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STATE METHODS FOR DELINEATING SOURCE WATER PROTECTION AREAS FOR SURFACE WATER SUPPLIED SOURCES OF DRINKING WATER

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ACKNOWLEDGMENTS

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CONTENTS

1.0 Introduction and Background

A review of Federal-, State- and local-government methods to delineate surface Source Water Protection areas (SWPAs) in watersheds, or basins, indicates that primarily three methods have been used. These methods are:

- Topographic boundary delineation,
- Setback/buffer zone delineation, and
- Time-of-travel calculation.

Modeling techniques have been used to enhance these three methods. A summary of these methods is presented in this report.

In August 1997, the U.S. Environmental Protection Agency (EPA) stated that for public water systems (PWSs) relying on surface water, the SWPA will "include the entire watershed area upstream of the PWS's intake structure...up to the boundary of the state borders." The method to be used to delineate the SWPA will be the topographic boundary delineation method. The EPA recognizes that the susceptibility of a PWS to any given contamination source will depend, to a significant degree, on the location of that contamination source in the watershed area; that is, in some locations, a source would be a significant threat to a PWS while in other locations, particularly within a large watershed, the source would be less significant or even non-significant. Therefore, EPA encourages the segmenting of SWPAs into smaller subunits for the purposes of source identification and susceptibility determinations. Many of the methods/approaches described in this document can be used to delineate these subunits of a surface water SWPA.

1.1 Rationale for Source Water Protection

The Safe Drinking Water Act Amendments of 1996 (P.L. 104-182) and many State drinking water laws include provisions for drinking water protection in SWPAs. These areas are the source areas of surface water or ground water that supplies drinking water systems. Drinking water protection activities fostered under the Safe Drinking Water Act or other statutes, such as the Clean Water Act, range from voluntary efforts to mandatory controls. As envisioned under the 1996 Amendments, Federal-, State- and local-government and private-sector activities would help prevent pollution of PWSs from a wide variety of contaminant sources. Source Water Protection programs can potentially reduce the long-term costs associated with PWS monitoring and treatment. In addition, these programs can provide an added degree of public safety for those occasions when human or mechanical errors temporarily interrupt water treatment.

Source Water Protection programs for surface water based systems are implemented through steps similar to those in Wellhead Protection programs for ground water based systems. That is, both programs have provisions for: (1) delineating the areas to be protected; (2) identifying potential contaminant sources; (3) implementing management measures for those sources; and (4) planning for emergency water supply. Many communities begin the Source Water Protection process by developing a local program planning and implementation team.

In order to protect drinking water supplies, Federal, State and local managers need to understand the basis for identifying the geographic areas to be protected. Drinking water programs should delineate surface SWPAs and are encouraged to delineate SWPA segments in order to facilitate the determinations of susceptibility and identification of the contaminant sources that may impact drinking water intakes.

1.2 Summary of TAD Contents

This document is organized into two chapters and three appendices. Following this Introduction and Background, Chapter 2 describes methods that have been used to delineate SWPAs (and SWPA segments), and includes State and local case studies of the methods. Appendix 1 provides additional examples of the use of delineation methods. Appendix 2 is an annotated bibliography of the technical literature describing source water delineation and some management methods related to delineation. Appendix 3 is a list of the literature cited in this document.

2.0 Source Water Protection Area and Segment Delineation Methods

Local, State and Federal agencies have predominantly used three methods to delineate Source Water Protection areas (SWPAs) for surface water supplied PWSs:

- Topographic boundary delineation,
- Setbacks/buffer zone delineation, and
- Time-of-travel calculation.

Although States are now required to use the topographic boundary delineation method to delineate SWPAs, setback/buffer zone delineation and time-of-travel calculations are important methods for the delineation of SWPA segments, which can facilitate differential protection management. The delineation methods and example applications are described below.

2.1 Topographic Boundaries

Topographic boundaries are, irrespective of scale, defined by the elevation of the land. A topographic boundary of a <u>watershed</u> (Figure 1) is the perimeter of the catchment area of a stream. Analogously, a topographic boundary of a <u>subwatershed</u> is the perimeter of the catchment area of a <u>tributary</u> of a stream. The distinction between a watershed and a subwatershed is purely one of nomenclature. That is, the catchment area of a tributary is both the watershed of the tributary and a subwatershed of the main stream. Thus, the occurrence of one watershed (subwatershed) within another may be thought of as nested watersheds. (Note however, that the catchment area of <u>any</u> stream that drains directly to an ocean is always considered a watershed, because, by definition, the stream is not a tributary of another stream.) The topographic boundary of the area <u>contributing surface water to a PWS</u> is the perimeter of the catchment area that is upslope of the PWS intake, that is, the <u>watershed area</u> (Figure 2).

A key initial step in Source Water Protection for surface water supplied PWSs is the delineation of the watershed area contributing water to the drinking water intake. This area is composed of the land and the surface water (i.e., lake, reservoir, tributaries and streams) uphill of the drinking water intake.

<u>Method Description</u>

A watershed area is easily delineated on a topographic map by the drawing of a line connecting the highest points uphill of the intake, from which overland flow drains to the intake.

Figure 1. Topographic Boundary of a Watershed

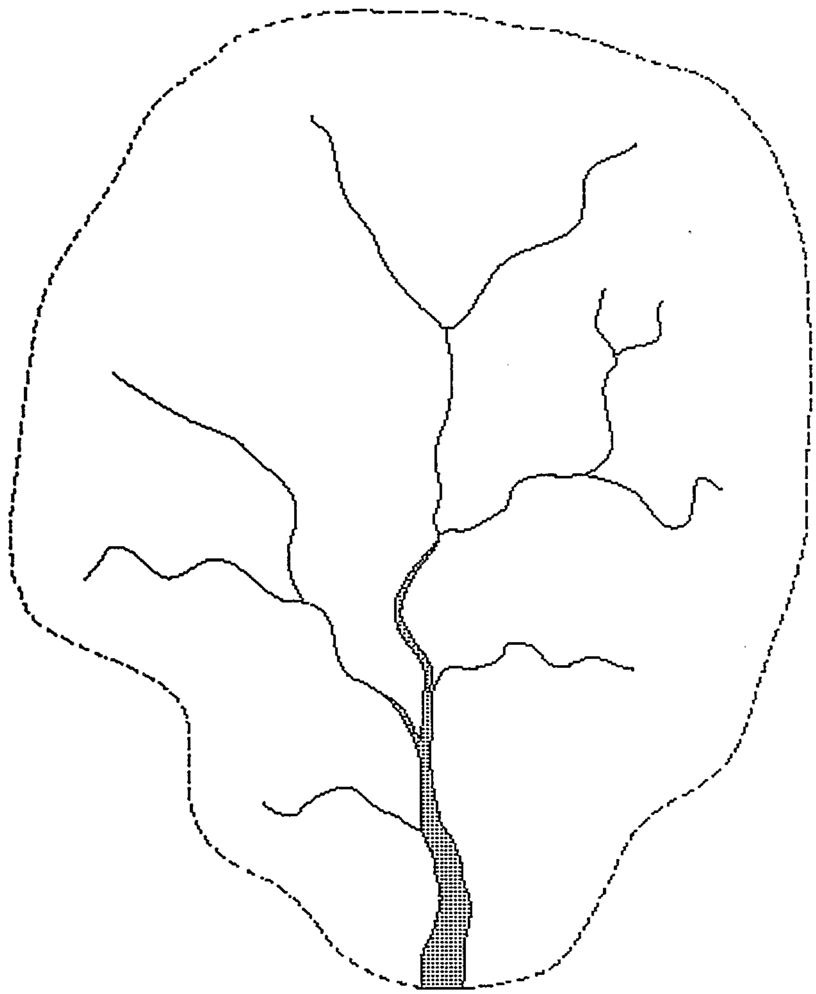
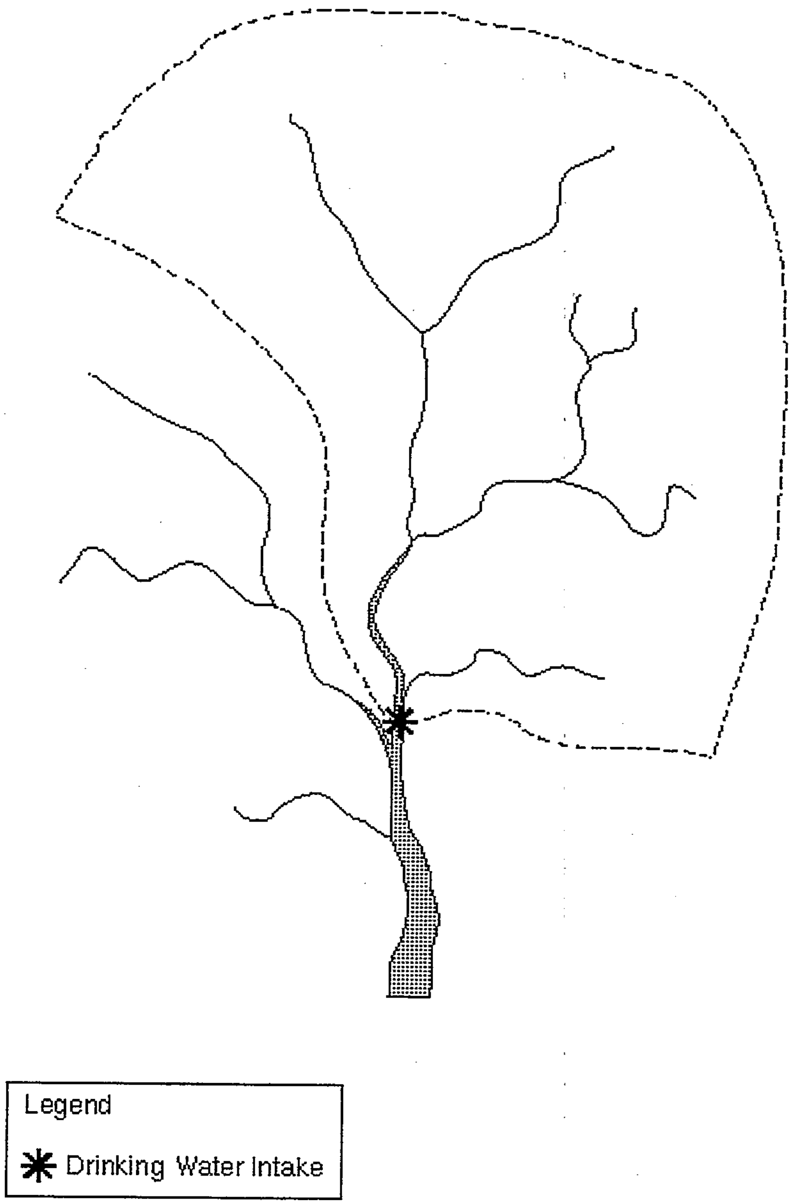


Figure 2. Topographic Boundary of a Watershed Area



Example: The Topographic Boundary Method in Idaho

Idaho's watersheds have been delineated by the topographic boundary method. The State used the U.S. Geological Survey's topographic hydrologic units for Idaho's basin/watershed/subwatershed boundaries (Seaber, 1987). In its delineation approach, Idaho uses a three-tiered strategy. Idaho's first level of topographic delineation includes each of the State's major river systems, which are represented by a unique drainage basin (six basins total). Each basin includes the area of land drained by the major river system. Within these basins, Idaho delineates watersheds, that is, the area of land drained by a stream or a system of streams, or a geographic area in which water, sediment and dissolved materials drain to a common outlet. Finally, the State may delineate subwatersheds, which are smaller geographic management areas delineated to address site-specific concerns.

2.2 Setbacks/Buffer Zones

Surface water setbacks and buffer zones are often used as a means of reducing the adverse impacts of runoff on drinking water sources. The primary purposes of setbacks/buffers are to filter overland flow and, to a lesser extent, slow overland flow and encourage increased ground water infiltration. Buffer zones ("green areas") may be intended to serve several functions such as: wildlife habitat, residential or commercial exclusion, or Source Water Protection.

<u>Method Description</u>

Determination of the width of buffer zones is often based on consideration of such factors as: topography of the land, local land uses, political and legal feasibility of setting aside such buffers, slope, size of the stream and land ownership rights. A typical buffer/setback zone (Figure 3) for protecting the water withdrawn by an intake in a stream, is a strip of vegetated land generally 50 to 200 feet wide, upstream of the PWS intake, along the shores of the stream. Analogously, a setback/buffer zone can be delineated to protect the water withdrawn from a reservoir (Figure 4).

Setback/buffer zones filter out some portion of sediment-borne contaminants. In addition, by slowing down overland-flow velocity, these green areas briefly increase the exposure of overland flow to such processes as photolysis and encourage an increase in infiltration to the ground water reservoir, where travel times are longer (but, where contaminant cleanup is more difficult). Forested buffer zones may be effective in reducing nutrients.

Figure 3. Watershed with a Buffer/Setback Zone for a Drinking Water Intake in a Stream

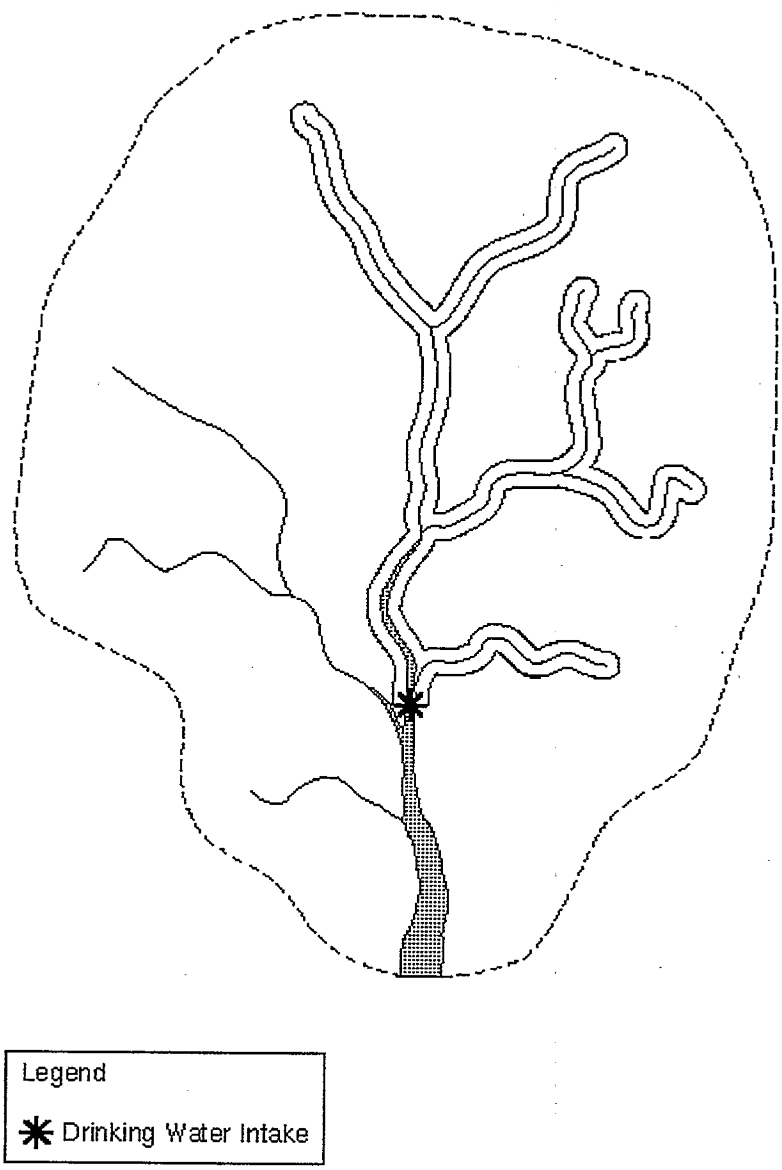
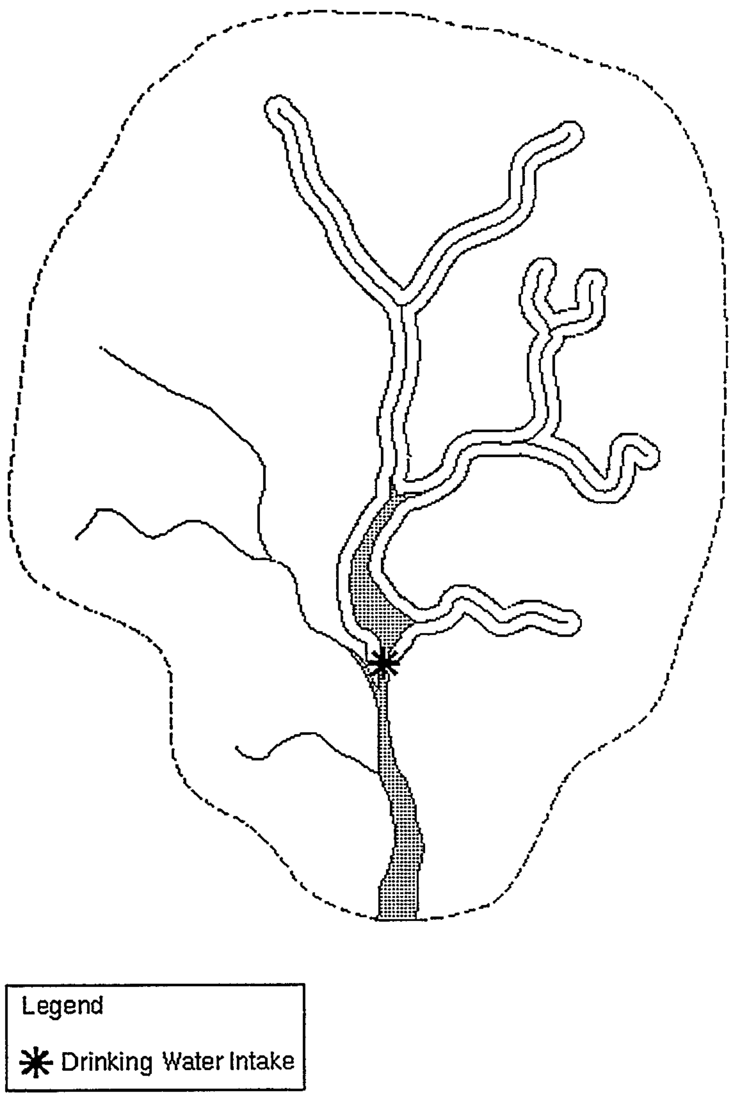


Figure 4. Watershed with a Buffer/Setback Zone for a Drinking Water Intake in a Reservoir



The sediment-load carrying capacity of moving water is related to its velocity. When overland flow reaches the edge of a buffer zone, the velocity of the water is reduced and sediment is dropped. Thus, with time, a berm may form along the edge of a buffer zone. A berm will cause future contaminant-laden overland flow to travel parallel to the stream, until a topographically low area is encountered. There, the overland flow will cross the buffer zone and enter the stream; transported with the overland flow will be its load of contaminants. Additionally, if a buffer zone is overtopped during a major precipitation event, any portion of the load that flows above the vegetation will not be removed by filtration. (Contaminants may also be transported to surface water through the vadose zone or by ground water discharge from the saturated zone.)

Example: The Setback/Buffer Zone Method in Georgia

As part of its Rules for Environmental Planning (Georgia State Statutes for Planning, 1991) Criteria (Georgia State Statutes for Criteria, 1991), Georgia requires buffers and setbacks:

1) In watersheds greater than 100 square miles, Georgia requires 100-foot buffer zones and 150-foot setbacks within a 7 mile radius of all water supply reservoirs upstream of all governmentally owned public drinking water intakes; the buffer zone around the water-supply reservoir is required to be 150 feet (measured from the normal pool); and

2) In water-supply watersheds of less than 100 square miles, in addition to the buffers/setbacks in (1) above, Georgia requires 50-foot buffers and 75-foot setbacks at distances greater than 7 miles from the water-supply intake or reservoir.

No buffers or setbacks are required in water-supply watersheds greater than 100 square miles that lack a water-supply reservoir.

Georgia's planning criteria specify that the buffers be naturally or enhanced vegetated tracts of land with no, or limited minor, land disturbances. The State precludes the development of impervious surfaces and the installation of septic systems within setbacks. State constraints also limit to 25 percent, the amount of impervious surface in a small watershed (less than 100 square miles) upstream of a PWS intake.

Georgia determined the size of its buffer zones through the work of an Advisory Group to the Governor, which was comprised of 116 representatives from numerous organizations and interested parties, including the State, local governments, citizens' groups, environmental organizations, industry, and the general public. This group held twenty public briefings throughout the State to obtain input and comment.

2.3 Time-of-Travel Calculation

In addition to the two methods above, drinking water utilities may delineate stream reaches to facilitate spill- and other emergency-response activities for the protection of source waters. (In this method, the protection "area" is actually a stream reach, rather than an area.) The following section describes the use of time-of-travel (TOT) calculations for emergency planning for Source Water Protection.

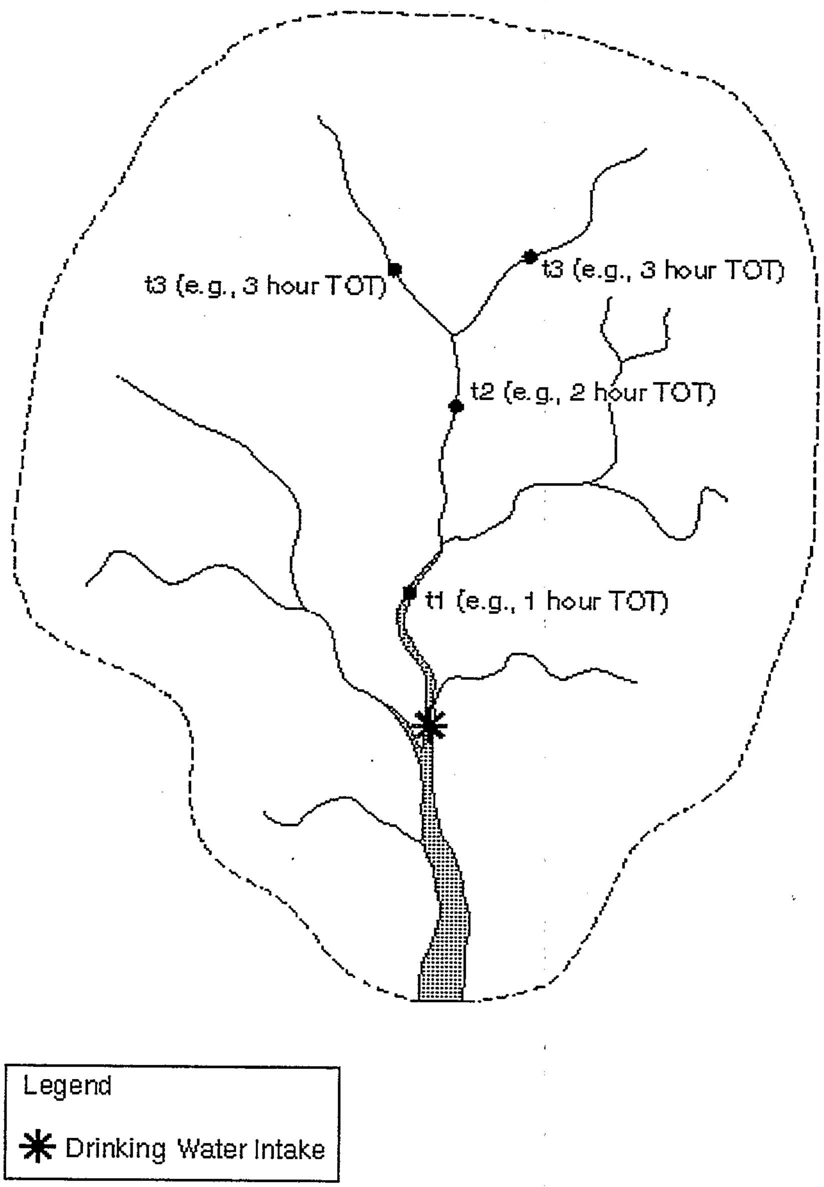
Method Description

This delineation method is based on the time it takes for a contaminant, moving at the same velocity as a stream, to travel from an upstream monitoring point to the point of interest, the drinking water intake (Figure 5). In this method, the TOT is calculated between these two points. It is this travel time that provides the opportunity for managers to respond to a contamination event. Use of this method would be of greatest importance for drinking water utilities tapping streams, or reservoirs on streams, designated for commercial transport or other industrial use. Water quality flow models provide a means through which specific hydrologic, geographic and water quality parameters can be used to estimate the travel time for a contamination incident such as a spill into a river to reach a drinking water intake, and to estimate the level of contamination once it is at the intake.

The TOT method is often used to alert a downstream drinking water supplier that a contaminant spill has occurred and provides the managers with lead time to close downstream intakes. Because stream TOTs are short (generally in the range of hours or days), the in-situ remediation that occurs as a stream flows towards an intake may be limited. However, some remediation does occur; some very volatile contaminants may undergo significant reduction in concentration as a result of volatilization, the concentration of contaminants from point sources is often reduced as a result of dilution mixing in the stream and some processes, such as photolysis, may reduce contaminant concentrations. In addition, along their journey, some portion of waterborne contaminants may adhere to clay or other particles and settle out of the stream onto the stream bed.

Although the examples below are part of large scale monitoring and contingency planning programs, the principles involved can apply equally to smaller systems. Specifically, the TOT estimation techniques (described in 40 CFR 112, Appendix C-III) (U.S. Government Printing Office, 1995) and the algorithms used in the model described below in the ORSANCO example, and other water quality models, can be used to determine the TOT from an upgradient spill site to a PWS intake. A 1993 pipeline leak to Sugarland Run in Fairfax County, Virginia, resulted in fuel oil in that stream and in the Potomac River, to which the stream is tributary. It took 2 hours to shut down the raw-water supply from the Potomac River. No oil entered the water system.

Figure 5. Watershed Showing Points at Three Different Stream Times-of-Travel (TOT) to a Drinking Water Intake



Example: *Ohio River Valley Water and Sanitation Commission (ORSANCO)*

The ORSANCO is an interstate commission established in 1948. The Commission coordinates monitoring for specific organic contaminants in the Ohio, Allegheny, Monongahela and Kanawha Rivers, in cooperation with local water utilities. The Commission notifies downstream water utilities of detections so that the utilities can implement protection measures. The ORSANCO's monitoring locations encompass six States from Pennsylvania to Illinois, and include 14 organics sites at industrial plants and drinking water suppliers on the rivers.

Personnel at water treatment facilities collect samples directly from raw river water feed lines, for analysis by gas chromatograph. If contamination above the predetermined action level for a specific chemical is found, a protocol is activated for increased sampling and notification of downstream water suppliers, that is, the individual facility operators, who decide what action to take. Actions could include shutting down the intake or finding an alternative water supply.

The ORSANCO uses a flow model to estimate contaminant concentrations and travel times when a notification is issued. The model utilizes river flow data that are provided daily by the Army Corps of Engineers, Ohio River Division. Other variables which are input to the model include: spill location, spill duration, spill amount, initial time of the spill, and a decay coefficient. For a rough estimate of travel time on a daily basis, the river stage is used to calculate velocity. Potential time of contaminant arrival is reported to downstream utilities.

Each of the drinking water utilities has an emergency response plan in case of a contamination incident. The City of Pittsburgh, for example, has a spill response plan that includes provisions for coordinating with a variety of City and State departments, such as the Allegheny County Health Department, the State Fish and Game Department, the Coast Guard, and the State Department of Health. The City does not have an alternate water supply and, depending on the potential duration of the spill, the City either shuts down the water intake (for shorter spills in the range of 8 to 12 hours) or treats contaminated water that has entered the system.

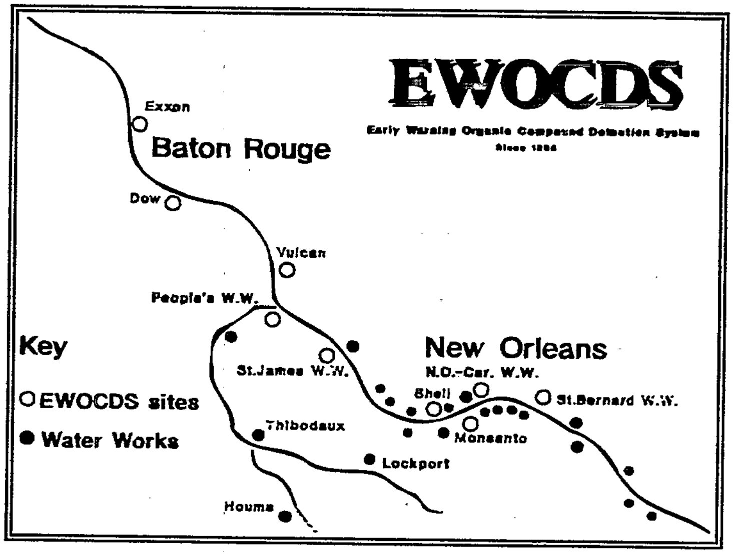
Example: *The Lower Mississippi River Industrial Corridor: Baton Rouge to New Orleans, Louisiana*

The Early Warning Organic Compound Detection System (EWOCDS) was established in 1986 to provide both municipal and industrial water suppliers with early warnings of contaminant spills on the lower Mississippi River. Through this monitoring and warning system, suppliers are able to assess the travel times for a contaminant and take appropriate measures to avoid an intake of contaminated water.

The EWOCDS is a cooperative program among the Department of Environmental Quality (DEQ), five industrial water users and three municipal users. The State provides the monitoring equipment, computers and modems used to transmit, store and analyze water quality data. The water users provide volunteer staff time for sampling, and some provide a building for the monitoring equipment.

Monitoring stations are located at each of eight water intakes (St. Bernard is no longer a EWOCDS site) along the approximately 100-mile river corridor (Figure 6) (Wagenecht, 1991). Gas chromatographs are used to test for 20 volatile organic chemicals identified as priority pollutants. Samples are taken twice daily at all monitoring stations (Wagenecht, 1997).

Figure 6. EWOCDS



Based on river velocity data (related to river height) provided weekly by the Army Corps of Engineers, the water providers and DEQ calculate the time of travel for the leading edge, peak, and trailing edge of a spill. The DEQ developed TOT models which were used to predict the probability of a spill remaining undetected at the monitoring stations and contaminating downstream water intakes. These studies led DEQ, in 1989, to require increased sampling frequency from once to twice daily. The model results have been compared to actual travel times for several spills, and were found to accurately predict the peak travel times over the 100 mile corridor. In general, the information supplied by the Army Corps of Engineers is reasonably accurate and when used in conjunction with twice daily sampling, generally provides sufficient time for early warnings to be issued (Wagenecht, 1997).

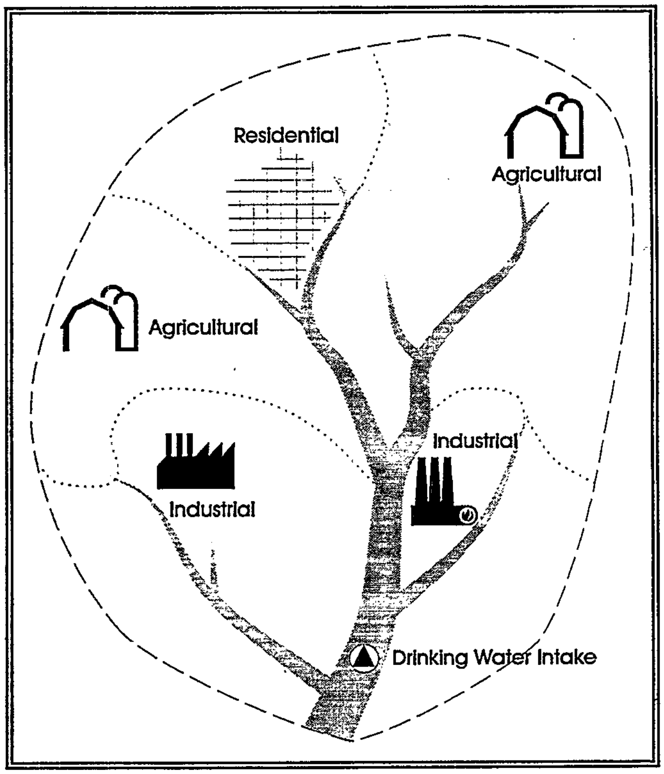
2.4 Modeling to Enhance the Efficacy of Delineating Source Water Protection Areas and Segments

Ground water discharge and surface runoff models can be used to assess the potential impact of individual contaminant sources, and to identify SWPA segments with the greatest potential impact on source water quality. Modeling can be used in conjunction with SWPA and segment delineation techniques to enhance source water quality protection efforts.

Method Description

A variety of models has been developed to assess the impact of changing land use on surface water quality. Simpler models require less detailed, site specific hydrologic information and provide more generalized and descriptive output. More complex models require more extensive input data and provide output with greater predictive capability and site specificity. Site specific output can provide locations of contamination sources and yield relatively accurate predictions of variable flows and water quality at any point in a watershed.

Figure 7. Land Use Parcels



Contaminant source loading models estimate chemical loading rates to surface water. These methods are most useful for estimating variation in loading rates as a function of changing land uses within the watershed. For example, as shown in Figure 7, land may be divided into residential-, industrial-, and agricultural-use parcels. If agricultural land is subdivided by soil type, crop type, and land management practice, the nonpoint source loading rates for runoff, sediment yield, and ground water discharge may be estimated for each parcel type. These parcel estimates are summed to obtain the total loading rate for the watershed or watershed areas (Haith and Shoemaker, 1987).

Several States, local governments, water suppliers, and watershed management authorities have begun modeling to identify those land uses that have the greatest potential impact on source water quality. Modeling can also be used to assess the impact of differing land management strategies within a SWPA to foster more effective Source Water Protection.

Common uses for models include: evaluation of urban and agricultural runoff scenarios, determination of the impacts of changes in agricultural practices, and assessment of the impacts of various point and nonpoint source releases.

Example: Minnesota

The Agricultural Nonpoint Source Pollution Model (AGNPS) was designed to evaluate water quality impacts of land use and land management strategies in agricultural watersheds. The primary purposes of the AGNPS model are to prioritize watersheds in terms of water quality problems, to identify critical areas within a watershed that are large contributors to nonpoint source pollution, and to evaluate and predict the effects of alternative management practices.

Because the model simulates sediment and nutrient transport in steps, water quality impacts can be assessed at any point in the watershed. The AGNPS's principal variables are hydrology, erosion, sediment, and chemical transport. However, the model also incorporates point sources of sediment from gullies and inputs of water, sediment, nutrients, and chemical oxygen demand (COD) from such sources as animal feedlots.

The model operates on a grid cell basis, allowing the user to determine sediment and nutrient transport rates for each cell. Existing soil, topographic, and land use conditions are input for each cell. Based on this data, the model provides erosion, sediment transport, nutrient transport, and flow information. In addition to the standard output, the model has the capability to perform more specific analyses for any individual cell. These analyses include: 1) calculation of drainage area, runoff volume and peak runoff rate; 2) estimates of adsorbed and soluble nutrients in mass per unit area, and nutrient and COD concentration in runoff; and 3) for each of five particle size classes, estimates of upland erosion, sediment yield, percent of yield from within a cell and from outside the cell, and cell deposition.

Currently, the model is used to estimate the results of specific hydrologic events. However, with some modification, the model could provide a continuous representation of the average annual response of a watershed to a representative annual distribution of rainfall events. The model can also be used to evaluate and predict site-specific sedimentation in a watershed.

Minnesota has used the AGNPS model to evaluate water quality in several watersheds. In the Garvin Brook watershed, the model was used to determine sediment and nutrient loading in response to a 25-year frequency, 24-hour duration storm. The cell structure of the model was used to identify feedlots with high potential pollutant contributions and individual cells with excessively high upland erosion rates. These "critical areas" were then targeted for the application of control measures. The model also identified one subwatershed that contributed high sediment loads but that did not contain any high sediment yielding cells. This subwatershed was targeted for a different set of management strategies designed to reduce sediment yield over the entire area. Information from the model was used to encourage farmers in this subwatershed to sign up for an agricultural cost sharing program.

Appendix 1

Examples Of State and Local Source Water Protection Area and Segment Delineation Methods

This section provides an overview of the delineation methods used in several programs that have implemented Source Water Protection activities for surface water supplies.

The descriptions below illustrate the manner in which Source Water Protection may be incorporated into existing drinking water and surface water protection programs.

Topographic Boundary Delineation Method

Massachusetts Source Water Protection Delineation Method

Major delineation efforts in Massachusetts have been made by the State to map watersheds for use by the Watershed Management Program, and by the Massachusetts Water Resources Authority (MWRA) to delineate the Metropolitan District Commission's (MDC's) watersheds at the Quabbin and Wachusett Reservoirs, and at the Ware River. The Massachusetts Department of Environmental Protection (MDEP) has mapped the major river basins of the State in a Geographic Information System (GIS), which also contains wellhead protection area information, municipal boundaries, land uses, and other pertinent planning data. The main impetus for this mapping effort was passage of the 1986 Water Management Act, which required identification of outstanding resource waters. The Drinking Water Supply Division led the effort, with assistance from Watershed Management. The basis of the delineation of surface water watersheds was the USGS topographic hydrologic units for watersheds and subwatersheds. Professional judgment was often necessary when interpreting subwatershed data, because tributaries may be split by the presence of gaging stations, and small tributaries may be combined. In general, delineation was based on determining a set of upstream points of high elevation from which surface water drains. Choosing these points was subject to technical judgement.

The MWRA, which is responsible for treatment and distribution of waters from MDC sources, delineated the MDC watersheds. The sole purpose for delineating the watersheds was drinking water source protection. The MWRA delineated three surface water zones, mapping them in a GIS: (1) Zone A, a 400 foot buffer around the water supply; (2) Zone B, a half-mile buffer beyond Zone A; and (3) Zone C, the remainder of the watershed including protection zones. Watershed boundaries were based on surface water divides, and ground water recharge areas tributary to each supply were included in the ground water zones.

Once the watersheds were delineated and the data were input into the GIS, MWRA conducted a threat assessment to determine the level of threat to Zones A and B from various human-induced activities. The MWRA rated and prioritized risks to their watersheds using the potential quantity of pollutants. After consideration of these criteria, MWRA was better able to isolate those watersheds that might be most vulnerable to certain types of threats (Chernin, 1992, Willmer, 1992).

In addition to MWRA GIS mapping efforts, the MDC also maps its watersheds to comply with the Watershed Protection Act. The MDC used USGS hydrologic units at 1:24,000 scale to map tributaries, and used FEMA maps for floodplain delineation. The MDC, in consultation with the MDEP, may adopt more accurate maps.

North Carolina Source Water Protection Delineation Method

The topographic boundaries of North Carolina's water supply watersheds are delineated on USGS 1:24,000 scale topographic maps. The location of a surface water intake is the lowest point on a watershed boundary. The remainder of the boundary encompasses the land area draining to the intake as defined by the topography of the land (North Carolina Administrative Code, 1994; North Carolina Department of Health, 1995; North Carolina Division of Environmental Management, 1995).

Within each watershed, the State defines critical areas in which certain land use restrictions or management practices are applied. The minimum critical area is defined as: 1) extending to either one-half mile from the normal pool elevation of a reservoir containing a drinking water intake or to the ridge line (topographic boundary) of the watershed (whichever is closer to the reservoir); or 2) extending to one-half mile upstream of and draining to a river intake or extending to the ridge line of the watershed (whichever is closer to the drinking water intake). Local governments may extend this area as needed. Analogously, the State has designated protected areas for certain WS-IV class watersheds (North Carolina Administrative Code, 1994; and North Carolina Department of Health, 1995).

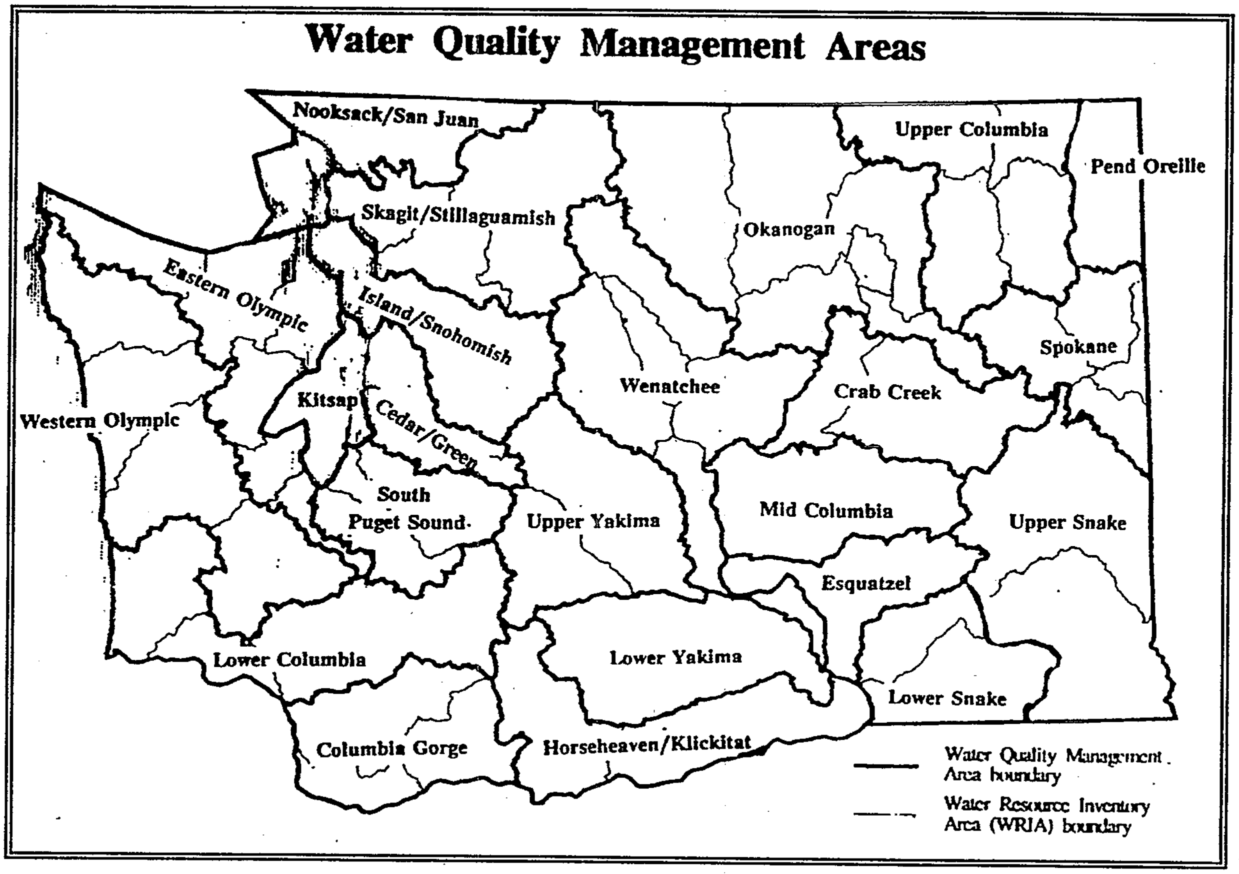
In classifying the 208 surface water sources in the State, the Division of Environmental Management (DEM) worked with local governments to determine the location of all surface water intakes. The DEM used this information, coupled with information on existing land use within the watersheds, and the types and locations of wastewater discharges, to determine appropriate classifications for each of the water supply watersheds. North Carolina used the topographic method to delineate water supply watersheds to protect sources of drinking water.

The State defines five water supply classes according to existing land uses and the amount and types of permitted point source discharges (WS-I through WS-V). State Rules require that all local governments having land use jurisdiction in watersheds that are classified as water supply watersheds, implement and enforce nonpoint source management strategies related to urban development. These strategies must meet minimum standards adopted by the State and typically include the development of water supply watershed protection ordinances, maps and a management plan. The State then limits the point source dischargers that can locate within the watershed (North Carolina Division of Environmental Management, 1995).

Washington Water Quality Management Areas

The State of Washington has established twenty three Water Quality Management Areas (WQMAs). For planning purposes, WQMAs are considered to be the State's major watersheds (Figure 8) (Washington Department of Ecology, 1996). The WQMAs are generally large drainage areas that include several river basins. The boundaries of the WQMAs are partly dependent on the location of smaller Water Resource Inventory areas (WRIAs), which were delineated in the 1970s as Sewage Drainage Basins for water supply and sewer system planning. Typically, each WQMA contains several WRIAs.

Figure 8. Washington State Water Quality Management Areas



Public water suppliers are required to delineate a watershed, defined as "the hydraulic drainage upstream of the intake", within the WQMAs. Most of the public water supply systems have watersheds of 300 square miles or less, although systems drawing water from large rivers may have watersheds of several thousand square miles.

Salt Lake City, Utah Source Water Protection Delineation Method

Figure 9. Salt Lake City's Water Supply Watersheds

The water supply watersheds for Salt Lake City (Figure 9) (Utah Automated Geographic Reference, 1989) were originally delineated in the early 1900s and have been used ever since. Each watershed is a canyon. A watershed boundary is defined topographically and corresponds to the top of the ridge surrounding the canyon.

Drinking water source protection was not explicitly considered in the original delineation of the canyon watersheds. The locations of PWS intakes define the lowest points on the boundaries of Salt Lake City's management areas. In these areas, ordinances and land use controls are implemented for the sole purpose of drinking water source protection. Salt Lake City uses the entire watershed area upstream of its surface water intakes as the basis for its management decisions. Because of the mountainous nature of the region, drainage areas are smaller, and can thus be more easily managed, than the drainage area of a river of similar size in the coastal plain of the U.S. The total drainage area for all seven water supply canyons is slightly less than 200 square miles and yields approximately 152,000 acre-feet of water per year.

In developing its land use plan and management recommendations, Salt Lake City delineated areas of varying development suitability. The City mapped and analyzed these areas using computer modeling and map overlay techniques to generate development suitability maps for each watershed.

The availability of surplus water is one of the more critical development constraints in the canyons, because the City is maintaining a moratorium on new surplus water contracts. In addition, the Department of Health requires a 50 foot setback from any water source for all structures designed to be occupied by people or animals.

Most other development constraints are related to the hydrologic and soil conditions of Salt Lake City's canyon watersheds. In calculating erosion tolerance, the City used the universal soil loss equation to estimate soil loss in tons/acre/year. The equation considers a number of variables, including precipitation intensity, soil erosion factors, slope length and steepness, and the height, type, and density of native vegetation. Based on the results of this equation, the City assigned erosion tolerance values to different areas, delineating regions of potential soil quality degradation. Slope data are included in the City's erosion tolerance model. However, the County also considers slope in setting development restrictions, generally prohibiting development on slopes with greater than 30 percent grade. Finally, soil conditions such as: a very shallow water table; very shallow or outcropping bedrock; high shrink-swell potential; very high or high erosion potential; strong salt or alkali effect; impermeability; very slow, or slow permeability; high runoff potential; and susceptibility to hillside slippage, can be significant constraints on development.

Area boundaries based on the constraints were mapped for private lands in each of the canyons. Boundaries were then combined in a series of overlays to construct a development suitability map for all private landholdings (Salt Lake City, 1988).

Illinois Source Water Protection Delineation Method

Illinois has divided the State into seven major watershed areas, which were determined by matching, to the extent possible, the boundaries of the Illinois Environmental Protection Agency's seven regional office locations, with major river basins (as defined on USGS topographic maps). The State has also delineated 860 subwatersheds. Illinois uses these delineations in its watershed approach, which addresses watershed prioritization, monitoring, point and nonpoint source pollution, and water quality criteria, including both biological and human health based criteria. The prioritization process identifies the watersheds with the most critical water quality problems. Drinking water source (both surface water and ground water) quality is a primary consideration in this prioritization process (Illinois Environmental Protection Agency, 1995).

Setbacks/Buffer Zone Segment Delineation Method

Clifton Park, New York, Land Conservation Districts

The town of Clifton Park, New York, established a Land Conservation District that protects the wetlands and streams recognized by the State. The District established 50 foot buffers on either side of classified streams and 100 foot buffers for certain named stream confluences. These buffer zones are not delineated on town zoning maps, but are protected. Building permits within the District are referred to the New York State Department of Environmental Conservation to verify locations of buffers. Within these buffer zones, construction, expansion or alteration of the land is prohibited except for purposes of parks, residential boat launches, game preserves and similar uses (New York State Department of Environmental Conservation, 1995).

Austin, Texas, Buffer Zones

The City of Austin, Texas uses buffer zones to define the protection area in the Town Lake watershed. The City requires buffers of 100 feet from the center line of "minor" streams, 200 feet from the center line of "intermediate" streams, and 300 feet from the center line of "major" streams. In addition to these buffer zones, Austin has implemented several structural best management practices, such as sedimentation/sand filtration basins to mitigate impacts of urban runoff (Robbins et al, 1991).

Napa County, California, Setbacks and Zoning Restrictions

As part of a Napa County county-wide effort to control erosion problems in the Napa River watershed, the cities of Calistoga, St. Helena, and Yountville passed ordinances on property creek setbacks, ranging from 35 to 100 feet, as well as zoning restrictions on building on slopes over 30 percent grade. Generally, development and any activities which could cause erosion or other detrimental impacts within the riparian zone, or the "woodlands/watershed" zoning district, are prohibited.

Through the Napa County Resource Conservation District, a watershed-wide set of protection measures is recommended, including measures targeted at agricultural lands, open space, urban and rural residential areas, commercial and industrial areas, and recreation space. General recommendations include developing buffer and setback areas from riparian zones, sensitive habitats, and critical erosion zones (California Water Resources Control Board, 1995; and Napa County Resources Conservation District, 1995).

Appendix 2

Annotated Bibliography of the Technical Literature Addressing Source Water Protection Area and Segment Delineation

1.0 Delineating Watersheds Using Topographic Boundaries

Black, Peter E. 1991. Watershed Hydrology, Prentice-Hall, pp. 251-270, "Characterizing the Watershed."

This text provides a straightforward description of the hydrologic principles involved in delineating a watershed. The text emphasizes that "watersheds are often not immediately discernible from a map or on the ground." The text discusses the distinction between the topographic divide and the phreatic divide to account for the contribution of soil water and ground water runoff in watershed delineation. Fundamental watershed modeling concepts, such as runoff per unit areas, peak flow, time of concentration, and hydraulic similitude are also described.

Seaber, Paul R., F. Paul Kapinos, and George L. Knapp. 1987. "Hydrologic Unit Maps," United States Geologic Survey Water-Supply Paper 2294.

This paper provides an overview of the United States Geological Survey's (USGS's) approach for cataloging the 2,149 river-basin units in the United States. The USGS has developed a series of four-color maps that present information on drainage, culture, hydrography, hydrologic boundaries and unit codes for (1) the 21 major water-resources regions and the 222 subregions designated by the U. S. Water Resources Council, (2) the 352 accounting units of the USGS's National Water Data Network, and (3) the 2,149 cataloging units of the USGS's "Catalog of Information on Water Data." A complete list of all the hydrologic units, along with their drainage areas, their names, and the names of the States or outlying areas in which they reside, is contained in the report.

Terrene Institute. 1993. "Delineating Watersheds - A First Step towards Effective Management."

This document provides step-by-step descriptions of methods for delineating watersheds, using topographic boundaries. The document discusses sources of topographic data, methods for determining drainage direction in a watershed, and sources of assistance for completing topographic delineations.

2.0 Delineating Segments for Land Use Management: Buffers, Setbacks, and Management Districts

Bona, John and James Murray. 1993. "Watershed Selected for National Program," *Water Environment & Technology*, August 1993, p33-34.

This paper describes a federally funded national demonstration program addressing urban runoff and combined sewer overflows (CSOs) in the Rouge River watershed in southeastern Michigan. The program is to establish methods for determining the optimal combination of control measures and regulations to provide the greatest water quality improvement at reasonable costs. These methods are to be transferrable to urban watersheds throughout the U.S. The program began in late 1992 and is expected to last three years. The intent of the program is to quantify and define contaminant loadings from wet weather sources and identify the amount of reduction in contamination levels due to various control measures. Computer models will simulate responses to rainfall and the magnitude and frequency of CSOs and stormwater runoff quantities. Results will be used to predict the quality of water throughout the watershed during and after storms.

Bowerin, Reginald, Kenneth H. Spie, Alfred T. Neal, and William E. Bullar. 1990. Watershed Control for Water Quality Management, Pollution Control Council, Portland, OR.

The purpose of this water supply and watershed protection document is to demonstrate the basic principles and problems of long-range programs of water quality protection and management on forested watersheds in the Pacific Northwest. Consideration is given to natural as well as human-caused variations in water resource characteristics and their relationships to municipal, industrial and agricultural consumptive uses and the non-consumptive uses of water including fisheries and recreation. The report summarizes water supply and quality requirements for the various water uses in the Pacific Northwest, indicates how lack of adequate control measures and management practices adversely affect these uses, and includes recommendations for improvements in watershed protection and management.

Chernin, Philip R., and Frederick O. Brandon. 1992. "Protecting Local Supplies: Perspectives from a Regional Water Purveyor," *WATER/Engineering & Management*, October 1992, p20-22.

The Massachusetts Water Resources Authority (MWRA) has implemented a water resources management program designed to protect sources of drinking water it does not own, for the mutual benefit of its customers and their neighbors. The program was intended to help partially supplied communities protect their local water sources and to ensure that MWRA would not have to meet an unforeseen future

demand as a result of contaminated local supplies. The MWRA funded studies in its 14 partially supplied communities. These studies assessed the local water supply and delineated protection areas for both surface and ground water supplies, identified potential hazards, evaluated existing water supply protection mechanisms, and recommended a strategy to develop or supplement existing management measures. The GIS datalayers of all the mapped data and a database of potential contaminant sources were developed during the study and now serve as useful planning tools, both for the communities and for MWRA. The study's information and recommendations have helped one community revise its water supply protection overlay district by law, and aided another community in preparing a successful application for an exception to filtration under the federal Safe Drinking Water Act Amendments.

Ehrman, Richard L., Martha L. Link, and Jeffrey J. Gottula. 1990. "Special Protection Areas: A New Nonpoint-Source Management Option in Nebraska," *Journal of Soil and Water Conservation*, March-April 1990, p263-264.

Extensive nonpoint source contamination prompted Nebraska to enact legislation creating a Special Protection Area Program. Under this program, the State Department of Environmental Control evaluates applications for special protection area consideration for areas with ground water contamination. After setting a priority list, department personnel work with local officials to determine the cause or causes of the contamination, a study that includes surface water sampling and consideration of ground water/surface water interaction. If there is evidence of nonpoint source contamination, the department designates a special protection area and the local district develops an action plan and a monitoring program for the protection area to address the contamination. The State has experienced some difficulties with insufficient funds to implement action plans and with setting the boundaries of the protection areas.

Eichner, Eduard M. 1993. "Watershed Protection: A Cape Cod Perspective on National Efforts," *Environmental Science & Technology*, 27(9):1736-1740.

In response to rapid development, the Cape Cod Commission established a Regional Policy Plan (RPP) containing a strategy for watershed delineation and protection. Because Cape Cod's hydrologic system is dominated by ground water, watersheds are delineated based on the configuration of ground water lenses rather than on topographic configurations. Once delineated, the RPP classified the watersheds and identified water resources of concern, developing watershed-specific standards and frameworks for development. High nitrogen concentrations limit land use development. This strategy is dependent on having land use information and GIS technology to assess the amount of nitrogen loading to each watershed. Cape Cod has found the concept of single contaminant regulation and land use planning to be fairly effective. However, as new technology reduces nitrogen loading, the need for land use controls based on additional criteria is becoming apparent.

Goldstein, Kenneth J., Anne B. Benware, and David M. Kutner. 1994. "A New York State of Mind," *Water Environment & Technology*, January 1994, 34:34-39.

Municipalities served by a Schenectady, NY aquifer have joined together to create a wellhead and watershed protection strategy. Tools used in this strategy include: intermunicipal watershed rules, uniform land use regulations for the protected areas, and wellhead protection areas around each municipal well field. The intermunicipal watershed rules and regulations have three main objectives: minimum standards, uniform application, and accountability. Limitations on land uses are most stringent within the wellhead protection zone and become progressively less stringent in the primary recharge zone (zone 2), the general aquifer recharge zone (zone 3), and the tributary watershed zone (zone 4). The tributary watershed zone is defined as the surface water drainage basins located in the valley uplands where runoff flows overland and into defined stream beds until it reaches the general aquifer recharge zone. In the tributary watershed zone, snow or ice collected off-site from roadways, agricultural chemicals or pesticides, and coal or chloride salts are prohibited within 100 feet of any body of water.

Harryman, M. B. M. 1989. "Water Source Protection and Protection Zones," *Journal of the Institute of Water and Engineering Management*, December 1989, p548-550.

This paper discusses United Kingdom Government policy to August 1989 on the use of protection zones to protect drinking water sources from pollution by nitrate. The concept of protection zones was established to provide a mechanism to limit pollution from nonpoint sources. The paper outlines the use of the powers in the Water Act 1989 to declare Nitrate Sensitive Areas, and the procedures that would be followed in declaring protection zones. It outlines the circumstances in which compensation would be paid in Nitrate Sensitive Areas and presents the reasons for departing from the 'polluter pays' principle. In addition, it discusses the similarities between the UK policy and the proposed European Community Directive on the control of nitrate.

Machorro, Eric. 1994. "Portland Prepares New Watershed Plan," *Water Environment & Technology*, February, 1994, p33.

Portland, Oregon and several neighboring communities are developing a second-generation watershed management plan for Johnson Creek, a tributary of the Willamette River, which drains a 54 square mile partially urbanized watershed with a population of 200,000. The plan outlines a more comprehensive approach to watershed protection, linking point and nonpoint source control programs. The plan's goals include reducing flood frequency, restoring salmon and steelhead populations, and developing the creek corridor as a refuge for wildlife. To meet these goals, the plan may include construction of passive treatment facilities, temporary storage facilities for stormwater, and revegetation of the stream corridor.

Osterman, Douglas, Frederick Steiner, Theresa Hicks, Ray Ledgerwood, and Kelsey Gray. 1989. "Coordinated Resource Management and Planning: The Case of the Missouri Flat Creek Watershed," *Journal of Soil and Water Conservation*, September-October 1989, p403-406.

This paper describes a working method of coordinated resource management and planning that has evolved from, and is being tested through, the Missouri Flat Creek Watershed Plan. The ultimate goal is to reduce and finally eliminate sediment and other agricultural runoff in Missouri Flat Creek. The strategy includes planning and implementing actions on a watershed basis; taking into consideration the social, political, economic, institutional, and biophysical processes of the area; implementing farm conservation plans on all of the cropland in the watershed; stabilizing the streambank and channel of the creek; and supplementing all actions with area wide education and information programs. Addressing the problem on a watershed basis provided a clear picture to farmers and planners of the dynamic natural and social interactions affecting soil erosion and water quality in the watershed. The watershed approach, combined with excellent communication, enabled planners to effectively target their efforts and united farmers in their attempts to reduce soil erosion. In addition, increased awareness, education and cooperation has enabled the farmers to reach consensus on goals for general resource management in the watershed.

Porter, Keith. 1994. "Development and Watershed Protection: Finding the Middle Ground," *Cornell Engineering Quarterly*, Spring 1994, p8-13.

An interdisciplinary team at Cornell University is researching several issues related to proposed protection measures for New York City's water supply, which were contained in regulations proposed by New York City's Department of Environmental Protection (NYCDEP) in 1990. Although it was intended to promote public debate, the document created a public uproar by residents of the nearly 2,000 square mile watershed. Degradation of the Croton reservoir system, located in Westchester and Putnam counties, has required filtration. To avoid the costs of filtration for the Catskill-Delaware part of the system, strict watershed management plans are required. One of the major threats to water quality are the phosphates used as fertilizers by farms, which cause eutrophication. Also, pathogenic protozoa may be spread by farm animals. The Cornell Pathogen Group is focusing on farm animals as vectors for water-borne disease. The Cornell group is also focusing on "whole farm planning", by bringing together specialists from a variety of fields to focus on farm management. New York City has provided $3.9 million for the first phase of a long-term demonstration program involving ten dairy farms, and has committed $35 million to the second phase. The theory behind "whole farm planning" has also been applied more widely, using the concept of "whole community planning" within the watershed. This effort was led by the Coalition of Watershed Towns and the NYC DEP. Although political issues have made progress difficult, a Cornell group and the City Department

of Regional Planning plan to use the research issues, which emerged from these studies, to continue work.

Robbins, Richard W., Joseph L. Glicker, Douglas M. Bloem, and Bruce M. Niss. 1991. Effective Watershed Management for Surface Water Supplies, Journal of the American Water Works Association.

This report is designed to assist water utility managers and local governments in developing effective watershed protection programs for their surface water supplies. It presents a detailed discussion of the management options and control measures that are available to limit the water quality impacts of land-use activities. It describes general control measures that apply to several types of land use, such as land acquisition, trespass control, watershed inspection programs, reservoir-use restrictions, stream and reservoir buffers, plan review, written agreements with landowners, and public education and involvement. The report also describes best management practices (BMPs) for agricultural land and silvicultural activities and structural and nonstructural nonpoint source controls. In addition, the report provides information on the implementation of watershed management programs. Finally, the report documents twenty-four case studies of effective watershed management programs used by water utilities or their cooperating jurisdictions to protect raw water quality.

U.S. Environmental Protection Agency. 1993. Guidance Specifying Management Measures For Sources of Nonpoint Pollution in Coastal Waters, USEPA, Office of Water. EPA-840-B-92-002, January 1993.

This document provides guidance on the implementation of management measures for the control of sources of nonpoint pollution. It addresses five source categories of nonpoint pollution: agriculture, silviculture, urban, marinas, and hydromodification. A variety of management practices are discussed for each source category. The guidance provides information on the applicability, selection, implementation, and effectiveness of each practice. In addition, one chapter discusses other management tools that are available to address many source categories of nonpoint pollution. These tools include the protection, restoration, and construction of wetlands, riparian areas, and vegetated treatment systems.

U.S. Environmental Protection Agency, Chesapeake Bay Program. 1993. "Role and Function of Forest Buffers in the Chesapeake Bay Basin for Nonpoint Source Management."

This document addresses the impact that urbanization and deforestation have had on water quality in the Chesapeake Bay. The EPA summarizes research from a variety of sources on the effectiveness of the riparian forest in reducing nonpoint source load in runoff and ground water. Most of the research has been done in agricultural watersheds or in connection with silvicultural activities. The document also describes the use of buffer strips as a management practice. Forest buffers are also recognized for their high value in wildlife and fish habitat and maintaining ecosystem integrity.

Whipple, William Jr. 1993. "Buffer Zones Around Water-Supply Reservoirs," *Journal of Water Resources Planning and Management*, 119(4):495-499.

This paper outlines the use of buffer zones to protect reservoir water quality from the effects of development and presents an approach to preclude development in a front buffer zone adjacent to a reservoir and the lower portions of the tributaries draining to the reservoir. Development in a wider zone up-slope from the front buffer would be required to implement special controls for nonpoint source pollution. This special control buffer zone would provide for reduction in pollution from the runoff that reaches the reservoir from channels and tributaries.

3.0 Modeling Land Use Impact on Source Water Quality

American Society of Civil Engineers Task Committee on Definition of Criteria for Evaluation of Watershed Models of the Watershed Management Committee, Irrigation and Drainage Division. 1993. "Criteria for Evaluation of Watershed Models," *Journal of Irrigation and Drainage Engineering*, 119(3):429-442.

This paper does not provide an overview of delineation methods; however, it does provide criteria and recommendations for evaluating site-specific hydrologic models. The ASCE Committee is seeking to promote a standard set of reporting criteria for descriptions of all watershed models. The report recommend that the following be addressed in all watershed model documentation:

- a complete description of model parameters, parameter selection, or discussion of the range of parameters describing hydrologic flow in the watershed;
- availability of the types of data needed to set up and run the model (e.g., readily available USGS gaging data);
- reports of model validation and testing and the range of conditions over which the model was tested; and
- the model results in relation to other models or modeling approaches.

Bou-Saab, Jamil F. 1993. "Runoff as a Resource," *Civil Engineering*, October 1993, p70-71.

This article examines the BMPs used by one university to reduce pollutant loads in storm water runoff and to use the runoff to recharge ground water sources of drinking water. Storm water flows typically contain significant quantities of the same pollutants found in wastewater and industrial discharges, making storm water an important factor in source-water and public-health protection. This article explores how BMPs can be used to treat runoff as a resource, controlling it on the surface rather than building treatment plants at the discharge point. The BMPs were designed to both reduce pollutant loads in runoff and to conserve water through ground water recharge. In addition, these BMPs had the effect of reducing storm water flows, increasing flood control and erosion protection, and lowering costs for storm water storage and transport.

Cooper, A. Bryce and Adelbert B. Bottcher. 1993. "Basin-Scale Modeling as Tool for Water-Resource Planning," *Journal of Water Resources Planning and Management*, 119(3):306-323.

This paper describes the development of a basin-scale model designed to simulate long-term average losses of water, sediment, and nutrients from large, rural watersheds. The CREAMS model (Chemicals, Runoff, and Erosion from Agricultural Management Systems) was used. This model incorporates diffuse and point sources and riparian and stream channel processes. The model was accurate in predicting the direction and magnitude of changes resulting from implementation of a riparian pasture retirement scheme (a BMP used in New Zealand). Model predictions of soluble nutrient losses were sensitive to variation in stream attenuation coefficients, and users are cautioned that uncertainties in watershed and riparian processes can affect model results.

DeVantier, Bruce A., and Arlen D. Feldman. 1993. "Review of GIS Applications in Hydrologic Modeling," *Journal of Water Resources Planning and Management*, 119(2):246-261.

This paper describes applications of GIS technologies to support hydrologic modeling. The GIS data architecture provides a digital representation of watershed characteristics. This paper summarizes applications of GIS-based digital terrain models to support hydrologic analyses. Three methods of geographic information storage are discussed: raster or grid, triangulated irregular network, and contour-based line networks. The computational, geographic, and hydrologic aspects of each data-storage method are analyzed. The use of remotely sensed data in GIS and hydrologic modeling is also reviewed. Lumped parameter, physics-based, and hybrid approaches to hydrologic modeling are discussed with respect to their geographic data inputs.

El-Kadi, Aly I. 1989. "Watershed Models and Their Applicability to Conjunctive Use Management," *Water Resources Bulletin*, 25(1):125-137.

This paper assesses the applicability of typical watershed hydrograph models to provide data on ground water recharge to support conjunctive use management. The paper assesses the degree to which 28 models, including HEC-1, CREAMS, and HSP, allow for estimations of the conjunctive use of ground water and surface water resources. The author concluded that the large number of processes that these models simulate prohibits detailed analysis of subsurface flow, due to excessive computer and data requirements. The models emphasize surface flow and include only that portion of water lost to the subsurface and the portion returned to the stream as baseflow. These models do not easily accommodate the impacts of conjunctive use, although the paper does describe a framework for including these considerations in watershed models.

Engel, B. A., R. Srinivasan, J. Arnold, C. Rewerts, and S. J. Brown. 1993. "Nonpoint Source (NPS) Pollution Modeling Using Models Integrated with Geographic Information Systems (GIS)," *Water Science & Technology*, 28(3-5):685-690.

This paper assesses three nonpoint source pollution models which were integrated with a GIS and used to simulate a watershed response to a series of rainfall events. Simulated responses were compared with actual runoff and sediment data from observed events, and were found to match reasonably well. ANSWERS (Areal Nonpoint Source Watershed Environmental Response Simulation), AGNPS (Agricultural Nonpoint Source Pollution), and SWAT (Soil and Water Assessment Tool) were used and integrated with the GRASS GIS. ANSWERS was developed primarily for agricultural watershed analysis, AGNPS analyzes nonpoint source pollution in agricultural watersheds, and SWAT is another watershed model that is flexible in watershed configuration. The match between observed and simulated results was noted, especially since inputs were estimated using GIS data and were not calibrated for the particular watershed.

Etzel, Ronald A., and Ginger K. Ellis. 1990. "Comprehensive Watershed Management Planning - A Case Study - The Magothy River." In Riggins, Robert E., et al., editors. Watershed Planning and Analysis in Action, *Proceedings of the Symposium sponsored by the Committee on Watershed Management of the Irrigation and Drainage Division of the American Society of Civil Engineers, Durango, Colorado, July 9-10, 1990.*

This paper examines existing hydrologic, hydraulic, and environmental conditions in the Magothy River Watershed to estimate impacts of future development. The objectives of the Magothy River Comprehensive Watershed Management Plan Study were to: identify existing water quality, flooding and sedimentation problems; evaluate the interaction of upstream flows and water quality with estuarine flows and water quality of the river to reduce upstream pollutant loadings; and identify and evaluate existing and potential management strategies, recommend appropriate strategies, and compose a master plan for overall guidance. Estuary dynamics were modeled using a mathematical simulation and calibrated by comparing results with those of a dye study. From this, it was concluded that concentrations of pollutants were diluted in the river and the effects of pollutant loads were seen at the mouth of the tributaries. Historic data and Nationwide Urban Runoff Program data were used to assess existing water quality, which met state standards, although water uses were restricted in certain locations. Soil Conservation Service methodology was used to determine existing and future stormwater runoff rates and volumes, erosion, sedimentation, and flooding potential. Of the 18 subareas analyzed, 11 showed reaches of stream channel erosion. No sedimentation problems in the streams were noted, although sedimentation has become a problem at the tidal interface. Twelve flood prone areas were identified; these were usually roadways with undersized culverts. Common watershed management approaches, such as stormwater facility management projects, were easily cited, while more difficult management approaches, such as land use zoning changes and BMP ordinances, were only suggested.

Gburek, William J. 1983. "Hydrologic Delineation of Nonpoint Source Contributing Areas," *Journal of Environmental Engineering,* 109(5):1035-1048.

This paper describes a model that determines the area of a watershed that contributes surface runoff to a stream after a rain storm. The paper describes steps taken to develop the return period within a watershed, and the potential for nonpoint source pollution to enter the stream. Design rainfall data and initial watershed soil moisture content are used as inputs. The model is demonstrated using a small, agricultural watershed in east-central Pennsylvania. Areas of the watershed having the potential to deliver surface-applied contaminants to the stream channel for one-hour storms at different periods of occurrence (1 to 25 year occurrence periods) are delineated, and travel distances are compared between different areas of the watershed.

Griner, Axel J. 1993. "Development of a Water Supply Protection Model in a GIS," *Water Resources Bulletin*, 29(6):965-971.

This paper describes a water supply protection model developed using the Southwest Florida Water Management District's ARC/INFO GIS software. Several hydrologic and hydrogeologic layers were overlaid to develop maps showing ground-water supply suitability, protection areas for surface water supply, protection areas for major public supply wells, susceptibility to contamination, and recharge to an aquifer. Protection areas for surface water supply were derived for 11 existing and potential withdrawal points. The most critical areas were those immediately adjacent to rivers and their tributaries upstream from the withdrawal point. Actual delineations of these

areas were determined by generating buffers around the stream courses. Wellhead protection areas were also delineated.

Houlahan, John, W. Andrew Marcus, and Adel Shirmohammadi. 1992. "Estimating Maryland Critical Area Act's Impact on Future Nonpoint Pollution Along the Rhode River Estuary," *Water Resources Bulletin*, 28(3):553-567.

The authors present the results of a study assessing the impact of the Maryland Critical Area Act on the generation of nonpoint source loads of phosphorus, nitrogen, and sediment to the Rhode River Estuary. Three different nonpoint simulation models (CREAMS, Simple Method, and Marcus/Kearney regressions) were used to estimate the generation of annual areal nutrient and sediment loadings under four development scenarios. The Simple Method Model was used to estimate generation of nitrogen and phosphorus loads from developed and forested areas. Sediment erosion from non-agricultural lands was estimated using Marcus and Kearney's regressions for suspended sediment data derived from continuous suspended sediment collected at seven sites between 1975 and 1987. The CREAMS model was used to model nitrogen, phosphorus, and sediment from farmland. Development conditions modeled included: present conditions, maximum land use development allowable with the Critical Area Act, and two development scenarios without the Act's restrictions in place. Results indicate that the Act can reduce the present generation of nonpoint nutrient and sediment loadings 20 to 30 percent from the regulated area, while preserving agricultural lands and allowing limited development. This reduction is primarily due to agricultural BMPs. Impacts of the Act are even greater when compared with unregulated future development, primarily through limiting uncontrolled woodland cutting.

Kimball, Kathleen, and Doug Beyerlein. 1990. "Intergovernmental Agreements in Watershed Planning." In Riggins, Robert E., et al., editors. Watershed Planning and Analysis in Action. *Proceedings of the Symposium sponsored by the Committee on Watershed Management of the Irrigation and Drainage Division of the American Society of Civil Engineers, Durango, Colorado, July 9-10, 1990.*

Cooperative efforts among three communities in Washington are described. A detailed inventory of the drainage network was performed, and slopes of culverts were noted for use in modeling. An existing USGS model for Scriber Creek was used as a starting point of the inventory; the watershed was split into subbasins, the model was calibrated using two years of streamflow and rainfall data, and peak stream flows were used to assess the impact of land use changes on flood peaks. Recommendations in the watershed plan included structural and non-structural solutions to increased flood peaks caused by land-use changes. Structural solutions included regional detention facilities and local conveyance-systems improvements, while nonstructural solutions included public information programs, ordinances and guidelines for BMPs. Specific BMP recommendations included: new policies regarding revegetating roadside ditches, expansion of existing regulations for clearing and grading, and ordinances for buffers and nature-protection growth areas adjacent to riparian zones.

Kuo, Chin Y., Kelly A. Cave, and G. V. Loganathan. 1988. "Planning of Urban Best Management Practices," *Water Resources Bulletin*, 24(1):125-132.

This paper describes a user friendly computer model that was developed to compare the feasibility and cost effectiveness of alternative urban nonpoint source pollution control measures. The model determines the effectiveness of individual BMPs and addresses concerns about management strategies for combining facilities into an effective basin-wide control program. The model is a tool that allows planners to select the size, location, and type of BMP and to plan land uses to meet stormwater quantity and quality requirements. The model generates hydrographs and pollutographs at the basin and sub-basin outlets for the present and the post-development conditions, and with or without BMP measures. The model includes detention basins, infiltration trenches, and porous pavements. In general, it was found that the extended wet ponds were the most cost effective controls of the measures evaluated.

Lackaff, Beatrice B., Bruce J. Hunt, and Ian E. Von Essen. 1993. "The Development and Implementation of a GIS-Based Contaminant Source Inventory over the Spokane Aquifer, Spokane County, Washington," *Water Resources Bulletin*, 29(6):949-955.

This study describes the use of GIS in the development of a protection program for a large and contaminant sensitive underground source of drinking water. Because of its extremely high transmissivity, all wells in the Spokane-Rathdrum Aquifer are included in one wellhead protection zone called the Aquifer Sensitive Area (ASA). Because of the large area and population within the ASA, the use of GIS technology and existing datasets was required to create a Contaminant Source Inventory (CSI) for the ASA. Datasets listing businesses and agencies within the ASA were imported into the GIS from State, county, city, and local agencies. These datasets were selected, joined, and sorted using GIS relational database capabilities into one ASA "business master file." Map files were projected and transformed into common coordinates. Next, business sites within the master file were spatially related by address to the digital map files. Likely Critical Materials Users (CMU) were identified by sorting on selected Standard Industrial Codes (SIC). Additional files of CMUs were imported into the Contaminant Source Inventory. Geographic Information System queries were performed to locate specific materials, quantities, and storage facilities, and to analyze CMU activity within selected buffer zones. The GIS technology was critical in this project in the development, management, maintenance, and analysis of the vast quantities of data associated with this aquifer protection program. The GIS proved to be a valuable tool for future resource and land use planning.

Summer, R. M., C. V. Alonso, and R. A. Young. 1990. "Modeling Linked Watershed and Lake Processes for Water Quality Management Decisions," *Journal of Environmental Quality*, 19:421-427.

This paper describes the use of a watershed, agricultural nonpoint source model, AGNPS, and a lake model, FARMPND, to link watershed and lake processes and to assess effects of various land use practices and weather conditions. Parameters used in the AGNPS model were: hydrology, erosion, nitrogen and phosphorus transport, sediment transport, and chemical oxygen demand. These variables provided input for the lake model, which simulated temperature stratification, mixing by wind, sedimentation, inflow density current, and algal growth. Outflow from the lake provides input to downstream segments in the watershed model. Simulations were conducted on Eagle Lake watershed in west central Minnesota. Changes in water quality were examined by modifying land area in wetlands and land area with retired cropland (permanent grass cover with terraces). Less volume of runoff and less transported sediment were noted under wetland versus non-wetland conditions, and improvements in water quality of both in-lake and outflow were noted with more erodible cropland taken out of use.

Tim, Udoyara S. and Robert Jolly. 1994. "Evaluating Agricultural Nonpoint-Source Pollution Using Integrated Geographic Information Systems and Hydrologic/Water Quality Model," *Journal of Environmental Quality*, 23:25-35.

This study describes integration of the AGNPS model with a GIS to analyze nonpoint source pollution in an agricultural watershed. The GIS organized the data spatially, while the AGNPS model was used to predict soil erosion and sedimentation within a watershed. The model and GIS were used to evaluate the impact of BMPs implemented in a watershed in Iowa, where agricultural runoff was creating sedimentation. Several land management strategies were simulated, including the use of vegetative filter strips along the primary streams (strategy 1), using contour buffer grass strips on all cropland areas (strategy 2), and combining the first two strategies (strategy 3). Strategy 3 yielded the highest sediment load reduction (71 percent), while contour buffer strips alone would not make an appreciable difference in sedimentation improvement. The study concludes that the GIS and the model are powerful interpretive tools, and are useful in providing a framework for assessing the effectiveness of several land management strategies; however, the time investment may be considerable.

U.S. Environmental Protection Agency. 1984. "Modeling Water Quality and the Effects of Agricultural BMPs (Best Management Practices) in the Iowa River Basin," EPA-600/D-84-112.

This paper describes a demonstration application of comprehensive hydrology and water quality modeling on a large river basin, to evaluate the effects of agricultural nonpoint pollution and proposed BMPs. The model application combines detailed simulation of agricultural runoff and soil processes, calculates surface and subsurface pollutant transport to receiving water, and simulates instream transport and transformation. The result is a comprehensive simulation of river basin water quality. The investigation of the Iowa River Basin described in this paper was part of a large study which included application, and evaluation, of the Hydrological Simulation Program -- FORTRAN (HSPF). The HSPF was applied to, and evaluated at, the data-intensive Four Mile Creek watershed and at the Iowa River above Coralville Reservoir. This study allowed the exploration of problems associated with modeling hydrology, sediment transport, and chemical fate and transport in a large river basin with varying meteorologic conditions, soils and agricultural practices.

4.0 Time-of-Travel Calculation

Lindsley, R.K. 1985. Hydrology for Engineers. McGraw-Hill. New York.

This text describes methods for calculating stream velocity based on channel size, channel roughness, gaged discharge rates, and regional topography, to assist in determining time-of-travel estimates for spills or other releases. This text also describes available stream stage and gaging data, and methods for interpolating between gaged data in order to estimate discharge and velocity in ungaged reaches.

U.S. Government Printing Office. 1995. Code of Federal Regulations, 40 CFR Section 112: Oil Pollution Prevention, Appendix C-III: Calculation of the Planning Distance.

This regulation provides guidance for determining if an oil storage or transport facility is located at a distance such that a discharge from the facility would result in the shutdown of a public drinking water intake. The method discussed takes into account river velocity, the material discharged, and a planning "time-of-travel." This method may be applied to determining travel time from points upgradient of the intake.

Appendix 3

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