EPA-600/2-76-237
October 1976

Environmental Protection Technology Series

CONTROL OF SEDIMENTS, NUTRIENTS, AND ADSORBED BIOCIDES IN SURFACE IRRIGATION RETURN FLOWS

Robert S. Kerr Environmental Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Ada, Oklahoma 74820

RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environmental Protection Agency, have been grouped into five series. These five broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The five series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies

This report has been assigned to the ENVIRONMENTAL PROTECTION TECHNOLOGY series. This series describes research performed to develop and demonstrate instrumentation, equipment, and methodology to repair or prevent environmental degradation from point and non-point sources of pollution. This work provides the new or improved technology required for the control and treatment of pollution sources to meet environmental quality standards.

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

EPA-600/2-76-237
October 1976

CONTROL OF SEDIMENTS, NUTRIENTS, AND ADSORBED BIOCIDES IN SURFACE IRRIGATION RETURN FLOWS

by

David L. Carter
James A. Bondurant
U.S. Department of Agriculture
Agricultural Research Service
Western Region
Snake River Conservation Research Center
Kimberly, Idaho 83341

Interagency Project No. EPA-IAG-D5-F648

Project Officer

Arthur G. Hornsby
Source Management Branch
Robert S. Kerr Environmental Research Laboratory
Ada, Oklahoma 74820

ROBERT S. KERR ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
ADA, OKLAHOMA 74820

DISCLAIMER

This report has been reviewed by the Robert S. Kerr Environmental Research Laboratory, U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

ABSTRACT

The technology available for the control of sediments, nutrients, and adsorbed biocides in surface irrigation return flows has been reviewed and evaluated. Some of this technology could be applied immediately to reduce sediment and associated nutrient and biocide concentrations in surface irrigation return flows. Much of the available information needs to be integrated to develop improved control practices. New ideas and new control technology are needed. Economic incentive programs are needed to improve acceptance of control technology. The factors controlling erosion and subsequent sediment concentrations in surface irrigation return flows, and how these factors can be managed to reduce erosion and sediment concentrations are reviewed and discussed. Three approaches (1) eliminating surface runoff, (2) reducing or eliminating erosion, and (3) removing sediments and associated nutrients and biocides from surface irrigation return flows, and control measures for each approach are discussed. Research and demonstration needs for improving and developing new control technology are presented. These include simulation modeling of known erosion parameters, the development of improved irrigation systems and methods, the design of improved irrigation water distribution systems, and field management practices. The need for more information on design and operational criteria for sediment retention basins is discussed.

This report was submitted in fulfillment of Interagency Agreement Number EPA-IAG-D5-F648 by the U. S. Department of Agriculture, Agricultural Research Service, under the partial sponsorship of the Environmental Protection Agency. Work was completed as of April 1976.

CONTENTS

Sections		Page
I	Conclusions	1
II	Recommendations	3
III	Introduction	4
IV	Sediments and Adsorbed Nutrients and Biocides in Surface Irrigation Return Flows	
	A. Erosion on Irrigated Land	6
	B. Sediment in Surface Irrigation Return Flows	10
	C. Nutrients in Surface Irrigation Return Flows	15
	D. Biocides in Surface Irrigation Return Flows	16
V	Technology Available for Controlling Sediments and Associated Nutrients and Biocides in Irrigation Return Flows	18
	A. Eliminating or Reducing Surface Irrigation Return Flows	18
	B. Reducing or Eliminating Erosion	22
	1. Controlling Slope	22
	2. Controlling Furrow Stream Size	24
	3. The Run Length	25
	4. Controlling Irrigation Frequency and Duration	27
	5. Cultural Practices to Control Erosion	27
	C. Removing Sediment and Associated Nutrients and Biocides from Surface Irrigation Return Flows	28
	1. Controlling Tailwater	28
	2. Utilizing Sediment Retention Basins to Remove Sediments	29
VI	Simulation Techniques for Estimating Sediment and Associated Nutrient and Biocide Loads in Surface Return Flows	32
VII	Research and Demonstration Needs	34
VIII	Literature Cited	37
IX	Bibliography	40

FIGURES

No.		Page
1	Soil loss rate as a function of eroded cross-sectional area, and furrow spacing, for a soil bulk density of 1.20 g/cm^3.	11
2	Erosion occurring under surface irrigation on 2 percent slope land. These furrows were eroding at the rate of 100 t/ha (45 tons/a) at the point shown.	12

TABLES

No.		Page
1	WATER FLOW AND SOIL LOSS ALONG IRRIGATION FURROWS (Mech and Smith, 1967)	7
2	SEDIMENT CONCENTRATIONS IN IRRIGATION AND DRAINAGE WATERS FOR TWO LARGE TRACTS DURING THE 1971 IRRIGATION SEASON, PPM	13
3	IDENTIFIED CHLORINATED HYDROCARBON AND THIOPHOSPHATE PESTICIDES DETECTED IN SURFACE DRAIN WATER IN THE SAN JOAQUIN VALLEY, CALIFORNIA* (Johnson *et al.*, 1967)	17
4	TOTAL ANNUAL ENERGY INPUTS, IN THOUSANDS OF KILOCALORIES (OR GALLONS OF DIESEL FUEL) PER ACRE IRRIGATED FOR NINE IRRIGATION SYSTEMS, BASED ON 36-IN. (915-mm) NET IRRIGATION REQUIREMENT AND ZERO PUMPING LIFT (Batty *et al.*, 1975)	19
5	DESIGN SUMMARY OF NINE IRRIGATION SYSTEMS (Batty *et al.*, 1975)	20
6	SUMMARY OF RECIRCULATING SURFACE IRRIGATION SYSTEMS, SOUTHERN IDAHO 1964-1965 (Bondurant and Willardson, 1965)	23
7	COMPUTED DISTRIBUTION OF WATER UNDER MULTI-SET AND STANDARD IRRIGATION PRACTICES FOR A 50-mm (2.0 in) IRRIGATION	26

SECTION I

CONCLUSIONS

1. Sediment and adsorbed nutrients and biocides in surface irrigation return flows originate primarily from furrow erosion on furrow irrigated land. Some sediment is derived from soil erosion that occurs with other irrigation methods such as improperly used sprinkle systems and certain flood irrigation practices.

2. The sediment and associated nutrient and biocide concentrations in surface irrigation return flows depend primarily upon the land slope in the direction of irrigation, the furrow stream size, the run length, the condition of the soil surface, the infiltration rate in relation to the application rate, the duration of the irrigation, tillage practices, the number of irrigations per season, the crop, and tailwater management. Sediment concentrations in surface irrigation return flows vary widely, from 0 to more than 15,000 ppm.

3. The sediment and associated nutrient and biocide concentrations in surface irrigation return flows could be reduced by applying control technology developed during the past 40 years. Much of the available technology needs further development and new technology integrating relationships among soil erosion parameters needs to be developed.

4. An incentive program for applying erosion and sediment control practices on irrigated land is needed. This program could be in the form of low interest loans or cost participation. Acceptance of new control practices will depend upon economic benefits.

5. Additional technology should be developed on multi-set irrigation systems, trickle irrigation methods, tillage practices emphasizing minimum tillage, design and operational criteria for sediment retention basins, within-row irrigation, tailwater management, irrigation system design to facilitate water delivery on farmer demand, simulation models for predicting sediment and associated nutrient and biocide losses, use of grass buffer strips for filtering sediments, and land forming and shaping to reduce erosion and sediment losses.

6. The dissolved nutrient concentrations in surface irrigation return flow differ little from those in the irrigation water, except where nutrients are added directly to the water for fertilizing the crop. Some nutrient enrichment can result from leaching of nutrients from decaying plant residue on the soil surface.

7. The limited available information indicates that essentially all biocides in surface irrigation return flows are adsorbed on sediments except where they are sprayed directly into the water or washed from plant material into the water by rainfall or sprinkler irrigation. Thus, controlling sediments in surface irrigation return flows will also control the biocides.

8. There are three ways to control sediments and associated nutrients and biocides in surface irrigation return flows: (1) Reduce or eliminate surface irrigation return flow; (2) reduce or eliminate soil erosion so that there will be little sediment in surface runoff from irrigation; and (3) implement practices that will remove sediments and associated nutrients and biocides from irrigation return flows before these waters enter natural streams. The last two ways will be necessary for adequate control if surface return flows cannot be eliminated.

9. The awareness of the need for sediment and associated nutrient and biocide control in surface irrigation return flows, coupled with economic incentives or direct economic benefits of new control technology, should stimulate farmer and irrigation company acceptance of control technology.

SECTION II

RECOMMENDATIONS

1. Technology available for controlling sediments and associated nutrients and biocides in surface irrigation return flows should be promoted through education programs such as workshops, field observations, limited demonstrations on farmers' fields and other training experiences.

2. Incentive programs such as low interest loans or cost participation programs should be developed for farmer and irrigation company implementation of erosion and sediment control practices on irrigated land. Direct economic benefits of implementing control practices should be projected and publicized where possible.

3. Research effort should be intensified toward integrating basic relationships among erosion and sediment control parameters including stream size, flow velocity, furrow slope, run length, sediment settling velocity and forward velocity into new control technology. Simulation modeling with predictive equations should be used to assess the relative importance of the various parameters so that control measures can be applied first to parameters that will have the most impact upon control.

4. Additional design, construction and operational criteria for sediment retention basins need to be developed. Sediment retention basins will be needed to remove sediments from surface irrigation return flows until techniques can be developed to prevent sediment losses from highly erosive soils. Economic uses of the sediment collected in these basins should be developed to reduce the net costs of cleaning.

5. Efforts to develop and improve irrigation methods that apply water efficiently, without erosion, at a low cost with low energy requirements should receive major attention and support. These efforts should include the design and improvement of irrigation water delivery systems that will deliver water to farms on demand.

6. Intensified research efforts should be directed toward developing field management practices for erosion and sediment control. These should include, but not be limited to, within-row irrigation, minimum tillage, grass buffer strips, tailwater control, residue management, and land forming.

SECTION III

INTRODUCTION

Surface irrigation return flow is that portion of the irrigation water applied to soil which passes over the soil surface and becomes runoff. On an irrigation project it usually also includes direct spill from canals and water that flows through farm ditches but is not applied to the soil. Typically, about 10 to 30% of the water applied to furrow-irrigated land becomes surface runoff. Surface irrigation runoff can also occur from lands irrigated by wild flooding, some border streams, and where sprinkle systems apply water too rapidly on sloping land. Surface irrigation return flows from these latter three situations comprise only a small portion of the total flows. There is no surface runoff from fields when the water application rate is equal to or less than the infiltration rate. Such application rates can be achieved with properly designed sprinkle irrigation systems and with trickle irrigation, but the expense and energy requirements of these systems limit their use. Surface irrigation return flow does not exist with subsurface irrigation or with certain border irrigation and furrow methods that confine applied water to a given area, including pumpback systems.

Water passing over the soil surface has limited contact and exposure to the soil at the soil surface, and flow at the interface is into the soil. Therefore, the quantities of soluble salts, fertilizer nutrients and pesticides dissolved or washed off the soil into the water flowing over the surface are expected to be extremely small. Such water does pick up debris, crop residue, applied manure residue, nematodes, plant pathogens, and other foreign matter. When erosion occurs, the most important material picked up is soil and material attached to it. Soil picked up in the erosion process is usually referred to as suspended sediment or sediment.

Erosion of irrigated land has been recognized as a serious problem for many years. Israelsen *et al.* (1946) stated that excessive erosion of irrigated lands was adverse to the perpetuation of permanent agriculture in arid regions. Gardner and Lauritzen (1946) reported that it was apparent to every farmer that serious damage resulted when attempting to irrigate steep slopes unless the stream was very small. They recognized that little erosion occurred on lands with gentle slopes even with relatively large streams. These observations led them to suggest the vital importance of finding a means of estimating the rate at which soil would erode with various stream sizes at various slopes.

Today, 30 years later, it is still common to observe furrow irrigation on steep slopes with streams that are too large, resulting in serious erosion. Much technology has been developed to control erosion of irrigated land and to reduce sediment concentrations in surface irrigation return flows, but much of this technology has not been applied. Hence, serious erosion still exists on furrow irrigated land.

The purposes of this report are to provide an overview and an assessment of the problems associated with sediment and adsorbed nutrients and biocides in surface irrigation return flows, to assess currently available technology for implementing control measures, and to suggest research and demonstration needs for improving control.

The available literature has been reviewed, evaluated and summarized, and results from some current investigations have been incorporated to provide this state-of-the-art report. Gaps in available technology are identified, and research and development needs for reducing or eliminating sediments and adsorbed nutrients and biocides from surface irrigation return flows are suggested and discussed.

SECTION IV

SEDIMENTS AND ADSORBED NUTRIENTS AND BIOCIDES IN SURFACE IRRIGATION RETURN FLOWS

EROSION ON IRRIGATED LAND

Whenever water flows over cultivated land, erosion may occur. Factors influencing the amount of erosion include (1) the slope in the direction of irrigation, (2) the stream size, (3) the soil texture, (4) the condition of the soil surface, (5) the duration of the irrigation, and (6) the crop. Most erosion on irrigated land results from furrow irrigation, and basically is erosion of the furrows. Israelsen et al. (1946) reported that furrows near the head ditches eroded 2.5 to 10 centimeters (cm) (1 to 4 inches) in sugarbeet fields. Mech (1959) showed similar results with row crops. He reported soil losses of 50 metric tons(tonnes)/hectare (t/ha) (22.7 tons/a) during a 24-hour irrigation of corn on a Sagemoor fine sandy loam soil on a 7% slope. He further stated that even on relatively flat fields with short runs, 30 cm (12 in.) of surface soil have sometimes been lost after about 10 years of cultivation. Similar loss rates have been observed in the 1970's on irrigated Portneuf silt loam planted to dry beans, sugarbeets, and corn.

In furrow irrigation, each furrow functions as the absorbing surface and as a channel for conducting water to irrigate the remainder of the run (Mech and Smith, 1967). The stream size at the head of the furrow must be sufficient to meet the infiltration requirements over the entire furrow length and to propagate the stream to the end of the furrow fast enough to give a reasonable uniform distribution throughout the length of run. Ideally it should not exceed that size. Larger streams are required to irrigate longer runs. But larger streams have greater capabilities to erode soils and transport sediment on sloping land, and thereby cause more erosion. Therefore, more erosion would be expected near the heads of furrows where irrigation runs are long. Practically, short irrigation runs have not been used because cross ditches interfere with equipment during tillage, seeding, cultivating, and harvesting operations. Shorter irrigation runs require more labor. Also, it is difficult to control furrow stream sizes so that just enough water is added to each furrow during the irrigation to supply the needed water for the run length because infiltration generally changes during the irrigation and considerable variability exists between furrows. As a result of these practical factors, irrigation runs are usually longer than ideal for erosion control, and furrow stream sizes are generally larger than required for irrigating the run length to assure that all furrows are irrigated sufficiently during an irrigation. These practices increase erosion, particularly at the heads of the furrows.

Mech and Smith (1967) reported the characteristics of flow and silt load along irrigation furrows (Table 1) in two closely controlled tests. The flow was carefully controlled into each furrow, and the runoff and sediment loss were measured from the upper, middle, and lower third of each furrow. The run length was 274 meters (m) (900 ft), and the slope was 2%. The flow into each furrow was about 15% greater in test 2 than in test 1. The results from these field tests clearly illustrated that erosion was greatest where the stream size was largest. Soil loss was much greater from the upper third of the furrows than from the middle and lower thirds. Furthermore, the soil loss was greater in test 2 where flow was 15% more than in test 1. The soil eroded from the upper third was deposited in the middle and lower thirds as the stream size, and thereby the energy to erode and capacity to transport sediment, decreased. Erosion occurred further down the furrow and sediment was deposited further down the furrow in test 2 because the stream size was larger along the entire furrow length than in test 1. The critical stream size where erosion essentially ceased and deposition began came at a point further down the furrow in test 2. These results would probably be confirmed by computation of tractive force if sufficient data were available.

Table 1. WATER FLOW AND SOIL LOSS ALONG IRRIGATION FURROWS (Mech and Smith, 1967).

Distance from upper end		Flow per furrow per minute		Soil loss per furrow		Runoff	Travel Time: From point of application	Travel Time: For 91-m (300-ft) distance
m	ft	liters	gal	kg	lb	%	min	min
				Test no. 1				
0	0	26.6	7.03	0	0		0	
91	300	17.0	4.49	43.3	116	61	48	48
183	600	7.3	1.94	4.8	13	21	211	163
274	900	2.5	0.67	0.4	1	2	682	471
				Test no. 2				
0	0	30.6	8.08	0	0		0	
91	300	20.7	5.46	51.1	137	66	24	24
183	600	11.9	3.14	14.2	38	35	98	74
274	900	5.4	1.42	0.7	2	8	436	338

Results from these studies are in contrast to erosion resulting from rainfall, which is usually most severe down slope where stream sizes become large enough to erode and where slopes are steepest. Erosion and soil loss on a sloping irrigated field can be greater from a heavy rainfall than from irrigation because of the different stream sizes and locations along the furrows.

The two tests also demonstrate that much better erosion control and higher irrigation efficiencies are achieved with short runs because smaller stream sizes are required. Consider the lower third of the furrows in test 1. With an inflow of 7.3 liters/min (ℓ/min) and an outflow of 2.5 ℓ/min, erosion was negligible. If the entire 274-m run length had been irrigated with the stream size used on the lower third, the total water requirements would have been 21.9 ℓ/min or 21% less, and there would have been no erosion. Actually, had the field been irrigated with three separate 91-m run lengths, the inflow could probably have been less than 7.3 ℓ/min because a runoff of 2.5 ℓ/min would not have been necessary. However, 91-m run lengths are not normally considered practical because field equipment operations could be much more costly as a result of the extra time required for turning. New techniques being developed that may allow short run lengths without interfering with equipment operations will be discussed later in this report.

The common practice on many irrigated farms today is to place a large enough stream in each furrow so that the water reaches the lower end in about 2 to 3 hours for a 12-hour set. This usually allows sufficient infiltration time to replenish water depleted by the crop without reducing the stream size or requiring other labor during the set. Where infiltration rates are low, when the application of more water is desired, and where slopes are nearly flat, 24-hour sets are used. The irrigating stream must reach the end of the run in about 1/4 of the total time of irrigation to obtain reasonable uniformity of application throughout the run. With these practices, the stream sizes are often large and 40 to 60% of the applied water becomes runoff. This is much like the upper third of the furrows in the tests reported by Mech and Smith (1967), and erosion can be extensive.

Another serious erosion problem is associated with the practice common in some irrigated areas of keeping the drain ditch at the lower end of the field about 10 to 20 cm deeper than the furrow and at a slope steep enough that the tailwater flows rapidly away. With this practice, the ends of the furrows erode rapidly, even with very small streams. This erosion gradually moves up the slope because erosion increases the effective slope near the end of the furrow. As the practice is continued, the slope is increased on the lower 5 to 10 m of the field, making it difficult to control erosion and soil loss from this portion of the field, and to achieve adequate intake because of smaller wetted perimeters. The lower ends of fields may have to be reshaped every few years because of this practice. This type of erosion is easily controlled by different tailwater management.

Many fields with steep slopes are irrigated, and usually in the direction of the steepest slope, even though it has been recognized for decades that serious erosion results from irrigating down steep slopes. Israelsen et al. (1946) clearly demonstrated that more soil was eroded from furrows with greater slopes. One example they pointed out was that a fivefold increase in slope, from 1.15 to 6.07%, increased the erosion 16 times. The same year, two other publications were released from work done in Utah presenting the relationships between furrow slope and furrow erosion (Gardner et al. 1946; Gardner and Lauritzen, 1946). These publications contain usable graphs illustrating relationships among furrow slope, stream size, and erosion, and also several useful equations. Unfortunately, irrigation farmers gave little attention to results from these studies, and today many fields are irrigated with furrow slopes too steep and with stream sizes that are too large, resulting in serious erosion.

Following the early work in Utah, numerous investigations were conducted in other western states relating slope to erosion on irrigated land. The USDA-SCS Division of Irrigation conducted many tests throughout the Western USA from 1948 to 1953 to determine maximum non-erosive stream size as a function of slope. These data suggested a relationship:

$$\text{Max. Non-Erosive Stream Size, } \ell/\text{sec} = \frac{0.63}{\text{slope, \%}}$$

or (1)

$$\text{Max. Non-Erosive Stream Size, } \frac{\text{gal}}{\text{min}} = \frac{10}{\text{slope, \%}}$$

Evans and Jensen (1952) studied soil loss from furrows disturbed by a recent cultivation so that the soil surface was loose and from furrows that had not been cultivated since a previous irrigation. Furrow slopes were 1, 2, and 3.5% and stream were 0.38, 0.76, and 1.14 ℓ/sec (6, 12, and 18 gal/min). Their results showed little erosion with stream sizes of 0.38 and 0.76 ℓ/sec (6 to 12 gal/min) at 1% slope, but considerable soil was lost at the steeper slopes and particularly with a stream size of 1.14 ℓ/sec (18 gal/min). Mech (1949) investigated the effects of stream size and slope on erosion in irrigation furrows at Prosser, Washington. His results were similar to those reported from earlier work. All of the work to date suggests that erosion may be expected on most row-cropped soils when slopes exceed 1%. Erosion may be controlled reasonably well on slopes up to 2% if the stream size is carefully controlled.

The foregoing discussion suggests that there is an optimum stream size for controlling erosion for a given furrow, soil, and crop condition. In alfalfa, grass, and other close growing crops, large furrow streams can sometimes be applied at slopes of 7% or more without much erosion (Mech, 1949). In contrast, serious erosion can occur in row crops when stream sizes are too large even at slopes of 1%.

Public Law 92-500, which includes requirements to regulate the quantity of sediment in surface return flows, has increased the interest among farmers and irrigation districts to control erosion and sediment in surface return flows. Many questions raised about erosion and sediment loss indicate that few irrigators and other personnel associated with irrigation have a good concept for visual determination of erosion in furrows. Equation (2) is a simple relationship for estimating soil erosion in tonnes/ha (t/ha).

$$\text{Soil erosion, } \frac{t}{ha} = \frac{1.2 \times \text{eroded area, cm}^2}{\text{furrow spacing, m}} \qquad (2)$$

Equation (2) assumes a soil bulk density of 1.2 g/cm^3 or t/m^3. (Metric abbreviations are: m = meters, cm = centimeters, g = grams, t = tonnes, or metric tons, and ha = hectare.) An alternative to using equation (2) would be to use Figure 1 to estimate the amount of erosion in either metric or English units.

Equation (3) is a simple relationship for estimating the furrow length necessary to contribute 1 tonne of sediment.

$$\text{Furrow length to erode 1 tonne} = \frac{10,000}{1.2 \times \text{area eroded, cm}^2} \qquad (3)$$

The furrows shown in Figure 2 have eroded at a rate of 100 t/ha (45 tons/acre) near the head ditch. The cross section of the eroded area in these furrows was approximately 70 cm^2 (12.5 in^2).

SEDIMENT IN SURFACE IRRIGATION RETURN FLOWS

Sediment concentrations in surface irrigation return flows vary widely. Brown et al. (1974) reported concentrations ranging from 20 to 15,000 ppm. Data in Table 2 illustrate the wide sediment concentration variation in some drains during an irrigation season. These data were collected from the five main drains from the 82,030-ha Twin Falls tract and the six main drains from the 65,350-ha Northside tract in southern Idaho. Sediment concentrations were measured at the point where drain waters returned to the Snake River, except for the Kimberly and Hansen drains which were subunits within the Twin Falls tract. These two drains emptied into canals from which water was redistributed for irrigation. The monthly mean sediment concentrations in the water diverted from the Snake River and reaching the two tracts are shown in the last two lines of Table 2 for comparison. The sediment concentrations in most drains exceeded those in irrigation water severalfold. An exception was the W drain, which serves much like a sediment retention basin. Water from this drain was being returned to the river with about the same sediment concentration as in the irrigation water. Brown et al. (1974) also presented total sediment inputs and outputs for the two large irrigation tracts and within-tract erosion and sediment deposition.

These studies showed that the Northside Canal Company lost 12,080 t of sediment from their system in 1971. The company mechanically removes about 295,000 t from canals and drains annually. The Twin Falls Canal Company, on the south side of the Snake River, returned 113,060 t of sediment to the Snake River in return flows and mechanically removes an estimated 78,000 t from canals and drains annually. These quantities of sediment represent average soil losses of 4.0 t/ha (1.76 tons/A) for the Northside Canal Company and 1.42 t/ha (0.62 tons/A) for the Twin Falls Canal Company - neither of which is considered excessive by present standards.

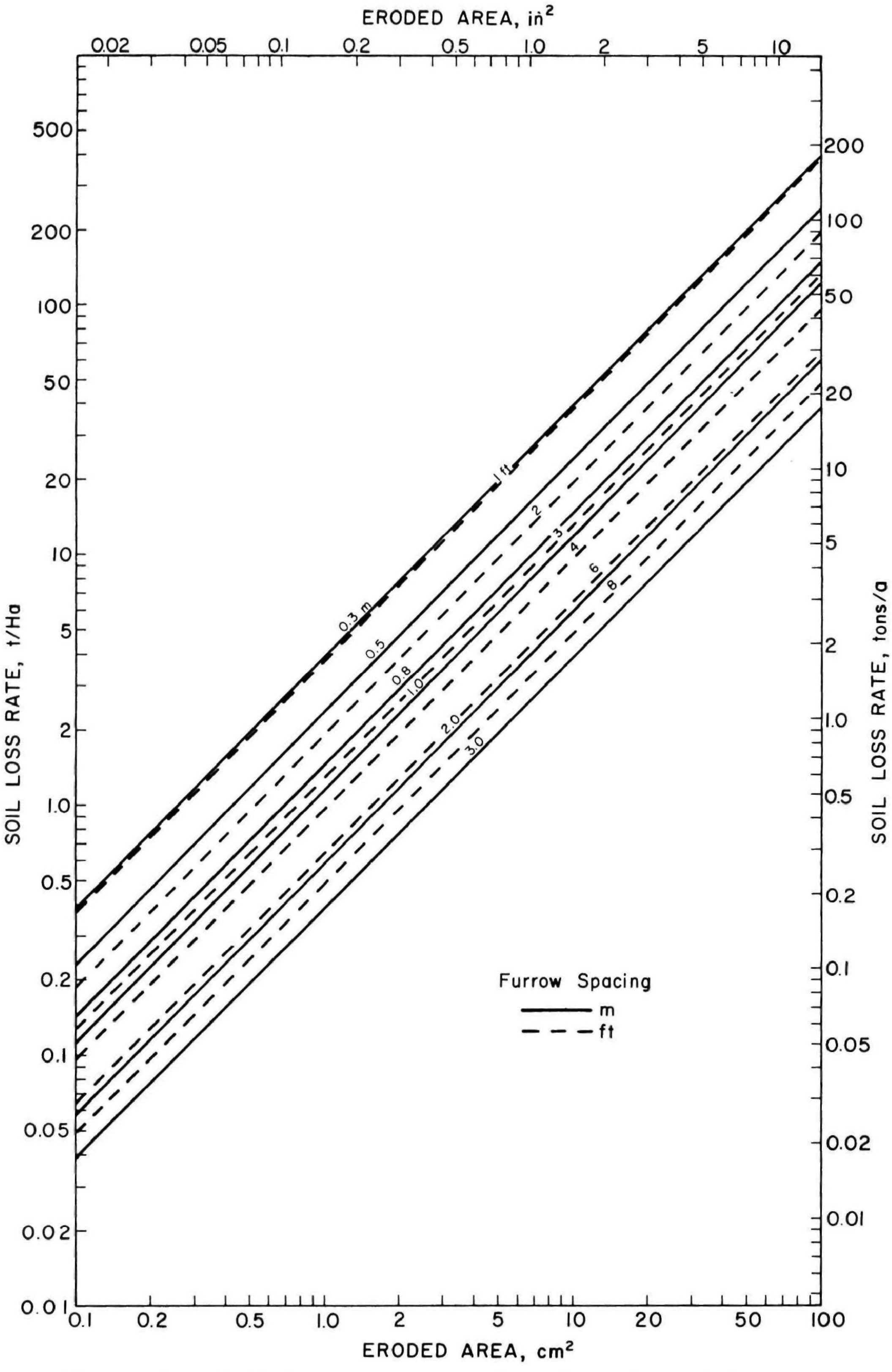

Figure 1. Soil loss rate as a function of eroded cross-sectional area, and furrow spacing, for a soil bulk density of 1.20 g/cm^3.

Figure 2. Erosion occurring under surface irrigation of 2 percent slope land. These furrows were eroding at the rate of 100 t/ha (45 tons/a) at the point shown.

Table 2. SEDIMENT CONCENTRATIONS IN IRRIGATION AND DRAINAGE WATERS FOR TWO LARGE TRACTS DURING THE 1971 IRRIGATION SEASON, PPM

Drain	Sampling date												
	4/20	5/3	5/17	5/28	6/7	6/15	6/29	7/13	7/26	8/10	8/24	9/8	9/28
	Northside Canal Company												
K	240	190	270	140	200	160	110	120	90	90	90	40	40
N-32	380	100	150	120	170	90	70	30	180	20	20	60	50
J-8	1,580	1,430	2,610	510	660	660	300	80	170	110	70	100	110
S	320	350	110	140	100	200	440	110	130	90	60	130	140
W-26	160	80	100	60	100	130	100	60	160	100	40	50	50
W	160	50	60	30	30	40	20	20	30	20	20	10	40
	Twin Falls Canal Company												
				5/25	6/2	6/15	6/29	7/13	7/26	8/10	8/24	9/8	9/28
Rock Creek	—	—	—	540	300	140	190	310	320	390	200	120	150
Cedar Draw	—	—	—	200	210	100	120	220	550	520	330	150	200
Filer Drain	—	—	—	710	400	210	710	2,250	2,120	1,410	820	270	290
Mud Creek	—	—	—	260	180	140	130	120	200	190	250	260	130
Deep Creek	—	—	—	200	110	70	80	60	70	110	100	100	90
			4/20	5/14	5/26	6/23	7/6	7/20	8/3	8/17	9/2	9/16	10/5
Hansen Drain	—	—	—	1,550	380	510	3,180	14,500	4,970	290	3,160	280	—
Kimberly Drain	—	—	4,180	1,080	360	610	2,860	1,420	4,960	180	150	70	40

Canal Waters

	April	May	June	July	August	Sept.	Oct.	Nov.	Dec.
Northside	63	63	29	37	33	26	26	26	—
Twin Falls	74	40	52	85	55	29	29	29	29

Sediment deposited in canals can cause operational difficulties by blocking gates and turnouts. Allowance for sediment deposition in canal systems requires that the system be built larger than would otherwise be necessary. Also, sediment deposits in canals are usually removed with a dragline at current costs of 50¢ to $1.00 per cubic meter of material.

Carlile (1972) reported suspended solid concentrations ranging from 751 to 7,850 ppm for surface irrigation return flows from the Rosa Irrigation District in the Yakima River Basin of central Washington. The irrigation water applied contained only 91 ppm. Fitzsimmons et al. (1972) measured mean total solids concentrations of 1,550 ppm in surface runoff from 79 sites on irrigated land in the Boise Valley of Idaho. They attributed most of the total solids to sediments.

Factors other than the amount of soil eroded from the fields influence the sediment concentration in surface irrigation return flows. One is the flow velocity in the drains. When drain flow velocities are low, sediments settle in the drain channels and require mechanical removal. Passing drainage water through sediment retention basins can remove 60 to 95% of the suspended sediment from some surface drainage waters before they are discharged to a river (Robbins and Carter, 1975). When surface runoff waters are used to irrigate grass pastures and other close-growing crops, most of the suspended sediments are removed. This reuse practice merits consideration as a means to control sediment in surface irrigation return flows.

Damage to the productivity of cultivated land from topsoil loss from erosion depends largely on the amount of topsoil available. An annual soil loss of 11 t/ha (5 tons/a) is considered allowable if the soil profile contains subsoil which will develop into topsoil or otherwise can be enriched with organic matter and fertilizer nutrients. A loss of 11 t/ha represents a soil depth loss of 0.80 mm (0.03 in). At this erosion loss rate, 0.5 m (about 20 in) of soil would be lost in about 625 years. Where soils are shallow over bedrock, erosion losses are more critical.

Some data on erosion and sedimentation costs for nonirrigated agricultural land may be used for comparison. Stallings (1950) reported that erosion reduced corn yields from 5.3 to 8.8% per 2.5 cm (inch) of topsoil lost. Gottschalk (1962) estimated that the loss of gross income to farmers from reduced corn yields in a 2,528-ha (6,246-acre) Illinois watershed would amount to $1.87 million over a 50-year period, or about $14.79/ha per year ($6.00/a per year). Narayanan et al. (1974), in a study of five watersheds in Illinois, estimated that loss of income associated with the loss of productivity from erosion ranged from $1.00 to $10.00/ha per year (40¢ to $4.00/a per year). Larger amounts were associated with continuous row crop and up/down hill cultivation practices. The smaller amounts were from chisel plow tillage on contoured or terraced land, and a wheat-meadow-meadow-meadow rotation. This study included estimates of damage from soil erosion; sediment deposition in reservoirs, and drainage ditches; flooding; and loss of recreational benefits. Soil losses ranged from 0.52 to 52 t/ha (0.23 to 23 tons/a) in these studies. Conclusions were that the effect of erosion on the farm costs about 1% of farm net income and that change of farming practice due to this cost was not likely. The effect of erosion on farm income losses does not represent all of the economic impact of erosion. The damages from eroded sediment, where it deposits, on downstream use, etc., range from 0 to 12 percent of the annual net farm income (Lee, et al., 1974). Similar relationships are likely for irrigated agricultural land.

NUTRIENTS IN SURFACE IRRIGATION RETURN FLOWS

Nutrients in surface irrigation return flows are in dissolved forms or they are attached to sediments eroded from the land. Bondurant (1971) showed mathematically that little soluble nutrient pickup could be expected to result from nutrient diffusion out of the soil into water passing over the soil surface, and he presented field data to verify his contention. Carter et al. (1971) found that soluble nutrient and salt concentrations in surface irrigation return flows are essentially the same as those in the applied irrigation water, providing additional evidence that appreciable soluble nutrients are not picked up by water passing over the soil surface. Edwards et al. (1972) stated that once nitrate enters the soil surface, it does not re-enter surface runoff.

Fitzsimmons et al. (1972) and Naylor and Busch (1973) reported that nitrate and ammonium nitrogen concentrations were about the same in surface runoff as in the irrigation water. A higher organic nitrogen concentration in the tailwater than in the irrigation water was attributed to the organic matter associated with sediment lost from the fields and to plant debris picked up and carried from the field by runoff water. Their studies, along with those of Naylor et al. (1972), illustrated that nitrogen concentrations in surface irrigation return flows from fields can be markedly increased when liquid nitrogen is added to the irrigation water for fertilizing the crop. Fertilizer nitrogen losses from this practice were proportional to the fraction of the applied water that became surface runoff during the fertilizer application. Carlile (1972) also found little difference in nitrate nitrogen concentration in surface runoff and the irrigation water.

Results from the investigations discussed indicate that the concentrations of soluble nitrogen forms in surface irrigation return flow are usually about the same as the concentration in the applied irrigation water except when soluble nitrogen is added to the irrigation water. Another source of soluble nitrogen is decaying plant material with which the water comes in contact. Organic and total nitrogen concentrations may be greater in the surface irrigation return flow than in the irrigation water when the water contacts decaying plant material. These differences are directly associated with the organic nitrogen in the organic matter of the soil eroded from the fields.

Phosphorus is tightly held by soil, and essentially all phosphorus in surface irrigation runoff is associated with sediment. Fitzsimmons et al. (1972) and Naylor and Busch (1973) reported greater total phosphorus concentrations in surface irrigation return flow than in the irrigation water, and these greater concentrations were related to greater sediment concentrations. Carter et al. (1974) and Carter et al. (1976) have extensively studied phosphorus-sediment relationships in irrigation return flows. Their results show that total phosphorus and sediment concentrations in surface runoff are closely related, but that no such relationship exists between soluble orthophosphate and sediment concentrations. A regression equation was developed relating sediment and total phosphorus concentrations as follows: sediment concentration, ppm = 140 + 0.72 (total phosphorus concentration, ppm), with an r value of 0.94. These data were collected from surface irrigation return flows in main drains from two large irrigated tracts, 82,030 and 65,350 ha, and therefore represent a wide spectrum of conditions. Data reported by Carlile (1972) also show a close relationship between sediment and total phosphorus concentrations in return flows.

Water-soluble orthophosphate concentrations in surface irrigation return flows are usually less than 1 ppm (Carter, et al., 1974; Fitzsimmons, et al., 1972). Occasionally a condition arises where the soluble organic phosphorus concentration is high enough to be important. Under special conditions where water is in contact with dead plant material, sufficient organic P may dissolve to show a P enrichment in the surface runoff (MacKenzie and Viets, 1974).

BIOCIDES IN SURFACE IRRIGATION RETURN FLOWS

There is little published information on biocide concentrations in surface irrigation return flows. Table 3 presents data for some biocides in drainwater in California (Johnston, et al., 1967). Considerable information has been published on biocide concentrations in surface runoff from nonirrigated lands. A review of that literature suggests that, except where biocides are applied to the water or where they are washed off the plant material by rain, the biocides in surface runoff are adsorbed to sediments. This appears to be true also for biocides in surface runoff from irrigation (Evans, and Duseja, 1973). Unpublished data from analyses of surface drainage waters and sediments from the Twin Falls and Northside irrigation tracts in southern Idaho similarly showed that biocides are generally adsorbed to the sediments.

Table 3. IDENTIFIED CHLORINATED HYDROCARBON AND THIOPHOSPHATE PESTICIDES DETECTED IN SURFACE DRAIN WATER IN THE SAN JOAQUIN VALLEY, CALIFORNIA * (Johnston, et al., 1967)

	Times detected	Reported concentrations in parts per billion (ppb)		
		Maximum	Minimum	Average
	Chlorinated Hydrocarbons			
DDE	12	0.15	0.01	0.06
DDD and/or DDT	54	5.70	0.06	0.61
Dieldrin	1	0.12	0.12	0.12
Heptachlor Epoxide	6	0.10	0.01	0.02
Lindane	7	0.22	0.01	0.07
Toxaphene	60	7.90	0.10	2.01
Thiodan-Endusulfan	1	0.21	0.21	0.21
Methoxychlor	1	0.45	0.45	0.45
	Thiophosphates			
Baytex-Fenthion	4	0.16	0.03	0.09
Ethion	11	1.20	0.02	0.26
Malathion	7	0.32	0.06	0.12
Methyl Parathion	3	6.40	0.30	2.53
Parathion	19	3.60	0.02	0.52
Thimet	1	0.03	0.03	0.03

* Panoche Drain, Western Fresno County, California that collects both surface and subsurface drainage waters.

SECTION V

TECHNOLOGY AVAILABLE FOR CONTROLLING SEDIMENTS AND ASSOCIATED NUTRIENTS AND BIOCIDES IN SURFACE IRRIGATION RETURN FLOWS

There are three ways to control sediments and associated nutrients and biocides in surface irrigation return flows. One is to reduce or eliminate surface irrigation return flow. The second is to reduce or eliminate soil erosion so that there will be little or no sediment in surface runoff from irrigation. This is a good objective, but to reach it, time will be required for implementing known practices and for developing and applying new technology. The third way is to remove sediments and associated materials from surface irrigation return flows before these waters enter natural streams. Any farmer or irrigation district making sufficient progress on the first and second ways so that sediments and associated materials are reduced below problem levels will no longer need the third. Such progress should be the aim of irrigated agriculture, with the recognition that many years may be required to achieve it. However, much immediate progress could be made if presently available technology were applied.

ELIMINATING OR REDUCING SURFACE IRRIGATION RETURN FLOWS

There are irrigation methods that produce no runoff. These include properly designed and operated sprinkle systems, basin, trickle, and some border irrigation and level furrow methods. These methods all have limitations. Energy requirements for sprinkle systems are high and energy resources are limited. Batty _et al._ (1975) recently compared the energy inputs involved in installation and operation of various sprinkle and surface irrigation systems. Compared on a total annual energy basis, surface irrigation systems required 10 to 22% as much energy as sprinkle or trickle systems where some pumping energy was required for surface systems (Table 4). Energy requirements would be less for gravity surface systems than for those using pumping. A design summary showing the assumed efficiencies, required flow, and horsepower and quantities of pipe and leveling is given in Table 5.

The capital investment is high for center pivot, side roll, and solid set sprinkle systems, even though saving in labor costs associated with these systems over several years partially offset the capital investment. There are serious labor availability and cost problems associated with hand-moved sprinkle systems. Furthermore, serious erosion problems can result from improperly designed and operated sprinkle systems where the application rate exceeds the intake capacity of the soil (Pair, 1968).

Sprinkle irrigation is an efficient means of applying water to land for crop production even though this method has the disadvantages discussed in the preceding paragraph. Sprinkle systems make possible the irrigation of lands with slopes too steep for surface irrigation and lands with undulating topography. The sprinkle irrigated acreage is rapidly

Table 4. TOTAL ANNUAL ENERGY INPUTS, IN THOUSANDS OF KILOCALORIES (OR GALLONS OF DIESEL FUEL) PER ACRE IRRIGATED FOR NINE IRRIGATION SYSTEMS, BASED ON 36-IN. (915-mm) NET IRRIGATION REQUIREMENT AND ZERO PUMPING LIFT (Batty, *et al.*, 1975)

Irrigation system (1)	Installation energy[a] (2)	Pumping energy (3)	Installation per pumping energy ratio (4)	Labor energy (5)	Total energy (6)
Surface without Irrigated Runoff Recovery System	103.2	35.2	2.93	0.50	138.9 (15.0)
Surface with Irrigated Runoff Recovery System	179.9	48.0	3.75	0.30	228.2 (24.6)
Solid-set sprinkle	614.1	770.0	0.80	0.40	1,384.0 (149.5)
Permanent sprinkle	493.6	770.0	0.64	0.10	1,263.7 (136.5)
Hand-moved sprinkle	159.7	804.0	0.20	4.80	968.5 (104.6)
Side-roll sprinkle	200.3	804.0	0.25	2.40	1,007.1 (108.8)
Center-pivot sprinkle	388.5	864.0	0.45	0.10	1,252.6 (135.3)
Traveler sprinkle	288.9	1,569.0	0.18	0.40	1,858.0 (200.7)
Trickle	530.5	468.0	1.13	0.10	998.6 (107.8)

[a] These figures were obtained by dividing the installation energy by the system life and by the net acres irrigated and multiplying by 1.03 to include annual maintenance energy for all systems except for solid set where 1.01 was used.

Conversion factors: 1 kcal = 4.19 kJ; 1 kcal = 0.000108 gal of diesel.

Table 5. DESIGN SUMMARY OF NINE IRRIGATION SYSTEMS (Batty et al., 1975)

Irrigation systems	Irrigation efficiency [a]	Area irrigated	Flow,[b]	Head	Power	Pipe PVC[c]	Aluminum	Other equipment	Earth Work Grading	Earth Work Ditching
	%	a	gal/min	ft	hp	tons	tons	tons	cu yd	ft
Surface without Irrigated run-off recovery system	50	156	1,300	5	2	0.26			128,000	7,890
Surface with irrigated run-off recovery system	85	155	1,300	5	2	2.66	5.00		131,500	7,890
			500	30	5					
Solid-set sprinkle	80	158	1,275	175	75	7.11	38.10	9.53		3,750
Permanent sprinkle	80	158	1,275	175	75	30.46		10.56		147,180
Hand-moved sprinkle	75	158	1,300	173	76	7.11	2.78	9.61		3,750
Side-roll sprinkle	75	158	1,300	173	76	7.11	4.76	2.80		3,750
Center-pivot sprinkle	80	125	974	196	65	4.18		17.50		1,500
Traveler sprinkle	70	152	1,300	312	136	9.71	0.03	8.32		5,107
Trickle	90	158	1,153	115	45	18.62		0.85		7,826

[a] Assumed numbers for determining system capacities for the specific systems as designed for a net capacity of 0.33 in./day (8.4 mm/day). These numbers are relatively high because of field topography.

[b] A 1300 gpm capacity well was assumed.

[c] Trickle irrigation required 14.38 tons of polyethylene in addition to the 18.62 tons of pipe.

Conversion factors: 1 acre = 0.405 ha; 1 gpm = 3.78 ℓ/sec; 1 ft = 0.305 m; 1 hp = 746 W; 1 ton = 907 kg; 1 cu yd = 0.764 m.

increasing. Where land slopes are too steep to be irrigated by surface methods without serious erosion and sediment runoff, sprinkle irrigation is the most economical alternative. If all such irrigated lands were sprinkle irrigated with properly designed and operated systems, there would be marked reduction in surface irrigation return flows and sediments and associated nutrients and biocides in these flows.

In some older irrigation systems, runoff and erosion have been greatly reduced by changing from surface to sprinkle irrigation. On the Osgood project near Idaho Falls, Idaho, water deliveries were reduced by approximately 50% by conversion to sprinklers. However, conversion to sprinkle irrigation is not the answer for all runoff and erosion problems. The larger, center pivot systems apply water at high rates and may cause considerable runoff and erosion.

Trickle or drip irrigation is a new, efficient method undergoing rapid development. This method is particularly well adapted to tree fruit, cane fruit, vine and other high-value crops. There is no erosion or surface irrigation return flow from this method, but current costs of trickle systems are too high for most crops. Also, elaborate filtering systems are sometimes required to maintain uniform application rates with trickle systems. Where the crop value and the cost of the water saved justifies the cost of trickle irrigation systems, this method has a great potential for efficient water use without surface irrigation return flow problems. The Second International Drip Irrigation Congress held in San Diego, California, July 7-14, 1974, indicated a great worldwide interest in trickle irrigation systems, their design and operation. Future development of this irrigation method may reduce costs and make the method economical for use with more crops. Where drip irrigation is feasible, it could be recommended as a method to eliminate surface irrigation return flow problems.

Basin and border irrigation are limited to nearly level land. Generally, surface irrigation return flows from nearly level lands contain little sediment. Therefore, these methods contribute almost no sediment or associated nutrients and biocides to surface irrigation return flows. The level furrow systems used in some areas of Texas and Arizona also are erosion free.

The recirculating or pump-back system described by Bondurant (1969) and others (Davis, 1964; Pope and Barefoot, 1973) is a useful method for eliminating or greatly reducing surface irrigation return flows from farms. This method uses a basin or pond at the lower end of the field to catch surface runoff. A pump returns the water from the pond to the top of the field, or to a different field, for reuse as irrigation water. Erosion is not eliminated and sediments deposited in the basin must be removed mechanically, but sediment is prevented from leaving the farm and returning to natural streams. Stringham and Hamad (1975) have shown how furrow systems can be operated so that reuse waters can be more easily incorporated into the irrigation cycle.

Bondurant and Willardson (1965) found 66 return systems operating in the Twin Falls area of southern Idaho in 1964. The average contributing area ranged from 90 to 130 ha (225-320 a) and the water was redistributed to 25 to 30 ha (60 to 75 a) (Table 6).

Completely eliminating or greatly reducing surface irrigation return flows may cause other problems in the irrigated West. Many farmers depend wholly or in part upon surface return flows from other areas for their irrigation water supply. Thus, eliminating surface return flow from one district may limit the supply to another district. Also, many irrigation systems operate on a reuse principle. This means that most of the surface runoff from irrigating the higher elevation lands is directed back into the canal system and redistributed for irrigating land at lower elevation within the district. This process continues through the district until the lands at the lowest elevation within the district are irrigated. Often the only surface return flow that enters natural streams from irrigated tracts is that from the fields at the lowest elevations in the district. Eliminating or reducing surface runoff would reduce the quantity of water applied, both for districts as a whole and for fields within districts, leaving more water in streams or canals for distributing to those lands formerly dependent upon runoff for supply. In many instances, this approach would also require redesign and construction of the water distribution system for present irrigation districts.

REDUCING OR ELIMINATING EROSION

Controlling slope: Land slope greatly influences erosion. Mech (1959) and Mech and Smith (1967) summarized extensive work on the effects of slope on irrigation furrow erosion. Swanson (1960), Swanson and Dedrick (1967), and Harris and Watson (1971) investigated the effects of slope on furrow erosion for both irrigated and nonirrigated land. Results from these studies showed that erosion may be expected on most row-cropped soils where slopes exceed 1%. Erosion may be controlled reasonably well on slopes up to 2% if the furrow stream size is small. Fields with slopes greater than 2% in the direction of run should be examined carefully to see if the direction of run should be changed to a lower slope or if the field can be irrigated by a different method. Contour furrows are well suited for crops that require ridging, such as corn, potatoes, and some perennials. The ridges confine the water and reduce danger of overtopping. Contour farming has not been used widely in irrigated areas because short rows and turns are not compatible with use of large equipment.

Land can be graded to reduce the slope near the lower ends to decrease water flow velocity, thereby causing the sediment to be deposited in the furrows. This practice can essentially eliminate sediment losses from the field but it does not reduce erosion at the upper ends of the furrows. Farmers resist the practice because furrows fill with sediment and flooding or lateral flow between furrows occurs if the stream size

Table 6. SUMMARY OF RECIRCULATING SURFACE IRRIGATION SYSTEMS, SOUTHERN IDAHO, 1964-1965 (Bondurant and Willardson, 1965)

	Eden, Hazelton, and Murtaugh areas		Oakley area	
	w/pipe[1/]	w/o pipe[2/]	w/pipe	w/o pipe
Pump installations, no.	16	6	26	20
Area irrigated, avg.	61.0	75.0	75.0	64.0
Contributing area,avg.	261	320	250	226
Total pumping head, ft avg .	38.5	9.5	23.0	12.0
Pipeline length, ft avg.	1485	<100	777	<100
Reservoir storage, a-ft, avg.	1.9	1.8	2.3	2.3
Total cost per installation, avg.	$3746.00	$2375.00	$2920.00	$1516.00
Cost per a, avg.	$ 61.40	$ 31.60	$ 39.00	$ 23.70
Cost per hp per a,avg.	$ 6.33	$ 3.60	$ 3.48	$ 2.60
Pump, turbine type, no.	11	5	2	2
Pump, paddle wheel type, no.	5	0	23	18
Pump horsepower, avg.	9.7	8.8	11.2	9.1

1/ With pipeline for returning water to distribution system longer than 100 feet.

2/ With pipeline for returning water to distribution system less than 100 feet long.

is not carefully controlled. Leveling the end of the field will reduce the amount of sediment leaving a field, but does not appreciably affect the amount of runoff.

Controlling furrow stream size: Excessive stream sizes can cause serious erosion on sloping land (Mech, 1959; Mech and Smith, 1967). Devices that positively control the amount of water from the pipeline, flume, or ditch into each furrow are essential to effective erosion control and efficient irrigation. Most valves, gates, siphon tubes and other flow control devices permit small flow adjustments that remain unchanged until reset. Such equipment is available, but is often not used or is used incorrectly. Some gated pipe gives excellent and easy control of stream size, but the stream of water issuing from the gate may cause considerable erosion where it impacts the soil. Also, the gates in some gated pipe clog readily with debris causing stream size to change.

Each irrigation furrow increment serves both as an infiltrating surface for replacing water depleted by the crop, and as a channel conducting water to irrigate the remaining furrow length. Therefore, the stream size at the head of the furrow must be sufficient to meet the infiltration requirements over the entire furrow length. As a result, the stream size at the head of the furrow is usually large enough to cause erosion on sloping land unless the run is short. It is imperative that the furrow stream size be kept as small as possible to meet the irrigation requirements with reasonable efficiency if erosion and sediment loss are to be kept low.

A common practice on many furrow-irrigated farms is to use a large enough stream size so that water will reach the lower ends of the furrows quickly to assure a fairly uniform water distribution. This approach also allows making water sets on a regular schedule, usually morning and evening, without being bothered with the water during the remainder of the day while involved with farming operations. This practice conserves labor, but often causes erosion because generally stream sizes are larger than needed after the water reaches the furrow ends. Technology and equipment are available to change this practice.

A greater initial flow is often desired to get the water to the end of the furrow and allow a uniform intake time. Once the water reaches the end, the flow should be reduced or cutback to decrease erosion and runoff. However, when the stream size is reduced for a given water set, the excess water from the set after the cutback must be used elsewhere or wasted in most systems with open ditches. If it is applied to another section of the field or to a different field, irrigation sets must be started several times during the day, and irrigation management becomes more complex. Humpherys (1971) developed several systems for reducing flow in furrows after water has reached the ends. One system has good potential for reducing stream size and controlling runoff and erosion while avoiding split sets.

The system supplies water to the center point of a gated pipeline equipped with automated control valves. The entire stream is directed to only half of the line until water has reaches the end of the furrows receiving water from that portion, which can be indicated by a detector or timing device. The entire stream is then directed to the other half of the line until the water reaches the ends of these furrows. Then the water is directed to the entire length of gated pipe so that the stream size into each furrow is only half that of the initial stream for the remainder of the irrigation. The controls operate automatically in response to sensing or timing devices. Such an approach can greatly reduce erosion, runoff, and the sediment in irrigation flow and can also solve the problem of managing the excessive water after a cutback is made. The use of cutback stream systems such as this requires pipe systems and automated controls.

It is important that the stream size delivered to the farm be regulated to assure a constant flow. Otherwise, proper furrow stream size control cannot be assured. Adequate technology and equipment are available to assure a constant flow at the delivery point. However, delivery systems may need to be redesigned in many areas before systems such as the one described above will be adopted because such systems operate best if water is available upon demand.

The run length: The run length and the furrow stream size are closely related because a sufficient stream size must be placed into each furrow to meet the infiltration requirements of the entire furrow length. Obviously decreasing the run length decreases the stream size requirements. This in turn can reduce the amount of erosion, because smaller streams erode less. Irrigating a field 300 m long by using three 100-m runs or two 150-m runs would require a smaller stream size and result in less erosion than irrigating the entire length in one run (Gardner and Lauritzen, 1946; Mech, 1959; Mech and Smith, 1967).

The multi-set irrigation system developed by Rasmussen et al. (1973) provides an alternative to cross ditches for shortening the run length. Aluminum or plastic pipe is used to distribute water at several points along the furrows, which effectively decreases the run length and greatly improves stream-size control. Field tests showed that this system markedly reduced runoff and erosion. The multi-set system applied a 50-mm (2-in) irrigation with 95% uniformity with only 4% runoff and 5% deep percolation as compared to a non-cutback check stream which had 96% uniformity, 62% runoff and 2% deep percolation (Table 7). Reducing the run length from 152 m to 50 m (500 ft to 165 ft) and proportionally reducing stream sizes reduced the amount of erosion to 2%. The multiset system is portable, so the pipe can be removed for cultivating. Another advantage is that the system can be readily automated.

Worstell (1975) field tested another adaptation of the multi-set system in which laterals were buried, so that farm operations could be carried out without moving the pipe. Plastic pipe with holes drilled into it at the proper size and furrow spacing were buried below the tillage depth.

Table 7. COMPUTED DISTRIBUTION OF WATER UNDER MULTISET AND STANDARD IRRIGATION PRACTICES FOR A 50-mm (2.0-in) IRRIGATION[1/]

Treatment practice	Total applied mm (in)	Stored (minimum) mm (in)	Stored (minimum) %	Deep percolation mm (in)	Deep percolation %	Runoff mm (in)	Runoff %	Uniformity[2/] %	Sediment ppm
Solid set	73 (2.9)	51 (2.0)	70	17 (0.67)	23	5.1 (0.20)	7	75	4,000
Downfield	56 (2.2)	51 (2.0)	91	2.5 (0.10)	5	2.3 (0.09)	4	95	1,200
Upfield	65 (2.6)	51 (2.0)	78	11.9 (0.47)	18	2.0 (0.08)	3	81	1,800
Alternate	70 (2.7)	51 (2.0)	73	14.0 (0.55)	20	4.8 (0.19)	7	78	1,300
Check, cut back[3/]	86 (3.4)	51 (2.0)	59	2.5 (0.10)	3	30.0 (1.18)	35	95	9,600
not cut back[4/]	142 (5.6)	51 (2.0)	36	2.5 (0.10)	2	89.5 (3.51)	62	96	

1/ 136.5 m (450-ft) run divided into three, 45.5 m (150-ft) multiset subruns.

2/ Uniformity = $\frac{\text{Stored}}{\text{Stored + Deep Percolation}} \times 100$

3/ 0.38 ℓ/s (6.00 gpm) stream used until runoff started, then cut back to 0.19 ℓ/s (3.00 gpm).

4/ Not actually run. Computed from cutback check treatment

Water under low pressure in the pipe passes through the holes upward into the irrigation furrow directly above. Laterals can be placed at the desired run length. Any runoff from one run length passes on to the next. The system is fully automated and can be programmed to add water daily according to ET depletion or less often as desired. Water application efficiency was very high, there was essentially no runoff, and there was no erosion with the system during the first season of testing. Further testing and some modifications of the system are needed, but it has great potential as a fully automated furrow irrigation system with positive water control and a very small labor requirement. Proper application of the multi-set concept could reduce or eliminate the sediment in surface irrigation return flows on some irrigated fields.

Controlling irrigation frequency and duration: Erosion and sediment loss are highest during the early part of an irrigation after soils have been disturbed by cultivation. Mech (1959) reported a soil loss of 39.9 t/ha (17.8 tons/a) from a recently cultivated corn plot during the first 32 minutes of runoff. The total soil loss of 50.9 t/ha (22.7 tons/a) for a 24-hour irrigation, occurred within the first 4 hours, even though runoff slowly increased after that because of decreasing intake. Based on these results, less sediment should be lost if fields were irrigated less frequently and for a longer duration, particularly where irrigations follow cultivations. Increasing the duration may increase leaching and associated nutrient losses, and decreasing the frequency may not be practical for shallow rooted crops. Erosion is also slight with frequent light irrigations that keep the furrows moist. With this type of irrigation, small streams are used because of the lower initial infiltration rate of moist furrows and there is no cultivation between irrigation.

Another practice related to irrigation frequency is alternate furrow irrigation. With this practice only half as much soil surface is in contact with flowing water as when water is applied to every furrow. Erosion and sediment loss should be only about half as much under alternate furrow irrigation as under every furrow irrigation. However, the success of alternate furrow irrigation depends upon soil conditions. Some soils do not permit adequate lateral water movement, or deep percolation losses may be too great during the increased time required for lateral movement. But, there are many soils on which this practice works well. Usually the duration of the irrigation has to be increased to effectively irrigate the crop.

A study in southern Idaho showed that much runoff resulted from surface irrigation because farmers lacked knowledge on crop water use and, consequently improperly timed irrigation applications (USDI, Bureau of Reclamation, 1971). Also the farmers had a very poor concept of the amount of water applied. This study led to the establishment of the irrigation scheduling work now known as Irrigation Management Services.

Cultural practices to control erosion: Tilling the soil contributes to erosion and to sediment in surface irrigation return flows. Some erosion is almost inevitable with the first irrigation after tillage on many fields. Mech and Smith (1967) summarized results from several investigations that indicated the soil losses from furrows were 10 or more times greater during the first than during the second irrigation after cultivation. Brown et al, (1974) found that sediment concentrations in surface irrigation return flows from two large tracts were much lower after weeding and refurrowing cultivation of row crops was stopped. Proper chemical weed control and management changes can eliminate the need for some cultivations on surface irrigated lands.

Crop residues can be utilized to control erosion. Miller and Aarstad (1971) showed that erosion can sometimes be eliminated by incorporating straw into the irrigation furrows. Crop residue provide a physical resistance that increases infiltration and decreases the flow velocity, both of which decrease erosion. Residues can also filter sediment from water. In most furrow-irrigated areas, the general tendency is to clean till so that there is little crop residue in the furrows. However, minimum tillage and the no-till techniques are effective for reducing erosion and have been used with furrow irrigation (Somerhalder et al., 1971). The practicability of no-till and minimum tillage with furrow irrigation has not been throughly investigated.

Another approach is to grow the crop in the irrigation furrow. Rasmussen (1976) successfully grew dry beans by this method, with high irrigation efficiency and no erosion. The growing crop slows the flow velocity in the furrow and the roots hold the soil in place. This method may not be applicable to all crops, but the concept merits testing with other crops.

REMOVING SEDIMENT AND ASSOCIATED NUTRIENTS AND BIOCIDES FROM SURFACE IRRIGATION RETURN FLOWS

Controlling Tailwater: The most important factor in controlling tailwater is to limit the amount of runoff. The smallest stream that will irrigate to the end of the furrow will add nearly as much water to the soil as a larger stream, and the amount of runoff will be much less and more easily controlled. Practices that will assure more uniform intake rates of individual furrows need to be developed and utilized for better runoff control.

The drain ditch at the field end should be shallow and at a low slope so that water moves away slowly and sediments settle out before the water leaves the field. Soil checks can be placed at intervals in the drain ditch so that flows from only three or four furrows enter each section between checks. This practice forms miniature sediment basins and the sediment eroded from the furrows settles in the sections of drain ditch. Where field and drain ditches are adjacent to larger drains with sod banks for transporting drainwater from several farms, the water from each checked section of drain ditch can be allowed to trickle slowly across the sod bank into the larger drain. The grass on the sod bank filters the remaining sediment from the surface drainage water and acts as a control section to prevent further erosion.

Grasses and other close-growing crops efficiently filter sediments from water. Grass buffer strips at the end of fields can effectively remove sediments from surface runoff. For example, Wilson (1967) found Bermuda grass to be very effective in warmer regions. Irrigating border checks with silty water showed that water with a turbidity of 5000 ppm could be lowered to approximately 50 ppm in 152 to 213 m (500 to 700 ft). The data indicate that velocities were in excess of critical tractive velocities so that some bed load was moved downstream after having settled out.

Another alternative is to utilize tailwater to irrigate alfalfa, pasture, or other close growing crops so that the sediments will be filtered out before the water reaches a natural stream.

Utilizing sediment retention basins to remove sediments: Much of the sediment in surface irrigation return flows can be removed in sediment retention basins. The need to remove sediments from surface irrigation return flows before they enter natural streams will continue for many years, even though much can be done to reduce soil loss from irrigated fields. Basins are a partial cure to the sediment problem, not a prevention. Their construction and periodic cleaning are relatively expensive.

Many new sediment retention basins are being constructed and used in irrigated areas of the western U.S. Robbins and Carter (1975) reported that approximately 150 natural or man-made basins larger than 0.2 ha were on the 82,030-ha Twin Falls Tract. Since their report, more have been constructed, and many more farmers are planning to construct them. The Northside Canal Company plans to construct sediment retention basins on all six of the main drains carrying surface return flow back to the Snake River, and three have been constructed. One of these basins was specifically designed to remove at least 50 percent of the sediment entering it. It has removed an average of about 70 percent of the sediment over a 3-year period. Most of the time, the sediment concentration in water leaving this basin is near the concentration in the diverted irrigation water and sometimes less.

The effectiveness of simple sediment retention basins is illustrated by a typical basin catching part of the runoff from an approximately 117-ha (289 a) sub-basin (Robbins and Carter, 1975). The land area drained was intensively cropped to dry beans, sugarbeets, cereal grains, alfalfa and some pasture. The soils were highly erodible Portneuf silt loam, and the slopes varied from less than 1 to about 15 percent along the furrows. A total of 2390 t (2633 tons) of sediment was deposited in the 0.45-ha (1.1-a) basin during two irrigation seasons. This represents a severe erosion loss of 20.5 t/ha (9.14 tons/a) over a 2-year period from the 117-ha (289-a) area. This figure includes only the sediment removed by the basin. The sediment removal efficiency exceeded 80 percent when the sediment concentration exceeded 0.1 percent and was never below 65 percent during the period of operation.

Sediment basins for trapping sediment eroded from irrigated fields have been studied in southern Idaho (Bondurant et al. 1975). Trap efficiency is directly related to the velocity, settling depth and particle size. Sedimentation basins can be designed to trap given particle sizes if the flow rate is known so that velocity relationships can be established. Major problems in designing sediment basins are to estimate the inflow rates and total amounts of sediment to be stored in the pond.

Several types and sizes of sediment retention basins can be used to remove sediments from irrigation return flows. Basins can be located to receive runoff from individual fields, from entire farms, from several farms, or along irrigation district drainways. They can be excavated or located in a natural depression area by constructing a dike or dam with proper outlet. More information is needed about the design and operational criteria for sediment retention basins for different conditions.

Sediment collected in basins is a valuable resource that can be used for many purposes, and it is often salable. Unfortunately, transportation costs from the basins to the use area may be excessive. It is important to locate basins as near as possible to the point of sediment use. Where natural depressions can be filled by constructing dikes or dams to form basins, no transportation is needed. Some cropping area may be lost while the sites are used for sediment basins, but after these basins are filled, the drain water can be placed in controlled channels and the deposited sediment can be farmed along with adjacent farmland, thus expanding and combining fields into more economical operating units. Other uses of sediment include landscaping, filling depressions and old channels in fields, and increasing soil depth over bedrock. A golf course has been developed by covering basalt with sediment from one district drainway basin in southern Idaho.

Drainage channels sometimes serve as sediment retention basins. Brown et al. 1974 and Carter et al. 1974 reported the effectiveness of drains in removing sediment and phosphorus from irrigation return flows on the 65,350-ha Northside tract in southern Idaho. Many of these drains were constructed to a grade small enough that the flow velocity permits sediment to settle.

Particle size segregation takes place as sediments settle in basins or drains. Sediments remaining in suspension are mostly in the clay size fraction, although much of the clay settles in aggregates because dispersion is seldom complete. Dispersion is greater in waters of low salt concentrations, and more clay remains suspended in such waters. The clay size fraction is richer in attached phosphorus than the larger size fractions, so that passing water through a sediment retention basin can give an apparent phosphorus enrichment when the phosphorus is measured per unit of suspended material. However, recent studies (Carter et al., 1974) have shown that sediment retention basins conserve phosphorus. The authors and associates have recently shown that 55 to 65% of the incoming phosphorus is retained in a sediment retention basin that removes 65 to 75% of the incoming sediment. On the Northside Canal Company Tract, 88% of the phosphorus in diverted water was deposited on the tract. Some of the phosphorus associated with the clay size fraction is lost through sediment retention basins because it is not practical to construct basins large enough to remove clay size particles.

The use of sediment retention basins to remove sediments from surface irrigation return flows can be discontinued for any field, farm, or district where the implementation of erosion control practices have eliminated excessive sediment concentration in the water. Also, use of basins for individual fields may not be needed every season. During seasons when alfalfa, grass, or other close-growing crops are grown and there is no erosion, the runoff water could bypass the basin. Non-use for one or more seasons would allow the collected sediment to dry and allow time for cleaning. Then when the field is returned to the row crops, the basin could again be used to remove most of the eroded soil or sediment from the tailwater.

SECTION VI

SIMULATION TECHNIQUES FOR ESTIMATING SEDIMENT AND ASSOCIATED NUTRIENT AND BIOCIDE LOADS IN SURFACE RETURN FLOWS

Many factors influence the sediment and associated nutrients and biocides in surface irrigation return flows. Simulation modeling techniques could be useful in providing such information on the relative impact of each of these factors and their interactions. Once the relative impact of different factors is determined by these techniques, control practices can be more effectively applied in the field. Simulation models specific for estimating sediment and associated nutrients and biocides in surface irrigation runoff have not been developed, but the literature contains information useful for predicting erosion and sediment loss. Hornsby and Law (1972) discussed general concepts for modeling irrigation return flows with the surface water system as a submodel. Law and Skogerboe (1972) presented a diagrammatic model of the irrigation return flow system in which tailwater was a component. Fleming (1975) described some of the components which are available for use in the simulation process and presented a sediment flow chart for modeling the sediment flow process from the field to the stream. He also presented a conceptual sediment simulation model outlining its basic structure and showing key processes from precipitation through erosion to reservoirs and channels and ending at the ocean. This information is not directly applicable to predicting sediment loss in surface irrigation return flows, but some of the information would be applicable, especially to sprinkle irrigation.

Development of the Universal Soil Loss Equation (Wischmeier and Smith, 1965) has made possible predicting soil erosion losses under rainfall with reasonable accuracy. The equation is:

$$A = RKLSCP \tag{4}$$

Where:

- A = the computed soil loss per unit area;
- R = the rainfall factor: The number of erosion-index units in a normal year's rain. The erosion index is a measure of the erosive force of specific rainfall;
- K = the soil-erodibility factor: The erosion rate per unit of erosion index for a specific soil in cultivated continuous fallow, on a 9% slope 72.6 ft long;
- L = the slope-length factor: The ratio of soil loss from the field slope length to that from a 72.6-ft length on the same soil type and gradient;
- S = the slope-gradient factor: The ratio of soil loss from the field gradient to that from a 9% slope;
- C = the cropping-management factor: The ratio of soil loss from a field with specified cropping and management to that from the fallow condition on which the factor K is evaluated;
- P = the erosion-control practice factor: The ratio of soil loss with contouring, stripcropping, or terracing to that with straight-row farming, up-and-down the slope.

Adapting this equation to irrigated land would be a complex and difficult task. Mech and Smith (1967) discussed such an adaptation. They suggest that the factor, R, would not apply. The erosive force is the furrow flow rather than rainfall. Indices for the erosion potential of different streams would have to be developed. Establishing K values would involve relating soil erodibility to flow and soil water conditions associated with furrow irrigation. The length of slope factor, L, would be resolved into stream flow. The steepness of slope factor, S, would be determined as the slope in the irrigation furrow. Whether this grade is the natural slope of the land or is made by contouring would be immaterial. The S factor would include the P factor. The crop management factor, C, is very important, because management determines compaction, detachment, intake rate, permeability, and other conditions in the furrow at the time water is applied.

Useful information for predicting erosion and sediment loss from irrigated land is available. Gardner and Lauritzen (1946) developed several graphs relating erosion to stream size and slope. This information would be useful in characterizing factors L and S for adapting the Universal Soil Loss Equation to irrigated land. The equation developed by Evans and Jensen (1952) relating erosion to stream size and slope factors would be useful in characterizing factor S and for developing indices for the erosion potential of different streams. The findings of Tovey et al. (1962) on the effects of soil moisture at the time of irrigation on erosion would be useful in assessing factors K and C. Mech (1949) and Mech and Smith (1967) summarized several studies showing the effects of stream size, furrow slopes, and different crops, on erosion and sediment loss which would be useful in characterizing K, L, S, and C factors.

The advance of high-speed computer capability and the development of modern simulation techniques facilitate predicting sediment and associated materials concentrations and loads in surface irrigation return flows. Such a task will not be easy because of the complexity of the factors involved.

SECTION VII

RESEARCH AND DEMONSTRATION NEEDS

Considerable technology is available for controlling sediments and associated nutrients and biocides in irrigation return flows. Some of this technology could be directly applied by farmers, but much of it needs further development and refinement to be feasible and acceptable. There is also a need for new technology which will achieve erosion and sediment control. The basic relationships among stream size, flow velocity, erosion, and sedimentation, and among run length slope, stream size, sediment settling velocity, and forward velocity need to be integrated into new technology that will permit modification of various control parameters. New ideas are needed, and new and better water control systems need to be developed.

Public Law 92-500 has greatly increased farmer and irrigation company interest in applying sediment and associated nutrient and biocide control measures into irrigation practices. In response to this interest, programs to provide information on available control technology should be developed. Demonstration of some control practices on farmers' fields may be beneficial. In some areas the advantages of irrigating with smaller streams might be demonstrated. The automatic cutback and the multi-set systems could be used in controlling erosion by controlling the stream size. In some cases, the direction of irrigation could be changed 90 degrees so that slope in the direction of irrigation would be less. Methods to manage tailwater and the principles involved might be successfully demonstrated or compared in some areas. The advantages of fewer cultivations could also be shown. Other practices could be demonstrated as they are developed.

One reason that available technology for sediment and associated nutrient and biocide control has not been accepted and applied by farmers is because economic incentives have been lacking. We must remember that farmers farm to make a living, and that they adopt new practices that they believe will increase their profits and thereby enhance their living standard. There has, in the past, been little or no economic incentive for using erosion control practices. The only incentive has been preservation of topsoil, and the economic value of topsoil preservation has been very subtle and difficult to assess in dollars, while costs of control practices have been measurable. We need to consider who cares if 0.5 mm of soil is lost each year, if the soil is several meters deep, and if the loss does not decrease income. There is a need to show the income benefits or provide economic incentives for erosion control practices on irrigated land. Another approach would be to show the economic loss from failure to apply available control practices. This latter approach could be through enforcement by fining when sediment, nutrient, and biocide losses exceed established critical levels, but such enforcement should be used only as a last resort.

More research and development is needed on multi-set irrigation and similar systems that allow small, non-erosive stream sizes and long farm equipment runs. The buried lateral concept needs further study and development. Such systems have good potential for erosion control, but they will be accepted only if costs are not excessive.

More information is needed on within-row irrigation. Conceivably, this practice would be suitable for corn, peas, cereal grain seeded in rows, and other crops. This practice is not likely suitable for all crops. Studies conducted on within-row irrigation should have at lease two aims. One is to control sediment losses and the other is to achieve greater water use efficiency.

Another method that should be investigated is grading the field in the direction of irrigation so that the slope varies from the top to the bottom of the field. The close relationship between slope, erosion, and stream size suggests that erosion and sediment loss could be controlled by altering the slope with distance from the top of the field. Methods for computing and analyzing major leveling and the associated economics need to be developed.

The use of grass or other close-growing crop buffer strips to filter the soil eroded from row-cropped fields before tailwater leaves the field needs to be evaluated. Buffer strips would be more acceptable if they could be harvested and the crop sold. An alternative to this approach would be to direct all runoff water from row-cropped fields onto pasture, alfalfa, or other close-growing crop fields. This would filter eroded sediments from the water before it entered a natural stream. Other tailwater management practices to reduce sediment losses need to be developed.

Additional research is needed to improve cultivation practices toward fewer cultivations and no-till farming methods as they apply to both surface and sprinkler irrigated land. Better weed control practices for irrigated land need to be developed. Methods of predicting erosion under various cultivations and irrigation practices need to be developed. particularly in surface irrigation. This information in needed so that simulation models can be developed to predict benefits of erosion and sediment control practices. Studies of the applicability of the Universal Soil Loss Equation for predicting erosion under all types of sprinkler systems need to be conducted. The development of a soil loss equation for furrow irrigated land should be pursued.

Research is needed on the design of irrigation delivery systems which would facilitate delivery of irrigation water to the farmer on demand so that the farm irrigation system can be made more flexible.

More information is needed on the design and operational criteria for sediment retention basins. The Agricultural Research Service and the University of Idaho are conducting research on this subject, and their results will provide useful information. However, additional research on this subject should be encouraged. There are three different kinds or sizes of basins--field, farm, and district--and more information is needed on all sizes. Further work is needed on the use of sediment collected in sedimentation basins and on more economical methods of cleaning them.

SECTION VIII

LITERATURE CITED

1. Batty, J.C., S.N. Hamad, and J. Keller. 1975. Energy inputs to irrigation. J. Irrig. and Drain. Div., Proc. Amer. Soc. Civil Eng. 101(IR4):293-307.
2. Bondurant, J.A. 1969. Design of recirculating irrigation systems. Trans. Amer. Soc. Agr. Eng. 12:195-201.
3. Bondurant, J.A. 1971. Quality of surface irrigation runoff water. Trans. Amer. Soc. Agr. Eng. 14:1001-1003.
4. Bondurant, J.A., C.E. Brockway, and M.J. Brown. 1975. Some aspects of sediment ponds design. 3rd National Symposium on Urban Hydrology and Sediment Control. Proceedings Paper C4, p. C35-41.
5. Bondurant, J.A. and L.S. Willardson. 1965. Recirculating irrigation systems. Proc. Specialty Conf., Irrig. and Drain Div., Amer. Soc. Civil Eng. p. 243-256.
6. Brown, M.J., D.L. Carter, and J.A. Bondurant. 1974. Sediment in irrigation and drainage waters and sediment inputs and outputs for two large tracts in southern Idaho. J. Environ. Qual. 3:347-351.
7. Carlile, B.L. 1972. Sediment control in Yakima Valley. Proc. Natl. Conf. on Managing Irrigated Agriculture to Improve Water Quality, U.S. Environmental Protection Agency and Colo. State Univ. p. 77-82.
8. Carter, D.L., J.A. Bondurant, and C.W. Robbins. 1971. Water-soluble NO_3-Nitrogen, PO_4-phosphorus, and total salt balances on a large irrigation tract. Soil Sci. Soc. Amer. Proc. 35:331-335.
9. Carter, D.L., M.J. Brown, and J.A. Bondurant. 1976. Sediment-phosphorus relations in surface runoff from irrigated lands. Proc. Third Federal Inter-Agency Sedimentation Conf., p. 3-41 to 3-52.
10. Carter, D.L., M.J. Brown, C.W. Robbins, and J.A. Bondurant. 1974. Phosphorus associated with sediments in irrigation and drainage waters for two large tracts in southeastern Idaho. J. Environ. Qual. 3:287-291.
11. Davis, J.R. 1964. Design of irrigation tailwater systems. Trans. Amer. Soc. Agr. Eng. 7:336-338.
12. Edwards, D.M., P.E. Fischbach, and L.L. Young. 1972. Movement of nitrates under irrigated agriculture. Trans. Amer. Soc. Agr. Eng. 15:73-75.
13. Evans, J.O. and D.R. Duseja. 1973. Herbicide contamination of surface runoff waters. Environmental Protection Technology Series, EPA-R2-73-266.
14. Evans, N.A. and M.E. Jensen. 1952. Erosion under furrow irrigation. North Dakota Agr. Expt. Sta. Bimonthly Bull., Vol. XV, No. 1, p. 7-13.
15. Fitzsimmons, D.W., G.C. Lewis, D.V. Naylor, and J.R. Busch. 1972. Nitrogen, phosphorus and other inorganic materials in waters in a gravity-irrigated area. Trans. Amer. Soc. Agr. Eng. 15:292-295.
16. Fleming, G. 1975. Sediment-Erosion-Transportation-Deposition Simulation: State of the Art. In Present and Prospective Technology for Predicting Sediment Yields and Sources. USDA, ARS-S-40, p. 274-285.

17. Gardner, Willard and C.W. Lauritzen. 1946. Erosion as a function of the size of the irrigation stream in the slope of the eroding surface. Soil Sci. 62:233-242.
18. Gardner, Willard, John Hale Gardner, and C.W. Lauritzen. 1946. Rainfall and irrigation in relation to erosion. Utah Agr. Expt. Sta. Bull. 326.
19. Gottschalk, L.C. 1962. Effects of Watershed Protection Measured on Reduction of Erosion and Sediment Damages in the United States. International Union of Geodesy and Geophysics, Association of Scientific Hydrology, Symposium on Continental Erosion, Bari, Italy. Publication No. 59, 1962, pp. 426-450.
20. Harris, Warren S. and William S. Watson, Jr. 1971. Graded rows for the control of rill erosion. Trans. Amer. Soc. Agr. Eng. 14:577-581.
21. Hornsby, Arthur G. and James P. Law, Jr. 1972. The role of modeling in irrigation return flow studies. Proc. Natl. Conf. on Managing Irrigated Agriculture to Improve Water Quality, U.S. Environmental Protection Agency and Colo. State Univ. p. 203-210.
22. Humpherys, A.S. 1971. Automatic furrow irrigation systems. Trans. Amer. Soc. Agr. Eng. 14:466-470.
23. Israelsen, O.W., G.D. Clyde, and C.W. Lauritzen. 1946. Soil erosion in small irrigation furrows. Utah Agr. Exp. Sta. Bull. No. 320, p. 39.
24. Johnston, W.R., F.T. Ittihadieh, K.R. Craig, and A.F. Pillsbury. 1967. Insecticides in tile drainage effluent. Water Resour. Res. 3:525-537.
25. Law, James P. Jr., and Gaylord V. Skogerboe. 1972. Potential for controlling quality of irrigation return flow. J. Environ. Qual. 1:140-145.
26. Lee, M.T., A.S. Narayanan, and E.R. Swanson. 1974. Economic Analyses of Erosion and Sedimentation on Sevenmile Creek Southwest Branch Watershed. Illinois Agr. Exp. Sta., Agr. Econ. Res. Rep. No. 130.
27. MacKenzie, A.J. and F.G. Viets, Jr. 1974. Nutrients and other chemicals in agricultural drainage waters. Ch. 18. In J. van Schilfgaarde (ed), Drainage for Agriculture. Agron. Monograph 17:489-508.
28. Mech, Stephen J. 1949. Effect of slope and length of run on erosion under irrigation. Agr. Eng. 30:379-383, 389.
29. Mech, Stephen J. 1959. Soil erosion and its control under furrow irrigation in the arid west. USDA, ARS, Agr. Inf. Bull. No. 184.
30. Mech, Stephen J. and Dwight D. Smith. 1967. Water erosion under irrigation. In Robert M. Hagan, Howard R. Haise and Talcott W. Edminister (ed.) Irrigation of Agricultural Lands. Agronomy 11:951-963, Amer. Soc. Agron., Madison, Wis.
31. Miller, D.E. and J.S. Aarstad. 1971. Furrow infiltration as affected by incorporation of straw or furrow cultivation. Soil Sci. Soc. Amer. Proc. 33:492-495.
32. Narayanan, A.S., M.T. Lee, and E.R. Swanson. 1974. Economic Analysis of Erosion and Sedimentation - Crab Orchard Lake Watershed. Illinois Agr. Econ. Res. Exp. No. 128.

33. Naylor, D.V. and J.R. Busch. 1973. Effects of irrigation,fertilization, and other cultural practices on water quality. Res. Tech. Comp. Rep. Idaho Water Resour. Res. Inst. p. 19.
34. Naylor, D.V., G.C. Lewis, D.W. Fitzsimmons, and J.R. Busch. 1972. Nitrogen in surface runoff resulting from addition of fertilizers to irrigation water. Proc. 23rd Ann. Pac. NW Fert. Conf. p. 67-73.
35. Pair, C.H. 1968. Water distribution under sprinkler irrigation. Trans, Amer. Soc. Agr. Eng. 11:648-651.
36. Pope, D.L. and A.D. Barefoot. 1973. Reuse of surface runoff from furrow irrigation. Trans. Amer. Soc. Agr. Eng. 16:1088-1091.
37. Rasmussen, W.W. 1976. New techniques saves irrigation water. Agr. Res. 24:14.
38. Rasmussen, W.W., J.A. Bondurant, and R.D. Berg. 1973. Multiset surface irrigation system. Int. Comm. on Irrig. and Drain. Bull. p. 48-52.
39. Robbins, C.W. and D.L. Carter. 1975. Conservation of sediment in irrigation runoff. J. Soil and Water Conserv. 30:134-135.
40. Somerhalder, B.R., D.E. Land, and H.D. Wittmuss. 1971. Increased corn yields with less tillage. Amer. Soc. Agr. Eng. Mid-Central Reg. Mtg, April 16-17. Paper MC-71-604.
41. Stallings, J.H. 1950. Erosion of topsoil reduces productivity. SCS-TP-98.
42. Stringham, Glen E. and Sofa N. Hamad. 1975. Irrigation runoff recovery in the design of constant flow furrow discharge irrigation systems. Trans. Amer. Soc. Agr. Engr. 18:79-84.
43. Swanson, N.P. 1960. Hydraulic characteristics of surface runoff from simulated rainfall on irrigation furrows. ARS 41-43:90-102.
44. Swanson, N.P. and A.R. Dedrick. 1967. Soil particles and aggregates transported in water runoff under various slope conditions using simulated rainfall. Trans. Amer. Soc. Agr. Engr. 10:246-247.
45. Tovey, Rhys, Victor I. Myers, and J.W. Martin. 1962. Furrow erosion on steep irrigated land. Idaho Agr. Expt. Sta. Res. Bull. No. 53.
46. USDI, Bureau of Reclamation. 1971. Use of Water on Federal Irrigation Projects-Minidoka Project, Northside Pumping Div. Unit A., 7 Volumes.
47. Wilson, L.G. 1967. Sediment removal from flood water by grass filtration. Trans. Amer. Soc. Agr. Engr. 10:35-37.
48. Wischmeier, W.H. and D.D. Smith. 1965. Predicting rainfall-erosion losses from cropland east of the Rocky Mountains. USDA, ARS, Agr. Handb. 282.
49. Worstell, R.V. 1975. An experimental buried multiset irrigation system. Amer. Soc. Agr. Eng. Paper No. 75-2540.

SECTION IX

BIBLIOGRAPHY

1. Ballard, F.L. 1975. Analysis and Design of Settling Basins for Irrigation Return Flows. Unpublished M.S. Thesis (Agr. Eng.) University of Idaho.
2. Biggar, J.W. 1966. Factors affecting the appearance of pesticide in drainage water. In Agricultural Waste Waters, L.D. Doneen, (ed.), Report No. 10, Water Resource Center, University of California, p. 113-118.
3. Bondurant, J.A. 1970. Get double use out of irrigation water. Idaho Farmer 88:24-27.
4. Bower, C.A. and L.V. Wilcox. 1969. Nitrate content of the upper Rio Grande as influenced by nitrogen fertilization of adjacent irrigated lands. Soil Sci. Soc. Amer. Proc. 33:971-973.
5. Branson, R.L., P.F. Pratt, J.D. Rhoades, and J.D. Oster. 1975. Water quality in irrigated watersheds. J. Environ. Qual. 4:33-40.
6. Bristol. A.L. 1973. Phosphorus chemistry of some drainage waters and sediments from irrigated land in the Boise River Valley. Unpublished M.S. Thesis (Soils), University of Idaho.
7. Brown, L.N. 1951. Irrigation methods to conserve soil and water on steep lands. Calif. Agr. Ext. Circ. No. 177.
8. Busch, J.R., D.W. Fitzsimmons, G.C. Lewis, and D.V. Naylor. 1972. Cultural influences of irrigation drainage water. Proc. Specialty Conf., Irrig. and Drain. Div., Amer. Soc. Civil Eng., p. 45-56.
9. Carlson, Ronald D. 1974. A water, nutrient, and sediment budget for an irrigated farm in the Boise Valley. Unpublished M.S. Thesis (Agr. Eng.), University of Idaho.
10. Carter, D.L. 1972. Irrigation return flows in southern Idaho. Proc. Nat. Conf. on Managing Irrigated Agriculture to Improve Water Quality, U.S. Environmental Protection Agency and Colo. State Univ. p. 47-53.
11. Carter, D.L. 1976. Guidelines for sediment control in irrigation return flows. J. Environ. Qual. 5:119-124.
12. Carter, D.L., C.W. Robbins, and J.A. Bondurant. 1973. Total salt, specific ion, and fertilizer element concentrations and balances in the irrigation and drainage waters of the Twin Falls tract in southern Idaho. USDA, ARS-W-4.
13. Coleman, C. 1970. How to recycle runoff. World Irrig. 10:20-24.
14. Comes, R.D., P.A. Frank, and R.J. Demint. 1975. TCA in irrigation water after bank treatment for weed control. Weed Sci. 23:207-210.
15. Criddle, Wayne, D., Sterling Davis, C.H. Pair, and D. Shockley. 1956. Methods for evaluating irrigation systems, USDA,SCS Agr. Handb. No. 82.
16. Davis, Sterling and S.D. Nelson. 1970. Surface irrigation easily automated. J. Irrig. and Drain. Div., Proc. Amer. Soc. Civil Eng., 96(IR1):47-51.

17. Demint, R.J., P.A. Frank, and R.D. Comes. 1970. Amitrole residues and rate of dissipation in irrigation water. Weed Sci. 18:439-442.
18. DeRemer, R.D. 1970. Starting with trickle irrigation. Reclamation Era 56:15-17.
19. Doneen, L.D. (ed.) 1966. Agricultural waste waters. Calif. Water Resources Center Rep. No. 10.
20. Eldridge, Edward F. 1963. Irrigation as a source of water pollution. J. Water Pollnt. Contr. Fed. 35:614-635.
21. Eldridge, Edward F. 1959. The effect of irrigation on the quality of water for industrial use. Proc. 14th Ind. Waste Conf., 104:52-67.
22. Eldridge, Edward F. 1960. Return irrigation water-characteristics and effects. U.S. Public Health Service, Region IX, Portland, Oregon.
23. Faulkner, L.R. and W.J. Bolander. 1970. Agriculturally-polluted irrigation water as a source of plant parasitic nematode infestation. J. Nematology 2:368-374.
24. Fischbach. P.E. and H.R. Mulliner. 1974. Every-other furrow irrigation of corn. Trans. Amer. Soc. Agr. Eng. 17:426-428.
25. Fischbach, P. E. 1968. Design of an automated surface irrigation system with reuse system. Proc. Nat. Irrig. and Drain. Specialty Conf., Amer. Soc. Civ. Eng. p. 219-236.
26. Fok, Yu-Si and L. S. Willardson. 1971. Subsurface irrigation system analysis and design. J. Irrig. and Drain. Div., Proc. Amer. Soc. Civ. Eng., 97(IR3):447-454.
27. Fox, W.M. 1966. Products of soil erosion in agricultural effluent. In Agricultural Waste Waters, L.D. Doneen, (ed.) Report No. 10, Water Resource Center, University of California, p. 113-118.
28. Garner, B.J. 1971. Irrigators shape their land for water control. Soil Cons. 36:149-150.
29. Goldberg, D. and M. Shmueli. 1970. Drip irrigation - a method used under arid and desert conditions of high water and soil salinity. Trans. Amer. Soc. Agr. Eng. 13:38-41.
30. Hall, J.K., M. Pawlus, and E.R. Higgins. 1972. Losses of atrazine in runoff water and soil sediment. J. Environ. Qual. 1:172-176.
31. Haney, P.E. and T.W. Bendixen. 1953. Effect of irrigation runoff of surface water supplies. J. Amer. Water Works Assoc. 45:1160-1171.
32. Hansen, Vaughn E. 1958. The importance of hydraulics of surface irrigation. J. Irrig. and Drain. Div., Proc. Amer. Soc. Agr. Eng. Paper No. 1788.
33. Heinemann, W.H. and M.J. Brown. 1972. Fractional water-sediment sampler. Soil Sci. Soc. Amer. Proc. 36:376-377.
34. Hiler, E.A. and T.A. Howell. 1972. Crop response to trickle and sub-surface irrigation. Amer. Soc. Agr. Eng. Paper 72-744.
35. Howe, O.W. and D.F. Heermann. 1970. Efficient border irrigation design and operation. Trans. Amer. Soc. Agr. Eng. 13:126-130.
36. Hurley, P.A. 1968. Predicting return flows from irrigation. J. Irrig. and Drain. Div., Proc. Amer. Soc. Civ. Eng., 94(IR1):41-48.
37. Jobling, G.A. and A.K. Turner. 1973. Physical model study of border strip irrigation. J. Irrig. and Drain. Div., Proc. Amer. Soc. Civ. Eng., 99(IR4):493-510.

38. Kincaid, Dennis C. and Norris P. Swanson. 1974. Rainfall runoff from irrigation furrows. Trans. Amer. Soc. Agr. Eng. 17: 266-268.
39. Lal, R., and A.C. Pandya. 1970. Furrow irrigation with decreasing infiltration rate. J. Irrig. and Drain. Div., Proc. Amer. Soc. Civ. Eng., 96(IR4):451-460.
40. Law, James P., Jr., Jeffrey D. Denit, and Gaylord V. Skogerboe. 1972. The need for implementing irrigation return flow quality control. Proc. Nat. Conf. on Managing Irrigated Agriculture to Improve Water Quality., U.S. Environmental Protection Agency and Colo. State Univ. p. 1-17.
41. Law, James P., Jr., and Jack L. Witherow. 1971. Irrigation residues. J. Soil and Water Conserv. 26:54-56.
42. Law, James P., Jr. 1971. National irrigation return flow research and development program. Environmental Protection Agency Report 13030WRV12/71.
43. Law, James P., Jr., James M. Davidson, and Lester W. Reed. 1970. Degradation of water quality in irrigation return flows. Okla. Agr. Exp. Sta. Bull. B-168. p. 26.
44. Law, James P., Jr. and Harold Bernard. 1970. Impact of agricultural pollutants on water uses. Trans. Amer. Soc. Agr. Eng. 13:474-478.
45. Law, James P., Jr. and Jack L. Witherow (ed.) 1970. Water quality management problems in arid regions. U.S. Environmental Protection Agency. Water Pollution Control Research Series 1303 DYY06/69.
46. Lewis, G.C. 1959. Water quality study in the Boise Valley. Idaho Agr. Expt. Sta. Bull. No. 316.
47. Lyons, C.G., Jr., 1972. Trickle irrigation - a more efficient means of water management. Texas Agr. Prog. 18:3-4.
48. McGauhey, P.H. 1968. Quality changes through agricultural use. In Eng. Management of Water Quality. McGraw-Hill Book Co., New York, p. 58-66.
49. Mech, Stephen J. 1960. Soil management as related to irrigation practices and irrigation design. Trans. 7th Int. Cong. Soil Sci. 1:645-650.
50. Miller, C.W., W.E. Tomlinson, and R.L. Norgren. 1967. Persistence and movement of parathion in irrigation waters. Pestic. Monit. J. 1:47-48.
51. Muir, J., G.E. Seim, and R.A. Olson. 1973. A study of factors influencing the nitrogen and phosphorus contents of Nebraska waters. J. Environ. Qual. 2:466-470.
52. Musick, J.T., W.H. Sletten, and D.A. Dusek. 1973. Evaluation of graded furrow irrigation with length of run on a clay loam soil. Trans. Amer. Soc. Agr. Eng. 16:1075-1080.
53. Neal, O.R. 1944. Removal of nutrients from the soil by crops and erosion. Agron. J. 36:601-607.
54. Nicolaescu, I. and E.G. Kruse. 1971. Automatic cutback furrow irrigation system design. J. Irrig. and Drain Div., Proc. Amer. Soc. Civ. Eng., 97(IR3):343-353.

55. Office of Water Resources Research. 1972. Agricultural runoff-a bibliography. Water Resources Scientific Information Center, PB-207514, 248p.
56. Reddick, H.E. and John G. Bamesburger. 1938. Erosion control on steep irrigated slopes. Agr. Eng. 19:531.
57. Richardson, C.W. 1973. Runoff, erosion, and tillage efficiency on graded-furrow and terraced watersheds. J. Soil and Water Conserv. 28:162-164.
58. Robinson, A.R. 1971. Sediment. J. Soil and Water Conserv. 26:18-19.
59. Romkens, M.J., D.M. Nelson, and J.V. Mannering. 1973. Nitrogen and phosphorus composition of surface runoff as affected by tillage method. J. Environ. Qual. 2:292-295.
60. Sakkas, J.G. and W.E. Hart. 1968. Irrigation with cut-back furrow streams. J. Irrig. and Drain. Div., Proc. Amer. Soc. Civ. Eng. 94(IR1):91-96.
61. Scofield, C.S. 1932. Steam pollution by irrigation residues. J. Ind. Eng. Chem. 24:1223-1224.
62. Skogerboe, G.V. 1973. Agricultural impact on water quality in western rivers. In Environmental Impact on Rivers, Hsich Wen Shen (ed) ch. 12, p. 12-1 to 12-25.
63. Skogerboe, Gaylord V. and James P. Law, Jr. 1971. Research needs for irrigation return flow quality control. Water Pollution Control Research Series, Environmental Protection Agency, Project 13030, 98 p.
64. Skogerboe, Gaylord V., W.R. Walker, and J.E. Ayars. 1972. Modeling water quality from agricultural lands. In Modeling of Water Resource Systems, Volume II, A.K. Biswas, (ed.), p. 530-540.
65. Smith, J.H. and C.L. Douglas. 1973. Microbiological quality of surface drainage water from three small irrigated watersheds in southern Idaho. J. Environ. Qual. 2:110-112.
66. Sylvester, Robert O. and R.W. Seabloom. 1963. Quality and significance of irrigation return flow. J. Irri. and Drain. Div., Proc. Amer. Soc. Civ. Engr. 89(IR3):1-27.
67. Sylvester, Robert O. and Robert W. Seabloom. 1963. A study on the character and significance of irrigation return flows in the Yakima River Basin. Univ. of Wash., 103 p.
68. Tatorova-Krysteva, V.S. 1971. Erosion of some Bulgarian soils by irrigation. Pochvovedeiye 12:107-115.
69. Taylor, C.A. 1940. Transportation of soil in irrigation furrows. Agr. Eng. 21:307-309.
70. Taylor, C.A. 1935. Orchard tillage under straight furrow irrigation Agr. Eng. 16:99-102.
71. Utah State University Foundation. 1969. Characteristics and pollution problems of irrigation flow. USDI, Fed. Water Poll. Contr. Adm., 237 p.
72. van Schilfgaarde, J., L. Bernstein, J.D. Rhoades, and S.L. Rawlins 1974. Irrigation management for salt control. J. Irrig. and Drain. Div., Proc. Amer. Soc. Civ. Engr., 100 (IR3):321-328.
73. Vanoni, V.A. (ed.) 1975. Sedimentation Engineering. Amer. Soc. of Civ. Eng., New York, N.Y.

74. Viets, F.G., Jr. 1970. Soil use and water quality - a look to the future. J. Agr. Food Chem. 18;789-792.
75. Wadleigh, Cecil H. 1968. Wastes in relation to agriculture and forestry. USDA, Misc. Pub. No. 1065.
76. Watts, F.J., C.E. Brockway, and A.E. Oliver. 1974. Analysis and design of settling basins for irrigation return flow. Idaho Water Resources Institute, 74p.
77. Webb, H.J. 1962. Water pollution resulting from agricultural activities. J. Amer. Water Works Assoc. 54;83-87.
78. Wells, D.M. and E.F. Gloyna. 1967. Estimating the effects of return flows. J. Amer. Water Works Assoc., p. 805-819.
79. Westlake, W.E. 1966. Pesticides as contaminants of agricultural waste waters. In Agricultural Waste Waters, L.D. Doneen, (ed.) Report No. 10, Water Resource Center, University of Caliornia, p. 90-93.
80. Wilke, O.C. 1973. Theoretical irrigation tailwater volumes. J. Irrig. and Drain. Div., Proc. Amer. Soc. Civ. Eng., 99(1R3): 415-420.
81. Wilke, O.C. and E.T. Smerdon. 1969. A hydrodynamic determination of cutback stream sizes or irrigation furrows. Trans. Amer. Soc. Agr. Eng. 12:634-637.
82. Wright, C.C. 1928. Surface and subsurface waters of the Yakima and Klamath projects. Wash. Agr. Expt. Sta. Bull. No. 228.
83. Wu, I.P. 1972. Recession flow in surface irrigation. J. Irrig. and Drain. Div. Proc. Amer. Soc. Civ. Engr. 98(IR1):77-90.
84. Wu, I-Pai, and Tung Liang. 1970. Optimal design of furrow length of surface irrigation. J. Irrig. and Drain. Div., Proc. Amer. Soc. Civ. Engr., 96(IR3):319-332.
85. Yoo, Kyung H. 1974. Characteristics of nutrients and total solids in irrigation return flows. Unpublished M.S. Thesis (Agr. Eng.) University of Idaho.
86. Zimmerman, J.D. 1966. Irrigation. John Wiley and Sons, Inc. New York.

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/2-76-237	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE CONTROL OF SEDIMENTS, NUTRIENTS, AND ADSORBED BIOCIDES IN SURFACE IRRIGATION RETURN FLOWS		5. REPORT DATE October 1976 (Issuing Date) 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) David L. Carter and James A. Bondurant		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Department of Agriculture Agricultural Research Service, Western Region Snake River Conservation Research Center Kimberly, Idaho 83341		10. PROGRAM ELEMENT NO. 1HB617 11. CONTRACT/GRANT NO. EPA-IAG-D5-F648
12. SPONSORING AGENCY NAME AND ADDRESS U.S. Environmental Protection Agency Office of Research and Development Robert S. Kerr Environmental Research Laboratory Ada, Oklahoma 74820		13. TYPE OF REPORT AND PERIOD COVERED Final 14. SPONSORING AGENCY CODE EPA-ORD

15. SUPPLEMENTARY NOTES

16. ABSTRACT

The technology available for the control of sediments, nutrients, and adsorbed biocides in surface irrigation return flows has been reviewed and evaluated. Some of this technology could be applied immediately to reduce sediment and associated nutrient and biocide concentrations in surface irrigation return flows. Much of the available information needs to be integrated to develop improved control practices. New ideas and new control technology are needed. Economic incentive programs are needed to improve acceptance of control technology. The factors controlling erosion and subsequent sediment concentrations in surface irrigation return flows, and how these factors can be managed to reduce erosion and sediment concentrations are reviewed and discussed. Three approaches (1) eliminating surface runoff, (2) reducing or eliminating erosion, and (3) removing sediments and associated nutrients and biocides from surface irrigation return flows, and control measures for each approach are discussed. Research and demonstration needs for improving and developing new control technology are presented. These include simulation modeling of known erosion parameters, the development of improved irrigation systems and methods, the design of improved irrigation water distribution systems, and field management practices. The need for more information on design and operational criteria for sediment retention basins is discussed.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
*Irrigation *Soil conservation *Pesticides Management	Sediment control Nutrient leaching Irrigation return flows	02C

18. DISTRIBUTION STATEMENT RELEASE TO PUBLIC	19. SECURITY CLASS (This Report) Unclassified	21. NO. OF PAGES 53
	20. SECURITY CLASS (This page) Unclassified	22. PRICE

EPA Form 2220-1 (9-73)

☆ U. S. GOVERNMENT PRINTING OFFICE: 1977-757-056/5452 Region No. 5-11