data requirements, and requires much coordination between water quality and land treatment personnel. The paired watershed design consists of monitoring downstream from two or more agricultural drainages where at least one drainage has BMP implementation and at least one does not. This design entails simultaneous monitoring of two drainages in close proximity during a calibration and post-treatment phase.

The major advantage of this design is that it controls for meteorologic variability. Water quality improvements related to BMP implementation can be documented within a much shorter time frame. In addition, this design provides stronger statistical evidence of the cause-effect relationship between agricultural nonpoint source control efforts and water quality changes.

A disadvantage of this design is that land treatment and water quality personnel must coordinate closely to match BMP implementation efforts with monitoring and data analysis needs. This design is most often used on individual fields or study plots. As drainage area increases, this approach becomes less effective.

Another disadvantage is that control basins do not receive as much land treatment, thus reducing water quality improvement throughout the project area.

The hypothesis that can be tested using this design with the Rock Creek RCWP is

- **H_O:** There will be no difference in pollutant concentrations, loadings, or levels over time in subbasins 4 and 5 vs. subbasin 7.

Subbasins 4 and 5 combined have close to the same amount of acres as subbasin 7. Throughout this project, subbasin 7 received a greater amount of BMP implementation (especially conservation tillage) than subbasins 4 and 5; therefore, the paired watershed analysis will be used to determine differences relative to BMP implementation levels.

Linear regressions of the water quality variables of interest for the treatment versus the control watershed for the calibration and BMP implementation periods will be performed. A student's t-test will be performed to determine if the predicted treatment watershed values at the mean control watershed concentration decrease over time.

A decrease in the predicted treatment watershed values suggests a positive effect of BMPs on water quality. This evidence of a cause-effect relationship is stronger than any derived from the designs previously discussed because of greater control over the complex meteorologic, hydrologic, and temporal factors.

Water Quality Results

Trend Analysis

Water quality trend analysis for sediment concentration, sediment loading, phosphorus, and fecal coliform bacteria has been completed for all subbasin stations and Rock Creek stations in the project area. Because of the data's seasonality, a seasonal Kendall was run using WQHYDRO (Aroner, 1991). Most monitoring stations did show significant downward trends at the 90 percent level (Table 2). Some noteworthy upward trends, however, also appeared, especially in the upper watershed with fecal coliform bacteria. This may be the result of overwintering cattle in the upper basin during the later years of the study.

Table 2.—Summary of the seasonal Kendall analyses performed on the Rock Creek RCWP project data. NS denotes not significant; (+) denotes a significant upward trend; and (–) denotes a significant downward trend. Level of significance is 90 percent.

STATION	TOTAL SUSPENDED SEDIMENT	TOTAL PHOS-PHORUS	FECAL COLIFORM BACTERIA	FLOW
Rock Creek				
S-2	(–)	(–)	NS	NS
S-3	(–)	(–)	(–)	NS
S-4	(–)	(–)	(–)	NS
S-5	(–)	(–)	(+)	NS
S-6	NS	(–)	(+)	(–)
Subbasins				
1-1	(–)	(–)	(–)	(+)
1-2	(–)	(–)	(–)	NS
2-1	(+)	(–)	NS	NS
2-2	(–)	(–)	(–)	NS
2-3	NS	NS	(–)	NS
2-4	(–)	(–)	NS	NS
2-5	NS	(–)	(–)	NS
4-1	(–)	(–)	(–)	NS
4-2	(–)	(–)	(–)	(+)
4-3	(–)	(–)	(–)	(+)
4-4	(–)	(–)	(–)	NS
5-1	(–)	(–)	NS	NS
5-2	(–)	(–)	NS	NS
7-1	NS	(–)	NS	NS
7-3	NS	NS	NS	NS
7-4	(–)	(–)	NS	(+)
7-6	(–)	(–)	(–)	(+)
7-7	(–)	NS	NS	NS
10-1	(+)	(+)	(+)	NS

Upstream-Downstream Design

The upstream-downstream design was straightforward for the Rock Creek stations but not for the subbasin stations. Station S-4 samples were paired with samples from S-2 and used as background levels to determine the reduction of sediment load to Rock Creek from agricultural irrigation return flows (Fig. 2). Irrigation season loadings adjusted for upstream inputs significantly decreased (p=0.05) between 1982 and 1990 at S-2.

This design was not so straightforward in the subbasins because of the water management regime. Lateral splits and runoff types are additional factors that must be dealt with before any estimate of background levels.

Linkage of Water Quality to Land Treatment and Land Use

Water quality improvements result from changes in the watershed. RCWP projects target reduction of agricultural nonpoint source loads through BMP implementation. Therefore, land use/land treatment must be linked with water quality to determine BMP effectiveness. Making this link is part of the Rock Creek RCWP project's post-project analysis. The results will make it possible to discuss overall BMP effectiveness and may even provide enough information to address individual BMPs. Determining individual BMP effectiveness, given factors such as soil type, land use, irrigation type, and BMP implemented, should be the ultimate goal of any agricultural pollution abatement program.

The complexities of linking the two databases are immense. Water quality and land use/land treatment information differ temporally and spatially. In addition, many external interferences had to be documented during the project, such as changes in water management and BMP maintenance.

Temporal Difference

The difference between the land use/land treatment and water quality databases is simply that land use/land treatment information is annual (one record per year) and water quality information has multiple records per year, depending on the number of samples collected. The Rock Creek RCWP project replicated the land use/land treatment information for each year to equal the number of water quality samples taken. This does not read into the statistical procedures as multiple BMPs implemented for that year; rather, it indicates that when water quality sample "i" was collected, BMP "j" was implemented, and crop "k" was on the field. Taking this approach helped ensure that no data were lost or replicated.

Spatial Differences

Spatial considerations of linking the two databases are even more complex because water management

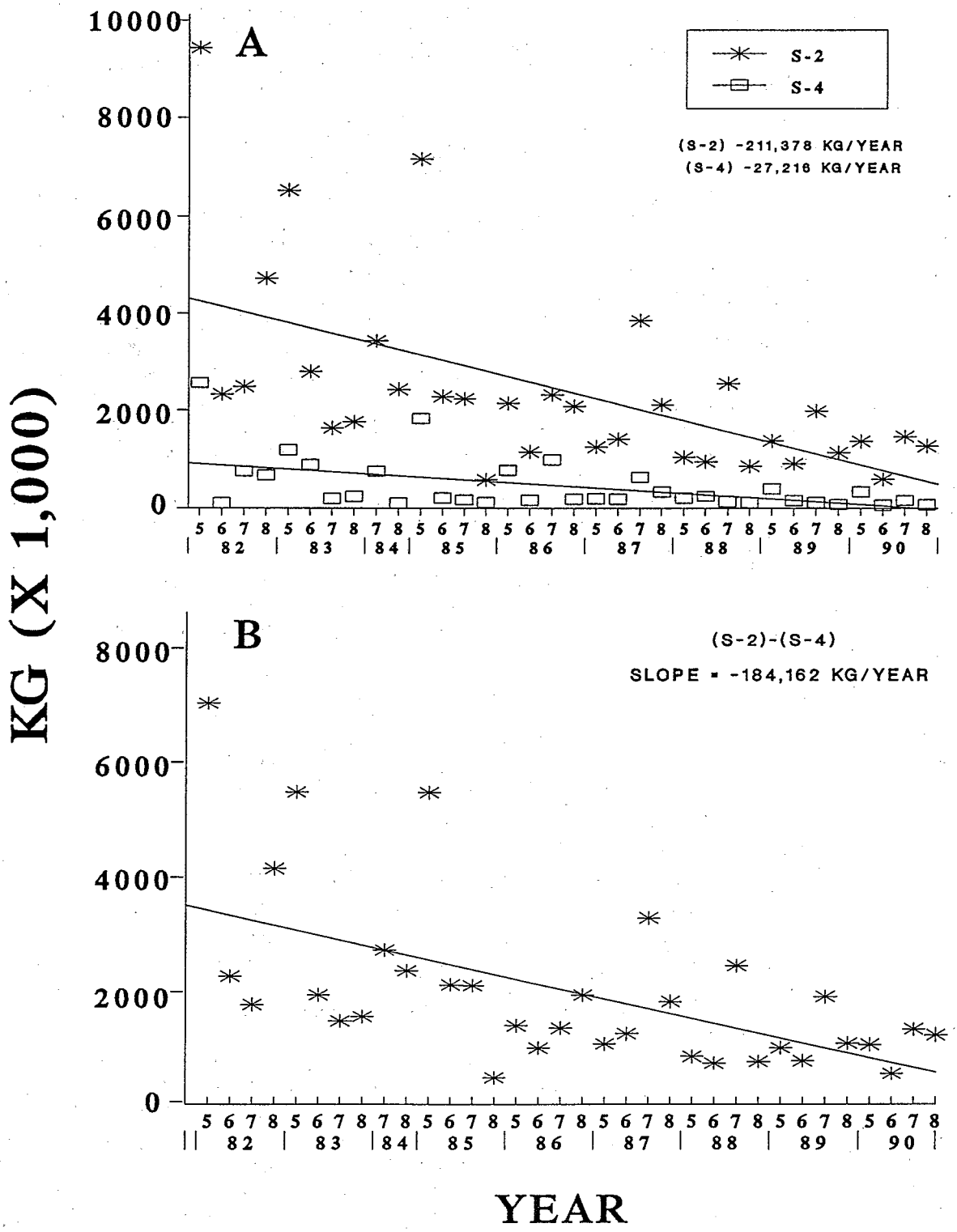

Figure 2.—Seasonal Kendall statistics for (a) Rock Creek stations S-2 and S-4 and (b) Rock Creek station (S-2)–(S-4).

is already complex and fields were often distant from pertinent monitoring sites. Water management is confounded by lateral splits and the amount of water that flows in each direction. Some instances occur in which a lateral splits below a monitoring site so that the water from it ends up in two or more monitoring

sites. This split is the reason that the upstream-downstream design for water quality analysis is not straightforward for the subbasins.

The land treatment database is set up such that each field has a designated nearest monitoring or irrigation control site above and nearest monitoring or control site below. Irrigation control sites are the lateral splits. The Rock Creek project has obtained the flows at the splits for the years of the study; therefore, each split can be assigned a proportion denoting the volume of water and the direction it flows. Ultimately, each monitoring site was mapped to ensure that the watershed's hydrology and its effect on each monitoring site was accurate (Fig. 3).

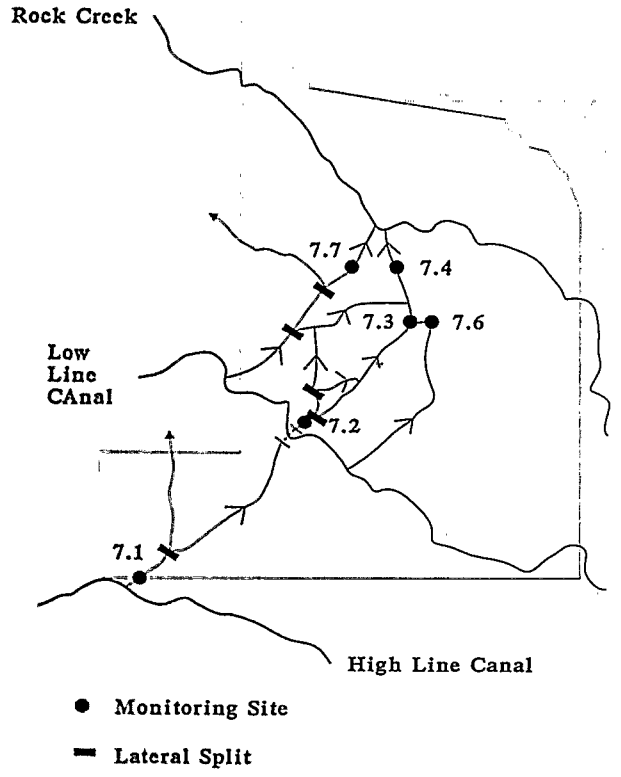

Figure 3.—Schematic of subbasin 7 showing lateral splits in relation to monitoring stations.

Another spatial aspect of the data is the distance a field is from the nearest monitoring site it affects. This aspect is dealt with in the database as type of runoff. The four defined categories of runoff include

- direct,
- lateral reapplied,
- reapplied cropland, and
- reapplied pastureland.

Direct runoff denotes runoff that directly affects the monitoring site; no opportunity exists to re-use the water. Lateral reapplied runoff is water that is directed back into a lateral which has opportunity for reapplication farther downstream. Reapplied cropland runoff is water that is directly placed on another field that is in crop production. Lastly, reapplied pastureland runoff is the same as reapplied cropland runoff except that the receiving land is permanent pasture. Each field, depending on its runoff type, is weighted 1.00, 0.50, 0.35, or 0.10 for direct, lateral reapplied, reapplied cropland, and reapplied pastureland runoff, respectively. This procedure is an indirect way to solve the proximity problem because the closer a field is to a monitoring site, the less opportunity there is for reapplication; therefore, the more likely it is that the runoff will be direct.

External Interferences

External interferences were documented throughout the study to help explain discrepancies or anomalies in the water quality. The water quality data should not be used as a tool to look back at land treatment information; it needs to be used the other way around. Interferences — such as improper management of BMPs, changes in irrigation water management, or chaining the canals to remove algal growth — have profound effects on water quality. The Rock Creek land use/land treatment database accounts for this type of information but, in many cases, the data were only documented in field notes. This information must be incorporated into the database before its results are used to explain variability.

BMP Effectiveness

In the past, improvements in water quality have been assumed to be the result of land treatment practices. The postevaluation phase of the Rock Creek RCWP project will attempt to document water quality improvements resulting from implementation of BMPs. BMPs have been shown to be beneficial on small plots but little has been done to document BMP effectiveness on large-scale agricultural projects, such as the Rock Creek RCWP project. The Rock Creek project showed significant trends in BMP implementation that resulted in significant increases in water quality (Yankey et al. 1991).

BMP effectiveness is also compounded by multiple BMPs benefiting the same field or one BMP benefiting multiple fields. The latter is particularly the case with community-sized sediment ponds. Although constructed at one site, the area benefiting from this type of practice is much greater than the field on which it is constructed. SCS at Twin Falls has created a dominant BMP practice list to deal

Table 3.—Dominant best management practices incorporated in the Rock Creek RCWP project. The table is read by reading the vertical entry first (i.e., Filter Strips < Ponds). DOM means practices dominant over all other practices; < means practices that are less effective than others; and NA denotes not applicable.

	PONDS	MINI BASINS	SLOTS	BURIED PIPE	FILTER STRIPS	IRRIGATION PRACTICES	TILLAGE	SPRINKLERS
Ponds	—	NA	NA	NA	<	<	<	DOM
Mini basins	NA	—	NA	NA	NA	<	<	DOM
Slots	NA	NA	—	NA	NA	<	<	DOM
Buried pipe	NA	NA	NA	—	NA	<	<	DOM
Filter strips	DOM	NA	NA	NA	—	<	DOM	DOM
Irrigation practices	—	—	—	—	—	—	DOM	DOM
Tillage	—	—	—	—	—	—	—	DOM
Sprinklers	—	—	—	—	—	—	—	—

with this type of problem (Table 3). This list is incorporated into the statistical procedure, ensuring that the more dominant practice is used in the analysis.

Erosion Index

Another way to link land use/land treatment with water quality variables is by using the erosion index (Carter, 1984). The erosion index considers crop type and land slope. Slope information is available as an average per basin. Cropping information is available for the participants by field and for nonparticipants by farm unit. Plots will be developed for each monitoring site to indicate its percent of acres treated (x-axis), water quality parameter of interest (y-axis), and erosion index (z-axis). This approach may be the best way to incorporate crop type into the analysis.

Lessons Learned

The Rock Creek RCWP, like every project, offers many recommendations that can make future projects smoother. The following are some of these recommendations.

1. Interagency cooperation is essential for proper data interpretation. Expertise from both land use/land treatment and water quality professionals is a must for a quality end product.
2. A database and experimental design should be part of the project proposal; they should not be done as the project progresses. Both land treatment and water quality monitoring designs must be clearly defined, consistent, and sufficient to meet project goals.
3. The watershed's hydrology should be mapped before monitoring sites are determined.
4. Monitoring plans should be clearly written to define objectives and agency roles.
5. Monitoring schemes and land treatment tracking should be set up by hydrologic units to facilitate evaluation of BMP effectiveness.
6. External interferences that may mask benefits from implemented BMPs must be documented throughout the project period.
7. Land treatment databases should include nonparticipant data when water quality and BMPs are being evaluated at the watershed level.

Although broad, these recommendations may be overlooked when trying to start a project. Preliminary tasks, such as mapping the hydrology, setting up the relational database, and determining the proper experimental design at the project's beginning, will save many headaches at its end.

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Effectiveness of Agricultural Best Management Practices Implemented in the Taylor Creek/Nubbin Slough Watershed and the Lower Kissimmee River Basin

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ABSTRACT

During the past 20 years three generations of best management practices (BMPs), including those associated with the Rural Clean Water Program (RCWP), have been implemented in the Taylor Creek/Nubbin Slough and the Lower Kissimmee River basins. Over the last four years intensive animal waste collection and nutrient recycling systems have been installed at each dairy to reduce phosphorus loads to Lake Okeechobee from dairy and beef pasture operations. Water quality grab samples have been collected biweekly at basin outlet structures and tributary sites for the last 10 to 15 years. Grab samples have been collected on dairies since 1986. The samples show a significant decreasing trend in the median total phosphorus concentration at most tributaries in Taylor Creek/Nubbin Slough basin where there is a high level of participation in the RCWP program. The total phosphorus concentration values decreased by an average of 60 percent at the tributaries and by 50 percent at 75 percent of the dairies. Median total phosphorus concentration values decreased by 84 percent and phosphorus load by 40 percent for the Taylor Creek/Nubbin Slough basin. However, the phosphorus load in the Lower Kissimmee River basin increased significantly at the S154 structure.

The South Florida Water Management District participates in two Rural Clean Water Programs (RCWPs) within the Okeechobee basin north of Lake Okeechobee (Fig. 1). Lake Okeechobee is in danger of becoming hypereutrophic because of nutrient inputs, primarily phosphorus from agricultural activities (Federico et al. 1981). Historically, this area has contributed nearly 50 percent of the phosphorus load to the lake. The RCWP was implemented to reduce phosphorus inputs to the lake and determine the effectiveness of agricultural best management practices (BMPs) for improving water quality. This paper describes three generations of BMPs implemented over the last twenty years, and evaluates the changes in water quality as they relate to land treatment within the Taylor Creek/Nubbin Slough and Lower Kissimmee River basins.

The RCWP was initiated in Taylor Creek/Nubbin Slough basin in 1981 and in the Lower Kissimmee River basin in 1987. The goal of the Taylor Creek/Nubbin Slough RCWP was to reduce the

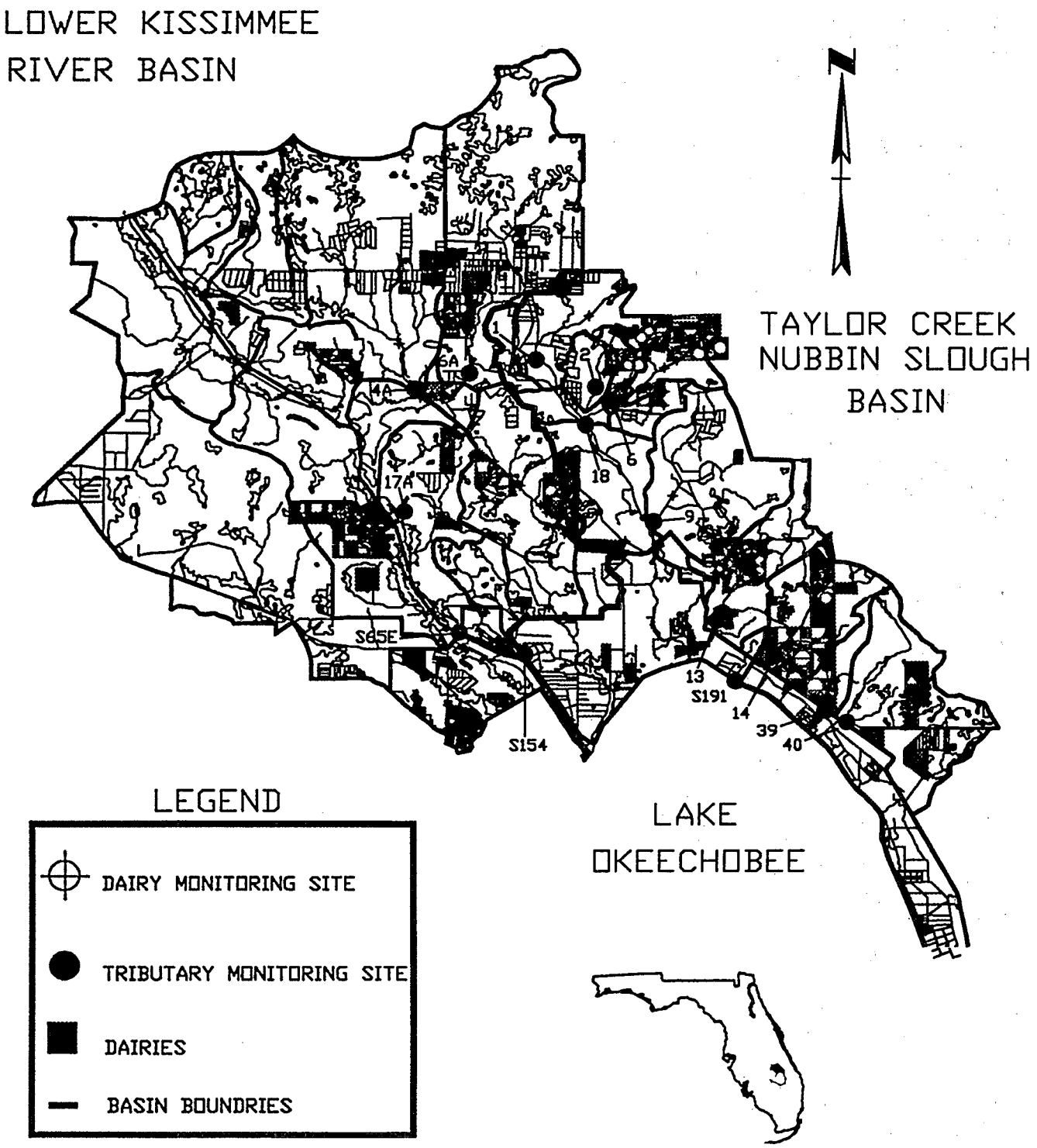

Figure 1.—Taylor Creek/Nubbin Slough and Lower Kissimee River basins and water quality monitoring stations.

phosphorus concentrations entering Lake Okeechobee by 50 percent by 1992. The goal of the Lower Kissimmee River RCWP was to reduce phosphorus loads to Lake Okeechobee by 43 percent. In 1987, the Florida Department of Environmental Regulation promulgated a "dairy rule" requiring that all dairy operations within the Taylor Creek/Nubbin Slough and Lower Kissimmee River basins implement a specific set of BMPs. The dairy rule conservation plans provided for collection and treatment of surface water runoff from the barn and high intensity areas and for recycling nutrients within the farm. Concurrent with the dairy rule, the dairy industry requested that a buy-out program be implemented for those dairies that either chose not to comply or could not comply with the dairy rule. This program

was adopted and dairy owners were offered $602 per cow. In return, a deed restriction prohibited the property from being used for any future dairy farming practices associated with the milking operation. The dairy proprietor retained ownership of the cows and the property but had to remove the cows from the property after the buy-out contract was signed. Eighteen dairies participated in the buy-out program, removing approximately 14,000 milking cows from the basins.

In this paper, the changes in surface water phosphorus concentrations (total phosphorus concentration) and total phosphorus loads following implementation of BMPs will be analyzed. First, the trends in total phosphorus concentrations for the tributaries will be presented. Second, total phosphorus concentration at the dairy sites will be presented to determine the changes resulting from the dairy rule and implementation of the buy-out program. Finally, the phosphorus loads and concentrations at the discharge structures to Lake Okeechobee will be presented.

Description of Project Area

The Taylor Creek/Nubbin Slough basin consists of several tributaries connected by canals to drain to the lake through a gated structure, S191. The Lower Kissimmee River basin consists of tributaries west of Okeechobee City that are drained to the lake through structure S154 and the channelized Kissimmee River, C-38, which drains to the Lake through structure S65E (Fig. 1). The lower two pools of C-38 are included in the Lower Kissimmee River basin RCWP. This area is characterized by flat landscape, sandy soils, and poor off-site drainage. The average annual rainfall for the project area is 127 cm; the majority of rainfall occurs during the summer wet season supplemented by occasional tropical storms. The typical soils of the region are sandy spodosols that have a low phosphorus holding capacity (Blue, 1970). The combination of rainfall in excess of evapotranspiration and low phosphorus retention capacity creates a high potential for phosphorus transport within the Lake Okeechobee basin (Flaig and Ritter, 1989).

The largest sources of net phosphorus imports to the basin are dairy operations and improved beef pasture operations (Fonyo et al. 1991). Over 95 percent of the project area in the Taylor Creek/Nubbin Slough and Lower Kissimmee River basins is currently devoted to agricultural activities. Most of the improved pasture has been fertilized for increased forage production and ditched to improve runoff during the summer wet season. Dairy cows, contained on large dairies of 800 to 1,200 animals each, tend to congregate in holding areas adjacent to the milking barn. There were 24 dairy barns in the Taylor Creek/Nubbin Slough basin and 19 in the Lower Kissimmee River basin; a total of 23,000 and 25,000 dairy and beef cows, respectively, in the Taylor Creek/Nubbin Slough basin and 12,700 and 68,000 dairy and beef cows, respectively, in the Lower Kissimmee River basin. Both of these land use practices (dairy and beef operations) have great potential to produce nonpoint sources of poor water quality (Flaig and Ritter, 1989). Nutrient transport in the area is governed by intense, localized rainfall and poorly drained soils.

Best Management Practices

Three generations of BMPs have been implemented in the Taylor Creek/Nubbin Slough and Lower Kissimmee River basins. The following criteria were used to categorize the BMP generations:

- BMPs implemented before the RCWP;
- BMPs implemented during the RCWP; and
- Dairy rule plan BMPs.

The first generation, 1972 to 1978, consisted of dairy barn lagoons that primarily trapped solids. t-These BMPs were the first attempt to eliminate barn wash from the water in adjacent tributaries. Unfortunately, the lagoons were poorly managed, resulting in occasional leaks or in some instances continual lagoon discharge into adjacent tributaries. Phosphorus concentrations observed in lagoons ranged from 20 to 40 mg/L (Goldstein, 1986).

The second generation, 1978 to 1986, included BMPs implemented in the RCWP project. Second generation BMPs included several practices. Stream fencing and stream crossings were used to restrict dairy and beef cow access to adjacent waterways and provide a vegetative filter strip. Second-stage lagoons were altered to provide recycled wastewater for the dairy barn washwater. Pasture management was improved by the introduction of portable shade structures to relieve heat stress and provide better use of pastures. BMPs implemented during this generation required an active maintenance program to ensure their effectiveness for attenuating nutrients. Problems associated with the first generation were also experienced in the second generation, including poor maintenance of lagoons and seepage fields, which resulted in the degradation of off-site water quality.

The third generation BMPs, 1987 to the present, were developed in response to the dairy rule. Three typical management strategies were used in dairy

rule conservation plans. The first approach used a perimeter ditch around the barn and high-intensity areas to capture surface water runoff and divert it to a waste storage pond. The wastewater was spray irrigated on silage crops for nutrient recovery. Animals were allowed to graze and feed in the pastures outside the high-intensity areas. The second approach was similar, except that the animals were fed, watered, and shaded in the high-intensity areas. This technique was known as "dry lot confinement," and required a high degree of management to properly maintain the high-intensity areas. The manure from the area had to be removed and either sold or spread on appropriate pasture lands. The third technique was a total confinement facility that housed the milk herd in a free stall barn. The animals were fed, watered, and cooled within the barn. The barns were flushed with water two to three times per day, and the water was then routed to the first stage lagoon. The success of the confinement dairy relied largely on management of the barn facility.

Analysis of Water Quality Data

Water quality data have been collected in the Taylor Creek/Nubbin Slough basin since the early 1970s (Osking and Gunsalus, 1992). In 1972, a biweekly water sampling program was established to determine phosphorus loads to the lake at all inflow structures, including S191, S154, and S65E (Fig. 1). Since the late 1970s, monitoring in the Taylor Creek/Nubbin Slough basin focused on quantifying long-term trends for the nine major tributaries. Water quality samples were collected and analyzed for nitrogen and phosphorus, pH, specific conductivity, turbidity, and color.

Following implementation of the third generation BMPs, runoff water quality from each dairy was monitored. Beginning in 1986, grab samples were collected weekly at each dairy to provide data on pre- and post-dairy rule conservation plan water quality. Monitoring was conducted on each dairy in the both Taylor Creek/Nubbin Slough and Lower Kissimmee River basins. At a few dairies, all runoff was monitored at a single site. At most dairies, the discharge site with the poorest water quality was monitored; other source areas on the dairy were not monitored. A synoptic monitoring program was developed to identify the impacts of those other source areas not covered in the routine monitoring program (Sawka et al. 1992). Water quality monitoring also began at selected tributary sites in the Lower Kissimmee River basin in 1986.

Water Quality Analysis

Three data sets were developed for evaluation of the effectiveness of BMPs: dairy runoff total phosphorus concentration; ambient tributary total phosphorus concentration; and total phosphorus concentration and total phosphorus load data collected at outfall structures draining to the lake. Table 1 lists the complete set of statistical analyses performed. The dairy data were used to evaluate the site specific effects of the dairy rule conservation plan BMPs. The tributary data were used to determine the long-term effects of dairy and beef pasture BMPs. The total phosphorus values from biweekly grab samples at the structures were used to evaluate water quality, particularly loads, for each basin.

Tributary Water Quality

The tributary water quality data were analyzed to determine the changes in water quality resulting from the implementation of BMPs in the critical areas of each subbasin. Nine tributary sites in the

Table 1.—Statistical analysis used for total phosphorus concentrations (TPC) and total phosphorus load data (TPL) for dairies, tributaries, and structures in the Taylor Creek/Nubbin Slough (TCNS) and Lower Kissimmee River (LKR) basins.

DATA SET	PARAMETER	TEST				TIME PERIOD
TCNS dairies	TPC	Wilcoxon Sum Rank/Satterthwaites T-test				1988-92
LKR dairies	TPC	Wilcoxon Sum Rank/Satterthwaites T-test				1086-92
TCNS tributary	TPC	Seasonal Kendall Tau				1978-92
LKR tributary	TPC	Seasonal Kendall Tau				1986-92
Structure						
S-191	TPC	Seasonal Kendall Tau				1978-92
S-65E	TPC	Seasonal Kendall Tau				1978-92
S-154	TPC	Seasonal Kendall Tau				1978-92
			PRE-RCWP	RCWP	PRE-DRP	POST-DRP
Structure						
S-191	TPL	ANOVA	1977-81	1982-85	1985-88	1988-92
S-65E	TPL	ANOVA	1973-80	1980-88	n/a	1988-92
S-154	TPL	ANOVA	1973-80	1980-88	n/a	1988-92

Note: Pre-RCWP = prior to implementation of BMPs; RCWP = implementation of BMPs in TCNS and LRK basins; Pre-DRP (dairy rule plan) = post-RCWP BMPs, coincides with pre-DRP on dairies; Post-DRP = average time frame for post-DRP construction.

Taylor Creek/Nubbin Slough basin and three tributaries in the Lower Kissimmee River basin were evaluated. The seasonal Kendall Tau test for trend (Hirsch et al. 1984) was performed on the total phosphorus concentration time series from each tributary. The Kendall Tau test was selected because it could detect the gradual change in total phosphorus concentration values in the presence of anomalous data.

The implementation of BMPs occurred over eight years, distributed spatially throughout the basin. The change in water chemistry due to adjustments in stream sediments was also gradual. Consequently, the changes in total phosphorus concentration at the tributary scale were gradual. Where the data are skewed and exhibit seasonality the Kendall Tau test was most powerful (Hirsch et al. 1984). For the Kendall Tau test the data were grouped into 12 monthly seasons and the monthly median values were used in the analysis. Taking monthly medians reduced the effect of serial correlation among the data and the problems associated with missing data. However, the exact power of this test when unequal monthly sample sizes occurred is not known (Gilbert, 1987). Insufficient information was available at each site to adjust these data for hydrologic variability such as stream stage, discharge, rainfall, or groundwater stage. Hirsch et al. (1984) concluded that the seasonal Kendall Tau is appropriate for both adjusted and unadjusted time series. With only five years on record, the significance levels of the test are less certain. Biweekly sampling historically, and weekly sampling since 1986, have provided sufficient data for this analysis.

The Tau test was conducted to determine homogeneity of trend among months using the Battelle Northwest's Trend program (Gilbert, 1987). When the trend is heterogeneous among seasons, the overall trend test is misleading.

Dairy Water Quality Analysis

The dairy water quality data contained weekly grab sample values collected from 1987 to 1992. The total phosphorus concentration data were partitioned into pre- and post-construction data sets. The frequency distributions from these data were positively skewed and the data were log-transformed, which produced approximately normal distribution values. Bradley (1968) indicated that determining the degree of departure from normality is difficult and assessing the loss of power is tedious and unsatisfactory. The hypothesis that there were no significant differences between the two periods was tested using the Wilcoxon sum rank test and the t-test. Montgomery and Loftis (1987) showed that both tests are relatively insensitive to the shape of the distribution. However, they are both sensitive to serial correlation among observations. Rekhow and Chapra (1983) recommended that both tests be applied when there is doubt about the assumptions.

The Wilcoxon rank sum test was used to test no differences in populations. The test is robust to outliers but not as powerful as a t-test when the data are gaussian. This test was used to test the null hypothesis that the means were not significantly different. Satterthwaite's t-test is adjusted for unequal sample sizes and unequal variance (Snedecor and Cochran, 1980), which was the case in these comparisons. These analyses were conducted using SAS Univariate and t-test procedures (SAS Inst. 1990).

Basin Water Quality Analysis

Total phosphorus concentration time series and flow-weighted monthly total phosphorus concentrations were analyzed at structures S154, S65E, and S191, which control discharge to Lake Okeechobee from the Taylor Creek/Nubbin Slough basin and Lower Kissimmee River basins. Two analyses were performed on the phosphorus data, the seasonal Kendall Tau test and analysis of variance. The Kendall Tau was applied to the raw total phosphorus concentration data and the analysis of variance (ANOVA) was used to evaluate significant differences in loads among the different BMP implementation periods.

The data used in this analysis were biweekly total phosphorus concentration values from grab samples and estimated daily discharge. Monthly flow-weighted total phosphorus concentration values were calculated to provide total phosphorus level normalized for discharge. Although these data are not sufficiently dense to calculate accurate loads, they do provide a consistent index for analysis of trends and differences between time periods. Compared with daily composite data, these loads may differ by as much as 40 percent.

The total phosphorus load data were positively skewed and effectively normalized by the logarithmic transformation. The monthly data were tested for homogeneity of variance using Bartlett's test (Reckhow and Chapra, 1983). As expected, a significant difference in variance resulted from seasonality. When the data were partitioned into dry season (November to April) and wet season (April to October), the resulting data were homogeneous. Simple linear regression, log-total phosphorus concentration regressed against log-discharge, was performed to account for possible long-term hydrologic variability simultaneously within ANOVA for compar-

ing total phosphorus load values for each BMP period. The residuals were checked for deviations from normality using the W-test and tested for autocorrelation using the Durbin-Watson test (Reckhow and Chapra, 1983). The residuals were approximately normal and exhibited no autocorrelation.

The specific test time periods are defined in Table 1. The resulting mean values for total phosphorus load for each BMP period were compared as multiple treatment effects using Ryan's Q-test (Einot and Gabriel, 1975). Day and Quinn (1989) recommended Ryan's Q-test for samples of equal variance and unequal sample size. Ryan's test is powerful and controls type I error rates for multiple comparisons. The mean total phosphorus load values were calculated using the minimum variance unbiased estimator (Gilbert, 1987) of total phosphorus load and the mean flow by season and site. These analyses were completed using the SAS General Linear Models procedure (SAS Inst. 1990) on a SUN SPARC 1+ work station.

Results of Water Quality Analysis

Tributary Water Quality

The results of the analyses indicated that significant decreasing trends in most subbasins (Table 2). The larger Tau values indicated a steeper, more significant trend. The significance level is adjusted for serial correlation (Hirsch et al. 1984). The monthly trends were found to be homogeneous at all sites. The percent change in period of record median total phosphorus concentration is provided for comparison.

Over the course of BMP implementation, the total phosphorus concentration has been considerably reduced in the Taylor Creek/Nubbin Slough basin. Overall, capture of animal waste with the dairy rule conservation plan and improved pasture management greatly improved total phosphorus concentration values. No significant trend was found at Northwest Taylor Creek (site 01), probably because of the increase in animal density throughout the RCWP period and the low percent of critical land impacted by BMPs. The increasing trend at Lettuce Creek (site 40) probably resulted from a low rate of land owner participation in the RCWP program and poor animal waste handling.

The specific effects of BMP implementation on total phosphorus concentration are illustrated for Mosquito Creek at site 13 (Fig. 4). An improvement in pasture management in the early 1980s was followed by an increase in animal density in 1984. One dairy near site 13 participated in the buy-out program in 1988, which substantially improved downstream water quality. Although total phosphorus concentrations improved slightly as a result of the RCWP, the buy-out and dairy rule conservation plan on adjacent dairies was most effective.

In the Lower Kissimmee River basin, total phosphorus concentration values are lower than in the Taylor Creek/Nubbin Slough basin, reflecting the lower intensity of animal management. The increasing trend at Chandler Slough (04A) reflects the presence of one dairy and lack of BMP implementation for improved pasture. Two dairies were located in the Cypress Slough (06A) basin trend, one of which has converted to a beef operation through the buy-out program. No significant trend was found at

Table 2.—Seasonal Kendall Tau total phosphorus concentration trends for tributary sites in the Lower Kissimmee River and Taylor Creek/Nubbin Slough basins.

LOCATION	SITE NUMBER	LENGTH OF RECORD (YEARS)	PERCENT LAND TREATED	TAU	∝	MEDIAN SLOPE	PERCENT CHANGE
Chandler Sl.	04A	5	1	.52	.05	.044	+120
Cypress Sl.	06A	5	8	-.52	.07	-.029	-60
Yates Marsh	17A	5	10	-.38	.17	-.024	-87
NW Taylor Ck.	01	13	68	.12	.24	.009	-26
Little Bimini	02	13	100	-.23	.13	-.042	-60
Otter Ck.	06	13	97	-.64	.001	-.187	-220
Taylor Ck.	18	12	85	-.36	.007	-.046	-90
Will. Ditch	09	14	99	-.34	.008	-.012	-66
Mosquito Ck.	13	14	89	-.61	.001	-.158	-140
Nubbin Sl.	14	14	84	-.46	.007	-.092	-86
Henry Ck.	39	10	57	-.45	.015	-.133	-92
Lettuce Ck.	40	10	20	.47	.006	.021	+84

Yates Marsh (17A), which drains a substantial wetland and one small dairy. The trends for Lower Kissimmee River basin sites should be interpreted with caution because of the short period of record.

Results of Dairy Analysis

The results of the analysis for total phosphorus concentration in dairy runoff are summarized in Figure 2. The results at individual dairies have been combined to illustrate the effectiveness of the overall dairy rule conservation plan.

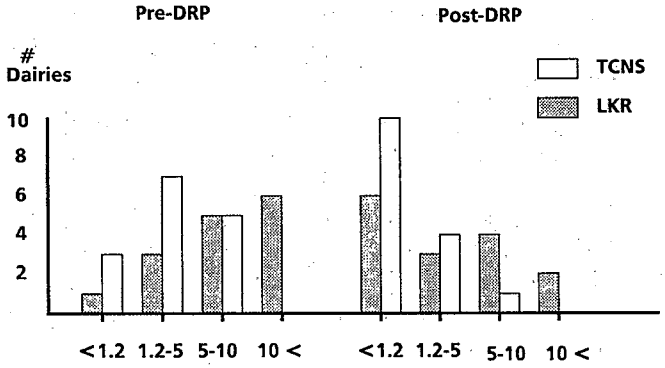

Figure 2.—Number of dairies in Taylor Creek/Nubbin Slough and Lower Kissimmee River basins with discharge total phosphorus concentration in the range < 1.2 mg/L to > 10 mg/L.

Results of both the Wilcoxon test and t-test indicated highly significant differences between pre- and post-dairy rule conservation plan at 25 dairies. The other three sites either had too few data (N<6) for comparison, or the total phosphorus concentration values were small and no significant change was detectable, or no significant improvement was found.

Implementation of the dairy rule conservation plans has significantly improved water quality in monitored discharge from 80 percent of the dairies. Of the 30 remaining dairies, total phosphorus values collected at the representative monitoring site on 16 dairies are below the regional 1.2 mg/L average total phosphorus concentration target (Fig. 2). Prior to the dairy rule conservation plan only 4 dairies met the target. Of the dairies that have not met the target, six have significant site specific problems related to poorly drained pastures and high animal densities. Several reasons account for this condition, including (1) small high-intensity areas that provide few incentives such as feed and shade to encourage deposition within the waste management system; (2) poorly drained swale areas through which manure phosphorus is readily transported off site; and (3) old wetland areas that historically received high phosphorus loads and may be washing out excess phosphorus. Additional BMPs may be necessary to resolve those specific water quality problems. On the other dairies, it appears that poor management is responsible for poor water quality. As the dairy managers become more adept at herd rotation, animal waste redistribution, and application of pasture buffer strips, these dairies should come into compliance.

The effect of the dairy rule conservation plan on off-site water quality depends on the degree to which other BMPs have been installed on the dairy. In the Taylor Creek/Nubbin Slough basin, the dairies had installed second generation BMPs that improved pasture runoff and reused barn washwater. Nearly 70 percent of the Taylor Creek/Nubbin Slough basin dairies have reached the target total phosphorus concentration at the representative monitoring site. Before the dairy rule conservation plan, few BMPs had been installed on dairies in the Lower Kissimmee River basin. Only 40 percent of the Lower Kissimmee River basin dairies have reached the target, and 40 percent of the dairies have problem areas. Some of these problems reflect the lack of second generation BMPs. Where pasture BMPs have been installed, implementation of the dairy rule conservation plan produced an immediate improvement in water quality.

One concern in analyzing these data was the effect of time lag on dairy rule conservation plan discharge. Review of the data indicates that those dairies that effectively installed the dairy rule conservation plan are meeting the appropriate standard. Dairy rule conservation plan BMPs were completed recently on three dairies. On these sites, one notes a significant improvement in total phosphorus concentration but the values are still above the target.

The results of dairy rule conservation plan implementation can be illustrated by reviewing one case study. At one dairy, Site 40, the milking herds had free access to farm drainage ditches. After the construction of fencing, additional cooling ponds, and shade structures, the cows were restricted from the ditches. The off-site water quality has significantly improved, with average total phosphorus concentration of less than 1.2 mg/L (Fig. 3). The primary effect of the dairy rule conservation plan has been to redirect concentrated wastewater to other land where the nutrients can be recovered.

Dairy Buy-out Program

The buy-out program was expected to produce a phosphorus load reduction by reducing phosphorous imports and concentration of manure. Although the land owners were restricted from dairy

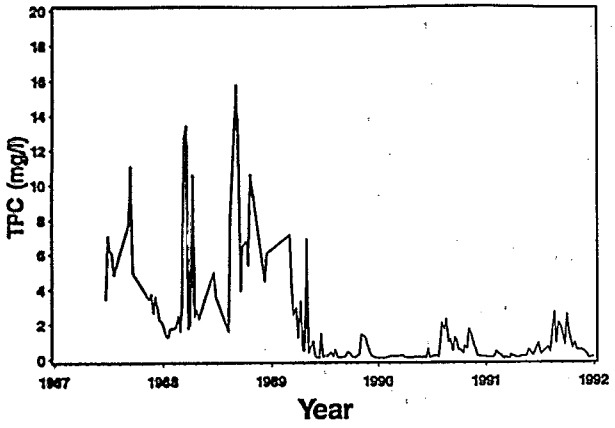

Figure 3.—Total phosphorus concentration (TPC) time series for dairy site 40.

and feedlot operations, intensive operations such as heifer and dry cow operations were not prohibited. For the 18 dairies participating in the program, most of the land remains associated with intensive animal management. With the buy-out program 14,040 milking cows were relocated and replaced by 6,600 heifers or beef cows. Other changes in land use include citrus and vegetables.

The short-term results on total phosphorus concentration in runoff from these operations are presented in Figure 4 for each category of current land use. The average runoff total phosphorus concentration results are presented by classes. The lowest class, average total phosphorus concentration less than 0.35 mg/L, represents the regulatory targets for these land uses. The second class, 0.35 to 1.2 mg/L, should include those operations making the transition from dairy to improved pasture. The other classes include the number of farms that have problems meeting regional water quality targets. Total phosphorus concentration values have significantly improved at half the buy-out sites; however, the total phosphorus concentration values are still unacceptably high, greater than 0.35 mg/L. At some farms, the runoff water quality has not improved because the current heifer operations are as intensive as the previous dairy. This total phosphorus concentration data are uncertain because they reflect the short lapse in time since the change in operations on some farms. The first cows were removed from the early buy-out participants in fall 1989. The last participants have recently removed their milk herds.

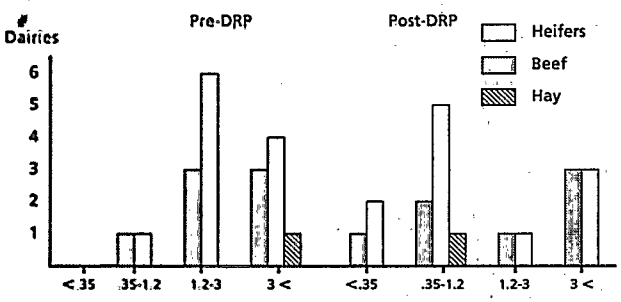

Figure 4.—Number of dairies by current land use in Taylor Creek/Nubbin Slough basin and Lower Kissimmee River basins participating in the buyout program with total phosphorus concentration in the range < 0.35 mg/L to > 3 mg/L total phosphorus.

Basin Scale Water Quality

In the Taylor Creek/Nubbin Slough basin, which drains to Lake Okeechobee at S191, there has been a significant decrease in total phosphorus concentration and total phosphorus load following implementation of RCWP and dairy rule conservation plan BMPs. The median concentration decreased 84 percent between 1979 and 1992 (Table 3). The trend in total phosphorus concentration at S191 increased during the 1970s, but has decreased during the 1980s following implementation of BMPs (Fig. 6). During the 1970s, dairy operations intensified and additional milk herds were brought into the basin. The trend in total phosphorus concentration had decreased through the 1980s as BMPs were installed. The total phosphorus concentration time series at each structure was marked by wet season peaks; extended peaks and troughs indicate the occurrence of droughts and hurricanes.

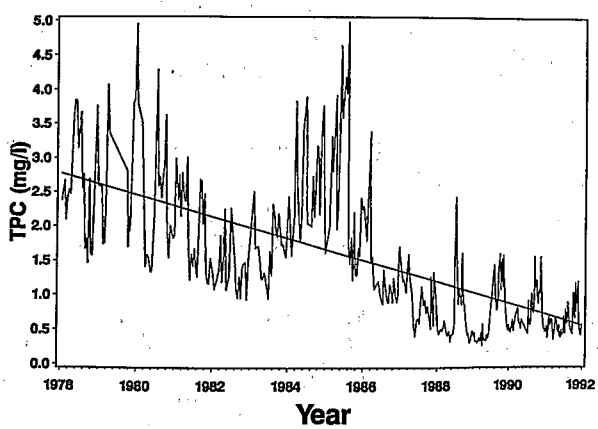

Figure 5.—Total phosphorus concentration (TPC) time series and trend line (slope = -.0158 mg/L-yr) for Mosquito Creek (Site 13).

The median total phosphorus concentration increased at S154 and decreased slightly at S65E within the Lower Kissimmee River basin. The trend at S154 has increased significantly during the 1980s following the establishment of two dairies that increased the number of milk cows by 40 percent. A slight decreasing trend at S65E during the project was significant at the 0.10 level.

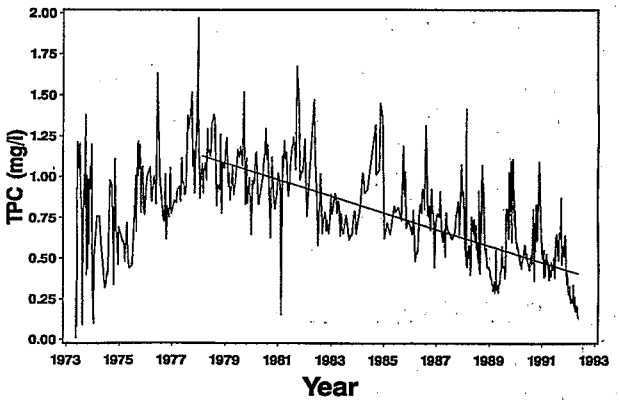

Figure 6.—Total phosphorus concentration (TPC) time series and trend line (slope = -0.049 mg/L-yr) for structure S191, Taylor Creek/Nubbin Slough basin.

The total phosphorus concentration data exhibit strong seasonality due to high runoff during the late summer wet season. High total phosphorus concentration values are usually associated with high flow, but may also be associated with small intense storms that produce significant flushes with low total discharge.

The trend in total phosphorus concentration and total phosphorus are a function of the area of BMP implementation in each basin. A much greater portion of the land in the S191 basin was involved in BMPs. The percent of the land treated in each basin varied from less than 1 percent in the S65E basin and 8 percent in S154, to 58 percent in the S191. The BMP coverage in S65E and S65D basins was small relative to the entire area.

The monthly phosphorus loads, expressed as average daily loads, have varied greatly during the period of record. The total phosphorus load values were strongly influenced by basin discharge. Variation in discharge accounts for 30 percent of total phosphorus load at S154, 11 percent at S65E, and 50 percent at S191. Most of the variation in total phosphorus load occurred within season and the longer-term trend was less than 5 percent.

The phosphorus load at S191 decreased 40 percent during the period 1979 to 1992 (Table 4). The Total phosphorus load decrease from pre-RCWP to post-dairy rule conservation plan was significant at the .001 level, with a standard error of 26 kg per day. A significant increase of 54 percent occurred in Total phosphorus load at S154 during the RCWP period (1980-88), coincident with increased dairy activity. The standard error for total phosphorus load at S154 was 9 kg per day. Although there was no significant change at S65E over the entire period, the total phosphorus load significantly increased during the mid-1980s and is now decreasing.

General Discussion

The primary effect of the dairy rule conservation plan has been to redirect concentrated wastewater to other land where nutrients can be recovered. Advanced plans have been designed to capture greater amounts of animal waste by total confinement or by increasing the areal extent of the high-intensity areas. The wastewater from the high-intensity areas is more concentrated and easier to handle. Failures of the dairy rule conservation plan have occurred so areas of manure concentration exist outside the high-intensity areas. Within the high-intensity areas it has been assumed that the lagoons and waste storage ponds will seal to prevent groundwater pollution. Although there is some data indicating the presence of elevated phosphorus concentrations in groundwater, nothing indicates that groundwater is a source of off-site contamination.

Table 3.—Seasonal Kendall Tau test statistics for total phosphorus concentrations at Lake Okeechobee outfall structures in the Taylor Creek/Nubbin Slough and Lower Kissimmee River basins.

STRUCTURE	LENGTH OF RECORD (YEARS)	SEASONAL KENDALL TAU TREND STATISTICS (mg/L)				
		TAU	∝	SLOPE	MEDIAN	% CHANGE
S-154	13	.421	.002	.035	.72	+63
S-191	13	-.725	.001	-.049	.76	-84
S-S65E	13	.130	.11	-.0012	.083	-19

Table 4.—Mean total phosphorus loads for outfall structures to Lake Okeechobee in the Taylor Creek/Nubbin Slough and Lower Kissimmee River basins.

STRUCTURE	LENGTH OF RECORD (YEARS)	MEAN TOTAL PHOSPHORUS LOADS (kg per day)				
		PRE-RCWP	RCWP	POST-RCWP	POST-DRP	% CHANGE
S-154	13	46a	70b	n/a	92b	+54
S-191	13	374a	338a	275b	227c	-40
S-65E	13	370a	402b	n/a	33ab	-10

A major effect of the RCWP and the dairy rule has been to reduce net phosphorus imports into the basins. Improved recycling of wastewater and forage production have also reduced the import of feed and fertilizer. The dairy buy-out program significantly reduced these imports. Although an exact phosphorus budget has not been calculated on these effects, a previous analysis indicates a strong relationship between net phosphorus imports and phosphorus loads to the lake for several Lake Okeechobee basins (Fonyo et al. 1991).

A source of complication in the analysis of phosphorus load reduction is the impact of wetlands. The phosphorus loads at the structures is greatly influenced by the presence of wetlands in each basin. Phosphorus transport through wetlands can be significantly attenuated. The S191 basin has few wetlands, while large sloughs and marshes occupy a significant portion of the S154 and S65D basins. Phosphorus temporarily or permanently stored in these systems may explain the difference between the tributary total phosphorus values and the total phosphorus values measured at the structures.

Many interactions and field observations have been conducted within the Lower Kissimmee River and Taylor Creek/Nubbin Slough basins during the tenure of the RCWP. Interactions have included on-site discussion with landowners to help identify site specific water quality problems. Success or failure in resolving these problems depends on the ability of the landowners to understand the problems and respond with appropriate solutions. Unfortunately, on many occasions the problems were fairly simple but solutions were complicated and costly. Nevertheless, these interactions were important and helped resolve many problems, thus improving off-site water quality.

Conclusions

Agricultural best management practices were implemented in the Taylor Creek/Nubbin Slough and Lower Kissimmee River basins over the last twenty years to reduce phosphorus loads to Lake Okeechobee. The BMPs were installed in series of projects beginning with control of dairy barn washwater. Additional projects included improved pasture management and development of animal waste collection systems and nutrient recycling. Water quality data were collected at many sites during the projects and analyzed for changes in total phosphorus concentrations. From the beginning of the project, total phosphorus concentration data were collected from tributaries and basin discharge structures to evaluate the effectiveness of the RCWP and related BMP projects. In 1986 sample collection began at representative dairy sites to determine the effectiveness of animal waste collection systems. These data were analyzed for trends in median values using the seasonal Kendall Tau test. In addition significant differences in mean values of total phosphorus concentration and load were evaluated.

Significant decreasing trends in total phosphorus concentration were found for most tributaries. Total phosphorus concentrations decreased approximately 55 percent in the tributaries following implementation of BMPs. In a few tributaries where the percent of land treated was below 50 percent, or where the number of animal units has increased, total phosphorus loads also increased. At S191 total phosphorous concentrations decreased 84 percent, while total phosphorus concentration at S154 increased 63 percent. A small total phosphorus increase of 19 percent at S65E was significant at the 0.11 level.

Total phosphorus concentrations have decreased approximately 50 percent at 75 percent of the dairies. Fifty percent of the dairies have met the total phosphorus concentration target based on one to three years of monitoring. The total phosphorus values have not been adjusted for variation in rainfall and a few few dairies remain that have exhibited site-specific difficulties in the management of animal waste.

The phosphorus load discharged to Lake Okeechobee from the Taylor Creek/Nubbin Slough basin has decreased 40 percent during the project. About 75 percent of the reduction occurred during the RCWP program and the remaining reduction occurred following the dairy rule conservation plan implementation. There was a small load increase in the Lower Kissimmee River basin. The lack of response to BMPs in the Lower Kissimmee River basin is probably due to the low percent of land treated with BMPs, the presence of dairies with site specific problems, and large wetland areas that may be responsible for attenuating phosphorus loads. Overall there has been a 20-percent reduction in phosphorus load from the Lower Kissimmee River and Taylor Creek/Nubbin Slough basins during this project.

In the future, additional analysis will be conducted to evaluate several factors influencing phosphorus loading. The impact of wetlands on phosphorus assimilation and attenuation will help quantify the magnitude of total phosphorus buffering. A basin phosphorus analysis will be completed to assess the impact of various management strategies and watershed characteristics on the success of BMPs.

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Estimation of Lag Time for Water Quality Response to BMPs

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ABSTRACT

The St. Albans Bay Watershed Rural Clean Water Program project was one of 21 experimental projects aimed at improving water quality through use of agricultural best management practices (BMPs). After 10 years of comprehensive monitoring and extensive BMP implementation covering 74 percent of critical acres, a significant reduction in nutrient concentrations and mass exports was not observed in either tributary streams or the bay. However, decreases in sediment concentrations and loads as well as bacteria counts did occur. Two reasons offered for the lack of nutrient response are (1) the BMPs were insufficient to cause change or (2) the study had ended before changes started to occur. This paper presents a method to estimate the length of time needed to obtain a given water quality response from a certain level of land treatment. The technique was applied to several BMP scenarios in the St. Albans Bay RCWP, including pre-BMP, reduced runoff, reduced inputs, and achievable export cases. The results show that reducing exports may take many years, depending on the amount of input reduction and the initial field nutrient concentrations. This method can be applied to other land treatment nonpoint source projects interested in determining lag time to BMP implementation.

When best management practices (BMPs) are applied in watersheds to control nonpoint source pollution, it is often assumed that water quality improvements will occur in a relatively short period of time. Models such as CREAMS, GLEAMS, and AGNPS (Knisel, 1980; Leonard et al. 1987; Young et al. 1989) that are commonly used to plan selection of the most effective BMPs assume watershed conditions are in equilibrium or steady state—that export values do not change, beyond normal variation, with respect to time. However, these models do not provide a means to predict how long it may take to reach equilibrium.

This uncertainty was exemplified by the St. Albans Bay Watershed Rural Clean Water Program (RCWP) project, located in northwestern Vermont. Dairy agriculture dominated land use in this 13,000-ha watershed with 98 farms, where the major BMP implemented was animal waste management, including waste storage during the winter and waste application and incorporation in the spring. However, other BMPs—such as permanent vegetative cover, cropland protective system, and fertilizer management—were used as well.

Four tributaries to St. Albans Bay were continuously monitored for nitrogen, phosphorus, sedi-

ment, and bacteria. Sampling was also conducted in St. Albans Bay and on individual farm fields. After 10 years of monitoring and the implementation of BMPs over 74 percent of critical acres, a significant reduction in nutrient concentration and mass export was not observed in tributary streams (Vt. RCWP Coor. Comm. 1991). The question was whether the lack of nutrient response resulted from an insufficient use of BMPs or whether insufficient lag time had been allowed for changes to occur. Lag time is the time elapsed between initiating a land treatment and achieving a certain percentage of a new equilibrium water quality.

This paper describes a method for estimating the lag time for a quality of runoff to respond to BMPs. Knowledge of lag times would assist watershed planners interested in documenting the benefits of nonpoint pollution controls. Lag times may also help evaluate the effectiveness of alternative BMPs.

Study Area

Farm fields used for the calculation of lag times were located within the St. Albans Bay watershed. The phosphorus export values were from the 1,384-ha Jewett Brook watershed, located in the St. Albans Bay watershed. Over two-thirds of the watershed soils had formed on lacustrine deposits, the remainder had formed on glacial till, and over 90 percent of these soils are poorly drained. Flow in Jewett Brook, which averaged 60 percent of annual precipitation, occurred during both stormflow and baseflow periods. The dominant land use in the watershed was dairy agriculture (86 percent), with 32 percent of the watershed being planted to silage corn.

Of the 18 farms in the watershed, 16 signed RCWP contracts. Dairy farms averaged 134 ha, with an average herd size in 1,991 of 120 animal units. At the completion of the RCWP project, 74 percent of the critical acres and 83 percent of the animal units were controlled by RCWP contracts. The Jewett Brook watershed has been described in greater detail by Meals (1992) and the Vermont RCWP Coordinating Committee (1991).

Method

Predicting the time required for lake recovery as a result of decreasing nutrient inputs is not new to lake scientists. Equations for this process have been described by Lorenzen (1974) and reported in various texts, such as that by Chapra and Reckhow (1983). These equations may also be suitable for application to an agricultural field or watershed receiving BMPs for several reasons:

- The concentration in the field export is related to the field surface concentration; the lake equations assume that the export and lake concentrations are equal.
- The rate of change of the export concentration is proportional to the field concentration, which also is assumed for a lake.
- The assumption of a well-mixed system may apply equally to a lake or the surface of a soil. Neither system is perfectly well mixed. For the simple model presented in this paper, the soil is mixed once per year to the depth of the plow layer.
- The law of conservation of mass applies in both systems.

The phosphorus mass balance for a 1-ha field is presented in Figure 1. This conceptual diagram shows phosphorus being added to the field as manure, fertilizer, and precipitation; outputs from the field are shown as silage yield, runoff, and leakage into deeper soil layers. Runoff is composed of two sources, surface and subsurface (Fig. 1), which collectively become streamflow. For this paper, the leakage into subsurface soil layers was assumed to be zero.

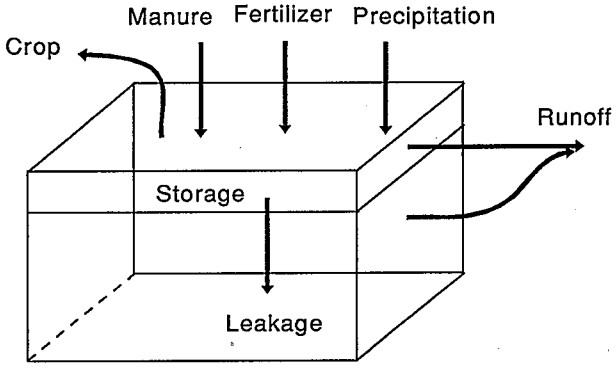

Figure 1.—Phosphorus mass balance diagram for lag time calculations.

The concentration of phosphorus in the export from the field (C_Q) is assumed to be proportional to the concentration of phosphorus stored in the surface 1 cm of the field (C) according to

$$C_Q = EC \quad (1)$$

where E = extraction coefficient (Frere et al. 1980). These phosphorus concentrations must be considered in terms of availability for runoff and not necessarily the availability for plant growth. This

relationship shows that, to improve the quality of surface runoff, the field concentration must be reduced. This emphasis on field concentration rather than runoff concentration has been widely overlooked in nonpoint source management strategies.

The mass balance equation that describes the rate of change in field concentration of phosphorus per unit soil volume is:

$$\frac{dC}{dt} = \frac{MC_m + FC_f + PC_p}{V} - \frac{YC_y}{V} - \frac{ECQ}{V} \qquad (2)$$

where dC/dt = change in mass stored in the field/change in time; C = phosphorus concentration in upper 1 cm of soil (g/m^3); t = time (yrs); M, F, P, Y = amount of manure, fertilizer, precipitation, and crop yield, respectively (m^3/yr); C_m, C_f, C_p, C_y = P concentration of manure, fertilizer, precipitation, and yield, respectively; E = extraction coefficient; Q = rate of surface runoff (m^3/yr); and V = volume of soil (m^3). The term YC_y, which represents the loss of phosphorus in the crop, could be made a function of the soil concentrations rather than handled as a constant.

The steady-state solution of the equation for the field concentration of phosphorus is determined from Equation 2 by setting dC/dt = 0, which gives:

$$C_e = I\theta \qquad (3)$$

where C_e is the equilibrium field concentration of P (g/m^3), I is the net loading (kg/yr) obtained by the summation of all inputs as shown in Equation 4:

$$I = \frac{MC_m + FC_f + PC_p - YC_y}{V} \qquad (4)$$

and Θ is the phosphorus runoff residence time (yrs), based solely on the total phosphorus export from the field, given by:

$$\theta = \frac{V}{EQ} \qquad (5)$$

where E = the extraction coefficient and Q is the outflow (m^3/yr). The quantity EQ is determined by dividing the mass export in runoff (ECQ) by the concentration (C) in that runoff. This runoff residence time underestimates the total residence time of phosphorus for the field since it ignores the removal of phosphorus by the crop or deeper burial of phosphorus in the soil. A more complex model could account for these fluxes.

The general solution of Equation 2 that permits the calculation of the field phosphorus concentration at any point in time, given an initial concentration (C_o) at time t = 0 , and solved for t is given by:

$$t = -\Theta \ln\left(\frac{C - C_e}{C_o - C_e}\right) \qquad (6)$$

where C is the field phosphorus concentration at any time t, and C_O is the initial concentration at time t = 0. Equations (3) and (6) will serve as the basis for determining the length of the lag time (years) associated with alternative management strategies.

Two techniques were used to determine lag times. The first was analytical calculations using these equations on a hand calculator. The second technique used a dynamic simulation model that allows observation of the continuous change in both field and runoff concentrations. The software package, STELLA II, was used to construct the model (Bogen, 1989; High Performance Syst. 1990). The structural diagram for the 1-ha field used in STELLA to describe Equations 1 and 2 is presented in Figure 2. The model in STELLA uses the same equations as described previously.

Results

For the purpose of not presenting a highly complex model to estimate lag times, several simplifications were made in mass balance. Additional fluxes could be modeled that would likely improve the estimate of the lag time. To estimate lag time, the following information is needed:

- the mass of manure, fertilizer, and precipitation nutrient inputs,
- the output mass values for crop yield and runoff export, and
- the field and runoff nutrient concentrations.

The nutrient contents of precipitation, crop yield, and runoff could be measured or estimated from literature values, such those provided in Knisel (1980). Regional values of phosphorus in runoff would be preferred. However, the nutrient content of field inputs such as manure and fertilizer should be measured or estimated more directly. An actual sampling of field nutrient concentration is crucial to reasonable lag time estimations.

This method to determine the time lag was applied to several BMP scenarios in the St. Albans Bay RCWP, including pre-BMP, reduced runoff, reduced input, and setting an export goal as achievable water quality. Since actual total phosphorus concentration for the field surface was unknown, calculations were made for both a high concentration (1,000 g/m^3) and a low concentration (350 g/m^3), as reported in the literature (Thompson and Troeh, 1978).

Pre-BMP

In the first application, the pre-BMP condition is given to describe the existing phosphorus mass

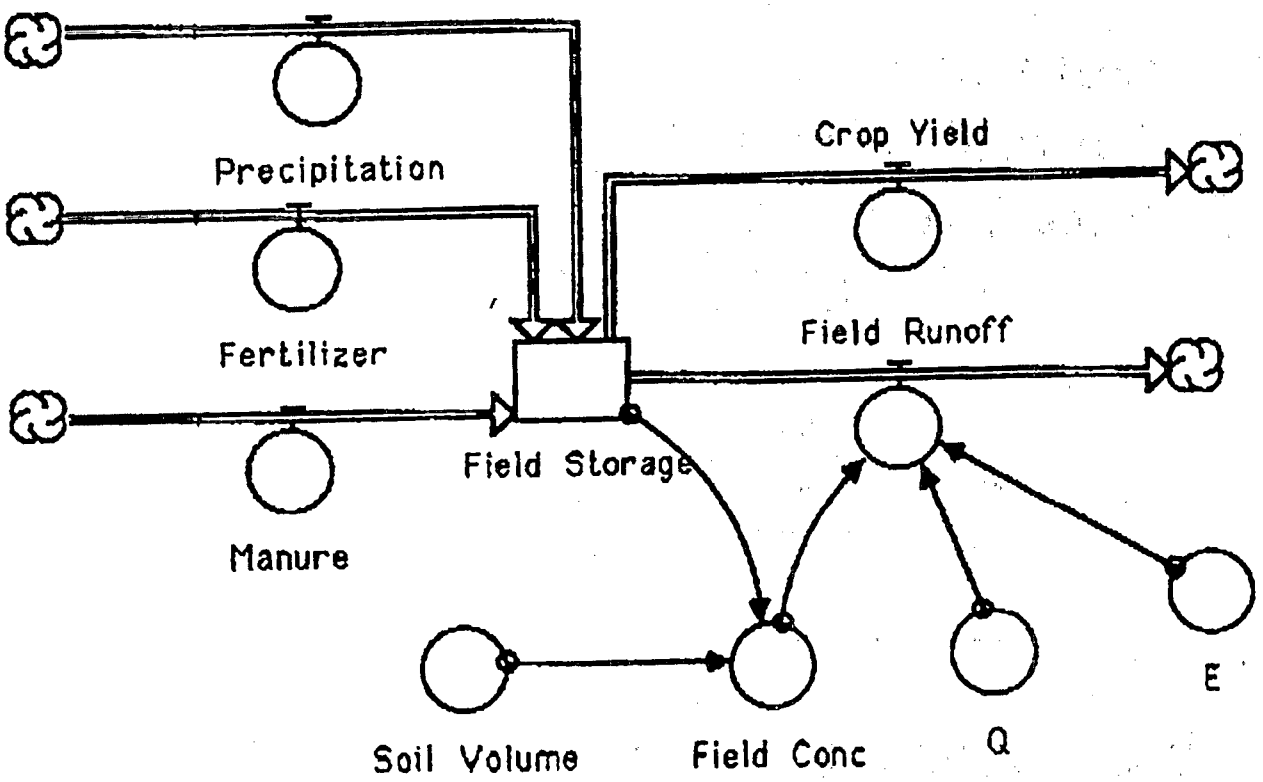

Figure 2.—Structural diagram for dynamic simulation model of agricultural field using STELLA II. Clouds are sources (arrow out) and sinks (arrow in) of phosphorus. Double-lined arrows are pipelines through which phosphorus flows. Circles connected to pipelines are controllers that regulate the rate of flow of the mass of phosphorus through the pipelines. Rectangle represents the storage of phosphorus in the field. Plain circles are converters and convert inputs into outputs. Single-lined arrows are connectors depicting causal linkages in the model.

balance for the watershed. Inputs of manure and fertilizer were based on averages from 11 farms in the St. Albans Bay watershed as reported by Jokela (1991). The phosphorus content of the corn silage yield output was from Frere et al. (1980). The export of phosphorus in runoff was measured in the St. Albans Bay watershed (Vt. RCWP Coor. Comm. 1990). Based on these averages, mass inputs of phosphorus exceeded outputs (Table 1). These loads would result in rising field concentrations (Fig. 3) and therefore increasing runoff export values (Table 1). It was assumed that only the upper 1.0 cm of soil "actively" produced phosphorus in runoff (Frere et al. 1980). Therefore, the volume (V) of the one hectare storage unit was 100 m^3. If the depth of this layer were increased, the lag time would become proportionally longer.

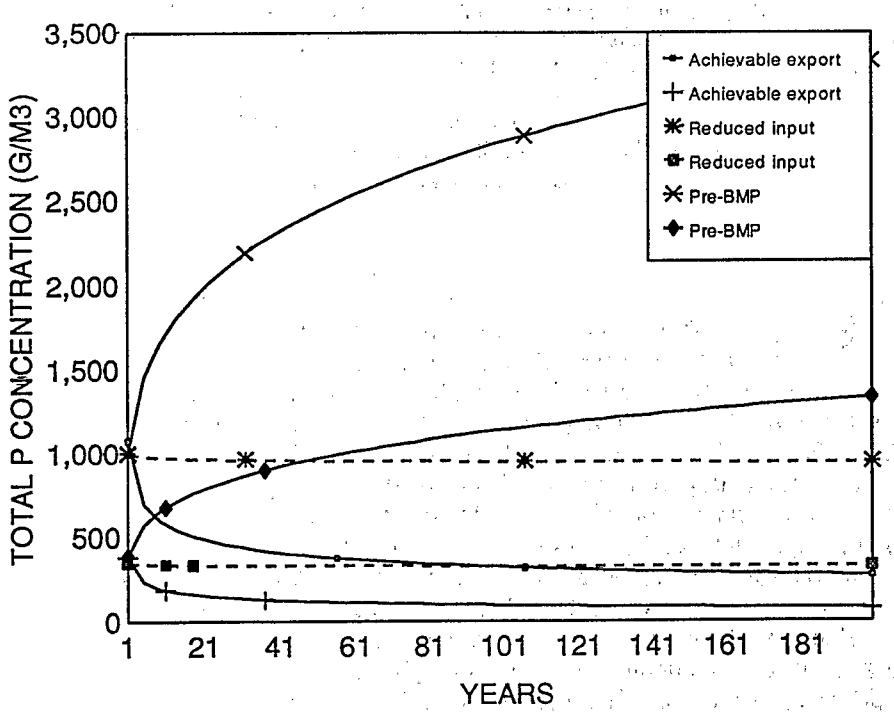

Figure 3.—Changes in field phosphorus concentrations resulting from alternative BMP scenarios.

Table 1.—Summary of phosphorus mass balance calculation to determine lag time for alternative BMPs.

PARAMETER	PRE-BMP	REDUCED FERTILIZER	ACHIEVABLE EXPORT
Initial Conditions			
MC_m (kg/ha)	36.	36.	34.
FC_f (kg/ha)	5.	0.	0.
PC_p (kg/ha)	0.036	0.036	0.036
Inputs (kg/ha)	41.036	36.036	34.036
YC_y (kg/ha)	34.	34.	34.
ECQ (kg/ha)	2.16	2.16	0.496
Outputs (kg/ha)	36.16	36.16	34.496
Results of BMP Scenarios			
For C_0 = 1,000 g/m^3			
C_e (gm/^{3})	3,257.	943.	230.
C_{90} (g/m^3)	3,031.	948.	307.
C_{50} (g/m^3)	2,128.	971.	615.
t_{90} (yrs)	107.	107.	107.
t_{50} (yrs)	32.	32.	56.
EC_eQ (kg/ha)	7.04	2.04	0.496
For C_0 = 350 g/m^3			
C_e (g/m^3)	1,140.	330.	80.
C_{90} (g/m^3)	1,061.	333.	107.
C_{50} (g/m^3)	745.	340.	215.
t_{90} (yrs)	37.	18.	37.
t_{50} (yrs)	11.	11.	11.

V = 100 m^3
for C_0 = 1,000 g/m^3, Θ = 46.3 yrs; EQ_{out} = 2.16 m^3/yr
for C_0 = 350 g/m^3, Θ = 16.2 yrs; EQ_{out} = 6.17 m^3/yr

Reduced Runoff

This application begins with the pre-BMP conditions, then at 50 years, the runoff export is reduced by 50 percent. This reduction might occur as a result of a decrease in runoff as when conservation tillage replaced conventional tillage or when concentrations are reduced in runoff as a result of erosion protection. The results from STELLA are presented in Figure 4A for the initial field concentration of 1,000 g/m^3 and in Figure 4B for the field phosphorus level of 350 g/m^3. For both situations, the reduction of phosphorus in the runoff export is short-lived. The field concentration and runoff export continue to increase over time because field inputs exceed outputs. Land management practices that are designed to contain nutrients in the field effectively reduce exports to a point; a further reduction in exports would require a reduction in inputs.

Reduced Fertilizer

For this application, phosphorus additions from manuring and precipitation remained, and no additional phosphorus was applied to the fields as fertilizer. Assuming a high field concentration of 1,000 g/m^3 (ppm), the new field concentration in equilibrium with these inputs and outputs would be 943 g/m^3 (Table 1). To obtain 90 percent of the change to this new field concentration would take 107 years (Fig. 3). The resulting runoff export would not change appreciably from the original export of 2.16 kg/ha. Only 32 years would be needed to achieve 50 percent of the change to a new concentration.

Assuming a low initial field concentration of 350 g/m^3, it would take 18 years to achieve a field concentration of 333 g/m^3 (90 percent change), and 11 years to reach a concentration of 340 g/m^3 (50 percent change) (Table 1).

Achievable Export

For this application, the runoff export was set to a final value of 0.496 kg/ha, which represents the average annual phosphorus export from the control Subwatershed 3 in the LaPlatte River watershed (Meals, 1990). We consider this value to be the achievable runoff export of phosphorus for agriculture in Vermont as described by Clausen and Meals (1989). Also for this example, the field inputs were reduced to equal yield outputs. To achieve 90 percent of the change from the original concentration to a new concentration would require 107 years, assuming a high field concentration (Fig. 4). Using a low field concentration, 37 years would be needed to achieve 90 percent of the change and 11 years to observe 50 percent of the change (Table 1).

Conclusions

The estimation of the lag time for a water quality response to BMP implementation shows that effects may take many years to occur, depending upon the amount of input reduction and initial field nutrient concentrations. For the St. Albans Bay RCWP, a new equilibrium in water quality, in response to the BMPs, was probably not reached during the monitoring period. This procedure is adaptable to setting various goals, such as a desired mass export level or some percent change in export. A significant reduction might be defined as exceeding two standard deviations of the average export before BMPs are implemented.

This method emphasizes the importance of managing water quality by managing the field concentration. Future nonpoint source studies evaluating the effectiveness of BMPs on nutrients in runoff should include a soil sampling program of total nutrient concentrations.

This procedure is applicable to other nutrients. Nitrogen, for example could be evaluated, although the mass balance equations would be more compli-

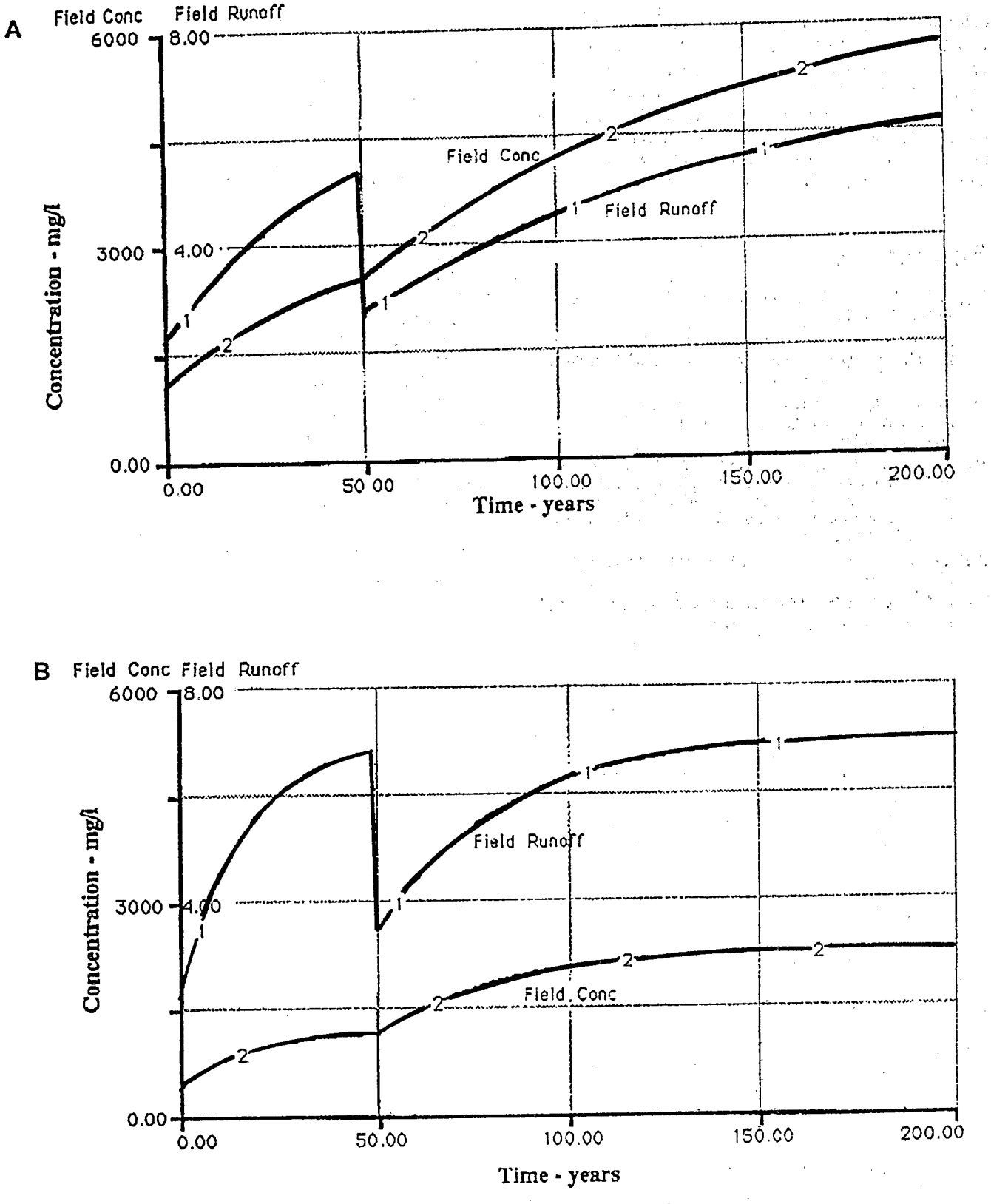

Figure 4.—STELLA output of changes in field phosphorus concentrations (g/m^3) and runoff phosphorus export(kg/ha) resulting from a 50 percent reduction in the export of phosphorus at 50 years for (A) initial field concentration = 1,000 g/m^3 and (B) initial field concentration = 350 g/m^3.

cated since volatilization, denitrification, and leakage could be prominent mass fluxes. Also, different soils and different crops would result in different lag times; however, the mass balance approach would be similar. This procedure for estimating the lag time for a water quality response to BMPs should aid in selecting appropriate BMPs and documenting the effectiveness of nonpoint source programs.

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Water Quality Trends in Big Pipe Creek During the Double Pipe Creek Rural Clean Water Program

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ABSTRACT

The Double Pipe Creek watershed in Carroll County, Maryland, was the focus of the Double Pipe Creek Rural Clean Water Program project initiated in 1980. The watershed encompasses 175 square miles divided into two subwatersheds: Little Pipe Creek and Big Pipe Creek, the latter being 58 percent of the total area in Double Pipe Creek watershed. Animal waste management facilities constructed as a result of the project increased animal waste storage capacity in the Double Pipe Creek basin by 28 percent; soil conservation practices reduced soil erosion by an estimated 4 percent. Water quality was monitored in the Big Pipe Creek subbasin between 1982 and 1985 and again between 1987 and 1990. Base flow and storm flow water quality were monitored at the base of the watershed in conjunction with a U.S. Department of the Interior Geological Survey streamflow gaging station. Results of the trend analysis indicated that ammonium and total organic carbon concentrations decreased significantly during the project period (44 percent and 51 percent, respectively), while total nitrogen and nitrate+nitrite nitrogen concentrations increased significantly (25 and 34 percent, respectively). Total Kjeldahl nitrogen, orthophosphate, total phosphorus, total suspended solids, and fecal coliform showed no significant change. While the increase in manure storage may have decreased nitrogen losses during storage and application, the amount of nitrogen being applied to cropland and lost through leaching increased, as suggested by the increasing concentrations of total nitrogen and nitrate+nitrite nitrogen. These results suggest that in addition to structural practices, more aggressive nutrient management efforts are needed in the basin.

The Double Pipe Creek watershed, 175 square miles located in Carroll County, Maryland, is divided into two subwatersheds, Big Pipe Creek and Little Pipe Creek (Fig. 1), which are 58 and 42 percent, respectively, of the total area in the Double Pipe Creek watershed. Double Pipe Creek watershed is predominately agricultural; dairy farming is the main activity. In 1980, approximately 18,000 dairy cattle produced more than 300,000 tons of manure, most of which was not stored in adequate facilities.

Water quality problems in the watershed were twofold: both fecal coliform and turbidity were at levels consistently in excess of State water quality standards. These problems were directly related to the large numbers of dairy cattle found in the basin. Animal manure is a source of fecal coliform that contributes, when poorly managed, to in-stream coliform levels. The basin's turbidity problems were aggravated by concentrations of animals around the streams and nutrient enrichment in the streams from year-round manure application on the fields.

The Double Pipe Creek Rural Clean Water Program (RCWP) project was initiated in 1980. Its primary goal was to improve water quality in the basin through the application of best management

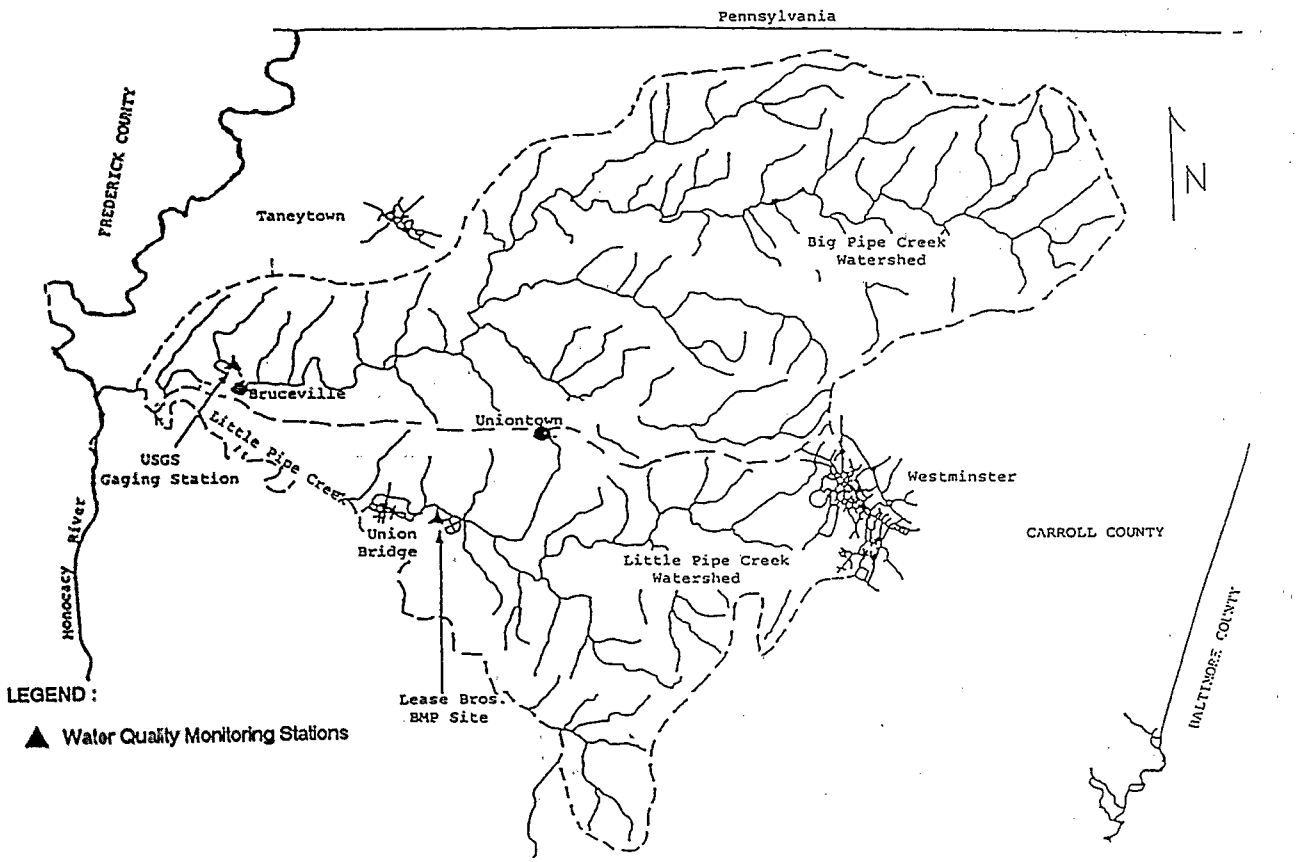

Figure 1.—Carroll County, Maryland, Double Pipe Creek Rural Clean Water Program project area BMP-nonpoint source monitoring sites.

practices (BMPs). The project's emphasis was management of animal waste. Its specific water quality goals were to reduce the level of fecal coliform bacteria in Big Pipe and Little Pipe creeks below the State standard of 200 MPN/100 mL (MPN is a standard total multiple-tube test) and to meet the State standard for turbidity in both streams (150 Nephelometric Turbidity Units [NTUs], Jackson Turbidity Units [JTUs], or the essentially obsolete Formazin Turbity Units [FTUs] or a monthly average of 50 units) at all times. The more general goal of the project was to improve water quality.

A water quality monitoring program to support the Double Pipe Creek RCWP was established to detect long-term trends in water quality, measure the effectiveness of BMPs, and determine the project's impacts on turbidity levels and fecal coliform.

Methods

Background

The water quality monitoring program has been conducted in two phases. Versar Inc., under contract with the Maryland Department of Health and Mental Hygiene, conducted a water quality monitoring program for the Monocacy River basin (Versar, 1982), with special emphasis on the Double Pipe Creek subwatershed. The work plan developed by Versar for the first phase of the water quality monitoring program had three objectives:

1. To establish a near-term water quality database for Double Pipe Creek,
2. To evaluate the short-term effectiveness of animal waste and erosion control practices, and
3. To plan a long-term monitoring program to be implemented at the conclusion of the Versar work.

Data was collected by Versar Inc. at the U.S. Geological Survey (USGS) gaging station on Big Pipe Creek at Bruceville and three single land use sites within the Double Pipe Creek basin from November 1982 to June 1985. Water quality and flow data were collected during storm events and periodically during base flow at all four sites.

The contract with Versar Inc. expired in 1986, the company provided a final report of its findings (Versar, 1986), and the monitoring stations were deactivated. Versar's final report included an ambitious design for Phase II of the water quality monitoring program that was too expensive to implement.

In 1987, the Bruceville site was reactivated by the Maryland Department of the Environment to begin Phase II of the water quality monitoring program. The work plan for Phase II (Md. Dep. Environ. 1989) called for monitoring at the Bruceville site on Big Pipe Creek and installation of a monitoring site in one small agricultural land use basin. This paper focuses on data collected at the Bruceville site.

Data Sources

Water quality and flow data during storm events were collected at the Bruceville site between 1982 and 1985 as part of Phase I and, since 1987, as part of Phase II of the water quality monitoring program. The stormwater quality and flow data from the two phases of the water quality monitoring program have since been merged into a single data set.

Water quality data have also been collected monthly at the Bruceville site since 1978 as part of the State's ongoing Core Monitoring Network. These data have been merged with the stormwater quality data (collected during Phase I and Phase II) for purposes of this analysis.

Frequency of Collection

Two to three storms per season (8 to 12 per year) were sampled at the Bruceville site during both phases of the water quality monitoring program. To maintain comparability between the data sets, the parameters were identical to those collected by Versar during Phase I.

Sampling Procedures

■ **Flow.** The Big Pipe Creek site is a USGS gaging station; the monitoring equipment was installed in an adjoining shed. Equipment was set up to use the specific streamflow rating tables calculated by USGS, whose local district office is contacted regularly for rating curve adjustments and flow records.

■ **Water Quality.** Base-flow sampling is conducted monthly at the Big Pipe Creek site. Samples are collected, packed in ice, and sent to the Maryland Department of Health and Mental Hygiene for analysis (Md. Dep. Health Human Hygiene, 1981). Flow proportioned composite stormwater quality samples are collected at the Big Pipe Creek site, where the automated water quality sampler is triggered by a calibrated flowmeter. Data on approximately 10 storm events per year are collected at the site.

The sampling equipment is stage-activated. Before a predicted event (any storm occurring during the work week with a 50 percent or greater chance of rain), the samplers are iced and serviced. Following a sampled storm event, field personnel collect the samples, perform necessary in-field operations, ice the samples, and return them to the laboratory. Then staff examine and service the equipment at the station and set it up to sample the next storm. Sampling lines are cleaned, flowmeters are recalibrated, and strip charts are retrieved (Md. Dep. Environ. 1989).

A portion of each sample is collected in a plastic bottle, packed in ice, and analyzed for total Kjeldahl nitrogen, volatile suspended solids, total phosphorus, total suspended solids, total organic carbon, and turbidity. Another portion is filtered through a 0.45 μm membrane filter, packed in ice, and analyzed in the laboratory for total Kjeldahl nitrogen, ammonium nitrogen, nitrate+nitrite nitrogen, orthophosphate, dissolved organic carbon, and total dissolved solids. A separate sample is collected in a sterilized 250 mL plastic bottle pretreated with thiosulfate and packed in ice until processed in the laboratory for total and fecal coliform. Total nitrogen is calculated as the sum of total Kjeldahl nitrogen plus nitrate+nitrite nitrogen.

Data Handling and Analysis

Water quality data collected by Versar during Phase I, by the Maryland Department of the Environment as part of the Core Monitoring Program, and during Phase II of the RCWP water quality monitoring program were compiled in a single database and verified for analysis in this paper. The data set contains storm event and base-flow water quality data collected between 1982 and 1990. The data were then plotted against time (Fig. 2) and the plots were reviewed. The Maryland Department of Health and Mental Hygiene laboratory detection limits for orthophosphate, ammonium, and total phosphorus were 0.1, 0.2, and 0.1 mg/L, respectively, on numerous occasions between January 1983 and November 1985. Current laboratory detection limits for these parameters are .004, .008, and .01, respectively.

Changes in detection limits over the time period of interest complicate trend analysis. When data are

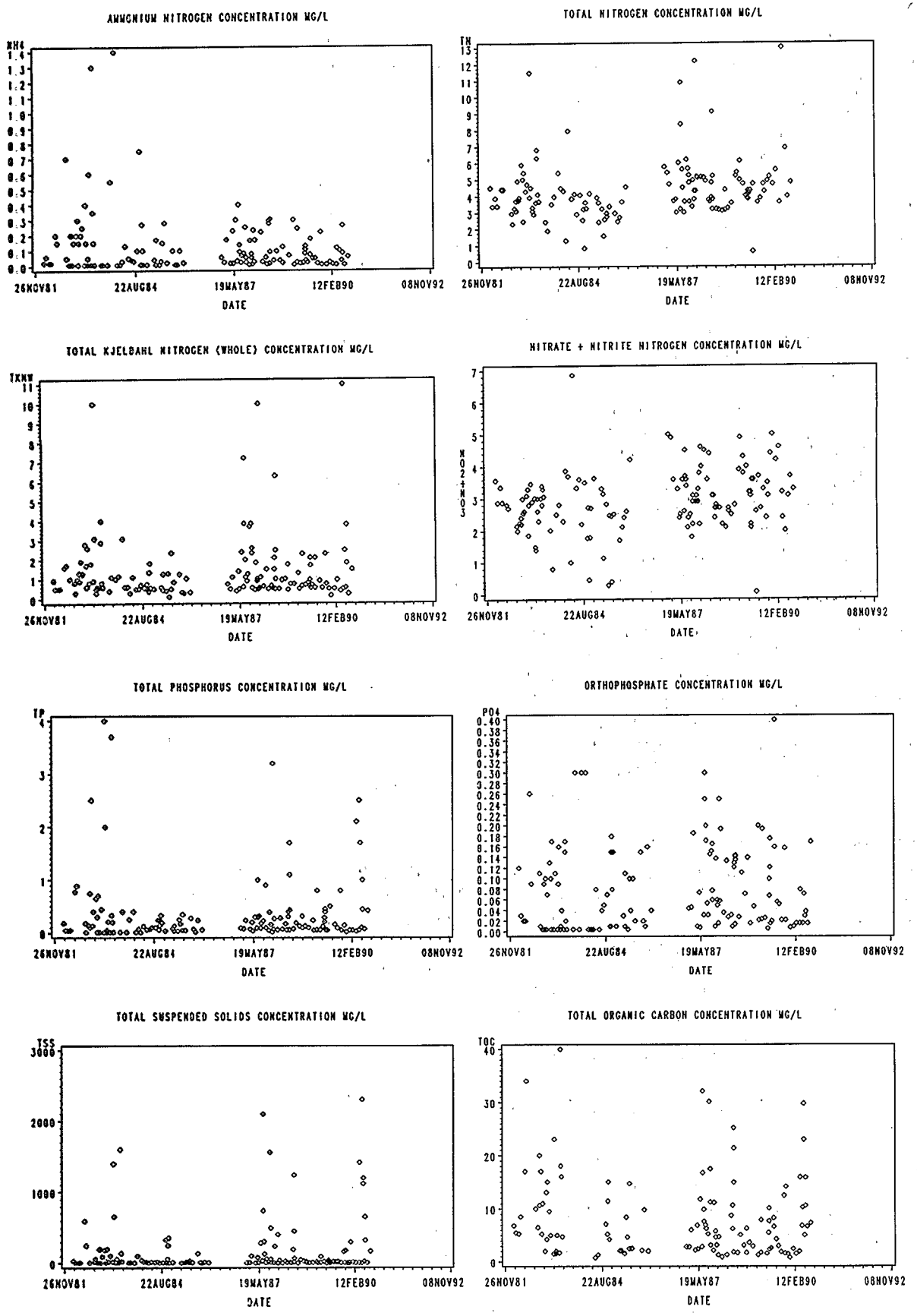

Figure 2.—Big Pipe Creek at Bruceville data set.

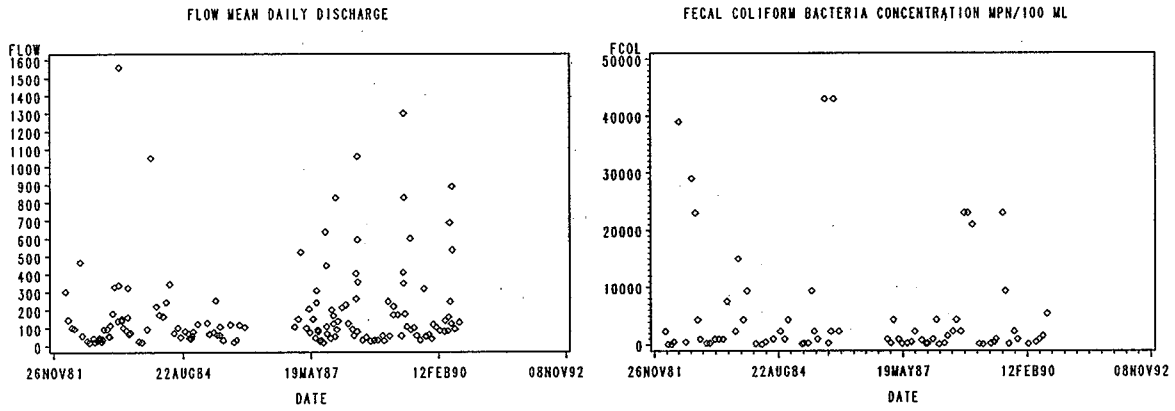

Figure 2.—Continued.

simply assigned the value of the detection limit, a false decreasing trend may be observed in cases where the higher detection limit occurs earlier in the period of record. The higher detection limits provide estimates for the earlier period that are set at the upper limit of possible values, making it more likely that an improvement in water quality will be detected and increasing the probability that the trend will be incorrect.

When data are assigned the value of the lower detection limit, estimates for the earlier period are set at the lower limit of possible values, resulting in a conservative data set for evaluating negative trends. This approach makes it less likely that an improvement in water quality will be detected; however, it also minimizes the chance that an incorrect finding of improvement in water quality will be reported. By using both approaches, both the upper and lower boundaries of the trend are defined.

Two different methods were used to evaluate time trends in the data. Simple linear regression of the water quality constituent of interest against two parameters, time and time squared, results in a curved line fit to the data. The significance of the time parameters of the regression model indicates the significance and direction of the overall time trend. The second trend analysis method involves the LOWESS method (Cleveland, 1979). The LOWESS curve, which is a smooth line through the center of the data, results in a visual confirmation of the trend.

The trend analysis was first carried out on the log transformed data. Log transformation spreads out the distribution of data in the lower concentration ranges where arithmetically plotted data tend to bunch up. In addition, the data more closely follow a normal distribution and have constant variance, both necessary assumptions of linear regression analysis. The final step in the trend analysis was to regress the log transformed water quality data against flow and season. The residuals of this regression were then regressed against time and time squared to give an indication of trends in the data adjusted to account for differences in streamflow.

Results

Time plots of water quality and flow are given in Figure 2. The results of the trend analysis on log transformed data are presented in Figure 3. Each of these plots presents a scatter plot of the log transformed data, a smoothed line through the data, the regression line for log transformed constituent concentrations against time, and a reference line at the mean predicted log concentration. A significant increasing trend (95 percent confidence level) for total nitrogen is shown. Figure 3 also shows a significant (90 percent confidence level) increasing trend in nitrate+nitrite nitrogen concentrations and no trend in total Kjeldahl nitrogen or ammonium concentrations. A significant decreasing trend (90 percent confidence level) in orthophosphate concen- trations and a significant (90 percent confidence level) increasing trend in total phosphorus concentrations are shown in Figure 3. Figure 3 also shows no trend in either total suspended solids or total organic carbon concentrations and a significant increasing trend (95 percent confidence level) in flow and no trend in fecal coliform.

As presented above, the variability in the data is only addressed using time. Concentration is a function of flow for most constituents and flow varies both seasonally and annually. Flow during the study period increased significantly with time. To detect a true trend it is necessary to adjust the data for both flow and seasonal variations. In effect, by holding flow and seasonal differences constant, the relation-

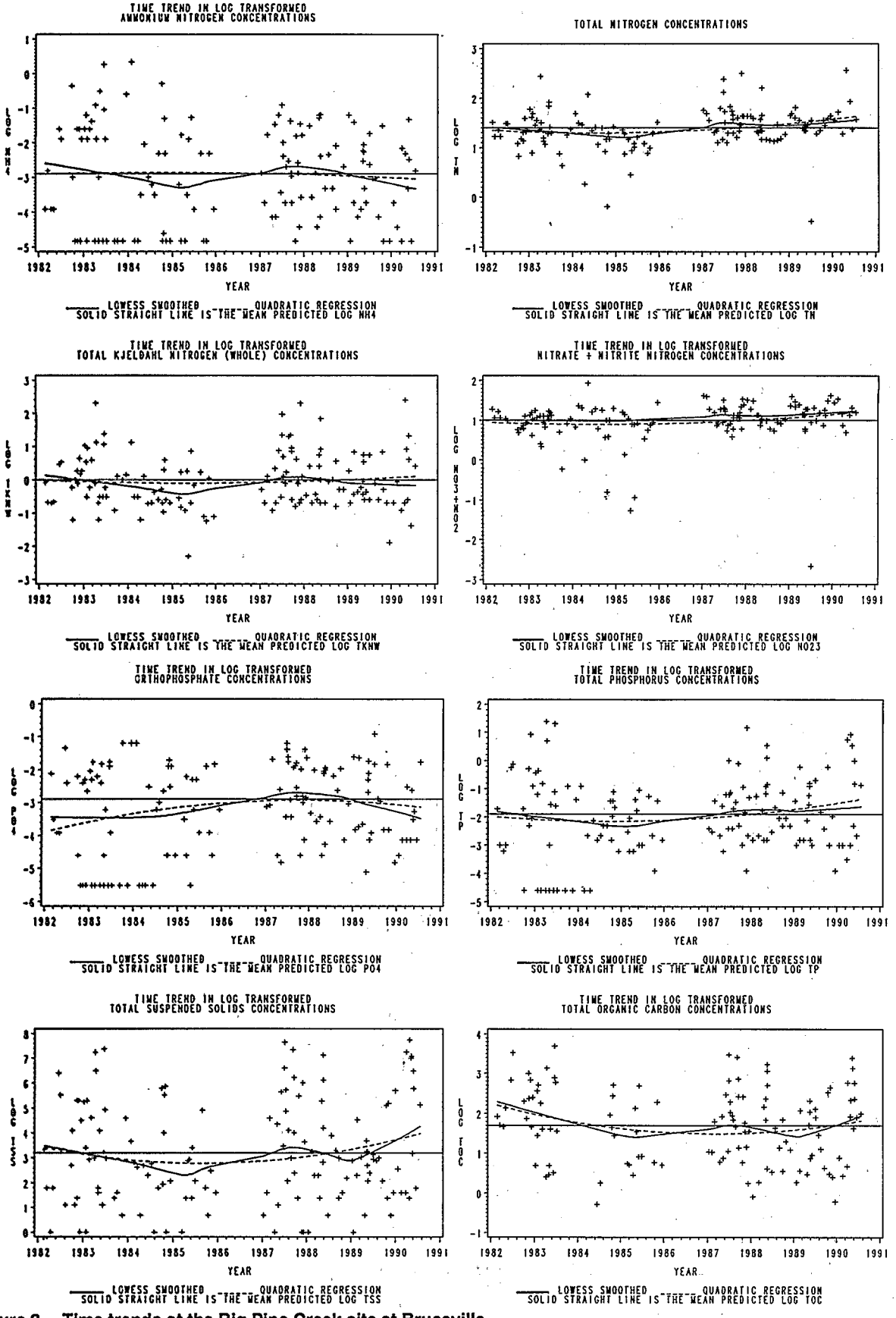

Figure 3.—Time trends at the Big Pipe Creek site at Bruceville.

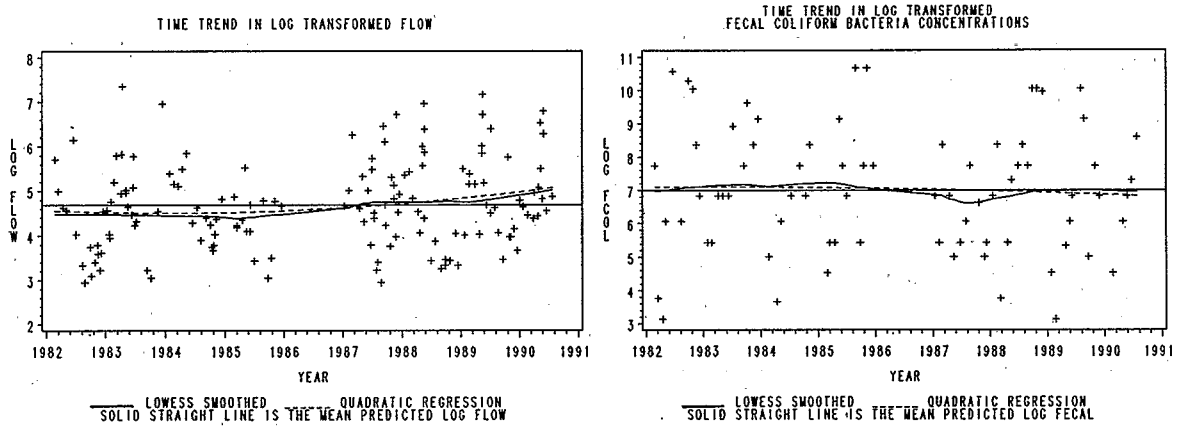

Figure 3.—Continued.

ship between concentration and time (trend) can be determined.

Time trends in flow- and season-adjusted residuals are presented in Figure 4, including a scatter plot of the flow and season adjusted residuals, a smoothed line through the data, the regression line for flow- and season-adjusted residuals against time, and a reference line at zero. Figure 4 shows a significant (90 percent confidence level) decreasing trend in ammonium concentrations, significant increasing (95 percent confidence level) trends in total nitrogen and nitrate+nitrite nitrogen concentrations, and no trend in total Kjeldahl nitrogen concentrations. No trend in orthophosphate, total phosphorus, and total suspended solids concentrations was evident; however, a significant (95 percent confidence level) decreasing trend in total organic carbon concentrations was observed. Figure 4 shows no trend in fecal coliform. When the data were kept at the upper detection limit for the analysis, there was a significant trend (90 percent confidence level) in ammonium concentrations; however, decreasing trends (95 percent confidence level) in total phosphorus and orthophos- phorus were also significant.

Discussion

The project established two specific quality goals. The first was to meet the State's water quality standards for fecal coliform at all times. The State water quality standard for fecal coliform is 200 MPN/100 mL, based on a minimum of five samples taken within a 30-day period (10 percent of the samples taken during the 30-day period may not exceed 400 MPN/100 mL [Code Maryland Reg. 1989]).

Figure 5 shows the fecal coliform data collected during this study and a reference line at the 200 MPN/100 mL level. Most of the data collected during the study was above 200 MPN/100mL. Seventy-one percent of the samples collected during this study exceeded 400 MPN/100 mL. These data indicate that fecal coliform standards are regularly exceeded in the creek.

The BMPs implemented by this project were designed to manage manure and reduce soil erosion. The BMPs used in association with this project did not appear to reduce fecal coliform densities in Big Pipe Creek; therefore, additional work is required to determine what practices would accomplish this objective.

The second specific water quality goal of the project was to meet the State's water quality standard for turbidity at all times. The State standard for turbidity states that "turbidity in the surface water resulting from any discharge may not exceed 150 units at any time or 50 units as a monthly average" (Code Maryland Reg. 1989). The units of measurement may be NTU, JTU, or FTU. Between 1982 and 1990, the turbidity in Big Pipe Creek exceeded the State standard on several occasions (Fig. 5). Using the turbidity water quality standard as a measure of nonpoint source pollution is a problem because the standard was developed for point sources. (Turbidity is closely associated with the concentration of suspended solids in a stream.) As has been shown (Fig. 2), considerable variation was evident in the concentration of total suspended solids in Big Pipe Creek. The variation in in-stream suspended solids concentrations depends on flow, land use, rain fall intensity, antecedent moisture, and a number of other factors. The application of this standard during storm events always produces substandard results. Since this standard was not designed for nonpoint source pollution, the selection of the State's turbidity standard was an inappropriate objective for this project.

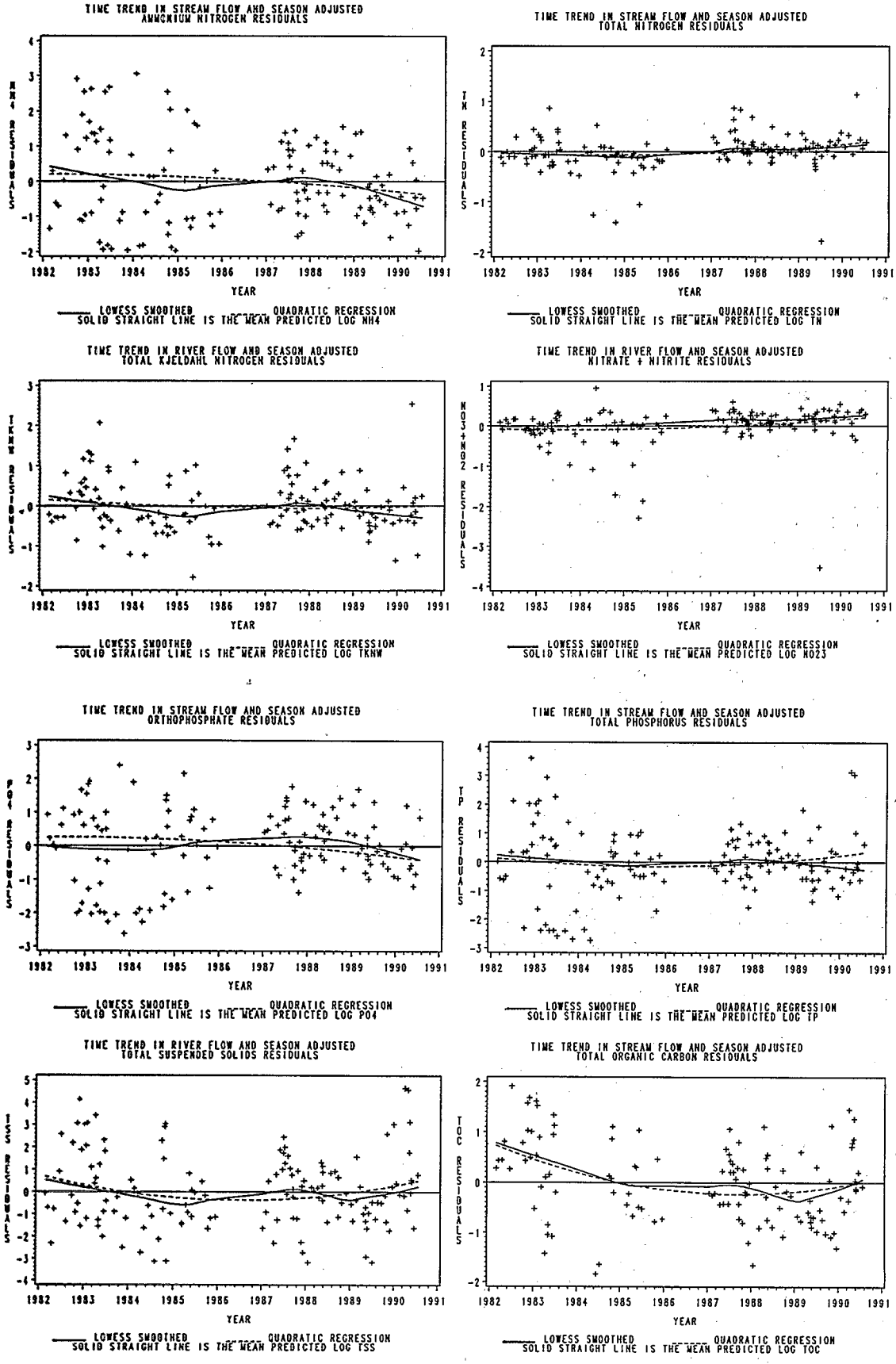

Figure 4.—Time trends at the Big Pipe Creek site at Bruceville.

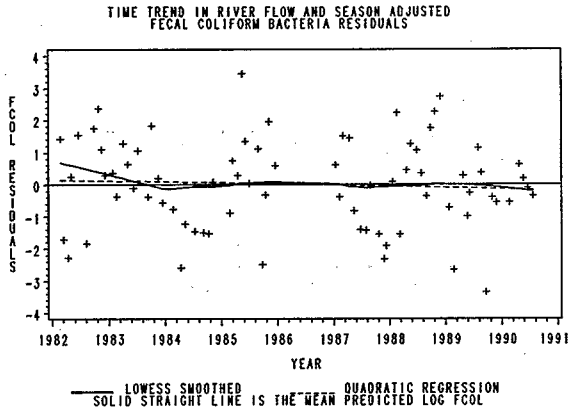

Figure 4.—Continued.

The more general goal of this project was to improve water quality. To assess the degree of expected change in water quality, the magnitude of change resulting from the land treatment should be estimated. From 1982 through 1990, the RCWP and farmers in the basin invested approximately $3,400,000 in best management practices. The RCWP's investment in the basin was approximately $2,700,000. The installation of BMPs in the basin resulted in an estimated 25,646 ton reduction of in-field soil erosion from cropland per year and the storage of 99,919 tons of manure per year by 1989. Based on an average erosion rate of 9.6 tons of soil per acre of cropland for the basin, the net reduction of in-field soil erosion from cropland was approximately 4 percent. Based on the livestock population numbers for 1989, the net quantity of stored manure increased by 28 percent (Table 1). The reduction in soil erosion and the increase in stored manure can be converted into pounds of nitrogen (N) and phosphorus (P) using the conversion factors of 1.1 pounds of P/ton and 5.4 pounds of N/ton for soil and 1.3 pounds of P/ton and 7.0 pounds of N/ton for manure (U.S. Environ. Prot. Agency, 1987). The net reduction of nutrients available from eroded soil and manure as a result of the implementation of BMPs was 13 percent for both N and P.

The water quality results to date indicate that, during the period from 1982 through 1990, ammonium and total organic carbon concentrations decreased with time. Based on the predicted values from the regression of the flow- and season- adjusted residual against time, ammonium concentrations have decreased 44 percent and total organic carbon concentrations have decreased 51 percent over the period.

The decreasing trends in ammonium and total organic carbon concentrations are encouraging. They indicate that some of the more mobile forms of nutrients and organic matter are being held up in the system, possibly the result of land treatment sponsored by the Double Pipe Creek RCWP. The project increased the storage of animal waste in the basin by approximately 99,919 tons/yr and decreased the quantity of nitrogen and phosphorus readily available from manure for transport to the stream system by 28 percent. The trends may indicate that less manure is being washed off the land surface (ammonium and total organic carbon are major constituents in manure runoff).

Estimates show that the project has reduced the quantity of nutrients available for export from soil erosion and manure application in the basin by approximately 13 percent (Table 1). This reduction has not shown up in orthophosphate and total phosphorus constituent trends because a 13 percent change is too slight to be statistically detected given the large natural variability in these concentrations with changes in river flow. Orthophosphate and total phosphorus are more generally associated with soil erosion and sediment transport and are thus more influenced by storm events than ammonium and total organic carbon, making trends much more difficult to detect.

Similarly, estimates indicate that the project has reduced soil erosion by only 4 percent. This reduction has not shown up in total suspended solids constituent trends because the magnitude of the change is too small to be statistically detected given the variability of total suspended solids concentrations with storm events.

The increasing trend in nitrate+nitrite nitrogen, which leads to a corresponding increase in total nitrogen, indicates that the soluble forms of nitrogen are leaching through the system. A variety of factors

Table 1.—Manure, soil, and nutrient savings resulting from Double Pipe Creek RCWP implementation.

	TOTAL (TONS/YR)	NUTRIENT EQUIVALENT (TONS/YR)		REDUCTION (TONS/YR)	NUTRIENT EQUIVALENT (TONS/YR)		PERCENT REDUCTION	
		N	P		N	P	N	P
Manure	361,228	1,264	235	99,919	350	65	28	28
Soil	696,960	1,882	383	25,646	69	14	4	4
Total		3,146	618		419	79	13	13

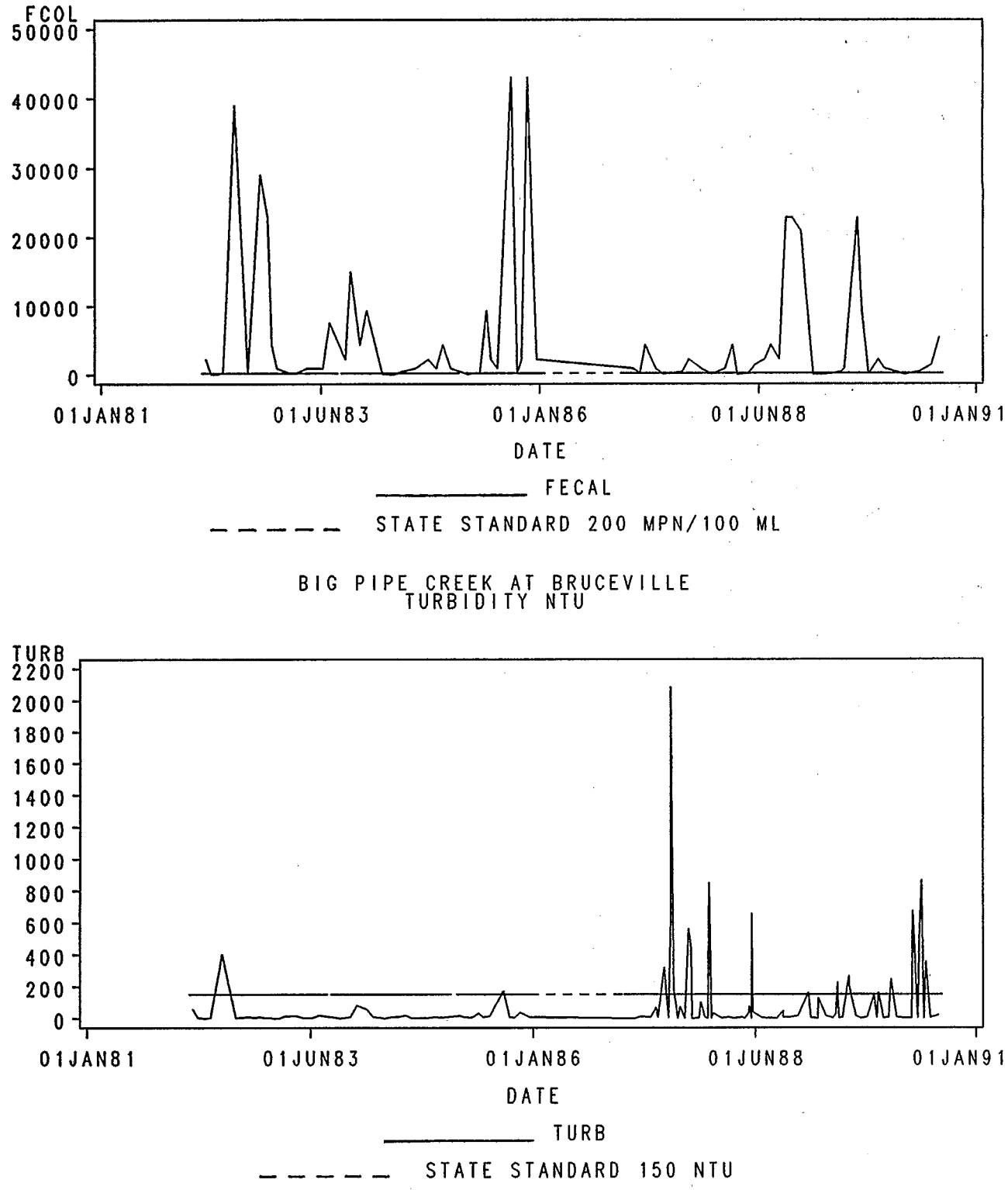

Figure 5.—Big Pipe Creek at Bruceville, fecal coliform MPN/100 mL.

is probably contributing to the observed increase in nitrate+nitrite nitrogen. The increased use of conservation tillage in the region over the last 15 years may have increased infiltration and thus increased the leaching of soluble chemicals into the groundwater. The increased storage of animal waste has reduced nitrogen losses to the atmosphere and to streams through direct runoff. However, storage of animal

waste does result in more manure being applied to fields, which increases the potential for leaching. The proper timing of manure applications and the incorporation of applied manure also reduces atmospheric loses of nitrogen and increases the quantity of nitrogen being applied. Increased atmospheric deposition of nitrogen and increasing numbers of residences with septic systems also contribute to the nitrogen load increases.

Future Work

The water quality monitoring program is scheduled to continue indefinitely. Water quality monitoring at the single land use site will be extend into 1993, depending on the implementation schedule for BMPs. The 15-year report for the Double Pipe Creek RCWP will include a trend analysis for 1982 through 1994 and a before-and-after study of BMP effectiveness at the single land use site.

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Effects of Nutrient Management on Surface Water Quality in a Small Watershed in Pennsylvania

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ABSTRACT

The effects of nutrient-management practices on surface water quality were investigated from 1984 to 1989 in a mostly agricultural watershed underlain by carbonate rock in the Conestoga River headwaters in Lancaster County, Pennsylvania. Nutrient management applied to approximately half the cropland in the watershed resulted in no significant change in median base-flow nitrate nitrogen concentrations after 3.5 years. Changes in surface water quality were evaluated using a pre- and posttreatment design supplemented by a paired-subbasin experiment. Base-flow nutrient concentration data were collected for 24 months prior to implementation and for 42 months after the implementation of nutrient management. Dissolved nitrate plus nitrite concentrations in monthly base-flow samples from the watershed ranged from 1.7 to 14 mg/L as nitrogen largely as a result of seasonal- and flow-related dependencies. Dissolved nitrate plus nitrite concentrations exceeded 10 mg/L as nitrogen in 3 percent of the samples collected before and 9 percent of the samples collected after implementation of nutrient-management practices. An average 67 percent of the monthly nitrogen load in surface water discharged from the watershed was nitrate nitrogen.

The paired subbasins consisted of two 1.4 square-mile subbasins — one in which nutrient management was not prescribed and one in which nutrient-management practices were applied to 90 percent of the tillable land. No significant change was detected in median dissolved nitrate plus nitrite concentrations in the base flow despite an estimated 35 percent decrease in nitrogen applications to cropland in the nutrient-management subbasin. No significant change was detected in median dissolved nitrate plus nitrite concentrations in the base flow in the nonnutrient-management subbasin. Analysis of covariance detected a significant change in the relation between concurrent dissolved nitrate plus nitrite concentrations in base flow from the subbasins. Dissolved nitrate plus nitrite concentrations exceeding 10 mg/L as nitrogen were detected in 3 percent of base-flow samples collected from the nutrient-management subbasin both before and after implementation of nutrient management.

Trends toward expanding farm animal populations, although of substantial economic benefit to agricultural producers in the United States, have left many producers with large quantities of excess manure. This manure is commonly disposed of by application to cropland, and, in some areas, it greatly exceeds commercial fertilizers as the largest source of nutrients to agricultural lands. The result can be excessive fertilization and nonpoint-source contamination of surface and groundwater resources. In one small watershed in the Conestoga River headwaters in Lancaster County, Pennsylvania, excessive fertilization from repeated and localized land applications of manure, in addition to applications of commercial fertilizers, has been implicated as a major source of excessive nutrient concentrations in the surface and groundwater resources of the area (U.S. Dep. Agric. 1984). Nitrate concentrations in stream base flow average about 7 mg/L as nitrogen and have occasionally exceeded the 10 mg/L Maximum Contaminant Level Goal for drinking water (U.S.

Environ. Prot. Agency, 1986). Reducing the effect of nutrient applications on water quality through nutrient management, an agricultural best management practice (BMP), is a goal of the Rural Clean Water Program (RCWP) projects. Although implementation of BMPs is an important step toward the goal of improved water quality, more specific information about the effectiveness of individual BMPs is needed. To provide that information, a 5.5-year investigation of the effects of the nutrient-management BMP on surface water quality was completed by the U.S. Geological Survey (USGS) in cooperation with the Pennsylvania Department of Environmental Resources (PADER), Bureau of Water Quality Management, under the aegis of the RCWP.

Purpose and Scope

This paper summarizes the effects of nutrient management on surface water quality in a small watershed (5.82 square miles) and a smaller subbasin (1.4 square miles) in the watershed located in the Conestoga River headwaters (Fig. 1). Hydrologic, BMP-implementation, and agricultural-activity data were collected from April 1, 1984, through September 30, 1989 — from 2 years prior to the implementation of the nutrient-management BMP to 3.5 years after implementation. Also presented are qualitative and statistical inferences regarding the effects of nutrient management on surface water quality, principally base-flow nitrate-nitrogen concentrations and loads.

Methods

The investigation consisted of a before and after treatment experiment and a paired-subbasin experiment. The experimental treatment was the implementation of nutrient management, that is, the use of animal-waste and fertilizer best management practices as defined by the Agricultural Stabilization and Conservation Service (ASCS). The paired subbasins were added to the study after preliminary contacts with landowners indicated that contracted nutrient-management implementation would be clustered in a specific area of the watershed. This

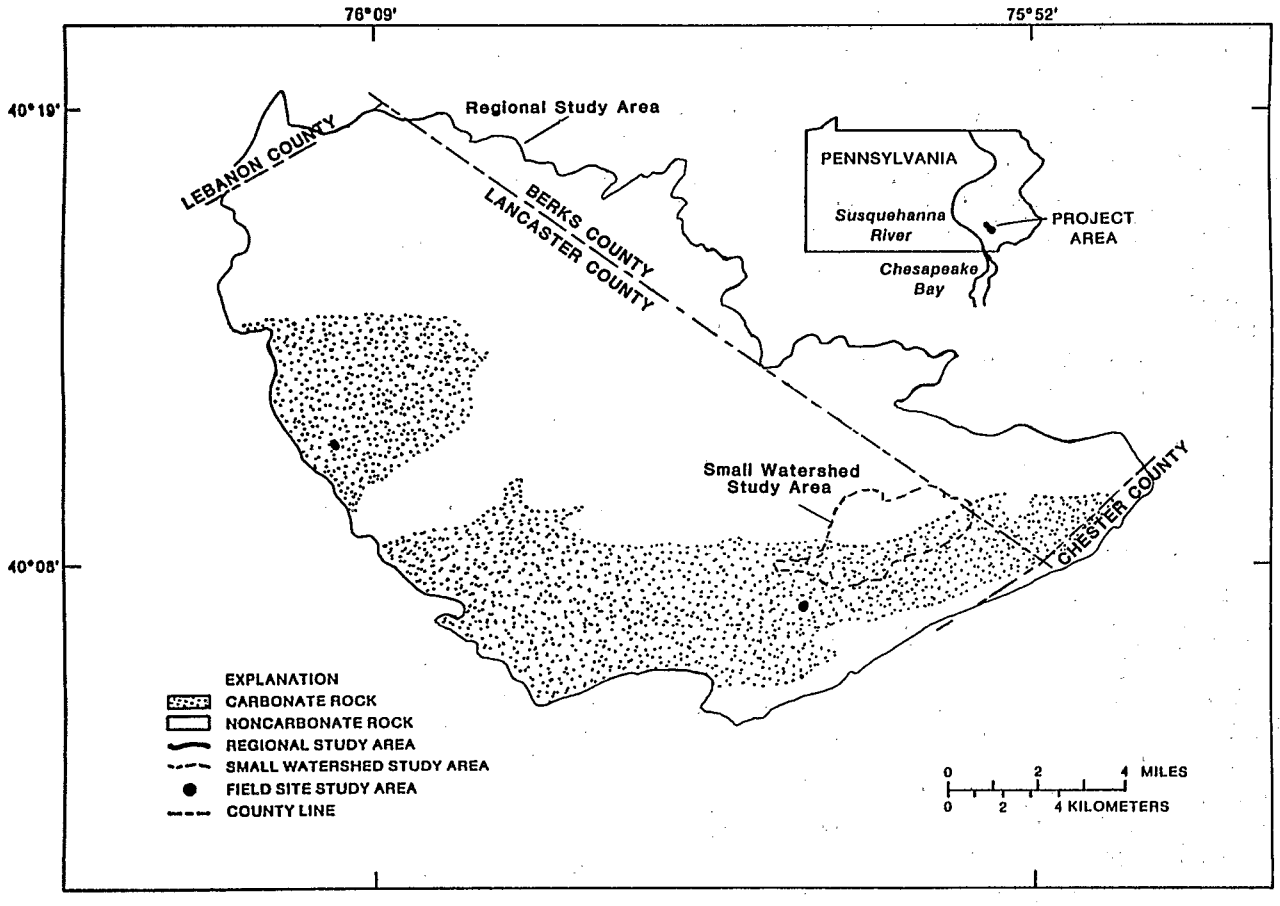

Figure 1. — Location of the small watershed.

area, the nutrient-management subbasin, was located in the eastern part of the watershed where about 90 percent of the agricultural land was under RCWP contract. The nonnutrient-management subbasin, where farm operators chose not to participate in the RCWP, was located in the northwestern part of the watershed.

The evaluations presented in this report on the effects of nutrient management on surface water quality are qualitative. Initially, a major objective of the investigation was to quantify the effects of nutrient management on base-flow water quality. However, quantitative evaluation requires separation of all non-BMP influences from BMP influences on water quality and the development of a statistically and functionally sound relationship between agricultural activities and water quality. Although a simple multilinear regression model of the relationship was constructed, factors, such as undefined variation in nutrient-application timing and location and groundwater recharge timing and quantities, prevented the use of the regression model.

Data Collection

Data including precipitation, agricultural activity, and water quality were collected according to a collection schedule summarized in Table 1. Precipitation data were recorded by an accumulating precipitation gage located near the southern boundary of the study site. Nutrient-management plans were prepared by the Lancaster County, Nutrient-Management Office operated by the Pennsylvania State University Cooperative Extension Service. Agricultural-activity data from the nutrient-management subbasin were collected by staff from the Lancaster County ASCS during semiannual interviews with farm operators. Information collected included statistics on

- animal populations,
- applications of manure and commercial fertilizer,
- manure exports, and
- crop acreages.

Agricultural-activity data for remaining areas of the watershed were limited to crop acreages and animal populations collected during initial contact by RCWP personnel. Estimates of manure nutrients produced in, applied in, and exported from the nutrient-management subbasin were calculated by multiplying manure quantities produced, applied, or exported by nutrient-content values supplied by the ASCS, for livestock and poultry manure. The manure quantities produced were calculated from animal-unit averages for the pre- and post-BMP periods.

Table 1.—Data collection schedule for the small watershed study.

SOURCE	DATA TYPE	FREQUENCY
2 continuous-record stations	Water quality	Monthly during base flow and major storms
3 partial-record stations	Water quality	Monthly during base flow
7 soil-sampling sites	Soil nutrients	Spring and fall
1 precipitation gage	Precipitation intensity and total accumulation	5-minute intervals
13 farm operators[1]	Agricultural activity	Spring and fall

[1]Nutrient-management subbasin only.

Streamflow was recorded continuously at stations that drained the nutrient-management subbasin and the entire watershed. Instantaneous streamflow was measured at the time of base-flow sampling at all other stations. Base-flow water quality samples were collected by USGS and PADER personnel and measured or analyzed for total and dissolved forms of ammonia, ammonia plus organic nitrogen, nitrate plus nitrite, nitrite, and total phosphorus. All nutrient concentrations are expressed as elemental nitrogen for the nitrogen species and elemental phosphorus for the phosphorus species. All statistical tests were evaluated for significance at the 95 percent confidence interval ($p \leq 0.05$). Additional detail on data collection and methods for the Conestoga Headwaters RCWP are published in Chichester (1988).

Site Description

The 5.82-square mile watershed (Fig. 2), about 50 percent underlain by carbonate rock, is drained by the Little Conestoga Creek and includes all or part of 43 farms. The nutrient-management subbasin covers 1.42 square miles and the nonnutrient-management subbasin covers 1.43 square miles. Both subbasins are underlain by carbonate and noncarbonate rock, but about 24 percent less of the nonnutrient-management subbasin is underlain by carbonate rock. Land use in the watershed and the subbasins is predominantly agriculture (Table 2). During the study, about 50 percent of the total crop acreage in the nutrient-management subbasin was planted in corn; 22 percent, in hay (alfalfa or alfalfa and grass mixes), and about 8 percent was pasture. Limited land-use data for the nonnutrient-management subbasin indicates that about 65 percent of the cropland was planted in corn.

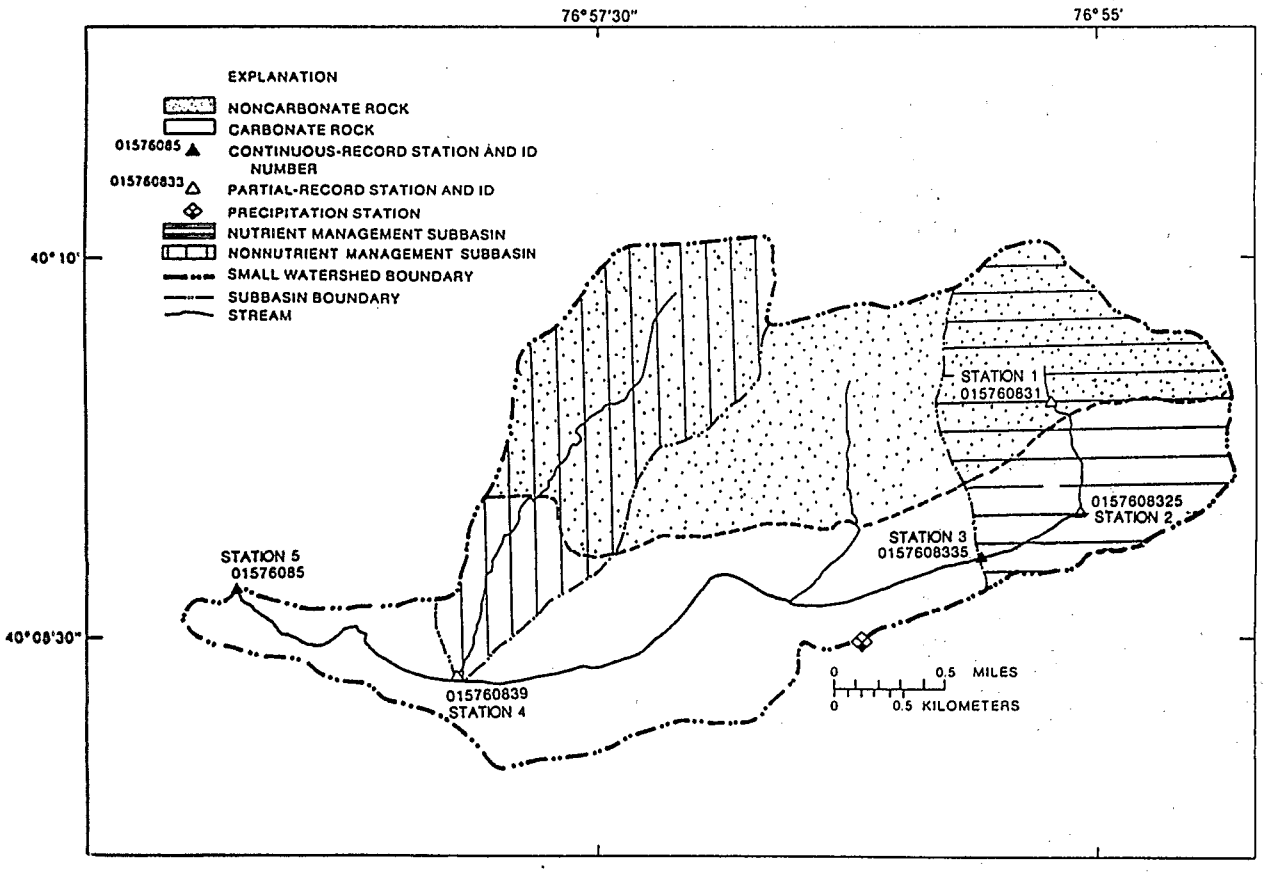

Figure 2.—Surface water and precipitation station locations.

Table 2.—Land use in the watershed by percent of total land-use area (computed from U.S. Department of Agriculture photographs).

	WATER-SHED	NUTRIENT-MANAGEMENT SUBBASIN	NONNUTRIENT-MANAGEMENT SUBBASIN
Agriculture	76.0	78.0	68.0
Woodland	21.4	20.6	30.6
Urban	2.6	1.4	1.4

■ **Precipitation.** The long-term average annual precipitation for the watershed is approximately 41.5 inches. Precipitation during each of the study years, 1985, 1987, and 1988 was within 5 percent of the long-term average. Precipitation averages for the first year of the pre-BMP period, 1984, and the first year of the post-BMP period, 1986, were 14 and 25 percent below the long-term average, respectively.

■ **Streamflow.** At Station 3, the average flow for the study period was 0.9 cubic foot per second per square mile and, at Station 5, the flow was 1.0 cubic foot per second per square mile. The base-flow contribution to total monthly streamflow averaged 65 percent.

■ **Best Management Practices and Agricultural Activities.** Nutrient-management implementation began in April 1986. In the first year, nutrient-management plans were prepared for 11 of 14 farms in the nutrient-management subbasin and 13 of 43 farms in the entire watershed (Fig. 3). By 1989, 11 additional farms in the watershed had implemented nutrient-management plans. Farm operators in the nonnutrient-management subbasin did not participate in the RCWP or supply agricultural-activity data; therefore, farming practices there were assumed to remain constant. However, some farms did receive nutrient-management plans during the period of the study.

In the nutrient-management subbasin, the plans included fertilizer management (both manure and commercial fertilizer) on 10 of the cooperating farms, and animal-waste management on one farm. The nutrient-management plan supplied nutrient-application recommendations intended to allow desired crop yields and minimize nutrient availability for transport to groundwater or in surface runoff. Not all plans recommended reductions in nutrient applications. Nutrients deposited by grazing livestock

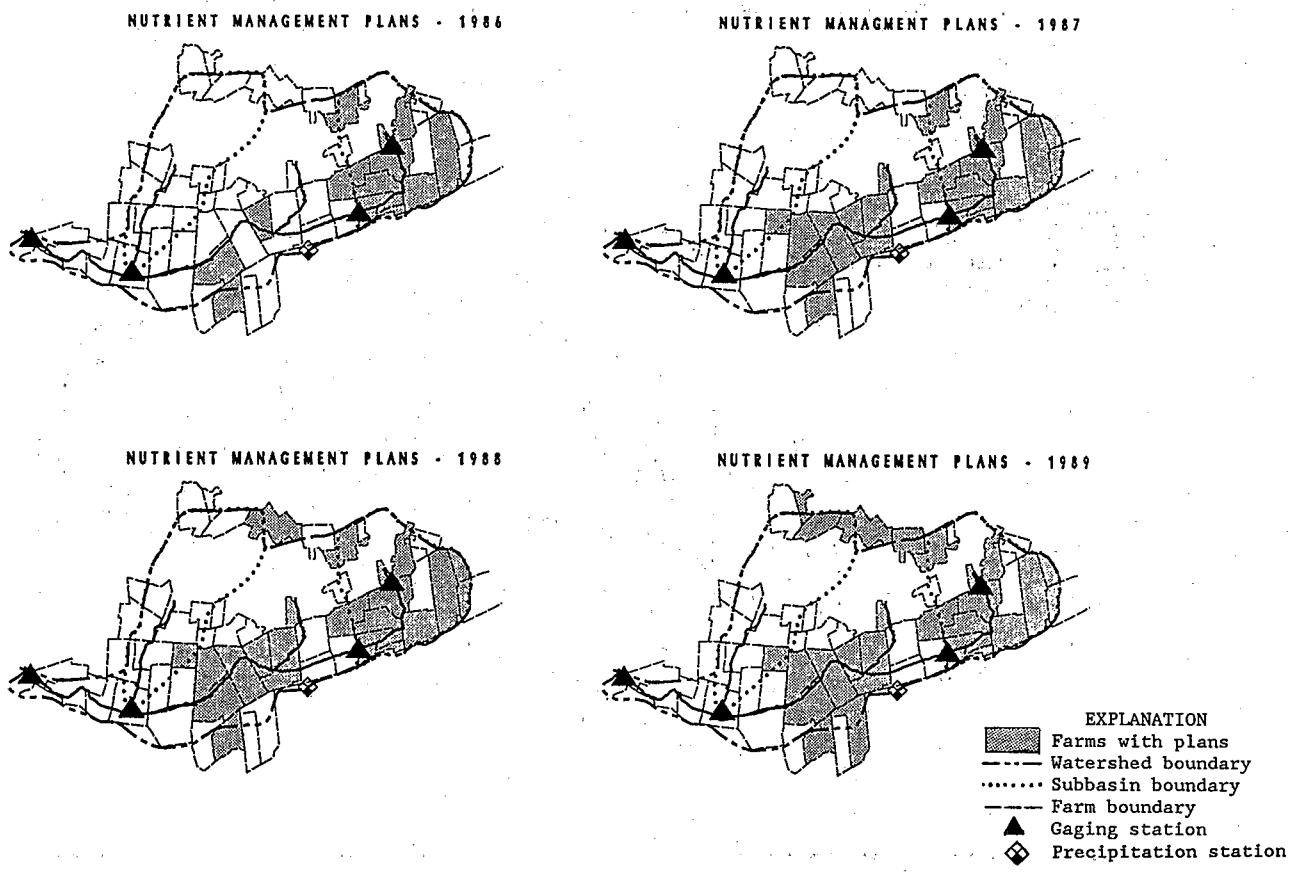

Figure 3.—Annual nutrient management plan census from 1986 through 1989 for farms in the watershed.

were not accounted for in the nutrient-management plans. Because nutrient management plans may require manure storage for as many as 180 days, one farm with a large swine population increased its manure storage capacity to 200 days by the addition of a storage tank.

Animal populations in the watershed included beef and dairy cattle, sheep, swine, poultry, and draft animals. In the nutrient-management subbasin animal populations on individual farms varied considerably from year to year and within a year but, in the subbasin overall, the proportioning of animal types was generally stable. The total animal population consisted of about 50 percent poultry, 30 percent dairy, and 15 percent swine by weight. Estimates of manure and manure-nutrient production indicate that poultry and dairy manure contributed, by weight, 40 and 35 percent, respectively, of the total manure-nutrient production (Table 3). Manure-nutrients production decreased about 5 percent in the post-BMP period.

Agricultural-activity data indicate that manure applications were the largest nutrient input to cropland (Table 4). Grazing livestock deposited an estimated additional 22,000 and 18,000 lb of nitrogen, respectively, and 4,200 and 3,500 lb of phosphorus, respectively, annually in the pre- and post-BMP periods. The contribution of nitrogen and phosphorus from commercial fertilizers (Table 4) was nearly equal to that from manure deposited by grazing livestock. Average annual applications of nitrogen and phosphorus to cropland in the nutrient-management subbasin decreased about 35 percent from the pre- to post-BMP period. Not all of the decrease was a result of nutrient management; reductions in the number of animal units and in the acreage being actively farmed accounted for an estimated 5 percent of the 35 percent decrease. Because of uncertainties in the agricultural-activity data, actual reductions in nutrient applications may differ from estimated reductions by 20 percent or more.

Comparison of manure production and application data show that between 30 and 50 percent of the estimated manure production was not accounted for either as applications or export. A large part of the "missing" production was probably applied to cropland outside the subbasin. Because this manure

Table 3.—Manure and nutrient production in the nutrient-management subbasin.

MANURE TYPE	PERIOD	AU	MANURE PRODUCTION (tons)	NITROGEN PRODUCED (lb)	PHOSPHORUS PRODUCED (lb)
Dairy	Pre-BMP	476	14,760	147,600	26,570
	Post-BMP	472	25,610	256,100	46,100
Beef	Pre-BMP	120	2,640	29,040	9,240
	Post-BMP	107	4,120	45,320	14,420
Swine	Pre-BMP	218	3,840	53,760	16,900
	Post-BMP	188	5,790	81,060	25,480
Poultry	Pre-BMP	254	5,590	167,700	49,190
	Post-BMP	247	9,510	285,300	83,690
Sheep	Pre-BMP	30	396	8,710	1,390
	Post-BMP	0	0	0	0
Horse/mule	Pre-BMP	26	863	10,360	1,900
	Post-BMP	26	1,510	18,120	3,320
Annual average	Pre-BMP	1,124	14,050	208,600	52,600
	Post-BMP	1,040	13,300	196,000	49,430

AU = animal units; BMP = best management practice; pre-BMP = April 1, 1984, through March 31, 1986; post-BMP = April 1, 1986, through September 30, 1989.

Table 4.—Nutrient applications, in pounds, to cropland in the nutrient-management subbasin.

		NITROGEN			PHOSPHORUS		
DATE	PERIOD	MANURE	+ COMMERICAL FERTILIZER	= TOTAL	MANURE	+ COMMERICAL FERTILIZER	= TOTAL
April 1984–March 1985	Pre-BMP	83,500	25,100	108,600	21,200	7,100	28,300
April 1985–March 1986	Pre-BMP	107,000	24,600	131,600	28,400	6,100	34,500
April 1986–March 1987	Post-BMP	62,300	20,200	82,500	14,300	5,300	19,600
April 1987–March 1988	Post-BMP	53,800	18,300	72,100	13,700	4,200	17,900
April 1988–March 1989	Post-BMP	73,000	18,300	91,300	19,200	4,700	23,900
April 1989–Sept. 1989	Post-BMP	37,400	10,900	48,300	8,700	2,800	11,500
Annual average	Pre-BMP	95,250	24,850	120,100	24,800	6,600	31,400
	Post-BMP[1]	63,000	18,900	82,000	15,700	4,700	20,500

[1]April 1989 through September 1989 excluded when calculating average.

did not leave the farm on which it was produced, it was not recorded as export. If the unaccounted manure production remained in the subbasin, estimated decreases in nitrogen input would be substantially less than stated.

Effects of Nutrient Management on Surface Water Quality

Monthly Constituent Loads

Monthly nitrogen, phosphorus, and suspended-sediment loads for Station 3 (Fig. 4), the nutrient-management subbasin, and Station 5 (Fig. 5), the small watershed, were calculated by summing daily base-flow loads and stormflow loads for the month. Daily base-flow loads were calculated by multiplying daily base-flow discharge by the constituent base-flow concentration. Daily base-flow concentrations were estimated by linear interpolation from concentrations measured monthly in the base flow. Stormflow loads were calculated by the subdivided method described by Porterfield (1972) for sampled stormflows and by a mean concentration to discharge regression for stormflows not sampled.

The monthly nitrogen loads consisted mostly of nitrate plus nitrite and the proportion of nitrate plus nitrite in the monthly nitrogen loads did not change significantly from the pre- to post-BMP period. Maximum monthly loads of total phosphorus and suspended sediment at Stations 3 and 5 were lower during the first year of the post-BMP period than during the pre-BMP period. Correspondingly, precipitation was 25 percent below average in 1986. From April 1987 through the remainder of the post-BMP period, statistically significant increases in total phosphorus loads were detected at Station 5 and statistically significant increases in the sediment load were detected at Station 3. Increases in

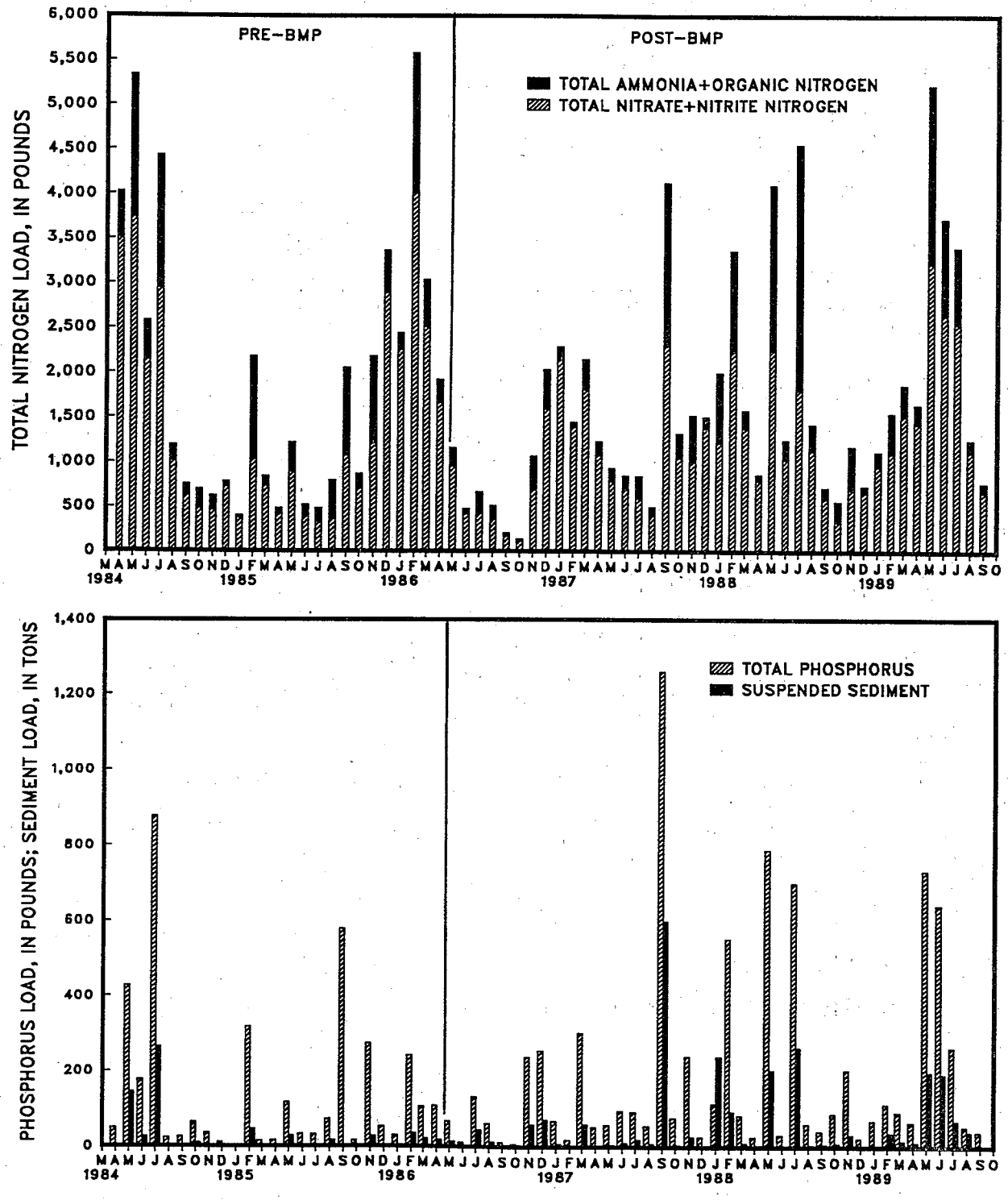

Figure 4—Monthly loads of nitrogen as N (above) and total phosphorus as P and suspended sediment (below) at Station 3.

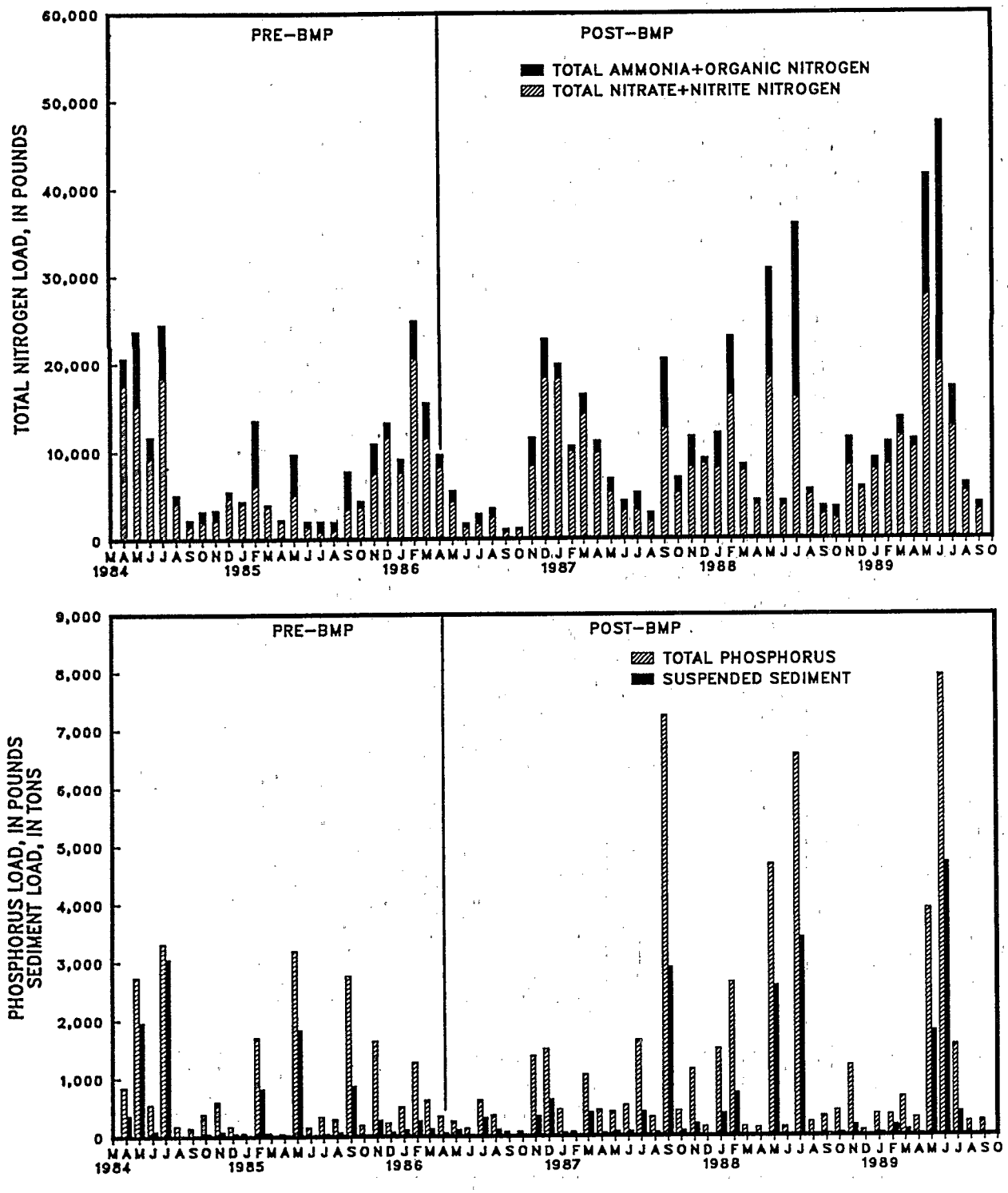

Figure 5.—Monthly loads of nitrogen as N (above) and total phosphorus as P and suspended sediment (below) at Station 5.

streamflow accounted for most of the increases in the monthly loads.

Monthly streamflow was factored out of each monthly load to produce a discharge-weighted mean concentration that could be used to determine if monthly mean concentrations of nutrients changed significantly from the pre- to post-BMP period. When pre-BMP and post-BMP monthly discharge-weighted mean concentrations were compared, no significant change was detected in total nitrogen, dissolved nitrate plus nitrite, total ammonia plus organic nitrogen, total phosphorus, or suspended sediment at either Station 3 or 5.

Base-flow Nitrogen

Monthly base-flow nitrogen concentration data collected at Stations 1 through 5 are summarized in Figures 6 through 8. The data are separated into the pre- and post-BMP periods.

Within the nutrient-management subbasin, base-flow concentrations of dissolved nitrate plus nitrite, which is primarily in groundwater, increased with downstream distance (Fig. 6). This increase correlated with increasing proportions of agricultural land use and carbonate rock in the contributing drainage area. In the nonnutrient-management subbasin (Station 4), median dissolved nitrate plus nitrite concentrations were 3 mg/L lower than in the nutrient-management subbasin during both the pre- and post-BMP periods. Although the difference in nitrate plus nitrite concentrations in base flow between basins could be a result of the difference in proportion of agricultural land use (Table 2), Thomas and others (1992) propose (1) that the parent geology of a watershed is of greater importance in explaining average nitrate concentrations in streamflow than agricultural land use, and (2) that the largest nitrate concentrations occur in streamflow from carbonate rocks. The nonnutrient-management subbasin is underlain by about 24 percent less carbonate rock than the nutrient- management subbasin. Fishel and Lietman (1986) found that median concentrations of nitrate in groundwater, the source of base flow, were three times greater on average in areas of the Conestoga River Headwaters underlain by carbonate rock. The presence of sinkholes and large fractures in carbonate rock allow direct and rapid transport of surface applied nutrients to the groundwater. Nitrate plus nitrite concentrations in the base flow from the entire watershed (Station 5) were similar to concentrations at Station 3, though concentrations at Station 5 had greater variation. The drainage basins for Stations 3 and 5 are underlain by approximately equal percentages of carbonate rock.

Unlike nitrate, ammonia nitrogen and total ammonia plus organic nitrogen are commonly found

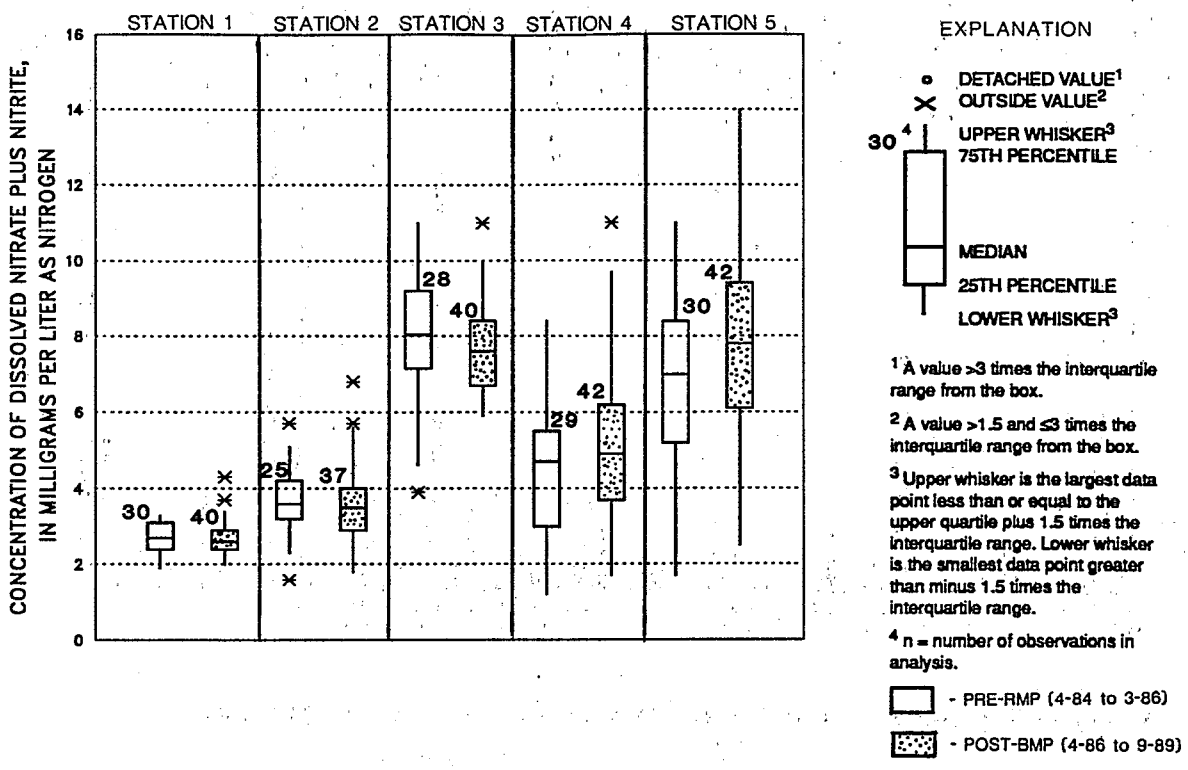

Figure 6.—Concentrations of dissolved nitrate plus nitrite nitrogen in base flow at Stations 1 through 5.

only in trace concentrations in groundwaters of the area. Rather, concentrations of these constituents in surface water have their source in and near the stream channel. With the exception of Station 1, concentrations of each of these constituents were similar in water samples collected at all stations suggesting similar in- or near-stream conditions (Figs. 7 and 8). Stations 2 through 5 are located in agricultural settings and Station 1 is located in a forested setting.

Concentrations of nitrate plus nitrite in base flow exhibited seasonal variation and flow dependency.

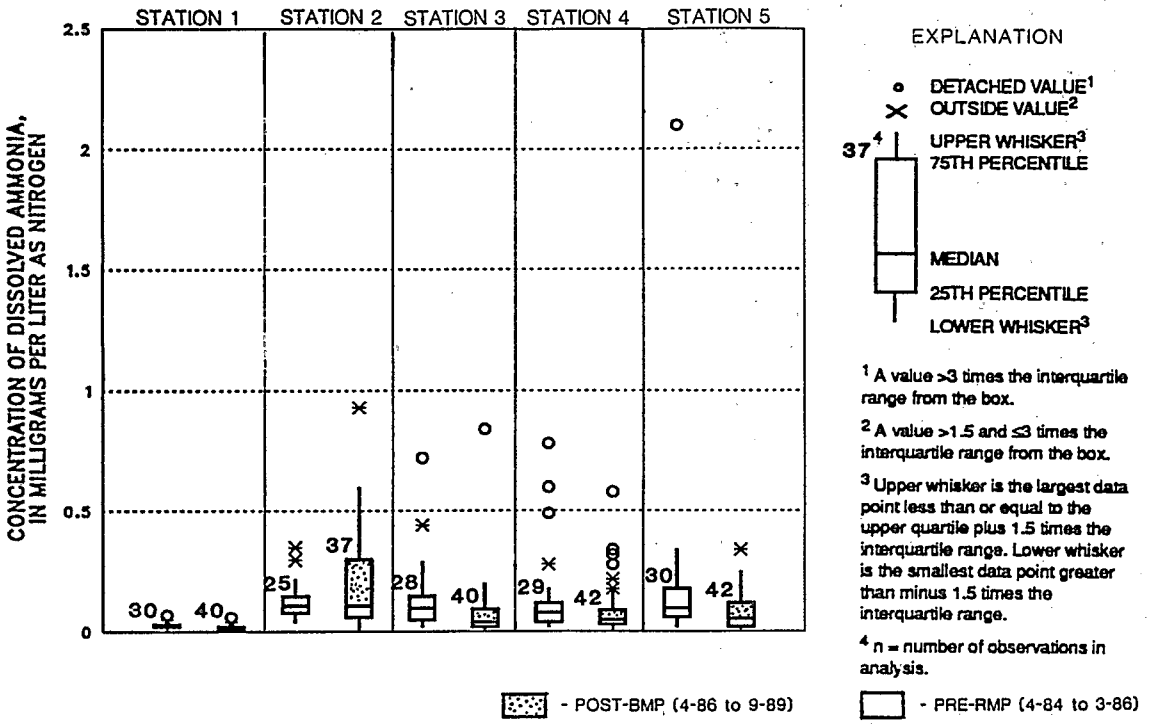

Figure 7.—Concentrations of dissolved ammonia nitrogen in base flow at Stations 1 through 5.

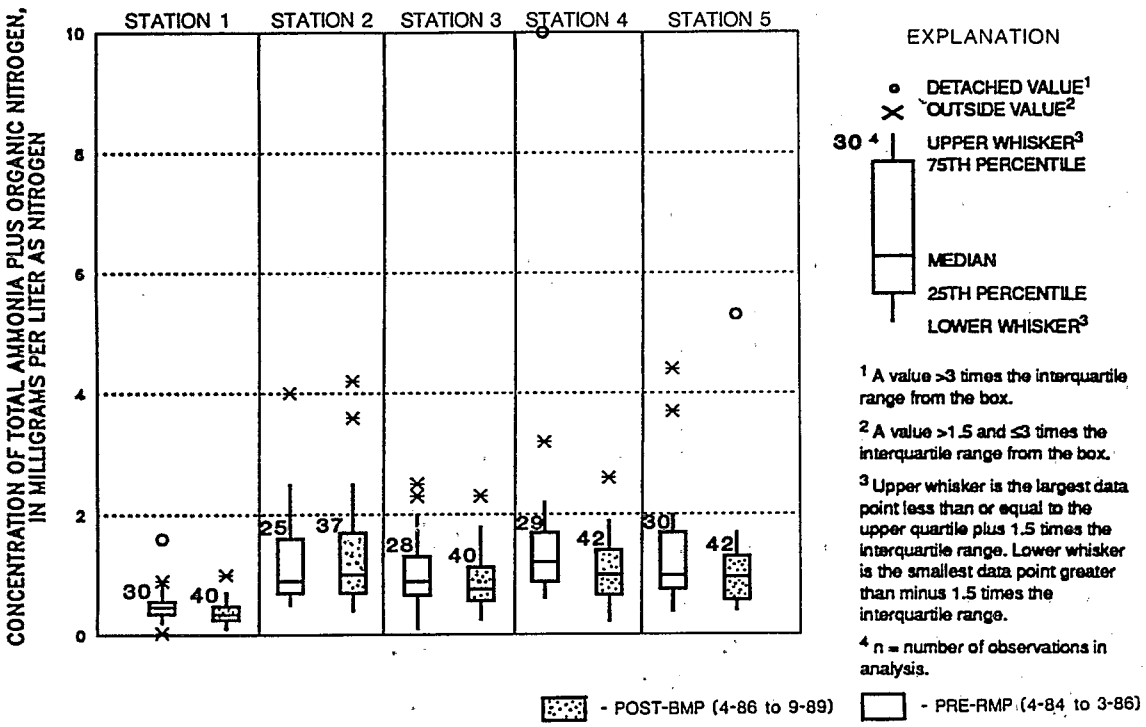

Figure 8.—Concentrations of total ammonia plus organic nitrogen in base flow at Stations 1 through 5.

Examples of the seasonal variation can be seen in the time-series plot for Station 5 (Fig. 9). The smallest seasonal variation was found at Station 1 and the greatest variation was found at Station 5. Seasonal adjustment was employed in the test for step trends between the pre- and post-BMP periods. Flow dependency was removed from the observed data by subtracting observed concentrations from a locally weighted scatterplot smooth estimate of the concentration/discharge function (LOWESS) (Cleveland, 1979) and adding the overall mean concentration to the difference. Flow-adjusted concentrations were then tested for trends associated with the implementation of nutrient management.

Pre-Post Comparison

Before comparing pre- and post-BMP nitrogen concentrations in the base flow, the first year of post-BMP data (April 1986 through March 1987) was deleted from the data set for the following reasons:

- not all farms in the nutrient-management subbasin received their nutrient-management plans exactly at the start of the post-BMP period, and
- a lag time was expected between the implementation of nutrient management and any response in the quality of base flow. At a hydrogeologically similar site also located in the Conestoga River headwaters, a lag of about 6 months to 2 years was observed before nitrate nitrogen concentrations in groundwater responded to changes in surface-applied nitrogen (D.W. Hall, pers. comm. 1991).

A seasonally adjusted rank-sum test was used to determine whether a step trend had occurred in nitrogen concentrations between the pre- and post-BMP periods. Few significant changes in median concentrations of the nitrogen species occurred in base flow between the pre- and post-BMP period for observed or flow-adjusted data (Table 5). Median concentrations of nitrate, the predominant base-flow nitrogen species, did not change. Significant decreases of 0.10, 0.03, and 0.28 mg/L, were detected in dissolved-ammonia concentrations at Stations 1 and 4 and in total ammonia plus organic nitrogen concentrations at Station 5, respectively. These decreases represent a very small percentage of the median total nitrogen concentrations in base flow. Moreover, because these constituents have their source in or near the stream channel, they are most likely not a result of nutrient management.

Water quality goals established at the start of the Conestoga Headwaters project (U.S. Dep. Agric. 1984) stated that maximum nitrogen concentrations should not exceed 10 mg/L nitrate as nitrogen and 1.5 mg/L ammonia as nitrogen. Dissolved-nitrate plus nitrite concentrations exceeded the 10 mg/L goal in 3 and 9 percent of the samples collected before and after nutrient management, respectively, at Station 5. At Station 3, in the nutrient-management subbasin, the dissolved nitrate plus nitrite concentrations exceeded 10 mg/L in 3 percent of the base-flow samples collected both before and after nutrient management implementation. Dissolved-ammonia concentrations exceeded the goal in 3 percent of base-flow samples at Station 5 only in the pre-BMP period and did not exceed the goal at any of the stations during the post-BMP period.

Paired-Subbasin Comparison

Large variations in water quality due to seasonal, climatic, and other non-BMP factors, make it difficult to conclude that changes detected in water quality were a result of nutrient management. Many of the non-BMP factors influencing water quality can be corrected for using paired-subbasins with nearly identical characteristics.

A paired-subbasin comparison of nitrate plus nitrite concentrations in base flow in the nutrient-management subbasin and the nonnutrient-management subbasin was made by use of double-mass plots and an analysis of covariance. A double-mass plot will show a regression line of constant slope, if the relation between fluxes (discharge times and concentration) from each subbasin remain trend free during the period of interest. Streamflow measurements indicated an unexpected increase in base-flow discharge from the nutrient-management subbasin relative to the nonnutrient-management subbasin about 12 months into the post-BMP period. If nitrate plus nitrite concentrations were trend free, the discharge increase would increase nitrate plus nitrite flux from the nutrient-management subbasin. However, a double-mass plot (Fig. 10) shows a small decrease in nitrate plus nitrite flux from the nutrient-management subbasin relative to the nonnutrient-management subbasin, thus suggesting a decrease in nitrate plus nitrite concentrations.

Analysis of covariance detected significant pre- to post-BMP changes in the relation between nitrate plus nitrite concentrations in base flow from the subbasins. Although not statistically significant by themselves (Table 5), small changes in median nitrate plus nitrite concentrations in each subbasin combined to result in a significant change in the pre- to post-BMP relation between concentrations of nitrate plus nitrite in concurrent base-flow samples from the subbasins (Fig. 11). A decrease in nitrate plus nitrite concentrations in the nutrient-management subbasin accounted for most of the change.

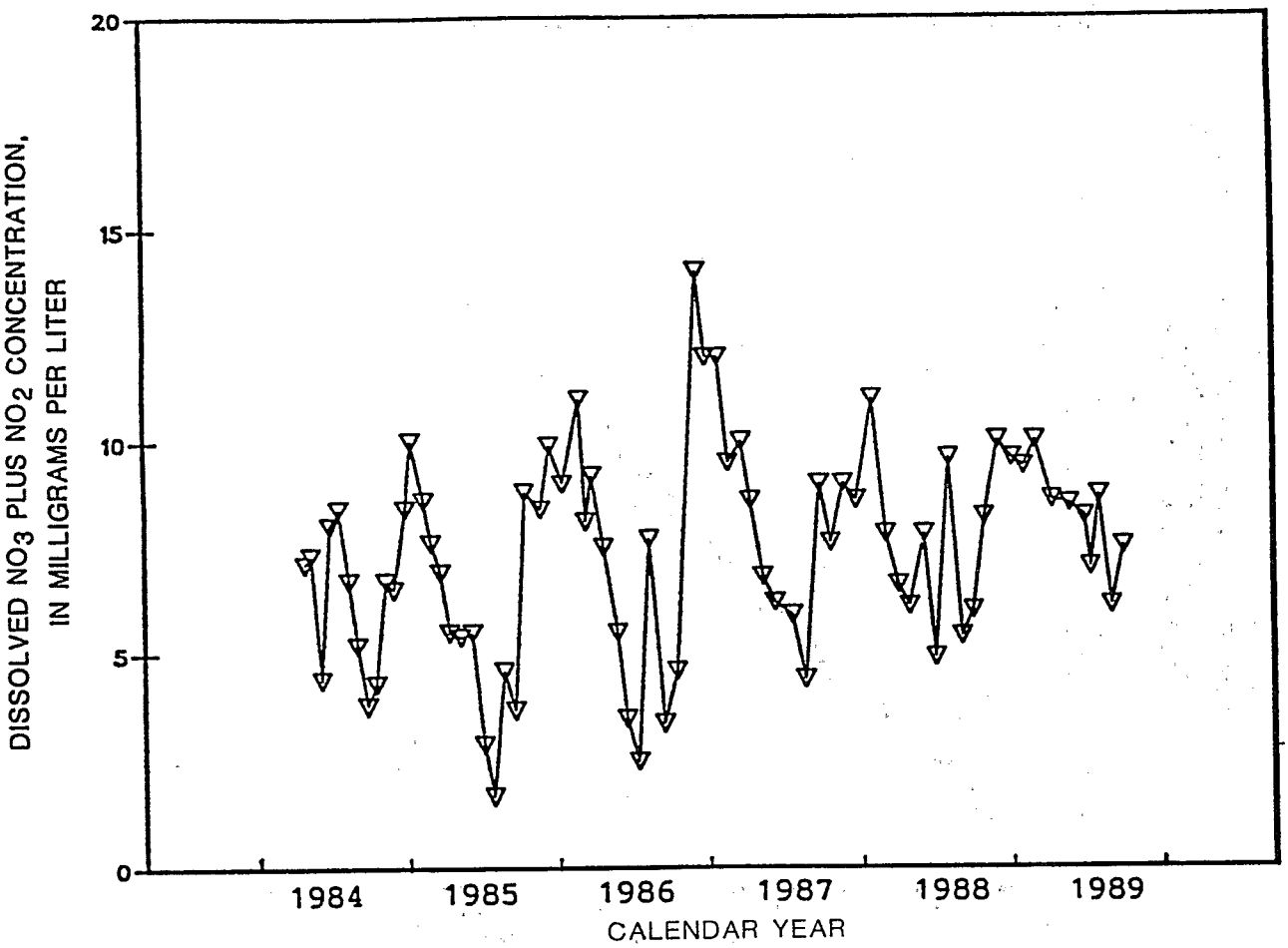

Figure 9.—Time series of base-flow dissolved nitrate plus nitrite concentrations at Station 5, April 1984 through October 1989.

Table 5—Results of step trend analysis tests between pre-BMP (April 1984 through March 1986) and post-BMP (April 1987 through September 1989) on observed and flow-adjusted base-flow nitrogen concentrations in the small watershed detected by use of the seasonal rank-sum test.

		OBSERVED DATA		FLOW-ADJUSTED DATA	
STATION	PARAMETER	STEP TREND (mg/L)	PROBABILITY (P)	STEP TREND (mg/L)	PROBABILITY (P)
1	Dissolved nitrate plus nitrite	–.10	0.21	–.22	0.21
	Dissolved ammonium	–.10	<.01*	—	—
	Total ammonia plus organic nitrogen	–.08	.13	—	—
2	Dissolved nitrate plus nitrite	.00	.90	–.25	.41
	Dissolved ammonium	–.10	.64	—	—
	Total ammonia plus organic nitrogen	–.15	.19	—	—
3	Dissolved nitrate plus nitrite	–.78	.20	–.50	.20
	Dissolved ammonium	–.03	.09	—	—
	Total ammonia plus organic nitrogen	–.19	.30	—	—
4	Dissolved nitrate plus nitrite	.40	.36	.37	.30
	Dissolved ammonium	–.03	.01*	—	—
	Total ammonia plus organic nitrogen	–.22	.15	—	—
5	Dissolved nitrate plus nitrite	.80	.31	.69	.06
	Dissolved ammonium	–.04	.17	—	—
	Total ammonia plus organic nitrogen	–.28	.01*	—	—

mg/L = milligram per liter; < = less than; — = no flow dependency
*Significant at the 95 percent confidence level.

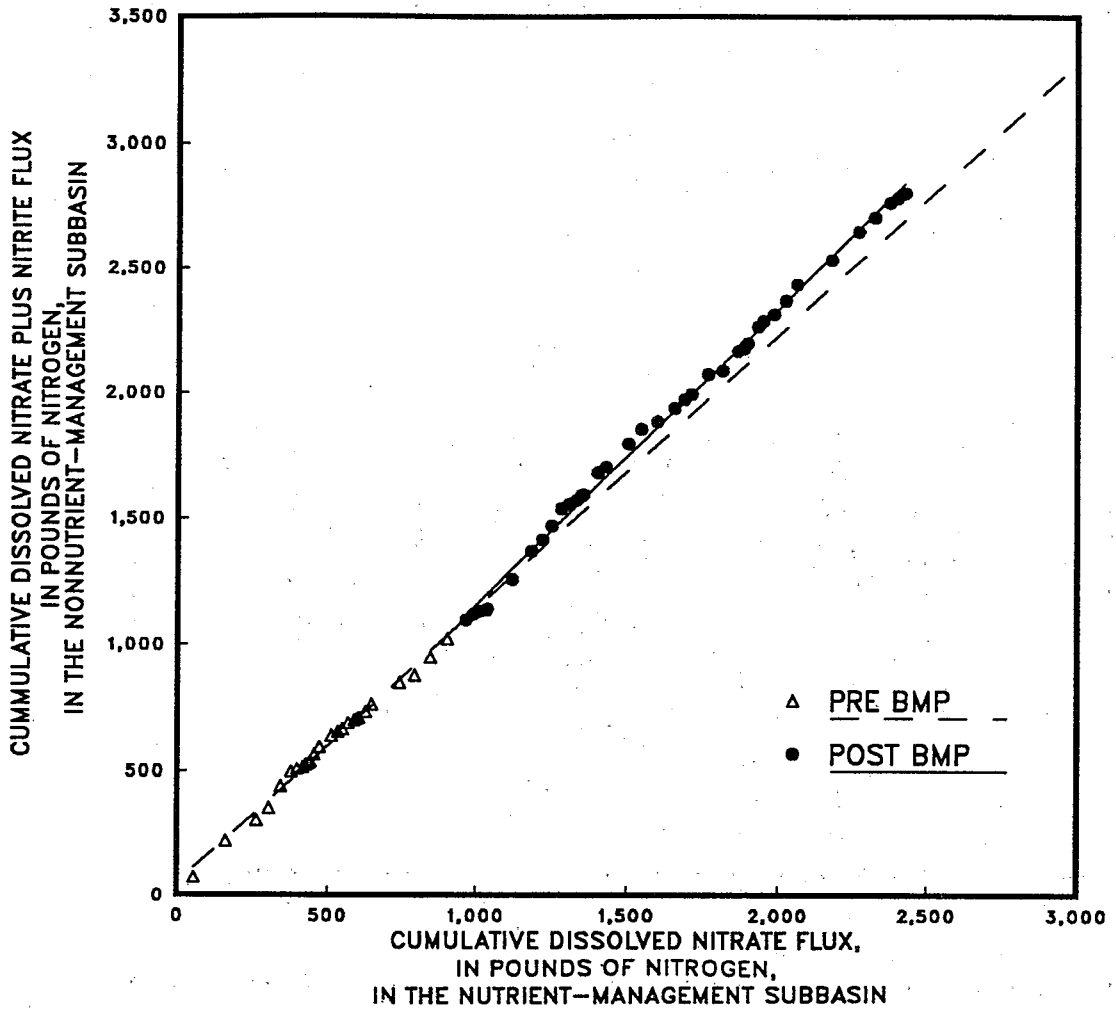

Figure 10.—Comparison of cumulative base-flow dissolved nitrate flux for the nutrient-management and nonnutrient-management subbasins during the pre-BMP (April 1984 through March 1986) and post-BMP (April 1986 through September 1989) study periods.

Conclusions

Median concentrations of dissolved nitrate plus nitrite in base-flow discharge from the watershed and from two subbasins within the watershed showed no statistically significant change 3.5 years after nutrient management was implemented on 50, 90, and less than 10 percent of the croplands in the watershed, the nutrient-management subbasin, and the nonnutrient-management subbasin, respectively. During the period of nutrient management, dissolved nitrate plus nitrite concentrations that exceeded 10 mg/L as nitrogen occurred more frequently in base flow from the entire watershed and the nonnutrient-management subbasin and at the same frequency in base flow from the nutrient-management subbasin.

Although these results indicate that implementation of nutrient management had no significant effect on median nitrate plus nitrite concentrations, they should be considered specific to this study for the following reasons:

1. No correlation was made between the percent of cropland covered by nutrient-management plans and the percent of reduction in nutrient applications. Some plans recommended substantial reductions in nutrient applications and others recommended none.
2. Real reductions in nitrogen applications were difficult to determine. Estimates of grazing deposition and large differences between estimates of nutrient production and records of nutrient application and export in the nutri-

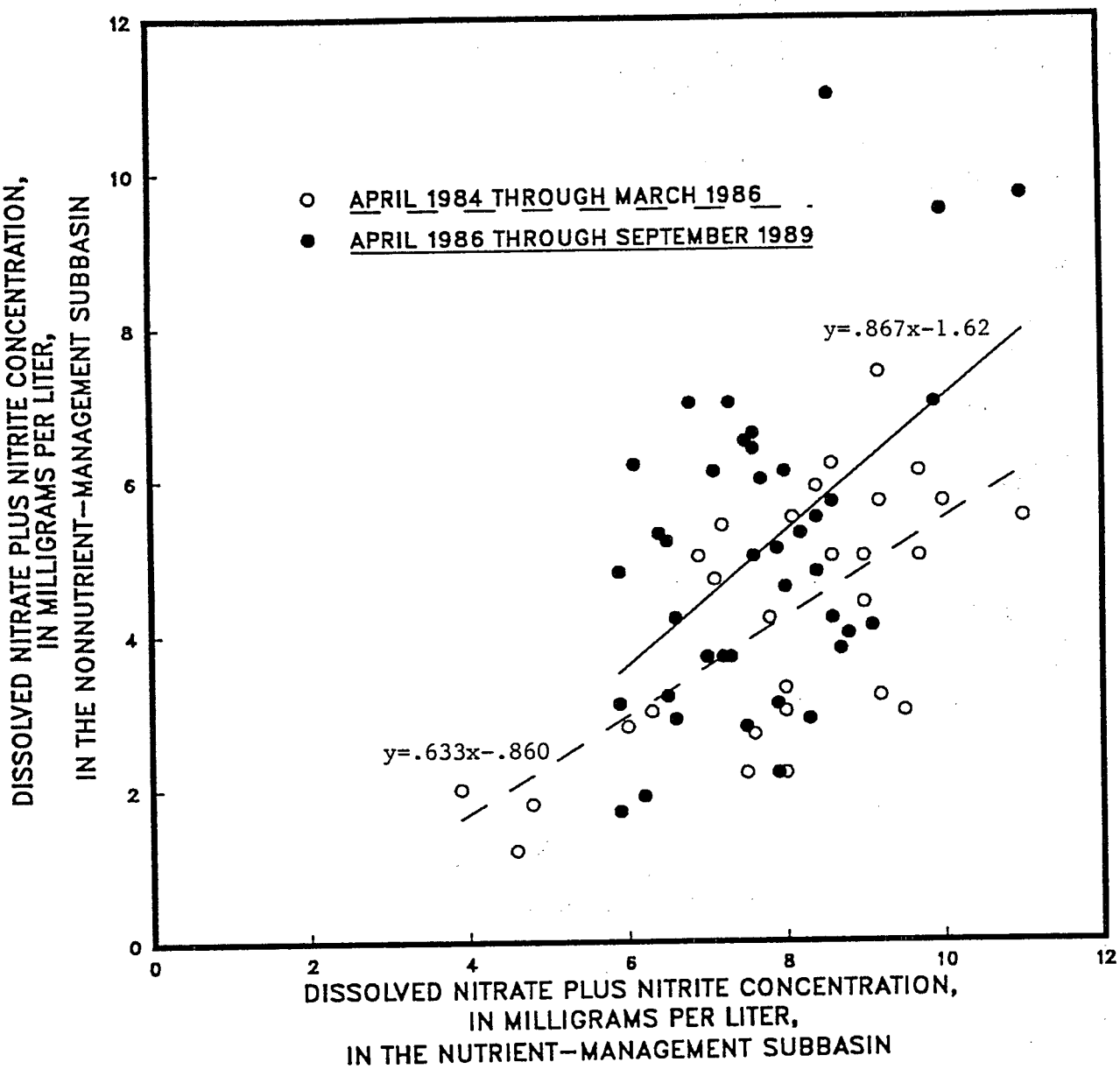

Figure 11.—Relation between base-flow nitrate plus nitrite nitrogen concentrations from the nutrient-management and nonnutrient-management subbasins.

ent-management subbasin limited the accuracy of calculated nitrogen reductions.

3. Large natural variations in nitrate plus nitrite concentrations could have masked smaller changes in concentrations expected from the nitrogen application reductions recommended under nutrient management.

4. Carbonate geology probably limited the achievable reductions in average nitrate plus nitrite concentrations in base flow under the recommendations of nutrient management.

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Cedar Revetment and Streambank Stabilization

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ABSTRACT

Cedar revetments were one of the most innovative and successful practices implemented in the Long Pine Creek Rural Clean Water Program project. The Long Pine Creek watershed had become degraded by agricultural runoff that had seriously eroded streambanks. A method was needed to stabilize and revegetate these areas. Over 19,000 feet of cedar revetments were installed throughout the Long Pine Creek Watershed under best management practice No. 10—Stream Protection System. In addition to streambank stabilization, these revetments provided a variety of benefits to trout and other aquatic life. Before the Rural Clean Water Program, little was known about revetments in Nebraska. Although the Nebraska Game and Parks Commission had experimented with tree revetments in the watershed area, these structures had not been widely employed. The Rural Clean Water Program provided 75 percent in cost-share funding for best management practices implemented through the Long Pine Creek project.

In 1981, the Long Pine Creek Watershed was selected for the experimental Rural Clean Water Program (RCWP), established as a 10 to 15-year experiment in controlling nonpoint source pollution. The Long Pine Creek project offered cost-sharing and technical assistance as incentives for voluntary implementation of best management practices (BMPs).

Fifteen BMPs were selected to address nonpoint source problems on 60,242 acres determined as critical and targeted for treatment in the Long Pine Creek watershed area. Each practice consisted of several individual practices that could be implemented to achieve the total BMP. All components had to meet Soil Conservation Service (SCS) technical specifications.

The Long Pine Creek RCWP project addressed both land and stream treatment. Land treatment practices widely implemented in the Long Pine Creek RCWP included

- irrigation management structures,
- grazing land protection systems,
- establishing permanent vegetative cover on critical areas,
- water and erosion control structures, and
- fertilizer and pesticide management.

Stream protection systems implemented during the project included

- channel vegetation,
- fencing livestock out of the stream, and
- establishing revetments to stabilize the streambank.

The revetments proved to be one of the most successful and innovative practices employed in the Long Pine Creek project.

Description

The Long Pine Creek watershed is located in north central Nebraska. The watershed borders the northeastern edge of the Nebraska sandhills, the largest grass-covered sand dune area in the world. The sandhills rest upon the Ogallala Aquifer, a 200-mile-wide corridor of underground water that extends south through Kansas and Oklahoma into Texas.

Surface elevations throughout the watershed range from 2,700 to 1,930 feet in the stream channel. Unique geologic and topographic factors have combined to create a fragile environment. The sandhills rise to 400 feet and then drop below the groundwater level, creating many wetland areas. This unique environment is home to plants and animals found in both semiarid and marsh habitats (Conserv. Surv. Div., Inst. Agric. Nat. Resour. 1989). The stream channel in the Long Pine Creek watershed was formed in eolian sands and residuum weathered from sandstone. These materials are especially susceptible to streambank erosion when vegetative cover is destroyed.

Originally settled in the mid-1800s, the area supported ranching and a small amount of farming. The native grass cover of sand, big and little bluestem, switchgrass, Indian grass, and prairie sandreed grass provided excellent grazing for livestock. In the mid-1960s, irrigation was developed on 35,000 acres within the watershed. This sudden change from grasslands to intensive row crop production had a significant environmental impact. The natural or geologic erosion and subsequent sedimentation process, which was accelerated by increased agricultural activity, field runoff, and severely eroded streambanks, had a negative effect on aquatic life along the creek and its tributaries.

Discussion

A significant amount of pre-BMP implementation data reflecting deteriorating conditions in the Long Pine Creek watershed had been collected over the years. The U.S. Geological Survey (USGS) had been monitoring surface water quality and flow on Long Pine Creek since 1948, and the Nebraska Game and Parks Commission had conducted numerous fish population studies determining abundance and distribution of fish species throughout the watershed. In 1979, the Nebraska Department of Environmental Control began an extensive surface water quality monitoring project in the watershed that continued through 1985. This study (Maret, 1985) was the primary source of pre-BMP implementation baseline data used for project evaluation.

Pre-BMP implementation monitoring included sampling of ambient stream conditions, in-stream runoff conditions, and rainfall. The stream conditions monitored included physicochemical conditions of the water column, biological conditions (i.e., bacteria, periphyton, macroinvertebrates, fish), aquatic habitat (i.e., flow, substrate, cover), and riparian conditions along streams.

Maret's report found extremely high sediment loads at several monitoring stations, especially in Subbasins 6, 8, 10, and 11 (see Fig. 1). The excessive sediment was destroying food-producing organisms, filling in pool habitats required for good trout production, and creating a wider, shallower, and warmer stream. Fisheries at some sites exhibited low diversity and low populations. Monitoring determined that aquatic life was being impaired by excess sedimentation from streambank and gully erosion.

Streambank erosion was occurring mainly along bends in the creek where the current's velocity was the greatest. A BMP practice had to be applied to address the eroding streambanks and improve and preserve the coldwater stream.

Although the Nebraska Game and Parks Commission had experimented with tree revetments, they were not widely employed in Nebraska. BMP 10 (Stream Protection System), selected for use in the Long Pine Creek RCWP, included component 580, Streambank Protection, the installation of vegetative filter strips, protective fencing, livestock crossings, and mechanical (structural) practices to protect streams from sediment or chemical pollutants and thereby improve water quality. BMP 10 was applicable to streams or lakes located on or adjacent to farmland. All practices under BMP 10 received 75 percent cost-share on the total cost of implementation and had to be maintained for 10 years following the installation.

Revetment Method

The revetment method of streambank stabilization uses trees to trap sediment and promote revegetation along the streambank. As stabilization techniques, revetments cost less than structures. SCS technicians believed that tree revetments could be adapted for effective streambank stabilization throughout the fragile watershed environment.

Planning for revetment installation requires several preliminary steps, which include

- obtaining a permit from the Army Corps of Engineers before beginning construction,
- selecting the sites for revetment installation,

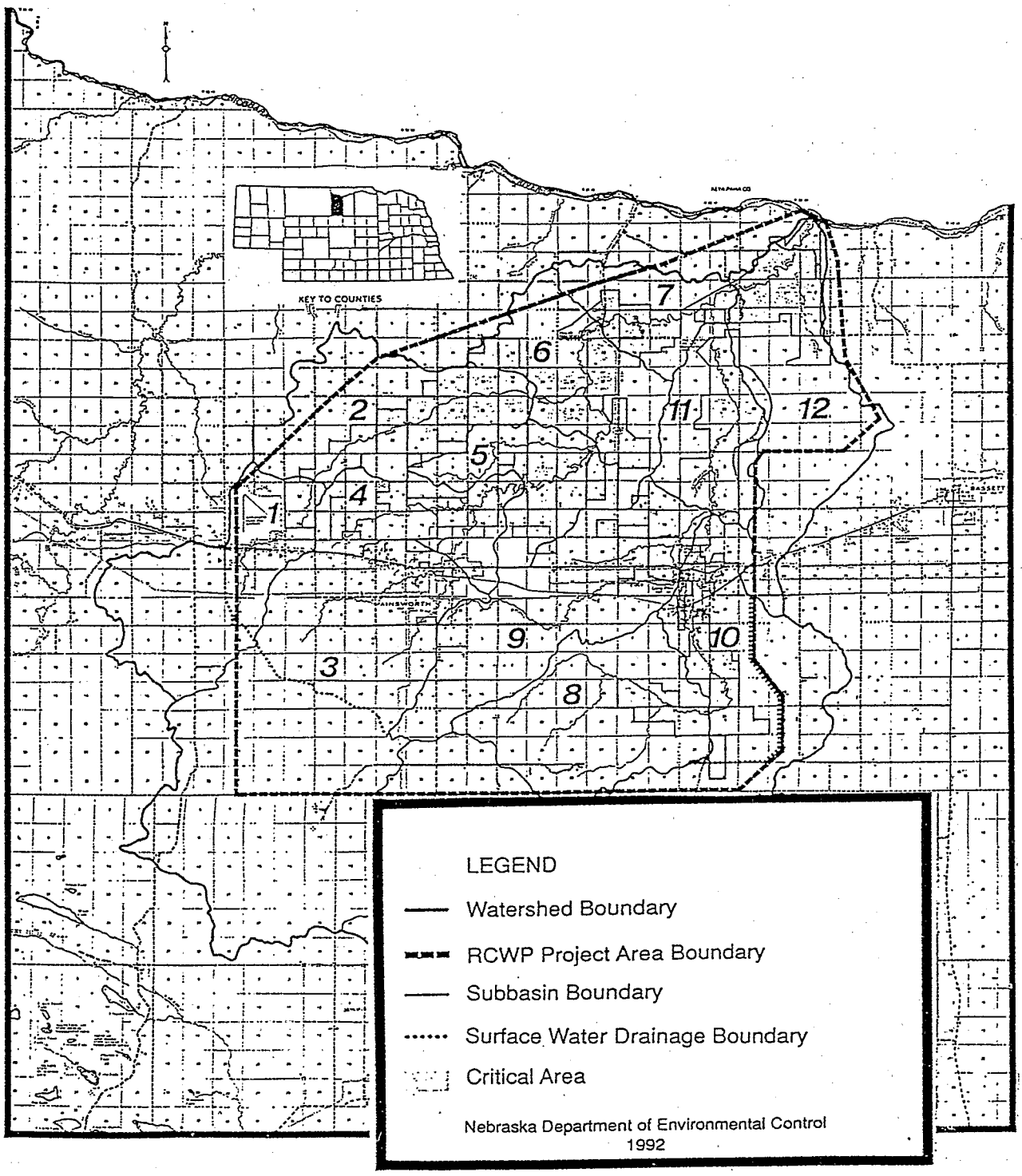

Figure 1.—Long Pine Creek Watershed: Project area, subbasin, and critical area boundaries. Map from Nebraska RCWP 10-year report (Hermsmeyer, 1991).

- determining the type of tree and method for anchoring trees to the streambank, and
- selecting the type of vegetative cover to be used for revegetation (when the revetment traps sediment).

■ **Permits.** The Long Pine Creek RCWP project needed a permit from the Army Corps of Engineers before it could begin construction of revetments in the watershed. A general permit applicable for all revetment installations in the watershed area was obtained through the Nebraska Game and Parks Commission.

■ **Site Selection.** Selection of sites for revetment construction was based upon the degree of degradation of the streambanks, the availability of trees for revetment construction, and the degree of channel deflection following installation. The more seriously degraded streambanks were given priority. To prevent further erosion, revetment construction had to begin and end where the bank was not eroding. The revetment could not deflect the channel to such an extent that it caused additional streambank erosion downstream.

■ **Tree Selection and Method of Anchoring.** Next, trees were selected that had many branches to better trap sediment. The densely branched eastern red cedar trees that lined the creeks and streams throughout the watershed were ideal for revetments. Live trees approximately 20 to 25 feet tall and 8 to 10 feet in diameter were used. (Dead trees break apart before a streambank can be stabilized and should not be used in revetment construction.) If beavers are active along streams, trees should be cut before installation and dried out for several months or even a year. The first revetments constructed in the Long Pine watershed suffered damage from beavers because the trees were green; immediately after construction, the beavers cleaned off branches and removed the trees. After that, trees were felled in the fall for use the following spring.

Materials for construction (see Appendix: Construction Notes) and methods of anchoring trees to the streambank depended on soil types and location of trees to the streambank. Soils can be sand, clay, or bedrock and each requires different methods and materials. The trees must be well anchored. In the Long Pine Creek watershed, cedar trees grew close to the stream; therefore, a tractor was not needed to move them. The streambed consisted of mainly sandy soil, making tree anchoring fairly easy.

Revetments were constructed with Number 9 wire, 5/16-inch cable, and steel fence posts (see construction notes). Steel posts were driven horizontally into the streambank about every 10 feet. A deadman post was set on the upstream end of the revetment and a 5/16-inch cable was attached to it at the water line and wired to the fence posts. The trees were placed horizontally in the stream in the direction of the flow and wired to the cable. The revetment deflected water away from the eroding streambank and began trapping sediment. Within a few days, the revetment was filled.

■ **Vegetative Cover.** After sediment has been trapped, the site must be revegetated. Tree seedlings are often used at revetment sites for this purpose; however, the Long Pine Creek Watershed needed an immediate cover. The first revetments were damaged by heavy rains and runoff. In the search for a way to better stabilize and protect the newly constructed revetments, reed canary grass, a deep-rooted perennial plant that spreads rapidly, was broadcast and sodded on the tops of trapped sediment. This solution proved to be extremely successful. The canary grass, which spread rapidly across revetments and throughout the stream, provided habitat for aquatic life and occasional forage for livestock.

Within a year, the reed canary grass reached maturity and produced seeds, which dropped into the channel, were carried downstream, and were eventually deposited along stretches of bare banks. Thus reed canary grass became established on many untreated eroding banks and spread throughout the area.

Within two to three years, reed canary grass had trapped additional sediment, narrowing the stream channel. The velocity of the stream increased, removed the sediment that had been deposited, and eventually flushed out the channel and exposed gravel bottom in the streambed. Within four to five years, the additional vegetative growth along the revetment narrowed the stream channel further. Some revetments installed in the Long Pine Creek RCWP reduced the stream channel from 15 feet to 3 to 5 feet within five to six years. Although constricting a stream channel is not always desirable, in the Long Pine Creek watershed, narrowing the stream channel helped restore stretches of the stream to its previous dimensions.

At several points along Long Pine Creek where revetments were installed, SCS technicians cross-sectioned portions of the stream before and after installation of revetments and measured the depth and width. Results have indicated a significant decrease in the stream width and an increase in stream depth. The narrowing of the channel was also documented in pictures taken over 10 years and through SCS-conducted annual status reviews. Some revetments have

restored the stream to such an extent that the original revetment sites are difficult if not impossible to find.

Conclusions

Revetments increased the velocity of the channel and created a deeper, narrower, and cooler stream. The faster and deeper creek flushed out sand and sediment and exposed gravel in the streambed, a condition necessary for trout spawning. Revetments gave trout a place to hide, feed, and rest. The deeper and cooler stream was conducive to trout species and other aquatic life.

Revetments proved to be extremely beneficial to fish populations, including trout. The Nebraska Game and Parks Commission and Soil Conservation Service used the Habitat Quality Index Procedures Manual (Binns, 1982) Model II methodology to document the amount of change in carrying capacity after revetment installation. According to this modeling system, cedar revetments have increased the mean carrying capacity of Long Pine Creek from 75.4 pounds/acre to 119.2 pounds/acre, a positive increase of 58.1 percent for the sites analyzed.

Cedar revetments were one of the most innovative and successful practices implemented in the Long Pine Creek RCWP. To date, 19,287.2 feet of revetments have been constructed throughout five subbasins in the watershed through the program (see Table 1). Forty-eight individual revetments were installed (7.5 percent of the total practices implemented in the program) on 15 participating contracts (17.6 percent of the total participating contracts). Installation costs were $55,163. Cost-share provided through RCWP totaled $41,384 (4.8 percent of the total cost-share expended in the program).

Cedar revetments would not have been installed along Long Pine Creek without funding from the Rural Clean Water Program. Revetments are not an approved agricultural conservation practice and therefore are not eligible for cost-share assistance in any other annual USDA program. In addition to streambank stabilization, the revetments have provided a variety of benefits to trout and other aquatic life and have dramatically improved the health and vitality of the stream and its tributaries.

References

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Table 1.—Nebraska's Long Pine Creek Rural Clean Water Program. Best management practice 10, practice code 580—streambank stabilization—cedar revetment.

YEAR	SUBBASIN	INSTALLATION COSTS	COST-SHARE ($)	ACRES SERVED	UNITS APPLIED
1989	6	997	748	1	180.0 ft.
Subtotal Subbasin 6:		997	748	1	180.0 ft.
1986	7	1,350	1,013	1	570.0 ft.
Subtotal Subbasin 7:		1,350	1,013	1	570.0 ft
1985	8	10,188	7,543	7	5,436.0 ft.
1987	8	1,261	946	2	904.0 ft.
Subtotal Subbasin 8:		11,449	8,589	9	6,340.0 ft.
1984	10	1,125	844	2	339.0 ft.
1985	10	1,593	1,195	1	750.0 ft.
1986	10	8,328	6,248	7	2,214.4 ft.
1989	10	477	358	1	225.0 ft.
Subtotal Subbasin 10:		11,523	8,645	11	3,528.4 ft.
1984	11	18,251	13,692	21	5,403.0 ft.
1985	11	4,156	3,118	5	1,133.0 ft.
1986	11	5,260	3,946	1	1,102.8 ft.
1989	11	2,177	1,633	2	1,030.0 ft.
Subtotal Subbasin 11:		29,844	22,389	29	8,668.8 ft.
TOTALS		55,163	41,384	51	19,287.2 ft.

NOTE: 15 participating contracts (17.6% of total participating contracts); 48 individual practices implemented (7.5% of total practices implemented). Taken from Nebraska RCWP 10-year report (Hermsmeyer, 1991).

Appendix: Construction Notes

Taken from Nebraska RCWP 10-year report (Hermsmeyer, 1991)

FOR CEDAR REVETMENT

SPACE STEEL "T" POSTS AT APPROXIMATELY 10 FT. INTERVALS. PLACE ANCHOR DEAD-MAN AT A NON TURBULENT SPOT, SO AS NOT TO "CUT" BEHIND ANCHOR. IF NOT POSSIBLE, LOCATE ANCHOR APPROXIMATELY 10 FT. INTO BANK, AWAY FROM CHANNEL, AT 45 DEGREE TO 90 DEGREE ANGLE WITH RESPECT TO SHORELINE. DRIVE POSTS INTO GROUND, EXPOSING 1/2 TO 1 FT. OF "T" POST, NORMALLY IN A STABLE BANK. IN VERTICAL OR VERY STEEP BANKS DRIVE POST INTO STREAMBANK AT 30 DEGREE TO 45 DEGREES.

STRETCH 3/8 OR 5/16 INCH STEEL (AIRCRAFT TYPE) CABLE FROM ANCHOR DEAD-MAN (USUALLY CONSISTING OF 2 "T" POSTS CROSSED) TO LAST POST ON REVETMENT, USING A LOOP OR MULTIPLE LOOPS AND CLAMPS TO SECURE CABLE TO ANCHOR AND LAST POST.

HOLES SHOULD BE DRILLED THROUGH POSTS AND PASS CABLE THROUGH HOLES IN POSTS THROUGHOUT REVETMENT LINE OR TIE CABLE TO ALL MIDDLE "T" POSTS WITH NO. 9 SOFT WIRE.

BEGIN REVETMENT AT DOWNSTREAM END AND WORK UPSTREAM. TIE TRUNK OF TREE 2 OR 3 TIMES WITH WIRE.

TIE APPROXIMATELY 2 TO 4 TREES WITH TRUNK DIA. OF 4 TO 6 INCHES IN A 10 FT. SPACE OF WHICH 4 FT., MORE OR LESS, REMAINS ON BANK. TREES MAY BE TRIMMED BACK FROM BASE 3 TO 4 FT., LEAVING STUB BRANCHES 6 TO 8 INCHES TO FACILITATE TIEING TO CABLE AND FITTING TO STREAMBANK. THE BUSHIER TREE IS BETTER WITH SEVERE (RAW STEEP) BANKS, A ROW OF CEDARS SHOULD BE PLACED LONGITUDINAL ALONG PATH OF CABLE AFTER MAIN REVETMENT HAS BEEN PLACED DIAGONALLY.

UNDER NO CIRCUMSTANCES SHOULD REVETMENT INCLUDE MORE THAN 1/3 OF STREAM WIDTH ACCORDING TO RULES OF U.S. CORPS OF ENGINEERS.

PLANT VEGETATION (USUALLY REED CANARY GRASS OR SPRIGS) AS SOON AS SEDIMENT DEPOSITS ALLOW.

CONSTRUCTION NOTES

FOR CEDAR WING-DIKE REVETMENT

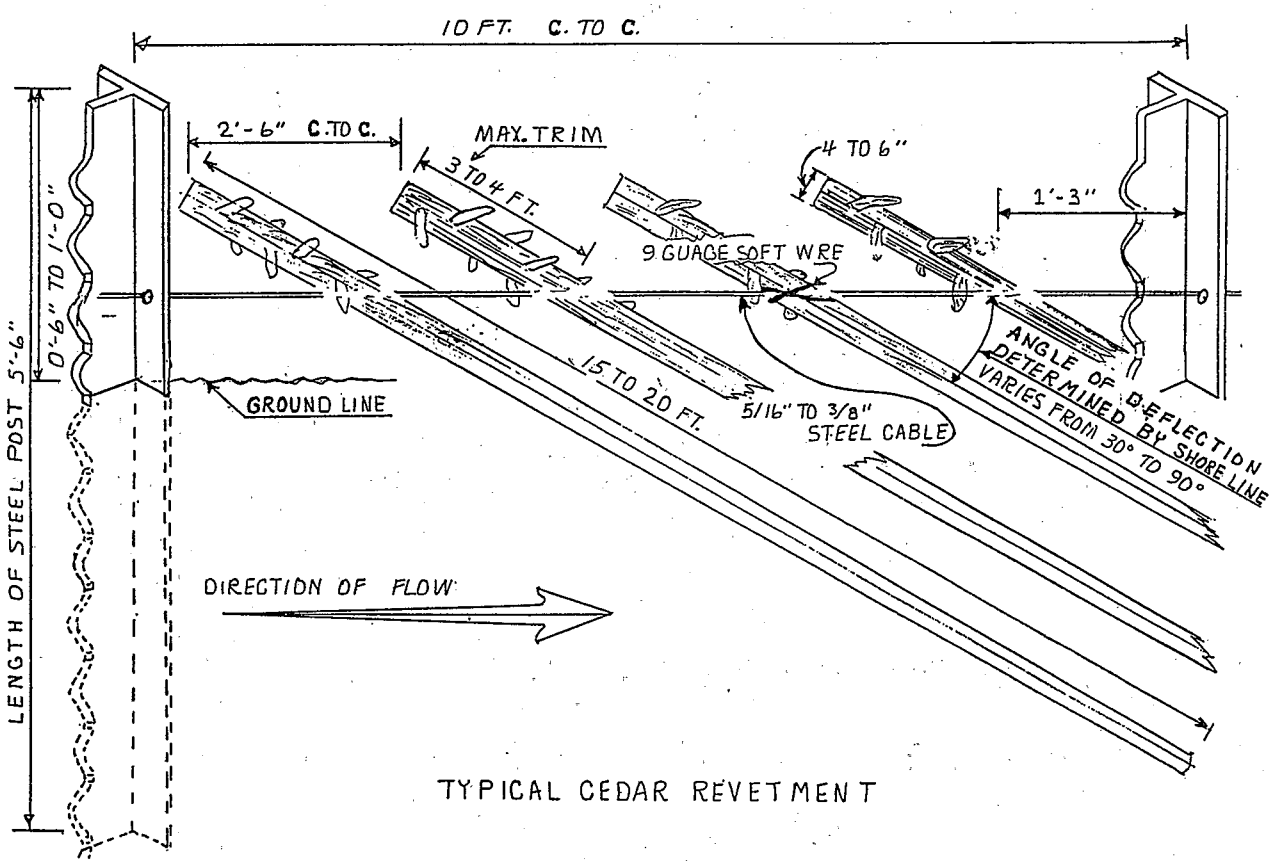
WING DIKES SHALL CONSIST OF 2 CEDAR TREES PLACED 1ST DIAGONALLY WITH STREAM CURRENT, AND 2ND LONGITUDINAL ALONG STREAM BANK.
TREES WILL BE ANCHORED WITH 1 "T" POST AND TIED WITH NO. 9 GA. SOFT WIRE A MINIMUM OF THREE SEPARATE TIES.

WING DIKES WILL BE APPROXIMATELY 20 FT. APART.

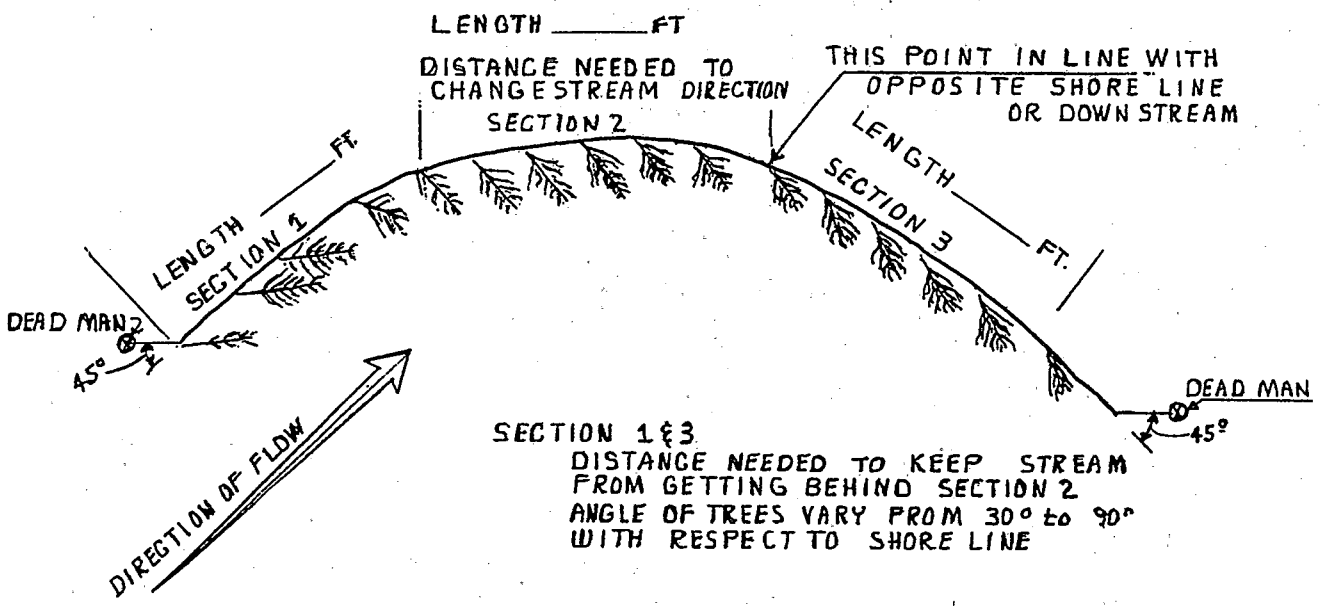
TREES WITH TRUNK DIA. OF 4 TO 6 INCHES AND LENGTHS AVERAGING 15 FT. SHOULD BE USED. DRIVE POST BETWEEN BRANCHES AND SECURE TREES TO POST WITH WIRE, OR THE TREES MAY BE TRIMMED BACK FROM BASE 3 TO 4 FT. LEAVING STUB BRANCHES 2 TO 4 INCHES TO FACILITATE TIEING TO ANCHOR AND FITTING TO STREAM BANK.

UNDER NO CIRCUMSTANCES SHALL REVETMENT DIKE INCLUDE MORE THAN 1/3 OF STREAM WIDTH ACCORDING TO U.S. CORPS OF ENGINEERS.

PLANT VEGETATION (USUALLY REEDS CANARY GRASS OR SPRIGS) AS SOON AS SEDIMENT DEPOSITS ALLOW.



TYPICAL CEDAR REVETMENT



PLAN VIEW

CEDAR REVETMENT

Manure Testing and Manure Marketing: Tools for Nutrient Management

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ABSTRACT

Nutrient management is a key part of any livestock operation in the nineties. As a part of the Upper Conestoga Rural Clean Water Program, Penn State Cooperative Extension staff prepared individual nutrient management plans for farmers in the watershed. Successful nutrient management planning requires the use of a number of tools, including manure testing, which enables farmers to better determine nutrient content. Over 500 manure samples were tested for moisture, nitrogen, phosphorus, and potash (some were also tested for micronutrients) and individual nutrient management plans were developed. During this process, the Upper Conestoga Rural Clean Water Program identified numerous farms that had surplus animal manure and other farms that needed to purchase crop nutrients. To encourage redistribution of animal manures, Penn State Cooperative Extension compiled a buy and sell list that proved effective. This concept was then expanded to southeastern Pennsylvania counties as a part of the Chesapeake Bay Program.

Southeastern Pennsylvania is noted for intense livestock operations on small farms. Lancaster County farms are home to 99,000 dairy cows, 161,000 beef cattle and dairy heifers, 335,000 hogs, and 8,170,000 laying hens, and they produce more than 50 million broilers each year. However, high land values have forced farmers to seek ways to increase income per acre; increasing animal units per acre and purchasing additional feed have been the solutions chosen by many. Farmers export animal products, such as milk, eggs, beef, and pork, but they still have to deal with a surplus of crop nutrients in the form of animal manure. The Upper Conestoga Rural Clean Water Program (RCWP) project was located in the northeastern corner of Lancaster County to address the increasing environmental concerns about agricultural nonpoint source pollution from animal manure.

Purpose

In 1986, as a part of the Upper Conestoga RCWP project, Penn State Cooperative Extension opened a Nutrient Management Office and assigned two agents to develop nutrient management plans for farmers in the watershed. Their planning process included

- soil testing to determine soil fertility levels,
- using soil type, farmer management ability, and past history to determine yield goals,
- using livestock inventories and manure analysis to estimate the amount of manure nutrients produced on the farm annually,
- developing a plan to use manure on priority fields,

- reducing fertilizer recommendations by the amount of available nutrients in the applied manure and the residual nitrogen from previous manure applications,
- verifying nitrogen availability for corn with the nitrogen soil test, and
- determining how to market surplus manure.

The agents visited farmers to collect information on livestock numbers, cropping plans, and acreages and to take soil and manure samples. To determine the total amount of crop nutrients produced on the farm — an essential step in the planning process — total manure production had to be calculated and nutrient content determined. One option for estimating nutrient content is to use values from the literature for manure, but experience in the Upper Conestoga RCWP project demonstrates that manure testing whenever possible is preferable.

Study Methods and Results

The agents took more than 500 manure samples over five years while developing 365 individual nutrient management plans. A large variation existed among tests of single species (Table 1) and the averages of the tests were consistently higher than shown in the literature on manure values for species other than poultry. Poultry samples also varied, but their averages were fairly close to the literature value. Manure test values vary because of different feeding programs, bedding sources, and handling systems. Samples taken by Extension staff were tested for moisture, nitrogen, phosphorus, and potash (Table 1), and some were tested for micronutrient content (Table 2).

Extension staff also investigated techniques to collect a representative sample for manure nutrient testing. The staff developed procedures for sampling

Table 1.—Manure sample data of 513 samples, 1986–91.

MANURE TYPE*	NO. OF SAMPLES	PERCENT MOISTURE		NITROGEN	PHOSPHORUS (P_2O_5)	POTASH (K_2O)
Dairy (solid manure)	120	82.2	Mean	10.8	5.8	9.1
			Median	10.4	5.13	8.23
			Maximum	19.60	23.90	33.88
			Minimum	5.20	2.57	2.09
Dairy (liquid manure)	64		Mean	3.4	1.6	2.9
			Median	3.53	1.68	3.26
			Maximum	5.52	3.05	5.87
			Minimum	1.26	0.47	0.85
Dairy (heifers)	60	75.8	Mean	13.0	7.0	14.4
			Median	12.8	6.87	14.25
			Maximum	23.2	18.20	24.70
			Minimum	7.2	4.37	5.70
Beef	161	75.1	Mean	14.20	7.4	12.90
			Median	13.60	6.90	12.30
			Maximum	27.00	17.50	23.00
			Minimum	6.80	3.25	1.33
Swine (fattening)	27		Mean	6.10	4.40	2.50
			Median	6.18	4.08	2.40
			Maximum	8.91	9.78	4.20
			Minimum	3.76	1.30	1.03
Swine (farrowing)	40		Mean	3.0	1.8	1.7
			Median	2.80	1.31	1.59
			Maximum	5.09	5.42	3.05
			Minimum	0.70	0.09	0.27
Swine (solid manure)	10	74.3	Mean	21.6	18.4	15.2
			Median	22.10	18.30	17.25
			Maximum	33.60	24.20	25.90
			Minimum	11.80	10.40	5.53
Poultry (layers)	10	57.7	Mean	37.7	48.20	24.80
			Median	36.1	41.30	24.50
			Maximum	60.20	88.90	40.90
			Minimum	20.00	21.20	12.80
Poultry (broilers)	14	31.4	Mean	59.8	54.3	34.0
			Median	63.5	52.4	35.75
			Maximum	87.60	94.90	50.00
			Minimum	27.80	31.10	11.20
Turkeys	7	42.4	Mean	49.3	45.5	30.0
			Median	51.00	42.4	30.30
			Maximum	61.80	60.70	39.10
			Minimum	34.60	38.90	19.90

* Manure values for solid manure are based on lbs/ton. Liquid manure values are expressed in lbs/100 gals.

Table 2.—Micronutrient content of manure samples taken from Pennsylvania farms, 1986–91.

FARM MANURE	% MOISTURE	S	Ca	Mg	Na	Fe	Al	Mn	Cu	Zn	Cd
Poultry											
1. Broiler	31.6	NA	NA	NA	NA	NA	NA	NA	NA	NA	13.0
2. Broiler	69.2	4.32	20.60	2.59	3.21	12.83*	0.80	0.13	0.03	0.25	1.5
3. Broiler	38.2	5.81	23.60	8.53	2.84	2.47	2.22	0.28	0.04	0.28	ND
4. Broiler	34.7	4.96	25.70	3.66	5.74	1.36	0.57	0.17	0.03	0.47	ND
5. Turkey	42.8	6.98	23.20	4.01	7.67	0.91	0.86	0.28	0.13	0.33	ND
6. Layer	21.8	11.30	154.00	11.40	8.45	3.19	1.05	0.44	0.10	0.65	10.0
7. Broiler	45.0	9.57	41.80	2.42	6.60	1.76	2.04	0.52	0.20	0.57	ND
8. Broiler	28.4	8.44	34.00	8.15	7.72	5.58	4.82	0.37	0.05	0.52	1.5
Livestock											
9. Cow	79.5	0.94	5.34	2.33	2.50	0.50	0.24	0.05	0.01	0.06	NA
10. Heifer	78.6	1.62	6.15	3.02	1.79	0.82	0.76	0.10	0.02	0.09	NA
11. Cow	83.7	0.98	7.26	3.99	1.01	0.30	0.23	0.06	0.01	0.09	ND
12. Steer	80.2	4.75	4.71	1.94	1.43	3.76	0.89	0.05	0.01	0.04	NA
13. Cow/calf	79.8	1.25	5.22	1.74	1.54	2.92	0.94	0.15	0.01	0.04	NA
14. Steer	73.5	6.56	6.14	2.65	2.17	5.22	1.92	0.10	0.02	0.09	ND
15. Steer	80.3	2.56	3.27	1.38	1.73	0.26	0.17	0.03	0.01	0.03	ND
Swine (liquid manure)											
16. Sow	8.54	0.69	1.26	0.62	0.55	0.25	0.10	0.02	0.03	0.06	1.0
17. Fattening	8.53	0.93	2.55	1.08	0.18	0.25	0.11	0.02	0.04	0.03	0.5

Note: All values for poultry and livestock samples are expressed as lbs/ton except for cadmium, which is expressed as ppm on a dry matter basis. All values for swine manure are expressed as lbs/100 gallons except for cadmium, which is listed as ppm on a dry matter basis. S = sulfur; Ca = calcium; Mg = magnesium; Na = sodium; Fe = iron; Al = aluminum; Mn = manganese; Cu = copper; Zn = zinc; and Cd = cadmium.

NA = not available; ND = cadmium was not detected as 0.5 ppm; * contains rust particles.

animal waste (see the appendix). Sampling bedded pack manure that has been trampled by livestock can be a challenge. To evaluate the difficulty of obtaining representative samples under these conditions, the project assistant took three samples of steer manure from the same pen on the same farm monthly while the steers were being raised.

The results of this study are listed in Table 3. As the feeding program increased in grain concentrate fed, the manure's nutrient content generally increased. Nutrient content in the last two samples that were taken during high concentrate feeding to finish the steers for market also increased. The samples taken on the same day varied as little as 3 percent for a given nutrient to as much as 15 to 20 percent.

Because obtaining representative samples in a bedded pack situation is difficult, researchers should take several samples on one farm and use that average — or averages developed from a number of farms in a region with similar feeding programs — instead of sampling once on one farm.

The final step in nutrient management planning is determining how to deal with surplus manure after crop needs are met. While many farmers in the RCWP project area had a surplus, other farmers needed to purchase plant food. To encourage redistribution of manure, Extension developed a buy and sell list for the area that identified farmers with surplus manure (suppliers) along with a description of the manure type and test values; a list of farmers that needed additional crop nutrients (receivers) was also developed. Every farmer who had a nutrient management plan got this list, which was printed in an RCWP newsletter.

The buy and sell list stimulated phone calls and activity; obviously, it was an effective way to redistribute nutrients. Later, when the RCWP Extension agent was assigned to a regional Extension position in nutrient management, the manure marketing list was expanded to eight counties in southeastern Pennsylvania.

Extension staff also developed a manure marketing survey that was distributed at farmers' meetings and through farm mailing lists. Farmers completing this survey indicated whether they were potential manure suppliers or receivers and included other information about delivery, custom-spreading, willingness to supply free manure, and availability of composted manure. Potential receivers indicated whether they preferred composted manure, were willing to pay for the manure, or required custom manure application.

Supplier and receiver lists were compiled by county and township. These lists are updated and sent out twice a year in March and October. Farmers on the supplier list receive a copy of the receiver list and vice versa. Individual farmers then contact each other to make the arrangements.

As of March 1992, almost three times as many farmers have signed up to receive manure as to supply it (290 versus 105), indicating that a marketing opportunity exists for those with excess manure. In this dense livestock area, the fact that fewer

Table 3.—Bedded pack manure study test values.*

	% MOISTURE	NITROGEN	PHOS-PHORUS (P_2O_5)	POTASH (K_2O)
9/23	78.6	12.80	5.57	12.80
9/23	78.8	10.40	5.52	12.70
9/23	76.3	14.00	6.74	13.50
Mean	77.9	12.40	5.94	13.00
10/19	79.3	9.80	4.65	11.60
10/19	80.5	7.80	4.47	9.75
10/19	79.4	8.00	4.05	9.88
Mean	79.7	8.53	4.39	10.41
11/22	75.5	10.60	6.95	11.50
11/22	75.8	11.40	6.20	11.60
11/22	76.7	11.60	5.54	11.70
Mean	76.0	11.20	6.23	11.60
12/19	75.1	9.00	6.15	10.80
12/19	78.0	11.20	4.23	11.00
12/19	75.6	11.20	5.25	9.13
Mean	76.2	10.47	5.21	10.31
1/10	77.8	10.8	5.80	11.40
1/10	78.6	11.40	5.97	11.20
1/10	80.3	11.00	5.23	11.00
Mean	78.9	11.06	5.66	11.20
2/17	79.2	13.00	6.78	10.85
2/17	79.9	13.00	6.98	10.07
2/17	80.7	14.60	6.71	9.35
Mean	79.9	13.53	6.82	10.09
3/15	80.4	11.80	7.70	10.50
3/15	80.5	12.40	7.93	9.99
3/15	80.3	13.00	8.10	10.10
Mean	80.4	12.40	7.91	10.20
4/12	77.3	12.60	9.05	11.20
4/12	76.7	13.00	8.10	10.90
4/12	77.3	12.80	7.48	10.90
Mean	77.1	12.80	8.21	11.00
5/26	74.2	17.50	7.92	11.50
5/26	76.4	14.00	7.67	12.50
5/26	75.7	13.40	7.11	11.50
Mean	75.4	14.97	7.57	11.83
7/6	73.8	20.60	12.70	14.80
7/6	72.3	19.80	13.30	15.30
7/6	72.8	20.00	12.70	16.10
Mean	73.0	20.13	12.90	15.40
Project Average	77.5	12.75	7.09	11.50
Summary				
Moisture	Maximum		80.7	
	Minimum		72.3	
Nitrogen	Maximum		20.6	
	Minimum		7.80	
Phosphorus	Maximum		13.30	
	Minimum		4.05	
Potash	Maximum		16.1	
	Minimum		9.13	

* Manure values are expressed as lbs/ton.

farmers signed up to supply manure is not an indication of limited supply; it more likely reflects the fact that farmers who have excess manure do not want it known for fear of repercussions.

A summary of the survey indicates that, among suppliers,

- 25 percent can custom apply manure,
- 13 percent can deliver manure but will not apply it,
- 33 percent will supply the manure free if the receiver picks it up, and
- 3 percent have a composted product.

Among the receivers,

- 27 percent are especially interested in compost,
- 49 percent are willing to pay for the manure,
- 39 percent are only interested if manure is free, and
- 22 percent are only interested if the supplier can custom apply the manure.

These figures demonstrate that farmers who offer composted manure or custom application service will increase their potential markets. Other survey answers indicate that 34 percent of the farmers have tested their manure, 73 percent have never calibrated their manure spreader, and 13 percent regularly market manure to other operations. The survey will be a continuing part of Penn State Cooperative Extension's program in Lancaster County and southeastern Pennsylvania.

Manure is being marketed successfully in southeastern Pennsylvania. Because of its concentrated nutrients, poultry manure is shipped the farthest and in the greatest quantity. Weaver and Souder (1990) reported that broiler litter can be economically shipped 100 miles for fertilizer use or 300 miles for feed supplement use in Virginia. Two Lancaster County firms are each marketing, annually, over 20,000 tons of broiler litter, a large portion of which is sold to the mushroom industry in neighboring Chester County. Some manure is shipped as far away as 300 miles and sold without subsidy — sales that are usually in conjunction with a back haul of another product, such as bark mulch or mushroom compost. With increasing environmental concern and problems from over-application of crop nutrients, marketing of surplus manure for agricultural use will continue to grow.

Conclusion

Nutrient management is a key part of any livestock operation in the 1990s. Successful nutrient management planning requires a number of old and new tools. Traditional tools, such as soil testing and developing realistic yield goals, are key; new tools in-

clude manure testing, which enables farmers to better determine the nutrient content of their animal waste.

Developing a plan to deal with surplus nutrients on a farm is important to sound nutrient management planning. Manure marketing provides one solution to a sometimes difficult problem.

Reference

Weaver, W. D. Jr. and G. H. Souder. 1990 Feasibility and economics of transporting poultry waste. Proc. Natl. Poultry Waste Manage. Symp., Auburn Univ., AL.

Appendix: Manure Sampling Procedures

Compiled by Jeffrey H. Stoltzfus, project associate, and Leon Ressler, Extension agent

Several precautions should be observed when taking manure samples.

1. When sampling bedded pack manure, take samples from 10 to 20 different areas of the pen. Do not take samples near feed troughs or water bowls because the manure in these areas may be abnormally diluted with water, feed, and hay.
2. Do not take samples from freshly bedded manure packs; it is difficult to obtain the proper proportion of bedding in these manure samples.
3. Manure pits containing liquid manure should be agitated before the sample is taken. The best time to do this is when the pit is being cleaned out. If the pit cannot be agitated, a sample from several loads should be taken and mixed in a bucket. However, the first and last loads should not be used for sampling because they contain either a very high or very low percentage of solids.
4. If a liquid manure sample cannot be taken during spreading time, a representative sample should be taken from the pit. The best way to accomplish this is by using a section of 2.5 cm or larger PVC pipe that is long enough to reach the bottom of the pit and has a screw-on cap on one end. Put the pipe in the pit, then screw the cap on the top end and remove the pipe. The suction created should keep the manure in the pipe. Take 8 to 10 samples this way and mix them in a bucket to prepare the final sample.

Averages and published values provide a general view of the manure's nutrient value. However, manure values can vary from farm to farm because of differing feeding programs, types of bedding, amounts of wash water or bedding added, and manure handling systems. Nevertheless, manure tests, when done properly, are the best ways to determine manure values for individual farms.

Operation and Maintenance of RCWP BMPs in Idaho to Control Irrigation-induced Erosion

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ABSTRACT

The Rock Creek Rural Clean Water Program (RCWP) project in Twin Falls County, Idaho, controlled nonpoint source pollution from irrigated agricultural land on 185 contracted farms. Best management Practice-12 (BMP-12) — sediment-retention erosion or water-control structures — was a mandatory contract item planned to be installed annually on fields with a cultivated row crop. The component practices of BMP-12 included minibasins, I-slots, excavated and embankment sediment ponds, water control structures, buried pipe runoff control systems, and vegetative filter strips. Irrigation system improvements were the incentive to encourage voluntary participation.

RCWP contracts were flexible in allowing landowners to exchange one sediment-retention practice for another. For example, during the Rock Creek RCWP Project, landowner preference for one component within BMP-12 often changed to another component. A practice that would serve several fields was frequently selected over a practice that served just one field, thus making compliance easier while achieving equally effective results.

Of the components used, sediment ponds were the most valuable practices for illustrating how much topsoil was eroding. Community-type sediment ponds often collected irrigation wastewater from neighbors' fields and farms. Generally, these community ponds were installed on major watershed drainages, constructed on nonfarm land, and averaged 87 percent sediment-removal efficiency.

Rock Creek in Twin Falls County, Idaho, had long been recognized as one of the most severely degraded streams in the State because of point and nonpoint pollution sources. While point source pollutants had been virtually eliminated by the end of the 1970s, Rock Creek was still carrying high loads of sediment and agricultural pollutants.

The Rock Creek watershed covers a total of 198,400 acres: 51,900 acres are irrigated pasture and cropland containing 28,159 designated critical acres; 109,000 acres are rangeland; 25,400 acres are woodland; and 12,000 acres are in other uses such as urban land, roads, and farmsteads. Approximately 350 farm units are located within the watershed. Figure 1 shows the location of the Rock Creek watershed in Idaho and subbasin boundaries. The map is taken from the final interagency report on the Rock Creek Project. Basic crops include dry beans, dry peas, sugar beets, corn, small grains, potatoes, alfalfa, and pasture. Because of low annual precipitation, all crops are irrigated. Irrigation water is diverted from the Snake River to individual farms through a network of canals and laterals owned by the Twin Falls Canal Company. Water is available at a constant flow from about April 15 through October 15.

Idaho's Rock Creek Rural Clean Water Program (RCWP) project successfully reduced suspended sediment and total phosphorus in the drainages flowing into Rock Creek by 75 and 68 percent, respectively. Good operation and maintenance of the best management practices (BMPs) — those measures determined to be the most effective and practical means of preventing or reducing pollution

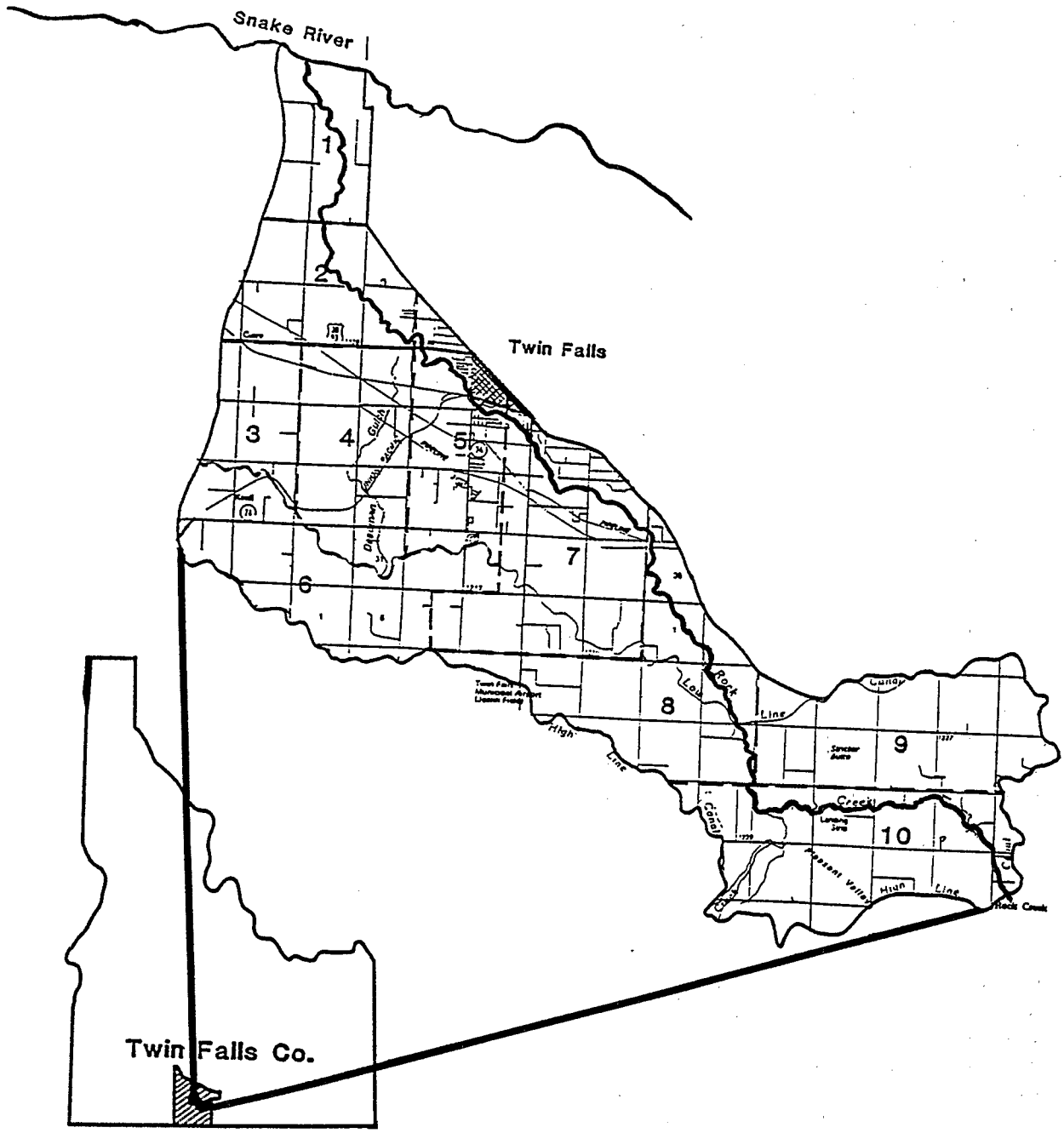


Figure 1.—Map of the Rock Creek, Idaho, RCWP project area and subbasin boundaries.

from nonpoint sources — are the major reason that water quality improved. BMP-12, which was composed of sediment-retention, erosion, or water control structures, was particularly effective. Table 1 shows the sediment-removal efficiencies of several BMP-12 components. Comments on the BMP were documented by the Agricultural Research Service, Kimberly, Idaho. This paper will describe how the components of BMP-12 (minibasins, I-slots, sediment ponds, buried pipe runoff practice control systems, vegetative filter strips, and water control structures) were applied and evolved through the years. Several techniques for installing the BMPs will also be described to indicate the problems and solutions the Soil Conservation Service (SCS) experienced with voluntary participants.

Minibasins

Minibasins, or small, excavated ponds that retain waste irrigation water, were an effective practice to trap the topsoil sediment coming from a single field.

Table 1.—Evaluation of BMPs (source: Carter, 1987).

BMP	SEDIMENT REMOVAL EFFICIENCY (PERCENT) AVERAGE	RANGE	COMMENTS
Sediment basins (field, farm, subbasin)	87	75–95	Cleaning costly
Minibasins	86*	0–95	Controlled outlets essential; careful management required
Buried pipe systems	83	75–95	High installation cost; potential for increased production to offset costs; eliminates tailwater ditch; good control of tailwater
Vegetative filters	50*	35–70	Simple; proper installation and management needed

*Average of those BMPs that did not fail.

Minibasins worked best on flat field bottoms, but they also required considerable effort to install and maintain, because their outlets must be protected if they are to retain their storage capacity. PVC pipe, sheets of plastic, and grass sod ditch banks were used to establish and protect the outlet and storage capacity of each minibasin. Figure 2 shows a diagram of minibasins.

Early in the Rock Creek RCWP project, several implements were used to install minibasins. A bulldozer was used to push out storage capacity, leaving a large mound of topsoil. When the excavated topsoil was not spread out to a field, a weed problem developed on the mounds. A carryall was used to excavate the minibasin and then deposit soil to create an earthen berm, which was necessary between each minibasin to regulate trap efficiency. Another landowner scraped down an entire field bottom to the design depth, then used a small bulldozer to blade up the berm between each minibasin. The minibasin outlet was then surveyed and cut in with a hand shovel.

Sometimes the dead furrow caused during the plow's final pass in a field created a problem in the minibasin component. Normally, this dead furrow was used as the field's drainage ditch. When a minibasin was installed before the field was plowed, however, the dead furrow created a drainage ditch in front of the minibasin, preventing it from working properly. Extensive hand labor was then needed to cut irrigated furrows into each minibasin.

I-Slots

I-slots are small, excavated sediment ponds dug into a field's wastewater drainage ditch. Generally, I-slots are 3 to 4 ft wide, 20 ft long, and 2 to 4 ft deep. They are used to drain a single field. (Initially, T-slots were used, but evolved into the easier to install I-slots.) Figure 3 shows a diagram of I-slots. A back hoe was normally used to install I-slots. Excavated topsoil was then scraped up and spread out on the immediate or adjacent field.

I-slots can be used on flat and steeply sloped field bottoms. On flatter field bottoms, a back hoe was used to dig a drain ditch lower than the field surface between each I-slot to keep wastewater out of the field.

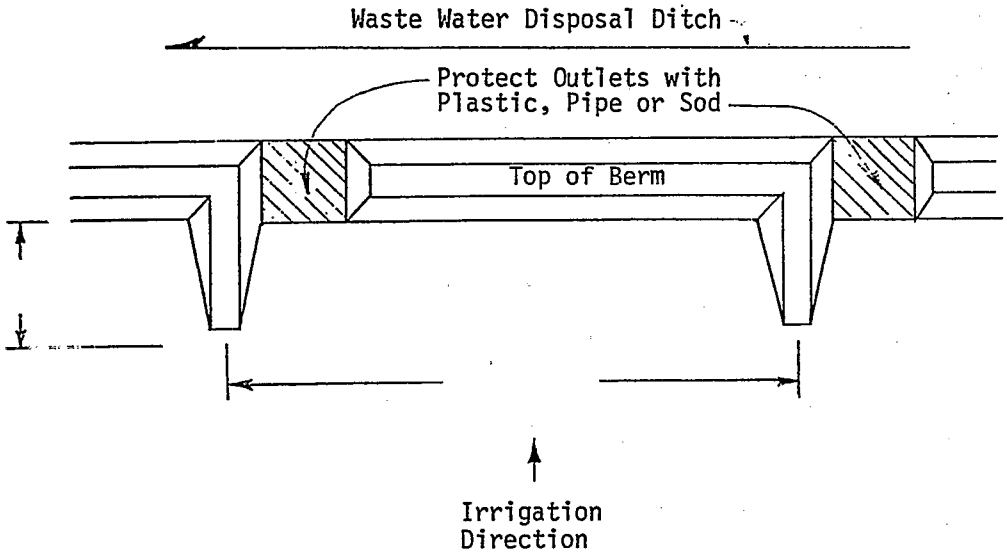
Not all field bottoms, however, were good for I-slots. In some fields, drainage ditches were deep, resulting in a lack of storage capacity in I-slots. In such cases, sheets of plastic were used to help raise and stabilize the outlet of each I-slot to make it functional. Also, I-slots were sometimes dug wider to achieve the design storage capacity in shallow soils and to help prevent spreading of caliche and other rocky debris to the field.

I-slots proved to be an excellent "show-and-tell" BMP. When they filled up at the end of the first or second irrigation, landowners and farm operators soon realized that better irrigation water management was needed.

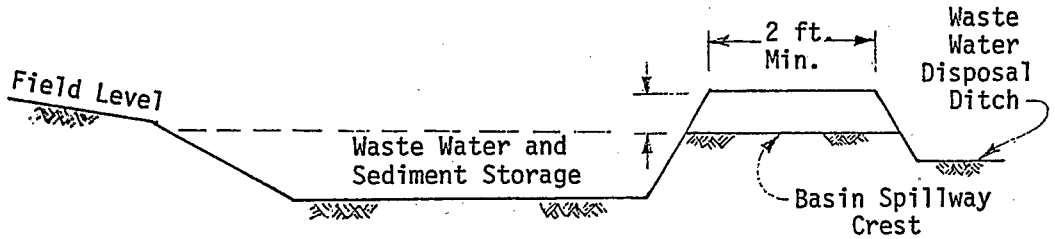
Sediment Ponds

Excavated sediment ponds were installed during the Rock Creek RCWP project where the pond could collect wastewater from one or more fields. The closer the pond was to the field(s) it drained, the sooner it filled with sediment.

Excavated sediment ponds were designed for a minimum of one- and a maximum of five-years' storage capacity. The greater-than-one-year storage capacity was desirable because it helped reduce the landowner's maintenance expense. To help the sediment pond last longer, a vegetative filter strip was planted above the pond along the entire field bottom, thus reducing maintenance and related expense. Quite often, landowners who owned excavation equipment had used sediment ponds even before the RCWP to collect the valuable topsoil eroding from



TYPICAL PLAN VIEW



TYPICAL CROSS SECTION

NOTE

Construction shall be in accordance with Construction Specification ID-350-B.

_____ Mini Basins Required

I have reviewed the plans and specifications and agree to construct this project to the best of my ability in accordance with them.

_____ Date_____

NOT TO SCALE

MINI-BASINS

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

Designed Date | Approved by
Drawn | Title
Traced | Sheet | Drawing No.
Checked | No. of | Job Class

Figure 2.—Diagram of minibasins.

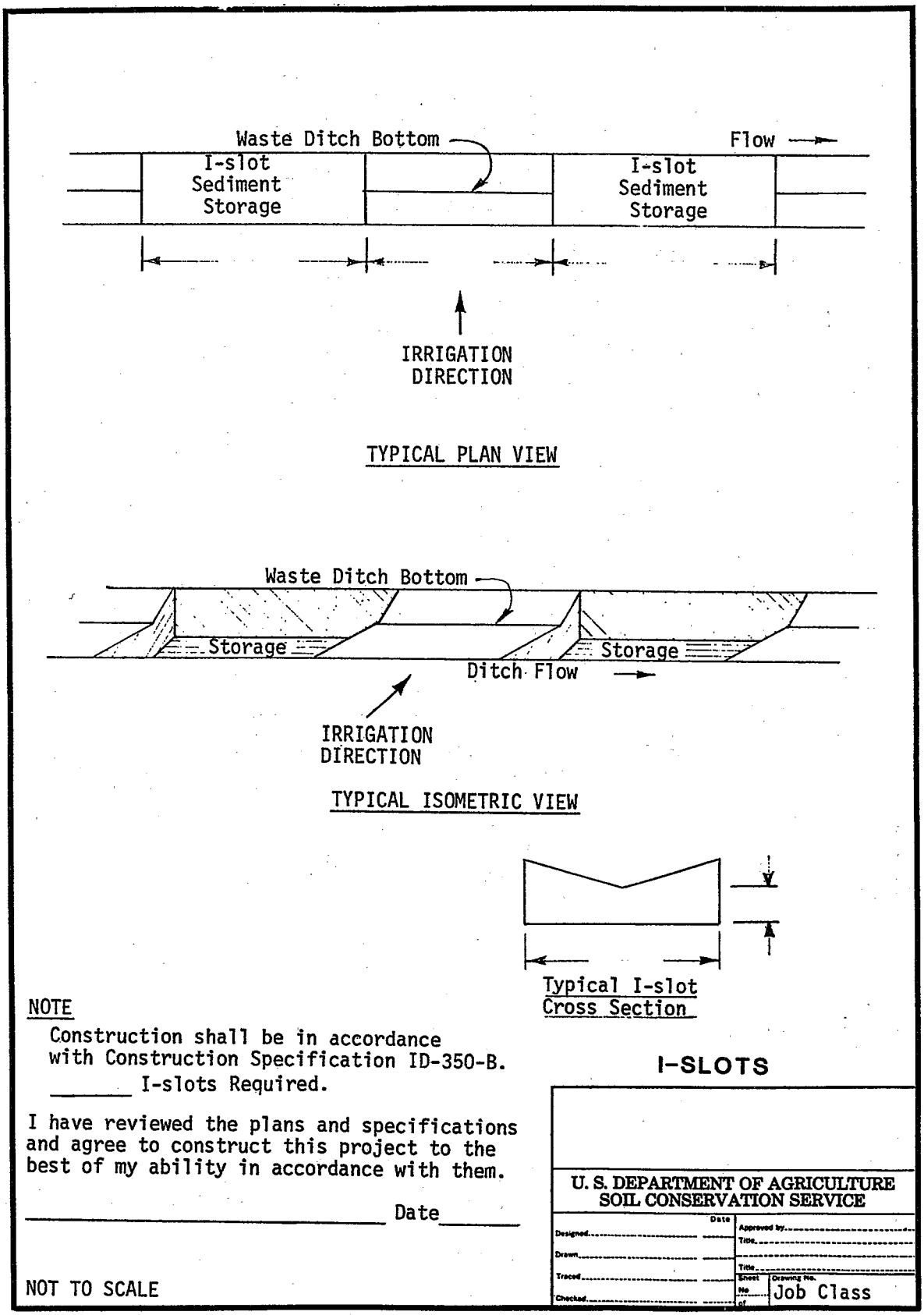


Figure 3.—Diagram of I-slots.

their own and their neighbors' fields or farms. Figure 4 is an Idaho standard engineering drawing used to design excavated sediment ponds.

Community embankment sediment ponds were often installed where they could trap irrigation waste water pollutants from the fields of neighbors who were not project participants. Usually, the embankment pond site was land that was out of production and not being farmed. For example, at one location, old sheep corrals next to Rock Creek were converted to an embankment pond with a three-year sediment storage capacity for an 1,100-acre watershed. All embankment sediment ponds resulted in an immediate improvement of water quality and eventually developed as good wildlife habitats. Figure 5 is an Idaho standard engineering drawing used for embankment sediment ponds and water control structures.

Water control structures were needed to establish storage capacity within excavated and embankment sediment ponds. Care had to be taken to protect these structures from washing out. A trash rack was needed at the inlet, and rock rip-rap was needed at the outlet to further protect the structure from failing. Figure 6 is an Idaho standard engineering design of a pipe inlet or outlet commonly used for buried pipelines but sometimes used for sediment ponds.

Buried Pipe Runoff Control Systems

The buried pipe runoff control system (BPRCS) consisted of a buried plastic mainline, with inlet risers installed every 20, 40, or 60 feet, depending on steepness of the field bottom. Earthen berms were installed near each inlet riser to control and direct the irrigation wastewater flowing to each inlet riser. Hand labor was needed to adjust the berms and to survey and cut the inlet risers to keep water from flowing around the berm into the field. In a few instances, the field was irrigated before the inlet risers were properly adjusted, which caused serious erosion.

One land operator was particularly fond of BPRCS. He operated six farms with RCWP contracts and wanted the BPRCS installed on each farm. Some fields he chose did not have a convex end (a progressively increasing slope over the lower 20 to 80 ft of the field into the drained ditch that develops as a result of farmers keeping drainage ditches lower than the furrow ends and cleaned so that water will run off the field bottom quickly). These BPRCS required a good back berm. If that berm did not exist, it had to be created, which required minibasins to be excavated and the topsoil used to create the back berm and the individual minibasins. The inlet riser was then surveyed and cut to an elevation that kept the wastewater in the minibasin and out of the cropland. Figure 7 is a hand-drawn sketch of the top and side view of the buried pipe runoff control system invented by Dr. David Carter, a supervisory soil scientist for the Agricultural Research Service. (No Idaho standard engineering drawing exists for this system at this time.)

Vegetative Filter Strips

Vegetative filter strips were used annually in Idaho's RCWP project and planted to spring grain, winter grain, oats, or an alfalfa and grass mixture. Non-cost-share filter strips used permanent pastureland or a strip of alfalfa left along the entire field bottom when the field was plowed for the next crop.

Soil moisture was critical to get spring-planted filter strips to grow tall enough before the first irrigation. The corrugates were pulled a third of the way into the filter strip to get the wastewater into and across it. Ponding sometimes occurred in front of the filter strip causing crop damage on flat field bottoms with no convex end.

Permanent filter strips were used and were effective for two to three years. In the third year, sediment deposition sometimes created the need to dig berms to force water into and across the filter strip. The field bottom then had to be reshaped and replanted following harvest. Additionally, the plow's dead furrow presented a problem when an alfalfa strip was left as the filter strip. The dead furrow often became the wastewater ditch in front of the filter strip, rendering it ineffective.

Ideally, filter strips should be managed as grassed waterways. In other words, the field bottom should be graded down to the depth of the plow's dead furrow and planted in the fall. A winter-hardy plant species should then be planted in the graded area. When the farmer plows the field in the spring, the plow's depth must blend into the depth of the graded field bottom. Adequate vegetation will be present in the spring time to help clean irrigation wastewater of sediment and fertilizer nutrients. When sediment bars build up, the filter strip or grassed waterway should be reshaped and reseeded. Figure 8 is an Idaho standard engineering drawing for a grassed waterway. (No Idaho standard engineering drawing for vegetative filter strips exists at this time.) The author chose to use the grassed waterway drawing because it depicts the way annual vegetative filter strips should be managed in the future.

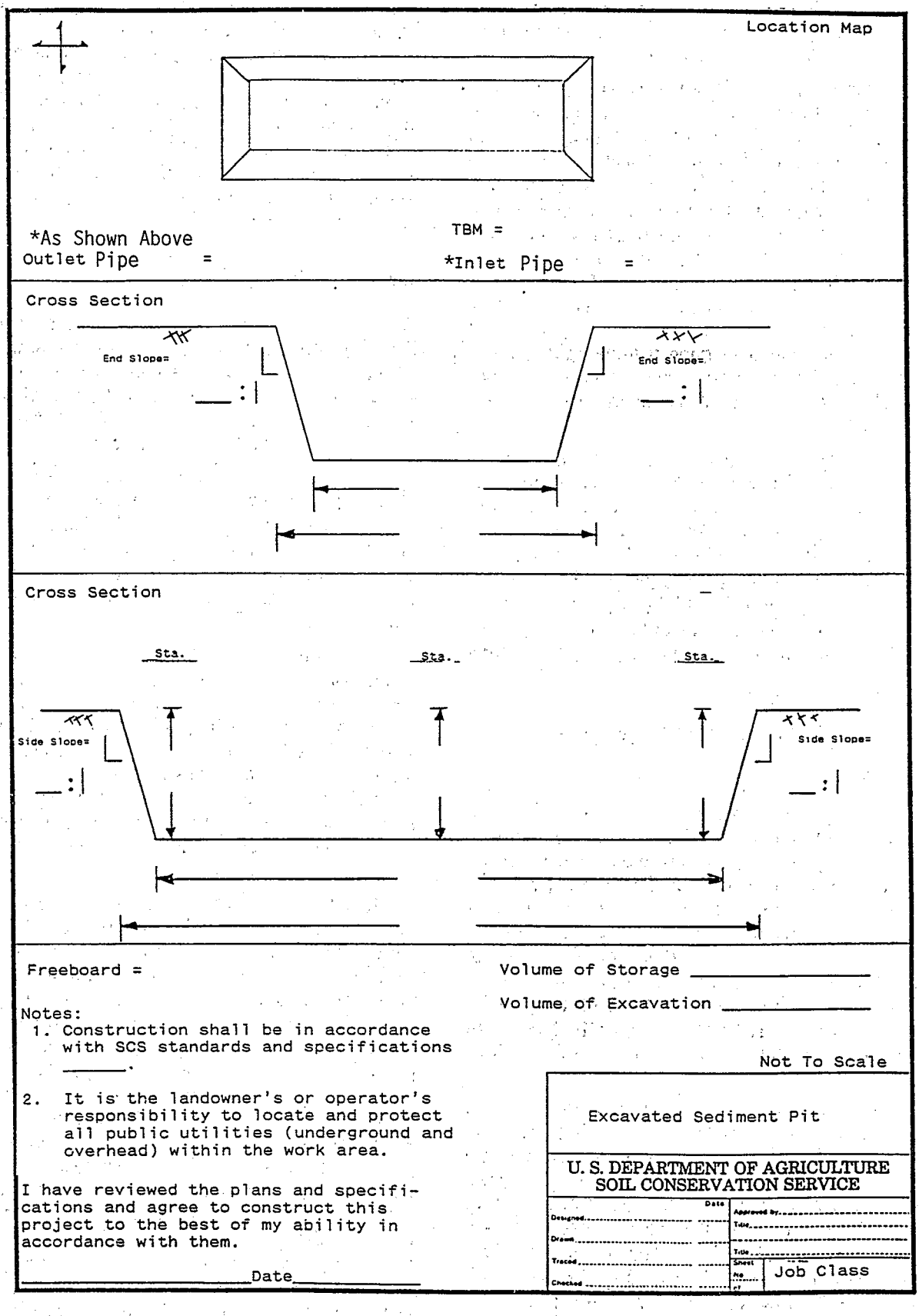


Figure 4.—Idaho standard engineering diagram used to design excavated sediment ponds.

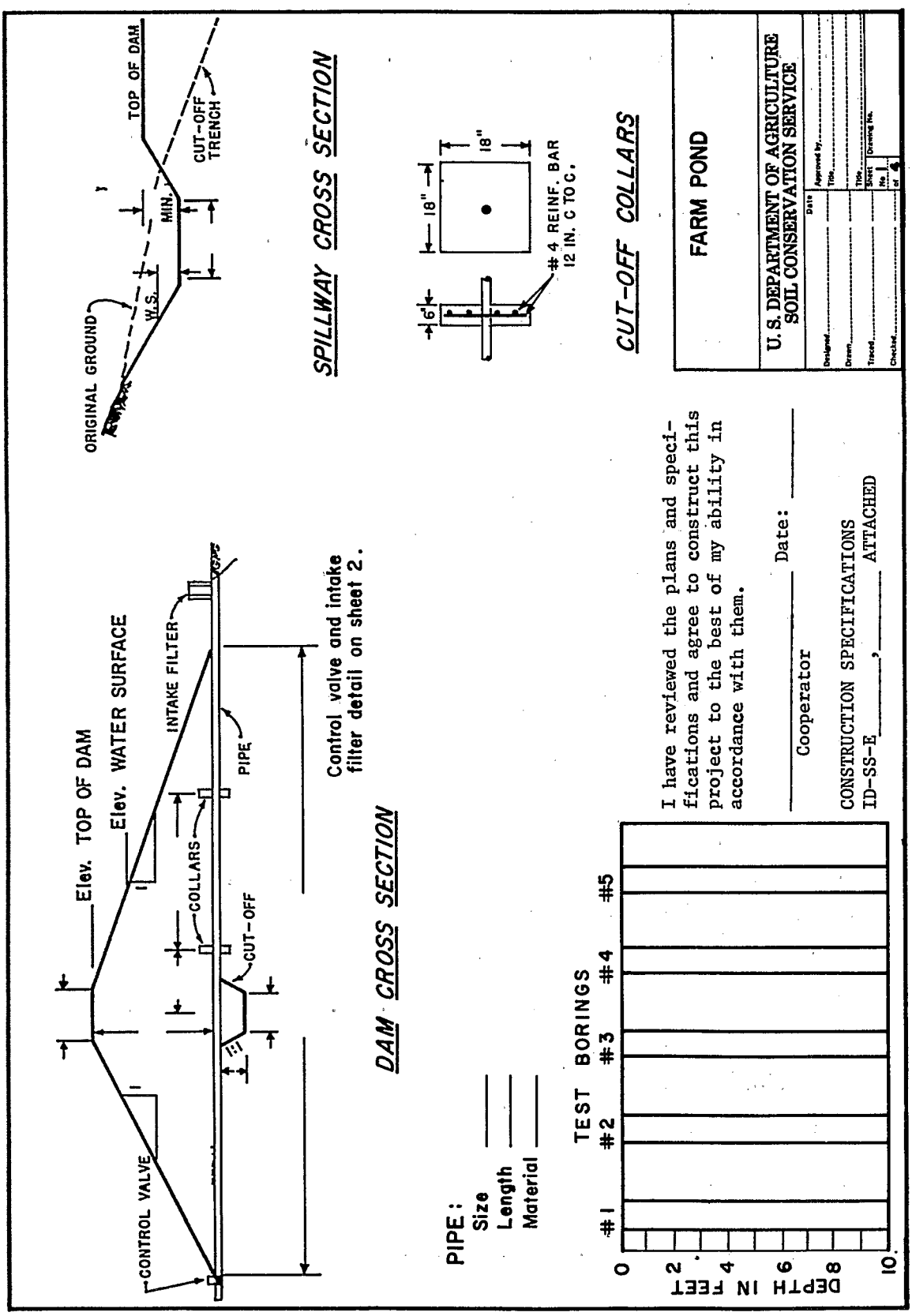


Figure 5.—Idaho standard engineering diagram used to design embankment sediment ponds and water control structure.

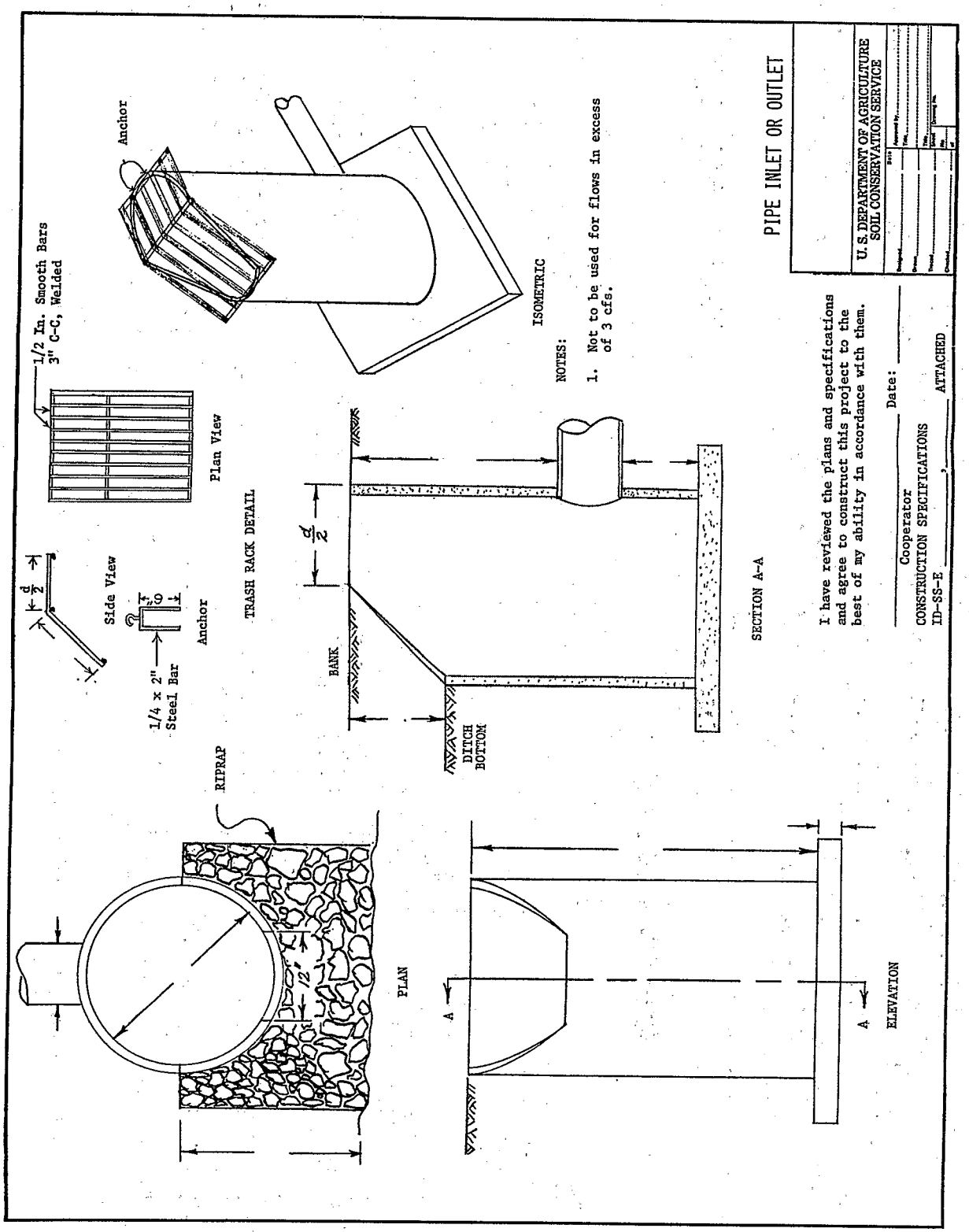


Figure 6.—Idaho standard engineering diagram depicting design of a pipe inlet or outlet.

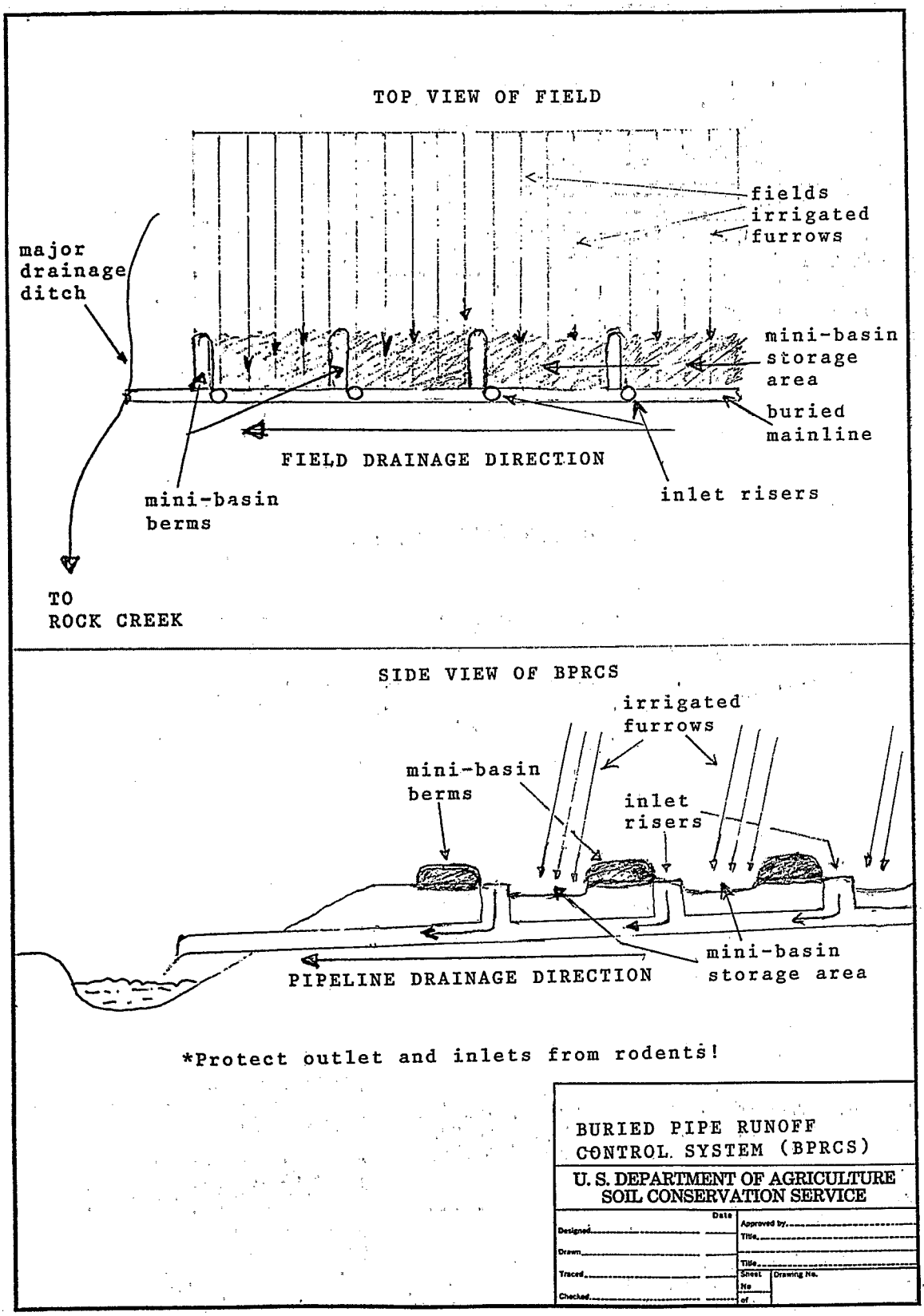


Figure 7.—Hand-drawn sketch of top and side view of a buried pipe runoff control system.

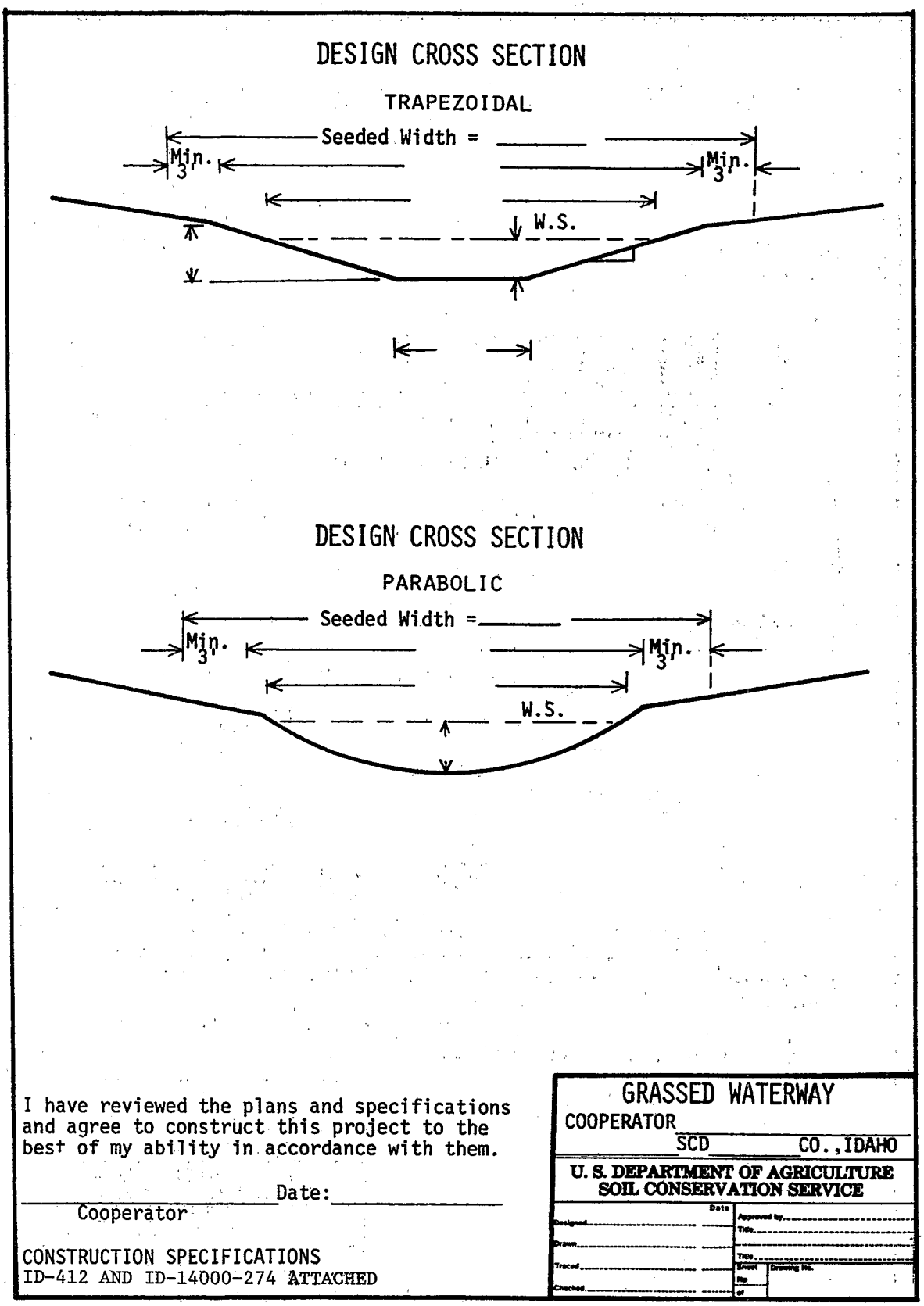


Figure 8.—Idaho standard engineering diagram for a grassed waterway.

Conclusions

Through the process of installing and evaluating BMP-12 component practices, the following lessons have been learned and shared:

- Minibasins work best on flat field bottoms. Scraping the entire field bottom down to the design depth and using a small bulldozer to push up berms is the best way to install this practice. Be sure to protect the outlet of each minibasin.

- I-slots can be used on steeper field bottoms by reducing the length of the I-slots so that all excavated storage capacity will be used. The I-slots are excavated in the field's drainage ditch. A shallow drainage ditch between each I-slot is desirable to help increase the I-slot's storage capacity.

- Excavated sediment ponds located in the corner of a field may eliminate the need for small ponds along the entire field bottom (i.e., minibasins or I-slots).

- A vegetative filter strip can be used along the entire field bottom above the sediment pond to keep the pond from filling up with sediment so quickly.

- Embankment sediment ponds normally drain more than one field or farm. The best location to install these larger ponds is in major drainages and on land not being farmed.

- Structures for water control are a necessary component of all embankment sediment ponds. Excavated sediment ponds may need a structure for water control in the form of a piped outlet depending on the pond site.

- Buried pipe runoff control systems work best on steep field bottoms with a severe convex end. To maintain pipeline gradient, the corrugated plastic pipe mainline needs to be carefully hand bedded before being covered. Protection is needed at the inlet and the outlet so the system does not get plugged by trash and rodents.

- Vegetative filter strips became the more popular BMP when a field needed sediment retention. Filter strips used on flat field bottoms created crop damage by water scalding. To solve this problem, field bottoms should be scraped down to the plow's depth (6 to 8 inches deep) and planted using a winter-growing plant species. When the farmer plows the field in the spring, the plow's dead furrow (6 to 8 inches deep) won't adversely affect the filter strip's effectiveness by creating a wastewater ditch in front of the filter strip.

- The Soil Conservation Service has kept the standards and specifications for installing the BMP-12 components flexible enough to allow for any needed modifications in the experimental RCWP project.

- Cropland fields with 0 to 1 percent field slopes have a tolerable soil loss and may not be critical acres in need of treatment.

- Cropland fields adjacent to wastewater drainages in which no opportunity exists for reusing the wastewater are the most critical irrigated acres to be treated.

Reference

Carter, D. 1987. RCWP Annual Report. Agric. Res. Serv., U.S. Dep. Agric., Kimberly, ID.

Coordination is the Project Cornerstone

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ABSTRACT

The success of the Oakwood Lakes–Poinsett Rural Clean Water Program project resulted from the coordination that existed between all the agencies involved. At the county level, excellent cooperation and coordination existed among the Agricultural Stabilization and Conservation Service (ASCS), the Soil Conservation Service (SCS), county committees, and conservation districts, which provided an excellent forum for local input and control. This cooperation carried through to the State level, where ASCS, SCS, Cooperative Extension, and South Dakota Department of Environmental and Natural Resources (DENR) worked closely to ensure that the project would move ahead smoothly with little interruption. DENR served as the main agency in the comprehensive monitoring and evaluation portion of the project by contracting with ASCS and the South Dakota State University Water Resources Institute to implement the project's goals and objectives. SCS and the Cooperative Extension worked with DENR to support any activities that were needed—from identifying critical areas and planning project tours to completing annual progress reports. A team approach, used to accomplish this coordination, gave every agency or group a say in what was being done and the ability to make changes as needed. This approach also allowed the team to bring in national-level specialists and experts to assist the project and maintain the national perspective of the Rural Clean Water Program project.

The goal of the South Dakota Oakwood Lakes–Poinsett Rural Clean Water Program (RCWP) project was to reduce the total nitrogen, pesticides, and animal waste entering the ground and surface water in the project area by implementing fertilizer and pesticide management and conservation tillage on 60,000 acres. The comprehensive monitoring and evaluation portion of the project monitored the effects and evaluated the impacts to groundwater and surface water from the implementation of best management practices (BMPs).

The success of the Oakwood Lakes–Poinsett RCWP project was measured in three areas:

1. Producer participation was high—over 80 percent of the highest priority area was under RCWP contracts and a majority maintained BMPs even after the cost-share period had ended.
2. Cooperation between participating agencies was outstanding, with all agencies maintaining an active involvement throughout the project.
3. Water quality monitoring indicated that the implementation of BMPs to protect and improve the surface water quality did not adversely affect the groundwater.

This paper focuses on the cooperative efforts and the use of committees, interagency teams, and a project coordinator to implement successful RCWP projects.

Discussion

Committees

At the county level, cooperation and project coordination occurred among county committees, conservation districts, the ASCS, and the SCS in all three counties. Vital local input and control were possible through a local coordinating committee, which received support from county, State, and Federal agencies, lake associations, and local farm communities. The local coordinating committee was comprised of individuals from the three county conservation districts and county committees with one member from a county committee serving as chairperson. Acting as the local project sponsor, local coordinating committee members used their knowledge of the project area and information from the land treatment team to recommend priority areas, goals, and objectives to the State coordinating committee for its consideration and action. The local coordinating committee also served as a mechanism to distribute information to individuals in the project area.

The State coordinating committee served as the project decisionmaking body and was represented by the following agencies: ASCS, SCS, Cooperative Extension Service (CES), Farmers Home Administration (FmHA), Statistical Reporting Service (SRS), Environmental Protection Agency (EPA), South Dakota Department of Agriculture, Economic Research Service (ERS), Water Resources Institute (WRI), and South Dakota Department of Environment and Natural Resources (DENR). The State coordinating committee directed most aspects of the project by acting on recommendations from the local coordinating committee or the comprehensive monitoring and evaluation team, depending on the project objectives. Excluding CES and ERS, all funding decisions were made by the State coordinating committee, thus ensuring that adequate funding was dedicated to meeting project objectives. This approach allowed the State coordinating committee to base its decisions on local coordinating committee recommendations and national coordinating committee directives; it also encouraged all participating agencies to share input on how project funds were to be used. Finally, the State coordinating committee served as the main contact for the national coordinating committee.

Most agencies represented on these committees remained active throughout the 10-year project period. The State and local coordinating committees were successful in planning, requesting, and securing approval from the national coordinating committee for additional cost-share and monitoring funds to meet project goals. These committees were successful because everyone serving on the committees believed in and supported the project from its beginning to end.

Teams

Another concept that worked well in this project was the use of technical teams. Three teams were developed to implement planning and contract development, to monitor the project, and to provide information and educational activities as needed for the project. These teams included the land treatment team, the comprehensive monitoring and evaluation team, and the report management team.

The land treatment team, consisting of Cooperative Extension specialists, three SCS district conservationists, three ASCS county executive directors, and a conservation district technical planner, acted as technical advisors to the local coordinating committee. The committee guided the team on how to obtain public acceptance for the project, and in turn, the team advised the committee on the project's technical aspects; for example,

- fertilizer management, pesticide management, and conservation tillage were identified as the best BMPs for water quality problems and the most likely to be accepted for the area; and
- the critical area and the process for establishing priority areas was identified and developed.

The land treatment team's main role was to work directly with producers by supplying information and education and by developing conservation plans and water quality contracts for BMP implementation. Although all team members worked with producers, the technical planner provided the one-on-one contact that accelerated producer participation. The land treatment team also decided which producers to contact, what BMPs to cost-share, and how to address day-to-day problems with contracts and operators.

The comprehensive monitoring and evaluation team's role was defined in contractual agreements developed by ASCS and DENR (with the concurrence of SCS). This team managed and conducted the comprehensive monitoring and evaluation project. DENR, in turn, contracted with several agencies to implement various portions of the project. This team consisted of five technical people from DENR and WRI and was directed by the DENR

project manager. It was responsible for monitoring the cause-and-effect relationships between agricultural BMPs and the water quality in the study area. Therefore, it monitored the ground and surface waters and water in the soil profile by using the strategy and standards established in the contractual agreements and the project workplan.

An SCS employee coordinated the comprehensive monitoring and evaluation activities. This coordinator served as a direct link between the State coordinating committee, DENR, and the monitoring team and as a passive link between the local coordinating committee and the land treatment team (see Fig. 1). The coordinator maintained vital communication between the comprehensive monitoring and evaluation team and the land treatment team, helped establish schedules for meetings and reports, and served as an information contact for everyone involved in the project. Near the project's end, the coordinator and the comprehensive monitoring and evaluation team manager served as report coordinators. By consensus of the report management team, they directed the work and coordinated the preparation of the final report.

The role of the report management team was to plan and prepare the 10-year report. The report team was comprised of the project coordinator, the comprehensive monitoring and evaluation team, the information and education coordinator, the technical planner, a WRI representative, and several State coordinating committee members. Using the national coordinating committee's outline, the team cooperatively prepared and reviewed each section of the final report for content and format. As a result, the final report was concise and correct when completed.

Lessons Learned

Many lessons were learned from this project, but the following lessons stand out as strong points in project coordination:

■ The full support of everyone involved—from the grass roots to the State level—is vital for a project to succeed. This support was very evident in the Oakwood Lakes–Poinsett RCWP project, which had the full commitment of the local coordinating committee, State coordinating committee, and the various groups and agencies they represented.

■ Using teams to implement project activities worked well because each team had an identified structure, goals, and objectives. Team leaders were identified who could work with team members to ensure that tasks were completed according to the schedules established in workplans and contractual agreements. This concept allowed the teams to identify who would be working with producers on a one-to-one basis, thus eliminating producer confusion and helping the project to run much more effectively and efficiently.

■ Using the State water quality agency (DENR) to conduct comprehensive monitoring and evaluation also added to the project's efficiency. Again, the team concept allowed those individuals with monitoring experience and expertise to control the project's work in that area and to implement established goals and objectives.

■ The project coordinator (whose role varied somewhat throughout the project) was essential for a successful project. For the first five years of the project, the coordinator was located 200 miles from the project area, isolating the coordinator from the land treatment team and most members of the comprehensive monitoring and evaluation team. The coordinator's position was then moved nearer to the project area, which resulted in greater communication between the teams and more effective leadership for the report management team. The coordinator maintained communication between the comprehensive monitoring and evaluation team (who were water quality people) and the land treatment team (who were U.S. Department of Agriculture [USDA] personnel). The coordinator also supplied a direct link between the teams and the State coordinating committee, where all primary project decisions were made. This individual, an SCS employee, was familiar with USDA programs and workers on the district, area, and State levels, which made communication among the teams and different disciplines much easier. The coordinator's location proved most effective when located in the project area.

■ One weakness in the RCWP project coordination was that after the sign-up period for BMP contracting had ended, the land treatment team and the local coordinating committee became less involved in the project, mainly because its members acquired additional responsibilities under the 1988 Food Security Act. More involvement from the local coordinating committee and the land treatment team throughout the project would have improved the information exchange among teams and producers involved in the project. This increased involvement would also have provided a larger group to help develop the land treatment portions of the 10-year report.

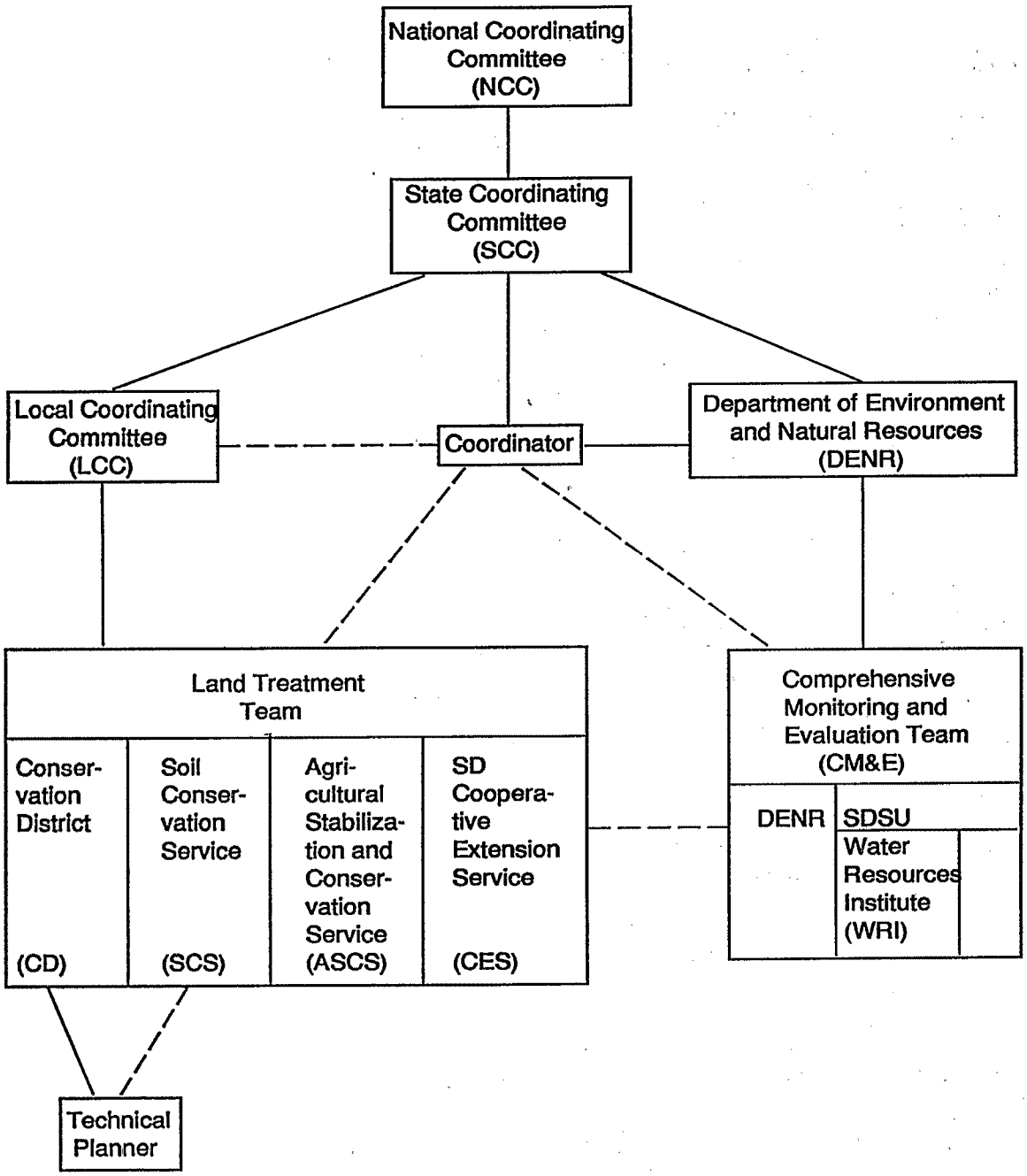

Figure 1.—Oakwood Lakes–Poinsett RCWP project organizational chart.

Conclusion

Coordination is very important for any project. Without proper coordination the chances for complete project success are reduced considerably. Effective project coordination begins before the project's implementation and continues throughout the project's life. The coordination of the Oakwood Lakes–Poinsett RCWP project was exceptional. All agencies, groups, and individuals worked together and were highly motivated to make the project succeed—the primary formula for success. And the process has continued: the cooperation developed between agencies during the Oakwood Lakes–Poinsett RCWP project has carried over to the Big Sioux Aquifer Demonstration project and several other nonpoint source projects now being developed in South Dakota.

Taylor Creek-Nubbin Slough RCWP Institutional Arrangement and Program Administration

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ABSTRACT

Institutional arrangements and program administration were key to many of the successes in the Taylor Creek-Nubbin Slough Rural Clean Water Program project. The Okeechobee Agricultural Stabilization and Conservation Service county executive director acted as project administrator and was assisted on the administrative subcommittee by representatives of three State agencies. These four people met regularly (and as necessary) to handle the project's day-to-day operations. Each agency fully understood the other's role; therefore, one agency could assist another with its problems. This cooperation proved helpful for participants, who could get the whole picture from any of the four agencies. This arrangement was key to the project's success—89 percent of the critical area were contracted and 99 percent of the best management practices installed—and helped to hold the agencies working closest to the project together for 10 years. (This paper is based on the Taylor Creek-Nubbin Slough 10-year Report.)

The Taylor Creek-Nubbin Slough Rural Clean Water Program (RCWP) project is located primarily in Okeechobee, Florida. Funded in 1981, the only RCWP project in Florida defined 63,109 acres of the Taylor Creek-Nubbin Slough basin as critical and identified 59 farms that needed treatment.

The Taylor Creek-Nubbin Slough RCWP project was coordinated by a project administrator—the Okeechobee Agricultural Stabilization and Conservation Service county executive director—who headed an administrative subcommittee. Because most of project acreage was located in Okeechobee County, the Okeechobee county executive director coordinated submission of the project and assumed the role of administrator responsible for coordinating all activities, keeping the project on track, and understanding all project phases and each agency's roles and responsibilities.

While organizing the project, the local coordinating committee realized it could not meet often enough to solve problems as they arose, so it established an administrative subcommittee to coordinate project activities. This subcommittee included representatives of agencies that would be the most actively involved in the project: the project administrator, the Soil Conservation Service district conservationist, County Cooperative Extension agent, and a representative of the local South Florida Water Management District office.

The administrative subcommittee met monthly and as needed to keep the project on track. This project's success resulted from the cooperation and close working relationship of these four agencies and their representatives; the group's small size made it easy to call meetings and keep in contact on the project's day-to-day operation. Each member understood the others' roles and therefore could assist

in solving problems and meeting goals. By working closely together, the administrative subcommittee was able to overcome many obstacles early in the project. The administrative subcommittee and local coordinating committee met several times a year to review project progress.

Local Coordinating Committee/State Coordinating Committee Coordination

The local and State coordinating committees worked mainly through their respective agencies. Representatives from both committees met to review the annual report and the local coordinating committee invited State committee members to participate in field days or tours of the RCWP area. The two committees gave the administrative subcommittee the flexibility it needed to run the day-to-day operations and make recommendations and changes. Any major changes were considered by the administrative subcommittee, the local coordinating committee, the State coordinating committee, and finally, the national coordinating committee.

Tables 1 and 2 list the agencies represented on the State and local coordinating committees. The local coordinating committee had an official membership, but the committee itself was made up of several members of the different agencies involved. No formal memoranda of understanding (MOU) were signed because the local agencies had such close working relationships. (One MOU was signed with the South Florida Water Management District for monitoring, but only because it was mandated under national procedure.)

Institutional Arrangements

The Agricultural Stabilization and Conservation Service handbook *1-RCWP* outlined the institutional arrangements and each agency's role. The Taylor Creek-Nubbin Slough project was not restricted by the *1-RCWP* and expanded these roles as needed. The four key agencies participated in all areas and phases of the project, even though they were not specifically mandated to do so. This coordination and understanding brought the agencies closer together:

Table 1.—Taylor Creek-Nubbin Slough RCWP project Okeechobee County local coordinating committee membership.

- Okeechobee Agricultural Stabilization & Conservation Service Commitee
  609 SW Park Street
  Okeechobee , FL 34972
- Okeechobee Soil & Water Conservation District
  419 SE 8th Avenue
  Okeechobee, FL 34974
- USDA-Farmers Home Administration
  314 NW 5th Avenue
  Okeechobee, FL 34972
- Cooperative Extension Service
  501 NW 5th Avenue
  Okeechobee, FL 34972
- Game & Fresh Water Fish Commission
  3991 SE 27th Court
  Okeechobee, FL 34974
- Martin Agricultural Stabilization & Conservation Service
  P.O. Box 385
  Palm City, FL 34990
- Dairy Farmers Inc.
  P.O. Box 7854
  Orlando, FL 32854
- USDA-Agricultural Research Service
  Bldg. 164, University of Florida
  Gainesville, FL 32611
- South Florida Water Management District
  1000 NE 40th Avenue
  Okeechobee, FL 34972
- USDA-Soil Conservation Service
  611 SW Park Street
  Okeechobee, FL 34972
- Florida Division of Forestry
  5200 Highway 441 North
  Okeechobee, FL 34972
- USDA-Soil Conservation Service
  2401 SE Monterey Road
  Stuart, FL 34996
- Martin Soil & Water Conservation District
  P.O. Box 362
  Palm City, FL 34990
- Department of Environmental Regulations
  1900 S. Congress Avenue
  West Palm Beach, FL 33406

Table 2.—Taylor Creek-Nubbin Slough RCWP project Florida State coordinating committee membership.

- Florida State Agricultural Stabilization & Conservation Service
  P.O. Box 141030
  Gainesville, FL 32614-1030
- Office of the Governor
  Tallahassee, FL 32399-0001
- Florida Farmers Home Administration
  P.O. Box 1088
  Gainesville, FL 32602
- National Agricultural Statistical Service
  1222 Woodward Street
  Orlando, FL 32803
- U.S. Environmental Protection Agency
  345 Courtland Street, NE
  Atlanta, GA 30308
- U.S. Forest Service
  227 N. Bronough Street, #4061
  Tallahassee, FL 32301
- South Florida Water Management District
  P.O. Box 24680
  West Palm Beach, FL 33416
- USDA-Agricultural Research Service
  Bldg. 164, University of Florida
  Gainesville, FL 32611
- Florida State Soil Conservation Service
  P.O. Box 1208
  Gainesville, FL 32602
- Department of Environmental Regulations
  2600 Blair Stone Road
  Tallahassee, FL 32301
- Soil & Water Conservation Bureau
  P.O. Box 1269
  Gainesville, FL 32602
- Cooperative Extension
  1038 McCarty Hall
  Gainesville, FL 32611
- Florida Division of Forestry
  Collins Building
  Tallahassee, FL 32301

agencies did not feel that one was trying to overshadow the other.

Agricultural Stabilization and Conservation Service

The Agricultural Stabilization and Conservation Service was responsible for the overall day-to-day operation of the RCWP project. The Service's Okeechobee County committee chairman chaired the local coordinating committee. The agency took applications for participation, and, along with the Soil Conservation Service and Soil and Water Conservation District, set priorities for each application. After the plans were written, the Agricultural Stabilization and Conservation Service county committee reviewed and approved them and contacted participants for the formal signing.

The Agricultural Stabilization and Conservation Service tracked all best management practice (BMP) implementation, issued cost-share approvals and payments, and monitored the contracts to ensure plans were followed properly. The agency participated in the information and education program, was a member of the administrative subcommittee, and was responsible for coordinating, writing, publishing, and distributing the annual and 10-year reports.

Soil Conservation Service

The Soil Conservation Service was responsible for planning and implementing the BMPs and took part in setting priorities with the Agricultural Stabilization and Conservation Service and the Soil and Water Conservation District board. Soil Conservation Service provided the annual status review on contracts, worked with the Agricultural Stabilization and Conservation Service to make sure BMPs were applied, and monitored maintenance and operation of the installed BMPs. The agency participated in the information and education program, served on the administrative subcommittee, and helped write the annual report.

Cooperative Extension

Cooperative Extension provided news releases and publications, organized field days and tours for the project, conducted some field studies, and contributed to the annual report. Cooperative Extension was also involved in other areas of the project and a member of the administrative subcommittee. The University of Florida provided assistance to the project and participants in conjunction with the local Cooperative Extension office.

South Florida Water Management District

Although it did not receive funding, the South Florida Water Management District provided a comprehensive monitoring network and funds for some research and evaluated water quality for the project. The agency also participated in the information and education program, helped write the annual and 10-year reports, and was a member of the administrative subcommittee, where it worked closely with the three Federal agencies.

Soil and Water Conservation District

The Soil and Water Conservation District helped set the priorities for each application and reviewed and approved the plans written by the Soil Conservation Service. This State agency participated in field days and tours and was an active member of the local coordinating committee.

Other agencies participated as members of the local coordinating committee but did not have a role in the day-to-day operation of the project.

Other Representatives

The administrative subcommittee worked closely with several groups to administer the project. Local and State dairy organization representatives were consulted and participated in many phases. The State Dairy Association's environmental specialist was a member of the local coordinating committee and played an active daily role, working to help coordinate implementation of the project with dairymen. (Local cattlemen also provided similar assistance.) State and local environmental groups were consulted and invited to participate in the project. All these representatives played a vital role in the project's institutional arrangement and administration.

Successes and Failures

The Taylor Creek-Nubbin Slough RCWP project contracted 54,709 critical acres on 48 farms, which far exceeded its goal. Cooperation among the four key agencies helped in this effort: the group coordinated visits with potential participants individually or as a group to increase participation. One-on-one contact with the farmer brought the best results, as illustrated in Table 3, which divides the basin into subwatersheds and breaks down the contracted acres, percent of contacted acres compared to the total critical acres, total farms and number of farms contracted in each subwatershed by each year of the

Table 3.—Taylor Creek-Nubbin Slough critical acres and farms by subwatershed.

SubWatershed			1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
NW Taylor Creek	Acres	Contracted	0	0	718	2765	4311	4809	4809	4809	4809	4809
		% Contracted	0%	0%	11%	43%	67%	74%	74%	74%	74%	74%
	Farms	Total	9	9	9	9	9	9	9	9	9	9
		Contracted	0	0	1	3	4	5	5	5	5	5
Little Bimini	Acres	Contracted	0	0	2523	9689	9689	9689	9689	9689	9689	9689
		% Contracted	0%	0%	26%	99%	99%	99%	99%	99%	99%	99%
	Farms	Total	6	6	6	6	6	6	6	6	6	6
		Contracted	0	0	1	5	5	5	5	5	5	5
Otter Creek	Acres	Contracted	0	0	0	0	3663	3663	3663	3663	3663	3663
		% Contracted	0%	0%	0%	0%	89%	89%	89%	89%	89%	89%
	Farms	Total	4	4	4	4	4	4	4	4	4	4
		Contracted	0	0	0	0	2	2	2	2	2	2
Main Taylor Creek	Acres	Contracted	0	8032	8032	8032	8032	9845	9845	9845	9845	9845
		% Contracted	0%	68%	68%	68%	68%	92%	92%	92%	92%	92%
	Farms	Total	3	3	3	3	3	3	3	3	3	3
		Contracted	0	1	1	1	1	2	2	2	2	2
Williamson Ditch	Acres	Contracted	0	3162	3485	3485	4050	4050	4050	4050	4050	4050
		% Contracted	0%	78%	98%	98%	100%	100%	100%	100%	100%	100%
	Farms	Total	9	9	9	9	10	10	10	10	10	10
		Contracted	0	4	6	6	10	10	10	10	10	10
Mosquito Creek	Acres	Contracted	0	6532	7012	7012	10433	10487	10487	10487	10487	10487
		% Contracted	0%	61%	67%	67%	98%	98%	98%	98%	98%	98%
	Farms	Total	11	11	11	11	11	11	11	11	11	11
		Contracted	4	7	7	7	9	10	10	10	10	10
Nubbin Slough	Acres	Contracted	0	0	3051	4785	5967	6978	6978	6978	6978	6978
		% Contracted	0%	0%	43%	57%	84%	98%	98%	98%	98%	98%
	Farms	Total	11	11	11	11	11	12	12	12	12	12
		Contracted	0	0	3	7	9	12	12	12	12	12
Henry Creek	Acres	Contracted	0	0	2445	2445	2445	2445	2445	2445	2445	2445
		% Contracted	0%	0%	57%	57%	57%	57%	57%	57%	57%	57%
	Farms	Total	3	3	3	3	3	3	3	3	3	3
		Contracted	0	0	1	1	1	1	1	1	1	1
Lettuce Creek	Acres	Contracted	0	0	0	1353	942	2743	2743	2743	2743	2743
		% Contracted	0%	0%	0%	38%	20%	58%	58%	58%	58%	58%
	Farms	Total	5	5	5	5	5	5	5	5	5	5
		Contracted	0	0	0	1	1	4	4	4	4	4

Table 4.—Percent implementation of best management practices by subwatershed by year.

SUBWATERSHED	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
NW Taylor Creek			2%	43%	56%	69%	100%	100%	100%	100%
Little Bimini		31%	36%	48%	87%	91%	95%	99%	99%	100%
Otter Creek		10%	35%	50%	75%	77%	97%	99%	99%	99%
Taylor Creek Main			1%	6%	57%	90%	99%	100%	100%	100%
Williamson Ditch				25%	80%	100%	100%	100%	100%	100%
Mosquito Creek					20%	50%	77%	99%	100%	100%
Nubbin Slough			8%	14%	39%	81%	97%	100%	100%	100%
Henry Creek			60%	60%	94%	98%	100%	100%	100%	100%
Lettuce Creek					5%	10%	77%	100%	100%	100%

project. Note that the contracting period was from 1981 until 1986; therefore, the numbers remained constant for the rest of the project's lifespan.

The administrative subcommittee targeted several areas for contracting. Changes in water quality in the Taylor Creek headwaters were measured first because the State had allocated funding for BMPs and early studies of water quality for this area. The Taylor Creek headwaters include NW Taylor Creek, Little Bimini, and Otter Creek subwatersheds. Table 3 shows that most of the contracting in the headwaters area was completed early in the project.

The second area targeted was Williamson Ditch: the subcommittee thought it important to have good participation in an area that was predominately beef operations—and Table 3 shows their success in recruiting participants. Dairies were also targeted. Because of the large herds, dairies were the largest contributors to water quality problems in the basin. The project goal—to contract with all dairies in the project—was accomplished.

Contracting critical acres is important only if these acres are treated as contracted. In the Taylor Creek-Nubbin Slough project, 99 percent of the BMPs had been installed and were being maintained at the end of the 10 years. Table 4 shows the percent of implementation in the subwatersheds. Because many practices were installed early, trend analyses were possible and indicated that BMPs were having a positive effect. These areas were also targeted for early implementation. Table 4 shows that in NW Taylor Creek, Little Bimini, Otter Creek, and Williamson Ditch most of the implementation was completed by 1987—another result of the administrative subcommittee's coordinated effort.

The administrative subcommittee decided to add more BMPs after they saw that initial plans lacked the practices needed to mitigate water quality problems in the Taylor Creek-Nubbin Slough basin. A request for additional BMPs was submitted to the local coordinating committee, then to the State coordinating committee, and lastly to the National Coordinating Committee, which gave final approval. Table 5 lists the BMPs originally selected and those that were added. The project experienced a wide variety of problems installing BMPs—but the subcommittee helped resolve them quickly. (For example, most farm plans had to be modified to accommodate conditions at the time of installation, but these changes were easily coordinated.)

Table 5.—Approved best management practices for the Taylor Creek-Nubbin Slough project.

BMP-1*	Permanent vegetative cover
BMP-2*	Animal waste management system
BMP-5	Diversion system
BMP-6*	Grazing land protection system
BMP-8*	Cropland protection system
BMP-10	Stream protection system
BMP-11*	Permanent vegetative cover on critical areas
BMP-12*	Sediment retention, erosion, or water control structures
BMP-13*	Improving an irrigation and/or water management system

*BMPs added during project

The project weathered several environmental crises and regulatory programs. Progress was aided by the project administrator, who understood all phases of the project and worked closely with the administrative subcommittee to make sure it was kept abreast of project activities. The administrator also kept other interested parties informed on the project's progress and kept up-to-date on the scientific and political environment. On several occasions, the administrator brought farmers and environmental groups together with the project agencies to discuss and try to understand differences on issues affecting the project.

The information and education program was coordinated by the subcommittee and the local coordinating committee. In retrospect, the subcommittee recognized the following problems, which were not identified early enough to be funded in the project:

- Cooperative Extension should have had a more actively funded program,

- Demonstration projects were needed to show the effectiveness of growing row crops on dairies,
- Work on the use of dairy wastewater was limited by funding, and
- Management guides were needed for operation and maintenance of installed BMPs.

Farms in the project area were assigned a high, medium, or low priority as they signed up in the program. High priority plans were written first. For example, if a farmer came in and signed up, the farm would be assigned a priority based on the committee's determination of the water quality problem. High priority farms would get the next sequentially high priority number.

Looking back, the local coordinating committee now thinks each farm identified in this project should have been preassigned a priority number based on the degree of its water quality problem. In this manner, the farm determined to have the worst problem would be Number 1 and the one with the least important problem would be Number 59. If the farm with preassigned Number 1 contracted later in the sign-up period, its plan would be written immediately. The method actually used by this project would have given farm Number 1 the next sequential high priority number available when the farmer signed an application, and its plans would have been written only after the plans for farms with higher priority numbers. Using this method, plans for farms that strongly affected water quality might be delayed.

The project worked with State agencies and environmental and farm groups to get additional funding for research, cost-share monies, technical assistance, and water quality monitoring. The State of Florida put $250,000 into cost-shares in the project. The South Florida Water Management District provided $12,000 for technical assistance, funded several research projects with Cooperative Extension, and provided a comprehensive monitoring program. The District also conducted meetings with the assistance of other subcommittee members to show participants the results of BMP implementation—a tactic that encouraged installation of additional BMPs.

The overall success of the RCWP project and its administration should be measured by improvements in water quality. Figures 1 and 2 show the phosphorous and nitrogen concentration over the life of the project. The goal of a 50 percent reduction in phosphorous was achieved; however, the goal of 50 percent reduction in nitrogen fell short at 46 percent. Many factors affect water quality other than BMP implementation. Because of these factors, such as cow numbers, rainfall, and surface water levels, the project has yet to prove statistically that BMPs caused the water quality improvements. Nevertheless, looking at these factors subjectively, the BMPs seemed to have had a positive effect.

Conclusion

This project was run efficiently and effectively because it established a subcommittee that was allowed to manage day-to-day activities. The subcommittee also increased participation and implementation by working closely with key people from the farmer groups. Because of these factors, the project's water quality goals were met and participation goals exceeded. The subcommittee's smaller size made decisionmaking easier.

However, these factors only established the framework for the most important element—people. This project succeeded because people had the dedication and desire to see it through to success.

Findings and Recommendations

■ One person must be in charge to see that the project stays on course and that goals are met. This person, who should be selected by the local coordinating committee, must understand all aspects of the project so that coordination among the different agencies can be maintained.

■ A close working relationship must be maintained among the key players of a project. This relationship among the Taylor Creek-Nubbin Slough project players made the project work.

■ The project players need local autonomy and flexibility.

■ The key agencies must share and understand the roles of other key agencies so that interactions can take place in all phases and areas of the project.

■ Projects should not limit their search for resources to the Federal sector. This project was awarded State monies for cost-sharing, technical assistance, research, and water quality monitoring.

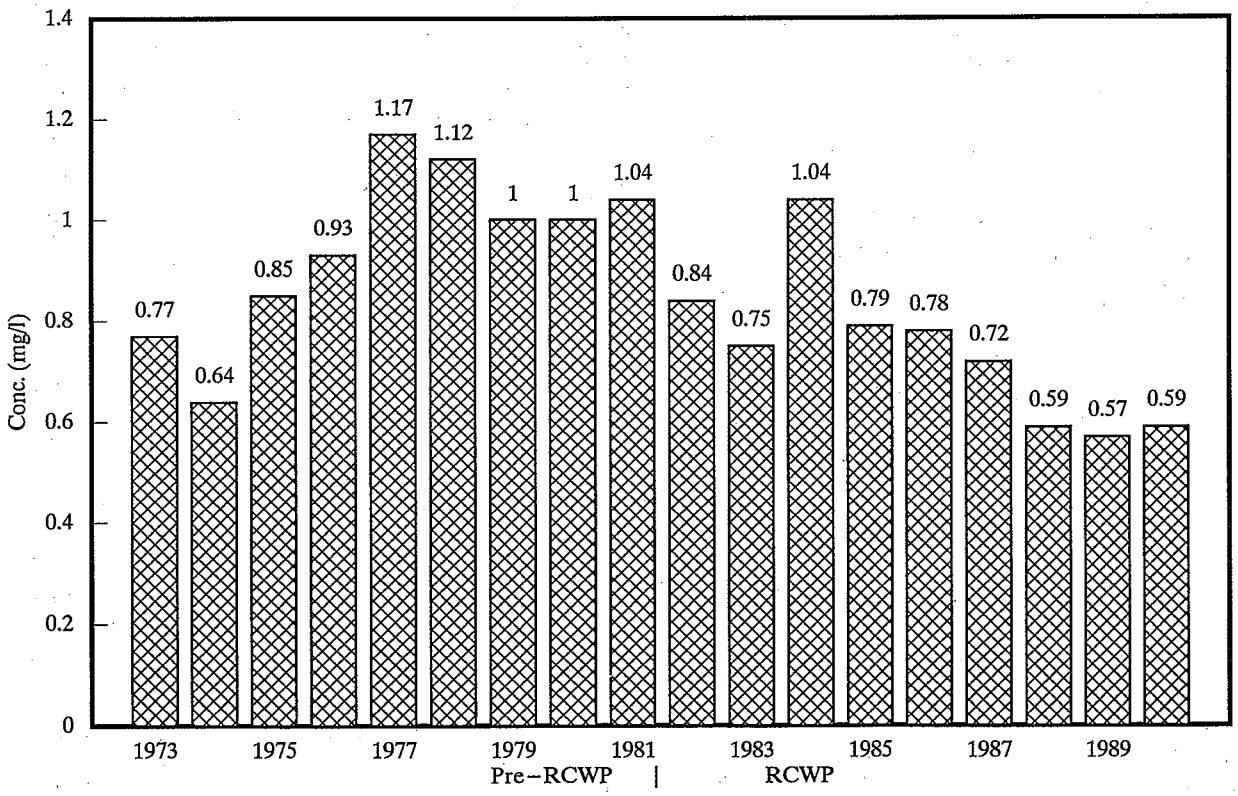

Figure 1.—Total phosphorus annual averages over the life of the project.

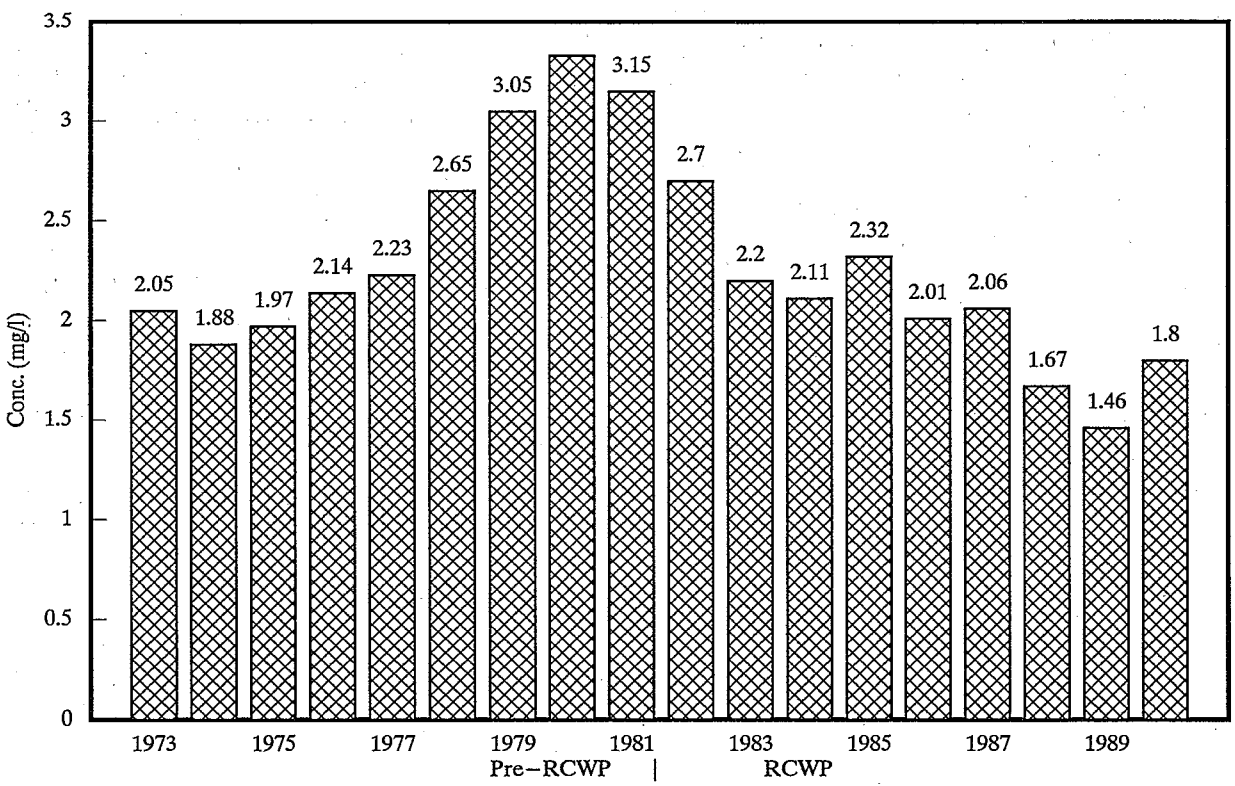

Figure 2.—Total nitrogen annual averages over the life of the project.

Farm Operators' Attitudes About Water Quality and the RCWP

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ABSTRACT

Because participation in the Rural Clean Water Program (RCWP) was voluntary, water quality improvements ultimately depended on farm operators' willingness and ability to use best management practices (BMPs). Evaluation of the RCWP, therefore, must include a systematic analysis of a farm operator's knowledge, attitudes, and behavior. For this project, telephone interviews were conducted with 1,111 farm operators, selected at random from the 21 RCWP project areas. Interviews were about equally divided between participants and nonparticipants. This paper describes the survey results in terms of the following: attitudes about water quality; attitudes and adoption of BMPs; attitudes about the RCWP; and attitudes about public policies. The interviewers also asked participants and nonparticipants specifically why they did or did not participate in the RCWP.

The goal of the Rural Clean Water Program (RCWP) has been to reduce pollution from agricultural land. Improvements in water quality depend on changes in farm operators' attitudes and adoption of best management practices (BMPs). Such changes should be facilitated by participation in RCWP and increased awareness of water quality issues. Evaluation of the success of the RCWP should, therefore, include analysis of farm operator's knowledge, attitudes, and behavior. To do this, we developed and conducted a telephone survey to determine farm operator participation in the RCWP and adoption of BMPs. This paper describes the major results of that survey.

This survey builds on a long-standing research tradition. For the past 50 years, social scientists have studied the process by which farm operators and others accept and use new practices (Rogers, 1983). During the past 15 years, much of this attention has focused on farm operators' adoption of soil conservation practices (Nowak, 1984; Buttel et al. 1990). A subset of this work has specifically considered farm operators' use of BMPs for controlling nonpoint source water pollution. Research has shown that decisions about using BMPs represent an ongoing process for most farm operators (Korsching and Nowak, 1983). Water quality improvements from nonpoint source control depend on changes in farm operators' attitudes and behavior. Voluntary adoption of BMPs means that farm operators must initially gain sufficient awareness of and interest in water quality problems and related issues (Napier et al. 1986). Next, they must develop favorable attitudes toward the recommended BMPs (Bultena and Hoiberg, 1986). Finally, these attitudes must be translated into adoption of the BMPs.

Research Methods

We established an advisory committee—made up of agency officials, project personnel, social scientists, and other people who had experience with the RCWP—to provide advice on sampling design and survey content. The survey content was based on review of previous research as well as comments from the advisory committee, which had the opportunity to review the survey instrument.

One major goal of this project is to compare farm operators who participated in the RCWP with those who were eligible but did not participate. Local U.S. Department of Agriculture Agricultural Stabilization and Conservation Service (ASCS) offices provided lists of all farm operators who designated whether or not they had participated in the RCWP. The sampling procedure was developed in consultation with a professor of statistics at North Carolina State University (NCSU). The approach involved a compromise between drawing a proportional sample from each RCWP area based on the number of farm operators in each area and drawing an equal size sample from each RCWP area regardless of the number of farm operators. The sample of farm operators drawn from each area was proportional to the cubic root of farm operators from that area participating in the RCWP. Once the target sample size for each RCWP area was determined, farm operators were selected at random from the ASCS lists. Careful attention was paid to completing the target number of participants and nonparticipants from each RCWP area.

A standard telephone survey was used to collect data. Telephone interviews were selected because they provide the most effective and efficient means to systematically collect comparable information from a large sample, especially when the populations are widely dispersed geographically. Data was collected by the Applied Research Group at NCSU, an organization with over 15 years experience conducting telephone interviews for all types of public agencies and private organizations. Their telephone interviewers are well trained and carefully supervised.

All telephone interviews, which averaged 20 minutes, were conducted during November and December of 1991. In many cases, callbacks were scheduled at times convenient for the farm operators. The overall response rate for the survey was almost 85 percent of the selected respondents. In general, the response rate was even higher for farm operators who had participated in the RCWP compared to those who were eligible but did not participate. Respondents appear to be representative of the farm population. Sample demographics and farm structure characteristics will be published in the final report.

Results

This research, which will ultimately analyze farm operators' participation in the RCWP as well as their adoption of BMPs, will include the development and testing of a theoretical model that specifies a set of factors that may influence farmers' actions. Interrelationships among the factors will be tested in future analysis. This paper describes the general results and highlights the major findings from the survey in terms of

- water quality awareness and information,
- attitudes about water quality problems,
- adoption of BMPs,
- participation in the RCWP, and
- attitudes about public policies and programs.

Water Quality Awareness and Information

Awareness of water quality problems will likely be related to farm operators' adoption of BMPs and participation in the RCWP. In general, farm operators expressed quite a bit of awareness. When asked "How much have you heard or read about how agriculture might affect water quality," 52 percent reported "a lot"; 32 percent had heard "some"; 14 percent had heard "a little"; and only 2 percent claimed to have heard "nothing."

Interest in learning more about water quality was relatively low, compared to awareness. Farm operators were asked "Overall, how much more information do you need about what you can do on your own farm to help protect water quality." Ten percent said they wanted "a lot more information"; 36 percent said they needed "some more information"; 29 percent wanted "a little information"; 24 percent said they did not need any more information about protecting water quality.

Respondents were also asked about their use of various information sources: "Farmers can do many things to protect water quality. How much information about protecting water quality have you received from (source)? Have you gotten a lot, some, a little, or no information?" Results for the 12 different information sources are shown in Figure 1. Farm magazines represent the most frequently used source of information, followed by government agricultural and conservation agencies, with the U.S. Department of Agriculture's Soil Conservation Service (SCS) being most popular. Newspapers were the fifth most commonly used source of information.

A substantial drop in frequency of use was exhibited for the remaining seven sources of information. Respondents listed other farm operators next and reported about the same level of use for television, meetings, or workshops. Farmers used pesticide or fertilizer dealers, other farm organiza-

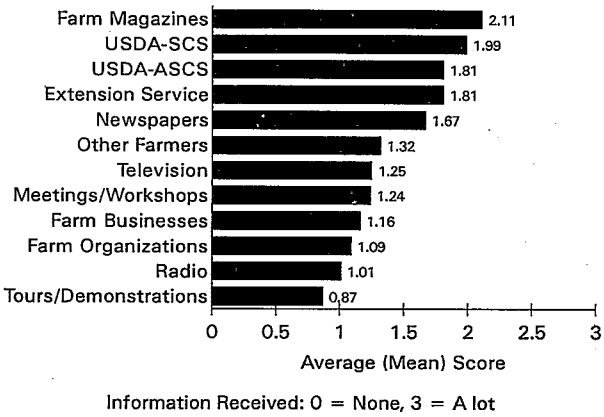


Figure 1.—Farmers' sources of water quality information.

tions, and radio programs infrequently for information on water quality. Tours and demonstrations were the least frequently used sources of information.

Attitudes about Water Quality Problems

Attitudes about the severity and causes of water quality problems should have important impacts on adoption of BMPs and participation in the RCWP. Respondents were first asked "Is water pollution a serious problem, somewhat of a problem, or not a problem *in your area*?" Only 14 percent said water pollution was a "serious problem," with the remainder evenly divided between 43 percent, who felt pollution was "somewhat of a problem" and 43 percent, who felt it was "not a problem." Problem perception was even lower when respondents were asked the same question about their own farm. In this case, only 2 percent said pollution was "a serious problem," and over 79 percent claimed no problems with water pollution on their farms. The rest said "somewhat of a problem."

Concerns for specific impacts of water pollution appear moderately high. Respondents were asked "Are you very concerned, somewhat concerned, or not concerned about pollution of your own drinking water?" Responses are evenly split between those who were very concerned (33 percent), somewhat concerned (34 percent) and not concerned (34 percent). Two-thirds of all respondents either strongly agreed (11 percent) or agreed (55 percent) that "agricultural water pollution is a serious threat to fish and wildlife."

The survey also determined if respondents felt that agriculture represented a serious cause of water pollution. Near the start of the interview, respondents were asked an open-ended question: "What do you think are the major causes of water pollution in your area?" After an initial answer, respondents were asked if there were any other causes and could give more than one answer to this question. General results are shown in Figure 2.

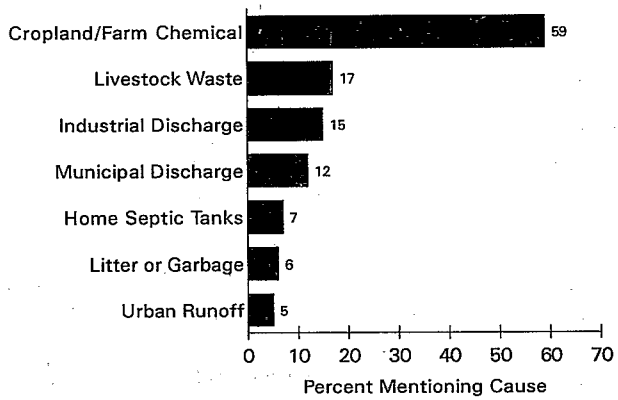


Figure 2.—Farmers' perceptions of major causes of water pollution.

The most frequently mentioned cause of water pollution (from over a third of respondents) was "runoff from cropland": almost 25 percent specifically mentioned pesticides (including herbicides or insecticides), while 20 percent mentioned fertilizers or specific nutrients, such as nitrogen. To account for respondents who might have reported two or more of these responses, we combined these three causes into one indicator of pollution: Cropland/Farm Chemical. In this case, just over half (59 percent) saw cropland as a major cause of pollution. Far fewer respondents (17 percent) recognized livestock or animal waste as a cause of pollution. Combining crop and livestock nonpoint source pollution, we found two-thirds of all respondents believed agriculture to be a major cause of water pollution.

Respondents reported a variety of other nonagricultural causes of water pollution in their areas. Twenty-seven percent said that point sources were major causes of pollution. In this case, 15 percent said industrial waste or factory discharge was the major source, while another 12 percent cited municipal sewage treatment. Other sources of pollution mentioned included household septic systems (7 percent), litter or garbage (6 percent), and urban runoff (5 percent).

Several other questions directly addressed respondents' attitudes about the potential contribution of agriculture to water pollution problems. Over half of all respondents either strongly agreed (8 percent) or agreed (46 percent) that "The farming practices I use now have *no* significant effect on water quality in my area." In fact, over three-quarters

strongly agreed (14 percent) or agreed (63 percent) that "agriculture is being unfairly blamed as a cause of water quality problems."

Adoption of Best Management Practices

One major goal of this project was to determine the extent to which farm operators had adopted recommended BMPs to control water pollution from their farms. Respondents were read the following: "Some farming practices are available to help farm operators protect water quality. These are often called best management practices or BMPs. Are you now using any of these BMPs?" Respondents were then asked specifically about the 17 BMPs being promoted overall as part of the RCWP (Fig. 3). Future analysis will determine in a general way whether specific BMPs were relevant for a particular type of farm operation as well as whether specific BMPs were promoted by a particular RCWP project.

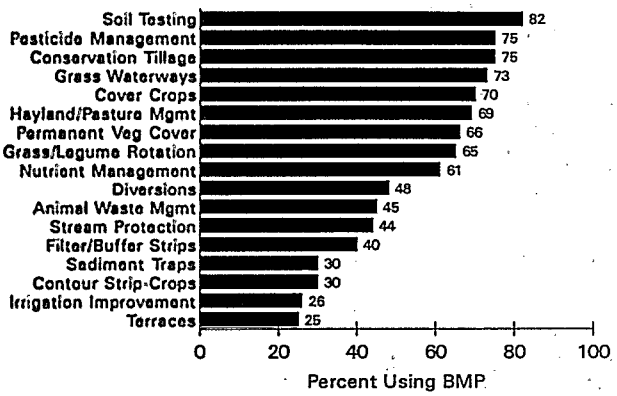


Figure 3.—Adoption of best management practices (BMPs) by farmers.

Nine of the BMPs listed were relatively more popular with the farm operators in our sample. These BMPs tended to be more management-oriented than structural. Three-quarters or more of the respondents were reportedly using soil testing (82 percent); conservation or reduced tillage (75 percent); and pesticide management or reduction (75 percent). Almost as many were using other management practices: grass waterways (73 percent); cover crops (70 percent); hayland or pasture planting or management (69 percent); permanent vegetative cover (66 percent); grasses or legumes in rotation (65 percent); and nutrient management or reduction (61 percent).

The remaining eight BMPs do not appear to be as acceptable or applicable, as evidenced by their lower adoption rate. Less than half of the respondents reported adoption of diversions (48 percent); animal waste management or storage (45 percent); stream protection or fencing (44 percent); and filter or buffer strips (40 percent). Less than one-third of all respondents had adopted sediment traps (30 percent); contour strip-cropping (30 percent); irrigation improvement (26 percent); and terraces (25 percent). Ninety-eight percent of the respondents, when asked, replied they planned to continue using the BMPs.

We also wanted to determine the features of a BMP that affect a farm operator's decision about using it. Respondents were read the following question: "How important would each of the following factors be in your decision about whether to use a new BMP to help protect water quality? Would (item) be very important, somewhat important, or not important in your decision to use a new practice?" Results are shown in Figure 4. It is probably most meaningful to consider respondents who said a particular factor was "very important," since relatively few said the factors would not be important.

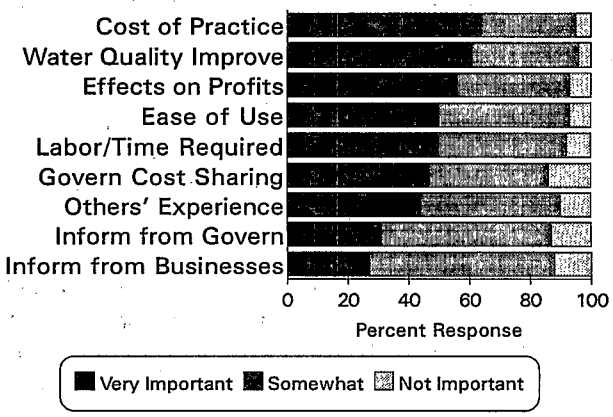


Figure 4.—Influences on farmers' adoption of best management practices (BMPs).

About 64 percent of all respondents said the cost of the practice would be very important. Almost as many (61 percent) believed the potential of the practice to improve water quality would be very important, while 56 percent said that the effects of the practice on profits would be very important. Exactly half of all respondents thought that ease of use as well as labor or time required would be very important. Just under half (47 percent) said availability of government cost-sharing would be very important, and 44 percent found the experience of other farm operators to be very important. Two factors appear to be relatively unimportant for the farm operators in this sample: less than a third stated that information from government agencies (31 percent) and farm businesses (27 percent) would be very important.

Several additional questions addressed farmers' attitudes about BMPs. Most respondents either

strongly agreed (10 percent) or agreed (74 percent) that "We need less expensive farming practices that will help protect water quality." Over half either strongly agreed (4 percent) or agreed (56 percent) that "Farm practices that protect water quality usually require more labor." It appears, therefore, that economic and labor constraints may be important factors that limit the adoption of BMPs.

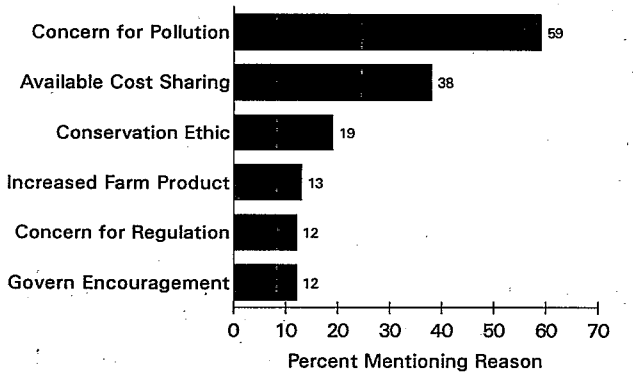
Participation in the Rural Clean Water Program

Another major goal of this project is to determine the reasons why farmers either did or did not participate in the RCWP. As discussed earlier, our sampling design was developed to include both participants and nonparticipants from each of the RCWP project areas. We based our sampling design on the written designation of eligibility and participation provided by the local ASCS offices and verified the information by asking farm operators if they had participated. Results, however, showed some significant discrepancies (about 15 percent) between the official designation and farmers' own reports. Attempts are being made to clear up this problem. However, it is interesting to note that over 10 percent of all farmers interviewed had *never heard* of the RCWP despite the fact that the local ASCS had designated all respondents as eligible for participation.

Depending on whether or not respondents said they had participated in the RCWP, they were asked a somewhat different series of questions. The 630 farm operators who claimed they had participated in the RCWP were asked the following open-ended question "What were the reasons you decided to participate in the RCWP?" A probe ("Are there any other reasons you participated?") was then used if respondents gave an initial answer. This means some respondents gave more than one answer to this question. Results are shown in Figure 5.

Over half (59 percent) mentioned something related to concern for water pollution or its effects. Just over one third (38 percent) said that the availability of cost-sharing funds was an important reason. Almost one in five (19 percent) said they felt it was "the right thing to do" or in some way expressed a conservation ethic. Three other reasons were given by a sizeable number of respondents: increased farm productivity (13 percent); concern over future pollution regulations (12 percent); and assistance or encouragement from government agencies (12 percent).

Respondents who participated were also asked to rate their satisfaction with the RCWP. Overall, satisfaction was very high. Almost all respondents

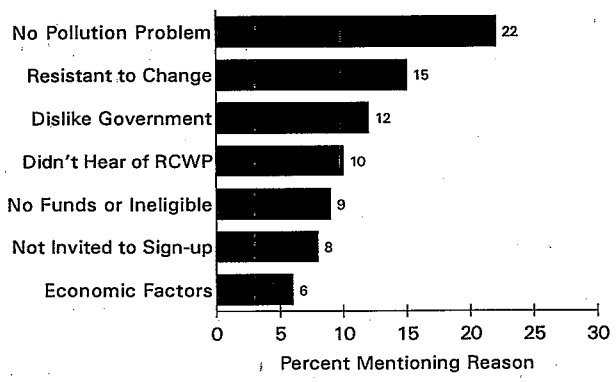


Only includes the 630 RCWP participants.

Figure 5.—Farmers' reasons for participating in the Rural Clean Water Program (RCWP).

were either very satisfied (52 percent) or satisfied (42 percent) with the *technical* assistance and information they received from the RCWP. Satisfaction with the *financial* assistance was just as high with most being either very satisfied (47 percent) or satisfied (46 percent). Another indication of effectiveness was found by determining the impact of the RCWP on adoption of BMPs. Respondents were evenly divided when asked "If the RCWP had not been available would you have been very likely [13 percent], likely [35 percent], unlikely [34 percent], or very unlikely [18 percent] to have used all of the best management practices you are now using?"

The 481 respondents who had not participated in the RCWP were asked a somewhat different set of questions, including the following open-ended question: "What were the reasons you decided *not* to participate in the RCWP?" An appropriate probe—"Are there any other reasons you did not participate?"—was used for respondents who gave an initial answer. Some respondents gave more than one answer; results are shown in Figure 6.



Only includes the 481 RCWP nonparticipants.

Figure 6.—Farmers' reasons for not participating in the Rural Clean Water Program (RCWP).

Almost 25 percent of the nonparticipants said they did not participate because they did not believe water pollution was a problem, either on their own farm or in general. The next major reason for nonparticipation (15 percent) involved some form of resistance to change, which included the idea that a farmers' present system works well or that changing practices is too much trouble. Over 10 percent said they simply did not like government programs, including the red tape or complicated procedures. Almost as many (10 percent) said they had never heard of the RCWP at the time it was available, and 9 percent claimed they had tried to sign up but were either ineligible or no money was available. In addition, 8 percent volunteered that they were never asked to participate. Only 6 percent said anything about economic factors, including a belief that the cost-share rates were too low.

Respondents who had not participated in the RCWP were asked specific follow-up questions about contacts by government agencies asking them to participate. Almost two-thirds (59 percent) of the nonparticipants claimed that no government agencies had ever contacted them about participating in the RCWP. However, on a more positive note, almost two-thirds said they would be either very likely (15 percent) or likely (49 percent) to participate if a new program (like the RCWP) were available today.

The survey also determined how participants and nonparticipants assessed the overall impacts of the RCWP on a variety of different outcomes. Both groups were asked "Would you say the RCWP had a positive effect, no effect, or a negative effect on (item)?" (This question was not asked those respondents who had never heard of the RCWP.) Results are shown in Figure 7. Ninety percent of the respondents thought that the RCWP had a positive effect on farm operators' knowledge about water quality, and 86 percent also stated the RCWP had a generally positive effect on surface water quality in the area.

Approximately two-thirds believed the RCWP had a positive effect on operating costs for participating farm operators (70 percent) as well as on farm income (66 percent). Only 8 percent of the respondents felt that the RCWP had negative effects on these economic conditions. Just over half (56 percent) believed that the RCWP had a positive effect on drinking water quality in the area, while 41 percent thought the RCWP had no effect on drinking water quality. These results might be explained by the fact that few RCWP projects specifically targeted drinking water problems.

Earlier in the interview all respondents had been asked "Compared to ten years ago, do you think water quality in your area is better, about the same, or worse?" Respondents were divided when asked to assess trends in water quality. Over one-third (36 percent) believed that water quality had gotten better over the previous decade; almost half (47) felt it had remained about the same; and nearly one-fifth (17 percent) felt water pollution was now worse.

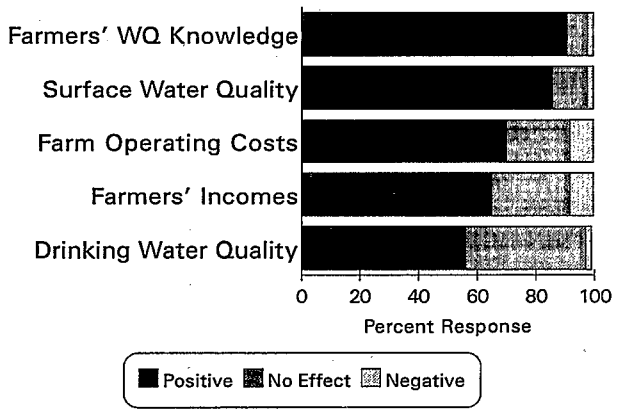


Figure 7.—Farmers' perceptions of effects of the Rural Clean Water Program (RCWP).

Attitudes about Public Policies and Programs

The RCWP was an experiment to determine whether agricultural nonpoint source water pollution could be controlled adequately through voluntary implementation of BMPs on farms. The key assumption of the RCWP approach was that targeted high levels of financial and technical assistance and education would be adequate to promote widespread cooperation. Some of the questions in this survey have direct relevance to the issue of voluntary versus mandatory control of agricultural nonpoint source pollution. Further analysis of results should provide additional insights.

Most farm operators appear to support the voluntary approach taken by the RCWP. Almost all respondents either strongly agreed (12 percent) or agreed (84 percent) that "Water pollution can best be controlled through educational programs that encourage farm operators to use BMPs." As further evidence of support for the voluntary approach, 9 percent strongly agreed and 60 percent agreed that "the government should help pay more for water pollution control on farms."

On the other hand, many farm operators recognized that the voluntary approach may not work in all cases. Most seem resigned to the inevitability of government regulations. Almost all either strongly agreed (15 percent) or agreed (74 percent) that "If farm operators don't do more to protect water quality on their own, the government will force them to

through regulation." In fact, most also either strongly agreed (9 percent) or agreed (76 percent) that "Farm operators do *not* have the right to farm in ways that damage water quality." Almost as many either strongly agreed (6 percent) or agreed (72 percent) that "land should be farmed in ways that protect water quality even if this means lower profits."

Conclusions and Discussion

This final section will draw several general conclusions and discuss some preliminary implications of this research. More detailed recommendations and conclusions will be forthcoming once further analysis is completed. In the next few months, we will determine the types of farmers who were most likely to participate in the RCWP as well as adopt BMPs. Such analysis will assess the relative influence of demographic variables, farm structural characteristics, information and awareness, and various attitudes.

Respondents reported fairly high general awareness of water quality but rather low interest in learning more about it. The major sources of information appear to be print media (especially farm magazines) and government agencies. However, over 10 percent of all respondents did not recall having heard about the RCWP. Awareness and concern for the impacts of agriculture on water quality, on the other hand, appear rather low. (This is particularly true for respondents' perceptions of water quality impacts associated with their farms.) One-third of all farmers did not see agriculture as a major cause of pollution in their area, which is contrary to the fact that these areas were selected as RCWP projects presumably because of serious nonpoint source pollution problems from agriculture. Also, respondents were even less likely to perceive impacts of agriculture on drinking water quality. However, not all projects specifically addressed drinking water pollution as a water quality problem.

Some BMPs appear to have reached a fairly high level of acceptance. (This is especially true for management-oriented practices.) Further analysis will be necessary to account for the extent to which a specific BMP was promoted as applicable in a particular area. Likewise, certain practices may be appropriate only for certain types of farm operations. Respondents did indicate that the costs associated with certain BMPs would be an important factor in their adoption decisions.

Participation in the RCWP appears to have been driven, at least in part, out of concern for the environment; economic factors do not appear an important consideration. This last assumption seems especially true when one considers the reasons given for not participating in the RCWP. Many farmers did not participate because they did not think water pollution was a problem or did not want to deal with changing practices. Furthermore, almost one-third of the nonparticipants said they either had never heard of the RCWP, claimed they were never asked to participate, or voiced general dislike for government programs.

An initial reading of these results indicates that the RCWP should have more actively promoted awareness of and interest in water pollution problems associated with agriculture. Further analysis of these results should help to evaluate the extent to which the RCWP led to changes in behavior, such as BMP adoption. Most farmers seem to recognize that the completely voluntary approach will not be viable much longer and seem to accept the fact that society has a right to demand higher levels of pollution control from agriculture. Most, however, would also generally agree that it is "that other farmer" who has the problem and needs to be more tightly regulated.

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Factors Leading to Permanent Adoption of Best Management Practices in South Dakota Rural Clean Water Program Projects

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ABSTRACT

The Oakwood Lakes/Poinsett Rural Clean Water Program (RCWP) project has had a permanent influence on the farming practices within and around the project area. Project participation accelerated after key community persons became active and after a local technical planner was hired. Cash incentives were the primary reason persons signed up for RCWP; however, most continued applying best management practices (BMPs) even after cash incentives ceased. A post-RCWP questionnaire was given to all participants to find out how the program influenced them, why they signed up, and if they changed farming methods as a result of the program. This paper describes the methodology used to assess these permanent influences.

Under Section 208 of the 1972 Amendments to the Federal Water Pollution Control Act, individual states identified nonpoint water quality problems and began to develop plans to control these sources (U.S. Congress, 1972). The most significant problem identified in South Dakota was sediment and associated chemicals and nutrients from farmland.

In response to Section 208, a new federal program called the Rural Clean Water Program (RCWP) was created (*Federal Register*, 1980). This program offered cost-share and technical assistance to landowners who adopted specific erosion control and water quality practices on a voluntary basis.

These practices were referred to collectively as best management practices (BMPs). Each participant signed up for a minimum of three BMPs. Participants were also required to adopt conservation measures that limited soil losses to "T" or less, that is, to the annual soil loss tolerance for each soil map unit in each field. Water quality plans were written by Soil Conservation Service (SCS) field personnel for entire farms.

The Oakwood/Lakes Poinsett RCWP project included Brookings, Hamlin, and Kingsbury Counties. Sign-up was slow the first year until farmers became familiar with the requirements and benefits of the project. Eventually, RCWP contracts covered 48,088 acres or 60 percent of the project's critical area. Cost-share assistance was provided by RCWP funds through the Agricultural Stabilization and Conservation Service (ASCS) at a rate of 75 percent. The total cost-share assistance provided to producer participants was $744,729. To assess the effect of this project and to better handle other watershed projects, a follow-up questionnaire was administered at the project's end to RCWP participants only.

Methods

The Brookings Conservation District mailed public input questionnaires to all operators who had an RCWP water quality plan in the period from 1982 to 1990. This mailing took place as part of the Brookings Conservation District Hydrologic Unit Area process. A cover letter accompanied each questionnaire explaining the importance of the operators' responses and how their input could aid future watershed planning. Ninety-five letters were sent; 49 operators responded and returned their questionnaires to the Conservation District — a 50 percent response.

The questions were reviewed by SCS personnel at the field office and area office levels; water quality specialists at the Water Resources Institute at South Dakota Sate University (SDSU); and by a social scientist, also at SDSU. Advice was sought on question design and content. The project goal was to answer questions on farmer acceptance of BMPs, what motivated them to participate, and whether or not they had achieved permanent change as a result of the RCWP participation. Only operators who participated in RCWP received a questionnaire. Self-addressed stamped envelopes were included for their return to the Brookings Conservation District.

Data analysis includes descriptive statistics, chi-square, and frequencies. Analysis was performed at SDSU using the Statistical Analysis System (SAS). The data are not appropriate for an analysis of variance. Parts of the questionnaire and individual questions tended to be interrelated; however, responses for each part can be individually interpreted: First, how much farmer acceptance was there? Did cost-share influence their decision to participate? Or did the program itself influence their decision to participate? Did the program influence them enough to change their farming methods after the cessation of cost-share?

Results

The average age of respondents was 47 years. Two and three-way comparisons with other responses did not yield a particular age group that adopted BMPs more or faster than others.

In general, most operators used the moldboard plow prior to their participation in the RCWP. Thirty-two operators (65 percent) used the plow either in the fall or in the spring as some part of their usual field preparation. Seventeen (35 percent) used some type of conservation tillage method (chisel and disk was the most common system).

Table 1 compares tillage methods (conservation tillage and moldboard plow) prior to RCWP participation to tillage methods after RCWP participation. In general, 29 (59 percent) changed tillage methods from plowing to conservation tillage as a result of RCWP participation. One of the goals of this study was to assess the degree of permanent change that RCWP fostered by use of attainable BMPs. Table 1 shows that only 6 percent continued plowing after the cessation of cost-share for BMP-9 (conservation tillage).

Table 1.—Comparison of conservation tillage users before and after RCWP participation.

	FREQUENCY (PERCENT)		
	CONSERVATION TILLAGE AFTER RCWP	PLOWED AFTER RCWP	TOTAL
Used conservation tillage before RCWP	11 (22%)	6 (12%)	17 (35%)
Plowed before RCWP	29 (59%)	3 (6%)	32 (65%)
Total	40 (82%)	9 (18%)	49 (100%)

STATISTICS FOR TABLE 1

STATISTIC	DF*	VALUE	PROBABILITY
Chi-square	1	4.974	0.026
Likelihood Chi-square	1	4.751	0.029
Phi coefficient		–0.319	
Sample size = 49			

*DF = degree of freedom

Question 4 (Table 2) also shows acceptance of new tillage methods by asking why post-RCWP changes in tillage were made. Fifty percent of the respondents have not changed tillage methods since RCWP participation. Of those that did change, all but one respondent changed to a more specialized conservation tillage method, including ridge-till and no-till. Forty-eight of the 49 respondents said they would recommend a program similar to the RCWP to others.

Table 2.—Question 4: If your current tillage methods are different than while you were enrolled in RCWP, explain why you changed (n = 30).

RESPONSE	FREQUENCY	PERCENT
1: Stayed the same	16	53
2: Enrolled in CRP or other program	5	17
3: Changed crop rotation (bases and farm)	5	17
4: Changed to control more erosion	3	10
5: Conservation tillage did not work — too wet	1	3

To further pinpoint farmer acceptance among the 92 percent full-time farmers (the remaining 8

percent were part-time farmers), respondents were asked about farm productivity while they were RCWP participants. Responses were varied depending on how they defined productivity; however, 55 percent thought their productivity increased, with increased moisture for crop growth the most common reason for this increase.

Interesting results were achieved from a comparison of three questions; two, eight, and nine. These results are in Table 3. Tallied results of questions 2 and 9 were compared to the ranked results of question 8. Table 3 looks at sums of the ranked responses only; categorical modeling was not appropriate with only a three-way table. In the first case, persons who used conservation tillage before RCWP and after the program expired cited monetary incentives as the most important reason they signed up for RCWP. The same respondents cited concern for the environment as their second most important reason, and fertilizer recommendations as the third.

The second group was comprised of persons using conservation tillage before RCWP who switched to a different system after the program expired — for example, to ridge-till or no-till. Cost-share incentives ranked third after the fertilizer recommendation and concern for the environment.

The third and largest group was composed of those who plowed before RCWP participation and used some form of conservation tillage after the program. Twenty-nine of the respondents were in this category, and cash incentives were the primary reason they got involved in RCWP. The second reason for their involvement was the "free scouting" offered by BMP-16 (pesticide management). The fertilizer recommendations offered by BMP-15 (fertilizer management) ranked as the third most important reason for their involvement. These results indicate that cash incentives are the primary reason farm operators signed up for the RCWP and that the RCWP influenced them to change permanently.

In future questionnaires, questions involving ranking will not be used. Seven responses were not used (n=42) because the respondents incorrectly ranked their responses (by simply checking them) or failed to choose five responses. These seven responses to question 8 were not used in final tabulation and in comparison with other questions' results.

The last comparison on Table 3 concerns farmers who plowed before and after RCWP. They also cited monetary incentives and concern for the environment; however, the lack of proper ranking does not allow accurate comparisons for this category.

Now we know that 32 persons (65 percent) changed from being nonconservation tillage farmers to being conservation tillage farmers as a result of the RCWP experience; and 29 of those 32 persons went from plow to conservation tillage (91 percent). The six persons that went from conservation tillage to a plow method did so because of changes in crop rotation that required some plowing to break sod, although one person said that his ground was simply too wet to use conservation tillage methods. Other farmers continued the same conservation tillage methods that they had been applying prior to RCWP participation (see Table 1).

Table 3.—Tillage methods before and after RCWP compared to incentive. Three-way comparison of questions 2, 8, and 9 using ranked results of question 8.

OBSERVATION	VARIABLE	SUM
Conservation tillage before and after RCWP	Cost-share	34
	Pest scouting	12
	Fertilizer management	15
	Concern for environment	23
	Other	11
	Time for change	5
	Project	3
Conservation tillage before, plow after	Cost-share	7
	Pest scouting	6
	Fertilizer management	12
	Concern for environment	13
	Other	1
	Time for change	2
Plowed before RCWP, conservation tillage after	Cost-share	79
	Pest scouting	64
	Fertilizer management	62
	Concern for environment	57
	Other	19
	Time for change	38
	Project	3
Plowed before and after RCWP	Cost-share	6
	Concern for environment	2

But how did farm operators hear about RCWP? Fourteen persons heard about RCWP from a neighbor, 13 from the SCS, 10 from ASCS, 6 from news or radio media, and 1 from a public meeting.

The farm operators' perceptions of their impact on water quality proved to be positive. Keep in mind that the project experienced extremely wet conditions in the period from 1984 to 1986 — during the implementation of BMPs on most acres. Most (76 percent) felt that RCWP increased overall water quality in Oakwood Lakes or Lake Poinsett. Twenty-four percent felt that the RCWP did not improve water quality. Most responses were positive, such as the 47 percent who said that erosion decreased; negative responses (16 percent) indicated that more operators within the watershed needed to be in RCWP (Table 4).

Table 4.—Question 10: (a) Do you think that RCWP has increased water quality in Oakwood Lakes and/or Poinsett? (b) Why?

RESPONSE		FREQUENCY	PERCENT
(a)	Yes	32	76
	No	10	24
(b)	Decreased erosion	15	47
	More education needed	4	16
	Overall, fertilizer and pesticide management helped	4	13
	More participation needed to make impact	4	13
	Extreme wetness and flooding negated effects of RCWP	4	13

Question 11 asked farm operators whether practices that they specifically applied did or did not help water quality. Ninety-one percent indicated that the practices they applied on their farms helped water quality; 9 percent said the practices did not help.

Interesting responses to questions 12 and 13 are found in Table 5. Crop scouts provided by SDSU were generally liked and perceived well by the respondents. The persons occupying this position were not the same each year. Some individuals were not well received and this had an impact on the benefits of fertilizer and pesticide management, according to the respondents.

To better understand how the SCS could improve its technical service to participants, questions 15 and 16 asked farm operators to rank the most and least beneficial parts of the project. In general, the SCS did a good job (36 percent), but improvements could be made by more farm visits, more knowledge of tillage systems, and better listening skills (See Table 6). Overall, 95 percent said they were pleased with the help they received from the SCS; 5 percent said they were not.

So far, results have shown that farmers did accept the program, that they were primarily motivated by the cost-share incentive, and that 40 of the respondents continued with conservation tillage after the program benefits ceased (82 percent).

Table 5.—Question 12: What was the most beneficial part of the program to you? (n = 39)

RESPONSE	FREQUENCY	PERCENT
The money (cost-share)	18	46
Conservation tillage (BMP-9)	7	18
Pesticide management (BMP-16)	6	15
Fertilizer management (BMP-15)	4	10
Education	2	5
Increased soil quality (less runoff)	1	3
Question 3: What was the least beneficial part of the program to you? (n = 22)		
Pesticide management (BMP-16)	10	45
Fertilizer management (BMP-15)	5	23
Conservation tillage (BMP-9)	3	14
Animal waste system	2	9
Cost-share was not enough (participant portion too high)	1	5
Restricted crop rotation	1	5

Table 6.—Question 15: How could the Soil Conservation Service have improved technical assistance to you? (n = 11)

RESPONSE	FREQUENCY	PERCENTAGE
Soil Conservation Service did a good job	4	36
Would like to participate in another program like this	2	18
Soil Conservation Service should have helped more on tillage systems	2	18
Need more timely visits to farms	1	9
Soil Conservation Service needs better listening skills (about values of crop rotations)	1	9
Need more on-farm visits	1	9

Discussion

Has the project in the Oakwood Lakes and Poinsett RCWP accomplished its original goals? Farmer acceptance, as reported, was high. We can conclude that given agency contacts, media coverage, and farm visits, the SCS influenced and educated participating farmers to change tillage practices permanently. Economics was the primary reason why they chose to participate. Many farmers used the extra income to help out their farms in general; others, to purchase specialized conservation tillage equipment, and in one case, a satellite dish. Nevertheless, the adoption of new conservation practices are not accomplished in a vacuum.

Concurrent with early (1982-1984) RCWP efforts, the SCS, ASCS, and Cooperative Extension Services increased their educational efforts by talking to dealers and universities about alternative tillage methods. Ridge-till and one pass soil saver rigs became popular. Farmers also became increasingly aware of health and environmental issues. In addition to these educational sources, a comprehensive monitoring and evaluation study on the RCWP was conducted by South Dakota State University Water Resources Institute, and the Department of Water and Natural Resources. The study was implemented on several cooperator plots and on a well-researched and publicized master site.

Other U.S. Department of Agriculture (USDA) programs that were concurrent with the RCWP tended to interfere with practice implementation. These programs include the Dairy Buy-Out, Conservation Reserve Program (CRP), and Payment in Kind (PIK). Responses to Question 4 show that of those who have changed tillage methods since RCWP, 20 percent enrolled in CRP or a similar program. Ten percent changed to better control erosion and are now using no-till or ridge-till, 20 percent changed crop rotations to take better advantage of the USDA Feed Grain program, and 3 percent felt that the conservation tillage method they had used did not work well given the excess rainfall in the area during the mid-1980s. Most of the programs that USDA sponsored in the 1980s stressed soil erosion and water quality (for example, the 1985 Food Security Act). Thus, farmers had a growing awareness of the need for change.

Still, program sign-up patterns in 1982 and 1983 support the adoption diffusion model used by sociologists (Brandner and Straus, 1959). RCWP was a unique program because it provided immediate financial incentives (annual payments). Educational and cultural efforts made farmers aware of the need for change, and technology provided the vehicle. These complementary forces helped farmers to accept the RCWP and to make permanent changes. Nowak (1987) points out that all these factors are necessary if farmers are to adopt new practices. Because they were in place in the South Dakota RCWP, the program had a maximum chance for success. Nowak (1987) also says that "diffusion factors increase in importance as the complexity of the innovation increases and decrease in importance as risk is reduced through institutional support." Cooperative agency efforts by Cooperative Extension Service, SCS, and ASCS helped to reduce risk.

In all three counties in the South Dakota RCWP, sign-ups increased after the project hired a full-time technical planner. The planner increased one-on-one farmer contacts. With increased contacts and technical information, sign ups "snow-balled" as key persons in various townships signed up for the RCWP. The adoption diffusion model calls these persons "early adopters." On the other side are persons who are resistant to change. Once the early innovators and adopters recognized the problem (erosion and water quality), they decided whether or not to adopt conservation practices (Ervin and Ervin, 1982). This model is complementary to- economic incentives that led to successful program adoption.

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Techniques to Obtain Adequate Farmer Participation

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ABSTRACT

Before 1980, Rock Creek in Twin Falls County, Idaho, had been recognized as one of the most severly degraded streams in the State. In 1980, the national RCWP coordinating committee selected Rock Creek as a Rural Clean Water Program (RCWP) project. The project's original goals were to reduce the amount of sediment entering Rock Creek by 70 percent, phosphorus by 60 percent, total nitrogen by 40 percent, pesticides by 65 percent, and fecal coliform by 70 percent. These project goals could only be obtained through the adequate participation of Rock Creek farmers. An Information and Education (I&E) committee was formed to develop an I&E program. The key elements identified for obtaining farmer participation included actively involving local Soil Conservation District supervisors and Agricultural Stabilization and Conservation Service county committee members; identifying and targeting local farm leaders; meeting with farmers to gain information on best management practice implementation; and holding yearly update meetings with landowners and the media. By conducting a well-planned I&E program, the Rock Creek RCWP project was able to meet its project goals.

To obtain adequate farmer participation, a well-planned information and education (I&E) program must be developed at the beginning of a water quality project with input from all participating agencies and organizations. But the I&E program should also be continued during the project's life span to demonstrate progress and publicize success. Above all, a good program will require input from local farmers. Once developed, the I&E program should be directed by someone with a thorough knowledge of the water quality project. The Rock Creek Rural Clean Water Program (RCWP) project was able to meet its contracting goal because these premises were followed.

Project Description

Rock Creek in Twin Falls County, Idaho, had long been recognized as one of the most severely degraded streams in the State. Point source pollutants had been virtually eliminated by the end of the 1970s, yet Rock Creek still carried high levels of sediment. In 1980, the national RCWP coordinating committee selected Rock Creek as an RCWP project. It was also selected for comprehensive water quality monitoring and economic evaluation.

The Rock Creek watershed covers a total of 198,400 acres (Fig. 1), of which 51,900 acres are irrigated cropland and pasture. Approximately 28,000 acres of irrigated cropland were defined as critical acres because they contributed excessive amounts of sediment to Rock Creek. The original goals were to reduce the amount of sediment entering Rock Creek by 70 percent, phosphorus by 60 percent, total nitrogen by 40 percent, pesticides by 65 percent, and fecal coliform by 70 percent. Best management practices (BMPs) used on the Rock Creek Project included

- conservation tillage,
- sediment-retention structures,

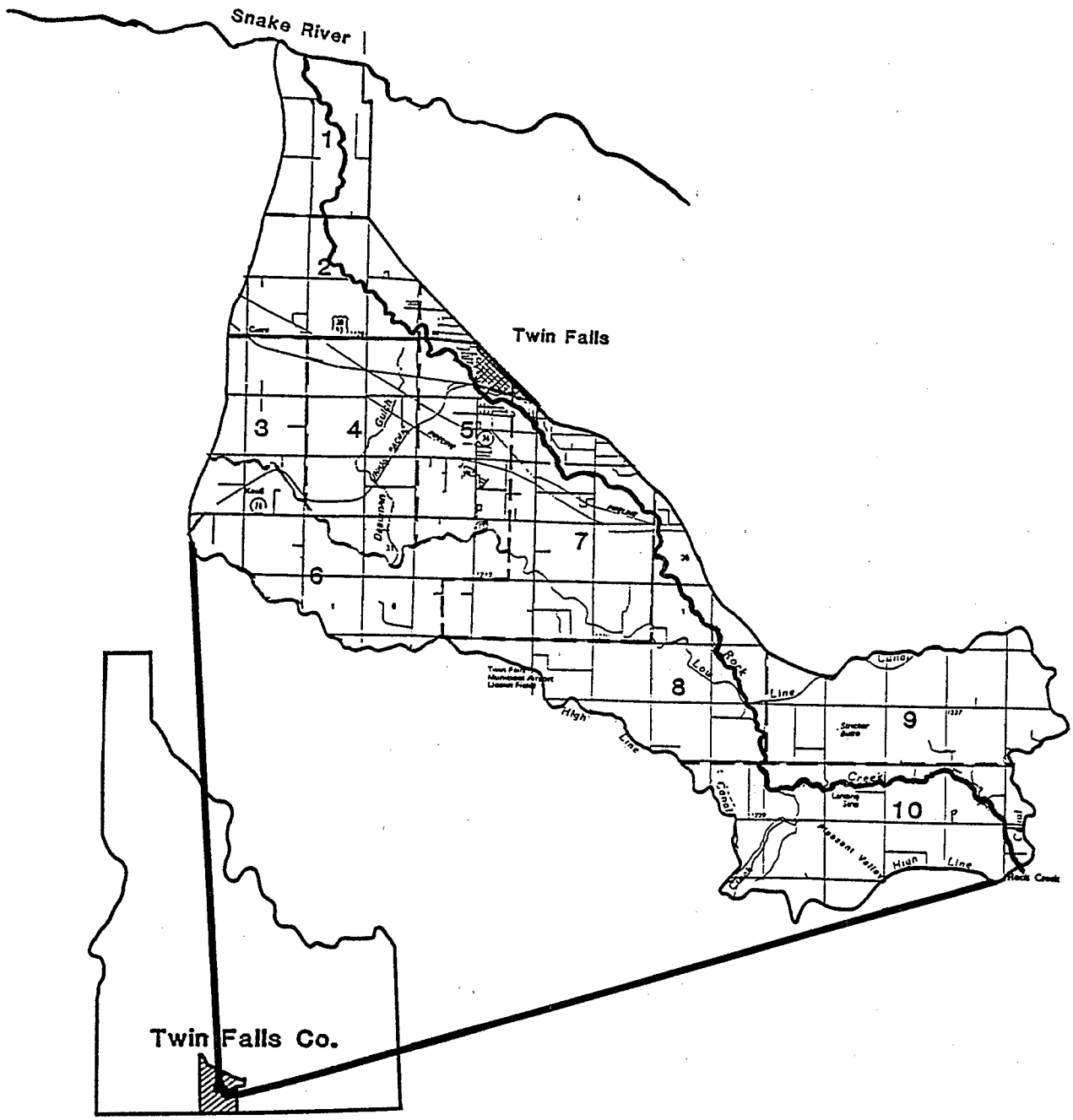

Figure 1.—Map of the Rock Creek RCWP project in Twin Falls County, Idaho.

- irrigation improvements,
- irrigation water management, and
- animal waste control systems.

Information and Education

When the project began, an I&E committee was formed (see Fig. 2). Representatives from the Agricultural Stabilization and Conservation Service (ASCS), Soil Conservation Service (SCS), Cooperative Extension Service (CES), Idaho Division of Environmental Quality, and the Snake River and Twin Falls Soil and Water Conservation Districts participated on the committee. The Snake River Soil and Water Conservation District became the lead I&E group. In 1985, it was able to hire a full-time I&E specialist, who coordinated the I&E program and implemented many I&E activities.

The I&E program consisted of a mixture of news releases, newsletters, flyers, brochures, slide presentations, informational meetings, demonstrations,

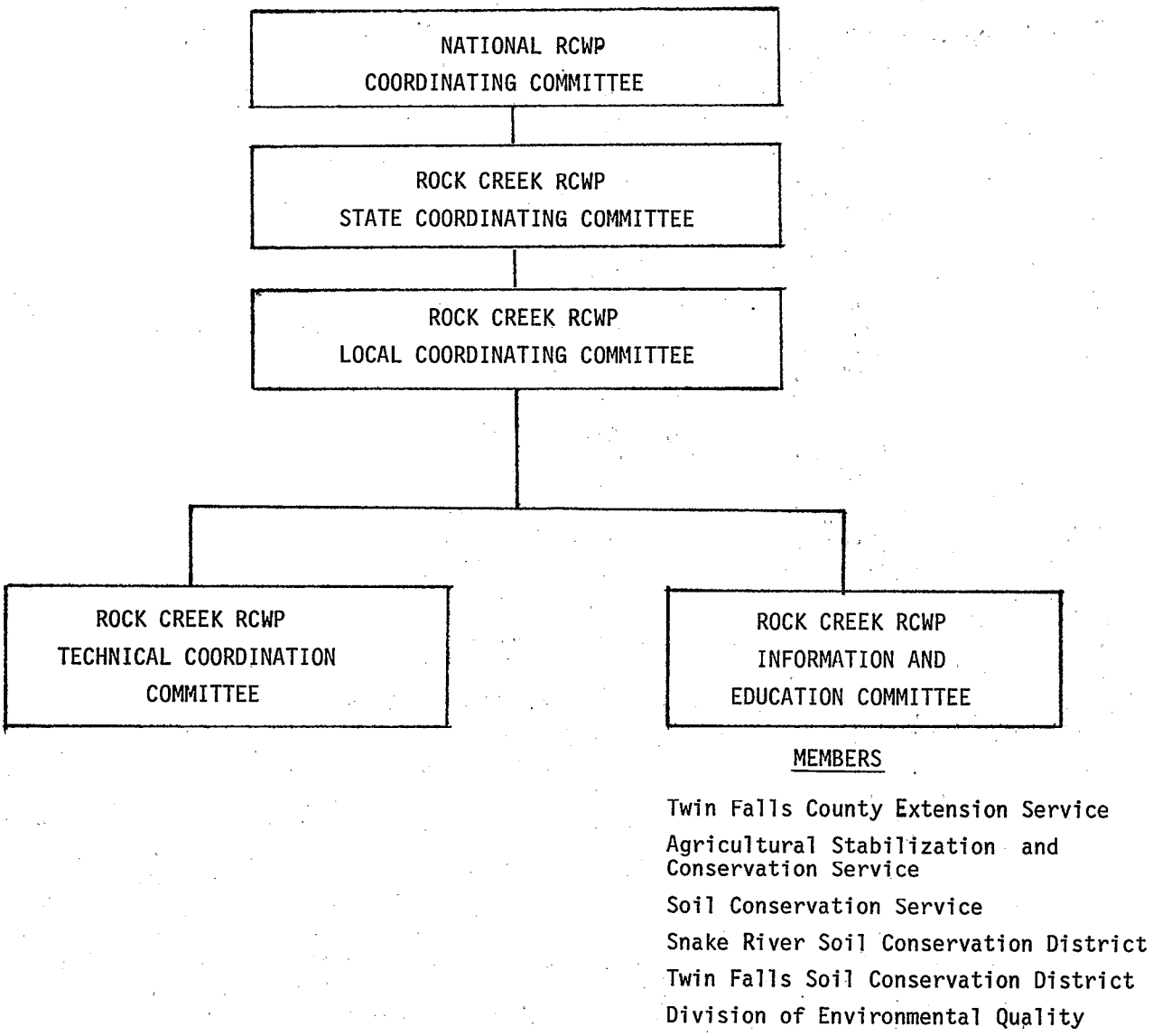

Figure 2.—Flow chart of the Rock Creek RCWP project committees.

tours, posters, displays, public service announcements on radio and television, and awards programs. The Rock Creek RCWP Final Report contains a complete bibliography. (Copies of the report may be requested by contacting the author; a section of it is appended in this report.) Six hundred and eighteen separate reports, newsletters, and publication are cited. Evaluation of the I&E program after the end of the contracting period identified the following elements as the most valuable in obtaining farmer participation:

- actively involving local Soil Conservation District (SCD) supervisors and ASCS county committee members;
- identifying and contacting local farm leaders;
- meeting with farmers to gain input on how to implement and manage BMPs; and
- meeting with landowners and the media to provide a yearly update on water quality monitoring and BMP implementation.

The active involvement and leadership of SCD supervisors and ASCS county committee members was effective in gaining the trust of local farmers. SCD supervisors spent many hours visiting farmers, to explain the RCWP project. The supervisors' participation made farmers receptive to the suggestions and ideas presented by soil conservationists. After water quality plans were jointly developed by the farmer and soil conservationists, they were reviewed and approved by SCD supervisors. The ASCS county

committee members met with each farmer before the contract was signed to provide cost-share funds for implementing the water quality plan. This process helped ensure that the farmers thoroughly understood the project rules and procedures.

To help get the RCWP project off to a good start, farm leaders were identified and contacted first. When the program had been thoroughly explained to them, they then helped promote it among other farmers. This technique was very successful. During the project's contracting period, the ASCS office always had a waiting list of farmers requesting contracts.

Many BMPs approved for use in the Rock Creek RCWP project were new practices for Rock Creek farmers. The BMPs had been developed, researched, and tested by the University of Idaho and U.S. Department of Agriculture's Agricultural Research Service. They had not, however, been previously implemented by area farmers. Many farmers initially believed that BMPs would not be compatible with their farming operations. Small group meetings were held with farmers after they initially implemented BMPs. At these meetings, farmers shared information on how BMPs could best be installed and managed. The information benefited the farmers in attendance, and soil conservationists later shared it with new applicants. These meetings were successful because they consisted of farmers telling other farmers how to implement BMPs.

Keeping farmers and the public informed on the progress and achievements of the RCWP project was very important. During the contracting period, a meeting was held every winter. All Rock Creek farmers and the local media were invited. These meetings were well attended. They served not only to provide water quality and land treatment data but also to build enthusiasm and pride for the Rock Creek Project.

It is also important to note that not only was the contracting goal of 75 percent of the critical area achieved, but very few farmers cancelled contracts after they were signed. The key elements noted previously were effective in obtaining trust, participation, understanding, commitment, and pride for the Rock Creek Rural Clean Water Program. This, in turn, resulted in the achievement of the water quality goals established for the project.

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Appendix

from Rock Creek RCWP Final Report (Yankey et al. 1991)

4.1 FINDINGS AND RECOMMENDATIONS

- Information and education activities for the Rock Creek Project were invaluable aids in explaining the Project to landowners, operators, and the general public and in enlisting their involvement.
- Through the use of news releases, newsletters, flyers, brochures, slide presentations, informational meetings, demonstrations and tours, posters, public service announcements on radio and television, awards programs for participating farmers, cooperation and support was gained from Project participants and non-participants alike.
- Information and education activities should be initiated at the project's inception to explain its concept, continue throughout the project to demonstrate its progress, and proceed to the project's completion to emphasize its success.
- An information and education specialist should be hired at the outset of the project in order to facilitate information and education activities.
- Personal contact between SCD supervisors and landowners is an extremely valuable information and education activity.
- A mixture of media is essential in information and education activities since different types of communications reach different people.
- The need for information and education exists at two levels: the public's level and the farmer's level. Information and education for the public should be provided by a communication expert, while the farmers should receive information and education from those who are more technically oriented.
- Someone with a deep knowledge of the project should organize communication efforts so that a coordinated I & E message is disseminated.
- Major emphasis should be placed on educating the public about water quality benefits derived from the Project. The public was interested in and eager to learn about those benefits of the Rock Creek Project.
- Monitoring results are helpful in an information and education program. Such data reassures the public and farmers alike that BMPs are producing the desired results.

Farmer Participation in the Double Pipe Creek, Maryland, Rural Clean Water Program Project

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ABSTRACT

Initiated in 1980, the Double Pipe Creek Rural Clean Water Program project was established to provide farmers with cost-share assistance as an incentive to voluntarily implement best management practices. The primary objective of the project was to improve water quality and reduce sedimentation in the Double Pipe Creek Watershed. Farmer participation was affected by economic conditions, current government program requirements, and farmer-agency relationships. By the project's conclusion, farmers will have been awarded over $3 million in cost-share funds.

The Double Pipe Creek Rural Clean Water Program (RCWP) project is located in Carroll County, Maryland, within the multicounty Monocacy River basin that runs from Pennsylvania south to the Potomac River above Washington, D.C. Historically, dairy and cash grain farming have predominated in Carroll County. Other crops in this piedmont area include corn, soybeans, small grain, and hay. Farm size averages 136 acres. At the time of the project, livestock on participants' farms ranged from 400 dairy cows to 5 beef cows.

Water quality plans covering 20,273 acres had been written and approved for 149 contracts by the end of the contracting period in 1986. Two priority critical areas were established:

1. farms where livestock and animal waste management and severe gully erosion presented water quality problems and
2. farms where sheet and rill erosion produced control problems.

The local coordinating committee coordinated activities of the participating agencies — the Agricultural Stabilization and Conservation Service (ASCS), which provided administrative assistance; the Soil Conservation Service (SCS), which gave technical assistance; and the county Cooperative Extension Service, which acted as the primary agency in leading the information and education efforts. Water quality monitoring was conducted by the Maryland Department of the Environment.

Farmer Participation

Approach Taken

Program participation was encouraged through project tours, government literature, and articles in local newspapers. An SCS field office soil conservationist provided general information about project benefits and, following a request for a contract, worked with the applicant to develop a water quality

plan outlining the best management practices (BMPs) to be installed or carried out and the estimated cost-share funds needed. The ASCS office maintained contract information and issued payments.

The BMPs installed included:

- permanent vegetative cover,
- animal waste control systems,
- strip-cropping systems,
- diversions,
- grazing land protections,
- grassed waterways,
- cropland protective cover,
- conservation tillage systems,
- stream protection systems,
- permanent water control structures, and
- fertilizer and pesticide management.

The topography of the watershed and the need for improved animal waste containment made animal waste control systems (BMP-2) and grassed waterways (BMP-7) the most heavily used practices, accounting for 85 percent of the cost-share funds earned — over $2 million.

The Double Pipe Creek Watershed now serves as a demonstration of how water quality goals can be accomplished through voluntary adoption. Many of the practices would not have been installed without the incentive provided by the cost-share program. The cost-share limitation of $50,000 gave the SCS the flexibility to design innovative practices large enough to meet participants' needs. These BMPs now serve as examples of installations that meet water quality goals. Farmers from within and outside the targeted area have visited participant farms to view projects completed with RCWP funds.

Since 1988, Carroll County has been the focus of a gamut of water quality projects that have resulted from successful farmer participation in the Double Pipe Creek Watershed project. The Piney/Alloway Creek Watershed, which borders Double Pipe Creek to the north, has been targeted for an ASCS Special Water Quality Project, State of Maryland-Targeted Watershed Project, and a Federal Demonstration Project. The justification for these activities focused on local agencies' ability to successfully implement these programs and farmers' willingness to participate in demonstrations, as illustrated by the success achieved through the RCWP project.

Factors Affecting Participation

The farmers in the project area were very receptive to the Rural Clean Water Program. The ASCS, SCS, and the county Cooperative Extension Service had developed an excellent working rapport with local farmers before the start of the project, which made farmer recruitment an easy task. County farmers were enthusiastic about the opportunity to install innovative BMPs with a more liberal payment limitation than traditional Federal programs had afforded.

However, during the 1980s, many outside factors affected the RCWP project area, including a three-year drought that placed a severe financial hardship on the project participants and problems within the dairy industry, which is the most prevalent type of farming in Carroll County. During the 1980s, 33 percent of the dairy producers in the county went out of business. Milk prices fluctuated from $12.90/cwt in 1986 to $14.90/cwt in 1990, which produced uncertainties about market conditions that negatively affected dairy operators' willingness to spend large amounts of money to construct conservation BMPs.

State and Federal Programs

Several State and Federal programs have been implemented during the RCWP project. Those programs that affected the project area are described in the following paragraphs.

■ **Maryland Agricultural Land Preservation Program.** For a farm to be accepted in the Maryland Agricultural Land Preservation Foundation, a conservation plan must be developed when easement rights are sold. Since 1980, 21,473 acres have been accepted into this program in the Double Pipe Creek Project area. By enrolling in the Agricultural Land Program and making a financial commitment to water quality through RCWP, many farmers have become committed to remaining in farming.

■ **Food Security Act of 1985.** Approximately 75 percent of the land in Carroll County is highly erodible, according to 1985 Food Security Act criteria. The SCS's district conservationist has estimated that 25 percent of the cropland acreage will need cropping system modification or additional conservation measures to bring the soil loss each year within the established acceptable level. These changes should affect the project area's water quality positively by reducing soil particles, animal waste, commercial fertilizer nutrients, and pesticides in the water.

■ **Wheat and Feed Grain Program.** Since 1986, the 1985 Food and Security Act Wheat and Feed

Grain Program has become a major influence in the project area. Each year, enrollment has fluctuated because of changing markets, prices, and producer needs; however, the average county enrollment has been 200 farms, with 140 in the project area. Approximately 4,200 acres have been designated as an acreage conservation reserve (ACR). Farm operators must use control measures when needed for erosion, insects, and weeds on their ACR land. In general, ACR land is on hillsides or other areas where erosion control is important. The Wheat and Feed Grain Program through ACR is decreasing erosion and preventing animal waste and pollutants from reaching streams in the RCWP area.

■ **Conservation Reserve Program.** Carroll County has limited participation in the Conservation Reserve Program because of high land values; however, 75 percent of the land enrolled (approximately 700 acres) is in the project area.

Time Line of Events

This summary time line of the Double Pipe Creek Project is not all-inclusive but highlights major events. Information for this summary was extracted from local coordinating committee minutes for the last 10 years.

- **1979** — Proposal for Double Pipe Creek Project submitted
- **1980** — Proposal approved for Double Pipe Creek Project
  - — Local coordinating committee determined that any farm in the project area that critically affected water quality, regardless of the distance to streams, would be considered a high priority request
  - — Cost-share earned: $8,953
  - — Contracts approved: 5
- **1981** — Cost-share earned: $176,518
  - — Contracts approved: 25
- **1982** — Cost-share earned: $283,642
  - — Contracts approved: 25
- **1983** — Versar, Inc., completed baseline data, Stage 1 of monitoring
  - — Cost-share earned: $316,515
  - — Contracts approved: 18
- **1984** — Law passed requiring that a conservation plan accompany easement rights bid to enter Maryland Agricultural Land Preservation Program
  - — State agreed to continue monitoring when Versar contract expired
  - — Demonstration Day held (85 people attended)
  - — Cost-share earned: $187,815
  - — Contracts approved: 21
- **1985** — Fertilizer and pesticide management added to the project
  - — Contracting period extended through December 31, 1986
  - — Cost-share earned: $502,836
  - — Contracts approved: 19
- **1986** — Cooperative Extension agent hired to write nutrient management plans and carry out BMP-15 and BMP-16
  - — Cost-share earned: $382,125
- **1987** — Cost-share earned: $489,773
- **1988** — Best Management Progress Tour to demonstrate progress and practices completed (150 attended)
  - — Cost-share earned: $236,014
  - — Contracts approved: 1
- **1989** — Cost-share earned: $168,033
- **1990** — Cost-share earned: $136,464

Results

By the end of the sign-up period in 1986, contracts had been completed for 149 farms, all located in the critical area as defined by the local coordinating committee. Ninety-four percent of the cost-share monies used for BMP application was spent for animal waste control systems (BMP-2), grazing land protection (BMP-6), and grassed waterways (BMP-7), the primary practices installed. These BMPs were completed in 80 percent of the contracts. Of the 60 percent of landowners with active contracts who completed animal waste control systems, 74 percent installed one or more grassed waterways and 44 percent installed grazing land protection BMPs. A total

of 203 animal waste control systems (BMP-2) were recorded, including repairs, modifications, and additions to existing practices. Over the 10 years, 221,616 feet of waterway were cost-shared and 110 grazing land protection systems installed.

In 1990, the local coordinating committee conducted a survey to evaluate farmers' perceptions of the project. Thirty percent of the questionnaires were returned, and many responses reflected producers' positive feelings toward the project.

"The BMPs installed on the farm were very influential in preventing erosion, runoff, and other problems we were having."

"There were no weaknesses. Strengths — it stopped the erosion, which is what it was supposed to do; the ASCS people we worked with are very good."

"I think the field manpower was good, getting through the practices smoothly was a real plus. Having plenty of time (extensions) also is a real plus. I never felt pushed at any time."

"The major strengths were adequate cost-sharing and flexibility of design, with my wishes and ideas being incorporated."

"The only way to improve would be to continue the project. There are probably still a lot of problem areas around the county."

Lessons Learned

The Double Pipe Creek RCWP truly served as a demonstration project. The local coordinating committee compiled a list of conclusions, some of which follow:

- Implementation is correlated to farm income and farm income is difficult to predict over 10 to 15 years.
- Contractors who are not only available but also have equipment and experience are a necessity. (Contractors were not a problem for this project.)
- Because of the experimental nature of the project, a wide range of innovative options were planned and installed, particularly through BMP-2.
- The flexibility to try new ideas during practice application and the $50,000 payment limitation was a great asset.
- ASCS's administration of the project was a great advantage because the agency already had experience in administering cost-sharing programs.
- Landowners were willing to try new ideas after ASCS staff explained that, through the project, their contract could be modified to alter the BMP if the original facility did not provide expected results.
- The water quality improvements placed on the land and subsequent publicity greatly improved the agricultural community's image in the eyes of the public and county government.

By offering voluntary incentives to achieve farmer participation and exhibiting a positive, cooperative approach, the agencies involved at the local level of the Double Pipe Creek RCWP project successfully administered $2,680,366 in cost-share funds through 1990.

The Key to Successful Farmer Participation in Florida's Rural Clean Water Program

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ABSTRACT

The high percentage of farmer participation in Florida's Rural Clean Water Program resulted from several factors, many not controlled by direct contact with the participants. Different strategies were used to arouse interest. A farmers' meeting held to inform potential participants of the program and encourage them to contract had limited attendance. The media was used as well as local agency newsletters and small group meetings—again with limited results. The most successful strategy was one-on-one contact with potential participants. An external factor in the process was what the local regulatory agency called the "carrot and stick approach," the carrot being the Rural Clean Water Program and the stick, a regulatory program. In addition, in the 1960s, most of the dairies in the project area had sold land elsewhere at a profit and moved to Okeechobee. In the 1990s, these dairies would not gain the same financial rewards by moving away from regulation.

The Taylor Creek-Nubbin Slough Rural Clean Water Program (RCWP) project exceeded its goals for farmer participation and implementation of best management practices (BMPs). Two factors influenced this success: things the project could control and those it could not. This paper, based on the Taylor Creek-Nubbin Slough 10-year Report (Stanley and Gunsalus, 1991), reviews both factors and draws some conclusions about how each influenced participation and how the lessons learned here could aid other projects.

Background

The Taylor Creek-Nubbin Slough RCWP defined 63,109 acres as critical and 59 farms that needed treatment. The project used the following definitions for determining the critical areas:

- All dairy farms in the project are considered critical areas.
- All beef cattle farms that have been extensively drained are considered critical areas.
- All areas within one quarter mile on each side of a stream, ditch, or channel that hold water year-round are considered critical.

After five years of contracting, 48 farms (Fig. 1) and 54,709 critical acres (Fig. 2) were under contract, representing 89 percent of the total critical acres contracted. An additional 5,267 acres on eight farms, originally considered critical acres, were determined not to have a water quality problem when surveyed by the Soil Conservation Service. This left 3,133 acres (5 percent) on three farms that needed treatment but were not contracted. The total acres contracted far exceeded the goal set by the RCWP project (75 percent of the critical acres). Figure 1 shows the progression of contracts signed at the end of each year. Projects had five years from their inception to contract farms and 10 years to complete implementation of BMPs.

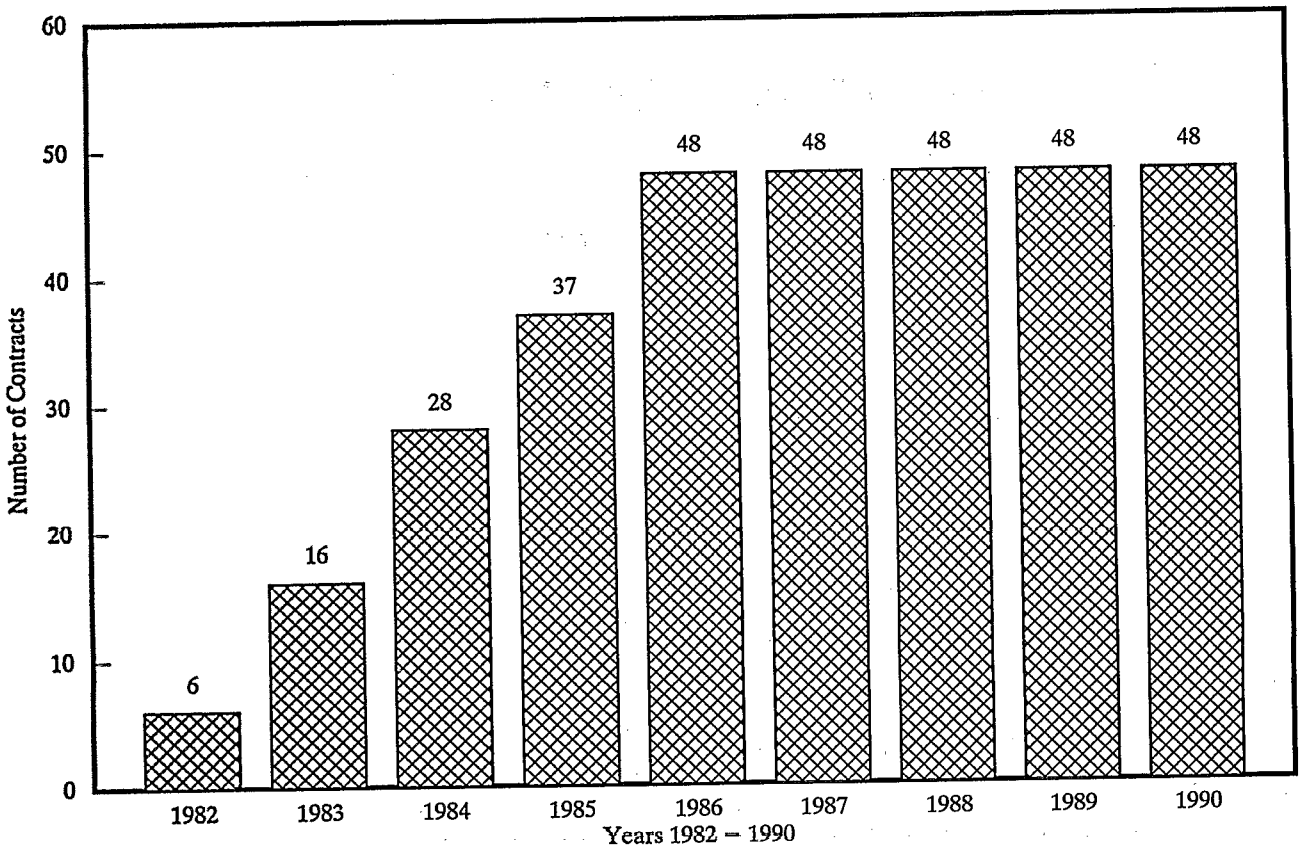

Figure 1.—Active RCWP contracts in the Taylor Creek-Nubbin Slough basin.

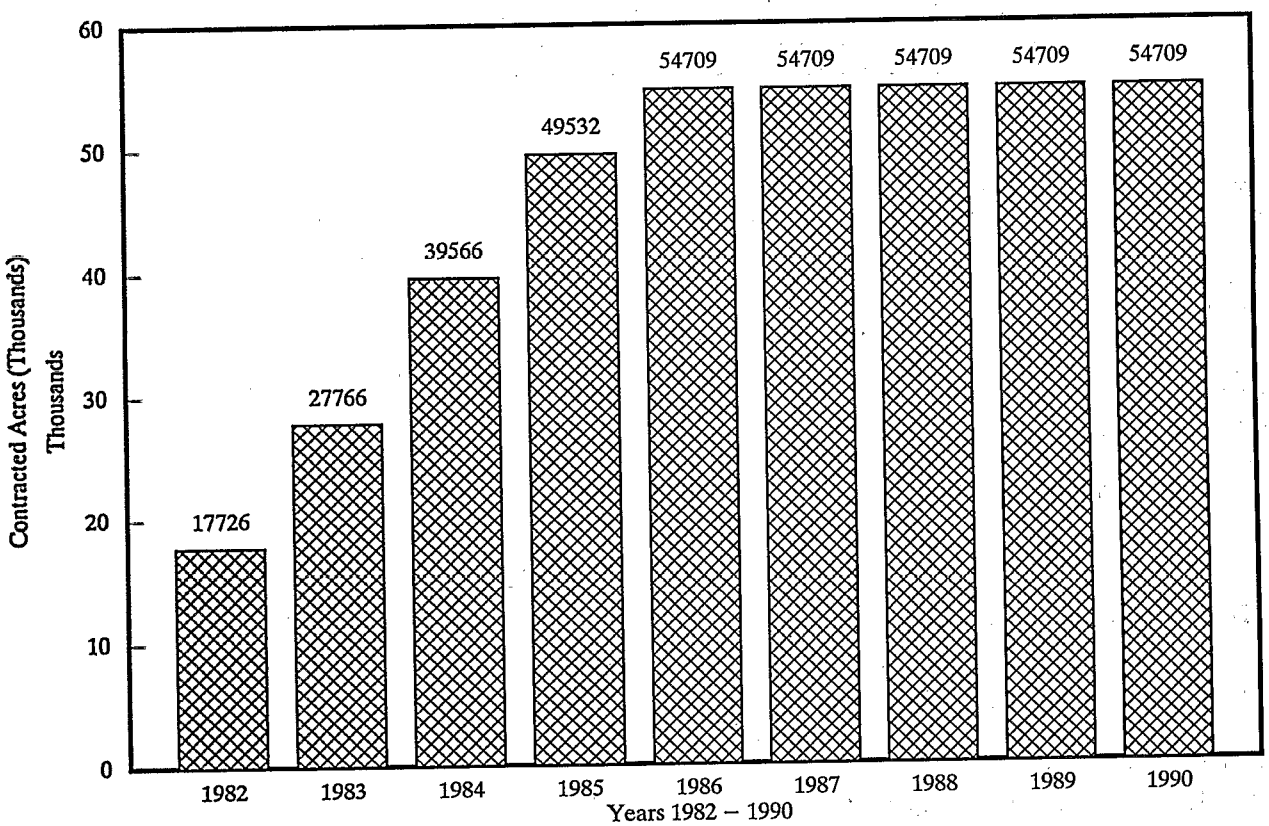

Figure 2.—Contracted acres for the Taylor Creek-Nubbin Slough basin.

Ninety-nine percent of the practices scheduled were completed (Table 1), which is important because it shows that the farmers were not only willing to sign a contract, but they were committed to helping solve an environmental problem. Many of the subwatersheds had a substantial number of signed contracts and acres treated early in the project. Table 1 shows that Little Bimini, Taylor Creek Main, and Henry Creek subwatersheds (all predominantly dairy) had most implementations completed by 1986. Williamson Ditch, a predominately beef cattle subwatershed, had 100 percent implementation by 1986. Table 1 and Figure 2 for 1987 show that most of the critical acres in all subwatersheds were under contract and most of the project's BMPs had been implemented by this time. This progress enabled early trend tests to detect BMP effectiveness.

Farmer Participation

Controlled Factors

Defining the area should have been the first step in getting participation. Initially in the Taylor Creek-Nubbin Slough RCWP proposal, the critical area was defined as the total Taylor Creek-Nubbin Slough basin, which was 110,000 acres and approximately 150 farms. In 1982, the local coordinating committee reduced the critical acres after a *1-RCWP* handbook amendment clarified the definition of critical area to be "that area that needs treatment"—not the total basin, as originally defined. The committee reviewed aerial photographs and reduced critical land area by 15 percent to 93,500 acres.

In 1983, the committee established a final critical area definition after initial contract planning showed that not all acres were critical. Using the three criteria mentioned earlier and deleting urban areas that fell within the project, the committee determined 63,109 acres with 59 farms were critical areas that needed treatment. These important steps defined the potential participants and kept the project focused on the most critical farms. Nevertheless, time should have been taken in the initial stages to better define critical areas. However, as it became clear that changes were needed, the project made them.

Farmer meetings were held to encourage participation but with limited success. In these meetings, the purpose and the goals of the project were stated, and each agency involved explained its role. Articles about RCWP were placed in news media and agency newsletters, but they were of limited success in getting participants to sign up for the program. However, these communications reinforced the initial meetings.

One-on-one contact with potential participants was the most successful, overall. Meeting people face-to-face and listening to their individual problems and concerns made the process more personal. This success was augmented by the structure and operation of the administrative subcommittee, whose members visited individual farms to explain the program and encourage participation.

The administrative subcommittee consisted of the Agricultural Stabilization and Conservation Service county executive director, Soil Conservation Service district conservationist, County Cooperative Extension water quality specialist, and a representative from the South Florida Water Management District. This group ran the day-to-day operation of the project.

Each subcommittee member understood the role and goals of the project and each other; therefore, a potential participant could talk to any one of these four agency representatives to get information about the farmer's role and that of each agency. Subcommittee members either individually or as groups visited the farms that had not signed initially. The project's goal was to identify and visit all potential participants.

Dairies in this project were an easier sell because the high animal densities on their farms appeared to be the most obvious problem (and because of uncontrollable factors that will be discussed later). Beef operators, with fewer livestock, did not think they had a problem. The subcommittee used two ap-

Table 1.—Percent implementation of best management practices by subwatershed by year.

SUBWATERSHED	1981	1992	1983	1984	1985	1986	1987	1988	1989	1990
NW Taylor Creek			2%	43%	56%	69%	100%	100%	100%	100%
Little Bimini		31%	36%	48%	87%	91%	95%	99%	99%	100%
Otter Creek		10%	35%	50%	75%	77%	97%	99%	99%	99%
Taylor Creek Main			1%	6%	57%	90%	99%	100%	100%	100%
Williamson Ditch				25%	80%	100%	100%	100%	100%	100%
Mosquito Creek					20%	50%	77%	99%	100%	100%
Nubbin Slough			8%	14%	39%	81%	97%	100%	100%	100%
Henry Creek			60%	60%	94%	98%	100%	100%	100%	100%
Lettuce Creek					5%	10%	77%	100%	100%	100%

proaches to convince beef operators to sign: it pointed out that, collectively, beef operators had as many animals as dairies and that cattle also sought (and polluted) water. The subcommittee noted that, if beef operators participated, they could help prove their animals were not a problem.

To try to obtain maximum participation, the subcommittee allowed farmers to select the order in which the BMPs would be installed. Most participants first chose to install practices that they thought might bring financial or other benefits and not necessarily those that would have the greatest effect on water quality. In retrospect, this flexibility on BMP installation was a poor decision because BMPs were not implemented first on the most critical acres.

Many factors entered into the project's success, but the fact is that most of the farmers understood the need to do their part in preserving the environment and therefore completed 99 percent of their scheduled work.

Uncontrollable Factors

During the contracting period, Florida was entering into a regulatory phase that defined agriculture's role in protecting State resources. Part of the reason these farms signed RCWP contracts was the threat of regulation. The local regulator agency called this the "carrot and stick" approach, the carrot being the RCWP program and the stick, regulation.

The South Florida Water Management District began to assess water quality along with water quantity. Specifically, the District was looking at ways to regulate the quality of surface water runoff. The Taylor Creek-Nubbin Slough basin was the area of greatest concern and, therefore, the District's first priority. The District implied that people who did not participate in the RCWP project would have to get a surface water management permit. Because of public pressure, this threat became more of a factor toward the end of the sign-up period. Now, after the end of the contracting period (1981 to 1986), surface water management permits are required on most farms in the area, including RCWP farms.

The farm economy also played a role in participation. In 1983, milk prices dropped considerably, keeping some dairies from signing and causing some to cancel their request for contracts. In 1985, prices improved and all the dairies were signed by the end of the contracting period. Depressed beef prices also slowed beef operators' participation.

In the 1960s, many dairies had moved to Okeechobee from south Florida (primarily from Dade and Broward counties) because, as the population grew up around these dairies, their holdings had become valuable development land. In south Florida, dairies sold out at inflated prices, moved to Okeechobee, and paid cash for land. However, the opportunity to sell this land for development at inflated prices was not available in Okeechobee in the 1980s, so dairies could not as easily move away from regulation. This situation made the RCWP project more attractive to dairy farmers.

Summary

Individual contact was the most successful method in getting farmers to participate. When agency representatives sat down with a potential participant to explain how RCWP would affect an operation and enumerate benefits that could be realized, that person was more likely to sign on to the project. Farmer meetings, news media, and other resources were important in laying the foundation for individual contacts and keeping the project visible. Also important were the people making contacts: they had to be able to explain the program and the roles of participants and agencies.

As much as this project's personnel would like to claim credit, external factors played a large part in successful participation. Threat of regulation, the economy, and a changing real estate climate had an effect. However, project personnel used these uncontrollable factors to achieve the project's goals.

Findings and Recommendations

- Farmer meetings were good places to explain the project but few contracts were signed at meetings.
- One-on-one contact had the most success in getting participants to sign contracts.
- The individual key players must understand the role of each agency, so that participants can talk to one person to get initial information.
- The project area and potential participants must be defined or redefined to keep the project focused on the most critical areas.
- To get participation, the subcommittee allowed flexibility in selecting the order in which practices would be installed. In retrospect, this had little effect on participation. Therefore, BMPs giving the greatest benefit to water quality should be addressed first.

Reference

Stanley, J. and B. Gunsalus. 1991. Taylor Creek-Nubbin Slough RCWP 10-year Report. Okeechobee Agric. Stabil. Conserv. County Off., Okeechobee, FL.

Document It! Procedures for the Documentation of Nonpoint Source Project Data — Land Treatment

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ABSTRACT

The Rural Clean Water Program (RCWP) was established as a 10- to 15-year experimental program offering cost-sharing and technical assistance to farm operators as incentives for implementing best management practices (BMPs) to control agricultural nonpoint source pollution. The RCWP emphasized interagency cooperation, and as many as 15 agencies were involved in some capacity at various stages of project development. To provide project continuity and establish a base of consistent information, procedures for documenting economic and technical data must be established and assigned. This paper defines procedures for identifying and documenting critical acres, acres under contract, project development, and subbasins on a master aerial photograph of the watershed and a master set of aerial section map photographs. It also provides methods to record economic and technical project information on a standard nonpoint source pollution data log format, addresses documentation of nonproject land treatment data, and discusses problems with the use of acres served data from CRES forms. It recommends that agencies adopt a standard data log format for all nonpoint source projects involving BMPs, determine standard methods for reporting acres served or benefited for each individual practice, and adopt procedures for documenting other project and nonproject land treatment data.

The Long Pink Creek watershed is located in north central Nebraska on the northeastern edge of the Nebraska Sandhills, the largest grass-covered sand dune area in the world. In the mid-1960s, irrigation was developed on 35,000 acres within the watershed. This sudden change from grasslands to intensive row crop production had a significant environmental effect on the area. Excessive sediment from agricultural runoff and erosion filled creeks and streams and negatively affected aquatic life. Agricultural chemicals were found to be leaching into the groundwater. In 1981, the Long Pine Creek watershed was one of 21 watersheds in the United States selected for the experimental Rural Clean Water Program (RCWP). The program emphasized interagency cooperation. A total of 15 State and Federal agencies made significant contributions to the project.

The Nebraska RCWP project addressed both land and stream treatment. Fifteen best management practices (BMPs) were selected to address nonpoint source pollution problems on 60,242 acres identified as critical. A wide variety of land treatment practices were employed throughout the watershed, including

- water management systems,
- water and erosion control structures,
- grazing land protection systems,

- permanent vegetative cover,
- stream protection systems, and
- fertilizer and pesticide management.

Although plans for water quality monitoring were extensive, the documentation of land treatment data to be linked to water quality monitoring data was not fully realized. Land treatment data is complex and includes many variables. To link water quality monitoring to BMP effectiveness, significant land treatment documentation by hydrologic unit must take place. The Nebraska Department of Environmental Control (NDEC) began a three-year postmonitoring project in the Long Pine Creek watershed in spring 1992. A significant amount of research is necessary to provide the NDEC with the land treatment documentation it will need to link BMP installation to any changes in water quality. The following recommendations for documentation of project and nonproject land treatment data have evolved out of the Nebraska RCWP experience. This paper addresses procedures for identifying and documenting critical areas, subbasins, and contract acres and for collecting land treatment data.

Identification and Documentation Procedures

At the beginning of each project, the project area, critical area, and hydrologic units (subbasins) must be identified and documented. Data log formats must be created to record all project data, including cost-share and non-cost-share practices, technical and economic data. Technical personnel must decide what other land treatment data will be needed in accordance with each project area's agricultural and urban activities. Formats to document procedures to collect this land treatment data must then be established and data log formats distributed to facilitate the process.

Step 1

Order a large (four or eight inches to a mile) aerial photograph of the watershed and surrounding area from the Cartographic Unit of the Soil Conservation Service (SCS). This map is an invaluable visual aide in determining critical areas. The SCS and the State's Department of Environmental Control, along with other agencies with technical expertise, should work together to determine and delineate the following:

- **The Project Area.** The general watershed area.
- **The Hydrologic Units — (Subbasin Lines).** Use the large aerial photograph in conjunction with topography maps to determine hydrologic units that are unlikely to change because they are based on drainage. In the future, post-monitoring may be a part of all projects; therefore, the agencies involved in monitoring should agree with other technical agencies on the locations of drainage lines. Delineate the subbasins on the large aerial photograph.
- **The Critical Area Targeted for Treatment.** For surface water projects, use topography maps to determine the acres contributing to surface runoff and pollutant delivery within each subbasin. These lines will be delineated on the large aerial photograph of the watershed and can be used to determine critical areas. Critical areas will be adjusted according to each project's variables, which can include amount of cropland, cropping practices, animal unit density, erosion rates, proximity to streams and lakes, and percentages of cover. Delineate the critical area(s) on the large aerial photograph.

Critical areas are likely to change as the project evolves. If changes occur, document them. Include a detailed description and rationale for each change.

Step 2

Assign responsibility for documentation. Someone such as the project coordinator or Agricultural Stabilization and Conservation Service (ASCS) program clerk must establish and maintain permanent documentation of critical areas, subbasins, acres under contract, and the like. ASCS, which is involved in RCWP projects as the administrative body and as head of the local coordinating committee, should provide a full-time person to establish and maintain RCWP maps during the contracting period.

After the project area, subbasins, and critical areas have been determined and delineated on the large aerial photograph, the ASCS RCWP clerk will

- pull small aerial photographs (section, legal, or subbasin maps) of all sections within the critical area to form the permanent RCWP file (these photographs are identified by legal descriptions);
- stamp "RCWP MAP" on each photograph in the upper left-hand corner;
- delineate the critical area on the small aerial section photograph and write the number of

acres in the critical area in the upper left- hand corner;

- delineate (if necessary) the subbasin areas and indicate subbasin identification and acres in the upper left-hand corner of the map or subbasin area; and
- assign each field a "Farm Field ID" number to link photographic information to the geographical information system and other databases.

The large aerial photograph of the watershed and the small aerial section map photographs are now the permanent record of the project. As acres are put under contract, the ASCS clerk will

- delineate the acres under contract and write the contract number, year, and name (example: RCWP-25-1992, Bob Smith) on the large aerial photograph, and
- pull the small aerial section map photograph(s) and delineate the acres under contract with the same notation as the large aerial photograph.

If acres are added to or taken out of the critical area, changes should first be drawn on the large aerial photograph with a notation (example: added [or deleted] 1993) and then documented on the small aerial photographs.

Note any activity within the critical area first on the large aerial photograph and then on the small aerial photograph. This method is consistent with ASCS procedures for making changes. When agencies need photographs, make a copy of the small aerial photographs with current information. At the end of the project, all of the activity regarding critical acres, acres under contract, years, producers, and subbasins will be documented on the maps.

As practices are completed and documented in the proposed standard nonpoint source data log, the ASCS program assistant should note the designation of each practice and the site on both the large and small aerial photographs. This procedure is consistent with ASCS procedures for documenting Agricultural Conservation Program (ACP) practices on large and small aerial photographs. These notations can be extremely valuable as reference points and visual aides in determining implementation progress through project development.

Establishing Data Log Formats

The data log records for future evaluation all pertinent data for each practice that is installed or implemented. Although much attention has been given to water quality monitoring data, in many instances, land treatment data have not been sufficiently addressed. Land treatment data are complex: in addition to data on an immense array of agricultural activities, including dairies, feedlots, and livestock, feed grain, hay, food, and fiber production, these data include information about participants and nonparticipants, cost-share and non-cost-share, management, and cropping practices. Data logs and procedures must be established to provide consistent and uniform reporting of this technical and economic information, which must cover two basic areas:

1. documentation of project data and
2. documentation of other data deemed essential for evaluation or future use.

In all nonpoint source projects, project data should be reported using a standard format. The BMPs' effectiveness will vary according to location, and these differences cannot be properly evaluated if nonstandard formats are used. (An example of a standard format for reporting data appears at the end of this paper.) Documentation of other pertinent land treatment data must be tailored to each project.

In establishing procedures for land treatment documentation, several things must be kept in mind.

- The information must be recorded at the easiest point in project implementation.
- The data must be consistently reported at all stages of data collection.
- The data log should be easily accessible throughout each project period so that interested agencies can immediately view or analyze specific data.
- Annual summaries of data for all practices completed should be made by subbasin.

Documentation of Project Data

■ **Technical and Cost-share Data.** The technical and economic data for all cost-share practices are present whenever a payment is issued. According to the RCWP manual, upon certification by SCS that BMPs have been properly installed, the producer can receive cost-share payment for each practice. In the Long Pine Creek (Nebraska) RCWP, SCS certified that the practices were completed by returning a copy of the Conservation Reporting and Evaluation System Data Sheet (AD-862 CRES Form) with the ACP-245 to ASCS.

ACP-245s are issued at the beginning of each fiscal year for each planned cost-share BMP to serve as

a reminder of scheduled BMPs, provide claims for cost-share payment, and account for disbursement of cost-share funds. The CRES form filled out by SCS technicians records all technical data pertaining to each practice. At this point, all of the information pertaining to BMP costs and technical data are in place. The ASCS program assistant should record pertinent information in the standard nonpoint source data log for every practice completed, regardless of overlapping detail (i.e., two or more practices completed in the same field).

■ **Documentation of Non-cost-share and Management Practices.** Each year, SCS technicians perform annual status reviews on all contracts implementing BMPs. At this point, they can use the standard nonpoint source data log forms to document technical and economic information for non-cost-share and management practices that were implemented.

Documentation of Other Land Treatment Data

At the beginning of each project, technical personnel from all agencies must decide, in addition to project data,

- what other data will be needed for future use,
- what information is obtainable,
- what procedures are there for obtaining data, and
- who will record the information.

Data logs should be created to record the selected data. Design formats should be used in conjunction with the standard nonpoint source project data log format. For example, if annual data is collected on the standard nonpoint source project by subbasin, then annual data by subbasin should be collected in other formats.

Each project will have a separate set of goals and data needs based on the area's agricultural and urban activities. Because information other than project data must be specifically tailored for future use, technical personnel must decide how extensively to collect data. Some data, such as cropping histories, management practices, fertilizer and pesticide use, and waste management, may be documented annually.

Cropping histories are available in the ASCS office on the ASCS-578, which is the certification of a producer's annual cropping history. Both participants and nonparticipants certify their activities yearly; farm program participants are required to certify, but nonparticipants generally also certify to retain crop base records.

Several approaches exist for recording these data. Copies could be made of maps accompanying a producer's certification and given to the RCWP clerk. These maps identify the fields, acres, and crops for each specific year and are the same section maps used in the master aerial photograph section map file of the critical area. The RCWP clerk could file these maps in the master small aerial photograph map file. Also plan to obtain cropping histories on farms that do not certify each year. Mail maps to producers and ask them to identify crops planted or visit the producers. You may have to send data logs that require detailed reporting of specific information by field or farm (for example, fertilizer use) to producers so they can document this information.

Uniform Reporting of Technical Data

"Acres served" and "units applied" data are used to evaluate cost and water quality monitoring information to determine

- the cost-effectiveness of specific BMPs,
- the general effectiveness of specific BMPs, and
- the effectiveness of each project in general.

These data are recorded by SCS technicians on CRES forms whenever practices have been completed. SCS employs over 140 practices, and SCS technical standards explicitly define reporting "units applied" for each BMP.

However, guidelines for determining acres served are less explicit. Acres served is defined for 10 practices. A general guideline given for other BMPs states that acres served is "land in whole acres served, benefited, or protected by application of a conservation practice or system. When installation benefits adjacent land, report the acres benefiting from the practice, plus the area taken up by the installation. Acres affected little or not at all should not be reported as acres served."

In the Long Pine RCWP project, acres served was thought of in different ways by different technicians. One technician considered a diversion as serving only the acre on which it was applied, another believed the practice served a whole field, while another thought the BMP served acres both above and below or adjacent to the diversion site. Sometimes this definition of acres served even involved land not in a contract. Therefore, acres served were inconsistently reported.

In addition, acres served data often do not reflect the amount of land treated annually within the contract, within a subbasin, or within the project area. In the Long Pine RCWP project, if the acres served data are added by practice for each subbasin (taking into account practices serving the same acres, such as BMP 6-516-pipeline, 614-tanks, and 642-wells), the acres served will not reflect the number of acres treated.

Often, the outline of the critical area was drawn around an entire quarter section (160 acres) that was contributing to surface runoff. This section may have contained a 125-acre center pivot where BMP 15-fertilizer management and BMP 16-pesticide management were implemented. That year, a 20 percent Acreage Conservation Reserve (ACR) (set-aside requirement) was in effect. Therefore, the acres-served figure for BMP implementation documentation will not include the corners around the pivot or the ACR, which was not considered treated by the practice because it was not physically treated. Cost-share was issued at $1 per acre or acres treated. Acres treated was reported as acres served.

Many similar situations occurred in the Long Pine Creek RCWP project. Acres within the critical area were actually considered treated but not documented as treated. Therefore, data are not available on the amount of acreage under contract that was treated annually. ASCS only knows that, when all of the practices in the contract are complete, all of the acres in the contract will have been treated.

Conclusions

If agencies throughout the United State use acres served data to determine a practice's cost-effectiveness or its effectiveness in general, then a standard method of reporting acres served for each practice must be established. Because this information is becoming increasingly important in determining a project's effectiveness and in planning and applying future BMPs, SCS should clearly define standard methods of reporting acres served for every practice code and various situations (specifically, for acres under contract in nonpoint source projects). The standard methods for reporting acres served or benefited should be included in the SCS technical manuals under each practice code description.

A workshop for technical personnel from all agencies should be held to adopt a standard data log format for all nonpoint source projects involving BMPs and to discuss and determine standard methods for reporting acres served (or benefited) for each BMP.

Standard procedures and a documentation plan for all nonpoint source projects are vital to future evaluation. Many areas can also be expanded, including alternative data collection formats, use of computerized database programs, computer mapping, and documenting of BMP implementation. However, the data log format serves as the base for documenting all nonpoint source project data and is the source of all data used in any computer program.

Standard Nonpoint Source Data Log Format: Technical and Cost-share Data Recorded by BMP Item.

	DATE PRACTICE INSTALLED	RCWP CONTRACT	SUBBASIN NUMBER	FARM FIELD ID #	BMP NUMBER	PRACTICE CODE DESCRIPTION	PRACTICE		
							COST-SHARE	OR	NON-COST-SHARE
1.									
2.		**NOTE:**							
3.		According to the RCWP manual, individual ACP-245s are issued at the beginning of each fiscal year for each							
4.		planned cost-shared BMP. These serve as a reminder of scheduled BMPs, provide claim for cost-share pay-							
5.		ment, and account for disbursement of cost-share. Upon certification by SCS that BMPs have been properly							
6.		installed, the producer can receive cost-share payment. SCS certifies that the practice has been completed by							
7.		returning a copy of the Conservation Reporting and Evaluation System Data Sheet (AD-862 CRES Form) with							
8.		the ACP-245 to ASCS. The cost-share payment can then be made to the producer.							
9.									
10.									
11.									
12.		At this point all information pertaining to BMP costs and technical data are in one place. The CRES form has all							
13.		of the technical data pertaining to each BMP. The installation costs and cost-share information are present. This							
14.		is when the data log should be addressed. Whenever a cost-share payment is made, the RCWP program assis-							
15.		tant can use the data log to document cost-share practices. When annual status reviews are performed, SCS							
16.		technicians can use the data log to record noncost-share practices. This data log would be easily accessible at							
17.		any point during the project. At the end of the project, all of the information regarding all of the BMPs is in one							
18.		place. The data can be entered into a computer at any time and sorted accordingly.							
19.									
20.									
21.									
22.									
23.									
24.									

Data Log Format: Technical and Cost-share Data Recorded by BMP Item.

	INSTALLATION COSTS	COST-SHARE	ACRES SERVED	UNITS APPLIED	*MISC. UNITS REPORTED	SOIL LOSS SAVINGS (T/ACRE)	WATER SAVED (AC.-FT.)
1.							
2.		**NOTE:**					
3.		All columns are not applicable at every practice. The purpose of the data log is to record ALL of the relevant					
4.		data for each practice installed or implemented. Because it is difficult to know what data will be pertinent a					
5.		decade from now, it will be necessary to record all available information regarding each practice. If data other					
6.		than that noted in the format are available, applicable columns should be added to this two-page format and					
7.		the data recorded. All practices must be entered in the data log as they are completed. This includes overlap-					
8.		ping data (i.e., two or more practices completed in the same field). Many situations will occur: (1) acres					
9.		served may be less than acres in the field; (2) a practice may serve several fields; and (3) several BMPs may					
10.		serve the same field. Record all data pertaining to every BMP.					
11.							
12.							
13.							
14.							
15.							
16.							
17.							
18.		* Misc. Units Reported are units of interest that are reported, such as the number of trees for tree planting,					
19.		cubic yards in regard to structures, and so on. Misc. Units Reported are not the "Units Applied" data that are					
20.		officially reported by the Soil Conservation Service technicians on CRES forms.					
21.							
22.							

Problems and Conflicts Associated with the Administration of the Long Pine, Nebraska, RCWP Project

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ABSTRACT

This presentation addresses problems associated with the administration of the Long Pine Rural Clean Water Program project in Nebraska. On the local level, administration was hampered by staff turnover, burnout, leadership problems, and personal conflicts. A review of those problems discusses how they were overcome to result in a successful project and provides suggestions for improving local administration of projects. Finally, this presentation focuses on problems between the State and local coordinating committees that led to three years of little or no communication, examines the possible causes, and gives ideas for avoiding these problems.

The Long Pine Creek watershed located in north central Nebraska includes Long Pine Creek and three major tributaries, Bone Creek, Willow Creek, and Sand Draw. According to the Nebraska Game and Parks Commission, Long Pine Creek is the longest (26 miles) self-sustaining trout stream in Nebraska. Anglers who travel from all parts of the State in search of the brown and rainbow trout in this coldwater stream are having a positive impact on the area's economy.

The focus of the Long Pine Rural Clean Water Program (RCWP) project was to reduce the amount of agricultural contaminants and sediment being introduced into Long Pine Creek because both these nonpoint sources affected the stream's ability to sustain trout fisheries. In addition to its recreational benefits, Long Pine Creek is one of the few rapid-flowing, coldwater streams in Nebraska, which makes its watershed an even more important resource for the entire State.

Like other RCWP projects throughout the United States, the Long Pine RCWP project was administered locally by a coordinating committee that was responsible to the State coordinating committee (see Fig. 2). This presentation focuses on the local administration of the project, the agencies involved, and how they worked together, and it outlines successes and failures of this arrangement. Although all RCWP projects are unique, the lessons we learned in Nebraska may be of value to future water quality projects.

As manager of the Middle Niobrara Natural Resources District, I was a member of the local coordinating committee. Because I became involved in the project halfway through the 10-year process, I could observe the administration of the Long Pine project from a different perspective than members who had initiated the effort. Conversations with committee members as well as reviews of meeting minutes and letters have led me to some strong conclusions about the successes and failures associated with the project (other members who worked on the project during the same five years have similar conclusions). However, problems or failures associated

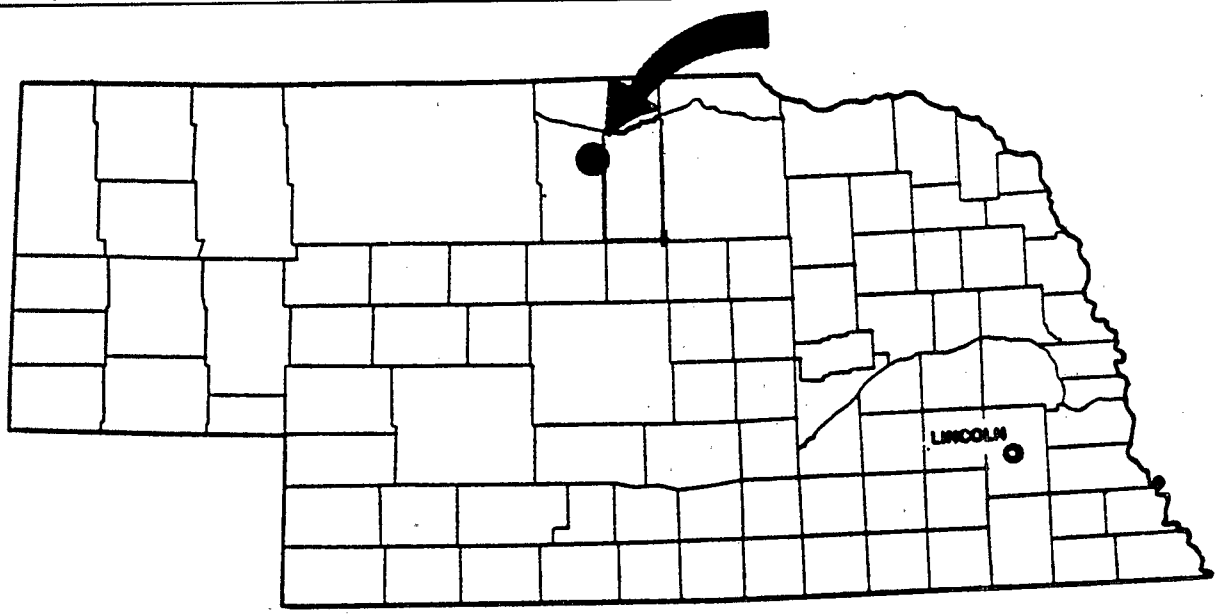

Figure 1.—Location of Long Pine Creek RCWP project in Nebraska.

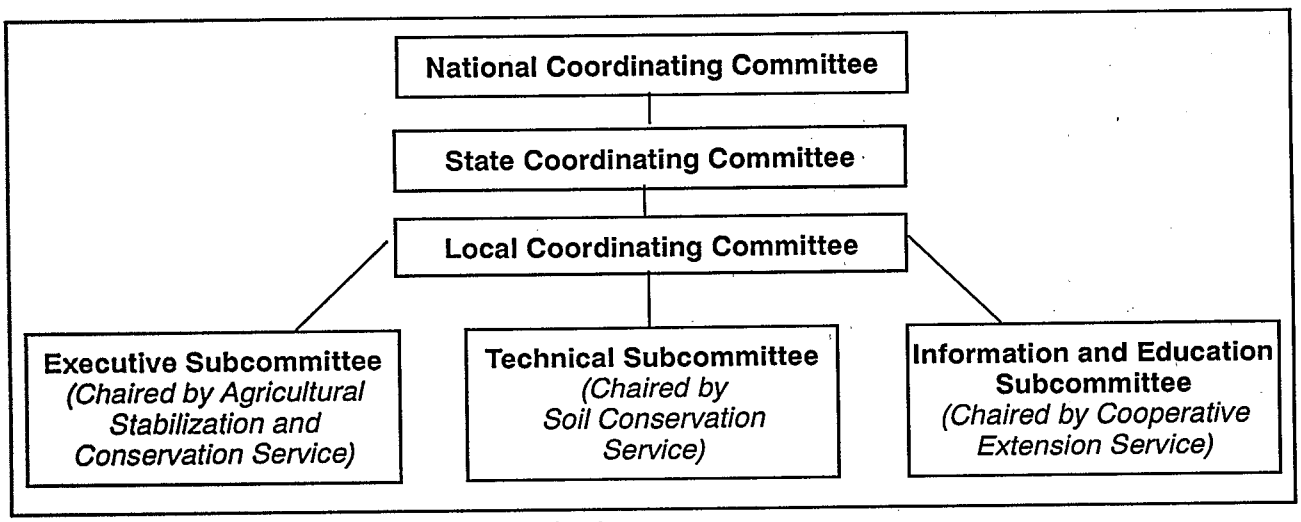

Figure 2.—Long Pine Creek RCWP management structure.

with the Long Pine project should not overshadow the program's success and the efforts of the members of the local coordinating committee. In general, conditions in the Long Pine Creek watershed have improved over the last 10 years, and knowledge developed through the RCWP should have a positive effect on this resource in the future.

It would be impossible to put together a perfect project. Considering the number of people involved, the Long Pine Creek project probably fared quite well. For the Long Pine project, the problems associated with local level administration fell into four major areas:

1. Declining interest and attendance at local coordinating committee meetings,
2. Inadequate planning and goal setting,
3. Communication problems with the State coordinating committee, and
4. Frequent Soil Conservation Service staff turnover.

Declining Interest and Attendance at Local Coordinating Committee Meetings

The Long Pine Creek RCWP project involved a total of 16 agencies and groups at the local level. Key agencies included the Agricultural Stabilization and Conservation Service, Soil Conservation Service,

Cooperative Extension Service, Nebraska Game and Parks Commission, Nebraska Department of Environmental Control, and the Middle Niobrara Natural Resources District. Several other agencies and groups were also part of the local committee, among them the Brown County Board, Ainsworth Irrigation District, the Long Pine Landowners Association, and North Central Research Conservation and Development (see Fig. 3). Generally, communication between local agencies was acceptable, and problems could usually be worked out over a doughnut and cup of coffee. However, it was difficult to keep all those agencies and groups focused on the administration of the project. Reviews of the minutes indicate that, after five or six years, several participants began to attend infrequently or no longer took part in the meetings.

AGENCY	LEVEL
Agricultural Stabilization and Conservation Services	Federal
Soil Conservation Service	Federal
Middle Niobrara Natural Resources District	Local
Cooperative Extension Service	State/Local
North Central Research Conservation and Development	Federal
Game and Parks Commission	State
Ainsworth Irrigation District	Local
Brown County Board	Local
Nebraska Department of Environmental Control	State
Nebraska Forest Service	State
Long Pine Landowners Association	Local non-government
Fertilizer representative	Local non-government
Farmers Home Administration	Federal
U.S. Environmental Protection Agency	Federal
Agricultural Research Service	Federal
Economic Research Service	Federal

Figure 3.—Members of the Long Pine RCWP local coordinating committee.

From 1984 through 1986, meeting attendance averaged 15 persons and 39 local coordinating committee meetings were held; 19 meetings (49 percent) were attended by 15 or more people, and only one meeting was attended by less than 10. Compare these figures to 1989 through 1991, when 25 meetings took place and the average attendance dropped to 10 participants. Even more dramatic, during those three years, only three meetings drew more than 12 people and 13 involved less than 10 participants. The minutes show that attendees represented the key program agencies: Soil Conservation Service, Agricultural Stabilization and Conservation Service, Cooperative Extension Service, Middle Niobrara Natural Resources District, and the Game and Parks Commission. Other members became uninterested and frequently failed to attend. Several factors led to this drop in attendance.

■ **Loss of enthusiasm for the project.** It is not uncommon for any effort to generate initial interest that fades, leaving a small group of devoted members who are burdened with the task of seeing the project through. In the early 1980s, enthusiasm ran high. As the years passed, interest declined and attendance at meetings suffered.

■ **Lack of accomplishment at local meetings.** Many people (particularly those who value their time) tend to get very frustrated at meetings that accomplish nothing. As this project moved into its middle stages, it became obvious that several goals would not be met. Some members had pet projects that did not progress at what they considered an appropriate pace. Many local meetings turned into ax-grinding sessions, accomplishing little. Some members believed that the process had failed and lost interest in the meetings; others who were tired of hearing the same gripes hashed and rehashed became infrequent participants.

■ **Not enough direct involvement with the project administration.** Several of the original members (Nebraska Forest Service, fertilizer representative, Farmers Home Administration, and the Agricultural Research and Economic Research Service) were essentially on the local committee to provide expertise. Because the need for their advice was infrequent, these representatives may not have felt part of the project administration. At any rate, they soon took an inactive role in the project.

Proposed Solutions

Limit the Size of the Local Coordinating Committee

Public boards and committees generally work best if their size is limited. Much (or more) work can be accomplished if the members are strong, dedicated individuals. For RCWP projects, the local coordinating committee should be limited to 7 to 11 members to provide better local administration. Members should include representatives of key agencies, such as the Agricultural Stabilization and Conservation Service, Soil Conservation Service, local Research Conservation and Development, Cooperative Extension Service, the conservation district, and Game and Parks — plus a landowner. Two or three additional members could be considered if appropriate (see Fig. 4).

Other interested parties should be incorporated into the subcommittee structure rather than the local coordinating committee. Each subcommittee (assuming a limited number) might be allowed to have a representative on the local coordinating committee.

- Agricultural Stabilization and Conservation Service
- Soil Conservation Service
- Research Conservation and Development
- Conservation District
- Cooperative Extension Service
- State Fish and Game Representative
- Landowner Representative
- Optional Seat
- Optional Seat

Figure 4.—Proposed membership of a local coordinating committee.

Encourage Strong Local Coordinating Committee Leadership

The success of any committee is dependent on its leadership. A strong chairperson should be designated to ensure that meetings accomplish their intended goal. The chairperson should be responsible not only for chairing the meeting but also for establishing the meeting agenda, properly notifying members, providing copies of appropriate documents, and distributing meeting minutes. For the purpose of the Rural Clean Water Program, it might prove advantageous to use the same chairperson for a number of years.

Hold Occasional "Fun" Events to Maintain Interest

Nothing will discourage a committee more than month after month of long, dry meetings. Our experience with the Long Pine Project showed that meetings followed by tours tended to attract the largest audience. Nothing will invigorate a committee like seeing the fruits of its labor. Many times, tours were preceded by before and after slides of problems tackled by the project. The tours not only gave an overview of the project, they helped bond members of the committee. Other like events might include visiting with project landowners, assisting with BMP installation, or scheduling a dinner or barbecue in conjunction with a meeting.

Inadequate Planning and Goal Setting

Many of the local coordinating committee members clearly did not understand the purpose of the Rural Clean Water Program. Some members were simply uneducated about RCWP; others were unwilling to accept the purpose of the program. Some members viewed acceptance of the Long Pine Creek watershed into the nationwide Rural Clean Water Program as a savior for the watershed's ills. These people visualized RCWP's access to funding as a way to construct projects that had been talked about for years but never built. A few of these projects failed to fit into the scope of the Rural Clean Water Program, and when the State coordinating committee turned them down, supporters became defensive and blamed the State for not understanding the situation. As the Long Pine Creek project winds down, some members still harbor hard feelings over issues that were never settled, and others view the program as a failure even though numerous accomplishments were realized.

The importance of following a well-thought-out plan was overlooked by the Long Pine local coordinating committee, and the plan developed at the beginning of the project was not used effectively. Old ideas were rehashed, stalling meeting productivity. Except for minor attention given to the plan during the writing of the annual report, the local coordinating committee as a whole never formally reviewed it to discuss progress and make revisions. Members who joined the local coordinating committee in mid-project had little idea as to the project's direction and were forced to set their own path, leading some agencies in different directions.

Proposed Solutions

Make Sure Local Members Understand the Project's Purpose

The ground rules for what the project can and cannot accomplish should be established at the start. Time should be spent explaining why specific projects may not fit into the overall program. All those involved should be allowed to express their opinion on the purpose of the project so that everyone understands the interests of others. If questions occur regarding the purpose of the project, answers should be sought from appropriate agencies. The purpose and goals of the project should be periodically reviewed not only to benefit

new members but to serve as a reminder for veteran members.

Develop Comprehensive Project Plans and Hold Annual Review Sessions

At the outset of the project, all agencies and groups should meet and develop a plan that includes all the perceived needs in the project area. Ideas for establishing management practices as well as larger projects should be considered. Needs should be prioritized and timetables developed for their completion. At that time, projects and programs that would benefit the overall project and meet the established guidelines should be included as part of the plan. If a specific need does not fit within the scope of the overall project, evaluate other methods outside the RCWP to address it, including agencies that could be responsible as well as potential sources of funding.

Once a plan is developed and agreed to, all efforts should focus on completing elements of the plan as outlined. A comprehensive plan review should be held annually. Elements of the plan that have been completed should be highlighted. If a specific project is no longer a priority or will not be completed, it should be dropped from the overall plan. If an item is dropped from the plan, it should not be discussed at meetings.

Communication Problems with the State Coordinating Committee

During the Long Pine Creek RCWP project, communication broke down between the State and local coordinating committees. Early in the 10-year effort, a number of what the local coordinating committee felt were key projects were not supported by the State coordinating committee. This disagreement became a catalyst for communication problems that lasted throughout the project as members of the local coordinating committee blamed the State coordinating committee and the agencies it represented for the demise of these projects. Communication totally broke down for several years, when no meetings were held between the two groups. However, better communication was established between the two groups during the final years of the project.

Much of the problem could be blamed on simple geography. The project area was located 280 miles from Lincoln, Nebraska, where the State coordinating committee resided. Most communication had to be done by mail or telephone because State committee members could not attend local meetings regularly. As a result, the members of the State coordinating committee seemed to have a hard time getting a feel for what was occurring at the project level. However, the reverse was also true. Decisions were made by the State coordinating committee that members of the local committee did not understand or agree with, which made accomplishing the project's goals very difficult.

Proposed Solutions

Form a Strong Bond Between the State Coordinating and Local Coordinating Committees

When the project is established, the State and local coordinating committees should cooperate to set its scope and goals. By working together, each entity will get a better understanding for the other's concerns. A strong effort should be made to include the State coordinating committee in the initial planning process. The State coordinating committee should be included in as many project tours, BMP installations, and social functions as possible.

Encourage Greater Participation By the State Coordinating Committee

The State coordinating committee should actively participate at local committee meetings. In situations where distance is a major factor (as in Nebraska), one State committee member should be appointed to attend local committee meetings on a rotating basis. Regular attendance would give local members the assurance that interest exists on the State level and a feeling that committee concerns are being heard. In turn, State committee members would have a better feel for the attitudes on the local level. State coordinating committee members could indicate which BMPs, projects, or ideas they think inappropriate, potentially avoiding conflicts between the two committees.

Include More Technical Staff

Many members of the Long Pine Creek State coordinating committee were heads of State and Federal agencies (see Fig. 5) and generally did not have the time to work with local members administering the program. To form a stronger bond between the State and local coordinating committees, include technical staff from State and Federal agencies who may have

more time to work directly with the project on the State coordinating committee, where their technical expertise could be an asset. Or have the State coordinating committee establish appropriate subcommittees that would include technical staff from the State and Federal agencies who could advise and make recommendations about the project. Members of the subcommittee would then serve as a direct link to the local coordinating committee, passing ideas and advice from the State to the local level (and vice versa).

AGENCY	LEVEL
Agricultural Stabilization and Conservation Service	Federal
Soil Conservation Service	Federal
Game and Parks Commission	State
Nebraska Department of Environmental Control	State
Cooperative Extension	State
Nebraska Natural Resources Commission	Local
Farmers Home Administration	Federal
U.S. Environmental Protection Agency	Federal

Figure 5.—Present membership of the Long Pine State Coordinating Committee.

Frequent Soil Conservation Staff Turnover

Two agencies were involved with most of the one-on-one contact with the individual cooperators: the Agricultural Stabilization and Conservation Service and the Soil Conservation Service. The Soil Conservation Service played an important role in the project as it provided almost all of the technical assistance, a role that required a high level of one-on-one contact with landowners, who needed to trust the technician they were working with. Each Soil Conservation Service technician also had to understand a cooperator's operation before suggesting ideas and developing contracts. Unfortunately, turnover among soil conservationists working on the RCWP project was high. (It was not uncommon for soil conservationists to transfer after one or two years of working on the project.) The continuity of the RCWP program suffered greatly, and many of the cooperators never became comfortable with the program or developed trust in Soil Conservation Service staff.

Because the Soil Conservation Service staff assigned to work on RCWP were usually at GS-7 or GS-9 levels, project membership became a stepping-stone position rather than one that was (at least) semipermanent. Even though soil conservationists enjoyed their work with the program, if they wanted to improve their status and salary, they were forced to transfer. When putting together the 10-year report for the project, members found that this turnover rate not only affected relationships with cooperators but project administration as well.

Proposed Solutions

Require a Full-time Project Coordinator

Any project that involves over $1 million and requires 10 years to complete should employ a full-time project coordinator. The position should be established at a GS-11 level to maintain uniformity over the life of the project and reduce turnover. It would also make one person responsible for overseeing the entire project rather than many people with other, outside responsibilities. The project coordinator would help coordinate activities between agencies and assist cooperators. In addition, the project coordinator could serve as the local coordinating committee chairperson (or assist the chairperson).

Designate Agency Staff to the RCWP

All agencies or groups that provide staff support to the effort should designate the person(s) that will be working on the project (particularly the Agricultural Stabilization and Conservation and Soil Conservation services because they provide the bulk of the staff time). Too many people provided technical assistance over the life of the Long Pine Creek RCWP project. By the end of the project, local soil conservationists did not know how much time (if any) they should be spending on the program. Agencies providing staff assistance need to complete an annual workload analysis to assign staff members to the project and determine how much time they should devote to the effort.

Use More State and Local Resources

Generally, State and local agencies have greater flexibility than Federal agencies. By using the conservation districts, Cooperative Extension Service, Game and Parks, and other local groups, some turnover problems could be reduced. As an example, Federal funds could be passed to the local agencies to supply technical assistance and project administration as is commonly and successfully done with other Federal programs (319, Clean Lakes, Dingle-Johnson). This option would further address personnel turnover because agencies, such as the

local conservation district or Cooperative Extension, tend to have fewer personnel changes.

To support this option, I reviewed a 1989 survey that documented statistics showing that 141 full-time employees averaged 8.4 years with Nebraska's 23 locally governed natural resources districts. In some cases, local groups or agencies may be able to match Federal dollars with local funds or in-kind services that could further improve the program and perhaps allow incorporation of projects outside the scope of RCWP into the program.

Conclusions

The Rural Clean Water Program provides a unique experience for Federal, State, and local agencies to work together for a common goal. However, as with any program involving multiple agencies, problems can occur. One of the best aspects of the RCWP concept is that it was designed to be a learning experience. A final judgment on the contributions of an RCWP project cannot be made if problems, mistakes, and weaknesses are not recognized along with the successes.

We had several recognizable problems when administering the Long Pine Creek project, including size of the local coordinating committee, failure to communicate the purpose of the project to local coordinating committee members, inadequate use of an overall plan, communication problems with the State coordinating committee, and excessive staff turnover. Closer evaluation of these problems reveals one commonality — a failure to communicate. Improved communication would have had the strongest positive impact on the Long Pine project.

In addition to the need for better communication what else was learned? If the clock could be turned back to 1980 and we were to start the process over, I would offer the following key suggestions for better RCWP project administration:

1. Keep the local coordinating committee membership manageable. Seven to 11 members is an appropriate size for this type of project.
2. Make sure all committee members fully understand the purpose and goals of the project.
3. Develop a solid, workable plan and review it annually.
4. Communicate with the State coordinating committee and keep it an active part of the project.
5. Employ a full-time project coordinator.

Had we followed these suggestions, the Long Pine Creek RCWP project would have achieved even greater success. The RCWP experience provided a great opportunity to put into practice what many already knew — that cooperation and good communication is the best formula for success. Let us hope that future water quality programs will use what was learned from the RCWP and incorporate it into their efforts. If they fail to do so, then much of what was learned during the past 10 years will be wasted.

RCWP—The Federal Perspective

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ABSTRACT

The Rural Clean Water Program, like any experimental program, has had some false starts and marginal results, but it has been a success from a number of viewpoints. It influenced policymakers within the U.S. Department of Agriculture (USDA) to make water quality the second most important priority in policy set through the Resource Conservation Act process, exceeded only by erosion control, the USDA's initial mission. The continued debate over how to resolve water quality problems brought about policy changes in other USDA programs and led to the development of tools to address nutrient and pesticide management. The resulting partnerships provided a consistent framework for developing proposals for congressional consideration. The program's uninterrupted 10-year funding ensured results that have helped develop new nonpoint source programs. The President's Water Quality Initiative (which came on-line in 1990) benefited particularly from the interagency coordination that developed during the program. This paper examines how the program came into being, the original expectations, how it has worked to meet those expectations, and what has been learned at the Federal level.

Section 208 of the 1972 Clean Water Act, which called for areawide wastewater planning and management, included language that, for the first time, addressed agricultural sources of pollution. Section 208(j)—added by the 1977 amendments—authorized $800 million over four years for implementation of agricultural elements in State and local nonpoint source programs. (No implementation funding was included in the original section 208.)

Initially, implementation was assigned to the Soil Conservation Service (SCS), which completed an environmental impact statement and regulations in 1978. However, the USDA's Agricultural Stabilization and Conservation Service (ASCS) had traditionally administered money or grant programs. The 1980

USDA appropriation bill included a provision for an experimental Rural Clean Water Program (RCWP) to be administered by ASCS in lieu of funding section 208(j). The first year, $50 million was provided; $20 million was added in 1981, making a total of $70 million for the experimental RCWP. This amount was later reduced to $64 million as part of a Federal budget reduction measure.

Since SCS had developed regulations and held four national meetings to explain its program under 208(j), there was initial confusion in the field with the shift to the program funded under the Appropriation Bill and administered by ASCS. However, when funding was made available, the agencies quickly organized to set up a committee structure to manage the experimental program, develop new guidance for the field, and select projects. Memoranda of understanding were developed among the agencies to define specific roles and transfer funds.

These initial agreements within USDA and with the U.S. Environmental Protection Agency (EPA) have continued to this day. ASCS has been the administering agency for new cost-share programs, with funds transferred directly to SCS and the Forest Service for technical assistance, to the Cooperative Extension Service for educational assistance, and to the Economic Research Service for monitoring and evaluations.

The first challenge was to design a cooperative project selection process and select appropriate projects from some 75 applications. The projects were rated and ranked by each of the participating agencies; competition was stiff and congressional interest high. The National Coordination Committee, made up of heads of the participating agencies, took its task seriously and debated every project recommended for funding. This agency interaction translated into positive support for the program and made coordination easier. The second challenge was to develop an evaluation program including selecting projects that would receive additional resources for formal evaluations. Initially, 10 percent of the resources were reserved for five projects chosen to represent a range of agricultural water quality problems. One project in Kansas was terminated after a review confirmed that a water quality problem did not exist. However, contracts existing at the time were honored. Table 1 lists the projects and funding.

Program Expectations

An earlier effort, the Model Implementation Program, taught the agencies several important lessons—but especially that the imperial "we" from Washington, D.C., does not sell at the local level. Consequently, RCWP, which was designed to work directly with the project managers at the field level. The RCWP was a natural fit for EPA's nonpoint source program as an expansion of the existing section 208 nonpoint source emphasis. EPA expected to initiate needed implementation and testing of nonpoint source controls, while USDA hoped to gain more experience with water quality projects through increasing responsibility and to show that conservation practices on agricultural lands produce positive water quality benefits.

In general, USDA expected that the RCWP would play a major role in water quality as it related to impacts from agricultural nonpoint sources. Becoming an active manager in protecting water quality from agricultural nonpoint source pollution was logical and necessary for effective use of available resources. Thus, water quality managers in EPA, USDA, and the States used the RCWP to institutionalize cooperation for implementation projects focused on priority watersheds. An increasing role for USDA in water quality was initiated by the following objectives, which were spelled out in the 1980 regulations for RCWP:

> *The program provides long-term financial and technical assistance to owners and operators having control of agricultural land. The purpose of this assistance is to install and maintain best management practices to control agricultural nonpoint source pollution for improved water quality.*

Congress intended appropriated funds to be used in geographic areas with critical water quality problems. Only the highest priority projects would be funded from the applications submitted to the Secretary of Agriculture and approved in consultation with the EPA's Administrator.

This was the first specific inclusion of protection and/or maintenance of water quality as a USDA objective. Early efforts to coordinate USDA activities under the section 208 water quality management program were frustrated; the department was unable to fund participation because water quality was not a department mission. Funds are now appropriated directly, and USDA places more emphasis on water quality.

The stated objectives of the RCWP were to

- achieve improved water quality in the project area in the most cost-effective manner possible in keeping with the provision of adequate supplies of food, fiber, and a quality environment,

Table 1.—Rural Clean Water Program projects.

PROJECT	LOCATION	ESTIMATED COST[1]	STATUS
Lake Tholocco	Alabama	$1,850,827	Implemented in 1980; 80% of its critical acres and 95% of its best management practice (BMP) funds are under contract.
Appoquinimink	Delaware	972,319	Implemented in 1980; 87% of its critical acres and 99% of its BMP are under contract.
Taylor Creek-Nubbin Slough/ Lower Kissimmee River	Florida	2,982,111	Nubbin Slough project was implemented in 1981; 87% of its critical acres and 98% of its BMP funds are under contract. Lower Kissimmee River was added in 1988; 58% of its critical acres and 62% of its BMP funds are under contract.
Rock Creek[2]	Idaho	5,328,108	Implemented in 1980; 73% of its critical acres and 90% of its BMP funds are under contract.
Highland Silver Lake[2]	Illinois	3,974,849	Implemented in 1980; 82% of its critical acres and 94% of its BMP funds are under contract.
Prairie Rose Lake	Iowa	732,607	Implemented in 1980; 97% of its critical acres and 84% of its BMP funds are under contract.
Upper Wakarusa	Kansas	2,230,728	Implemented in 1980; terminated 1982.
Reelfoot Lake	Kentucky	932,186	Implemented in 1980; 64% of its critical acres and 90% of its BMP funds are under contract.
Bonne Idee	Louisiana	4,354,188	Implemented in 1980; 75% of its critical acres and 88% of its BMP funds are under contract.
Double Pipe Creek	Maryland	4,993,057	Implemented in 1980; 100% of its critical acres and 88% of its BMP funds are under contract.
Westport River	Massachusetts	733,924	Implemented in 1981; 67% of its critical acres and 88% of its BMP funds are under contract.
Saline Valley	Michigan	2,727,997	Implemented in 1980; 32% of its critical acres and 98% of its BMP funds are under contract.
Garvin Brook	Minnesota	2,525,100	Implemented in 1981; 42% of its critical acres and 100% of its BMP funds are under contract.
Long Pine Creek	Nebraska	2,384,711	Implemented in 1981; 79% of its critical acres and 77% of its BMP funds are under contract.
Tillamook Bay	Oregon	5,500,428	Implemented in 1981; 98% of its critical acres and 99% of its BMP funds are under contract.
Conestoga[2]	Pennsylvania	4,165,038	Implemented in 1981; 40% of its Headwaters critical acres and 84% of its BMP funds are under contract.
Oakwood-Lake Poinsett[2]	South Dakota	3,646,134	Implemented in 1981; 58% of its critical acres and 60% of its BMP funds are under contract.
Reelfoot Lake	Tennessee	3,934,774	Implemented in 1980; 58% of its critical acres and 99% of its BMP funds are under contract.
Snake Creek	Utah	463,223	Implemented in 1980; 100% of its critical acres and 100% of its BMP funds are under contract.
St. Albans Bay[2]	Vermont	5,179,120	Implemented in 1980; 75% of its critical acres and 99% of its BMP funds are under contract.
Nansemond-Chuckatuck	Virginia	2,116,131	Implemented in 1981; 75% of its critical acres and 92% of its BMP funds are under contract.
Lower Manitowoc	Wisconsin	2,270,619	Implemented in 1980; 57% of its critical acres and 88% of its BMP funds are under contract.
TOTAL:		$63,998,179	

[1] Includes funds for best management practices, information, and education, Federal and non-Federal technical assistance, and comprehensive monitoring and evaluation

[2] Comprehensive monitoring projects

- assist agricultural landowners and operators in reducing agricultural nonpoint source water pollutants and in improving water quality in rural areas to meet water quality standards or goals, and
- develop and test programs, policies, and procedures for the control of agricultural nonpoint source pollution.

Program Organization

To administer the program, a series of committees was established at the Federal, State, and local level. A National Rural Clean Water Coordination Committee, whose members were the administrators of the participating agencies, was set up to manage the overall program. Responsibility for administration of the program was delegated to ASCS and coordination of technical assistance was assigned to SCS.

State Rural Clean Water Coordinating committees were set up to assist the State ASCS committees, and local Rural Clean Water Coordinating committees were established at the project level to assist the county ASCS committees. All these committees were made up of agencies that have responsibility or interest in water quality. This structure encouraged and facilitated leadership from those managing the program and resulted in effective coordination among the three levels. Table 2 illustrates RCWP's administrative structure.

Previous experiences with water quality projects demonstrated the absolute need for water quality monitoring. A concerted effort was made to ensure water quality data would be collected, analyzed, and used to evaluate the activities' effectiveness. Five projects were designated for comprehensive monitoring, and State water quality agencies were generally funded through the Clean Water Act, section 208, to monitor the other projects.

To ensure that data evaluation would be a continuing effort, a project was established with North Carolina State University to provide guidance, technical assistance to projects, develop workshops and annual reports, and evaluate data to determine best management practice (BMP) effectiveness. The key elements for effective monitoring and evaluation are identified in Table 3.

This administrative/evaluation structure provided an opportunity to look at USDA's traditional conservation programs in an environmental/water quality context. Transitions are never easy, and the agencies were concerned about the change. SCS employees tended to think only in terms of erosion—not water quality; Federal cost-share dollars were viewed as entitlements to be used on a first-come, first-served basis, rather than targeted at the highest water quality priorities; and least-cost alternatives were not always developed, nor was innovation pursued at all levels.

At the national level, a major component of managing RCWP was establishing a process (a team) to review projects regularly to determine how

Table 2.—RCWP's administrative structure.

	Secretary of Agriculture administers in consultation with EPA
	• Secretary delegates responsibility for administration to ASCS. • Approvals made through the ASCS system
The Rural Clean Water Program is managed through the following committees:	• Secretary delegates the coordination of technical assistance to SCS
National Rural Clean Water Coordinating Committee ⟷	Assists the administrator of ASCS in managing the program
• Policy Committee • Technical Committee • Program Review Teams	Advises the Coordinating Committee Advises the Policy, Technical Committees Assists the State RCWP Coordinating Committee
↕	
State Rural Clean Water Coordinating Committee ⟷	Assists the State ASC Committee
↕	
Local Rural Clean Water Coordinating Committee ⟷	Assists the County ASCS Committee

Note: Committees made up of representatives from USDA agencies with programs or interest in water quality to include ASCS, SCS, FmHA, ES, FS, ARS, EPA, and (as appropriate), water quality agencies at State and local levels as well as farmers.

Table 3.—RCWP's monitoring and evaluation structure.

RCWP projects will be monitored in sufficient detail to determine BMP application progress and document water quality improvement trends using the following elements:

- description of WQ monitoring
- schedule
- parameters
- analytical methods
- existing data and trends
- funding from State/local (no RCWP funds allowed)

Selected projects for comprehensive monitoring (joint USDA/EPA) use the following elements:

- objectives — purpose and scope
- strategy to identify changes in WQ
- socioeconomic impacts and cost/benefit on landowners
- institutional aspects for participating agencies
- educational aspects for individual landowners
- quality assurance
- data storage
- reporting to NCC
- funding

Evaluation of the RCWP projects will be carried out annually.

well objectives were being met and whether midcourse corrections were needed—and to report successes or problems. Farmer participation in many of these project reviews was enthusiastic and direct. Problems were discussed at these open meetings (often to the chagrin of USDA and EPA field personnel) and resolved: new practices were authorized, policies were developed or revised, and partnerships were formed where adversarial relationships had existed.

The review team concept focused decisionmaking and provided a constancy that had not existed in earlier projects. Even in cases where national appeals were made, review team decisions were upheld. The review teams developed a "can-do" attitude and made changes to ensure that each water quality problem could be fully addressed.

New practices were instituted as a result of the review team visits. For example,

- portable pumps were cost-shared to allow recycling of wastewater for prewashing cows before milking, reducing the need to pump groundwater,
- animal waste spreading equipment was cost-shared where multiple-use agreements were in place,
- portable shade structures for cows were approved to allow animal exclusion from watercourses,
- a hog operation was relocated from a lake shore,
- new furrow irrigation techniques developed in Idaho are now cost-shared in other approved States, and
- nutrient and pest management practices were developed and implemented. (This last effort became the basis for national standards and specifications for BMPs put in place in 1990.)

National workshops were effective ways to exchange information among projects and manage their direction. Generally, the workshops resulted in

- a tightly knit program,
- advances in statistical approaches to analyzing nonpoint source data,
- advances in nonpoint source modeling approaches,
- improvements in reporting land treatment activities,
- increased understanding of the need for groundwater monitoring, and
- improved nonpoint source monitoring protocols.

Annual reports have provided standard summaries of RCWP and other agricultural nonpoint source projects, statistical analyses of data from selected projects, and analyses of lessons learned from the RCWP.

As USDA conservation programs are broadened to address water quality, the RCWP experience of innovatively changing traditional approaches to keep the focus on water quality must be emphasized. The pendulum must not swing back to the old traditional soil erosion conservation programs—such as the conservation compliance provision of the Food Security Act of 1985—because these programs do not fully address water quality.

Project Selection

The agencies made a concerted effort to ensure that the RCWP would not repeat past mistakes. First, they decided that RCWP should not reinvent programs but build on existing ones. To avoid a new round of planning, a proposed RCWP project had to be in an area where a critical water quality problem was identified during the section 208 planning process and be consistent with the section 208 water quality management plan. RCWP would implement a select group of projects to demonstrate BMP effectiveness in controlling agricultural nonpoint source pollution—not an easy task.

Projects had to

- have strong institutional and local support,
- protect identified beneficial uses,
- deal with a critical problem,
- correct point sources,
- have benefits proportional to the investment, and
- be of manageable size.

Table 4 specifies the criteria for project eligibility and selection. A series of regional workshops were held to develop applications. Additional workshops were held for selected projects to explain the work plan requirements. About 800 agency professionals from USDA and EPA attended these nationwide workshops.

Table 4.—RCWP project selection.

ELIGIBILITY
Priority water quality areas identified under 208 WQM; i.e., hydrologic boundaries with water quality problems related to agricultural nonpoint source pollutants (only critical areas and sources of pollutants significantly contributing to water quality problems).
CRITERIA
• Severity of the problems – Designated uses affected – Miles or acres of waterbody affected • Public benefits – Population affected – Human health • Feasibility – Size – Cost per participant – Cost-effectiveness of BMPs • Suitability – As an experiment/test of programs – Potential for monitoring (baseline data/evaluation) • State/local – Funding – Commitment of leadership • Contribution to national water quality goals • Participant's water quality plan – Developed with assistance from SCS – BMPs to reduce agricultural chemicals – Treatment of all critical areas – Compliance with all applicable laws – Time schedule

National Level Results

The successes and failures of the RCWP program revealed several factors that differed from the national perspective.

Resources

At the outset, the ASCS set aside full funding for each project plus contingencies—technical assistance, other agency participation, and funding for an outside group to evaluate the effectiveness of selected BMPs. Such assured funding for the life of the project allowed projects to plan and carry out activities without the uncertainty of dependence on annual budgets or appropriations. More importantly, it allowed the projects to operate for 10 years — long enough to look at the water quality impact of changing farm management practices — and also allowed a consistent level of program support throughout this period while other programs were being reduced.

Structure for Managing

While considerable guidance was given at the national level to get the process started, the projects were completely developed on the grass roots level, with organizational support through a series of local committees. Local institutional support came principally from agricultural interest groups, which created a strong institutional base and ensured a consistency in approach and staffing. Where this did not happen, projects did not meet all their objectives.

Staffing

At the national level over the 10 years of this project, a fairly consistent group of people have been directly involved or in the background. ASCS experienced the most changes but it has retained some staff who were part of the initial process. This consistency adds stability instead of unsettling changes of direction to fit new personalities. RCWP has a relatively low profile because top management are not continuously involved. Delegation of responsibility has been a major factor in the success of the program.

Communication

The participants have done an excellent job in moving information from the national to the field level—and back. National workshops have allowed excellent exchange of information. Newsletters and directives facilitated communications among the projects and provided both support and interaction.

Evaluation

From the beginning, agencies recognized a need for an independent group to carry out continuing evaluation of projects and to document what did and did not work. The North Carolina Agricultural Extension Service was selected to carry out this function because it could devote full time and attention to RCWP. The ensuing series of workshops, annual reports, on-site evaluations, and technical assistance

have been summarized in an EPA document, "Lessons Learned." EPA and USDA have also tapped this group's expertise for help with other nonpoint source issues.

In summary, the program benefited from several factors: adequate resources, stability of staff, better than usual communication, and a strong evaluation component.

How RCWP Changed Some State Programs

■ In Alabama, the RCWP provided the impetus for one county to deal with severe erosion on road banks and implement conservation measures on land owned by the Department of Defense. In addition, RCWP was the model for the new State cost-share program.

■ In Oregon, a computer model was developed to explore management options for animal waste management and coliform bacteria in Tillamook Bay. The model approach was expanded to other estuarine drainage areas, and RCWP project staff provided training.

■ In Vermont, local staff developed new bacterial tracing methods and computer models to determine management options for controlling barnyard runoff.

■ In Iowa, the RCWP triggered complete restoration of Prairie Rose Lake. Without the program, the State might never have undertaken the fisheries restoration project.

■ In South Dakota, the RCWP was responsible for developing both groundwater and lake management expertise in the State.

■ In Florida, the success of the RCWP project prompted additional Federal and State funding to address the problems of Lake Okeechobee.

What RCWP Learned from States

■ The Pennsylvania RCWP project showed that some farmers are very reluctant to sign contracts with the Federal Government and that other mechanisms may be needed to accomplish program goals.

■ The Idaho RCWP project demonstrated the importance of identifying the actual problem. Agricultural BMPs applied to farmland are (not surprisingly) ineffective in dealing with unrelated streambank erosion problems.

■ The Oregon RCWP project discovered that the possibility of a lawsuit or the loss of a market for farm products stimulated interest in applying BMPs.

■ The Kansas RCWP project illustrated the necessity of field reviews and the importance of cooperative planning in developing project applications and operating plans.

■ Several projects demonstrated the importance of face-to-face interactions with the project review team, the local coordinating committee, and the State coordination committee as well as the importance of a "can-do" attitude and the need for imagination and program flexibility.

■ USDA has also learned where the Food and Drug Administration bans shellfish harvesting and what should be done—beyond land treatment—to get these areas reopened, knowledge that has increased USDA's confidence when operating in estuarine areas.

The Future

The program name may change but the concept will live on. As this paper was written section 208(j) (the original Rural Clean Water Program) has become part of the 1992 reauthorizing bill for the Clean Water Act (S-1081). The initial funding level would provide $200 million to SCS through the section 304(k) transfer mechanism and $400 million to EPA for grants to States. S-1081 leaves the program specifics up to USDA and EPA.

EPA and the States are stressing a watershed approach to comprehensively abate point and nonpoint pollution sources. The lessons learned from RCWP about implementing targeted watershed solutions will continue to influence overall control and management of agricultural and other nonpoint sources.

Thinking About a Postproject Evaluation — Start NOW!

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ABSTRACT

Evaluating water quality improvement projects on irrigated areas requires a complex and complete database that includes information on land use, best management practice (BMP) implementation, cropping patterns, irrigation system operations, and water quality information for the project area, including the nonparticipating lands. In surface irrigated areas, runoff and associated pollutants are returned to irrigation laterals and drains, which supply irrigation water to other users. This canal network is often highly complex and regulated differently by watermasters each year. The quality and quantity of runoff entering a natural stream from an irrigated watershed are very dependent on the operation of the canal network and irrigation systems, in addition to the land use.

Under the Rock Creek Rural Clean Water Program project, the U.S. Department of Agriculture (USDA) Soil Conservation Service tracked BMP implementation, and the Idaho Division of Environmental Quality monitored and tracked water quality. BMP cost data was collected by the USDA Agricultural Stabilization and Conservation Service. Planted crop data was collected by the local soil conservation districts. After 10 years, a great deal of information was available on planning, BMP implementation and installation, and water quality and cropping patterns. However, crucial data elements for a complete and rigorous postproject evaluation were lacking, including nonparticipant implementation, implementation and operational status after contract completion, cropping information by field and year, and canal network operation. This paper covers data elements that must be addressed at the inception and initial implementation of water quality and erosion control projects on irrigated areas for which a postproject evaluation is planned or even considered.

Because of point and nonpoint source pollution, Rock Creek in Twin Falls County, Idaho, has long been recognized as one of the most affected streams in Idaho. While most point source loads had been addressed and minimized by end of the 1970s, Rock Creek was still carrying high loads of sediment and nutrients from irrigated agricultural activities. In 1980, the stream was selected as one of the Rural Clean Water Program (RCWP) projects. Additionally, the project was selected to be one of five funded for comprehensive water quality monitoring and economic evaluation. At the end of the RCWP, the project was also chosen for a postproject evaluation.

A tributary to Snake River, Rock Creek is located almost entirely within Twin Falls County in south-central Idaho. The headwaters are located in the Cassia District of the Sawtooth National Forest at elevations of 2,133 meters (7,000 ft). Shortly after leaving the national forest, Rock Creek flows through the Twin Falls tract, an intensively farmed, irrigated area of 82,500 ha (204,000 acres) that has been farmed since 1907. The Rock Creek RCWP project watershed covers approximately 18,200 ha (45,000 acres) of irrigated pasture and cropland, rangeland, woodland, and urban lands (Sterling, 1983). The soils are highly productive but extremely erosive in the project area and lie on gently sloping plains. The climate is semiarid with annual precipitation averaging about 228 mm (9 inches) and a growing season of 120 days. Most precipitation occurs during the winter months. Because of low annual precipitation, all crops in the project area are irrigated (Yankey et al. 1991).

The predominant irrigation method is furrow irrigation. Irrigation water for the project area is

diverted from the Snake River near Milner, Idaho. Twin Falls Canal Company delivers irrigation water to and removes surface and subsurface runoff from the individual farms through a network of canals, laterals, and drains. When the irrigation tract was developed in the early 1900s, natural streams and drainage patterns were used to deliver irrigation water and carry away surface runoff. Recharge to the underlying groundwater caused the water table to rise over 80 feet in a 20- to 30-year period. The canal company and farmers installed gravity drainage systems to lower the water table. These systems discharge the subsurface drainage water to the delivery system's surface drains. The canal company uses runoff from higher farms to supply irrigation water to lower farms. From early April through mid-October, water is continuously supplied to farms.

Problem Statement

In performing the postproject evaluation, three major problem areas were encountered with BMP implementation, land use, and water quality data. A key element associated with each problem was the network of canals, laterals, and drains used to deliver the irrigation water and remove surface runoff and subsurface return flows. Another element was the agencies' definition of the hydrologic or treatment basins (subbasins). The subbasins delineated by the agencies were not based on hydrological features and should not have been referenced with the word "basin." Subbasin boundaries were established along property lines, not by topography. The water quality monitoring network was designed to document in-stream changes in water quality of Rock Creek and overall changes in water quality from subbasins and not within subbasins. The last element was the agencies' focus on data supporting their activities by subbasins.

Because land and water use data were not collected for fields in farms not under a current RCWP contract, evaluation of water quality improvements resulting from levels or types of BMP implementation was difficult for the postproject evaluation. The postproject evaluation question — what mixture of BMPs and implementation levels in a subbasin exhibits the most improvement in the quality of water leaving the basin — could not be adequately answered.

Irrigation System Network

The potential loads of nutrients and sediments being transported past a water quality monitoring station depend on their origin and the canal company's operation of the various laterals and drains. In the initial planning stages of the Rock Creek RCWP project, subbasins were delineated and prioritized for planning activities. These subbasins were identified with irrigation return flow drains entering Rock Creek, and monitoring stations were established along the drain. The monitoring stations were usually located near the drain's mouth, with one near the primary canal on a turnout or diversion. However, subbasins were not hydrologically formulated — property lines were the prime delineating features of the subbasin boundaries. Often, laterals or drains enter a subbasin, traverse across the subbasin to a primary drain, and mix with the drain water. Water is then rediverted and traverses the subbasin to the opposite boundary and leaves the subbasin. A monitoring station located at the end of the primary drain will never reflect the entire sediment and nutrient load of surface returns from fields upland of the traversing lateral or drain. It may reflect a portion, depending on how the canal company operates the diversion where the lateral and drain mix. Fields in a farm unit along a subbasin typically never drain to the same primary drain. To illustrate this monitoring problem, this paper will examine the delivery system, followed by an examination of a typical farm unit.

Overall Irrigation System

To deliver and remove irrigation water, canals, laterals, and drains traverse the Rock Creek RCWP project watershed. As water is delivered to upstream farms, runoff water is collected by various drains and laterals and delivered again to downstream farms. Over the entire Twin Falls Canal Company system, 36 percent of the diverted irrigation water (plus precipitation) is used by crops consumptively, 50 percent is lost to subsurface drainage, and 14 percent returns to Snake River through surface streams such as Rock Creek (Carter et al. 1971). However, approximately 50 percent of the water delivered to an individual farm unit leaves as surface runoff (Yankey et al. 1991). Thus, eroded soil and nutrients leaving upland fields with surface runoff enter the irrigation distribution system and have high potential to be diverted to another field before leaving the watershed or passing a water quality monitoring station.

Lateral or Drain Operation

Figure 1 is a simplified schematic diagram showing the complexity of water flow within a typical farm drain system. The canal company delivers water to Farm A at Point 1 and to Farms B and C at Point 3. The surface runoff leaves Farm A and reenters the

lateral at Point 2. The canal company has to spill sufficient water at Diversion 1 to supply Farms B and C, with allowance for runoff from Farm A. At Diversion 3, the company will deliver this mixture as irrigation water to Farms B and C and spill any excess water. This excess water flows down the drain and is monitored by the water quality station at Point 5. Thus, the surface runoff from Farm A is partially applied to fields in Farms B and C and a portion of the runoff passes the water quality monitoring station. The nutrients and sediments associated with the runoff from Farm A applied on Farms B and C will be deposited. "New" sediments and nutrients will be transported off fields from these farms in their surface runoff. The runoff from Farm B enters the drain at Point 4, above the water quality station (Fig. 1). The runoff from Farm C enters a lateral that supplies other farms at Point 6. Thus, the water passing the monitoring station is a mixture of the lateral supply, runoff from Farm A, and runoff from Farm B. If the canal company minimizes the spill at Diversion 3, the mixture will be primarily composed of runoff from Farm B. Thus, water quality improvements measured at the monitoring station are not entirely associated with BMP implementation on Farm A, but are instead masked by operation of Diversion 3 and the land use and BMP implementation on Farm B.

Within Farm Operations

Field irrigations are based on some schedule — the calendar, soil moisture, or crop use. Figure 2 depicts the fields of Farm C. Each field will be irrigated individually in sets that may or may not cover the entire field. Sometimes irrigation will occur on multiple fields. At other times, no fields will be irrigated, and the irrigator will bypass the water being delivered to the farm to Point 6 without using it. In the earlier example, runoff from this farm was identified as leaving in one location. That was true with the exception of the field identified as C4 (Fig. 2). The surface runoff from this field enters the drain receiving the runoff from Farm B at point 7. The runoff from Field C1 can be routed for use on Field C3 or to the usual runoff location at corner of Field C3. The runoff from Field C4 will affect the water quality at the monitoring station only when it is being irrigated. Because of crop rotations, the amount of sediment and nutrients leaving this field will change annually. Runoff from alfalfa will have the least effect at the monitoring station. However, runoff from beans or sugar beets will have a high effect on water quality at the monitoring station. The measured effect of irrigation of this field with or without treatment also depends on whether it was being irrigated at the

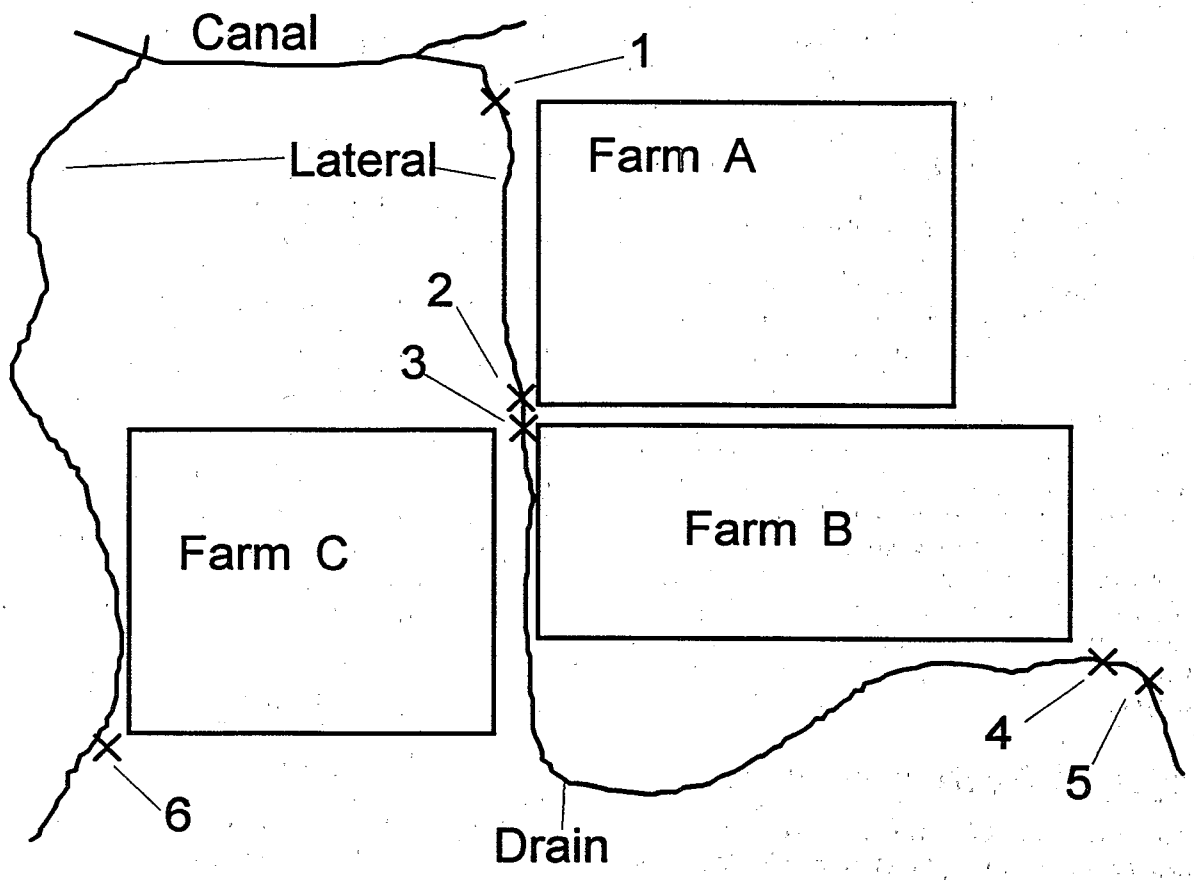

Figure 1.—Portion of a lateral and drain network within surrounding farms.

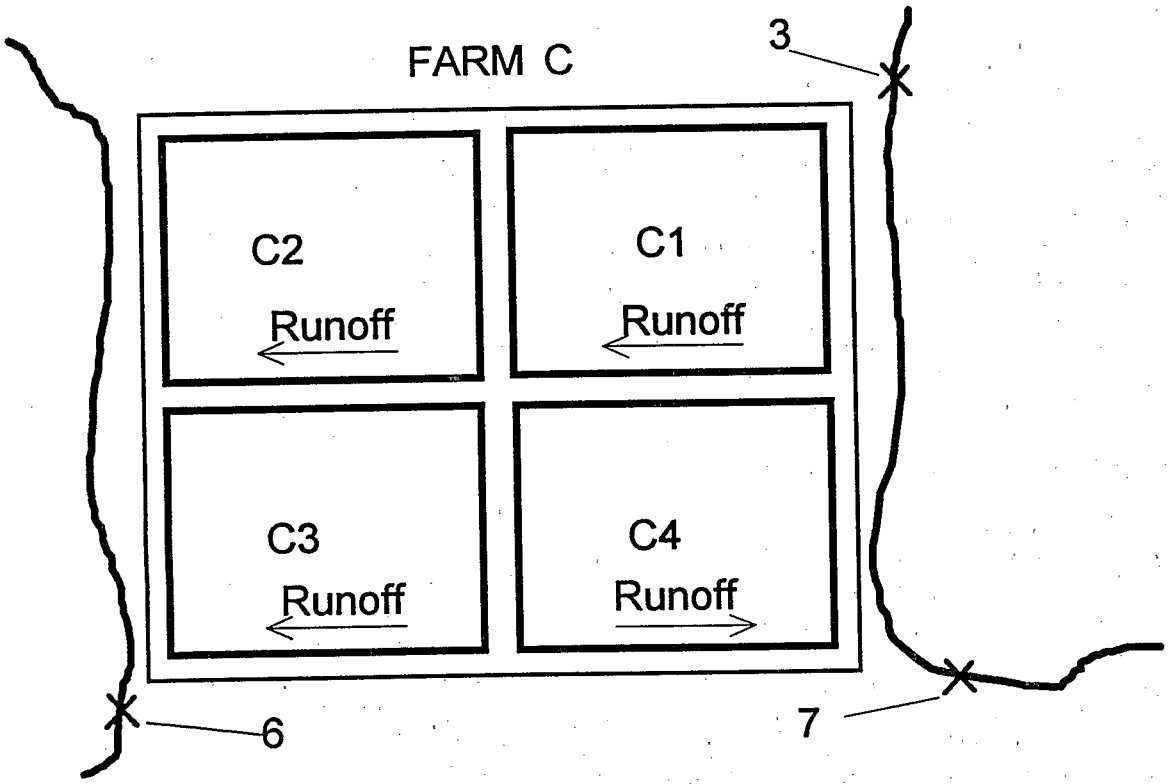

Figure 2.—Farm C and its associated fields.

time water quality samples were taken at the monitoring station.

Rock Creek Aspects

Participation in the RCWP was voluntary. In the Rock Creek project, many farm units along the lower portion of drains (like Farm B) did not participate. A cooperator in the program did not have to participate for the project's entire 10 years. Several farms were only involved with the project for three to five years. Because cropping and BMP implementation data were not collected on these farms during the nonparticipation period, the cause of water quality improvements associated with BMP implementation on participating farms could not be evaluated.

Changes in the operation of the Twin Falls Canal Company distribution system network occurred during the 10-year project period. During that time, different watermasters operated the lateral system. Some watermasters control the system for minimal waste (spill); others work better with a larger waste amount. Because of the multiple interconnections between laterals and drains, watermasters may change their primary spill or drain location. During the project, no agency collected information on how the watermasters operated the various diversions along a drain. Because watermasters serve an entire irrigation season, this lack of data confuses year-to-year comparisons.

Agency Data Collection Efforts

The objectives of the Rock Creek RCWP project were originally to reduce sediment and sediment-related pollutants entering Rock Creek by implementing BMPs and to control animal waste entering Rock Creek by applying animal waste management systems (Yankey et al. 1991).

The primary agencies involved in the project were the U. S. Department of Agriculture (USDA) Agriculture Stabilization and Conservation Service (ASCS), USDA Soil Conservation Service (SCS), Twin Falls and Snake River Soil Conservation Districts (SCD), USDA Agricultural Research Service (ARS), and the Idaho Department of Health and Welfare Division of Environmental Quality (DEQ). The ASCS administered the project. The SCS provided technical planning and, with the assistance of the SCDs, attempted to track BMP implementation and associated cropping information. DEQ was responsible for implementing a water quality monitoring program for irrigation return flows and in-stream

conditions of Rock Creek. The Snake River and Twin Falls SCDs collected cropping information and helped track BMP implementation. The ARS was responsible for evaluating individual BMPs.

Agency performance was in part judged with these project objectives in mind; thus, an agency's data collection and tracking information were focused on attaining its goals. For example, the SCS was primarily involved with planning and implementing BMPs. Therefore, its land treatment database only contained information on planned and installed practices on a farm unit while it was under contract. The DEQ was responsible for collecting and maintaining water quality data for Rock Creek and its various tributaries and irrigation return flows. Thus, its database only included water quality for Rock Creek at several locations, and irrigation return flow entering Rock Creek and at the head of the drains (where they leave the main canal). The individual effect of a BMP on runoff associated with the practice was documented by the ARS. This effect was obtained by monitoring the inflow and outflow of a practice. Man-agement does affect various BMPs and was well documented, along with BMP efficiencies and erosion rates for various crops (Carter, 1984). No agencies collected information about operating the lateral and drain network within subbasins.

Recommendations

At the beginning of a water quality improvement project, clear definitions of project objectives and procedures for measuring goals should be established. Potential questions that would be asked in a postproject analysis should be formulated or hypothesized. Data requirements to answer the potential postproject questions and for documenting attainment of project goals should be clearly identified. A single agency should be responsible for data management. This agency should determine early in the project whether the proper type, amounts, and quality of data are being collected. The irrigation delivery and drainage system should be defined on a clear hydrological basis.

Effects on water quality leaving a subbasin because of implementation of a mixture of practices within the subbasin are difficult to determine without intensive water quality monitoring of each inflow and outflow along a drain and land and water use information. One subbasin in the Rock Creek RCWP project includes over four canal company irrigation diversions from the drain, not including other diversions along laterals in the subbasin and associated inflows from the various farms. To provide adequate data for hypothetical postproject questions, the water quality monitoring network should be designed to account for the intricate irrigation delivery and drainage system configuration and management.

Land use, management, and BMP implementation for all lands in the project area should be collected during the entire project period. Collecting land use, treatment, and water management data for every farm in the subbasin would help explain changes in water quality that cannot be explained by BMP mixtures and implementation levels of participants in the subbasin. Clearly, some items will be financially unattainable, which can affect a postproject evaluation outcome.

Conclusions

If surface runoff from irrigated fields may be reused, water quality improvements associated with BMPs before reuse will be masked. Therefore, it is extremely important to adequately describe the irrigation and drainage channel network. The last fields using the water before a monitoring station will have the largest effect on the measured water quality. The operation of the lateral system by the watermaster controls surface runoff effects from upland fields on water quality at a monitoring station. Even with sufficient knowledge about the operation of the canal system and drainage patterns, land and water use information (practice implementation and crops) is required for all lands in the watershed for the entire project period. The monitoring of the drain end allows assessment of the effect of general BMP implementation. However, without land and water use information for all watershed lands, it is not possible to determine which BMP mixture and level caused the improvement in the subbasin runoff water quality.

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Utah's Snake Creek RCWP Stimulates Additional Efforts to Improve Water Quality in Wasatch County

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ABSTRACT

Deer Creek Reservoir, located in central Utah on the Provo River, holds 152,000 acre-feet of municipal, industrial, agricultural, and recreational water. In 1980, environmental concerns prompted Utah's governor to organize a committee to prepare a water quality management plan for the Provo River drainage, where agriculture is the largest contributor of nonpoint source pollution. Also, in 1980, a Rural Clean Water Program grant was awarded to help reduce the impact of local agriculture on water quality. The Soil Conservation Service, Mountainland Association of Governments, Agricultural Stabilization and Conservation Service, Wasatch Soil Conservation District, Utah State University Extension Service, and local dairymen formed a partnership to implement conservation plans on individual dairies located on the Snake Creek drainage (a tributary to Provo River). The Rural Clean Water Program paved the way for additional planning and implementation. A Clean Lakes project funded by the U.S. Environmental Protection Agency in 1984 finished what was started by the program. Wasatch County adopted a no-phosphorus discharge policy and now requires county developers to produce water quality plans before construction. Sediment basins have been installed for new road construction and newly developed ski resorts. Water quality within the watershed is showing significant improvement, noxious species of blue-green algae have been reduced, and the reservoir is responding to the reduced phosphorus load.

The Snake Creek Rural Clean Water Program (RCWP) project provided implementation grants to six dairy and livestock operators on 700 acres of irrigated farmland. The project's specific objectives were to reduce pollution entering Deer Creek Reservoir from agricultural nonpoint sources and determine best management practices (BMPs) that would reduce pollution.

Several animal waste control BMPs were applied to lands within the project area. The main measures were

- establishing waste management systems for livestock operations,
- limiting livestock access to streams,
- improving irrigation efficiencies, and

- establishing vegetative cover on streambanks.

The project included BMPs on six sites along Snake Creek and Huffaker Ditch. About 90 percent of significant animal waste pollution problems within the project area were treated from 1980 to 1982, resulting in an annual reduction of over 1,000 kg of total phosphorus.

Project Area Description

The Snake Creek RCWP project area is located in Heber Valley of Wasatch County, Utah. Heber Valley, a high mountain valley surrounded by higher mountains, experiences a wide variation in climate. The floor of the valley is approximately a mile above sea level; 15 miles to the west, the Wasatch Mountains tower to more than 10,000 feet.

Soils range from being well-drained and deep to moderately well-drained, with some poorly drained, deep soils on floodplains, low stream terraces, and the valley bottom. Slopes range from 1 to 6 percent; therefore, snowmelt, heavy rainwater, and tailwater from flood irrigation systems readily flow across the fields and transport manure, rich in nutrients, to Snake Creek.

An estimated 600 acres of alfalfa grown on the valley bottom are fertilized with 29 metric tons of nitrogen (including 1.4 metric tons of commercial fertilizer), 22 metric tons of phosphorus (including 4 metric tons of commercial fertilizer), and 61 metric tons of potassium (no commercial fertilizer) each year. Most of the nutrients applied to the cropland are animal waste products; only 4 percent of nitrogen and 18 percent of phosphorus are applied as commercial fertilizer.

Livestock enterprises within the project area include four dairies, four small beef operations (less than 50 head), and two horse farms. Most of the operations are located on a waterway. When the project began in 1980, livestock totaled approximately 650 dairy cattle, 100 beef cattle, and 35 horses. As a result of the Federal dairy buy-out program, dairy cattle have been reduced to approximately 400.

Deer Creek Reservoir, which is approximately seven miles long and up to three-quarters of a mile wide, contains 152,000 acre-feet of water at capacity. Completed by the Bureau of Reclamation in 1941, Deer Creek dam stores water primarily for municipal, industrial, and irrigation purposes in Utah Valley and Salt Lake Valley. Development of the Deer Creek State Park has increased the already heavy recreational demand on the reservoir, where fishing, boating, and waterskiing are increasingly popular.

Comprehensive Planning

As plans were being formulated for the Snake Creek RCWP, Sowby and Berg (1984) were developing additional plans for the remainder of the watershed. The Deer Creek Reservoir and Proposed Jordanelle Reservoir Water Quality Management Plan was completed and approved by Wasatch County, the State of Utah, and the U.S. Environmental Protection Agency (EPA) as an amendment to the Mountainland Association of Governments' Areawide Water Quality Management Plan. Local government was assisted by the Deer Creek–Jordanelle Reservoir technical advisory committee, which was composed of representatives from local, State, and Federal agencies and other water quality consultants. The committee's role was to develop a technically sound plan that could be implemented through the legal authority of the county and State.

The Snake Creek RCWP, the first attempt in Wasatch County to address nonpoint source water quality problems, provided a demonstration project where farmers could see the results of a combined effort between government agencies and local people. Other farmers in Wasatch County and across the State benefited from this knowledge. Assistance through the Clean Lakes Program, Agricultural Stabilization and Conservation Service cost-share programs, and the technical advisory committee provided funding for water quality problems derived from animal waste on additional farms.

The Clean Lakes Program in Heber Valley is administered by the Utah Department of Environmental Quality. A Phase I study (diagnostic/feasibility) kicked off the program in 1981; in 1986, Phase II implementation funds were awarded. The 13 participating dairy and livestock operators have installed BMPs patterned after those implemented under the Snake Creek RCWP. The Agricultural Stabilization and Conservation Service provided additional assistance through the Agriculture Conservation Program and its special water quality grants.

During the RCWP project, the U.S. Department of Interior (1979) developed an environmental impact statement (EIS) for the proposed Jordanelle Dam, which is to be located on the Provo River upstream of Deer Creek Reservoir. In a review of that EIS, the EPA found that no management plan had been developed for Jordanelle Reservoir. As a result, in 1979, then-Governor Scott Matheson committed the State to develop a management plan for the proposed municipal and industrial system of the Central Utah Project's Bonneville Unit. This commitment was followed by Bureau of Reclamation action to include a reservoir management plan in the list of

mitigating measures for construction of Jordanelle Reservoir. The Mountainland Association of Governments (1979) supported this concept after reviewing a section 208 water quality study that recommended comprehensive reservoir management plans to protect Deer Creek and Jordanelle reservoirs.

Local county government took the lead role to determine what, if any, land use or nonpoint source control regulations should be considered in implementing the plan. The county actively enforced planning and zoning regulations to require that water quality consideration be given to all proposed construction projects. This comprehensive local, State, and Federal planning effort included the Snake Creek RCWP as one component.

The Jordanelle Reservoir Technical Advisory Committee has continued to meet regularly to review results of the Snake Creek RCWP, Clean Lakes Program, and other projects. The Soil Conservation Service (as a member of that committee) has provided technical assistance to each RCWP, Clean Lakes and Agriculture Conservation Program participant. Soil Conservation staff developed detailed conservation plans that involved inventory of resources, development of alternatives with costs, assistance for landowners, final design of all facilities and management components, and implementation of all BMPs in each contract.

The Wasatch County Soil Conservation District Board of Supervisors reviewed each RCWP and Clean Lakes contract with participants to ensure that the developed plan would to meet the program's overall objectives. It also held joint meetings with the Wasatch Agricultural Stabilization and Conservation Service county committee to review requests for contracts and establish priorities for contract development.

Technical expertise in planning animal waste facilities was provided by an animal waste specialist from Utah State University Cooperative Extension Service. This important link to state-of-the-art technology in handling these wastes was extremely valuable in planning effective waste management facilities. In addition, several private companies that dealt with agricultural waste handling equipment acted as consultants in planning and designing waste storage facilities and handling equipment. Mountainland Association of Governments and the Utah Department of Environmental Quality took the lead in implementing water quality management plans and evaluating project effectiveness through water quality monitoring and reporting.

As a result of an interagency, interdisciplinary approach to planning animal waste systems, the Snake Creek RCWP and other programs have pulled together the best technical knowledge to develop sound alternatives and solve resource problems found in the critical areas. Wann (1986) quoted an EPA official as saying, "The work at Snake Creek seems to have been successful from several standpoints: water quality has significantly improved, the farms are now much more efficient operations, and a model for other similar projects has been created." In addition, the charge given by Lawrence Jensen (1986), then EPA's assistant administrator for water, for upstream users to manage the resource properly so that downstream uses are protected, has been achieved. In 1990, Wasatch County was recognized with an award by Utah's governor for the State's most outstanding water quality program.

The total installation cost of BMPs in the RCWP was $210,508. Of this amount, 68.3 percent ($143,684) was paid by project participants. Although the program authorized cost-sharing at a level of 75 percent, a $50,000 payment limitation reduced the overall percentage.

Implementation of a water quality plan in Heber Valley has significantly benefited the reservoir. Point and nonpoint sources have been abated through the Snake Creek RCWP and Clean Lakes Program. After studying the phytoplankton in the reservoir for a number of years, Rushforth (1988) noted,

> *It seems to be very likely that the phosphorus limitation program that has been instigated for Deer Creek Reservoir has improved the biological water quality of the water and will continue to lead to further water quality improvements. It is significant that the water quality seems to have improved each year during the past four years. Long term monitoring is providing an excellent opportunity to chronicle what appears to be the significant recovery of Deer Creek Reservoir.*

Water Quality Investigations

Water quality studies conducted on Deer Creek Reservoir during the 1970s (Mountainland Ass. Gov. 1979) and early 1980s (Utah Dep. Health, 1984; Sowby and Berg, 1984) concluded that the reservoir was eutrophic and phosphorus was the nutrient of concern. Excessive nutrients were entering the reservoir from human-caused pollution as well as natural sources. Studies showed that the average annual phosphorus load reaching Deer Creek Reservoir before implementation of water quality management practices was approximately 25,000 kg/yr. Water quality models predicted that the phosphorus

load had to be reduced by 11,000 kg/yr to protect the beneficial uses of the reservoir.

To achieve the desired reduction level of nutrient loading to the reservoir, the Jordanelle Technical Advisory Committee interdisciplinary task force identified phosphorus sources. Although dairies and feedlots represented only 12.1 percent of the total phosphorus load, they were a nutrient source that could be controlled cost effectively. Water quality goals and project objectives were planned to reduce agricultural nonpoint sources of pollution by 40 percent to Deer Creek Reservoir and determine if selected BMPs could improve water quality effectively.

Water quality studies determined that the Snake Creek drainage was contributing excessive amounts of nutrients to the reservoir. Data indicated that the lower Snake Creek drainage (which covers 7,302 acres — 1.4 percent of the Deer Creek drainage) was contributing 12.73 percent of the total phosphorus loads; in addition, these studies identified and quantified other sources of phosphorus pollution. Other programs, including the Clean Lakes Program, targeted those sources for improvement.

The RCWP project goal was to reduce total phosphorus in Snake Creek by 650 kg (50 percent); in Huffaker Ditch by 600 kg (75 percent); and in Bunnel Ditch by 120 kg (75 percent). The following three animal waste control measures were identified for this project:

1. Control transport of animal waste to Deer Creek Reservoir through Snake Creek by applying waste management systems to livestock operations within the project area.
2. Protect stream water quality by limiting livestock access to streams in the project area, thereby reducing the amount of animal wastes directly entering the stream system.
3. Reduce overland transport of nutrients by improving irrigation efficiency on all irrigated lands in the project area.

Responsible for an approximately 1,000 kg/yr reduction of the total load, the Snake Creek RCWP was a major stimulating force for additional nutrient decreases occurring under other programs. This RCWP project developed the model that is now being used by all other livestock waste management systems designed in the county as well as the State.

Results

Beginning in November 1979, 20 stations were selected on the basis of their location within the Snake Creek drainage system and monitored regularly to determine which agricultural activities actually contributed the highest level of nutrients to Snake Creek. Sites included eight on Snake Creek, two on Epperson Ditch, three on Huffaker Ditch, four on Bunnel Ditch, two on the Provo River, and one on an unnamed ditch.

Monitoring on sites immediately above and below dairies participating in the project provided background data on water entering Heber Valley. Other sites provided estimates of runoff from irrigation practices and data that compared impacts from point versus nonpoint sources. Deer Creek Reservoir and other tributaries in the watershed were also monitored.

Water samples from all monitoring sites were analyzed for

- total and fecal coliform bacteria,
- organic nitrogen,
- total Kjeldahl nitrogen,
- ammonia,
- nitrate,
- nitrite,
- total phosphorus,
- orthophosphorus,
- biochemical oxygen demand,
- total suspended and dissolved solids,
- conductivity, and
- pH.

Water samples were collected monthly in the Snake Creek drainage. During spring runoff when most of the snowmelt water flows into Deer Creek Reservoir, water samples were collected biweekly and analyzed by a certified analytical laboratory. Monitoring began in 1979 and has continued to the present, with modifications.

Tables 1, 2, and 3 show the average concentration of total phosphorus as well as the total phosphorus load from sites on Snake Creek between 1980 and 1990. During 1980 and 1981, before implementation (Table 1), the total cumulative phosphorus load to Snake Creek at Sites 03 and 04 (Pride Lane Dairy) resulted in an increase of 802 kg/yr and 300 kg/yr, respectively; in 1982, during implementation (Table 2), the increase dropped to 282 kg/yr. During 1983, the load measured higher above the dairy than below it; from 1984 to 1990, total phosphorus loads were 196, 516, 223, 301, 69, 35, and 0 kg/yr, respectively.

Table 1.—Average of total phosphorus concentration (mg/L) and total load (kg/yr) from sites on Snake Creek before RCWP implementation (1980-81).

	1980		1981	
STATION NO.	mg/L	kg/yr	mg/L	kg/yr
01	.018	163	.019	107
02	.026	739	.023	335
03	.039	737	.027	486
04	.082	1,539	.200	786

Table 2.—Average of total phosphorus concentration (mg/L) and total load (kg/yr) from sites on Snake Creek during RCWP implementation (1982).

	1982	
STATION NO.	mg/L	kg/yr
01	.034	308
02	.053	1,270
03	.043	1,233
04	.075	1,515

Even though some water quality impacts occurred during 1985 and 1987, data shows that the average total phosphorus load before implementation was 551 kg/yr, whereas following implementation, the average phosphorus load was 217 kg/yr.

The following observations were made by comparing average phosphorus concentrations above and below the dairy:

1. Before implementation (1980-81), the average total phosphorus concentration above the dairy was 0.033 mg/L; the average concentration of total phosphorus below the dairy was 0.141 mg/L. The difference between those average concentrations is 0.108 mg/L.
2. Following implementation (1983-90), the average total phosphorus concentration above the dairy was 0.044 mg/L and the average concentration below the dairy was 0.057 mg/L. The difference between those average concentrations is 0.013 mg/L.

Tables 4, 5, and 6 show the average concentration of total phosphorus as well as the total phosphorus load on Huffaker Ditch between 1980 and 1990. During 1980, the average phosphorus load from Vincent's Dairy reached a high of 553 kg/yr (Fig. 1). During implementation, that load decreased to 138 kg/yr in 1982 (Fig. 1). Following implementation (1983 through 1990; see Table 6 for average concentrations), the phosphorus yearly load to Huffaker Ditch from Vincent's Dairy was 67 kg, 74 kg, 16 kg, 63 kg, 14 kg, 0 kg, 11 kg, and 4 kg, respectively (Fig. 1). In 1988, Vincent's Dairy participated in the Federal dairy buy-out program and dairy cattle were removed from that site.

Table 4.—Average of total phosphorus concentration (mg/L) and load (kg/yr) from sites on Huffaker Ditch before RCWP implementation (1980-81).

	1980		1981	
STATION NO.	mg/L	kg/yr	mg/L	kg/yr
05	.029	99	.050	184
06	.200	652	.202	600

Table 5.—Average of total phosphours concentration (mg/L) and total load (kg/yr) from sites on Huffaker Ditch during RCWP implementation (1982).

	1982	
STATION NO.	mg/L	kg/yr
05	.200	703
06	.256	841

Similar water quality benefits are being seen at sites near dairies and feedlots participating in the Clean Lakes Program. Wasatch County's aggressive enforcement of planning and zoning regulations has also been a factor in improving water quality.

Groundwater monitoring was not an original component of the Snake Creek RCWP water quality monitoring program. Beginning in 1986, concerns were expressed that BMPs used to improve surface water quality might only be rerouting, storing, and delaying transport of nutrients to the reservoir. These opinions were based on a growing understanding of the makeup of the unconsolidated Heber Valley fill and the quality of groundwater found there.

Jeppson et al. (1991) from Utah State University installed vadose zone samplers near the Pride Lane

Table 3.—Average concentration of total phosphorus (mg/L) and total load (kg/yr) from sites on Snake Creek following RCWP implementation (1983-90).

	1983		1984		1985		1986		1987		1988		1989		1990	
STATION NO.	mg/L	kg/yr	mg/L	kg/yr	mg/L	kg/yr	mg/L	kg/yr	mg/L	kg/yr	mg/L	kg/yr	mg/L	kg/yr	mg/L	kg/yr
01	.027	442	.038	754	.026	484	.063	1,051	.033	166	.022	80	.015	41	.023	65
02	.047	2,360	.041	1,546	.029	924	.041	1,279	.027	376	.039	599	.021	225	.023	219
03	.059	2,275	.050	1,665	.029	869	.058	1,593	.036	523	.032	275	.038	238	.028	156
04	.053	1,675	.058	1,885	.048	1,397	.069	1,816	.061	824	.052	344	.039	273	.023	95

Table 6.—Average concentration of total phosphorus (mg/L) and total load (kg/yr) from sites on Huffaker Ditch following RCWP implementation (1983-90).

STATION NO.	1983		1984		1985		1986		1987		1988		1989		1990	
	mg/L	kg/yr	mg/L	kg/yr	mg/L	kg/yr	mg/L	kg/yr	mg/L	kg/yr	mg/L	kg/yr	mg/L	kg/yr	mg/L	kg/yr
05	.057	120	.048	110	.030	69	.094	172	.047	74	.042	45	.028	21	.029	22
06	.088	187	.076	184	.043	85	.146	235	.056	88	.039	39	.032	32	.024	26

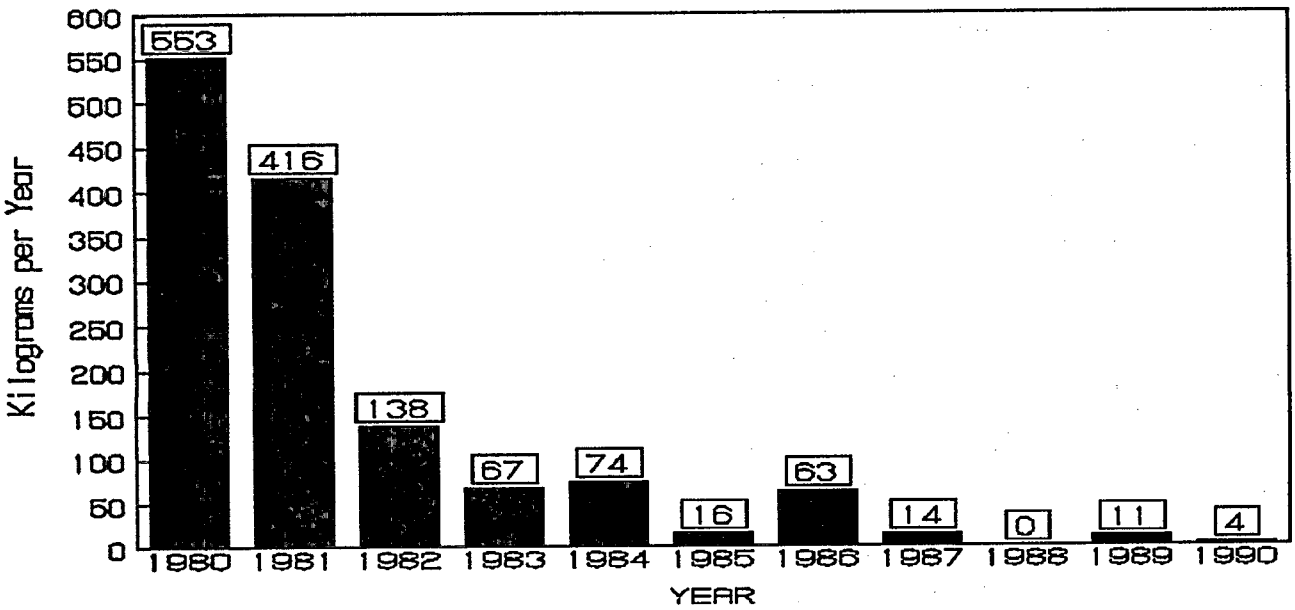

Figure 1.—Total phosphorus load from Vincent's Dairy.

Dairy lagoon at depths of 54, 70, and 90 inches to determine if this waste pond was contaminating underlying groundwater. Only small amounts of water were extracted even though the samplers were within the free surface seepage zone that would theoretically exist if the porus media below and surrounding the lagoon were homogenous. These dry soil conditions suggested that seepage from the lagoon into the groundwater was minimal. In addition, water from the lagoon was observed flowing into the field immediately south of that pond.

Vadose samplers were also installed in a similar manner near a liquid waste lagoon at a second dairy that was not part of the RCWP project. This study determined that most of the nutrients that flowed into that lagoon probably moved into the groundwater system over time. This could be a concern for future lagoons, which may have to incorporate an impervious liner.

Conclusion

The Snake Creek RCWP is a dramatic success. Phosphorus concentrations have steadily decreased in the Snake Creek drainage since the project was implemented in 1982. The goals of the project were accomplished because management practices were assertive and dealt with the problem directly. The various BMPs have included manure bunkers, liquid waste lagoons, off-stream watering systems, fencing of streams, piping of ditches, and fertilizer management practices.

Participants are satisfied with the results. Others who did not participate in the original RCWP observed the success of the project and decided to take part in similar projects through the Clean Lakes Program.

Deer Creek Reservoir is responding to the project's broad-based approach to improving and protecting the water quality in the watershed. As a result of the RCWP project, the beneficial uses of the water are better protected.

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Information and Education — Lessons Learned from RCWP

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ABSTRACT

The value of information and education (I&E) to the administration of Rural Clean Water Program (RCWP) projects was recognized at a very early stage. I&E was identified as a distinct component in planning and was to be an integral part of each project. In actual practice, its role and function varied considerably among the various RCWP projects, possibly because the RCWP concept was in its infancy. Many other factors also influenced the evolution and scope of I&E; still, after 10 years of practical experience with the projects, I&E committees have learned much and can make definite recommendations based on their experience. A significant lesson is the proper distinction between information and education. Most I&E committees did an excellent job with information but may need to re-examine the role of education in future water quality projects. This paper will consider how information and education are incorporated into RCWP projects, with an emphasis on the appropriate separation and coordination of these components. The author contends that the ultimate goal of water quality demonstration projects is behavioral modification, which places great emphasis on education.

The value of information and education (I&E) was recognized early by RCWP project managers and others even though no one could predict the outcome of I&E efforts, and no one had any prior experience with water quality projects to give us direction. We didn't know how the fully developed, mature water quality project should or would look—it is difficult to evaluate something that hasn't happened yet.

Many factors shaped and influenced the way that I&E efforts developed in the various projects. These factors relate to the widely differing environments of the RCWP projects. Environmental differences affecting each project were physical and cultural, economic and social.

Some projects were designed to address surface water concerns; others to address groundwater problems. Project size varied greatly. The Long Pine Creek RCWP project involved a watershed of 325,000 acres; others dealt with problems confined to a much smaller physical area. The number of participants, the size and nature of the individual farming operations, the proximity of industry, and local cultures and traditions influenced the character and variety of the RCWP projects and their goals and objectives.

We also need to remember that some best management practices (BMPs) may be relatively inexpensive and quite easy to implement, while others may be costly and unable to yield an immediate, evident economic return. Some RCWP projects assigned full-time I&E responsibility to their staffs; in other cases, the workload was shared among several people or handled as an extended responsibility by one person. Some projects had an I&E component

throughout their duration; others had initial support only, while still others had I&E on an as-needed basis. A significant difference also existed between projects with a comprehensive monitoring and evaluation component and those without it.

The definition of I&E also varied from project to project. In some cases, a vague position description made it difficult to have a clear understanding of responsibility. But now, as I&E staff view the RCWP projects in retrospect, they can see that they have learned a great deal about I&E.

The I&E involvement in the RCWP has been a learning process—an exercise in education. It offers 10 years of valuable hands-on experience that can enhance the prospect of success in future water quality projects and help us avoid pitfalls. The lessons learned about the role of information and education can be applied to many parallel situations in which the end result is behavior modification. However, our concern here and now is to look at the lessons we have learned in terms of water quality.

The following ideas were shared at an RCWP workshop in South Dakota in September 1990. The meeting included a brainstorming session for the I&E component in future water quality projects.

- Appropriate personnel are needed to contact producers. Ongoing I&E responsibility should be assigned to one agency that directly contacts producers, with other agencies providing input and support.
- Initial I&E efforts are very important, but I&E needs funding throughout a project's life.
- I&E funding needs to be less restricted so that demonstration projects and field days receive sufficient funding. Both are helpful ways to disseminate information.
- I&E needs to be the RCWP project's primary component. I&E is important; it sells a project to farmers, informs the public, and provides interagency training.
- I&E expertise is needed to coordinate project efforts, assess efficiency of methods, evaluate progress, and recommend changes.
- Extension Service offices can be the lead agencies for I&E, but support is also needed from other agencies involved in the project.
- I&E includes communicating and transferring information among agencies at each level—Federal, State and local—and across levels.
- The local coordinating committee is the most important component for ensuring that an RCWP I&E effort succeeds.

Many other suggestions were expressed at this meeting but these few suffice to illustrate I&E value. Of course, these observations take nothing away from other aspects of a water quality project. Rather, they attach appropriate significance to the role of I&E.

We have traditionally included "information" and "education" in the same phrase, knowing that they were closely related. Perhaps we did not give appropriate credit to their differences. It is one thing to know the facts and be aware of the information; it is quite another to absorb this information usefully.

I&E Observations and Ideas

In the last 10 years, the importance of I&E was recognized but not its modus operandi. We didn't know how to handle the education part, or perhaps we just didn't plan to handle the education part. Any teaching must be based on sound information that has been evaluated through solid research.

We did an excellent job with information in terms of collecting, organizing, and publishing it. We learned a great deal about handling water quality information.

At the same time, one of the most important things we learned from RCWP is the difficulty of taking the step from knowledge to adoption of best management practices. Taking this step mandates that we enter an "educational" mode.

When we initially staffed the RCWP projects, we hadn't had the opportunity and experience to appreciate how important it is to select staff carefully with this particular concern in mind. Consequently, we selected people who were good information people, knowledgeable about their subject, and good at man-aging data. And, the people we selected did a good job at what they were asked to do.

One important result of the RCWP is the amount and kind of information that we collected, organized, evaluated, categorized, and summarized. Many future decisions can be based on the significant data that RCWP I&E staffers gained through observation and research.

A second important result is the lesson we learned about "teaching," that is, about effecting behavioral modification. It would seem to me that we should have some people who are trained to teach.

RCWP from an Educational Perspective

By comparing RCWP to a school system, we can draw several parallels between the lessons we have learned and the classroom. The following table illustrates the parallels I have in mind.

SCHOOL SYSTEMS	RCWP PROJECTS
Superintendent needed to work with the whole district.	Project coordinator needed for overall supervision.
Big school systems are different from one-room schools.	Project area size determines the program approach.
Not all students have the same needs.	Different projects in different areas have different needs.
Classrooms should have a maximum of 20 students.	The number of project participants governs staff numbers (or vice versa).
A one-on-one relationship with a student is important in the learning process.	One-on-one contact with producers is important in the adoption of change.
Students who understand the benefits of education learn more readily.	People who appreciate the long-term benefits are more ready to adopt change.
Diverse cultural backgrounds may challenge the teacher.	Local culture and tradition may affect the project approach.
"That's the superintendent's job."	Responsibilities must be defined and understood.
Society has a common goal to educate children.	Agency cooperation and partnerships contribute to an effective program.
Learning is greatly enhanced for children who are actively involved with hands-on participation.	On-farm demonstrations can increase project participation.
Good teachers use long- and short-term lesson plans.	Each project needs a definite plan of action—with modifications if needed.
School boards need to budget for the whole year.	I&E needs to be funded for the duration of a project.
Report cards are distributed quarterly.	I&E includes systematic and regular project evaluation.
Good public support helps a school system.	Good public support helps a water quality project.
Teachers have opportunities for continuing education.	Project leaders enhance their skills through appropriate training and workshops.
Teachers use a variety of aids and techniques to improve the learning atmosphere.	Good project I&E requires a variety of methods and approaches.
"I can't afford to go to college."	The economics of particular BMPs may demand unique methods for their adoption.

These comparisons illustrate many of the educational aspects of water quality protection and enhancement. They are features that need to be included and coordinated for project success—particularly for long-term success.

Conclusion

A definite relationship exists between information and education. They belong together and complement and supplement each other, but they are distinct components of RCWP projects and each is important. They cannot be merged to the point that the identity of either is lost.

As it relates to information and education, the RCWP's biggest present challenge is the appropriate transfer of "lessons learned" to present and future projects. I believe we are doing well with information. How will we handle the education? The challenge in many endeavors and not least in the future of RCWP is to move from theory to reality, from plan to practice, from information to education.

Diversity of Information and Education Help Obtain Goals for Double Pipe Creek RCWP Project

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ABSTRACT

A wide diversity of communication methods were used to promote the Double Pipe Creek Rural Clean Water Program (RCWP) project in Carroll County, Maryland. These methods were developed at the project's start by the Information and Education (I&E) subcommittee and attached to a five-year timetable. The subcommittee met semiannually in the early years, then annually the final two years. As a result of the I&E efforts, the following findings were made relative to the promotion of the project: (1) an initial sharing of ideas among the 21 RCWP projects would have provided additional mechanisms to reach potential participants; (2) the excellent cooperation and support developed between sister agencies, farm organizations, and public officials helped reduce duplication of efforts; (3) having I&E funds handled through the State Cooperative Extension Service enabled I&E projects to be approved and funded on a more timely basis; (4) a greater effort in developing one-on-one contacts at the project's end would have resulted in a higher number of participating contracts; and (5) guidelines should have been developed at the project's beginning to better track and evaluate the results of I&E initiatives.

The primary objective of the Double Pipe Creek Rural Clean Water Program (RCWP) project was to improve water quality in the drainage basin within Carroll County and downstream. The major project emphasis was to manage livestock waste rather than concentrate on sediment reduction. To accomplish this objective, the goal was to have an acreage equal to 50 percent of the critical area under RCWP contract by the end of the third year.

The Information and Education (I&E) subcommittee goals were to accomplish the project goals and inform the general public and government officials about the progress of the RCWP effort. This paper addresses the following components of the I&E effort in the Double Pipe Creek RCWP project:

- Plan of Action to accomplish I&E goals,
- I&E subcommittee activities conducted to implement the Plan of Action,
- adjustments to the initial I&E plan of action,
- factors influencing the rate of program participation,
- evaluating the success of the I&E effort, and
- recommendations to improve future water quality demonstration projects.

Plan of Action

The long range objectives of the I&E program were divided into two stages. The first was the awareness stage: the I&E subcommittee wanted to inform the general public and the farming community about the project. The nature of the project and its goal to improve the water quality in farm runoff needed to be communicated along with information about how the project would be administered and funded. The objective in the second stage of the I&E subcom-

mittee's plan was to encourage farmer and landowner participation in the RCWP project.

Even though most members had little prior experience in creating a large educational effort, the I&E subcommittee developed a diverse number of promotional ideas to accomplish the designated objectives, among them:

- holding a press conference to announce the approval of the Double Pipe Creek RCWP project,
- distributing an informational flyer to describe the general outline of the project,
- sponsoring three community information meetings at different locations within the Double Pipe Creek area to discuss the project and answer questions from the farm community and the general public,
- preparing newsletters and news releases to encourage farmers to sign up for the project and to describe agricultural best management practices (BMPs) that could be implemented to help farmers meet water and soil conservation goals, and
- creating informational and media material to localize the project in Carroll County and Maryland, promote the project among area farmers, and inform the farming community and the general public of the importance of improving water quality.

Media and informational materials in the last named category needed to be carefully planned and diverse to appeal to a variety of age and interest groups. Some were promotional; others, more technical, and some were intended to appeal to school children. Thus, for example, the committee's plans included a slide and tape series on the Carroll County RCWP and the BMP components of the project; a booklet called WATER "The Basics of Life" for distribution with other RCWP literature to county school children; and an album of sample BMPs to be developed by Soil Conservation Service (SCS) technicians to show participants what these practices entailed. Other projects planned by the I&E subcommittee are detailed in the implementation section of this paper.

Activities Conducted to Implement the Plan of Action

A wide array of I&E activities were conducted during the project's first six years to encourage participation in the RCWP project, including the following:

- **Press Conference.** This meeting was held when the Double Pipe Creek project first received approval.
- **Tours.** Two waste management tours were arranged so that farmers could observe completed BMPs. Another tour was held for county, State, and Federal administrators to observe the progress of the Double Pipe Creek project.
- **Television.** Two telecasts on the Double Pipe Creek Project were aired on public TV (Channel 67).
- **Radio.** Several RCWP announcements were made on the local radio station by the county extension agent during his weekly radio program and by a soil conservationist in special public service announcements.
- **News Releases.** Announcements were written and printed in local county newspapers detailing the Double Pipe Creek meetings, tours, and field days.
- **News Articles.** News and feature articles were printed in local county newspapers and the *DelMarVa Farmer.*
- **Newsletters.** Articles on the Double Pipe Creek Project appeared many times in county Agricultural and Stabilization Service (ASCS) newsletters, Soil Conservation District (SCD) newsletters, and Cooperative Extension Service (CES) "Farm Notes."
- **Informational Displays.** Models were built for the Carroll County Fair, CES mid-winter meetings, and the Maryland State Fair.
- **Slide Tape Show.** A general information series on RCWP was created and has been used numerous times at meetings, civic clubs, and local feed and machinery stores.
- **Picture Album.** Photographs of sample BMPs were assembled and made available to all agencies working in the project area and used as a review with prospective applicants.
- **Metal Signs.** The local coordinating committee designed and distributed signs to participants after they had completed the first BMP in their contract. These signs read "RCWP Cooperating Farm."
- **Communication.** Throughout the project communication has been encouraged. In particular, vocational agriculture teachers in the county high schools were encouraged to bring students to field days to see completed BMPs

and to discuss the Double Pipe Creek project in their classes.

- **Individual Farm Visits.** Landowners in critical areas were visited and encouraged to participate in the Double Pipe Creek project. Soil Conservation Service supervisors mounted a campaign to visit various farms in the project with known soil conservation problems.
- **Meetings.** A meeting was held with contractors who build soil conservation BMPs to inform them of the project, and topics describing the benefits of participating in the Double Pipe Creek project were included on the agenda of Cooperative Extension Service Mid-winter Meetings.
- **Plaques.** Plaques were presented to RCWP cooperators who had completed all of their BMPs.
- **Mechanical Groundwater Model.** A display was used to show the interaction between ground and surface water and the effects of human activity on that water. Demonstrations were given to school classes, service clubs, and farm meetings.
- **Manure Spreader Calibration Demonstrations.** Technical demonstrations were included during field days and tours.
- **The RCWP Newsletter.** This publication was initiated and mailed to all farms under contract on a quarterly basis.

The use of published and printed information augmented other types of I&E activities and advertised and promoted special events. Published pieces included

- **Booklets**
  - *Best Management Practices Tour*—December 8, 1981
  - *Animal Waste Management Tour*—November 16, 1982
  - *Annual Report and Conservation News*—1984
  - *Rural Clean Water Program: Double Pipe Creek Project Tour*—March 11 and 12, 1985
  - *Best Management Progress Tour*—July 28, 1988
- **Flyers**
  - Double Pipe Creek Rural Clean Water Project
  - Questions and Answers About Soil and Water Conservation
  - Rural Clean Water Program Double Pipe Creek Water Quality Management
  - RCWP Update Session—October 1982
  - Rural Clean Water Demonstration Day—November 7, 1984
  - Best Management Progress Tour—July 28, 1988
- **Invitation**
  - Best Management Progress Tour —July 28, 1988
- **Newspaper Articles**
  - Contracts Available for Pipe Creek Area—July 23, 1980, *Evening Sun*
  - Farm News: Clean Water Contracts Open—July 25, 1980, *Carroll County Times*
  - Double Pipe Creek: Water Cleanup Project Funded—August 9, 1980, *The Evening Sun*
  - Ceremony to Mark First Rural Clean Water Contract—September 16, 1980, *DelMarVa Farmer*
  - 1st in Nation—September 18, 1980, *Carroll County Times*
  - Project Reduces Animal Wastes in Little Pipe—September 18, 1980, *Carroll County Times*
  - Father-Son Team Get First Check in RCWP—September 23, 1980, *DelMarVa Farmer*
  - Carroll Gets First Facility—October 1980, *Maryland Farmer*
  - Water Meetings Begin—December 10, 1980, *The Evening Sun*
  - Pure Water Pilot Program Launched—December 10, 1980, *Carroll County Times*
  - Farm Briefs: Clean Water—December 30, 1980, *DelMarVa Farmer*
  - Rural Clean Water Program: It's Helping to Manage Waste in Carroll County—December 15, 1981, *DelMarVa Farmer*
  - Double Pipe Creek: A New Outlook on Handling Waste—April 28, 1981, *DelMarVa Farmer*
  - "Clean Water" the Byword as Double Pipe Creek Farmers Spruce Up Their Operations—November 2, 1982, *DelMarVa Farmer*

- Farming: Rural Clean Water Project Right On Schedule—November 2, 1982, *Carroll County Times*
- Waste Management Tour Tuesday—November 15, 1981, *Carroll County Times*
- Pits Help End Runoff—April 25, 1983, *Carroll County Times*
- Rural Clean Water Program—Summer 1983, *Carroll County Times*
- Ag Briefs: Rural Clean Water Program—October 26, 1984, *Carroll County Times*
- Carroll County Farmers Face Tough Decision—October 30, 1984, *DelMarVa Farmer*
- Maryland to Hold BMP Open House Wednesday—October 30, 1984, *Lancaster Farming*
- RCWP Day Set in Carroll—November 6, 1984, *Frederick Post*
- Carroll Farmers Join Clean Water Program—November 6, 1984, *Carroll County Times*
- Farm/Business: The Clean Way—November 19, 1984, *Carroll County Times*
- Farmers Urged to Apply for RCWP Plan—November 20, 1984, *Frederick Post*
- Extension Service to Expand Offices—*Carroll County Times*

■ **Folders**

- Rural Clean Water Program: Double Pipe Creek—Water Quality Management

■ **Fact Sheet**

- University of Maryland developed a Grassed Waterway Maintenance fact sheet.

Adjustments to the Initial I&E Plan of Action

The I&E subcommittee's plan, like any long-range plan, needed certain midcourse adjustments during the implementation process to compensate for program changes and variations in program participation. The I&E subcommittee was able to make these adjustments without dramatic changes to the initial plan of action.

The I&E subcommittee's initial goal was to meet semiannually to plan various I&E projects and evaluate work accomplished to date. This schedule was adhered to the first six years. After the sign-up period had lapsed, the committee met annually but usually only the agency people attended.

Additional educational activities and promotions were added over the course of the project's first six years. These additions included recognition of farms that had completed at least one BMP: farmers were presented metal signs signifying that they were "RCWP Cooperating Farms." During a particularly slack period in sign-ups, a meeting was arranged with contractors who construct BMPs to inform them of the project and to see if they could help stimulate interest.

Near the end of the sign-up period, a list was developed of farms that had been targeted as priorities but had not shown any interest. These targeted individual farmers were visited by SCS, ASCS, County Extension, or SCD personnel. In addition, vocational agriculture teachers in the high schools were kept informed about the RCWP project and encouraged to discuss the project with their classes. All adjustments to the original I&E goals were made near the end of the sign-up period to help increase participation.

Factors Influencing the Rate of Program Participation

Obviously, economic and political factors play a significant role in the willingness of farmers to participate in any government cost-sharing program. During the 1980s, the project area experienced three major droughts that placed a severe economic hardship on farmers and, to some extent, limited their willingness to participate in this cost-sharing program. But also during the 1980s, the environmental concern for cleaning up the Chesapeake Bay created an awareness in the farm community that a problem existed with nonpoint source pollution coming from farms and that farm owners would be expected to help solve the problem.

Other State and Federal government programs affected the rate of farmer participation in the RCWP effort either positively or negatively; some programs are still in existence, and others have gone. The following programs are large enough to have had some effect on the project area.

Maryland Agricultural Land Preservation Program

For a farm to be accepted in the Maryland Agricultural Land Preservation Foundation, a conservation

plan must be developed before easement rights are sold. Since 1980, 21,473 acres have been accepted into the Maryland Agriculture Land Preservation Program in the Double Pipe Creek project area. By enrolling in this program, many farmers have committed to remain in farming. Therefore, these landowners are willing to make a long-term commitment to water quality through RCWP. The Maryland Agriculture Land Preservation program has had a very positive effect on RCWP participation.

Food Security Act of 1985

Preliminary information indicates that approximately 75 percent of the land in Carroll County is highly erodible based on the 1985 Food Security Act criteria. The SCS district conservationist estimated that 25 percent of the cropland acreage will need cropping system modification or the establishment of additional conservation measures to bring the soil loss each year within the established acceptable level.

The emphasis in this act on the need to establish conservation plans if farmers want to participate in government programs had a positive effect on the willingness of farmers to participate in the RCWP program and eventually on water quality in the project area.

Conservation Reserve Program

Carroll County has limited participation in the Conservation Reserve Program because of high land values and investment opportunities. Although participation in this program is not widespread, 75 percent of the land that is enrolled in the county (approximately 700 acres) is in the RCWP project area. By taking highly erodible cropland out of production, the Conservation Reserve Program had an effect on improving water quality, but a slight one because of the limited acreage enrolled in the program.

Dairy Situation

Although the dairy industry is the most prevalent type of farming in the county, the 1980s saw a 33 percent reduction in the number of dairy producers. As indicated in Table 1, not only did the number of dairy producers decline but the wholesale price of milk remained flat or declined during the sign-up period and did not keep up with the increase in the inflation rate. Although these are countywide statistics, a vast majority of the dairy farms are in the project area.

The economics of the dairy situation during the 1980s tended to have a negative effect on the willingness of dairymen to participate in the RCWP project. Although most dairy farms were located in critical or high priority areas, many dairymen just did not have the money to match RCWP's cost-sharing assistance. Therefore, a large percentage of I&E efforts focused on encouraging these dairy farmers to participate in the program because of its high potential to affect water quality.

Rate of Program Participation

The following summarizes several significant events that occurred during the past decade within the Double Pipe Creek project. The summary also shows that the rate of participation was fairly consistent between 1981 through 1986.

- **1979** – Proposal for Double Pipe Creek project submitted.

Table 1.—Carroll County, Maryland, dairy summary: 1980 to 1990.[1]

YEAR	COW NUMBERS	MILK PRODUCED (1,000 LBS.)	NUMBER OF PRODUCERS[2]	WHOLESALE MILK DOLLARS PER HUNDRED-WEIGHT (CWT)[3]
1980	17,700	252,200	293	13.60
1981	18,000	259,800	289	14.30
1982	18,100	262,000	284	14.00
1983	18,800	262,800	266	14.00
1984	19,500	252,200	247	14.00
1985	19,800	271,000	238	13.10
1986	20,000	262,900	222	12.90
1987	17,500	249,300	215	13.10
1988	13,500	240,000	215	13.00
1989	12,900	235,000	197	14.50
1990	12,900[4]	241,900[5]	192	14.90

[1]Source: Maryland Agricultural Statistics Summaries from 1979-89.

[2]Source: Federal Milk Market Administrator, Middle Atlantic Milk Marketing Area. All figures are for the December reporting period.

[3]Source: Average price, F.O.B. or receiving station.

[4]Source: Estimates.

[5]Source: Estimates.

- **1980**
  - Proposal approved for Double Pipe Creek Project.
  - The Local coordinating committee determined that "any farm in the project area having a critical impact on water quality regardless of the distance to streams, will be considered a high priority request."
  - Cost-share earned: $8,953.00
  - Contracts approved: 5
- **1981**
  - Cost-share earned: $176,518
  - Contracts approved: 25
- **1982**
  - Cost-share earned: $283,642
  - Contracts approved: 25
- **1983**
  - Versar, Inc., completed baseline data Stage I of monitoring.
  - Cost-share earned: $316,515
  - Contracts approved: 18
- **1984**
  - Signs given to participants completing BMPs.
  - Critical area definition was questioned by the national coordinating committee.
  - Law was passed requiring that a conservation plan accompany easement rights bids on land entering the Maryland Agriculture Land Preservation Program.
  - State agreed to continue monitoring when Versar contract expired.
  - Demonstration Day held (85 people in attendance).
  - Cost-share earned: $187,815
  - Contracts approved: 21
- **1985**
  - BMP-15 and BMP-16 added to the project.
  - Contracting period extended through December 31, 1986.
  - Cost-share earned: $502,836
  - Contracts approved: 19
- **1986**
  - Extension agent hired to write nutrient management plans and to implement BMP-15 and BMP-16.
  - Cost-share earned: $382,125
  - Contracts approved: 15
- **1987**
  - Cost-share earned: $489,773
- **1988**
  - Lease Brothers received special approval for a contract in the expectation that monitoring on their farm would benefit the project.
  - Best Management Progress Tour was held to demonstrate progress and practices completed (150 participants).
  - Cost-share earned: $236,014
  - Contracts approved: 1
- **1989**
  - Cost-share earned: $168,033
- **1990**
  - Cost-share earned: $136,464

Evaluating the Success of the I&E Efforts

The Double Pipe Creek RCWP project's overall goal of having 50 percent of the designated critical areas in the watershed under contract was not quite met. However, the individual BMP goals for the project were met. According to the results of the monitoring program conducted so far, water quality improvement goals have been achieved for phosphorus but not for nitrogen. A continuing effort to reduce nitrogen levels in streams coming from farm land will be made through the efforts of Maryland's Nutrient Management Program conducted by the Cooperative Extension Service.

The goals and objectives of the I&E effort were completed as originally outlined. The I&E subcommittee was very active throughout the sign-up period and received excellent cooperation from all government agencies. Extension provided the leadership in organizing and supervising the I&E effort. Funding for the educational effort was administered through the Maryland Extension Service.

The plan developed to inform farmers was followed completely with only minor changes and additions. Just about every type of creative method of disseminating information and motivating farmers to participate was tried in this program.

Of all the promotion efforts used, obviously some were more effective than others. The tours had excellent participation and always resulted in an increased rate of contract sign-up. Feature and news articles in the local and county papers had the most positive effect by constantly keeping the project before potential participants. Individual farm visits

near the end of the program helped recruit farmers from highly critical areas. All other educational efforts had less impact but were useful in encouraging participation to some degree.

Many of these same innovative methods of drawing attention to the need for improving water quality and promoting conservation have been implemented in other water quality projects such as the Piney-Alloway Creek Watershed project (also located in Carroll County, Maryland).

Recommendations to Improve Future Water Quality Demonstration Projects

The I&E effort for the Double Pipe Creek RCWP project was implemented primarily during the program's first six years. Our efforts centered on securing participation in the program. Now that the project is complete, it is easy to see that some things should have been done differently, not at all, or more extensively.

Recommendations to improve future water quality demonstration projects include the following:

1. Although a wide array of information and education activities were used to promote the Double Pipe Creek project in Carroll County, a sharing of ideas with some of the 21 other RCWP projects could have provided additional ideas during the first four years. RCWP project sharing should be included in future I&E planning.
2. In the Double Pipe Creek project, excellent cooperation existed between all the agencies. The local coordinating committee and I&E subcommittee had good participation from local farm organizations and public officials. Having I&E funding handled separately through the Cooperative Extension Service worked extremely well and enabled projects to be funded quickly. This funding method should be continued.
3. As the sign-up period was nearing the end, more time should have been devoted to making one-on-one contacts with potential participants. A greater effort during this time could have resulted in a higher number of contracts. One-on-one methods should be more vigorously pursued in the initial stages of future I&E efforts.
4. A separate budget line should be developed to provide for the printing of the annual and 10-year reports.
5. The original guidelines for the project should indicate the expected contents of the yearly, 10-year, and close-out reports.
6. A tracking and record system should be developed at the beginning of the project to facilitate easier and more pertinent data collection. In addition, the forms used to report the data should be designed early in the project.

Conclusion

All government agencies worked closely with the local coordinating committee and the I&E subcommittee under the CES leadership. It is impossible to separate activities performed by individual agencies because all projects were coordinated under the aegis of the I&E subcommittee; however, the bulk of work was done by CES, ASCS, and SCS. The local coordinating committee and the State coordinating committee approved and helped promote various projects. The agencies responsible for water quality monitoring had a very limited role in the I&E work. The I&E subcommittee made a substantial contribution to the promotion and eventual success of the Double Pipe Creek RCWP project.

Nutrient Management Educational Initiative: Using Demonstration and Research Plots and the Penn State Nitrogen Quick Test in the Upper Conestoga RCWP

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ABSTRACT

The Upper Conestoga Rural Clean Water Program project was started in the late 1970s to address water quality problems, including excessive runoff and soil erosion. By 1985, U.S. Geological Survey monitoring identified nutrient over application and leaching as the major contributors to high nitrates in surface and groundwater. In January 1986, Penn State Cooperative Extension began developing nutrient management plans for farmers. Between 1986 and 1991, 365 farms developed nutrient management plans. An average of 10 demonstration and research plots were conducted each year to demonstrate the validity of the nutrient management plans, and a soil nitrogen quick test was administered (both developed by Penn State Extension). Using a randomized block design with 3 to 4 replications, plots were scattered throughout the project to help farmers see the effect of the proposed recommendations on crop yields. Annual reports showing the amount of fertilizer recommended and its results as measured by yield increases were sent to farmers in the project area. By allowing farmers to experience these demonstrations, the recommendations made by the nutrient management plan and soil nitrogen quick test became believable to the farm community.

The Conestoga River drains approximately 477 square miles of land in northeastern and central Lancaster County and portions of Lebanon, Berks, and Chester counties (see Fig. 1). Major streams within the Conestoga watershed include the Cocalico, Muddy, Mill, and Little Conestoga creeks. About 35,000 people live on the predominantly rural farmland, mostly in rural homes and small villages. The project area contains 132 square miles (110,000 acres), half of which is used for farming, while much of the remaining is open woodland. Approximately 1,250 farms are located in the project area, each with an average of 52 acres of cropland. About 55 percent of the cropland (36,000 acres) is planted to corn; 11 percent (7,500 acres), to various small grain crops (barley, wheat, and oats); 28 percent (18,000 acres), to alfalfa and other hay crops; and 2 percent (1,500 acres), to tobacco and other cash crops. Most farms in the project area are intensive livestock farms.

Area residents depend on water that originates within the watershed. With the exception of the city of Lancaster and the borough of New Holland, residents living within the watershed rely solely on groundwater.

The topography is rolling with 0 to 40 percent slopes; slopes on farmed land ranges from 0 to 10 percent. The soils, mostly well-drained, derive from limestone, with smaller areas of shale and sand-

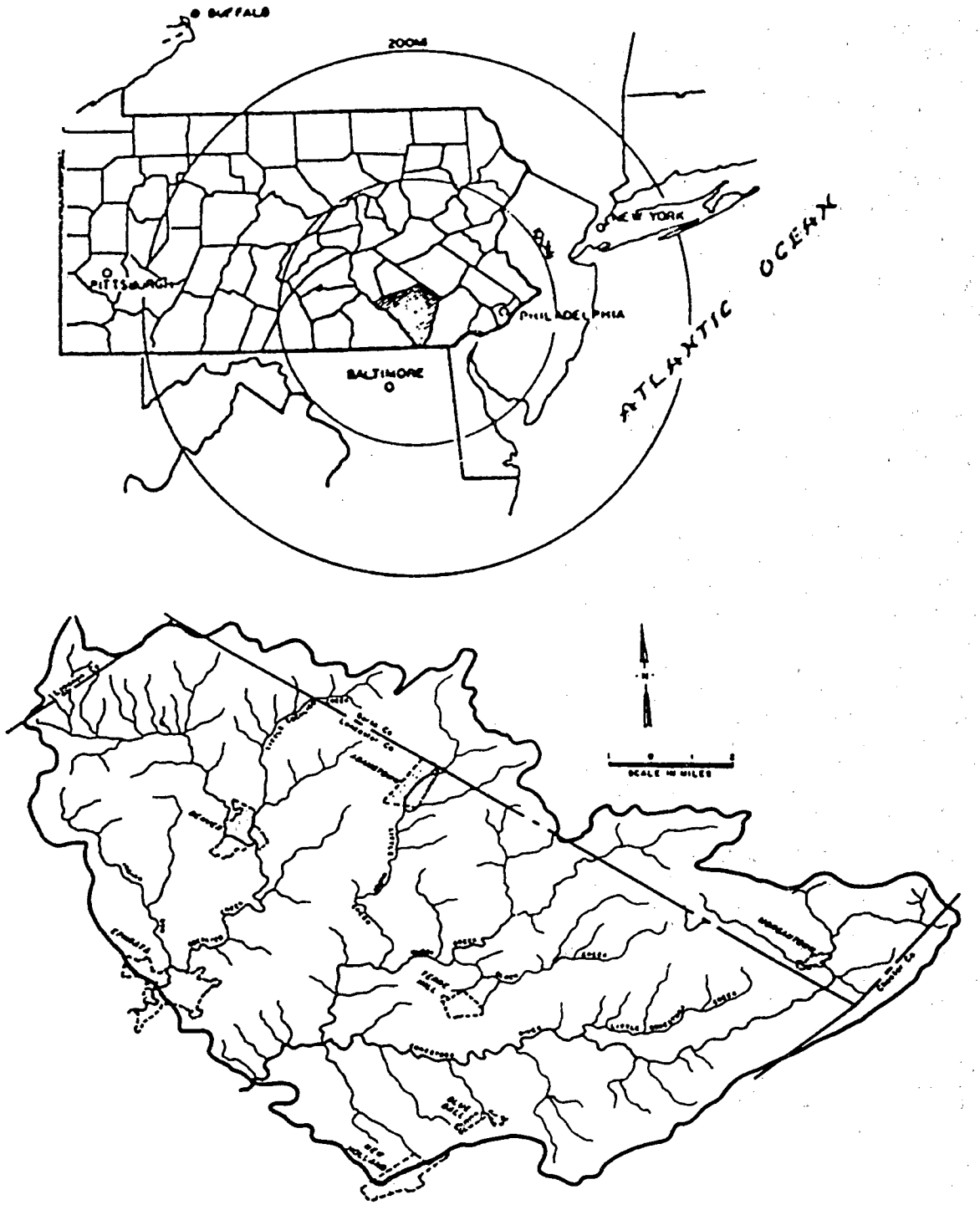

Figure 1.—Maps of the Conestoga Headwaters RCWP project area.

stone. Soil depth ranges from 2 to 8 feet. The limestone soils, located near rivers, are bounded on the north by upland soils formed from Triassic rocks and on the south by soils derived from ingenues and metamorphic rock. Average yearly rainfall in the area is 42 inches, with 22 inches occurring during the growing season. About 20 inches of the total rain in the area will evaporate or transpire, 9 inches will run off, and the remaining 13 inches will percolate into the soil to help recharge the groundwater system.

The farming population, comprised almost entirely of people with German and Swiss heritage, is often referred to as the Pennsylvania Dutch or Plain

People. More than 70 percent of all farm families are members of the Old Order Mennonite or Amish churches, which inculcate a close tie to land and farming. Education is limited to one-room parochial schools. Students are not educated beyond the age of 14, and teachers are usually young women with no formal education. The most conservative believers use horses and mules for power on the farm and transportation; some of the more liberal use tractors on steel wheels, while a few are so liberal as to drive tractors with rubber tires and cars painted entirely black (including the chrome). Very few farm families have radio or television.

The Nutrient Management Problem

The area's access to major markets (Philadelphia, Baltimore, Washington, D.C., and New York), the population's desire or church mandate to farm, and the limited land available for farming have contributed to dwindling farm size and an increased dependence on livestock as an income source for area farmers. Families have divided farms several times to help other family members earn their living on the land. Livestock numbers have increased by importing feed. Data from the Pennsylvania "Crop and Livestock Summary" for 1960, 1970, 1980 and 1990 show this dramatic change on farms in Lancaster County (see Tables 1 and 2).

In 1960, Lancaster County had 482,579 acres of farm land; however, by 1989, that area had declined to 304,212 acres—a decrease of 37 percent. In 1960, 33 percent of the total farm land was planted to corn, but by 1989 that percentage had increased to 52 percent. Increased animal numbers (and manure), less land to spread the manure on, and an increasing proportion of land in row crops contribute to increased soil erosion and transport of nutrients to surface water. Compounding these problems is the fact that Lancaster County has the fastest growing population in Pennsylvania. The population is projected to exceed 440,000 by the year 2000.

Several studies in the area indicate problems of bacterial contamination and high nitrate levels in surface and subsurface waters. Agriculture is not the only nonpoint source of water pollution; other contributing factors include

- residential septic systems,
- land application of sewage sludge, and
- lake eutrophication resulting from large numbers of wild ducks and geese.

In 1977, as part of a statewide plan for agriculture and earth-moving activities, the Conestoga River was designated as the watershed with the greatest potential to be polluted by agricultural nonpoint pollution sources. This conclusion was based on (1) the number of farms, (2) the animal density on the farms, (3) the percentage of the land used in growing row crops, and (4) previously identified water quality problems in the area. Detailed information about using commercial fertilizer, manure, and pesticides was gathered and tabulated for the project area.

Table 1.—Lancaster County farms: land use changes 1960 to 1989.

CROPS	1960	1970	1980	1989	% CH.
Corn acreage:	113,500	142,600	200,700	157,000	+38
Oat acreage:	9,100	3,600	3,000	2,800	–69
Barley acreage:	20,800	23,500	8,600	9,700	–53
Wheat acreage:	58,400	36,300	28,500	15,400	–74
Tobacco acreage:	27,700	17,270	12,000	8,640	–69
All hay acreage:	97,000	89,200	81,800	82,000	–15
Total all acreage:	345,000	330,000	336,150	304,217	–12

Table 2.—Lancaster County farms: livestock number changes 1960 to 1989.

ANIMALS	1960	1970	1980	1989	% CH.
Dairy cows	64,000	67,100	94,000	97,000	+52
All cattle	N/A	N/A	273,700	259,000	
Hogs	44,000	109,000	337,000	358,000	+714
Chickens:					
Layers	3,100,000	3,109,000	7,579,400	8,979,700	+190
Broilers	7,468,000	18,028,000	42,106,000	55,268,640	+640

In June 1982, a 208 assessment survey of 409 farms, called "Assessment of Nonpoint Sources of Pollution from Agriculture in The Conestoga River Watershed," showed that an average of over 400 pounds of nitrogen per acre was being applied to land used to grow corn. In addition to the nitrogen, the survey showed that farmers were applying 250 pounds of phosphorus and 200 pounds of potassium per acre each year to the same land. These nutrients came from manure or manure plus commercial fertilizer.

Critical sources of pollution identified in the Rural Clean Water Program (RCWP) funding proposal included

- animal waste,
- high rates of commercial fertilizer and pesticides applied to cropland, and
- inadequate erosion and sediment control on intensively farmed cropland.

The initial project emphasized soil erosion control as the primary means to improve water quality. The 208 assessment made the following recommendations to improve water quality:

1. Better management of manure and commercial fertilizer applications is needed.
2. Fertilizer recommendations should consider the nutrient value of manure.
3. Since only 29 percent of the farmers reported having a conservation plan, more effort is needed to encourage farmers to develop and implement conservation plans that include practices, such as terraces, waterways, diversions, and manure storage, to reduce soil erosion and to handle manure properly.
4. Minimum and no-till farming systems should be promoted to reduce soil erosion.
5. Encourage farmers to incorporate manure as soon after application as possible.
6. Animal waste storage structures should be monitored to evaluate groundwater pollution.

Nutrient management was identified as a priority in the RCWP project application (on page 8 under a discussion of soil loss):

> *Soil loss in the critical area has been estimated to be approximately 9 tons per acre per year. One of the goals of this project is to reduce soil loss to 4 tons per acre. This reduction should result in a pollution reduction of approximately 40 pounds of nitrogen (land Resource Area 148) (ST soil loss reduction x 8 pounds nitrogen/ton = 40 pounds) and 10 pounds of phosphorus (ST soil x 2 pounds/T = 10 pounds) per acre of cropland. This is a calculated annual reduction of 480,000 pounds of nitrogen and 120,000 pounds of phosphorus entering the water in the project area from the 12,000 acres targeted for treatment.*

Although the project application identified a very close relationship between erosion or runoff and nutrient management, the major problems associated with nitrates on page 9 of the 1984 Progress Report states, "The goal of this project is to reduce the levels of agricultural pollutants in both ground and surface waters." When the project was funded, money was also provided for the U.S. Geologic Survey (USGS) to monitor several small watersheds (which were confined to a single farm) and several streams for water quality improvement that resulted from conservation practices being installed on the land. A review of their findings in 1985 showed that conservation practices used to control erosion would not to be enough to deal with all water quality problems in the project area.

Between 1980 and 1985, several research projects were conducted in the area by Penn State's Department of Agronomy staff, including Richard Fox's effort to develop a soil or tissue test to determine how much nitrogen (if any) should be added to corn as a sidedress application to optimize yields; Dale Baker's work on corn-growth and soil nitrate-leaching models to help determine how excessive nitrates enter the soil profile; and Les Lanyon's development of a farm monitoring system to follow inputs and outputs of nutrients. In addition, Douglas Beegle developed a computer program to help farmers determine how much manure their livestock produced and where it should be spread to meet fertilizer recommendations based on soil test results.

Dale Baker, a professor of soil chemistry, studied 23 fields during the 1983 growing season. His study indicated that nitrogen was not the limiting factor as measured by yield. Table 3 shows his findings. Research since that date by Richard Fox suggests little response of corn to additional nitrogen if the spring nitrate-nitrogen level is above 20 to 25 ppm (76 to 95 pounds of nitrogen) per acre.

By 1984, USGS had established a network of 42 wells and one spring in the area for monitoring. It found that 67 percent of the wells in the carbonated rock portions of the project area had nitrate levels above 10 mg/L of nitrogen, while only 27 percent of the wells in the noncarbonate areas exceeded 10 mg/L.

Table 3.—Summary of selected field data collected in 1983 on 22 farms located in the Conestoga RCWP project area.

	NITROGEN APPLIED:		NO_3-N LBS/ACRE		YIELD WHOLE PLANT
	FERTILIZER	MANURE	BY SOIL ANALYSIS		DRY MATTER
SITE NO.	N	N	SPRING*	FALL*	TON/A
201	50	400	227.6	47.5	3.62
501	165	100	267.9	121.6	5.44
1002	7	650	695.8	106.4	7.52
1201	112	0	64.6	19.0	5.71
1401	12	200	39.9	19.0	5.63
1801	8	720	122.7	62.7	4.83
1901	90	180	315.4	49.4	7.64
2101	118	400	315.4	39.9	8.95

* Caculated by multiplying ppm values of NO_3-N by 3.8, which is based on the number of pounds of soil in an acre-foot.

Surface water monitoring indicated that the base flow in streams accounted for about 75 percent of the total nitrates, and median concentrations of dissolved nitrate increased steadily in the watershed's eastern end where the Little Conestoga River leaves the noncarbonate forested area and enters the intensively farmed carbonate valley. The maximum of 8.0 mg/L occurred at two sites in an area already marked by land use data (collected by the Lancaster County Conservation District) as having soils rich in nutrients available for transport to the stream (see Table 4).

Table 4.—Pre-BMP sampling results for selected sites.

	1	2A	3A	9	CHURCHTOWN
Streamflow (ft^3/second)	0.59	1.05	1.93	2.38	7.11
Nitrate (mg/L)	2.40	3.40	8.00	5.00	7.10

Nutrient Management Begins

Based on these Penn State research projects and the USGS monitoring efforts, the following major statements were made in the interim evaluation of the 1984 Progress Report for the Conestoga Headwaters:

1. Soil conservation practices are effective for controlling surface losses of chemicals (dissolved in runoff or sediment-associated) but not necessarily for controlling nitrate losses out of the root zone that ultimately reach groundwater. Sound management of nutrients from commercial fertilizer, animal manures, and legumes is necessary to prevent undue contamination of groundwater drinking supplies by nitrates, organic nitrogen, and fecal coliform bacteria.

2. Manure storage that inhibits volatilization and maximizes the plant nutrients available for field application is a potential problem. Animal waste systems on farms with high animal-to-land ratios should be designed so that plant nutrients in manure do not exceed crop fertilization requirements. Consideration should be given in the future to storage structures that minimize nitrogen availability on those farms with high animal-to-land ratios.

In the economic evaluation section of the 1984 report, Dr. Edwin Young, U.S. Department of Agriculture, Economic Research Service, Pennsylvania State University, used the CREAMS model (the Agricultural Research Survey's field-scale model for chemicals, runoff, and erosion from agricultural management systems) to estimate the surface losses of soil, nitrogen, and phosphorus that were delivered to the edge of fields. He also used the model to estimate the percolate losses of nitrate-nitrogen leached out of the root zone:

> *While structural and other [best management practices or] BMPs are effective means of controlling nutrient losses, the most effective method for controlling them is to reduce the nutrients applied to the field via fertilizer and manure management. A reduction in manure applications from 40 to 20 tons per acre results in a 40 percent reduction in nitrogen and phosphorus losses. Storage of manure to improve timing of applications leads to reductions in nutrient losses at recommended application rates. However, if excess manure is being applied to the field, nutrient losses may actually increase.*

The only BMP that reduced the amount of nitrogen getting into the groundwater using the CREAMS model was no-till planting, which leaves most of the nutrient on the surface; however, no-till planting on soils with heavy manure applications is very difficult.

Young predicted that BMPs that reduce runoff would also affect the amount of nitrogen leached into groundwater supplies. This prediction was later confirmed by monitoring. Young concludes:

> *. . . nutrient management has the potential to be the single most effective measure for controlling nutrients losses. The CREAMS modeling showed no practice nearly as effective as reducing the application of nutrients to levels compatible with crop needs. Education of farmers is needed to assist them to better manage nutrients, particularly manure nutrients. Timing, rates of application, and methods of application should be part of an overall farm plan to provide adequate fertilization for crops while minimizing losses of nutrients in surface runoff and deep percolate. . . . Further efforts to contract or simply provide technical assistance for nutrient management for farms not in the program are expected to significantly reduce the loss of nutrients from fields and barnyard areas. . . . Reliable tests for soil nitrogen and manure nutrients are necessary if farmers are to make informed choices in the fertilization of their crops. Further research and educational efforts are needed to provide local SCS or other technicians with the continuing information they need to establish state-of-the-art nutrient management plans for farmers. Factors such as animal density, crops grown, tillage practices, type of animal operations, and length of manure storage will require that technicians be able to tailor individual plans for each farm.*

A proposal to begin a Nutrient Management Education Initiative was submitted to the national RCWP committee in 1985. This initiative outlined a plan to educate farmers in the project area about nutrient management and develop nutrient management plans using the approved technologies of the time–soil and manure testing. The portion of the nutrients available in the manure was to be deducted from the soil test fertilizer recommendations for the yields obtained on the farm. Goals of the Nutrient Management Plans were to reduce

- nitrogen applications by 750,000 pounds on 20,000 acres by 1988 (about 37.5 pounds per acre) and
- phosphorus applications by 375,000 pounds on 20,000 acres by 1988 (about 18.75 pounds per acre).

The National RCWP Committee approved the transfer of funds set aside for the construction of conservation structures to this initiative. On January 2, 1986, Penn State Extension opened its Nutrient Management Office in New Holland, Pennsylvania, with two staff members. (Approval for the project had come earlier in 1985, and the Eastern Lancaster County School District helped by granting me an 18-month leave to work on this project.)

During October, November, and December 1985, soil samples were taken in this area on 11 farms in a small watershed monitored by USGS. The Lancaster Conservation District had also been gathering information about manure spreading and fertilizer applications in this area. Therefore, this area was viewed as a good place to introduce nutrient management.

Nutrient Management Planning

Nutrient management plans were developed using the following procedure:

1. Soil test each field to determine the soil reserves of P_2O_5 and K_2O.
2. Obtain an official Penn State recommendation for fertilizer needed to yield the projected goal for each field.
3. Determine livestock numbers, types, and average weights; the number of days livestock were present on the farm; and the number of days manure was collected from the livestock for field application.
4. Perform a nutrient analysis of each manure type used on the farm.

This information was computer-analyzed, and each farmer received a plan containing a manure application rate for each field and a recommendation for any additional fertilizer nutrients needed to obtain optimum yields. Because of time limitations, plans for the first 11 farms were developed without using a manure analysis. Tables 5 and 6 show the manure values used for these farms derived from the 1985 to 1986 Penn State Agronomy Guide.

Initially, the first 11 plans were to be written using book values for manure nutrients so that we could begin the first growing season with some nutrient management plans in place. Manure tests would be taken after the spring rush, and plans changed, if necessary, for the 1987 growing season. However, a large pool of nitrogen was identified that had not been addressed in the planning process.

For example, a dairy farm is applying 25 tons of dairy manure per acre each year; the manure is spread on a daily basis. The amount of nitrogen per

Table 5.—Total plant nutrient values from manure.

KIND	DAILY MANURE PRODUCTION (lb/1000 lb LIVE WEIGHT)	APPROXIMATE NUTRIENTS (lb/ton)		
		N[1]	P_2O_5	K_2O
Cattle (fresh, 85% water)	85	10	3	5
Poultry				
(liquid, 95% water)	300	10	7	3
(fresh, sticky, 75% water)	61	30	20	10
(moist, crumbly, 50% water)	32	40	40	20
(crumbly, 30% water)	22	60	55	30
(dry, 15% water)	18	90	70	40
Swine	100	10	6	9
Sheep	40	12	7	15
Horses	50	6	3	10

[1]Important: Only a portion of the total nitrogen is available to crop in the year in which it is applied. The actual amount depends on handling (see the Penn State Agronomy Guide).

Table 6.—Nitrogen available from manure.

APPLICATION METHOD	N AVAILABILITY FACTOR*		% POTENTIAL LOSS OF AVAILABLE N	
	POULTRY	OTHER	POULTRY	OTHER
Immediate incorporation	0.75	0.50	0	0
Incorporation after 2 days	0.45	0.35	40	30
Incorporation after 4 days	0.30	0.30	60	40
Incorporation after 7 days or no incorporation	0.15	0.20	80	60

*Use these factors and total nitrogen values or a manure analysis to calculate available nitrogen as follows: Available N = (total N) X (N availability factor).

ton using the book value in Table 5 is 10 pounds. The Penn State Agronomy Guide (1985 to 1986) procedure for calculating nitrogen is Total nitrogen = (tons of manure applied) x (nitrogen per ton) x (nitrogen availability factor [Table 6]) In this example, Total nitrogen = (25 tons) x (10 pounds per ton) x (0.20 availability factor), which calculates to a total of 50 pounds of nitrogen available from the manure application. The total nitrogen in the manure is 25 tons times 10 pounds per ton or 250 pounds of nitrogen.

Approximately 75 pounds of nitrogen (30 percent) was lost to the atmosphere because it was not incorporated. Therefore, after subtracting the 50 pounds of nitrogen for the crop plus the 75 pounds lost to the atmosphere from the 250 total pounds of nitrogen in the manure, 125 pounds of nitrogen remains that has not been accounted for.

Major Change in Nutrient Management Planning

On October 21, 1987, a letter was sent to Dr. Myron Johnsrud, administrator of the Cooperative Extension Service, stating:

> *Manure nitrogen management using the traditional approach can result in applying as much as 875 pounds of manure nitrogen to supply 175 pounds of nitrogen to a corn crop (20 percent of 875 = 175 lbs.). This excess nitrogen (700 lbs/acre in this example) will escape into the environment. With the lack of research addressing the residual nitrogen in manure, the nutrient Management Office made the following assumption: if the amount of manure applied per acre was constant over a period of years, 35 percent of the residual nitrogen will become available in any given year. Using this approach, it is only necessary to apply 318 pounds of manure nitrogen to supply the 175 pounds of nitrogen needed by a corn crop ([20 percent + 35 percent] of 318 = 175 lbs.). This leaves only 143 pounds of nitrogen to escape into the environment, a savings of 557 pounds of nitrogen. During the 1986 and 1987 growing season many test plots were conducted to validate this assumption. Farmers were asked to apply livestock manure in their usual manner. After corn was planted, the nutrient management staff applied nitrogen at the following rates: zero pounds, 50 pounds, 75 pounds, and 100 pounds per acre. Plots were randomly replicated in blocks of four. An attempt was made to have plots on farms that had different amounts of nitrogen recommended using this assumption. Plots were hand harvested and yields calculated on the per acre basis.*

The results of this data are shown in Table 7.

Table 7.—1986 and 1987 yield data (assume: residual N from manure will contribute an additional 35 percent nitrogen).

NITROGEN RECOMMENDATION	NUMBER OF PLOTS	OPTIMUM YIELDS (no. at rate of N)
0	12	10 at 0 2 at 50
50	6	5 at 0 1 at 50
75	1	1 at 0
100	1	1 at 50
180	1	1 at 200

Over the two-year period, a total of 21 plots was used to check the validity of this assumption. Only three fields responded to more nitrogen than projected, while eight fields needed less nitrogen than was estimated using the assumption. Ten fields had optimum yields at the projected amount of nitrogen. Eighty-six percent of the fields tested had adequate nitrogen using this assumption, and none of the fields that had yield increases with additional nitrogen above the recommended level had yields that were significantly different.

If this assumption were followed on the 3,736 acres of corn grown in the project area, an additional 186,800 pounds of nitrogen could be reduced from the fertilizer recommendations to bring the total reduction to approximately 67 pounds of nitrogen per acre per year. Penn State University's College of Agriculture adopted a change in its 1989-1990 Agronomy Guide to reflect this residual nitrogen from manure. Because the limited data was created in only a small portion of the State, the values adopted in the Guide are less than the 35 percent used in the RCWP project area. The residual nitrogen credit ranged from 7 percent to 25 percent in the Agronomy Guide. These credits are shown in Tables 8 and 9, which also reflect increased information on manure nutrients. Starting in 1986, crop management meetings sponsored by the Cooperative Extension Service have stressed the need for manure analysis. (A program to test manure, which was also administered through county offices, generated the additional information included in Tables 8 and 9.)

The use of starter fertilizer was also analyzed in the project area. If a significant reduction in phosphorus was to be achieved, only two areas of soil fertility management had possibilities (other than reducing manure application rates):

- **phosphorus** applications would have to be removed from the starter fertilizer (if this could be done without affecting yields), and
- **potassium** would have to be taken out of the hay fertility programs.

Removing potassium from the hay program was not a problem because soil test recommendations for hay management on soils high to excessive in potassium do not recommend additional application. Information was not available, however, to support the elimination of phosphorus from corn starter fertilizer. Between 1986 and 1987, 17 test plots were conducted on farms in the project area to assess if the starter fertilizer applications could be eliminated. Participating farmers were asked to disconnect the fertilizer applicator drive on half their corn planter. With a four-row planter, this process created a plot of four rows with, and four rows without, starter fertilizer, replicated a minimum of four times. An attempt was made to have plots on farms with different

Table 8.—Average total nutrient content of manure.

ANIMAL TYPE	DAILY PRODUCTION (lb/1000 lb live wt.)	MANURE % DRY MATTER	(lb/ton or 100 gal) N	P_2O_5	K_2O
Dairy cattle:					
Solid	82	13	10	4	8
Liquid			2.8	1.3	2.5
Veal	63	2	8	2	11
Beef cattle	60	12	11	7	10
Swine:					
Pigs	65	9	14	11	11
Gestating sows	32	9	14	11	11
Sow and pigs	88	9	14	11	11
Boar	31	9	14	11	11
Liquid			3.5	2.0	1.5
Sheep	40	25	23	8	20
Horses	45	20	12	5	9
Poultry:					
Fresh	61	25	30	20	10
Moist	32	50	40	40	20
Crumbly	22	70	60	55	30
Dry	18	85	100	70	40

Important note: Have manure analyzed when possible. Actual values may vary over 100 percent from averages in table.

Table 9.—Percentage of total manure nitrogen remaining available to crops after storage and handling as affected by application method and field history.

A. CURRENT YEAR, TIME OF APPLICATION, AND INCORPORATION	N AVAILABILITY FACTOR*	
	POULTRY MANURE	OTHER MANURE
Manure applied for corn or summer annual following year:		
Applied in spring		
Immediate incorporation	0.75	0.50
Incorporation within 2 days	0.50	0.40
Incorporation within 3-4 days	0.45	0.35
Incoporation within 5-6 days	0.30	0.30
Incorporation within 7 days		
No incorporation	0.15	0.20
Applied previous fall or winter with no cover crop	0.15	0.20
Applied previous fall or winter with cover crop		
Harvested as silage*	0.15	0.20
Used as green manure	0.50	0.40
Manure applied for small grains		
Applied previous fall or winter	0.50	0.40
B. HISTORY FREQUENCY OF MANURE APPLICATION ON THE FIELD		
Rarely received manure in the past	0	0
Frequently received manure (4-8 out of 10 yrs.)	0.07	0.15
Continually received manure (>8 out of 10 yrs.)	0.12	0.25

* Low availability factors do not indicate a net loss of nitrogen (N). A large amount of N is removed in the cover crop silage. This N will be recycled in the manure when silage is fed.

Note: To calculate total amount of nitrogen available from manure, add the appropriate value from Table 9, section A based on application method and livestock type to the appropriate value from Table 9, section B based on the frequency of manure applications and livestock type, then multiply this answer by the manure analysis value or the nitrogen value from Table 8.

levels of phosphorus. Results of these plots can be seen in Table 10.

Although it is difficult to draw any conclusions from the data, it appears that a large percentage of the farms in the project area could eliminate starter fertilizer applications without reducing yields. Data for the 10 replicated plots conducted in 1986 showed that only three locations had increases in yield, three had the same yield, and four locations had decreased yields when starter fertilizer was used (Table 10). Statistical differences were not calculated for the plots. However, the three plots that had increased yields with starter fertilizer averaged an increase of 9 bushes per acre, while the four plots that had decreased yields with starter fertilizer averaged a decrease of 21.5 bushels per acres. Less dramatic differences were found in 1987 (Table 10). Over the two years, 17.6 percent of the fields (3 of 17) showed a response to starter, 47.1 percent (8 of 17) had increased yields by not applying starter fertilizer, and 35.3 percent (6 of 17) had the same yield with or without starter fertilizer. The nonstarter plots showed an average increase of 16.8 bushels per acre, while those that received starter fertilizer showed an increase of 8.25 bushels per acre.

Table 10.—Starter fertilizer vs. no starter fertilizer.

YEAR	NO. PLOTS	STARTER FERTILIZER NO. WITH INCREASE IN YIELDS BUSHELS/ACRE INCREASE	NO STARTER FERTILIZER NO. WITH INCREASE IN YIELDS BUSHELS/ACRE INCREASE
1986	10	3 9 bu	4 21.5 bu
1987	7	3 7.5 bu	4 8.5 bu

Using Demonstration and Research Plots

The educational initiative portion of the RCWP project was successful primarily because participating farmers had personal contact with Extension agents that resulted in one-on-one instruction related to nutrient management and water quality issues (leading to the development of a site-specific plan based on soil and manure tests) and the use of on-farm demonstration and research plots. During each year of the program, each agent taught approximately 40 farmers how to develop a nutrient management plan, and test plots were a valuable teaching aid. Over 50 demonstration and research plots were conducted between 1986 and 1991. Although 28 plots compared the recommended rate of fertilizer in the nutrient management plan with a higher rate of fertilizer, only one showed a significant yield increase by adding more nitrogen than the nutrient management plan recommended (perhaps because of a wet growing season and identification). Twenty-three

plots compared starter fertilizer with no starter fertilizer; only three showed a significant increase in yield resulting from starter fertilizer.

The design of the nitrogen demonstration and research plots was a simple 4 x 4 random block arrangement. Each replication contained four or eight rows of corn 25 to 35 feet long. Under most circumstances the nitrogen application rate was (1) 50 pounds per acre less than the plan called for, (2) what the plan called for, (3) 50 pounds more than the plan called for, and (4) 100 pounds per acre more than the plan called for. Harvesting was done by hand.

The starter demonstration and research plots used a simple strip plot design. Depending on the number of rows planted with one planter pass, the plot would vary from two to four rows in width. On some occasions, the starter strips overlaid the random block nitrogen plots. When this design was used, nitrogen plots were always eight rows wide—four with and four without starter fertilizer. Plots were located where they could be seen easily by the cooperating farmer and several neighbors. Whenever possible, the farmer was asked to help harvest and evaluate the plots.

The Penn State Nitrogen Quick Test

Nitrogen fertilization rates are the most difficult to formulate. Many factors (including the weather, nitrogen source, time of application, and crop) influence how much nitrogen is needed to produce optimum crop yields. Research continues to seek a chemical analysis method for nitrogen either in the soil or in the plant at early stages of growth to calibrate the addition of nitrogen to reach optimum yields.

The total nitrogen requirement of plants can be met in several ways. First, soils supply nitrogen through organic matter decay. Second, legumes and manure can supply significant amounts of nitrogen. Third, nitrogen fertilizer can be used. However, nitrogen behavior in the soil is very complex (Fig. 2). Over 98 percent of the nitrogen in a typical soil profile is unavailable to plants, according to Fox. The availability of nitrogen as nitrate is based on microorganisms in the soil that are very sensitive to weather and soil conditions. Soil nitrates are most available in late spring when soils are warm and in late fall when crop demand drops. Since corn has its greatest demand for nitrogen 30 to 40 days after emergence, a soil test used at this time is ideal for determining if additional nitrogen is needed to optimize crop yields.

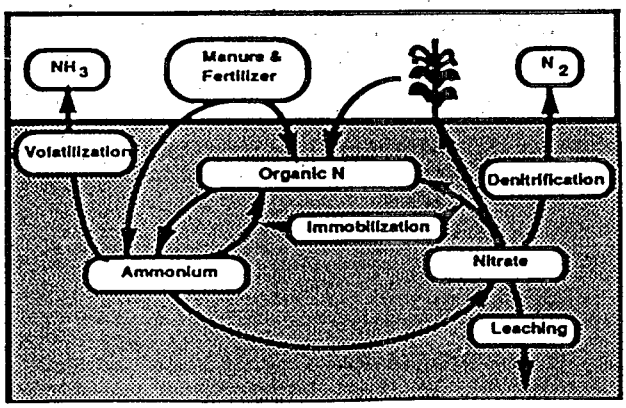

Figure 2.—The nitrogen cycle.

The graph in Figure 3 shows the results of 87 field research experiments by Fox and associates at Penn State before the test was made available in Pennsylvania. The graph indicated that the nitrate-nitrogen level from this test was very good for identifying soils in which a yield increase will occur after fertilizing with nitrogen. In the graph, relative corn yield is the yield with no nitrogen applied relative to the maximum yield achieved by adding nitrogen fertilizer. A relative yield near 1 indicates that the yield without nitrogen is near or equal to the maximum yield, which means little or no yield increase can be expected from adding nitrogen fertilizer. The test is primarily recommended for use on fields with significant organic nitrogen contributions from manure applications or forage legumes in a rotation. However, the test has not been able to predict nitrogen from alfalfa in a no-till farming system. The Nitrogen Quick Test became the final educational tool and initiative that the Extension staff had to help farmers deal with balancing crop nutrient needs.

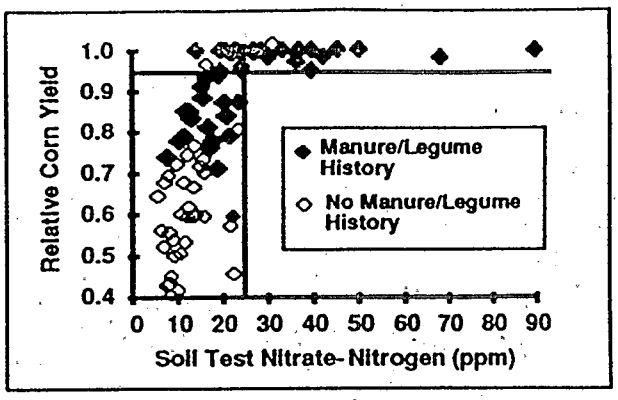

Figure 3.—Yield comparisons.

The procedure to use the Nitrogen Quick Test is relatively easy:

1. Apply manure based on nutrient management plan recommendations.
2. If nitrogen is needed based on the plan, apply a minimum at planting. If nitrogen is used as a herbicide carrier, use a maximum of 50 pounds per acre.
3. When the corn is 12 inches tall, take 10 to 20 core samples to a depth of 12 inches if possible.
4. Combine, crumble, and dry the samples as soon a possible.
5. Using the Penn State Nitrogen Quick Test, analyze the soil for nitrate-nitrogen.
6. Determine the sidedress nitrogen recommendation from Table 11.

Accomplishments

The potential value of fertilizer savings is estimated to be $165,415.75 for nitrogen at $0.25 per unit; $100,973.10 for phosphorus at $0.30 per unit; and $42,223.20 for potassium at $0.15 per unit for a total potential fertilizer savings on the 365 farms of $308,612.05 annually. Actual reductions were slightly less. Two surveys were performed to see what farmers had actually done with the recommendations. The first survey conducted in 1987 found that farmers had reduced their nitrogen application rates by 55 percent of recommended levels and their phosphorus application rates by 33 percent. A second survey in 1989 found that farmers had reduced their nitrogen application rates by 79 percent of the recommended levels and their phosphorus application rates by 45 percent. Actual accomplishments in the nutrient management project are shown in Table 12.

Table 12.—Project accomplishments.

	GOALS	ACCOMPLISHMENTS
Plans	20,000 acres	24,134 acres
Reduce N	750,000 lbs.	661,663 lbs.
Reduce P_2O_5	375,000 lbs.	336,577 lbs.
Reduce K_2O	No goal	281,488 lbs.

Conclusion

Nutrient management and soil nitrate testing are great tools to help reduce excessive applications of nitrogen. However, even with the use of these tools, crops cannot be grown without allowing some nitrogen to leach beyond the root zone. Elimination of nitrate leaching will be accomplished only when plants are able to glean 100 percent of the nitrogen in the soil and when application rates do not exceed plant needs. Currently, however, to meet the nitrogen needs of a plant, nitrogen must be applied at rates beyond this level.

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Table 11.—Sidedress N fertilizer recommendations for corn.

SOIL TEST LEVEL (ppm NO_3-N)	CORN YIELD GOAL: GRAIN (bu/a) OR SILAGE (T/A)				
	100/17	125/21	150/25	175/29	200/33
	SIDEDRESS N RECOMMENDATIONS (lbs. N/A)				
0–10	100	130	160	190	220
11–15	75	100	125	150	150
16–20	50	75	100	125	125
21–25	25	50	75	100	100
25 +	0	0	0	0	0

Involving the Agricultural Chemical Industry in Nutrient Management

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ABSTRACT

Nutrient management planning was a major component of the Upper Conestoga Rural Clean Water Program project. Nutrient management plans called for the total reduction of 661,663 pounds of nitrogen, 336,577 pounds of phosphorus, and 281,488 pounds of potash, all of which amounted to $308,612/year in fertilizer savings for the 365 farmers. A financial bonus for farmers, these reductions cut into the profits of the local fertilizer companies that served them. From the opening of the nutrient management office in 1986, a yearly fertilizer dealer meeting was held to keep fertilizer and pesticide dealers abreast of the Upper Conestoga's goals and accomplishments. These meetings also surveyed business opportunities related to nutrient management, such as crop consulting and manure marketing. Fertilizer dealers participated in field testing the Pre-Sidedress Nitrogen Soil Test. Communication channels opened through these meetings were crucial to the success of nutrient management plans and the support of fertilizer dealers in the farm community was critical to the credibility of the RCWP nutrient management program.

Nutrient management planning was a major component of the Upper Conestoga Rural Clean Water Program (RCWP) project. Nutrient management plans that were developed called for the total reduction of 661,663 pounds of nitrogen, 336,577 pounds of phosphorus, and 281,488 pounds of potash, reductions that amounted to $308,612/year in fertilizer savings for the 365 farmer-participants. Although this was a financial bonus for farmers, it cut into the profits of the local fertilizer companies.

Support from the agricultural chemical industry was important to the success of an educational nutrient management program. Fertilizer salesman were respected and valued crop consultants in the Upper Conestoga watershed. The local fertilizer vendors had a long history of working with the Cooperative Extension Service and local agriculture teachers on educational programs. Most fertilizer vendors were following then-current Penn State recommendations when calculating manure nutrients and fertilizer needs. However, as a result of agronomic research done in the Upper Conestoga RCWP, in 1987 Penn State changed the way manure nitrogen availability was calculated — a change that accounted for most of the fertilizer reduction gained in the RCWP nutrient management program.

In 1986, Penn State Cooperative Extension opened a nutrient management office for the RCWP project and hired two staff to develop nutrient management plans for local farmers. In January 1987, the first fertilizer dealer meeting was held, and 22 participants from 13 dealerships attended. These dealerships represented most of the fertilizer sales in the county. At the meeting, dealers learned about the nutrient management component of the project, heard some preliminary results from water quality monitoring, and discussed soil fertility as well as Penn State's nutrient management computer program.

In 1988, the fertilizer vendor meeting included an explanation of the new figures recommended by

Penn State's Agronomy Department for calculating residual nitrogen from manure applications. These figures gave credit to the breakdown of organic nitrogen from previous years' manure applications and led to a decrease in fertilizer recommendations for fields receiving manure. Results of local test plots conducted by RCWP staff and Penn State researchers were shared each year. Information on pesticide safety was also incorporated into the programs because most fertilizer vendors also sell pesticides.

In 1989 and 1990, fertilizer vendor meetings began to focus on business opportunities created by nutrient management, among them custom manure hauling, crop consulting, manure marketing, and processing and packaging of poultry litter. Attendance at these meetings increased to 45 or 50 people representing approximately 25 fertilizer companies; many of these visitors, although located in other parts of Pennsylvania, were interested in nutrient management and its impact on their businesses.

Increased fertilizer vendor attendance could be attributed to their excitement about the opportunity to be a part of the solution. The agricultural chemical industry had historically felt unfairly blamed because the increase in livestock numbers — not pounds of commercial fertilizer — had exacerbated nutrient problems. However, of all the agricultural service people (including veterinarians, feed salesmen, and milk inspectors) who educate farmers regularly, the agricultural chemical salesmen had the most expertise in nutrient management and agronomic crop production. Although nutrient management in many cases reduced fertilizer sales, vendors recognized farmers' need to use crop consultants. Through fertilizer sales, agricultural chemical dealers had traditionally profited by increasing farmers' profitability. Now that fertilizer sales were not increasing profits, fertilizer dealers were anxiously looking for new opportunities to serve farmers.

The meetings were the most visible aspect of the fertilizer vendor involvement. In addition to providing information about RCWP, these meetings encouraged an open dialogue that enabled RCWP personnel to better understand how to help the fertilizer industry meet nutrient management goals and set the stage for intensive fertilizer industry involvement in the Pequea Mill Creek Hydrologic Unit Project, which serves as the sequel to the Upper Conestoga RCWP.

One nutrient management tool that fertilizer vendors used was the Pre-Sidedress Nitrogen Soil Test. An effective addition to a nutrient management plan, this test determines which cornfields need additional nitrogen fertilizer. Field-tested in the RCWP nutrient management office in 1989, this test was released to the public in 1990. It is taken in early June when the corn is 6 to 18 inches tall and some of the organic nitrogen has broken down into nitrate. (Vendors often find it hard to apply nitrogen at this time of year because of bad weather conditions.) For the test, fertilizer vendors pulled soil samples and analyzed them for their clients; samples taken from heavily manured fields rarely called for additional nitrogen. This test took some of the pressure off the spreading schedule and helped further reduce nitrogen applications. Fertilizer vendors received approximately $5 per sample for testing, which helped them profit from their investment in testing while still allowing farmers to save money on fertilizer. More fertilizer vendors have begun to use this test, and farmers are relying on it more heavily to plan fertilizer applications.

The dialogue created by the agricultural chemical dealer meetings also allowed an opportunity to include them in Cooperative Extension test plots. In 1990, one fertilizer company allowed Extension to test a micronutrient enhancer with the starter fertilizer on a high phosphorus soil. This product produced a 20-bushel yield increase. Making sure farmers achieve their maximum economic yield is essential for effective nutrient management. Higher yielding crops take up more nutrients; therefore, farmers must use the fertilizer vendors' agronomic expertise to promote nutrient management.

In the future, nutrient management in Pennsylvania (particularly within the Chesapeake Bay watershed) and agricultural chemical industry involvement will continue to evolve. The cooperation and communication developed in the Upper Conestoga RCWP project is now the basis for a new level of industry involvement in water quality projects. The Pequea Mill Creek Hydrologic Unit Project funded in 1991 in an adjoining watershed is certifying agricultural chemical dealers and private consultants to write nutrient management and integrated crop management plans. If this program is successful, it may spread statewide and create a positive impact long after the Pequea Mill Creek project has ended. The agricultural chemical industry is excited about this project; interested companies had to be turned away from the first training session to keep a manageable group size.

Conclusions

When the focus of water quality programs shifts to cultural practices such as nutrient management, integrated pest management, and farmstead assess-

ment, private consultants, vendors, and other agricultural service industries should be brought into the process. Whether the program is national, State, or watershed-specific, the process is the same. The first step is to identify which agricultural service sector has expertise in the practice we want to promote. (For example, milk company fieldmen are experienced in performing farmstead assessments and wellhead protection.) The second is to identify benefits the market can provide the agricultural service industry for promoting this BMP — e.g., advertising benefits or a new service for farmers.

Most importantly, an uncomplicated method for implementing the practice should be developed to decrease the amount of paperwork required while still allowing a minimum level of tracking. Although the agricultural service industry is eager to be a part of the water quality solution, they still need to survive in the marketplace. An overly bureaucratic process can cut well-intentioned businesses out of the process. Finally, the Federal cost-share and incentive programs should include private industry. Currently, most Agricultural Stabilization and Conservation Service programs specifically exclude private industry.

As we attempt to address environmental issues in the information age, we need to become partners with the agribusiness industry. Feed and fertilizer salespeople, veterinarians, and the host of other professionals in service industries whom farmers rely on for information must become a part of the environmental solution. Government has too often taken the "us versus them" approach in dealing with private industry. As bureaucratic budgets tighten at all levels of government, private industry will have to be involved in any successful regulatory or educational environmental effort. The Upper Conestoga RCWP project laid the groundwork for a new level of industry cooperation that will be essential for addressing the water quality issues of the 1990s.

Economic Evaluation of the Rural Clean Water Program

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ABSTRACT

The key objective of the Rural Clean Water Program (RCWP) was to "achieve improved water quality in the approved project area in the most cost-effective manner possible." The program also called for socioeconomic evaluation to "identify the positive and negative impacts on the landowners in the project area and estimate the community or off-site benefits expected of the project if completed as planned."

This paper discusses some insights gained and lessons learned from the economic evaluation conducted by the U.S. Department of Agriculture's Economic Research Service. Strong points of the economic evaluation included successful linking of physical and economic models and some state-of-the-art analyses of the cost-effectiveness of existing and alternative practices and approaches. The evaluation could have been improved by greater consistency across projects. Ending the evaluation in 1987 also created problems for projects needing updated information for subsequent annual and 10-year reports.

Economic models used in the RCWP ranged from simple budgeting to multiactivity linear programming. Links were made to physical models, ranging from simple soil loss and delivery models to complex field and watershed models. Results indicated that the RCWP projects generally increased farmers' net returns and reduced pollutant loadings. However, water quality benefits and program efficiency could have been significantly improved by greater targeting of efforts to the most critical areas and greater emphasis on management practices rather than structural measures. The economic efficiency of future programs may be increased if economic assessments are initiated much earlier to provide information for project selection and best management practice planning.

The Rural Clean Water Program (RCWP) was envisioned and authorized as a large-scale, $600 million-a-year effort to reduce agricultural nonpoint pollution sources. Appropriations were only provided, however, for a much smaller "experimental" program. Although the reduced scale was disappointing at the time, the experimental RCWP has permitted the gathering of valuable experience in planning, coordinating, implementing, monitoring, and evaluating water quality projects before launching a larger-scale effort. This paper assesses the RCWP and its projects from an economic perspective.

Assessments were based on model predictions and the use of alternative scenarios. Monitoring data were not used because several alternatives needed to be evaluated. The U.S. Department of Agriculture's (USDA) Economic Research Service (ERS) was responsible for economic evaluation of the RCWP, with concentration on five comprehensive monitoring and evaluation projects in Idaho, Illinois, Pennsylvania, South Dakota, and Vermont. Less-detailed evaluations of the 15 other projects and an overall program evaluation were proposed but not funded.

Economic Aspects of a Project

Economic aspects of a project include its

- costs,
- cost-benefits to producers,
- cost-effectiveness, and
- the off-site economic benefits generated in relation to the costs.

Federal regulations for RCWP included these aspects as expectations for the program:

> *The objectives of RCWP are to: (a) Improve impaired water use and quality in the approved project areas in the most cost-effective manner possible in keeping with the provision of adequate supplies of food and fiber . . ." (Federal Regulations, Section 700.2 as amended).*

> *(3) Socioeconomic Impacts. Identify the positive and negative impacts on the landowners in the project area and estimate the community or off-site benefits expected of the project if completed as planned. (Federal Regulations, Section 700.41).*

Figure 1 helps put these economic aspects into perspective with other aspects of a rural nonpoint water quality project. Beginning at the top of the chart, the project extends direct educational, technical, or financial assistance to farmers who implement practices to reduce pollutants leaving the site or leaching downward. The expenditures and time required to extend this assistance are project costs. Because some best management practices (BMPs) require greater assistance to the producer than others, it is important to determine the differences among BMPs relative to time and assistance.

The adoption of BMPs affects the farm operation by altering the farmer's costs and returns. The extent to which farmers implement BMPs and continue to use them after direct assistance winds down depends on these effects, both on the average and from year-to-year.

Farmers in the project area not receiving direct assistance to implement water quality practices may be influenced indirectly through project publicity or contacts with program participants. Some may implement water quality practices on their own, particularly if such practices are more profitable. Others may continue or engage in practices that increase pollutant generation. What takes place on these "other farms" is often not assessed, yet it can be crucial to achieving water quality results. Other farmers and point sources will — it can be hoped — also contribute to the reductions in pollutant loadings achieved among program participants so that an overall reduction will occur in pollutant loadings to the impaired waterbodies.

To generate water quality economic benefits, the reductions in pollutant loadings and the resulting preservation or improvement in water quality have to be large enough to increase water use or enjoyment or to reduce user costs. This point is crucial. It is possible to implement practices that reduce site-level pollutants and therefore reduce pollutant loadings to a waterbody to improve water quality slightly without significant changes in use or generation of benefits. It is also possible that the preservation or improvement in water quality may occur over such a long time that the current value of those benefits is small. Both possibilities occurred in the RCWP.

Two measures of economic efficiency are cost-effectiveness and benefits. Cost-effectiveness is the cost of an action divided by some measure of the effectiveness of that action in reducing a critical pollutant or improving a key parameter of water quality. Costs may include government and net producer costs. To be useful, cost-effectiveness must be assessed comparatively. One action is more cost effective than another if either the cost is lower or the effectiveness is greater, other things equal.

Comparing economic benefits to costs can occur either as a ratio of one to the other, or by subtracting costs from benefits to estimate net economic benefits. A project — or one configuration of a project — is more economically efficient than another if it has a higher benefit cost ratio, i.e., more economic benefits per dollar of cost. Ideally, economic benefits of a project or program should exceed costs by as high a margin as possible.

Which of the following do you monitor and evaluate in a water quality project and program?

- BMP implementation;
- reduced pollutant loadings at the site level;
- reduced loadings to the impaired water bodies;
- water quality preservation or improvement sufficient to generate economic benefits; or
- generation of benefits that exceed costs.

Some people believe that BMPs are effective and see no need for evaluation beyond monitoring BMP implementation. Others focus on public desire to have water quality problems resolved and believe that voluntary programs must be made as effective and beneficial as possible if regulations are to be avoided.

Costs of RCWP and Its Projects

The experimental RCWP was funded in fiscal years 1980 and 1981 with Federal appropriations totalling $70 million. This amount was later cut to $64 million as a Federal budget-reducing measure. Fortunately, the funds were "no-year," allowing their disbursal as

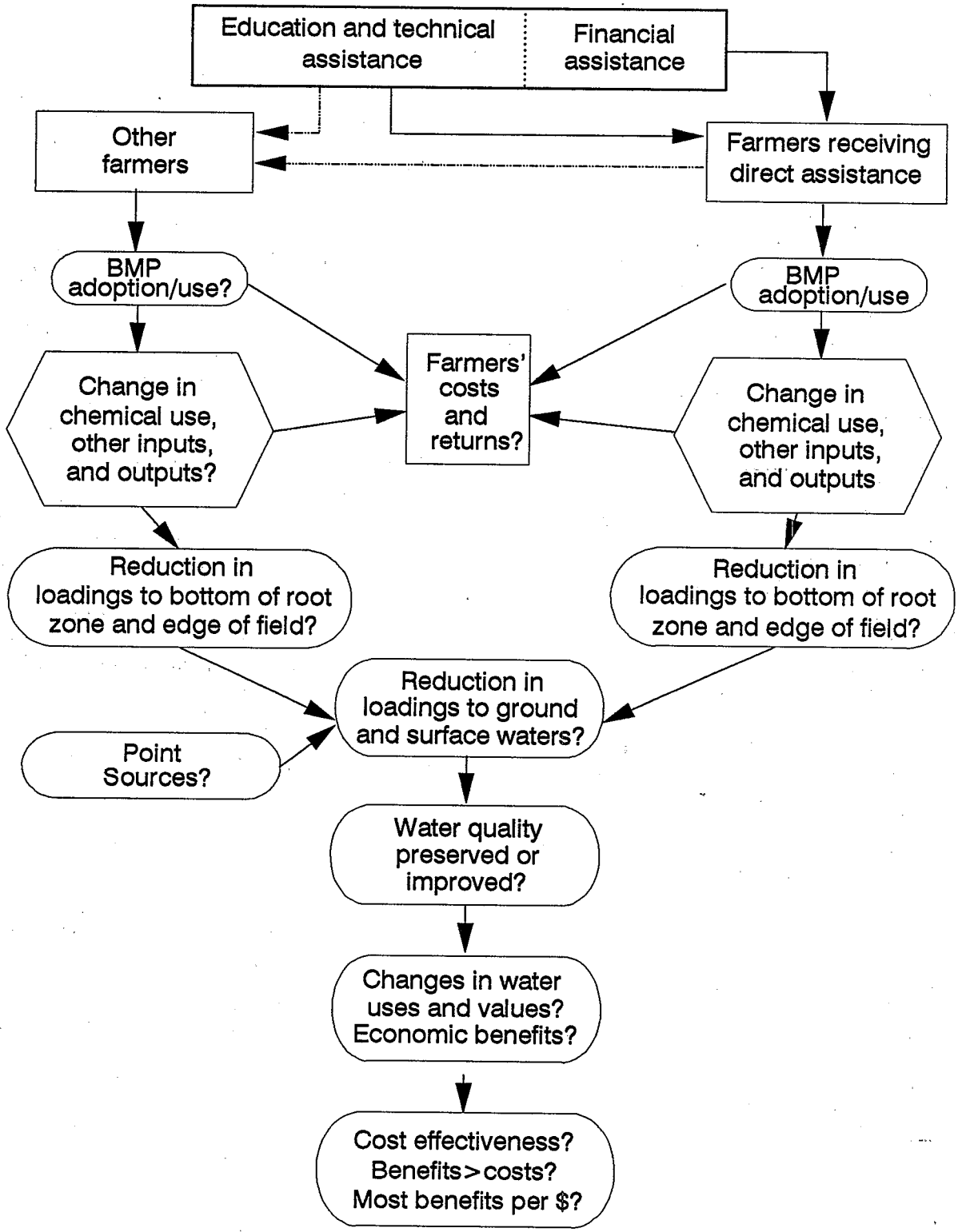

Figure 1.—Flow chart for rural water quality projects.

needed over time. Of the $64 million in Federal funds, about 53 percent provided financial assistance to farmers implementing BMPs in 21 projects; 30 percent was applied to technical and educational assistance, and 17 percent to monitoring and evaluation. In addition, State and local governments contributed over $4 million to the program.

The funds allocated to and spent by RCWP projects varied greatly, depending on their size, the nature of the water quality problems, the BMPs im-

plemented, and the degree of monitoring and evaluation required (Table 1). Projects ranged in total cost from $364,000 for the Utah project to $5.7 million for the Vermont project, including State and local contributions. State and local assistance was substantial in some projects; in the Florida project, for example, local contributions comprised nearly one-third of the total expenditures.

Nearly two-thirds of RCWP financial assistance supported structural BMPs, with about three-fourths of this put into animal waste systems (Table 2). Several projects allocated nearly all financial assistance to structural BMPs. Management BMPs received about one-fourth of total RCWP financial assistance, with the balance to permanent-cover BMPs.

Accounting procedures in the projects kept track of expenditures for specific BMP implementation but seldom for technical assistance or information and educational expenditures related to specific BMPs. The latter are significant components of some BMPs, and their accounting in future programs would facilitate economic evaluation and the determination of the most cost-effective BMPs.

Effects on Farm Costs and Returns

Effects on farm costs and returns were evaluated for the five comprehensive monitoring and evaluation projects by using BMP and enterprise budgeting (Table 3). In general, farmers in these projects who implemented BMPs with financial and technical assistance increased their net returns, and thus had economic incentives to participate. In the case of conservation tillage properly implemented and managed, net returns would have been higher even without cost-sharing. In the Illinois and South Dakota projects, upward trends in conservation tillage use existed before the projects, but the projects further increased the rate of adoption in both cases.

In the Pennsylvania and Vermont projects, farmers implementing manure storage and management practices with project assistance increased their net returns. They would, however, have lowered their net returns had they not received assistance. The Vermont project achieved high participation. An interesting issue in this project's economic evaluation was whether a lower cost-share rate, one that provided an increase in net returns but not as much, would have achieved as much or nearly as much participation. Some project personnel felt strongly that the full incentive was needed. In Pennsylvania, cultural factors discouraged farmers' acceptance of financial assistance and hence their participation in manure storage.

In the Idaho project, farmers implemented sediment basins and other sediment-retention devices with project assistance. However, analysis indicated that there would be no incentive of increased returns to maintain these basins and devices after the con-

Table 1.—Expenditures by RCWP projects and area treated.

PROJECT	GOVERNMENT EXPENDITURES (In thousands)					STATE AND LOCAL EXPENDITURES[1]	CRITICAL AREA (ACRES)	AREA TREATED (ACRES)	PROPORTION TREATED (PERCENT)
	FINANCIAL ASSIST.	TECHNICAL ASSIST.	I&E	M&E, OTHER	TOTAL				
Alabama	1,215.1	490.0	14.4	[2]	1,719.5	105.9	6,300	3,811	60
Delaware	873.2	304.1	0.0	315.0	1,492.3	[2]	13,000	9,750	75
Florida	1,267.5	432.9	79.0	400.0	2,179.5	722.1	93,500	54,709	59
Idaho	1,988.8	1,446.7	135.5	1,389.0	5,242.5	280.7	28,159	21,147	75
Illinois[3]									
Iowa	331.2	19.7	[2]	[2]	421.0	.7	3,920	3,359	90
Kansas[3]									
Louisiana	2,300.0	830.3	[2]	[2]	3,130.4	64.4	44,800	27,103	60
Maryland	3,576.1	946.0	511.8	[2]	5,033.9	270.1	[2]	2,883	
Massachusetts	518.4	215.1	10.8	[2]	917.2	1.0	24	24	100
Michigan[3]									
Minnesota	1,747.0	623.8	119.7	55.0	2,545.5	303.5	20,255	10,793	53
Nebraska	978.2	422.7	230.6	[2]	1,631.5	[3]	60,242	42,879	71
Oregon	3,574.6	680.5	7.5	198.6	4,461.2	127.8	5,300	2,544	48
Pennsylvania	794.0	1,268.4	88.5	2,614.1	4,765.0	[2]			
South Dakota	744.7	614.6	163.9	2,581.6	4,043.1	644.6	[2]	17,700	80
Tenn./Kentucky	[2]	[2]	[2]	[2]	[2]	[2]	41,830	33,465	80
Utah	143.7	88.8	85.8	46.2	364.5	[2]	[2]	[2]	
Vermont	1,686.3	3,227.8	18.7	2,414.1	5,779.5	640.8	15,431	11,277	73
Virginia	1,721.0	496.6	65.9	120.4	2,403.9	98.4	23,908	16,655	70
Wisconsin	817.1	125.0	1.9	5.0	949.0	5.0	26,000	23,598	91

Source: Project 10-year reports.
I&E = Information and Education; M&E = Monitoring and Evaluation
[1]Included in "Government expenditures." Excludes farmers' costs.
[2]Not reported.
[3]10-year report missing.

Table 2.—BMP financial assistance expenditures (in thousands) under the Rural Clean Water Program.

	PERMANENT COVER BMPs[1]					STRUCTURAL BMPs[1]						MANAGEMENT BMPs[1]							
PROJECT	1	7	11	14	SUB-TOTAL	2	4	5	12	13	SUB-TOTAL	3	6	8	9	10	15	16	SUB-TOTAL
Alabama	117	23	179	3	322	78	335	16	109		538		142	119	81	11		1	354
Delaware	4	20	31		55	40		1	52		93			39	686				725
Florida						192		15	25		232		91			944			1,035
Idaho[2]																			
Illinois[2]																			
Iowa	2	36			38		237		38		275				18				18
Kansas[2]																			
Louisiana	69	161	69		299		23		345	713	1,081			322	414		92	92	920
Maryland	36	754			790	1,632		28	12		1,672	27	238			34	13	15	327
Massachusetts	3	1			4	191	3	3			197			2					2
Michigan[2]																			
Minnesota	79	19	147		245	675	25	4	51		755	6			45		97		148
Nebraska	27	9	10	20	66	28		46	95	440	609		97		3	46	19	18	183
Oregon	1				1	3,602			1		3,603		1			2			3
Pennsylvania[2]																			
South Dakota	25	5	1		31	39	4				43	1	3	2	627		38		671
Tenn./Kentucky																			
Utah						116				22	138		4			1			5
Vermont	25	17	6		48	1,290		2	331		1,623	2	3			10			15
Virginia																			
Wisconsin	21	95	1		117	805		1	3		809	6			17	10			33
Total above	409	1,140	444	23	2,016	8,688	627	116	1,062	1,175	11,668	42	579	484	1,891	1,058	256	126	4,436

Source: Project 10-year reports.

[1]The BMP code numbers have the following meanings: 1 = permanent vegetative cover; 2 = animal waste management system; 3 = strip-cropping system; 4 = terrace system; 5 = diversion system; 6 = grazing land protection system; 7 = waterway system; 8 = cropland protective system; 9 = conservation tillage system; 10 = stream protection system; 11 = permanent vegetative cover; 12 = control structures for sediment, erosion, and flooding; 13 = improving irrigation system; 14 = tree planting; 15 = fertilizer management; and 16 = pesticide mangement.

[2]Data not available at time of table preparation.

Table 3.—Major components of the economic evaluations in five RCWP comprehensive monitoring and evaluation projects.[1]

Idaho Rock Creek Project:
—Best management practices (BMPs) and enterprise budgets of costs and returns
—Farm level simulation of economic effects of BMPs
—BMP cost-effectiveness (CE) analysis on representative sites
—Project CE analysis using Universal Soil Loss Equation, sediment delivery ratios, and linear programming (LP)
—Off-site benefit estimates based on existing studies
Illinois Highland Silver Lake Project:
—BMP and enterprise budgets of costs and returns
—Representative farm analysis using LP
—Project CE analysis using AGNPS (Agricultural Nonpoint Source model) and LP
—Recreational fishing estimate based on special survey.
—Other off-site benefit estimates based on special studies
Pennsylvania Conestoga Headwaters Project:
—BMP and enterprise budgets of costs and returns
—Site-level CE analysis of BMPs using CREAMS (Chemicals, Runoff, and Erosion from Agricultural Systems) and budgets
—Feasibility evaluations of alternative uses of manure
—Drinking water benefit estimates based on cost of alternatives
South Dakota Oakwood Lakes–Poinsett Project:
—BMP/enterprise budgets of costs and returns
—Project CE analysis using AGNPS and CREAMS
—Recreation benefit estimates based on special survey
—Drinking water benefit estimates based on cost of alternatives
Vermont St. Albans Bay Project:
—BMP/enterprise budgets of costs and returns
—BMP analysis using AGNPS
—Representative farm analysis using LP
—Recreation benefit estimates based on special survey
—Property value benefit estimates based on special survey

Source: compiled by author.
[1]The level of funding allocated to the separate economic evaluations varied widely and, in some cases, limited the scope of the evaluation.

tracts expire, which appears to be the case in an adjoining watershed, where some farmers who had implemented these practices under another program have not maintained them after the contractual period.

Insights on Cost-Effectiveness

In keeping with the RCWP's objective of improving impaired water use and quality ". . . in the most cost-effective manner possible," ERS evaluated cost-effectiveness in the five comprehensive monitoring and evaluation projects. Methods and procedures differed among the projects (Table 3). Budgeting and linear programming were used to generate the cost measures. Physical models were used to predict the pollutant reduction effectiveness for the project when the BMPs were fully implemented as planned — and for alternative scenarios. Monitoring results were not used because they did not cover all alternatives being considered and could not be easily controlled for weather variations.

The first step in evaluating cost-effectiveness was to identify significant trends that would have continued in the project area in the absence of RCWP, so as to not overestimate the effects of the program. In the Illinois and South Dakota projects, significant upward trends occurred in the use of conservation tillage. These trends were projected forward and incorporated into "future without RCWP" runs of the models. Subtracting the results of "future without" from "future with RCWP" provided an estimate of the net effect of RCWP. In the two projects, the predicted net effectiveness of RCWP was one-third to one-half lower than biased estimates that did not consider the conservation tillage trend.

Model predictions showed the net effectiveness of the RCWP in the Idaho, Illinois, South Dakota, and Vermont projects as follows:

- **Idaho:** a reduction of 13 to 56 percent in agricultural sediment entering Rock Creek would be achieved, depending on the level of adoption of conservation tillage and the maintenance of structural BMPs over time.

- **Illinois:** a net reduction of 14 percent in agricultural sediment entering Highland Silver Lake would result from the RCWP, compared to a 24 percent reduction if the conservation tillage trend was not factored out.

- **South Dakota:** the RCWP would provide a net reduction of 13 percent in phosphorus from agricultural sources entering the project's three impaired lakes, compared to a

21 percent reduction if the conservation tillage trend was not excluded.

- **Vermont**: the RCWP would provide a reduction of 17 percent in phosphorus from agricultural pollutants entering St. Albans Bay.

To gain insights into how these projects might have achieved greater cost-effectiveness, alternative scenarios were developed that included different mixes of BMPs or greater targeting of treatment to the most critical areas. The alternatives were developed in consultation with project staff. For the Idaho and Illinois projects, the model results indicated that larger acreage in conservation tillage and less use of structural measures would have increased effectiveness for the same or less cost.

For the South Dakota project, the results indicated that adding a more ideal form of fertilizer management (split application and injection, in addition to soil testing and nutrient budgeting) to existing contracts could greatly improve the project's effectiveness in reducing nutrient loss at minor added cost. In contrast, urging farmers with existing contracts to change from mulch to ridge- or no-till was shown not to be cost-effective because the effort would have added to project cost with no significant reduction in nutrient loadings.

Model results for the Idaho, Illinois, and South Dakota projects indicate that greater targeting of conservation tillage or ideal nutrient management to the most critical acres would have added more to effectiveness than to cost. The results also indicate that greater financial incentives could have been offered to farmers in critical areas to speed adoption of conservation tillage and split application of fertilizer, and these practices would still have been the most cost-effective alternative.

Is putting lands into the Conservation Reserve a cost-effective way of achieving pollutant reductions? For the South Dakota project, model results indicate that ideal fertilizer management would be a much less costly and more cost-effective to achieve nutrient reductions. However, taking the land out of production and placing it in permanent cover may contribute to other societal objectives.

In considering the cost-effectiveness of alternatives and deciding on practices to implement, it is helpful to know how much reduction is needed in critical pollutants to achieve water quality objectives in the impaired resources. Some less cost-effective measures may be needed in addition to cost-effective ones to achieve the needed reductions. For the Idaho, Illinois, and South Dakota projects, reductions over 60 percent in agricultural pollutant loadings would require incentives sufficient to induce farmers to place most cropland under improved management practices, or to put some of the critical land into structural measures or permanent cover (such as in the Conservation Reserve Program). For the Vermont project area, the reduction of loadings sufficient to eventually restore St. Albans Bay required adding agricultural practices to the more cost-effective sewage treatment program.

In the Pennsylvania project, only the cost-effectiveness of practices at the field- or farm-level was evaluated. The analysis shows that conservation tillage and nutrient management, contouring, and sod waterways were much more cost-effective than terraces and permanent vegetative cover in reducing sediment and nutrients in runoff. The CREAMS model also indicated that terraces may significantly increase the infiltration of nitrogen into groundwater. Monitoring results have since confirmed this. Alternative uses or disposal of manure to reduce field application were also found to have low economic feasibility.

Insights on Economic Benefit Generation

The RCWP projects have reduced pollutants at the site level, and most projects will reduce loadings to some waterbody. However, only 10 to 13 projects (one-half to two-thirds) have or may be able to measure significant improvements to water quality in the impaired water bodies (Natl. Water Qual. Eval. Proj. 1988; Coffey, pers. comm.) Possibly another 3 to 6 projects, while not making a significant impact on water quality, could contribute to water quality preservation or improvement if they become part of larger regional programs that do make a significant difference.

Clearly, projects that do not significantly contribute to water quality improvement will not generate significant economic benefits. Economic benefit estimates for other RCWP projects were developed by estimating the range of potential benefits that might be generated from preserving water quality from further deterioration and from improving water quality over preproject conditions. These two sources of benefits were projected for 50 years, adjusted to reflect likely changes in water quality, and discounted to current value.

The estimates of the potential benefits for the Idaho, Illinois, South Dakota, and Vermont projects involved special surveys or studies. (A bibliography including these studies is appended to this paper.) Travel costs and contingent valuation techniques were used in some cases. Estimates for other

projects were based on available information on water uses, potential users, and the values of different uses. For all projects with drinking water impairments, potential benefits for this use were based on costs of obtaining water from alternative sources, such as bottled water.

Results of this benefit analysis suggest that two to four of the projects may generate relatively high economic benefits; five to six, moderate benefits; and four to five, low benefits. For six to twelve of these projects, generation of economic benefits may be sufficient to exceed project costs. Six other projects received an "uncertain" rating because of the potential for benefit generation outside the project area if they become part of larger regional programs that successfully preserve or improve water quality in major downstream resources. These results indicate that not all water quality projects will generate high benefits and that a high economic return on water quality dollars would require a development of economic information for use in project selection.

In two projects (South Dakota and Oregon), available information indicates that the RCWP will probably generate significant economic benefits from preserving water quality that would otherwise deteriorate. Nine projects may generate moderate-to-high economic benefits by improving water quality from baseline conditions.

The four projects with high potential economic benefits involve lakes, bays, or estuaries in close proximity to, and highly affected by, the project area. The waterbodies are also in high demand for recreation and, in some cases, commercial fishing. Four projects with moderate potential economic benefits also involve lakes or bays highly used for recreation. Preserving or improving water quality in a lake or bay does not automatically generate sizeable benefits, especially if there are few users, or if restrictions exist on use. For example, in the Illinois project, recreational use of the lake is restricted to fishing in low-powered boats and only one ramp is permitted. A low level of economic benefit generation does not necessarily mean that economic benefits won't exceed costs; costs can also be kept low. Two projects that produced relatively low economic benefits could have had positive net benefits if more cost-effective BMPs had been implemented.

Steps for Increasing Economic Efficiency of Future Programs

ERS staff learned from the economic evaluation of the RCWP. Strong points of the evaluation included the successful linking of physical and economic models and the application of state-of-the-art analyses of cost-effectiveness to existing and alternative practices and approaches. Some early results also provided insights for modifying project implementation. The evaluation could have been improved by greater consistency across projects. Ending the evaluation in 1987 created problems for projects needing updated economic information for subsequent annual and 10-year reports.

For the most part, the economic evaluation of the RCWP occurred midway during project implementation. Results and experience indicate that initiating economic evaluation much earlier in future programs would provide program and project decisionmakers more timely information for increasing economic efficiency. In particular:

- **Before project selection.** Conduct feasibility assessments of proposed or potential projects to provide information for comparing projects on at least these aspects:
  - Extent of water use impairments;
  - Potential economic benefits if impairments are reduced;
  - Reductions in pollutant loadings from various sources needed to reduce impairments, with attention to the possible need for a regional program, and the levels of expected improvement in both surface and groundwater quality;
  - Treatment levels needed to achieve desired reductions in loadings, considering local trends in agriculture;
  - Likelihood and cost of achieving needed treatment levels in comparison to potential economic benefits; and
  - Other environmental or nonuser considerations.
- **After project selection but before implementation.** Identify and appraise the cost-effectiveness of feasible alternative targeting and BMP strategies for achieving the needed reductions in pollutant loadings. To what extent can management BMPs be used to reduce project costs? What incentives will achieve the needed BMP adoption? Will the BMPs be maintained?
- **During project implementation.** Periodically reappraise implementation strategies to see if changes would contribute to greater cost-effectiveness. Can costs be reduced or

greater reductions in pollutant loadings be achieved? Are higher incentives needed for the more cost-effective BMPs?

- **After project completion.** Review the achieved and expected results to see what insights on cost-effectiveness and benefit generation can be gleaned of value for the future.

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Technology Application in BMP Planning, Design, and Application

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ABSTRACT

Initially, traditional survey, design, and drafting methods were used in the Okeechobee Rural Clean Water Program project. However, evolution and expansion of the original project required development of detailed waste management plans, irrigation systems for wastewater, and best management practices (BMPs), such as waste storage ponds, floodwater-retarding structures, and methods to treat high intensity areas. Because of compliance deadlines imposed by State regulatory agencies, the Soil Conservation Service had to revise its traditional survey, design, and layout methods, which had proven to be too time-consuming. New survey, design, and drafting technologies were implemented to prepare engineering designs and provide technical assistance in their installation within the time frame allowed by State regulatory agencies. These new technologies ultimately improved the quality of these designs and staff productivity, which was stimulated by the need to complete topographic and planimetric surveys and design waste management systems under a time constraint. Increased quality stemming from accurate field data and waste management system designs resulted in more efficient use of land resources.

The original Rural Clean Water Program (RCWP) focused on the Taylor Creek–Nubbin Slough drainage basin, which contained 24 dairies on approximately 33,000 acres. The average dairy milked 1,000 cows. A 1978 study by the South Florida Water Management District determined that this basin contributed 4 percent of the wastewater flow to Lake Okeechobee and 27 percent of the total phosphorus load; moreover, it attributed most of the lake's phosphorus and nitrogen loading to the dairy operations. Approximately 64,000 acres (which included all dairies in the basin) were required to have conservation plans addressing water quality.

Implementation of the original RCWP project began in 1981, with goals of a 50 percent reduction of phosphorus discharge and conservation plans on 75 percent of the critical acres and 100 percent of the dairies. Typical BMPs installed under the original RCWP project included

- fences to keep dairy cattle out of waterways,
- waterway crossings,
- portable livestock shade structures, and
- wastewater recycling.

As a result, project goals were met or exceeded in 1986. Among the accomplishments were a 50 percent reduction of phosphorus discharge and conservation plans for 96 percent of the critical acres and all dairies.

In 1986, the occurrence of large algae blooms in Lake Okeechobee prompted the Florida Department of Environmental Regulation (FDER) to enact a rule specifically for the dairies in the lake's drainage basin. Commonly called the "Okeechobee Dairy Rule," the FDER rule, which became effective June 3, 1987, as part of Rule 17-6.300 of the Florida Administrative Code, imposed requirements on 25 additional dairies covering approximately 52,000 acres in the Lower Kissimmee River basin and specified that "discharge of dairy farm wastewater and runoff to the waters of the State shall not cause or contribute to a violation of water quality standards." This expansion of the RCWP project led to the development of new, nontraditional BMPs for the dairies in the Lake Okeechobee drainage basin. BMPs included those previously used in the Taylor Creek–Nubbin Slough drainage basin and

- waste utilization,
- irrigation systems,
- subsurface drainage,
- waste storage ponds,
- floodwater-retarding structures,
- surface drainage field ditches, and
- water table control.

With the need to design and install waste management systems on 49 dairies with approximately 50,000 dairy cows within three years, the South Florida Water Management District contracted with the Soil Conservation Service (SCS) to design waste management systems for 30 of the dairies. Waste management system designs complying with these requirements were more detailed than those developed for the original RCWP project; therefore, SCS had to develop water budgets that would account for the large amount of wash water used as well as evapotranspiration, rainfall, runoff, and drainage.

SCS also developed cropping sequences to utilize nutrients from dairy wastes. Since phosphorus was the limiting nutrient, sequences were planned to increase crop uptake of phosphorus. These cropping sequences required landowners to adopt practices new to the south Florida dairy industry.

To maximize phosphorus uptake by crops, SCS provided water table control systems by installing drainage ditches or subsurface drainage tile with structures for water control. In many cases, existing natural outlets did not have the capacity for the required drainage rate; therefore, floodwater-retarding structures were constructed to provide an adequate outlet for the irrigation field through pumping or gravity flow.

Traditional Methods for Installing BMPs

Planning

For the initial RCWP project, planning was based on aerial photographs, U.S. Geological Survey quadrangle maps, and site visits, which were used to determine the areas that needed detailed surveys. The initial planning phase also established a priority system for surveying and designing individual dairies involved in the project.

Surveying

A team of three or four persons was needed to perform the detailed topographic and planimetric surveys for planning and design. The design required a detailed topographical survey of the high intensity areas, which are nonvegetated areas around the milking barn where dairy cows are concentrated for feeding and watering before milking. Typically, high intensity areas ranged between 10 and 30 acres and were usually covered by two to three feet of manure, making them difficult to survey. In addition, they were often overgrown with brush and vegetation along the numerous fence lines, a condition that required multiple instrument setups for standard levels and transits. The waste storage ponds were also difficult to survey because of their location, vegetative cover, and size — an average of 40 to 50 acres, with the largest being 300 acres.

The size of the irrigation sprayfield, which ranged from 150 to 674 acres, was based on crop nutrient uptake or the volume of wastewater to be applied. A complete topographical survey was needed on these fields to properly design the drainage and irrigation system.

A survey for the high intensity areas, waste storage pond, and irrigation sprayfields required approximately three to four weeks for the average dairy, followed by up to four days to reduce survey notes and plot, by hand, the topographic information for use in the design phase.

Design

Waste management systems were designed based on crop use of nutrients, with phosphorus being the limiting nutrient. The result was a waste management system that collected wash water from the barn and rainfall and runoff and drainage water from high intensity areas for temporary storage in a waste storage pond until it could be used for irrigation.

Development and analysis of alternative systems required six to eight weeks.

Traditional methods for designing waste storage ponds were based on an average monthly water budget that included dairy wash water, rainfall, runoff and drainage water from the high intensity area, and evapotranspiration. The irrigation sprayfield size was determined based on crop nutrient use and volume of wastewater applied.

To achieve high crop uptake rates (up to 75 pounds of phosphorus per acre), it was necessary to improve the drainage in the irrigation sprayfield. If the available outlet could not provide adequate drainage for optimal plant growth, the system was designed to include a floodwater retarding structure, the size of which was based on the required crop drainage coefficient and the discharge rate allowed by the South Florida Water Management District.

These alternatives were presented to the landowners for their review and selection of the best alternative for their particular operation. However, the limited availability of computers and the time required to perform these evaluations reduced the number of alternatives that could be analyzed and presented to the landowners.

Implementation

Soil Conservation Service staff performed periodic and final construction checks on all practices installed. Construction layout was performed by SCS technicians for the first several dairies using standard levels, transits, and electronic distance measuring equipment. Cross sections were taken before and after construction to compute earthwork volumes.

Current Technology for Installing BMPs

Because of the size and complexity of the dairies, the traditional technology used to design waste management systems was inadequate to meet the time frame imposed by State regulatory agencies; therefore, SCS decided to implement newer technology to provide waste management plans to landowners.

Surveying

Introduction of the new technology proved to be beneficial, particularly in the areas of survey and design. Surveying quality and accuracy noticeably improved with the use of total station surveying instruments and data collectors. A crew of three could complete the survey of a typical dairy in one to two weeks (instead of four). The data collectors allowed electronic coding and storage of survey measurements and physical features, such as existing fences, drainage ditches, structures, and buildings. The use of total station surveying instruments allowed for more accurate measurements of the physical features of sites that were hard to access.

SCS downloaded survey data from the data collector to the computer and used commercial software to produce topographic maps for design and planning. These maps were available within three hours of survey completion, as opposed to several days when survey notes were reduced and plotted by hand.

Design

The introduction of computer-aided drafting (CAD) helped develop standard construction details that could be used on several designs. Many of the waste management system plans were drawn with the CAD system, which allowed computerized changes in the drawings, saved time, and resulted in quality drawings.

Paralleling the use of CAD was the development and implementation of several computer models that help to evaluate existing or proposed drainage systems and determine required capacity of the waste storage ponds and floodwater-retarding structures.

SCS used DRAINMOD, a drainage simulation computer model developed by R.W. Skaggs of North Carolina State University, to evaluate and design drainage and irrigation systems. DRAINMOD incorporated 20 years of historic rainfall and temperature data for these evaluations. SCS estimated potential evapotranspiration and appropriate factors for south Florida conditions for the DRAINMOD model.

The output from DRAINMOD was then used in an SCS-developed water budget model known as WASTESTO. WASTESTO took the daily output files from DRAINMOD to size waste storage ponds by balancing all sources of water, including rainfall, runoff, drainage, evapotranspiration, and wash water. This water budget model allowed SCS engineers to simulate field scale installations with varying drain spacings and depths, size of irrigation sprayfield, size and depth of waste storage ponds, and amount of dairy wash water to optimize land use and provide alternatives for the landowners.

Floodwater-retarding structures, where needed, were sized using the computer model, RESROUT, developed by SCS. The required drainage rate (gravity or pumped), South Florida Water Manage-

ment District allowable discharge rate or outlet capacity, drainage area, and structure stage-discharge curves were input into RESROUT, which quickly evaluated the adequacy of the floodwater retarding structure to retain runoff and drainage water. SCS could also vary these inputs to evaluate alternative sizes of floodwater-retarding structures to help the landowner make decisions on the drainage rate and size of floodwater-retarding structure based on the economics of the system.

Use of these computer models resulted in increased productivity of field office staff and improved quality of overall waste management system plans.

Implementation

As the project evolved and construction occurred concurrently with design surveys, SCS technicians found it necessary to reduce time required to perform construction layout and checkout. SCS accomplished this by providing benchmark elevations and setting initial alignments and control points for the contractor. The use of total station surveying equipment allowed for improved accuracy and reduced time in setting the initial alignments by referencing existing points set during the planning stage.

The construction check of installed practices was improved by adopting Ohio Engineering Software, developed by SCS in Ohio. This software can compute earthwork volumes, complete as-built drawings, and allows quick computer plotting of planned versus as-built cross sections and quantity computations.

Future Technology

With the ongoing development and introduction of geographic information systems and global positioning systems and improvements in total station surveying equipment and computer modeling software, the quality and accuracy of BMP planning, design, and implementation will continually improve.

Implementing these technologies will allow for evaluations of several alternatives and their impacts on water quality and quantity. New technologies will provide the necessary alternatives for landowners to make environmentally and economically sound land use decisions.

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A Method for Ranking Farms and Tracking Land Treatment Progress in the St. Albans Bay Watershed RCWP Project, Vermont

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ABSTRACT

The St. Albans Bay Watershed Rural Clean Water Program project strived to reduce agricultural nonpoint source phosphorus loadings to the bay. In 1980 when the project was formulated, few tools existed to evaluate phosphorus runoff from agricultural sources. The concept of critical acres was used in the project; however, critical acres were broadly defined and did not adequately address sources of nutrients on farms and implementation of BMPs that might affect them. The project's comprehensive monitoring and evaluation program provided in-stream loading data, but these values could not be readily related to individual farm operations. Soil Conservation Service in Vermont developed several desktop computer models to estimate phosphorus loads from various on-farm sources and employed them to evaluate the pre- and post-treatment phosphorus loading conditions from each of the watershed's farms and at the subwatershed and watershed level. The models were used to estimate pre- and post-BMP phosphorus loadings from various nonpoint sources on each farm, array farms by phosphorus loads for priority implementation considerations, and track implementation progress toward phosphorus reduction goals.

Challenges in nonpoint source management projects include tracking progress and determining when a satisfactory level of treatment has been achieved — and both are hindered when the project is formulated on perceived land-based problems without ideal characterization of pollutant sources, their control, and their relationship to the impaired waterbody.

In 1980, when the Rural Clean Water Program (RCWP) projects were created, the ability to evaluate the land and receiving water relationship was limited. Consequently, most projects featured some level (often 75 percent) of application of best management practices (BMPs) to critical areas in the watershed. Similarly, projects frequently used a subjective rating procedure to rank applications for assistance. Quantification of the nonpoint source problem on each farm would have helped to better align this ranking with the farm's pollution potential.

Progress tracking was often described in terms such as critical areas treated, BMPs applied, farms treated, dollars obligated, and erosion controlled. These factors were important to track but gave no clear indication of the pollutant load reduction level.

Through experience in the RCWP and other projects, Vermont has determined that a set of simple planning models is most useful in planning, implementing, and tracking nonpoint source water quality projects.

Background

An explanation of the Vermont RCWP project plan of work development and implementation management is necessary to appreciate the need for an improved tracking system.

In the St. Albans Bay watershed project, impaired water quality resulting in eutrophication had affected uses of the bay. Phosphorus concentrations in the bay were high and a major source was thought to be farms in the watershed.

After considering numerous studies by the Vermont Agency of Environmental Conservation, the St. Albans Bay RCWP local coordinating committee (1980) acknowledged phosphorus as the target nutrient for nonpoint source management and developed a phosphorus runoff control strategy "to encourage the use of those management practices on the farm which will have the largest effect in phosphorus reduction." The committee commissioned an assessment of agricultural runoff problems in the watershed to identify critical acres and sources that needed treatment and to develop a plan of work. This assessment included a 30 percent sample of the farms to characterize their waste management and soil loss status; later, this sample was expanded to represent the total watershed.

Critical acres were defined as that "portion of the farm on which animal wastes were spread or excessive cropland erosion was occurring" (Vt. RCWP Coor. Comm. 1980). Critical sources were generally considered to be the barn and adjoining areas where the wastes were generated. The assessment did not include phosphorus load estimations because Vermont had not adopted a measurement technique.

The project set treatment goals as 75 percent of the total critical acres and sources. Treatment needs were based on an expansion of BMPs needed to address these areas on sample farms. Table 1 provides the baseline treatment needs and target goals contained in the original plan.

Implementation of the Vermont RCWP Project

At the start of the project, the committee recommended an application rating system (adopted by the U.S. Department of Agriculture's Agricultural Stabilization and Conservation Service county committee) that was based on scores from questionnaires completed by applicants (Fig. 1). The committee designed these questionnaires to determine the highest priority farms with critical acres and sources needing treatment and the proximity of the farms to streams and the bay, the presence of nonpoint

Table 1.—Treatment needs and target goals, St. Albans Bay RCWP original plan of work.

			TOTAL NEEDS	CUM. TARGET	1980 TARGET	1981 TARGET	1982 TARGET	1983 TARGET	1984 TARGET
Information/Education			100%	75%					
Treatment needs									
Acres needing treatment			15,355	11,584					
Sources needing treatment									
Dairies (no.)			84	63					
Truck farms			1	1					
RCWP contracts	No.		85	64	8	20	15	15	6
	Ac.		15,355	11,584	1,448	3,620	2,715	2,715	1,086
BEST MANAGEMENT PRACTICES (BMPs)									
1.	Perm. veg. cover	Ac.	93	70		5	10	10	10
2.	Ag. waste mgt.	No.	75	60	3	5	12	10	10
3.	Strip-cropping	Ac.	2,520	1,890			100	150	150
4.	Terrace systems	Ac.	40	30					
5.	Diversions	Lf.	73,733	55,300			2,000	4,000	4,000
6.	Grazing land prot.	No.	21	16		1	1	1	2
7.	Waterways	Ac.	32	24			2	2	2
8.	Cropland prot. cover	Ac.	1,162	872		50	50	50	50
9.	Conservation tillage	Ac.	116	87				5	10
10.	Stream protection	Lf.	5,733	4,300		100	200	300	400
11.	Perm. veg. on crit. areas	Ac.	88	66		3	6	8	8
12.	Sediment retention struc.	No.	6	4					1
14.	Tree planting	Ac.	20	15					2
15.	Fertilizer management	Ac.	815	611		11	50	100	100
	Cons. cropping system	Ac.	7,200	5,400	350	450	500	500	500
	Pasture/hay management	Ac.	7,800	5,850	400	450	500	550	600

QUESTIONNAIRE:	YES	NO	ALL CATTLE NO. OF HEAD
1. Do you spread manure daily?	_____	_____	_____
2. Do you have a disposal system for milkhouse waste?	_____	_____	
Check one: Filter field _____ Holding pipe _____ Lagoon _____ Dry well _____ Open pipe _____ Other _____			
3. Do you plant corn on your land or land rented by you?	_____	_____	_____ ACRES
4. Do you plant corn continuously on the same pieces?	_____	_____	_____ ACRES
5. Do you plant corn on sloping pieces?	_____	_____	
6. Do you feel you have an erosion problem on planting sloping pieces?	_____	_____	
7. Do you plant a winter cover crop after corn harvest?	_____	_____	
8. How often do you rotate corn pieces to grass cover?			_____ YEARS
9. Does your livestock have access to a stream, brook or river?	_____	_____	
10. Distance your farm is from St. Albans Bay?			_____ MILES
11. Does a major water course run through your land?	_____	_____	_____ SPECIFY
12. Do you have an erosion problem due to a water course running through your land?	_____	_____	
13. Do you have a water storage facility in grazing areas?	_____	_____	
14. Year in which you will have the financial capability to carry out the needed practices in your Water Quality Plan			_____ YEAR

SIGNED _____

SCORING:			SCORE
1. If yes	10		_____
2. Filter field	2	Holding pipe 8	
Dry well	4	Open pipe 10	
Lagoon	6	Other 12	_____
3. If yes	5 for 10 acres or less	6 for 11 to 20 A. 7 for 21 to 30 A.	
	8 for 31 to 40 A.	9 for 41 to 50 A. 10 for 51 to 60 A., ect.	_____
4. If yes	10		_____
5. If yes	10		_____
6. If yes	10		_____
7. If no	10		_____
8. Number of years			_____
9. If yes	10		_____
10. Number of miles			_____
11. If yes	10		_____
12. If yes	10		_____
13. If no	5		_____
14.	Enter year		_____

Figure 1.—Application rating questionnaire for St. Albans Bay RCWP.

source phosphorus loads that could reach streams, the potential for efficiently controlling more than one major phosphorus source on the farms, and the applicants' financial capability to follow an implementation schedule.

The committee kept records of the critical acres treated and BMPs installed as the project progressed (Fig. 2). The success of the project in terms of physical effects was judged on these parameters, as measured against the original project goals. Comprehensive monitoring and evaluation proceeded concurrently; however, there was a lag between implementation of BMPs and the period required to process and evaluate monitoring data.

Cont. No.	Farm No.	Name	Contract[1] Period	No. Years	Critical Acres	Federal Contract Amount	BMPs[3]	Paid To Date
1	F 32		9/80-86	6.3	150	$50,000	1 2 6 11 12	$50,000
2	F 48		9/80-90	10.3	260	24,293	1 2 5 7 8 10 11 12	24,293
3	G 95		10/80-84	4.2	207	44,564	2 8 10 12 15	44,564
4	F 17		10/80-83	3.2	162	48,521	1 2 5	48,521
5	F 72		10/80-85	5.2	90	25,830	2 8 11 12	25,830
6	F 13		10/80-84	4.2	94	41,603	1 2 5 8 11 12 15	6,153
7	F 62		10/80-84	4.2	199	6,153	1 2 5 8 11 12 15	6,153
8	G 123		11/80-86	6.2	126	47,889	2 8 11 15	47,889
9	F 46		11/80-84	4.2	52	37,487	2 8 11	37,487
10	G 83		3/81-87	6.8	110	18,527	2 8 11 12 15	18,527
11	G 74		3/81-86	5.8	164	21,910	2 8 11 12	21,910
12	F 66		4/81-89	0.7	81	24,601	1 2 8 15	24,601
13	F 56		5/81-88	7.7	425	23,283	1 2 8 10 11 12 15	23,283
14	F 64		5/81-88	5.7	87	35,581	1 2 8 9 12	35,581
15	F 14		8/81-86	5.4	370	33,668	1 2 7 8 11 12 15	33,668
16	F 53	[2]	8/81-85	4.4	262	33,164	1 2 6 8 10 11 12 15	33,164
17	F 84		8/81-84	3.4	212	19,574	1 2 8 11 15	19,574
18	F 31		8/81-85	4.4	155	18,344	2 5 8 11 12 15	18,344
						1,166	1 11	1,166
19	F 82		8/81-84	3.4	184	13,100	1 2 8 10 11 12 15	13,100
20	F 38		8/81-87	6.4	198	24,745	1 2 8 10 11 12 15	24,745
21	F 70		8/81-88	7.4	309	28,392	1 2 8 10 11 12 15	28,392
22	F 42		9/81-88	7.3	146	12,249	1 2 8 10 11 15	12,249
23	F 1		11/81-85	4.2	154	50,000	1 2 8 10 11 12 15	50,000
24	F 49		11/81-89	8.2	191	15,583	1 2 10 12 15	15,583
25	F 34							
			11/81-85	4.2	162	18,270	1 2 8 10 11 12 15	18,270
26	F 4		11/81-85	4.2	161	25,839	1 2 8 11 15	25,839
27	F 77		11/81-85	4.2	217	27,586	1 2 8 10 11 12 15	27,586
28	F 71		11/81-84	3.2	142	47,361	1 2 7 8 10 11 12 15	47,361
29	F 3	[2]	11/81-85	4.2	166	18,344	1 2 8 10 11 12 15	18,344
30	F 27	[2]	4/82-86	4.7	124	18,494	1 2 8 11 15	18,494
31	F 24		5/82-85	3.7	310	27,064	1 2 10 11 12 15	27,064
32	G 110		5/82-88	6.7	159	33,882	1 2 8 10 11 12 15	33,882
33	F 47		2/82-87	5.9	7	16,143	1 2 8 12 15	16,143
34	F 18		5/82-85	3.7	358	35,198	1 2 8 10 11 15	35,198
35	G 116		5/82-86	4.7	145	17,321	1 2 5 8 10 11 12 15	17,321
36	F 55		6/82-85	3.6	236	50,000	1 2 8 11 12 15	50,000
37	F 44		6/82-87	5.6	200	27,886	1 2 8 10 11 12 15	27,886
38	Cancelled FY 88							
39	G 65		6/82-88	6.6	183	23,929	1 2 8 10 11 12 15	23,929
40	F 63		9/82-87	5.3	154	50,000	1 2 7 8 10 11 12 15	50,000
41	F 123	[2]	9/82-85	3.3	144	6,119	8 10 12 15	6,119
42	Cancelled 2/85							
43	F 80		12/82-87	5.1	227	27,520	1 2 6 8 10 12 15	27,520
44	G 91		2/83-86	3.9	41	20,416	1 2 8 11 12 15	20,416
45	F 5		5/83-86	3.7	315	25,357	1 2 6 8 10 11 12 15	25,357
46	F 61		5/83-87	4.7	156	25,412	1 2 8 10 11 12 15	25,412
47	F 107		5/83-90	7.7	455	35,330	1 2 8 10 11 12 15	35,330
48	F 150		5/83-88	5.7	251	31,235	1 2 8 10 11 12 15	31,235
49	F 114		5/83-86	3.7	168	8,633	8 11 12	8,633
						30,004	2 8 15	30,004
50	F 29	[2]	6/83-86	3.6	176	2,165	1 8 11 12 15	2,165
51	F 35		10/83-86	3.2	226	35,628	1 2 8 11 12 15	35,628
52	G 99		1/84-87	4.0	175	34,915	1 2 8 10 11 12 15	34,915
53	F 30		3/84-87	3.8	188	21,699	1 2 8 11 12 15	21,699
54	G 104		5/84-88	4.7	87	21,446	1 2 8 11 12	21,446
55	F 185		7/84-88	4.5	147	14,132	1 2 8 11 12 15	14,132
56	F 120		7/84-88	4.5	160	36,454	1 2 8 11 12 15	36,454
57	F 142		9/84-87	3.3	105	11,257	1 2 12	11,257
58	F 156		4/85-88	3.7	74	19,428	1 2 8 12	19,428
59	F 74		7/85-88	3.5	189	8,975	1 2 8	8,975
60	G 63		7/85-88	3.5	87	16,747	2 7 8 11 15 16,747	
61	F 79		8/85-88	3.5	295	41,581	1 2 8 10 11 12	41,581
62	Cancelled FY 88							
63	Cancelled 7/86 (DTP)							
64	G 66		8/85-89	4.4	280	44,506	2 8 10 11 12 15	44,506
65	G 71		8/87-90	3.4	219	29,846	1 2 8 12	29,846
61		Total		--	11,277	1,686,349		1,686,349
--		Average		4.9	185	27,645		27,645

1 All contracts expire December 31st of the year indicated.
2 DTP - Dairy Termination Program participant.
3 BMPs are displayed in Table 1

Figure 2.—St. Albans Bay RCWP signed contract status as of September 30, 1990.

Vermont Evaluation Models

At the same time, the Soil Conservation Service was studying agricultural runoff and developing management plans for other agricultural watersheds in Vermont. To develop strategies for nonpoint source phosphorus management, the Soil Conservation Service developed simple desktop computer models — now known as BARNY, FIELDS, MILK, and STACK (Keeler, 1989) — to provide estimates for existing and treated condition phosphorus loading from barnyards, fields where manure was spread or where there was significant erosion, milkhouse effluent discharges, and runoff from stacked manure.

The Soil Conservation Service also applied the models to the St. Albans Bay watershed to provide estimates of agricultural nonpoint source phosphorus loads. The model estimates afforded a comparison with observations from the comprehensive monitoring and evaluation activities and provided another means of tracking progress. These models are particularly useful for tracking nonpoint source project progress as well as planning treatment for farms and project areas (Mahood, 1988).

Procedures for Using the Models

The models use data from on-farm inventories made from a baseline data inventory worksheet, Form VT-PDM-1 (Fig. 3 shows the first page of this worksheet). The inventory, which includes information on crops grown; types, numbers, and management of livestock; handling of milkhouse wastes; manure management practices; and cropland management practices, characterizes a dairy farm's

SECTION I: OPERATIONAL UNIT

Landuser _____
Farm Number _____
Town _____
Subwatershed Stream _____
Interest in project participation _____
(High, Med., Low, None)

ACRES OWNED/RENTED OUTSIDE WATERSHED

_____ Cropland _____ Avg. Ann. Row Crop
_____ Continuous Hayland
_____ All Other Land

_____ TOTAL OUTSIDE WATERSHED

ACRES WITHIN WATERSHED

_____ Cropland Owned
_____ Cropland Rented
_____ Avg. Ann. Row Crop
_____ Cont. Hayland Owned
_____ Cont. Hayland Rented

_____ Pasture
_____ Woodland
_____ Other

_____ TOTAL IN WATERSHED

SECTION II: LIVESTOCK

	Number	Breed	Pasture Season (Months/Yr)	CONFINEMENT (Hrs/Day)[1] Pasture Season	Non-Pasture Season
Milk Cows					
Heifers					
Beef Cattle					

1/ Confinement = time livestock are in the barn and/or a scraped LCA resulting in accumulated manure which must be removed.

SECTION III: MILKHOUSE WASTE SYSTEM: See Page 3 for Buffer Info.

MILKING SYSTEM

(___) 1.BUCKET/DUMP STA.
(___) 2.PIPELINE
(___) 3.PARLOR
(___) 4.NON-DAIRY

BUFFER DATA	Sheet Flow Now	Sheet Flow Plan	or/ and	Channel Now	Channel Plan
Cover Factor				1.0	1.0
Length (ft)					
Slope (%)					

WASTE DISPOSAL SYSTEM

Now		Plan	S.O. Use
(___)	OUTSIDE WATERSHED	(___)	2
(___)	DIRECT TO STREAM	(___)	0
(___)	THRU NON-SCS BUFFER*	(___)	0
(___)	LAGOON	(___)	1
(___)	INTO MANURE STORAGE	(___)	1
(___)	THRU SCS FILTER*	(___)	3
	SEPTIC FIELD/DRY WELL		-
(___)	WORKS PROPERLY	(___)	5
(___)	WITH OVERFLOW*	(___)	6
(___)	_____	(___)	-

*Complete Buffer Data
Notes: _____

Figure 3.—Baseline data inventory worksheet.

activities for both input to the planning models and use in detailed planning and design of the BMPs.

Model Results

The models process data from the worksheets to provide a farm-by-farm analysis (Table 2). The analysis estimates phosphorus runoff values for existing conditions, the magnitude of which can be evaluated for management at the source, farm, subwatershed, and watershed levels (Table 3) to enable project managers to target certain subwatersheds and farms for priority assistance.

The models provide estimates of phosphorus loads from each of the various source types so the significance of each source can be evaluated. Figure 4 shows that manure spreading was a principal treatable phosphorus source, while cropland erosion was least significant in the St. Albans Bay watershed.

Table 2 ranks farms in terms of critical or treatable nonpoint source phosphorus. The critical portion of nonpoint source phosphorus is considered to be that portion of total phosphorus that can be reasonably controlled on the farm. This portion includes 85 percent of the animal waste phosphorus (an average value found from model runs

Table 2.—St. Albans Bay watershed: farms ranked by pre-RCWP average annual critical total phosphorus (TP) (lbs/yr).

FARM NUMBER	SHEET/RILL EROSION TP (EROS. >T)	AGRICULTURAL WASTE (TP)					CRITICAL NPS* PHOSPHORUS	RCWP CONTRACT?
		SPREAD MANURE	STACKED MANURE	BARN-YARDS	MILK-HOUSES	85% OF TOTAL		
48	475	139	14	30	0	156	631	Yes
24	0	384	0	17	35	371	371	Yes
61	0	234	0	42	132	347	347	Yes
49	0	243	0	105	34	325	325	Yes
27	0	147	0	112	38	252	252	Yes
4	0	162	0	79	41	240	240	Yes
65	0	144	0	90	37	230	230	Yes
25	17	125	0	107	19	213	230	Yes
131	0	70	172	1	27	230	230	No
1	0	182	0	35	46	224	224	Yes
16	0	125	0	111	16	214	214	Yes
121	7	8	179	35	22	207	214	No
64	0	159	0	59	25	207	207	Yes
115	0	3	198	42	0	207	207	No
102	0	78	45	104	11	202	202	No
6	0	156	0	56	25	201	201	Yes
50	124	52	0	26	11	76	200	Yes
28	0	122	0	93	20	200	200	Yes
140	41	51	73	20	27	145	186	No
26	0	144	52	22	0	185	185	Yes
43	0	90	0	7	105	172	172	Yes
13	11	14	0	174	0	160	171	Yes
124	0	79	17	105	0	171	171	No
141	23	168	0	3	0	145	168	No
59	0	165	0	20	11	167	167	Yes
32	0	69	46	7	71	164	164	Yes
29	7	102	0	62	19	156	163	Yes
122	0	43	106	26	10	157	157	No
2	9	137	2	0	34	147	156	Yes
113	0	31	71	82	0	156	156	No
11	0	89	0	42	51	155	155	Yes
15	3	148	0	9	20	150	153	Yes
120	0	59	49	50	21	152	152	No
53	56	105	0	2	0	91	147	Yes
39	0	107	37	19	9	146	146	Yes
36	0	57	0	61	54	146	146	Yes
3	0	79	0	86	0	140	140	Yes
144	8	142	0	8	0	128	136	No
127	0	142	0	0	18	136	136	No
8	0	72	0	0	84	133	133	Yes
139	0	77	0	51	28	133	133	No
33	0	20	0	109	24	130	130	Yes
45	0	63	51	16	22	129	129	Yes
18	48	49	22	16	6	79	127	Yes
20	0	114	0	23	9	124	124	Yes
106	0	63	0	82	0	123	123	No
30	6	75	53	0	7	115	121	Yes

Table 2.—Continued.

FARM NUMBER	SHEET/RILL EROSION TP (EROS. >T)	AGRICULTURAL WASTE (TP) SPREAD MANURE	STACKED MANURE	BARN-YARDS	MILK-HOUSES	85% OF TOTAL	CRITICAL NPS* PHOSPHORUS	RCWP CONTRACT?
14	0	141	0	0	0	120	120	Yes
148	0	72	0	55	11	117	117	No
116	0	33	73	28	0	114	114	No
12	0	19	0	113	0	112	112	Yes
38	0	123	0	8	0	111	111	Yes
23	0	128	0	0	0	109	109	Yes
34	0	54	15	0	54	105	105	Yes
21	0	82	0	13	26	103	103	Yes
19	0	50	0	45	25	102	102	Yes
128	0	114	0	0	6	102	102	No
22	0	77	0	6	33	99	99	Yes
155	0	113	0	0	0	96	96	No
51	0	79	0	8	24	94	94	Yes
129	0	0	0	15	95	94	94	No
135	21	4	4	11	64	71	92	No
118	39	0	28	31	0	50	89	No
57	0	52	0	36	15	88	88	Yes
35	0	37	17	27	22	88	88	Yes
152	21	79	0	0	0	67	88	No
62	0	74	0	0	23	82	82	Yes
37	13	68	0	13	0	69	82	Yes
56	3	27	0	9	53	76	79	Yes
40	0	49	24	7	12	78	78	Yes
7	0	48	0	3	37	75	75	Yes
44	14	32	0	25	13	60	74	Yes
31	0	31	36	18	0	72	72	Yes
10	0	48	0	15	22	72	72	Yes
143	8	58	14	1	0	62	70	No
41	5	0	13	26	33	61	66	Yes
9	0	17	0	39	18	63	63	Yes
147	0	73	0	0	0	62	62	No
47	0	31	13	22	0	56	56	Yes
149	0	9	37	12	6	54	54	No
108	0	45	1	18	0	54	54	No
46	0	39	7	9	7	53	53	Yes
17	0	45	0	2	0	40	40	Yes
138	0	7	27	12	0	39	39	No
58	0	16	0	0	18	29	29	Yes
134	0	0	13	17	0	26	26	No
126	0	7	14	9	0	26	26	No
5	0	29	0	0	0	25	25	Yes
133	14	11	0	0	0	9	23	No
150	0	22	0	0	0	19	19	No
60	0	20	0	0	0	17	17	Yes
114	0	3	6	8	0	14	14	No
54	0	14	0	0	0	12	12	Yes
52	0	12	0	0	0	10	10	Yes
142	0	0	0	9	0	8	8	No
132	0	6	0	0	0	5	5	No
55	0	0	0	0	0	0	0	Yes
137	0	0	0	0	0	0	0	No
Totals:								
98	973	7,185	1,529	2,916	1,786	11,404	12,377	63: Y; 35: N

*NPS = nonpoint source

Table 3.—A comparison of agricultural nonpoint source phosphorus loads by subwatershed — St. Albans Bay Watershed RCWP project.

ITEM	SUB-WATERSHED MILL	WETLAND	GUAYLAND	DIRECT TO BAY	WATER-SHED TOTAL
Total P (lbs/yr)	7,350	10,975	1,025	1,570	20,920
Percent of total	35.1	52.5	4.9	7.5	100
Critical P (lbs/yr)	5,190	6,900	210	1,100	13,400
Percent of total	38.7	51.5	1.6	8.2	100

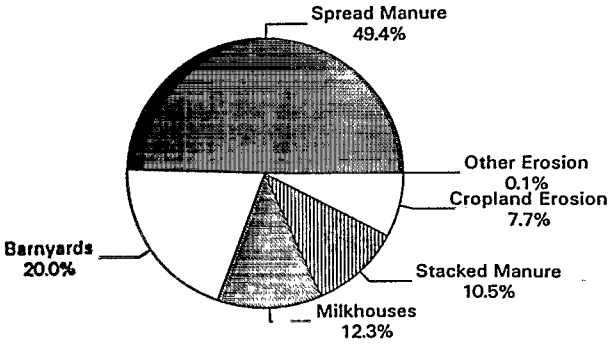

Figure 4.—St. Albans Bay watershed: agricultural sources of treatable phosphorus, pre-project.

and monitoring) and total phosphorus associated with enriched sediment yield at the watershed outlet from accelerated sheet and rill erosion. Only sediment derived from erosion in excess of "T" (or the soil's regeneration level) is considered. Erosion control below "T" is generally cost-prohibitive on Vermont farms.

Use of Targeting and Tracking

Table 2 would have been very useful in ranking farms for project assistance. Several of the higher priority farms did not enter into contracts to treat problems, while some of the lower priority ones did. This information would have provided an opportunity to direct more attention to bringing the higher load farms under contract. However, other farmer variables — such as attitude, financial considerations, and expected tenure — may have been governing this process.

Aside from these variables — and assuming all farmers were willing to participate — the project could have achieved phosphorus load reductions more quickly. Figure 5 compares the phosphorus load reductions that would have been achieved each year if the project had been based on treating for critical phosphorus rather than critical acres. The project might possibly have achieved the estimated phosphorus reductions by 1982 rather than 1987, a full five years earlier.

Also, assuming all farmers were willing to participate, the project might have been more efficient in achieving phosphorus load reductions. Figure 6 shows that 61 farms entered into contracts to achieve the goal of treating 75 percent of the critical acres. The same level of phosphorus reduction could have been achieved by entering into contracts on only 45 farms, if the highest priority farms had been treated first. At an average contract cost of $27,645, this might have saved over $442,000 in cost-share funds.

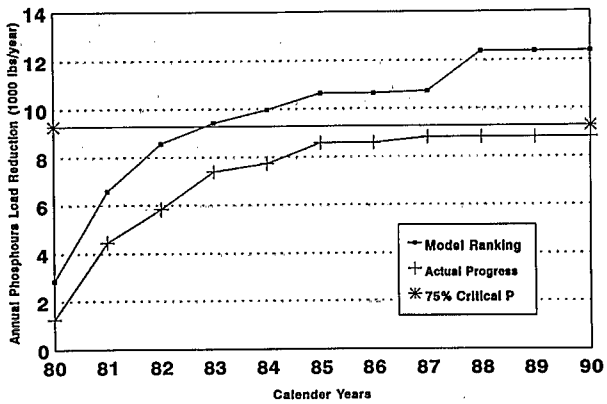

Figure 5.—Comparison of estimated phosphorus reductions by year: model priority (treat 75 percent of critical phosphorus) vs. actual implementation (treat 75 percent of critical areas).

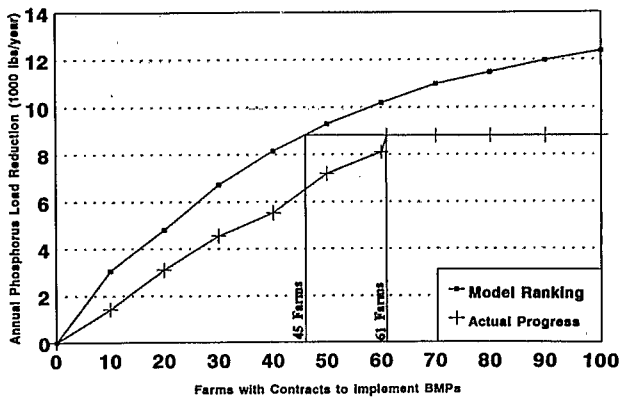

Figure 6.—Comparison of estimated phosphorus reductions by farm: model priority vs. actual implementation.

Conclusion

Managers have often evaluated progress in agricultural nonpoint source projects (such as the St. Albans Bay watershed) in terms of treatment measures applied rather than units of loading reduction. The Vermont Soil Conservation Service has developed planning models to estimate loads at the edge of field, farm, and watershed level for various treatment conditions, and the results can be used to better plan nonpoint source projects. During implementation, managers can track project progress directly in terms of pollutant load reduction rather than indirectly in terms of treatment measures applied.

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Elements of a Model Program for Nonpoint Source Pollution Control

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ABSTRACT

Rural Clean Water Program (RCWP) projects have contributed significantly to the knowledge necessary for reducing nonpoint source pollution and achieving water quality goals. An RCWP evaluation, conducted during 1991 and 1992 by the National Water Quality Evaluation Project (NWQEP) at North Carolina State University, shows that many of the 21 projects were highly effective and others had some effective elements. When expected results were not achieved, the NWQEP attempted to analyze program and project deficiencies that may have affected the outcome. Despite difficulties, the RCWP is the best program to date for evaluating agricultural nonpoint source pollution control methods, and it should serve as a model for developing future programs. RCWP was effective because it had good overall program management and institutional arrangements that encouraged consultation between the U.S. Department of Agriculture (USDA) and the U.S. Environmental Protection Agency, excellent program guidance, and effective technical support for reviewing reports and providing ongoing evaluation.

NWQEP has developed a model program and a model project based on the RCWP and added refinements to strengthen weaker elements identified during the evaluation. The model program includes a technical support group with access to resources for visiting project sites to assist in project selection, monitoring, evaluation, and developing the plan of work. The model program needs technical support from the USDA Agricultural Research Service (ARS) for developing and evaluating best management practices. Increased assistance for monitoring is also needed and should be provided by the U.S. Geological Survey.

NWQEP suggests three project levels, based on complexity and level of monitoring detail. This paper discusses the NWQEP model and lists monitoring protocols that should be incorporated in program guidance to improve the chances of detecting water quality trends. All projects need a preimplementation plan of work development to strengthen the problem definitions, select the critical area, model the watershed to set treatment goals, and establish a means for land treatment tracking. Projects also need a manager, technical support, and core project staff to improve efficiency and encourage accountability.

A growing awareness of agriculture's contribution to the nonpoint source pollution problem, increasing concern about water quality, and pressure from special interest groups have influenced Federal agencies to respond to these concerns by developing a demonstration of nonpoint source pollution control capabilities. In response to the 1989 President's Water Quality Initia-

tive, the U.S. Department of Agriculture (USDA) has developed programs that accelerate soil conservation and best management practice (BMP) implementation on farms, ranches, highly erodable lands, and watershed projects. Implementing these programs produces many important benefits, including increased adoption of soil conservation practices and BMPs that improve water quality. Many programs, however, do not target specific critical area pollutant sources. With only limited targeting of pollution sources (and even less water quality monitoring to document the linkage between land treatment and water quality), our knowledge of the water quality benefits in these measures will not expand appreciably.

New nonpoint source control programs must build on current knowledge to be effective. The evaluation of the section 108a Great Lakes Demonstration projects showed that nonpoint source pollution is more persistent and more difficult to treat than previously thought (Newell et al. 1986). It also showed that using a pollutant runoff model to determine critical areas is an efficient way to use project funds. In addition, the Model Implementation Program (MIP) evaluation demonstrated that a project should target critical areas for treatment to improve the likelihood of success, and that BMPs should be selected and applied to promote water quality results (Natl. Water Qual. Eval. Proj. and Harbridge House, 1983a,b).

Lessons learned from the Rural Clean Water Program (RCWP) provide critical information about nonpoint source pollution control technologies and approaches for the U.S. Environmental Protection Agency (EPA), U.S. Department of Agriculture (USDA), and other Federal, State, and local nonpoint source pollution control agencies and programs. The RCWP is significant among nonpoint source control programs because it combines land treatment with water quality monitoring to document the effectiveness of nonpoint source controls.

The RCWP has 21 projects located in nearly every region of the United States that address a wide range of water quality problems. The program is unique in that it received a higher level of up-front funding for a longer period (10 to 15 years) than other federally sponsored nonpoint source programs. The longevity and dependability of RCWP funds enhanced efforts to establish a clear link between water quality and land treatment, and several RCWP projects have been able to demonstrate such a link. The publication of RCWP rules and regulations in the *Federal Register* (1980a) provided clear guidelines for RCWP projects, facilitating the overall program evaluation by standardizing many of the projects' administrative and technical aspects. Finally, the approach taken to address water quality problems — providing Federal cost-share funds to producers willing to implement BMPs — makes the RCWP experiment important as a way to evaluate voluntary versus regulatory approaches to the problems of agricultural nonpoint source pollution.

Because of its unique characteristics as an experiment in nonpoint source control, the RCWP is an important source of insights and technology transfer for the many ongoing and future nonpoint source programs, including the 319 National Monitoring Projects, other shorter-term 319 projects, the USDA Demonstration and Hydrologic Unit Projects, the Clean Lakes Program, and State nonpoint source programs, among others. Because so many other nonpoint source programs are being planned and conducted, the need for clear articulation and dissemination of the lessons learned from the RCWP is even more important. To share these valuable lessons in the most effective way possible, the National Water Quality Evaluation Project (NWQEP) has restated them as a set of recommendations for a model nonpoint source pollution control program and project.

NWQEP's evaluation of the RCWP has been conducted to establish a set of recommendations for developing Federal nonpoint source pollution control and water quality programs — programs whose primary goal is to evaluate the water quality improvements from nonpoint source controls. The objectives of the evaluation were to assess

- cooperation among project team members, committees, and agencies;
- agreement between the water quality problem and the choice of solutions;
- project achievements;
- results of monitoring and assessment of project impacts; and
- project findings to compile lessons learned.

Methods

For the program analysis, we reviewed the MIP evaluation (Natl. Water Qual. Eval. Proj. and Harbridge House, 1983a,b) and the section 108a Great Lakes Demonstration Programs (Newell et al. 1986). We also reviewed literature for the USDA President's Water Quality Initiative and the EPA's section 319 Nonpoint Source Program (U.S. Environ. Prot. Agency, 1991). From these reviews we gained valuable insights on methods that could be used to evaluate the RCWP.

Including our own past experience, we used five sources of information to evaluate RCWP projects:

1. an in-person interview questionnaire for project personnel during site visits,
2. a short answer questionnaire administered to project personnel,
3. a telephone survey of producers who did not participate in the 21 projects,
4. 10-year reports from the RCWP projects, and
5. NWQEP's own 10 years' experience in offering technical assistance to the projects and performing program evaluations.

For site-visit evaluations, an interagency evaluation team (led by a NWQEP member) visited each project. In-person interviews of local and state project staffs using a standardized questionnaire were conducted during site visits (Coffey and Smolen, 1991). Questions were designed to gather specific information on project elements, including State and local coordination, local program administration, information and education, land treatment, and water quality monitoring and evaluation.

Project staff responses to a short answer questionnaire (Coffey and Hoban, 1992) were used to gather information on project coordination, advisory committees, project effectiveness, Information and Education (I&E), farm operator participation, and BMP implementation. A companion telephone survey of farm operators was used to determine factors that influenced participation and BMP implementation (Hoban and Wimberley, 1992). RCWP projects also produced detailed 10-year reports that provided important insights, findings, and recommendations for each project element.

For each RCWP project, the NWQEP wrote a comprehensive analysis, including

- a project synopsis;
- a section on findings, successes, and recommendations for each of the project elements; and
- a detailed project description.

At the foundation of the analysis were the RCWP regulations and the findings from individual RCWP project evaluations. The results of the RCWP analysis are presented here as a set of recommendations for a model program and a model project, including selected examples from RCWP projects that support the results.

Results

Based on NWQEP's review of agricultural nonpoint source pollution control programs, the RCWP is, to date, the best program available for achieving water quality goals. For example, the RCWP had a set of rules and regulations (*Federal Register*, 1980), technical oversight, and secure, long-term funding. Some projects have documented water quality improvements, and all projects have contributed to a greater understanding of water quality problems and to cooperation among agencies charged with addressing nonpoint source pollution.

The overall RCWP assessment has shown that it was not possible to document water quality benefits for RCWP projects in which

- agricultural activities were not the primary pollution source,
- the areal extent and magnitude of land treatment was inadequate, or
- the monitoring designs were inadequate to document water quality improvements.

However, each project did have one or more nonpoint source pollution control benefits, including

- development of cooperative relationships among Federal, State, and local agencies necessary to achieve an effective nonpoint source pollution control program;
- achievement of widespread adoption of BMPs to improve water quality under this assistance program;
- visual improvements in water quality associated with the use of BMPs; or
- water quality improvements documented by water quality monitoring.

Therefore, the model program and project described herein builds on the RCWP's structure and essential features, while adding refinements to strengthen weaker components identified during the RCWP evaluation.

Elements of a Model Program for Evaluating Nonpoint Source Pollution Controls

Guidance written in the form of regulations must be available to help implement the program (*Federal Register*, 1980a). The model program's major features (as outlined in the RCWP regulations) will include

- clearly defined responsibilities of Federal, State, and local agencies and landowners or operators;
- criteria for project selection, approval, and implementation;
- contracting requirements for technical and financial assistance to farm operators;
- provisions for project funding and termination;
- requirements for making cost-share payments to participants; and
- plans for program and project monitoring and evaluation.

The model program guidance will include these important features and strengthen water quality and land treatment monitoring, evaluation, and reporting.

Program guidance would also list the roles of project staff at the Federal, State, and local levels, and would help staff understand the responsibilities of interagency counterparts.

The RCWP objectives were to

- achieve improved water quality in the most cost-effective manner possible in keeping with the provision of adequate supplies of food, fiber, and a quality environment;
- help agricultural landowners and operators reduce agricultural nonpoint source pollutants and improve water quality in rural areas to meet water quality standards or goals; and
- develop and test programs, policies, and procedures for the control of agricultural nonpoint source pollution.

These objectives can be restated as model program objectives that are relevant, comprehensive, and nonoverlapping. Thus, the model program is to

- achieve improved water quality to restore and protect the designated use of surface or groundwater resources,
- help agricultural landowners and operators reduce agricultural nonpoint source pollutants and habitat perturbations, and
- develop, test, and evaluate policies and programs to control agricultural nonpoint source pollution.

Program Administration and Management

The model nonpoint source pollution control program should be administered by a single department. The USDA would administer the model program in consultation with the EPA Administrator and the Director of the U.S. Geological Survey (USGS). Or, the Secretary of Agriculture could delegate the responsibility of program administration to the ASCS, which has a long history of program administration and leadership that contributed to the RCWP's success. Local project funding would have to be received on time through the State ASCS office. Technical assistance for identifying and documenting the water quality problem through monitoring and evaluation could be provided by EPA. Technical assistance for land treatment and land treatment monitoring would become a joint responsibility of USDA Soil Conservation Service (SCS) and Extension Services. The Extension Service (ES) should be responsible for information, education, and BMP recommendations. The SCS should be responsible for the development of farm plans and structural BMPs.

The Agricultural Research Service (ARS) would also provide technical assistance for developing and evaluating BMPs. Technical assistance for water quality monitoring and linking land treatment data to water quality data would be coordinated by EPA, with additional technical assistance on sampling, instrumentation, and data management from USGS and ARS.

The model program will also need a national coordinating committee to oversee functions currently defined for this committee by the RCWP, including

- developing program regulations and cost-share rates,
- reviewing technical aspects,
- selecting projects to fund based on a technical assessment of likelihood of success,
- developing annual project reviews, and
- reviewing project progress.

The national coordinating committee should have the ability to assign provisional status to projects if State or local program staffs are not meeting minimum performance standards. In addition, the committee should have the authority to terminate projects that fail to meet minimum requirements after two complete years on provisional status.

■ **Program Planning.** Program planning is necessary to ensure adequate attention to all project elements and stages of development. Problem identification, the selection of critical areas, and the development of project proposals precede funding (Fig. 1). The first two elements may extend into the first year to allow refinement. Assistance from a technical support group is also needed before funding and throughout the project.

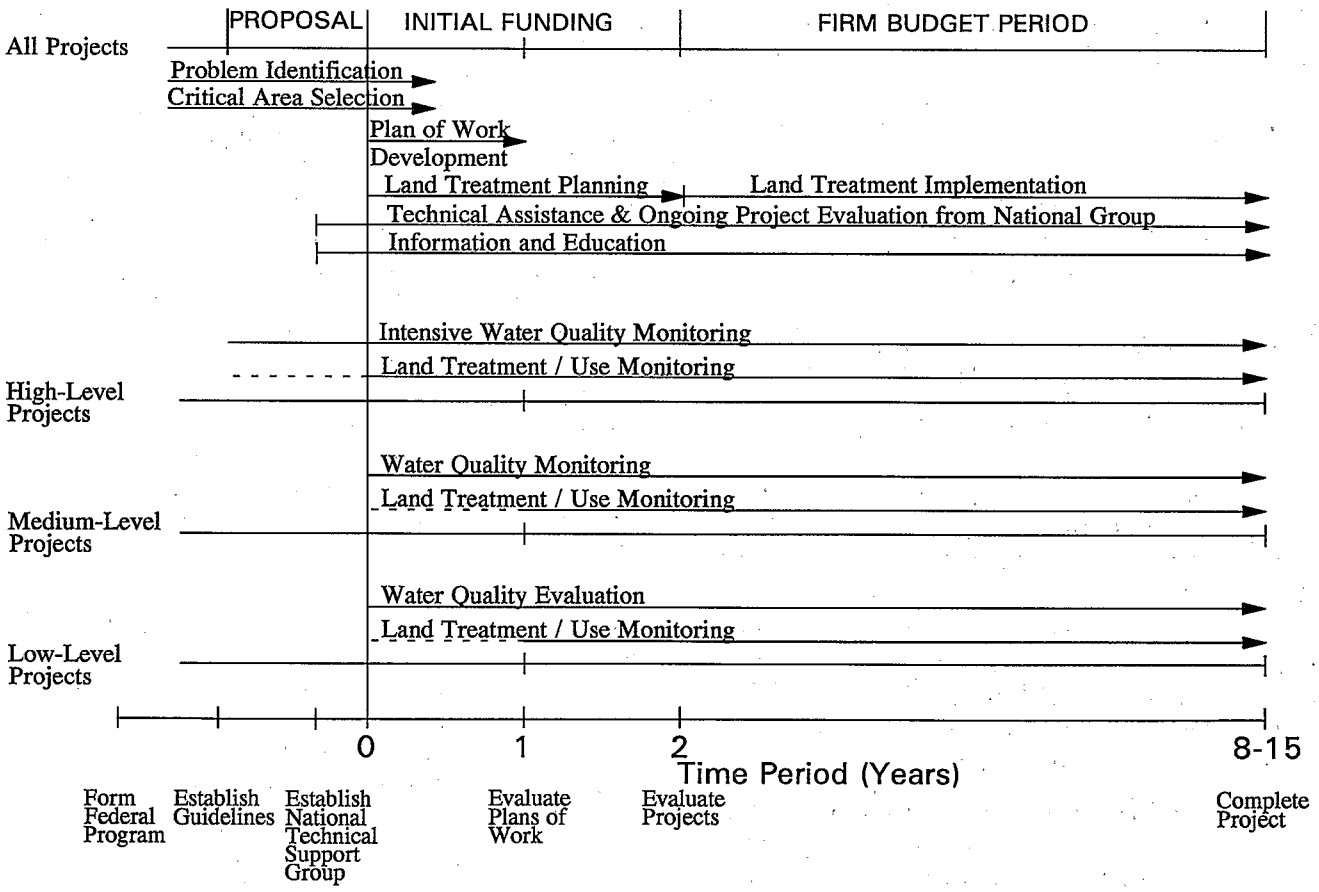

Figure 1.—Model program and project timetable.

Project funding occurs in stages (Fig. 1). The first two years are designated for initial funding only, whereby projects may be terminated at any time. Successful advancement to the firm budget period (after which the project will be funded continuously throughout its life) requires

- detailed and accurate problem identification,
- adequate selection of critical areas based on problem pollutants,
- a detailed plan of work for land treatment and water quality monitoring, and
- demonstrated progress toward key agency cooperation and the development of institutional arrangements.

Land treatment planning before BMP implementation is critical to ensure adequate targeting of resources. We suggest allocating two years for this activity so that technical assistance may be sought if needed. A baseline should also be established for water quality monitoring before BMP implementation. Succeeding land treatment periods are for installing structural and management BMPs. Water quality monitoring must be consistent before, during, and after the implementation periods.

Program Technical Support

The model program must be structured so that projects are carefully selected to improve chances for meeting program objectives and obtaining water quality improvements. A national technical support group (outside the administrative organizations and the national coordinating committee) should be in place at program initiation to help develop program and project guidelines. This group should also provide technical assistance during (and after) the planning period for project selection, critical area and BMP designation, watershed modeling, land treatment and water quality monitoring, and project evaluation.

This technical support group must be provided adequate resources for site visits to projects to gain information and develop cooperative relationships before project selection, during BMP and monitoring implementation, and during final project evalua-

tion. The support group may respond to program and project technical requests from administrative agencies and individual projects and be responsible for verifying the accuracy and completeness of water quality analyses. Finally, the support group may take responsibility for the final evaluation by emphasizing lessons learned, identifying water quality improvements, and making recommendations for future programs.

Project Selection

Project selection is a key factor for program success. Selection criteria are needed to ensure that all possible projects are evaluated for their potential to contribute to program objectives. Projects should be selected because they have

- high priority water resources with documented water quality problems, or
- highly valued water resources threatened by documented agricultural nonpoint source pollution (because prevention of severe degradation is often more cost-effective than restoration).

In addition, projects should have the following characteristics:

- water resources having the highest public use value (e.g., recreation or water supply) because these projects can show a significant economic benefit;
- smaller watersheds of less than 30,000 acres because problems in these areas can be more readily identified, are easier to treat, and respond more rapidly to treatment;
- the potential for effective control of nonpoint source pollutants;
- the capability to use water quality models and monitoring to determine if significant pollution reductions are likely with BMP implementation;
- clearly stated objectives and goals related to water quality impairments or conditions threatening designated use;
- the ability to establish and maintain strong interagency cooperation and institutional project coordination;
- well-defined critical areas in which implementation of BMPs targeted to a specific pollutant (or group of pollutants) can be emphasized;
- the potential for a high level of landowner participation in the critical area;
- the potential that landowners will accept and implement the necessary BMPs and, perhaps, adopt alternative agricultural systems (e.g., changing from row crops to hayland or pasture), which are integrally tied to water quality improvements and project goals;
- a plan of work development process to obtain baseline monitoring data, determine problems, refine critical areas and develop BMP systems, conduct I&E programs, and document effective project administration staffing and cooperative relationships;
- the ability to conduct an effective I&E program in advance to determine if key BMPs (e.g., fencing or dairy waste use) will be acceptable to farm operators;
- the characterization of the hydrology and pollutant transport system to allow adequate development of water quality goals and monitoring systems; and
- the ability to monitor explanatory variables, such as season, stream discharge, water table depth, precipitation, other hydrologic and meteorologic variables, and land use changes.

The most successful RCWP projects were those that met most or all of these criteria. The Florida, Idaho, Utah, Vermont, and Oregon RCWP projects contained most of these elements and were among the most successful projects in implementing land treatment and documenting water quality improvements as a result of RCWP treatment. For example, the Utah RCWP project was relatively small (700 acres) with a well-defined critical area in which BMPs were targeted to the major source of pollutants (i.e., the dairies). Also, the project had a high level of landowner participation in the critical area. The Utah project's commitment to a two-year preproject monitoring program proved to be the key monitoring element that helped document substantial water quality improvements.

Several other effective projects contained many of the stated criteria but could have been strengthened if the missing elements had been present. The Nebraska RCWP project, for example, suffered in its early years from the lack of clearly defined water quality and land treatment goals. However, this project developed quantitative water quality and land treatment goals, a critical area definition that included BMPs targeted to sediment and erosion control, and a strong I&E program — resulting in a high level of landowner participation in the critical area.

The Delaware and Maryland RCWP projects were successful but lacked preproject water quality monitoring baselines, which impeded the ability to make quantitative statements regarding water quality improvements. The Iowa project contained most of the suggested components but had only a one-year pre-BMP monitoring database and initially did not understand that the turbidity problem in Prairie Rose Lake resulted not only from incoming sediment but also from resuspended sediment and algal growth.

Although the Massachusetts RCWP project met several key project selection criteria in that the Westport River estuary was a high priority resource with significant economic value (shellfish beds), the source of the water quality problem was not well documented. This lack of clarity was one of several factors that contributed to a lack of consensus within the community and, therefore, to poor producer participation. The Kansas RCWP project also lacked a clearly documented water quality problem that could be linked to a critical area pollutant source. Careful application of project selection criteria could have prevented the selection of this project and its subsequent termination three years later.

The Michigan RCWP project had only vague information indicating that the Saline River was a large contributor of nutrients (mainly phosphorus) to Lake Erie. The project had not clearly identified the critical pollutant source or critical area, and the project did not document any water use impairments. On the other hand, the Pennsylvania RCWP project presented a documented water quality impairment of agricultural origins and had the high visibility of a project that could reduce pollutants entering Chesapeake Bay. However, careful evaluation of project potential would have shown that the large number of small farms and the conservative nature of the farmers would impede BMP acceptance and implementation, thereby limiting the project's potential.

Program Funding

In the RCWP, all funds were identified and made available at each project's initiation so that long-term project planning and budgeting were possible. In contrast, budgets for the current USDA Demonstration and Hydrologic Unit projects must be approved each year. The associated delays have caused work plan uncertainties, budgetary burdens on State and local agencies, and incompatibility with fiscal budget requirements. In the model program, funds should be provided for preproject planning periods, which may last from six months to two years (as defined under "Project Proposal and Plan of Work Development").

Elements of a Model Project for the Evaluation of Nonpoint Source Pollution Controls

The model *program*, which is based on RCWP guidelines, carefully selects the individual *projects* that will be undertaken. The model *project is* based on the outline provided by RCWP regulations. The following discussion of the model project is supported by examples from the RCWP projects. The model project would operate under the primary authority of USDA with consultation and concurrence from EPA. ASCS would be the administrative lead agency. SCS should be responsible for the development of structural BMPs, and ES should be responsible for I&E and management BMPs. While agencies supervise project activities, committees would be responsible for setting priorities and coordination. All agencies, committees, and program participants would be guided by model program regulations published in the *Federal Register*.

Project Administration and Management

Because of its management abilities, administration for the model project at the State and local levels should remain with ASCS. To implement the project at the State level, each successful project must have strong administrative and technical support from a State coordinating committee, which also provides a link to the national coordinating committee and the local coordinating committee. The local coordinating committee needs to have strong and continual support from the State coordinating committee, which must establish and maintain open communication lines and a willingness to allow the local coordinating committee to implement the project.

The fundamental project administration and management elements are a local coordinating committee, a county Agricultural Stabilization and Conservation (ASC) committee, a project manager, and project advisory committees. The local coordinating committee should provide guidance for the agencies, community leaders, and citizens to oversee the administrative and technical tasks of a local project. The committee serves many functions, including

- assuring an adequate level of public participation,
- developing a plan of work,
- enlisting the help of needed agencies,
- overseeing information and educational activities,
- determining priorities for water quality plans,

- enlisting the help of one or more agencies for land treatment and water quality monitoring and evaluation,
- developing a plan for critical area selection,
- creating a plan for implementing targeted recommendations,
- establishing a plan for linking land treatment and water quality data and analysis, and
- developing a plan for project reporting.

The Florida, Vermont, Idaho, South Dakota, Pennsylvania, Oregon, Delaware, Utah, Maryland, and Iowa RCWP projects all had strong local committees that contributed profoundly to the success of their projects.

The county ASC committee, elected by county farm operators, is responsible for encouraging project participation and compliance. It can also play a major role in promoting the project. The involvement of the county ASC committee for the Appoquinimink River RCWP project in Delaware was a significant factor affecting participation: BMPs were implemented in 87 percent of the project's critical area.

A project manager is also essential (Brichford and Smolen, 1991). The manager should have a water quality and management background, ideally should work with the project from its inception, and hold the designation for the length of the project. The manager coordinates and monitors all project activities, including project reports, and has the authority to exert pressure on agencies or individuals not performing adequately. The project manager is responsible to the local and State coordinating committees and can report problems and successes directly to the national coordinating committee.

Examples of RCWP projects that used managers with positive results are South Dakota, Kansas, Virginia, and Minnesota. The South Dakota project hired a temporary, full-time manager during its initial phase to conduct individual visits with farmers to lay groundwork for their participation. The manager also organized project activities and compiled information so that the local coordinating committee could operate quickly and efficiently. The position continued until the last few years of the project. Likewise, Minnesota RCWP project recommendations suggested that a manager should be hired at the program's start who is familiar with all government agencies involved in the project but autonomous. A half-time manager was hired in Minnesota after the project had begun. As a respected area farmer, the project assistant was able to encourage the participation of his neighbors through one-on-one visits, well testing, and newsletter preparation.

Project advisory committees (e.g., administrative, technical, I&E, land treatment and water quality monitoring and evaluation, and modeling) are useful for gaining progress in areas where input from a smaller, more focused group improves decisionmaking. Advisory committees should be formed, disbanded, or regrouped as needed. For example, an advisory committee comprised of land treatment and water quality monitoring and modeling personnel can help coordinate efforts to link land treatment and water quality information. In the Vermont RCWP, an advisory committee proved to be highly effective; it ensured cooperation among agencies and kept work activities on schedule. Similarly, the key to success in the Florida RCWP project was the implementation of an administrative subcommittee. The subcommittee (comprised of major agencies) met regularly to coordinate project activities.

Project Proposal and Plan of Work Development

Activities before project start-up influence the operation and success of each project and the total program. Pre-project programs and periods are specified in Figure 1 for three different levels of projects based on problem magnitude, monitoring intensity, and project complexity.

Initially, the Federal program administration is formed to develop and publish program and project guidelines. Thereafter, a proposal development period without funding is specified for all three project levels. The national technical support group provides leadership for proposal evaluation and determines which projects will be funded for plan of work development.

The high-level, or most complex, projects are required to have baseline water quality monitoring data or to initiate water quality monitoring during the proposal development period. Monitoring of water quality explanatory variables and land treatment are to continue throughout the total project.

Medium-level projects may begin water quality monitoring during the plan of work development and continue for the total project. Land treatment monitoring will be conducted throughout the project period. Sampling design for water quality and explanatory variables would be less comprehensive at this level than in a high-level project.

Projects at the lower level may require periodic water quality evaluation, such as visual examinations or simple measurements of an unambiguous water

quality problem, or a citizens' group may provide monitoring.

After a successful two-year initial funding period, a firm budget can be allocated and guaranteed for the duration of the project as long as satisfactory progress continues on the project.

Project Technical Support

To provide technical support for the project's first two or three years, a minimum core project staff must be created using individuals from the cooperating agencies. Core project staff will be responsible for project activities and required to work cooperatively with the project manager. Core project staff and the lead administrative agencies will have primary authority over project technical activities but will also seek input from other agency staff, farm operators, and local groups. Final technical decisions need not require a consensus of local coordinating committee members as long as decisions are consistent with program guidance and recommendations from the national technical support group.

Because they will be accountable for project progress, the core project staff will have a great investment in the project. Agencies must establish a mechanism for accountability and credit for good performance. The minimum core project staff should consist of a land treatment planner, and an I&E specialist. In the Alabama RCWP project where over 100 percent of the critical area was treated with BMPs, an extension agent was instrumental in encouraging producer participation.

A full-time planner will be needed to help develop farm plans, assist in BMP installation, help farm operators maintain practices, and track land treatment. Other core project staff positions beyond the minimum (e.g., an engineer, a water quality monitoring specialist, and an agronomist) may be needed.

When an adequate level of technical capability is not available at the project level, outside help should be employed to assist the project. Core project staff at the local level will enjoy greater freedom of communication and have a larger team of experts for technical support, compared to the limited communication that happens when technical assistance must be sought through line agency procedures. In the Idaho RCWP project, ARS provided valuable research and recommendations regarding the development and evaluation of conventional and new BMPs, particularly conservation tillage and no-tillage.

Because staff turnover can be problematic, incentives should be provided to encourage core project staff to make a minimum commitment of three years to the project. In the Louisiana RCWP project, annual turnover of the SCS soil scientist hired specifically to help implement the RCWP made it difficult to track BMP implementation and maintain consistency.

Problem Definition

Water quality monitoring cannot be left as an afterthought in an effective nonpoint source project. Monitoring must be used to identify specific pollutants (and their variability) responsible for the impairment or threat to designated use. Initital problem identification monitoring serves to help the project team understand sources and response characteristics of the affected water resource. The RCWP projects have vividly illustrated that clear identification of the source of the water quality problem and acceptance of this information by the public and producers are crucial to project success.

In Iowa, heavy sediment and a blanket of corn stalks covering a recreational lake surrounded by farmland helped make the problem and its source especially clear. RCWP projects in Utah, Vermont, Florida, Idaho, Nebraska, Oregon, and Pennsylvania also had ample visual and analytical evidence of problems in the receiving waters. In Massachusetts, however, where both intensive dairy farming on small acreages and booming residential development were taking place adjacent to an estuary containing important shellfish resources, the source of the problem needed to be more clearly documented to generate community support for project activities. South Dakota's project required several intense monitoring programs to gain a thorough understanding of the water quality problem and its causes because of complex interactions between the surface and groundwater sources feeding the target lakes.

Refinement of problem definition may occur as the result of new information obtained from water quality monitoring or modeling. Monitoring provides a way to track BMP effectiveness and progress toward water quality goals. Feedback on project effectiveness provided by monitoring is important to land treatment personnel and farm operators. For example, Vermont's RCWP project was able to reduce bacterial contamination enough to reopen public beaches for swimming. This accomplishment was heavily promoted in the news media, which gave the participating farmers pride and an investment in nonpoint source control and their project.

Project Plan of Work and Time Frame

The plan of work is a written strategy used to organize agencies, project staff, and interested parties for project implementation. An effective plan is dif-

ficult to write, primarily because the linkage between land treatment and water quality is not known with certainty. A national technical support group is needed to help the project address key obstacles, define the water quality problems, and develop effective land treatment and water quality monitoring strategies.

Project objectives and goals as stated in the plan of work must be measurable, quantitative, and (for the most part) attainable, given best available information. Project objectives and goals must be critically reviewed to ensure consistency with overall program objectives and goals.

■ **Time Frame.** A model project should last from 6 to 15 years, depending on size and the ability to implement land treatment. The median project length should be 8 to 10 years, but some projects may need 12 to 15 years to implement enough practices and document results. Larger areas could require long periods to show improvement. Examples of projects that successfully made use of longer time frames are the Idaho, Florida, Oregon, and Utah RCWP projects. The long pre- and post-BMP water quality and land treatment monitoring time frames for these projects, along with high levels of BMP implementation, made it possible to track irrigation water management, sediment control structures, and conservation tillage in the Idaho project, and animal waste management in the Florida, Oregon, and Utah projects. On the other hand, the Pennsylvania RCWP project found that more time was needed than originally expected to establish firmly the reduction in nutrient levels from BMP implementation on experimental sites.

■ **Critical Area Definition.** Critical areas are pollutant source areas in which the greatest improvement in the water resource can be obtained for the least investment in BMPs (Maas et al. 1987). The effectiveness of a nonpoint source pollution control program is likely to be a function of where, when, and how many BMPs are installed. Therefore, cost-share funding should only be available for the treatment of critical areas. Smolen (1988) reports that in critical areas cause and effect are clear, hydrology is simple, and response time to treatment is short. The Utah, Oregon, and Vermont RCWP projects documented major reductions in bacterial concentrations resulting from land treatment efforts in animal waste management. The project areas exhibit simple surface water hydrology, and treatment occurred in the critical areas. Bacterial populations, especially in surface waters, respond to BMP implementation, thus making bacteria in water a prime candidate to demonstrate project effectiveness.

■ **Targeting BMP Systems.** BMP systems directed at water quality improvements are far more effective than the installation and maintenance of individual BMPs. In Oregon, for example, the development and use of BMP systems to store and use manure were essential in reducing fecal coliform levels in Tillamook Bay. However, whether a BMP system or an individual BMP is to be used, each should be targeted to control specific pollutants identified in the water quality problem definition and project plan of work.

For example, BMP systems used to control lake sedimentation may be different from and target a different soil particle size than systems used to control lake turbidity. The South Dakota RCWP project targeted its BMPs to a specific problem; consequently, nutrient management was found to be the most effective BMP for reducing nutrient contamination in an area dominated by cropland with only a few scattered animal operations. On the other hand, the Utah RCWP project saw marked improvements in phosphates through animal waste management systems in a watershed totally composed of animal operations.

Implementing the Plan of Work

Federal agencies and committees provide direction and funding to support local administration and coordination of project activities such as I&E and land treatment. Local committees, however, are responsible for carefully defining project objectives and implementing project activities to meet goals. In addition, local committees receive guidance and support from the State coordinating committee and the national coordinating committee.

■ **Information and Education.** Extension Service should provide leadership for the development, implementation, and coordination of I&E programs for agricultural nonpoint source water pollution control. The local coordinating committee, the county ASC committee, the soil and water conservation district, and SCS should help with I&E efforts to ensure that the I&E message is being received by participants.

During the proposal development, the community and relevant agencies must be informed about problems in the project area, objectives, and design. Local people also need to take part in decisions from the start. An advance I&E effort should be used to ensure that the majority of the population and project staff agree about the problem, its causes, and the treatment approach. The effect of general and farm community support (or lack of support) was clearly demonstrated in several RCWP projects. In the Iowa RCWP project, three public

meetings were held to inform the community about the RCWP before the Prairie Rose Lake project application was submitted. This strategy of early community involvement helped the project to a strong start. Delaware producers also participated in the selection of and planning for the Appoquinimink River RCWP project, again contributing to a successful effort with strong producer participation. The Westport River RCWP project in Massachusetts, on the other hand, would have benefited from advanced information and education programming (as well as water quality monitoring for baseline data collection) to address and resolve conflicting views on the source of the water quality problem and the validity of the approach being recommended in the RCWP project.

Informational and educational efforts are take part in stages that change over time. Initially, the I&E team seeks to develop general awareness of the water quality problem and support for the project through mass media and public educational programs. Then, I&E seeks to increase farm operators' knowledge about nonpoint source control and improve their agricultural management skills through educational programs and one-on-one contact. Ultimately, I&E works to modify behavior by promoting the adoption of BMPs for improved management of agricultural chemicals, conservation of irrigation water, use of animal wastes, and conservation of soil.

The I&E message was received and implemented differently by the RCWP projects. For example, in Vermont, the efforts of the local Extension Service office were essential in informing producers and convincing them to participate in the RCWP. In Tennessee, every farmer received at least one (and sometimes three) personal visit from an I&E team member to encourage participation. In Florida, field days, demonstration sites, and tours were the most effective methods for promoting land treatment and presenting accomplishments in the RCWP project.

Where fertilizer management and pesticide management are important parts of the BMP program, the I&E staff assists with soil sampling or pest scouting and provides tailored recommendations to project participants. The I&E program develops or strengthens existing commodity associations to support integrated pest management and other specialized programs.

Extension Service can also initiate other programs to improve water quality. A good example is the Pennsylvania RCWP project. There the Extension office set up an animal waste trading exchange to enable farmers who wanted animal manure to find farmers who had excess manure. The Nebraska RCWP developed a strong fertilizer testing and management program, along with pest scouting. Both components resulted in a significant decrease in the use of fertilizers and pesticides.

■ **Producer Participation.** Water quality improvements depend on changes in farm operators' attitudes, knowledge, and BMP implementation. Hoban and Wimberley (1992) surveyed eligible participants and nonparticipants from the 21 RCWP project areas. Their findings on the farm operators' water quality awareness, need for more information, attitudes about water quality problems, adoption of BMPs, and participation in RCWP and other programs provide significant information on ways to improve education and participation in water quality programs. In addition, results from the short answer questionnaire (Coffey and Hoban, 1992) show that cost-share funding was a key incentive to participation.

Other important factors affecting producer participation in RCWP projects included:

- strong leadership within the farm community (as demonstrated in Iowa and Oregon),
- consensus within the farm community and the general public on the source of water quality problems and the importance of water resources (for example, the high value placed on local recreational lakes by the Iowa and Delaware farmers in their projects' critical areas),
- the threat of regulation if the sources of pollution were not voluntarily reduced (as in the Taylor Creek-Nubbin Slough project in Florida),
- economic penalties for producers who did not participate (as in the Oregon RCWP project where producers received lower milk prices from the local cheese cooperative if they were not implementing BMPs), and
- producer perception that BMPs implemented to reach the project goals would also benefit the farming operation (as in Alabama).

Producer participation also came about through other means. Concern for stewardship of the land encouraged many Pennsylvania farmers to participate (many implemented BMPs but refused cost-share funding). In Vermont, a long-standing commitment to keep the community clean was the impetus for participation.

■ **Land Treatment.** The Soil and Water Conservation District (SWCD) participates on the local coordinating committee, prepares applications, and

promotes the project. The SWCD, together with the county ASC committee, determines the priority of technical assistance among applicants for water quality plans based on criteria developed by the local coordinating committee. The SWCD also approves water quality plans and revisions.

SCS coordinates technical assistance for BMPs and recommends the appropriate agency for assistance. SCS provides technical assistance for setting priorities among applicants and developing and certifying their water quality plans. The role of SCS as the lead technical agency for land treatment should be retained; however, the contribution that can be made by other agencies and opportunities for interagency cooperation in achieving land treatment goals should be recognized. As a result of the Massachusetts RCWP project, a new approach to farm visits was developed by the local USDA agencies; ASCS and SCS staff members now routinely visit farms together to perform their duties under several USDA programs.

The role of Extension Services should be expanded to emphasize management practices to complement structural practices. For example, during the latter phases of the Pennsylvania RCWP project, most of the land treatment effort was facilitated by the ES through individual contacts and nutrient management plans. For this project, the high number of farms needing animal waste storage facilities and the resistance to installing such facilities made the use of the ES and nutrient management plans the only effective way to reduce nutrients in the area streams.

■ **Water Quality and Land Treatment Monitoring.** The State water quality agency should participate on the State and local coordinating committees and monitor and evaluate the project's effectiveness. Because Federal assistance is required to encourage consistent and continuous water quality and land treatment monitoring throughout the project period, Federal funding for water quality monitoring must be authorized as a part of the model program. Funding for monitoring is required to document progress, the need for continued treatment, and water quality changes. Funding would be provided to all projects to meet minimum monitoring requirements for both land treatment and water quality.

Greater accountability by the State water quality or other monitoring agency is needed to ensure adequate water quality monitoring. Where applicable, USGS, ARS, local universities, SCS, and Extension Services should provide technical assistance for monitoring program design and implementation. Minimum monitoring protocols for high- and medium-level projects should be reported in the *Federal Register*. Projects would risk cancellation if monitoring efforts fail to meet minimum requirements.

All approved projects should have monitoring to determine BMP application progress and to document trends in one or more variables related to the water quality problem. Stream water quality monitoring requirements for high-level projects should be consistent with the EPA 319 National Monitoring Protocol (U.S. Environ. Prot. Agency, 1991; Spooner, 1992). The protocol requires 20 samples per season at a weekly or biweekly frequency for physical and chemical variables and measurements of explanatory variables (e.g., flow and precipitation) for each sample. If biological monitoring is desired, biological and habitat variables should be monitored one to three times per year. Land use and land treatment data must be reported on a drainage basin relative to the water quality monitoring station. In addition, paired watershed studies are strongly encouraged.

The protocol's main objective for high- and medium-level projects is to monitor water quality and land treatment simultaneously to determine if water quality changes can be documented and associated with changes in land treatment. Two features of this objective must be met: (1) detecting significant or real trends in both water quality and land treatment implementation, and (2) associating water quality trends with land treatment trends.

Guidance for minimum monitoring of land treatment and associated water quality changes for the model program and its projects should be maintained and enhanced by EPA and USGS in consultation with other Federal, State, and local agencies. This approach will allow valid technical evaluations of individual projects. For example, the monitoring requirements established by the EPA Clean Lakes Program have been published in the *Federal Register* (1980b). The lack of a complete and uniform database has limited the effectiveness of evaluations of the Model Implementation Program (MIP), RCWP, and (by current indications) the present USDA Demonstration Hydrologic Unit Areas as well as Management Systems Evaluation Areas (MESA) water quality project.

The paired watershed approach involves monitoring two or more similar subwatersheds before and after BMP implementation in one of the watersheds. This design is the most technically sound and reliable method available to document water quality changes in the shortest time period (3 to 5 years). The Vermont RCWP project employed the paired watershed approach successfully and

demonstrated that winter storage of manure (instead of winter spreading) was an effective nutrient management strategy.

Land treatment information for high- and medium-level projects should be reported and linked directly to the water quality monitoring data. For example, each observation should be paired hydrologically to a water quality monitoring station on an annual or seasonal basis. All significant land use changes and other nonpoint and point source control efforts should be documented. The monitoring design should include multiyear monitoring of both land treatment or use and water quality before and after BMP implementation.

Several RCWP projects had strong water quality monitoring programs emphasizing pre- and post-BMP monitoring and above and below site testing in combination with a large land treatment effort. These projects were able to document substantial water quality improvements. In the Utah RCWP project, animal waste management systems reduced phosphorus concentrations leaving the watershed by 75 percent and reduced nitrogen and fecal coliform by 40 to 90 percent. In the Florida RCWP project, fencing, water management, and animal waste management systems reduced phosphorus concentrations in water entering Lake Okeechobee by 45 percent.

In the Oregon RCWP project, animal waste management systems installed on dairies reduced bacterial contamination of oyster beds by about 40 to 50 percent. Sites in the bay restricted to shellfishing based on Food and Drug Administration classification decreased from 12 in 1979-80 to 1 in 1985-86. In the Idaho RCWP project, water management and sediment control BMPs reduced sediment loads in return flows from irrigated land by 70 percent. Trout fishing has been partially restored to this coldwater trout stream.

Likewise, the Idaho and Nebraska RCWP projects realize that a substantial effort would have been saved if they had established clear protocols in the beginning for documenting water quality and land treatment on a subbasin and annual basis such that the two databases could be linked hydrologically and temporally. Both projects have taken the initiative to reconstruct and link the two databases. For these projects, the land treatment databases were the most difficult to reconstruct.

The Vermont project used extensive monitoring of BMP implementation and agricultural activities to establish a link between cows under BMP manure management and bacteria levels in streams. The Minnesota RCWP project used vadose zone monitoring to establish the relationship between agricultural practices, best management practices, and ecological niches to groundwater contamination.

Explanatory variables, which should be monitored in the high-level projects, can include other land-use changes, the seasons, stream discharge, precipitation, groundwater table depth, impervious land surface area, and others. In Alabama, technicians were unable to determine the cause of a sudden increase in fecal coliform levels in a particular stream until they determined that beavers had built a dam upstream of the sampling site. The Florida RCWP project confirmed that the changes in cow numbers and water table depth affected the water quality monitoring results and that documentation and adjustment for these changes allowed valid conclusions to be made regarding changes in water quality.

Evaluation and Reporting

Regular review of progress helps ensure that the project is working toward its goals and that its activities are on track. As part of the evaluation process, regular meetings must be held by the local coordinating committee to keep the project team informed and to coordinate activities. In addition, quarterly meetings of technical groups can help guide the project to water quality improvements. Both the South Dakota and the Vermont RCWP projects used frequent meetings of technical staff to identify needs and document progress.

Annual progress reports on the projects create an opportunity to compile and analyze findings; annual progress reviews by the national coordinating committee and the national technical support group can help projects meet their goals.

Feedback Loop

Regular meetings are a must for project staff, if water quality and land treatment monitoring are to be used to make mid-project adjustments. The project manager can facilitate communication by scheduling local coordinating committee meetings on a quarterly basis. The State and local coordinating committees should meet jointly at least once each year.

Regional workshops should be scheduled to provide information transfers between projects with similar hydrology and agriculture. National workshops are helpful and especially beneficial if all projects are represented. Some of the most important RCWP lessons were learned from projects that were seldom represented at national RCWP workshops.

In the early part of the Virginia RCWP project, extremely high levels of coordination and cooperation existed among the different agencies, and communication was excellent. However, after BMP implementation, which occurred about five years into the project, both the State and local coordinating committees stopped meeting, which caused a breakdown in communication between the land treatment and water quality groups.

Conclusion

The Rural Clean Water Program has demonstrated that nonpoint source pollution control programs can be successful in protecting and restoring water resources if they are carefully structured and based on the findings of previous programs. The model program we propose requires administrative and technical support from all levels — Federal, State, and local. The States and their local counterparts need guidance on project implementation. Much of this guidance can best be communicated through program regulations similar to the regulations written for the RCWP (*Federal Register,* 1980a). A national technical support group, independent of designated cooperating agencies, should be in place to help develop program guidance, provide technical assistance, and conduct project evaluations.

Water quality monitoring is required to document the problem and track project effectiveness. We suggest minimum monitoring requirements to guide the development of the monitoring program design. BMP systems must be targeted to treat critical areas and specific pollutants responsible for the present or potential problem. Finally, a project manager and a core project staff (from various coordinating agencies) are needed to implement the project. Greater accountability among project staff and incentives to avoid turnover will improve the likelihood of meeting project goals. Information and educational efforts should be expanded to encourage greater adoption of BMPs.

Continual evaluation of programs and projects and full communication of technical information are key factors in controlling nonpoint source pollution and achieving water quality goals.

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Extending the RCWP Knowledge Base to Future Nonpoint Source Control Projects

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ABSTRACT

The Rural Clean Water Program (RCWP) and its associated database and practice implementation experiences represent a wealth of information that can and should be used in current and future nonpoint source watershed projects. This paper presents an expert system configuration based on lessons learned from the RCWP experience. The RCWP EXPERT system emphasizes design of nonpoint source control systems. Design methods include site-specific characterization of problems. Water quality monitoring information, contaminant properties, transport, and mobility are accounted for in the practice design process. Examples and data from RCWP projects are included in the system. Powerful linkages to AGNPS, climate data, the GRASS geographic information system, and Soil Conservation Service practice design modules add computational power to RCWP EXPERT control system design solutions.

The experimental Rural Clean Water Program (RCWP) was initiated in 1981 in 21 agricultural watersheds located throughout the United States. To date, this effort represents the most intensive water quality monitoring and implementation of nutrient, sediment, and pesticide reduction practices undertaken in the United States. With almost 10 years of monitoring data from a variety of hydrologic and physiographic regions, RCWP projects represent state-of-the-art approaches for implementing best management practices (BMPs) and controlling nonpoint sources of water pollution.

Before RCWP, nonpoint source control practices involved applying traditional soil and water conservation practices to cropland primarily to control erosion and improve surface water quality. In many cases, participation was based solely on willingness to cooperate in cost-sharing programs. RCWP projects have greatly advanced these early efforts by achieving several generations of practice designs, site selection criteria, and direct linkages with specific water quality goals.

The RCWP Knowledge Base and Technology Transfer

The completion of the RCWP provides an opportunity to extend project results to current and planned nonpoint source watershed projects, including hydrologic unit areas and demonstration watershed projects. This paper presents two components of the RCWP experience that will be critical to the success of future nonpoint source watershed projects. The first, documentating the RCWP

knowledge base, involves identifying and recording successful components of nonpoint source planning, design, and implementation. This knowledge base includes engineering designs, monitoring systems, innovative water quality control practices, animal waste systems, beneficial uses, and successful implementation methods. Other areas of knowledge, such as institutional and economic factors, are equally important and should be documented.

The second topic is technology transfer. This transfer can occur in several ways, for example, through published RCWP reports, conferences, databases, traditional training, and workshops. But another method of technology transfer uses state-of-the-art computer technology to develop a system for designing nonpoint source control systems. This type of system uses the RCWP knowledge base and directly facilitates improved control practice design procedures. The RCWP EXPERT system is presented here as an example of a computer-aided design for technology transfer.

Documenting the Knowledge Base

Engineering Design

The RCWP has initiated new or modified design methods for several types of practices to achieve water quality objectives or adapt to site-specific conditions. For example, improved design procedures for surface and subsurface controls in high source areas (such as confined livestock areas, conservation tillage, and off-site sediment retention) were initiated in several projects. In particular, animal waste system designs involved two and three generations of practice designs at some RCWP sites, resulting in more efficient floor designs, better pump selection with higher reliability, and improved manure storage unloading ramps, augers, and pumps. Because animal waste disposal is a serious water quality problem in many agricultural regions, the engineering design and implementation experience gained from RCWP projects can be a cornerstone for future nonpoint source control projects.

■ **Animal Waste Systems.** As many RCWP projects demonstrated, simply storing manure is not an effective BMP. The design and development of integrated collection, storage, unloading, and field application systems is the key to success. The Tillamook, Oregon, RCWP project developed dual animal waste handling systems for both collection-storage and field application of solid and liquid animal waste systems. The transfer and unloading systems were changed and improved to incorporate special farm requirements. Other examples include the following:

- animal waste collection, storage, and transfer systems using both gravity and pressurized components were implemented in RCWP projects in Vermont, Oregon, Maryland, and Alabama;
- integrated animal waste storage and disposal systems were implemented in Oregon, Utah, and Idaho;
- swine floor design and collection systems were implemented in Virginia; and
- a solid separator to remove heavy organic aggregates from confined livestock runoff is now in use in Maryland.

Special attention was focused on animal waste systems in Virginia. A flushing system was developed together with lined lagoons and spray irrigation systems to provide total system control. Because of the proximity of water supply reservoirs, the irrigation disposal systems were specifically managed to minimize any effects on nearby streams.

The Alabama RCWP project improved animal waste uses by creating waste management systems with holding ponds, lagoons, and spray irrigation systems. An associated program in which the conservation district provided equipment loans or helped purchase used equipment was particularly helpful for developing farm capabilities in lagoon unloading and spray irrigation of stored manure. Thus, the control system included technical assistance and supporting practices design through the pollutant delivery phase.

Monitoring Systems

Before RCWP projects were initiated, the design and selection of nonpoint source control practices were conducted without comprehensive and accurate water quality monitoring data. Without such data, no scientifically defensible method existed for judging the effectiveness of control practices. RCWP projects introduced event-based, long-term water quality monitoring strategies to nonpoint source programs. Florida and Vermont developed comprehensive and specialized monitoring systems to characterize the many and varied sources of contaminants. Projects in both States used monitoring data to select and place BMPs and to evaluate the effect of nonpoint source pollutant loads on the water quality of receiving lakes and streams. The long-term experience and advances in monitoring design and evaluation

methods are the RCWP's unique and vital contribution to the scientific basis of nonpoint source controls.

Perhaps the most important element in designing effective control systems is how water quality monitoring data is used to modify practice design and site selection. The extent to which water quality data are used to identify high source areas or critical seasonal loads is essential for developing effective control systems. In fact, if a BMP does not change contaminant mass loading, it is, by definition, not an effective practice. Here are other examples of RCWP projects that used monitoring data to isolate or identify high source areas:

- St. Albans Bay, Vermont, used four levels of water quality monitoring to identify spatial and temporal mass contaminant loads, including bay sampling, trend stations, mobile monitoring, and random sampling. The St. Albans Bay monitoring effort resulted in the isolation of a subwatershed (Jewett Brook) and the identification of several farms that had high direct-to-bay loading.
- Also in St. Albans Bay, similar watersheds were paired to provide comparative loading and effectiveness data. This approach is particularly promising for watersheds with similar uncontrolled variables, such as soil, cropping, and livestock systems.
- The Rock Creek, Idaho, RCWP project used extensive biomonitoring methods to identify, track, and evaluate contaminant effects and the effectiveness of control practices.
- The Alabama RCWP project used bacteria counts to isolate problem areas.
- The Virginia RCWP project developed comprehensive integrated worksheets to characterize farms with high loading potential. This effort focused BMPs on farms with a high impact on nearby water supply reservoirs.
- The Snake River, Utah, RCWP project recorded dramatic reductions in nutrient loading and related effects on the Deer Creek Reservoir after intensive treatment of a problem watershed, which their monitoring program had identified as critical.

Innovative Practices

RCWP projects have inspired the design of innovative practices and systems that address the special implementation problems and site-specific design requirements of control practices that are effective and compatible with modern agricultural systems. Examples of innovative practices in RCWP projects include:

- Several projects practiced integrated control and disposal of surface and subsurface water flows in high intensity areas, such as confinement facilities and satellite pasture areas, by specifically designing these areas for production and water pollution control.
- Vegetative filter treatment systems were designed for milkhouse wastes in Vermont.
- Short- and long-term manure storage integrated with land application systems, milkhouse waste disposal, and pasture management to achieve water quality loading objectives evolved during the RCWP project in Vermont. In each case, special implementation problems or farm limitations were incorporated into practice design over time.
- Conservation tillage systems to reduce contaminant loading to streams were developed in Alabama, Idaho, Virginia, and Maryland.
- Roof runoff control structures were constructed in confinement areas and high rainfall zones in Oregon.
- Intensive treatment of high loading areas resulted in maximum reductions of contaminant impact in Florida, Virginia, Oregon, and Utah.
- Small tributary control and relocation through high intensity areas were practices implemented in Utah.
- In Idaho, off-site sediment retention basins decreased delivery of sediment and adsorbed pollutants to receiving streams.
- Modified drop inlets for safe runoff disposal were constructed in Virginia wherever elevation differences of 2 to 5 meters existed between edge of field and stream discharge points.

Beneficial Uses

Because of advances in monitoring system design at a few sites, the RCWP has begun to establish a relationship between land treatment and water quality improvements and beneficial uses. RCWP projects were the first in the Nation to directly relate the application of nonpoint source control practices to specific water quality objectives in receiving lakes, streams, and estuaries. RCWP projects in Florida, Vermont, Oregon, Maryland, and Idaho are excel-

lent examples of projects that relate nonpoint source control programs in upland watersheds to direct effects on drinking water supplies, fish populations, shellfish industries, and recreational uses.

■ **Farm Water Supplies.** One example of a beneficial use that evolved from RCWP activities relates to improved quality of farm water supplies. Of all rural water supply systems, farm supplies are often the most at risk. Poor siting, well construction, protection, and maintenance cause many systems to be inadequate. Robillard and Walter (1982), Sharpe et al. (1985), and others have found the incidence of contamination of farm wells to be high. Surprisingly, at a time when modern production practices and computer-assisted farm management is common, many farms are still using 19th century water supply technology. Not only is the productivity of livestock affected; the health of the farm family is also at risk.

Four RCWP projects solved dual water quality problems by developing and protecting farm water supplies. Although in some applications protection measures resulted in improved quality of the entire farm system, improved water quality for livestock consumption was the principal objective. In all instances, high source loading of nutrients was eliminated as livestock were moved away from streambanks. As part of its high intensity use areas program, the Taylor Creek, Florida, RCWP project included water troughs, shade, and feeding areas in satellite pastures. Low-cost trough units were designed in Tillamook Bay, Oregon, to improve livestock water quality and decrease associated loading to streams. Other examples include limited access gravity and pumped livestock water supply systems (Maryland) and combined livestock watering and streambank protection systems (Alabama).

The Maryland RCWP project developed and protected livestock water supplies with trough systems that not only improved livestock water quality but also greatly decreased biological oxygen demand, nitrogen, and bacteria loading to streams. Alabama also developed farm water supply systems to improve access to potable water and improve the quality of water for livestock consumption. By limiting the access of livestock to streams, localized streambank erosion was also reduced.

Technology Transfer

From their inception, RCWP projects have been the source of emerging technology for nonpoint source control programs. Two examples of the far-reaching influence of these projects are Oregon and Idaho. New and innovative designs for animal waste systems in Oregon have been directly incorporated into the Oregon Engineering Handbook (U.S. Soil Conserv. Serv. 1989), a state-of-the-art reference for engineers who design nonpoint source pollution control practices. Idaho's project provides another example of RCWP technology that has attained national importance. In Idaho, intensive work with different types of water quality monitoring systems resulted in the development of effective low-cost biomonitoring methods that complement and, in some cases, substitute for traditional inorganic and organic water sample analysis techniques. Technology transfer of animal waste systems, vegetative filter strips, conservation tillage systems, and high intensity water control practices also occurred in the Vermont, Florida, Virginia, Alabama, and South Dakota projects.

The massive, long-term implementation of control systems through the RCWP is an excellent source of new field-verified technology. Tillamook Bay, Oregon, has used several methods of disseminating technology that emerged from the RCWP effort. Most important, new plans and calculation procedures for waste storage, facilities, waste stacking facilities (covered and uncovered), covered liquid manure storage, and watering troughs have been included in the Oregon Engineering Handbook. In addition, RCWP project personnel are used in State and regional workshops to assist in training and other educational programs oriented toward new water quality initiatives.

Extending the Technology

RCWP EXPERT

Those who design and select BMPs to control nutrients, pesticides, and sediment loads in agricultural watersheds must consider the complex interactions between hydrologic, soil, crop, tillage, and management variables. In particular, when contaminants exhibit different physical and chemical characteristics resulting in varying mobility and transport patterns in surface and groundwater regimes, the effectiveness of control practices is difficult to predict. One aspect of technology transfer related to applications of the RCWP knowledge base will be the development of design procedures and computational methods to improve practice effectiveness as it relates to specific water quality loading objectives.

One example of this type of emerging technology is the development of expert systems that help design and select nonpoint source controls. The RCWP EXPERT computer program is being developed to solve problems and aid technical train-

ing. It is also being developed to help Soil Conservation Service engineers design control systems and support and train State and Federal water quality staff. The interactive, user-friendly nature of the Apple™ Macintosh computer system provides an excellent focus for small group training activities.

The complex problem of designing practices to control contaminants of different solubilities, soil adsorption properties, toxicity, and persistence requires consideration of numerous, and sometimes competing, factors. For example, control practices that decrease soluble nutrients in surface runoff may increase loading to groundwater for certain soil types. Similarly, the design of control systems requires that water quality monitoring information be used to evaluate and quantify contaminants as well as focus on the BMP implementation programs in watersheds. RCWP EXPERT was developed to deal with these complex design and implementation problems by providing a problem-solving format and supporting data. The problem-solving format specifies rules by which control practices are recommended for certain contaminants, hydrologic conditions, contaminant loadings, and time-of-year.

Other modules provide data and information about contaminant characteristics, monitoring methods, and how contaminant transport processes influence the effectiveness of control practices. This latter information is particularly important as a bridge to help design teams reach a common understanding of the mechanics of water quality monitoring and the design of control measures. Often, an engineer will have specific training in the design of control practices, but not in water quality monitoring systems or how data from such systems can be used. In many RCWP projects, the opposite case was also true because members of the monitoring teams had limited experience with practices or structures that decrease or control contaminant loading. RCWP EXPERT is designed to provide both types of users with procedures, data, and information to help design and select nonpoint source control systems.

System Overview and Status

The RCWP EXPERT system configuration combines RCWP's extensive monitoring and practice implementation and computer-aided design features to improve control practice design and siting on a field and watershed basis (Fig. 1). Version 2.0 of RCWP EXPERT, which will be completed in 1992, incorporates links to a Nonpoint Source Database and the AGNPS simulation model (Young et al. 1987). This linkage allows actual field practice data and simulated contaminant losses to be evaluated for site-specific variables. In addition, technical reference modules (contaminants, transport, monitoring, and case studies) are available throughout the design procedure.

During 1993, geographic information systems, practice design modules, and climate linkages will be initiated. All control system design options and tools will be accessed from the control systems module. System output will include calculated contaminant mass load to surface, subsurface, and groundwater. To the extent possible, mass loading on a watershed and subwatershed basis will be spatially represented and used to evaluate alternative siting of control systems.

All reference modules, calculation procedures, and database interfaces are organized to help users design and evaluate nonpoint source control systems on both a field and watershed scale (Fig. 1). The knowledge base includes both heuristic data and knowledge from field applications of key RCWP projects.

■ **Computer-aided Design Procedures.** The control systems module assembles complementary sets of practices, including a control practice for each stage of contaminant transport (source-transfer-field-delivery) and associated practices that enhance the overall effectiveness of the control system.

RCWP EXPERT allows the user to design control systems for three primary purposes:

- Control systems design assembles alternative systems for total contaminant pathway control (source-transfer-field-delivery);
- Simulation models (AGNPS is the first one) and a nonpoint source database will be used as evaluation tools to compare the effectiveness (contaminant load reduction) of specific practice applications and control systems; and
- Through linkages with climate data and a geographic information system application, the effectiveness of control systems can be improved with respect to their siting in a watershed and the control of contaminant source availability.

Control Systems Module

The control systems module (Fig. 2) is the platform for design evaluations and comparison of management operations. RCWP EXPERT provides users with total control over the sequencing of practice design operations. Reference modules are available at all stages of the design process.

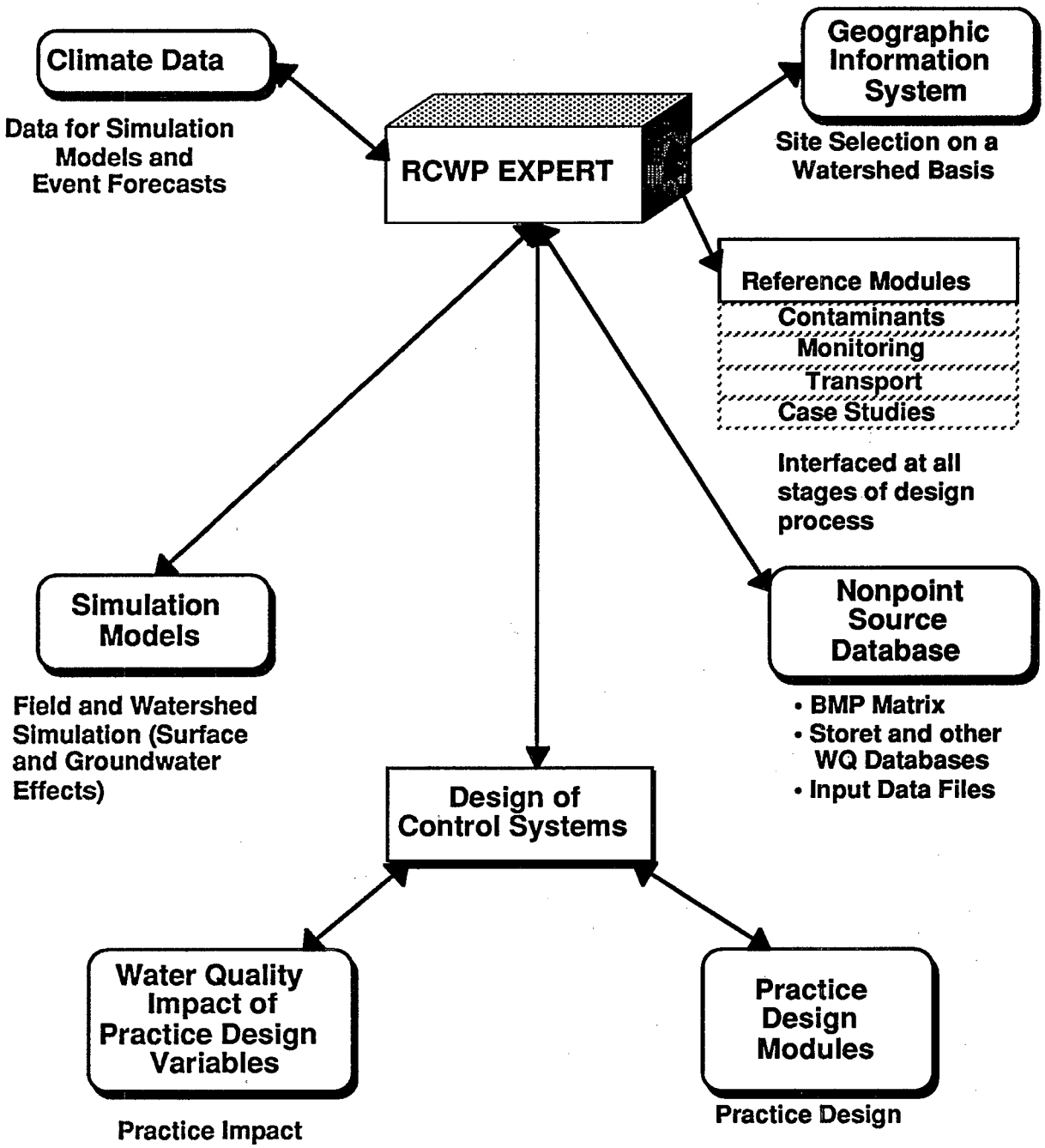

Figure 1.—Example of the RCWP EXPERT system (computer-aided design of nonpoint source control systems).

The control systems module consists of a site-specific selection process and a control systems mode. The site-specific selection mode matches practice contaminant control mechanisms with pollutant transport variables. Each control practice is evaluated for important contaminant, hydrologic, and soil variables. The output of these evaluations, called "Dependency Networks," screens practices for their effectiveness under specific field conditions. RCWP EXPERT currently contains 16 dependency networks — one for each of the 16 types of practices used in RCWP projects.

■ **Nonpoint Source Database.** The nonpoint source database allows users to access research data on the effectiveness of practices. All 16 practice categories and all individual practices (referenced by SCS Technical Practice Codes) are available for individual contaminants and site-specific variables, such as climatic region and soil type.

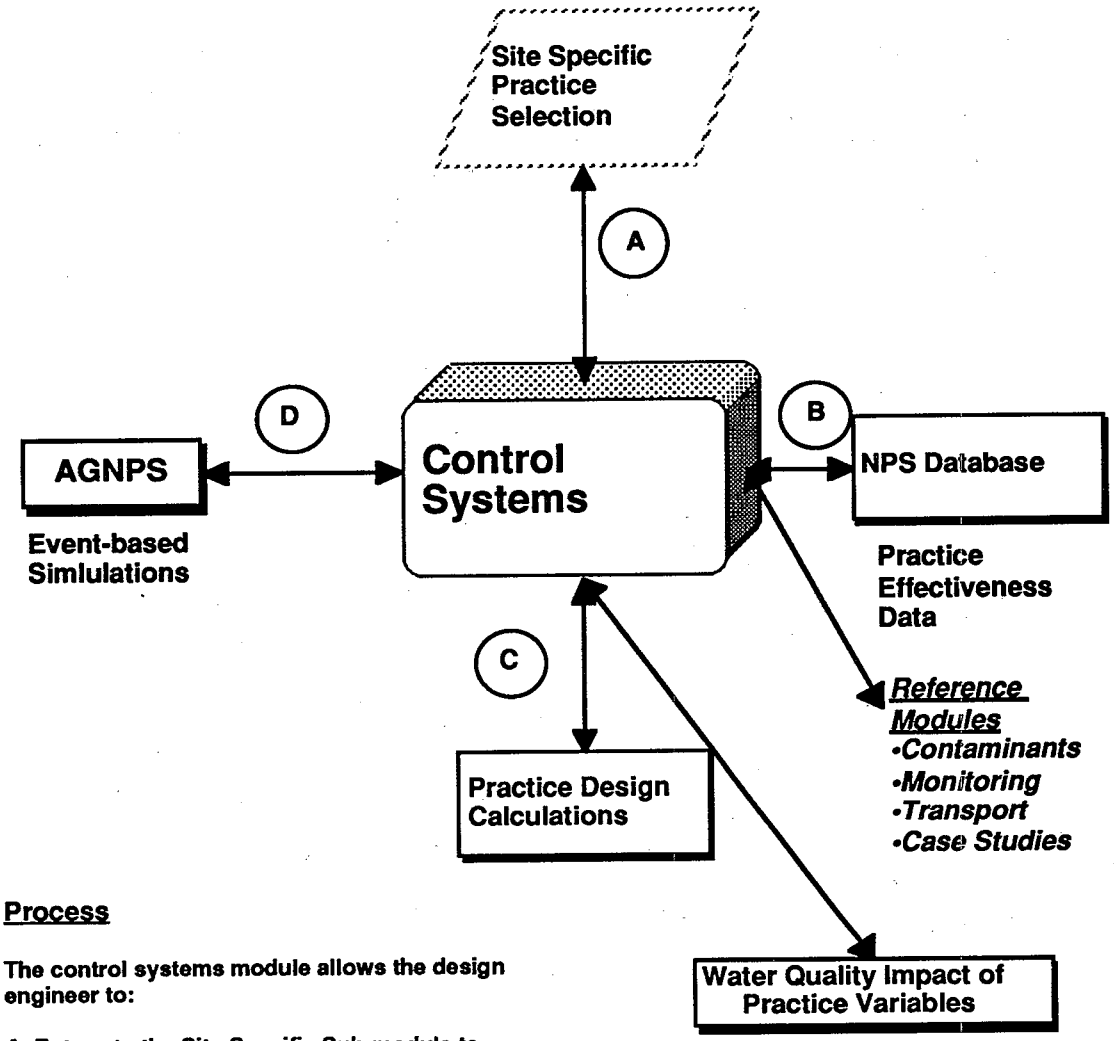

Figure 2.—Example of the control systems module.

■ **Simulation Models.** AGNPS is currently linked to RCWP EXPERT. This linkage facilitates evaluation of practices under varying conditions (22 input variables) as defined by the user. The nonpoint source database also allows verification and comparison of AGNPS results with published field effectiveness data.

■ **Climate Data.** Three types of climate data will be used in the completed expert system, including

- historical precipitation and temperature data,
- 10-day antecedent precipitation and temperature data, and
- five-day forecast data.

Precipitation data is the key climate variable in all cases. Temperature is important for snowmelt routines and rate constants, such as mineralization of nitrogen.

Climate data, data interpretations, and examples of data use will help users estimate losses in surface and subsurface flows and estimate the probability of

losses occurring during a five-day period on a real-time basis. Climate data will be used for both field and watershed simulations. These data will also be an element of the monitoring and transport modules. In locations that have detailed data available, special and spatially varied precipitation data applications will be used, including variations in intensity, droplet size, and other parameters affecting the detachment and mobility of contaminants.

Three reference modules (monitoring, transport, and case studies) will provide expert input and climate databases to use for different applications and as an evaluation of the usefulness and quality of the databases.

■ **Geographic Information System (GIS).** GIS linkage (using GRASS) will provide the basis for site selection and control system designs that minimize contaminant loading on both farm and watershed bases. Although several components of the GIS linkage are useful for designing nonpoint source control systems, the ability to spatially orient practices to achieve contaminant loading objectives is perhaps the most important feature.

■ **Practice Design Modules.** These modules provide standard engineering procedures for practice design. Typically, they will be used in conjunction with the Practice Impact Module. The user can change design variables to achieve specific water quality improvements for a site-specific application.

■ **Water Quality Impact of Practice Design Variables.** Each design practice variable can affect source availability, the partitioning of contaminants between surface and groundwater flow, soil erosion and sedimentation, and other factors relating to contaminant transport. This module provides guidance about how practice design variables can be used to affect contaminant loadings.

■ **Reference Modules.** At any stage of the design procedure, users can consult reference modules that provide information, guidance, and data about contaminant properties, transport variables, and examples of applications from RCWP projects.

Four reference modules are available in RCWP EXPERT:

- Contaminants;
- Monitoring;
- Transport; and
- Case Studies.

All four modules use graphics to demonstrate design procedures and contaminant control processes.

The *contaminants* module provides information about 11 categories of pollutants cited in various RCWP projects and their effects on surface and groundwater and on drinking water supplies. This module includes four types of information:

- **Impact** — the effects specific contaminants have on stream and lake water quality. If appropriate, human health effects are also given. Sixteen pesticides are currently included in the module.
- **Standards** — concentrations of various contaminants are given relative to their environmental impacts on aquatic systems and to standards of the Safe Drinking Water Act.
- **Background Concentrations** — typical concentration ranges are supplied for those substances existing naturally in soil-aquatic systems.
- **Case Studies** — examples of how water quality impacts, standards, and background concentrations were used in RCWP projects.

The *monitoring* module describes different aspects of water quality sampling and analysis systems. In addition, methods for calculating mass loads and statistical analyses are presented. Key references in this section include the recent EPA Monitoring Guide and examples from RCWP projects. This module contains six types of information:

- System Design,
- Parameter Selection,
- Sampling,
- Handling Preservation and Analysis,
- Loading Calculations, and
- Statistical Analyses.

The *transport* module describes contaminant pathways in surface and groundwater. In particular, the solubility and adsorption processes of each contaminant are described and compared in the context of control mechanisms and options. Contaminant loading and critical loading periods are also described in this module. The transport module includes six types of information:

- Surface Flow,
- Subsurface and Groundwater Flow,
- Adsorption and Solubility,
- Critical Events,
- Delivery, and
- Control Mechanisms.

The *case studies* module presents detailed examples from key RCWP projects. Both practice selection and implementation aspects of BMP systems are covered. Regional precipitation, temperature, soil, groundwater, and common agricultural practices data as well as descriptions and data from individual RCWP sites are provided.

The RCWP provides a key source of information for agricultural nonpoint source control programs. The massive implementation of BMPs has resulted in successes and failures that should be documented. The case studies module includes the following examples of implementation topics:

- continued emphasis on protection of farm water supplies;
- design of total control systems for high contaminant source areas;
- use of monitoring data to target subwatersheds and high source areas for treatment;
- application of technology transfer efforts that result in increased engineering assistance and staff training to provide expertise in animal waste systems, or other specialty areas;
- use of an experimental design phase that allows new technology to be tested on farms, which in turn leads to improved design procedures;
- use of on-farm monitoring to evaluate changes in concentration or load before and after practice implementation;
- further development of biomonitoring as a method for identifying problems and evaluating practice effectiveness;
- use of watershed and stream assessments to provide guidelines and public awareness of water quality improvements;
- establishment of flexible cost-share incentives so farms with more serious problems can be treated more intensively;
- minimization of technical staff turnover during design phase of project; and
- implementation of practices most likely to reduce water quality loading.

Conclusion

RCWP projects have accumulated valuable data and information about the design of control practices, monitoring systems, and successful implementation strategies; they also have data on institutional and economic successes and failures, which are an important knowledge base for future nonpoint source projects. Successes resulted from improved practice designs and widespread implementation of BMPs by the farm community. Failures are associated with inadequate design and the lack of water quality monitoring data. In either case, useful guidance can be gained from these RCWP lessons.

An important element in future technology transfer efforts from RCWP to new nonpoint source watershed projects will be the development of computer-aided procedures to integrate data and information into helpful tools. RCWP EXPERT is an example of such a tool.

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Research Needs and Future Vision for Nonpoint Source Projects

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ABSTRACT

The importance of the Rural Clean Water Program (RCWP) to future nonpoint source control projects depends on careful identification of its experimental nature and results, and perhaps most important, on the analysis of research that should be accomplished to correct and enhance those results before future projects are undertaken. Consequently, this paper reports on research areas and technology that will lead to better correlations between agricultural best management practices and water quality results in future projects. The review of key research areas is essential to an understanding of the likely evolution of nonpoint source programs over the next 10 years.

The experimental nature of the Rural Clean Water Program (RCWP) provides an excellent opportunity to assess research needs for future nonpoint source projects. During the 10-year RCWP effort, the effectiveness of best management practices (BMPs) in reducing contaminant loading to groundwater became increasingly important. Widespread adoption of reduced tillage systems was observed in most RCWP project areas; control of pesticide losses to surface and groundwater flows redirected efforts in several RCWP watersheds; and intensive treatment of high source contributing areas (such as livestock confinement facilities) was another example of the changing focus and technology that can be derived from RCWP implementation efforts. This paper has two objectives: it reviews the need for research in key areas and helps provide a vision of the future and how nonpoint source programs might evolve during the next 10 years. Research topics related to the RCWP's recent experience and future nonpoint source projects include

- monitoring networks,
- tillage systems,
- critical area delineations,
- control system design, and
- improved implementation strategies.

Research Needs

Monitoring Networks

Several RCWP projects (Vermont, Idaho, Florida, South Dakota, Minnesota) developed and used both conventional and innovative water quality monitoring systems. However, the use of water quality monitoring systems to judge the success of the land treatment program and improve the siting and effectiveness of control practices was a formidable challenge for many RCWP projects (Dickinson et al. 1990; Chadderton and Kropp, 1985; Humenik et al. 1987). In several cases, baseline (or pre-BMP implementation) monitoring was not accomplished. Other sites established trend monitoring stations only for the entire project watershed; thus, little or no change in water quality parameters resulted from BMP implementation programs.

Similarly, the dynamic nature of cropping and livestock systems required complementary monitoring of watershed changes in livestock numbers and location, acreage, and types of crops. Among the projects that established monitoring stations, limited resources often prevented comprehensive coverage of the watershed. In response to these limitations, different levels and types of water quality monitoring were designed. For example, biological monitoring offered a low-cost alternative to conventional techniques and produced data that were more meaningful to the public.

Nonpoint source projects will need to use integrated site-specific methods for monitoring land treatment systems. Designs for many of these monitoring systems were developed and refined during RCWP watershed projects. Generally, the design of water quality monitoring systems needs to meet the following criteria:

1. Although baseline water quality requirements are dependent on numerous hydrologic and land use variables, a preproject water quality status must be established and control watersheds (subwatersheds) maintained during the project and postimplementation period. From a practical viewpoint, one year of data is often the most that can be obtained for the entire watershed, while use of control or paired subwatersheds may allow for the more desirable three-to-five-year baseline data needed to evaluate overall effectiveness of the land treatment program.

2. Design of monitoring systems should encourage the use of multilevel networks. Allocating all resources to long-term trend monitoring is not recommended. Field and subwatershed monitoring systems should be used to evaluate individual practices or practice systems. These types of monitoring systems will vary considerably — from mobile units (including rainfall simulation devices) to noncontinuous stations of evaluation of experimental practices, to permanent continuous stations for longer-term trend analyses.

The monitoring system must develop a method for relating water quality parameters to land treatment. Land use information that can be linked to water data must be collected. Collection of accurate land use data is extremely difficult; it is also uncertain how long monitoring should continue (Clausen et al. 1992). A land use information collection system should be designed parallel with the water quality monitoring system. For example, significant changes in nutrient loading may not occur as a result of BMPs implemented on a watershed basis (Meals, 1992). The time required for changes (improvements) in water quality parameters after BMP implementation is likewise uncertain.

Based on these criteria, the following design requirements have been identified:

- Determination of the frequency of sampling needed to achieve water quality trend or evaluate practice objectives. Current guidelines provide insufficient advice regarding sample size.
- Better methods for collecting accurate land use monitoring data. It is difficult to be field-specific about practices and timing of operations; however, this information is critical for event-based evaluations.
- Improved techniques to link land use and water quality data, especially at the watershed level, are needed to show causal relationships. At a minimum, land use and in-stream water quality monitoring must be measured simultaneously.
- Development and improvement of field-validated computer models that can simulate the outcomes of control systems must continue. Models can be important tools in selecting alternative management practices. Similarly, models can be used to estimate the time needed for a practice to be effective.

- Linking bioassessment to other water quality parameters and land use activities with statistical confidence. The relationship between bioindicators and traditionally used chemical and physical parameters has not been firmly established.
- Use of monitoring data to determine the effectiveness of existing BMPs and to develop new and innovative BMPs must be better defined and documented for a variety of conditions. For example, the water quality benefits of field nutrient management are largely assumed.
- Time needed for water quality parameters to respond to BMPs. Knowledge of this response time will improve management decisions and result in more accurate and realistic expectations of the impact of control systems on changes in monitored parameters.

3. The use of monitoring methods not directly related to practice effectiveness or trend analysis must be developed or improved. Monitoring water column chemistry alone has limited applications. The health of the broader aquatic ecosystem including both the biological and physical habitats and aquatic chemistry must also be measured. Land treatment practices and the aquatic ecosystem must be evaluated at the same level of intensity.

   Biological monitoring such as that used during RCWP projects provided low-cost alternative techniques that were a basis for quantifying changes in aquatic life and the quality of riparian zones. In addition, this type of monitoring data is often more meaningful to users of the water resource and the general public. Well water data can also be used to supplement effectiveness evaluations and inform the public about water quality. These data are particularly helpful since groundwater quality directly affects farms and other users of water resources in the project area.

4. Because we must continually define and restate agricultural water quality goals, both conventional and biological monitoring are useful because they have enough flexibility to assist in the short-term evaluation and redirection of the land treatment program.

Tillage Systems

Widespread adoption of reduced tillage systems by RCWP project participants resulted in increased emphasis on several research topics — for example, the impact of increased pesticide applications associated with reduced tillage and tillage-manure systems on water quality.

Control of Pesticide Losses

Changes in tillage and cropping systems require changes in weed and insect control methods. A principal reason for the success of reduced tillage systems has been the development of effective pesticide control techniques. Research continues to investigate the effect of pesticide application rates, timing, and techniques on surface and groundwater quality. In particular, computational methods that can predict biological degradation rates and the attenuation of pesticides between the field and delivery to a waterbody are important topics. Finally, with increased emphasis on the impact of pesticides on groundwater quality, the cycling and transport of pesticides in fractured bedrock and deep confined aquifers are topics of increasing interest.

Tillage Manure Options

An inherent conflict exists in the maintenance of surface residue in tillage-manure systems. One objective clearly indicates that surface residue should be conserved to reduce erosion. On the other hand, manure applications should be incorporated as soon as possible, specifically to minimize contaminant losses and retain nutrients in the soil profile to meet crop needs. Experimental results indicate that nutrient and pesticide losses associated with tillage-manure systems vary widely depending on application rates, incorporation depths, and times of application. The following principles are derived from studies that provide criteria for the development of tillage-manure systems:

- The time between initial application of nutrients or pesticides and the first precipitation event that induces runoff is a key factor in determining the magnitude of contaminant losses.
- Drying conditions during the period between manure application and precipitation events will vary greatly between seasons and the probability of losses changes accordingly.
- Minimal incorporation of applied manure greatly decreases nutrient losses.

- After one or two wet-dry cycles following application, the benefits of manure amendments to soil can be observed in terms of greater surface storage, infiltration, and lower runoff volumes.

- The amount of bedding in manure will influence residue cover for surface manure applications. The benefits of this residue are similar to plant residues associated with reduced tillage systems. However, the quality of this cover is different, and much of the bedding will be transported off the application site over time.

The number of possible combinations of manure disposal systems associated with various tillage practices on different soils is myriad. In addition, individual farm objectives, resources, and limitations will influence the choice of tillage-manure systems. For these reasons, the development of a single set of criteria will probably not lead to an efficient implementation program.

The monitoring needs discussed in the previous section directly apply to tillage-manure systems. The mobile rainfall simulator method for evaluating nutrient and pesticide losses for various tillage-manure systems is a promising option. Because mobile units can be used on operating dairy farms, the number of specific tillage-manure systems that can be evaluated is much greater than traditional plot studies provide. Most important, mobile unit treatments on different farms in different areas can be directly compared and evaluated, since all precipitation variables are constant. Finally, the unit can be used for evaluations during the late winter and early spring periods when losses are typically high.

Contaminant Mobility and Transport

Contaminant pathways are difficult to predict in time and space. One aspect of the transport process with implications for control of pesticides and nutrients through residue management involves a zone of interaction at the soil surface. Precipitation striking the surface reacts with a shallow depth (typically < 1 cm) of soil. Water mixing with soil in the shallow zone of interaction is the source of contaminant mobility and losses. The concentration of pesticides and nutrients leaving the field will be determined by the complex and dynamic equilibrium between the dissolved phase and suspended sediment interactions in this shallow zone. There are several opportunities for improving our understanding of these processes.

■ **Effects of Tillage Practices on Contaminant Transport and Delivery.** Several researchers (Mueller, 1979; Oloya and Logan, 1980; Robillard and Walter, 1991) have interpreted experimental results that are consistent with the concept of a shallow zone of interaction originally proposed by Sharply et al. (1981). In particular, the mixing of soil and water in the zone of interaction can help explain losses of soluble nutrients and pesticides in surface runoff. Tillage practices change the depth of the interaction zone, redistribute pesticides and nutrients, and change surface runoff and infiltration conditions. The depth of the interaction zone is affected by tillage because inversion or stirring of the soil by tillage operations changes surface density and porosity. This effect is typically short-lived, as consolidation and compaction decrease the zone of interaction over time.

■ **Soluble Contaminant Losses.** In the physical process of contaminant availability and loss, a mass of soil in the interacting zone mixes with a volume of water from a precipitation event. The release rates and amount of contaminant made available or lost can be related to initial contaminant concentration, pH, and other parameters. Consistent with the concept of a shallow zone of interaction, the mass of pesticides or nutrients remaining will, in part, determine subsequent losses. The relatively high concentration of nutrients and pesticides in the shallow zone associated with surface applications validates this concept. Experimental results also indicate that residual soluble contaminant concentration sustains somewhat higher losses during subsequent precipitation events. Therefore, a larger pool of contaminants must be available in reduced tillage systems than in conventional tillage.

Additional important research is needed to characterize the physical and chemical changes in the zone of observed interaction when pesticides or manure are applied to the soil surface or incorporated into the soil profile. The depth of interaction and the soil-to-water ratio should be observed or derived for the rapidly changing conditions associated with biological degradation and stabilization in this zone. This relationship is similarly important, since manure applications directly influence soil pH levels (Westerman et al. 1981; Muck et al. 1978) and make available a large pool of soluble nutrients. In fact, manipulation of pH in the zone of interaction should be investigated as a control option. Residue cover and its effect on surface storage and mixing in the zone of interaction should be examined more closely. Other related aspects of prediction and control of soluble pesticide and nutrient losses that should be investigated include

- the effect of storm intensity on mixing depth and efficiency;
- the effect of quantity and quality of residue on soluble contaminant losses seasonally;
- the influence of precipitation patterns on mixing, particularly in wet-dry cycles; and
- differences in soluble contaminant availability during the nongrowing season.

Critical Area Delineations

The definition of and emphasis on critical area treatment changed considerably during the RCWP. However, a direct link is needed between critical area delineations and specific water quality parameters. The use of water quality monitoring data should be a key element in this process (Koehn and Stanko, 1988). An example of critical area identification and development of control options can be associated with land uses where the potential for high loss rates is evident.

High Source Contributing Areas

The changing technology in agricultural systems during the past 50 years has increasingly emphasized more intensive utilization of inputs and more control of production-related environmental conditions. These crop and animal production systems create areas with a high nonpoint pollution source contamination potential — for example, animal confinement facilities, manure, pesticide and fertilizer storage areas, livestock and material handling areas, and transport lanes. Methods for intensive control of surface and subsurface flow from these areas are required. For example, the Florida RCWP designed and implemented "high intensity use areas" to provide maximum control over surface and subsurface phosphorus losses. Confinement areas were integrated with satellite pastures to provide animal control until all manure collection, storage, and spray irrigation systems had been designed to meet nutrient requirements and achieve water quality concentration standards.

Control Systems

Initially, RCWP focused efforts on control of sediment and nutrients in surface runoff. Then increasing concern about groundwater contamination forced a more integrated evaluation of the effectiveness of control practices at certain project sites. Consequently, future design of control practice systems will need to incorporate the estimated change in total mass load delivered to surface and groundwater as a result of BMP implementation.

During the initial stages of the RCWP, specific control practices were installed to reduce contamination, primarily at the field level. The concept of practice systems designed to control all phases of contaminant transport began to evolve at a few RCWP watersheds. Thus, where only manure storage or lagoons were installed at some sites, other projects designed practices for source-field and delivery control. For example, manure storage may have been an element of a control system incorporating nutrient management, conservation tillage, and detailed land application procedures. The practices used in a control system can be management measures, vegetative controls, or structural components. Identification of associated practices is one element of control systems design that improves overall effectiveness. This type of control can include animal waste transfer systems, improved farm roads, or livestock confinement facilities. Associated practices can extend to implementation of control systems through equipment modification, equipment rental, and consulting activities used collectively by several RCWP sites to enhance the overall quality effectiveness of control systems.

Field Evaluation and Monitoring of Control Systems

The use of different levels and types of monitoring systems to evaluate water quality impacts is an important nonpoint source activity that was lacking at most RCWP sites. In particular, monitoring systems to evaluate practice effectiveness were almost nonexistent. Additional research is needed to develop low-cost, practical methods of using these tools (Laflen et al. 1991). For example, mobile monitoring resources are an excellent method for collecting practice effectiveness data. Two primary methods of mobile monitoring are grab sampling and rainfall simulation units. Grab sampling systems can be designed to isolate the water quality impact of control practices or land uses in both space and time.

Mobile rainfall simulators can be used to evaluate practice effectiveness. Control of precipitation variables in order to compare practices or treatments provides an opportunity to make direct comparisons. The mobile units can evaluate practices for actual farm conditions, and they are a more efficient way to evaluate multiple sites and obtain measurements in a short time. For example, a combination of laboratory and field evaluations of tillage-manure systems can be undertaken for controlled conditions as well as more realistic field conditions.

If additional site-specific details of rate, depth, and time interactions are needed, field soils can be collected and prepared for evaluation in the laboratory. Constant or variable precipitation intensities can then be used to meet pesticide or nutrient evaluation needs.

Rainfall simulators can also be used to evaluate contaminant losses for particular precipitation patterns. For example, historical precipitation data can be used to estimate the probability of specific storm intensities and dry periods for different seasons. These intensities and dry periods can be physically simulated under field or laboratory conditions for various rate, depth, and time treatments. Finally, a distinct advantage of using a mobile simulator unit is the accumulation of a baseline data file. This file consists of laboratory and field runs that can be referenced to specific rate, depth, and time values. Therefore, a field run can be related to a set of measurements made for precisely the same treatment on other fields or soil types. A scale or index value can be calculated to provide probable pesticide or nutrient loading for each case. In addition, a series of runs can help determine the statistical variability for a particular field or soil. Finally, the soil can be evaluated under laboratory conditions for a particular treatment, time series, or controlled environmental condition, such as a freeze-thaw cycle.

Implementation Strategies

Selection and design of control systems will increasingly involve more efficient use of inputs and waste products. Whether integrated pest management, nutrient management, or improved land application of waste methods, the objectives of nonpoint source systems are consistent with improved farm operations and management. Several RCWP sites demonstrated this compatibility. Additional research is needed to quantify and verify this approach, and establish its economic implications and agricultural sustainability (Karlen, 1990; Onstad et al. 1991; Highfeld, 1983).

RCWP provides numerous examples of practice implementation techniques that increase adoption rates within a voluntary program. Typically, these techniques involve both water quality impacts and related farm improvements. Three examples of these implementation methods include

- development of farm water supplies to decrease farm animals' direct access to streams and improve livestock drinking water quality;
- design of reduced tillage systems to decrease nutrient losses along with labor and energy costs; and
- improved farmstead equipment and livestock access and control integrated with structural practices that decrease total contaminant load and allow more efficient use of heavily trafficked areas within a farmstead.

An institutional aspect of nonpoint source watershed projects that requires additional research involves the sequencing of these activities. In most instances, three primary activities occurred during RCWP: land treatment, monitoring, and cost-sharing. For a project to accomplish water quality objectives, these activities need to be sequenced; for example, monitoring data should be used to select practices, target critical areas, and evaluate effectiveness of the land treatment program. Similarly, cost-sharing should be used early to encourage the adoption of the most effective water quality control practices in the critical areas requiring treatment. Because of the experimental nature of RCWP, this sequencing and coordination was difficult to accomplish and often not achieved.

Future Projects

Progress toward nonpoint source water quality goals during the past 20 years has been modest. RCWP represents the most extensive, long-term nonpoint source implementation effort in the United States (Larsen et al. 1988; Wall et al. 1989). The completion of the RCWP provides an opportunity to extrapolate these accomplishments to the future.

Although the original qualitative water quality goals are not likely to change in the next 10 years, methods for achieving "fishable and swimmable" status are likely to change dramatically. New strategic approaches will include

- the integration of water quality control programs to account for surface, subsurface, and groundwater effects; similarly, simultaneous, basinwide evaluation and control of point and nonpoint contaminant sources will be emphasized;
- water quality parameters will become more broadly based and include composite physical, chemical, and biological indicators;
- advances in monitoring networks and computer applications will develop the links between land treatment activities and their impact on water quality parameters; and
- use of spatially oriented watershed data, based on geographic information system concepts, will help to target critical areas and guide more intensive management measures for im-

plementation in high source cells (McNain and Prutz, 1990).

As nonpoint source projects begin to use research findings and the practice implementation techniques realized in RCWP projects, it is possible to distinguish emerging methods and technologies.

Artificial Intelligence Application

The power of computers will be enhanced by interactive systems using both heuristic guidance and computational tools. For example, the links between expert systems and simulation models are advantageous because they provide the user with a flexible, intelligent interface to the deep knowledge encoded in simulation models (Stone et al. 1986; Parsaye et al. 1989). Such integration exemplifies a growing trend toward the coupling of artificial intelligence methodology (e.g., expert systems) and conventional computer science (e.g., simulation models) for problem-solving in agriculture and natural resource management (Whittaker and Tieme, 1990; Robillard et al. 1990; DeCoursey, 1985). Further, this integration allows the design of practices to make site-specific calculations for alterative control systems. A further extension of this concept can include access to weather data.

Real Time Control Systems

The use of computer-aided design creates an opportunity to provide real time guidance and recommendations for farm operators to minimize the effect of agricultural operations on surface and groundwater quality. As research improves our understanding of contaminant mobility and transport, it will be possible to focus resources on control systems or decision aids that can be utilized by water quality control personnel and farm operators. In developing real time control systems, two primary applications are possible:

- the use of antecedent and forecast climate data to minimize losses of nutrients, pesticides, and sediment; and
- the use of microclimate data to improve the application efficiency of nutrients and pesticides and reduce losses to surface and subsurface flows.

In both cases, the timing and rate of application are sensitive to both water quality impact and inefficient utilization of farm inputs. Real time control systems assemble 5 to 10 days of antecedent precipitation and temperature data coupled with short-term forecast data to derive contaminant loss estimates (Lehman, 1989). These estimates are then expressed as the probability of load or concentration thresholds that can be exceeded for various nutrient or pesticide application rates on a given day. Such probability calculations can guide timing and rate decisions by farm operators. With the increasing importance of event-based monitoring coupled with the increasing cost of establishing and maintaining monitoring networks, real time control systems can also be used to activate monitoring networks for more intensive coverage of selected events.

Access to radar and satellite data on real time can also be advantageous. These products can take the form of spatially-depicted precipitation coverage areas, similar to geographic information system databases, and they greatly enhance single-point rain gage measurements by providing detailed rate and total precipitation information. Localized storm cells that create heavy precipitation are often missed by low-density gage networks; however, they can be instantly captured by radar and satellite database information. When these data systems are coupled with forecasted events they provide powerful tools to improve the management of nutrient and pesticide applications. The new, almost unlimited potential of computer graphics allows for development of practical user interfaces in most cases.

Concluding Observations

Lessons learned from the RCWP must be incorporated into new nonpoint source programs. Opportunities exist to extend monitoring, land treatment, practice design, and implementation methods to new projects through research and technology transfer. These efforts will lead to efficient and standardized methods for achieving nonpoint source goals. Without this advantage, new projects may repeat errors made in the RCWP and the effectiveness of the projects will remain uncertain.

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Synoptic Survey of Dairy Farms in the Lake Okeechobee Basin: Post-BMP Water Quality Sampling

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ABSTRACT

High phosphorus loadings from dairy operations in the Lake Okeechobee Basin threaten Lake Okeechobee's water quality; therefore, best management practices have been implemented to control nutrient runoff to surface waters. An extensive water quality monitoring network operated by the South Florida Water Management District monitors the water quality of lake inflows, basin tributaries, and off-site dairy farm discharge. Synoptic surveys have been developed to give a more comprehensive on-farm evaluation of water quality problems that cannot be identified by routine water quality monitoring at dairy farm outflows along property boundaries. Synoptic surveys are performed on selected dairies where phosphorus concentrations greater than 1.2 mg/L are consistently detected. Water quality samples are taken within property boundaries to identify high nutrient sources and identify problem areas that influence off-site runoff. The data are reviewed with landowners and used as a tool to correct design problems and develop on-farm nutrient management strategies. This paper presents a case study in which field scale problems were identified to help the landowner properly manage the operation and maintain the animal waste disposal system.

Lake Okeechobee covers 189,216 hectares and serves as a source of drinking water for area municipalities, irrigation for agriculture, local tourism, and recreation. The lake supports a large commercial and sport fishing industry and provides habitat for a variety of wildlife. The eutrophic lake has experienced large algal blooms driven by high nutrient inputs—particularly phosphorus (Joyner, 1971; Davis and Marshall, 1975; Federico et al. 1981). Northern inflows to the lake contribute a large portion of phosphorus from primarily dairy and beef agricultural operations (Allen et al. 1976; Federico, 1977; Ritter and Allen, 1982). Nutrient discharge is high during the spring and summer rainy season when the water table is within 25 cm of the ground surface in many areas.

Under the authority of Section 700.3 (Public Law 96-108, 93 Stat. 821, 835), Rural Clean Water Program (RCWP) projects were initiated in the Taylor Creek-Nubbin Slough basin in 1981 and in the Lower Kissimmee River basin north of the lake in 1987. The purpose was to assist landowners in implementing best management practices (BMPs) designed to control nutrient discharges, including

- fencing to keep cows out of waterways,
- improved water use efficiency,
- lagoon systems to capture barn wash, and
- pasture management (Stanley et al. 1988; Stanley and Gunsalus, 1991).

In 1987, the Florida Department of Environmental Regulation initiated a technology-based dairy rule: the Florida Administrative Code Chapter 17-670. This rule required additional BMPs specifying that each dairy operation must collect waste from its milking parlor and runoff from denuded herd pasture areas around the barns in which a high volume of animal waste is produced. The effluent from this high intensity area is diverted into waste storage ponds. Effluent from the ponds is applied to crops through sprayfield irrigation for nutrient uptake (Fla. Dep. Environ. Reg. 1987).

Thirty dairies are involved in the dairy rule BMP program. As of April 1992, BMPs are complete and operational at 29 dairies with one dairy under construction. In support of the FDER dairy rule, water quality monitoring by the South Florida Water Management District provides nutrient concentration measurements at dairy outflows. Concentration-based standards for total phosphorus were set for dairy off-site discharges (1.2 mg/L) and basin outlets to the lake (0.18 mg/L). These concentrations, based on phosphorus assimilation of wetlands and streams in the flow path to the lake (S. Fla. Water Manage. Distr. 1989a), were established to meet the Surface Water Improvement Management Plan's phosphorus-loading reduction goal of 42 percent from controllable sources (S. Fla. Water Manage. Distr. 1989b).

Water quality monitoring consists of grab and automated sampling at off-site discharges from dairy operations, tributary, and structure locations. A revision in the water quality network, implemented in October 1991, included synoptic surveys of dairy farms.

Review of the literature indicates that synoptic surveys were included in river quality data programs by the U.S. Geological Survey (Hines et al. 1977). These surveys are problem-oriented studies that result in interpretive reports performed to make sound resource decisions. The surveys—more flexible than rigidly structured routine monitoring—are tailored to fit the needs of each particular project area. In the dairy program, synoptic surveys are on-site water quality investigations designed to give a more detailed look at the sources of phosphorus within the farm operation than is possible from routine off-site discharge monitoring. The surveys are intended to be a "snapshot" look at the dairy. Data collected are not comparable with other long term routine monitoring data or intended to determine trends. An important function of this program is to provide a tool to landowners to correct on-farm nutrient management problems and improve operation and maintenance plans. In addition, this survey gives information on the efficiency of specific BMPs.

Methods

Dairies are selected for synoptic surveys when off-site discharges are consistently greater than the 1.2 mg/L target standard. Surveys are performed when off-site discharge is occurring. Sampling is conducted within the property boundaries at various locations upstream from off-site discharge points and areas where high phosphorus sources are suspected, including field ditches, major water courses, sprayfield outlets, primary and secondary water retention structures, wetlands, and animal lounging areas.

The first step in conducting the survey on a specific dairy is a background search of all literature pertinent to the operation. Historical water quality discharge data are reviewed along with computer maps of the dairy operation. Engineering design drawings, aerial photographs, and soil survey information are used to determine flow paths and soil drainage. Samples collected in the field are analyzed for soluble reactive phosphorus in the laboratory using a HACH DR2000 spectrophotometer. To ascertain other environmental factors that may be occurring (such as groundwater infiltration and dilution), physical parameters, including pH, conductivity, dissolved oxygen, and temperature, are measured *in situ* using a Hydrolab Surveyor II.

Following field investigations, phosphorus concentrations are plotted on maps of the dairy for presentation to the landowner and research staff. The landowner and South Florida Water Management District staff discuss the survey results, that is, the problems it identifies, any farm practices that may have contributed to them, and potential solutions to the problems within the operation.

Case Study

The following case study of a dairy operation along the Lower Kissimmee River illustrates the process and its value. A description of the study area, dairy statistics, historical water quality data, survey sampling scheme, and survey data are given to document the usefulness of the synoptic approach.

Study Area Description

This synoptic survey was conducted on a large dairy operation in the Lower Kissimmee River project area located approximately 14 km north of Lake Okeechobee. Surface drainage leaves the dairy primarily through a marsh wetland system that joins a tributary and canal before reaching the lake. This

dairy was selected because high phosphorus concentrations were consistently detected in the discharge waters (Table 1).

Table 1.—Total phosphorus period of record averages of pre- and post-BMP values at routine monitoring sites.

SITE	P.O.R.[1]	PRE-BMP	POST-BMP	% CHANGE
32B	3.64	4.77	2.78	–41.7*
49	7.44	7.41	7.50	1.2
IR1	1.81	NA	NA	NA
IR2	2.81	NA	NA	NA
33	2.80	2.14[2]	4.05[3]	—
32C	2.67	—	2.67[3]	—

[1]Period of record for each site is within the date range of 4/87-3/92
[2]Historical data were not continuous
[3]Sites initiated 10/1/91 (n=2)
*Data were significant at P=0.0001

The dairy consists of two barns and encompasses about 995 hectares with 2,340 cows. (Cow numbers include milk herd, dry herd, calves, and heifers.) On-farm BMPs include a waste management system consisting of a first stage anaerobic lagoon (approximately 1 hectare) and a second stage aerobic waste storage pond (approximately 6 hectares) at each barn. Effluent is pumped from the waste storage pond and applied to the sprayfield using a center pivot irrigation system. The largest sprayfield is approximately 94 hectares; smaller sprayfields range from 20 to 77 hectares. Sprayfields are used for hay and sorghum production. Waste management BMP construction was completed in February 1990.

Dominant soils in the area are poorly drained; a high seasonal water table within 25 cm of the surface and other soils creates occasional ponding above the surface. Most soils have a spodic horizon, or organic hardpan, occurring within 50 to 125 cm of the surface. The hardpan varies in thickness and consistency and promotes lateral subsurface drainage. These soils are very permeable and somewhat responsive to drainage. Other soils on lower landscape positions lack subsurface restrictive layers and are periodically ponded. Most of these areas lack drainage outlets and are used for native range or as watering places for livestock (McCollum and Pendleton, 1971). Soils on this dairy are similar to soils found within the two basins. Soils within the region have a low phosphorus retention capacity and do not inhibit phosphorus transport.

Water Quality Historical Data and Site Locations

Phosphorus discharge concentrations are collected biweekly from sites 32B, 32C, 32D, 33, and 49 (see Map 1). Sprayfield discharge has also been monitored since 1988 at sites IR1 and IR2. Sites 32C and D were added to the routine monitoring program in October 1991 to monitor oncoming water from a dairy operation to the north of the property and outer pastures.

Table 1 lists the period of record discharge averages, pre- and post-BMP phosphorus values at the routine monitoring sites, and the percent of change between the pre- and post-BMP values. The data indicate that high phosphorus concentration discharges were common to this dairy operation. Some of these high phosphorus values can be attributed to poor soil drainage in the area, past practices of animal lounging in wet areas, residual soil effects, and animal density.

Although phosphorus concentrations have steadily decreased since implementation of BMPs, high phosphorus concentration discharges are still observed (Fig. 1).

Synoptic Survey Sampling

Field investigations were conducted on October 15, 16, and 22, 1991. Before and during the field investigations, 5.5 cm of rainfall were recorded between October 10 and 17. Soils in the pasture and interior farm roads were saturated during the first two survey visits but were considerably dryer on the last visit. Sampling was performed at 39 individual sites during the three days of investigation. Map 1 gives an overview of the property boundaries, location of BMPs, hydrologic flow pathways, and routine monitoring sites. Maps 2 and 3 (enlarged sections of Map 1) show the synoptic survey site locations.

■ **Barn 1.** Off-site discharges from Barn 1 are routinely collected at sites 49, 32B, and 32C (Map 1). The main source of discharge from site 49 (Map 2) originates from the four smaller sprayfields serving Barn 2. Sprayfield discharge flows through a series of conveyance ditches before reaching site 49. Other discharge sources from site 49 originate from animal lounging areas located south of the Barn 1 high intensity area and pasture areas east of the two southern-most sprayfield pivots. Off-site discharge from site 32B (Map 3) originates from lounging areas north of Barn 1's high intensity area, the large center pivot sprayfield located north of Barn 1, outer pasture areas and wetlands on the northern boundary of the property, and inflow from a dairy operation north of the property. Discharge at site 32C originates from wetland and pasture areas in the northeast area of the property.

■ **Barn 2.** Sampling was conducted upstream from site 33 near the south end of the dairy property

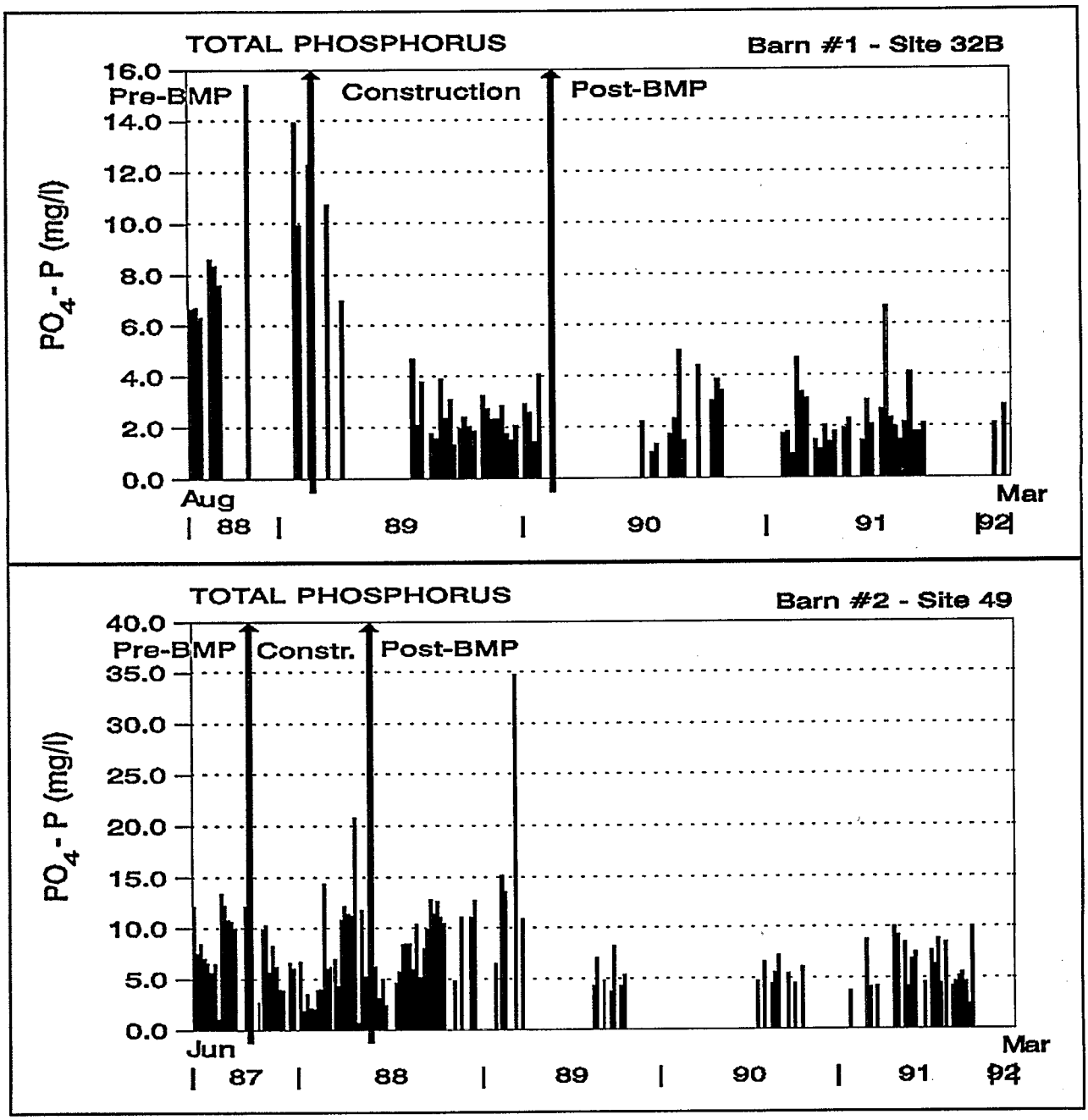
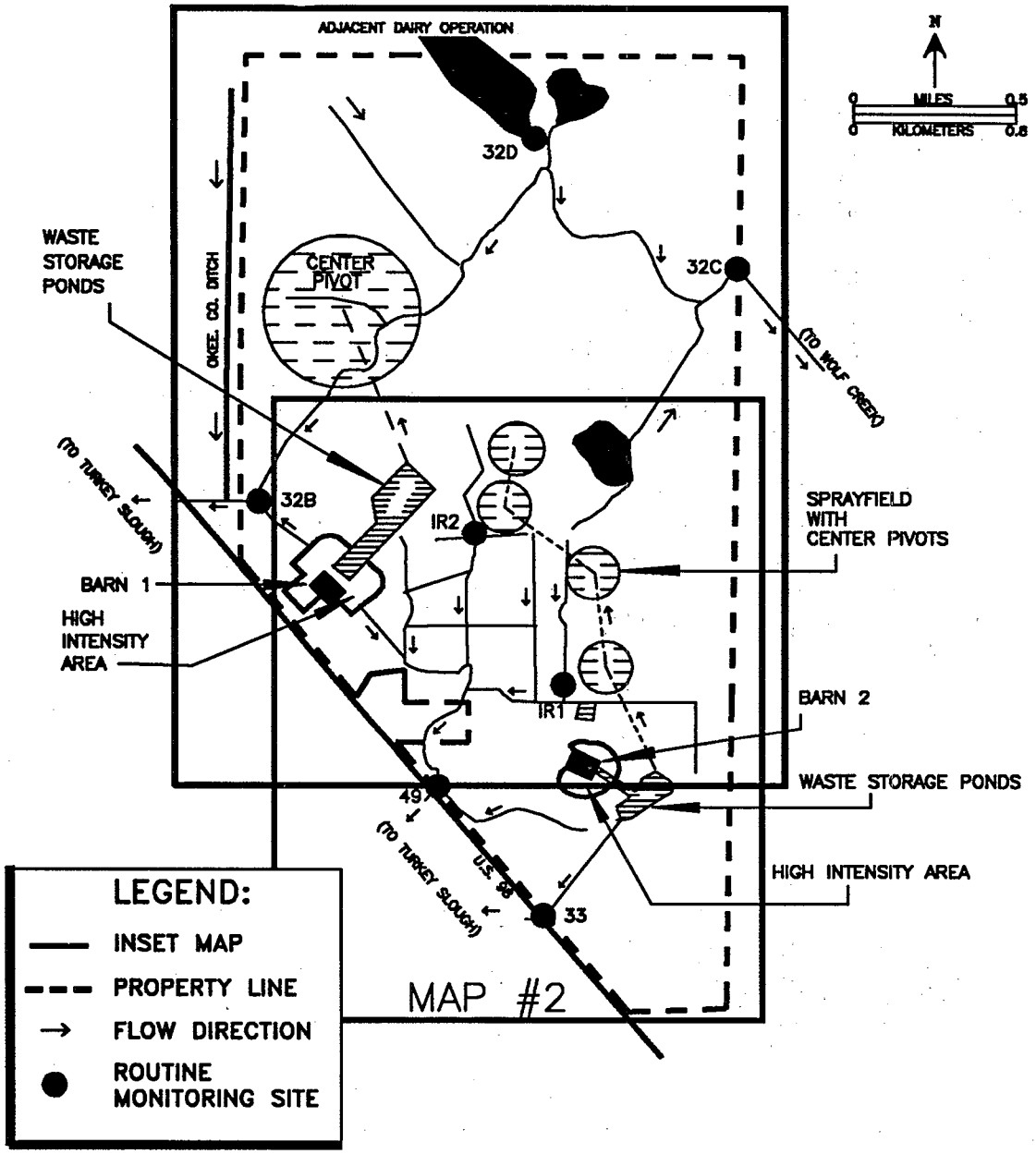


Figure 1.—Time series graphs of total phosphorus concentrations at the primary outflows of dairy Barns 1 and 2.

(Map 2). The main source of off-site discharge from site 33 originates from areas adjacent to the waste storage pond and outer pastures. Runoff from pastures southeast of Barn 2 is treated with an alternative nutrient management system (labeled on Map 2) known as an "eco-reactor," which uses chemical precipitation methods to remove nutrients from surface water runoff. Discussion of this experimental system (being developed by private consultants) is beyond the scope of this paper.

Results and Discussion

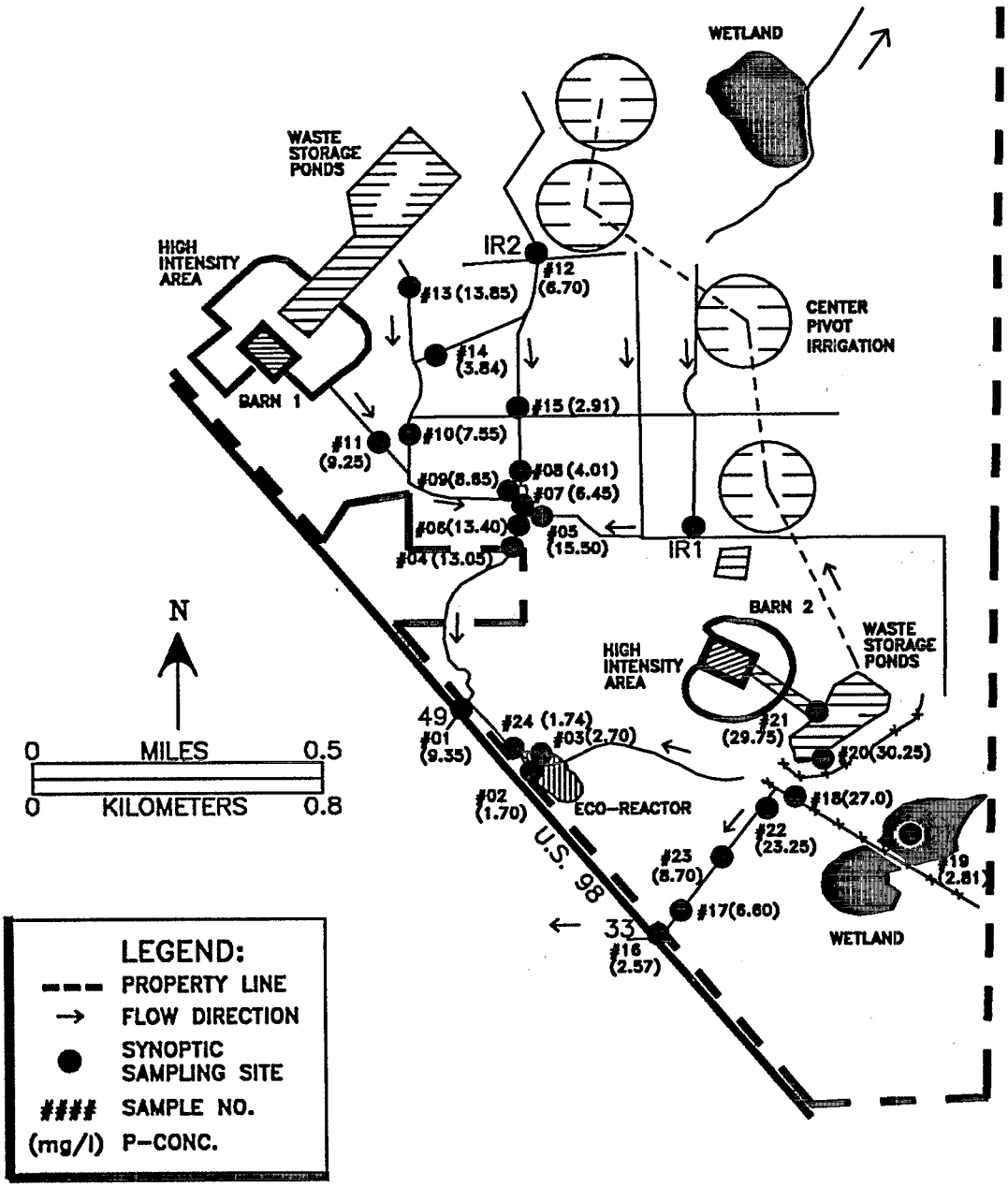
As indicated by the pre- and post-BMP data, phosphorus concentrations at farm discharge sites have decreased since the implementation of BMPs. Average concentrations have decreased and concentrations are less variable within the post-BMP data. However, high total phosphorus concentration discharges above 1.2 mg/L were still detected. Concentrations of soluble reactive phosphorus from the



Map 1.

synoptic survey ranged from 0.24 mg/L (sample #26) to 30.24 mg/L (sample #20). Routine off-site discharge points from Barn 1 at sites 49, 32B, and 32C had soluble reactive phosphorus values of 9.35, 3.72, and 1.50 mg/L respectively. Off-site discharge from Barn 2 at site 33 was 2.57 mg/L. Values obtained during the synoptic survey are similar to phosphorus concentrations observed through the routine monitoring network—all above the 1.2 mg/L standard.

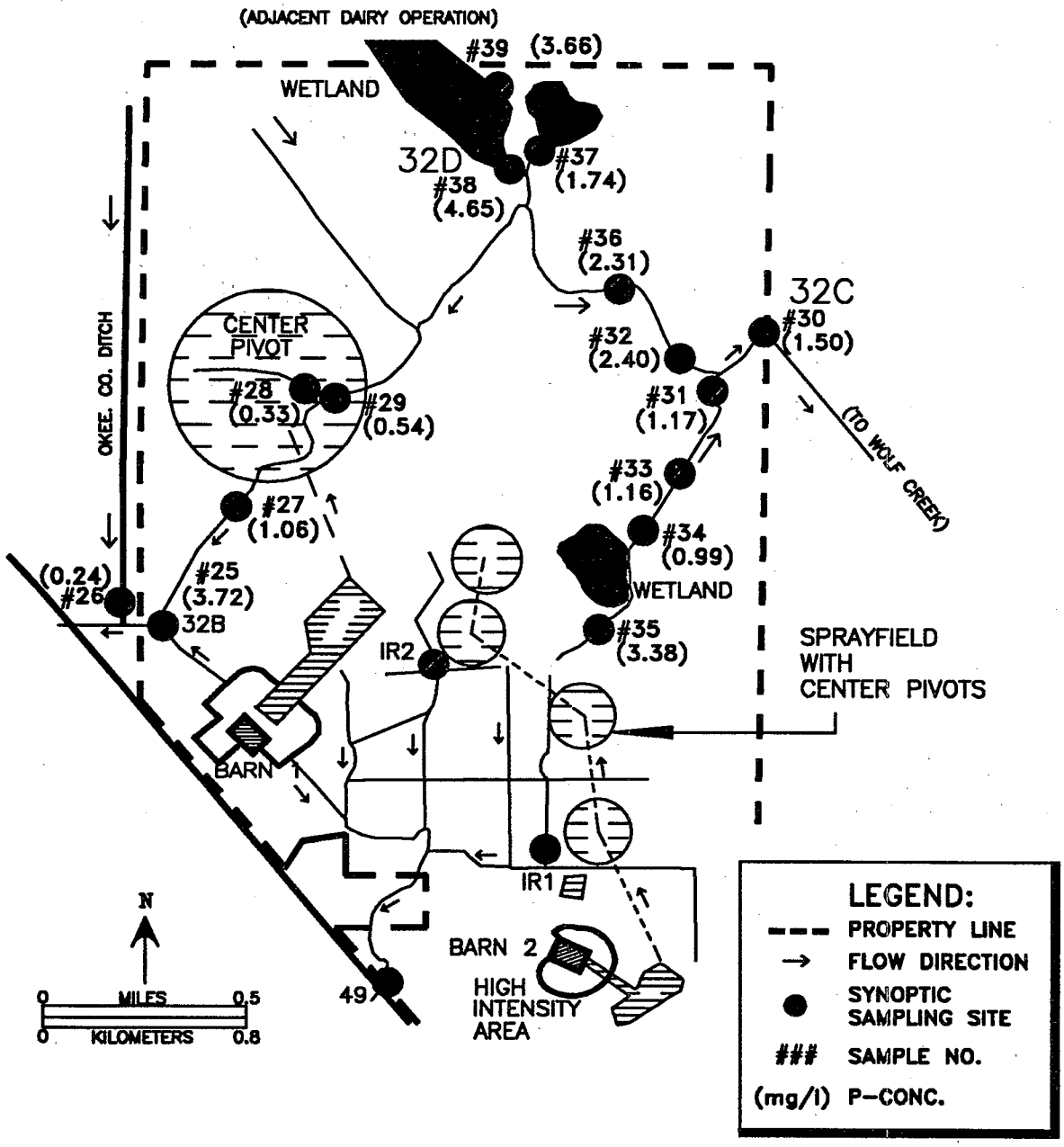
■ **Barn 1.** Upstream of site 49 (Map 2), soluble reactive phosphorus concentrations (samples #04 and #06) were greater than 13 mg/L. Inflows from the east-west lateral ditch that originate from the small sprayfields and the lounging area north of



Map 2.

Barn 2 had a concentration of 15.50 mg/L (sample #05). West of the confluence, samples from ditches draining animal lounging areas south of the Barn 1 high intensity area (samples #11 and #13) had concentrations of 9.25 and 13.85 mg/L. Ditches from pastures near the small sprayfields exhibited extremely light flow to ponded conditions, making it difficult to accurately assess impacts from this area.

Survey results indicate that the primary sources of high phosphorus concentrations at site 49 are from the east-west lateral ditch (sample #05) and ditches draining the animal lounging areas south of the Barn 1 high intensity area. Further investigation of lounging areas north of Barn 2 and the sprayfield ditches is needed.



Map 3.

Off-site discharge at site 32B (Map 3) northwest of Barn 1 had a soluble reactive phosphorus concentration of 3.72 mg/L. Flows from the large sprayfield north of site 32B were 1.06 mg/L or less. While no other samples were taken in this area, potentially high concentrations may originate from animal lounging areas northeast of site 32B.

Along the northeast property line, site 32C had a soluble reactive phosphorus concentration of 1.50 mg/L. Flows originate from a small wetland and pastures to the south and a larger wetland with adjacent pastures to the north. Discharge from the northern wetland had a soluble reactive phosphorus concentration of 4.65 mg/L at site 32D, which receives inflow from another dairy operation located to the north. South of the smaller southern wetland, the ditch discontinues, resulting in minimal flushing while receiving input from surrounding pastures.

This area had a soluble reactive phosphorus value of 3.38 mg/L. In addition to applying soil amendments, the landowner is considering fencing out the heifers that currently graze along the north sections of the property and in areas of inflow to site 32C.

■ **Barn 2.** Water leaving the property at site 33 (Map 2) measured 2.57 mg/L. Upstream, outflows from the waste storage pond measured 30.25 mg/L (sample #20). During the survey, water from the storage pond flowed through adjacent wetlands into the ditch leading to the off-site discharge point. Survey results infer that the high concentrations of soluble reactive phosphorus at off-site discharge site 33 result from overflow from the waste storage pond. A decision was made with the landowner that maintaining proper storage capacity of the waste storage pond would help eliminate high off-site nutrient discharges. Further investigation of drainage ditches from the Barn 2 waste management area is suggested.

Conclusion

Following BMP installation, proper management of dairy farms is necessary to achieve the desired phosphorus reduction results. Long-term monitoring does not provide the data needed to identify site-specific high sources of phosphorus within the farm and assist in nutrient management decisions. Unlike routine monitoring, synoptic surveys are investigative surveys that provide detailed information to assess on-farm water quality problems and improve nutrient management strategies. These surveys also provide the opportunity to better relate and assess water quality improvements resulting from BMP implementation. In this study, intense outer pasture grazing, animal lounging in wet areas, improper waste storage pond operation, and phosphorus-contaminated ditches were identified as potential source contributions that result in high phosphorus discharge.

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