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Delineation of Source Water Protection Areas, A Discussion for Managers;

Part 1: A Conjunctive Approach for Ground Water and Surface Water

DELINEATION OF SOURCE WATER PROTECTION AREAS, A DISCUSSION FOR MANAGERS

PART 1: A CONJUNCTIVE APPROACH FOR GROUND WATER AND SURFACE WATER

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INTRODUCTION

The quality of surface water used for drinking and other purposes is determined by the quality of the water that is received from overland flow, upstream surface water and ground water. Drinking water withdrawn from surface-water sources, the fishability and swimability of surface waters, and ecosystems all rely on the protection of upstream surface-water quality and the protection of the quality of the upgradient ground water that discharges to, and therefore effects the quality of, upstream surface water. This range of varied uses underscores the many different demands on the hydrologic cycle from human activity and ecosystem needs. Of particular concern to state and local governments is assessment of the areas which may need heightened protection from contamination of the ground water upgradient, and the surface water upstream, of specific "critical-use sites" (CRUSs). Such CRUSs might be, for example, surface-water-supplied drinking-water intakes, endangered-species habitats and fresh-water fishing areas.

In protecting CRUSs, it is important to understand the nature of the Zones Of ground-water Contribution (referred to as "ZOC"s in this document) to surface water which underlie and border rivers, lakes and reservoirs. Although ground water may travel very slowly, all flowing ground water that is not transpired by plants, evaporated near the land surface or withdrawn by wells, given enough time, ultimately discharges to surface water bodies (Figure 1). Delineation of a ground-water ZOC within this ground-water continuum is difficult and must be based on management needs, in addition to hydrologic and geologic considerations. These ZOCs are often areas vulnerable to contamination from human economic activities that do not recognize the interaction of the components of the hydrologic cycle. In contrast to the difficulty encountered in the delineation of ground-water ZOCs, the areas that contribute surface water to rivers, lakes and reservoirs are usually relatively easy to delineate.

Purpose of Delineated Protection Areas

Delineating and assessing protection-area boundaries around source areas of ground-water supplies or surface-water supplies provides water-resource managers with lead time to intervene when a water supply has been contaminated. Protection-area boundaries also provide some degree of natural remediation of the water. Ground water in most hydrogeologic settings undergoes natural remediation over a longer period of time than does surface water. Many of the natural remediation processes present in ground water are similar to those in surface water. However, the slow movement of ground water (generally feet/year, under natural conditions), in most non-karst[1] settings, provides more time for natural in-situ remediation than does the rapid movement of surface water. Natural protection of surface water depends principally on dilution and on exposure of contaminants to natural remediation for periods that, in most cases, do not exceed hours or days. Thus, these natural processes should be considered when delineating protection areas.

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[1] Karst is a "type of topography that is formed over limestone...by dissolution, and that is characterized by sinkholes, caves, and underground drainage." (Bates and Jackson, 1984) An aquifer with such features is informally called a karst aquifer.

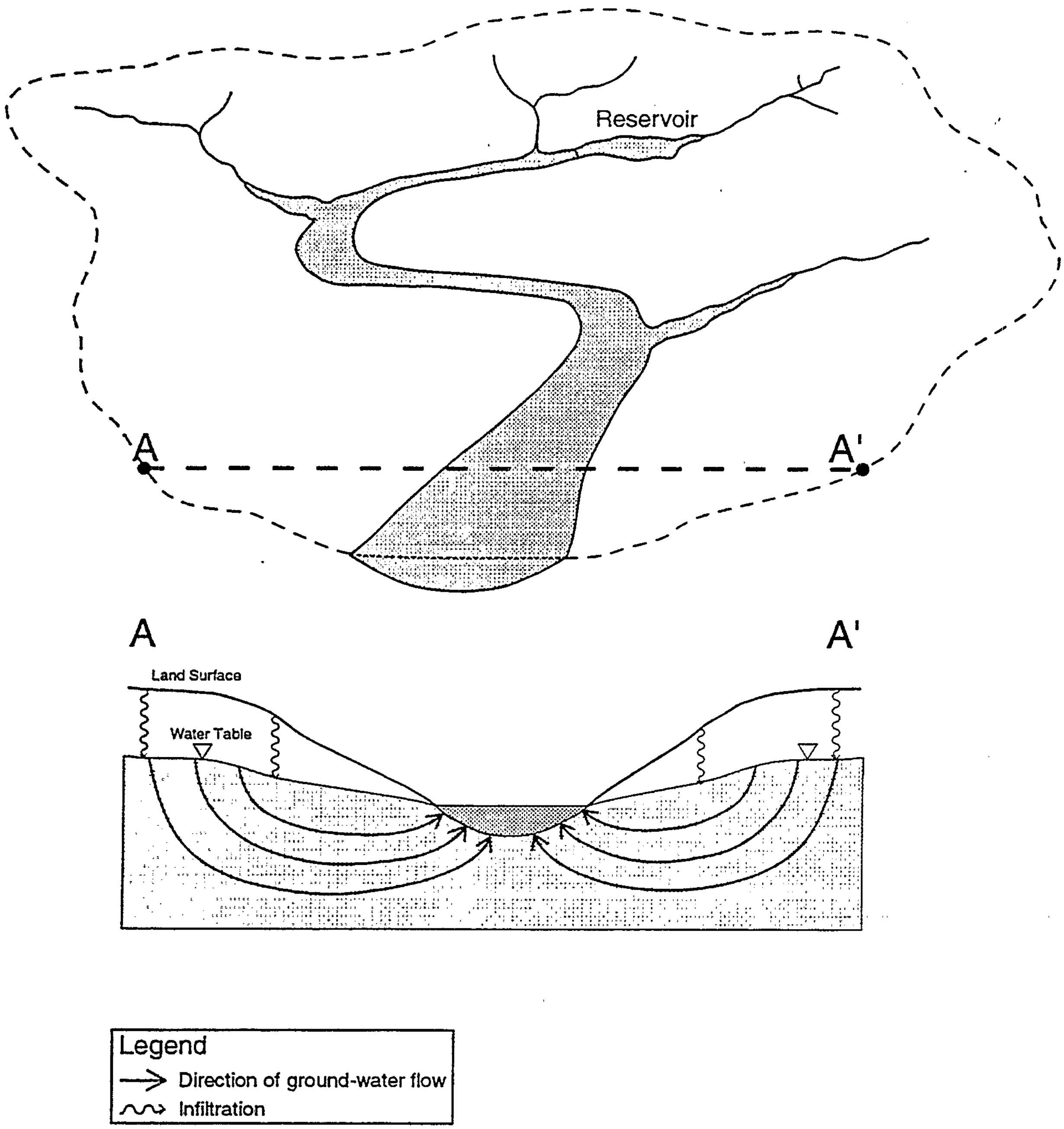

Figure 1. Ground-water flow paths between a ground-water recharge area and a stream. (In this setting the geographic position of the ground-water basin boundary approximates that of the surface-watershed boundary.)

Such natural processes for ground water begin as the water percolates through the unsaturated zone, with some contaminants, such as nutrients, being removed through vegetative uptake. The ground water is also exposed to physical and biochemical processes that provide some degree of in-situ remediation, such as adsorption of contaminants by soils, and breakdown of contaminants by chemical reactions and by soil organisms. Ground water in most non-karst settings is similarly afforded in-situ remediation when it reaches the saturated zone. There, ground water: 1) flows slowly enough to allow time for at least partial degradation of some contaminants (e. g., by radioactive decay and microbial inactivation), 2) moves tortuously, making contact with rock surfaces that adsorb contaminants, 3) undergoes dilution mixing of contaminated and uncontaminated waters as it flows away from a contamination source, and 4) flows through the fine pores of an aquifer matrix with the resultant sieving (filtering out) of some microbes and particulates. If management decisions allow ground-water based protection areas of adequate size, ample time will be available for: natural in-situ remediation of many contaminants, deepening or relocating a well threatened by the encroachment of contaminated ground water, or taking remedial actions to manage contamination.

Many of the natural remediation processes acting on ground water also act on surface water, for example, dilution, dispersion and biological or biochemical inactivation. Additionally, such processes as volatilization of VOCs, digestion by protozoa, and photolysis may improve water quality, and contaminant-laden particles may settle out of a stream and be deposited onto the streambed. Surface-water quality is also improved by the deposition of particulates filtered out by vegetation intercepted in the overland flow path. Vegetation also slows overland flow, providing more time for overland flow to be recharged to the ground-water reservoir.

In part because of these natural processes, the ground-water and the surface-water pathways present very different management challenges. In spite of natural remediative processes, once contaminated, the ground-water reservoir may be permanently degraded or require costly augmented remediation. In general, the surface-water pathway allows less time for natural remediation; however, contaminant spills or discharges into surface water quickly move past CRUSs, although perhaps after causing irreparable damage. Therefore, successful protection of CRUSs requires the conjunctive protection of the upgradient ground water that contributes to surface water and of the upstream surface water. Such protection may encompass the entire surface watershed upstream of the CRUS (this area is called the watershed area, see Figure 2) and areas of ground-water contribution that may extend beyond the upstream surface watershed.

Where the management goal is protection of surface-water supplied drinking water, the CRUS is a drinking-water intake. The surface area draining to the intake is called the source-water protection area (SWPA). 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 EPA also stated that the SWPA for a surface-water

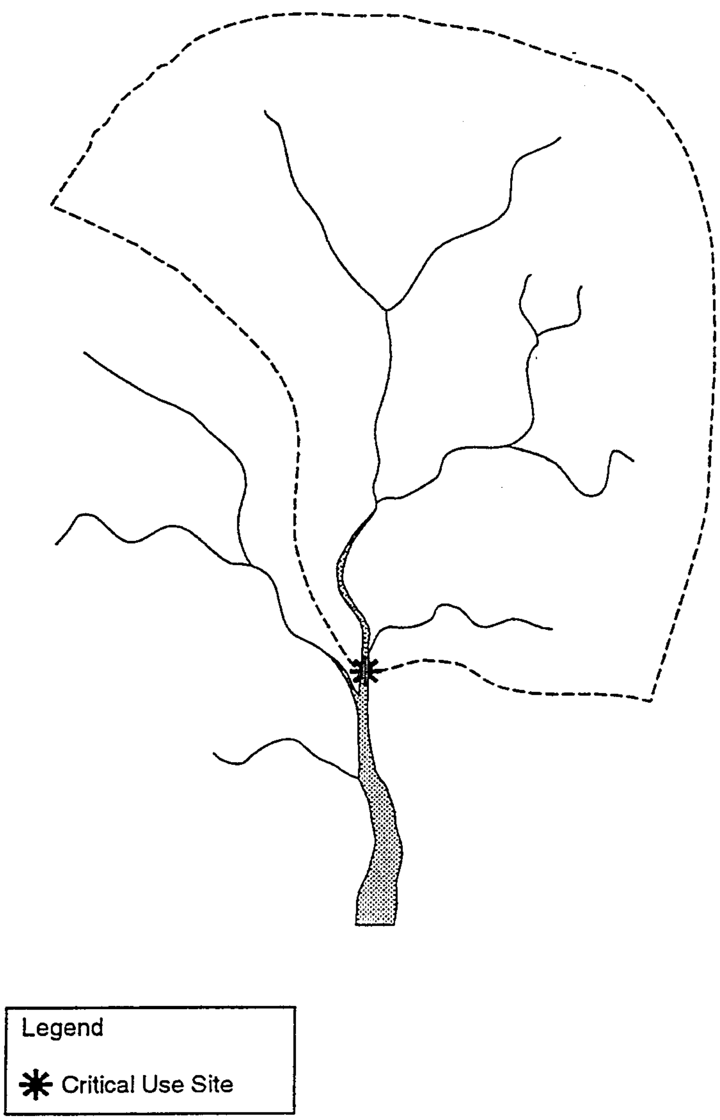

Figure 2. Boundary of the watershed area contributing to a critical-use site.

supplied CRUS [that is, a drinking-water intake] will be delineated topographically.) For settings in which the areas of ground-water contribution to a PWS intake extend beyond the surface watershed boundary, complete protection of the drinking-water intake might also extend beyond that boundary. (The EPA encourages states to work cooperatively to protect SWPAs extending across state borders, and to consider protecting areas beyond the surface watershed boundary, if the ground-water basin boundary is external to the SWPA.) In this document, the term source-water protection area is used to identify the area delineated to assess and protect not only drinking-water intakes, but also any other type of CRUS.

Goal of This Document

The goal of this document is to provide combined ground-and-surface water delineation approaches to assist states in determining the areas that should be assessed, in order to identify those areas that need heightened management of contaminant sources to help protect CRUSs. The first part of this document presents protection-area boundary delineation approaches and methods. The second part of this document (to be published separately) presents case studies demonstrating the development of SWPAs, extended SWPAs and SWPA segments for the protection of CRUSs in the Nanticoke-Blackwater River Basins in Maryland and Delaware.

Presented below are several methods for delineating, for management/assessment purposes, the area of ground-water contribution to surface water, the area that supplies surface water to a CRUS, and SWPA segments. Approaches to combining surface-water delineation and ground-water delineation methods are also described. States and communities can do both surface-water and ground-water conjunctive delineation in order to achieve complete protection. That is, management to protect the two interrelated water resources is facilitated when ground-water protection-area boundaries and surface-water protection-area boundaries are combined.

In the following pages, Part 1 discusses: 1) combined ground-water/surface-water approaches to delineating SWPAs that best meet state/local protection needs; 2) methods for delineating a ground-water boundary to protect the quality of the ground-water sources that impact drinking water, riparian habitat and fresh-water recreation areas; 3) methods for delineating a surface-water boundary to protect the quality of the surface-water sources (rivers, lakes and reservoirs) that impact drinking water, riparian habitat and fresh-water recreation areas; and 4) methods for segmenting SWPAs to facilitate differential management of potential contaminant sources.

PART 1
PROTECTION-AREA BOUNDARY DELINEATION

Introduction

KEY TERMS, AS USED IN THIS DOCUMENT	
Segment	a subarea delineated within a source-water protection area
Watershed area	the portion of a watershed uphill of a point of interest (for example, a critical-use site) on a stream; that portion of a watershed that drains to a point of interest on a stream
Buffer zone (or setback)	1) the area between a reservoir and a boundary around, and at some distance from, the reservoir, 2) the area within two boundaries, one on either side of a stream; these boundaries extend along some portion, or the total length, of the stream

Under the 1996 Safe Drinking Water Act Amendments, source-water protection areas (SWPAs) will be delineated for all public water supplies (PWSs). Some of these are wellhead protection areas, others are surface-water areas. In a Wellhead Protection (WHP) Program[3], a wellhead protection area (WHPA) is defined around a public water-supply (PWS) well or wellfield (a well or wellfield is the critical-use site [CRUS] of the WHP Program); sources of contamination are managed within the WHPA. The purposes of the WHPA are to allow natural remediation of contaminated ground water before it reaches a well, and/or to allow time to relocate or deepen a well or to implement remediation measures. Most states have chosen to delineate "tiers" of WHPAs. That is, the WHPAs have inner zones, outer zones and, in some states, intermediate zones. Management of contaminant sources becomes increasingly stringent from the outer to the inner zone.

A surface-water protection area would also be delineated about a CRUS; and, as in a WHP Program, sources of contamination would be managed within the SWPA. A "tiered" approach to CRUS protection in these surface water areas, therefore, would be analogous to the WHP approach. Tiers of protection about the CRUS would provide the opportunity for flexibility while allowing the most protection where it is most needed. The EPA recognizes

[3]Those readers unfamiliar with the Wellhead Protection [WHP] Program or WHP approaches are referred to "Guidelines for Delineating Wellhead Protection Areas" [U.S. Environmental Protection Agency, 1987a] and "Guidance for Applicants for State Wellhead Protection Assistance Funds Under the Safe Drinking Water Act" [U.S. Environmental Protection Agency, 1987b]. Currently, there are forty three states and two territories with an approved WHP Program.

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.

The conjunctive use of ground-water protection-area boundaries and surface-water protection-area boundaries can facilitate implementation of CRUS-protection efforts by segmenting SWPAs into smaller assessment/management units (that is, segments and subsegments). States have the opportunity to creatively combine ground-water and surface-water boundaries to meet state environmental needs. Various approaches to conjunctively delineating and segmenting a SWPA may be possible; two are presented below. These are the Combined Ground-Water/Surface-Water approach and the Combined Nested-Watershed Area/Ground-Water Flow approach.

Combined Ground-Water/Surface-Water Approach

In the "Combined Ground-Water/Surface-Water" approach, ground-water and surface-water boundaries define a series of segments that are at increasing distances from the CRUS. This approach facilitates reduction of contaminant-source controls with increasing distance from the CRUS.

In this approach, four different delineation scenarios can occur: the selected Zone of ground-water Contribution (ZOC) boundary approximately coincides with the watershed-area boundary; the selected ZOC boundary is within the watershed-area boundary; the selected ZOC boundary is external to the watershed-area boundary; and the selected ZOC boundary is in-part within, and in part external to, the watershed-area boundary.

Table 1 presents an example demonstrating this approach to CRUS protection. This approach is analogous to the tiered approach many states have chosen for delineating WHPAs. (In this Table, the ZOC boundary is based on ground-water time of travel [TOT] and has been given a specific value [10 years], to aid reader comprehension.)

The delineation approach depicted in Table 1 is equally applicable to protecting surface-water-supplied drinking-water intakes, endangered-species habitats and recreational areas. Protection of drinking-water intakes can be enhanced by calculating (1) the streamflow-TOTs and distances needed for sufficient remediation of upstream streamborne contaminants, and 2) the streamflow TOT available for a water supplier to respond to an upstream contaminant spill.

TABLE 1

Combined Ground Water/Surface-Water-Time-of-Travel Approach

Example Comparison of Wellhead Protection Area Boundaries, With Source Water Protection Area Boundaries that Conjunctively Protect Ground Water and Surface Water

(The selected ZOC boundary is the ground-water TOT boundary.)

Tier	WHPA Boundary	SWPA Boundary for a CRUS: Watershed-area boundary is in a similar position to (10-yr GW[4] TOT) ZOC boundary	SWPA Boundary for a CRUS: Watershed-area boundary is within (10-yr GW TOT) ZOC boundary	SWPA Boundary for a CRUS: Watershed-area boundary is external to (10-yr GW TOT) ZOC boundary	SWPA Boundary for a CRUS: Watershed-area boundary is alternatively within and external to (10- yr GW TOT) ZOC boundary
Inner Zone (Management Zone)	200 ft from well	setback from stream (upgradient of CRUS) equals 200 ft	setback from stream (upgradient of CRUS) equals 200 ft	setback from stream (upgradient of CRUS) equals 200 ft	setback form stream (upgradient of CRUS) equals 200 ft
Middle Zone (Management Zone)	10-yr GW TOT boundary	watershed-area boundary	watershed-area boundary	10-yr GW TOT ZOC boundary	inner-most geographic extent of superimposed 10-yr GW TOT ZOC and watershed-area boundaries (see Figure 3)
Outer Zone (WHPA/SWPA)	20-yr GW TOT boundary or hydrologic boundary	watershed-area boundary (note that in this scenario there is no distinct Middle Zone)	watershed-area boundary (note that in this scenario there is no distinct Middle Zone)	watershed-area boundary	watershed-area boundary (see Figure 3)
Extended Protection Zone	----	watershed-area boundary	10-yr GW TOT ZOC boundary	watershed -area boundary	outermost geographic extent of superimposed 10-yr GW TOT ZOC and watershed-area boundaries (see Figure 3)

[4] GW = Ground Water

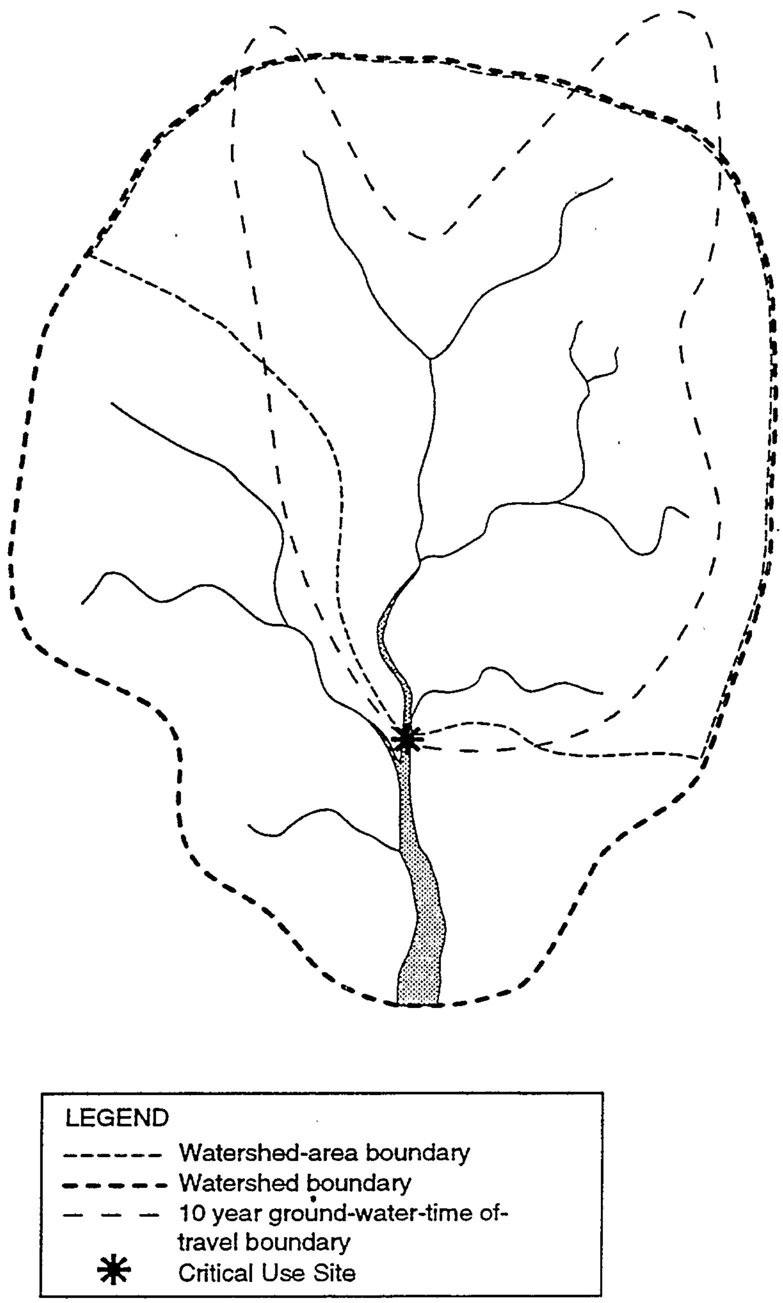

Figure 3. Watershed showing watershed-area and 10-year ground-water time-of-travel boundaries.

Combined Nested-Watershed Area/Ground-Water Flow Approach

In this approach, segment boundaries are the boundaries of progressively embedded (nested") watersheds, delineated at increasing distances upgradient from the CRUS (Figure 4). One or more ground-water ZOC boundaries along the stream are superimposed on, and intersect, the nested-watershed boundaries (the intersection of ground-water and nested watershed boundaries creates subsegments). This approach facilitates differential management of subsurface contaminant sources and surficial contaminant sources. Figure 5 depicts an example segmented SWPA; in this example, the ground-water setback is based on a TOT. In this approach, although nested-watershed boundaries are topographically defined, ground-water boundaries could be based on the same criteria and thresholds that are used in a state's WHP Program.

Methods for Delineating Ground-Water Boundaries to Protect the Quality of Ground-Water Sources Upgradient of Critical-Use Sites

Protection of CRUSs should recognize that ground water (via base flow to streams) is generally a component, possibly a major one (and during some parts of the year, possibly the only component), of streamflow. Therefore, ground-water quality may significantly impact the quality of surface water.

Defining a ground-water ZOC is difficult, because with the exception of very, very deep water, much of which was emplaced millions of years ago, all ground water not withdrawn by wells or lost to evapotranspiration will ultimately be discharged from the ground-water reservoir to the ocean or to other surface-water bodies. In any regional setting, the deeper that ground water flows into the ground-water reservoir, the further ground water travels before discharging, and the greater the stream (the higher the "order" of the stream in the "nesting" hierarchy) to which it discharges (Figure 6). That is, deep ground water will discharge to a large regional stream draining a large watershed, and shallow ground water will discharge to a local tributary draining a local "nested" watershed. Thus, not only shallow, but also deep, ground waters will become surface water. (Conversely, surface water not lost to evaporation, runoff to the ocean, or pumping [or other human/animal-induced capture] will recharge the ground-water reservoir; this occurs most noticeably during periods of high stream flow.)

In order to facilitate protection of water supplies that have a ground-water component, states and communities may, for management purposes, want to designate a boundary for the difficult-to-define zone of ground-water contribution. Several such boundaries could be considered:

- Floodplain boundary setback for perhaps the 20-, 50- or 100-year flood -- this area would be wide where floodplains are flat or flooding is frequent, and narrow where flood plains are steep or flooding is rare. Although the floodplain defines the area over which surface water may infiltrate into the ground-water reservoir, the extent of a floodplain is not related to the area through which ground water contributes to surface water. Additionally, the selection of one

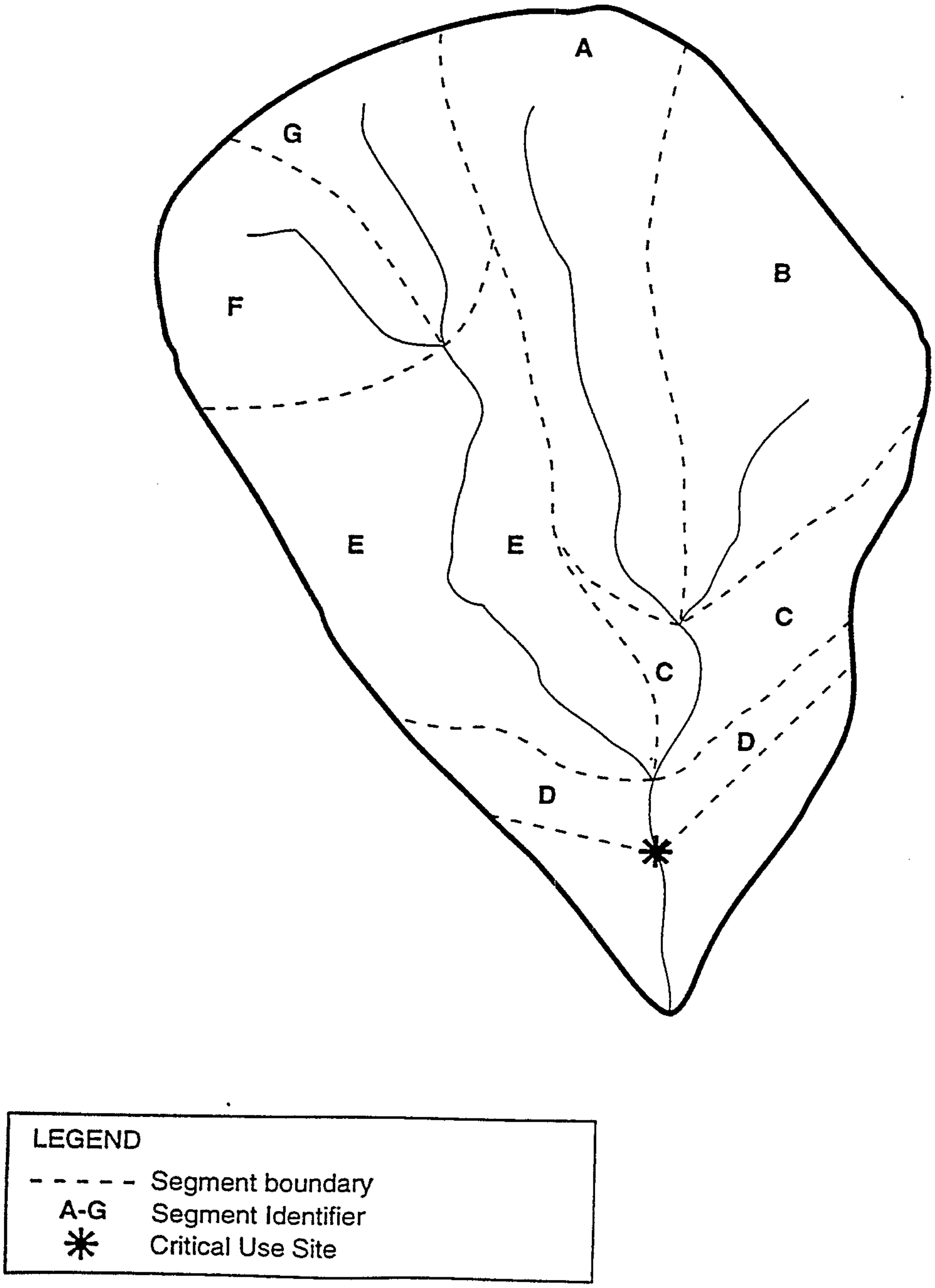

Figure 4. Watershed area showing a source-water protection area divided into time-of-travel management segments.

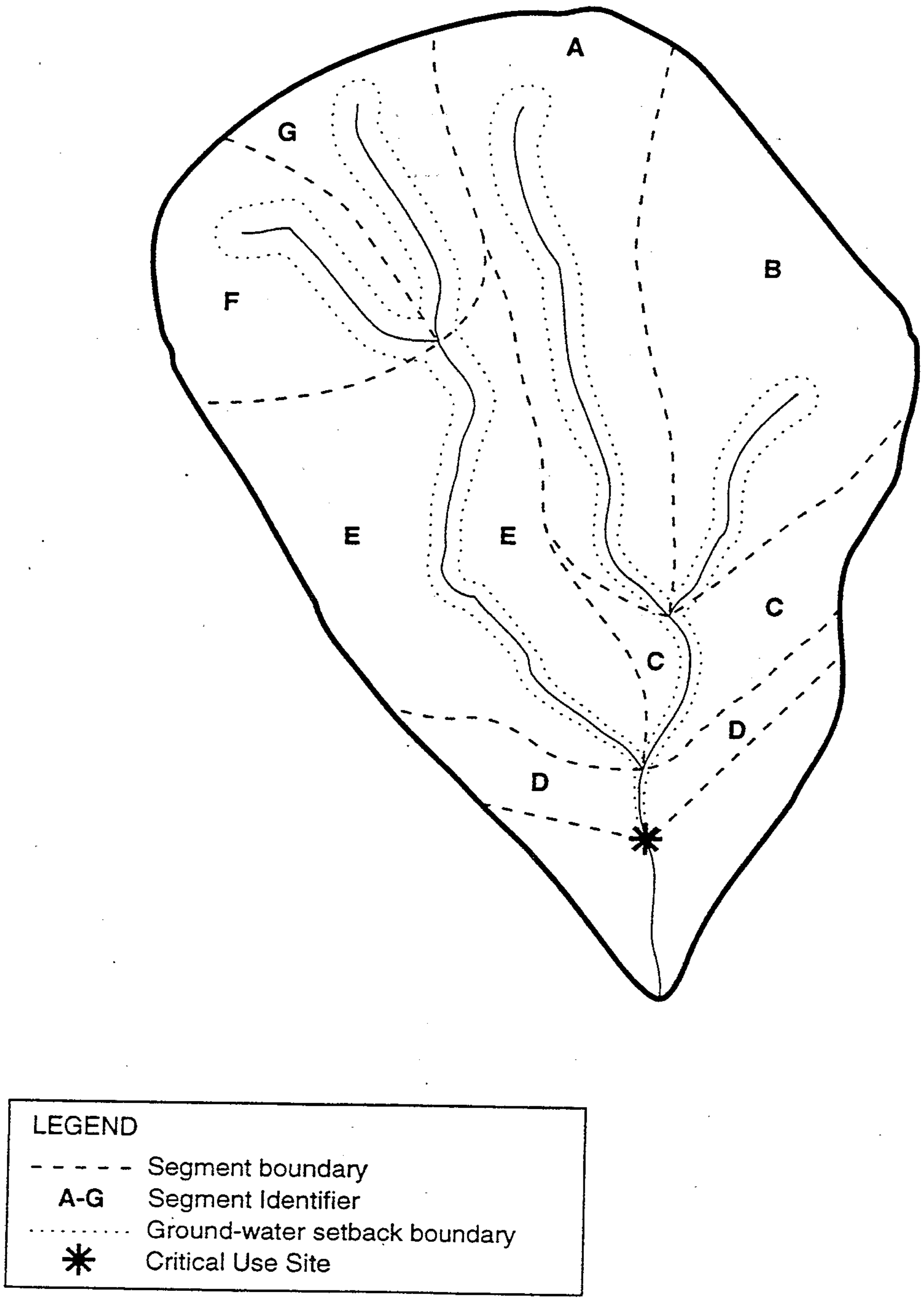

Figure 5. Watershed area showing time-of-travel segment boundaries and a ground-water time-of-travel setback from the stream.

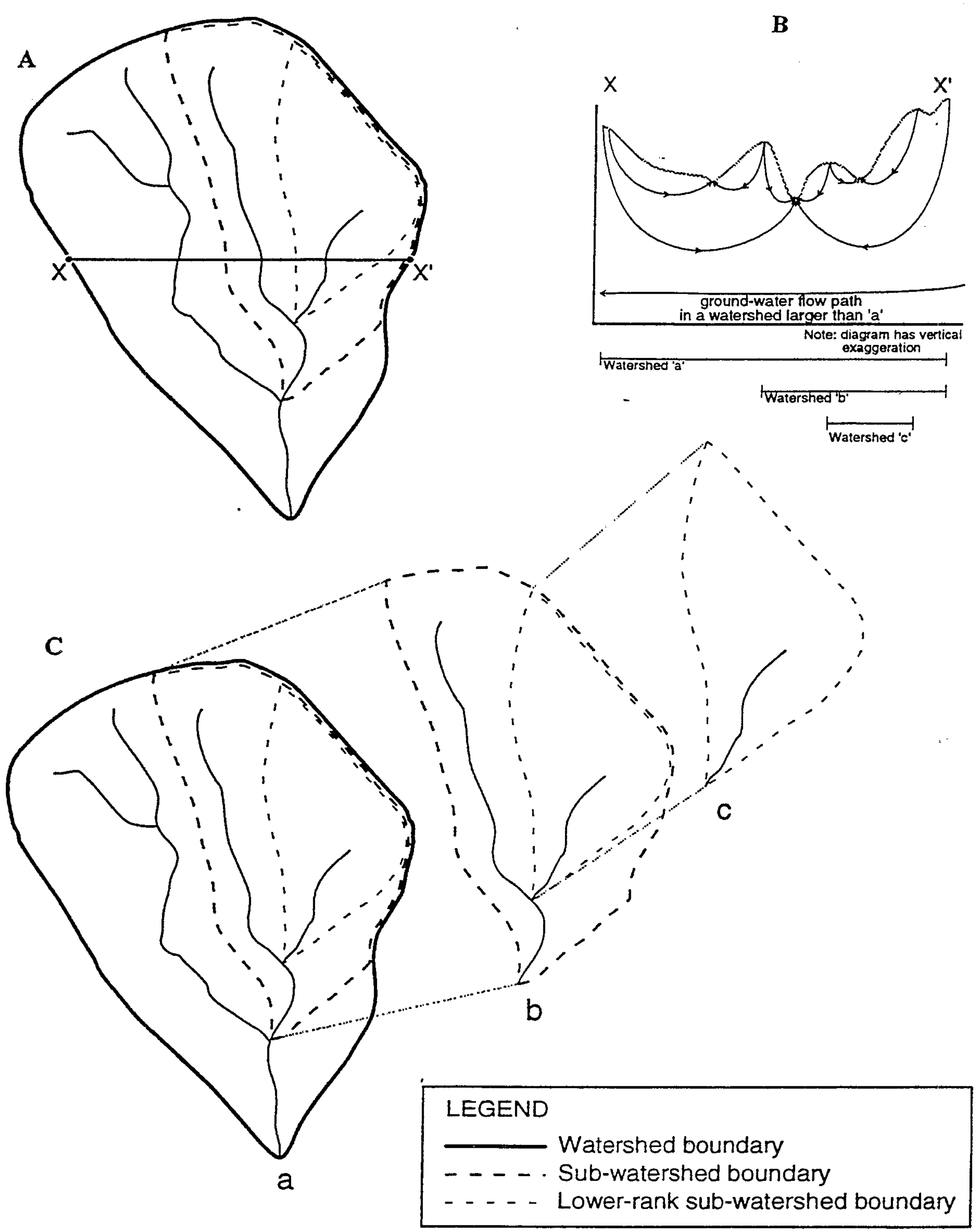

Figure 6. A and B show "nested" watersheds. C shows ground-water flow within the nested watersheds.

time-specific floodplain boundary over any other, must be made arbitrarily or be based on other-than-hydrologic factors.

- Hyporheic-zone boundary setback -- this zone may be defined by biological parameters, that is, by the presence of certain macro-organisms, or by physical parameters; however, the boundary of this zone can vary with the parameter used. One parameter is a particular suite of indicator organisms that can be withdrawn by wells; these organisms spend part of their life cycle in surface water and part in ground water. The delineation of the hyporheic-zone boundary may also be defined by the extent of the penetration of surface water into ground water as indicated by physical-parameter values in the ground water that are similar to the values in the surface water. The size of the hyporheic zone can vary seasonally and in response to drought. Research has not determined how rapidly the hyporheic zone is recolonized following the episodes of extensive surface-water intrusion into ground water that result from periods of flooding. Although the hyporheic zone might be used to define the extent of surface-water intrusion into ground water, this zone is not related to the area from which ground water flows towards streams.

- Ground-water time-of-travel, and fixed-distance, setbacks -- this concept relies on the ability of soil and rock media to improve water quality with time and travel distance. Given the current level of knowledge, specific distances needed for ground-water remediation are generally unknown; therefore, a fixed-distance or TOT setback has been used (most notably in the WHP Program) as a management approach to afford some measure of protection via ground-water flow distance and travel time. Because of the effect of high-capacity wells on ground-water TOT, states might choose to revise TOT boundaries after installation of high-capacity wells in or near protection zones.

- Ground-water basin boundary -- the position of this boundary is determined by the hydrologic, geologic and climatic characteristics of the hydrogeologic setting and generally fluctuates seasonally. The boundary marks the furthest locations from which ground water will flow to a hydraulically connected stream. The common assumption that the position of the surface watershed boundary approximates the position of the ground-water basin boundary is not universally true. Use of this approximation may introduce significant error into the estimate of the position of the outermost boundary of ground-water flow to a stream. Communities with highly valued water uses might choose to have hydrogeologic experts accurately determine the boundary of their ground-water basin.

In addition to the setbacks above, a chemical-standard setback may be a future option. Research being performed, for example, in a karst setting in Florida has shown that, based on radionuclide information, ground water has contributed to springs and to the Suwannee River.

Such research may someday be helpful in developing a chemical-quality "cutoff" to delineate an area where ground water and surface water "mix". Managers might choose to consider the boundary of this area to be the boundary of the ZOC. Further research will be needed to determine if this approach is a reasonable one and if such results would be applicable to other streams and hydrogeologic settings.

The reader may note that the ground-water TOT and fixed-distance setbacks are analogous to the TOT and fixed-radius delineation criteria used in the WHP Program (U.S. Environmental Protection Agency, 1987a). The reader may also note the analogy between the chemical-standard or hyporheic-zone setback and the calculated fixed-radius setback that is used as a delineation criterion in the WHP Program.

Methods for Delineating Surface-Water Boundaries to Protect the Quality of Surface-Water Sources Upstream of Critical-Use Sites

Three methods for delineating surface-water areas that contribute water to CRUSs, are described below. These methods are: stream TOT, setbacks/buffer zones, and nested-watershed areas. The first two methods have been used by states for protecting drinking-water intakes supplied by streams and reservoirs. The last two methods are directly applicable to protection not only of drinking-water intakes, but to other uses deemed critical by resource managers. Managers may choose to apply these methods to the protection not only of streams and reservoirs but to lakes as well, where lake-water quality protection is required for such critical uses as drinking water, recreation and endangered-species needs.

Streamflow Time-of-Travel Method

The intent of this method is different than that of the two that follow. This method is meant to provide direct protection to the CRUS, rather than protection of the water flowing to the CRUS. The method does not delineate a protection zone; rather, the method calculates the TOT of the flow of a stream between a CRUS and a point (such as a monitoring point) upstream (Figure 7). For a distance between the same two points, TOTs vary with stream-discharge volume. It is the streamflow travel time between the CRUS and the upstream point of interest that provides the opportunity for managers to protect the CRUS. The streamflow 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. The streamflow-TOT method also facilitates heightened assessment/management of those stream reaches most critical to protection of drinking-water intakes from upstream, long-term, potential sources of contamination.

Generally, the TOT approach is a suitable early-warning method for protecting CRUSs that can be temporarily isolated from surface-water contamination (for example, by the closing of a drinking-water intake). However, this early-warning method is of little or no value to CRUSs such as endangered-species habitats, that cannot be protected from contaminant exposure. Particularly sensitive habitats can be destroyed by brief exposure to toxic contaminants.

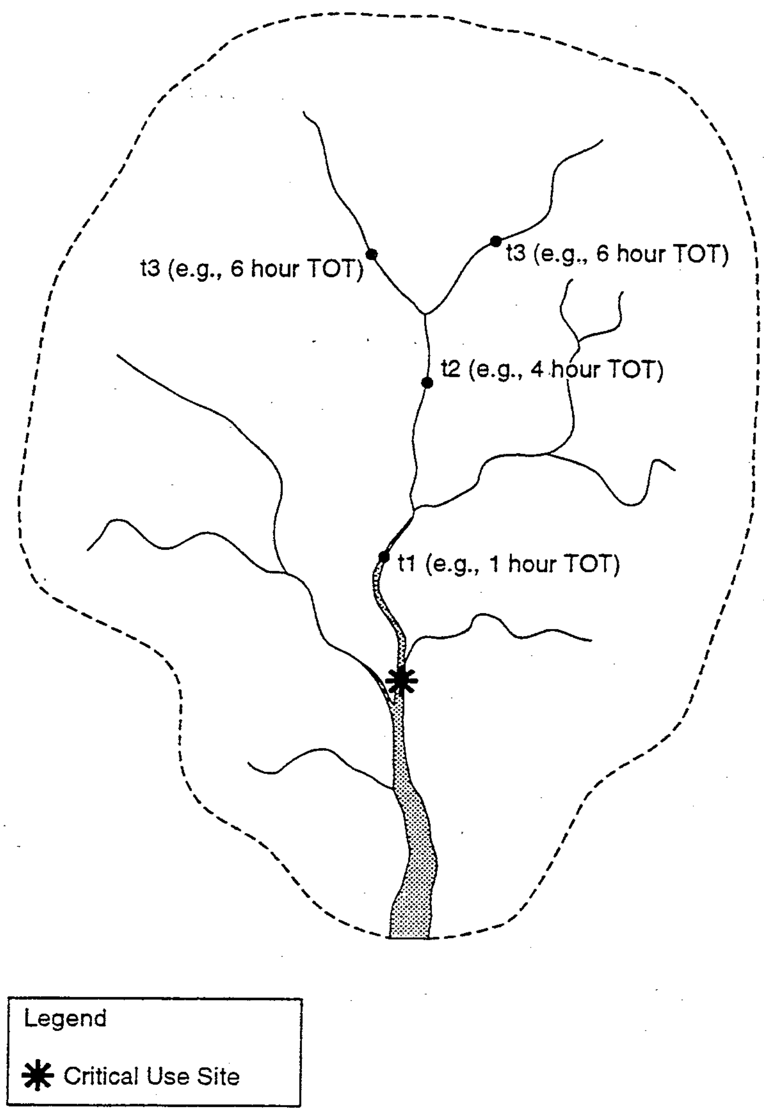

Figure 7. Watershed showing points at three different stream times-of-travel (TOTs) to a critical-use site.

At least two sophisticated "early warning" systems, the Ohio River Valley Water and Sanitation Commission (ORSANCO) along the Ohio River, and the Early Warning Organic Compound Detection System (EWOCDS) along the lower Mississippi River, have been established to protect downstream water supplies. ORSANCO is an interstate commission that coordinates monitoring for specific organic contaminants in the Ohio, Allegheny, Monongahela and Kanawha Rivers in cooperation with local water utilities. ORSANCO notifies downstream water utilities of detections so that utilities can implement protection measures. ORSANCO's monitoring locations encompass six states from Pennsylvania to Illinois. Personnel at water treatment facilities collect samples directly from raw river feed lines for analysis. If contamination above the predetermined action level for a specific chemical is found, downstream facility operators are notified. ORSANCO uses a flow model to estimate concentrations and travel times when a notification is issued; potential times of arrival of a spill are provided to the downstream utilities (Fraser, K., written communication, 1996).

EWOCDS was established to provide municipal and industrial water suppliers with early warnings of contaminant spills on the lower Mississippi River. The water providers and the Louisiana Department of Environmental Quality calculate the TOT for the leading edge, peak, and trailing edge of a spill, based on river velocity data (related to river height) provided weekly by the Army Corps of Engineers. Through this monitoring and warning program, suppliers are able to take appropriate measures to avoid intake of contaminated water.

Setback/Buffer-Zone Delineation Method

Setbacks/buffer zones (Figure 8) are natural or planted, vegetated areas along part or all of a stream's length. Buffer widths that have been selected by states are generally in the range of 50-200 ft. Buffer zones ("green areas") may be intended to serve several functions such as wildlife habitat, residential or commercial exclusion or source-water protection. Buffer zones filter out some portion of sediment-borne contaminants. In addition, by slowing down overland-flow velocity, buffer zones encourage increased infiltration to the ground-water reservoir, where travel times are longer (but, where contaminant cleanup is more difficult). To some degree, buffer zones also increase the time available for such processes as photolysis, evaporation and plant uptake of contaminants. Buffer zones help to reduce dissolved contaminants entering streams, and some research has shown that some forested buffer zones may be effective in reducing nutrients.

The remedial ability of buffer zones may decrease with time. Because the carrying capacity of moving water is related to its velocity; when overland flow reaches the outer 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 the 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. Therefore, maintenance of a buffer zone is critical to ensuring its effectiveness. The quality of overland flow overtopping buffer-zone vegetation during a major precipitation event, will not be improved by the buffer zone.

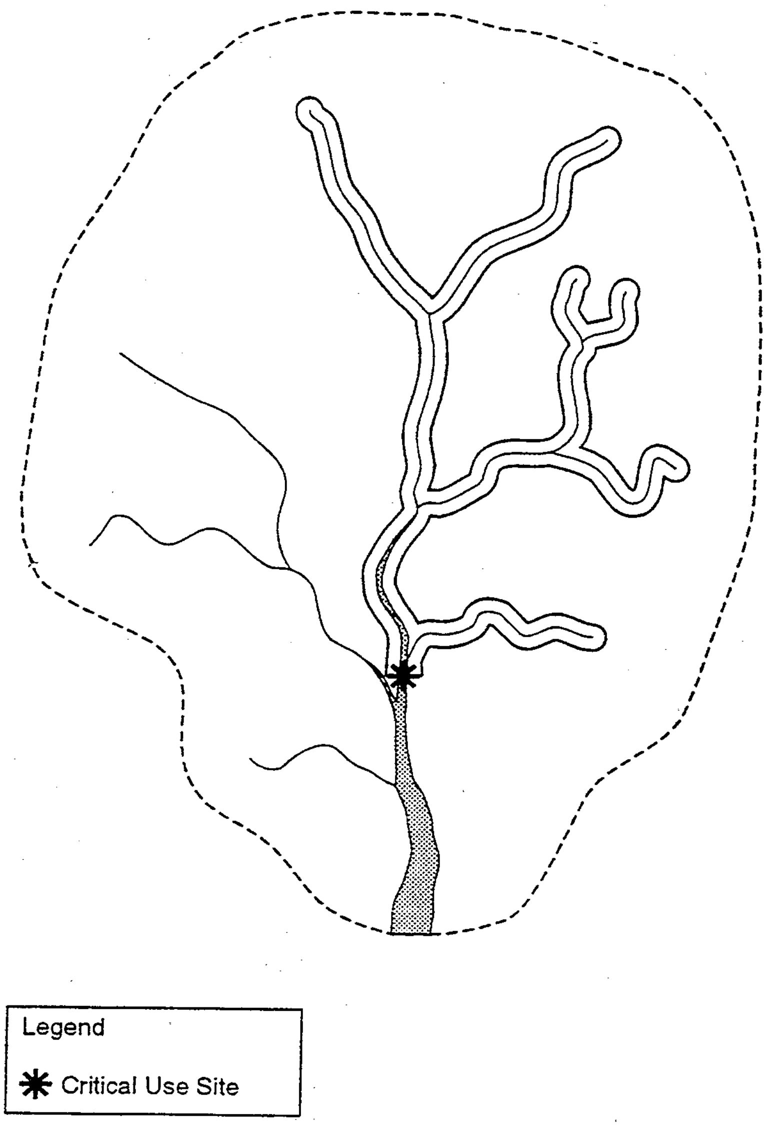

Figure 8. Watershed with a buffer/setback zone for a critical-use site in a stream.

Nested-Watershed Area Delineation Method

This method is an outgrowth of the Streamflow Time-of-Travel method described above. In the Nested-Watershed Area method, topographic boundaries of progressively "nested" watersheds (Figure 4) are delineated upstream of a CRUS and divide a SWPA into assessment/management segments. In this method, the TOT from any point in a nested watershed to the mouth of that watershed is considered equal to the TOT of the stream as it flows through the nested watershed. Stream TOTs are cumulated with decreasing distance to the CRUS. If the CRUS is located on a stream reach between the mouths of two nested watersheds, the TOT from the upgradient mouth to the CRUS is based on the relative distances of the CRUS to the upstream and the downstream mouths. Augmented management would be necessary for any potential contaminant source that occurs in a nested watershed whose distance from the CRUS does not provide enough time for sufficient natural in-situ remediation.

In this method, although no "credit" is given to overland-flow travel time, the TOT of surface water at any point on the stream in a nested watershed is considered to be the TOT of the stream through the entire nested watershed. For this reason, EPA recommends that states delineate as many "levels" of nesting as is useful for protection purposes. The greater the level of nesting, the more the error that is caused by assigning the total-stream TOT to every point on the stream is reduced.

The U.S. Geological Survey can provide travel times for many of the streams in large, and in nested, watersheds in the United States. States could select the number of levels of watershed "nesting" that is needed to facilitate the implementation of sufficient assessment/protection measures.

Summary

Conjunctive delineation of ground-water protection-area boundaries and of surface-water protection-area boundaries can facilitate protection of SWPAs. Delineations and assessments that lead to management of the quality of ground-water and surface-water resources within SWPAs can improve the quality of water at such CRUSs as drinking-water intakes, freshwater recreation areas and endangered-species habitats.

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