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GUIDELINES FOR GROUND-WATER CLASSIFICATION UNDER THE EPA GROUND-WATER PROTECTION STRATEGY

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Technical consultants played a significant role in the preparation of these guidelines. The primary technical consultant was Geraghty & Miller, Inc. (G&M), Dr. William Doucette, project manger. Other members of the G&M support team included Don Lundy, Michele Ruth and Laurie Haines. Shirley Reeder and Karen Kotschenreuther at G&M performed the majority of word processing. Subcontract assistance was provided by ICF, Inc., Peter Linquiti and Paul Bailey, project managers. Other ICF support team members were Richard Norton and Joseph Karam.

DISCLAIMER

These Ground-Water Classification Guidelines are meant to assist the U.S. Environmental Protection Agency as the Agency moves forward in ground-water protection. The Guidelines do not create any rights or obligations, substantive or procedural, enforceable by any party in an administrative, civil, or criminal proceeding.

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EXECUTIVE SUMMARY

Introduction

In August 1984, the U.S. Environmental Protection Agency (EPA) issued a Ground-Water Protection Strategy, setting out the Agency's plans for enhancing ground-water protection efforts by EPA and the states. A central feature of the Strategy is a policy framework for EPA's programs which accords differing levels of protection to ground water based on the resource's use, value to society, and vulnerability to contamination. A three-tiered ground-water classification system was established in the Strategy as a key operational tool to help implement this policy.

The classification system recognizes that special ground water exists due to its high vulnerability to contamination and high value for drinking-water purposes or its importance to a unique ecological habitat (Class I). The vast majority of the nation's ground water falls within Class II which encompasses all non-Class I current or potential sources of drinking water. Class III ground water is not a potential source of drinking water primarily due to levels of contamination either from naturally occurring conditions or the effects of broad-scale human activity that cannot be feasibly cleaned up.

These Final Guidelines for classifying ground water augment the Ground-Water Protection Strategy by

- Further defining the key terms and concepts of the classification system, and
- Describing procedures and data requirements to assist in classifying ground water.

The procedures in the Final Guidelines are generally intended for site-specific ground-water classification based on a review of the segment of ground water in relatively close proximity to a particular source. Although the specific procedures are not designed specifically for broader aquifer classification, many of the concepts and procedures developed for site-by-site classification will also be useful in such classification efforts.

The manner and extent to which the Guidelines will be incorporated into EPA regulatory, permitting, and planning decisions are addressed in a supplemental Implementation Policy Statement being issued concurrently with the Guidelines.

The key criteria for each class and procedural approaches for determining whether the criteria are met are outlined as follows:

Classification Review Area

The first step in making a classification decision is defining the area around the source that should be evaluated. Once this Classification Review Area has been determined, information regarding public and private wells, demographics, hydrogeology, and surface water and wetlands is collected and a classification decision is made based on the criteria for each class as described below.

The Guidelines specify an initial Classification Review Area as the area within a 2-mile radius of the boundary of the facility or activity under review. Under certain hydrogeologic conditions an expanded or reduced Classification Review Area is allowed.

It should be emphasized that the Classification Review Area defines a study area as one necessary to evaluate the appropriate ground-water class in connection with a specific site analysis and does not imply that action needs to be taken relative to other facilities within the area.

Class 1 - Special Ground Water

Class I ground waters are defined as resources of particularly high value. They are highly vulnerable and are either an irreplaceable source of drinking water for a substantial population or ecologically vital.

- Highly vulnerable ground water is characterized by a relatively high potential for contaminants to enter and/or be transported within the ground-water flow system. The Guidelines provide both quantitative and qualitative decision aids for determining vulnerability based on hydrogeologic factors.

- An irreplaceable source of drinking water for a substantial population is ground water whose replacement by water of comparable quality and quantity from alternative sources in the area would be economically infeasible or precluded by institutional barriers. The determination of irreplaceability is based on a three-step process that includes identifying the presence of a substantial population, applying screening tests designed to produce a preliminary determination, and reviewing relevant qualitative criteria in order to produce a final determination.

- Ecologically vital ground water supplies a sensitive ecological system located in a ground-water discharge area that supports a unique

habitat. Unique habitats include habitats for endangered species listed or proposed for listing under the Endangered Species Act as well as certain Federally managed and protected lands.

Class II - Current and Potential Sources of Drinking Water and Ground Water Having Other Beneficial Uses

Class II ground waters include all non-Class I ground water that is currently being used or is potentially available for drinking water or other beneficial use.

Subclass IIA is a current source of drinking water. Ground water is classified as IIA if within the Classification Review Area there is either (1) one or more operating drinking-water wells or springs, or (2) a water-supply reservoir watershed (or portion of it) that is designated for water-quality protection by either a State or a locality.

Subclass IIB is a potential source of drinking water. This ground water (1) can be obtained in sufficient quantity to meet the minimum needs of an average family; (2) has total dissolved solids (TDS) of less than 10,000 milligrams per liter (mg/L); and (3) is of a quality that can be used without treatment or that can be treated using methods reasonably employed by public-water systems.

Class III - Ground Water Not a Potential Source of Drinking Water and/or Limited Beneficial Use

Class III drinking waters have either (1) a TDS concentration equal to or greater than 10,000 mg/L; or (2) contamination by naturally occurring conditions or by the effects of broad-scale human activity that cannot be cleaned up using treatment methods reasonably employed in public-water systems. A two-step test, based on technical and economic feasibility, is presented in the Guidelines. Class III also encompasses those rare conditions where (3) yields are insufficient to meet the minimum needs of an average household. Subdivisions within Class III include the following:

Subclass IIIA ground water has an intermediate degree of interconnection with adjacent ground-water units and/or are interconnected with surface waters.

Subclass IIIB ground water has a low degree of interconnection with adjacent ground-water units.

CHAPTER ONE

INTRODUCTION

1.1 EPA's Ground-Water Protection Strategy

EPA currently administers more than eight statutes which direct the Agency toward reducing or eliminating threats to ground water from a large number and variety of sources. This is a far-from-simple task and one which commands a major part of the Agency's budget and personnel resources. Changes in statutes and resulting regulations have occurred in the past, and will continue to occur in the future, to further manage these pollution sources. Through EPA's long-range planning efforts and, more recently, an Agency-wide direction toward overall risk management, ground-water protection on a cross-media basis is receiving increased attention.

An important tool in this cross-program phase was made available in August 1984 when EPA released its Ground-Water Protection Strategy. The Strategy consists of four major elements:

- Strengthen State Institutions -- through technical assistance and State Grants.
- Cope with Contamination Sources of National Concern -- through source-specific protection programs.
- Improve consistency in Ground-Water Protection decisions -- through the establishment and implementation of protection policies.
- Strengthen EPA Institutions -- through the establishment of coordinating functions within the Offices of Ground-Water Protection at Headquarters and in the Regions.

Pursuant to the third element, the Agency adopted a differential protection policy which acknowledges that ground waters vary in terms of their current use, relative value to society, and vulnerability to contamination. Ground-water classification was introduced in the Strategy as an approach for setting priorities for regulatory action and resource management within this framework.

1.2 Purpose of the Classification Guidelines

This document provides technical guidelines for the classification system established in the Ground-Water Protection Strategy. When the procedures and methods outlined in this document are followed, ground water that may be affected by a facility or activity under EPA review will be placed within a relevant class or classes which represent an implied hierarchy of protection. This document should be viewed essentially as a set of technical guidelines for ground-water evaluation via classification. The issue of implementation of the Classification Guidelines by EPA programs is addressed in a separate Implementation Policy Statement.

It is important to note that these Guidelines are not designed specifically for classifying large segments of land, aquifers, etc., in advance of any specific decision. Instead, the system focuses on the classification of the ground water around specific sites or areas where a decision related to a permit, degree of clean up or regulation, etc., is to be made. The methods and techniques in the Guidelines will, however, provide useful information for State or local governments that choose to review or implement broader classification systems.

1.3 Guidelines Development

The development of these Guidelines began in August 1984, and consisted of three phases: definition, testing, and review. Throughout the process, the Office of Ground-Water Protection (OGWP) worked closely with representatives from several states, EPA regions, other EPA programs, and the U.S. Geological Survey.

In the definition phase, key terms and concepts related to the classification scheme described in the strategy were analyzed in detail. These key terms and concepts included irreplaceable source of drinking water to a substantial population, ecologically vital, highly vulnerable, and current source of drinking water. Several alternative options for defining each term were drawn up, along with data requirements and methodologies for employing each. Many of

the alternative options were derived from approaches used by other EPA, State, and local programs to address similar or related concepts. Each approach was examined with respect to the following:

- Adaptability with statutes, other programs, and with the overall intent of the Strategy;
- Flexibility for accommodating State- and region-specific characteristics or concerns;
- Arbitrariness; and
- Potential difficulties or complexities in implementation.

The next phase involved the preparation of detailed test case studies. The information acquired from this phase led to refinements of the classification procedures.

Finally, the project focused on review and revision of several drafts. A Final Draft was released for public comment in December 1986. The public comments received were considered in developing these Final Guidelines.

1.4 Organization of Guidelines Document

Chapter One introduces EPA's Ground-Water Protection Strategy and discusses the purpose and development of the classification Guidelines. Chapter Two provides an overview of the classification system and general classification procedures. The remaining chapters focus on individual aspects of the classification system. Chapter Three contains information about the Classification Review Area, including its purpose, the determination of the basic 2-mile radius review area, and the factors pertaining to its expansion or subdivision. Chapters Four, Five, and Six focus on Classes I, II, and III respectively. Each chapter contains a basic review of the class definition, as well as a discussion of key terms and concepts pertinent to the class. In each case the classification decision process is presented and discussed in detail. In addition, various techniques and background information that may be helpful in arriving at a classification decision are also presented.

A glossary and a series of appendices follow Chapter Six. Appendix A contains information supplemental to Chapter Three, including the technical basis for the 2-mile radius Classification Review Area as well as detailed procedures for

determining expanded or subdivided review area dimensions. Appendices B and C provide supplemental information for the non-economic aspects of Class I and Class II (Chapters Four and Six). Appendix D provides guidance for applying the common aspects of the Class I and Class II economic tests.

CHAPTER TWO

OVERVIEW OF THE GROUND-WATER CLASSIFICATION SYSTEM AND PROCESS

The three basic ground-water classes established in the 1984 EPA Ground-Water Protection Strategy, which represent a hierarchy of ground-water resource value to society, are as follows:

- Class I - Special Ground Waters
- Class II - Current and Potential Sources of Drinking Water and Water Having Other Beneficial Uses
- Class III - Ground Water Not a Potential Source of Drinking Water and of Limited Beneficial Use

The classification system is, in general, based on the principle that drinking water is the highest beneficial use of the resource. All drinking-water sources would fall within Class I or Class II.

Ground water is used in other beneficial applications, such as manufacturing, electric-power generation, livestock production, irrigation, and ecosystem support. Class I or Class II ground waters are compatible with such applications, in that water of a quality suitable for drinking will also be of suitable quality to serve as a raw-water source for most other beneficial uses. Class I does include a special non-drinking-water component for ecologically vital ground water. Class III ground waters, although not potential sources of drinking water, may be of limited beneficial use, such as for industrial process cooling water.

Some ground-water classification systems, generally termed anticipatory classification systems, classify and map aquifers or aquifer portions in advance of management or remediation decisions. Although the criteria and concepts in EPA's system can be used for such anticipatory classification, EPA's system is primarily designed for classifying the ground water in the vicinity of a particular facility or activity as appropriate within a given regulatory program. In this site-by-site classification approach, the classification criteria are applied on the basis of information collected in a review area, referred to as the Classification Review Area, around the site or activity.

This chapter provides an overview of the EPA ground-water classification system, each component of which is discussed in more detail in subsequent chapters.

2.1 Ground-Water Classes

As previously mentioned, the EPA Ground-Water Classification System consists of three major classes. Two of these classes are further differentiated into subclasses, allowing for the refinement in the hierarchy of recognized resource values (Figure 2-1). Key terms and concepts define the classes and subclasses.

2.1.1 Class I - Special Ground Waters

Class I ground waters are defined as resources of unusually high value. They are highly vulnerable to contamination and are (1) irreplaceable sources of drinking water to substantial populations and/or (2) ecologically vital. Ground water that is highly vulnerable to contamination is characterized by a relatively high potential for contaminants to enter and/or to be transported within the ground-water flow system. The number of Class I designations is expected to be small.

Ground water may be considered irreplaceable to a substantial population if alternative water-supply sources of comparable quality and quantity are beyond a reasonable transport distance, would be economically infeasible to develop, or are precluded from delivery (or would be very difficult to deliver) because of institutional constraints.

Ground water may be considered ecologically vital if it supplies a sensitive ecological system located in a ground-water discharge area that supports a unique habitat. A unique habitat is defined to include habitats for endangered or threatened species that are listed or formally proposed for listing pursuant to the Endangered Species Act (as amended in 1982), as well as certain types of Federally managed and protected lands.

A more detailed explanation of Class I concepts and procedures is provided in Chapter Four.

2.1.2 Class II - Current and Potential Sources of Drinking Water and Water Having Other Beneficial Uses

All non-Class I ground water currently used, or potentially available, as a source of drinking water and for other beneficial use is included in this category, whether or not

FIGURE 2-1

SUMMARY OF GROUND-WATER CLASSES

CLASS	KEY TERMS
I	HIGHLY VULNERABLE AND EITHER IRREPLACEABLE TO SUBSTANTIAL POPULATIONS OR ECOLOGICALLY VITAL
IIA	CURRENT SOURCE OF DRINKING WATER
IIB	POTENTIAL SOURCE OF DRINKING WATER
IIIA	NOT A SOURCE OF DRINKING WATER INT[illegible]MEDIATE TO HIGH INTERCONNECTION AN[illegible]0,000 MG/L TDS OR UNTREATA[illegible]LE OR [illegible] SOURCE OF DRINKING WATER [illegible]E TO INSUFFICIENT YIELD
IIIB	NOT A SOURCE OF DRINKING WATER LOW INTERCONNECTION ≥10,000 MG/L TDS OR UNTREATABLE

it is particularly vulnerable to contamination. This class is divided into two subclasses: current sources of drinking water (Subclass IIA), and potential sources of drinking water (Subclass IIB).

The concept of a current source of drinking water is rather broad by intent. Only a portion of the ground water in the Classification Review Area must supply drinking water. Ground water is considered a current source of drinking water under two conditions: (1) one or more operating drinking-water wells (or springs used as sources of drinking water); or (2) a water-supply reservoir watershed (or portion of a water-supply reservoir watershed), designated for water-quality protection by either state or local government, must be present within the Classification Review Area. In some circumstances, intakes on surface water (used for drinking water supply) may also warrant a Class IIA determination.

A potential source of drinking water is one capable of yielding a quantity of drinking water to a well or spring sufficient for the minimum needs of an average-size family. Drinking water is defined as water with a total-dissolved-solids (TDS) concentration of less than 10,000 milligrams per liter (mg/L) that can be used for drinking purposes without first being treated, or that can be rendered drinkable after being treated by methods reasonably employed in a public water-supply system. All ground waters are presumed to meet both the yield and quality criteria for a current or potential source of drinking water unless a successful Class III demonstration is performed.

Class II ground waters constitute the majority of the nation's ground-water resources that may be affected by human activity. Class II ground waters will generally receive the very high level of protection that represents the baseline degree of protection which is the standard for EPA programs. The procedures for making a Class II determination are discussed in greater detail in Chapter Five.

2.1.3 Class III - Ground Water Not a Potential Source of Drinking Water and of Limited Beneficial Use

Ground waters that are saline, or otherwise contaminated beyond levels that would permit their use for drinking or other beneficial purposes, are in this class. These include ground waters which (1) have a TDS concentration equal to or greater than 10,000 mg/L, or (2) are so contaminated by naturally occurring conditions, or by the effects of broad-scale human activity (unrelated to a specific activity) that they cannot be cleaned up using treatment methods reasonably employed in public water-supply systems. In addition, Class

III encompasses ground waters in those rare settings (3) where yields are insufficient to meet the minimum needs of an average household.

Two tests are provided to assist in determining Class III treatability. The first test, referred to as the reference technology test, is a screening tool which compares the treatment scheme needed to treat contaminated ground water in the area surrounding a facility, to a list of technologies which appear relevant for public water-supply treatment. If none is appropriate, then the ground water may be technically untreatable, pending economic analysis. The second treatability test, referred to as the economic untreatability test, is applied to determine whether treatment of the water for a hypothetical user population would be economically feasible. Both of these tests are described in more detail in Chapter Six.

Class III is subcategorized primarily on the basis of the degree of interconnection with adjacent ground-water units or surface waters. Subclass IIIA ground waters have an intermediate degree of interconnection to adjacent ground-water units and/or are interconnected with surface waters. As a result, they may be contributing to the degradation of the adjacent waters. Class IIIA ground waters may be managed at a level similar to a level at which Class II ground waters are managed, depending upon the potential for producing adverse effects on the quality of adjacent waters. In addition, Subclass IIIA encompasses all ground waters from low-yield settings unless Class I or Class II criteria have been demonstrated.

Subclass IIIB ground waters are characterized by a low degree of interconnection to adjacent ground-water units within the Classification Review Area. These ground waters are naturally isolated from sources of drinking water in such a way that there is little potential for producing additional adverse effects on human health and the environment. They have low resource values outside of mining, oil and gas recovery, or waste disposal.

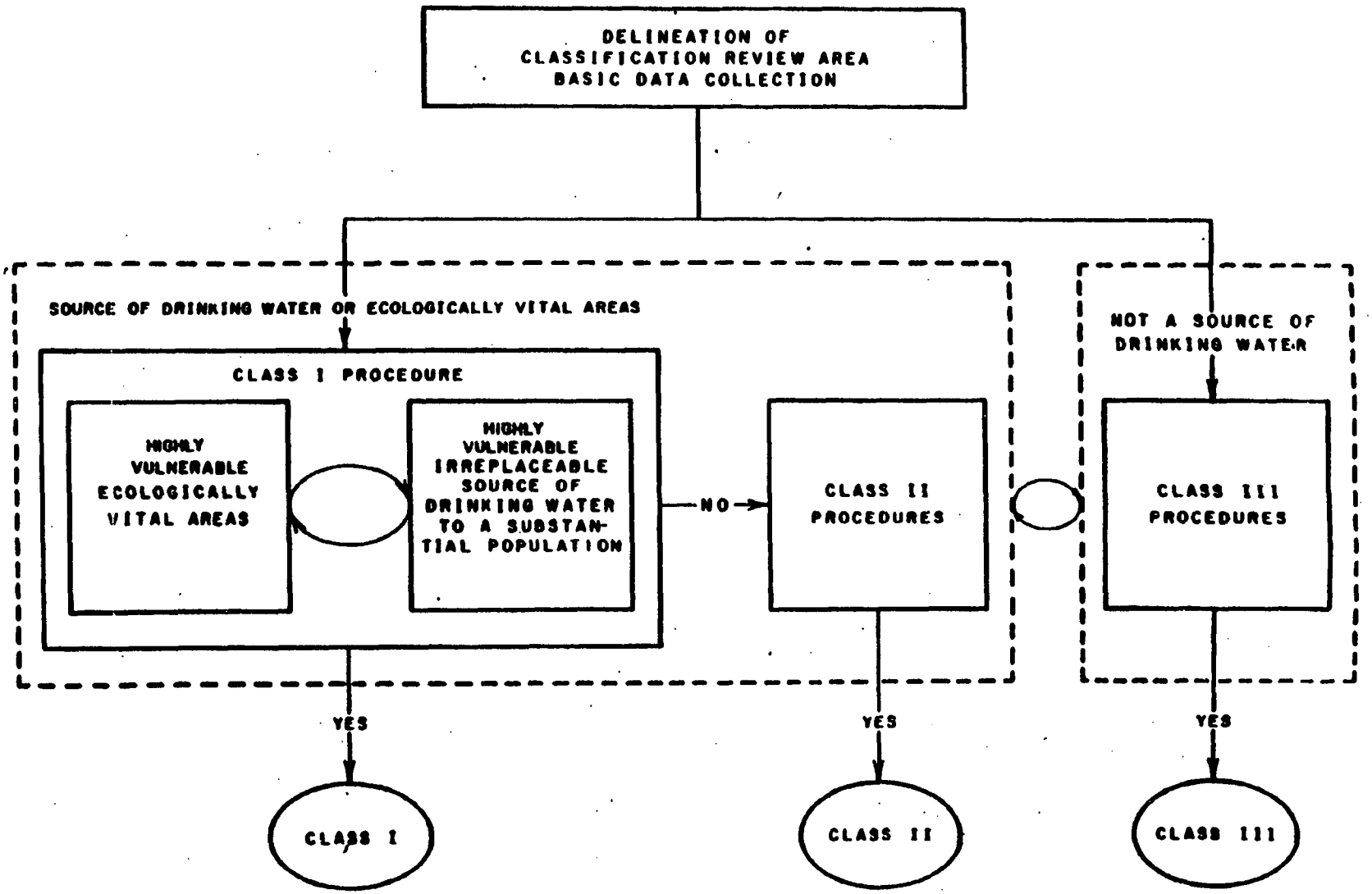
Detailed information concerning Class III determinations as well as hypothetical examples are provided in Chapter Six.

2.2 General Classification Procedures

This section provides guidance for initiating the classification process. An outline of general classification procedures is given in Figure 2-2. A likely sequence of classification steps, as well as alternative sequences are

FIGURE 2-2

SCHEMATIC CHART OF GENERAL CLASSIFICATION PROCEDURES



discussed in this section. Cross references are made to those chapters that contain more detail on a specific classification procedure. Sources of information and data needed for classification are discussed, generally, in Section 2.3.

The first step in EPA's site-by-site classification procedure is to draw a 2-mile radius around the site that is to be classified -- this is the standard Classification Review Area. The second step is to collect basic information about the Classification Review Area concerning demography, local use of ground water, general hydrogeologic conditions, and the presence of ecologically vital areas and surface waters. The information collected may indicate that expansion or subdivision of the standard 2-mile radius Classification Review Area would be appropriate. If the Classification Review Area is expanded, additional data about the expanded portion is normally gathered. If subdivision is contemplated, the classifier will typically collect additional hydrogeologic information to support a subdivision demonstration. Detailed procedures for determining the size and configuration of the Classification Review Area, including expansion and subdivision, are discussed in Chapter Three.

The third step in the classification procedure is to assign the ground water to a particular class, based on the data collected. A classifier beginning this step will typically face two choices: (1) to assess the likelihood that the ground water is a source of drinking water or ecologically vital (Class I or II), or (2) to assess the likelihood that the ground water is not a source of drinking water (Class III). (This procedure is illustrated in Figure 2-3.) Preliminary information should indicate which of the two choices is most likely. If the classifier chooses to begin the analysis with an initial look at the likelihood of a Class III determination, it is still necessary to demonstrate that the ground water is <u>not</u> a current or potential source of drinking water or ecologically vital. For example, while the ground water may be initially considered contaminated and untreatable, if a private drinking water well is present in the review area, the ground water should be assigned to Class II. Most classifiers will find it most efficient to begin with an analysis of the likelihood of a Class I determination, and then review the possibility of a Class III determination if there are no wells, drinking-water reservoirs or springs, and no ecologically vital areas within the Classification Review Area.

The classification procedure is an iterative process, with each iteration building upon the previous one. For example, if the classifier has gone through the classification process and determined that the ground water will most likely be Class I, it may be necessary to go back to Step 2

and collect additional information to ensure that the most appropriate class decision is made. This process can be repeated until an accurate and appropriate classification is obtained.

2.3 Collection of Basic Information

Basic informational needs for classification are outlined in this section. More detailed information is provided in Chapter Three (The Classification Review Area), as well as in subsequent chapters, which discuss each of the classes in turn. The collection of basic information is meant to reflect an approach to classification that begins simply and directly. It will typically include a well and reservoir survey, demographic information, basic water-quality data, and identification of ecologically vital areas. Regional and local hydrogeologic data will normally be gathered if an interconnection analysis is undertaken. Otherwise, a general description of the regional geology, geomorphology, and hydrogeology would normally suffice. Again, the emphasis is on available information rather than on detailed in-field analyses. A more rigorous analysis is, in general, necessary to support a Class III determination.

Well information may be obtained from water authorities, utilities, public-health agencies, regulatory agencies permitting well drilling, well drillers, or other State or local entities. Basic water-quality information is usually available from local health agencies, other State and local agencies, and national data bases such as STORET. In some cases, university research departments may be able to supply needed data. Assistance in identifying ecologically vital areas may be obtained from the U.S. Fish and Wildlife Service. Regional and/or local hydrogeologic and geologic information may be available from county/regional reports of the U.S. and State geologic surveys. Demographic information can be obtained from the U.S. Census Bureau.

CHAPTER THREE

THE CLASSIFICATION REVIEW AREA

3.1 Purpose of the Classification Review Area

Classifying ground water involves applying the classification system's criteria to a segment of ground water. In some systems, generally termed anticipatory classification systems, criteria are applied on a regional or aquifer basis, and class determinations are mapped in advance of specific management decisions. Although the criteria and concepts in EPA's system can be used for such anticipatory classification, EPA's system is primarily designed for classifying the ground water in the vicinity of a particular facility or activity as appropriate within a given regulatory program. Thus, this first step in EPA's site-by-site classification procedure is to determine the size and configuration of the Classification Review Area around the site to which the classification criteria will be applied.

EPA believes that it is appropriate to look at a broad area for characterizing the ground water which may be affected by the activity(ies) at a particular site. Within the Classification Review Area, basic information is collected concerning hydrogeologic conditions, public-supply wells, populated areas not served by public supply, wetlands, and surface waters, as described in Section 3.5 of this chapter. Through applying the use, value, and vulnerability criteria, a ground-water class determination is made which may be used as a factor in determining what specific regulatory action or decision is appropriate for the site. However, it should be noted that a classification decision will apply only to the specific facility or site in question and for which the Classification Review Area was drawn.

3.2 Determining the Classification Review Area

3.2.1 Introduction

As a first step, an initial Classification Review Area will most often be determined by drawing a 2-mile radius from the facility or activity for which the class determination is being made. Some EPA programs utilize a somewhat larger review area, the use of which is covered by the Implementation Policy Statement.

A Classification Review Area with a 2-mile radius around a proposed facility is shown on Figure 3-1. The site of the facility is approximately 500 feet in diameter. Water supplies in the Classification Review Area include a public water-supply system well and a densely settled area of private wells. A river with a wetland runs through the review area. Each of these facts may bear on the decision of the class of ground water.

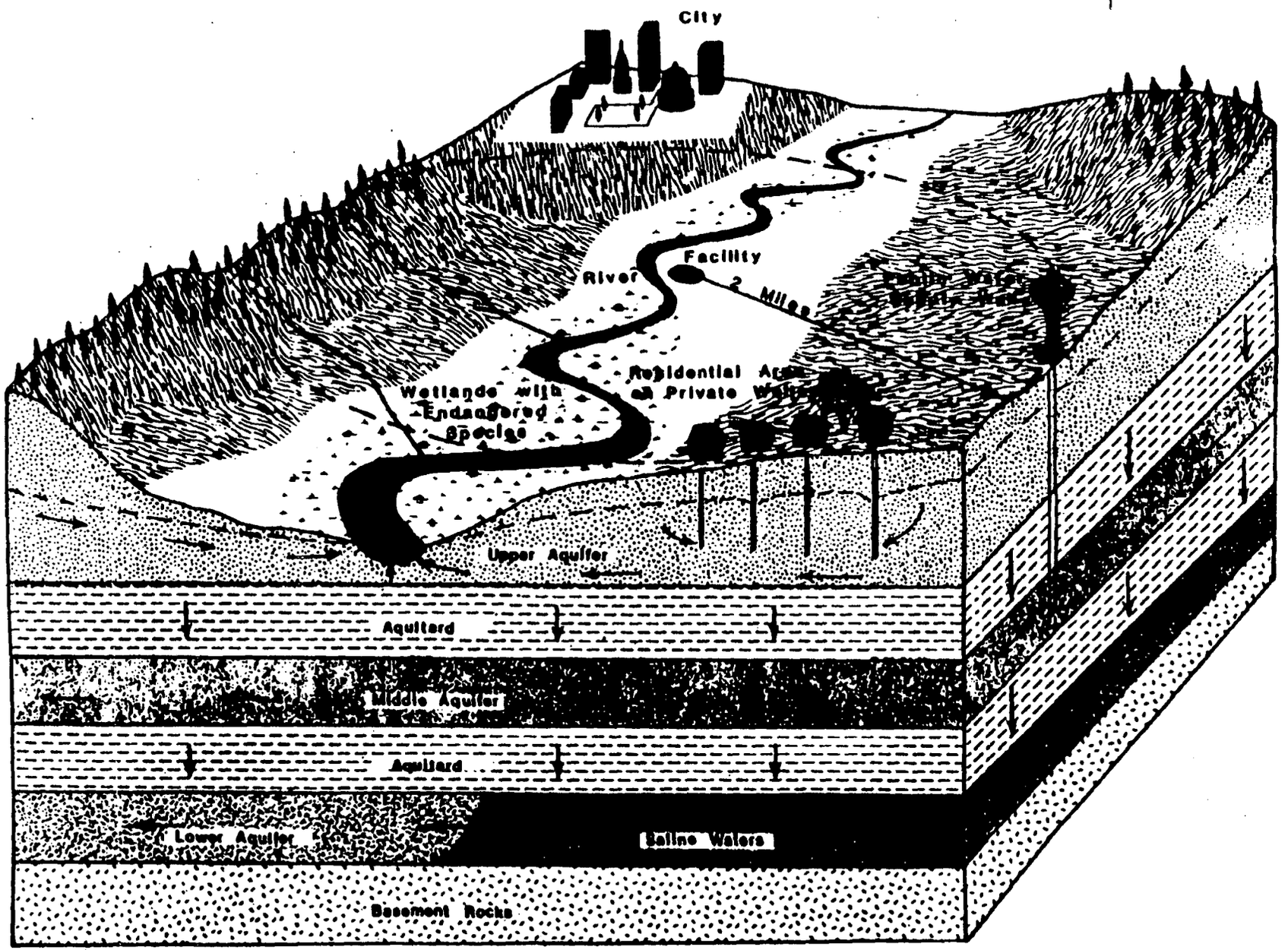
EPA selected 2-miles as a typically appropriate radius size for the Classification Review Area after analysis of three sources of data that provided insight into the length of the flow path over which high degrees of interconnection occur and indicated distances contaminants could be expected to move in problem concentrations should they be accidentally introduced into the ground-water system. The sources of data examined were as follows:

- A survey of contaminant plumes from investigations of existing spills, leaks, and discharges.
- A survey of the distances to downgradient surface waters from hazardous-waste facilities.
- Calculations of the distances from which pumping wells draw ground water under different hydrogeologic conditions.

Analyses of the data indicate that in 95 percent of the cases, the lengths and distances of contaminated ground-water plumes from hazardous waste facilities to downgradient surface waters likely to be discharge points for shallow ground water are less than 2 miles. A detailed discussion of these data and their interpretation is provided in Appendix A.

FIGURE 3-1

HYPOTHETICAL CLASSIFICATION REVIEW AREA
SHOWING POTENTIAL CLASS DETERMINING FACTORS



Under certain hydrogeologic conditions, however, expansion or subdivision of the 2-mile radius Classification Review Area may be appropriate. Sections 3.3 and 3.4 provide guidance on the types of situations where expansion or subdivision of the Classification Review Area may be warranted, as well as procedures for making these adjustments. Basic data needs for the characterization of the Classification Review Area prior to application of the classification criteria are discussed in Section 3.5. Guidance for drawing the Classification Review Area boundaries from various sized, regularly and irregularly shaped facilities is given in Section 3.6.

3.3 Expansion of the Classification Review Area

3.3.1 Introduction

As mentioned previously, under some hydrogeologic conditions, a 2-mile radius review area may be insufficient for characterizing the ground water that may potentially be affected by a facility. In areas of very high flow velocities that occur over distances greater than 2 miles, there is a potential for activity-related contaminants to move beyond a 2-mile radius in a relatively short time frame, especially under the influence of large-scale ground-water withdrawals. Though it is expected that the 2-mile review area will be sufficient in extent to accommodate the vast majority of classification decisions, this section presents guidance for identifying those unusual situations where an expanded review area may be appropriate. In addition, general procedures are suggested to establish the dimensions of the expanded Classification Review Area based on available information concerning hydrogeologic characteristics. (Note that some EPA programs routinely use a somewhat larger review area; this section addresses situations where a still larger area might be warranted due to hydrogeologic conditions.) A detailed discussion of Classification Review Area expansion is presented in Appendix A.2.

3.3.2 Determining Whether Expansion Is Warranted

Deciding whether to expand the Classification Review Area is a judgment of the classifier, made on a case-by-case basis. As a general rule-of-thumb, expansion is intended for those situations likely to result in the transport of contaminants beyond 2 miles during a period of 10 years or less. This translates to cases where ground-water velocities exceeding 1,000 feet/year (ft/yr) over a substantial distance are prob-able. Ten years is assumed to be a reasonably conservative time period for controlling contaminant(s) after the contaminants have been detected. Very few settings have ground-water migration exceeding a distance of 2 miles within a 10-year period; therefore, Classification Review Area expansion is likely to be the exception rather than the rule.

It is not necessary to have precise ground-water velocity data for the review area in order to decide if expansion is appropriate; however where possible, such data should be examined. It is anticipated that investigations pertaining to RCRA land-disposal facilities or Superfund ground-water contamination sites will, as a routine matter, already incorporate the information necessary to determine ground-water velocities.

Other situations will likely not be investigated in sufficient detail to gauge ground-water velocity; a general screening procedure can be employed in the absence of velocity information. This procedure involves matching hydrogeologic conditions in the 2-mile review area to generic hydrogeologic settings where high velocities are very commonly found. The following sections provide a discussion of high-velocity settings for the classifier's reference. Note that there may be specific high-velocity settings known to regional or State authorities that are not discussed here.

High-Velocity Hydrogeology

Hydrogeologic settings can generally be classified into two types of ground-water flow regimes, Darcian and non-Darcian. The identification of the dominant flow regime at a specific site can be useful in evaluating the need to expand the Classification Review Area.

Darcian flow refers to the movement of water under conditions where Darcy's law applies. Typically, these conditions involve intergranular, laminar flow, without turbulence. Darcy's law states that the velocity of flow, v, is equal to the product of a factor called hydraulic conductivity, K, and the hydraulic gradient (e.g., slope of the water table in an unconfined aquifer) divided by the aquifer

porosity. (These terms are defined in the glossary.) When turbulent flow occurs, as in water moving in a pipe, Darcy's law does not apply for determining flow velocities. Generally, the non-Darcian flow settings have higher velocities, due to the pipe-like flow, than Darcian flow settings and, for this reason, are strong candidates for an expanded review area.

Non-Darcian flow occurs in geologic settings where secondary porosity dominates the ground-water flow regime. Secondary porosity refers to relatively large continuous openings, fractures, or tunnels (i.e., the pipe-like features) that transport water. Intergranular flow moving according to Darcy's law contributes a proportionately insignificant volume of flow in these settings. Examples of non-Darcian flow settings include mature karst, fractured rock, and extrusive igneous rocks (basaltic lava). For hydrogeologic settings with predominantly non-Darcian flow, it is likely that the flow velocity is so great that Classification Review Area expansion is appropriate.

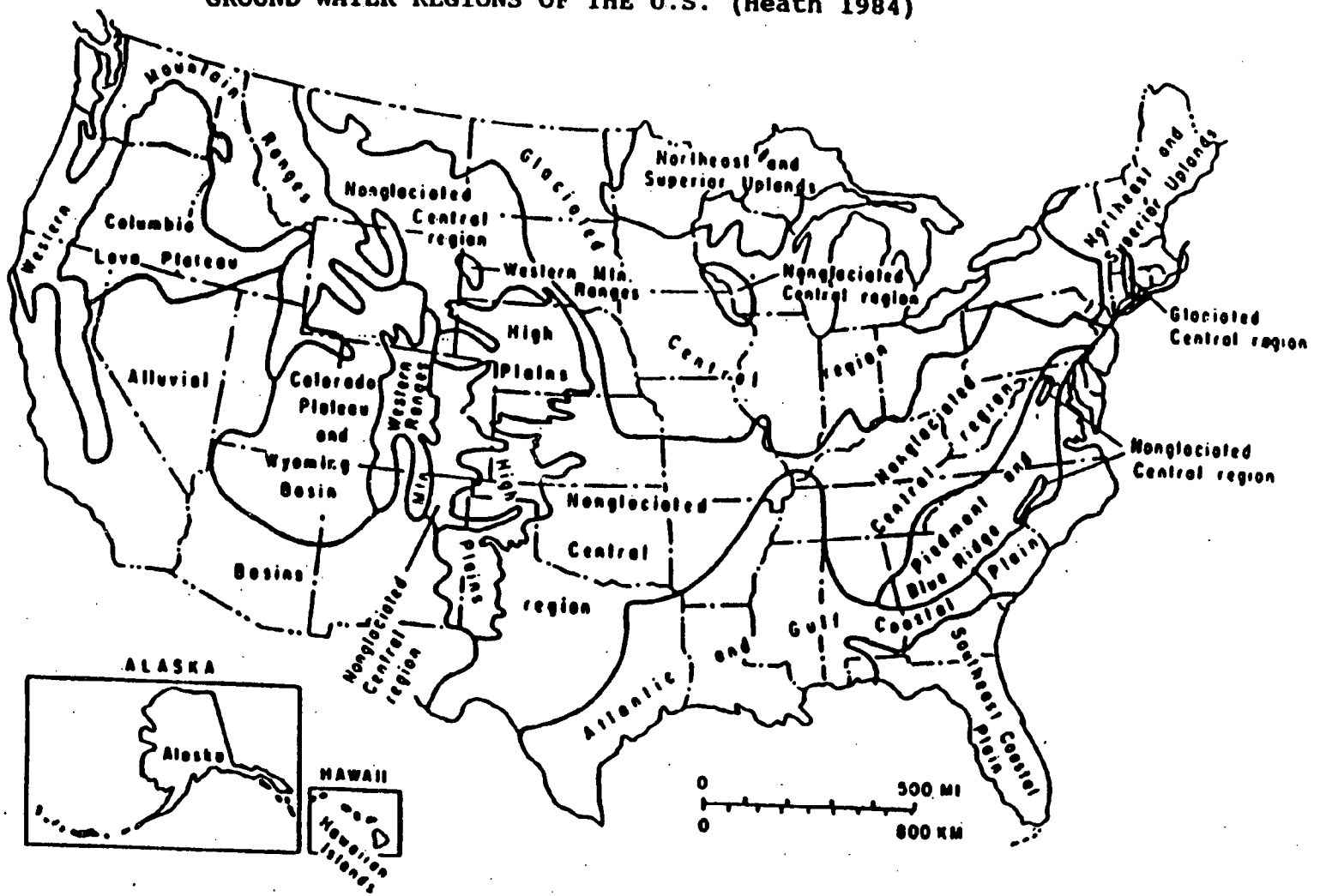
In Darcian settings, it will be unlikely that flow velocities as high as 1 mile a year will occur except over very short distances not representative of flow throughout a ground-water unit. However, velocities in the range of 1,000 ft/yr, although rare, can be expected and would be supportive of an expanded Classification Review Area. Settings where Darcian flow predominates and high velocities frequently occur include alluvial basins, other alluvial materials, coastal plains, and glacial outwash settings, that is, aquifers that are primarily composed of coarse sand and gravel.

Descriptions of high-velocity hydrogeologic settings, Darcian and non-Darcian, and where these settings are likely to occur are provided in the following subsections. The likelihood of encountering high-velocity flow regimes can be roughly associated with selected ground-water regions. Heath (1984) developed a map of ground-water regions (Figure 3-2) and summarized the hydrogeologic characteristics of each region. The general hydrogeologic conditions characteristic of each of the regions can be used to preliminarily evaluate the likelihood of encountering a high-velocity ground-water regime at a specific site. Information from the review area should be relied on for the final judgment concerning expansion.

<u>Non-Darcian Settings</u>. Non-Darcian settings can be grouped into three general categories: karst, fractured rock, and extrusive igneous rocks (e.g., basalts). These settings are very common in some regions and are expected to account for a significant, but not dominant, portion of hydrogeologic settings. For judging review area expansion, it is important to determine if the subject ground-water unit is

FIGURE 3-2

GROUND WATER REGIONS OF THE U.S. (Heath 1984)



predominately non-Darcian flow. If non-Darcian flow contributes to a minor part of the flow in the subject ground-water unit, the setting should be treated as a Darcian flow setting with respect to review area expansion.

Karst settings that are most likely candidates for an expanded Classification Review Area are those where the subject ground water is relatively shallow (<100 meters [m]) and the aquifer unit is composed of carbonate rocks, with a well-developed system of solution-enlarged openings (secondary porosity). The solution-enlarged openings serve as the main conduits for ground-water flow and are interconnected into distinct but dynamic ground-water basins feeding a complex of cave streams. These settings are often referred to as karst areas or karst aquifers. Flow through the conduit system is extremely rapid, as much as 1800 feet/hour (ft/hr) (Quilan and Ewers, 1985) over long distances, and in rare cases up to 15 miles. Soils derived from limestone parent materials above the karst flow system are often characterized by large pores (macropores) that are connected to the solution cavities. Such macropores allow a large portion of the infiltrating water to bypass the attenuative soil horizons and move rapidly into the ground water. Karst settings are more likely to be encountered in the following ground-water regions (Heath, 1984):

- Non-Glaciated Central Region.
- Glaciated Central Region.
- Atlantic and Gulf Coastal Plain Region.
- Southeast Coastal Plain Region.
- Puerto Rico and the Virgin Islands.

Fractured bedrock areas where higher ground-water velocities can occur are, in most cases, not the uppermost saturated unit, but rather are highly interconnected with the overlying formation. However, the fractured bedrock tends to be the zone for ground-water withdrawals, and the overlying material serves as a storage unit. The fractured rocks are commonly crystalline, such as granite, or metamorphic, such as gneiss and schist. The fractures may have resulted from folding or faulting and, in rare cases, subsidence. The fractures vary in aperture and frequency. Fractures near the bedrock surface are most numerous and have the largest openings. A general vertical pattern is for fracture porosity to decrease with depth such that there is little fracture porosity below 200 to 300 feet. Lateral fracture lengths can be on the order of several miles. The lateral pattern is typically asymmetric. Fractures tend to occur within narrow corridors that can often be recognized in aerial photographs. Velocities can be nearly as high as those in cave streams, especially under the influence of ground-water withdrawals. Fractured-rock aquifers are not

known to be high yielding and are primarily used for non-community domestic supply.

Fractured-rock settings are most prevalent in the following ground-water regions (Heath, 1984):

- Northeast and Superior Uplands.
- Piedmont and Blue Ridges.
- Western Mountain Ranges.
- Columbia Lava Plateau.
- Colorado Plateau and Wyoming Basin.
- Non-Glaciated Central Region.
- Glaciated Central Region.

Extrusive igneous rocks (e.g., basalts) will usually have zones of high transmissivities and velocities. They are often found in association with sedimentary rocks in the Columbia Lava Plateau Region. These aquifers are composed of sequences of basaltic lava flows that have developed extensive secondary porosity. A lava flow cools rapidly at the surface. As a result, brittle crust forms and is broken into angular fragments by the continued movement of underlying lava. These lava flows may also have lava tubes that act like large-diameter pipes. In addition, the lava flows are subject to fracturing, as lava cools, and the formation of bedding joints. The result is an earth material with considerable secondary porosity that, when saturated, may have a very high transmissivity. These settings are very common in the following ground-water regions (Heath 1984):

- Columbia Lava Plateau.
- Hawaiian Islands.

Darcian Settings. Darcian-type flow settings where high ground-water flow velocities can be expected are rare and are restricted to aquifers with relatively high hydraulic conductivities or transmissivities. Such settings are predominated by coarse grain size, e.g., sand and gravel, with very minor inclusions of silt and clay. Hydraulic conductivities in coarse-grained materials can sometimes be greater than 500 gallons per day per square feet (gal/day/ft^2) and have ground-water velocities greater than 1,000 ft/yr. Such Darcian settings may be found in any region of the country. Generally, they are found in alluvial basins, other alluvial materials, coastal plains, and glacial outwash settings.

3.4 Subdivision of the Classification Review Area

3.4.1 Introduction

For most classification determinations, the assumption is that all the ground water within the Classification Review Area is highly interconnected and, therefore, is classified as one unit. Sometimes, however, the classifier may wish to subdivide the Classification Review Area into separate ground-water units as there may be naturally occurring ground-water bodies of significantly different use and value within the Classification Review Area that need to be considered as part of the decision-making process for the activity or facility involved. These ground-water units may be adjacent laterally and/or vertically to one another. The principal technical issue is to what degree the adjacent units are interconnected, that is, to what extent would an adverse effect on water quality in one unit produce an adverse change in water quality in the adjacent unit. A low degree of interconnection suggests little potential for ground-water migration; a high degree suggests the need to consider the impact of potential migration between units.

The concepts of ground-water units and the interconnection between adjacent ground-water units are especially important in Class III determinations, where degree of interconnection distinguishes the subclasses IIIA and IIIB (see Chapter Six). Subdivision of the review area may also be appropriate in determining whether there is discharge to ecologically vital areas for Class I determinations. Finally, the classifier may wish to subdivide the Classification Review Area to permit a more sophisticated hydrogeologic analysis of the potential impacts of a facility or activity as a step in determining the specific prevention measure or remedial action to be employed at a site.

Subdivision of the Classification Review Area will generally be necessary to demonstrate the existence of the following types of conditions:

- Relative to a specific site, deep ground-water units with Class IIIB water are overlain at a shallow depth by ground-water units with Class I or II water.

- The ground-water unit associated with an activity does not discharge to an ecologically vital area present in the Classification Review Area.

- Relative to a specific site, a shallow, ground-water unit with Class IIB ground water (i.e., a potential source of drinking water) is underlain by a deeper ground-water unit with Class IIA ground water (i.e. a current source of drinking water).

Hydrogeologists routinely assess the interconnection between bodies of ground water for such purposes as designing water-supply systems, monitoring systems, and corrective actions to address contaminated water. Where ground-water bodies are shown to have low interconnection, it is possible to consider them separately in assessing their use and value. Waters within a ground-water unit are inferred to be highly interconnected and, therefore, a common use and value can be determined.

Prevention or cleanup decisions for a ground-water unit with low interconnection to adjacent ground water or surface water can be expected to have no, or very limited, impact on the quality of the adjacent waters. Conversely, where there is high interconnection to adjacent ground water or surface water, the classifier's decision should take into account the potential impact that contamination of one ground-water unit (which may not itself be of great value) may have on higher-quality ground-water units.

The identification of ground-water units and the evaluation of interconnection between ground-water units may, in critical cases, require a rigorous hydrogeologic analysis. The analysis may be dependent upon data collected off-site that is not part of the readily available information normally used in a classification decision. For these reasons, subdivision is expected to be on an exception basis rather than a routine part of classification; EPA will, in most cases, assume a high degree of interconnection within the Classification Review Area.

Once ground-water units within the Classification Review Area have been identified, each unit that may be affected by an activity/facility under review is reviewed according to the criteria or methods in these Guidelines. Note that in the relationship between subdivision and classification:

- All ground water within a ground-water unit has a single class designation with respect to the facility being considered.

- Boundaries separating waters of different classes must coincide with boundaries of ground-water units.

- Boundaries of the Classification Review Area do not constitute ground-water unit boundaries unless they meet the conditions for subdivision boundary (Type 1, 2, 3, or 4 boundaries).

- If a subdivision boundary cannot be acceptably demonstrated, then the existence of a single ground-water unit should be assumed.

3.4.2 Concepts of Ground-Water Units and Interconnection

Ground-water units are components of the ground-water regime, which is defined as the sum total of all ground water and surrounding geologic media (e.g., sediment and rocks). The top of the ground-water regime would be the uppermost surface of the zone of saturation while the bottom would be the base of significant ground-water circulation. Temporarily perched water tables within the vadose zone (see Glossary) would generally not qualify as the upper boundary of the regime. The Agency recognizes that upper and lower boundaries are sometimes difficult to define and their location must be established based on the best available information and professional judgment.

The ground-water regime, encompassed by the Classification Review Area, can be subdivided into mappable, three-dimensional, ground-water units. These are defined as bodies of ground water that are determined on the basis of four types of boundaries as described below,

Type 1: Permanent ground-water flow divides. These flow divides should be stable under all reasonably foreseeable conditions, including planned manipulation of the ground-water regime.

Type 2: Extensive, low-permeability (non-aquifer) geologic units (e.g., thick, laterally extensive confining beds), especially where characterized by favorable hydraulic head relationships across them (i.e., the direction and magnitude of flow through the low-permeability unit). The most favorable hydraulic head relationship is where flow is toward the ground-water unit to be classified and the magnitude of the head difference (hydraulic gradient) is sufficient to maintain this direction of flow under all foreseeable conditions. The integrity of the low-permeability unit should not be interrupted by improperly constructed or abandoned

wells, extensive, interconnected fractures, mine tunnels, or other apertures.

Type 3: Permanent fresh-water/saline-water contacts (saline waters being defined as those waters with greater than 10,000 mg/L of TDS). These contacts should be stable under all reasonably foreseeable conditions, including planned manipulation of the ground-water system.

Type 4: Hydraulic gradient-based boundaries separating permanent upgradient from permanent downgradient parts of a shallow ground-water unit (uppermost aquifer). These boundaries must be simulated assuming worst-case withdrawal rates in the upgradient region.

The type of boundary separating ground-water units reflects the degree of interconnection between those units. Adjacent ground-water units demarcated on the basis of boundary Type 2 are considered to have a low degree of interconnection. A low degree of interconnection implies a low potential for an adverse water-quality change in one ground-water unit to cause a similar adverse change in an adjacent ground-water unit due to the migration of contaminants. A low degree of interconnection is expected to be permanent, unless improper management (e.g., presence of significant numbers of improperly installed or abandoned wells) causes the low-permeability flow boundary to be breached. The lowest degree of interconnection occurs where a Type 2 boundary separates naturally saline waters in a deeper ground-water unit from overlying fresh waters (less than 10,000 mg/L TDS), and the hydraulic gradient (flow direction) across the confining layer (Type 2 boundary) is toward the saline waters.

Type 2 boundary conditions are particularly important for distinguishing Subclass IIIB ground-water units. In this regard, the Type 2 boundary criteria encompass, but are not limited to, the vertical interconnection criteria for Class I injection wells pursuant to the Underground Injection Control program.

Adjacent ground-water units demarcated on the basis of boundary Type 1 (ground-water flow divide), Type 3 (fresh-water/saline water contact), and Type 4 (gradient based) are considered to have an intermediate degree of interconnection. An intermediate degree of interconnection also implies a relatively low potential for adverse water-quality changes in one ground-water unit due to migration of contaminated waters from an adjacent ground-water unit.

A high degree of interconnection is inferred when the conditions for a lower degree of interconnection are not demonstrated. High interconnection of ground waters is assumed to occur within a ground-water unit and where ground water discharges into adjacent surface waters. A high degree of interconnection implies a significant potential for cross-contamination of waters if a component part of these settings becomes polluted.

The degree of interconnection across the boundary types defined here depends on selected key physical and chemical processes governing movement of water and dissolved solute in the subsurface. Under steady-state ground-water flow conditions, the principal mechanisms affecting potential contaminant movement across Type 1, 3, or 4 boundaries would be mechanical dispersion and chemical diffusion. These conditions are considered by EPA to represent an intermediate degree of interconnection. Under transient flow conditions caused by pumpage or accelerated recharge of fluids within the Classification Review Area, the potential exists to spatially displace any of these three boundaries. For this reason EPA believes that foreseeable changes in aquifer stresses and increased ground-water use in the Classification Review Area should be considered in determining the permanence (i.e., location over time) of such boundaries.

The primary mechanism for contaminant transport across a Type 2 boundary is the physical movement of ground water into or from the low-permeability geologic unit. The Agency recognizes that the physical and chemical processes that control fluid and solute transport through low-permeability non-aquifers is not as well understood as it is for aquifers. However, for the purposes of assessing the degree of interconnection, it is assumed that the flow rate of water through the non-aquifer is very small relative to the flow rates through adjacent aquifers.

Appendix A.2 presents further guidance and examples on how boundaries between ground-water units are identified.

3.5 Characterizing the Classification Review Area

After the Classification Review Area dimensions have been determined, the first step in making a classification decision involves collecting basic information about the Classification Review Area. This basic information on demography, the presence of ecologically vital areas, the local use of ground water for water supply, and the hydrogeology will serve as the starting point for the

classification process, pointing the way to where more detailed data collection or analysis may be needed to arrive at a class determination. At this stage, the emphasis is on collecting the most current, best data that is readily available.

The basic data needs are keyed to the principal distinctions between the ground-water classes. Use and value distinctions are based on the extent to which the ground water is now or could be used in the future as a source of drinking-water supply, and if contamination of the ground water could affect ecologically vital areas. Other distinctions between classes are based on hydrogeologic considerations, such as vulnerability and degree of interconnection with adjacent ground water and surface water.

Collection of the basic data needed to characterize the Classification Review Area is discussed below, along with suggestions for possible sources of data. For some decisions, the level of detail at this stage will be sufficient to make a class determination; for other decisions, or where readily available information is inadequate for making a class distinction, more detailed data collection and analysis may be needed. Subsequent chapters discuss each of the classes and provide further guidance on informational needs related to each respective class.

It is recommended that the sources of all information collected be recorded for future reference. When information is not readily available, noting this fact in the file along with what avenues were pursued, may avoid retracing steps at a later time.

Well Survey

A well survey to identify the presence of drinking water-supply wells, public and/or private, in the Classification Review Area is needed to determine local use of the ground water.

Public water-supply systems are defined under the Safe Drinking Water Act as those serving more than 25 persons or with more than 15 service connections. In the well survey, the location of any existing public water-supply wells and their pumpage capacity should be identified. Information on well depth and screened intervals may also prove useful, particularly if more detailed hydrogeologic analysis of the area is to be undertaken.

A detailed inventory of private residential wells is not necessary. One method for estimating the number of private wells is to obtain census data regarding the density of settlement in the area. The area served by public-water systems (surface or ground) is delineated and it is assumed

that the remaining homes have private wells. General characteristics of private wells, such as depth and screened intervals, may also be useful, if available.

Well information may be obtained from water authorities, public-health agencies, regulatory agencies permitting well drilling, well drillers, or other State or local entities.

Water-Supply Reservoirs and Surface Water Intakes

Water-supply reservoir watersheds designated for water-quality protection are specifically recognized in the ground-water classification system and should be identified and described if any are located within the Classification Review Area. The location of surface-water intakes for drinking supply purposes will also be relevant under certain conditions. Again, State and local agencies should be able to provide the information. A more detailed discussion concerning the identification of protected water-supply reservoirs is presented in Chapter Five.

Demography

Information on populations served by public and private wells will be needed if it is apparent that substantial populations may be involved, a finding that could lead to a Class I decision. A first-cut approximation for public-supply wells in the area can be made by dividing the total pumpage capacity by the typical per capita consumption rates for the region. Estimates of the number of private wells in densely settled areas within the Classification Review Area will also be necessary. Densely settled areas can be located on U.S. Census Bureau maps. Detailed procedures for determination of substantial population are provided in Chapter Four.

Ecologically Vital Areas

Ecologically vital areas are also recognized by EPA's classification system and are defined as those ground-water discharge areas that provide habitat for threatened or endangered species (pursuant to the Endangered Species Act) or discharge areas that are Federally managed for ecological value. If any areas that provide habitat for threatened or endangered species are located within the Classification Review Area, candidate discharge areas such as springs, streams, caves, lakes, wetlands, estuaries, coastlines, embayments, and playas, should be identified. (Further analysis of the hydrogeology may be needed to prove actual ground-water discharge; see Chapter Four.) The Regional Office of the U.S. Fish and Wildlife Service and the State Endangered Species coordinator or Heritage Program administrator are two sources for information regarding unique habitats and/or endangered or threatened species. A detailed

discussi on methods to identify ecologically vital areas is presente in Section 4.3. Information about Federal lands may also be obtained from Federal land-management agencies, such as the National Park Service, U.S. Forest Service, and Bureau of Land Management. The presence of Federal lands is indicated on most State and county road maps and U.S. Geological Survey quadrangle sheets.

Hydrogeologic Data

Information on the hydrogeology in the Classification Review Area is pertinent to class distinctions based on vulnerability (Class I) and degree of interconnection to adjacent ground water or surface water (Class III). In characterizing the hydrogeology, for these purposes, general data needs may include the following:

- Regional geology (e.g., surficial geologic maps).
- Depth to water/thickness of vadose zone.
- Regional ground-water recharge rates.
- Aquifer and ground-water flow system characteristics.
- Soil and vadose zone characteristics.
- Topography (slope).
- Landscape position/land form.
- Location of surface-water features.

This information may likely be obtained from county/regional reports and also State geologic surveys or the U.S. Geological Survey. The best available sources of published hydrologic/geologic information are the U.S. Geological Survey publications, State geological surveys, scientific books and journals, and U.S. Department of Agriculture county soil surveys. Data supporting facility permit applications, (e.g., for RCRA-related activities), Clean Water Act Section 208 studies, as well as Environmental Impact Statements, may also be useful. The U.S. Geological Survey District offices are a primary source of area-specific data and information.

The U.S. Geological Survey has two subdivisions which may supply useful information. These are the Hydrologic Information Unit and the Geologic Inquiries Group. They are described below.

1. The Hydrologic Information Unit

The Hydrologic Information Unit answers general questions on hydrology, water as a resource, and hydrologic mapping, as well as on the products, projects, and services of the Water Resource Division. Inquiries should be directed to the following:

The Hydrologic Inquiries Group
United States Geological Survey
419 National Center
Reston, VA 22092
(703) 648-6818

2. The Geologic Inquiries Group

The Geologic Inquiries Group is the primary information group of the geologic division of the U.S. Geological Survey. The geologic Inquiries Group provides information and answers inquiries on the activities and products of the geologic division. Questions concerning all aspects of geology, such as geology of specific areas, geochemistry, geophysics, and other geoscientific disciplines, as well as geologic map coverage should be directed to the following:

Geologic Inquiries Group
United States Geological Survey
907 National Center
Reston, VA 22092
(703) 648-4383

The hydrogeologic information collected during this characterization phase may suggest that there could be potential impacts in an area larger than the usual 2-mile radius (or other program-specific radius) of the Classification Review Area. Section 3.3.2 of this chapter describes those unique hydrogeologic conditions of very high ground-water flow velocities where an expanded Classification Review Area may be warranted and provides guidance on determining the size of the expansion.

Similarly, this review may indicate a need to evaluate the interconnection of ground water with adjacent ground-water units and with surface water, such as when a Class III determination is considered possible or when subdivision of the Classification Review Area into ground-water units is planned (e.g., to address multiple, layered aquifers). Section 3.4.2 of this chapter describes the information needs and considerations involved in assessing interconnection to adjacent water and in subdividing the Classification Review Area into ground-water units.

3.6 Location of the Classification Review Area Boundary Relative to the Facility/Activity Boundary

The facilities and activities subject to EPA actions range in surface area from very small (under 1 acre) to very large (over 40 acres). In some cases, there may be multiple activities located at the same facility for which a single class determination is desired. There may also be an unusually shaped unit or condition, such as a pipeline or an elongated plume. Drawing the limits of a Classification Review Area a given distance away from a facility/activity boundary obviously requires that the boundary be established first.

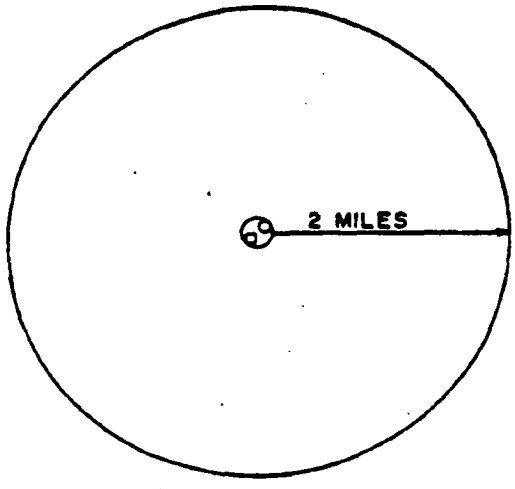
Because the Classification Review Area is intended to be a simple approximation of the zone where ground water may most likely be affected by a facility/activity, precise location of this boundary is not necessary. In general, the facility/activity boundary should encompass all potentially polluting activities related to the Federal action for which the classification decision is needed.

In some cases, it may be appropriate to use the legal boundaries of the facility/activity. Because classification will be in response to a Federal (e.g., regulatory) action, the definition of facility/activity boundary for the purpose of drawing the Classification Review Area limits should be consistent with regulatory definitions of the facility/activity, where applicable.

Figures 3-3 through 3-6 are provided as generic aids to assist in delineating the Classification Review Area for large multiple-activities or unusually-shaped facilities for which the classifier deems that a simple circle from the center of the activity/facility is inappropriate.

FIGURE 3-3. LARGE FACILITY

Approach 1: Draw circle encompassing entire facility. Draw radius from center of circle.



Approach 1: Draw radius from facility boundary (solid line).

Approach 2: Draw circle encompassing entire facility. Draw radius from boundary of circle (dashed line).

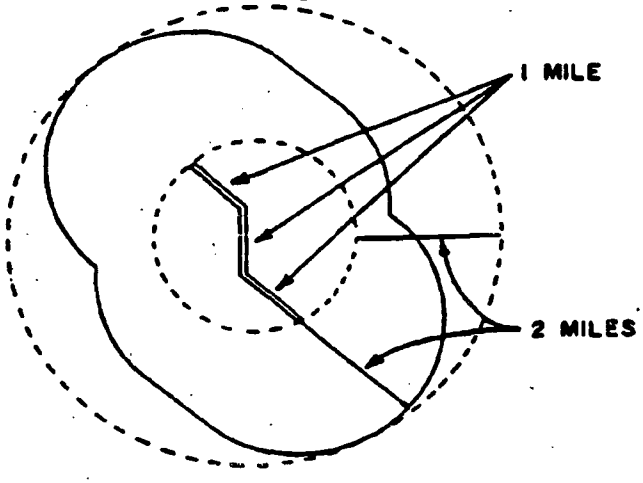
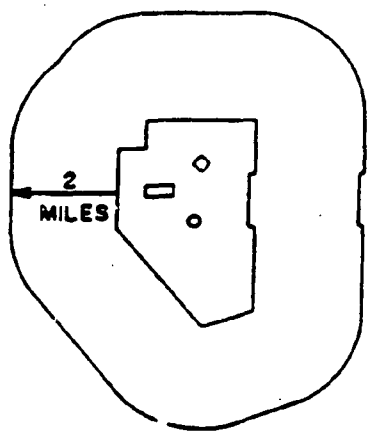
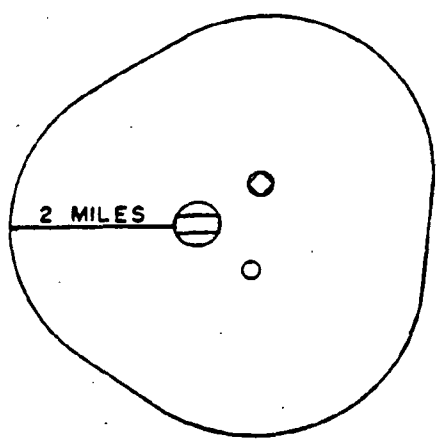


FIGURE 3-4. LARGE, MULTIPLE-ACTIVITY/FACILITY
(e.g., activities separated by more than 1/4 mile)

Approach 1: Draw radius from facility boundary.



Approach 2: Draw individual radii from each activity.



Approach 3: Draw circle encompassing all activities.
Draw radius from boundary of circle.

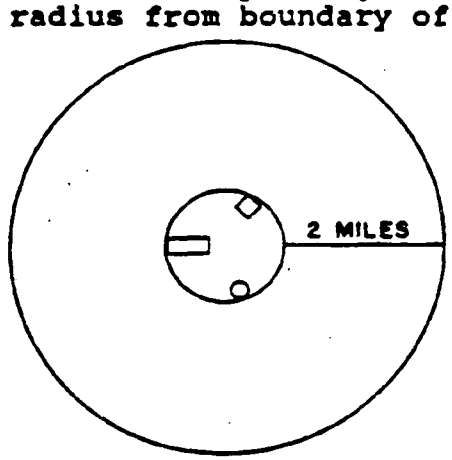


FIGURE 3-5. SMALL, MULTIPLE-ACTIVITY/FACILITY
(e.g., under 40 acres)

Approach 1: Draw circle encompassing entire facility. Draw radius from center of circle.

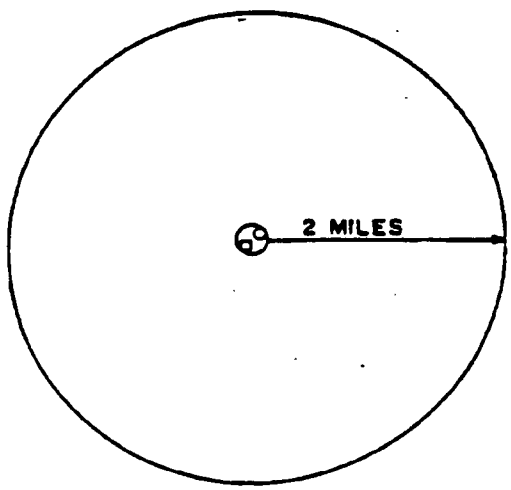
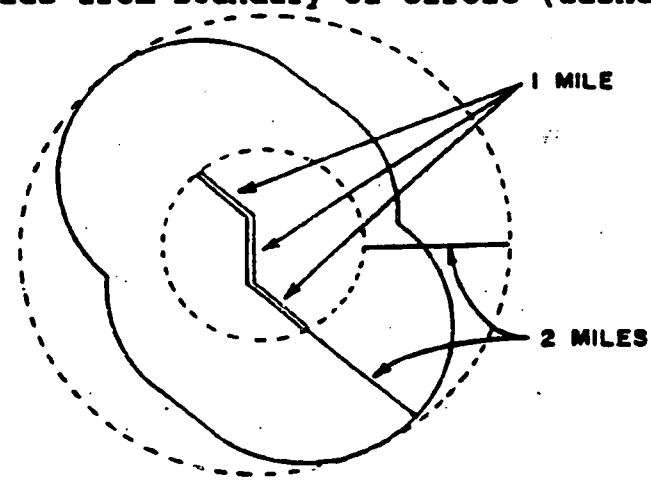


FIGURE 3-6. LONG, IRREGULARLY SHAPED FACILITY

Approach 1: Draw radius from facility boundary (solid line).

Approach 2: Draw circle encompassing entire facility. Draw radius from boundary of circle (dashed line).



CHAPTER FOUR

CLASSIFICATION CRITERIA FOR CLASS I GROUND WATER

4.1 Overview of the Decision Process

4.1.1 Definitions

In EPA's classification system, Class I ground water is ground water of unusually high value. Class I ground waters are defined as highly vulnerable to contamination and are (1) irreplaceable sources of drinking water and/or (2) ecologically vital. The definitions and procedures for identifying Class I ground water are designed to distinguish these special ground waters from the vast majority of other ground waters.

Ground water is considered irreplaceable to a substantial population if it would be economically infeasible to develop an alternative water-supply source of comparable quality and quantity in the area, or if delivery from an already existing alternate source is precluded by institutional constraints or transport distance. Ground water is considered Class I - Ecologically Vital primarily if it supplies a sensitive ecological system that supports a unique habitat. Such ground waters will generally have an unusually high value due to either the potential risk to the large number of people dependent upon the ground water as a source of drinking water or the risk of further endangerment to endangered or threatened species that depend on the unique habitat supported by that ground-water resource. Certain Congressionally-designated Federal land management areas, managed for the purpose of ecological protection, may also be considered unique habitats in some cases.

Chapter Four provides definitions and discussions of key words and concepts important to a Class I decision and discusses in detail the procedures for making a Class I determination. This chapter covers the possible sequence of classification steps, corresponding data needs, and technical methods for each step in the decision process. The classification procedure ultimately relies on the professional judgment of the classifier. The procedures presented here

may help to simplify and clarify the classification process and to promote consistency between classification decisions. Supplemental information about the Class I classification process is provided in Appendices B and D.

4.1.2 General Procedures

The Class I decision process will generally begin with either a determination of irreplaceability or the identification of ecologically vital areas, followed by a determination of ground-water vulnerability. Preliminary data may indicate that one of the Class I criteria can be more easily demonstrated than another. If so, the classification process should begin with the criterion that can be most easily demonstrated. It is important to note that the order in which Class I steps are performed is not fixed. The simplest, least expensive, and most appropriate method of arriving at the classification decision should be applied in any given situation. It will be up to the classifier to determine the order in which a Class I procedure is performed.

The general procedures that are followed in a Class I decision are illustrated in Figure 4-1. The steps involved in each general procedure, as well as basic data needs and techniques that may be used to evaluate each step are discussed below.

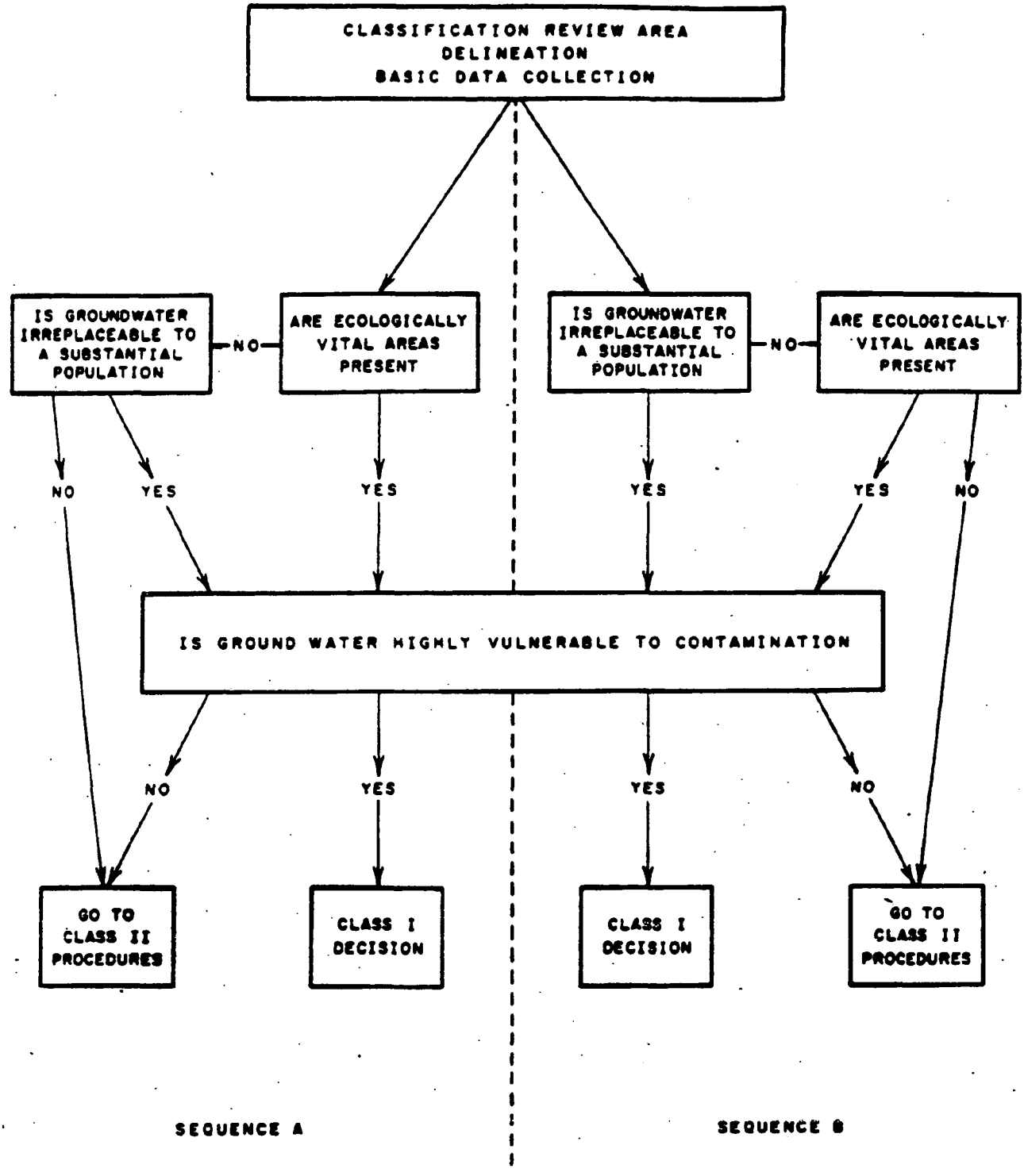
Determine Presence of Drinking-Water Wells

The presence of drinking water wells within the Classification Review Area may indicate to the classifier the possibility of a Class I - Irreplaceable Source of Drinking Water decision.

Basic data collection within the review area will most likely include a general survey of wells used for drinking water. Well surveys commonly include location, use, and pumpage capacity of existing public water-supply wells or fields within the Classification Review Area. A detailed inventory of private residential wells would be valuable, but should not be considered necessary. As a preliminary step, the delineation of areas not served by public-water supplies and the approximate number of homes in the review area can be evaluated. Census data can also be used to estimate the number of private wells within the Classification Review Area. The classifier may wish to summarize the well data to estimate the number of public and private wells present. Other general characteristics of aquifers used in the Classification Review Area may also provide information concerning vulnerability to contamination.

FIGURE 4-1

GENERAL PROCEDURE FOR CLASS I DETERMINATION



Well information may be obtained from water authorities, public-health agencies, regulatory agencies that permit well drilling, well drillers, or other State and local agencies. If wells do not exist within the Classification Review Area, the classifier will go to procedures for determining the presence of ecological vital areas within the Classification Review Area. A detailed discussion of information needs is presented in Chapter Three.

Determine Irreplaceability to a Substantial Population

A ground-water source may be classified as irreplaceable if it serves a substantial population and if creation of an alternate supply source would be economically infeasible or if reliable delivery of water of comparable quality and quantity from already existing alternative sources in the region is precluded by transport distance or institutional constraints. It is important to emphasize that the irreplaceability criterion is a relative test in that its goal is to identify those ground waters of relatively high value (compared to others). As a result, these may deserve to be treated as unique or special.

The first step in the evaluation of irreplaceability to a substantial population involves determining whether the user population is substantial. In general, user populations of 500 persons or more may be considered substantial for the purpose of these classification Guidelines. Ground water serving populations of less than 500 persons also may be considered irreplaceable in some cases, based upon factors discussed later in this section.

The Agency has adopted the 500-person value as a general substantial population threshold. Population size considerations are important given that, from a risk-related perspective, it is intended that the identification of Class I ground water be associated with the greater aggregate risk and potential economic damage faced by larger populations. The 500-person number also has the advantage of making implementation reasonable as it is the level at which many States apply well registration.

If the ground water under review does serve a substantial population, then the second step of the determination of irreplaceability is to make a preliminary determination by applying a number of screening tests. These screening tests, designed to demonstrate irreplaceability, include the following:

- Uncommon pipeline distance.
- Institutional constraints.
- Comparable quality.
- Comparable quantity.
- Economic irreplaceability.

Each test is discussed briefly here; a more detailed discussion is presented in the next section. The order in which the tests are presented is according to the relative cost and effort involved in collecting and applying each test, with the less costly tests discussed first. The tests may be applied in a different order, however, depending on site-specific situations.

Screening Test 1: Uncommon Pipeline Distance. The concept of an uncommon pipeline distance provides a means for estimating the limits of the area within which potential alternative water sources may be located. Without such a boundary, any water source in the country might be considered a replacement for any other water source, making the irreplaceability concept unworkable. If there are no replacement sources within a distance smaller than the uncommon pipeline distance, then the preliminary determination would be that the ground water under review is irreplaceable.

Screening Test 2: Institutional Constraints. For purposes of the Classification Guidelines, institutional constraints are defined as legal or administrative restrictions that preclude, or make very difficult, replacement water delivery and that may not be alleviated through administrative procedures or market transactions. Such constraints limit access to alternative water sources and may involve legal, administrative, or other controls over water use. The existence of institutional constraints can eliminate one or more possible alternative sources from consideration (and, likewise, indicate which alternate supplies are more viable than others) and, therefore, can result in a preliminary determination of irreplaceability.

Screening Test 3: Comparable Quality. Comparable quality is defined in terms of the quality of raw sources of drinking water used in the area, considering in a general way, both the types of contaminants that are present and their relative concentrations. The intent is to make rough order-of-magnitude comparisons to determine whether the potential alternative is of the same general quality as the source and as other water used for drinking in the region, without conducting a specific, parameter-by-parameter comparison. If none of the potential replacement sources is comparable in quality to the current source or typical sources within the region, then the preliminary determination for the current source would be that it is irreplaceable. This test is considered a true "screening approach" since the

utility of an alternative water source based on quality considerations is more completely assessed by the economic irreplaceability test.

Screening Test 4: Comparable Quantity. Comparable quantity means that the alternative source or sources, whether surface or ground water, is/are capable of reliably supplying water in quantities sufficient to meet the year-round needs of the population served by the ground water. If none of the potential replacement sources can provide a comparable quantity of ground water, then the preliminary determination for the current source would be that it is irreplaceable.

Screening Test 5: Economic Irreplaceability. The Agency has defined economic irreplaceability of an alternative water source principally in terms of total water supply costs per household. This does not in any way imply that the Agency expects that communities will be required to replace water supplies or pay for such replacements. Again, this is a relative measure to determine the extent to which ground waters potentially affected by a facility/activity are truly special. The economic infeasibility test is designed to identify situations where the cost of replacing a water supply would place an unusually high economic burden on the population served if the ground water now being used became unusable. If the cost of replacing the current source would be economically unreasonable, then the preliminary determination for that source would be that it is irreplaceable.

The third and final step for completing the determination of irreplaceability following the application of any of the five screening tests, or if the user population is not substantial, is to review site-specific, qualitative conditions and make a final determination (i.e., either irreplaceable or not irreplaceable). The following qualitative factors have been compiled by EPA for consideration during this step: the presence of transient populations; projected trends in population size, economic conditions, and water development projects; and the use of unreliable transport mechanisms. These factors are discussed in more detail in Section 4.2.3.

Determine Presence of Ecologically Vital Areas

Ecologically vital areas are primarily defined as ground-water discharge areas that serve as habitats for species that are listed, or proposed for listing, as endangered or threatened (pursuant to the Endangered Species Act as amended in 1982). The location of proposed endangered or threatened species habitats, or any Federal lands managed for ecological values within the Classification Review Area should be identified. The Regional Office of the U.S. Fish

and Wildlife Service and the State Endangered Species coordinator or Heritage Program administrator are two sources of information regarding unique habitats and/or endangered or threatened species. Information about Federal lands may also be obtained from Federal land-management agencies, such as the National Park Service, U.S. Forest Service, and Bureau of Land Management. The presence of Federal lands is indicated on most State and county road maps and on U.S. Geological Survey quadrangle sheets.

For the ground water to be considered ecologically vital, the ground water must discharge to a unique habitat as defined above. Another step in this determination, then, is locating discharge areas that may affect the unique habitat. Such areas may include springs, streams, caves, lakes, wetlands, estuaries, coastlines, embayments, and playas. Discharge areas can be located using topographic maps or Federal and State Water Resource reports. Section 4.3 provides detailed information on identifying Ecologically Vital Areas.

Determine Vulnerability

The determination that a setting is highly vulnerable to contamination is based on a best professional judgment approach. When attempting to evaluate vulnerability, a classifier should select the most appropriate vulnerability assessment tools for a given situation. The selection should be based on factors such as regional hydrogeologic conditions, availability of data, and professional experience of the classifier or support staff. It is recommended that the classifier examine multiple lines of evidence to support a vulnerability determination. Such an approach might include an evaluation of hydrogeologic factors relevant to vulnerability, matching the subject hydrogeologic setting to a highly vulnerable descriptive/qualitative setting as provided in this guidance, and/or employing one or more technical evaluation aids.

In Section 4.4.1, guidance is provided regarding the hydrogeologic factors to consider for evaluating vulnerability. Selected vulnerability evaluation aids are also presented. Where appropriate, benchmarks indicative of highly vulnerable hydrogeology are provided.

4.2 Procedures for Determining Irreplaceable Source for a Substantial Population

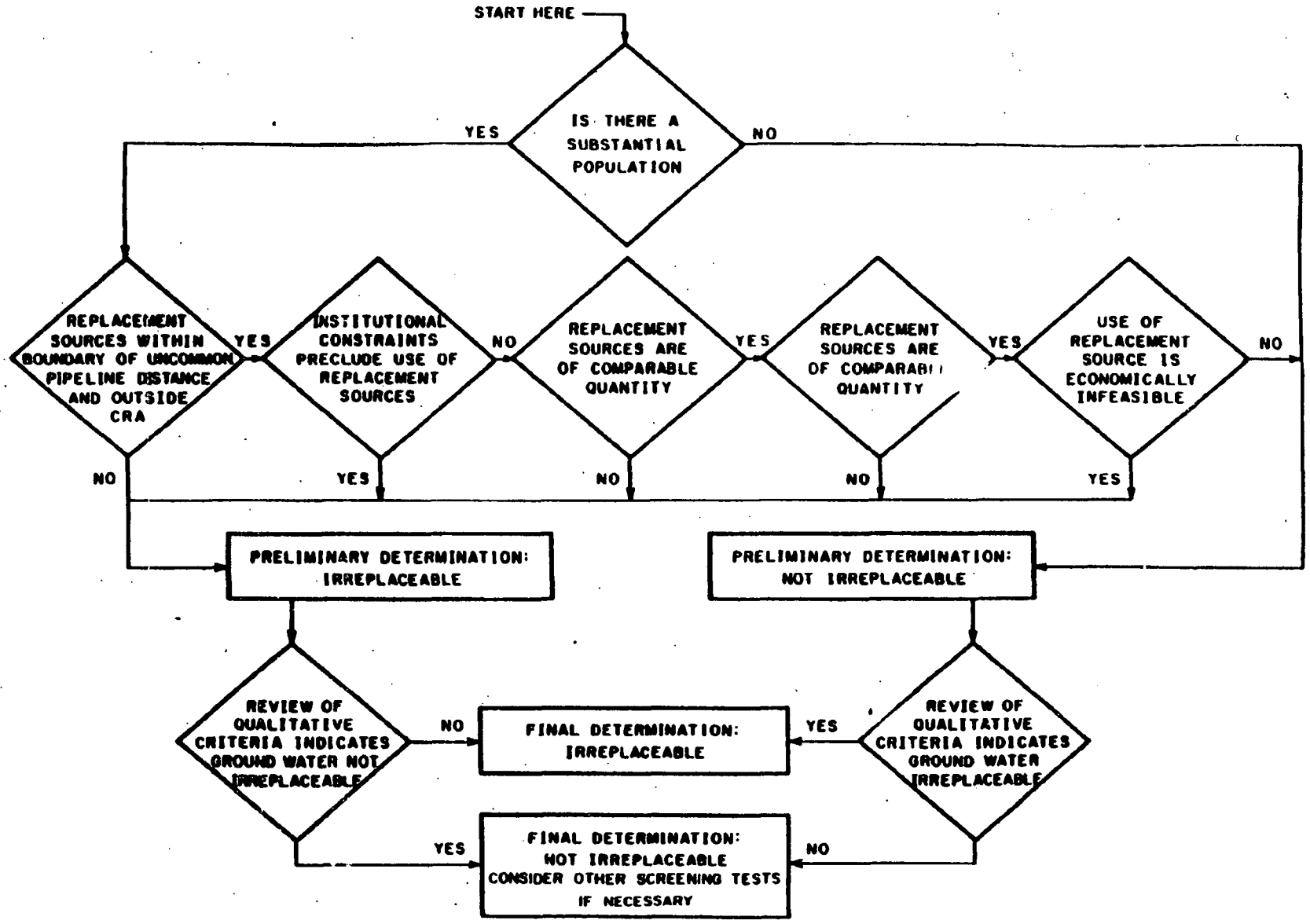
The purpose of evaluating the irreplaceability of ground-water supplies for substantial populations is to identify those waters of relatively high value. For the purposes of classification, this is not meant to require extremely rigorous or costly analyses. On the other hand, these Guidelines are designed to ensure that truly special ground waters, due to their use and irreplaceability, are identified and addressed appropriately.

The determination of irreplaceability process outlined here involves a three-step approach that is intended to be straightforward and to rely on readily available data. The purpose of this process is to determine whether the ground water within the Classification Review Area is irreplaceable to a substantial population. In the first two steps, a preliminary determination of irreplaceability is made based on the population size and a series of screening tests. The third step, in turn, produces a final irreplaceability determination that reflects consideration of several factors that may warrant adjustment of the initial determination.

In brief, the first step involves estimating the size of the ground-water user population and determining if the population should be considered substantial for the purposes of classification. If the population is not considered substantial, then the site in question may be given a preliminary not-irreplaceable determination and the classifier may proceed to the third step of the process (i.e., a qualitative review). If, on the other hand, the population is deemed substantial, then the second step of the determination of irreplaceability may be applied. The second step involves applying five screening tests related to population size and irreplaceability that are designed to yield a preliminary determination (i.e., either irreplaceable or not-irreplaceable). These screening tests include an uncommon pipeline distance test, an institutional constraints test, a comparable quality test, a comparable quantity test, and an economic irreplaceability test. Having made a preliminary determination in Steps 1 or 2 (e.g., not irreplaceable), based either on the population size or the outcome of the screening tests, the classifier may then apply a number of qualitative criteria designed to recognize site-specific factors that may warrant making a different final determination (e.g., irreplaceable). The end result of this third step, therefore, is the final determination of irreplaceability. Figure 4-2 presents a flow-chart designed to illustrate how a classifier might move through this three-

FIGURE 4-2

SUGGESTED METHOD FOR DETERMINING IRREPLACEABILITY TO SUBSTANTIAL POPULATIONS *



* A classifier may apply these criteria in a different order, if warranted by site-specific conditions

step method in order to make a ground-water classification decision.

Note that each of the five screening tests is designed to demonstrate that a ground-water supply is irreplaceable. Moreover, none of the tests can be used in and of itself to demonstrate that a ground-water supply is not irreplaceable. Therefore, if any single screening test demonstrates irreplaceability and is consistent with the appropriate qualitative criteria, the ground water would then be considered irreplaceable and the classifier would not need to perform any further analysis. On the other hand, if a given screening test cannot be used to demonstrate irreplaceability, then the next test should be applied. Only if none of the five screening tests, along with the qualitative review, demonstrates irreplaceability should the classifier conclude that the ground water is not irreplaceable.

The three steps for determining irreplaceability to a substantial population are described in detail below.

4.2.1 Step 1: Determination of Substantial Population

The first step of the determination of irreplaceability involves assessing whether the user population should be considered substantial. This step entails estimating the actual size of the user population first and then making the substantial size determination itself. Both of these decisions involve judgment by the classifier. A suggested process for making this estimation and determination is presented below.

For the purposes of estimating the size of the user population, persons using the ground water in question generally include those individuals served by the following:

- Public water-supply well(s) within the Classification Review Area (or appropriate subdivision); or
- Private wells within the Classification Review Area or appropriate subdivision for persons living in a densely settled area (i.e., census definition based on 1,000 persons per square mile, see Appendix B.1); or
- A combination of the above.

This definition of a user population is based largely on concepts already used by the Census Bureau. The population data necessary to make these determinations are widely accessible and sufficiently up-to-date.

In most instances, making these population determinations should be straightforward. If the well(s) in the Classification Review Area or appropriate subdivision serve a public-water system, then an estimate of the number of user households multiplied by the average number of persons per household (2.75 on a national basis, although each State or locality may be somewhat different) should approximate the total population served; if the population is served by other water sources, these should be accounted for proportionately. Water supplied for industrial and agricultural purposes should not be included. For private well users, it will be necessary both to estimate the population in the Classification Review Area not served by public-water systems and to calculate the population density. The EPA maintains a data system called GEMS (Graphical Exposure Modeling System) which can be used to estimate both population and population densities for a variety of areas around a point (see Appendix B.2 for details). The degree of uncertainty associated with making these estimates for a particular situation may necessitate greater or lesser reliance on reasonable and conservative assumptions.

Once the population size has been estimated, the classifier should decide whether the population is substantial. User populations of 500 persons or more may be considered substantial for the purpose of this classification. Likewise, populations less than 500 persons may warrant a preliminary not-irreplaceable determination immediately (i.e., skipping the second step of the determination of irreplaceability), with the possibility of shifting to a final irreplaceable determination based on a review of site-specific conditions (i.e., the third step). Population estimates close to 500 persons in size will require best professional judgment.

4.2.2 Step 2: Screening Tests to Make Preliminary Determinations

The second step of the determination of irreplaceability involves applying five separate screening tests in order to make a preliminary determination. Each of the five tests reflects the size of the user population or some measure of the ground water's irreplaceability or both. The tests are designed to identify ground waters that are truly special.

The tests are presented in a suggested order that attempts to minimize the level of effort and cost associated with the determination. Specific situations, however, may indicate applying the tests in a different order.

The five screening tests for making preliminary classification decisions are as follows:

1. Uncommon or unreasonable pipeline distance.
2. Institutional constraints.
3. Comparable quality.
4. Comparable quantity.
5. Economic irreplaceability.

The following sections describe methods for applying these screening tests. Each section also identifies and characterizes data sources that are relevant to the tests. The data sources are generally available from Federal and State agencies or other easily accessible sources.

Screening Test 1: Uncommon or Unreasonable Pipeline Distance

If there is no indication that a different test should be applied first (e.g., the classifier knows that all potential replacement sources will be unavailable due to institutional constraints), then the uncommon pipeline distance test will probably be the most appropriate test to apply first when making a preliminary determination. This test sets a hypothetical outer radial boundary around the site being classified which, in conjunction with the inner boundary set by the Classification Review Area, or subdivision thereof, establishes the zone within which alternative water supplies can reasonably be considered (i.e., the zone between the two boundaries). In other words, the test restricts the number of alternative sources that need be considered in the irreplaceability determination by excluding those sources that are unreasonably far away.

In theory, an uncommon pipeline distance could be defined as the typical maximum distance water is currently piped from the raw-water source to the distribution system for each population category within a given geographic region. Given this definition, current pipeline distances may vary considerably within a region due to a number of factors. For example, regions with diverse topographic, geologic, hydrologic, or seismic characteristics may have a wide variation in pipeline distances and, therefore, may not have a single typical pipeline distance. Moreover, pipeline

distances may vary greatly in length due to other factors, such as the availability of developed water resources (e.g., lakes, reservoirs, etc.), institutional constraints on water development, water demand, and economic resources, all of which may vary within a region. This variability in pipeline distance is especially apparent when considered across regions. In the semi-arid regions of the West, for example, water may be conveyed 50 miles or more from the source to the distribution system. On the other hand, water is typically piped 5 miles or less in the East due to other factors such as greater annual rainfall, a different set of property rights, and different levels of urbanization and population density. Finally, piping distances can range considerably even among neighboring states.

If sufficient data exist in a specific situation to determine an uncommon pipeline distance for the population in question, then the classifier may choose to use a value derived from that data. In doing so, the classifier should ascertain a consistent uncommon pipeline distance based on a reasonably defined geographic region (e.g., statewide) and populations similar in size to the population in question.

If, on the other hand, sufficient data are unavailable or pipeline distances vary widely for populations that are in the same region and are of similar size to the population in question, then it may not be practical to define an uncommon distance in this manner. Therefore, a second approach can be used in applying this test. This second approach is based on the observation that, due to economies of scale, water-supply systems serving larger populations can afford to pipe alternative sources of water from increasingly farther distances. In other words, for a given level of economic burden (i.e., the maximum affordable cost of piping a replacement water supply as a percent of average annual household income), larger populations will have larger areas within which they can consider alternative sources (i.e., longer uncommon pipeline distances).

In the absence of an exhaustive survey of pipeline distances, the threshold distances presented in these Guidelines are based on information provided by EPA's research laboratories and the Federal Reporting Data System (FRDS) managed by EPA's Office of Drinking Water. More specifically, data from EPA's Cincinnati water-quality laboratories were used to estimate the costs of transporting various quantities of water over various distances. Using this information, information concerning the water requirements of various population sizes, and household income data, a relationship between population size and uncommon distance was defined.

There are two benefits to using this approach for defining uncommon pipeline distances. First, this approach allows a reasonable and consistent method for delineating the

area within which classifiers might consider alternative sources. Second, this approach allows a fairly definitive measure of irreplaceability based on the economic burden of transporting water as it relates to population size.

Table 4-1 can be used to assess whether a preliminary irreplaceable determination is appropriate. The pipeline distances can be used as lower limits of uncommon pipeline distances. For example, if the user population is between 500 and 5,000 persons, then pipeline distances greater than 25 miles could be considered uncommon or unreasonable. Therefore, if there are no alternative water supplies within 25 miles of the site under review and outside the Classification Review Area, then the ground water in question would be considered irreplaceable for the preliminary determination.

After the appropriate pipeline distance has been established, the final step of the preliminary determination is to ascertain whether potential replacement water-supply sources are in fact present within the uncommon pipeline distance and beyond the Classification Review Area. Potential sources may include both surface or ground water outside of the ground-water unit under review. Common examples of surface water that can be considered as a replacement source are rivers, streams, natural lakes, and impoundments. Alternative ground-water sources may be located in the same aquifer, or in another nearby aquifer, horizontally or vertically separated from the source aquifer.

If a preliminary irreplaceable determination is made on the basis of the uncommon pipeline test and if there are no relevant qualitative criteria that would warrant a final not-irreplaceable determination (as described in Step 3), then the final determination would be irreplaceable. Note that if an alternative source falls within close range of the uncommon pipeline boundary, then a best professional judgment should be made by the classifier as to whether the source could be considered. Note also that if the final determination is based on this test (i.e., no alternative sources exist within an uncommon pipeline distance boundary), no further analysis need be done. If a final irreplaceable determination is not warranted at this point, however, the classifier should continue to the next screening test.

Screening Test 2: Institutional Constraints

The second screening test to be applied when determining the irreplaceability of a ground-water supply is whether institutional constraints exist which might preclude, or make very difficult, the delivery of an alternative supply. This section defines institutional constraints, provides a process

TABLE 4-1*
GENERALLY APPLICABLE UNCOMMON
PIPELINE DISTANCES

Population Size	Uncommon Pipeline Distance
500 - 5,000	25 miles
5,000 - 10,000	35 miles
10,000 - 25,000	70 miles
25,000 - 100,000	100 miles
> 100,000	150 miles

*Note: In developing this uncommon pipeline distance function (i.e., population size versus uncommon pipeline distance), a 1 percent economic threshold was used consistently across all population size categories in order to make the distance calculations as described above. This single threshold level differs from the economic infeasibility screening test, described below, which uses an absolute dollar economic burden threshold that varies based on population size. These two tests differ for two reasons. First, use of a single economic threshold simplifies the calculation of uncommon pipeline distances. Second, even in situations where replacement water supplies are deemed to be within a common pipeline distance using the 1 percent threshold, the economic irreplacability test will still be used to assess irreplaceability based on the size-dependent, absolute dollar threshold. There is no need, therefore, to calculate uncommon pipeline distances using variable economic burden thresholds.

for categorizing institutional constraints, and provides guidance for applying the screening test itself.

Institutional constraints involve legal, administrative, and other similar forms of control over access to water. For purposes of these Guidelines, the Agency has adopted the following definition of institutional constraint:

An institutional constraint is a situation in which, as a result of a legal or administrative restriction, delivery of replacement water may not be assured through simple administrative procedures or market transactions.

Note that this definition applies to situations where replacement, even though not strictly precluded, is made very difficult by institutional constraints.

While a detailed examination of legal and institutional issues is rarely called for, a preliminary review should indicate whether an institutional constraint is present. The following discussion presents a breakdown of potential institutional constraints and a general procedure for determining whether a binding institutional constraint is present in a particular situation. Appendix B.3 provides a more detailed description of constraints, as well as sources of information.

The Agency has identified various kinds of potential constraints and determined which are probably binding, which may be binding in some cases or possibly binding, and which are unlikely to be binding. For a straightforward assessment, comparison of the constraints affecting a particular source of water, as presented in Figure 4-3, should suffice. In those cases where a detailed assessment is warranted, the procedure outlined in Figure 4-4 is suggested. The case study presented in the next section, illustrating a somewhat complicated institutional constraint situation, may also prove useful when making less-straightforward assessments.

<u>Institutional Constraint Case Study</u>. A potential source of replacement water (e.g., the Rio Grande River) may be subject to an international treaty (e.g., the 1944 Treaty between the United States and Mexico on Utilization of the Waters of the Colorado and Tijuana Rivers and of the Rio Grande) limiting the amount of water that may be withdrawn by users in the United States, and to an Interstate Compact limiting the amount of water that may be used within a particular state. In addition, that portion of the river flow assigned to a particular state may already be fully taken up by other users. Finally, the use for which the water is being considered as a potential alternative source may be situated some distance from the river and require a right-of-way in order to get access to the water.

FIGURE 4-3
POTENTIAL INSTITUTIONAL CONSTRAINTS

Probably Binding Constraints

- Water is subject to international treaty.
- Water is subject to interstate water apportionment compact of litigation among states.
- Water is subject to Federal or Indian reserved right.

Possibly Binding Constraints

- Water is allocated by litigation among persons.
- Water is allocated by permit.
- Water is allocated by local water district or another local authority.
- Amount of water that may be used is limited:
  - By public trust doctrine.
  - By instream flow protection requirements.
  - By state law.
  - By permit.
  - By local management authority.
  - By prior appropriation(s) that are all for highest beneficial use.
  - By Federal navigational servitude.
- Place of use of water is limited:
  - By state law.
  - By permit.
  - By local authority.

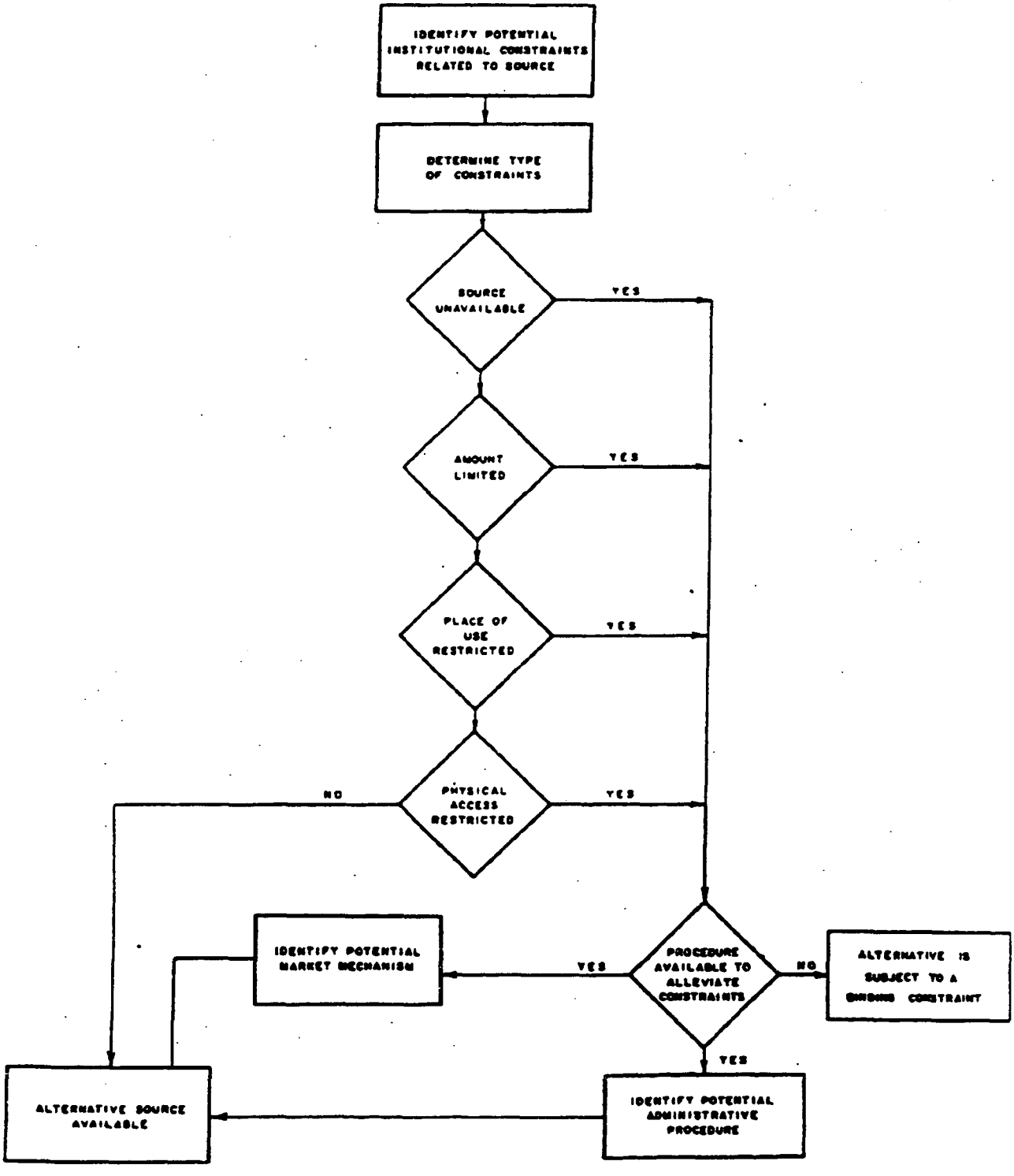
Constraints Unlikely to be Binding*

- Water is subject to prior appropriation (unless for highest beneficial use).
- Water is subject to riparian right.
- Physical access to property is restricted:
  - By property rights of other persons limiting rights-of-way for pipes, ditches, conduits, etc.
  - By Federal or State statutes requiring environmental impacts assessment or establishing other procedural requirements.

* Upon application of simple administrative procedures or market transactions.

FIGURE 4-4

OUTLINE OF PROCEDURE FOR ANALYZING POTENTIAL INSTITUTIONAL CONSTRAINTS TO THE USE OF AN ALTERNATIVE SOURCE OF WATER



In this situation, the treaty, the interstate compact, the water-allocation system, and the property rights of other persons, are all potential institutional constraints. Each should be considered separately. The treaty and the interstate compact may be impossible to avoid or change through simple administrative procedures. A telephone call to the State office in charge of water allocation would probably indicate that the water allocation could potentially be revised by a simple administrative procedure or that market transactions can be used to change the current allocation of water. Similarly, informal contact with a State Attorney General's office should indicate that the problem of access could potentially be resolved through purchase of an easement or right-of-way, or that the administrative process of eminent domain could potentially be used to provide access to the water. In such situations, a binding institutional constraint probably would not be present, despite the potential constraints that were identified.

Once the institutional constraints for a classification decision have been categorized in terms of their potential for being binding, the screening test itself should be applied. That is, if the institutional constraints affecting the delivery of alternative sources are considered to be sufficiently binding, then the classifier may conclude that the user population's current ground-water supply is irreplaceable for the preliminary determination. Note that the classifier should make a best professional judgment if several alternative sources with varying levels of constraint are available. If, upon review of the relevant qualitative criteria (Step 3), the final determination is also irreplaceable, then no further analysis need be performed. If application of this screening test in conjunction with the appropriate qualitative criteria does not result in an irreplaceable determination, however, then the classifier should apply the next screening test.

Screening Test 3: Comparable Quality Analysis

Once a potential alternative source(s) has been located within the boundary of an uncommon pipeline distance and outside the Classification Review Area and the classifier has determined that no institutional constraints exist that would preclude, or make very difficult, delivery of water from the alternative source, the next step is to determine whether the source offers water of quality and quantity comparable to the user population's current ground-water supply. This section describes the comparable quality screening test while the next section describes the comparable quantity test. Note that the comparable quality test need not be applied before the comparable quantity test. If the situation and availability of data suggest that the quantity test should be

applied first (and followed by the quality test if need be), then the tests may be applied in that order.

The term comparable quality is defined as the level of water quality that is not substantially poorer than other raw drinking-water resources in the region. To be considered of comparable quality, the quality of the alternative water resource should be (within an order-of-magnitude) as good as or better than existing drinking-water resources, taking into account the precision of the measurement of each parameter. For example, an existing water source may have an average of 93 mg/L TDS, with a range of 75 mg/L to 100 mg/L. An alternative water source may be considered not of comparable quality if it has an average TDS of 930 mg/L with a range of 750 mg/L to 1,000 mg/L. For some parameters of concern (e.g., taste, color, odor), the evaluation may be highly subjective. Again, the test is meant to be a relative evaluation which considers a few general categories of parameters (e.g., TDS, organic compounds, heavy metals, radionuclides, and other secondary physical/chemical properties).

The rationale for incorporating this test is to allow for quick and inexpensive appraisals of the utility of alternative water sources. More comprehensive assessments of irreplaceability can be obtained through the economic irreplaceability analysis outlined in Screening Test 5. This test does include a water treatment component.

Existing information on water quality should be used, given the very high cost of new series of sampling and analysis. The comparison is intended to be relative and subject to professional judgment. At the Federal level, three important sources for water-quality information may be consulted: EPA, the Army Corps of Engineers, and the U.S. Geological Survey. Each of these agencies has conducted, or continues to conduct, comprehensive surveys that describe water resources in the United States. Although not always designed specifically to provide detailed water-quality data, these studies provide information sufficient to facilitate the comparable quality considerations of the ground-water classification system.

EPA has funded comprehensive studies of Regional water quality to determine the principal point and non-point sources of pollution. These studies, conducted under Section 208 of the Clean Water Act, for example, give a broad overview of water quality (USEPA, 1980b). They are generally obtainable through the State and local agencies which received the funding. The Army Corps of Engineers conducts similar regional water-resource studies in order to examine water supply and demand within specified river and lake basins in the United States. The most useful data resource from the U.S. Geologic Survey will often be the published

basin-wide investigations of ground- and surface-water resources. The U.S. Geological Survey also maintains the National Water Data Exchange (NAWDEX), which is designed to assist users in the identification, location, and acquisition of information on water resources. The National Water Well Association (NWWA), Dublin, Ohio, maintains a library of all U.S. and State Geological Survey information on water supply and quality. Using automated searching capabilities, the NWWA can identify and list all publications concerning a specific geographic area.

On a more local level, regional planning boards and government councils also may have information on potential drinking-water supplies and river, lake, and stream quality in their regions. State agencies that administer environmental protection, land-use planning, agricultural, geological survey, public health, and water programs, are excellent sources of information. State universities (particularly land-grant universities) may sometimes serve as repositories of information concerning ground- and surface water supplies.

Screening Test 4: Comparable Quantity

The fourth screening test that may be applied to determine the irreplaceability of a user population's ground water supply is the comparable quantity test. As noted in the comparable quality test discussion, the quality and quantity tests can be applied in either order depending on the situation or availability of data. Regardless of which test is applied first, however, the second test would be applied if the first test does not demonstrate that the ground-water source is irreplaceable. The remainder of this section describes how the comparable quantity test should be applied.

The term comparable quantity is defined as the level of water quantity that is essentially equal to the quantity supplied by the current ground-water source. Determining whether the alternative source, or sources, can yield adequate quantity requires three analytical steps:

- Determine current supply needs of water users.
- Characterize potential sustainable water yield of the alternative water supply.
- Compare alternative water supply and existing water demand.

Step 1: Determine Current Supply Needs of Water Users. If the ground water to be classified supplies a public-water system, current supply needs will be known by the water utility. If the ground water to be classified serves a substantial population using private wells, current water needs must be estimated using population figures and assumptions concerning typical water use. For the purpose of this exercise, the Agency recommends using the assumption that the average household uses 100,000 gallons of water per year and consists of 2.75 persons.

Step 2: Characterize Potential Sustainable Water Yield of the Alternative Water Supply. The second step of this screening test is to estimate the potential sustainable yield of alternative water supplies. The information necessary to make this estimate is best obtained from the published studies discussed in Chapter 6 (Insufficient Yield Test) of these Guidelines. When making the estimate, the classifier should note that routine water shortages in communities currently served by an alternative source may indicate that the alternative source would be theoretically unable to provide water for an additional population increment. Rapidly falling ground-water levels over time also may indicate that an alternative source would not be capable of consistently providing sufficient yield year-round. Finally, even if levels are not falling, the alternative source may be unavailable for additional usage if proper resource management techniques are maximizing the yield while holding the water level constant. In cases where the ability of an alternative source to meet the needs of the substantial population is unclear, a more quantitative analysis may be necessary.

Step 3: Compare Alternative Water Supply and Existing Water Demand. The final step of this screening test is to compare the potential yield of the alternative water supply with current water needs. For this step, water needs may be considered on an annual or monthly basis. In cases where the alternative source is located in a water-rich area, the comparison of user needs and source yield may be done on an annual basis. The comparison should be conducted on a monthly basis, however, if the alternative source is ground water under existing or potential stress or if the alternative source is a surface water with considerable month-to-month variability in flow. Important sources for water-quantity information include local water utilities, State water agencies, and the U.S. Geological Survey.

Once the user needs and replacement source yields have been derived and compared, the comparable quantity test itself should be applied. That is, the classifier should use professional judgment to determine whether the replacement source could adequately supply the user population with sufficient quantities of water. If the replacement source

cannot supply essentially all of the user population's water requirements, then the current ground-water source should be considered irreplaceable for the preliminary determination. If this determination is made and review of the relevant qualitative criteria does not warrant a different final classification, then the final determination would be irreplaceable and no further analysis need be done. If application of the comparable quantity test does not demonstrate that the current ground-water supply is irreplaceable, on the other hand, then the final screening test can be applied.

Screening Test 5: Economic Irreplaceability

Having determined the location of acceptable replacement water sources that are institutionally available and of comparable quality and quantity, the final screening test to be applied is the economic irreplaceability test. The remainder of this section discusses the rationale behind the economic irreplaceability test, methods of estimating the cost of replacement water supplies, and the application of the test itself.

The Agency has defined economic irreplaceability of an alternative water source principally in terms of cost per household of using the alternative water source. This does not in any way imply that the Agency expects that communities will be required to replace water supplies or pay for such replacements. Rather, this relative measure is designed to determine the extent to which ground waters potentially affected by a facility or activity are truly special. The economic irreplaceability test itself is designed to balance different levels of replacement water affordability against various population sizes. Again, this approach is based on the concept that larger populations potentially face greater aggregate health risks and adverse economic impacts should ground-water contamination occur. Further, the test recognizes that smaller populations generally pay a higher per unit price for water than do larger populations due to economies of scale. Therefore, the test is designed to identify ground waters that are truly special by comparing economic burden of replacement to systems of similar size. Based on this rationale, the economic test presented here gives general guidance on when the costs of replacement for a given population size should be sufficient to warrant a preliminary irreplaceable determination.

In order to apply the economic irreplaceability test, the classifier will have to estimate the total cost of the user population's replacement water-supply system (i.e., once the affected system components, or the entire system, have been replaced) in terms of cost per household. Having made this estimate, the classifier can then compare the cost of the replacement system against an economic irreplaceability

threshold in order to determine whether or not the economic burden of replacing the existing supply would be unreasonable. The economic irreplaceability test, therefore, consists of three steps, including the estimation of the replacement supply costs, the determination of the appropriate economic irreplaceability threshold, and the application of the test itself. These three steps are discussed in more detail below.

Step 1. Estimate the Replacement Water-Supply Cost. The cost estimate for the replacement of a user population's water supply should reflect the annual costs of the total system once the potentially affected components of the existing system have been replaced. For example, the existing system may consist of public water supply wells, a treatment plant, and a distribution system. Further, conversion to a replacement water supply, in this case, might consist of sinking new wells in an aquifer outside of the Classification Review Area. The total annualized cost for the replacement water-supply system, therefore, would include current annual costs for treatment and distribution plus the annualized costs for the new wells and transmission of the new water to the existing system. If the current user population consists entirely of private wells, on the other hand, then the replacement system may consist of a new source, a new treatment plant, a new distribution system, and service costs associated with a water-supply utility. The replacement costs in this situation, therefore, would consist of the annualized total costs for creating an entirely new public water-supply system.

Appendix D provides detailed guidance for estimating the per household costs of replacement water-supply systems. Once the classifier has determined which components of the user population's existing water-supply system would require replacement, the annualized cost per household for the new system should be calculated using the methodology presented in Appendix D.

Step 2. Calculate the Economic Irreplaceability Threshold. The second step of the economic irreplaceability test is to calculate the irreplaceability threshold for a replacement water-supply system comparable in size to the system under review. The approach used for establishing economic irreplaceability thresholds for these Guidelines is based on three primary observations. These primary observations are as follows:

1. Due to a wide range of site-specific factors, the cost of water to typical household users varies significantly throughout the country.

2. Due to the economies of scale associated with delivery of water supplies, however, large user populations tend to pay less, on a per capita basis, for their water than do individuals receiving water from a small system. Nonetheless, even for systems of the same size, water costs may vary widely.

3. A threshold value that defines the maximum feasible cost of a replacement water source can be developed for various water system sizes by specifying the replacement water-supply cost that exceeds a reasonable economic burden (e.g, observable extreme water system costs). This threshold will vary as a function of system size.

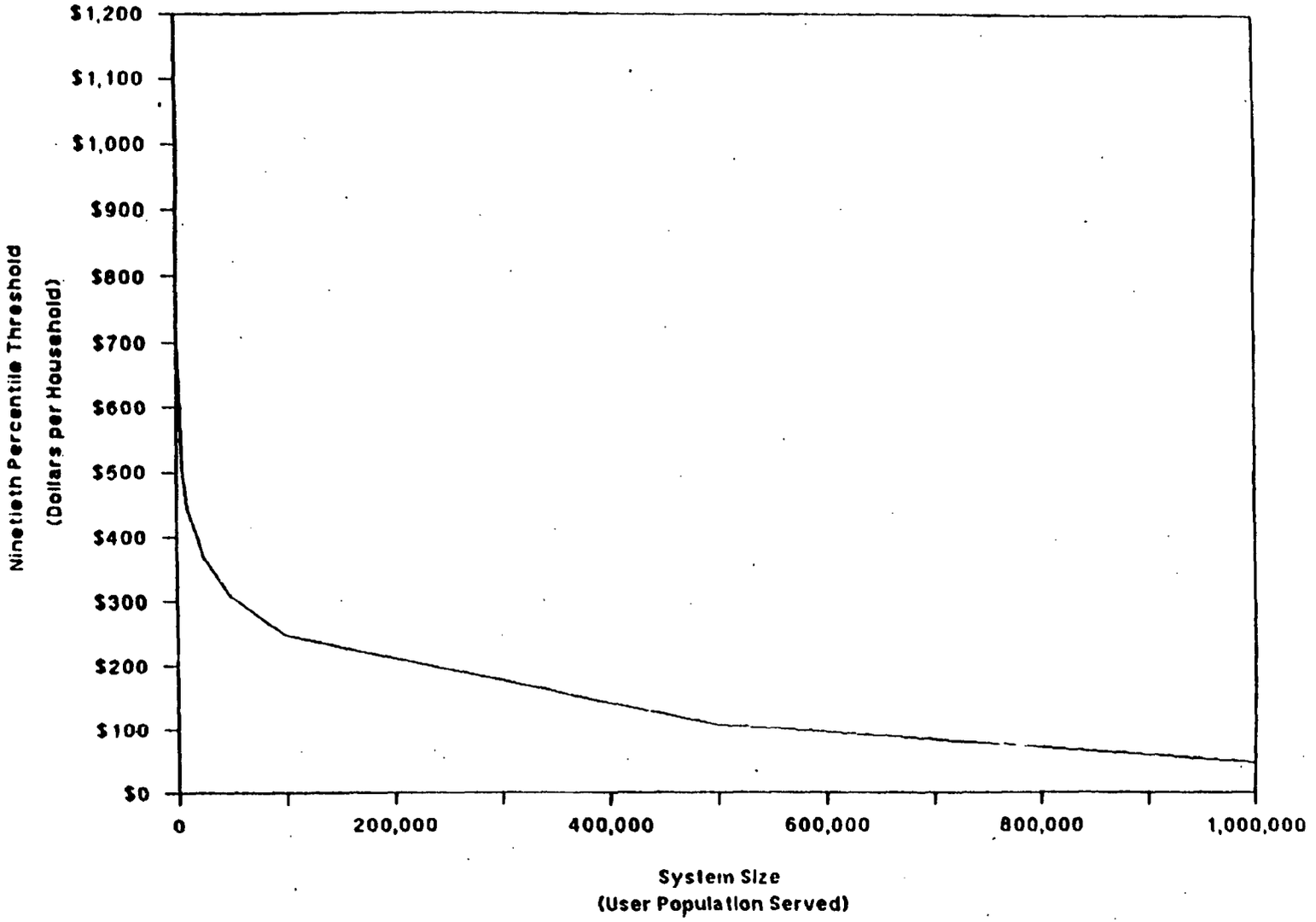
Given these observations, the Agency determined that, for a given population size, the per household water-supply cost (i.e., system costs such as operation and maintenance costs, capital costs, and interest payments) below which 90 percent of the households in a user population typically face, can reasonably be used as the economic irreplaceability threshold. In other words, if a replacement water supply would cost as much or more than the per household cost observed by only 10 percent of households, then the current ground-water source is irreplaceable. Therefore, the economic irreplaceability threshold for a replacement water supply can be calculated as the ninetieth percentile per household water-supply cost for water-supply systems of a given size (i.e., user population).

Using the best available data on community water supply system costs, the Agency derived an equation describing ninetieth percentile, per household water-supply costs as a function of system size. Using this equation, classifiers can calculate the appropriate economic irreplaceability threshold. Appendix D presents the derivation of this cost function and the methodology that should be used to calculate irreplaceability thresholds. Figures 4-5 and 4-6 present two representations of the cost function used to calculate threshold values; the first figure covers system sizes between 500 and 1,000,000 persons, while the second focuses on systems between 500 and 10,000 persons.

Classifiers should note that the full implementation of the Amendments to the Safe Drinking Water Act passed in 1986 will undoubtedly lead to higher costs for water-supply. In response to this statute, the Agency is conducting an

FIGURE 4-5

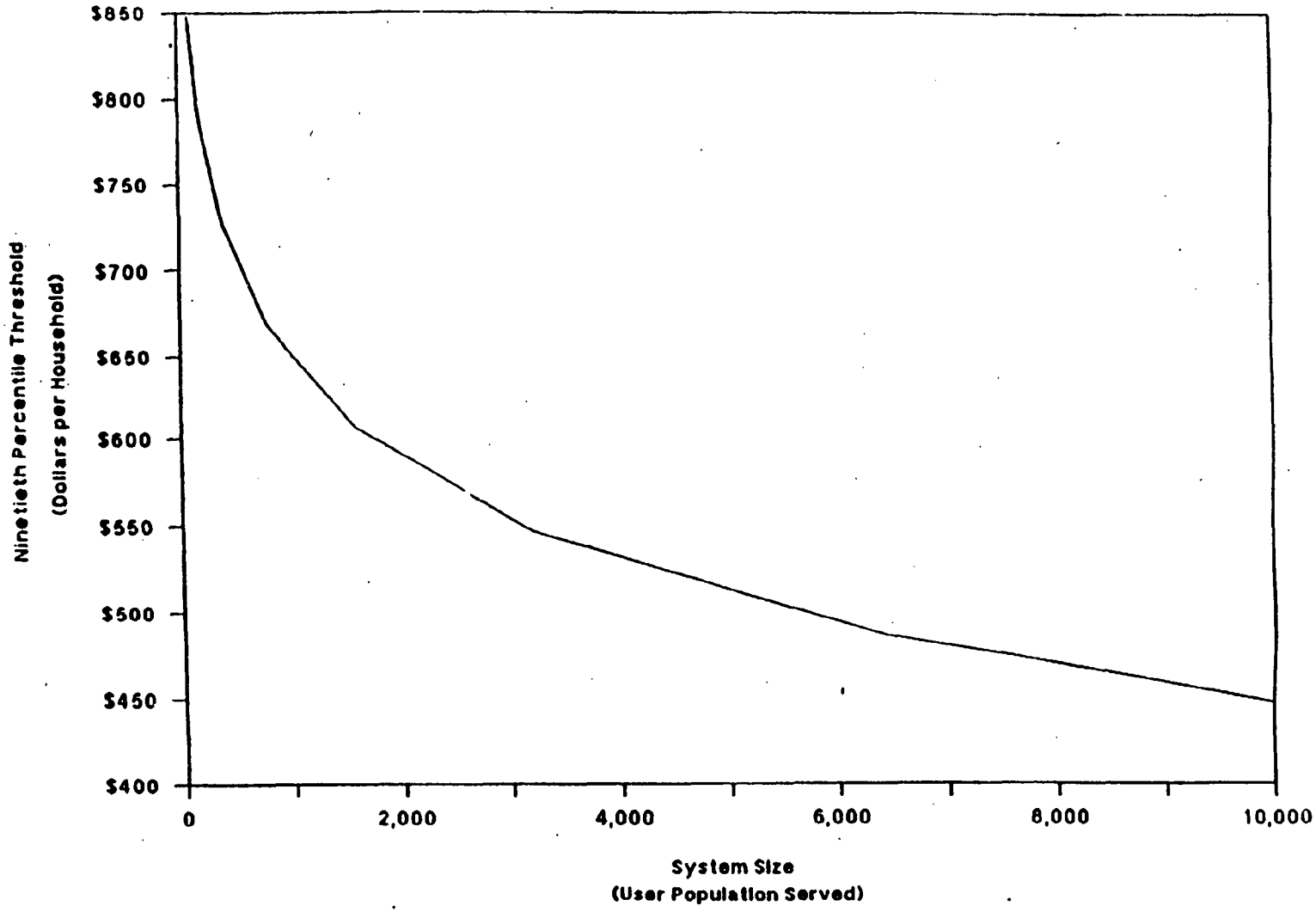
Ninetieth Percentile Economic Thresholds by System Size



Source: ICF Incorporated Analysis of Data Collected by Immerman (1987)
Date: 1988

FIGURE 4-6

Ninetieth Percentile Economic Thresholds by System Size



Source: ICF Incorporated Analysis of Data Collected by Immerman (1987)
Date: 1988

extensive review of community water-supply system affordability. Once published and available, these conclusions and criteria may lead to changes in the approach for calculating economic irreplaceability presented here.

Step 3. Apply the Economic Irreplaceability Test. Having estimated the total cost of the replacement water-supply system for the user population under review and calculated the appropriate ninetieth percentile threshold, the classifier should determine whether the per household cost of the replacement supply would be economically unreasonable. If the replacement supply cost is significantly higher than the threshold, then the economic burden of the replacement supply would be unreasonable and the existing water supply should be considered economically irreplaceable for the preliminary determination. If the replacement supply cost is relatively close to the threshold, especially if it is less than the threshold, then the classifier should consider the variability intrinsic in the threshold cost function and use best professional judgment to make a determination. Finally, if the replacement cost is significantly less than the threshold, then the economic burden of the replacement system would not be unreasonable, and the existing source should not be considered economically irreplaceable for the preliminary determination.

Following any of these preliminary determinations, the classifier should consider the relevant qualitative criteria and, if this test is the last of the five screening tests to be applied or if the test demonstrates irreplaceability, make a final determination of irreplaceability. Likewise, if the economic test is not the last test and the test does not demonstrate irreplaceability, then the remaining screening tests should be applied.

4.2.3 Step 3: Use of Qualitative Criteria for Final Irreplaceability Decisions

The third and final step for completing the determination of irreplaceability for any of the five screening tests, or if the user population is not substantial, is to review relevant qualitative criteria that either substantiate the preliminary determination or warrant changing the determination. Therefore, as discussed throughout this section, review of these criteria in conjunction with a given screening test can result in (1) substantiation of a preliminary irreplaceable determination based on that test; (2) an indication that the next screening test should be applied; or (3) if all five screening tests have been applied or the

population is not substantial, a final irreplaceable or not irreplaceable determination.

A list of qualitative criteria compiled by EPA is given below. Although the discussion for each criterion indicates whether the criterion can suggest a determination of irreplaceable or not-irreplaceable, the decision of whether the criterion is applicable and how much importance the criterion should be given is left to the judgment of the classifier.

Presence of Transient Populations

This criterion could be applied to recognize the presence of large transient populations or transient populations residing for relatively long periods of time for whom replacement water might be required. One approach to such situations would be to weight the transient population based on the duration of their residence. For example, a resident using ground water from within the Classification Review Area for 3 months out of the year would be assigned one-quarter of the weight given a permanent resident. If the preliminary determination was not clear, this criteria could favor changing a preliminary not-irreplaceable determination to a final irreplaceable determination.

Projected Trends (Population, Economic, and Water Development)

These criteria address situations of projected growth or decline in user population size, economic conditions, or water-development projects or use. If these projections are based on demonstrably likely events (e.g., a subdivision is under construction), reflect changes expected in the near future (i.e., town has issued bids for construction of a new water-supply well to be constructed within 2 to 3 years), and are significantly different from current conditions (e.g., substantially larger or smaller population to be dependent on the supply), then the classifier may be justified in making a determination according to the projections. Therefore, this criteria could favor shifting a preliminary determination in either an upward or downward manner, depending on how the relevant conditions were projected to change.

Unreliable Transport Mechanism

This criterion recognizes that although a pipeline or some other mechanism to transport an alternative water supply (e.g., use of a barge to bring water to an island) may be economically feasible, the mechanism may also be subject periodically to severely inclement weather or some other risk. If this risk were unacceptably high, thus making the ground water in question less replaceable, then a final

irreplaceable determination could be favored over a not-irreplaceable decision.

4.3 Procedures for Determining Ecologically Vital Areas

Ground water may be considered ecologically vital if it supplies a sensitive ecological system located in a ground-water discharge area that supports a unique habitat. A unique habitat is defined to include habitats for endangered or threatened species that are listed or formally proposed for listing pursuant to the Endangered Species Act (as amended in 1982), as well as certain types of Federally managed and protected lands.

In the above definition are two terms which require explanation. A sensitive ecological system is interpreted in these Guidelines as an aquatic or terrestrial ecosystem located in a ground-water discharge area. A unique terrestrial or aquatic habitat is primarily defined as a habitat for a species that is listed or proposed for listing as endangered or threatened, pursuant to the Endangered Species Act (as amended in 1982). In some cases, certain Federal land management areas, Congressionally designated and managed for the purpose of ecological protection, may also be considered unique habitats for ground-water protection, regardless of the presence of endangered or threatened species per se. Among those most likely to be included are the following:

- Portions of National Parks.
- National Wilderness Areas.
- National Wildlife Refuges.
- National Research Natural Areas.

A discharge area is an area of land through which there is a net annual transfer of water from the saturated zone to a surface-water body, the land surface, or the root zone. The net discharge is physically manifested by an increase of hydraulic heads with depth (i.e., upward ground-water flow). These zones may be associated with natural areas of discharge, such as seeps, springs, caves, wetlands, streams, bays, or playas.

Ground-water discharge to surface-water bodies occurs in many hydrogeologic settings and is the dominant condition in high rainfall areas. Where poor-quality ground-water

discharges to surface water, a potential to impact the quality of those surface waters exists.

The procedures for locating the presence of a Federally protected endangered or threatened species or the habitat of an endangered or threatened species is as follows:

1. Locate the appropriate (by state) U.S. Fish and Wildlife Service, Office of Endangered Species, Field Office.

2. Submit to the Field Office a letter describing the area of interest, including a map if possible, and the nature of the present habitat (e.g., cultivated field or mature woodland). The letter should request information on endangered or threatened species and their habitats located in the area.

3. The office will usually respond within 30 days.

The U.S. Fish and Wildlife Service is required under the Endangered Species Act to provide information about endangered or threatened species. Section 7 of the Endangered Species Act provides a consultative process for considering any action authorized, funded, or carried out by a Federal agency that is likely to jeopardize the continued existence of any endangered or threatened species or result in the destruction or adverse modification of the species habitat. The U.S. Fish and Wildlife Service's, field offices are responsible for providing this information upon request. A list of regional and field offices is presented in Appendix B.

In addition to the U.S. Fish and Wildlife Service, individual states also maintain agencies that keep track of endangered or threatened species, particularly those candidate endangered species and rare species not Federally listed. In most cases State-specific information can be obtained through the Natural Heritage Program (a list of program offices is presented in Appendix B) or through the non-game program within the various State Departments of Natural Resources. EPA offices such as the Marine, Estuarine, and Wetlands Programs, may also have information regarding important ecological habitats.

Information about Federal lands may also be obtained from Federal land management agencies such as the National Park Service, and Bureau of Land Management. The presence of Federal lands is indicated on most State and county road maps and U.S. Geological Survey quadrangle sheets.

4.4 Procedures for Determining Highly Vulnerable Areas

In addition to being an irreplaceable source of drinking water to a substantial population and/or ecologically vital, Class I ground water must also be highly vulnerable to contamination, i.e., the ground water must be determined to be highly vulnerable in order for a Class I designation to apply. Highly vulnerable ground water is characterized by a relatively high potential for contaminants to enter and be transported within the ground-water flow system. Thus, vulnerability encompasses the leaching potential of the soil and/or vadose zone and the ability of the saturated flow system to move contaminants over a large geographic area (not just beneath any given site). Vulnerability to contamination occurs across a continuum from very high to very low just as leaching potential and ground-water velocities occur in a continuum from high to low. For classification purposes, only situations at the higher end of the continuum are of concern.

The concept of ground-water vulnerability focuses only on the inherent hydrogeological characteristics of the Classification Review Area. The determination that a setting is highly vulnerable to contamination is based primarily on the best professional judgment of the classifier or technical support staff. This approach provides the flexibility needed to address the wide variation in hydrogeologic conditions that occur across the nation.

When attempting to evaluate vulnerability, a classifier should select the most appropriate vulnerability assessment tools based on consideration of factors such as regional hydrogeologic conditions, availability of data, and professional experience of the classifier or support staff. Classifiers are encouraged to examine multiple lines of evidence to support a vulnerability determination. Such an approach might include an evaluation of hydrogeologic factors relevant to vulnerability, matching the subject hydrogeologic setting to a highly vulnerable descriptive/ qualitative setting as provided in this guidance, and/or employing one or more technical evaluation aids.

In the following subsections, guidance is provided regarding the hydrogeologic factors to consider for evaluating vulnerability. Selected vulnerability evaluation aids are also presented. Where appropriate, benchmarks indicative of highly vulnerable hydrogeology are provided.

4.4.1 Factors Related to Vulnerability

A large number of factors may influence the vulnerability of a specific setting to ground-water contamination. Table 4-2 provides a comprehensive, though not exhaustive, list of these factors. The relative influence of any one factor on the degree of vulnerability to contamination varies from region to region and may vary from setting to setting within a region. For example, recharge rate may be more important in arid regions than in humid regions. The factors are also highly interrelated. A change in the magnitude of one factor may result in changes in the magnitude of other factors. The factors presented are to assist in the following discussion and not to be taken as a checklist for each classification decision.

The classifier will need to select a set of the most appropriate factors for evaluation based on a knowledge of the regional hydrogeology and the interrelationships between factors. No single factor will be likely to distinguish highly vulnerable from less vulnerable hydrogeologic settings. A combination of factors should be evaluated. Several of the vulnerability evaluation aids described in a subsequent section incorporate subsets of these hydrogeologic factors. The following discussion is intended to provide an overview of each factor and its importance to evaluating vulnerability. The discussion and list are not meant to be binding. In some settings, only a few factors will need to be assessed. Rarely will all or nearly all need to be reviewed in detail.

Regional Recharge

Recharge of precipitation is the principal means by which a contaminant released at or near the surface is leached and transported through the vadose zone to ground water. Net recharge rate is considered by many hydrogeologists to be one of the most important factors to consider in a vulnerability assessment. Net recharge can be thought of as the quantity of precipitation that is available for transport, dispersion, and dilution of a pollutant from a specific point/area of introduction.

Table 4-2
Factors Relevant to Judging
Vulnerability to Contamination
(Not Listed in Specific Order)

- Regional Ground-Water Recharge Rate
  - Natural recharge
  - Artificial recharge
- Topography
  - Slope
- Landscape Position/Land Form
  - Recharge/discharge area location
  - Proximity to water bodies, discharge areas
  - Geomorphic position or land form (e.g., river terraces, alluvial fans)
- Soil/Vadose-Zone Characteristics
  - Depth to water/thickness of vadose zone
    - Depth to the seasonal-high water table
    - Depth to the zone of saturation
    - Thickness of the unsaturation zone
  - Soil texture/clay content
  - Clay mineralogy
  - Infiltration capacity
  - Porosity (primary and macro/secondary)
  - Hydraulic conductivity/permeability
  - Attenuative capacity
    - filtration
    - biodegradation
    - sorption
    - fixation/precipitation
    - volatilization
  - Vadose-zone media
    - silt/clay; shale; limestone; sandstone; bedded limestone, sandstone, shales; sand and gravel with silt and clay; metamorphic/igneous; basalt; karst limestone
- Aquifer and Ground-Water Flow System Characteristics:
  - Hydraulic conductivity
  - Effective porosity (primary and secondary)
  - Hydraulic gradient (horizontal and vertical)
  - Ground-water flow velocity

- Attenuative capacity
  - . path length/media contact time
  - . sorption properties
  - . ion-exchange capacity
  - . conditions conducive to chemical demobilization
- Aquifer media
  - . rock type (shale, sandstone, limestone, metamorphic and igneous rocks, karst limestone)
  - . mineralogy
  - . grain-size distribution
  - . organic carbon content
- Sequence of aquifers and non-aquifers
- Degree of confinement

In general, the higher the recharge rate, the greater the potential for ground-water pollution where a source is present. In areas where there is little precipitation, there is correspondingly little recharge. For this reason, areas of low precipitation will tend to be considered as less vulnerable to contamination than areas of high precipitation.

The amount of precipitation that ultimately recharges is dependent on a number of site-specific parameters, including slope (topography) and soil/vadose conditions. Slope of the land is an indicator of the proportion of precipitation that runs off. Steeper slopes usually mean more runoff and less recharge. Soils that develop on steep slopes are generally thinner and less mature (i.e., lower subsoil clay content) than those that develop on less steep slopes. The attenuation capacity of the steep slope soils is, as a result, lower. Areas with low-permeability soils (e.g., clayey textured soils with low macro-porosity) also tend to have lower recharge rates and higher runoff rates.

Recharge rates and, thus, the potential for pollution, can be augmented by artificial recharge and irrigation. Artificial recharge is defined as any process by which man fosters the transfer of surface water into the ground-water system (Freeze and Cherry, 1979). In some areas, artificial recharge and irrigation are considerable and should, therefore, be factored into the vulnerability evaluation.

Topography

Topography (or slope) influences the likelihood that a pollutant will run off or recharge the ground water. In general, the flatter the slope, the more likely recharge will occur and contaminants will infiltrate to the ground water. A steeper slope implies a greater proportion of runoff than recharge and, therefore, less contaminant infiltration. Slopes greater than 18 percent have the greatest runoff capacity (Aller et al., 1985).

Soil/vadose zone conditions also influence the proportion of runoff and recharge (see below). Sandy textured soils generally allow for more recharge than clayey soils. For this reason, both topography and soil/vadose zone conditions must be considered together. Note that in the alluvial basins in southwestern states, most recharge occurs in the steep alluvial fans at the base of the mountains.

Water-table gradients may be related to topography. Areas with steep slopes are more likely to have high ground-water flow velocities due to the generally steeper ground-water gradients. The ground-water flow velocity influences potential for attenuation in aquifer media. High ground-water flow velocities usually result in lower attenuation due

to the shorter contact time between the contaminant and the soil and aquifer media.

The classifier should be aware that topography may not be very relevant to a vulnerability evaluation if significant artificial changes to control runoff (e.g., storm drains or drainage ditching) have occurred.

Landscape Position/Land Form

The position of a potential contamination source within the landscape or geomorphic landform can be used to screen ground-water vulnerability because of certain associated hydrogeologic conditions. For example, recharge and discharge areas are commonly inferred from landscape positions. Because recharge is the primary mechanism by which contaminants are leached and transported to ground water, contamination is more likely to occur if a facility/activity is located in a ground-water recharge area. On the other hand, discharge areas are less vulnerable to contamination because recharge is minimal. The net movement of water is to the surface in these areas and recharge is less likely to penetrate to an appreciable depth, except under some unusual conditions of highly induced head or geochemical density effects.

The position of a facility/activity within certain geomorphic units or landforms can also be used to screen for ground-water vulnerability. The topography and physical characteristics of certain geomorphic units/ landforms are sufficiently predictable in some regions to generally determine their hydrologic behavior. For example, alluvial fans and glacial outwash plains are commonly characterized by coarse-grained material which generally implies high hydraulic conductivities and ground-water flow velocities, both of which tend to increase vulnerability. Glacial moraines, on the other hand, may be composed of clayey till in some areas and be judged to be less vulnerable due to generally lower hydraulic conductivities.

Soil/Vadose-Zone Characteristics

Soil and vadose-zone characteristics influence ground-water vulnerability with respect to the amount and rate of recharge and attenuation of infiltering contaminants. The pollution mitigating potential of the soil/vadose-zone is dependent on the grain size (texture) and physical and chemical characteristics of the soil/vadose zone media. Attenuation mechanisms include mechanical filtration, volatilization, dispersion, chemical alternations (e.g., fixation and precipitation), neutralization, oxidation-reduction, ion-exchange, and biological (biodegradation) processes.

Soil/vadose-zone media characteristics, including grain size/texture, shrink/swell potential of the clay, porosity (primary and macro/secondary), and permeability, control the amount and rate of recharge that occurs. Soil texture includes considerations of the amount and size of various particle sizes (i.e., sand, silt, and clay). A soil with a high clay content or low secondary/macro-porosity, in general, allows less infiltration than a soil with high sand content or high secondary/macro-porosity. In general, a soil/vadose zone with a large grain size and/or large macro-porosity has a high pollution potential.

A longer path length and contaminant travel time through the soil/vadose zone allows for the maximization of attenuative processes. The depth-to-water/thickness of the vadose zone, in part, controls the path length and, thus, the time it takes for a contaminant to reach the aquifer. As path length and travel time increase, the time the contaminant is in contact with oxygen or the surrounding media increases. The attenuation processes of ion-exchange, adsorption, oxidation/reduction, bio-degradation, filtration, and volatilization are more likely to occur if the depth to water is great because contact time with surrounding media is increased.

Chemical attenuation processes include adsorption (e.g., ion-exchange and surface complexation) and precipitation reactions. The degree of attenuation that occurs due to adsorption processes is primarily a function of mineralogy (i.e., iron and manganese oxides and organic matter content). A high clay content generally increases the attenuation capacity of the soil/vadose zone because of the ion exchange and complexation reactions that occur at highly charged surfaces on clay particles. The presence of iron and manganese oxy-hydroxides enhances the adsorption of inorganic contaminants, particularly cationic metals, due to surface bonding and coprecipitation. The fraction of organic matter within the soil strongly influences the attenuation of organic contaminants because organic molecules preferentially partition to organic substances rather than inorganic minerals or water. Precipitation reactions are a function of redox conditions and pH. Oxidation and reduction processes are controlled by the presence of oxygen in the soil media. Redox reactions may decrease the solubility of some contaminants. For example, heavy-metal contaminants are likely to precipitate in oxygen-rich environments because of the formation of insoluble metal oxides and hydroxides. A high carbonate content tends to raise the pH of soil water, also causing heavy metals to precipitate. Contaminant concentrations are thus reduced due to precipitation of the contaminant from solution.

Mechanical attenuation processes include dispersion and filtration. Dispersion of contaminants results from flow

around particles and across pore spaces. This causes the contaminant to spread or disperse so as to gradually occupy an increasing volume. The greater the heterogenity, the more dispersion of contamination. Mechanical filtration removes contaminants which are larger than pore spaces of the host medium (Aller et al., 1985). Thus, fine-grained materials such as clay and silt, tend to remove contaminants with greater efficiency than a more coarse-grained media.

Aquifer and Ground-Water Flow System Characteristics

Aquifer and ground-water flow system characteristics govern the attenuation capacity of the ground-water environment and the ability of this environment to transport contaminants. Ground-water velocity, which is a function of hydraulic conductivity, hydraulic gradient, and porosity, controls the time available for attenuation processes to occur. Low permeability and small gradient will result in a slow ground-water velocity. Compared to higher velocity settings, the contaminant remains in contact with the aquifer medium for longer periods of time. This allows the attenuation processes, such as adsorption and precipitation, to occur to a much greater extent than if the ground water were moving at a faster velocity.

Aquifer media characteristics, such as clay and iron and manganese oxide content, mineralogy (e.g., carbonate content), and organic carbon content, also affect the attenuation capacity of an aquifer. The discussion on these attenuation processes as presented in the previous section concerning the soil/vadose zone also applies to the saturated zone.

Aquifer porosity and hydraulic conductivity are controlled, in part, by media type. In granular and clastic rocks, water travels primarily through primary, intergranular pore spaces (although these rock types can have fracture permeability as well). In nonclastic and nongranular rocks, water travels primarily through fractures and solution openings. A larger grain size or an abundance of fractures and solution openings within the aquifer usually indicate a relatively high hydraulic conductivity or transmissivity and a relatively low attenuation capacity and, consequently, a greater pollution potential.

Mechanical attenuation processes include dispersion and filtration. Dispersion of contaminants results from ground-water flow velocity variations around particles and across pore spaces. This causes the contaminant to spread or disperse so as to gradually occupy an increasing volume of the flow system (Aller et al., 1985). The greater the heterogenity, the more ground-water flow variations possible, thus, more dispersion of contamination. Mechanical filtration removes contaminants which are larger than the pore

spaces of the host medium (Aller et al., 1985). Thus, fine-grained materials, such as clay and silt, tend to remove contaminants with greater efficiency than a more coarse-grained media.

4.4.2 Evaluation Aids for Assessing Vulnerability

In this section, selected evaluation aids are presented as tools which may be used to assist in a vulnerability assessment. After selecting the most appropriate hydrogeologic factors, the classifier may choose to employ one or more of these quantitative evaluation aids. The aids provide a framework for examining the importance and interrelationships between factors. Each type of aid is described and general procedures for use in the vulnerability evaluation are provided. Vulnerability evaluation aids include the following:

- Descriptive/Qualitative Aids
  - Historical Evidence
  - Descriptions of General Hydrogeologic Scenarios
- Quantitative Evaluation Aids
  - Multiple Factor Methods
  - Numerical Ranking Systems
  - Integrative Methods

The choice of which evaluation tool to use is dependent on the quantity and quality of available data. If limited data are available, then it is best to use the descriptive/-qualitative tools. The quantitative approaches are generally dependent on detailed information for the Classification Review Area.

Descriptive/qualitative evaluation aids may be used as part of a screening process which would help determine if the ground waters are likely to be classified as highly vulnerable. In some cases, the vulnerability of the ground water to contamination may be readily apparent solely on the basis of descriptive/qualitative aids. The quantitative evaluation aids, along with available benchmarks indicating relative vulnerability, could be used when vulnerability is less apparent and more detailed area-specific information is available.

Descriptive/Qualitative Aids

Two descriptive/qualitative aids may be considered at a screening level, historical evidence and vulnerability scenarios. These aids generally require a minimum of information about the hydrogeology of the review area. The historical evidence approach is meant to be a "quick-and-dirty" assessment where information on water quality is available. It is not meant to be an analysis that can stand alone. The vulnerability scenarios are intended to help identify those areas where vulnerability is readily apparent.

Historical evidence of a number of serious ground-water contamination incidents in the ground-water unit or Classification Review Area is generally a good indication that an area is highly vulnerable to contamination. The lack of contamination does not necessarily mean that the area is not highly vulnerable, especially if no source activities have been present. On the other hand, a lack of significant contamination in areas with significant source activities may suggest a lower level of vulnerability or initiate a more detailed review.

Information about existing water quality is usually available through State and local health departments, the U.S. Geological Survey Water Resources Division, State geological surveys, and the EPA. Information about historic land-use activities can be gained from tax assessment maps, zoning maps, land deeds, air photos, facility permit applications, Environmental Impact Statements, and interviews with people familiar with the area.

Historical evidence is best used as one line of evidence indicative of vulnerability. The hydrogeologic factors as well as other evaluation aids should be examined.

A second qualitative approach is to compare a setting to vulnerability scenarios representing highly vulnerable and not highly vulnerable conditions. The general procedure for implementation is to match a real, candidate setting to a conceptual vulnerability scenario.

The regional hydrogeologic data necessary to implement this procedure may be available from U.S. Geological Survey reports, State geological surveys, U.S. Department of Agriculture (USDA) Soil Conservation Service soil surveys, scientific books and journals, county/ regional reports, facility permit applications, Clean Water Act Section 208 studies, Environmental Impact Statements, and Safe Drinking Water Act Sole Source Aquifer (SSA) studies.

Scenarios that are more likely to be judged highly vulnerable include the following hydrogeologic settings:

- Shallow unconfined sand and gravel aquifers with sandy soils/vadose zones.

- Karstic aquifer systems exhibiting conduit flow where this aquifer is exposed at the land surface or is covered by highly permeable surficial deposits with shallow depth to water.

- Shallow, basaltic, volcanic rock aquifers with extensive fractures, lava tubes, weathered zones, and large secondary porosity where such aquifers are overlain by highly permeable soils or soils developed in volcanic materials.

- Islands comprised of porous, sandy soils with an unconfined, fresh-water aquifer.

- Shallow coastal plain aquifers composed primarily of coarse sand and gravel, over semiconsolidated carbonate rocks or fine-grained aquitards.

- Other areas with thin, highly permeable unsaturated zones and/or saturated zones with rapid ground-water velocities (e.g., fractured bedrock areas).

Scenarios that are less likely to be judged highly vulnerable include the following hydrogeologic settings:

- Confined aquifers overlain by a very thick confining unit of low permeability.

- A buried valley aquifer overlain by thick, clayey deposits.

- Very low permeability stratigraphic units in close proximity to ground surface (e.g., clay, shales, unfractured crystalline or metamorphic rocks).

- Discharge areas or other areas with extremely low recharge.

Quantitative Evaluation Systems

Three general types of technical evaluations are available: multiple-factor criteria listing, numerical rating systems, and integrative analyses. Multiple factor criteria listing evaluations tend to require lower levels of sophistication and data, numerical rating systems require greater levels, and integrative analyses require the highest levels. Benchmarks indicative of highly vulnerable are provided only

for selected numerical rating systems and integrative analyses.

Multiple-Factor Criteria Listing

A common method for evaluating vulnerability is the Multiple-Factor Criteria Listing Approach. This type of measure requires the selection of specific, measurable hydrogeologic factors (e.g., depth to water) and a criterion for each factor against which a real, highly vulnerable type of setting will be compared (e.g., less than 10 feet depth to water). The criterion for each hydrogeologic factor will commonly be selected based on a knowledge of the natural range of that factor in the region. Criteria selection must consider the interrelationships between factors, such that mutually exclusive criteria are not selected. For example, a low-hydraulic conductivity soil, a thick vadose zone, and a high recharge rate, are usually mutually exclusive. Assessing compliance to the criteria, however, typically assumes that the factors are independent.

It is essential to establish decision rules for judging if a setting is highly vulnerable. For example, the decision rules could require that a setting be considered highly vulnerable if any single factor meets the highly vulnerable criterion. Alternatively, it may be decided that it is necessary for all, or perhaps a subset, of the factors to meet the highly vulnerable criteria in order to establish a setting as highly vulnerable.

The principal problem with the Multiple Factor Criteria Listing Approach is that interrelationships between factors are typically ignored when establishing the decision rules. Ignoring the interrelationships between factors can lead to erroneous vulnerability decisions, as well as inflexibility in considering unusual circumstances or compensating factor values. For instance, for a given hydrogeologic setting, the trade-off between a slightly below criterion, depth to water table measure and an above criterion, aquifer transmissivity measure might not be considered in a multiple-factor criteria-listing approach. A more sophisticated aid for evaluation may be needed to fully represent such relationships. As a result, the multiple-factor, criteria-listing measure can be somewhat inflexible when considering compensating hydrogeologic characteristics if the decision rules are inflexible.

One criteria-listing approach that will allow more flexibility is to use a classification system composed of three or more classes for each factor. One class is reserved for the true highly vulnerable conditions that are judged to be beyond compensation. Another class is established for the ideal true, not highly vulnerable conditions. The

intermediate class is designed for consideration of compensating factors.

The most troublesome aspect of multiple-factor criteria listing concerns the selection of a highly vulnerable criterion for each factor. Typically, the criterion value indicating a highly vulnerable setting may simply be chosen from the infrequently occurring values within the natural range of factor values. Alternatively, the selected criterion may be a surrogate for a more sophisticated analysis, such as time of travel or risk. In general, assigning a highly vulnerable cutoff value to a particular factor is a matter of best professional judgment. For example, it is difficult to find a cut-off value for depth to water such that a setting with a depth to water slightly less than the cutoff will always be considered highly vulnerable and a setting with a depth to water slightly greater than the cut-off value will always be considered not highly vulnerable. The selection of a highly vulnerable criterion for depth to water has no one correct value.

The multiple-factor, criteria-listing approach is exceptionally easy to implement where the factors selected are easy to measure or estimate. Any number of factors can be considered. Few single factors or criteria, though, will be appropriate at a regional or national scale; and a set of factors and criteria developed for one region may not be identical to a set of factors developed for another region.

It is recommended that at least three hydrogeologic factors listed in the numerical rating system referred to as DRASTIC (see the next section) be considered. At the State level, it may be possible to compare highly vulnerable criteria to the criteria for siting hazardous-waste disposal facilities. An acceptable site under such criteria would likely be considered not highly vulnerable. According to Monnig (1984), a majority of states have established such criteria.

Numerical Ranking System(s)

The numerical rating type of assessment tool, in addition to establishing factors, assigns hierarchial ranges to each factor. The range for each factor is subdivided and assigned a relative numerical rating indicating the relative importance of that range interval to vulnerability. For example, the factor depth to water could be subdivided into seven categories, as shown in Table 4-3 (see page 4-49). Each category would be given a rating from 1 to 10, with 10 being the most vulnerable. In this way, a vulnerability continuum is established. The numerical factor ratings can also be multiplied by a weight in order to reflect the relative importance of the factors. For example, depth to water may be a factor considered twice as important as the

slope of land. Therefore, the depth-to-water factor rating would be multiplied by a weighting factor of 2. Finally, the factor ratings, or weighted factor ratings, are added to give a total vulnerability score.

A number of numerical rating systems have been developed for various purposes. Those most appropriate for assisting in a vulnerability assessment generally meet the following criteria:

- Should not be activity specific (i.e., only relevant for one very specific contamination source).
- Should consider only hydrogeologic factors or the hydrogeologic section should be separable from the rest of the calculations.
- Should consider only a ground-water contamination pathway.
- Should be suitable for the setting in which it is being applied.

Two numerical ranking systems are presented as generally consistent with this vulnerability concept:

- DRASTIC (Aller et al., 1984)
- LeGrand System for Evaluating Water-Disposal Sites (LeGrand, 1980)

This list is not intended to be exhaustive. Other systems may meet the criteria listed above and may be deemed appropriate.

In preparing this list, a number of numerical rating systems were examined. Other systems were not listed because they encompass other contamination pathways (direct contact, surface water, or air) and/or source and contaminant characteristics which were found to be inconsistent with the concept of vulnerability. For some rating systems, the hydrogeologic portions could not be isolated and used separately as indicators of vulnerability. In some cases, the rating systems are too data intensive, too activity specific, or employ one of the systems listed above.

For each numerical ranking system listed, a bench mark score has been suggested that signals if an area may be classified as vulnerable. For example, in the DRASTIC system, a score of around 150 or greater generally indicates

that a review area is highly vulnerable for high rainfall areas.

The degree of confidence in a numerical rating system score is, in part, a function of the reliability of the hydrogeologic information used to rate each factor and the experience of the rater. In settings where the hydrogeologic information is well established, due to localized ground water and geologic studies, for example, the score will have a narrow confidence band. As in any procedure involving professional judgment, a more experienced or better trained evaluator will provide a more accurate portrayal of ground-water vulnerability to contamination.

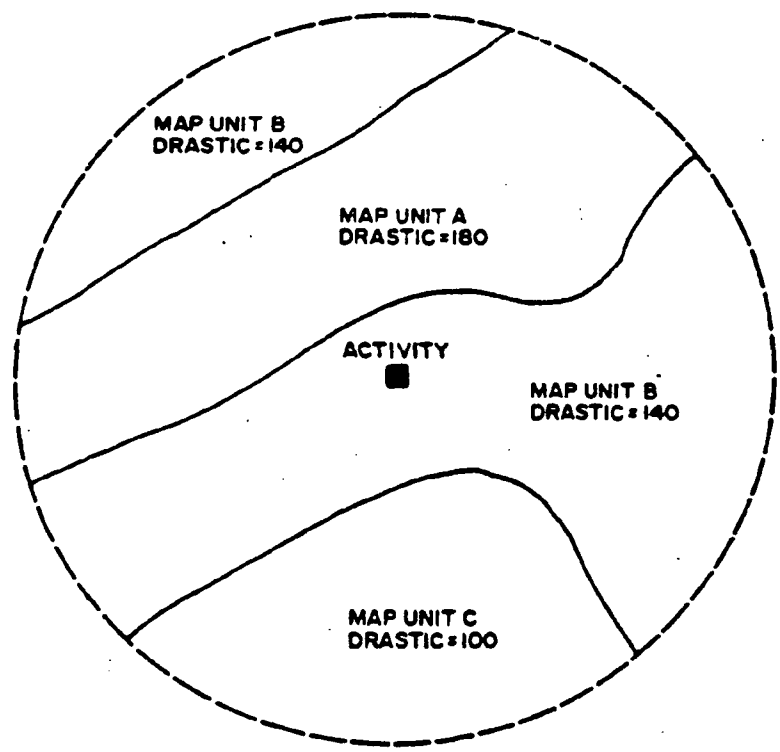
A numerical rating system can be applied to the Classification Review Area using one of two approaches. In the most general approach, the actual range of each hydrogeologic factor can be estimated from available information and a single score generated for the entire Classification Review Area. The average rating for each factor would be chosen where the range in the values of factor parameters spans two or more ratings. For example, if the depth to water across the Classification Review Area ranged from 5 to 30 feet, and this range covered two range categories (e.g., the 5 to 10 foot category and the 10 to 30 foot category), an average rating would be chosen. This approach does not allow for the differentiation between contrasting hydrogeologic settings within the Classification Review Area where the vulnerability score is distinctly different.

The second approach is to map out the major hydrogeologic settings that have significantly different vulnerabilities within the Classification Review Area. Differences in numerical rating scores of 10 to 20 percent are generally considered significant. Where vulnerability units are mapped out, an area -weighted, average score can be computed. However, if the activity occupies any portion of a highly vulnerable map unit, a judgment that the ground water is highly vulnerable is appropriate.

As an illustration of the mapping approach, consider the proposed activity shown in Figure 4-7. Within the Classification Review Area, three hydrogeologic settings have been mapped and labeled using the DRASTIC numerical rating system. The DRASTIC index for each hydrogeologic setting labeled A, B, and C is 180, 140, and 100, respectively. The areal proportion of the review area for each setting is 20 percent, 45 percent, and 35 percent, respectively. The weighted average DRASTIC index is calculated as follows:

FIGURE 4-7

ILLUSTRATION OF DRASTIC MAPPING



EXPLANATION

CLASSIFICATION REVIEW AREA BOUNDARY

0 1 2 MILES

Map Unit	DRASTIC Index	Proportion of Area	Area* Weighted Index
A	180	0.20	36
B	140	0.45	63
C	100	0.35	35
		Weighted Index	134

* DRASTIC index multiplied by the proportion of area.

For this illustration, the map-unit, area-weighted DRASTIC index of 134 is less than the recommended benchmark highly vulnerable criterion of 150. If the activity had occurred in map unit A, the designation of highly vulnerable would have been justified.

Each of the recommended numerical ranking systems is reviewed in turn. A brief discussion comparing the various system follows the review.

DRASTIC Methodology. DRASTIC is a numerical ranking system developed by the National Water Well Association (Aller et al., 1985) under contract to EPA. The DRASTIC methodology can be performed using readily available information. It yields a single numerical value referred to as the DRASTIC index. DRASTIC was prepared using a Delphi approach (a consensus building approach) on a panel of highly experienced, practicing professional hydrogeologists familiar with the potential for ground-water contamination across the county. It builds on earlier systems such as those of the LeGrand System (LeGrand, 1980) and the Surface Impoundment Assessment System (Silka and Sweringer, 1978). It is applicable on a regional level (i.e., several square miles) on par with the size of the Classification Review Area. It was designed to overcome problems of more simplistic methods that may ignore relevant factors or the relative importance of a factor compared to other factors.

DRASTIC is an acronym representing seven key hydrogeologic factors correlated to the potential for ground-water contamination listed below:

D - Depth to the water table

R - Net Recharge to ground water

A - Aquifer media

S - Soil media

T - Topography (slope of the land)

I - Impact of the vadose zone

C - Hydraulic Conductivity of the subject ground-water flow system

The DRASTIC methodology consists of several steps leading toward a single DRASTIC index number. In the first step, each factor is given a rating between 1 and 10 (except for net recharge, which is rated between 1 and 9) depending upon the range of parameter values within a hydrogeologic setting. Consider the range of values for depth to water, and corresponding ratings, shown in Table 4-3. A setting with a depth to water of 28 feet would be rated as a 7.

TABLE 4.3
RANGES AND RATINGS FOR DEPTH TO WATER
AS USED IN THE NUMERICAL RATING SYSTEM DRASTIC
(ALLER ET AL. 1985)

Depth to Water (feet)	
Range	Rating
0 - 5	10
5 - 15	9
15 - 30	7
30 - 50	5
50 - 75	3
75 - 100	2
100+	1
Weight: 5	

In the second step, each factor rating is multiplied by a factor weight to give a factor index. For instance, the weight for depth to water is 5 and, thus, if the rating is 7, the factor index is 35 (7 times 5). For the final step, the individual factor indices are added together to arrive at the DRASTIC index.

DRASTIC has been designed to account for a number of different conditions, among which are multiple aquifers and confined aquifers. The DRASTIC methodology allows for the depth-to-water rating to be adjusted for confined aquifers. With this technique, different aquifers within the Classification Review Area could receive a different DRASTIC index. If the aquifers are believed to be highly interconnected as defined Chapter 3 then the most vulnerable aquifer should be evaluated.

The focus of the DRASTIC system in assessing vulnerability is the uppermost aquifer. Where the uppermost aquifer is found to be vulnerable, all ground water with a high degree of interconnection to the uppermost aquifer is to be considered highly vulnerable. Confined aquifers with a low-to-intermediate interconnection to the uppermost aquifer are considered less vulnerable.

The DRASTIC method also establishes a separate and different set of factor weights for agricultural activities. Because the Agency has decided to consider vulnerability as independent of activity, only the regular factor weights will be applied.

A two-tier DRASTIC highly vulnerable benchmark is suggested. The tiers are distinguished according to hydrologic regions. In regions where estimated annual potential evapotranspiration exceeds mean annual precipitation, the DRASTIC benchmark for highly vulnerable is suggested to be 120. In regions where estimated annual potential evapotranspiration does not exceed mean annual precipitation, the DRASTIC benchmark for highly vulnerable is suggested to be 150.

<u>LeGrand System</u>. The LeGrand method (LeGrand, 1980) is a numerical rating system designed to evaluate the potential of ground-water contamination from waste-disposal sites.* The evaluation is divided into four stages which are subdivided into ten steps. The first stage, a hydrogeologic analysis, is developed in the first seven steps. Contaminant characteristics are not considered in the first stage. Stages 2,

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* Note there are three versions of the LeGrand System. Only the most recent version is referenced here.

3, and 4 develop descriptions, ratings, and grades that consider both site and contaminant characteristics.

Because EPA has decided that a classification decision should be independent of activity and contaminant considerations, only Stage 1 of the LeGrand system is directly applicable to a vulnerability assessment.

The hydrogeologic evaluation is based on four key parameters:

- The distance on the ground from a source of contamination to the nearest well, surface stream, or property boundary.
- The depth of water table below the waste or contamination source.
- The approximate slope of the water table and direction of ground-water flow.
- The character of earth materials through which a contaminant is likely to pass, expressed in terms of permeability and sorption.

The first four steps in Stage 1 involve estimating values for each of the four key hydrogeologic parameters. Steps 5 and 6 provide for the addition of letters that identify special features with respect to the site. In Step 7, the site numerical description is completed by adding the four values obtained in Steps 1 through 4, to get a total point value for the site.

The following is an example of a LeGrand site numerical description.

18 - 1539AA WQ

Descriptor	Step	Source
[illegible]	1	Distance to nearest water supply
5	2	Depth to water table
3	3	Water-table gradient
9A	4	Permeability sorption
A	5	Confidence in accuracy of ratings
W,Q	6	Miscellaneous site identifiers
18	7	Total point value, sum of Steps 1 to 4

The lower the total point value the less vulnerable a site; however, the total point value cannot be relied on

solely. A site may have a favorable rating for three parameters and be exceptionally unfavorable for the fourth. For example, a site may be ideal in all respects except for a high water table. The total point value is, therefore, followed by the values of the individual parameters. This allows both the weak and strong features of a site to be graphically recorded (LeGrand, 1980).

The total point value has been divided into five ranges (see Table 4-4). These five ranges are assigned grades which evaluate a site as to its ground-water pollution potential. The total number of points possible is 32. The higher the point value, the more vulnerable a site is to contamination. A site with a total point value ≥20 is assigned a grade of E or F which indicates it is a poor to very poor place to site a waste-disposal unit. This implies that the ground water is highly vulnerable to contamination. A total point value of around 20 can, therefore, generally be considered indicative of a highly vulnerable setting for the LeGrand rating system.

TABLE 4-4. (LeGrand, 1980)

GENERALIZED SITE GRADE BASED ON CRITICAL HYDROGEOLOGIC PARAMETERS

Grade	Total Points
A. Excellent	<10
B. Very Good	11-14
C. Good	15-17
D. Fair	18-20
E or F. Poor to Very Poor	>20

A classifier attempting to stay within a narrow definition of vulnerability will most likely ignore Step 1 of the analysis (i.e., measuring the distance from the contamination source to the nearest water supply or boundary) as consideration of well distance blends a use measure into what is intended to be essentially a hydrogeologically based determination. If Step 1 is ignored, the total maximum point value is 23 points. In this case, a benchmark of 15 may be generally considered to be indicative of a highly vulnerable setting.

For a more detailed discussion of the LeGrand methodology, including parameter ranking values and examples, see "A Standardized System for Evaluating Waste Disposal Sites" (LeGrand, 1980).

Integrative Methodology

Integrative methodologies are often considered the most sophisticated evaluation aids because they can represent the interaction and relative importance of the various hydrogeologic factors. The most common type of integrative method is a flow calculation based on the hydraulics of the ground-water flow system. There are two calculations available--velocity and time of travel. The time-of-travel measure is used to establish an acceptable time of travel within the ground-water flow system; the velocity must be known and a specified point, or a specified distance, must be given.

Flow calculations can be made for aqueous transport (i.e., movement of water molecules only) or for specific constituents where a reliable retardation factor can be determined. Because vulnerability is not constituent-specific by definition, only the aqueous transport flow calculations should be considered.

The principal advantage of a flow calculation measure is that it provides a more direct measurement of hydrogeologic system behavior. This type of measure uses factors directly related to ground-water flow, according to their theoretical relationship. For aqueous transport, travel velocity and travel time are calculated as follows:

$$\text{time of travel} = \frac{\text{distance}}{\text{velocity}}$$

$$\text{velocity} = \frac{KI}{n_e}$$

where:

K = hydraulic conductivity

I = hydraulic gradient, and

n_e = effective porosity.

The velocity measure can be reliably derived using analytical data generated from hydrogeologic investigations and time of travel.

The difficulties of this type of measure are in selecting a defensible travel distance or exposure point and selecting the time of travel criterion. Both these values will be somewhat arbitrary and difficult to justify on technical merit alone. Flow calculation measures, in order

to be accurate, also require considerable data for the entire Classification Review Area and, therefore, can lead to rather high costs for a vulnerability assessment.

The Office of Solid Waste has instituted a time-of-travel (TOT) criterion as part of RCRA vulnerability assessments. Vulnerable settings in the area immediately contiguous to the facility are defined to have a TOT of less than 100 years to travel 100 feet. In addition, the high-level radioactive waste (HLW) program within the Department of Energy has also established a time-to-exposure criterion as a site-evaluation criterion. Ten thousand years from point of release to a potential exposure is the HLW travel time criterion.

Due to the high cost and data needs for performing flow calculations, it is not expected that such evaluation aids will be used routinely. The two programs mentioned above use such approaches as well as stringent threshold values, because of the high risk to human health from unexpected contaminant releases from such facilities.

CHAPTER FIVE

CLASSIFICATION CRITERIA FOR CLASS II GROUND WATER

5.1 Overview of the Decision Process

A Class II designation is provided for all ground water that is currently or may be used as a source of drinking water regardless of its degree of vulnerability. The majority of ground water classification decisions are expected to fall within Class II. Class II ground waters generally receive the very high level of protection that represents the "baseline" of EPA programs designed to ensure ground-water quality for present and future generations.

All non-Class I ground water that is currently used or is potentially available as a source of drinking water is included in Class II, whether or not it is particularly vulnerable to contamination. This class is divided into two subclasses; current sources of drinking water (Subclass IIA), and potential sources of drinking water (Subclass IIB). It is assumed that any ground water which is currently used for drinking water will fall in Subclass IIA, unless Class I criteria apply. A detailed discussion of the decision process for the identification of Class I ground water is presented in Chapter Four. Other ground waters are considered potentially usable as a source of drinking water, both from quality and yield standpoints (Subclass IIB), unless a lower resource value is demonstrated.

The relatively shorter length of this section reflects the complementary interrelationship between the classification criteria for Class II and those for Class I and III ground water. The other relevant sections of the document should be consulted as indicated.

5.1.1 Subclass IIA: Current Source of Drinking Water

Ground water is considered a current source of drinking water under two conditions. The first and most common condition is the presence of one or more operating drinking-

water wells (or springs) within the Classification Review Area. The second condition occurs in the absence of wells or springs, and includes ground-water discharge to a water-supply reservoir (see Figure 5-1).

The concept of a current source of drinking water is rather broad by intent. Only a portion of the ground water in the Classification Review Area must supply drinking water to wells or springs or to water-supply reservoirs. It should also be noted that a current source of drinking water, which meets the irreplaceable/highly vulnerable criteria, is Class I.

Ground waters that discharge to a water-supply reservoir or portion of the reservoir watershed within the Classification Review Area are also classified as Class IIA, a current source of drinking water, if the reservoir has been designated by State or local government for water-quality protection. Water-quality protection can be shown by the following:

a. Specific measures providing more stringent protection within the watershed than in adjoining areas. The protective measures may include the following:

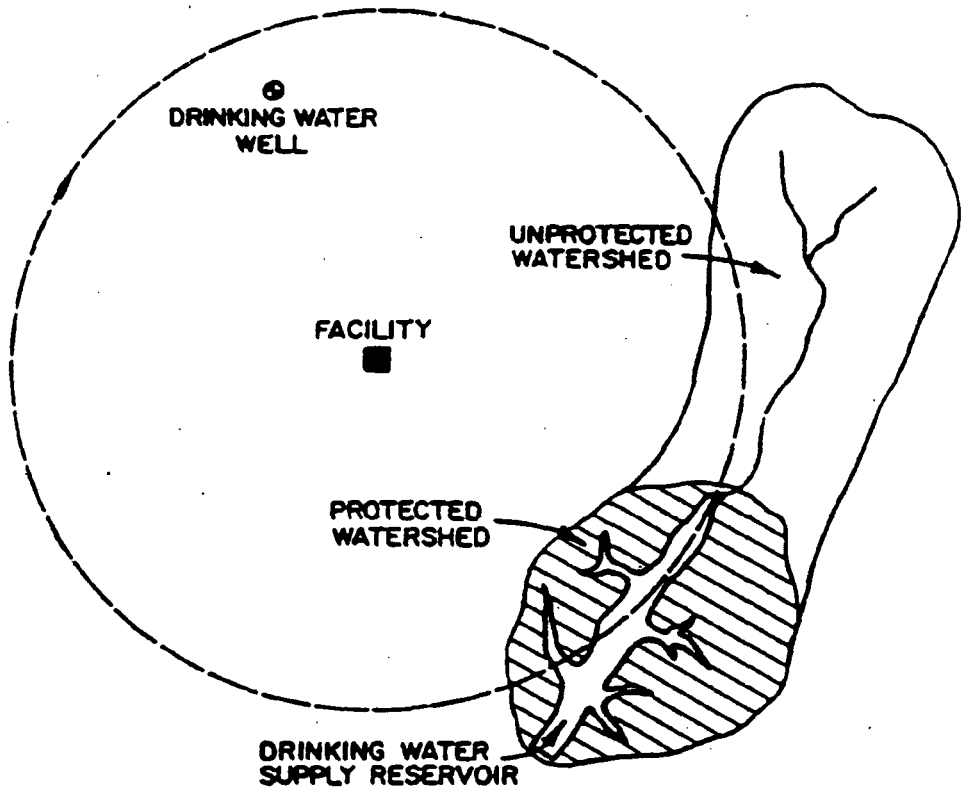
   - Sediment-control regulations that may consist of limiting the impervious surface area and encouraging the use of infiltration and wet ponds.
   - Lot-size restrictions.
   - Regulations for best-management practices.
   - Limiting waste disposal and working with waste-treatment plants to try and upgrade discharge standards.
   - Restrictions on land-use activities within the watershed (e.g., mining, logging, certain recreational practices).

b. Legislation or a memorandum of understanding with a general policy statement that indicates that watershed lands are to be protected so that reservoir water quality will be maintained or protected.

A protected watershed could also include lands purchased by the water-supply utility and managed to preserve water quality and yield.

FIGURE 5-1

EXAMPLE CLASS II - CURRENT SOURCE OF DRINKING WATER



There also may be circumstances where a water-supply intake on a stream or other surface-water body is located within or adjoining the Classification Review Area. The classifier may have evidence to indicate that such surface waters receive significant discharge of ground water from the Classification Review Area and these surface waters might be reasonably expected to be contaminated if the ground water were impacted. In such cases, best professional judgment should be exercised to ascertain whether a Class IIA designation is warranted.

5.1.2 Subclass IIB: Potential Source of Drinking Water

A potential source of drinking water in the Classification Review Area is one that is capable of yielding a quantity of drinking water to a well or spring sufficient for the minimum needs of an average family. It is assumed that all ground-water units are capable of supplying a yield sufficient to meet the minimum needs of an average family, unless an insufficient yield can be demonstrated as part of a Class III determination (see Chapter 6 for a discussion of the insufficient yield concept). Water is considered to be suitable for drinking if it has total-dissolved-solids (TDS) concentration of less than 10,000 mg/L and either can be used without first being treated or can be rendered drinkable after being treated by methods reasonably employed in a public water-supply system. All ground water should be presumed to meet this standard for drinking water, unless demonstrated otherwise according to a Class III demonstration described in Chapter Six.

An uppermost limit of 10,000 mg/L TDS was chosen for several reasons. Many State and Federal programs currently use 10,000 mg/L TDS to distinguish potable from nonpotable water. Some States set lower limits because the TDS of drinking water is usually well below 10,000 mg/L. A survey of rural water supplies (EPA, 1984a), for which ground water was the principal source, found a maximum TDS level of 5,949 mg/L. Eighty-five percent of rural water-supply systems used sources of water that contained less than 500 mg/L TDS. Given the range of TDS values, 10,000 mg/L provide the flexibility needed in a nationwide program. This concentration also ensures that other beneficial uses of ground water will be encompassed in Class II determinations.

5.2 Classification Procedures

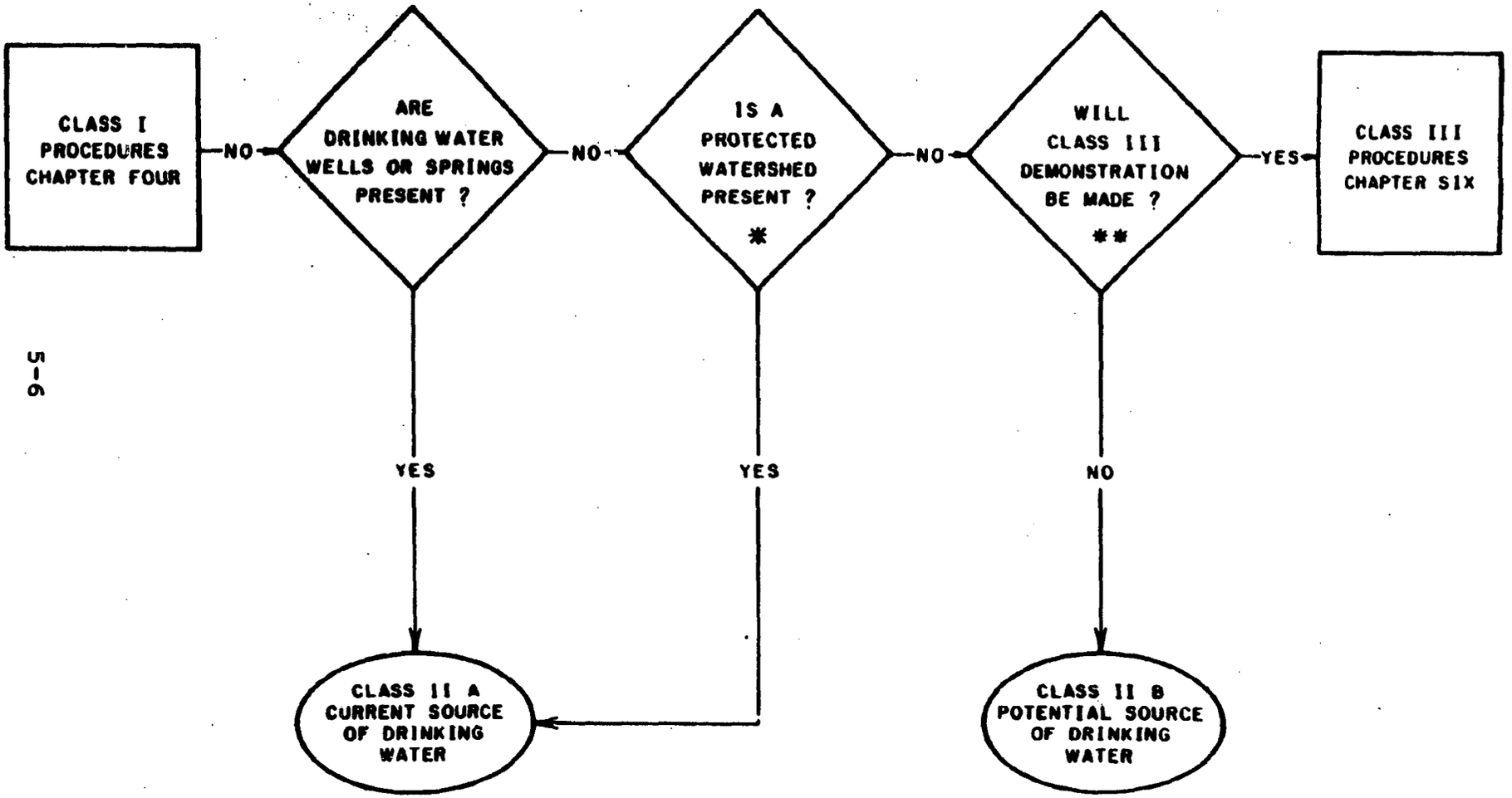
Assigning a Class II designation is, perhaps, the simplest of all the classification procedures. It is assumed that all ground waters currently used for drinking water or other beneficial uses will fall into Subclass IIA unless Class I criteria apply. All other ground waters are considered potentially usable as a source of drinking water (or water for other beneficial uses), both from a quality and yield standpoint, and are thus Subclass IIB, unless Class III criteria are demonstrated.

The general Class II classification procedure is outlined in Figure 5-2. If wells and/or springs used as a source of drinking water are present, or ground-water discharge to a water-supply reservoir occurs, then the ground water is considered Subclass IIA. All other ground waters would be considered Subclass IIB, unless a Class III demonstration is made.

Specific classification procedures and data needs for water-quality testing and water-yield testing were not established as part of the Class II criteria. The general rule is to presume, in the absence of data, that the quality and yield of a ground-water resource is sufficient to meet the criteria for a potential source of drinking water. Where the ground water can be demonstrated to fail the quality or yield criteria, the result could be a Class III designation. The classifier is referred to Chapter 6 for a detailed discussion of the decision processes for Class III ground-water identification.

FIGURE 5-2

FLOW CHART FOR CLASS II PROCEDURES



* OR WATER-SUPPLY INTAKE UNDER CERTAIN CIRCUMSTANCES

** ASSUME CLASS III CRITERIA ARE NOT MET UNLESS DEMONSTRATED OTHERWISE.

CHAPTER SIX

CLASSIFICATION CRITERIA FOR CLASS III GROUND WATER

6.1 Overview of the Decision Process

6.1.1 Definition of Class III

Class III ground waters are those that are not potential sources of drinking water because of one or more of the following reasons:

1. Salinity (i.e., greater than or equal to 10,000 mg/L TDS.

2. Contamination, either by natural processes or by broad-scale human activity (unrelated to a specific pollution incident), that cannot be cleaned up using treatment methods reasonably employed in public water-supply systems.

3. Insufficient yield at any depth to provide for the minimum needs of an average-size household.

Subclasses are differentiated primarily on the basis of degree of interconnection to adjacent ground waters and surface waters.

6.1.2 Background of Class III

In EPA's ground-water classification system, Class III is reserved for ground water that has virtually no potential as a source of drinking water. Because of the very low likelihood that Class III ground water would be used as a drinking-water source and thus pose a risk to humans, it may be appropriate in some situations to manage existing contamination differently or take different preventative measures than would be taken for Class I and II ground waters

where there is a greater possibility that contamination could result in human exposure.

Several of the following key technical points relative to the Classification procedures support this policy:

- All ground water is presumed to be a current or potential source of drinking water (Class I or II), unless a successful demonstration is made that the ground water meets the criteria for Class III.
- A contamination plume is not, per se, evidence of widespread contamination; the term untreatable is intended to describe general ground-water quality in the Classification Review Area.
- Ground water will not be considered Class III when contamination is due to an action or in-action on the part of the facility in question.

6.1.3 General Procedures

The first step in the Class III procedure is to decide whether to pursue a Class III determination based on the insufficient yield criteria or the water-quality criteria. Preliminary data may indicate that evidence of one determining criteria will be less difficult to demonstrate than another. It is important to note, however, that the order in which Class III steps are performed is left to the classifier.

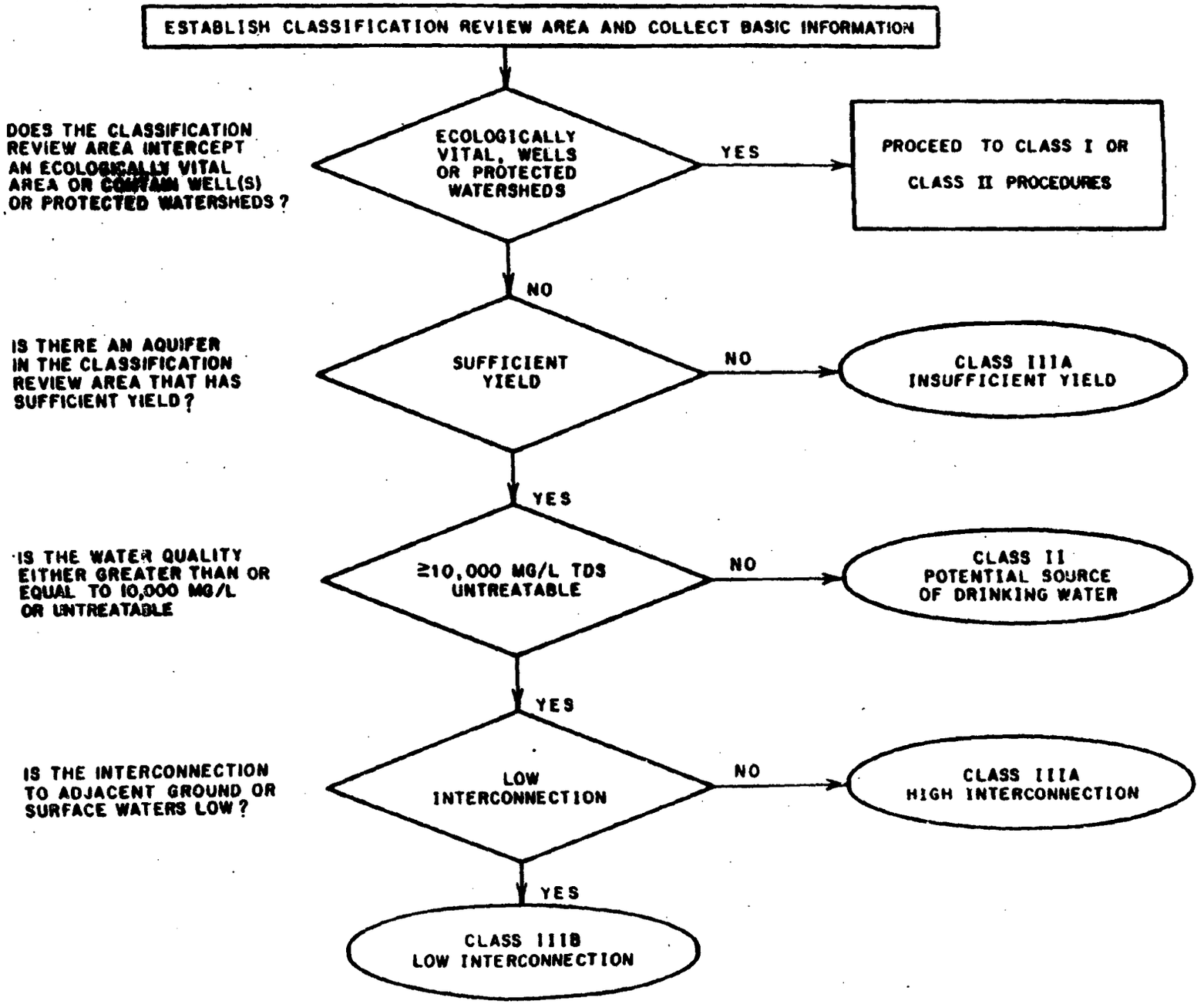
Figure 6-1 illustrates the general steps that are followed in the Class III procedure. In most cases, it is probably easiest to address the yield criteria first, unless data indicate otherwise. A demonstration of insufficient yield automatically results in a Class IIIA designation.

The sufficient yield criterion is discussed in detail in Section 6.2 of this chapter. In general, a ground-water unit is considered capable of producing a sufficient yield if it can produce enough water to meet the minimum needs of an average-size family. If the ground-water regime is not capable of meeting the minimum needs of an average-size family, it is automatically Class IIIA: Insufficient Yield unless Class I or Class II criteria have been demonstrated.

Ground-water quality and treatability in the Classification Review Area or unit of interest can also be used as criteria for a Class III designation. Ground water that has a TDS concentration of greater than or equal to 10,000 parts

FIGURE 6-1

STEPS IN THE CLASS III PROCEDURE



per million (ppm) is Class III unless criteria for Class I or Class II are met. Ground water that has less than 10,000 ppm TDS, but can be shown to be untreatable according to the definition in these Guidelines, is also Class III. The subclass designation A or B is assigned on the basis of degree of interconnection to adjacent ground-water units and surface-water.

Two treatability tests are presented in these Guidelines. The first is referred to as the reference technology test and is used as a screening step to identify various kinds of treatment methods needed to attain relevant health standards. If none of the treatment technologies currently employed to treat drinking water can adequately treat the ground water under review, then that ground water is initially considered technically untreatable, to be confirmed or denied by further economic analysis. If one or more currently available treatment technologies could be used to treat the water to the relevant quality standard, however, then the water is initially considered technically treatable (i.e., Class II). In this situation, the second treatability test, referred to as the economic untreatability test, could be applied if further analysis is warranted. The economic untreatability test is designed to determine whether the costs of treating the ground water would be reasonably expensive for a hypothetical user population. If the costs are deemed unreasonable, then the ground water may be considered Class III, untreatable. If the costs fall below the threshold, on the other hand, then the ground water should be considered a potential drinking-water supply (i.e., Class II). Treatability and water quality are discussed in greater detail in Section 6.3.

Subclassification of Class III is based on the degree of interconnection of ground-water units. For a Class IIIB determination, a low degree of interconnection must be demonstrated; otherwise, the ground-water unit is designated as Class IIIA. A detailed discussion of the interconnection criteria has been provided in Chapter Three.

6.2 Class III Designation Based on Insufficient Yield

One of the three criteria that can be used to define a ground-water unit as Class III is insufficient yield. Yield is defined as the quantity of water that can be extracted or produced from the ground-water regime. In order for yield to be considered insufficient, it must be practically infeasible to produce a sufficient supply of ground water to meet the minimum needs of an average-size household. Agricultural,

industrial, or municipal uses of these marginal, water-bearing areas would require significantly higher yields than a domestic well. The insufficient yield criterion is based, therefore, on a conservatively low yield, below which it is generally considered unlikely or impractical to support basic household needs. The insufficient yield concept is that all ground-water units within the Classification Review Area (regardless of the potential for subdivision), must be evaluated. If one such ground-water unit is found to provide sufficient yield, then a Class III A-Insufficient Yield designation should not apply.

A determination of insufficient yield will be made on a case-by-case basis at the discretion of the classifier considering the factors listed below:

- Water needs of an average family.
- Sustainability of yield.
- Number of wells per household.
- Minimum pumping rates.
- Use of storage.

The minimum water needs of an average person are estimated to be approximately 50 to 70 gallons-per-day (USEPA, 1975). However, most values reported in the literature are greater than 50 gallons-per-person-per-day, which can likely be attributed to non-essential uses such as irrigation of lawns and gardens. Water needs also vary for different regions of the country. Determination of this value is, therefore, left to the judgment of the classifier whose decision will be based on available data and consideration of other factors.

One factor that must be considered is that water is not used at a constant rate throughout the day; there are peak periods when demand is high and low periods when demand is not as great. A low-yielding well may be capable if it is possible to create adequate storage during low-use periods for use during high-use periods.

Barring more detailed information, a value of approximately 150 gallons-per-day (gpd) per household is a generally acceptable yield threshold. This value is based on EPA's water-supply guidelines that indicate per capita residential water minimum needs range from 50 to 75 gpd (EPA, 1975) for a single-family residence. Waste flows from single-family dwellings using septic systems average 45 gpd per capita (EPA, 1980, page 51). Based on an average family size of 2.75 persons, therefore, and a per capita water need of approximately 50 gpd, a value of about 150 gpd was obtained.

Classifiers should note that a per capita water need value of approximately 100 gpd (or 100,000 per household per year) is used for the Class I economic irreplaceability test and the Class III economic untreatability test (see Appendix D). The Agency believes that this higher 100 gpd value is more appropriate for sizing hypothetical public-water supply systems because such systems usually meet needs over and above basic household consumption requirements.

A sufficient yield threshold should be sustainable over time without temporary (e.g., seasonal) depletion of the resource. The yield can be obtained from any number and type of household wells, including drilled wells, dug wells, or any other type of well available.

Readily available hydrogeologic information exists that may assist a classifier in determining if a ground-water unit (or units) has a lithology capable of meeting the minimum yield requirements. This information can be obtained from U.S. Geological and State Geological Survey water resource publications. Logs and specific yield tests may be available for wells drilled in the area. Additional information can be obtained from university research publications and scientific journals. However, in some cases, the classifier may need more site-specific aquifer test data to determine the hydraulic properties of a particular ground-water unit. It is important to note that <u>if an active water-supply well is present and in use, the ground-water unit is considered to have a sufficient yield and should be designated Class II</u>.

6.3 Class III Designation Based on Ground Water Quality and Treatability

6.3.1 Areal Extent of Contamination

A Class III designation can be assigned to those ground waters that are naturally saline, or otherwise contaminated beyond levels that would permit their use for drinking or most other beneficial purposes. In order to be Class III, the ground waters must be so contaminated by naturally occurring conditions, or by the effect of broad-scale human activity (that is unrelated to a specific activity), that they cannot be cleaned up using treatment methods reasonably employed in public water-supply systems.

The determination that ground-water contamination is a result of broad-scale human activity is left to best professional judgment. The following lines of evidence are

suggested for assessing if ground-water contamination from broad-scale human activity is present:

- History of multiple contamination incidents.
- Nature and extent of contamination.
- Adequacy of water-quality data base.

An area that has been affected by a number of industrial and other potentially polluting activities over a long period of time in some cases may meet the concept of broad-scale human activity. Candidate areas will likely be identified by the presence of a large number and variety of potentially polluting sources that have been in operation over a number of years. In some cases, all or a portion of the sources may no longer be in existence, however, residual contamination remains. In any case, the contamination should not be traceable to a single source.

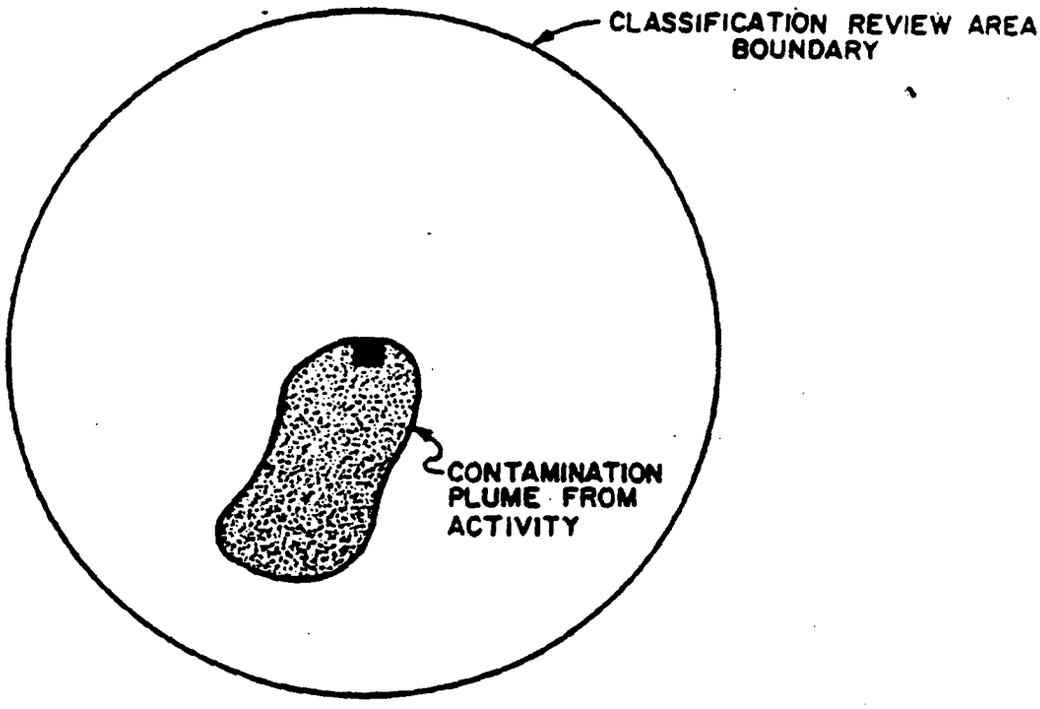
It is critical to recognize the difference between an untreatable plume, a concept irrelevant to classification, and untreatable ground water which receives the plume, a relevant classification factor. An example of a contamination plume that can be traced back to a specific activity is shown in Figure 6-2. The ambient ground water is, however, potable. Under these conditions a Class III designation should not apply. Figure 6-3 shows another contamination plume, however, in which extensive regional contamination is found that is technically and economically infeasible to treat with public-water-system technologies. In the latter case, a Class III designation may be appropriate.

In general, ground-water contamination due to broad-scale human activity is characterized by multiple constituents. Both constituent concentrations and the suite of constituents will also vary from point to point. Water-quality data would be expected to show the presence of relatively high concentrations of a few ubiquitous compounds, together with lower concentrations of a larger number of other constituents. The most commonly reported (i.e., ubiquitous) ground-water pollutants include chlorinated solvents; pesticides; miscellaneous hydrocarbons, such as gasoline; metals; salinity; and radionuclides (USEPA, 1985a). The entire ground-water unit being classified does not necessarily have to meet Class III untreatable criteria, but a major volume portion would. The definition of such significant portion is left to the best professional judgment of the classifier.

The water-quality data base, collected in support of the Class III determination, should reflect the full spatial variability of the various constituents, both vertically and

FIGURE 6-2

EXAMPLE OF CONTAMINATION THAT SHOULD NOT QUALIFY FOR CLASS III DESIGNATION

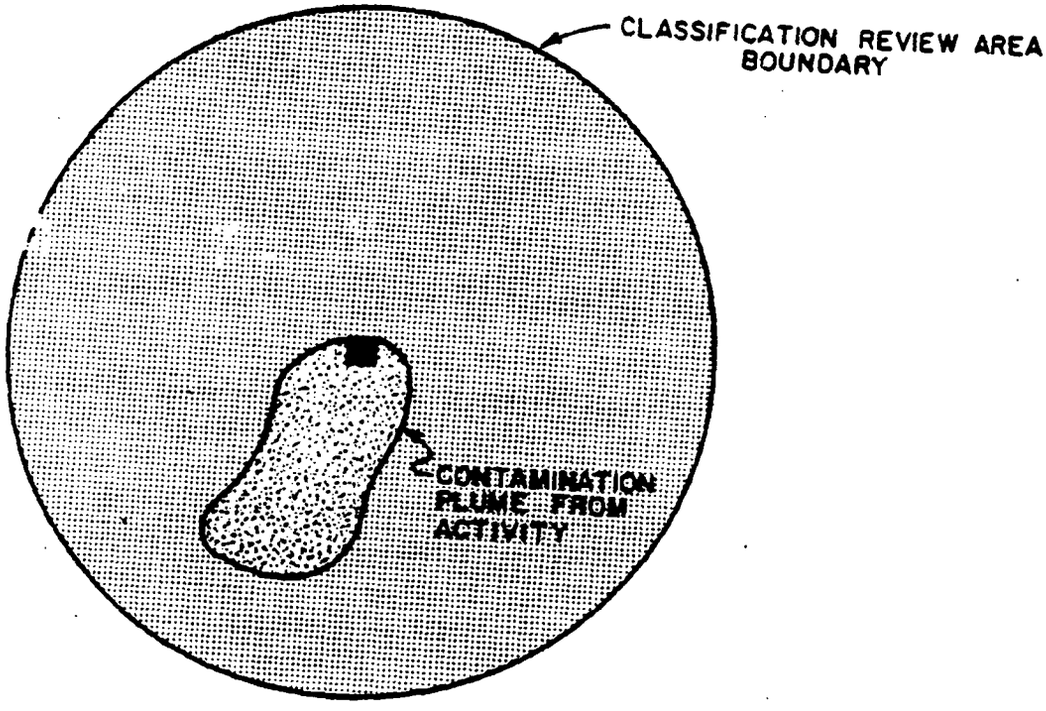


FACILITY / ACTIVITY

GROUND WATER UNTREATABLE USING METHODS REASONABLY EMPLOYED IN PUBLIC WATER SUPPLY SYSTEMS..CONTAMINATION DIRECTLY RELATED TO ACTIVITY.

FIGURE 6-3

EXAMPLE OF CONTAMINATION THAT MAY QUALIFY FOR CLASS III DESIGNATION



FACILITY / ACTIVITY

MAY OR MAY NOT BE TREATABLE USING PUBLIC WATER SYSTEM OR OTHER TECHNOLOGIES. CONTAMINATION DIRECTLY RELATED TO ACTIVITY.

GROUND WATER UNTREATABLE USING METHODS REASONABLY EMPLOYED IN PUBLIC WATER SUPPLY SYSTEMS.

horizontally. The most useful monitoring network for determining ambient conditions would employ a sampling pattern that minimized interdependence between samples. A monitoring network intended to determine a specific plume geometry will rarely suffice to provide full spatial representation across the ground-water unit.

The degree of uniformity of the sampling pattern can be measured using the statistical methods of quadrant analysis and nearest-neighbor analysis. Quadrant analysis is performed by dividing the area under consideration into a number of equal-sized subareas, such that each subarea contains a number of sampling points. If the data points are distributed uniformly, each subarea should contain the same number of points. The alternative to quadrant analysis is nearest-neighbor analysis which is performed on the distances between sampling points. For a more detailed discussion of statistics used to analyze uniformity, see "Statistics and Data Analysis in Geology," (Davis, 1973).

6.3.2 Standards and Criteria for Treatment

Both tests for defining Class III based on treatability imply that analyses of treatment methods should consider relevant standards and criteria for long-term drinking-water use. No one set of numbers is available and thus some professional judgment may be required.

EPA has issued National Interim Primary Drinking Water Regulations (NIPDWR) under the Safe Drinking Water Act. These regulations set maximum contaminant levels (MCLs) for a number of inorganic, organic, and microbiological contaminants in drinking water. These values are based on both health factors and technical/economical feasibility.

In addition to MCLs, which are enforceable standards, maximum contaminant levels goals (MCLGs) are set, reflecting EPA's goal of no known or anticipated adverse health effects. Both MCLG and MCL values are updated periodically. EPA also provides drinking-water suppliers with additional guidance. Under the authority of the Safe Drinking Water Act, EPA is now in the process of developing MCLGs for additional contaminants to serve as guidance for establishing new drinking-water MCLs. The Agency is accelerating the pace of both MCLG and MCL issuance. For current MCL and MCLG values contact the Agency at the following address:

The U.S. Environmental Protection Agency
Criteria and Standards Division
Office of Drinking Water (WH-550D)
401 M Street, S.W.
Washington, DC 20460

Other constituents may be intermittently encountered in a water system, and are believed to pose a risk, yet are not currently the subject of any MCL or MCLG. Some of these are addressed in the form of Health Advisories. The Health Advisories are not mandatory for public-water systems, but provide information for emergency situations. They are calculated at three exposure levels: 1 day, 7 or 10 days, and longer term (1 to 2 years). A margin of safety is factored in to protect the most sensitive members of the general population (EPA, 1985b; Federal Register, 1985). They are also available at the Office of Drinking Water at the address above.

Finally, the RCRA program in developing its corrective-action regulations and in responding to the land-disposal-bans portion of the RCRA amendments of 1984, is examining the applicability of other sets of criteria and standards for both carcinogenic and noncarcinogenic contaminants. These will likely be useful for addressing the large number of contaminants without current MCLs, MCLGs, or Health Advisories. Moreover, to the extent that EPA develops other standards related to ground-water or drinking-water quality, such standards should be given appropriate consideration.

6.3.3 Overview of Class III Treatability Tests

The first of two tests presented in these Guidelines is a reference technology test, which is a screening tool to determine if techniques commonly employed to treat water supplies are adequate to achieve Federal criteria or Guidelines relevant to the contamination found in the ground water. This test employs a relatively simple decision framework that does not involve detailed engineering or cost analyses.

The second test is an economic untreatability test. The purpose of this test is to augment the screening tool by assessing whether such technologies would be economically feasible. This two-tiered technical and economic feasiblity approach is discussed in the following sections.

6.3.4 Reference Technology Screening Test

Water-treatment technologies can be categorized at any point in time to fall into one of three categories:

- Methods then in common use in public water-treatment systems.

- Methods then known to be in use in a limited number of cases or under special circumstances in public water-treatment systems.

- Methods not then in use in public water-treatment systems.

At this time, methods in the first category (common use) are as follows:

- Aeration
- Air Stripping
- Carbon Adsorption
- Chemical Precipitation
- Chlorination
- Flotation
- Fluoridation
- Granular Media Filtration

Methods in the second category, known to be used under special circumstances at this time include:

- Desalination (e.g., reverse osmosis, ultrafiltration, and electrodialysis).

- Ion exchange.

- Ozonation.

- Granular Media and other simple point-of-use and point-of-entry technologies made available typically by water utilities on a short-term basis to a limited number of consumers.

When considering the application of these technologies, the classifier should also consider the treatment efficiencies given in Table 6-1 and the treatment descriptions given in Table 6-2. Some technologies, for example, may be appropriate for minor concentrations of contaminants and inappropriate for larger concentrations of the same contaminants.

Treatment methods not now believed to be in use by public water-treatment systems include distillation and wet-air oxidation. These methods are considered new to water treatment, although they have been applied for industrial purposes in the past.

TABLE 6-1

REPORTED TYPICALLY ACHIEVEABLE CONTAMINANT REMOVAL EFFICIENCIES a, b

	Air Stripping and Aeration	Carbon Adsorption	Chemical Precipitation	Desalination	Flotation	Granular Media Filtration	Ion Exchange	Ozonation
Arsenic	0 c	50	85	95	45	60	99	25
Barium	0 c	30	80	95		70	95	0
Benzene	98	75	70	75		40		97
Cadmium	0 c	85	90	60	60	70	99	
Carbon Tetrachloride	98	Moderate d	95		75	90		
Chlordane	Good d	Good d				40		
Chromium VI	0 c	95	98	90	50	50	96	
1,1-Dichloroethylene	98	97	98			55		
1,2c-Dichloroethylene	97	70				90		
1,2t-Dichloroethylene	75	95	30					
Dichloromethane	80	70	60	15	40	40		
2,4-D	Poor a	Good d	Good d					
p-Dioxane	0 c							
Endrin	0 c	99						Moderate d
Ethylene glycol	Good d	Good d						
Flouride		0	75			30		
Formaldehyde	Good d							
n-Hexane	99							
Lead	0 c	95	85	60	98	50	97	30
Lindane	0 c	95	Good d	65	85	50		
Mercury	0 c	90	80	90	75	55		
Methyl Ethyl Ketone	99							
Nitrate		15	96	70		10	90	50
PCB	0 c	15			97	20		
Selenium	0 c	10	70	97		60	98	99
Silver	0 c	25	70	40	45	20	99	
Tetrachloroethylene	98	99	95	80	30	0		40
Toluene	95	75	75	50	40	65		
Toxaphene	Good d	99						
1,1,1-Trachloroethane	80	99	50	98		97		
Trichloroethylene	98	Poor d	60					
2,4,5-TP	Poor d	Good d		Good d	Good d			
Trihalomethanes	75	99	95	80	80	60	50	
Xylenes	99		90	80	97	75		

a Data represent the percent of contaminant which can be expected to be removed from solution using treatment systems similar to those currently installed in full scale or pilot scale water treatment operations. Percent removal is generated from available literature as listed at the end of this section, and are rounded to the nearest 5 percent (below 95 percent). These numbers are representative of achievable efficiencies, and are not absolute indicators of specific system treatment efficiencies.

b Blanks indicate that no data were reported in the available literature.

c Although reported data were unavailable, the physical nature of those contaminants precludes effective removal via air stripping.

d Only qualitative data were available in the literature.

Table 6.2

DESCRIPTION OF TREATMENT PROCESS

	Air Stripping/Aeration	
ADVANTAGES	DISADVANTAGES	LIMITATIONS
Low Capital and O&M	Temperature sensitive (cold) contaminants	Removes only volatile contaminants
High removal efficiencies for some contaminants	May result in air pollution or a need for Emission Control	Suspended solids in influent may lead to removal efficiency loss due to biological growth (air stripping only).
Pretreatment is generally not required for ground water		
Equipment purchased off the shelf		

	Carbon Adsorption	
ADVANTAGES	DISADVANTAGES	LIMITATIONS
Low energy requirements	Management of spent carbon can be expensive and problematic -Regeneration -Disposal -Replacement	For organics removal where concentrations are high, frequent carbon regeneration necessary
High removal efficiencies for a wide range of contaminants over a broad concentration range	High capital and operating costs	Suspended soils should not exceed 50 mg/L
		Oil and grease should not exceed 10 mg/L
		Requires steady hydraulic loading

	Chemical Precipitation	
ADVANTAGES	DISADVANTAGES	LIMITATIONS
Equipment is readily available and easy to operate	Generates large quantities of sludge which must be treated and disposed	Frequent laboratory testing is required to maintain high efficiencies
Low energy requirements	Effluent quality may vary considerably	pH dependent
Low capital and O&M costs		No concentration limit

	Desalination Reverse osmosis, ultrafiltration	
ADVANTAGES	DISADVANTAGES	LIMITATIONS
Excellent removal or charged anions and cations	High energy requirements	Suspended solids must be low to prevent fouling
Good removal of high molecular weight organics	Requires extension pilot analyses for each system	Operating temperatures must be between 65 and 85 F
Effective treatment for removal of dissolved solids	Highly sophisticated instrumentation and control	
	Generates a concentrated brine which may require treatment	
	Pretreatment almost always required	
	High capital and O&M costs	

Table 6.2 (Cont.)

DESCRIPTION OF TREATMENT PROCESS

	Granular Media Filtration (e.g., sand filters)	
ADVANTAGES	DISADVANTAGES	LIMITATIONS
Highly reliable	Process generates a backwash which must be treated	Requires fairly steady hydraulic load
Relatively simple: easy to operate and control		Influent suspended solids should not exceed 200 mg/L
Multiple media can be used to improve efficiencies		Pretreatment may be required if suspended solids exceed 100 mg/L

	Ion Exchange	
ADVANTAGES	DISADVANTAGES	LIMITATIONS
Synthetic resins can tolerate a wide range of temperature and pH	High level of training necessary for operation	Influent concentrations should not exceed 4,000 mg/L
Can remove a variety of cationic and anionic inorganic and organic contaminants	Generates concentrated regenerant brine which must be disposed	O&G should not exceed 10 mg/L
Low energy requirements	Generally, but not always, high capital and O&M	Influent should not contain chemical oxidants (e.g., ozone)
		Filtration is required as pretreatment if suspended solids exceed 20 mg/L in the influent

	Ozonation	
ADVANTAGES	DISADVANTAGES	LIMITATIONS
Reduces chemical residuals generated (particularly trihalomethanes)	High capital and O&M costs	Treats only contaminants which can be oxidized
No dissolved solids generation	High energy	Does not remove iron-cyanide complexes
	Requires high level of training and safety precautions for operation	

	Flotation	
ADVANTAGES	DISADVANTAGES	LIMITATIONS
Easily implemented	May require substantial chemical addition	Narrow range of removal - e.g., not effective for contaminants with density greater than that of water
Usually highly effective for hydrocarbons with densities near or less than that of water	Generates large quanitites of sludge to be treated and disposed	
Low capital and O&M		
Low energy requirements		

The technologies currently used for treating surface and ground water that serve as public drinking-water supplies can be classed into five general categories:

- Volatile organic chemical removal.
- Non-volatile organic chemical removal.
- Metals removal.
- Non-metallic inorganic chemicals removal.
- Disinfection.

Some technologies are effective in reducing only a few types of contaminants, while others may efficiently treat several contaminant classes simultaneously. Although most processes are designed to treat a single class of contaminants, many will remove other types of contaminants. Brief descriptions of several generic treatment technologies and the applications are provided in Appendix C-1.

Although most of the reference technologies noted above are currently in use at public water-supply systems throughout the country, not all necessarily remove toxins (e.g., carbon adsorption is sometimes used in taste and odor applications and not for removal of volatile organics). The exceptions are desalination, ion exchange, and ozonation; these treatment technologies may be considered reasonably employed in certain circumstances, as noted above. Air stripping, which is most often used for removal of volatile organic solvents from ground waters, should be considered available for Class III analyses, despite its limited use in public water-supply systems.

Distillation techniques have long been employed for treating industrial process water, for example, but are generally reserved for areas such as islands, where potable water is scarce. Biological treatment techniques have been used for in-situ cleanup of ground waters rather than to treat supplies for general water distribution. Wet air oxidation techniques are currently used primarily in industry for removal of organics from process wastewater.

A partial bibliography of resources and references to assist in treatability analyses is given in Appendix C.2.

Treatment Efficiencies

Evaluation of treatment efficiencies for a single contaminant or group of contaminants requires the evaluation of interferences and interactions of contaminants. General

background data on treatment performance indicate ranges of values for efficiency. For example, EPA's Treatability Manual for Priority Pollutants (EPA, 1980a), presents examples of typically achievable, contaminant-removal efficiencies for a range of contaminants and technologies.

More precise determination requires pilot testing or comparison by experts with other similar waste streams. The general level of success the various treatment technologies have with frequently encountered contaminants is indicated in Table 6-1. Removal efficiencies are not reported in the literature for all contaminants, as experience using certain treatment technologies for removal of some contaminants is limited.

Contaminant concentration, physical conditions (e.g., pH, temperature), solution chemistry, and the presence of competing or interfering contaminants can all contribute to the large variations in removal efficiencies that are reflected in the literature. For situations in which a more accurate assessment of treatment efficiencies is desired, the user of these Guidelines may wish to consult the reference sources listed in Appendix C.2.

Some of the major advantages, disadvantages, and limitations associated with each treatment process are listed in Table 6-2. It is important to know the composition of the ground water to be treated in order to develop process configurations. Evaluation of potential interference problems and matrix effects is critical for some scenarios. If a system uses both granular media filtration for solids removal and ion exchange for softening, for example, the filtration stage should precede the ion-exchange stage in order to assure that potential resin-fouling solids are eliminated from suspension. As another example, plants with solvent contamination will commonly use air stripping or carbon adsorption to remove the organics prior to chlorination to prevent the formation of halogenated organics, which are less efficiently removed. The examples discussed above are only two of a very large number of potential chemical interactions that may interfere with the removal of contaminants and affect the treatment process configuration for a given condition. These factors must be considered and are likely to require professional judgment to properly evaluate the potential for treatment of contaminated ground water.

Example Procedures for Conducting Reference Screening Technology Tests

One approach which can be used in this screening test involves five steps:

1. Describe the contamination problem.

2. Determine the desired effluent quality.

3. Define and assess process configurations.

4. Evaluate treated water quality.

5. Determine if desired water quality is met.

Each of these steps is described in detail below.

Step 1: Describe the Contamination Problem

A description of the contamination problem might include data on the natural or background water quality, the extent of contamination, and the physical factors influencing both ground water and treatment. The natural quality of a ground water may be inferred from historical data or by comparison to background ground waters in the site vicinity.

Contaminants in the ground water of concern will then typically be specified and the range in concentrations noted. In particular, if the type and concentration of contaminant vary spatially, this may be indicated, as this variance has design implications for treatment configurations. Presentations of analyses used and the range of sampling and measurement errors included would assist the reviewer in understanding the degree of certainty of contamination. It is important to address the areal extent of contamination to be sure it meets the basic notion that contamination is not related to an individual facility or activity.

The physical parameters of concern include flow patterns, climatology, and other site-specific issues. Many of the treatment processes are highly sensitive to temperature fluctuations. Ambient temperature ranges, therefore, are important in selecting appropriate technologies or housing requirements. The climate in the area of concern, including data on the freeze/thaw cycles, and any storm or wind events that may affect the treatment processes, must also be considered. Other site-specific considerations may become important on a case-by-case basis.

Step 2: Determine the Desired Effluent Quality

To determine the desired quality of the treated water following completion of all treatment processes, acceptable target concentrations are established for each contaminant. Relevant Federal criteria include the MCL, the MCLG, the longest-term Health Advisory for each contaminant, and any other appropriate standards or criteria developed by EPA relating to ground-water or drinking-water quality.

Step 3: Define and Assess Available Process Configurations

The classifier then typically defines a set of treatment process configurations that may be used to remove contaminants from the ground water. These process configurations would be developed considering efficient contaminant removal to the minimum level required. The technologies selected would then be assessed based on their current and projected near-term future availability.

Step 4: Evaluate Treated Water Quality

To evaluate typically achieved water quality using any given treatment process configuration, the concentration of specific contaminants in the ground water/influent, levels of background water-quality parameters (pH, TDS, etc.), and the removal efficiencies of each contaminant using each treatment process should ideally be known.

Background data and/or manuals on treatability developed by EPA can be consulted for initial guidance on treatment (e.g., EPA's Treatability Manual for Priority Pollutants, 1980b). Contaminant removal efficiencies for common treatment technologies are presented in Table 6-2. A qualified water treatment engineer could also determine the relative contaminant removal effectiveness due, for example, to interference effects.

Step 5: Determine If Desired Water Quality Is Met

Once the approximate effluent concentration of each contaminant has been evaluated for a given treatment process, these can be compared to the appropriate water-quality standard. If all effluent concentrations are less than the desired water quality, the ground water can be cleaned up using treatment methods reasonably employed in public water-supply systems. Thus, a Class II determination is warranted. If some effluent contaminant concentrations exceed desired water quality, the treatment process configuration does not adequately clean the ground water, and an alternative configuration should be evaluated for contaminant treatability. If all available treatment process configurations do not remove contaminants to the levels that meet desired water quality, the ground water cannot be cleaned up using treatment methods reasonably employed in public water-supply systems; these units will then be candidates for Class III.

Hypothetical Example

The following example is illustrative in nature and is not meant to represent conditions at any specific facility.

A permit applicant has asked to site a facility and has made the claim that the site location will only affect Class III ground water. The chemical contaminants in the ground water, listed in Table 6-3, are apparently from multiple sources and occur throughout the Classification Review Area.

For trichloroethylene, carbon tetrachloride, cadmium, and selenium, the applicant defines the desired maximum effluent contaminant concentrations to be equal to the MCLs for those constituents. For tetrachloroethylene, a long-term Health Advisory was used.

The treatment processes that most readily remove volatile organics, such as carbon tetrachloride and tetrachloroethylene, include carbon adsorption and air stripping. Metals, such as cadmium and selenium, can be removed using chemical precipitation, desalination, and ion exchange. Granular media filtration would probably be considered for removal of residual particulate matter, following a chemical precipitation step, particularly if desalination, carbon adsorption, or ion exchange processes followed. All of these processes are currently in use in public water-supply systems.

Achievable effluent quality must be evaluated for each treatment process configuration to determine if the ground water can be treated to meet desirable levels. Process and contaminant specific removal efficiencies are provided for all five contaminants. (Please note: these values are to illustrate the process and are not intended to be actual efficiencies.) As indicated by calculated WQ_o values and comparing them with WQ_d values (Table 6-3), treatment process configuration A can result in removal of trichloroethylene, tetrachloroethylene, and carbon tetrachloride, such that acceptable levels are achieved. However, levels of cadmium and selenium, following treatment using process configuration A cannot meet the desired water quality. Therefore, the applicant must consider an additional treatment process configuration.

Removal efficiencies for the process configuration B including air stripping, chemical precipitation, filtration, and desalination can achieve acceptable water-quality levels for all contaminants. Thus, according to this methodology, this ground water is technically treatable using treatment methods reasonably employed in public water-supply systems. In this situation, therefore, the economic untreatability test should be applied to determine whether treatment configuration B would be economically feasible.

TABLE 6-3
EFFLUENT QUALITY WORKING TABLE FROM SAMPLE PROBLEM

Contaminant	WQ_i[a]	WQ_d[b]	Treatment Process Removal Efficiencies[c] Process A	Process B	Process C	Process D	Process E	Process F	WQ_o[d]	Desired Water Quality Achieved?
Process Configuration A			Air Stripping	Chemical Precip.	Filtration	--	--	--		
Trichloroethylene	0.6	0.005[e]	98	60	7				0.004	Yes
Tetrachloroethylene	150.0	1.9	98	95	0				0.15	Yes
Carbon Tetrachloride	40.0	0.005[e]	98	95	90				0.004	Yes
Cadmium	0.5	0.01	0	90	70				0.015	No
Selenium	2.0	0.01	0	70	60				0.24	No
Process Configuration B			Air Stripping	Chemical Precip.	Filtration	Desalination	--	--		
Trichloroethylene	0.6	0.005[e]	98	60	7	7			0.004	Yes
Tetrachloroethylene	150.0	1.9	98	95	0	80			0.03	Yes
Carbon Tetrachloride	40.0	0.005[e]	98	95	90	7			0.004	Yes
Cadmium	0.5	0.01	0	90	70	60			0.006	Yes
Selenium	2.0	0.01	0	70	60	97			0.007	Yes

[a] WQ_i = the influent contaminant concentration, in mg/l

[b] WQ_d = the desired maximum effluent contaminant concentration, in mg/l

[c] Removal efficiencies report in percent

[d] WQ_o = the calculated effluent contaminant concentration, in mg/l

[e] These MCLs are effective January 9, 1989

6.3.5 Economic Untreatability Test

The economic test has been developed to identify ground-water sources that have particularly low economic value under present or foreseeable future conditions. Water sources of low value are defined as those where future treatment and use of such ground waters for drinking purposes would be very costly and thus highly unlikely. This definition implies that ground waters may be considered to be of low value even though there may be technical procedures available to render these water sources drinkable (i.e., procedures identified in the reference technology test). Ground waters with particularly low value may warrant a lower level of protection than other ground waters.

As with the economic irreplaceability test used for Class I determinations, the economic untreatability test is based on t pical per household costs of drinking-water supplies. Total water-supply system costs are again estimated for a user population and then compared against threshold values to gauge economic feasibility. The process for applying the economic untreatability test, therefore, is generally consistent with the economic irreplaceability methodology.

The Class III economic untreatability test, however, differs from the economic irreplaceability test in two respects. First, the economic untreatability test is based on a hypothetical drinking-water system because a Class III candidate ground water by definition is not currently used. Second, the Class III untreatability test is designed to emphasize the ground-water treatment costs of the supply system while the Class I test considers all types of costs equally. The Class III test is constructed in this manner to ensure that ground water that meets both the technically and economically feasible treatment criteria will not be classified as Class III.

Because of these dissimilarities with the Class I economic irreplaceability test, the economic untreatability test involves four steps rather than three, with the additional step being the estimation of a hypothetical user population size.

The four steps for applying the economic untreatability test are as follows:

1. Estimate the hypothetical user population size.
2. Estimate the hypothetical system cost.
3. Calculate the economic untreatability thresholds.
4. Apply the economic untreatability test.

Each of these steps is described in detail below.

Step 1: Estimate the Hypothetical User Population Size

The first step in the economic untreatability test is to estimate the size of the hypothetical user population that could potentially use the ground water as a source of drinking water. The size of the hypothetical user population should be determined as the population that could be served by the maximum sustained yield of the aquifer in question.

A number of data sources are available for estimating the yield of an aquifer. The U.S. Geological Survey office (e.g., District Office) in the State or the State geological or water surveys will often have hydrogeological information (e.g., maps, reports, and surveys) on most aquifers within a state. Consultation with these sources and other individuals with local expertise and experience can likely provide a reasonable estimate of an aquifer's sustained yield. For more detailed assessments, a review of boring logs, geotechnical evaluations or other data sources will be needed. Field assessments and ground-water monitoring also may be needed to assess not only aquifer yield, but quality parameters as well.

Once the sustained yield is estimated, a population equivalent can be determined based on a per capita water use of 100 gallons per day, which is roughly equivalent to a per household water use of 100,000 gallons per year. For example, geotechnical and hydrogeological data may indicate that a ground-water source that is being classified has an estimated sustainable yield of 50 gpm or 72,000 gpd. The population equivalent that could be served by this yield is 720 (72,000 gpd divided by 100 gpd/person).

Step 2: Estimate the Hypothetical System Cost

The second step of the economic untreatability test is to estimate the cost of the ground-water supply system that could serve the hypothetical user population determined in Step 1. This test is structured around the four major components of water-system costs: acquisition, treatment, distribution, and service. As with the economic irreplaceability test methodology, Appendix D presents the cost-estimating methodology to assist in conducting such analyses.

Note that because the primary focus of this test is the treatability of the ground water under review, site-specific treatment costs should be used in all cases when estimating the total system cost. Moreover, the treatment costs used

should be based on the least expensive of all technically feasible treatment trains. With regard to appropriate costs for the remaining components, the default (i.e., nationally typical) values presented in Appendix D for acquisition, delivery, and service are provided for assistance. Even if a typical regional cost estimate is used in lieu of the typical national costs given in Appendix D, extreme costs for acquisition, delivery, and service generally should not be used in order to ensure that the results of the treatability test primarily reflect the costs of treatment rather than the costs of other system components.

Step 3. Calculate the Economic Untreatability Threshold

The third step of the economic untreatability test is to calculate the threshold against which the annualized per household water-supply system cost will be compared. As with the Class I economic irreplaceability test, and for the rationale noted in the economic irreplaceability discussion in Chapter 4, the threshold that should be used for a given classification is the ninetieth percentile of household water-supply cost for water systems serving populations similar in size to the hypothetical user population. The methodology for calculating this threshold is presented in Appendix D. For reference, Figures 4-5 and 4-6 (in Chapter 4) graphically illustrate this cost function for system sizes ranging from 500 to 1,000,000 persons and 500 to 10,000 persons, respectively.

As noted in Chapter 4, the Agency is currently reviewing the question of community water-supply system affordability which may lead to future changes in the way Class III assessments are performed.

Step 4. Apply the Economic Untreatability Test

Having estimated the size of the hypothetical user population, the annualized total cost of providing water to that population given site-specific treatment requirements, and the appropriate ninetieth percentile threshold, the final step of the economic untreatability test is to compare the estimated cost of the water-supply system to the threshold value to determine whether the ground water could be economically treated and provided to a user population.

If the cost of the hypothetical water supply significantly exceeds the ninetieth percentile threshold, then the classifier may conclude that the costs of treating the ground water would make the viable use of that water for drinking purposes highly unlikely. The ground water, therefore, is not a potential source of drinking water and should be classified as Class III - Economically Untreatable. Further, the classifier should proceed to the next section of

this chapter in order to determine in which Class III subclass the ground water belongs.

If the cost of the hypothetical water supply is significantly less than the threshold, then the cost of treating the ground water would not make the total costs of using the water for drinking purposes economically infeasible. Because the ground water is capable of providing a sufficient yield and is both technically and economically treatable, it, therefore, represents a potential source of drinking water and should be classified as Class IIB.

Finally, if the cost of the water supply is relatively close to the threshold, then the classifier should consider the variability intrinsic in the function used to derive the ninetieth percentile thresholds and make a final determination based on best professional judgment.

6.4 Subclasses of Class III

The subclasses of Class III ground water are differentiated in part by the relative degree of interconnection between these waters and those in adjacent ground-water units and/or surface waters. A discussion of ground-water units and the concept of degrees of interconnection are provided in Chapter Three. The subdivision of Class III into A and B designations provides further definition of the relative potential for contaminant release incidents to significantly reduce the quality and value of a valuable water resource.

Subclass IIIA ground-water units are defined as having an intermediate degree of interconnection to adjacent ground-water units and/or are interconnected to surface waters. Subclass IIIA is also associated with shallow, naturally saline ground water within a single ground-water unit that is continuous throughout the Classification Review Area. Note that all Class III designations based on insufficient yield are considered Class IIIA regardless of interconnection.

As mentioned in Chapter Three, a high degree of interconnection is inferred when the conditions for a lower degree of interconnection (low: Type 2 boundary or intermediate: Types 1, 3, and 4) are not demonstrated. High interconnection of waters is assumed to occur within a ground-water unit and where ground water discharges into adjacent surface-water bodies. The latter situation is especially relevant in identifying Subclass IIIA ground waters.

Subclass IIIB ground-water units are defined as having a low degree of interconnection to ground-water units within the Classification Review Area. Generally, Subclass IIIB excludes (1) unconfined and semiconfined ground-water units as well as (2) extensively confined ground-water units under natural conditions where substantial numbers of improperly cased and/or sealed wells significantly compromise such confinement. Note that the low degree of interconnection criteria includes, but is not limited to the interconnection criteria for Class I injection wells as regulated under the Safe Drinking Water Act.

Examples of Class IIIA Ground Water

Two examples of Class IIIA ground-water conditions are provided. The first example concerns an area with ground-water contaminated due to broad-scale human activity. The second concerns shallow, naturally saline (TDS greater than or equal to 10,000 mg/L) ground water. Note that these examples are extrapolated from a knowledge of similar settings, but do not represent any specific location or site.

The first example of Subclass IIIA is associated with shallow, unconfined, aquifers that have been contaminated to untreatable levels via broad-scale human activity. Figure 6-4 shows a hydrogeologic setting with an urban/industrial area located near a major surface water and overlying an alluvial aquifer with a relatively shallow depth to water. The area contains numerous diffuse sources of contamination that have degraded ground-water quality. As shown, the degraded water comprises the major volume of the ground-water unit that discharges to the local surface-water body. A ground-water unit boundary was identified coincident with the river, thereby allowing subdivision.

A second example of Subclass IIIA is associated with shallow naturally saline ground water within a single ground-water unit that is continuous throughout the Classification Review Area. In some hydrogeologic settings, such as the closed basin/arid climatic setting illustrated in Figure 6-5, it is possible that the extent of the saline ground waters could be very large compared to the review area. The Classification Review Area in Figure 6-5 represents only a small portion of the total extent of the saline ground waters. By definition, the saline ground-water unit within the Classification Review Area would be highly interconnected to other ground water both within and outside the review area boundaries. Under the conditions described, the shallow, saline, unconfined to semiconfined ground water would receive a Subclass IIIA designation.

FIGURE 6-4

ALLUVIAL AQUIFER SEPARATED INTO TWO GROUND-WATER UNITS WITH HIGH INTERCONNECTION TO A RIVER

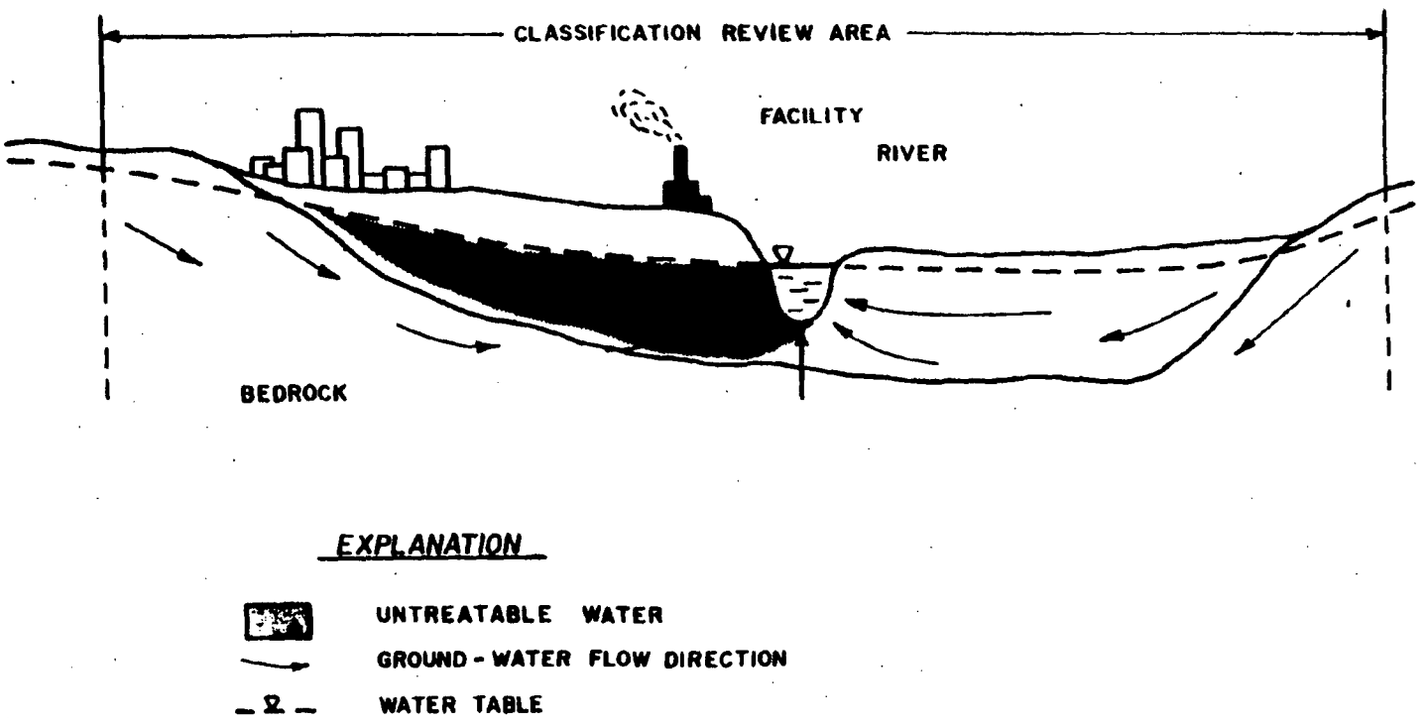
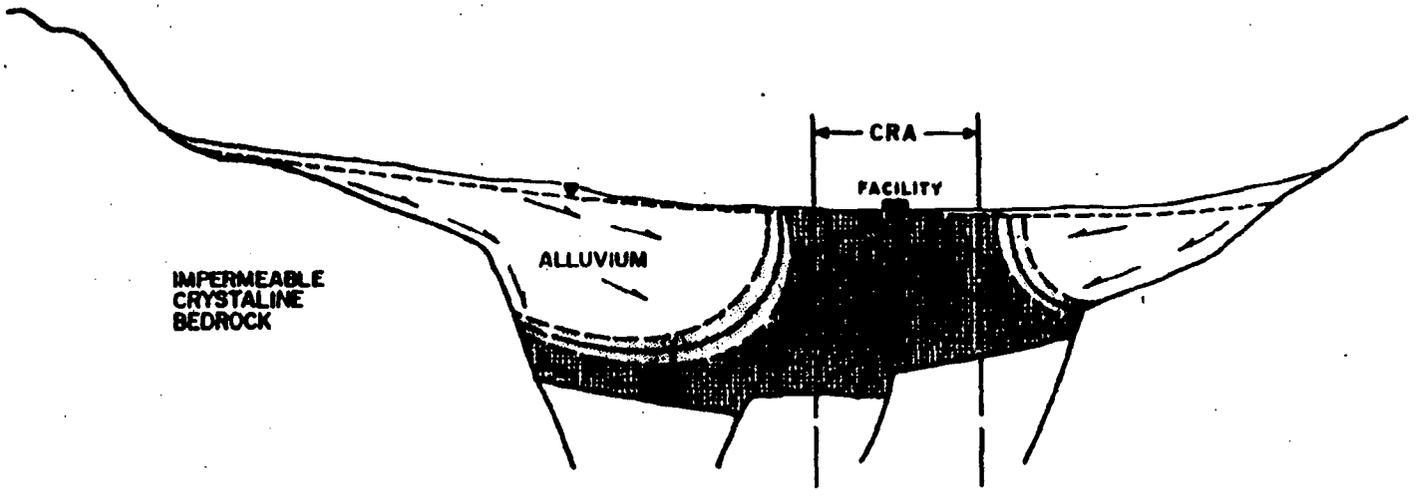


FIGURE 6-5

CLOSED BASIN/ARID CLIMATIC SETTING CONTAINING A CLASSIFICATION REVIEW AREA WITH A SINGLE GROUND-WATER UNIT



EXPLANATION

- HIGHLY SALINE WATER
- DIFFUSION ZONE
- WATER TABLE
- GROUND-WATER FLOW DIRECTION
- CRA — CLASSIFICATION REVIEW AREA

Example of Class IIIB Ground Water

An example of a Class IIIB ground-water unit within a sedimentary basin is shown in Figure 6-6. Sedimentary basins commonly contain multiple fresh-water aquifers, each separated by a regionally extensive low-permeability confining unit (Type 2 boundary) overlying deeper saline water. Figure 6-6 is an example of such a basin where ultimate discharge of the deep fresh water through overlying low-permeability confining units (flow barriers) is to local steams, the atmosphere, and the ocean. Deeper ground waters in these basins will be characterized by TDS concentrations that may be much greater than the 10,000 mg/L limit for Class III ground waters, and interconnection is considered to be low, even though hydraulic gradients are in the direction of less saline water.

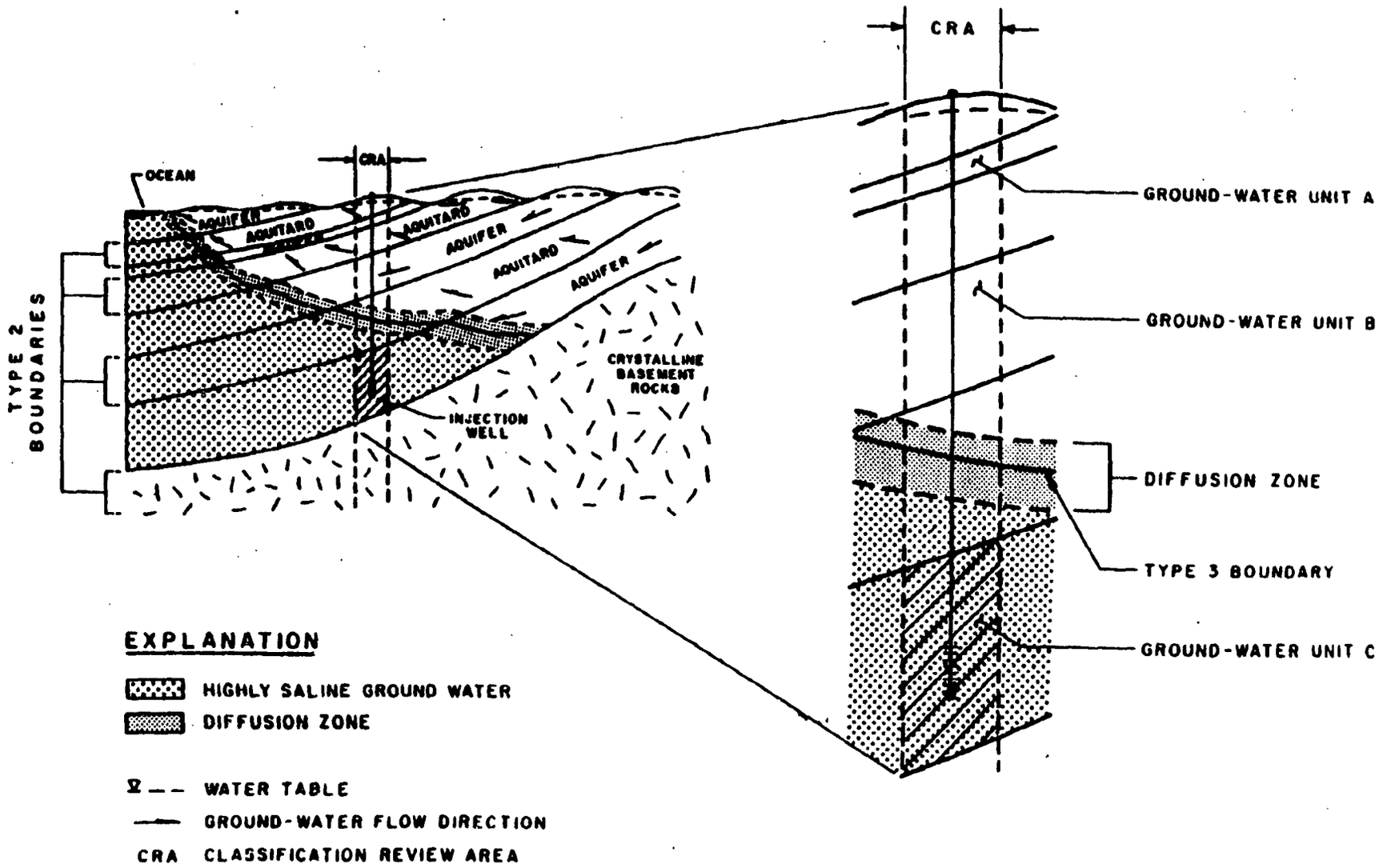
The deep saline water unit can be considered to be naturally isolated from overlying fresh ground-water units. The reasons for the low degree of interconnection are as follows:

- The flow of water through the confining units is exceedingly small.
- Travel time through the confining unit is very great.
- There are no significant breaches of confinement due to improperly cased or sealed wells.

Deep, confined, saline ground-water units with a low degree of interconnection to overlying fresh ground-water units are currently the primary hydrogeologic setting into which wells can be permitted to inject hazardous wastes under present EPA and State Underground Injection Control (UIC) regulations. These waters are encompassed within Class III, Subclass B ground water.

FIGURE 6-6

EXAMPLE OF PROBABLE CLASS IIIB GROUND WATERS



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APPENDICES

Three groups of supplemental informational materials are appended for the classifier's use. The technical basis for the initial 2-mile radius of the Classification Review Area is discussed in Appendix A. Detailed procedures for expanding or subdividing the Classification Review Area are also provided. Supplemental materials for the non-economic aspects of Class I and Class III determinations are provided in Appendix B and Appendix C, respectively. Supplemental guidance for applying the common aspects of the Class I and Class III economic tests is provided in Appendix D.

APPENDICES

GLOSSARY *

AQUIFER - A geologic formation, group of geologic formations, or part of a geologic formation that yields significant quantities of water to wells and springs.

AQUIFER SYSTEM - A heterogeneous body of intercalated permeable and less permeable material that acts as a water-yielding hydraulic unit of regional extent.

AQUITARD - A confining bed that retards, but does not prevent the flow of water to or from an adjacent aquifer; it does not readily yield water to wells or springs.

CONE OF DEPRESSION - A depression in the POTENTIOMETRIC SURFACE of a body of ground water that has the shape of an inverted cone and develops around a pumped well.

CONFINED CONDITIONS - Exists when an aquifer is confined between two layers of much less pervious material. The pressure condition of such a system is such that the water level in a well penetrating the confined aquifer usually rises above the top of the aquifer.

CONTAMINANT PLUME - Irregular volume occupied by a body of dissolved or suspended pollutants in ground water.

CRA - Abbreviation of Classification Review Area.

DISCHARGE AREA - A discharge area is an area of land beneath which there is a net annual transfer of water from the saturated zone to a surface-water body, the land surface or the root zone. The net discharge is physically manifested by an increase of hydraulic heads with depth (i.e., upward ground-water flow to the water table). These zones may be associated with natural areas of discharge such as seeps, springs, caves, wetlands, streams, bays, or playas.

ECOLOGICAL SYSTEM (ECOSYSTEM) - An ecological community together with its physical environment.

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* For general information only -- not to be viewed as suggested or mandatory language for regulatory purposes.

ECOLOGY - The science of the relationships between organisms and their environment.

ECOSYSTEM - See ECOLOGICAL SYSTEM.

FLOW NET - A graphical presentation of ground-water flow lines and lines of equal pressure head.

GEOLOGIC FORMATION - A body of rock that can be distinguished on the basis of characteristic lithologic features such as chemical composition, structures, textures, or fossil content.

GROUND-WATER - Subsurface water within the zone of saturation.

GROUND-WATER BASIN - (a) A subsurface structure having the character of a basin with respect to the collection, retention, and outflow of water. (b) An aquifer, or system of aquifers, whether or not basin-shaped, that has reasonably well-defined hydrologic boundaries and, more or less, definite areas of recharge and discharge.

GROUND-WATER FLOW DIVIDE - An imaginary plane (or curved surface) distinguished by the limiting flow lines of adjacent flow systems. Conceptually there is no flow across this plane between the flow systems.

GROUND-WATER FLOW REGIME - The sum total of all ground water (water within the saturated zone) and surrounding geologic media (e.g., sediment and rocks). The top of the ground-water regime is the water table while the bottom would be the base of significant ground-water circulation. Temporarily perched waters within the vadose zone would generally not qualify as part of the ground-water regime.

GROUND-WATER FLOW SYSTEM (GROUND-WATER SYSTEM) - A body of circulating ground water having a water-table upper boundary and ground-water flow divide boundaries along all other sides. These boundaries encompass distinct recharge and discharge areas unique to the flow system.

GROUND-WATER SYSTEM - See GROUND-WATER FLOW SYSTEM.

HYDRAULIC CONDUCTIVITY - The capacity of earth materials to transmit water.

HYDRAULIC GRADIENT - The change in STATIC HEAD per-unit-of-distance in a given direction.

HYDRAULIC HEAD GRADIENT - See HYDRAULIC GRADIENT.

PIEZOMETRIC SURFACE - See POTENTIOMETRIC SURFACE.

POTABLE WATER - Water that is safe and palatable for human use; concentrations of pathogenic organisms and dissolved toxic constituents have been reduced to safe levels, and it has been treated so as to be tolerably low in objectionable taste, odor, color, or turbidity.

POTENTIOMETRIC SURFACE (PIEZOMETRIC SURFACE) - An imaginary surface representing the STATIC HEAD of ground water and defined by the level to which water will rise in a well. The WATER TABLE is a particular potentiometric surface.

RECHARGE AREA - A recharge area is an area of land beneath which there is a net annual transfer of water through the vadose zone into the ground-water regime. The net recharge is manifested by a decrease in hydraulic heads with depth (i.e., downward ground-water flow from the water table).

SATURATED ZONE - A subsurface zone in which all the voids are filled with water under pressure greater than that of the atmosphere. This zone is separated from the overlying zone of aeration (unsaturated zone) by the WATER TABLE.

STATIC HEAD (HYDRAULIC HEAD) - The height above a datum plane of the surface of a column of water (or liquid) that can be supported by the static pressure at a given point.

STRESS (PUMPING STRESS) - Drawdown of water level and change in HYDRAULIC GRADIENT induced by pumping ground water.

SURFACE-WATER DIVIDE - The line of separation, or ridge, summit, or narrow tract of high ground, marking the boundary between two adjacent drainage basins, or dividing the surface waters that flow naturally in one direction from those that flow in the opposite direction.

TOTAL DISSOLVED SOLIDS (TDS) - The quantity of dissolved material in a sample of water determined either from the residue on evaporation by drying at 180°C, or, for waters containing more than 1,000 parts per million, from the sum of determined constituents.

UNCONFINED CONDITIONS - Exists when the upper limit of the aquifer is defined by the water table itself. At the water table, water in the aquifer pores is at atomospheric pressure.

UNSATURATED ZONE - See VADOSE ZONE.

VADOSE ZONE (ZONE OF AERATION) - A subsurface zone containing water under pressure less than that of the atmosphere, including water held by capillarity, and containing air or gases generally under atmospheric pressure.

WATER TABLE - The surface of a body of unconfined ground water at which the pressure is equal to that of the atmosphere.

WATER-TABLE GRADIENT - The change in elevation of the water table per unit of horizontal distance.

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SUPPLEMENTAL INFORMATION: CLASSIFICATION REVIEW AREA

APPENDIX A

SUPPLEMENTAL INFORMATION: CLASSIFICATION REVIEW AREA

A.1 Technical Basis for Initial 2-Mile Radius of the Classification Review Area

The EPA classification system utilizes the concept of a Classification Review Area around a specific facility or activity. EPA has determined that in general a Classification Review Area 2-miles in radius is a good starting point for this analysis. A larger radius may be appropriate in certain hydrogeologic conditions or in accordance with specific program practice.

The EPA examined three sources of data as the basis for identifying 2-miles as a generally appropriate Classification Review Area radius. The data provided insight into the length of the flow path over which high degrees of interconnection occur. In addition, the data indicate distances contaminants could be expected to move in problem concentrations should they be accidentally introduced into the ground-water system. The three sources of information examined were as follows:

- A survey of existing contaminant plumes documented through investigations of spills, leaks, and discharges.
- A survey of the distances to downgradient surface waters from hazardous-waste facilities.
- Calculations of the distances from which pumping wells draw ground water under different hydrogeologic settings.

These sources are described below.

A.1.1 Plume Survey

A survey of contaminant plume geometries (i.e., length, width and depth) was prepared in connection with the development of a stochastic model of corrective action costs at hazardous-waste management facilities (Geraghty & Miller, Inc., 1984). The plume survey was updated by Geraghty & Miller, Inc., in 1987. The plume survey provides generalized information on the distances contaminants have been known to migrate regardless of time, source type, or hydrogeologic setting. This information indicated the area that may be affected if contaminants were accidentally released from the site.

The data base for the survey included ground-water quality investigations, consultant reports, and other publicly available literature (e.g., scientific journals). The availability of data was limited by the confidential nature of many privately funded contamination investigations and the relatively small number of off-site investigations conducted by the government prior to the implementation of the Superfund program.

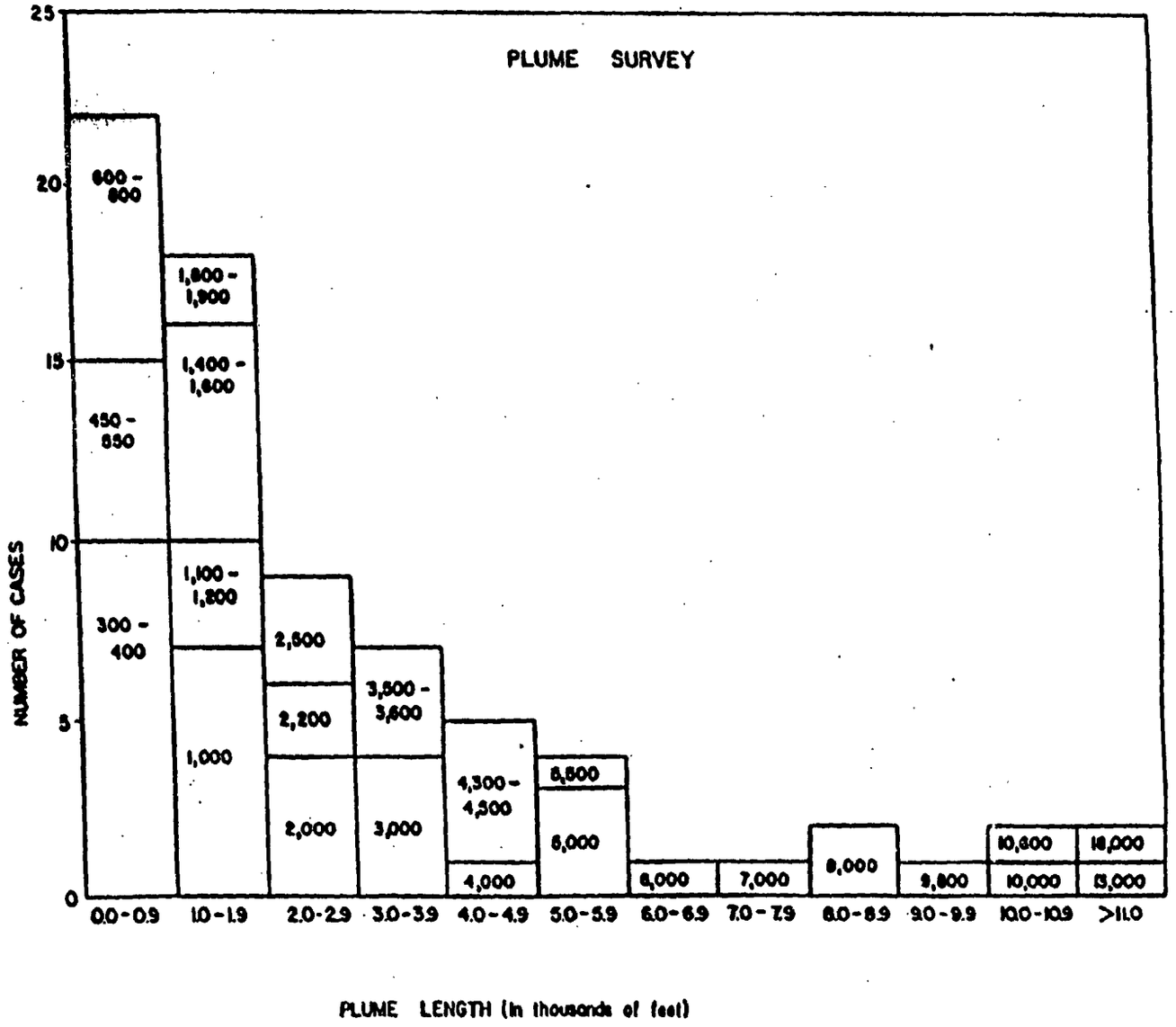
The survey found 74 contaminant plumes containing inorganic and organic contaminants. Hydrocarbon plumes consisted of dissolved and liquid phase (undissolved) materials. The sources of the plumes were spills, leaks, and discharges from diverse sources including municipal and industrial sites, transportation accidents, and unknown sources. Plume boundaries were generally defined as a detectable increase above background quality.

The survey showed that the median plume length was 1700 feet. Ninety-five per cent of the plumes were less than miles in length. A histogram of plume lengths is provided in Figure A-1.

The data were too limited to determine whether the plumes in this survey had reached their maximum lengths. Theoretically, if a contamination source is continuous and the contaminant is not degraded, transformed, or immobilized in route, the plume length will eventually be equal to the distance to a downgradient discharge point. Other factors that could prevent plumes from reaching their natural discharge points include insufficient time since the contaminant release, and the implementation of an effective remedial program. In some cases a steady-state condition may be reached between contaminant input by the source and dilution due to recharge. Although it is not known whether the plumes in this survey had reached equilibrium, it is not likely that any one of the above factors had any unusual degree of influence on the results.

Figure A-1

Plume Length Distribution
(Geraghty & Miller, Inc., 1987)



A.1.2 Distance to Downgradient Surface-Waters Survey

ICF, Incorporated, conducted a survey of 117 hazardous-waste management facilities for development of the EPA Liner/Location Model (USEPA, 1985). For each site, the downgradient distance to surface waters (e.g., lakes, streams, ocean, bay, or marsh) was calculated providing insight into the distance at which a flow boundary for the shallow ground-water system is likely to be encountered, thus, limiting the area potentially impacted by a facility.

Some of the facilities in the survey were included in EPA's site visit facility survey. Other sites were selected from among available Part B Permits. A site was included in the survey only if it provided information sufficient to operate the liner/location model (e.g., comprehensive facility design parameters and hydrogeologic information). Facility sites were located on U.S.Geological Survey topographic maps using latitude and longitude data. Geraghty & Miller assisted ICF by identifying the general direction of ground-water flow from the site on the topographic map. The frequency distribution histogram for distance to downgradient surface waters is shown on Figure A-2. Ninety-five percent of these distances are less than 2 miles.

A.1.3 Pumping Well Capture Zones Survey

One of the criteria for establishing the typical radius of the Classification Review Area was to identify the zone of influence supplying water to the pumping well. In examining the relationship between a 2-mile radius and the identification of water-supply wells capturing water from under a site, a formula (Todd, 1976) was used to determine the generalized dimensions of well-capture zones under different hydrogeologic conditions. The formula, illustrated in Figure A-3, provides a calculation of the maximum downgradient extent of well capture (XL) and the lateral distance (YL) (perpendicular to nonpumping, ground-water flow gradients). Lateral and downgradient capture distances were calculated for a range of transmissivities and water-table gradients under pumping conditions of 0.5 to 3.0 millions of gallons per day (mgd). Incompatible well yields and transmissivities were not used. The governing equations and the results of the calculations are shown in Table A-1. The well yields were selected to represent the common range of pumping rates for water-supply wells. With the exceptions noted below, water-supply wells are generally smaller than 2 mgd. The largest lateral capture distance for a 2 mgd supply well for the transmissivities and gradients examined is

FIGURE A-2
DOWNGRADIENT DISTANCE TO SURFACE WATER
(SOURCE: EPA, 1985)

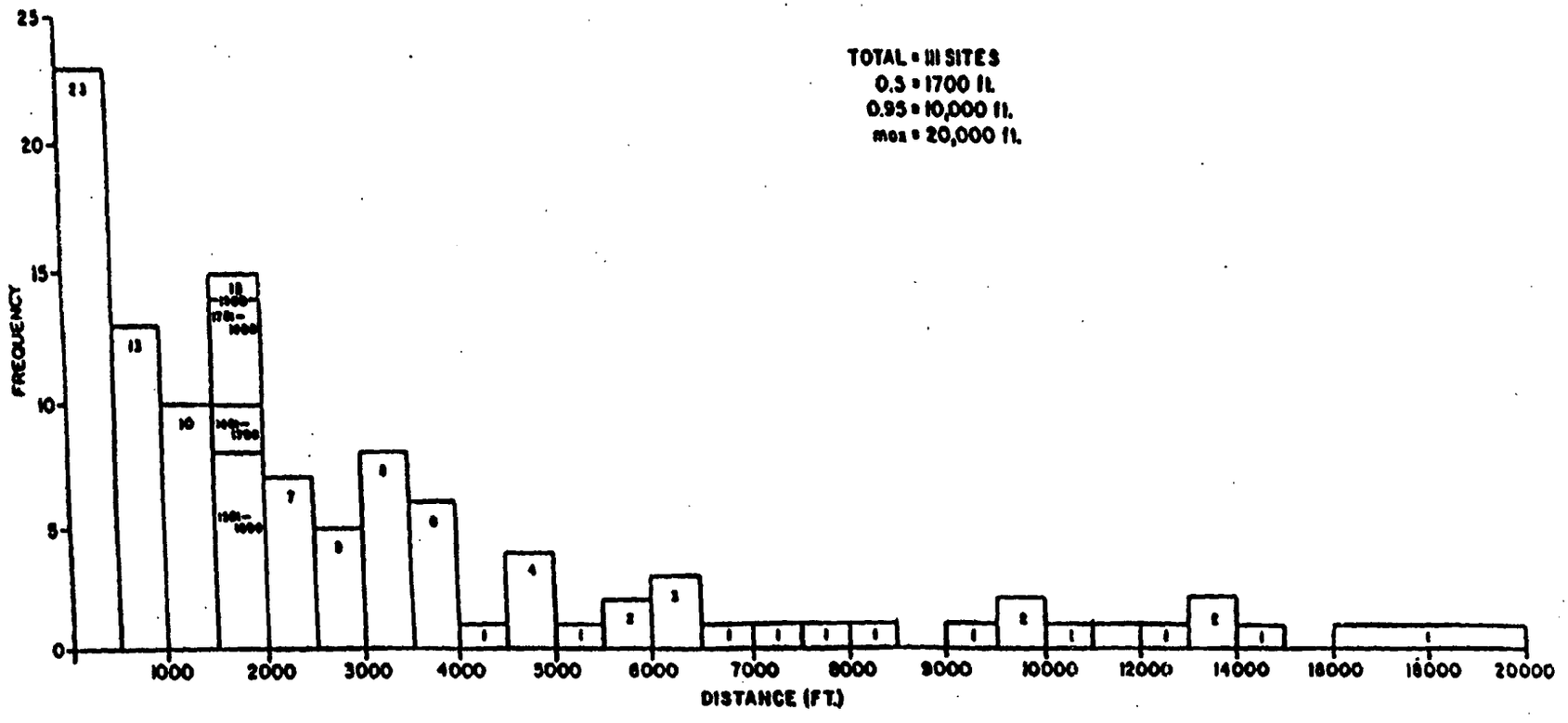


FIGURE A-3

WELL CAPTURE ZONE (Todd, 1976)

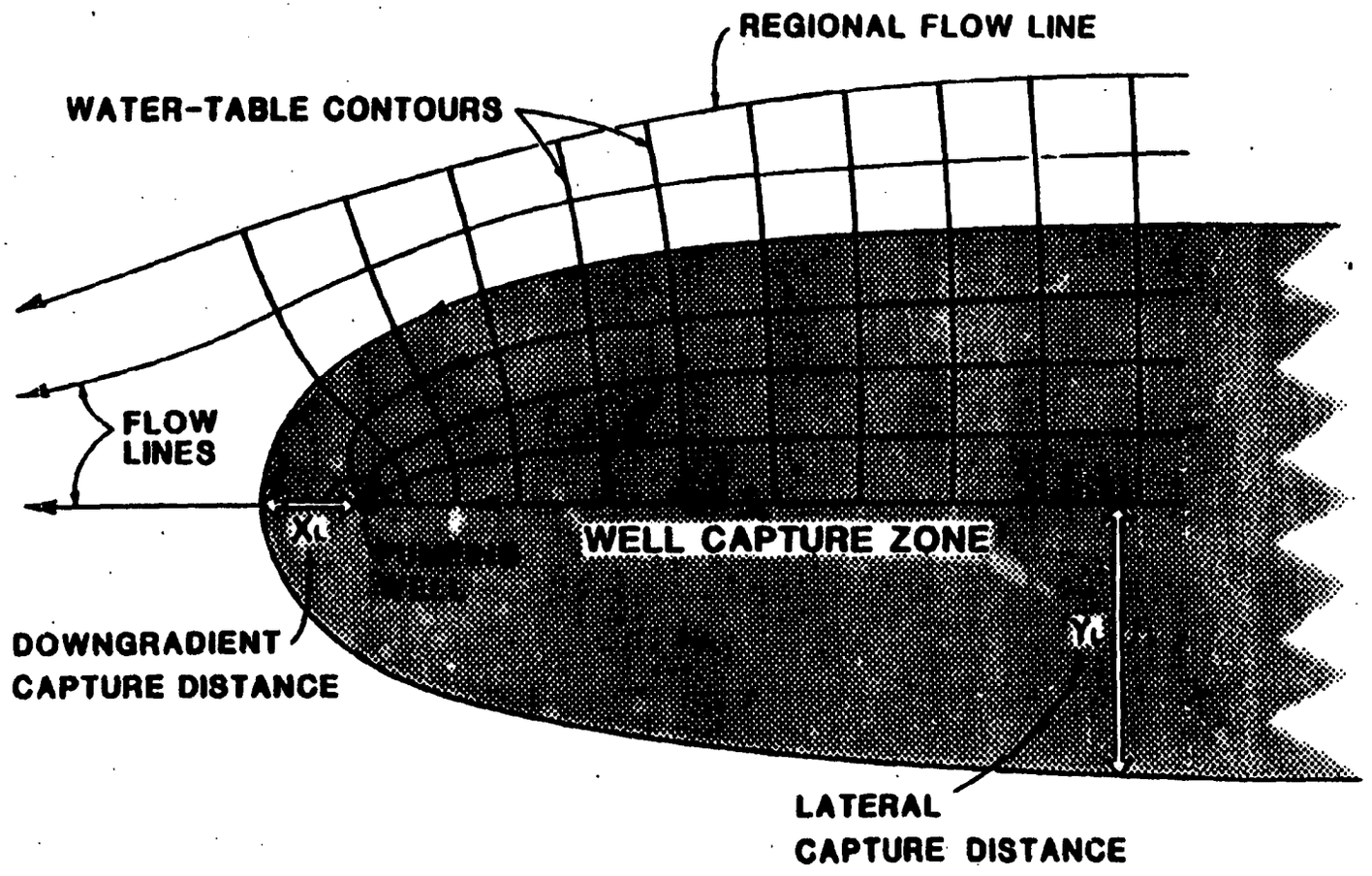


TABLE A-1.
LATERAL AND DOWNGRADIENT WELL CAPTURE DISTANCE (in feet)
(after Todd, 1976)

		Transmissivity/Gradient (ft/mi) 10,000/30-50	50,000/10-30	100,000/5-10
0.5 MGD	Lateral	4400-2640	2640-880	2640-1320
	Downgradient	1400-840	840-280	840-420
1.0 MGD	Lateral	N.A.	5280-1760	5280-2640
	Downgradient	N.A.	1680-560	1680-840
2.0 MGD	Lateral	N.A.	10,560-3520	10,560-5280
	Downgradient	N.A.	3360-1120	3360-1680
3.0 MGD	Lateral	N.A.	15,840-5280	15,840-7920
	Downgradient	N.A.	5040-1680	5040-2520

<u>Governing Equations</u>

Lateral Distance $Y_L = Q/2Ti$
Downgradient Distance $X_L = Q/2\pi Ti$

Y_L = ft
X_L = ft
Q = flow rate
T = transmissivity
i = Hydraulic Gradient

N.A. = Not applicable.

miles. Thus, the 2-mile radius would identify the majority of individual water-supply wells that could be drawing water from under a proposed facility or site in directions other than the downgradient direction.

> NOTE: Exceptions include the basalt aquifers of the Columbia Plateau and Hawaii, where common well sizes are up to 4 mgd and some may exceed 18 mgd; the Floridan aquifer in Florida and Georgia where common yields are up to 7 mgd and may exceed 8 mgd; and the Chicot aquifer of the Lake Charles Formation in Louisiana where common yields up to 3.5 mgd are found. Other regionally extensive high-yielding aquifers where wells may exceed 2 mgd include the Texas Edwards aquifer, thick members of the Atlantic and Gulf Coastal Plains, alluvium and older sedimentary basins in California and the Sparta Sands in Arkansas.

In summary, the plume survey and survey of distances to discharge boundaries support the 2-mile typical radius concept. The plume data indicate the distance that contaminants are known to migrate in problem concentrations, and the distance to discharge points data indicate the likelihood that a flow boundary will be intercepted. Pumping well capture distances provide the basis for including lateral and upgradient areas in the review area. Thus, 2-miles is a reasonable distance to use for initially identifying potentially highly interconnected ground waters related to a site under classification.

A.2 Determining Expanded Review Area Dimensions for Non-Darcian Settings

This appendix provides guidance for determining the dimensions of the expanded review area. In general, the dimensions of the expanded review area are governed by hydrogeologic conditions, particularly ground-water flow-system boundaries, flow directions, and flow velocities. The cases below illustrate various conditions and suggest methods for arriving at appropriate expanded review area dimensions.

For non-Darcian flow settings, the dimensions of the expanded review area can generally be based on the boundaries of the ground-water basin. A basin includes all areas extending from flow divides at the boundaries of recharge areas to the major perennial stream where discharge occurs. When the information base is too small to fully define these boundaries, the classifier can use the distance to the

LATERAL AND DOWNGRA
(af

		Transm: 10,000,
0.5 MGD	Lateral	4400-
	Downgradient	1400-
1.0 MGD	Lateral	N.A
	Downgradient	N.A
2.0 MGD	Lateral	N.A
	Downgradient	N.A
3.0 MGD	Lateral	N.A
	Downgradient	N.A

<u>Governing Equations</u>

Lateral Distance Y_L =
Downgradient Distance X_L =

Y_L = ft
X_L = ft
Q = flow rate
T = transmissivity
i = Hydraulic Gradient

N.A. = Not applicable.

nearest downgradient, perennial stream, where ground water from the activity area is likely to discharge, to establish the expanded review-area dimension.

Karst Settings

In karst hydrogeologic settings, the boundaries of a ground-water basin may vary considerably depending on water-level stage in the cave-stream complex. A hypothetical karst terrain, characterized by sinkholes, sparsity of surface streams and an integrated system of subsurface drainage conduits within a carbonate bedrock complex is shown on Figure A-4. Directly west of the activity, streams drain an upland area, flowing eastward to the sinkhole plain. On the plain, the streams intersect sinkholes, and surface water is diverted to the underground network of solution conduits within the karst bedrock. This zone where surface water is rerouted to the subsurface represents the termination of the eastwardly extent of the more resistant sandstone formation overlying limestone and dolomites. Without the resistant sandstone, surface water has reworked the carbonate bedrock into a network of vertical and horizontal solution cavities and conduits that drain the sinkhole plain eastward to the Little Blue River. A cross-section of this hypothetical terrain is shown on Figure A-5.

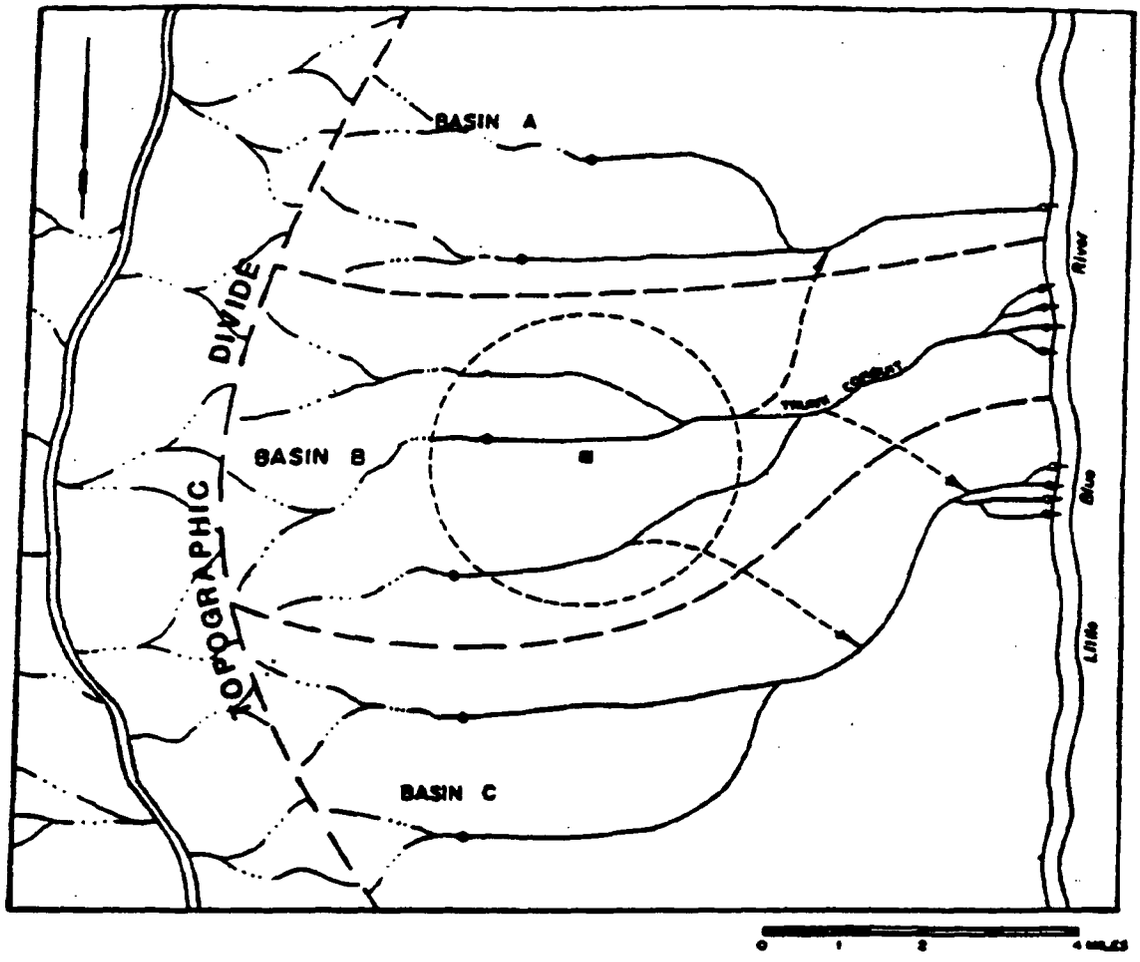
In a karst terrain, ground-water circulation occurs through a system of conduits having a variety of shapes and capacities. The ground-water flow system undergoes major changes depending upon the magnitude of a precipitation recharge event. For example, in the hypothetical example during periods of low flow (little or no precipitation), surface water recharges the carbonate aquifer at the sinkhole plain and travels through a series of solution cavities to the ground-water Basin B trunk conduit (Figure A-6 [A]). Under these conditions, each ground-water basin hydraulically operates as a separate entity. The general direction of flow in Basin B (although tortuous) is toward the Little Blue River.

As shown in Figure A-6 (B), recharge to the aquifer via sinkholes and swallets during peak rainfall events, causes ground-water levels within the Basin B trunk conduit to increase to the point where upper cavity transverse conduits are intersected and ground water migrates into the trunk conduits of Basins A and C. This process is termed ground-water piracy. During high-intensity recharge events, ground water from Basin B, which could potentially contain contaminants from the activity, will travel to all three ground-water basins.

Karst basins can be mapped using dye-tracing studies field mapping, spelunking, geochemical reconnaissance, and water-level maps. However, due to the expense of such

FIGURE A-4

HYPOTHETICAL KARST TERRAIN WITH 2-MILE REVIEW AREA



EXPLANATION

- ■ PROPOSED FACILITY
- CLASSIFICATION REVIEW AREA BOUNDARY
- SPRING/SEEP
- FLOW ROUTE
- HIGH-LEVEL OUTFLOW ROUTE
- GROUND-WATER BASIN BOUNDARY
- SWALLET OF SINKING STREAM

FIGURE A-5

GENERALIZED CROSS SECTION OF A KARST HYDROGEOLOGIC SETTING

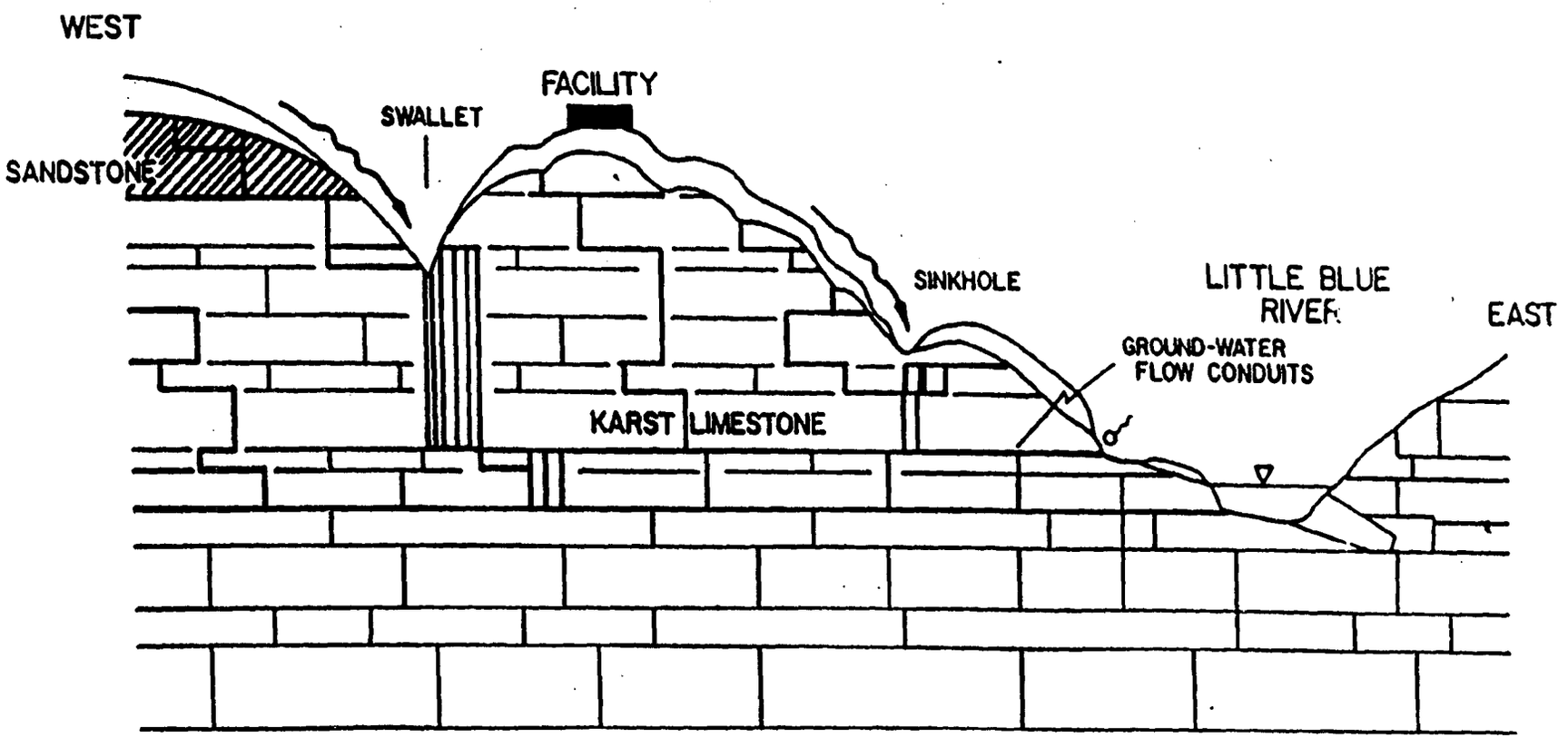
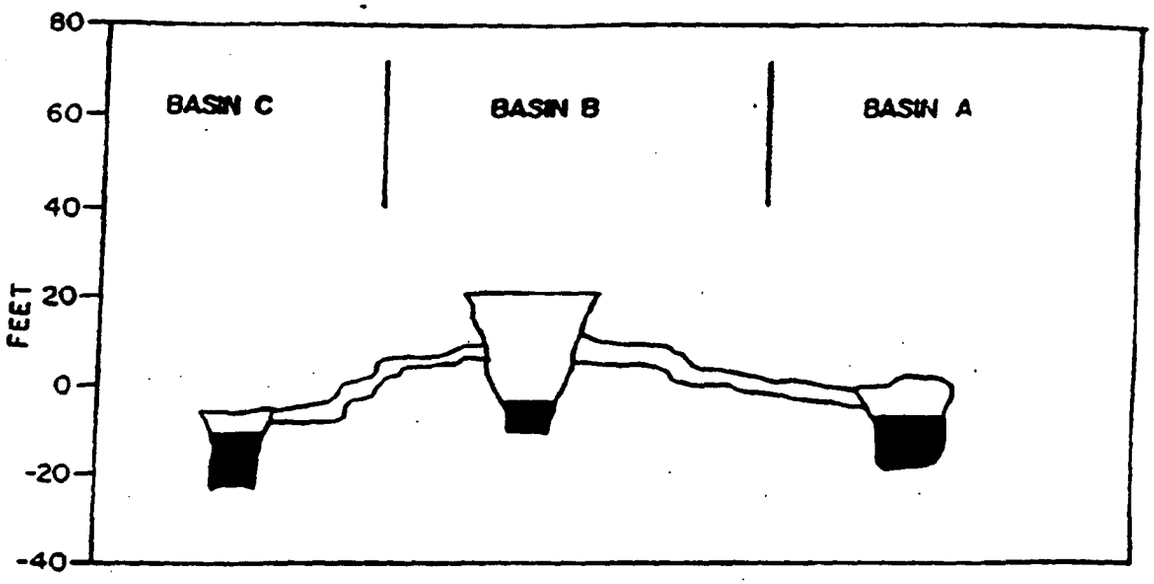
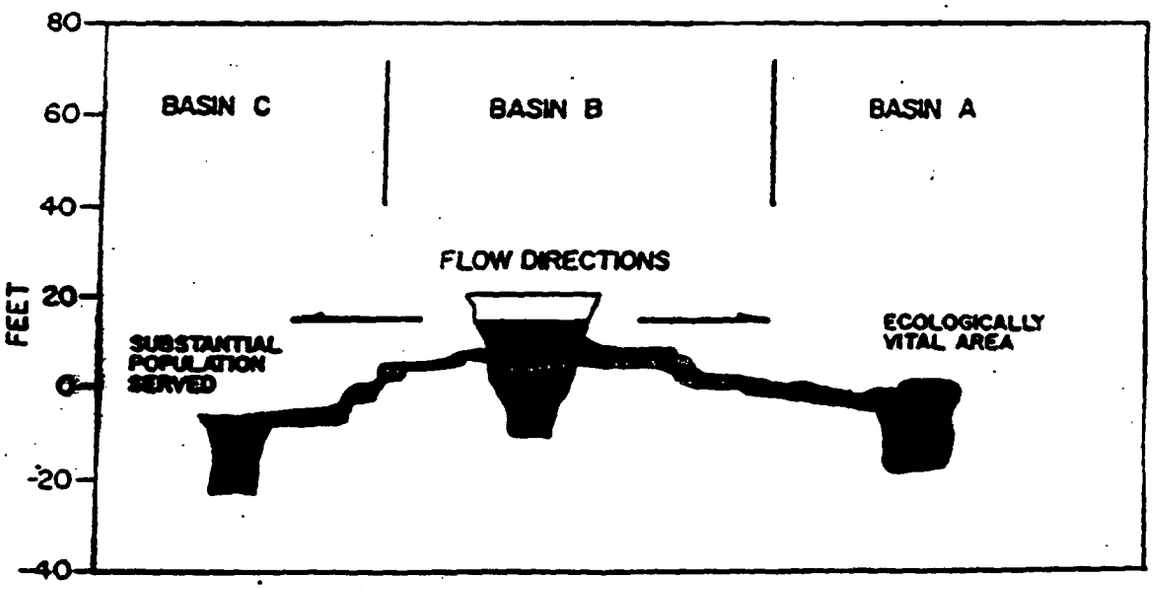


FIGURE A-6

EXAMPLE OF OVERFLOW ACROSS GROUND-WATER BASINS



BASE FLOW CONDITIONS
(A)



HIGH INTENSITY FLOW CONDITION
(B)

studies, few basins have been mapped. As a surrogate, it is recommended that the distance to the nearest downgradient, perennial stream be employed to establish the expanded review-area dimensions as illustrated in Figure A-7. Generally, the appropriate perennial stream segment will be spring fed (i.e., cave-stream discharge springs) and not subject to disappearance into cave-stream flow (i.e., sinking stream).

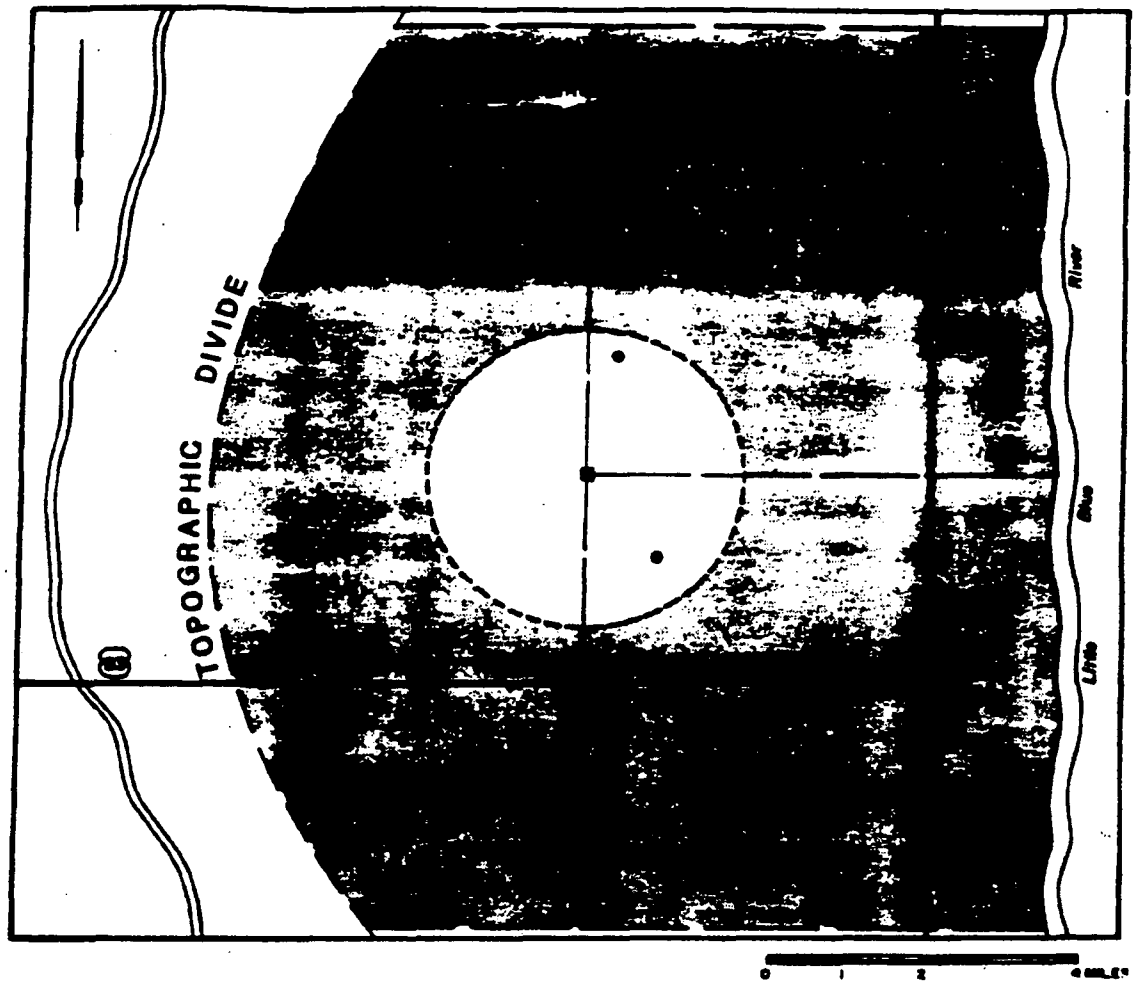
The classifier is cautioned that the nearest perennial stream may not be downgradient and, therefore, not the discharge point for the subject ground-water basin. Such an error can be minimized by locating the topographic high (the water-shed divide) between the nearest perennial stream and adjacent streams. The correct perennial stream to employ in this suggested methodology is generally on the same side of the topographic high as the activity. The ground-water basin of interest will generally be discharging to the perennial stream on the same side of the topographic high as the activity/facility. In rare cases, the activity or facility is located in the vicinity of the topographic high between perennial streams. In such a case, the expanded review area should extend to the nearest perennial stream on all sides of the topographic high, unless site-specific data concerning ground-water flow direction are available.

Other Settings

The expansion of review area dimensions for fractured rock and extrusive igneous (basaltic lava) settings can also be based on ground-water basin boundaries. In these types of settings, there is a strong potential for flow to be preferentially channeled through fracture zones at high velocities. Bedrock fractures are often expressed in surface features, such as streams and other surface depressions, and can often be identified through aerial photography and other forms of fracture trace analysis. The identification of these fracture zones can be very useful in predicting the direction and extent of non-Darcian, high-velocity flow. This information can then be employed to establish the expanded review-area dimensions. A hypothetical example is shown in Figure A-8. Similar to its use in the evaluation of karst settings, topography can be utilized to help identify the likely discharge points for ground water originating at the facility.

FIGURE A-7

HYPOTHETICAL KARST TERRAIN WITH EXPANDED REVIEW AREA

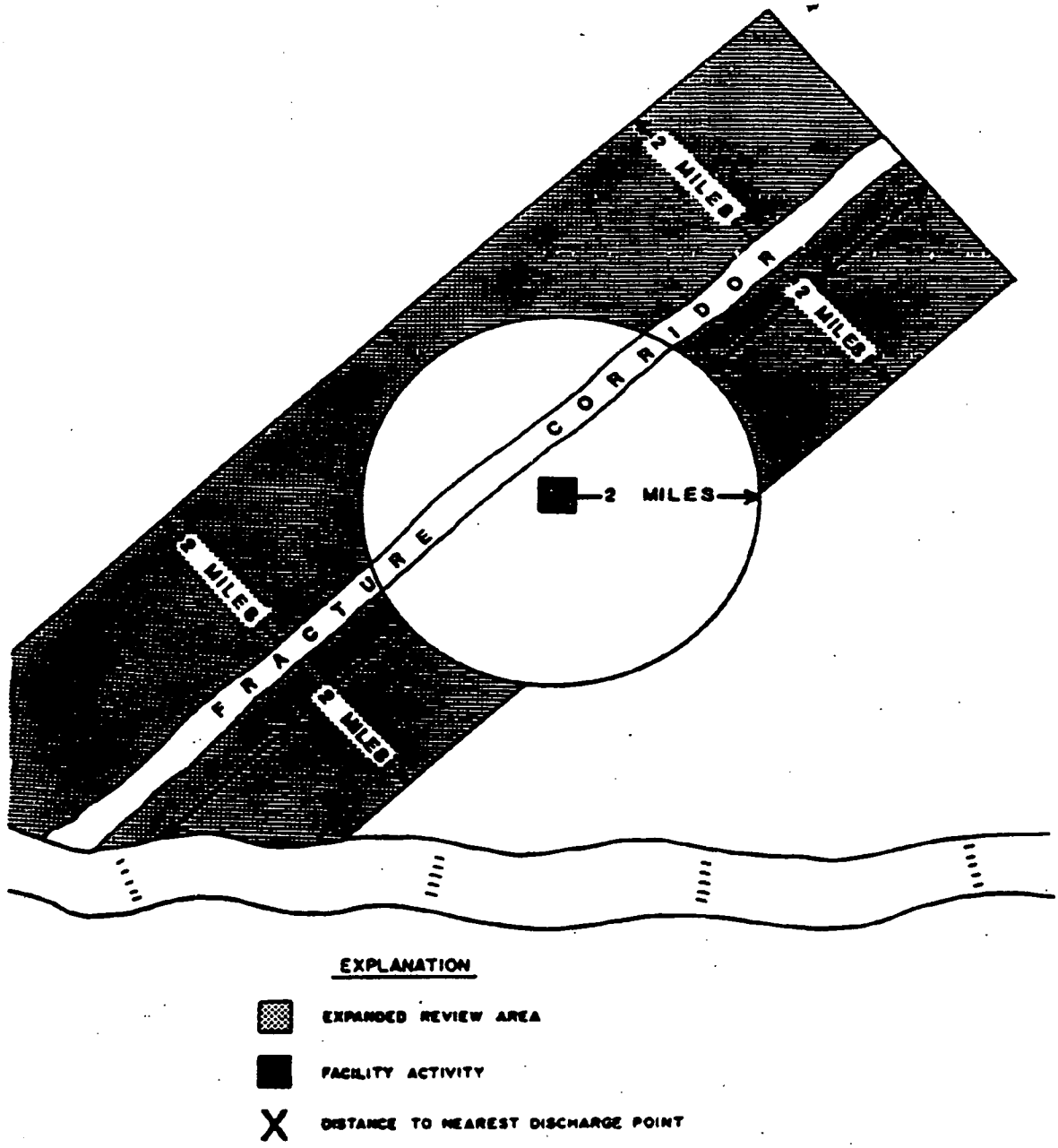


EXPLANATION

- PROPOSED FACILITY
- CLASSIFICATION REVIEW AREA BOUNDARY
- EXPANDED CLASSIFICATION REVIEW AREA
- SPRING HOUSE FOR DOMESTIC USE
- SPRING/SEEP
- ROADWAY

FIGURE A-8

HYPOTHETICAL EXAMPLE OF REVIEW-AREA EXPANSION IN A FRACTURED ROCK SETTING



A.3 Subdividing the Classification Review Area

A.3.1 Identifying Ground-Water Units and Analyzing Interconnection

Subdivision of the ground-water regime into ground-water units generally involves collecting and evaluating information related to geology, hydrology, and management of ground-water resources (controls on withdrawals/recharge, properly abandoning deep wells, etc.). The description of the ground-water regime and any potential subdivisions should be as quantitative as possible. The Agency recognizes that the degree of accuracy with which the Classification Review Area can be subdivided is limited by the abundance and quality of available data. Supplementing the existing data base with field and laboratory investigations both on-site and off-site may be needed to accurately confirm the existence of subdivisions. The following discussion will serve to guide the types of data needed to justify the subdivision of the Classification Review Area.

Background information on geologic formations and occurrence/movement of ground water can be obtained at a regional scale of accuracy from State and Federal agencies. Topographic maps published by the U.S. Geological Survey are now available at useful scales for most of the nation. These can help identify ground-water flow directions and flow divides for the uppermost aquifer. Data on the distribution and characteristics of soils are available from the U.S. Department of Agriculture Soil Conservation Service. General information on precipitation, run-off, and recharge rates can be obtained from the U.S. Geological Service and can be supplemented by climatic data from weather stations around the country. Ground-water pumpage and locations/depths of wells can generally be obtained from State agencies that issue well permits or from local public-health agencies and water districts.

The first step is to identify all aquifers occurring within the ground-water regime of the Classification Review Area. In areas that have been well-studied, these will be recognized and documented in government agency reports. In poorly studied areas, proper recognition of aquifers can be inferred from lithologic descriptions of geologic formations, structural features of the area (if flow is mainly through fractured rock), and the depth and design of wells. The areal and vertical extent of hydrogeologic units within the ground-water regime can be shown in a series of cross-sec-

tions and maps. For most hydrogeologic settings, it will be most useful to interpolate between locations where conditions are known (i.e., wells, outcrops, excavations, etc.) and present variations in thickness and elevations of important units with contour maps prepared at a common scale.

After the identification and graphical representation of the geologic framework, it is possible to identify ground-water units within the ground-water regime using the guidance provided in subsequent sections.

Type 1 Boundaries: Ground-Water Flow Divides

The concepts of ground-water flow systems may not be familiar to some readers and, therefore, may need to be reviewed so that the reader can understand the concept of flow-divide boundaries between ground-water units. Figure A-9 shows in vertical cross section a series of adjacent, shallow, ground-water flow systems for a single-layer, water-table aquifer. The systems are bounded at the base by a physical impermeable boundary. As is typical in humid regions, the water-table profile conforms to the topographic profile.

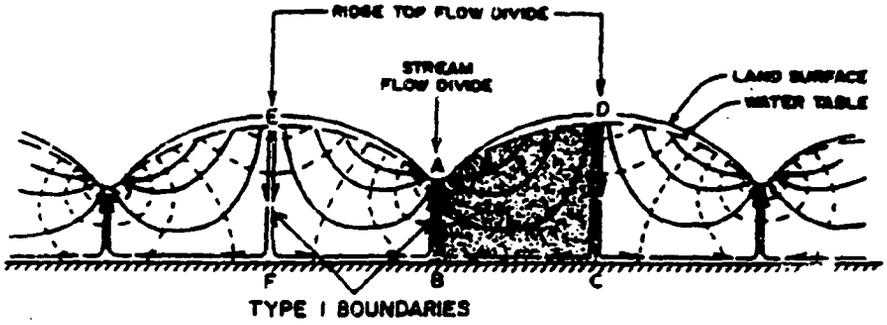
The flow net in Figure A-9 (a) shows that ground-water flow occurs from the recharge area in the highlands to the discharge areas in the lowlands (i.e., valleys). Vertical line segments AB and CD beneath the valleys and ridges constitute ground-water flow divides, i.e., imaginary impermeable boundaries across which there is no flow. In the figure, these ground-water flow divides separate adjacent flow systems ABCD and ABFE which, for purposes of subdivision, correspond to ground-water units separated by Type 1 boundaries.

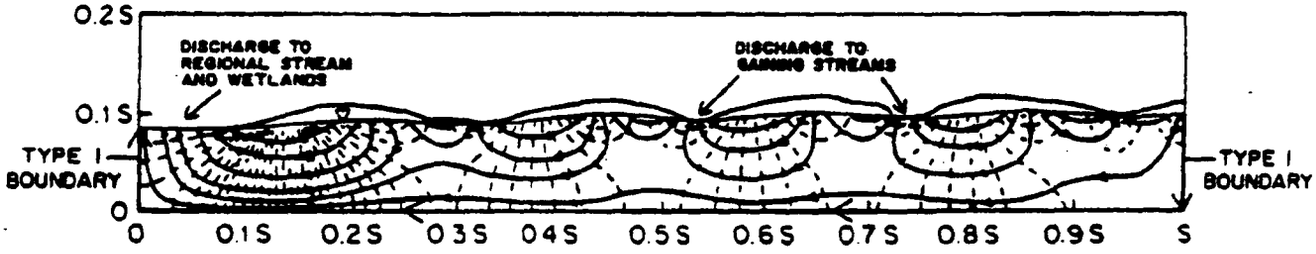
In simplified, symmetrical systems, such as those illustrated in Figure A-9 (a), ground-water flow divides coincide exactly with surface-water divides and extend vertically to the base of the aquifer. In more complex topographic and hydrogeologic settings, these properties may diverge substantially from the situation illustrated.

A comparison of Figures A-9 (a) and (b) reveals how flow patterns and divides are altered when the undulations in the water table are superimposed on the regional hydraulic gradient towards a more regional stream and discharge area. Ground-water flow divides in Figure A-9 (b) extend through the full thickness of the aquifer only at either end of the entire flow regime. The full dimension of the flow regime may or may not be encompassed by the 2-mile radius. The total length, S, in the figures, can range from hundreds to thousands of feet.

FIGURE A-9

HYDROGEOLOGIC SECTIONS SHOWING FLOW SYSTEMS OF INCREASING COMPLEXITY WITH TYPE 1 BOUNDARIES





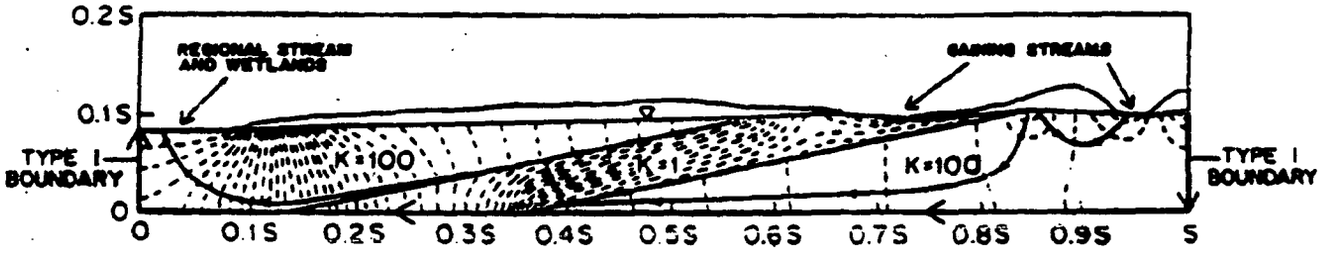


Figure A-9 (c) is an example of more complex conditions in which the flow patterns and flow systems are affected by both topography and regional variations in hydraulic conductivity of layered earth materials. Given adequate data, computerized models of real sites can provide approximations of ground-water flow patterns. In general, the level of sophistication employed to demonstrate the presence of a Type 1 boundary should be commensurate with the complexity of the hydrogeologic setting.

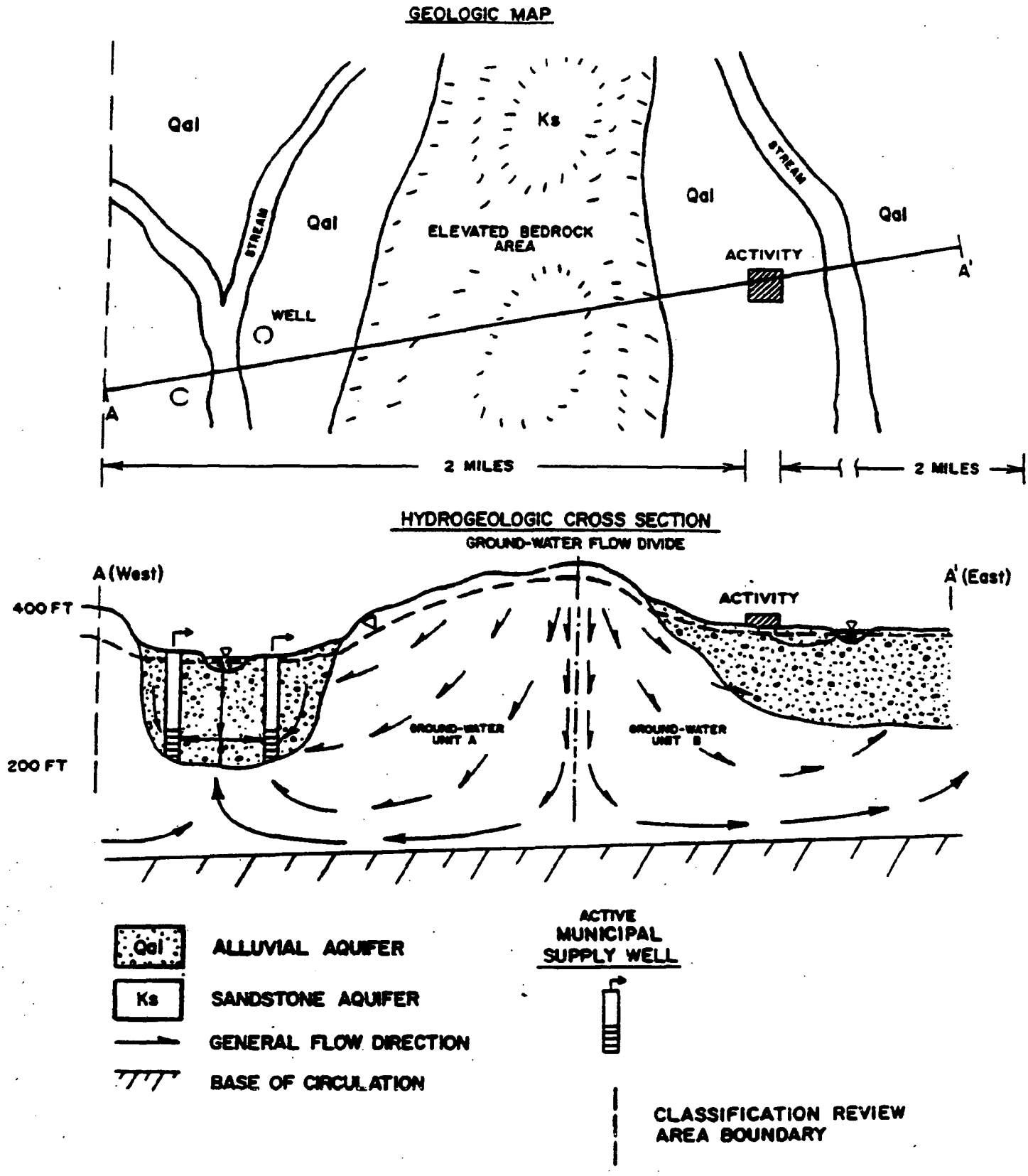
The spatial location of the water-table and ground-water flow divides may be stable under natural flow conditions but can be modified by man-made hydraulic stresses, such as large-scale ground-water withdrawals or recharge. In some cases it will be necessary to estimate the permanence (i.e., location with time) and position of ground-water flow divides under stressed conditions from available hydrologic and geologic data and foreseeable changes in water use.

A good example of ground-water units separated by a Type 1 flow divide boundary is shown in Figure A-10, The setting illustrated consists of two alluvial valleys with high-yield wells completed in sand and gravel deposits, separated by sandstone bedrock that can only provide limited supplies to domestic wells. Ground water in the alluvium is derived from precipitation and from the bedrock and discharges to the river under natural conditions. Under pumping conditions, the water pumped by the high-yield wells is derived largely from the river, from local precipitation, and from the bedrock. Near the wells in the western valley, flow-system boundaries are affected by ground-water withdrawals and are stable as long as the well discharges are steady. The ground-water flow divide separating the two valley aquifers is not affected by pumpage, and provides the essential characteristic that allows the delineation of ground-water units A and B.

Flow Analysis. In order to provide a defensible ground-water flow-divide delineation, a limited flow analysis is generally necessary. An acceptable approach is to prepare a water budget for the ground-water unit in order to show a reasonable order-of-magnitude balance on flow into and out of the system. This water budget could involve the preparation of a ground-water flow net (see Glossary for definition) for the uppermost aquifer with accompanying estimates of volumetric flow into and out of the unit. The flow net can be generalized and need not be rigorously corract in a quantitative sense. The analysis should be carried out even though part of the ground-water system continues outside the Classification Review Area, that is, if part or all of the discharge or recharge area of the unit extends beyond the Classification Review Area.

FIGURE A-10

EXAMPLE OF TYPE 1 FLOW DIVIDE BOUNDARY



The semiquantitative flow net of the uppermost aquifer should be supplemented by a vertical hydrogeologic cross section and supporting data showing that the uppermost aquifer is, in fact, underlain by an extensive aquitard or crystalline rock non-aquifer within the Classification Review Area. The flow net can be based on available water-table elevation data, as interpreted from water levels in relatively shallow wells, as well as on locations/elevations of springs, wetlands, and perennial streams, and supplemented with topographic elevations. The rates and directions of flow can be estimated in plan view given a water-table contour map and estimates of aquifer thickness and hydraulic conductivity. The conductivity can be obtained from the area-specific reports, field or laboratory tests, or by estimating a range from the scientific literature based on earth material type. Flow patterns inferred from these data must also consider significant spatial and directional variations in conductivity in areas having more complex stratigraphic and structural geologic conditions.

At the beginning of the flow analysis, it is important to determine whether the ground-water flow system is in a state of steady or transient flow. Areas that are characterized by a lack of ground-water development and usage can generally be assumed to be in steady state. This will simplify the analysis because the estimate of system discharge can be equated to recharge. If the natural recharge rate compares favorably with a reasonable percentage of mean annual precipitation, the ground-water flow divides can be considered reliable. The applicant can go to the ground-water literature to obtain reasonable estimates to recharge in any geographic/ground-water region of the United States (e.g., see USGS Water-Supply Paper 4 by R.C. Heath, 1984).

In areas characterized by large-scale withdrawals of ground water from shallow or deep aquifers, the flow regime is more prone to be in a transient state. Evidence of transient conditions are as follows:

- Declining ground-water levels.
- Depletion of ground-water storage.
- Movement of flow divides.

When such evidence of transient conditions exists, it may be necessary to estimate the ultimate steady-state position of the flow divides assuming conservatively large withdrawal rates and small water-flow and storage properties.

<u>Type 2 Boundaries: Low-Permeability Geologic Units</u>

The Agency would generally assign a low degree of interconnection across the low-permeability geologic unit (Type boundary) if the following conditions can be shown:

- The low-permeability geologic unit is laterally continuous beneath the entire area and/or limits the lateral continuity of the more permeable geologic unit.

- There are no known wells, mine shafts, etc. that are improperly abandoned or unsealed through the geologic unit.

- The geologic unit has a small permeability relative to both adjacent geologic units and to geologic media in general.

- The flow of water through the geologic unit per unit area is insignificant relative to the flow of water per unit area through adjacent strata.

Low-permeability geologic units include fine-grained sediments and sedimentary rocks, such as clays and shales, as well as crystalline igneous and metamorphic rocks that have few interconnecting fractures. Because these materials have small permeabilities, small quantities of water will be transmitted through them in response to hydraulic gradients. Such favorable head relationships further ensure that the direction of ground-water movement at the boundary serves to inhibit the migration of contaminants into and across this type of boundary into the adjacent ground-water unit.

In selected environments, such as deep geologic basins, it may be possible to show that the flow of fluids is negligibly small through the low-permeability unit. The actual cut-off values of key variables such as permeability, thickness, and hydraulic gradient are not specified in these Guidelines and are left to professional judgments.

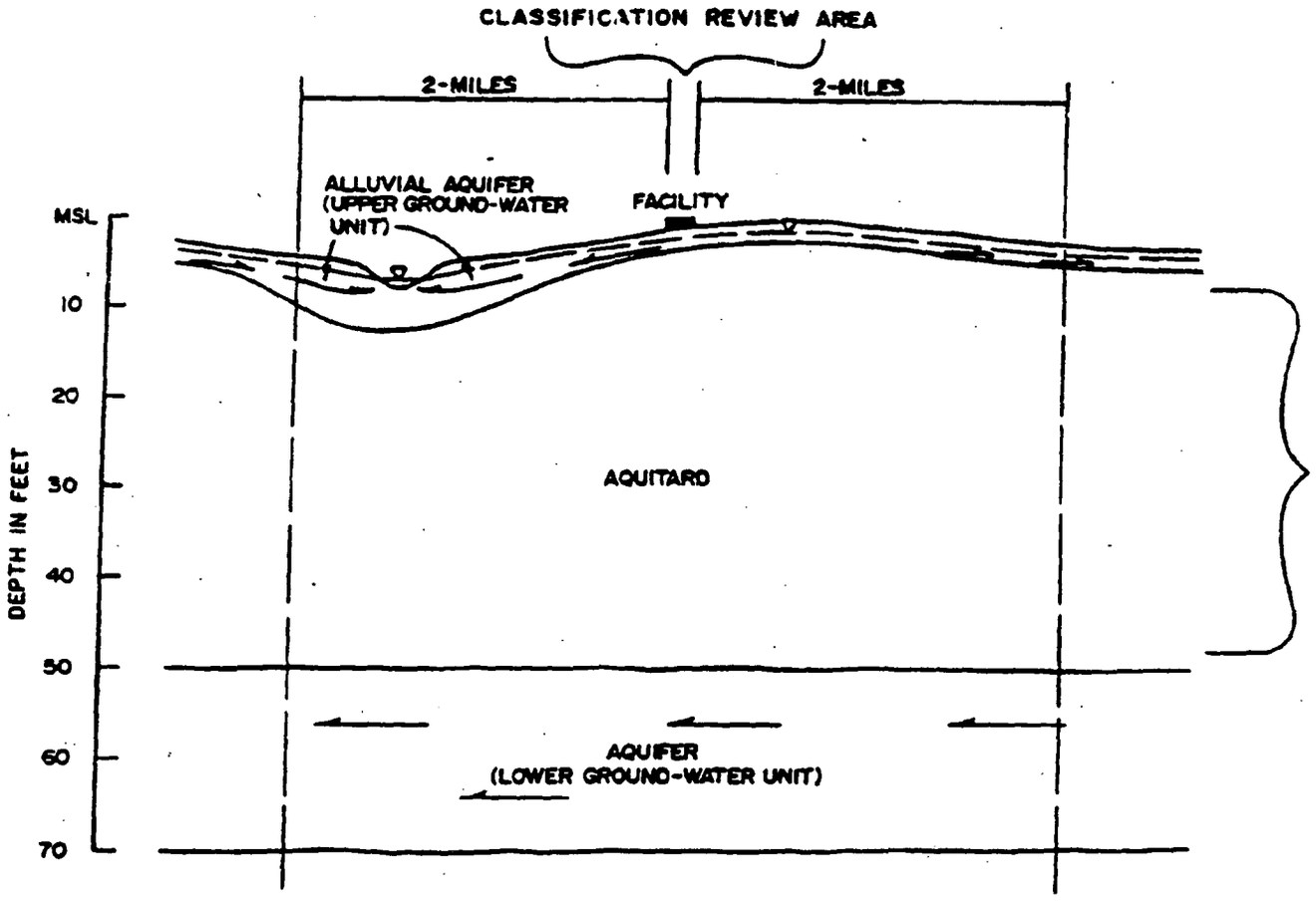
A setting where the presence of a thick, regionally extensive aquitard establishes a low degree of interconnection between a shallow ground-water unit and a deeper underlying ground-water unit (aquifer) is shown in Figure A-11. This configuration is common in the Atlantic and Gulf coastal plain settings where the lower aquifer is the principal regional aquifer and is a source of water supply. It is overlain by an extensive confining clay that may be tens of feet thick. The shallow ground-water aquifer system supplies only limited amounts of water to wells. The reasons for the low interconnection between aquifers in this setting are as follows:

- The flow of water through the aquitard is exceedingly small.

- Water travel time through the aquitard is very great.

FIGURE A-11

EXAMPLE OF TYPE 2 BOUNDARY



In general, the demonstration of the existence of a Type boundary requires that the laterally-continuous, low-permeability non-aquifer that constitutes the boundary be identified and characterized. The following factors should be considered in making this demonstration:

- Stratigraphic setting and lithologic characteristics.
- Structural setting and joint/fracture/fault characteristics.
- Hydrogeologic setting and hydraulic head/fluid flow characteristics.

The first distinction should be between whether the non-aquifer is of sedimentary or igneous/metamorphic origin. If it is sedimentary in origin, an identification of the environment of deposition will permit inferences about the expected geometry, thickness, and continuity of individual strata. These inferences should be defended with geologic sections including data from well logs and/or measured sections. The age of the unit, the degree of cementation, and degree of compaction are all qualitatively related to water-bearing characteristics (hydraulic conductivity and porosity).

If the unit is an igneous or metamorphic rock, the continuity and thickness can usually be inferred from geologic maps and reports for the region in which the Classification Review Area exists. Identification of igneous rocks that have tabular geometries such as volcanic flows, ash-fall deposits, or intrusive sills and dikes will allow inferences about thickness and continuity. These may serve as aquifers or aquitards within a sequence of sedimentary rocks. Crystalline basement rocks of igneous and metamorphic origin underlie the entire North American continent. In areas where these rocks are fractured and exposed at or near the land surface, they generally serve as poor-yielding aquifers. However, significant circulation can be assumed to be restricted to the upper few hundred feet because the fractures tend to close with depth. In other areas, where these rocks are buried by younger rocks, they can generally be assumed to represent the base of active circulation unless there is evidence to the contrary. In these situations the Type 2 boundary is equivalent to the bottom of the ground-water regime (see Glossary).

A general knowledge of the tectonic setting and structural geologic history of the region will provide insight into the types and frequency of geologic structures to be found in the Classification Review Area. Numerous field studies have shown that significant ground-water flow in

consolidated sedimentary and crystalline rocks is controlled by geologic structures. These features include folds, faults, and associated joints and fractures in the rock.

Major structures such as fault zones that intersect consolidated rock formations may hydraulically connect multiple aquifers into a system of aquifers. Fault zones in consolidated rocks are known to collect water from large areas and control the locations of ground-water discharge at major springs. In unconsolidated sediments and in some structural settings, fault zones can have the opposite effect by producing barriers to flow. Individual joints and small fractures in consolidated rocks and sediment can be mapped systematically with field studies; however, proof of their absence is the more important element in demonstrating the presence of a Type boundary.

The best evidence of low-permeability, non-aquifer conditions constituting a Type boundary are those related to the hydrogeologic setting and measured hydraulic parameters. The hydraulic conductivity of both sedimentary deposits and igneous/metamorphic rocks can be estimated within several orders-of-magnitude on the basis of lithology alone as shown in Table A-2. In parts of the United States associated with large ground-water usage, there has been a need to understand the ground-water regime, and these areas often will have been studied by various government agencies. Consequently, the hydraulic properties of aquifers and aquitards will be known in quantitative terms. In these areas the thickness, lateral extent, and hydraulic conductivity will be documented. A favorable condition would then be associated with a recognized aquitard or aquiclude that is known to be relatively thick, homogeneous, widespread, and poorly permeable. The optimum head condition would be such that vertical hydraulic gradients are directed upward through the unit, i.e., across the Type boundary.

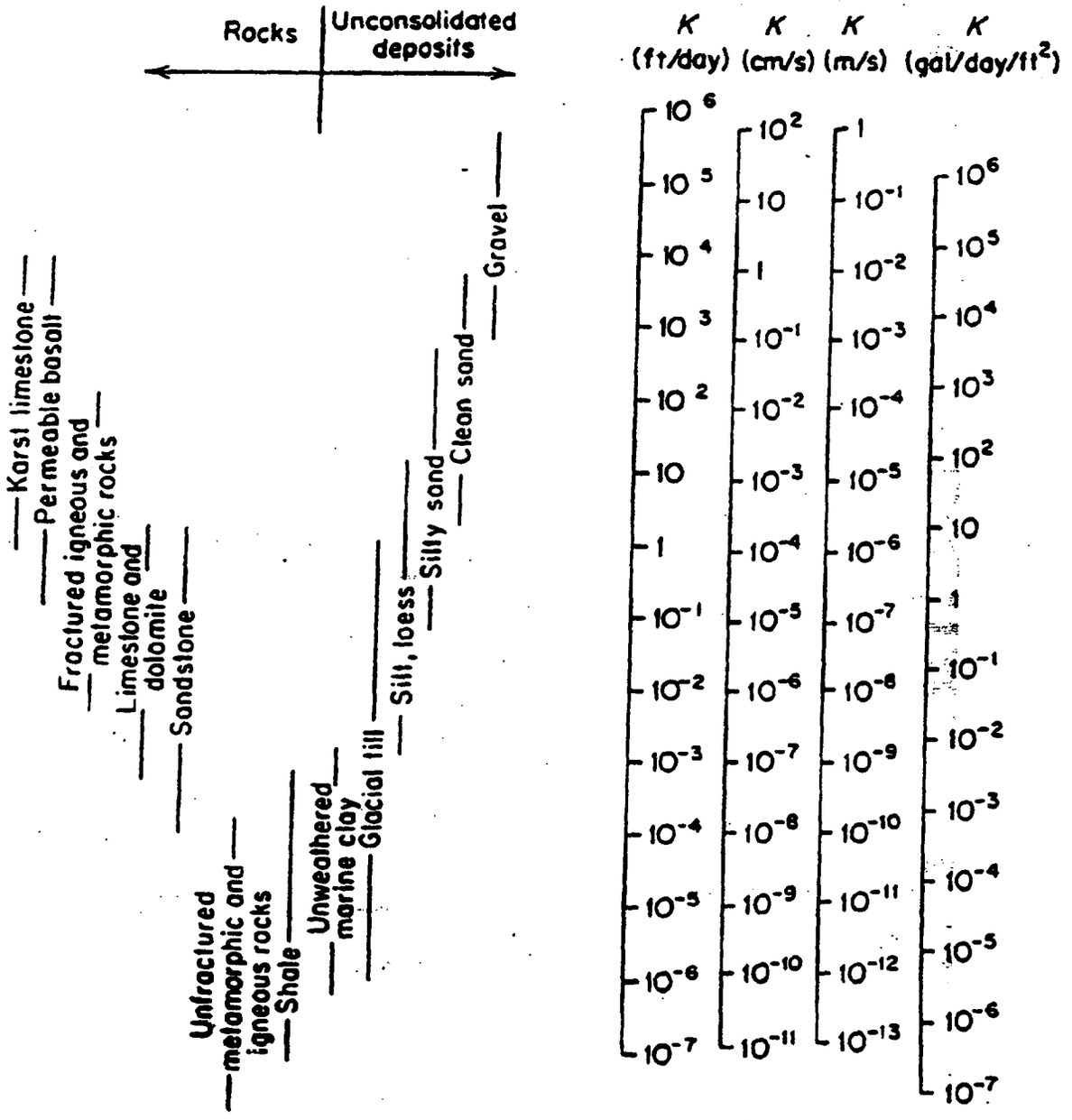
Type 3 Boundaries: Freshwater/Saline Water Contacts

Type 3 boundaries between bodies of ground water with contrasting TDS concentrations most commonly occur within the following types of hydrogeologic settings:

- Sea-water intrusion into fresh-water aquifers in coastal regions.
- Saline waters associated with ancient evaporite deposits in sedimentary basins.
- Saline waters associated with closed topographic basins in arid regions.

TABLE A-2

RANGE OF VALUES OF HYDRAULIC CONDUCTIVITY AND PERMEABILITY
(AFTER FREEZE AND CHERRY, 1979)



- Saline brines in deep geologic basins.
- Geothermal fluids in tectonically active regions.

In the above settings, the TDS of naturally occurring saline water may be 3 to 10 times greater than the 10,000 mg/L criterion. Owing to natural concentration gradients, a zone of diffusion is normally observable between the saline and fresh ground waters. The 10,000 mg/L TDS isometric surface will generally be situated within the diffusion zone separating the waters of contrasting salinities.

Figure A-12 illustrates how a wedge of sea water that has intruded into an unconfined aquifer is identified as a separate ground-water unit of higher salinity and density relative to an adjacent ground-water unit, in the same aquifer, that contains fresh water. In this setting, there exists a zone of diffusion between two flow systems that contain fresh water and sea water. The type 3 salinity boundary would occur along the 10,000 mg/L TDS isometric surface.

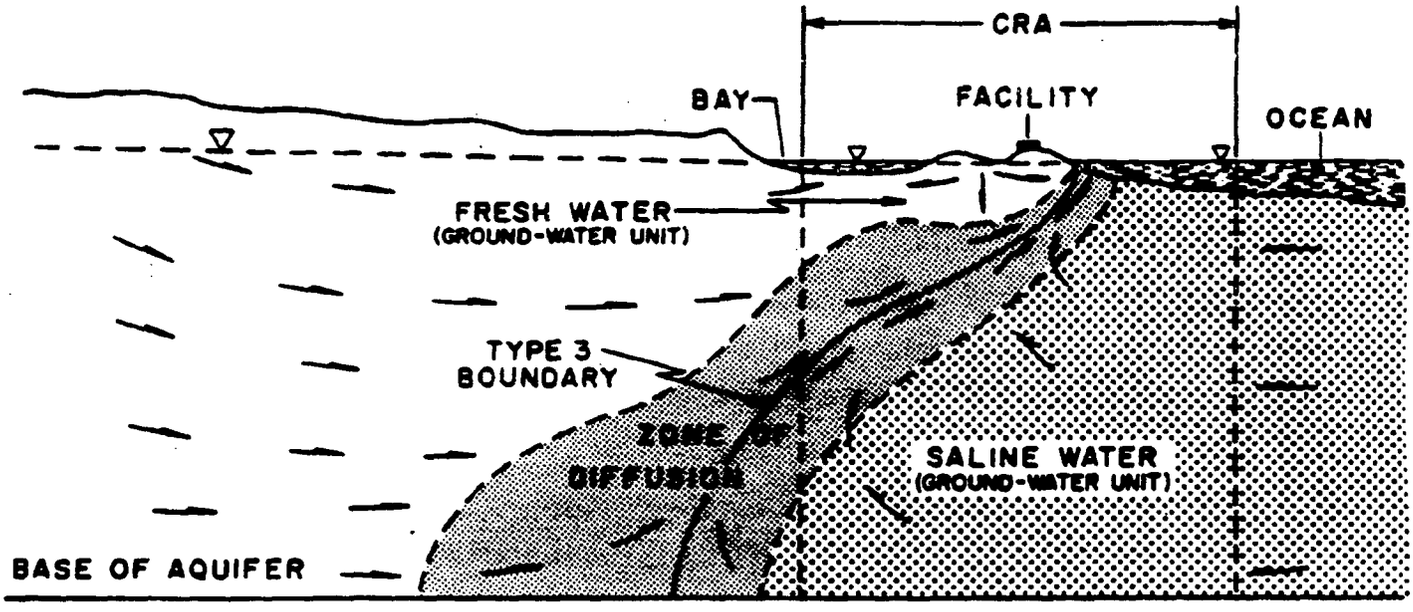
A second hydrogeologic setting characterized by the presence of near-surface evaporite deposits overlying deeper bedrock units is shown in Figure A-13. Salts are dissolved from the evaporite units by the circulating ground waters, and a shallow zone of saline waters coexists with fresh ground waters within the same flow system. However, based on the delineation of a Type 3 boundary, two distinct ground-water units can be identified.

Although the saline water is primarily confined to the low-permeability evaporite formation, this water leaks into the underlying aquifer creating a zone of diffusion within the underlying aquifer. The boundary between the two adjacent ground-water units would be drawn along the 10,000 mg/L TDS isometric surface within the diffusion zone. The diffusion zone would be a stable feature assuming the flow system is in both hydraulic and geochemical steady state. The degree of interconnection between these adjacent ground-water units is defined to be intermediate. The type of setting illustrated in Figure A-13 is not as common as the coastal intrusion setting illustrated in Figure A-1, but it is known to exist in selected parts of the United States.

In the above two settings, the intermediate degree of interconnection between ground-water units is due to the limited potential for the exchange of waters across a Type 3 boundary within a diffusion zone. In the first setting, the salt water and fresh water are in separate, but adjacent flow systems. In the second case, the diffusion zone is more extensive and may or may not be within a single flow system.

FIGURE A-12

EXAMPLE OF TYPE 3 BOUNDARY THROUGH AN UNCONFINED AQUIFER IN A COASTAL SETTING

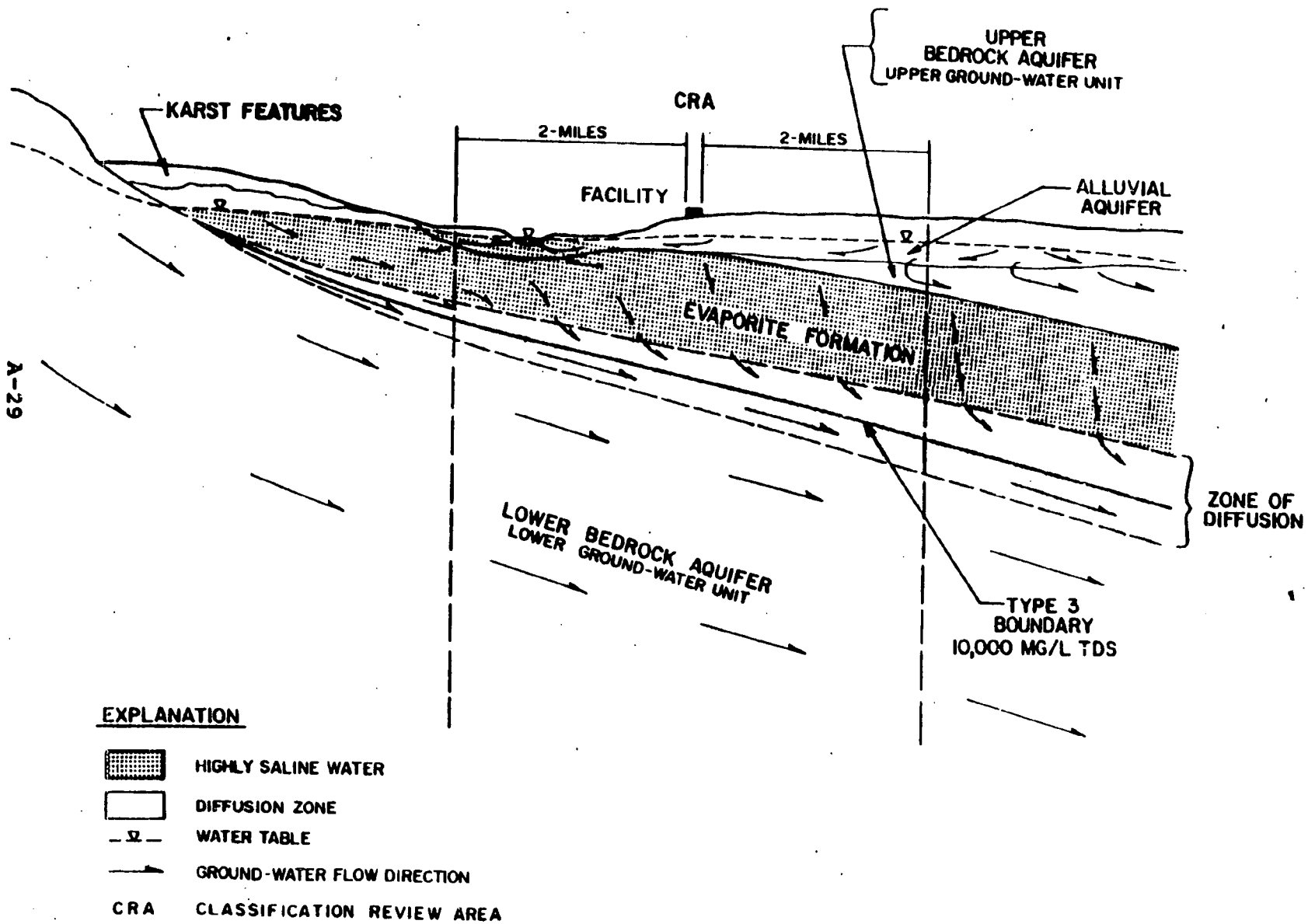


EXPLANATION

- >30,000 mg/l TDS WATER
- DIFFUSION ZONE
- GROUND-WATER FLOW DIRECTION
- WATER TABLE
- CRA — CLASSIFICATION REVIEW AREA
- 10,000 mg/l TDS ISOCONCENTRATION LINE

FIGURE A-13

EXAMPLE OF TYPE 3 BOUNDARY IN AN EVAPORITE/SALINE WATER SETTING



A third case involves a single regional flow system with the diffusion zone in the deeper and more downgradient end of the system.

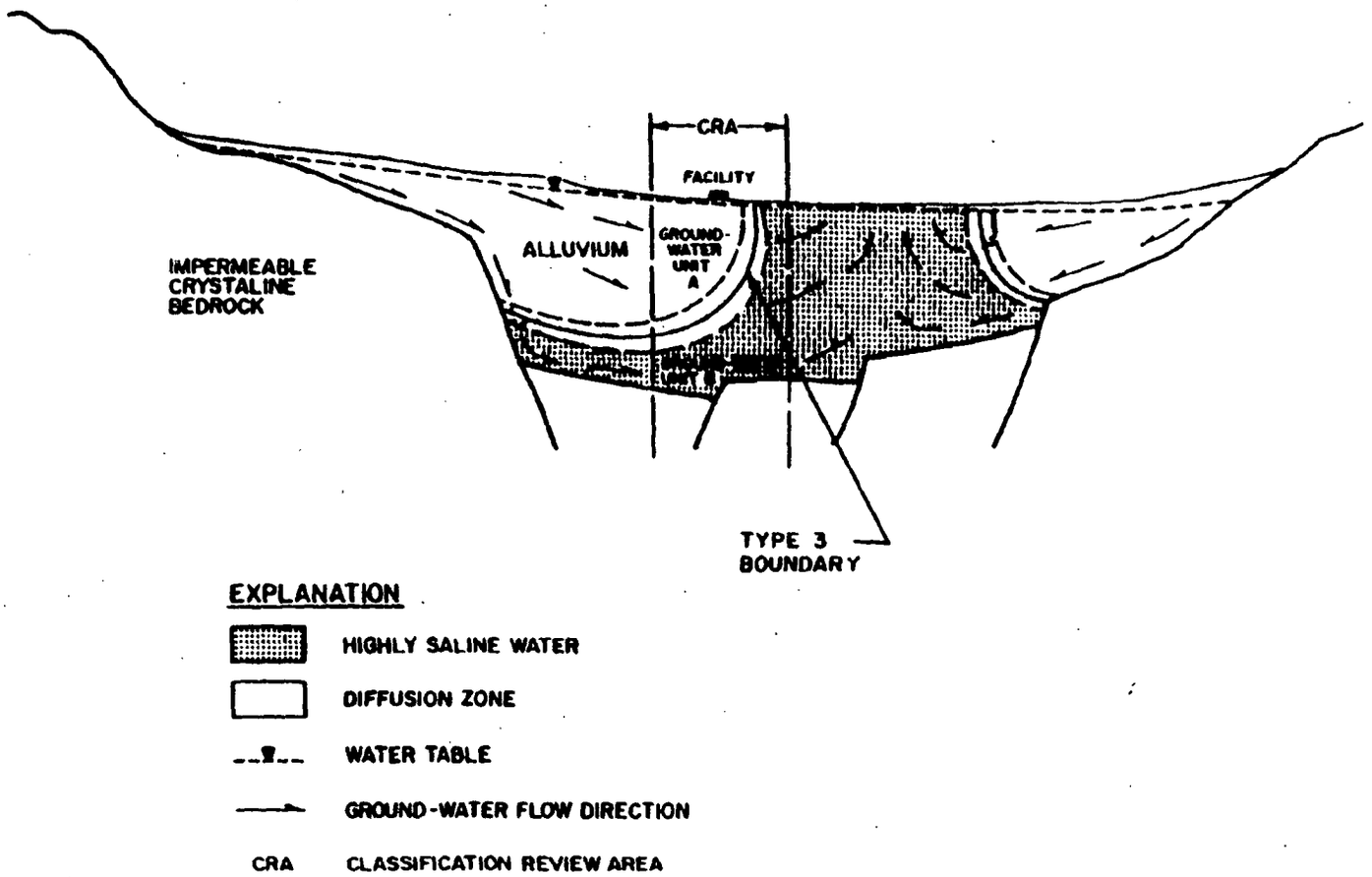
The third setting includes naturally saline ground water contained within topographically-closed structural basins within arid parts of the western United States (e.g., the Great Salt Lake Desert). An example of such a setting where the water is recharged from runoff from mountain ranges adjoining the basin, circulates to the center of the basin and discharges to playa lakes and the atmosphere is shown in Figure A-14. These settings are known to have brine waters whose salinity greatly exceeds the 10,000 mg/L Class III criteria within the discharge area to depths as great as 000 feet below land surface.

Distinct ground-water units can be delineated based on the identification of Type 3 boundaries as shown in Figure A-14. Under natural conditions, the diffusion zones encompassing these boundaries are stable, and ground-water units A and B can be identified as shown. Large-scale withdrawals from upgradient fresh ground water or injection into the saline ground water can laterally displace the diffusion zone. The pumped wells may eventually yield saline water and will cease to be sources of drinking water. Thus, the potential to cause adverse water-quality effects may result from improper resource management.

Type 3 boundaries are equivalent to the 10,000 mg/L TDS isometric surface through the ground-water regime. These boundaries can then easily be recognized and mapped when TDS data are available for ground waters from various depths and locations in the Classification Review Area. The elevations at which ground-water TDS is equal to or greater than 10,000 mg/L has been mapped and published for selected basins and regions. The principal sources for such data are the U.S. Geological Survey and State geological surveys, especially in states having abundant oil and gas resources. In areas of known sea-water intrusion, or upconing of salt water due to pumpage, published data are occasionally available that will show in vertical section or plan view the extent of the salt-water wedge. This may be conservatively taken as the 10,000 mg/L TDS boundary where more specific TDS data are not available. In areas of known high-temperature geothermal resources, published data are available to estimate the Type 3 boundary location. Because these areas are few in number and are limited in areal extent, few will be co-located with potential Classification Review Areas. Equally limited are data bases for saline-water settings associated with soluble evaporite deposits. At specific sites in these areas, the relationship between water quality, soluble strata, and ground-water flow directions can be established and the Type 3 boundary mapped. This relationship can be assumed in adjacent areas, where the stratigraphy and flow patterns are

FIGURE A-14

EXAMPLE OF TYPE 3 BOUNDARY THROUGH BASIN FILL
IN A CLOSED BASIN/ARID CLIMATIC SETTING



known, in order to extrapolate the Type 3 boundary to other parts of the Classification Review Area.

Type 4 Boundaries: Gradient-Based Boundaries

A Classification Review Area can also be subdivided on the basis of ground-water flow relationships under certain specific conditions such as, if the region of the Classification Review Area that will always remain upgradient of the facility or activity can be identified as another ground-water unit. The boundary separating the upgradient and downgradient regions is termed a Type 4, gradient-based boundary.

The demonstration of a gradient-based boundary must show that the section of the Classification Review Area upgradient from the facility/activity in question will not be significantly affected by any releases from such a facility/activity, even under worst-case conditions. These conditions would include the maximum sustainable level of hydraulic stresses associated with waste releases and ground-water withdrawals that cause the greatest change in ground-water flow pattern. If it can be shown that a section of the Classification Review Area would still remain far enough away in an upgradient or cross-gradient position from the facility/activity to preclude ground-water movement from the facility/activity to that section, EPA may recognize a Type 4 boundary separating these two sections.

The gradient-based boundary would generally be associated with a shallow uppermost aquifer that has a relatively small water-transmitting capacity (i.e., transmissivity) by virtue of its low-to-moderate hydraulic conductivity and/or small saturated thickness. When the transmissivity is small relative to the ground-water withdrawal rate at a well field, a steep and areally limited cone of depression develops around the well field. Ground-water flow pattern alterations would tend to be smaller and more restricted to the proximity of the area in which water is being added or withdrawn.

The maximum sustainable stress scenario for a worst-case analysis would assume two conditions:

- Ground-water withdrawal rates in the non-affected upgradient areas would be at the maximum steady sustainable yield of the aquifer.

- Leachate release rates at the facility/activity would be at a maximum steady rate given any excess hydraulic head at the facility/activity as well as the vertical hydraulic conductivity of earth materials beneath the facility/activity.

These stresses and the resulting steady-state ground-water flow regime within the ground-water unit can be simulated in order to define the gradient-based boundary. Numerous computerized flow models are now commercially available to make this simulation. This type of hydrologic modeling will involve special skills and professional judgment, but would not necessarily consume more resources than simulation modeling needed to support identification of Type 1 and 3 boundaries.

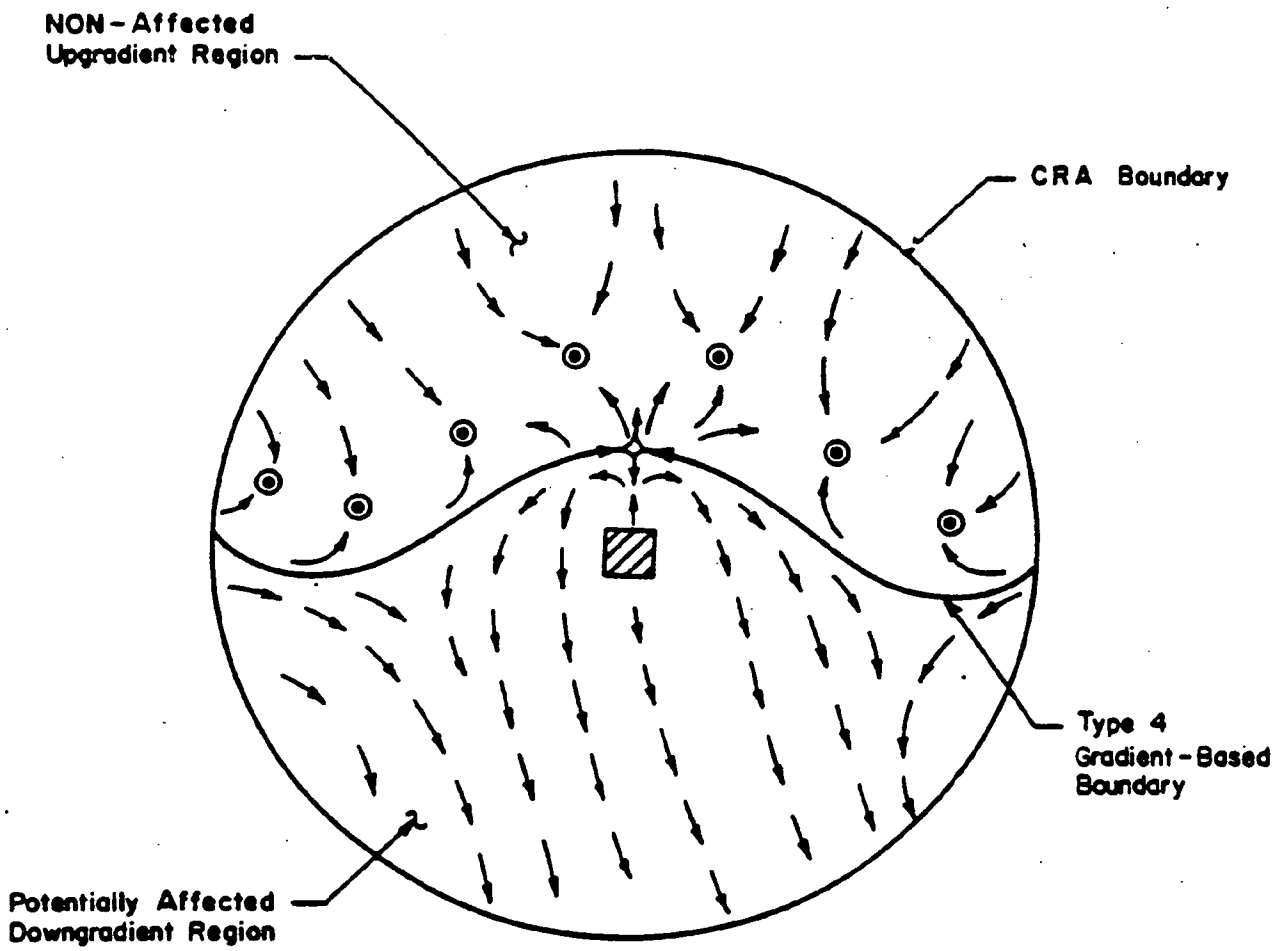
The modeling effort would generally proceed through the following steps:

- Characterize the key hydraulic parameters governing flow within the region to be simulated (hydraulic conductivities, thicknesses, and flow or hydraulic head conditions along boundaries of the region).
- Determine the areal distribution and magnitude of pumpage that would permanently draw ground-water levels down near the base of the aquifer.
- Simulate the steady-state drawdown and ground-water levels (heads) across the region and superimpose these on the pre-existing potentiometric surface of the aquifer in question.
- Infer the ground-water flow pattern from the simulated worst-case potentiometric surface.
- Identify the gradient-based boundary on the basis of flow patterns.

The Type 4 boundary can be recognized as the flowline that delimits a set of flowlines terminating at the ground-water withdrawal points in the upgradient region. An example of such a limiting flowline is illustrated in Figure A-15. On the upgradient side of this flowline, all ground water is ultimately contained by maximum sustained withdrawals at hypothetical wells. On the downgradient side, all ground water continues flowing around and away from the withdrawal area. This ground water eventually flows beneath or near the facility depending on the magnitude of volumetric releases at the facility. Significant releases can cause mounding of the water table and a local reversal of ground-water movement in an upgradient direction. In the particular hypothetical situation depicted in Figure A-15, this hydraulic stress is seen to be small relative to the withdrawal stresses in the upgradient region.

FIGURE A-15

EXAMPLE OF A TYPE 4 GRADIENT-BASED BOUNDARY DEFINED ON THE BASIS OF SIMULATED GROUND-WATER FLOW PATTERNS



EXPLANATION

- Facility / Activity
- Hypothetical center of pumping
- Generalized flow direction
- Limiting flowline / Type 4 Boundary
- Stagnation Point

CRA Classification Review Area

Under the worst-case flow pattern scenario, no ground water from the facility/activity can cross the limiting flowline and enter the upgradient region. The only mechanism for contaminants to enter the upgradient region would be by chemical diffusion and mechanical dispersion across the flowline. Because these mechanisms may be operable under a worst-case scenario, the Agency considers Type 4 boundaries to offer an intermediate rather than low degree of interconnection.

A.3.2 Example of Subdividing a Classification Review Area

Figures A-16 through A-18 illustrate how a hypothetical Classification Review Area is subdivided into ground-water units. It should be emphasized that for purposes of an actual classification decision not all the subdivisions illustrated here would be necessary, as only the ground-water relevant to the facility in question would be classified.

The geology of the Classification Review Area consists of essentially flat-lying sedimentary formations overlying a crystalline basement composed of undifferentiated granitic and metamorphic rocks. Three local aquifers and two aquitards are recognized in the area. The uppermost aquifer is a water-table aquifer defined as the saturated part of a sand and gravel deposit overlying a low-permeability shale formation. This aquifer is recharged by the infiltration of precipitation and discharges primarily to the stream and wetland areas. It is locally used for water supply by domestic wells in a nearby residential development.

Figure A-16 shows a deeper middle aquifer that is interbedded between two regionally extensive shales that serve as aquitard confining beds. Ground water is pumped from the middle aquifer at a municipal well that supplies water to a nearby city. The city also receives water pumped from deeper wells in the lower aquifer; however, these wells are located on the other side of the city off the left edge of Figure A-16. Pumpage from these wells has caused sea water to intrude into the lowest aquifer from the ocean (located off the right edge of Figure A-16). The lower aquifer is underlain by crystalline rocks which have low permeabilities and are not used as an aquifer in the area.

Figure A-17 illustrates the cylinder-shaped volume of earth material that underlies the Classification Review Area. The ground-water regime is defined to include all ground water and earth materials between the water table in the uppermost aquifer and the contact between the lower aquifer and the basement rocks. Figure A-18 shows how the regime can

FIGURE A-16

HYPOTHETICAL SETTING FOR DEMONSTRATING THE SUBDIVISION OF A CLASSIFICATION REVIEW AREA

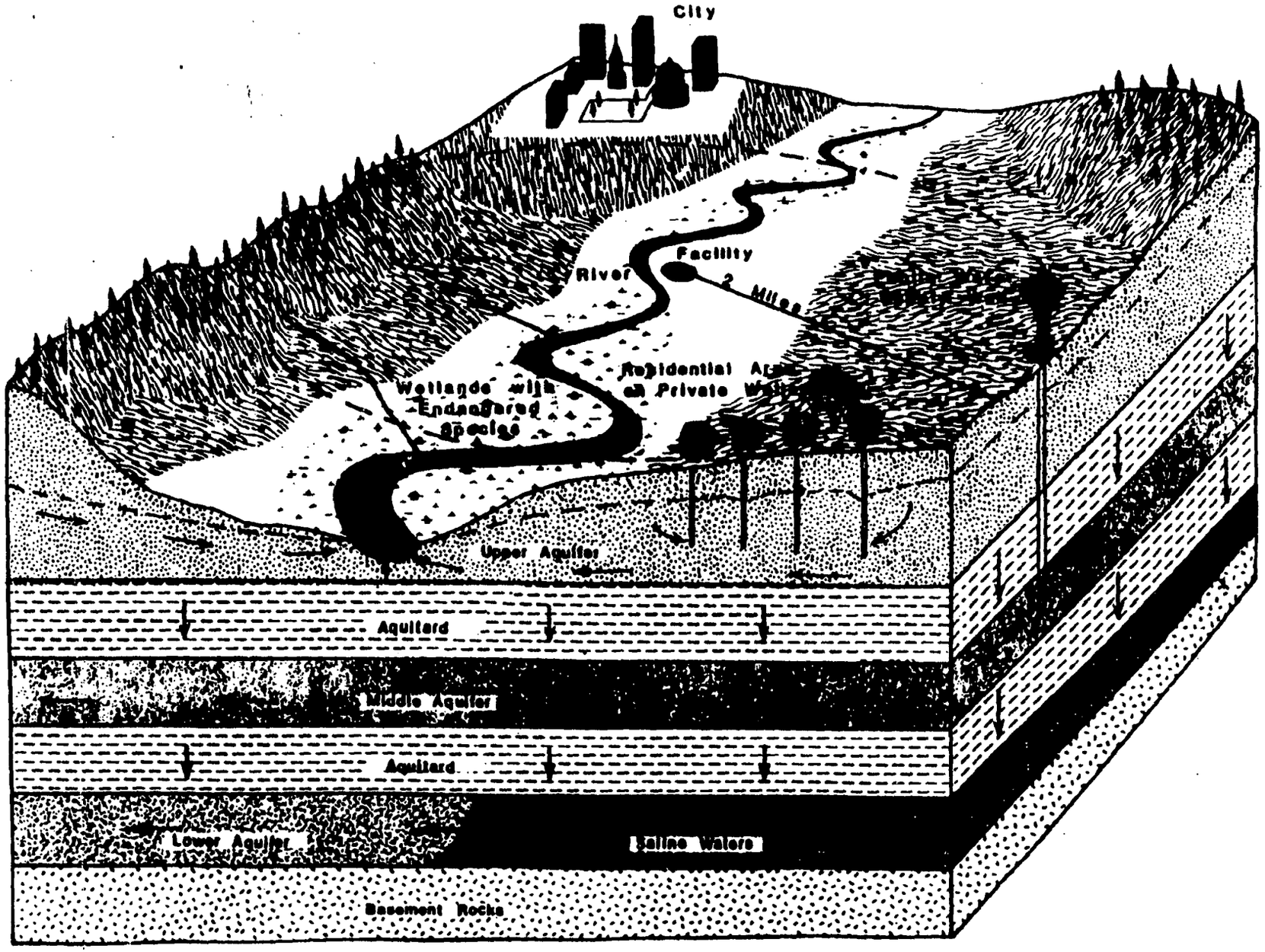


FIGURE A-17

HYPOTHETICAL CLASSIFICATION REVIEW AREA

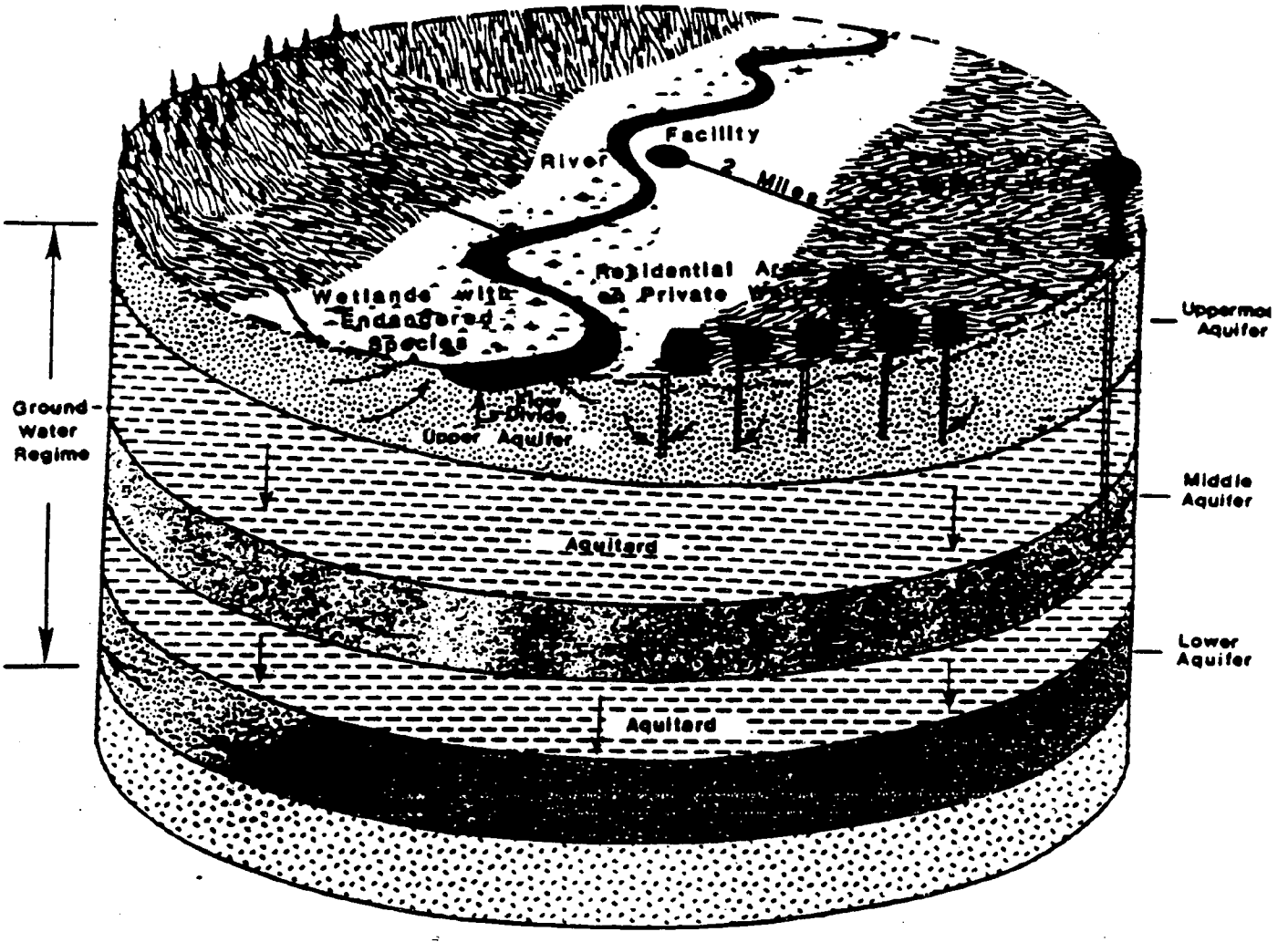
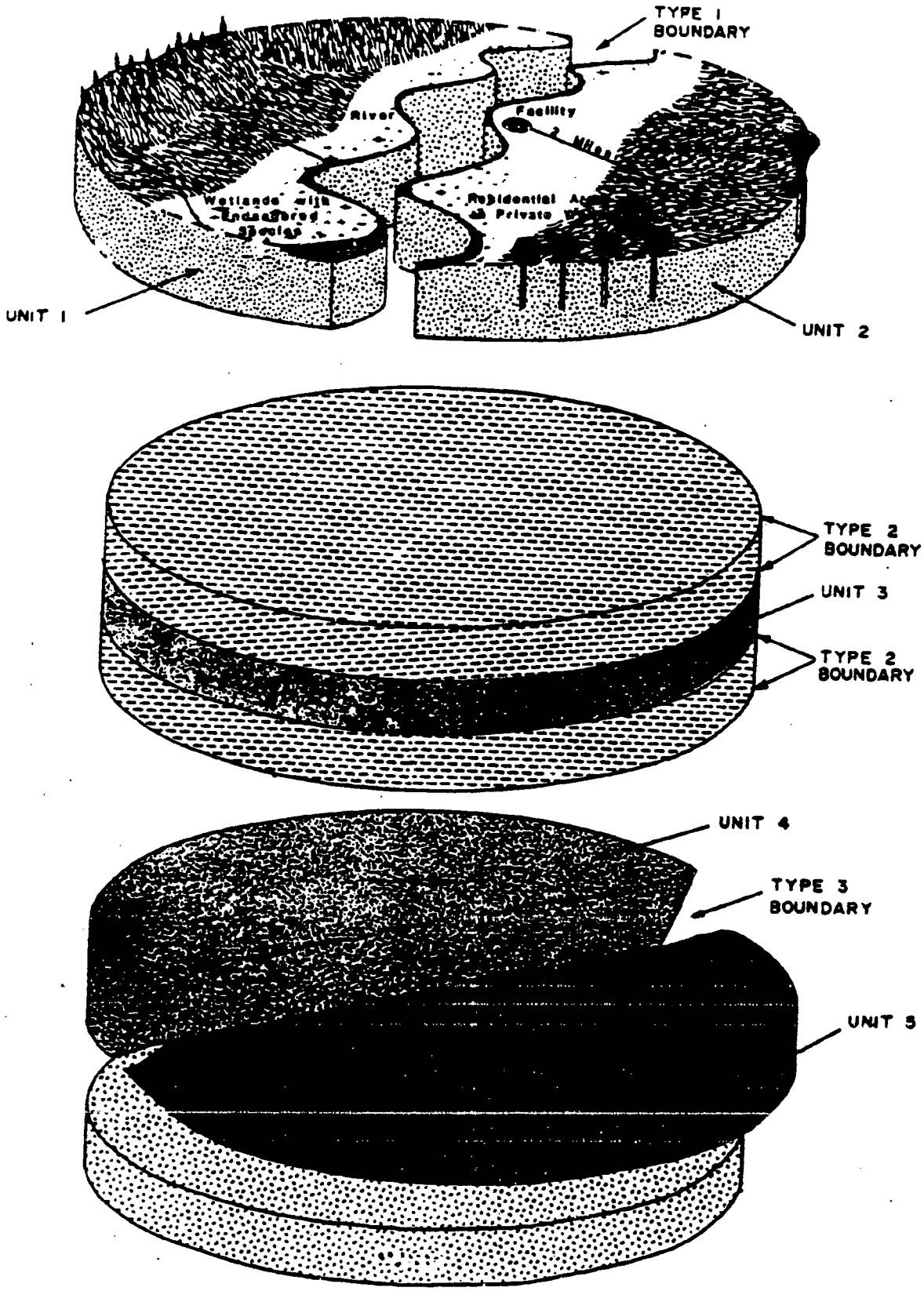


FIGURE A-18

SUBDIVISION OF A HYPOTHETICAL CLASSIFICATION REVIEW AREA INTO THE GROUND-WATER UNITS



be subdivided into five ground-water units. For purposes of an actual classification decision, only the ground-water unit that could potentially be affected by the facility would be pertinent.

Ground-water units 1 and 2 are subdivided along a Type 1 ground-water flow divide boundary beneath the sinuous perennial river. This boundary is inferred from a mapping of the flow pattern within the uppermost aquifer. The aquitard beneath the aquifer exhibits no evidence of discontinuities within the Classification Review Area. It is present in all deep wells in the area and consistently shows large vertical gradients across it. Even so, the estimate of the rate of ground-water flow per unit area through the unit (based on these gradients and hydraulic conductivities) is no greater than 10^{-6} cm/sec, which is negligibly small relative to ground-water flow rates in adjacent aquifers. Based on these characteristics, the aquitard constitutes a Type 2 low hydraulic conductivity, non-aquifer boundary. The vertical extent of ground-water units 1 and 2 is thus delineated by the existence of this physical boundary.

Ground water within the middle aquifer is identified as a third ground-water unit with the overlying and underlying aquitards constituting Type 2 boundaries. In addition to the characteristics described above for the uppermost aquitard, long-term aquifer tests have been performed on the municipal wells completed in the middle and lower aquifer. These tests indicate that less than 10 percent of water pumped from the aquifers is derived from the leaking aquitards, thus their designation as Type 2 boundaries is justified.

Ground water within the lower aquifer is generally moving towards a major pumping center located outside of the Classification Review Area. A significant part of the water in this aquifer has been replaced by sea water having TDS concentrations in excess of 30,000 mg/L. The problem has been studied by the U.S. Geological Survey in cooperation with the city. The movement of the interface between fresh and saline water is being monitored with a few deep wells (not shown in the illustrations). The approximate location of the interface at the time of subdivision was approximately known and, lacking specific TDS data, is taken as the 10,000 mg/L TDS Type 3 boundary separating ground-water units 4 and 5 on Figure A-18. Because the actual 10,000 mg/L TDS boundary is probably several hundred feet further towards the well field, use of the interface as this boundary makes ground-water unit 4 larger and unit 5 smaller than they may actually be. However, lacking specific data, such use of reasonable and conservative assumptions is necessary and appropriate.

A.4 Appendix A References

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APPENDIX B

SUPPLEMENTAL INFORMATION FOR CLASS I PROCEDURES

APPENDIX B

SUPPLEMENTAL INFORMATION FOR CLASS I PROCEDURES

B.1 Densely Settled Criterion

The determination of a substantial population is related to private wells in a densely settled area (i.e., a census-designated densely settled area). Urbanized areas and Census Designated Places (CDPs) also by definition are densely settled. The latter are unincorporated places with a population density of at least 1,000 persons per square mile (e.g., 500 persons located within a 0.5 square mile area). They are outlined on Census tract maps for metropolitan areas and on block-numbering area maps in non-metropolitan areas of less than 10,000 people.

Key terms used by the Census Bureau are as follows:

- Metropolitan statistical area (MSA): (a) a city of at least 50,000 population, or (b) a Census Bureau-defined urbanized area of at least 50,000 with a total metropolitan population of at least 100,000 (75,000 in New England). There are 277 MSAs (as of June 30, 1984). Every state has at least one MSA.

- Urbanized area (UA): a population concentration of 50,000 or more, generally consisting of a central city together with its surrounding densely settled contiguous territory or suburbs (the urban fringe). There are about 420 UAs.

- Urban place: any population living within urbanized areas; or places of 2,500 or more people outside urbanized areas.

- Densely settled area: not an official statistical division, but used by the Census Bureau to indicate an area with a population density of at least 1,000 persons per square mile within an urbanized area or Census Designated Place (CDP).

Urbanized Areas may include areas which do not qualify as densely settled (e.g., less than 1,000 persons per square mile) but are included within such geographic boundaries because of one of the following reasons:

- Eliminate enclaves of less than 5 square miles which are surrounded by built-up areas.

- Close indentations in the boundaries of densely settled areas that are no more than 1 mile across the open end and encompass no more than 5 square miles.

- Link outlying areas of qualifying density, provided that the outlying areas are as follows:

  Connected by road to, and are not more than 1 1/2 miles from, the main body of the urbanized area.

  Separated from the main body of the urbanized area by water or other undevelopable area, are connected by road to the main body of the urbanized area, and are not more than 5 miles from the main body of the urbanized area.

- Are nonresidential urban areas (e.g., industrial parks, office areas, or major airports), which have at least one-quarter of their boundaries contiguous to an urbanized area.

MSAs and their components are listed in the 1980 Census of Population - Supplementary Report: Metropolitan Statistical Areas and are mapped on State MSA outline maps. Urbanized area (UA) outline maps are generally contained within MSA publications.

B.2 Use of GEMS System for Estimating Well Density

One means of estimating private well usage in areas where no local information on private wells is available is to use population data for the area of interest available through the Graphical Exposure Modeling System (GEMS) maintained by EPA's Office of Toxic Substances (OTS), or a private census data service.

Information on the GEMS system is available from EPA's OTS modeling team. Using the GEMS Census Data (CD) pro-

cedure, it is possible to retrieve population and housing count data from the 1980 Census for circular areas around a point, which can be designated using latitude and longitude coordinates or the ZIP code of the location. The system provides information within defined concentric rings ranging from 0.1 to 10,000 km in radii. It is necessary to supply the number of sectors into which the rings are divided; the procedure allows from 1 to 16. Sectors are numbered clockwise with the first sector centered at zero degrees (the north compass point direction). The program tabulates total population and housing counts by ring distance and sector. A simple mathematical conversion can be used to transform the population counts into density.

The manner in which population data are recorded by the Bureau of the Census and reported by GEMS can result in reports of no population for some areas where people are living. This information can be verified or corrected by consulting local officials. It is unlikely that such areas would satisfy the densely settled test, however.

B.3 General Background Information on Institutional Constraints

Institutional constraints on the availability of water can arise from at least six general sources. Each of these is discussed below.

State Law

State law creates basic rights to the withdrawal and use of surface and ground water. For example, State law may regulate the rights to or ownership of water; the withdrawal, uses, and allocation of water; conjunctive use of surface and ground water; protection of in-stream users; and measures required to protect ground water. The law in most states, however, does not create a right to unlimited amounts of water, and may restrict where the water may be used (Council of State Governments, 1983). The States have created different methods for establishing rights to water and resolving conflicts over rights to withdraw and use water. There are three major systems of regulation of water withdrawal and use:

- The Eastern (common law) doctrine, used in about 37 states, provides that ownership of land carries with it a right to water in adjacent lakes or watercourses (a riparian right) and to water beneath the land.

The use of the water, however, may be restricted. Under the absolute use doctrine, it is possible for a landowner to withdraw unlimited amounts of water, without liability for damage to other landowners, and to transport the water off the land. Under the reasonable-use doctrine, it is possible to withdraw an amount of water necessary for the use or enjoyment of the overlying land, but the water may not be transported away from that land. Under the correlative-rights doctrine, the right to withdraw ground water is based on the relationship between the size of the aquifer and the area of the overlying land.

- The Western (appropriation) doctrine, used in about 13 states, provides that water is a public resource, and rights to water may be acquired by actual use. Conflicts in priority of use are ordinarily settled by the principle of "first in time, first in right." Hierarchies of use, however, may also be established.

- Permit systems, used in about 31 states, may be used in conjunction with the common law or appropriation doctrines, and may be applied to surface and/or to ground water. Rights to water under a permit system are acquired by application to a regulatory authority. If the authority determines that no superior claim exists to the water, it records the claim, issues a permit for use, and polices the actual use. Permit systems may co-exist with other forms of water regulation, such as designated ground-water protection zones or management areas. Many permit systems specify priorities for different types of uses of water (beneficial uses), generally making domestic use, such as drinking water, the highest beneficial use and making other uses, such as commercial or industrial use and irrigation, lower beneficial uses.

Conflicts among users, or prospective users, of water are resolved by most states in three ways: the conflict may be decided by the administrative organization that administers the water rights system in the State, particularly if water use permits are required; special organizations may be created to resolve water disputes; and the State or local courts may resolve disputes. State law in certain circumstances may allow the use of eminent domain powers to shift water from one use to another, or to allow physical access to water, and State law may grant the use of eminent domain to the Federal government for certain purposes. Frequently, when insufficient water exists for all claimed uses, lower beneficial uses may give way to higher beneficial uses.

Some states have attempted by law to restrict or preclude the export of water to users in other states, either

by requiring legislative approval of water exports, by requiring reciprocity agreements with the states receiving the water, or by absolute prohibitions. All of these forms of restriction have recently been subject to legal challenge.

A number of states, particularly in the West, designate ground-water protection zones or management areas, and seek to coordinate surface- and ground-water use (conjunctive management). Measures of conjunctive management may include restrictions on pumping ground water, requirements for aquifer recharge, and well spacing requirements. Some states (e.g., Texas, Nebraska) delegate aquifer protection authority to local administrative bodies.

Federal Law

As a user of water, the Federal government generally defers to State regulation of water. Federal laws often pertain to Federal and Indian reserved rights to water and Federal activities affecting water. In common law states, Federal rights to water are linked to ownership or control of land. In prior appropriation and permit states, Federal agencies (e.g., the Bureau of Reclamation) register claims to water. The Federal government may, however, have special access to water in certain circumstances. Statutes (e.g., the Oil and Gas Well Conversion Act) or executive orders (e.g., the Executive Order of April 17, 1926) may reserve water rights on Federal public lands for particular purposes.

For certain categories of Federal lands withdrawn from the public domain and reserved for such uses as national forests, wildlife refuges, and parks, Federal reserved rights doctrine can provide access to water irrespective of State law. The courts have created this doctrine, which holds generally that reservation of public domain lands for a particular purpose carries with it an implied reservation of sufficient water to satisfy the purposes for which the land was reserved. The right is not created by use or lost through non-use. Therefore, in certain circumstances, even if the water is being used by another person, the Federal government can obtain water for its own use. The purpose of the water is determined as of the time the land reservation was created, and the reserved right is limited to that purpose. (For example, if the reservation was created to provide agricultural land, reserved rights to irrigation water may exist, but there are no reserved rights to water for industrial purposes.)

An Indian-reserved right, similar to the Federal reserved right, has also been created by the courts. This doctrine is apparently based on the presumption that in creating an Indian reservation the President and/or Congress intended to reserve sufficient water for the use of the land. Indians may hold superior rights to water connected with

reservation lands. Apparently, such rights may be sold, although it is unclear whether only the amount of water actually being used or the entire potential right may be transferred. In addition to reserved rights, in a few instances Indians also hold special water rights based on treaties (e.g., Treaty of Guadalupe Hidalgo).

Federal water resource agencies, such as the Corps of Engineers, the Bureau of Reclamation, and the Soil Conservation Service, as well as such Federally chartered agencies as the Tennessee Valley Authority and the Bonneville Power Authority, can affect water availability, either through the water rights that they hold or through their decisions concerning water management (Congressional Budget Office, 1983). Numerous other Federal agencies and laws can affect water-resource decisions indirectly. Examples of such agencies or laws include the Forest Service and Bureau of Land Management (right-of-way decisions), the Fish and Wildlife Service (requirements under the Fish and Wildlife Coordination Act), the National Environmental Policy Act (Environmental Impact Assessment requirements), Clean Water Act (dredge and fill permit requirements), and the Wild and Scenic Rivers Act and National Wilderness Preservation requirements.

Interstate Compacts

Conflicts among two or more states or the Federal government concerning rights to water in streams generally are resolved either through interstate compacts or through litigation (Clyde, 1982, 1984; Schwartz, 1985; Sporhase vs. Nebraska, 1984). The result in either case is usually a decision allocating the in-stream flow among the states claiming the water. In a few cases, ground water has also been allocated among states by interstate compact or court decision.

Interstate compacts are agreements among states that have been ratified by the legislatures of the participating states and the U.S. Congress. The compact creates a binding law within the participating states and a binding contract among the states. In certain cases, the Federal government also joins the compact, and the compact is then also binding on the Federal government. The members and powers of the compacts currently in existence vary widely, from bilateral agreements (e.g., Snake River Compact between Idaho and Wyoming) to agreements affecting large numbers of states (e.g., Colorado River Compact), and from compacts exclusively devoted to allocating river water (e.g., Arkansas River Compact of 1949) to compacts establishing regional multipurpose water resources management (e.g., Delaware River Basin Compact). Approximately 25 interstate compacts currently are in operation.

In the absence of a resolution of conflicting claims through an interstate compact, litigation among states before the U.S. Supreme Court may be the only means to resolve the conflict. In deciding such cases, the Court ordinarily attempts to carry out an equitable apportionment of the interstate stream. Because the Court has been called upon less frequently to resolve disputes among states over ground water, the standard used in such cases is less clear.

Local Regulations

Local administrative bodies with jurisdiction over sources of water in particular areas may exercise powers such as well spacing and pumping rates that affect the availability of water. As previously noted, State legislatures may delegate power to local bodies to administer particular aspects of the water allocation or water protection system in the state. Examples of such local agencies include underground water conservation districts (Texas), which are empowered to provide for spacing of wells and to regulate well pumping in order to minimize the drawdown of the water table; ground-water management districts (California), which are authorized to manage ground-water withdrawals; and water conservation districts (Nebraska), which are authorized to regulate ground-water use. Other special purpose districts may also affect water availability. The Texas Harris-Galveston coastal subsidence district, for example, is authorized to regulate withdrawal of ground water in order to limit land subsidence.

Treaties and International Laws

Treaties between the United States and its neighbors, Mexico and Canada, allocate the waters of rivers flowing between the countries. The 1944 Treaty of Utilization of the Waters of the Colorado and Tijuana Rivers and the Rio Grande, for example, apportions the waters of those rivers between the two countries and creates an International Boundary and Water Commission (IBWC) to apply the treaty and settle disputes. Although ground water use is not fully covered by the treaty, the IBWC has attempted to address the management of international ground-water resources.

In addition to treaties signed by the United States, certain international law proposals being developed by the United Nations and the International Law Association may sometime in the future establish general principles for the allocation of ground and surface waters between two countries.

Property Law

State law governs the ownership and use of land. In particular, property law affects physical access to water

supplies through restrictions on rights of way and easements, or defining powers of eminent domain. State and local laws generally regulate land use and access to land by persons who are not landowners. Access to water, including the location of pipes, storage, pumping, treatment, and other facilities, can be delayed or restricted by the property rights of persons whose land must be crossed or used for such facilities. Special procedures, such as easements, eminent domain, and condemnation, may be required to obtain necessary rights-of-way. Special procedures vary from state to state.

B.4 List of Offices of Endangered Species, U.S. Fish and Wildlife Services

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The Fish and Wildlife Service, a unit of the U.S. Department of the Interior, has been delegated the main responsibility for coordinating national and international efforts on behalf of Endangered Species.

In the case of marine species, however, actions are taken in cooperation with the Secretary of Commerce, through the Director of the National Marine Fisheries Service. Similarly, in the area of import/export enforcement for Endangered plants, the Department of Interior cooperates with and is assisted by the Department of Agriculture through the Animal and Plant Health Inspection Service.

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Division of Law Enforcement
U.S. Fish and Wildlife Service
1735 K Street, NW., Third Floor
Washington, D.C.
Telephone: 202/343-9242

Mailing Address for Division of Law Enforcement

P.O. Box 28006
Washington, D.C. 20005

Special-Agent-in-Charge, Branch of Investigations
Telephone: 202/343-9242

Office of the Scientific Authority
U.S. Fish and Wildlife Service
1717 H Street, NW., Room 536
Washington, D.C.
Telephone: 202/653-5948, 49, 50

Mailing Address for Office of the Scientific Authority

U.S. Fish and Wildlife Service
Washington, D.C. 20240

Regional Endangered Species Coordinators

The U.S. Fish and Wildlife Service is comprised of seven Regional Offices. Each office has a senior official who has been designated as a Regional Endangered Species Coordinator. Additionally, each of the regions has several Field Offices. Problems of a local nature should be referred to these offices.

Region 1 Regional Director
U.S. Fish and Wildlife Service
Suite 1692, Lloyd 500 Building
500 NE. Multnomah Street
Portland, Oregon 97232
Telephone: 503/231-6131 (FTS: 8/429-6131)

Field Offices

California
1230 "N" Street, 14th Floor
Sacramento, California 95814
Telephone: 916/440-2791 (FTS: 8/448-2791)

Idaho
4696 Overland Road, Room 566
Boise, Idaho 83705
Telephone: 208/334-1806 (FTS: 8/554-1806)

Nevada
Great Basin Complex
4600 Kietzke Lane, Building C
Reno, Nevada 89502
Telephone: 702/784-5227 (FTS: 8/470-5227 or 5228)

Washington/Oregon
Building-3, 2625 Parkmont Lane
Olympia, Washington 98502
Telephone: 206/753-9444 (FTS: 8/434-9444)

Pacific Islands Administrator
300 Ala Moana Boulevard, Room 5302
P.O. Box 50167
Honolulu, Hawaii 96850
Telephone: 808/546-5608 (FTS: 8/546-5608)

Region 2 Regional Director
Endangered Species Specialist
U.S. Fish and Wildlife Service
500 Gold Avenue, SW.
P.O. Box 1306
Albuquerque, New Mexico 87103
Telephone: 505/766-3972 (FTS: 8/474-3972)

Field Offices

Arizona
2934 West Fairmont Avenue
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Telephone: 602/241-2493 (FTS: 8/261-2493)

New Mexico
P.O. Box 4487
Albuquerque, New Mexico 87196
Telephone: 505/766-3966 (FTS: 8/474-3966)

Oklahoma/Texas
222 South Houston, Suite A
Tulsa, Oklahoma 74127
Telephone: 918/581-7458 (FTS: 8/736-7458)

Texas
c/o CCSU, Box 338
6300 Ocean Drive
Corpus Christi, Texas 78411
Telephone: 512/888-3346 (FTS: 8/734-3346)

Fritz Lanham Building, Room 9A33
819 Taylor Street
Fort Worth, Texas 76102
Telephone: 817/334-2961 (FTS: 8/334-2961)

Region 3 Regional Director
Endangered Species Specialist
U.S. Fish and Wildlife Service
Federal Building, Fort Snelling
Twin Cities, Minnesota 55111
Telephone: 612/725-3276 (FTS: 8/725-3276)

Region 4 Regional Director
Endangered Species Specialist
U.S. Fish and Wildlife Service
The Richard B. Russell Federal Building
75 Spring Street SW.
Atlanta, Georgia 30303
Telephone: 404/221-3583 (FTS: 8/242-3583)

Field Offices

Alabama/Arkansas/Louisiana/Mississippi
Jackson Mall Office Center
300 Woodrow Wilson Avenue, Suite 3185
Jackson, Mississippi 39213
Telephone: 601/960-4900 (FTS: 8/490-4900)

Florida/Georgia
2747 Art Museum Drive
Jacksonville, Florida 32207
Telephone: 904/791-2580 (FTS: 8/946-2580)

Kentucky/North Carolina/South Carolina/Tennessee
Plateau Building, Room A-5
50 South French Broad Avenue
Asheville, North Carolina 28801
Telephone: 704/258-2850 ext. 382
(FTS: 8/672-0321)

Puerto Rico/Virgin Islands
P.O. Box 3005
Marina Station
Mayaguez, Puerto Rico 00709
Telephone: 809/833-5760 (FTS: 8/967-1221)

Region 5 Regional Director
U.S. Fish and Wildlife Service
Suite 700, One Gateway Center
Newton Corner, Massachusetts 02158
Telephone: 617/965-5100 ext. 316
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P.O. Box 1518
Concord, New Hampshire 03301
Telephone: 603/224-9558, 9 (FTS: 8/834-4726)

District of Columbia/Delaware/Maryland Virginia/West Virginia
1825 Virginia Street
Annapolis, Maryland 21401
Telephone: 301/269-6324 (FTS: 8/922-4197)

New Jersey/Pennsylvania
112 West Foster Avenue
State College, Pennsylvania 16801
Telephone: 814/234-4090 (FTS: 8/727-4621)

New York
100 Grange Place
Cortland, New York 13045
Telephone: 607/753-9334 (FTS: 8/882-4246)

Region 6 Regional Director
U.S. Fish and Wildlife Service
P.O. Box 25486, Denver Federal Center
Denver, Colorado 80225
Telephone: 303/234-2496 (FTS: 8/234-2496)

Field Offices

Colorado/Utah
Room 1406, Federal Building
125 S. State Street
Salt Lake City, Utah 84138
Telephone: 801/524-4430 (FTS: 8/588-4430)

Kansas/Nebraska/North Dakota/South Dakota
223 Federal Building
P.O. Box 250
Pierre, South Dakota 57501
Telephone: 605/224-8692 (FTS: 8/782-5226)

Montana/Wyoming
Federal Building, Room 3035
316 North 26th Street
Billings, Montana 59101
Telephone: 406/657-6059 or 6062
(FTS: 8/657-6059)

Region 7 Regional Director
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Anchorage, Alaska 99503
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(FTS: 8/907/786-3435)

B.5 List of State Natural Heritage Program Offices (October 1985)

Nongame Branch
ARIZONA HERITAGE PROGRAM
Arizona Game & Fish Department
2222 W. Greenway Road
Phoenix, Arizona 85023
Telephone: 602/942-3000 ext. 245

ARKANSAS NATURAL HERITAGE INVENTORY
225 E. Markham, Suite 200
Little Rock, Arkansas 72201
Telephone: 501/371-1706

CALIFORNIA NATURAL DIVERSITY DATABASE
c/o CA Department of Fish & Game
1416 9th Street
Sacramento, California 95814
Telephone: 916/322-2493

COLORADO NATURAL HERITAGE INVENTORY
Department of Natural Resources
1313 Sherman Street, Room 718
Denver, Colorado 80203
Telephone: 303/266-3311

CONNECTICUT NATURAL DIVERSITY DATABASE
Natural Resource Center
Department of Environmental Protection
State Office Building, Room 553
165 Capitol Avenue
Hartford, Connecticut 06106
Telephone: 203/566-3540

FLORIDA NATURAL AREAS INVENTORY
254 E. 6th Avenue
Tallahassee, Florida 32302
Telephone: 904/224-8207

HAWAII HERITAGE
1116 Smith Street, #201
Honolulu, Hawaii 96817
Telephone: 808/537-4508

IDAHO NATURAL HERITAGE PROGRAM
4696 Overland Road, Suite 518
Boise, Idaho 83705
Telephone: 208/334-3402 or 3649

INDIANA HERITAGE PROGRAM
Division of Nature Preserves, IN DNR
612 State Office Building
Indianapolis, Indiana 46204
Telephone: 317/232-4078

IOWA NATURAL AREAS INVENTORY
State Conservation Commission
Wallace State Office Building
Des Moines, Iowa 50319
Telephone: 515/281-8524

KENTUCKY HERITAGE PROGRAM
Kentucky Nature Preserves Commission
407 Broadway
Frankfort, Kentucky 40601
Telephone: 502/564-2866

LOUISIANA NATURAL HERITAGE PROGRAM
Department of Natural Resources
Coastal Management Division
P.O. Box 44124
Baton Rouge, Louisiana 70804-4124
Telephone: 504/342-4602

MAINE NATURAL HERITAGE PROGRAM
Maine Chapter
122 Main Street
Topsham, Maine 04086
Telephone: 207/729-5161

MARYLAND NATURAL HERITAGE AND ENVIRONMENTAL REVIEW
Department of Natural Resources
C-3, Tawes State Office Building
Annapolis, Maryland 21401
Telephone: 261-1402, 3656 or 269-3656

MODEL NATURAL HERITAGE PROGRAM
The Nature Conservancy
1800 N. Kent Street, Suite 800
Arlington, Virginia 22209
Telephone: 703/841-5307

MASSACHUSETTS HERITAGE PROGRAM
Division of Fisheries and Wildlife
100 Cambridge Street
Boston, Massachusetts 02202
Telephone: 517/727-9194

MICHIGAN NATURAL FEATURES INVENTORY
Mason Building, 5th floor
Box 30028
Lansing, Michigan 48909
Telephone: 517/373-1552

MINNESOTA NATURAL HERITAGE PROGRAM
Department of Natural Resources
Box 6
St. Paul, Minnesota 55155
Telephone: 612/296-4284

MISSISSIPPI NATURAL HERITAGE PROGRAM
111 N. Jefferson Street
Jackson, Mississippi 39202
Telephone: 601/354-7226

MISSOURI NATURAL HERITAGE INVENTORY
Missouri Department of Conservation
P.O. Box 180
Jefferson City, Missouri 65102
Telephone: 314/751-4115

MONTANA NATURAL HERITAGE PROGRAM
State Library Building
1515 E. 6th Avenue
Helena, Montana 59620
Telephone: 406/444-3009

NAVAJO NATURAL HERITAGE PROGRAM
Box 2429
Window Rock, Arizona 86515-2429
Telephone: 602/871-6453 or 5449

NEVADA NATURAL HERITAGE PROGRAM
Department of Conservation and Natural Resources
c/o Division of State Parks
Capitol Complex, Nye Building
201 S. Fall Street
Carson City, Nevada 89710
Telephone: 702/885-4360

NEW HAMPSHIRE NATURAL HERITAGE PROGRAM
c/o Society for the Protection of N.H. Forests
54 Portsmouth Street
Concord, New Hampshire 03301
Telephone: 603/224-8945

NEW JERSEY NATURAL HERITAGE PROGRAM
Office of Natural Lands Management
109 W. State Street
Trenton, New Jersey 08625
Telephone: 609/984-1339 or 1170

NEW MEXICO NATURAL RESOURCES SURVEY SECTION
Villagra Building
Santa Fe, New Mexico 87503
Telephone: 505/827-7862

NEW YORK NATURAL HERITAGE PROGRAM
Wildlife Resources Center
Delmar, New York 12054-9767
Telephone: 518/439-8014 ext. 203

NORTH CAROLINA NATURAL HERITAGE
Department of Natural and Economic Restoration
Division of State Parks
Box 27687
Raleigh, North Carolina 27611
Telephone: 919/733-7795

NORTH DAKOTA NATURAL HERITAGE INVENTORY
North Dakota Game and Fish Department
100 N. Bismarck Expressway
Bismarck, North Dakota 58501
Telephone: 701/221-6310

OHIO NATURAL HERITAGE PROGRAM
Ohio DNR, Division of Natural Areas and Preservation
Fountain Square, Building F
Columbus, Ohio 43224
Telephone: 614/265-6453

OKLAHOMA NATURAL HERITAGE PROGRAM
Oklahoma Tourism and Recreation Department
500 Will Rogers Building
Oklahoma City, Oklahoma 73105
Telephone: 405/521-2973

OREGON NATURAL HERITAGE PROGRAM
Oregon Field Office
1234 NW 25th Avenue
Portland, Oregon 97210
Telephone: 503/228-9550

PENNSYLVANIA NATURAL DIVERSITY INVENTORY
Bureau of Forestry
Department of Environmental Resources
34 Airport Road
Middletown, Pennsylvania 17057
Telephone: 717/783-1712

PROGRAMA PRO-PATRIMONIC NATURAL
Apartado 5887
Puerta de Tierra, Puerto Rico 00906
Telephone: 809/724-0960

RHODE ISLAND HERITAGE PROGRAM
Department of Environmental Management
Division of Planning and Development
22 Hayes Street
Providence, Rhode Island 02903
Telephone: 401/277-2776

SOUTH CAROLINA HERITAGE TRUST
S.C. Wildlife and Marine Resources Department
P.O. Box 167
Columbia, South Carolina 29202
Telephone: 803/758-0014

SOUTH DAKOTA NATURAL HERITAGE
South Dakota Department of Game, Fish & Parks
Division of Parks and Recreation
Sigurd Anderson Building, B-114
Pierre, South Dakota 57501
Telephone: 605/773-4226

TENNESSEE HERITAGE PROGRAM
ECOLOGICAL SERVICES DIVISION
Tennessee Department of Conservation
701 Broadway
Nashville, Tennessee 37203
Telephone: 615/742-6545

TEXAS NATURAL HERITAGE PROGRAM
General Land Office
Stephen F. Austin Building
Austin, Texas 78701
Telephone: 512/475-0660, 0661, 0621, 0800

TVA REGIONAL HERITAGE
Office of Natural Resources
Morris, Tennessee 37828
Telephone: 615/494-5600

VERMONT NATURAL HERITAGE PROGRAM
Vermont Field Office
138 Main Street
Montpelier, Vermont 05602
Telephone: 802/229-4425

WASHINGTON NATURAL HERITAGE PROGRAM
Department of Natural Resources
Mail Stop EX-13
Olympia, Washington 98504
Telephone: 206/753-2448

WEST VIRGINIA WILDLIFE/HERITAGE DATABASE
Wildlife Resources Division
DNR Operations Center
P.O. Box 67
Elkins, West Virginia 26241
Telephone: 304/636-1767

WISCONSIN NATURAL HERITAGE PROGRAM
Endangered Resources/4
Department of Natural Resources
101 S. Webster Street, Box 7921
Madison, Wisconsin 53707
Telephone: 608/266-0924

WYOMING NATURAL HERITAGE PROGRAM
1603 Capitol Avenue, Room 323
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Vice President, Science	841-5320
Director, Heritage	841-5325
Assistant Director	841-5367
Director, PS&D	841-5322
Budget Specialist	841-5368
National Ecologist	217/367-8770
Classification Ecologist	217/367-8770
Director, National Database	841-5361
National Databases Associate	841-5360
National Information Manager	841-5360
Microcomputer Analyst	841-5355
Microcomputer Specialist	841-5355
Senior Programmer/Analyst	841-5356
Administrative Assistant,HFA	841-5354
Part-time Secretary, HFA	841-5354
Executive Secretary, Science	841-5321

REGIONAL

EASTERN HERITAGE TASK FORCE
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MIDWEST HERITAGE TASK FORCE
Midwest Regional Office
The Nature Conservancy
1313 Fifth Street, SE
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Telephone: 612/379-2207

ROCKY MOUNTAIN HERITAGE TASK FORCE
The Nature Conservancy
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Denver, Colorado 60203
Telephone: 303/860-9142

B.6 Appendix B References

Council of State Governments, Interstate Compacts and Agencies, 1983, provides annual listing of names and phone numbers of commissioners of interstate compacts and compact administrators and citations to state and Federal legislature enactments of components.

U.S. Bureau of Census, Statistical Abstract of the US: 1986 (107th edition), Washington, DC 1986.

APPENDIX C

SUPPLEMENTAL INFORMATION FOR CLASS III PROCEDURES

APPENDIX C

SUPPLEMENTAL INFORMATION FOR CLASS III PROCEDURES

C.1 Overview of Treatment Technologies

The following discussions of treatment technologies indicate the typical area of application and limitations of particular significance and the potential problems encountered when treating water that contains multiple contaminants. A series of references that can be used for general background data is included. Many treatment processes, particularly those used in water polishing, develop reductions in treatment efficiencies in the presence of interfering contaminants, so that pretreatment is required. In existing water-treatment facilities, pretreatment requirements are met by employing successive processes -- in an order that progressively removes various interferences. For example, a facility that receives a water with high levels of adsorbable organics and high suspended solids may use granular media filtration prior to carbon adsorption in an effort to minimize the levels of solids in the influent to the carbon adsorption; the load of solids to the adsorption column will disrupt this process.

If several processes in a treatment configuration have disruptive interference problems, the particular combination of processes cannot be reasonably employed to treat the water. This situation might occur if an influent contained high levels of dissolved organics and inorganic chemical oxidants, and the treatment configuration under consideration was a combination of desalination and ion exchange. The dissolved organics, which would be removed by desalination, could severely disrupt the ion exchange efficiencies, while the chemical oxidants (removable by ion exchange) could disrupt the desalination process. This particular treatment configuration would, in this instance, be eliminated from further consideration because additional pretreatment would be required to manage the chemical interferences.

Air Stripping/Aeration

Air stripping and aeration can be used for removal of volatile contaminants from ground water, as well as for introduction of oxygen to the water. Air is passed through the water or the water is finely sprayed into the air, enhancing transfer of dissolved gases from the water to the air, which may be treated further or discharged. Cost-effective and efficient treatment requires continuous or semicontinuous flow. The process has been used for ammonia removal, hydrogen sulfide removal, and volatile organic carbon removal in both water and wastewater treatment operations. The treatment efficiencies and design are a function of the contaminant loading to the air, water ratio, the length of contact time, contaminant volatility, and temperature. Removal efficiencies of volatile organics ranging from 10 percent to greater than 99.0 percent have been reported in the literature.

Although air stripping is a relatively inexpensive technology for removal of volatile contaminants, its use in public water-supply systems to date has been somewhat limited. Its limited use is due primarily to a lack of need for the technology, which is in widespread use in Superfund remedial action and wastewater treatment operations. Traditional aeration, which is in common use among public-water utilities, has typically been installed to provide oxygenation of waters, and the removal of volatile contaminants is merely a beneficial side-effect.

Temperature limitations in regions experiencing severe winters may be such that air stripping and aeration processes must be housed indoors or in thermally protected facilities. If the treated water contains high levels of suspended solids (unlikely to occur with ground waters), some pretreatment, such as filtration or pH adjustment, may be required prior to air stripping.

Aeration and air stripping pose potential air pollution problems if large amounts of volatile contaminants in the treated waters are transferred to the air. If this is a problem, emission control devices are required. Most ground waters, however, are not likely to contain concentrations of volatile contaminants sufficiently large to warrant such controls.

Carbon Adsorption

Carbon adsorption treatment of ground waters entails contacting the water with activated carbon, which adsorbs contaminants and removes them from solution. Granular activated carbon, used in beds or columns, is the most commonly used form, although powdered activated carbon has been used in some wastewater treatment applications.

Treatment processes can use both batch and continuous-feed operations. Activated carbon adsorption effectively removes many organic and inorganic contaminants from solution. Treatment efficiencies are a function of the type of carbon used, the concentration and type of contaminants present, the length of contact time for each unit of water, and the interval between carbon regeneration or replacement. Removal efficiencies ranging from 0 to greater than 99.9 percent have been reported in the literature.

Although activated carbon adsorption theoretically can provide limitless removal of contaminants, in reality there are economic limitations to the applicability of activated carbon treatment. Removal of high concentrations of contaminants may require overly frequent carbon replacement, while hard to remove contaminants may require enormous treatment facilities with several carbon contact systems: both situations may incur excessive expense, and though technically feasible would be effectively unavailable.

Influent to the carbon adsorption process must be relatively free of suspended solids and oil/grease to prevent clogging of the adsorption beds. Suspended solids of less than 50 mg/L and oil/grease of less than 10 mg/L are recommended concentrations to avoid interferences. Biological activity in the carbon beds may become a problem in some instances, causing clogging and taste or odor generation.

Removal efficiencies in carbon adsorption systems are affected by changes in influent flow and influent chemical composition. The presence of multiple contaminants in the influent may reduce adsorption efficiency for some of the constituents, although in some instances where multiple contaminants are involved, increased removal efficiencies have been noted. For any given water to be treated, the selection of the appropriate carbon and system design requires laboratory testing to determine the specific adsorption efficiencies and interferences for that influent.

Chemical Precipitation

Chemical precipitation, coagulation, flocculation, and sedimentation are all interrelated processes that are most often used to remove metals and certain organics from solution. For waters containing dissolved solids, a precipitant is added which reacts with the contaminant to form a solid, or to shift solution chemistry in such a way that the contaminant solubility is reduced. The precipitated contaminant can then be removed by gravity sedimentation or mechanical solids removal processes. Commonly used precipitants include lime, caustic, soda ash, iron salts, and phosphate salts. Some waters contain colloidal suspended solids which cannot be readily removed using conventional sedimentation. Treatment of these contaminants, which are

usually organic in nature, entails addition of a coagulant (usually alum, cuprous sulfate, or ferrous sulfate) that forces the suspended solids to agglomerate into larger particles, which can then be removed using gravity sedimentation. Some facilities add polymeric coagulant or precipitation aids, which have been shown to enhance removal efficiencies in some cases. Chemical precipitation processes can be run as batch or continuous-flow operations. Treatment efficiencies depend upon the contaminant type and concentration present, the solution pH and temperature, the precipitants added, time and degree of mixing, and the time allowed for sedimentation.

Precipitation of metals from solution can be inhibited by the presence of chelating agents in the waters, such as humic materials (naturally occurring organic acids) or other organic compounds. This problem can be eliminated by using precipitants with stronger affinities for the metal than the complexion agent or by using pH adjustment to disrupt the metal complex.

Use of chemical precipitation processes generates a sludge that must be disposed of appropriately. Sludges containing heavy metals or certain organics may be considered to be hazardous wastes and as such should be disposed in RCRA-regulated facilities.

Desalination

Desalination processes remove contaminants from the influent using membranes to separate an enriched stream (high-contaminant concentration) from a depleted stream. Reverse osmosis and ultrafiltration use a pressure differential to drive the separation, while electrodialysis depends on an electric field. The concentrated or enriched stream frequently requires further treatment, while the depleted stream is usually potable. Desalination processes have been used to purify waters to drinking-water quality in certain regions of the country where fresh water is in short supply. The processes are in more widespread use for treatment of industrial process waters which must be of extremely high quality. Treatment efficiencies are a function of the molecular size and concentration of contaminants, strength of the separation driving force, membrane type, and system configuration. Removal efficiencies of greater than 90 percent have been reported in the literature.

Desalination processes are highly sensitive to variability in the influent, and drastic changes in pH, temperature, or suspended solids. Any of these factors can effectively reduce treatment efficiencies and the membrane life. The suspended solids in a desalination influent should be minimized to particle sizes 10 microns or less in order to

prevent membrane fouling. Biological activity can severely impair the process efficiency, and disinfection may be required prior to desalination. The presence of chlorine may also disrupt efficient desalination, dechlorination or non-chlorine disinfection processes may be desired.

Desalination processes are very expensive and energy-intensive. Because of this, desalination is not frequently used for removal of contaminants that are readily removed via other treatment processes. However, for high TDS waters and waters with large dissolved molecules, these processes may provide cost-effective contaminant removal.

Flotation

Flotation is used to remove oil and grease or suspended particles from the aqueous phase. The process involves introduction of a gas (usually air) into the solution, and subsequent attachment of the gas bubbles to particulate matter, which then floats to the surface. The floating particulates can be skimmed and removed for disposal or further treatment. Surfactants and pH-modifications are often used to improve process performance. Flotation is used in many public-water utilities across the nation for removal of organic matter from surface waters, but the most common use of the process is removal of oils and grease from industrial petroleum wastewaters. Removal efficiencies are a function of concentration, size, mass of contaminant particles, air-loading rate, types of chemical additives used, hydraulic-loading rate, and skimmer design. Removal efficiencies over 95 percent have been reported in the literature.

Flotation is effective for contaminants with densities less than or near to that of water, but is relatively ineffective for contaminants denser than water. It is not particularly effective for removing dissolved contaminants, although chemical additives can be used to decrease contaminant solubility. If volatile contaminants are present in the influent, flotation may result in simultaneous stripping of these contaminants from solution.

Granular Media Filtration

Granular media filtration is widely used to separate solids from aqueous streams. Water is fed (via gravity or applied pressure) through a bed of granular media, which may consist of sand, gravel, coke, or combinations of the three. Periodically the filter is backwashed, which removes the filtered particles into a relatively small volume of wastewater which must be disposed of or treated further. Granular media filtration is commonly used in water utilities following chemical precipitation to ensure that turbidity standards are met. Filtration performance depends upon the solubility of the contaminants, the strength and size of contaminant

particles, the type of granular media used, the hydraulic loading rate, and the interval between backwashings. Removal to suspended solid levels less than 10 mg/L has been reported.

Ion Exchange

Ion exchange processes, like carbon adsorption, operate by removing contaminants from solution onto a receptor. The ion exchange process uses a chemically reactive resin that exchanges innocuous ions for the contaminant ions in solution. The reaction is reversible, which allows a facility to regenerate the ion exchange resin and reuse it. Ion exchange processes are most commonly used to generate high-quality industrial processes waters, but recent applications have also included wastewater treatment and ion exchange water softening to remove hardness in drinking-water supplies. Ion exchange can be used for removal of almost any ion from solution, but is not very effective for removing uncharged contaminant species. Removal efficiencies, which have been reported in excess of 99.9 percent, are dependent upon the ionic charge of the contaminants, contaminant concentration, type of resin used, hydraulic loading, and interval between resin regeneration.

Although almost any ionic contaminant can be removed using ion exchange processes, the specific ion exchange resins used are usually specific to certain types of contaminants. Resin selectivity is based on the type (positive, or negative) and degree of charge on the contaminant ions. If several types of contaminants with varying charge are present, efficient ion exchange treatment may require a series of different resins.

Changes in pH or the presence of organic and inorganic complexing agents may cause certain ionic species to form uncharged or differently charged chemical complexes, which in turn can reduce the efficiency of ion exchange treatment. These problems are often overcome by adjusting pH so that the desired ionic species are present, or by pretreating the influent to remove complexing agents. Pretreatment may also be required if the influent to the ion exchange process contains excessive suspended solids which will clog the bed or foul the resin.

Ozonation

Ozonation is a chemical oxidation process in which the influent stream is contacted with ozone, which breaks refractory (nonbiodegradable) organic compounds into smaller, treatable or nontoxic compounds. Used alone or in conjunction with ultraviolet radiation, it is a highly effective means of treating dilute concentrations of organics. The process can achieve both effective disinfection and up to 99

percent removal of certain organic compounds, including pesticides, chlorinated hydrocarbons, alcohols, chlorinated aromatics, and cyanides.

The efficiency of contaminant removal using ozonation is dependent upon the retention time of the process reactor, the ozone dose rate, the ultraviolet light dose rate, and the contaminant type and loading. Treatability studies are required prior to installation of ozonation processes to treat specific influent streams.

Ozonation is currently used by only a few public-water supply systems, primarily as a disinfection process. It is an expensive process which is readily replaceable with chlorination for disinfection, but which has been gaining acceptance for use in public water-supply systems because it does not cause any by-product trihalomethane formation. Lack of use of ozonation in public water-supply treatment systems may be due to economic constraints and limited need for the technology.

Disinfection and Fluoridation

Two water-treatment processes that are universally available are chlorine disinfection and fluoridation. Chlorine disinfection is the most commonly used means of destroying bacteria in public-water supplies. Fluoridation of water supplies is used to prevent dental health problems. The processes do not remove chemical contamination from the wastestream; they serve instead as preventive measures taken to control disease and to maintain public health.

C.2 Partial Bibliography of References Evaluating Water Treatment Technologies

American Water Works Association. Research Foundation and Keuringsinstituut voor Waterleidingartikelen (Cooperative Report). "Occurrence and Removal of Volatile Organic Chemicals from Drinking Water." Denver, CO. 1983.

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APPENDIX D

SUPPLEMENTAL INFORMATION FOR CLASS I AND CLASS III ECONOMIC TESTS

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SUPPLEMENTAL INFORMATION FOR CLASS I AND CLASS III ECONOMIC TESTS

This appendix provides background material on the economic tests of irreplaceability (for Class I candidate sites) and untreatability (for Class III candidate sites) and is organized into five sections. Section D.1 presents the components and types of water-supply system costs. Section D.2 describes general procedures for estimating the costs of water-supply systems. Sections D.3 and D.4 emphasize cost-estimation procedures for Class I and Class III candidate sites, respectively, and present illustrative examples. Section D.5 explains the derivation of the economic threshold against which water-supply costs are compared and continues the examples started in Sections D.3 and D.4. Section D.6 provides references used in developing Class I and Class III economic tests.

D.1 Components and Types of Costs

Water-supply system costs can be broken down into four major components:

1. Acquisition.
2. Treatment.
3. Distribution and transmission.
4. Support services.

These cost components are described in more detail in Section D.1.1. For each of the four components, costs are distributed between two types of costs: (1) capital costs, and (2) operation and maintenance (O&M) costs. Furthermore, capital costs and O&M costs can be combined to derive total annualized costs. Section D.1.2 describes the various types of costs with an emphasis on how to derive total annualized costs. The composition of water-supply-system costs by cost component and type of cost is illustrated in Table D-1.

TABLE D-1

COMPONENTS AND TYPES OF WATER SUPPLY SYSTEM COSTS a/

Cost Component	Type of Cost: Capital Costs	Type of Cost: O&M Costs
Acquisition	Land Rights-of-way Dams/reservoirs Well field	Labor Materials Utilities Recurring payments for water rights
Treatment	Land Facilities Equipment	Labor Materials Utilities Parts and inventory
Distribution and Transmission	Rights-of-way Distribution network Pumping stations	Labor Materials Utilities
Support Services	Building	Administration

a/ List of capital and O&M cost items is provided for illustrative purposes and is not meant to be comprehensive.

D.1.1 Cost Components

Acquisition costs are the costs of producing or acquiring water and can be thought of as the costs of getting the water from the source to the treatment point. These costs include the capital and O&M costs of wells, reservoirs, and aqueducts, and payments to suppliers for purchased water. Treatment costs include the costs of treatment plants and equipment, and the costs of chemicals that are added to the water. Distribution and transmission costs are the costs of pumping the water from the treatment points to the service population and incorporate the capital and O&M costs of the piping network. Support services are the costs of administrative and customer services that are not directly related to the physical process of delivering water.

Acquisition

Acquisition costs depend primarily on the characteristics of the water sources for the system and the distance from the water source to the treatment point. At one extreme, these costs may be very low where reliable natural sources are sufficient to meet the needs of the system. For example, the Culpepper, Virginia, water utility acquired all of its water in 1976 from a free-flowing stream that fed directly into its treatment plant. The flow of the stream was regulated by upstream reservoirs constructed to control flooding using Federal funds. Therefore the utility had no acquisition costs. Other systems benefit from proximity to natural surface-water bodies, or reliable stream or river sources. In these cases, acquisition costs typically are limited to pumping water from the natural source to the treatment plant, although payments for rights to use the water may be required. In general, acquisition costs may be incurred in the construction and maintenance of dams and reservoirs to collect and store surface water, in the development and operation of well fields to utilize ground-water sources, and in pumping water from the source to treatment plants.

Treatment

Treatment costs depend on the quality of the water source: The physical, chemical, and bacteriological characteristics of surface water can vary on a daily and seasonal basis, depending on rainfall, temperature, flow rate, and the character of materials deposited over the run-off area or discharged upstream. Daily monitoring and adjustment of the treatment process may therefore be necessary. On the other hand, for some New England water

controlled, and the water may undergo natural filtration during run-off and consequently require no treatment, or merely a small volume of chemicals added directly to the reservoir. Similarly, ground water may require only limited treatment. Treatment costs typically range from 0 to 300 dollars per million gallons, but in extreme cases may be as much as three times greater. Costs are likely to increase, however, in the full implementation of the Safe Drinking Water Act, as amended in 1986.

Distribution and Transmission

Distribution and transmission costs depend primarily on the distance from treatment points to the service population, the altitude of the population served relative to the treatment points, and the density of the service population. As the distance or height that water must be pumped to the service population increases, the unit costs of distribution and transmission increase. Similarly, increased dispersion of the service population raises costs. This component of cost is a substantial fraction of total costs for water-supply utilities and typically ranges between $200 and $500 per million gallons supplied.

Support Services

The unit costs of support services are essentially independent of the physical characteristics of the system. These costs are primarily administrative and customer service costs and therefore depend primarily on the characteristics of the service population and the level of service chosen by the utility; however they are typically about $200 per million gallons.

D.1.2 Types of Cost

Capital costs are expenditures for items such as land, buildings, and equipment that have a long economic life. O&M costs are recurring expenses for items such as labor, materials, and utilities. Capital costs and O&M costs can be combined to derive total annualized costs using the following formula:

$$TAC = f\ CC + OMC \qquad (1)$$

where: TAC are total annualized costs ($ per year);

f is the annualization factor;
CC are capital costs; and
OMC are the operation and maintenance costs ($ per year).

Because capital expenditures generally are for investments in capital goods that have a relatively long life expectancy, capital costs are in units of dollars over many years.

The annualization factor is derived to obtain equal annual payments of capital costs in constant dollars. It can be derived using the following formula:

$$f = r / (1 - 1/(1+r)^n) \qquad (2)$$

where: r is the real discount rate; and
n is the life expectancy of the capital investment.

This formula is the same as the one used to obtain a total of n equal annual payments for a fixed mortgage in real dollars, where r is the real interest rate for the mortgage. As a first approximation, an annualization factor equal to 0.1 may be used.

The choice of real discount rate depends on the costs of available financing for the water-supply system. The U.S. Office of Management and Budget (OMB) recommends that a 10 percent rate (i.e., r = 0.1) be used to discount capital costs in the analysis of regulatory options. Therefore, a discount rate of 10 percent may be used to derive the annualization factor. Alternatively, real interest rates on tax-exempt bonds used to finance water projects can be used in the analysis. For a real discount rate of 10 percent, Equation (2) suggests annualization factor values of 0.131 and 0.106 for life expectancies n of 15 and 30 years, respectively. For a real discount rate of 5 percent (i.e., r = 0.05), the annualization factor is equal to 0.096 and 0.065 for life expectancies of 15 and 30 years, respectively.

D.2 General Cost Estimation Procedures

This section is organized in three subsections as follows: Section D.2.1 presents a general overview of the cost-estimation techniques and assumptions for the economic tests. Section D.2.2 discusses three general approaches to cost estimation, and Section D.2.3 shows how to derive the final cost estimate for either of the two economic tests used in these Guidelines.

D.2.1 Overview of Cost Estimation

The economic tests of irreplaceability and untreatability are intended to test whether total water-supply costs after replacement or treatment would exceed a given economic threshold. For Class I candidate sites, if total costs after replacement would exceed the economic threshold, then the ground water underlying the site is Class I-irreplaceable. For Class III candidate sites, if total costs after treatment would exceed the economic threshold, then the ground water underlying the site is Class III-untreatable. The economic tests therefore can be written as follows:

$$TAC \geq TAC_{th} \tag{3}$$

where TAC is the total annualized costs for the system ($/yr/hh); and

TAC_{th} is the threshold cost for the economic tests ($/yr/hh).

Cost estimates in Equation (3) are in units of dollars per year per household. For unit conversions, the classifier may assume 100,000 gallons per year per household.

Total annualized costs for a water-supply system can be calculated as the sum of total annualized costs over the four cost components identified in Section D.1:

$$TAC = TAC_a + TAC_t + TAC_d + TAC_s \tag{4}$$

where TAC_i are the total annualized costs for cost component i (i = a, t, d, or s).

For each cost component, total annualized costs are the sum of annualized capital costs and O&M costs. For example, total annualized costs for acquisition are equal to the following equation:

$$TAC_a = f\ CC_a + OMC_a \tag{5}$$

where: TAC_a are the total annualized costs for the acquisition component;
f is the annualization factor;
CC_a are capital costs of acquisition; and
OMC_a are operation and maintenance costs of acquisition.

D.2.2 Methods for Estimating Costs

There are several approaches to estimating the costs of water-supply systems, including the following:

1. Engineering cost estimates, i.e., estimates derived assuming certain design, construction, and operation specifications;

2. Existing system costs, i.e., costs currently incurred by specific water-supply systems; and

3. Typical system costs, i.e., costs typically incurred by water-supply systems in the nation.

Other approaches include combinations of the three methods mentioned above. Regardless of the cost estimation approach used, the matrix-form worksheet in Table D-2 can be used to estimate the cost of a water-supply system. This worksheet breaks down water-supply system costs by cost component (e.g., acquisition) and type of cost (e.g., capital costs).

Engineering Cost Estimates

Engineering cost estimates begin with a thorough inventory of items or activities resulting in costs. Table D-1 illustrates a sample of these cost items for each cost component broken down between capital costs and O&M costs.

Except for a site-specific analysis of engineering costs, cost estimates can be derived using engineering-based cost equations for the various capital and O&M cost items. These cost equations are available in the published literature for a number of possible water-supply system designs. For example, EPAs Culp et al. report (1978) presents capital and O&M cost curves and cost tables for construction. Another useful source of data for acquisition costs is the NWWA Nationwide Water Well Drilling Cost Survey (NWWA, 1979). The results of this survey are summarized in the form of tables giving drilling and casing costs as a function of the well diameter, hydrogeologic conditions, and

TABLE D-2

WATER SUPPLY SYSTEM COST WORKSHEET

Cost Component	Type of Cost		Total Annualized Costs
	Capital Costs	O&M Costs	
Acquisition			
Treatment			
Distribution and Transmission			
Support Services			
TOTAL			

other factors. Although this survey dates back to 1979, it provides useful information on costs which must be escalated to account for inflation.

In addition, several reports have been published by EPA on the costs of water treatment, including the following:

- Estimating Water Treatment Costs, Gummerman, Culp, and Hansen, EPA 600/2-79-162a.
- Treatability Manual, Technologies for the Control Removal of Pollutants, EPA 600/2-82-001C
- Estimation of Small System Water Treatment Costs, EPA 600/2-84-184a.

When using published cost curves, it is important to identify the system components included in the cost curve. Table D-3 lists the system components typically required for each treatment technology. Table D-4 indicates engineering-based annualized cost estimates for typical treatment components for four typical plant sizes.

Cost data provided in the sources mentioned previously must be updated to account for inflation and geographical variations (e.g., in costs of labor and energy). The Engineering News Record publishes cost indices for such items as materials, energy, and labor. Also, updated cost assessments will likely be available from EPA or the water utility industry under the public water-supply provisions of the Safe Drinking Water Act.

If engineering cost estimates are used for a given cost component, then estimates of capital costs and O&M costs must be entered into the worksheet for this component. Total annualized costs for this component then are calculated as the sum of O&M costs and annualized capital costs as indicated in Equation (5).

Existing System Costs

As an alternative to engineering cost estimates, the costs of an existing water-supply system can be estimated rather accurately if detailed accounts (e.g., financial statements) are available from the water utility that owns/operates the system. Not all water-supply systems may be willing to share detailed cost data with the classifier. In the absence of such detailed accounts, it is possible to use rates charged by the utility as an indicator of the system costs. However, rates charged and true system costs may differ for a number of reasons.

TABLE D-3

TYPICAL COMPONENTS OF SELECTED TREATMENT TECHNOLOGIES

Aeration/Air stripping

- Aeration tower
- In-plant pumping

Activated Carbon

- Carbon columns
- Backwash pumping
- Washwater surge basin

Chemical Precipitation

- Lime feed system
- Contact clarifier
- Sludge pumping
- Sludge drying beds
- Sludge hauling

Desalination

- Reverse osmosis
- In-plant pumping

Ancillary Operations

- Administrative
- Raw water pumping
- Polished water pumping
- Clearwell storage

Filtration

- Granular media filtration beds
- Granular media
- Backwash pumping
- Washwater sewage basin

Ion Exchange

- Pressure ion exchange system

Flotation

- Dissolved air flotation
- Sludge pumping
- Sludge drying beds
- Sludge hauling

Ozonation

- Ozonation system

TABLE D-4

ANNUALIZED COSTS OF TYPICAL
TREATMENT COMPONENTS FOR FOUR PLANT SIZES

Treatment Component	User Population Size			
	500	2,500	5,000	25,000
Aeration/ Air Stripping	$16,500	$20,700	$28,000	$70,200
Activated Carbon	$18,800	$27,000	$33,900	$113,900
Chemical Precipitation	$35,200	$51,500	$62,700	$127,700
Desalination	$43,900	$109,500	$171,500	$595,600
Flotation	$30,100	$37,300	$48,900	$109,800
Filtration	$56,200	$61,400	$69,100	$107,700
Ion Exchange	$10,100	$26,400	$38,900	$74,800
Ozonation	$6,000	$7,000	$9,300	$19,200
Ancillary	$25,900	$24,000	$46,200	$110,900

All figures in 1982 dollars.

The utility may not set rates on the basis of economic costs of supply or the utility may not face the true economic costs. The utility may charge different rates to different types of users in such a way that one type of user (e.g., industrial users) implicitly subsidizes other types of users (e.g., households). Also, some systems may receive subsidies from the Federal government or other public agencies; in such a sitution the rates charged by the system would be less than true economic costs.

Typical System Costs

Finally, it may also be possible to determine typical costs based on survey data drawn from water systems throughout the country. Typical system costs are defined here as the median (i.e., 50th percentile) cost of all water supply systems of equivalent size in the nation. Estimates of typical water-supply system costs are provided in Table D-5 for each of seven user population size ranges.

If typical estimates are used for a given cost component, then total annualized costs can be entered directly for this cost component. Typically, total annualized costs for a given component are equal to a certain fraction of the total annualized costs of the whole system (i.e., sum over all components of total annualized costs for each component). Table D-6 indicates this fraction of the total system cost-by-cost component and system size range. For example, the typical cost of acquisition for a water-supply system serving a population of 5,000 persons is equal to roughly $40 per household (i.e., the product of $180 per household from Table D-5 multiplied by the 22 percent value from Table D-6).

D.2.3 Final Cost Estimate

The total annualized costs for a given water-supply system are reported in the lower right cell of the cost estimation worksheet in Table D-2. As indicated earlier, the total annualized costs for the system can be derived by summing up total annualized costs for each of the four cost components (Equation 4). Section D.2.2 explained several possible methods for estimating total annualized costs for each component. As discussed in the following two sections, the choice of cost estimation method depends on the economic test considered.

TABLE D-5

TYPICAL WATER SUPPLY SYSTEM COSTS

User Population Size	Median Annual Cost ($/household)
101-500	240
1,001-3,300	190
3,301-10,000	180
10,001-25,000	130
25,001-50,000	120
50,001-500,000	100
500,001+	70

Total annualized costs, i.e., annualized capital costs (debt service of capital expenditures) plus O&M costs. Depreciation costs are not included. Costs are rounded to the nearest ten dollars.

Source: Data collected by the Research Triangle Institute (Immerman, 1987) and analyzed by Cadmus, Inc. and ICF Incorporated.

TABLE D-6

COMPONENT COSTS AS A PERCENTAGE OF TOTAL WATER SUPPLY SYSTEM COSTS

	User Population Size	
Cost Component	300-75,000	75,001+
Acquisition	22%	19%
Treatment	18%	13%
Delivery	43%	38%
Service	17%	30%

Total annualized costs of a component as a percentage of total annualized costs for the system.

Source: ACT Systems, Inc., 1979.

D.3 COST ESTIMATION FOR THE CLASS I - ECONOMIC IRREPLACEABILITY TEST

Given the general procedures described above for estimating the cost of a water-supply system, the procedures used for a specific Class I or Class III classification should reflect the intent and design of the economic irreplaceability test or the economic untreatability test, respectively. This section provides guidance for estimating costs in keeping with specific Class I, economic irreplaceability requirements while Section D.4 explains the cost estimation procedure for Class III.

D.3.1 Class I Cost Estimating Procedure

As noted in the discussion of the economic irreplaceability test for Class I sites (Chapter 4), the purpose of this test is to determine whether the economic burden of replacing an existing ground-water supply would be unreasonable. If the burden of the replacement costs would be unreasonable, then the ground water is Class I -- economically irreplaceable.

In order to apply this test, the annualized total system cost after the affected component(s) of the existing system has been replaced must be calculated. The replacement process may range from simply sinking a new well (or tapping a surface-water source) to creating an entirely new public-supply system for households previously served by private wells. Therefore, the classifier should first establish which components will remain unaffected and which will need replacement in the event that the ground water in the Classification Review Area becomes unusable. Once this division is established, the classifier can compile the various cost estimates to yield a total system cost.

In general, the classifier should rely on readily available cost information and use best professional judgment to determine which data sources are most appropriate when making a cost estimate. The classifier should note, however, that the Agency believes that some data sources (e.g., existing system costs) are more accurate and therefore preferable to other data sources.

For system components that will not require replacement (e.g., the distribution network for an existing system), current annual costs for those components represent the most accurate source of data and should be preferred. If the water-supply system(s) in question will not make these costs available, then engineering costs as described in Section D.2.2 are probably the next best source of accurate costs. Costs for the relevant components of similarly sized existing systems in the same geographic region as the ground water under consideration may also provide reasonably accurate information. If the total costs for the system(s) in question are available but not broken down into component costs, these aggregate costs could be disaggregated using the component proportions provided in Table D-6.

As a final source of data, the typical cost estimates for specific components can be developed by combining the information in Tables D-5 and D-6. In using these typical costs, however, the classifier should verify that the cost of the component at a particular site is unlikely to differ significantly from the median cost across the country of the system component. Classifiers should be aware that if the typical cost values presented in Table D-5, which represent national median values, are used in all cases, then the total system cost estimate will never exceed the ninetieth percentile threshold values demonstrating irreplaceability.

For system components that will require replacement, costs that are drawn directly or imputed from existing system components very similar to the anticipated replacement components should be preferred. If these costs are not available or are not disaggregated among cost components, then engineering costs are preferable. Likewise, costs drawn or imputed from existing system components of comparable systems in the same geographic region may be useful.

If only the total costs of the system(s) in question are available, then the classifier may be able to disaggregate total costs using the proportional values presented in Table D-6. In doing so, the classifier should recognize that these proportions represent entire components (e.g., the entire acquisition system). If only a part of the component (e.g., a single well) is being replaced, therefore, the classifier should correct the calculations accordingly to avoid overestimation of costs.

Finally, if no other sources of data are available and the classifier can verify that the replaced component(s) will not differ significantly in cost from the typical component(s) throughout the country, then the typical cost of the replaced component(s) can be estimated by combining the data provided in Tables D-5 and D-6.

Once the classifier has compiled the appropriate cost estimates for both unaffected and replacement components, these costs should be converted into annual household costs using the methodology presented in Section D.2.1. The following section presents a hypothetical example to illustrate this process.

D.3.2 Hypothetical Example of Class I Cost Estimation

This section provides an illustrative example of cost estimation procedures for a Class I candidate site. Within the Classification Review Area, there are 500 private wells, each serving a single household and one public well field serving a public-water system of 2,475 persons. Given an average of 2.75 persons per household, there are estimated to be 3,850 persons using water from within the Classification Review Area (i.e., 1,375 private well users plus 2,475 public system users). The classifier determines that, in the event that the ground water becomes unusable, the public water system will develop a new well field outside the Classification Review Area and the private well users will require connection to the public-water system.

The annualized per-household cost after replacement of the ground water is estimated as the sum of the four cost components. First, total annualized acquisition cost is estimated at $142 based on the technical specifications of the new well field and the distance from the new well field to the existing treatment plant. Second, total annualized treatment costs are assumed to remain constant at $118 on a per-household basis because the water quality of the replacement is comparable to ground-water quality within the Classification Review Area and the addition of the private well users does not increase the total system size significantly. Third, total annualized costs for delivery are increased to $248 to reflect extension of the existing delivery system to the private well users. Finally, per-household support service costs are assumed to remain the same at $92. In this example, total costs are estimated at $600 per household per year.

D.4 COST ESTIMATING FOR THE CLASS III ECONOMIC UNTREATABILITY TEST

As with the Class I economic irreplaceability test, the general procedures for estimating water-system costs, as presented above, should reflect the intent and design of the economic untreatability test when performing a Class III determination. This section provides guidance for estimating costs in keeping with specific Class III economic untreatability requirements.

D.4.1 Class III Cost Estimating Procedure

As noted in the discussion of the Class III economic untreatability in Chapter 6, the purpose of this test is to determine whether the costs of treating a ground-water source would make the total system cost of a hypothetical water-supply system unreasonably expensive. If the total system cost would exceed the applicable economic threshold due to excessive treatment costs, then the ground water would not be considered a potential source of drinking water.

In order to apply this test, the annualized per household cost of a hypothetical ground-water supply system must be estimated. Because the cost estimate is based on a hypothetical system, the total cost estimate should include costs for each system component, including acquisition, treatment, delivery, and services.

In order to ensure that the test focuses on treatment costs rather than on costs for the remaining components, typical cost values derived from the information presented in Tables D-5 and D-6 are provided as a source of default values for acquisition, delivery, and services. In some circumstances, the classifier may chose to use cost estimates for nontreatment components that are based on costs typical of similarlysized systems in the same geographic region as the ground water under review if these costs are clearly and substantially different from the national median costs.

In all cases, the cost estimate derived for the treatment component of the hypothetical system should be based strictly on site-specific treatment costs and <u>not</u> on default or typical national costs. Moreover, in applying this test, the classifier should ensure that the treatment component cost used is based on the least expensive, technically feasible treatment train. While the

identification of the least expensive treatment train may not be possible until all feasible trains are reviewed, some trains may be disregarded immediately. For example, any treatment train (e.g., aeration and flotation) that includes other technically effective treatment trains (e.g., aeration) clearly will be less cost effective and may be disregarded.

In estimating the cost of a feasible treatment train, a detailed site-specific engineering cost estimate should be compiled if possible. If such detailed costs are unavailable, then the classifier can compute costs using the methods given in Section D.2.2, which presents a discussion of engineering cost sources, typical components of potential treatment trains, and annualized costs for those treatment trains. Site-specific treatment costs may be calculated, therefore, by applying the engineering cost-estimation information presented in Section D.2.2 to the site-specific treatment trains available for the site under review and choosing the least expensive treatment train. This treatment cost, prepared as an annualized per household cost, should then be added to the cost estimates for acquisition, delivery, and services in order to produce a total system cost estimate.

The following section illustrates how a hypothetical water-supply system cost may be estimated using typical cost estimates for acquisition, delivery, and services and site-specific engineering cost estimates for treatment.

D.4.2 Hypothetical Example of Class III Cost Estimation

This hypothetical example is based on a ground-water source that is contaminated by trichloroethylene, tetrachloroethylene, carbon tetrachloride, cadmium, and selenium at levels that are above relevant water-quality standards. The ground water, therefore, would require treatment before it could be usable for drinking purposes. Based on information provided by the U.S. Geological Survey, it is estimated that the aquifer could sustain a daily yield of 440,000 gallons. Assuming a daily per capita need of roughly 100 gallons, the hypothetical user population that could be supplied by this well would be 4,400 persons, or, assuming 2.75 persons per household, 1,600 households.

Using this hypothetical population size, the annualized household cost for a water system that would include treatment technologies necessary to treat the water to relevant standards could be calculated using the following steps.

First, the default values for acquisition, delivery, and service can be calculated using the information presented in Tables D-5 and D-6. According to Table D-5, the median annual household cost for a total water-supply system serving a population of 4,400 people would be $180. Likewise, Table D-6 indicates that, for a system of 4,400 people, acquisition is typically 22 percent of the total system cost; delivery is typically 43 percent; and service is typically 17 percent. Based on these values, therefore, the default values would equal:

Acquisition	=	$39.60	(180 x .22),
Delivery	=	$77.40	(180 x .43),
Service	=	$30.60	(180 x .17).

Second, the reference technology test identified three possible treatment trains that could adequately treat the ground water to appropriate standards. These treatment trains include the following:

1. Air stripping and chemical precipitation.
2. Chemical precipitation and filtration.
3. Chemical precipitation, filtration, and desalination.

Because the third treatment train would add a treatment component to the second treatment train that is not necessary to meet relevant standards, the third treatment train may be disregarded. The costs of the remaining two treatment trains may be estimated using the engineering cost information provided in Table D-4. According to Table D-4, the cost of air stripping for a system size of 4,400 (rounding off to 5,000) is $28,000. Likewise, the cost of chemical precipitation is $62,700 while the cost of filtration is $69,100. Inflating these figures from 1982 to 1986 dollars (i.e., the year used to calculate the ninetieth percentile threshold function) using the Construction Cost Producer Price Index (i.e., an 8.1 percent increase) yields $30,300, $67,800, and $74,700 respectively. The first treatment train, therefore, would cost $98,100 while the second treatment train would cost $142,500. The first train is thus the least expensive. Because these costs are for the entire system, the cost of $98,100 should be divided by 1,600 in order to yield the cost per household of about $61. Finally, this treatment cost can be added to the default values

calculated above to yield an annualized total system cost per household of $209.

D.5 Derivation and Calculation of Economic Thresholds

Economic thresholds are used for both the Class I and Class III economic tests. For the economic irreplaceability test (Class I), the threshold is used to determine whether the cost of a replacement water-supply system would impose an economically unreasonable burden on the user population, hence making the existing source irreplaceable. For the economic untreatability test (Class III), the threshold is used to determine whether the cost of a water-supply system to a hypothetical user population would be made unreasonably burdensome by the need to treat the ground-water source in question, hence making that ground-water source economically untreatable. In both cases, the Agency has determined that if the annualized total costs of the replacement or hypothetical water-supply systems would exceed the costs faced by 90 percent of community water-supply system users, then the replacement or hypothetical systems would be economically unreasonable. The thresholds used for both tests, therefore, are the ninetieth percentile per household costs for community water-supply systems. This section briefly describes the derivation of the cost function used to calculate threshold values and then presents the actual methodology for making calculations. Two examples of the use of the thresholds are also presented.

D.5.1 Derivation of Economic Thresholds

As described in Section D.2.2, water-supply rates charged to residential users often do not reflect true economic costs. The costs used to develop threshold values for these Guidelines, therefore, are community water-supply system costs and not water rates. Using data collected by the Research Triangle Institute for the EPA Office of Drinking Water report "Final Descriptive Summary: 1986 Survey of Community Water Systems" (Immerman, 1987), ninetieth percentile water-system costs were calculated. Because the thresholds are to be applied as a function of system size (i.e., user population), for reasons noted in the economic irreplaceability test discussion of Chapter 4, the ninetieth percentile values were derived for each of the twelve size categories employed in the ODW report. Finally, based on the assumption that the average household water usage is 100,000 gallons per year, the data from the report,

given as cents per 1,000 gallons, were converted to dollars per household per year.

In order to make the twelve observations (i.e., the ninetieth percentile cost for each of the twelve system sizes) from the ODW survey usable for a continuous range of system sizes, a linear regression was performed with system size as the independent variable and cost per household as the dependent variable. The purpose of a linear regression analysis is to mathematically define the function which best describes the relationship between two variables. After adjusting the scale of system size with a logarithmic transformation, the following equation was developed:

$$THRESHOLD = (-200.255 \times LOG(SIZE)) + 1248.727$$

$R^2 = .712$
Standard error of Y estimate = 179.44
N = 12 (i.e., the number of system size categories)

where, THRESHOLD = threshold cost in dollars per household per year, and
SIZE = user population (individuals).

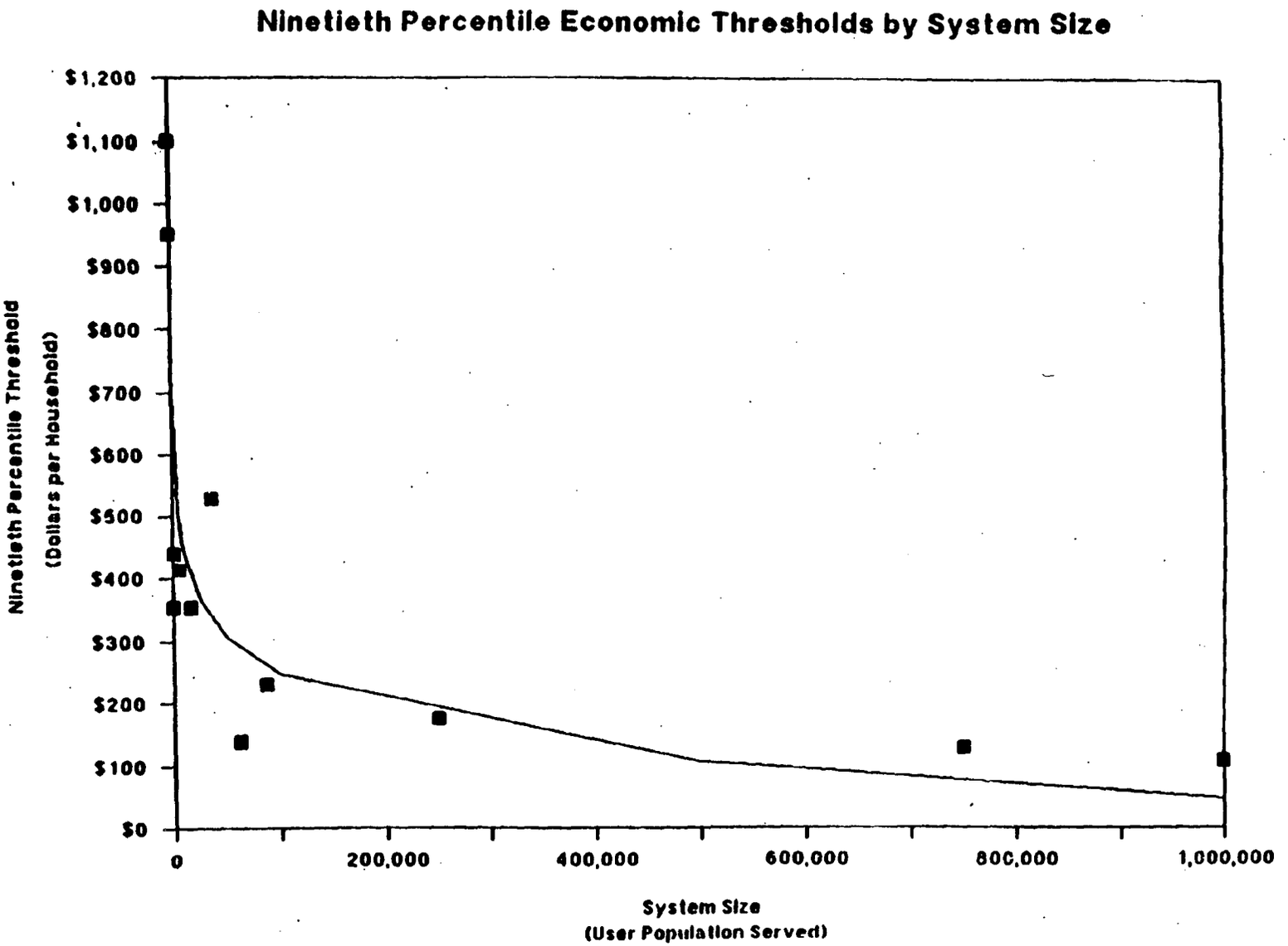
Figure D-1 presents this function graphically, along with the twelve observations used to define the function.

As the analysis results indicate, the equation appears to approximate the relationship between cost and system size fairly well, explaining roughly 71 percent of the variation in costs around different system sizes. Note, however, that the standard error of the estimate, which can be taken as the range above or below the estimate within which the true value will fall some 67 percent of the time, is somewhat large. The classifier should use best professional judgment, therefore, when making a determination of irreplaceability based on these threshold values; especially if the cost of the replacement water system falls very close to the threshold value.

D.5.2 Methodology for Calculating Economic Thresholds

In order to calculate the ninetieth percentile thresholds for either the economic irreplaceability or untreatability tests, the classifier should take the following three steps.

Figure D-1



SOURCE: ICF Incorporated Analysis of Data Collected by Immerman (1987)
DATE: 1988

First, the classifier should determine the number of individuals served by the water system. For Class I candidate sites, this number should have been estimated already for the substantial population analysis. For Class III situations, this number should be based on the maximum sustained yield of the aquifer in question as explained in Chapter 6. If the available size data is for households only, the classifier should convert households to individuals by assuming an average of 2.75 persons per household.

Second, the classifier should take the logarithm (base 10) value of the user population size. This transformation is necessary in order to manipulate the size variable in the proper scale. Most hand calculators have function keys allowing the easy log transformation of numbers.

Finally, the classifier should solve the equation given above by multiplying the log value of size by -200.255 and adding this value to 1248.272. The solution of this equation is the ninetieth percentile economic threshold for a user population the size of the system under review.

As an illustration of this methodology, consider a replacement water-supply system which would serve a user population of 4,500 persons and which is under review for a Class I determination. The cost function for estimating the ninetieth percentile economic infeasibility threshold should be applied as follows:

$$\begin{aligned} \text{THRESHOLD} &= (-200.255 \times \text{LOG}(4{,}500)) + 1248.728 \\ &= (-200.255 \times 3.653) + 1248.728 \\ &= -731.532 + 1248.728 \\ &= \$\ 517.20. \end{aligned}$$

If the annualized total cost per household of the replacement water-supply system would be greater than roughly $517, then the cost of that system would be an unreasonable economic burden on the user population and the current ground-water supply could be considered irreplaceable.

D.5.3 Illustrative Applications of Economic Thresholds

This section extends the examples related to Class I and Class III procedures provided in Sections D.3.2 and D.4.2, respectively, to demonstrate the use of economic thresholds.

Class I Example

Section D.3.2 presented an example of a Class I candidate site. In the example, a system with a user population of 3,850 persons was determined to face a per-household cost of $600 in the event that the ground water in the Classification Review Area became unusable. By using the equation described in Section D.5.2 above, an economic threshold of $530 for a system of this size is calculated. Because $600 exceeds $530, the ground water cannot be replaced at reasonable cost. Accordingly, the site is classified as Class I - irreplaceable.

Class III Example

Section D.4.2 illustrated the estimation of total system costs that reflected treatment of contaminated ground water at a Class III candidate site. Based on the maximum sustainable yield of the aquifer in question, the hypothetical water system was determined to have a size of 4,400 persons. Moreover, per household costs were estimated at $209. For a system of this size, the economic threshold is estimated at $519. The total costs of $209 fall below the threshold of $519; the site is not Class III and is instead a Class IIB - potential source of drinking water.

D.6 APPENDIX D REFERENCES

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