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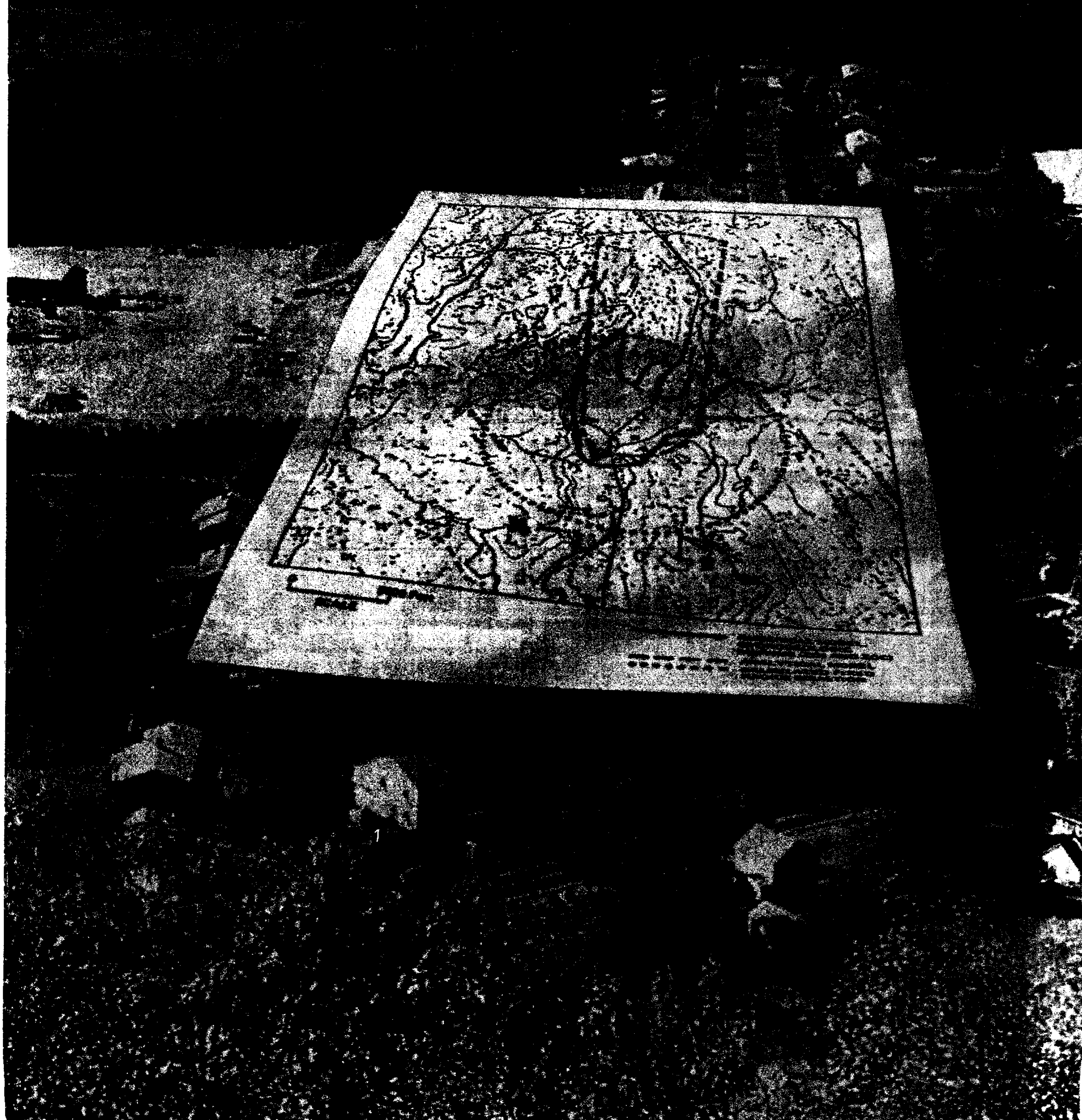
Wellhead Protection: A Guide for Small Communities



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February 1993

SEMINAR PUBLICATION

WELLHEAD PROTECTION: A GUIDE FOR SMALL COMMUNITIES

U.S. ENVIRONMENTAL PROTECTION AGENCY

OFFICE OF RESEARCH AND DEVELOPMENT
OFFICE OF SCIENCE, PLANNING AND REGULATORY EVALUATION
CENTER FOR ENVIRONMENTAL RESEARCH INFORMATION
CINCINNATI, OH 45268

OFFICE OF WATER
OFFICE OF GROUND WATER AND DRINKING WATER
GROUND WATER PROTECTION DIVISION
WASHINGTON, DC 20460

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Clem Wethington, Kentucky Rural Water Association

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Chapter 1

Introduction

Ground water is a life-sustaining resource for small communities throughout the United States. It supplies drinking water for 95 percent of rural communities and about one-half of the total U.S. population. It is also used for cooking, for raising livestock, and for agricultural purposes.

Ground water was once thought to be protected from contamination by layers of rock and soil that act as filters. We now know, however, that ground water is vulnerable to contamination. Contaminants can enter ground water from landfills and lagoons used for storing waste, chemical spills, leaking underground storage tanks, and improperly managed hazardous waste sites. Ground water pollution also can result from a myriad of common practices, such as the use of fertilizers and pesticides; the disposal of human, animal, and agricultural waste; and the use of chemicals for highway de-icing. More than 200 different chemicals, some harmful to human health, have been detected in ground water in the United States.

Preventing contamination is the key to keeping ground water supplies safe. Once a drinking water supply becomes contaminated, a community is faced with the difficult and costly task of installing treatment facilities or locating an alternative source. *Wellhead protection*—managing a land area around a well to prevent ground water contamination—offers an important opportunity to both ensure a high-quality water supply and save money. This document provides information that will help you protect your community's ground water resources.

Ground water supplies drinking water for 95 percent of rural communities in the United States.

Guidance for setting up wellhead protection programs is available at the state and federal levels, but *local initiative* is the key to developing an effective program. Each community can best determine how to develop its own wellhead protection program by taking into account local hydrogeological characteristics, land uses, and political and economic conditions.

This publication is designed to help small community decision makers, utility personnel, and other interested community members take intiative at the local level. It provides the basic information needed to begin a wellhead protection program (Figure 1-1):

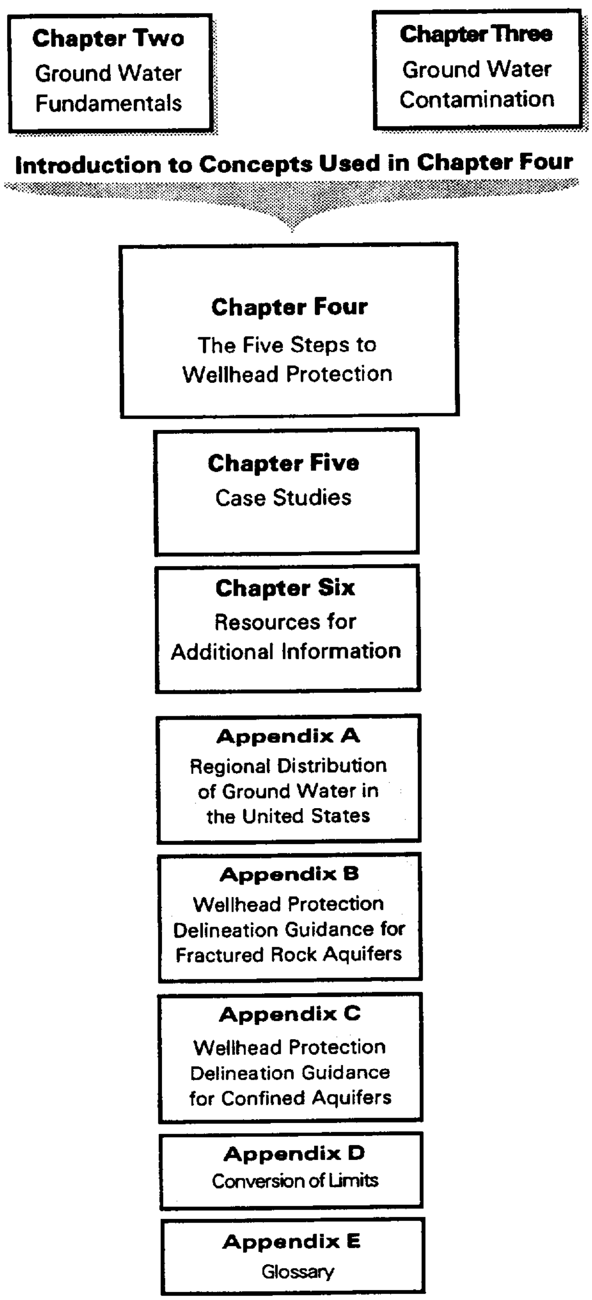


Figure 1-1. Guide to this publication.

- Chapter Two introduces some basic concepts about ground water that are useful in developing wellhead protection programs. It discusses the hydrogeologic cycle, types of aquifers, and fundamentals of ground water movement.
- Chapter Three explains how ground water becomes contaminated, discusses sources of ground water contamination, and describes the potential effects on human health and local economies. It also discusses legislation and regulations designed to protect ground water supplies.
- Chapter Four, the core of the publication, presents the five steps for developing a wellhead protection program (Figure 1-2). These steps form a simple, structured approach that communities with little or no experience in ground water protection or hydrogeologic methods can implement with some assistance (for ex-

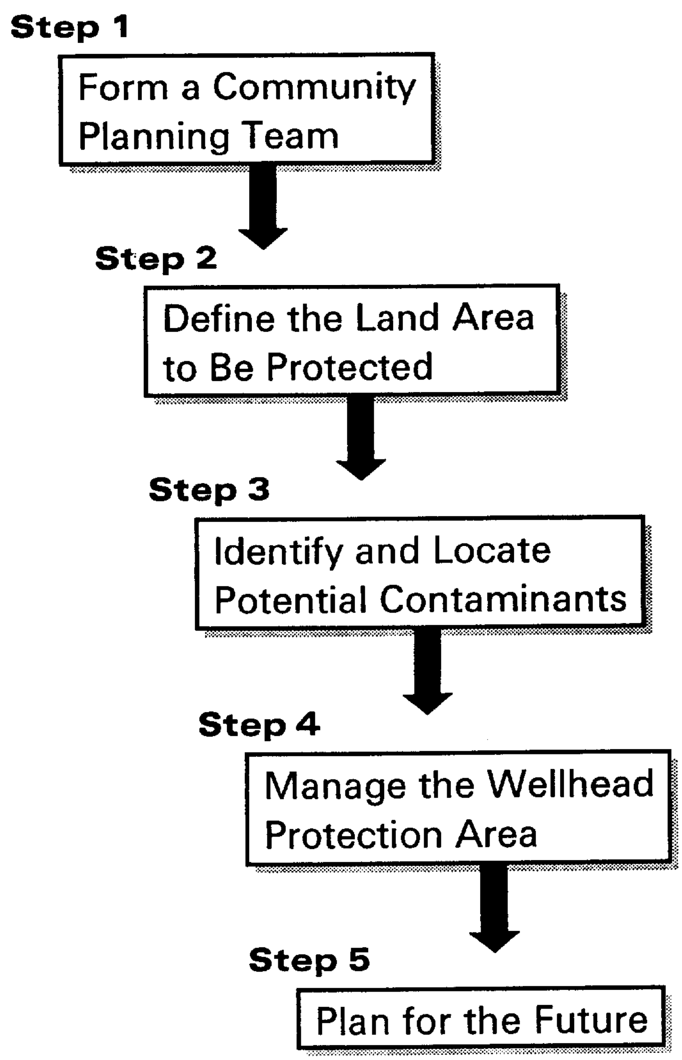


Figure 1-2. The five steps to wellhead protection.

THE EPA/NRWA WELLHEAD PROTECTION PROGRAM

Much of the material in this publication is based on the experience of a joint Environmental Protection Agency (EPA)/National Rural Water Association (NRWA) program. In March 1991, EPA's Office of Ground Water and Drinking Water provided a grant to NRWA to help small communities develop and implement wellhead protection programs. Through the EPA/NRWA Wellhead Protection Program, small communities gain access to a network of resources to help them protect their drinking water supplies.

To implement the program, NRWA hired 12 ground water technicians to work in 14 states: Arkansas, Georgia, Idaho, Iowa, Kentucky, Louisiana, Michigan, Massachusetts, New Hampshire, Pennsylvania, Utah, Vermont, West Virginia, and Wisconsin. The technicians were selected on the basis of their experience with municipal water programs, technical knowledge, communications skills, and willingness to travel. They received intensive training on the program's objectives, ground water pollution, wellhead protection, the five-step approach to wellhead protection, outreach and education strategies, and follow-up techniques. The technicians travel to small communities throughout their states, convincing them of the importance of wellhead protection, providing technical assistance, and taking them through the five steps to wellhead protection. Communities are encouraged to take the lead as they gain expertise in wellhead protection strategies and techniques.

The EPA/NRWA Wellhead Protection Program has made important strides in showing small communities the need for wellhead protection and helping them set up local programs. As of January 1993, 600 water systems had initiated wellhead protection, resulting in protection of the drinking water sources of more than 1 million people. It is unlikely that any of these systems would have developed wellhead-protection plans without assistance from the EPA/NRWA program.

To further disseminate the knowledge gained through this program, EPA's Office of Science, Planning and Regulatory Evaluation is coordinating a major technology transfer effort, consisting of workshops, publications, and other communications mechanisms. Workshops in eight states (California, Georgia, Iowa, New Jersey, Oklahoma, Pennsylvania, Utah, and Wisconsin) began in Fall 1992. "State Centerpiece" workshops are bringing together individuals and organizations involved in wellhead protection to coordinate efforts throughout each state and explore ways to help local communities develop wellhead protection plans. "Area-Wide" workshops promote awareness of ground water and wellhead protection and provide information to small community decisionmakers on how to set up local programs. This seminar publication is intended to bring information about wellhead protection to other small communities across the nation.

ample, from the state drinking water agency, the State Rural Water Association, the regional agricultural extension office, and/or the EPA regional office). Chapter Four includes an overview of methods for delineating wellhead protection areas.

NOTE: The reader might wish to begin with Chapter Four to learn about the steps involved in wellhead protection, and refer to Chapters Two and Three as needed.

- Chapter Five presents case studies describing the experiences of four small communities in setting up wellhead protection programs.
- Chapter Six lists many publications, financial assistance programs, and regional resources available to communities.
- Appendix A presents information on ground water regions of the United States.
- Appendices B and C discuss wellhead protection area delineation for confined aquifers and fractured rock.
- Appendix D provides information to help the reader convert numbers in this document to metric units.
- Appendix E presents a glossary of terms used in this publication.

Chapter 2

Ground Water Fundamentals

People involved or interested in developing a wellhead protection program should understand some basic scientific concepts about ground water, such as the hydrologic cycle, the different types of aquifers, and characteristics of ground water movement. These concepts are introduced briefly below. In-depth resource documents on ground water can be consulted for additional information (see Chapter Six). A municipality may choose to seek the expertise of a professional hydrogeologist to obtain more information about local ground water conditions and to perform ground water tests.

The Hydrologic Cycle

The exchange of water between the earth and the atmosphere through such processes as evaporation and precipitation is known as the **hydrologic cycle.** When rain or other precipitation reaches the land's surface, some of the water renews surface waters such as rivers, lakes, streams, and oceans; some is absorbed by plant roots; and some evaporates. The rest of the water infiltrates the ground to become ground water. Ground water moves beneath the land surface, but most ground water eventually discharges into springs, streams, the sea, or other surface waters. A portion of the surface water evaporates into the atmosphere, eventually forming clouds and more precipitation, thus completing the hydrologic cycle. Plants also contribute to the hydrologic cycle through transpiration, evaporation of moisture from the pores in plant leaves. Figure 2-1 illustrates the hydrologic cycle.

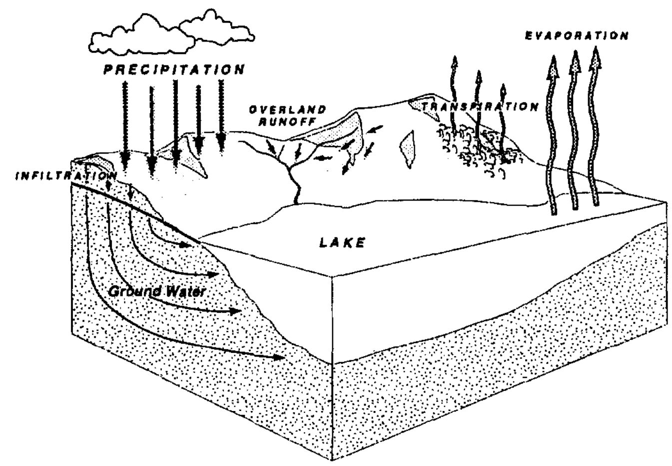


Figure 2-1. The hydrologic cycle.

Aquifers

Aquifers are composed of either consolidated or unconsolidated materials and yield useable quantities of water. **Unconsolidated** deposits are composed of loose rock or mineral particles of varying sizes; examples include clay, silt, sand, gravel, and seashell fragments. **Consolidated** deposits are rocks formed by mineral particles combining from heat and pressure or chemical reactions. They include sedimentary (previously unconsolidated) rocks, such as limestone, dolomite, shale, and sandstone, igneous (formed from molten) rocks, such as granite and basalt, and metamorphic rocks, such as quartzite and gneiss. Some limestones and sandstones may be only partly cemented and are considered to be **semiconsolidated** deposits. Aquifers can range in areas from several acres to thousands of miles wide and from a few feet to hundreds of feet thick.[1] In the rural setting, aquifer materials in much smaller-sized deposits are the source of water to private wells. Depending on their depth and size, these deposits can be very susceptible to contamination.

Water collects in the fractures, intergranular pores, and caverns in the rock. Water in the zone where all of the pores, fractures, and caverns are saturated with water (the **saturated zone**) is called ground water. The top of the saturated zone is called the **water table**. The underground zone above the water table contains both air and water and is called the vadose or **unsaturated zone.**

Confined and Unconfined Aquifers

There are two general types of aquifers, unconfined and confined. (Figure 2-2 shows an unconfined and a confined aquifer.) The top of an **unconfined aquifer** is the water table at atmospheric pressure. For this reason,

[1] Inch-pound units are used in this publication to facilitate its use by the intended audience. Appendix D contains a table for conversion to metric units.

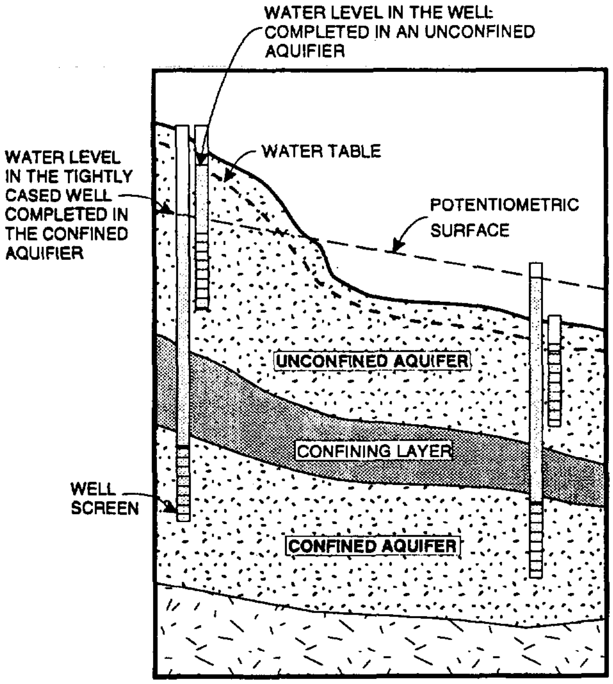


Figure 2-2. Water levels in wells completed in unconfined and confined aquifers. Prepared by Horsley and Witten, Inc.

unconfined aquifers are also called water table aquifers. Unconfined aquifers can be found anywhere from zero to thousands of feet below the land surface.

The water table depth and the composition of unsaturated zone materials above an unconfined aquifer are important factors in determining how rapidly the aquifer can become contaminated (U.S. EPA, 1987). Unconfined, shallow aquifers found close to the land surface are easily accessible, but are also easily contaminated. Conversely, deep aquifers are often more difficult to obtain water from, but may be less likely to become contaminated, depending on hydrogeologic conditions.

Above the **confined aquifer** is a confining unit of impermeable (or very slowly permeable) material such as clay or shale. It is difficult for water or other materials to flow through this layer. Confined aquifers are often found at greater depths than unconfined aquifers. Water in the confined aquifer is at greater than atmospheric pressures; for this reason, water in wells tapping confined aquifers rises above the top of the aquifer. Confined aquifers are also called **artesian aquifers**. Some wells in confined aquifers have so much artesian water pressure that they flow above the land surface without pumping.

The relatively impermeable materials overlying confined aquifers protect them from contamination to varying degrees. Confined aquifers, however, can become contaminated through natural or anthropogenic openings (e.g., rock fractures or well casings) or from contaminated ground water flowing into the aquifer from a distant location. Confined aquifers can be characterized as either semiconfined or highly confined. In semiconfined aquifers, leakage of water and possibly contaminants occurs through the confining layer above; in highly confined aquifers, leakage is negligible (U.S. EPA, 1991a). Thus, semiconfined aquifers are more susceptible to contamination from sources directly above than are highly confined aquifers.

Fractured and Carbonate Rock Aquifers

Fractures in consolidated rock (bedrock) play an important role in ground water movement. The structure of many **fractured rock aquifers** (Figure 2-3) allows water

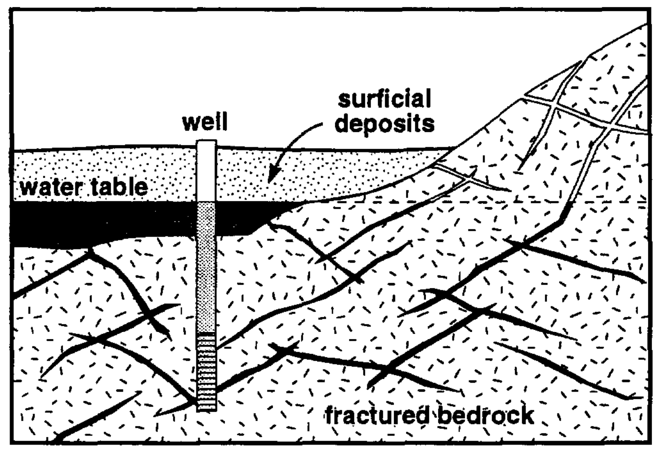


Figure 2-3. A fractured rock aquifer.

to flow through them in variable directions, making it difficult to predict and measure ground water flow (U.S. EPA, 1987; U.S. EPA, 1991b). In general, the direction of ground water flow through unconsolidated aquifers is less variable. (Fractures can, however, be important in dense unconsolidated materials, such as glacial tills and clay layers.) **Carbonate aquifers** are composed of limestone and other water-soluble rocks whose fractures have been widened by physical erosion to form sinkholes, caves, or tunnels (U.S. EPA, 1991b). Water and any accompanying contaminants often move very rapidly in carbonate aquifers.

Recharge of Aquifers

Replenishment of aquifers is known as **recharge.** Unconfined aquifers are recharged primarily by precipitation percolating, or infiltrating, from the land's surface. Confined aquifers are generally recharged where the aquifer materials are exposed at the land's surface (outcrop).

Surface waters also can provide ground water recharge under certain conditions. *Properly identifying the recharge area is critical in ground water protection because the introduction of contaminants within the recharge area can cause aquifer contamination.*

Ground Water Movement

An aquifer's ability to receive, store, or transmit water or contaminants depends on the characteristics of the aquifer (including the confining layers associated with a confined aquifer or the overlying unsaturated zone of an unconfined aquifer).

Porosity refers to the amount of space between soil or rock particles and reflects the ability of a material to store water. Expressed quantitatively, it is the ratio between the open spaces and the total rock or soil volume. Table 2-1 illustrates the porosity of various types of subsurface deposits. Soils are said to be porous when the percentage of pore space they contain is large (such as a soil with porosity of 55 percent).

Table 2-1. Porosity Values of Various Soils and Rocks

Material	Porosity (%)	Specific Yield[1] (% by vol)	Specific Retention[2] (%)
Soil	55	40	15
Clay	50	2	48
Sand	25	22	3
Gravel	20	19	1
Limestone	20	18	2
Sandstone, semiconsolidated	11	6	5
Granite	0.1	0.09	0.01
Basalt, young	11	8	3

[1]The amount of water yielded under the influence of gravity.
[2]The amount of water rocks or soils will retain against the pull of gravity to the rock/soil volume.
Source: U.S. EPA, 1990a.

Hydraulic conductivity is a term that describes the ease with which water can pass through subsurface deposits (and thus transmit water to a well). Generally, the larger the pores, the more permeable the material, and the more easily water can pass through. Coarse, sandy soils are quite porous and permeable, and thus ground water generally moves through them rapidly. Bedrock is often not very porous but may contain large fractures through which ground water passes quickly. Clay soils are quite porous but not very permeable, and water moves through clay very slowly.

Ground water generally moves quite slowly—from about several feet per day to several feet per year—although it can move much faster in very permeable soils or in certain geologic formations, such as cavernous limestone. Gravity and pressure differences are also important factors in ground water movement. The direction and speed that ground water and accompanying contaminants flow are to a large degree determined by the **hydraulic gradient**. The hydraulic gradient is the slope of a water table, or in a confined aquifer, the slope of the **potentiometric surface** (the surface defined by the elevation to which water rises in wells that are open to the atmosphere). In many cases, the hydraulic gradient parallels the slope of the land surface. The velocity of ground water movement also can be measured. Slope and velocity measurements can provide **time of travel** estimates, which indicate the amount of time it will take water or a contaminant to reach a predetermined location (Pettyjohn, 1989).

Well pumping alters the natural movement of ground water. When pumped, ground water around the well is pulled down and into the well. The underground area affected by the pumping is called the **cone of depression**; the same area as viewed on a map of the ground surface is known as the area or **zone of influence** (see Figure 2-4). The cone of depression may extend from a few feet to many miles, depending on local hydrogeological conditions. Generally, the cone of depression for an

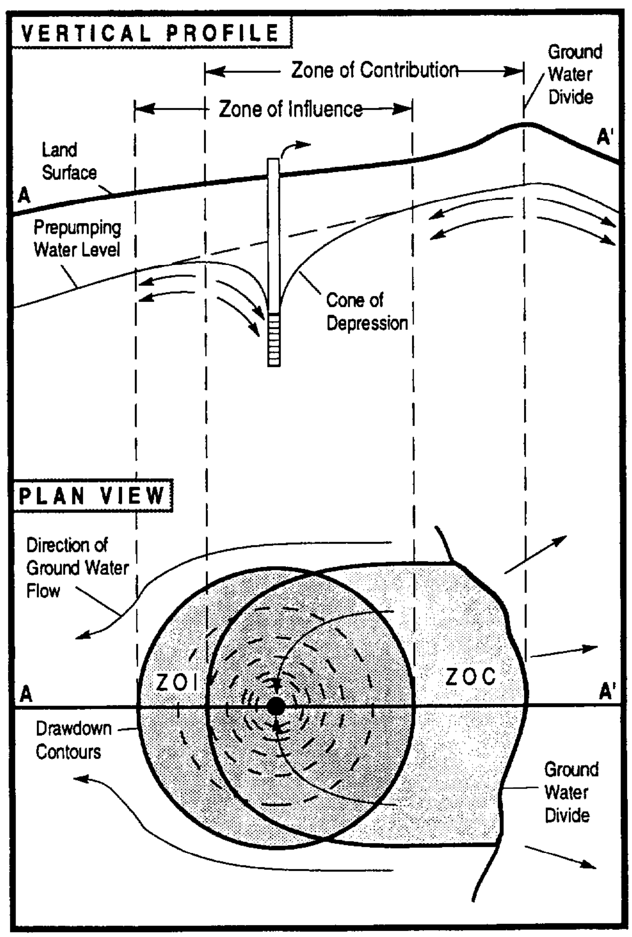


Figure 2-4. The zone of contribution, zone of influence, and cone of depression. Prepared by Horsley and Witten, Inc.

unconfined aquifer is smaller than for a confined aquifer (U.S. EPA, 1990a). Cones of depression increase the hydraulic gradient, and thus pumping can change the direction and velocity of ground water flow (U.S. EPA, 1990a; Pettyjohn, 1989). The **zone of contribution** (see Figure 2-4) is the area of the aquifer that recharges the well. The zone of contribution also can be altered by pumping. Any contaminants located in the zone of contribution might be drawn into the well along with the water; therefore, a wellhead protection area should encompass the zone of contribution if possible.

A selected list of terms frequently used in ground water hydrology is defined in the glossary (Appendix E).

Chapter 3

Ground Water Contamination

Nearly all public water supplies in the United States provide water that is safe to drink. Incidents of ground water contamination, however, have been reported in every state. The following statistics demonstrate the need for communities to protect their ground water supplies from contamination (U.S. EPA, 1990a; U.S. EPA, 1990c):

- More than 200 chemical contaminants have been identified in ground water.
- Some 52,181 cases of illness associated with ground water contamination (mostly short-term digestive disorders) were reported between 1971 and 1985.
- Seventy-four pesticides have been detected in the ground water of 38 states.
- Approximately 10 percent of public water supplies derived from ground water exceed federal drinking water standards for biological contamination.

This chapter discusses how ground water can become contaminated, the sources of contamination, and the potential effects on human health and local economies. It also presents an overview of federal laws and examples of state regulations designed to prevent ground water contamination.

How Ground Water Becomes Contaminated

Depending on its physical, chemical, and biological properties, a contaminant may move within an aquifer in the same ways that ground water moves. (Some contaminants, however, do not follow ground water flow). It is possible to predict, to some degree, the transport within an aquifer of those substances that move along with ground water flow. For instance, both water and certain contaminants flow from recharge areas to discharge areas. Soils that are porous and permeable tend to transmit water and certain types of contaminants with relative ease to an aquifer below.

Just as ground water generally moves slowly, so do contaminants in ground water. Because of this slow movement, contaminants usually remain concentrated in the form of a **plume** that often flows along the same path as the ground water. The size and speed of the plume depend on the amount and type of contaminant, its solubility and density, and the velocity of the surrounding ground water (U.S. EPA, 1990c). Figure 3-1 illustrates a contaminant plume.

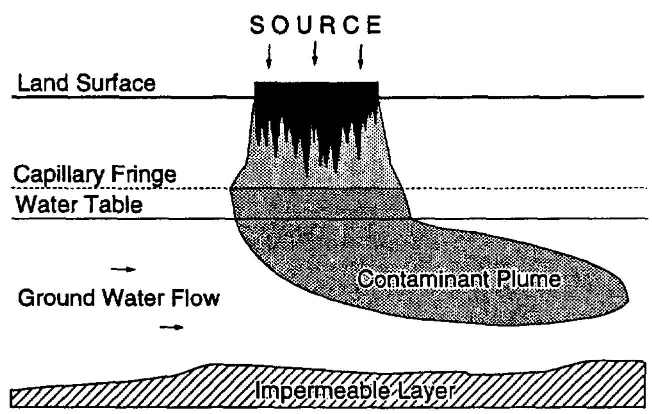


Figure 3-1. Schematic drawing of a contaminant plume. Prepared by Horsley and Witten, Inc.

Ground water and contaminants can move rapidly through fractures in rocks. Fractured rock presents a unique problem in locating and controlling contaminants because the fractures are generally randomly spaced and do not follow the contours of the land surface or the hydraulic gradient.

In addition, there is growing concern about the contamination of ground water through **macropores**. These are root systems, animal burrows, and other systems of holes and cracks that supply pathways for contaminants.

In areas surrounding pumping wells, the potential for contamination increases because water from the zone of contribution, a land area larger than the original recharge area, is drawn into the well and the surrounding aquifer. Some drinking water wells maintain an adequate water yield through **induced infiltration**, whereby water from a nearby stream, lake, or river contributes to the well discharge. Contaminants present in the surface water can degrade the water quality of the aquifer. Some wells rely on **artificial recharge** to increase the amount of water infiltrating an aquifer, often using water from storm runoff, irrigation, industrial processes, or treated sewage. In several cases, this practice has resulted in increased concentrations of nitrates, metals, viruses, or synthetic chemicals in the water (U.S. EPA, 1990a).

Under certain conditions, pumping can also cause the ground water (and associated contaminants) from another aquifer to enter the one being pumped. This phenomenon is called **interaquifer leakage**. Thus, properly identifying and protecting the areas affected by well pumping is important to the maintenance of ground water quality. Chapters Two and Four discuss pumping and wellhead protection in more detail.

Generally, the greater the distance between a source of contamination and a ground water source, the more likely that natural processes will reduce the impacts of contamination. Processes such as oxidation, biological decay (which sometimes renders contaminants less toxic), and adsorption (binding of materials to soil particles) may take place in the soil layers of the unsaturated zone and reduce the concentration of a contaminant before it reaches ground water (U.S. EPA, 1990a). Even contaminants that reach ground water directly, without passing through the unsaturated zone, can become less concentrated by dilution (mixing) with the ground water. Because ground water usually moves slowly, however, contaminants often undergo little dilution (U.S. EPA, 1990a; U.S. EPA, 1990c).

SOURCES OF GROUND WATER CONTAMINATION

Ground water can become contaminated from natural sources or numerous types of human activities. Residential, municipal, commercial, industrial, and agricultural activities can all affect ground water quality. Contaminants may reach ground water from activities on the land surface, such as industrial waste storage or spills; from sources below the land surface but above the water table, such as septic systems; from structures beneath the water table, such as wells; or from contaminated recharge water. Table 3-1 and Figure 3-2 describe common sources of potential ground water contamination; some of these sources also are discussed below.

Natural Sources

Some substances found naturally in rocks or soils, such as iron, manganese, chlorides, fluorides, sulfates, or radionuclides, can become dissolved in ground water. Other naturally occurring substances, such as decaying organic matter, can move in ground water as particles. Whether any of these substances appear in ground water depends on local conditions. Some of these substances may pose a health threat if consumed in excessive quantities; others may produce an undesirable odor, taste, or color. Ground water containing these substances often is not used as a supply for drinking or other domestic water uses, or is treated to remove these substances.

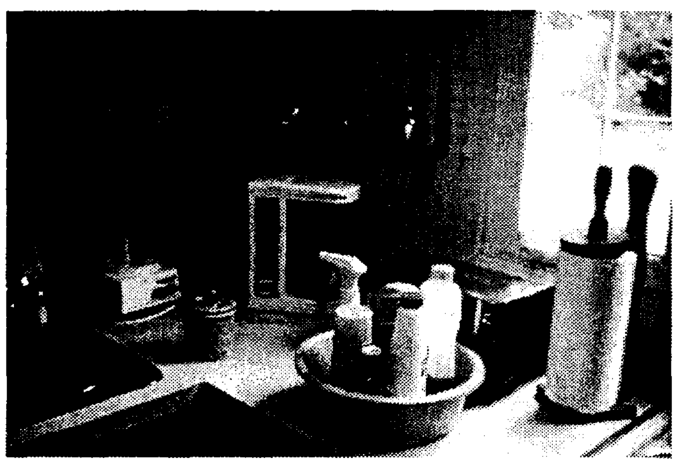
Septic Systems

One of the main causes of ground water contamination in the United States is the effluent (outflow) from septic tanks, cesspools, and privies (U.S. EPA, 1990a). Approximately one-quarter of all homes in the United States rely on septic systems to dispose of their human wastes (U.S. EPA, 1991c). Although each individual system releases a relatively small amount of waste into the ground, the large number and widespread use of these systems makes them a serious contamination source. Septic systems that are improperly sited, designed, constructed, or maintained can contaminate ground water with bacteria, viruses, nitrates, detergents, oils, and chemicals (U.S. EPA, 1990c). Commercially available septic system cleaners containing synthetic organic chemicals (such as 1,1,1-tricholoroethane or methylene chloride) have contaminated drinking water wells. These cleaners also interfere with natural decomposition processes in septic systems (Massachusetts Audubon Society, 1985a).

Some state and local regulations require specific separation distances between septic systems and drinking water wells. In addition, computer models have been developed to calculate suitable distances.

Disposal of Hazardous Materials

Hazardous waste should always be disposed of properly (e.g., by a licensed hazardous waste handler or through municipal hazardous waste collection days). Many chemicals should not be disposed of in household septic systems, including oils (e.g., cooking, motor), lawn and garden chemicals, paints and paint thinners, disinfectants, medicines, photographic chemicals, and swimming pool chemicals. Table 3-2 shows the potentially harmful



Many common household products contain chemicals that can contaminate ground water and should not be disposed of in septic systems.

Table 3-1. Typical Sources of Potential Ground Water Contamination by Land Use Category

Category	Contaminant Source	
Agriculture	Animal burial areas	Irrigation sites
	Animal feedlots	Manure spreading areas/pits
	Fertilizer storage/use	Pesticide storage/use
Commercial	Airports	Jewelry/metal plating
	Auto repair shops	Laundromats
	Boat yards	Medical institutions
	Construction areas	Paint shops
	Car washes	Photography establishments
	Cemeteries	Railroad tracks and yards
	Dry cleaners	Research laboratories
	Gas stations	Scrap and junkyards
	Golf courses	Storage tanks
Industrial	Asphalt plants	Petroleum production/storage
	Chemical manufacture/storage	Pipelines
	Electronics manufacture	Septage lagoons and sludge sites
	Electroplaters	Storage tanks
	Foundries/metal fabricators	Toxic and hazardous spills
	Machine/metalworking shops	Wells (operating/abandoned)
	Mining and mine drainage	Wood preserving facilities
Residential	Fuel oil	Septic systems, cesspools
	Furniture stripping/refinishing	Sewer lines
	Household hazardous products	Swimming pools (chemical storage)
	Household lawns	
Other	Hazardous waste landfills	Recycling/reduction facilities
	Municipal incinerators	Road deicing operations
	Municipal landfills	Road maintenance depots
	Municipal sewer lines	Storm water drains/basins
	Open burning sites	Transfer stations

Source: U.S. EPA, 1991a.

components of common household products. Similarly, many substances used in industrial processes should not be disposed of in drains at the workplace because they could contaminate a drinking water source. Companies should train employees in the proper use and disposal of all chemicals used onsite. The many different types and the large quantities of chemicals used at industrial locations make proper disposal of wastes especially important for ground water protection.

Chemical Storage and Spills

Underground and aboveground storage tanks are commonly used for chemical storage. Approximately five million underground storage tanks exist in the United States (U.S. EPA, 1990a). Some homes have underground fuel tanks for heating oil. Many businesses and municipal highway departments also store fuel oil, diesel, gasoline, or other chemicals in onsite tanks. Industries use storage tanks to hold chemicals used in industrial processes or to store hazardous wastes for pickup by a licensed hauler.

If an underground storage tank develops a leak, which commonly occurs as the tank ages and corrodes, chemicals can migrate through the soil and reach the ground water. It has been estimated that about one-third of underground storage tanks nationwide are leaking (U.S. EPA, 1990a). Newer tanks are more corrosion-resistant, but they are not foolproof. Abandoned underground tanks pose another problem because their location often is unknown. Aboveground storage tanks can also pose a

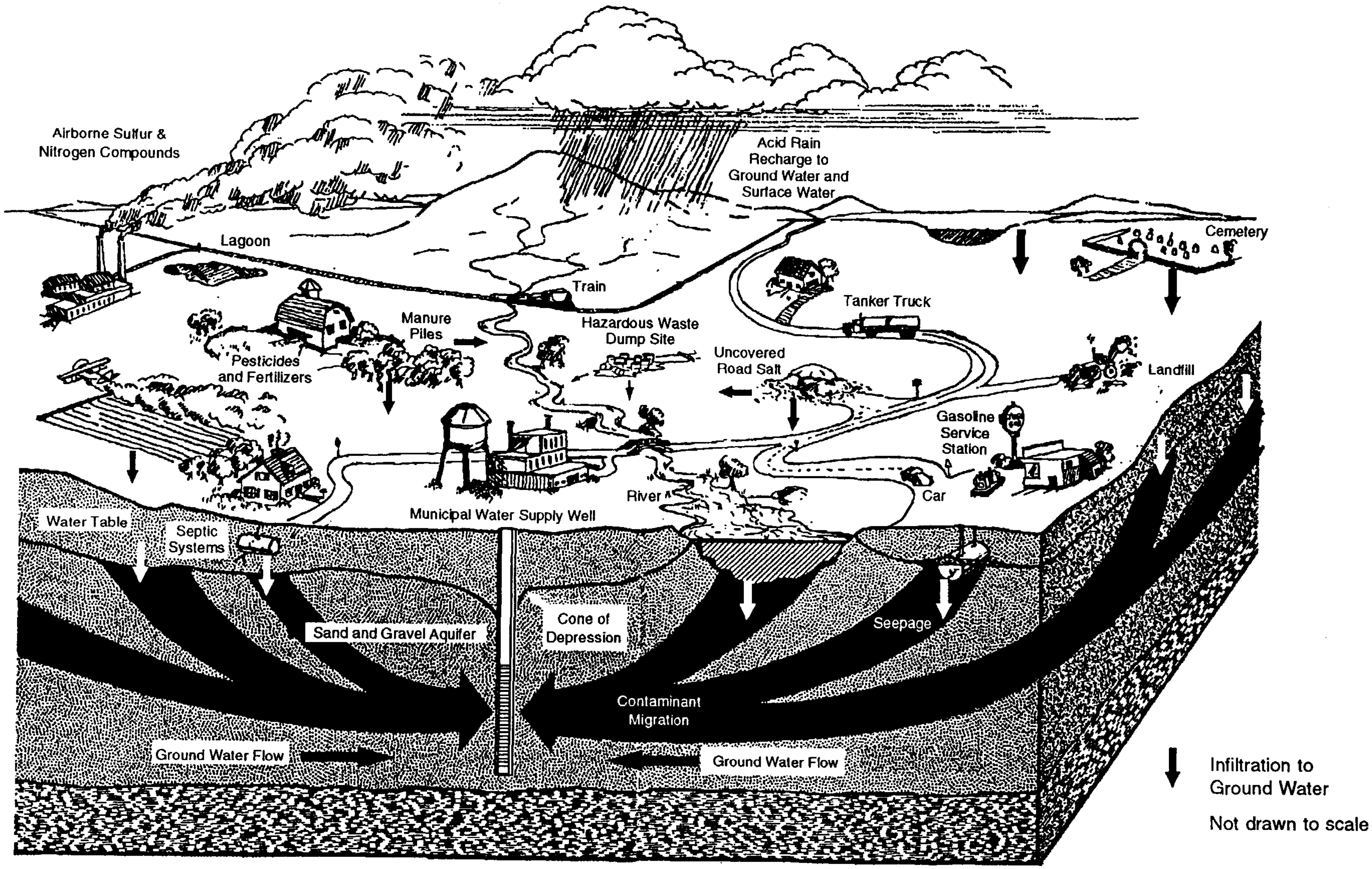


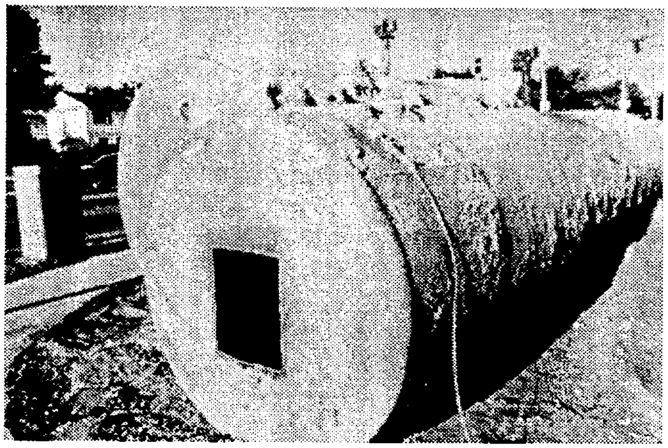
Figure 3-2. Some potential sources of ground water contamination. Source: Adapted from Paly and Steppacher, n.d.

Table 3-2. Potentially Harmful Components of Common Household Products

Product	Toxic or Hazardous Components
Antifreeze (gasoline or coolants systems)	Methanol, ethylene glycol
Automatic transmission fluid	Petroleum distillates, xylene
Battery acid (electrolyte)	Sulfuric acid
Degreasers for driveways and garages	Petroleum solvents, alcohols, glycol ether
Degreasers for engines and metal	Chlorinated hydrocarbons, toluene, phenols, dichloroperchloroethylene
Engine and radiator flushes	Petroleum solvents, ketones, butanol, glycol ether
Hydraulic fluid (brake fluid)	Hydrocarbons, fluorocarbons
Motor oils and waste oils	Hydrocarbons
Gasoline and jet fuel	Hydrocarbons
Diesel fuel, kerosene, #2 heating oil	Hydrocarbons
Grease, lubes	Hydrocarbons
Rustproofers	Phenols, heavy metals
Car wash detergents	Alkyl benzene sulfonates
Car waxes and polishes	Petroleum distillates, hydrocarbons
Asphalt and roofing tar	Hydrocarbons
Paints, varnishes, stains, dyes	Heavy metals, toluene
Paint and lacquer thinner	Acetone, benzene, toluene, butyl acetate, methyl ketones
Paint and varnish removers, deglossers	Methylene chloride, toluene, acetone, xylene, ethanol, benzene, methanol
Paint brush cleaners	Hydrocarbons, toluene, acetone, methanol, glycol ethers, methyl ethyl ketones
Floor and furniture strippers	Xylene
Metal polishes	Petroleum distillates, isopropanol, petroleum naphtha
Laundry soil and stain removers	Hydrocarbons, benzene, trichloroethylene, 1,1,1-trichloroethane
Other solvents	Acetone, benzene
Rock salt	Sodium concentration
Refrigerants	1,1,2-trichloro-1,2,2-trifluoroethane
Bug and tar removers	Xylene, petroleum distillates
Household cleansers, oven cleaners	Xylenols, glycol ethers, isopropanol
Drain cleaners	1,1,1-trichloroethane
Toilet cleaners	Xylene, sulfonates, chlorinated phenols
Cesspool cleaners	Tetrachloroethylene, dichlorobenzene, methylene chloride
Disinfectants	Cresol, xylenols
Pesticides (all types)	Naphthalene, phosphorus, xylene, chloroform, heavy metals, chlorinated hydrocarbons
Photochemicals	Phenols, sodium sulfite, cyanide, silver halide, potassium bromide
Printing ink	Heavy metals, phenol-formaldehyde
Wood preservatives (creosote)	Pentachlorophenols
Swimming pool chlorine	Sodium hypochlorite
Lye or caustic soda	Sodium hydroxide
Jewelry cleaners	Sodium cyanide

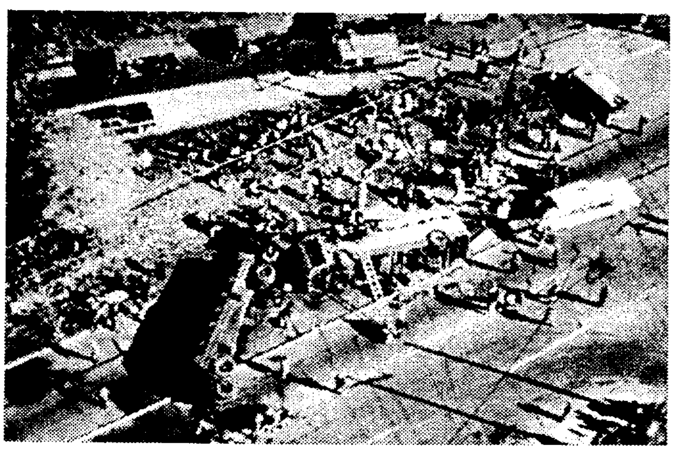
Source: "Natural Resources Facts: Household Hazardous Wastes," Fact Sheet No. 88-3, Department of Natural Science, University of Rhode Island, August 1988.

threat to ground water if a spill or leak occurs and adequate barriers are not in place.



If an underground storage tank develops a leak, chemicals can migrate through the soil and reach the ground water.

Improper chemical storage, sloppy materials handling, and poor quality containers can be major threats to ground water. Tanker trucks and train cars pose another chemical storage hazard. Each year, approximately 16,000 chemical spills occur from trucks, trains, and storage tanks, often when materials are being transferred (U.S. EPA, 1990a). At the site of an accidental spill, the chemicals are often diluted with water, washing the chemical into the soil and increasing the possibility of ground water contamination (Pettyjohn, 1989).



Chemical spills from trucks and trains can threaten ground water supplies.

Landfills

Solid waste is disposed of in thousands of municipal and industrial landfills throughout the country. Chemicals that should be disposed of in hazardous waste landfills sometimes end up in municipal landfills. In addition, the disposal of many household wastes is not regulated. Once in the landfill, chemicals can leach into the ground water by means of precipitation and surface runoff. New landfills are required to have clay or synthetic liners and **leachate** (liquid from a landfill containing contaminants) collection systems to protect ground water. Most older landfills, however, do not have these safeguards. Older landfills were often sited over aquifers and in permeable soils with shallow water tables, enhancing the potential for leachate to contaminate ground water. Closed landfills can continue to pose a ground water contamination threat if they are not capped with an impermeable material (such as clay) before closure (U.S. EPA, 1990a).

Improperly sited or constructed landfills can be a source of ground water contamination.

Surface Impoundments

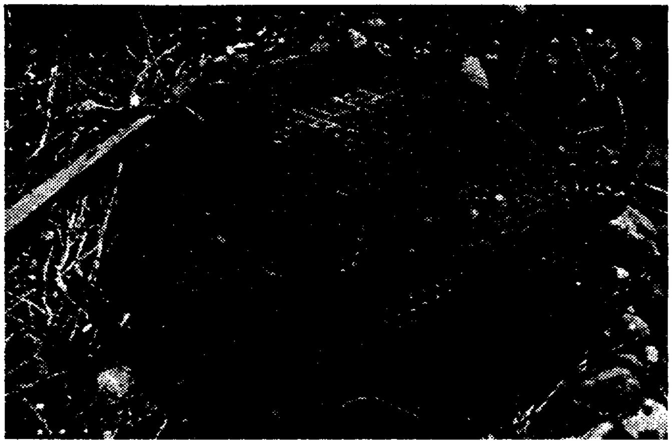
Surface impoundments are relatively shallow ponds or lagoons used by industries and municipalities to store, treat, and dispose of liquid wastes. As many as 180,000 surface impoundments exist in the United States. Like landfills, new surface impoundments facilities are required to have liners, but even these liners sometimes leak.

Sewers and Other Pipelines

Sewer pipes carrying wastes sometimes leak fluids into the surrounding soil and ground water. Sewage consists of organic matter, inorganic salts, heavy metals, bacteria, viruses, and nitrogen (U.S. EPA, 1990a). Other pipelines carrying industrial chemicals and oil brine have also been known to leak, especially when the materials transported through the pipes are corrosive.

Pesticide and Fertilizer Use

Millions of tons of fertilizers and pesticides (including herbicides, insecticides, rodenticides, fungicides, and avicides) are used annually in the United States for crop production. In addition to farmers, homeowners, businesses (such as golf courses), utilities, and municipalities



Sewer pipes sometimes leak fluids into the surrounding soil and ground water.

also use these chemicals. A number of these pesticides and fertilizers (some highly toxic) have entered and contaminated ground water following normal, registered use. Some pesticides remain in soil and water for many months to many years. Another potential source of ground water contamination is animal wastes on farm feedlots that percolate into the ground. Feedlots should be properly sited and wastes should be removed at regular intervals.

Pesticides and fertilizers have contaminated ground water following normal, registered use.

EPA's Office of Pesticides and Toxic Substances and Office of Water conducted a National Pesticide Survey (NPS) between 1985 and 1992. The purpose of the survey was to determine the number of drinking water wells nationwide containing pesticides and nitrates and the concentration of these substances. It also analyzed the factors associated with contamination of drinking water wells by pesticides and nitrates. The survey included samples from more than 1,300 public community and rural domestic water supply wells. The NPS found that approximately 3.6 percent of the wells contained concentrations of nitrates above the federal maximum contaminant level, and that over half of the wells contained nitrates above the survey's minimum reporting limit for nitrate (0.15 mg/L).

The NPS also reported that approximately 0.8 percent of the wells tested contained pesticides at levels higher than federal maximum contaminant levels or health advisory levels. Only 10 percent of the wells classified as rural were actually located on farms. The incidence of contamination by agricultural chemicals in farm wells used for drinking water is greater.

After further analysis, EPA estimated that for the wells that contain pesticides, a significant percentage probably contain the chemical at concentrations exceeding these federal health-based limits (e.g., maximum contaminant levels or health advisory levels). Approximately 14.6 percent of the wells tested contained one or more pesticides above the minimum reporting limit set in the survey. (EPA established specific minimum reporting limits for each pesticide tested for in the NPS, ranging from 0.10 µg/L for dibromochloropropane to 4.5 µg/L for ethylene thiourea.) The most common pesticides found were atrazine and metabolites (breakdown products) of dimethyl tetrachloroterephthalate (DCPA, commonly known as Dacthal), used in many utility easement weed control programs and for lawn care. Table 3-3 lists the percentages of wells in the survey in which pesticides and/or nitrates were found (U.S. EPA, 1990e; U.S. EPA, 1992).

Improperly Constructed Wells

Several problems associated with improperly constructed wells can result in ground water contamination from the introduction of contaminated surface or ground water. Types of wells that are a source of potential ground water contamination include:

- *Sumps and dry wells*, which collect storm water runoff and spilled liquids and are used for disposal. These wells sometimes contain contaminants such as used oil and antifreeze that may discharge into water supply areas.
- *Drainage wells*, which are used in wet areas to remove some of the water and transport it to deeper soils. These wells may contain agricultural chemicals and bacteria (U.S. EPA, 1990a).
- *Injection wells*, which are commonly used to dispose of hazardous and non-hazardous industrial wastes. These wells can range from a depth of several hundred to several thousand feet. If properly designed and used, these wells can effectively dispose of wastes. But undesirable wastes can be introduced into ground water from injection wells when the well is located directly in an aquifer, or if leakage of contaminants occurs from the well head or casing or through fractures in the surrounding rock formations (U.S. EPA, 1990a).

Table 3-3. National Estimates for Pesticides and Nitrates in Wells

	Estimated Number	95% Confidence Interval (Lower-Upper)	Estimated Percent	95% Confidence Interval (Lower-Upper)[a]
PESTICIDES				
CWS[b] wells nationally with at least one pesticide	9,850	(6,330 - 13,400)	10.4	(6.8 - 14.1)
CWS wells above HAL[c]	0	(0 - 750)	0	(0 - 0.8)
CWS wells above MCL[d]	0	(0 - 750)	0	(0 - 0.8)
Rural domestic wells nationally with at least one pesticide	446,000	(246,000 - 647,000)	4.2	(2.3 - 6.2)
Rural domestic wells above HAL[c]	19,400	(170 - 131,000)	0.2	(<0.1 - 1.2)
Rural domestic wells above MCL[d]	60,900	(9,430 - 199,000)	0.6	(0.1 - 1.9)
NITRATES				
CWS wells nationally	49,300	(45,000 - 53,300)	52.1	(48.0 - 56.3)
CWS wells above MCL[d]	1,130	(370 - 2,600)	1.2	(0.4 - 2.7)
Rural domestic wells nationally	5,990,000	(5,280,000 - 6,700,000)	57.0	(50.3 - 63.8)
Rural domestic wells above MCL[d]	254,000	(122,000 - 464,000)	2.4	(1.2 - 2.4)

[a]Numbers between zero and 0.05 are reported as less than 0.1 (<0.1).

[b]CWS — Community Water Supply.

[c]Health Advisory Level (HAL) is the concentration of a contaminant in water that may be consumed over a person's lifetime without harmful effects. HALs are non-enforceable health-based guidelines that consider only non-cancer toxic effects. Only pesticides with HALs were included in estimating the number of wells containing pesticides above the HALs.

[d]Maximum Contaminant Level (MCL) is the maximum permissible level of a contaminant in water that is delivered to any user of a public water system. MCLs are enforceable standards. Only pesticides with MCLs were included in estimating the number of wells containing pesticides above the MCLs. Although the MCL is not legally applicable to rural domestic wells, it was used as a standard of quality for drinking water.

Source: U.S. EPA, 1990e.

- *Improperly abandoned wells* act as a conduit through which contaminants can reach an aquifer if the well casing has been removed, as is often done, or if the casing is corroded. In addition, some people use abandoned wells to dispose of wastes such as used motor oil; these wells may reach into an aquifer that serves drinking water supply wells. Abandoned exploratory wells (e.g., for gas, oil, coal) or test hole wells are usually uncovered and are a potential conduit for contaminants.

- *Active drinking water supply wells* that are poorly constructed can result in ground water contamination. Construction problems, such as faulty casings, inadequate covers, or lack of concrete pads, allow outside water and any accompanying contaminants to flow into the well. Sources of such contaminants can be surface runoff or wastes from farm animals or septic systems. Contaminated fill packed around a well can also degrade well water quality. Well construction problems are more likely to occur in older wells that were in place prior to the establishment of well construction standards and in domestic and livestock wells.

- *Poorly constructed irrigation wells* also can allow contaminants to enter ground water. Often pesticides and fertilizers are applied in the immediate vicinity of wells on agricultural land.

Highway Deicing

More than 11 million tons of salt are applied to roads in the United States annually to remove ice from roadways (U.S. EPA, 1990c). Precipitation can wash the salt into soil and then into ground water. Stockpiles of salt stored on the ground can also be washed into the soil. High sodium levels in water pose a health risk and also damage vegetation, vehicles, and bridges (Massachusetts Audubon Society, 1987).

Mining Activities

Active and abandoned mines can contribute to ground water contamination. Precipitation can leach soluble minerals from the mine wastes (known as spoils or tailings) into the ground water below. These wastes often contain metals, acids, minerals, and sulfides. Abandoned mines are often used as wells and waste pits, sometimes simultaneously. In addition, mines are sometimes pumped to keep them dry; the pumping can cause an upward migration of contaminated ground water, which may be intercepted by a well (U.S. EPA, 1990a).

Effects of Ground Water Contamination

Contamination of ground water can result in poor drinking water quality, loss of a water supply, high cleanup costs, high costs for alternative water supplies, and/or potential health problems. Some examples include:

- In Truro, Massachusetts, a leaking underground storage tank released gasoline into the aquifer in 1977. The wellfield in nearby Provincetown had to be closed to prevent contamination of the town's drinking water supply. More than $5 million was spent on aquifer rehabilitation. More than 13 years later, treatment was still required, and daily monitoring will be required for 3 years following the completion of the aquifer rehabilitation program.
- The public water supply wells in Atlantic City, New Jersey, were contaminated by leachate from a landfill; the city estimated that a new wellfield would cost approximately $2 million.
- In Minnesota, 17 cities have spent more than $24 million and 18 companies have expended more than $43 million because of ground water contamination (U.S. EPA, 1991d; U.S. EPA, 1990c).

Degradation or Destruction of the Water Supply

The consequences of a contaminated water supply often are serious. In some cases, contamination of ground water is so severe that the water supply must be abandoned as a source of drinking water. (For example, less than 1 gallon of gasoline can render 1 million gallons of ground water nonpotable [U.S. EPA, 1991c].) In other cases, the ground water can be cleaned up and used again, if the contamination is not too severe and if the municipality is willing to spend a good deal of money. Water quality monitoring is often required for many years.

Costs of Cleaning Up Contaminated Ground Water

Because ground water generally moves slowly, contamination often remains undetected for long periods of time. This makes cleanup of a contaminated water supply difficult, if not impossible. If a cleanup is undertaken, it can cost thousands to millions of dollars.

Once the contaminant source has been controlled or removed, the contaminated ground water can be treated in one of several ways:

- Containing the contaminant to prevent migration.
- Pumping the water, treating it, and returning it to the aquifer.
- Leaving the ground water in place and treating either the water or the contaminant.

A number of technologies can be used to treat ground water. They most frequently include air stripping, activated carbon adsorption, and/or chemical treatment with filtration. Different technologies are effective for different types of contaminants, and several technologies are often combined to achieve effective treatment. The effectiveness of treatment depends in part on local hydrogeological conditions, which should be evaluated prior to selecting a treatment option (U.S. EPA, 1990a).

Costs of Alternative Water Supplies

Given the difficulty and high costs of cleaning up a contaminated aquifer, some communities choose to abandon existing wells and use other water sources, if available. Using alternative supplies will probably be more expensive than obtaining drinking water from the original source. A temporary and expensive solution is to purchase bottled water, but this is not a realistic long-term solution for a community's drinking water supply problem. A community might decide to install new wells in a different area of the aquifer. In this case, appropriate siting and monitoring of the new wells are critical to ensure that contaminants do not move into the new water supplies.

Potential Health Problems

A number of microorganisms and thousands of synthetic chemicals have the potential to contaminate ground water. Table 3-4 lists some of these substances and their health risks. Drinking water containing bacteria and viruses can result in illnesses such as hepatitis, cholera, or giardiasis. Methemoglobinemia or "blue baby syndrome," an illness affecting infants, can be caused by drinking water high in nitrates. Benzene, a component of gasoline, is a known human carcinogen. The serious health effects of lead are well known: learning disabilities in children; nerve, kidney, and liver problems; and pregnancy risks. These and other substances are regulated by federal and state laws. Hundreds of other chemicals, however, are not yet regulated, and many health effects are unknown or not well understood. Preventing contaminants from reaching the ground water is the best way to reduce the health risks associated with poor drinking water quality.

Table 3-4. Health Risks Associated with Contaminated Ground Water

Substance	Major Sources	Possible Risk
Lead	Piping and solder in distribution system	Learning disabilities in children, nerve problems, birth defects
Fluoride	Geological	Crippling skeletal fluorosis, dental fluorosis
Metals	Geological, waste disposal practices	Liver, kidney, circulatory effects
Nitrate	Fertilizer, treated sewage, feedlots	Methemoglobinemia (Blue baby syndrome)
Microbiological Contaminants	Septic systems, overflowing sewer lines	Acute gastrointestinal illness, meningitis
Chlorinated Solvents	Industrial pollution, waste disposal practices	Cancer, liver, and kidney effects
Pesticides and Herbicides	Farming, horticultural practices	Nervous system toxicity, probable cancer
PCBs	Transformers, capacitors	Probable cancer, reproductive effects
Trihalomethanes	Treatment by-product	Liver, kidney damage, possible cancer
Asbestos	Geological, asbestos cement pipes	Tumors
Radon	Geological radioactive gas	Cancer

Source: Adapted from Metcalf & Eddy, 1989.

Regulations to Protect Ground Water

Several federal laws help protect ground water quality. *The Safe Drinking Water Act* (SDWA) establishes the Wellhead Protection Program and regulates the use of underground injection wells for waste disposal. It also provides EPA and the states with the authority to ensure that drinking water supplied by public water systems meets minimum health standards. *The Clean Water Act* regulates ground water shown to have a connection with surface water. It sets standards for allowable pollutant discharges. *The Resource Conservation and Recovery Act* (RCRA) regulates treatment, storage, and disposal of hazardous and non-hazardous wastes. *The Comprehensive Environmental Response, Compensation, and Liability Act* (CERCLA, or Superfund) authorizes the government to clean up contamination or sources of potential contamination from hazardous waste sites or chemical spills, including those that threaten drinking water supplies. CERCLA includes a "community right-to-know" provision. *The Federal Insecticide, Fungicide, and Rodenticide Act* (FIFRA) regulates pesticide use. *The Toxic Substances Control Act* (TSCA) regulates manufactured chemicals. The SDWA and RCRA are discussed in more detail below.

The Safe Drinking Water Act

As specified in the SDWA, EPA sets standards for maximum contaminant levels (the maximum permissible level of contaminant in water delivered to any user of a public water system) in public drinking water supplies, regulates underground disposal of wastes, designates sole-source aquifers, and establishes public water supply protection programs. By 1986, EPA had developed standards for 34 contaminants, including microorganisms, pesticides, radionuclides, volatile synthetic organic chemicals, and some heavy metals.

Amendments to the SDWA were passed in 1986 to enhance drinking water protection. These amendments included the Wellhead Protection Program and the Sole Source Aquifer Demonstration Program. EPA provides technical assistance to the states, which implement these two programs. The 1986 amendments also required EPA to set drinking water standards for 83 contaminants and for an additional 25 contaminants every 3 years. Table 3-5 lists current federal drinking water standards, expressed as maximum contaminant levels. In addition, the amendments required EPA to develop regulations for public drinking water systems to monitor unregulated contaminants.

Wellhead protection emphasizes the prevention of drinking water contamination as a principal goal, rather than relying on correction of contamination once it occurs. Under the SDWA, each state must prepare a Wellhead Protection Program and submit it to EPA for approval. Certain elements must be included in the program, but the law provides flexibility for states so that they can establish programs that suit local needs in protecting public water supplies. State wellhead protection programs must:

- Specify the roles and duties of state agencies, local government offices, and public water suppliers regarding development and implementation of the program.
- Delineate a wellhead protection area for each wellhead, based on hydrogeologic and other relevant information. Delineation criteria might include distance from the well, drawdown of water from the well, time of travel of water and/or contaminants to reach the well, hydrologeologic boundaries, and assimilative capacity (such as the ability of soils to keep contaminants from reaching ground water at unacceptable levels).
- Identify sources of contamination within each wellhead protection area.
- Develop management approaches (such as approaches for designating a lead agency; acquiring technical and financial assistance; and implementing training, demonstration projects, and education programs).
- Prepare contingency plans (plans for alternative drinking water supplies) for each public water supply system.
- Identify sites for new wells that would protect them from potential contamination.
- Ensure public participation.

Wellhead protection programs require the participation of all levels of government. The federal government (EPA) approves state wellhead protection programs and provides technical assistance, state governments develop and execute the programs, and local governmental bodies implement wellhead protection programs in their areas. Figure 3-3 shows states with approved wellhead protection programs.

The Resource Conservation and Recovery Act

The Resource Conservation and Recovery Act (RCRA) regulates the storage, transport, treatment, and disposal of hazardous and solid wastes to prevent contaminants from leaching into ground water from municipal landfills, underground storage tanks, surface impoundments, and hazardous waste disposal facilities. The "cradle to grave" mandate of RCRA requires a trail of paperwork (a manifest document) to follow a hazardous waste from the point of generation, through transport and storage, to final disposal, to ensure proper handling of the wastes and provide accountability. RCRA includes technology re-

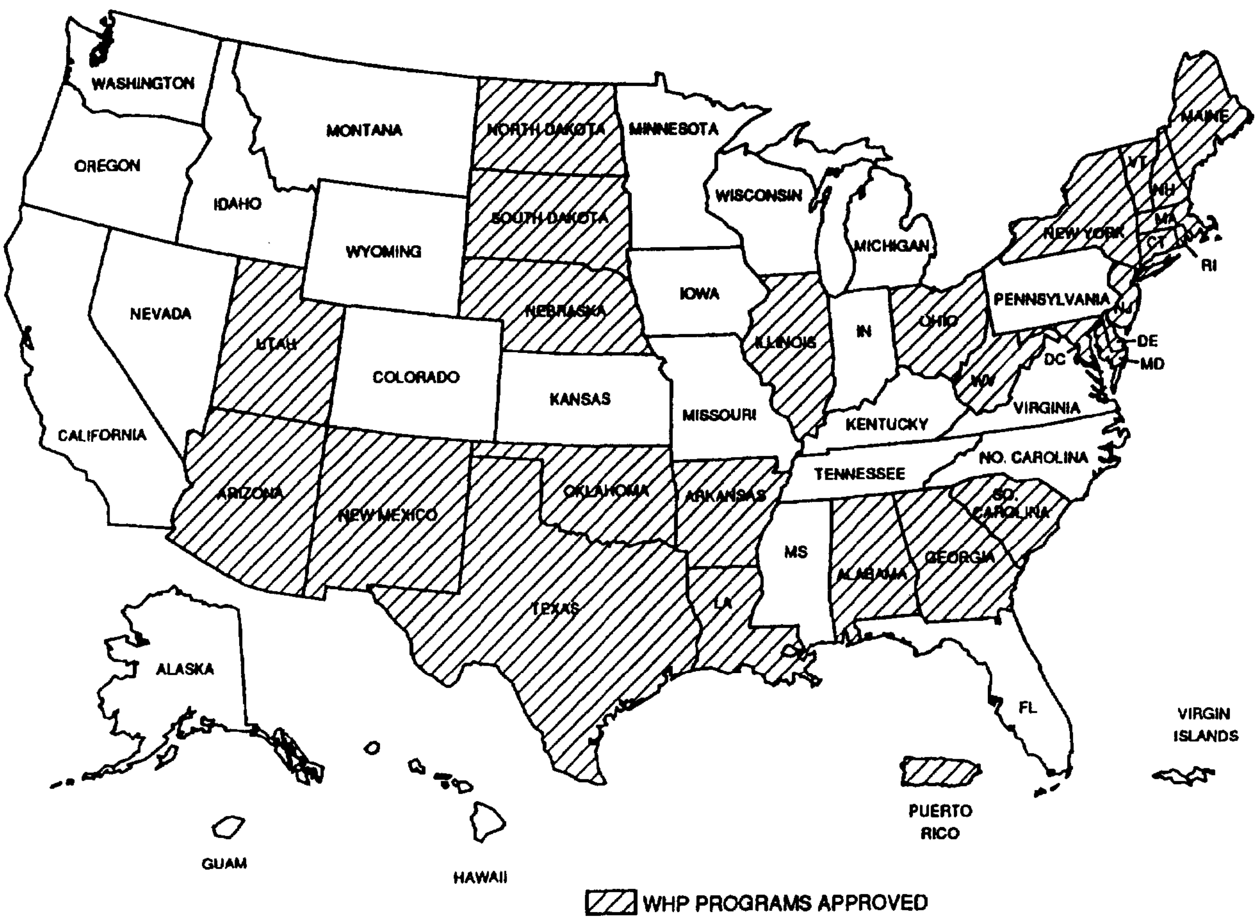


Figure 3-3. States with EPA-approved wellhead protection programs as of February 1993.

Table 3-5. Maximum Contaminant Levels (MCLs) for Drinking Water

Chemicals	Regulatory Status	MCL (mg/L)
ORGANICS		
Acrylamide	F	TT
Acrylonitrile	L	—
Adipates (diethylhexyl)	P	0.5
Alachlor	F	0.002
Aldicarb	F	0.003
Aldicarb sulfone	F	0.002
Aldicarb sulfoxide	F	0.004
Atrazine	F	0.003
Bentazon	L	—
Benz(a)anthracene (PAH)	P	0.0001
Benzene	F	0.005
Benzo(a)pyrene (PAH)	P	0.0002
Benzo(b)fluoranthene (PAH)	P	0.0002
Benzo(k)fluoranthene (PAH)	P	0.0002
Bromacil	L	—
Bromobenzene	L	—
Bromochloroacetonitrile	L	—
Bromodichloromethane (THM)	L	0.1
Bromoform (THM)	L	0.1
Bromomethane	L	—
Butyl benzyl phthalate (PAE)	P	0.1
Carbofuran	F	0.04
Carbon tetrachloride	F	0.005
Chloral hydrate	L	—
Chlordane	F	0.002
Chlorodibromomethane (THM)	L	0.1
Chloroethane	L	—
Chloroform (THM)	L	0.1
Chloromethane	L	—
Chloropicrin	L	—
Chlorotoluene o-	L	—
Chlorotoluene p-	L	—
Chrysene (PAH)	P	0.0002
Cyanazine	L	—
Cyanogen chloride	L	—
2, 4-D	F	0.07
DCPA (Daçthal)	L	—
Dalapon	P	0.2
Di[2-ethylhexyl]adipate	P	0.4
Dibenz(a,h)anthracene (PAH)	P	0.0003
Dibromoacetonitrile	L	—
Dibromochloropropane (DBCP)	F	0.0002
Dibromomethane	L	—
Dicamba	L	—
Dichloroacetaldehyde	L	—
Dichloroacetic acid	L	—
Dichloroacetonitrile	L	—
Dichlorobenzene o-	F	0.6
Dichlorobenzene m-[a]	F	0.6
Dichlorobenzene p-	F	0.075
Dichlorodifluoromethane	L	—
Dichloroethane (1,1-)	L	—
Dichloroethane (1,2-)	F	0.005
Dichloroethylene (1,1-)	F	0.007
Dichloroethylene (cis-1,2-)	F	0.07
Dichloroethylene (trans-1,2-)	F	0.1
Dichloromethane	P	0.005
Dichloropropane (1,2-)	F	0.005
Dichloropropane (1,3-)	L	—
Dichloropropane (2,2-)	L	—
Dichloropropene (1,1-)	L	—
Dichloropropene (1,3-)	L	—
Diethylhexyl phthalate (PAE)	P	0.004
Dinitrotoluene (2,4-)	L	—
Dinitrotoluene (2,6-)	L	—
Dinoseb	P	0.007
Diquat	P	0.02
Endothall	P	0.1
Endrin	P	0.002
Epichlorohydrin	F	TT
Ethylbenzene	F	0.7
Ethylene dibromide (EDB)	F	0.00005
ETU	L	—
Fluorotrichloromethane	L	—
Glyphosate	P	0.7
Heptachlor	F	0.0004
Heptachlor epoxide	F	0.0002
Hexachlorobenzene	P	0.001
Hexachlorobutadiene	L	—
Hexachlorocyclopentadiene	P	0.05
Hexachloroethane	L	—
Hypochlorite	L	—
Indeno(1,2,3,-c,d)pyrene (PAH)	P	0.0004
Isophorone	L	—
Lindane	F	0.0002
Methomyl	L	—
Methoxychlor	F	0.04
Methyl tert butyl ether	L	—
Metolachlor	L	—
Metribuzin	L	—
Monochloroacetic acid	L	—
Monochlorobenzene	F	0.1
Oxamyl (Vydate)	P	0.2

Table 3-5. Maximum Contaminant Levels (MCLs) for Drinking Water (continued)

Chemicals	Regulatory Status	MCL (mg/L)
Ozone by-products	L	—
Pentachlorophenol	F	0.001
Picloram	P	0.5
Polychlorinated biphenyls (PCBs)	F	0.0005
Prometon	L	—
Simazine	P	0.004
Styrene	F	0.1
2,3,7,8-TCDD (Dioxin)	P	5E-08
2,4,5-T	L	—
Tetrachloroethane (1,1,2,2-)	L	—
Tetrachloroethylene	F	0.005
Toluene	F	1
Toxaphene	F	0.003
2,4,5-TP	F	0.05
Trichloroacetic acid	L	—
Trichloroacetonitrile	L	—
Trichlorobenzene (1,2,4-)	P	0.07
Trichloroethane (1,1,1-)	F	0.2
Trichloroethane (1,1,2-)	P	0.005
Trichloroethanol (2,2,2-)	L	—
Trichloroethylene	F	0.005
Trichlorophenol (2,4,6-)	L	—
Trichloropropane (1,2,3-)	L	—
Trifluralin	L	—
Vinyl chloride	F	0.002
Xylenes	F	10
INORGANICS		
Aluminum	L	—
Antimony	P	0.006
Arsenic	—[c]	0.05
Asbestos (fibers/l>10 μm length)	F	7 MFL
Barium	F	2
Beryllium	P	0.001
Boron	L	—
Cadmium	F	0.005
Chloramine	L	—
Chlorate	L	—
Chlorine	L	—
Chlorine dioxide	L	—
Chlorite	L	—
Chromium (total)	F	0.1
Copper	F	TT[b]
Cyanide	P	0.2
Fluoride[c]	F	4
Lead (at tap)	F	TT[b]
Manganese	L	—
Mercury (inorganic)	F	0.002
Molybdenum	L	—
Nickel	P	0.1
Nitrate (as N)	F	10
Nitrite (as N)	F	1
Nitrate + Nitrite (both as N)	F	10
Selenium	F	0.05
Strontium	L	—
Sulfate	P	400/500
Thallium	P	0.002
Vanadium	L	—
Zinc	L	—
Zinc chloride (measured as Zinc)	L	—
RADIONUCLIDES		
Beta particle and photon activity (formerly man-made radionuclides)	F	4 mrem
Gross alpha particle activity	F	15 pCi/L
Radium 226/228	P	5 pCi/L
Radon	P	300 pCi/L
Uranium	P	20 μg/l
MICROBIOLOGY		
Cryptosporidium	L	—
Giardia lamblia	F	TT
Legionella	F[d]	TT
Standard Plate Count	F[d]	TT
Total Coliforms (after 12/31/90)	F	**
Turbidity (after 12/31/90)	F	PS
Viruses	F[d]	TT

[a]The values for m-dichlorobenzene are based on data for o-dichlorobenzene.
[b]Copper — action level 1.3 mg/L; Lead — action level 0.015 mg/L.
[c]Under review.
[d]Final for systems using surface water; also being considered for regulation under ground water disinfection rule.

Key:
F - final
L - listed for regulation
P - proposed (Phase II and V proposals)
PS - performance standard 0.5 NU - 1.0 NU
TT - treatment technique
MFL - million fibers per liter
** - No more than 5% of the samples per month may be positive. For systems collecting fewer than 40 samples/month, no more than 1 sample per month may be positive.

Source: U.S. Environmental Protection Agency, Office of Water, *Drinking Water Regulations and Health Advisories*, November 1992.

MONITORING WAIVERS

In certain cases, having a wellhead protection program in place may help a system obtain a waiver from some of the monitoring requirements under The Safe Drinking Water Act. Individual states have the authority to issue waivers consisting of statewide or areawide waivers for specific contaminants or individual system waivers. There are two types of monitoring waivers available: use waivers and susceptibility waivers. EPA allows monitoring waivers for asbestos, inorganic chemicals, synthetic organic chemicals, and volatile organic chemicals. Waivers are not allowed for nitrate/nitrite or for the monitoring requirements under the lead and copper rule.

Use waivers may be granted when it can be shown that a contaminant has not been used, manufactured, or stored in the area. A susceptibility waiver is based on prior analytic results and the environmental persistence and transport of the contaminant. There also are provisions to allow grandfathering, using previous analyses and compositing for specific contaminants, at the states' discretion.

Systems should request monitoring waivers and further information from their state primacy agency.

quirements for treatment, storage, and disposal facilities, such as the installation of double liners and leachate detection and collection systems, ground water monitoring, and site inspections.

In 1984, Congress passed the Hazardous and Solid Waste Amendments (HSWA) to RCRA. These amendments promote waste reduction, recycling, and treatment of hazardous wastes by requiring generators to certify in writing that they have taken steps to reduce the volume of hazardous wastes (such as source separation, recycling, substitution of materials, or manufacturing process changes). Generators are also encouraged to reduce the toxicity of their wastes if possible through various physical, chemical, or biological processes. HSWA also incorporates into RCRA the regulation of small quantity generators and underground storage tanks.

The 1984 amendments also included a Land Disposal Restrictions (LDR) Program, which prohibits land disposal of certain hazardous wastes unless they are treated according to set standards, thus expanding ground water protection measures. The standards specify either a concentration level or a method of treatment to render wastes less hazardous. The LDRs do not apply if EPA determines that the hazardous constituents will not migrate. Substances such as dioxins, some solvents, liquid hazardous wastes containing certain metals, cyanides, PCBs, halogenated organic compounds, and acidic wastes are covered by the LDR program.

HSWA also included more stringent standards for land disposal facilities for hazardous wastes, such as stricter structural and design conditions for landfills and surface impoundments (e.g., two or more liners, leachate collection systems above and between liners, and ground water monitoring); construction of facilities only in areas with suitable hydrogeologic conditions; and corrective actions if a hazardous waste is released.

In 1991, under RCRA, EPA developed revised criteria for municipal solid waste landfills that protect surface water and ground water from contamination. The criteria include location restrictions (such as restrictions on siting near wetlands, floodplains, or unstable areas, such as karsts); operating requirements (including a ban on hazardous wastes and liquid restrictions to control leachate sources); design standards; recordkeeping; closure and post-closure procedures; and ground water monitoring and corrective action. The ground water monitoring requirements include location, design, and installation requirements; standards for sampling and analysis; and statistical methods for identifying significant changes in ground water quality. If significant changes in ground water quality do occur, an assessment of the nature and extent of contamination (including the establishment of background values and ground water protection standards), and evaluation and implementation of remedial measures must be undertaken by the owner or operator.

In addition, to determine geographic boundaries for a landfill to which the new solid waste criteria apply, state agencies must review the hydrogeologic characteristics of the area, the volume and characteristics of the

WISCONSIN'S GROUND WATER STANDARDS LAW

Wisconsin passed a Groundwater Standards Law in 1984, which includes enforcement standards and preventive action limits for 60 substances that have been detected in or have the potential to reach ground water in the state. All applicable state programs (such as programs overseeing landfills, hazardous waste, wastewater sludge, septic tanks, salt storage, pesticides and fertilizers, and underground storage tanks) must use these standards. Depending on whether the substance is a carcinogen, is associated with other health risks, or is regulated only for aesthetic reasons, the preventive action limit is set at 10, 20, or 50 percent of the enforcement standard, respectively. The preventive action limit serves as an "early warning system," letting state agencies know that low concentrations of certain substances are appearing in ground water. Several state departments are responsible for various aspects of ground water protection, as is the case in most states. Ground water activities are integrated through a Groundwater Coordinating Council, which includes representatives from individual agencies. The Council has established a statewide ground water management program (Wisconsin Department of Natural Resources, 1989).

leachate, ground water quantity and direction of flow, ground water quality (including other sources of contamination and cumulative impacts on ground water), the proximity and withdrawal rate of ground water users, and the availability of alternative drinking water supplies.

State Programs and Regulations to Protect Ground Water

Many states are in the process of developing comprehensive ground water protection strategies. State ground water protection programs often include several components: a comprehensive plan for ground water protection, a set of standards to use to determine when an aquifer is contaminated, a ground water use classification system, land use management, and funding for implementation of the program. State ground water protection programs often provide oversight and technical assistance to municipalities.

States also regulate underground storage tanks and pesticide use, sale, application, and disposal. Ground water protection efforts in Wisconsin and underground storage tank regulations in Massachusetts (see boxes) are examples of state ground water protection activities.

UNDERGROUND STORAGE TANK REGULATIONS IN MASSACHUSETTS

In Massachusetts, underground storage tank regulations were updated in 1986 to include flammable, explosive, and leaking materials from tanks. The current regulations require owners of new and existing tanks to obtain permits from local fire departments that include the size, age, type, location, and use of each tank. New storage facilities must meet design standards to prevent leaks, and installation must be performed by contractors certified by the tank manufacturer. Requirements for leak detection include a continuous monitoring system or inventory control, and tank and pipe tests. The regulations outline specific procedures to follow if a leak is detected. A secondary containment system is required for all tanks installed within Zone 2 (the zone of contribution) of a public supply well (or within a one-half mile radius if Zone 2 has not been delineated).* The fire department may require that new tanks installed within 500 feet of a private well have secondary containment systems or equivalent protection. The fire department also can deny an application or impose conditions for replacement or modification of a tank if it is determined that the proximity of the tank to a public or private well, aquifer, recharge area, or surface water body constitutes a danger to the public. Finally, the fire department may require observation wells or other leak detection systems on existing tanks that could threaten public safety, including water supplies (Massachusetts Audubon Society, 1984).

*Zone 2 or the area of contribution is defined as "that area of an aquifer which contributes water to a well under the most severe recharge and pumping conditions that can be realistically anticipated" (527 CMR 5.00, 9.00, 10.12).

Chapter 4

The Five-Step Process for Wellhead Protection

The most effective way to protect the ground water used as a public water supply is to establish a wellhead protection program. Through this program, you can manage potential contamination sources on the land that contributes recharge to the well (see Chapter Three for a discussion of ground water contamination). Before planning a wellhead protection program, it is important to contact your state drinking water agency to determine whether there are any state requirements for local wellhead protection programs. It is also advisable to determine who might be able to help with the local planning process (such as a state agency contact, the State Rural Water Association, the local agricultural extension office, or the EPA regional office). You then can begin to plan and implement a wellhead protection program in five steps:

Step One Form a community planning team to initiate and implement a wellhead protection program.

Step Two Delineate the wellhead protection area. This delineation should be compatible with state or federal wellhead protection requirements. The wellhead protection area eventually may become part of a more extensive ground water protection area.

Step Three Identify and locate potential sources of contamination.

Step Four Manage the wellhead protection area. The complexity of this step will vary depending on the economic, industrial, and political conditions in your community. Management techniques can range from public education to simple permitting restrictions to intricate regulatory ordinances.

Step Five Plan for the future. This step concerns the long-term effectiveness of the plan and includes the development of a contingency plan to ensure alternate public water supplies if contamination occurs.

This chapter presents information to help your community carry out each of these steps.

Before planning a wellhead protection program, it is important to identify sources of expertise to assist with the planning process.

STEP ONE—Form a Community Planning Team

Developing Community Representation

The first characteristic of a successful community planning team is representation from the diverse interests of the community. The planning team might include:

- **Public organizations:** community service organizations, environmental groups, public interest groups, League of Women Voters.
- **Regulatory organizations:** elected officials, local government agencies(health, planning, natural resources, conservation), public works director.
- **Government/public service organizations:** fire department, public water supplier, local cooperative extension agent, county Soil Conservation Service office.
- **Private organizations:** businesses, farmers, land developers. (The participation of commercial and business interests can enhance the effectiveness of the team's protection strategy during the implementation stages.)

If wellhead protection areas cross community lines, it is critical to develop inter-jurisdictional relationships. This ensures consistency in designated land use and planning restrictions and allows communities to work together to protect your mutual resource. This interaction may involve the regional planning board, neighboring community boards, the agricultural extension service, and watershed associations.

Meetings of the planning team should be advertised in a local newspaper to attract as many concerned parties as possible and to inform the public of the aims of the program. It might be beneficial to contact your state ground water office prior to your first meeting. This office might be able to provide the team with valuable information and guidance on wellhead protection.

Selecting the Team Leader

The effectiveness of the planning team often depends on its leader's organizational and consensus-building skills. A local official who is familiar with the community and regulatory options and who has already gained community support may be a good choice.

Defining the Goals and Objectives of the Project

Once your planning team has been established, it is critical to define your team's main goals and the interim steps necessary to reach them. The long-term goals should include the delineation of a wellhead protection area to protect your wells from unexpected contaminant releases and the development of a management plan to control high-risk activities within the well's recharge area.

These long-term goals cannot be achieved overnight; therefore, a number of short-term objectives should be devised to bring you closer to your ultimate aim of ground water protection. Each step in the five-step process can be broken down into smaller tasks that can be handled easily by individuals on your team. Don't try to achieve too much too soon; rather, set feasible short-term objectives while maintaining sight of your long-term goals. Your team's initial short-term objectives should include:

- Finding out whether your state has established a wellhead protection program and how it could be implemented in your community.
- Becoming familiar with the geology of your community and with the location of your community's wells and the entire drinking water supply system. This knowledge will give your team insight into your community's existing and future water supply needs.
- Gathering all of the available information on the hydrologic and geologic nature of your community's underlying aquifers. This will form a basis for the delineation of your wellhead protection area in Step Two of the process and will allow your team to determine the current quality of your ground water supply.
- Finding out about any existing sources of potential contamination in your community and what measures have been taken to safeguard your water supplies.

Often initial goals and objectives are revised or expanded as the program develops and your planning team becomes more familiar with the process of wellhead protection.

Informing the Public

It is important to continually inform the public of your progress in establishing a wellhead protection program. This will help educate the community about the need to protect ground water while generating support for the program itself. It also gives members of the public an opportunity to voice their suggestions or complaints about the program. The success of the program will depend to a great extent on public support for the program as well as cooperation among those affected by the program and those who monitor and enforce the wellhead protection strategy.

Mailings, advertisements, flyers, and community meetings are low-cost techniques for reaching a broad spectrum of the community. Questionnaires can both provide information on the program and help the team gather information on ground water issues, particularly in regard to sources of contamination.

STEP TWO—Delineate the Wellhead Protection Area

Reasons for Delineating a Wellhead Protection Area

The purpose of delineating wellhead protection areas is to define the geographic limits most critical to the protection of a wellfield. Water yielded by a well may have traveled thousands of feet along surface (e.g., river) and subsurface routes to reach the well. Any areas that receive recharge that contributes water to municipal supply systems are known as "zones of contribution" (see Chapter Two). These zones are subject to alterations in shape and size depending on well pumping rates and other factors. Zones of contribution should be defined in order to begin protective management practices that could prevent contamination from reaching a well.

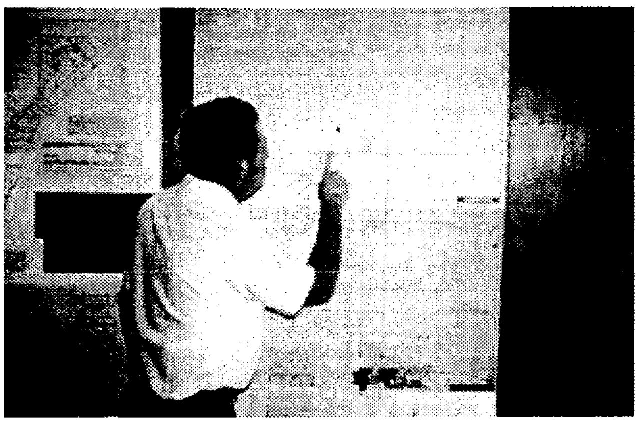
Sources of Information

Under the provisions of the 1986 SDWA amendments, many states have developed wellhead protection programs. A state program may recommend a particular delineation method. Check with your state ground water agency for guidance before you start delineating your wellhead protection area. Your state may actually delineate your wellhead protection area for you. Contact your

Regional EPA office to find out the status of your state's wellhead protection program (see Chapter Six for a listing of EPA's Regional offices).

EPA Publications

The U.S. Environmental Protection Agency has published many documents giving technical guidance on wellhead protection area delineation techniques (see Chapter Six). These documents describe a wide range of delineation methods. Some are complex, involving computerized numerical models. Others are simple, but effective, and involve less time, fewer resources, or less expertise to implement. In addition, EPA has published an easy-to-use, semianalytical computer model to delineate wellhead protection areas (see Chapter Six, Resources for Additional Information). Contact your Regional EPA office for more information on EPA publications.



The planning team should establish a base map of the community.

Base Maps

The first step in any delineation technique involves gathering as much information about the hydrologic and geologic nature of your water resource area as possible. At this stage the objective of the planning team should be to establish a **base map** of the community, giving detailed information on the natural features of the area, both surface and subsurface, and showing the location of all public supply wells and water supply sources. Table 4-1 shows the information contained on maps that may be available for your community. You can obtain much of the material you need from your town hall (Assessor's Office, Engineering Department, Department of Public Works, Water Board, Board of Health, Planning Board, Conservation Commission), and from state, federal, and regional natural resource agencies and planning departments. Once a base map has been prepared, overlay maps can be drawn up outlining drainage basins, wetlands, flood zones, ground water resources, sewer service areas, zoning districts, and land development plans.

The different types of maps that you can use to develop your base map are described below. It is important to consider the scale of the maps when using more than one source. Information collected for one purpose may not be appropriate for another.

Topographic Maps (Quadrangle Maps). A good choice for a base map is the U.S. Geological Survey (USGS) topographic map of your area (see Figure 4-1). These maps are readily available. Each covers approximately 58 square miles and is usually at a scale of 1:24,000, where 1 inch corresponds to 2,000 feet, or 1:25,000 where 1 inch corresponds to 1,083 feet.[2] In addition to marking constructed features, these show important natural features such as lakes and rivers. Most importantly, these maps show the land surface contour elevations of the area and allow the map user to visualize the three-dimensional land surface. The scale of this map may be a little small, depending on the size of your community. You might choose to enlarge this base map to a scale of 1 inch to 1,000 feet. Other maps then can be reduced or enlarged as necessary to overlay the base map. (Print shops can enlarge these maps in full color at a relatively low price.) In areas where unconfined aquifers occur, the surface water elevations shown on the USGS topographic map may provide a preliminary assessment of the hydraulic gradient and ground water flow directions.

Geologic Maps and Soil Maps. Geologic information is available from many sources. Surficial and bedrock geologic maps prepared by USGS geologists may be available for your community. These maps provide data on land forms and soil profiles and should be consulted to locate the permeable soils characteristic of recharge areas. Hydrogeologic mapping might be available from geologic investigations, including geophysical surveys and drilling programs. Bedrock maps and historical geologic maps also may be available from your USGS regional office. The U.S. Department of Agriculture Soil Conservation Service has prepared soil maps and related reports called "Soil Surveys" for a large portion of the United States (see Figure 4-2). These maps delineate soils types on aerial photographs. The soil survey report accompanying these maps describes various hydrologic and physical characteristics of each soil type and could be very useful in identifying recharge zones.

Aerial Photography and Satellite Imagery. Your regional Department of Agriculture Soils Conservation Service or Agricultural Stabilization and Conservation Service might be able to supply you with aerial photography of your community at a reasonable cost. Generally available in stereo pairs, these photographs can be viewed through stereoscopic glasses to give a three-dimensional, realistic picture of your community. It is possible to have these photographs enlarged, again at a reasonable cost, to identify natural features and potential sources of ground water contamination. Aerial photography can help map

[2]Generally, distances and elevations on 1:24,000-scale maps are given in conventional units (miles and feet) and on 1:25,000-scale maps in metric units (kilometers and meters).

Table 4-1. Information Available from Existing Mapping

	Ground Water Resources		Hydrogeologic Information												
	GW Quality	**GW Availability**	**Location of Wells**	**Transmissivity**	**Storativity**	**Hydraulic Conductivity**	**Soil Profiles and Surface Geology**	**Surface Water Resources**	**Wetlands**	**Flood Zones**	**Drainage Basins**	**Sewer Service Areas**	**Zoning Districts**	**Proposed Land Development**	**Location of Possible Contaminant Sources**
Topographic Maps			✓				✓	✓	✓		✓				✓
Geologic Maps		✓		✓			✓	✓	✓						
Soils Maps						✓	✓	✓	✓						
Aerial Photography			✓				✓	✓	✓		✓				✓
Satellite Imagery							✓	✓	✓						✓
Hydrologic System Mapping			✓					✓	✓		✓				
Wetlands Mapping								✓	✓						
Flood Mapping (FEMA, FIRM)								✓	✓	✓					
USGS Hydrologic Atlases	✓	✓	✓	✓			✓	✓	✓		✓				
Well Logs	✓	✓	✓	✓	✓	✓									
Test Boring Logs	✓	✓					✓*								
Water Table Maps		✓	✓												
Land Use Maps			✓					✓	✓					✓	✓
Zoning Maps			✓					✓	✓				✓	✓	✓
Roadway and Utility Maps												✓		✓	✓

*Test boring logs also may be used to obtain information on the subsurface geology of an area.

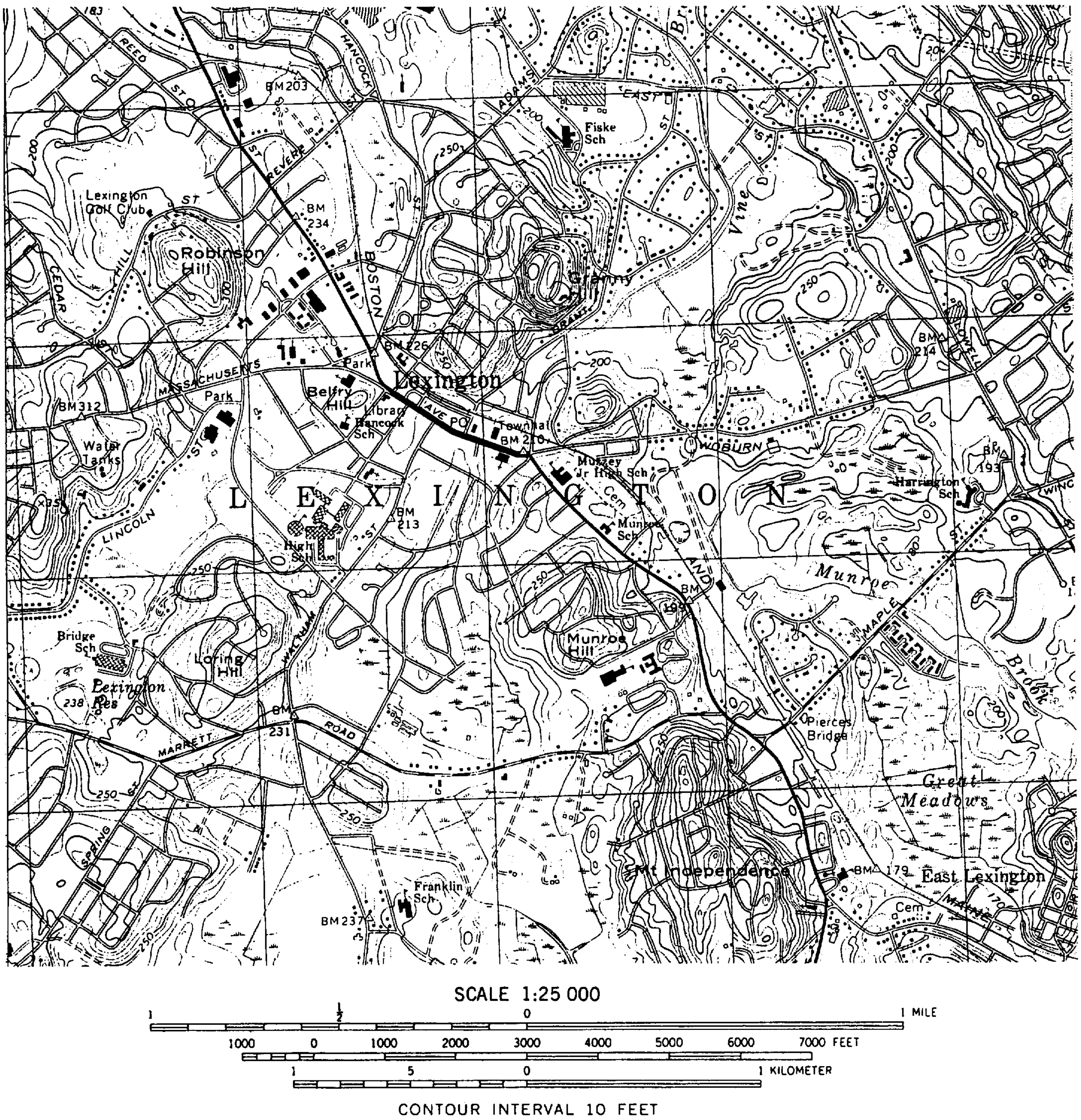
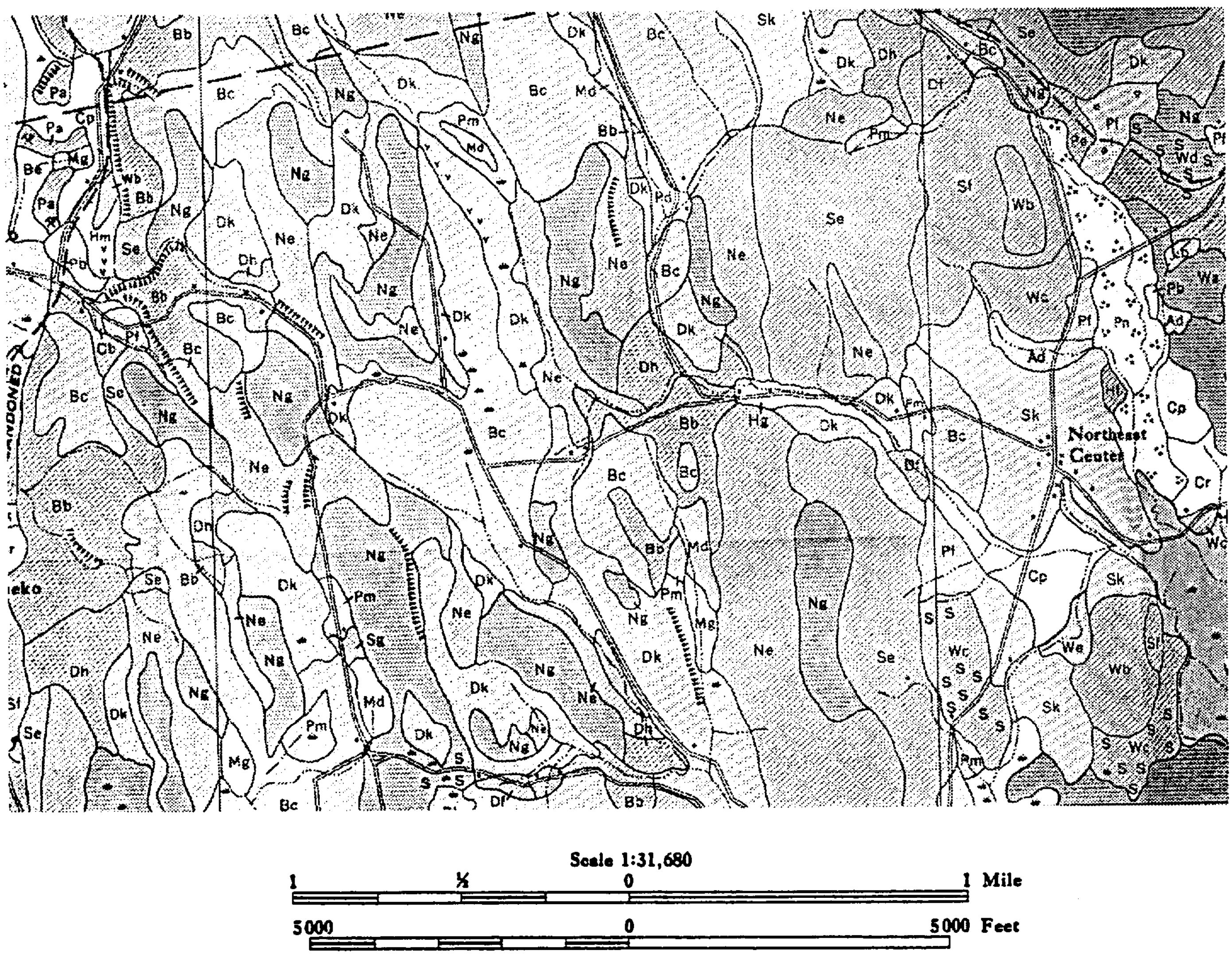


Figure 4-1. Portion of the U.S. Geological Survey topographic map, Lexington Quadrangle.



KEY

- **Bb** Bernardston gravelly silt loam, moderately steep
- **Bc** Bernardston gravelly silt loam, sloping phase
- **Df** Dutchess gravelly silt loam, eroded hilly phase (15-30% slopes)
- **Dh** Dutchess gravelly silt loam, hilly phase
- **Dk** Dutchess gravelly silt loam, undulating and rolling phases
- **Hg** Hoosic gravelly loam, nearly level and undulating phases
- **Md** Mansfield silt loam
- **Mg** Muck, acid, deep phase
- **Ne** Nassau slaty silt loam, ledgy hilly phase
- **Ng** Nassau slaty silt loam, undulating and rolling phases
- **Oa** Ondawa gravelly loam, alluvai-fan phase
- **Pf** Pittsfield gravelly loam, sloping phase
- **Pl** Pittsfield-Wassaic gravelly loams, undulating and rolling phases
- **Pm** Pittstown gravelly silt loam, nearly level and gently sloping phases
- **Se** Steep ledgy land(Nassau soil material)
- **Sf** Steep ledgy land (Wassaic and Straatsburg soil materials)
- **Sk** Stockbridge gravelly loam, gently sloping phases
- **Wb** Wassaic gravelly loam, ledgy hilly phase

Figure 4-2. Portion of a set of soils maps from a soil survey by the Soil Conservation Service, U.S. Department of Agriculture and Cornell University Agricultural Experiment Station.

readers gain a better understanding of the community's surface geology. The planning team may choose to consult with geologists or hydrogeologists who can view satellite imagery to detect trends of **lineaments** (distinctive geologic features or characteristics), which might reflect zones of high permeability. They can also view images to detect shallow ground water where a high moisture content has brought about subtle changes (such as differences in vegetation) (U.S. EPA, 1990a).

Hydrologic System Mapping. You can draw from many sources of data to prepare an overlay map of your community's hydrologic system. This system consists of drainage basins (watersheds), wetlands, and flood zones. The map can be prepared on clear film and then overlaid on your base map. Drainage basins or catchment areas collect water that might be ultimately transported into the aquifer. They are determined by finding the highest elevation points on your topographic map and connecting them by drawing boundary lines perpendicular to the surface contours. The resulting area will probably be much larger than your final wellhead protection area (and also may be a very different area). Be aware of scale at the level of detail.

Wetlands are mapped on topographic maps; however, more detailed wetland mapping of your area may be available from your state wetlands regulatory agency or your regional office of the U.S. Army Corps of Engineers. Wetland areas are critical elements of a drainage network because they act as natural filters for contaminants in surface water before it percolates down to ground water.

Flood mapping for every state has been prepared by the Federal Emergency Management Agency (FEMA). Two types of flood mapping are available: Flood Insurance Rate Maps (FIRM) and Flood Boundary and Floodway Maps (see Figure 4-3). These maps delineate the areas adjacent to surface waters that would be under water in 100-year and 500-year floods. The 100-year and 500-year floods are hypothetical flood events that might occur once in 100 years and once in 500 years. Historic flood data might also be available from your community and state libraries.

Ground Water Mapping. A major source of information for your ground water map is the USGS Hydrologic Atlases (see Figure 4-4). These maps often show the location of aquifers for entire river basins. They are based on the interpretation of all available geologic information from soil profiles, test wells, rock outcrops, observation wells, seismic surveys, and other means of subsurface observation. The location of aquifers on these maps is estimated by examining surficial geology, depth to bedrock, and depth to the water table. Hydrologic atlases give information on ground water availability, well locations, ground water quality, surficial deposits influencing transmissivity, basin boundaries, flow characteristics of surface water, and other hydrologic factors.

You can also obtain hydrogeologic information about your aquifer from an analysis of well logs, both public and private, and test boring logs. In addition to supplying geological information on your community's aquifer, well records show well discharge and water level fluctuations, which can be used to evaluate an aquifer's hydraulic conductivity, transmissivity, and storativity (Pettyjohn, 1989a). Water table maps, if available, can also be helpful in wellhead protection area delineation. These maps give information on the flow directions of ground water and its depth from the surface (Figure 4-5). These maps should be available from your state geology or ground water agency. Climatological data can be obtained from your state weather service. These data are important because they indicate precipitation events and patterns, which influence surface runoff and ground water recharge (U.S. EPA, 1991e).

In general, the following information should be included on your team's ground water map (Massachusetts Audubon Society, 1985b):

- The zone of influence and the zone of contribution for every existing and potential water supply well.
- The location of aquifers and aquifer recharge zones.
- The watershed within which aquifers are located.
- Surface waters from which wells may induce recharge.
- Direction of ground water flow.
- Soil and geology maps.

Land Use Maps. Other maps that might prove useful when determining potential contaminant sources and land management techniques include community tax assessors' maps, community zoning maps (see Figure 4-6), community master development plan, maps of reserved/conservation lands and waters (see Figure 4-7), endangered species maps, and roadway and utility maps (see Figures 4-8 and 4-9).

Once all the information is assembled, consider the source for each part of the information and how accurate the data are. You might wish to consider some information more valuable than other.

Local Talent

Your community planning team can benefit greatly from individuals within the community who have some expertise, either in the technical aspects of wellhead protection (engineers, water supply personnel, or agriculturists), or in regulatory or planning issues. Another source of talent is people from local universities or colleges that have programs in geology, hydrology, agriculture, or civil and/or environmental engineering. Faculty members of these institutions might be able to offer your planning team guidance, while the institutions might offer the use of such resources as testing laboratories, libraries, field testing equipment, or computer facilities. Local expertise might also be available from private businesses.

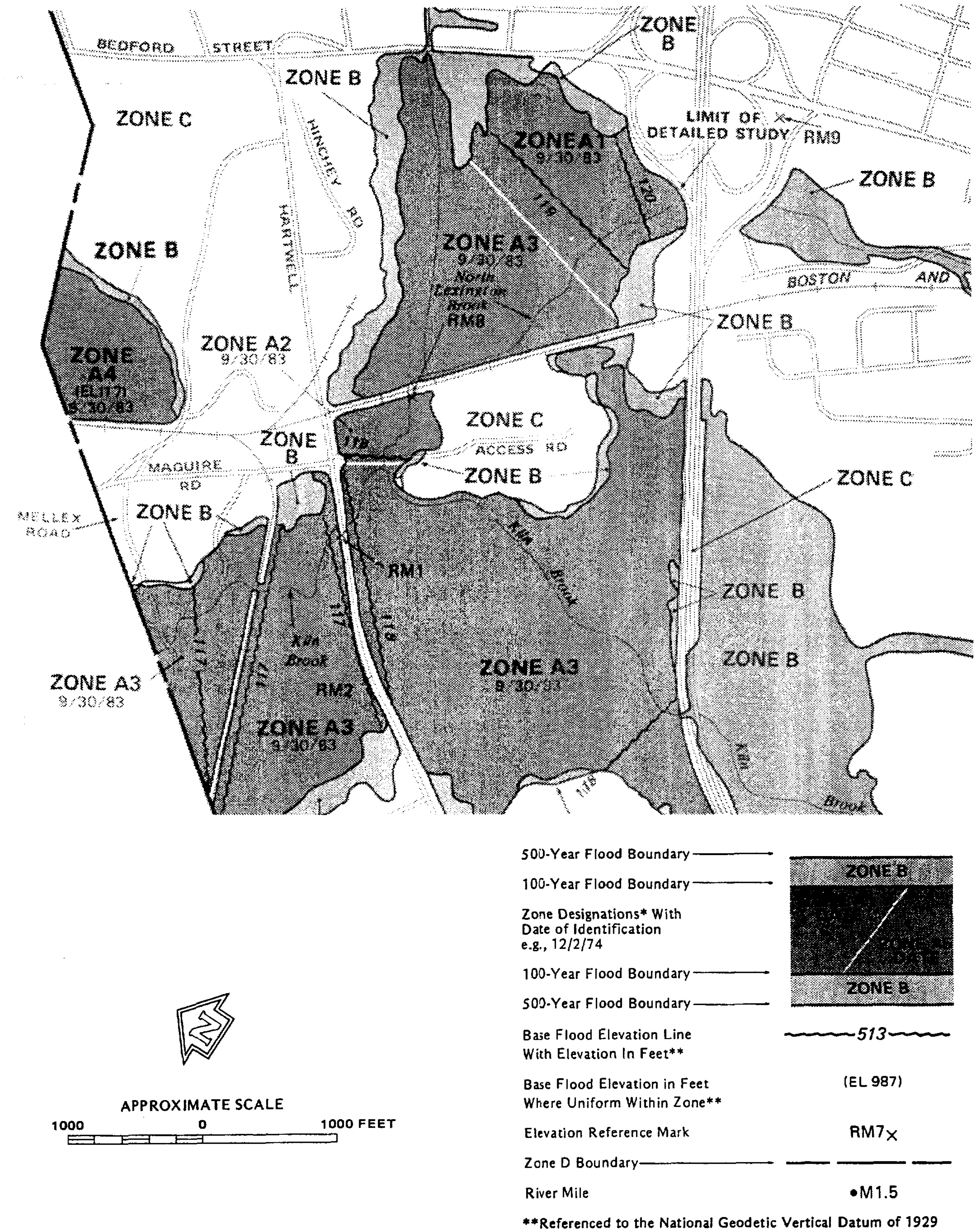


Figure 4-3. Portion of the Flood Insurance Rate Map (FIRM) for the Town of Lexington, Massachusetts. Prepared by the Federal Emergency Management Agency.

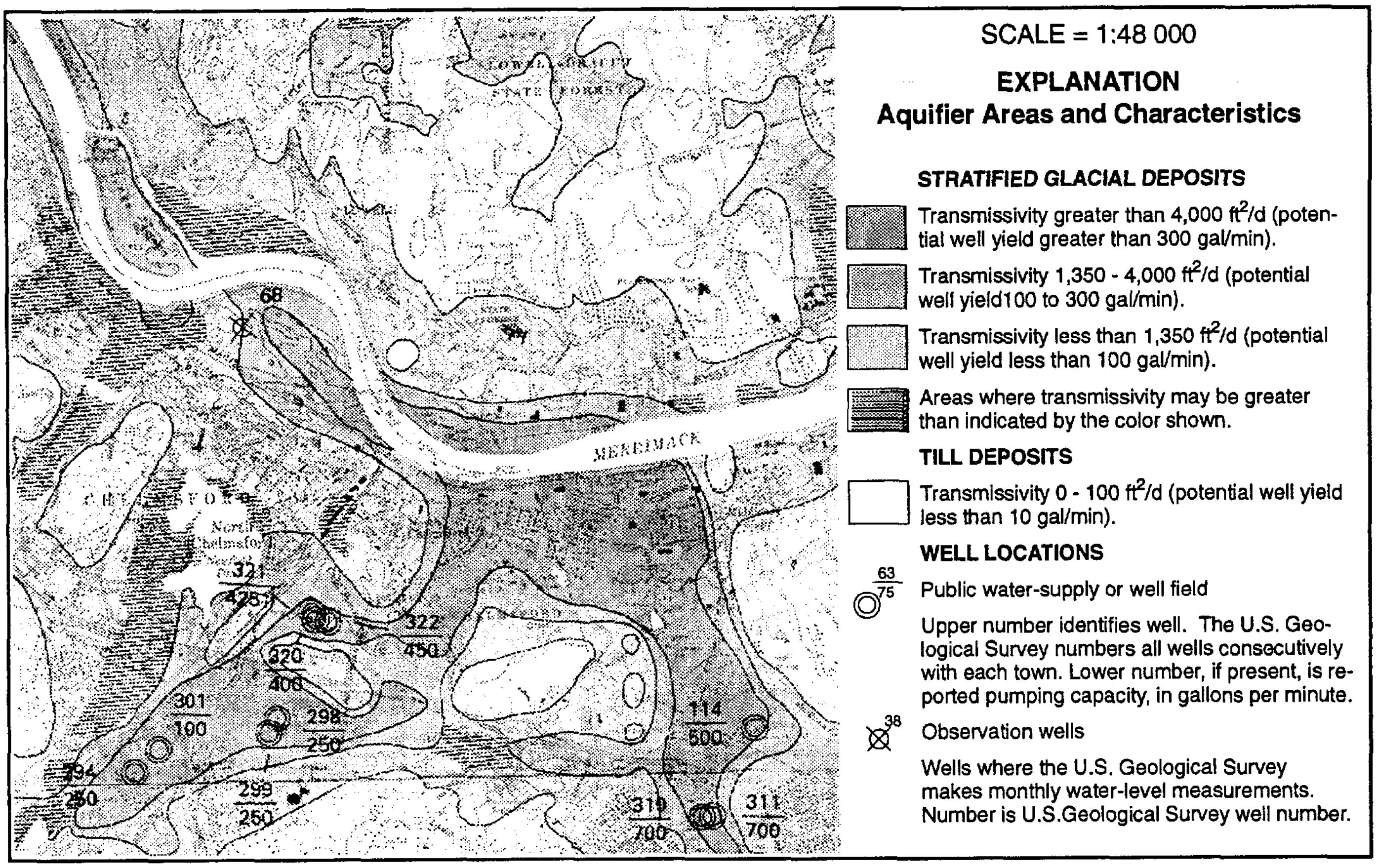


Figure 4-4. Portion of a U.S. Geological Survey Hydrologic Investigations Atlas - 662.

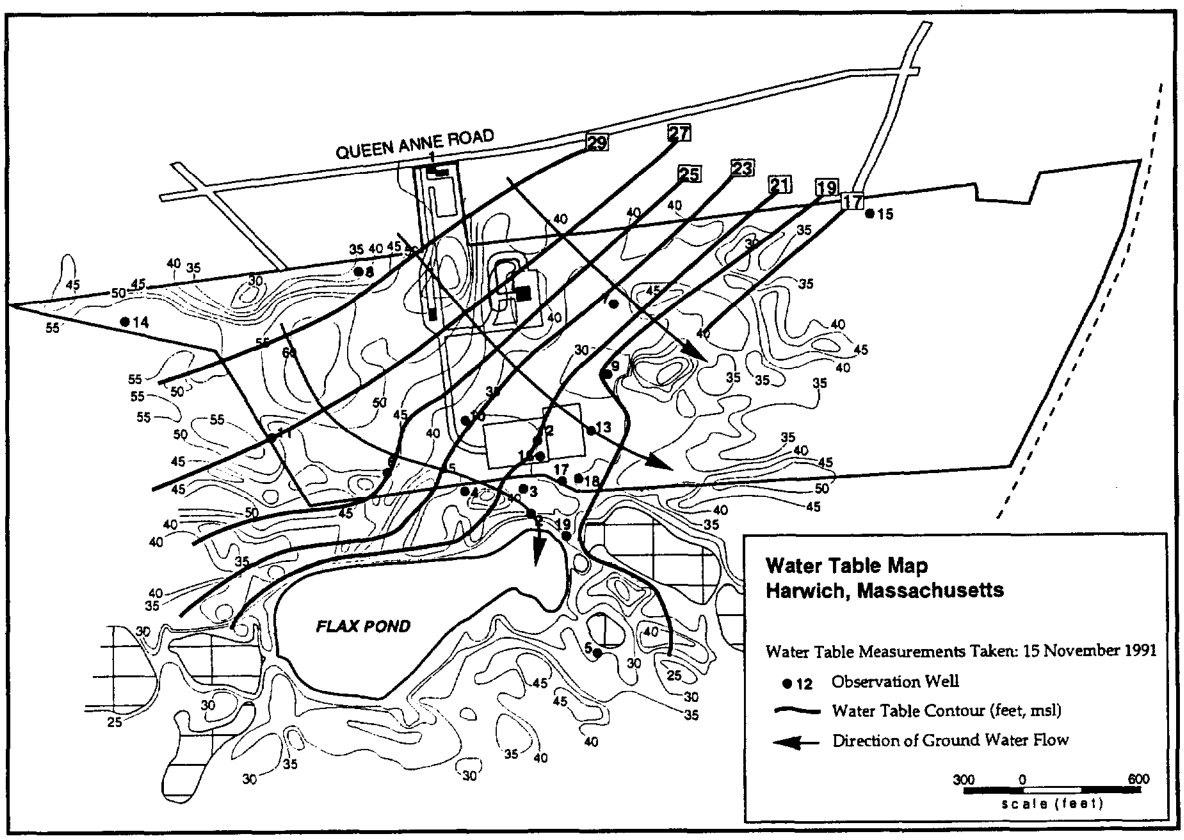
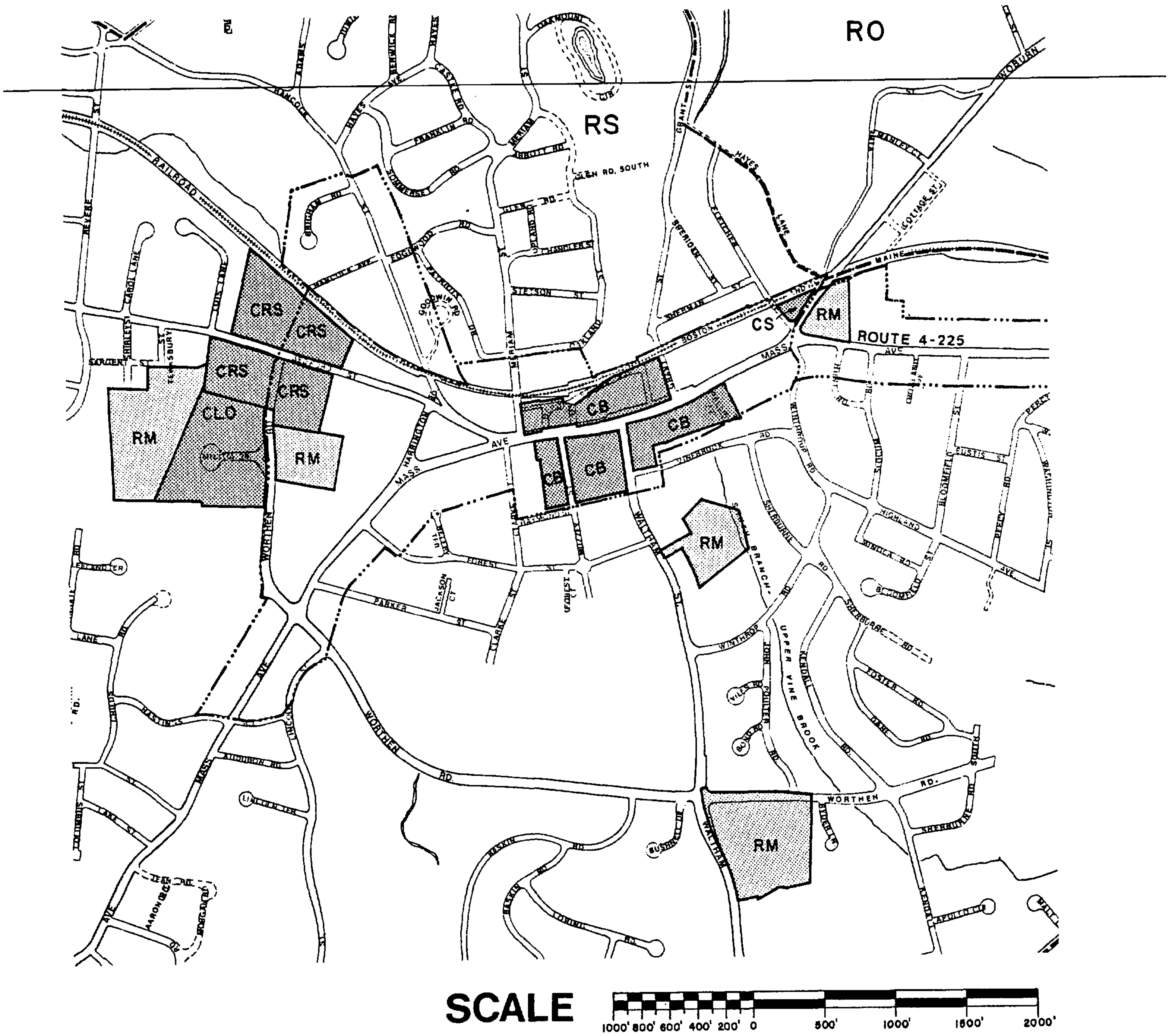


Figure 4-5. Water table map. Prepared by Horsley & Witten, Inc.



ZONING DISTRICTS

STANDARD ZONING DISTRICTS

RESIDENTIAL DISTRICTS

RO - One family dwelling
RS - One family dwelling
RT - Two family dwelling
RM - Multi-family dwelling

COMMERCIAL AND INDUSTRIAL DISTRICTS

CB - Central business
CLO - Local office
CM - Manufacturing
CN - Neighborhood business
CRO - Regional office
CRS - Retail shopping
CS - Service business

PLANNED DEVELOPMENT DISTRICTS

CD - Planned commercial
RD - Planned residential

NOTE: EACH PLANNED DEVELOPMENT DISTRICT HAS DIFFERENT STANDARDS AND MUST COMPLY WITH A SITE DEVELOPMENT AND USE PLAN APPROVED BY THE TOWN MEETING.

OVERLAY DISTRICTS

WPD - Wetland protection

FOR NATIONAL FLOOD INSURANCE DISTRICTS, SEE FLOOD INSURANCE RATE MAP.

BOUNDARY LINES

BETWEEN RS & RO DISTRICTS
HISTORIC DISTRICTS

DETAILED MAPS SHOWING THE BOUNDARIES OF ALL ZONING DISTRICTS EXCEPT THE RO AND RS DISTRICT ARE INCLUDED IN THE BOOKLET "ZONING DISTRICT MAPS" PUBLISHED BY THE PLANNING BOARD.

STREET CLASSIFICATION

STATE HIGHWAY OR TOWN STREET
UNACCEPTED STREET *

Figure 4-6. Zoning map.

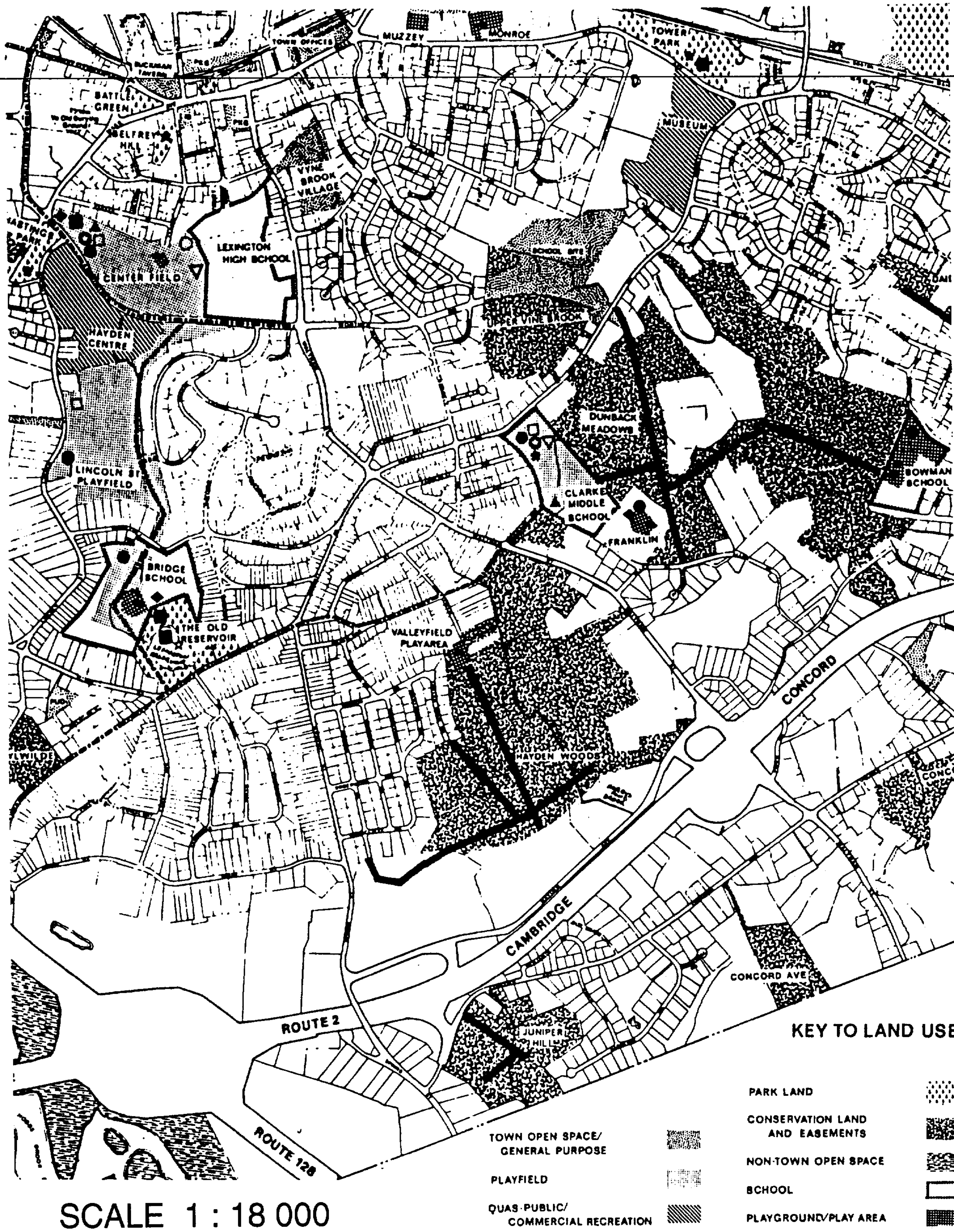


Figure 4-7. Recreation and open space land use map.

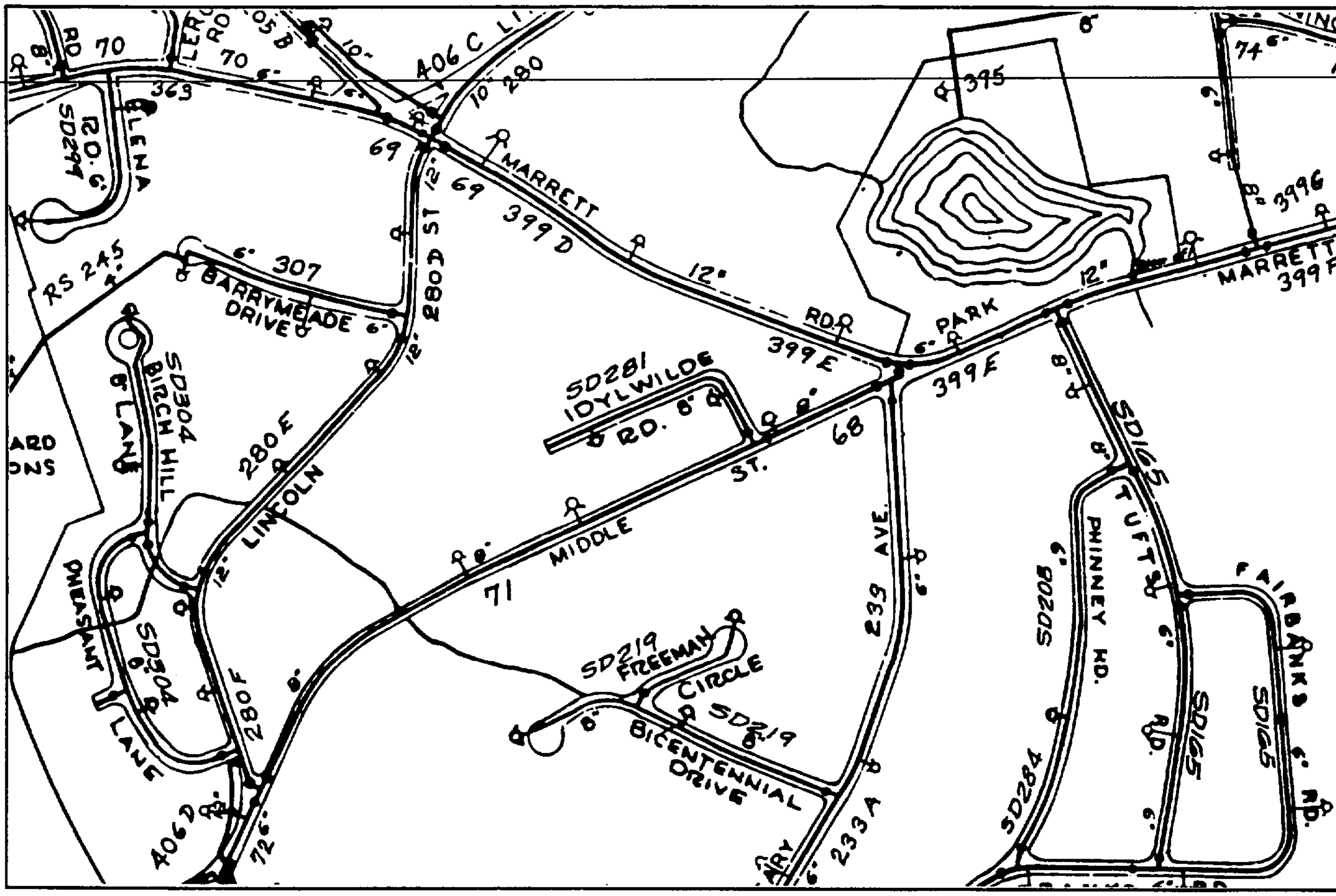


Figure 4-8. Utility map depicting existing drainage piping network. Scale: 1″ = 1,600′

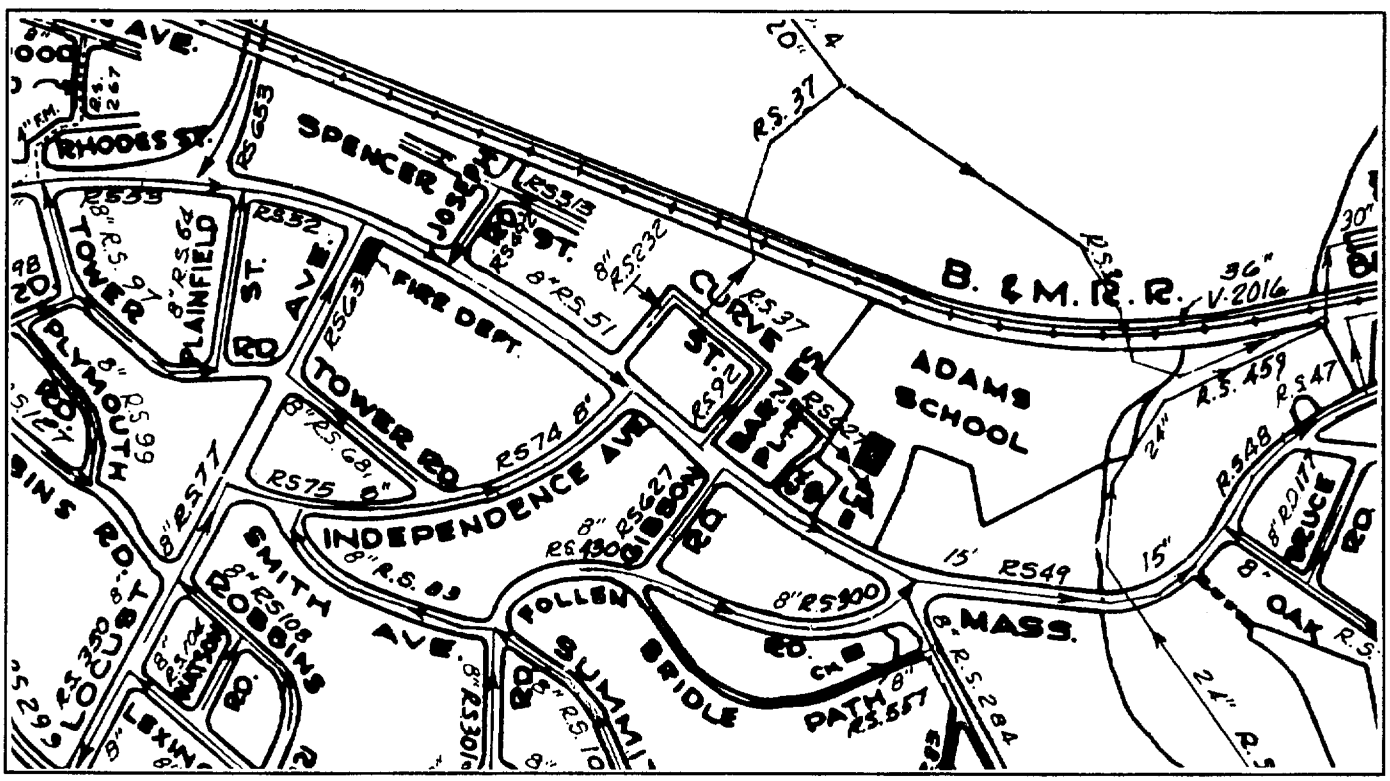


Figure 4-9. Utility map depicting existing sewer network. Scale: 1″ = 1,600′

Federal, State, and County Agencies

Federal, state, and county agencies can provide a wealth of information for your team. Much of the information described above is readily available in the archives of these agencies. (Massachusetts, for example, has developed a hydrogeologic information matrix that lists every important state, USGS, or consultant hydrogeologic report by geographic location.) It is worthwhile to contact as many of these governmental agencies as possible, not only to obtain their technical documents but also to receive guidance and technical assistance. Some states have developed their own water supply atlases with overlay maps depicting drainage basins, ground water parameters, the location of public drinking water supplies, and the location of possible sources of contamination. Agencies that may be helpful include USGS, U.S. Department of Agriculture Soil Conservation Service, U.S. Department of Fisheries and Wildlife, U.S. EPA Office of Ground Water and Drinking Water, County Extension Service, and state departments of health, environment, or natural resources.

Methods for Delineating a Wellhead Protection Area[3]

Several methods exist for delineating wellhead protection areas. These range in complexity and cost of implementation. A team's choice of delineation method depends on available resources, hydrogeologic conditions, state regulatory agency requirements, and the specific goals and objectives set by your community planning team. Most of the more sophisticated techniques involve analytical methods and/or computer modeling. If detailed townwide mapping of aquifers is required, for example, communities may need to involve consultants at this stage. Advantages and disadvantages of a number of delineation techniques are summarized on page 47. Table 4-2 shows the costs of delineation associated with each method described below (U.S. EPA, 1987). These costs are rough estimates only. If a large amount of data collection is necessary, the upper end of the scale applies.

The delineation techniques described below refer to one common type of aquifer: the permeable, granular aquifer existing under unconfined conditions. For information about delineation of wellhead protection areas in fractured rocks or in confined-aquifer settings, see Appendices B and C.

[3]Most of the information on methods for delineation is summarized from EPA's *Guidelines for Delineation of Wellhead Protection Areas.* This publication should be consulted for more detailed technical information on these techniques.

Table 4-2. Costs Associated with Various Wellhead Protection Area Delineation Methods

Method	Person-Hours Required per Well	Level of Expertise[1]	Cost per Well	Potential Overhead Costs[2]
Arbitrary Fixed Radii	1-5	1	$12-60	Low
Calculated Fixed Radii	1-10	2	$17-170	Low
Simplified Variable Shapes	1-10	2	$17-170	Low to Medium
Analytical Methods	2-20	3	$60-600	Medium
Hydrogeologic Mapping	4-40	3	$120-1,200	Medium to High
Numerical Modeling	10-200+	4	$350-7,000+	High

[1]Hourly wages per level of expertise assumed to be:

1. Non-technical	$12
2. Junior Hydrogeologist/Geologist	$17
3. Mid-Level Hydrogeologist/Modeler	$30
4. Senior Hydrogeologist/Modeler	$35

[2]Potential Overhead Costs include those for equipment to collect hydrogeologic data, computer hardware and software, and the costs associated with report preparation. *These figures do not reflect the costs for consulting firms potentially engaged in this work.*

Source: Adapted from U.S. EPA, 1987.

Arbitrary Fixed Radius

This approach to wellhead protection involves drawing a circle of specified radius around each well in your community to delineate the wellhead protection areas (see Figure 4-10). For example, several communities in Georgia have selected a radius of 1,500 feet around each well; the state of Louisiana uses a 1-mile radius for confined aquifers and a 2-mile radius for unconfined aquifers. The radius length should reflect the hydrogeology of the area.

Using an arbitrary fixed radius is an inexpensive, easily implemented method of wellhead delineation that requires little technical expertise (see Table 4-2). Choosing large fixed radii can increase this method's protective effectiveness and compensate somewhat for its technical limitations. Many wells can be protected quickly using this approach. It can be viewed as a temporary measure until a more sophisticated delineation method can be used. It can be especially useful if an imminent contamination threat exists that demands immediate attention.

The disadvantages of this method include the fact that it is not based on hydrogeologic principles and that there may be insufficient information available to choose an appropriate threshold radius. Therefore, this method might lead to inadequate protection of recharge areas. Alternatively, it could lead to overcompensation and increased costs of land management in areas that do not require it—especially in regions exhibiting complex geology where significant hydrologic boundaries are present. In addition, the limited scientific basis for establishing these wellhead protection areas might make them less defensible if challenged later.

Looking at potential contaminant sources near the wellhead protection area established with this method, as well as those inside the circle, can help you determine whether a more complex method might be needed.

Calculated Fixed Radius[4]

This delineation approach involves drawing a circular boundary around a well for a specified time of travel (see Chapter Two). Figure 4-11 illustrates the use of the calculated fixed radius method. In this method, Equation 4-1 is used to calculate the required radius of protection for the well. This equation is based on the volume of water that could be pumped from a well in a specified time period. The time period is chosen by estimating the time necessary to clean up ground water contamination before it reaches a well, or to allow adequate dilution or dispersion of contaminants (e.g., 5 years).

Equation 4-1:

$$r = \sqrt{\frac{Qt}{\pi n H}}$$

[4]This method is used mainly for delineating wellhead protection areas for confined aquifers. See Appendix C for more information about confined aquifers.

Where:

Q = Pumping Rate of Well (ft^3 per year)
n = Aquifer Porosity (percent)
H = Open Interval or Length of Well Screen (feet)
t = Travel Time to Well (years)—chosen based on hydrology and contaminant source locations.
π = 3.1416

As seen above, the input to Equation 4-1 consists of basic hydrologic parameters. The advantages of this form of delineation include its ease of application, low cost, and relatively limited need for technical expertise. As with the arbitrary fixed radius method, a large number of wells can be delineated in a relatively short time frame. Although the calculated fixed radius method does offer greater scientific accuracy than the arbitrary fixed radius method,

AN EXAMPLE OF WELLHEAD PROTECTION AREA DELINEATION USING THE CALCULATED FIXED RADIUS APPROACH

A rural village is located over a confined aquifer. The village well pumps steadily at 500 gallons per minute (gpm) and the length of the well screen is 100 feet. Available literature sources cite aquifer porosity as 0.25 as measured from aquifer samples. Choosing a travel time of 5 years the wellhead protection area for the village well can be determined as follows:

(1) $Q = 500$ gpm $H = 100$ ft $\pi = 3.1416$
$n = 0.25$ $t = 5$ yrs

(2) $1 \text{ gpm} = 2.23 \times 10^{-3} \text{ ft}^3/\text{sec}$
$Q = [(500)(2.23 \times 10^{-3})(86400 \text{ sec/day})(365 \text{ days/yr})] \text{ ft}^3/\text{yr}$
$Q = 3.52 \times 10^{7} \text{ ft}^3/\text{yr}$

(3) $r = \sqrt{(Qt) / (\pi\, n\, H)}$

$$r = \sqrt{\frac{(3.52 \times 10^{7} \text{ ft}^3/\text{yr})\ (5 \text{ yrs})}{(3.1416)\ (0.25)\ (100 \text{ ft})}}$$

$r = \sqrt{2.24 \times 10^{6} \text{ ft}^2}$

$r = 1500$ ft

The village uses a circle of 1500-ft radius to delineate a wellhead protection area for its well.

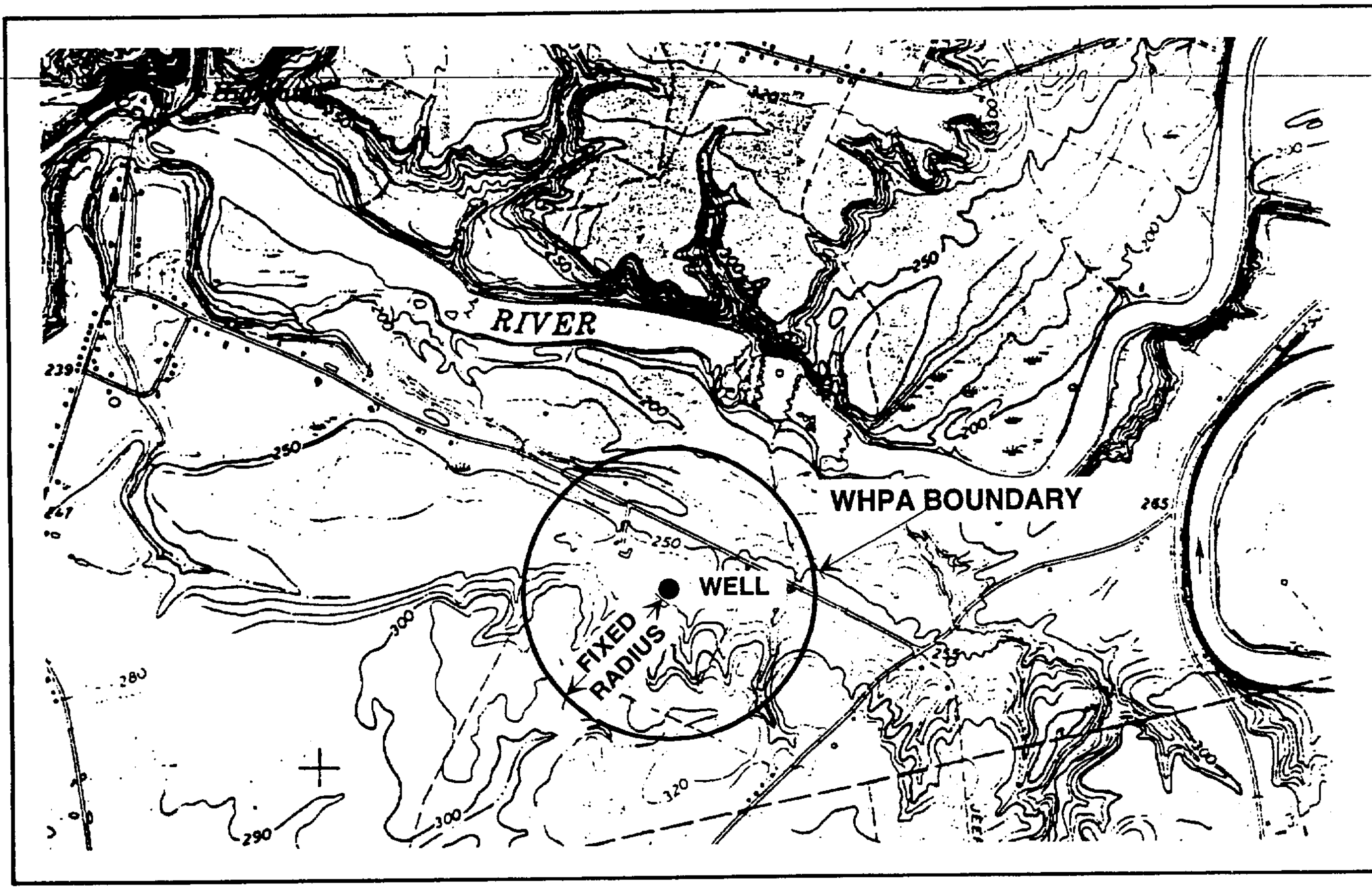
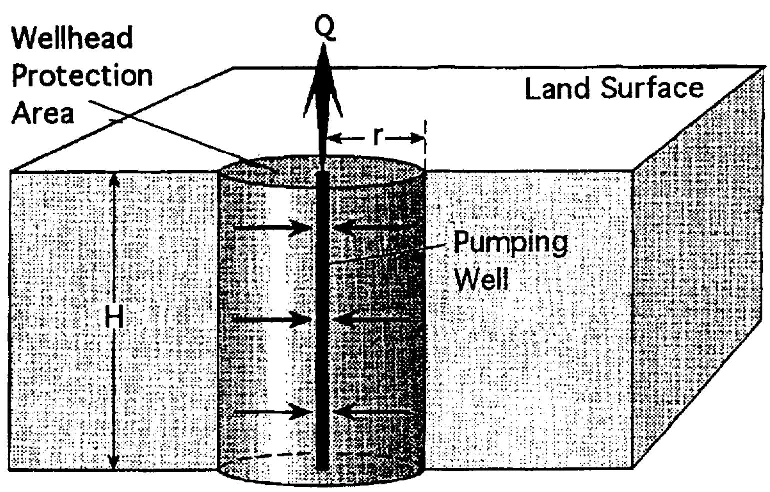


Figure 4-10. Wellhead protection area delineation using the arbitrary fixed radius method.



- Radius (r) is calculated using a simple equation that incorporates well pumping rate (Q) and basic hydrogeologic parameters.
- The radius determines a volume of water that would be pumped from well in a specified time period.
- H = open interval or length of well screen.

Figure 4-11. Wellhead protection area delineation using the calculated fixed radius method. (U.S. EPA, 1991a).

some results may be inaccurate because this technique does not consider all factors influencing contaminant transport. Again, this limitation is of special concern in regions of geologic complexity where hydrologic boundaries exist.

Although this method is relatively inexpensive, it may cost more than the arbitrary fixed radius method because of the amount of time needed to establish the hydrogeologic parameters required to solve Equation 4-1 (see Table 4-2).

Variable Shapes

This method involves the use of analytical models to produce "standardized forms" of wellhead protection areas using the representative hydrogeological criteria, time of travel (TOT), and flow boundaries (locations of physical or hydrologic features controlling ground water flow). Various standardized forms are calculated for different sets of hydrogeologic conditions. Many shapes are possible for each set of conditions; however, this methodology chooses a few generalized forms. The most suitable form is chosen for each well by determining how closely that form matches the hydrogeologic and pumping conditions exhibited at the wellhead. Once the appropriate standardized form has been identified, it must be correctly aligned around the wellhead based on the direction of ground water flow (see Figure 4-12). The upgradient extent of the wellhead protection area is determined by using a TOT equation and the well's zone of contribution (the entire area that recharges or contributes water to the well), including the distance downgradient. The downgradient ground water flow boundaries are calculated using the uniform flow equation (see Figure 4-13).

The advantages of using variable shapes lie in the fact that this method requires little actual field data and can be easily implemented once the standardized forms have been calculated. It offers a more comprehensive technical delineation than the fixed-radius method with only a minor increase in cost. Once the standardized forms are developed, the only necessary information required is well pumping rate, material type, and the direction of ground water flow (U.S. EPA, 1987).

The disadvantages of this methodology include the potential for inaccuracies in areas with many geologic changes and hydrologic boundaries. In addition, a large amount of data collection is essential to develop the shapes of the standardized forms accurately and to characterize ground water flow patterns in the locus of the wellheads adequately. At a simple level, this method is more well-specific than the arbitrary or calculated fixed radius methods, but its results can be skewed by small errors in information.

Analytical Models

Analytical methods involve the use of equations to delineate the boundaries of wellhead protection areas. These are extremely useful tools for understanding ground water flow networks and contaminant transportation systems. The uniform flow equations (Todd, 1980) are used to define the zone of contribution to a pumping well in a sloping water table (see Figure 4-13). These equations also define ground water flow within an aquifer.

Specific hydrogeologic input data are required to satisfy these equations at each well where this method is implemented. These data can include hydraulic conductivity, transmissivity, hydraulic gradient, pumping rate, and thickness of the saturated zone (see Chapter Two and Appendix E for definitions). Once this information has been obtained, the equations can be used to define specific features of the wellhead protection area, such as the distance to the downgradient divide (stagnation point) and the appropriate zone of contribution. The upgradient boundaries of the wellhead protection area are based on flow boundaries or TOT threshold values.

This method is relatively inexpensive, even though consultants may be involved, and is one of the most extensively used methods for delineating wellhead protection areas. Costs may escalate if site-specific hydrogeologic data are not readily available and test holes must be drilled or pump tests must be performed.

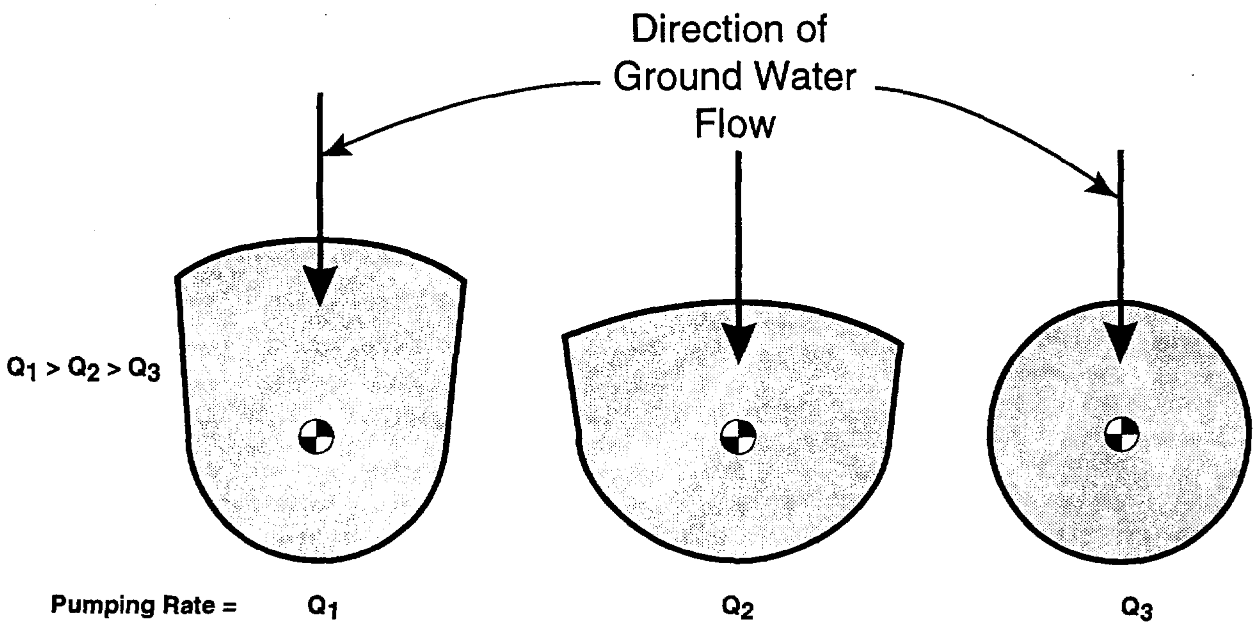
This technique can be used to determine distances that define the zone of contribution for a well pumping in a sloping water table, but it generally cannot calculate drawdown (lowering of water level in well due to pumping) which determines the well's zone of influence (cone of depression). Additionally, analytical methods generally do not assimilate geologic heterogeneities and hydrogeologic boundaries in their modeling. However, computerized analytical flow and contaminant transport models have been developed. (See *Model Assessment for Delineating Wellhead Protection Areas* [U.S. EPA, 1988] for an assessment of these models.)

WHPA Code 2.1

WHPA is a modular semianalytical ground water flow model developed by U.S. EPA's Office of Ground Water Protection (currently the Office of Ground Water and Drinking Water) primarily to assist state and local technical staff with WHPA delineation. It is distributed by the International Ground Water Modeling Agency (303-273-3103; contact this agency for the most recent version). The WHPA model uses a computer program to solve the analytical equations for two-dimensional flow to a well under various hydrologic conditions. WHPA can be used on most personal computers and is very straightforward to use. The user is prompted, through a series of pop-up windows, to provide the specific input required.

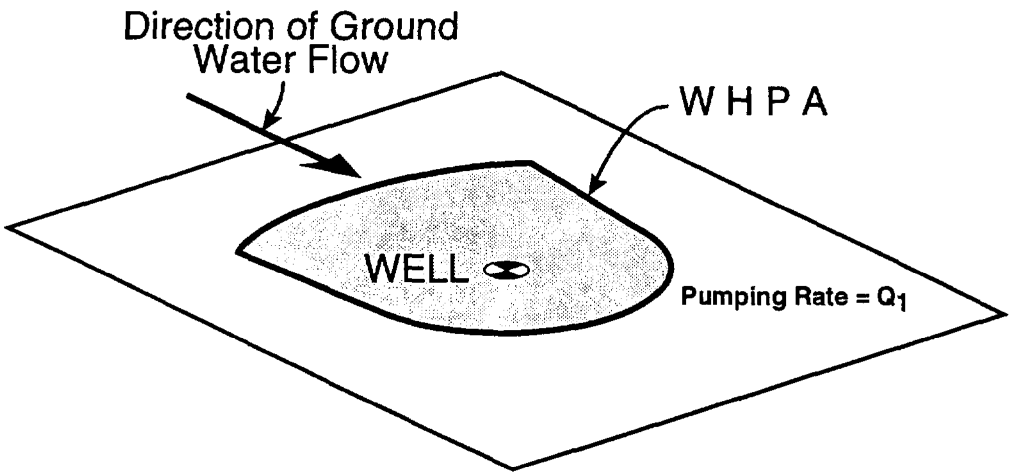
The WHPA model contains four independent modules: RESSQC, MWCAP (Multiple Well Capture Zone), GPTRAC (General Particle Tracking), and MONTEC (Uncertainty Analysis). These modules compute the zone of

STEP 1 ***Delineate Standardized Forms for Certain Aquifer Type***



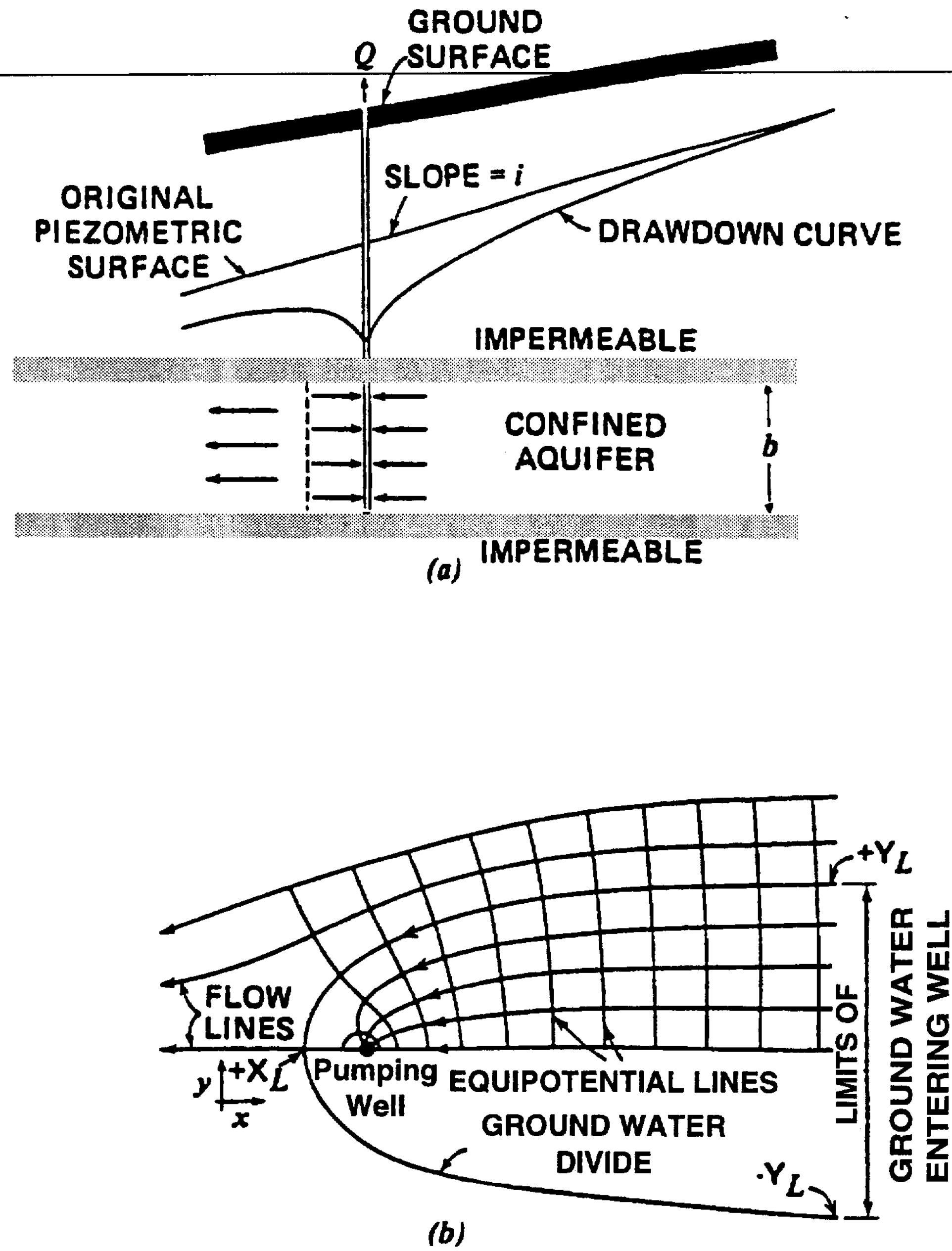
Various standardized forms are generated using analytical equations using sets of representative hydrogeologic parameters. Upgradient extent of WHPA is calculated with Time of Travel equation; downgradient with uniform flow equation.

STEP 2 ***Apply Standardized Form to Wellhead in Aquifer Type***



Standardized form is then applied to wells with similar pumping rate and hydrogeologic parameters.

Figure 4-12. Wellhead protection area delineation using the simplified variable shapes method (U.S. EPA, 1987).



$$-\frac{Y}{X} = \tan\left(\frac{2\pi Kbi}{Q} Y\right)$$

UNIFORM-FLOW EQUATION

$$X_L = -\frac{Q}{2\pi Kbi}$$

DISTANCE TO DOWN-GRADIENT DIVIDE OR STAGNATION POINT[1]

$$Y_L = \pm \frac{Q}{2Kbi}$$

BOUNDARY LIMIT

Where:
Q = Well Pumping Rate
K = Hydraulic Conductivity
b = Saturated Thickness
i = Hydraulic Gradient
π = 3.1416

[1] Place in ground water flow field at which ground water is not moving.

FIGURE 4-13. WHPA delineation using the uniform flow analytical model (Todd, 1980).

USING ANALYTICAL EQUATIONS FOR ZONE OF CONTRIBUTION (ZOC) DELINEATION

The figure below is a regional water-table map showing the elevation of the water table and other hydrologic features around the site of a village well in a fractured-rock terrain. The well is completed in an unconfined aquifer composed of fractured igneous rock overlain by thin soils. The water table is in the fractured rock. The municipal well pumps steadily at 65 gallons per minute (gpm), and is screened over the entire aquifer thickness of 150 ft. The only information on the hydraulic properties of the aquifer comes from literature values from a general study of the county that cites the hydraulic conductivity of the aquifer as 3×10^{-4} ft/sec.

The ZOC for the village well can be calculated using the uniform flow equation (see Figure 4-13), and estimating the horizontal hydraulic gradient from the water-table map.

(1) $$X_L = \frac{-Q}{(2\pi Kbi)} \qquad Y_L = \frac{\pm Q}{(2Kbi)}$$

$Q = 65$ gpm
$K = 3 \times 10^{-4}$ ft/sec
$\pi = 3.1416$
$b = 150$ ft

$1 \text{ GPM} = 2.23 \times 10^{-3}\ \text{ft}^3/\text{sec}$

(2) Hydraulic Gradient

$$i = \frac{145 \text{ ft} - 140 \text{ ft}}{1600 \text{ ft}} = 0.0031$$

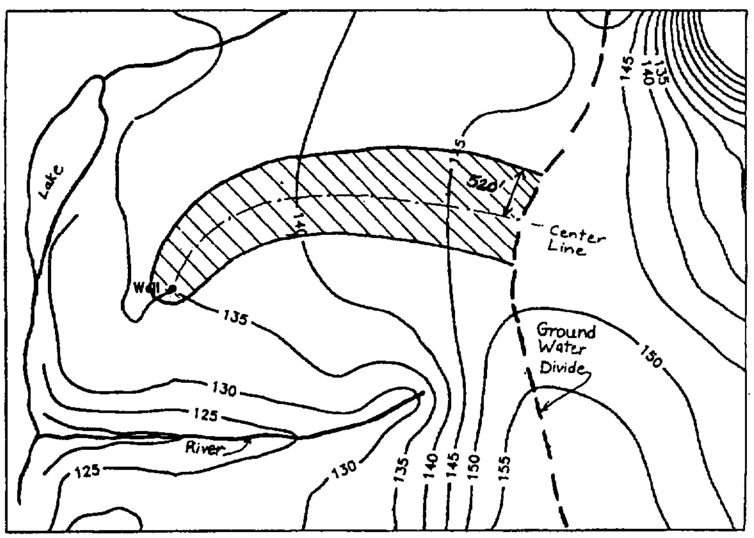
(3) $$X_L = \frac{-(65)(2.23 \times 10^{-3})}{2\pi(3 \times 10^{-4})(150)(.0031)} \approx 165 \text{ ft}$$

(4) $$Y_L = \frac{\pm(65)(2.23 \times 10^{-3})}{2(3 \times 10^{-4})(150)(.0031)} \approx 520 \text{ ft}$$

Source: K. Bradbury, Wisconsin Geological and Natural History Survey.

Regional Water Table

Contour interval 5 ft   Scale: 1/2 inch = 1000 ft   • – Village



contribution of wells based on a range of input data. Each module operates completely independently of one another. The input requirements for each module are shown in Table 4-3. Each module is discussed in detail in the EPA guidance manual accompanying the WHPA software.

The WHPA code can be used to model multiple pumping and injection wells, and can simulate barrier or stream boundary conditions that exist over the entire aquifer depth. Confined, leaky-confined, and unconfined aquifers with areal recharge can be modelled using WHPA.

The advantages of using the WHPA model in wellhead delineation are that it determines ground water flow paths and travel times very precisely, incorporates the effects of well interference, and provides rapid solution of analytical equations combined with delineation of the zone of contribution. The disadvantages include the limitation of solving only two-dimensional flow problems, the danger

Table 4-3. **Required Input for WHPA Model Computational Modules**

Required Input	RESSQC	MWCAP	GPTRAC Semi-analytical	GPTRAC Numerical
Units used				
Aquifer type*	■	■	■	■
Study area limits			■	
Maximum step length	■	■	■	■
No. of pumping wells	■	■	■	
No. of recharge wells	■	■	■	■
Well locations	■		■	■
Pumping/injection rates	■	■	■	■
Aquifer transmissivity	■	■	■	■
Aquifer porosity	■	■	■	■
Aquifer thickness	■	■	■	■
Angle of ambient flow	■	■	■	■
Ambient hydraulic gradient	■	■	■	
Areal recharge rate	■	■	■	
Confining layer hydraulic conductivity			■	
Confining layer thickness			■	
Boundary condition type		■	■	
Perpendicular distance from well to boundary		■	■	
Orientation of boundary		■	■	
Capture zone type		■		
No. of pathlines used to delineate capture zones	■	■	■	■
Simulation time	■		■	■
Capture zone time	■	■	■	■
Rectangular grid parameters				■
No. of forward/reverse pathlines	■		■	■
Starting coordinates for forward/reverse pathlines	■		■	■
Nodal head values				■
No. of heterogeneous aquifer zones				■
Heterogeneous aquifer properties				■

*Confined, unconfined, or leaky confined.

Note: The MONTEC module is not listed in this table. It has the same input requirements as MWCAP and semi-analytical GPTRAC, with the addition that uncertain aquifer parameters and their associated probability distributions must be specified.

Source: U.S. EPA, Office of Ground Water Protection. *WHPA—A Modular Semi-Analytical Model for the Delineation of Wellhead Protection Areas.* March 1991.

CRITERIA FOR DELINEATION OF WELLHEAD PROTECTION AREAS

The U.S Environmental Protection Agency (1987) has recommended five criteria as the technical basis for delineating wellhead protection areas. These criteria are:

- **Distance**
  The distance criterion is used to delineate wellhead protection areas by calculating a fixed radius or other dimension, measured from the well to the wellhead protection area boundary. This approach is the simplest, least expensive, and most direct approach to wellhead delineation. It is only recommended as a preliminary step, however, because it does not include the processes of ground water flow or contaminant transport.
- **Drawdown**
  Drawdown is the decline in water level elevation induced by a pumping well. The greatest drawdown occurs at the well and decreases with distance away from the well until an outer limit is reached where the water level is not affected by the pumpage. This outer limit is the zone of influence or the areal extent of the well's cone of depression. Ground water flow velocities increase toward a pumping well; therefore, drawdown can increase the flow of contaminants toward a well. The drawdown criterion may be used to delineate the boundaries of the zone of influence and this may be used as a wellhead protection area.
- **Time of Travel (TOT)**
  The time of travel criterion is used to represent the time it takes for ground water or a contaminant to flow from a point within a well's zone of contribution to a well. Using this criterion, isochrons (contours of equal time) of selected time periods are delineated on a map. The lateral area contained within an isochron is referred to as the zone of transport (ZOT) and this is used as the wellhead protection area.
- **Flow Boundaries**
  The flow boundary criterion uses determined locations of ground water divides and/or other physical/hydrologic features that control ground water flow to define the geographic area that contributes ground water to a pumping well. This area is the zone of contribution (ZOC) of the well and is used as its wellhead protection area. This approach assumes that contaminants entering the ZOC will eventually reach a pumping well. Ground water divides occur naturally or may be artificial, such as those created by a pumping well. The flow boundaries criterion is especially useful for small aquifer systems.
- **Assimilative Capacity**
  The assimilative capacity criterion takes into account the fact that the saturated and/or unsaturated section of an aquifer can attenuate the toxicity of contaminants before they reach a pumping well through the processes of dilution, dispersion, adsorption, and chemical precipitation or biological degradation. This approach, however, requires knowledge of sophisticated contaminant transport modeling and extensive information on the hydrology, geology, and geochemistry of the study area. Therefore, this approach is unrealistic for limited studies.

of hidden errors due to the simplicity of operation, and the assumptions in certain modules that the aquifer is homogeneous and isotropic (having properties that are the same in all directions). These assumptions could be very unrealistic.

Hydrogeologic Mapping

This method utilizes geological, geomorphic, geophysical, and dye tracing methods to map flow boundaries and time of travel criteria. To determine the appropriate flow boundaries, geological studies of the aquifer are undertaken to identify varying rock characteristics which indicate permeable and non-permeable rock material. Geophysical investigations can also determine the aerial extent and thickness of unconfined aquifers. Ground water drainage divides also can be used in hydrogeologic mapping (U.S. EPA, 1987). Figure 4-14 illustrates the use of geologic contacts and ground water divides in wellhead protection area delineation.

This method can be used to delineate wellhead protection areas for conduit karst aquifers (see Chapter Two), which exhibit high flow rates and are rapidly recharged due to their channel-like structure (karst is a region characterized by rock dissolution). The wellhead protection area can be delineated first by developing catchment area (drainage divides) mapping and water table mapping, and second by conducting dye-tracing testing to produce more accurate mapping of the karst recharge patterns. (Dye tracing is essential in karst aquifers because ground water flow patterns commonly do not follow topographic divides and can change significantly depending on whether high- or low-flow conditions exist.) This form of delineation works well for aquifers whose flow boundaries are relatively near the surface, as found in glacial and alluvial aquifers, and for aquifers exhibiting different physical properties in different directions, as found in fractured bedrock and channelled karst (U.S. EPA, 1987).

This delineation technique requires expertise in the geological sciences and professional judgment in determining flow boundaries. This approach may prove expensive if little hydrogeologic data exist and field investigations are necessary. Great care must be taken if extrapolated data are used.

Numerical Models

This method utilizes computer modeling techniques to simulate the three-dimensional boundaries of an aquifer using numerical equations. Much of the current emphasis

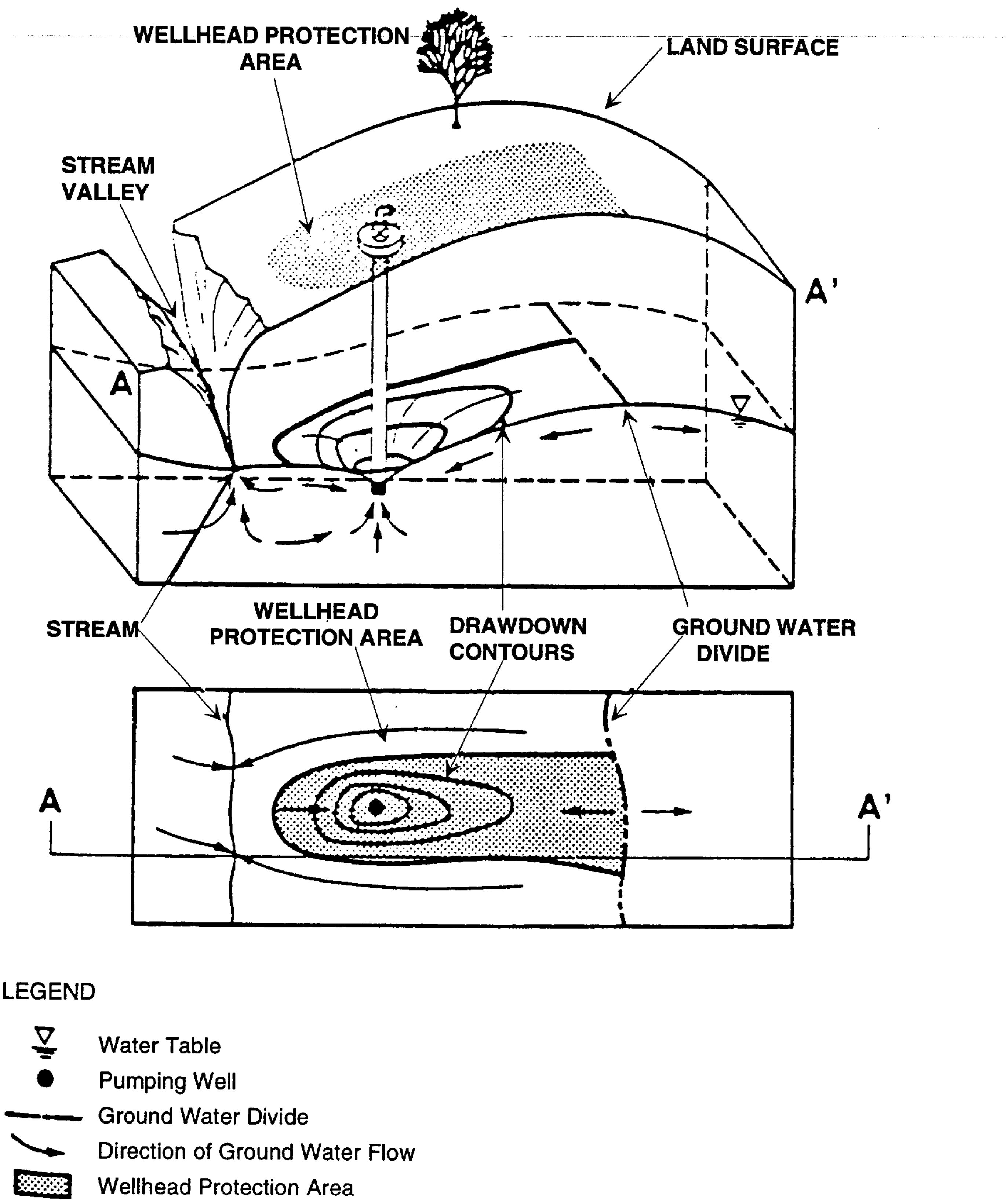


Figure 4-14. Wellhead protection area delineation using hydrogeologic mapping (use of ground water divides). (U.S. EPA, 1987).

Karst aquifers exhibit high flow rates and are rapidly recharged due to their channel-like structure.

ADVANTAGES AND DISADVANTAGES OF WELLHEAD PROTECTION AREA DELINEATION TECHNIQUES

Arbitrary fixed radius	Little data necessary Quick and easy to draw Very low cost Not very accurate
Calculated fixed radius	Need limited hydrogeologic data Relatively quick and easy Inexpensive Not highly accurate
Variable shapes	Based on relatively little field data Still fairly quick and easy If data are available, low cost In complex settings, not very precise
WHPA Code (Semianalytic model)	Based on substantial field data May require technical assistance Automatic delineation of capture zones Calculates the effects of well interference Danger of hidden errors because the program is simple to operate Most solutions assume homogeneous isotropic aquifers Moderate costs
Analytic models	Based on substantial field data Probably requires professional help Moderate costs, if data are available Widely used, fairly accurate
Numerical models	Based on extensive field data Requires computer/technical expertise Can be highly accurate Can be quite expensive

Source: Adapted from Paley and Steppacher, n.d.

in this field lies in mathematical flow models and contaminant transport models. Flow models are used to calculate changes in the distribution of hydraulic head of fluid pressure, drawdowns, rate and direction of flow, travel times, and the position of interfaces between immiscible fluids, while solute transport and fate models predict movement, concentrations, and mass balance components of water soluble constituents (U.S. EPA, 1988).

In general, the numerical approach requires the formulation of a grid that simulates the test aquifer. At each node, values such as water table elevation, hydraulic conductivity, and aquifer thickness are input. These form the basis for a matrix of equations that simulate the aquifer. The model can simulate changes in any of the hydrologic conditions characterizing the aquifer to investigate the effects of such alterations.

The main advantage of these computer models is their ability to model aquifers exhibiting complex hydrogeology. This requires a significant amount of field information because the data input usually covers a wide range of hydrogeologic parameters. A major advantage of computer modeling is the rate at which computers can synthesize and manipulate large amounts of analytical data. An additional advantage is the predictive nature of modeling techniques, which allows the user to determine the system's response to a variety of proposed management options. In addition to these useful predictions, these models provide a high degree of accuracy.

Because computer and hydrogeological expertise is needed to produce these models, this method can be costly. As shown in Table 4-1, it has the potential to be the most expensive of all the delineation methods discussed here. If a high degree of accuracy is demanded, however, this methodology can prove cost-effective, especially if a large, detailed data base is available from which to work. For a more extensive discussion of numerical modeling techniques, see *Model Assessment for Delineating Wellhead Protection Areas* (U.S. EPA, 1988).

Hiring a Consultant

Mapping wellhead protection areas might require technical expertise in the science of hydrogeology, depending on the complexity of your community's aquifer. If you cannot obtain sufficient help from a state or federal government agency, your team can consider hiring a hydrogeologist, engineer, and/or land planner as a technical adviser. Selecting a consulting engineering firm to undertake a hydrogeologic study requires careful judgment; the firm's services can be expensive and the delineated boundaries of your resource area could be challenged in court at a later date. The steps involved in choosing an engineering consulting firm include identifying potential candidate firms, issuing a request for proposals, interviewing, checking references, and preparing a contract once a consultant has been selected.

Potential candidates can be easily identified by your community's past experience, or by contacting your local extension service, the National Rural Water Association, a rural community assistance program, or state ground water agency. These organizations might also be able to offer you technical support. The National Ground Water Association, the American Institute of Professional Geologists, the National Society of Professional Engineers, and the American Academy of Environmental Engineers are good sources for consultant information.

A request for proposals will differ for every community, depending on its size and the nature of your project. This document should be as specific as possible and should, at a minimum, describe the major goal of the project, the anticipated scope of work, and the final product(s) required (such as reports, ground water mapping, geologic mapping, delineated wellhead protection areas, zoning map overlay, and analysis of future needs). It should contain a request for information on personnel qualifications and experience, and should include the standards by which the proposals will be judged. The deadline for proposals and the local contact person also should be noted.

Three or four firms should be selected from those that meet your judging standards. During the interviewing stages, the wellhead protection planning team should compare the professional reputation of each firm, its experience in similar projects, including facilities and equipment capabilities, project cost and billing policy, understanding of the nature of the project, and the potential quality of the finished product. The final selection should be the result of a consensus of the team on who will do the best job for your community. Once a firm is chosen, a contract must be prepared and submitted to local policy makers for approval. The firm's original proposal should be included in this contract.

The planning team should closely monitor and keep up to date with its consultant's progress. The public should be informed of this progress regularly.

STEP THREE—Identify and Locate Potential Sources of Contamination

This step serves two purposes: providing your team with information about existing and potential sources of ground water contamination and helping your team begin the process of land management that will ultimately protect your ground water supply.

Divide the Wellhead Protection Area into Different Land-Use Categories

The first stage in identifying potential contaminant sources is the preparation of a land use overlay map for your wellhead protection area. This map will help your team establish the threat that land uses pose to the quality of your water supply. A good starting point for this map is your community's zoning map (see Figure 4-6) or current land use map, which allocates sections of your community for specific land uses, including residential, commercial, and industrial uses. These zones create concentrations of businesses; if these concentrations are located in the recharge zone of your aquifer, they can increase the threat to your resource. Many industries are built along transportation corridors that follow river valleys, where high-yield aquifers are often located. Your team might discover that your community has been inappropriately zoned and does not limit high-risk activities within your aquifer's primary recharge zone. At this stage, your team might also find the aerial photographs that you collected in Step One to be very useful.

An important part of preparing your overlay map is identifying past and present waste disposal sites. These disposal sites might be easily recognizable as sewage treatment works, landfills, or underground injection wells, but care must be taken also to locate small commercial and industrial waste areas, such as lagoons and drywells. Residential underground septic systems also should be included on the map. The waste materials discharged at these sites can include solid waste, sludge, liquids, solvents, and oils. Your team should also establish whether any of the wastes discharged in your community are hazardous under the Resource Conservation and Recovery Act (RCRA). Information about industrial disposal facilities can be obtained from state and federal water pollution control agencies.

When identifying land uses, it is important to consider not only existing uses but also the historical and intended uses of the land. The historical uses (such as capped landfills, underground fuel storage facilities, abandoned mines, or tanneries) often play a major role in the land's present capacity to contaminate an aquifer. For example, land that was used for agricultural purposes at one stage should be researched to identify chemicals such as pesticides used, stored, or disposed of on site. Searching records and/or interviewing long-time residents will help ensure that you do not overlook past sources of contamination.

Review Potential Sources of Contamination

To identify potential sources of contamination adequately, it is useful to prepare a comprehensive inventory. Your team can list contaminant sources according to land use or type of source. (Table 3-1 lists some contaminant sources by land use category. Table 4-4 will help your team consider the contaminants that **might** be associated with various sources.) The inventory will prevent omission of any potential contaminant source, while making your team's management strategy easier to handle. Figure 4-15

Table 4-4. Potential Sources of Ground Water Contamination

Source	Health, Environmental, or Aesthetic Contaminant[1,2,3]
NATURALLY OCCURRING SOURCES	
Rocks and soils	*Aesthetic Contaminants:* Iron and iron bacteria; manganese; calcium and magnesium (hardness) *Health and Environmental Contaminants:* Arsenic; asbestos; metals; chlorides; fluorides; sulfates; sulfate-reducing bacteria and other microorganisms
Contaminated water	Excessive sodium; bacteria; viruses; low pH (acid) water
Decaying organic matter	Bacteria
Geological radioactive gas	Radionuclides (radon, etc.)
Natural hydrogeological events and formations	Salt-water/brackish water intrusion (or intrusion of other poor quality water); contamination by a variety of substances through sink-hole infiltration in limestone terrains
AGRICULTURAL SOURCES	
Animal feedlots and burial areas	Livestock sewage wastes; nitrates; phosphates; chloride; chemical sprays and dips for controlling insect, bacterial, viral, and fungal pests on livestock; coliform[4] and noncoliform bacteria; viruses
Manure spreading areas and storage pits	Livestock sewage wastes; nitrates
Livestock waste disposal areas	Livestock sewage wastes; nitrates
Crop areas and irrigation sites	Pesticides;[5] fertilizers;[6] gasoline and motor oils from chemical applicators
Chemical storage areas and containers	Pesticide[5] and fertilizer[6] residues
Farm machinery areas	Automotive wastes;[7] welding wastes
Agricultural drainage wells and canals	Pesticides;[5] fertilizers;[6] bacteria; salt water (in areas where the fresh-saltwater interface lies at shallow depths and where the water table is lowered by channelization, pumping, or other causes)
RESIDENTIAL SOURCES	
Common household maintenance and hobbies	*Common Household Products:*[8] Household cleaners; oven cleaners; drain cleaners; toilet cleaners; disinfectants; metal polishes; jewelry cleaners; shoe polishes; synthetic detergents; bleach; laundry soil and stain removers; spot removers and dry cleaning fluid; solvents; lye or caustic soda; household pesticides;[9] photochemicals; printing ink; other common products *Wall and Furniture Treatments:* Paints; varnishes; stains; dyes; wood preservatives (creosote); paint and lacquer thinners; paint and varnish removers and deglossers; paint brush cleaners; floor and furniture strippers *Mechanical Repair and Other Maintenance Products:* Automotive wastes;[7] waste oils; diesel fuel; kerosene; #2 heating oil; grease; degreasers for driveways and garages; metal degreasers; asphalt and roofing tar; tar removers; lubricants; rustproofers; car wash detergents; car waxes and polishes; rock salt; refrigerants
Lawns and gardens	Fertilizers;[5] herbicides and other pesticides used for lawn and garden maintenance[10]
Swimming pools	Swimming pool maintenance chemicals[11]
Septic systems, cesspools, and sewer lines	Septage; coliform and noncoliform bacteria;[4] viruses; nitrates; heavy metals; synthetic detergents; cooking and motor oils; bleach; pesticides;[9,10] paints; paint thinner; photographic chemicals; swimming pool chemicals;[11] septic tank/cesspool cleaner chemicals;[12] elevated levels of chloride, sulfate, calcium, magnesium, potassium, and phosphate
Underground storage tanks	Home heating oil
Apartments and condominiums	Swimming pool maintenance chemicals;[11] pesticides for lawn and garden maintenance and cockroach, termite, ant, rodent, and other pest control;[9,10] wastes from onsite sewage treatment plants; household hazardous wastes[8]

Table 4-4. Potential Sources of Ground Water Contamination (continued)

Source	Health, Environmental, or Aesthetic Contaminant[1,2,3]
MUNICIPAL SOURCES	
Schools and government offices and grounds	Solvents; pesticides;[9,10] acids; alkalis; waste oils; machinery/vehicle servicing wastes; gasoline and heating oil from storage tanks; general building wastes[13]
Park lands	Fertilizers;[6] herbicides;[10] insecticides[9]
Public and residential areas infested with mosquitoes, gypsy moths, ticks, ants, or other pests	Pesticides[5,9]
Highways, road maintenance depots, and deicing operations	Herbicides in highway rights-of-way;[5,10] road salt (sodium and calcium chloride); road salt anticaking additives (ferric ferrocyanide, sodium ferrocyanide); road salt anticorrosives (phosphate and chromate); automotive wastes[7]
Municipal sewage treatment plants and sewer lines	Municipal wastewater; sludge;14 treatment chemicals[15]
Storage, treatment, and disposal ponds, lagoons, and other surface impoundments	Sewage wastewater; nitrates; other liquid wastes; microbiological contaminants
Land areas applied with wastewater or wastewater byproducts	Organic matter; nitrate; inorganic salts; heavy metals; coliform and noncoliform bacteria;[4] viruses; nitrates; sludge;[14] nonhazardous wastes[16]
Storm water drains and basins	Urban runoff; gasoline; oil; other petroleum products; road salt; microbiological contaminants
Combined sewer overflows (municipal sewers and storm water drains)	Municipal wastewater; sludge;[14] treatment chemicals;[15] urban runoff; gasoline; oil; other petroleum products; road salt; microbial contaminants
Recycling/reduction facilities	Residential and commercial solid waste residues
Municipal waste landfills	Leachate; organic and inorganic chemical contaminants; wastes from households[8] and businesses;[13] nitrates; oils; metals
Open dumping and burning sites, closed dumps	Organic and inorganic chemicals; metals; oils; wastes from households[8] and businesses[13]
Municipal incinerators	Heavy metals; hydrocarbons; formaldehyde; methane; ethane; ethylene; acetylene; sulfur and nitrogen compounds
Water supply wells, monitoring wells, older wells, domestic and livestock wells, unsealed and abandoned wells, and test hole wells	Surface runoff; effluents from barnyards, feedlots, septic tanks, or cesspools; gasoline; used motor oil; road salt
Sumps and dry wells	Storm water runoff; spilled liquids; used oil; antifreeze; gasoline; other petroleum products; road salt; pesticides;[5] and a wide variety of other substances
Drainage wells	Pesticides;[9,10] bacteria
Well pumping that causes inter-aquifer leakage, induced filtration, landward migration of sea water in coastal areas; etc.	Saltwater; excessively mineralized water
Artificial ground water recharge	Storm water runoff; excess irrigation water; stream flow; cooling water; treated sewage effluent; other substances that may contain contaminants, such as nitrates, metals, detergents, synthetic organic compounds, bacteria, and viruses
COMMERCIAL SOURCES	
Airports, abandoned airfields	Jet fuels; deicers; diesel fuel; chlorinated solvents; automotive wastes;[7] heating oil; building wastes[13]
Auto repair shops	Waste oils; solvents; acids; paints; automotive wastes;[7] miscellaneous cutting oils
Barber and beauty shops	Perm solutions; dyes; miscellaneous chemicals contained in hair rinses
Boat yards and marinas	Diesel fuels; oil; septage from boat waste disposal areas; wood preservative and treatment chemicals; paints; waxes; varnishes; automotive wastes[7]

Table 4-4. Potential Sources of Ground Water Contamination (continued)

Source	Health, Environmental, or Aesthetic Contaminant[1,2,3]
Bowling alleys	Epoxy; urethane-based floor finish
Car dealerships (especially those with service departments)	Automotive wastes;[7] waste oils; solvents; miscellaneous wastes
Car washes	Soaps; detergents; waxes; miscellaneous chemicals
Camp grounds	Septage; gasoline; diesel fuel from boats; pesticides for controlling mosquitoes, ants, ticks, gypsy moths, and other pests;[5,9] household hazardous wastes from recreational vehicles (RVs)[8]
Carpet stores	Glues and other adhesives; fuel from storage tanks if forklifts are used
Cemeteries	Leachate; lawn and garden maintenance chemicals[10]
Construction trade areas and materials (plumbing, heating and air conditioning, painting, paper hanging, decorating, drywall and plastering, acoustical insulation, carpentry, flooring, roofing and sheet metal, wrecking and demolition, etc.)	Solvents; asbestos; paints; glues and other adhesives; waste insulation; lacquers; tars; sealants; epoxy waste; miscellaneous chemical wastes
Country clubs	Fertilizers;[6] herbicides;[5,10] pesticides for controlling mosquitoes, ticks, ants, gypsy moths, and other pests;[9] swimming pool chemicals;[11] automotive wastes
Dry cleaners	Solvents (perchloroethylene, petroleum solvents, Freon); spotting chemicals (trichloroethane, methylchloroform, ammonia, peroxides, hydrochloric acid, rust removers, amyl acetate)
Funeral services and crematories	Formaldehyde; wetting agents; fumigants; solvents
Furniture repair and finishing shops	Paints; solvents; degreasing and solvent recovery sludges
Gasoline services stations	Oils; solvents; miscellaneous wastes
Golf courses	Fertilizers;[6] herbicides;[5,10] pesticides for controlling mosquitoes, ticks, ants, gypsy moths, and other pests[9]
Hardware/lumber/parts stores	Hazardous chemical products in inventories; heating oil and fork lift fuel from storage tanks; wood-staining and treating products such as creosote
Heating oil companies, underground storage tanks	Heating oil; wastes from truck maintenance areas[7]
Horticultural practices, garden nurseries, florists	Herbicides, insecticides, fungicides, and other pesticides[10]
Jewelry/metal plating shops	Sodium and hydrogen cyanide; metallic salts; hydrochloric acid; sulfuric acid; chromic acid
Laundromats	Detergents; bleaches; fabric dyes
Medical institutions	X-ray developers and fixers;[17] infectious wastes; radiological wastes; biological wastes; disinfectants; asbestos; beryllium; dental acids; miscellaneous chemicals
Office buildings and office complexes	Building wastes;[13] lawn and garden maintenance chemicals;[10] gasoline; motor oil
Paint stores	Paints; paint thinners; lacquers; varnishes; other wood treatments
Pharmacies	Spilled and returned products
Photography shops, photo processing laboratories	Biosludges; silver sludges; cyanides; miscellaneous sludges
Print shops	Solvents; inks; dyes; oils; photographic chemicals
Railroad tracks and yards	Diesel fuel; herbicides for rights-of-way; creosote for preserving wood ties
Research laboratories	X-ray developers and fixers;[17] infectious wastes; radiological wastes; biological wastes; disinfectants; asbestos; beryllium; solvents; infectious materials; drugs; disinfectants (quaternary ammonia, hexachlorophene, peroxides, chlornexade, bleach); miscellaneous chemicals

Table 4-4. Potential Sources of Ground Water Contamination (continued)

Source	Health, Environmental, or Aesthetic Contaminant[1,2,3]
COMMERCIAL SOURCES (continued)	
Scrap and junk yards	Any wastes from businesses[13] and households;[8] oils
Sports and hobby shops	Gunpowder and ammunition; rocket engine fuel; model airplane glue
Above-ground and underground storage tanks	Heating oil; diesel fuel; gasoline; other petroleum products; other commercially used chemicals
Transportation services for passenger transit (local and interurban)	Waste oil; solvents; gasoline and diesel fuel from vehicles and storage tanks; fuel oil; other automotive wastes[7]
Veterinary services	Solvents; infectious materials; vaccines; drugs; disinfectants (quaternary ammonia, hexachlorophene, peroxides, chlornexade, bleach); x-ray developers and fixers[17]
INDUSTRIAL SOURCES	
Material stockpiles (coal, metallic ores, phosphates, gypsum)	Acid drainage; other hazardous and nonhazardous wastes[16]
Waste tailing ponds (commonly for the disposal of mining wastes)	Acids; metals; dissolved solids; radioactive ores; other hazardous and nonhazardous wastes[15]
Transport and transfer stations (trucking terminals and rail yards)	Fuel tanks; repair shop wastes;[7] other hazardous and nonhazardous wastes[15]
Above-ground and underground storage tanks and containers	Heating oil; diesel and gasoline fuel; other petroleum products; hazardous and nonhazardous materials and wastes[16]
Storage, treatment, and disposal ponds, lagoons, and other surface impoundments	Hazardous and nonhazardous liquid wastes;[16] septage; sludge[14]
Chemical landfills	Leachate; hazardous and nonhazardous wastes;[16] nitrates
Radioactive waste disposal sites	Radioactive wastes from medical facilities, power plants, and defense operations; radionuclides (uranium, plutonium)
Unattended wet and dry excavation sites (unregulated dumps)	A wide range of substances; solid and liquid wastes; oil-field brines; spent acids from steel mill operations; snow removal piles containing large amounts of salt
Operating and abandoned production and exploratory wells (for gas, oil, coal, geothermal, and heat recovery); test hole wells; monitoring and excavation wells	Metals; acids; minerals; sulfides; other hazardous and nonhazardous chemicals[16]
Dry wells	Saline water from wells pumped to keep them dry
Injection wells	Highly toxic wastes; hazardous and nonhazardous industrial wastes;[16] oil-field brines
Well drilling operations	Brines associated with oil and gas operations
INDUSTRIAL PROCESSES (PRESENTLY OPERATED OR TORN-DOWN FACILITIES)[18]	
Asphalt plants	Petroleum derivatives
Communications equipment manufacturers	Nitric, hydrochloric, and sulfuric acid wastes; heavy metal sludges; copper-contaminated etchant (e.g., ammonium persulfate); cutting oil and degreasing solvent (trichloroethane, Freon, or trichloroethylene); waste oils; corrosive soldering flux; paint sludge; waste plating solution
Electric and electronic equipment manufacturers and storage facilities	Cyanides; metal sludges; caustics (chromic acid); solvents; oils; alkalis; acids; paints and paint sludges; calcium fluoride sludges; methylene chloride; perchloroethylene; trichloroethane; acetone; methanol; toluene; PCBs
Electroplaters	Boric, hydrochloric, hydrofluoric, and sulfuric acids; sodium and potassium hydroxide; chromic acid; sodium and hydrogen cyanide; metallic salts
Foundries and metal fabricators	Paint wastes; acids; heavy metals; metal sludges; plating wastes; oils; solvents; explosive wastes

Table 4-4. Potential Sources of Ground Water Contamination (continued)

Source	Health, Environmental, or Aesthetic Contaminant[1,2,3]
Furniture and fixtures manufacturers	Paints; solvents; degreasing sludges; solvent recovery sludges
Machine and metalworking shops	Solvents; metals; miscellaneous organics; sludges; oily metal shavings; lubricant and cutting oils; degreasers (tetrachlorethylene); metal marking fluids; mold-release agents
Mining operations (surface and underground), underground storage mines	Mine spoils or tailings that often contain metals; acids; highly corrosive mineralized waters; metal sulfides
Unsealed abandoned mines used as waste pits	Metals; acids; minerals; sulfides; other hazardous and nonhazardous chemicals[16]
Paper mills	Metals; acids; minerals; sulfides; other hazardous and nonhazardous chemicals;[16] organic sludges; sodium hydroxide; chlorine; hypochlorite; chlorine dioxide; hydrogen peroxide
Petroleum production and storage companies, secondary recovery of petroleum	Hydrocarbons; oil-field brines (highly mineralized salt solutions)
Industrial pipelines	Corrosive fluids; hydrocarbons; other hazardous and nonhazardous materials and wastes[16]
Photo processing laboratories	Cyanides; biosludges; silver sludges; miscellaneous sludges
Plastics materials and synthetics producers	Solvents; oils; miscellaneous organics and inorganics (phenols, resins); paint wastes; cyanides; acids; alkalis; wastewater treatment sludges; cellulose esters; surfactant; glycols; phenols; formaldehyde; peroxides; etc.
Primary metal industries (blast furnaces, steel works, and rolling mills)	Heavy metal wastewater treatment sludge; pickling liquor; waste oil; ammonia scrubber liquor; acid tar sludge; alkaline cleaners; degreasing solvents; slag; metal dust
Publishers, printers, and allied industries	Solvents; inks; dyes; oils; miscellaneous organics; photographic chemicals
Public utilities (phone, electric power, gas)	PCBs from transformers and capacitors; oils; solvents; sludges; acid solution; metal plating solutions (chromium, nickel, cadmium); herbicides from utility rights-of-way
Sawmills and planers	Treated wood residue (copper quinolate, mercury, sodium bazide); tanner gas; paint sludges; solvents; creosote; coating and gluing wastes
Stone, clay, and glass manufacturers	Solvents; oils and grease; alkalis; acetic wastes; asbestos; heavy metal sludges; phenolic solids or sludges; metal-finishing sludge
Welders	Oxygen, acetylene
Wood preserving facilities	Wood preservatives; creosote

[1]In general, ground water contamination stems from the *misuse and improper disposal* of liquid and solid wastes; the *illegal dumping or abandonment* of household, commercial, or industrial chemicals; the *accidental spilling* of chemicals from trucks, railways, aircraft, handling facilities, and storage tanks; or the *improper siting, design, construction, operation, or maintenance* of agricultural, residential, municipal, commercial, and industrial drinking water wells and liquid and solid waste disposal facilities. Contaminants also can stem from *atmospheric pollutants*, such as airborne sulfur and nitrogen compounds, which are created by smoke, flue dust, aerosols, and automobile emissions, fall as acid rain, and percolate through the soil. When the sources listed in this table are used and managed properly, ground water contamination is not likely to occur.

[2]Contaminants can reach ground water from activities occurring on the land surface, such as industrial waste storage; from sources below the land surface but above the water table, such as septic systems; from structures beneath the water table, such as wells; or from contaminated recharge water.

[3]This table lists the most common wastes, but not all potential wastes. For example, it is not possible to list all potential contaminants contained in storm water runoff or research laboratory wastes.

[4]Coliform bacteria can indicate the presence of pathogenic (disease-causing) microorganisms that may be transmitted in human feces. Diseases such as typhoid fever, hepatitis, diarrhea, and dysentery can result from sewage contamination of water supplies.

[5]Pesticides include herbicides, insecticides, rodenticides, fungicides, and avicides. EPA has registered approximately 50,000 different pesticide products for use in the United States. Many are highly toxic and quite mobile in the subsurface. An EPA survey found that the most common pesticides found in drinking water wells were DCPA (dacthal) and atrazine, which EPA classifies as *moderately toxic* (class 3) and *slightly toxic* (class 4) materials, respectively.

[6]The EPA National Pesticides Survey found that the use of fertilizers correlates to nitrate contamination of ground water supplies.

[7]Automotive wastes can include gasoline; antifreeze; automatic transmission fluid; battery acid; engine and radiator flushes; engine and metal degreasers; hydraulic (brake) fluid; and motor oils.

[8]Toxic or hazardous components of common household products are noted in Table 3-2.

[9]Common household pesticides for controlling pests such as ants, termites, bees, wasps, flies, cockroaches, silverfish, mites, ticks, fleas, worms, rats, and mice can contain active ingredients including napthalene, phosphorus, xylene, chloroform, heavy metals, chlorinated hydrocarbons, arsenic, strychnine, kerosene, nitrosamines, and dioxin.

[10]Common pesticides used for lawn and garden maintenance (i.e., weed killers, and mite, grub, and aphid controls) include such chemicals as 2,4-D; chlorpyrifos; diazinon; benomyl; captan; dicofol; and methoxychlor.

[11]Swimming pool chemicals can contain free and combined chlorine; bromine; iodine; mercury-based, copper-based, and quaternary algicides; cyanuric acid; calcium or sodium hypochlorite; muriatic acid; sodium carbonate.

[12]Septic tank/cesspool cleaners include synthetic organic chemicals such as 1,1,1 trichloroethane, tetrachloroethylene, carbon tetrachloride, and methylene chloride.

[13]Common wastes from public and commercial buildings include automotive wastes; rock salt; and residues from cleaning products that may contain chemicals such as xylenols, glycol esters, isopropanol, 1,1,1-trichloroethane, sulfonates, chlorinated phenolys, and cresols.

[14]Municipal wastewater treatment sludge can contain organic matter; nitrates; inorganic salts; heavy metals; coliform and noncoliform bacteria; and viruses.

[15]Municipal wastewater treatment chemicals include calcium oxide; alum; activated alum, carbon, and silica; polymers; ion exchange resins; sodium hydroxide; chlorine; ozone; and corrosion inhibitors.

[16]The Resource Conservation and Recovery Act (RCRA) defines a hazardous waste as a solid waste that may cause an increase in mortality or serious illness or pose a substantial threat to human health and the environment when improperly treated, stored, transported, disposed of, or otherwise managed. A waste is hazardous if it exhibits characteristics of ignitability, corrosivity, reactivity, and/or toxicity. Not covered by RCRA regulations are domestic sewage; irrigation waters or industrial discharges allowed by the Clean Water Act; certain nuclear and mining wastes; household wastes; agricultural wastes (excluding some pesticides); and small quantity hazardous wastes (i.e., less than 220 pounds per month) generated by businesses.

[17]X-ray developers and fixers may contain reclaimable silver, glutaldehyde, hydroquinone, phenedone, potassium bromide, sodium sulfite, sodium carbonate, thiosulfates, and potassium alum.

[18]This table lists potential ground water contaminants from many common industries, but it does not address all industries.

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WELLHEAD PROTECTION AREA
INVENTORY OF POTENTIAL CONTAMINANT SOURCES

DIRECTIONS:

Place a number next to each category that you identify in your wellhead protection area. Place a corresponding number on a map at the location of the source. Maps that may be used for the inventory include: topography, zoning, village, city, and utility maps. Please consider ease of photocopying in your selection of a map. If there is more than one source for a category, label each site with a letter (i.e., 1A, 1B, 1C, 2A, 2B). Record the owner's name and address of each site on a separate sheet of paper. Please consider all sources within a 1/2-mile radius of each public water supply well and an assessment within the recharge area(s).

___ Abandoned Wells
___ Aboveground Storage Tank
___ Airport
___ Animal Feedlot/Waste Storage
___ Asphalt Plant
___ Auto Repair/Body Shop/Salvage Washes
___ Cemetery
___ Chemical Production/Mixing/Storage
___ Drainage Canal
___ Dumps
___ Electroplaters/Metal Finishers
___ Fertilizer/Pesticide Storage/ Production/Mixing
___ Golf Courses/Nurseries
___ Grain Storage Bin
___ Holding Pond/Lagoon
___ Inactive/Abandoned Hazardous Waste Site
___ Injection Well
___ Irrigation Practices
___ Laboratories
___ Laundromat/Dry Cleaner
___ Machine Shops
___ Major Highways and/or Railroads
___ Military Base/Depot
___ Mining
___ Oil/Gas Pipelines
___ Photo Processors
___ Printers
___ Production/Other Wells
___ Refineries
___ Refinishing
___ Road Salt Storage
___ Septic Systems
___ Service/Gas Stations
___ Sewage Plant
___ Underground Storage Tank
___ Waste Piles
___ Wood Preserving
___ Other (specify) ____________________

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____

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Figure 4-15. Inventory of potential contaminant sources for a wellhead protection area. Prepared by Wisconsin Rural Water Association.

presents a form that can be used to take an inventory of potential contaminant sources in your wellhead protection area. Your state might have a similar form to help you inventory potential sources of contamination.

There are many sources of information about potential contamination sources in your community. These include, but are not limited to, long-time residents of the community; Chamber of Commerce membership lists; the local phone book; local newspapers; the police and fire departments; fishermen; the utility companies serving your community's needs (including electricity supply, water supply, and waste disposal); community boards such as planning, conservation, health, engineering, and public works; and your own visual inspection. Information can also be obtained from state and federal environmental agencies on the transportation and discharge of hazardous materials, ground water discharge permitting, and discharges to surface waters. State and federal regulations also mandate that underground commercial storage tanks be registered. This information is available from your town hall or state environmental agency.

It is important that contaminated waters be identified at this stage of the process. This identification may involve contacting state water pollution control officials, state drinking water managers, water companies, and waste management agencies. The regional health director can advise you of known contamination problems, but this is a special opportunity for your team to survey the community completely to discover every contamination problem.

Your team should identify the location of any **point source** discharges within the community or in any neighboring communities that may affect your wellfield. Point sources discharge waste at a single location and generally consist of pipe outfalls to surface waters. Examples include sewage plant outfalls, water treatment plant outfalls, and industrial users. These discharges are regulated under the federal Clean Water Act (or a state law where primacy has been established), which usually requires continuous monitoring of such discharges. These monitoring logs are an additional source of water quality information.

Non-point sources are widespread sources of contamination that cumulatively present a threat to ground water. These sources are not regulated by permits and may be more difficult to track down. Examples include leakage from onsite septic systems, combined sewer overflow, roadway and parking lot drainage, landfill runoff, agricultural runoff, and runoff from stockpiles of roadway deicing materials, such as salt.

Identify Activities within the Wellhead Protection Area That Are Potential Sources of Contamination

In addition to locating actual sources of contamination, it is important to identify activities within the wellhead protection area that might result in ground water pollution. You can approach this by dividing your wellhead protection area into small sections and enlisting local volunteers to identify such activities in the field. Community organizations might be willing to participate in this effort. Volunteers should be instructed in how to survey for potential contaminant sources. Once the volunteers identify an activity that could undermine ground water quality, they should write a description of the activity, its exact location, the volume of material stored and handled (if readily avail-

VOLUNTEERS CONDUCT AN INVENTORY OF CONTAMINANT SOURCES: THE CITY OF EL PASO, TEXAS

The retired citizens of a community can be an important resource to draw upon when it is time to conduct an inventory of potential contaminant sources in a wellhead protection area. These individuals often have historical knowledge of the community, a tradition of local political involvement, an interest in environmental issues, personal technical expertise, and free time.

The City of El Paso, Texas, successfully utilized the talents and energy of retired persons to conduct a source inventory for its ground water protection pilot project in 1989 and 1990. In November 1989, project officials met with the El Paso Retired Senior Volunteer Program (RSVP), which offered to recruit volunteers to conduct an inventory. (RSVP is a national program, administered by the federal agency ACTION, with 750 projects and 400,000 volunteers throughout the United States.) El Paso RSVP members were able to recruit 23 volunteers, including retired geologists, engineers, planners, and housewives, to conduct the wellhead protection inventory.

The volunteers attended a day-long ground water protection seminar and signed up to inventory wellhead protection areas with which they were familiar. They were provided with a list of potential contaminant sources, inventory forms in both English and Spanish, maps of their assigned wellhead protection areas, inventory instructions, name tags identifying them as volunteer participants in the project, and a clipboard. Local media ran stories informing the public about the project and why public cooperation was needed.

The inventory was expected to take several weeks, but was actually completed in three and one-half days. The volunteers identified all known sources of ground water contamination within the designated areas. They also suggested several improvements for the inventory, such as identifying latitude and longitude locations instead of just a street location, and using a transverse Mercator grid system to locate potential sources on USGS topographic maps. After the inventory was completed, five of the volunteers formed a wellhead protection task force committee to help ensure that contaminant sources are properly managed (Cross, 1990).

able), and the name of an individual to contact for additional information.

A good map to consult when investigating potentially damaging activities in your community is the town mapping of the sewer service network (see Figure 4-9). The intent of the sewer network is to collect and transport raw waste to the sewage treatment plant where it can be treated prior to disposal. When a map of potential contaminant sources is compared to a utility map indicating where the sewers are, it will become obvious where to look closely for discharges to ground water—at those sources not served by a sewer network.

Plot the Potential Sources of Contamination on a Map

Once all potential sources of contamination have been identified, each source should be plotted on an overlay map of your wellhead protection area. This map should locate waste disposal sites, point sources, underground septic systems, and underground storage tanks. The map should indicate where ground water quality has been degraded or where there is a good possibility that it has been impaired. Different symbols should be used to distinguish among sources of contamination. The main objective of Step Three in your overall goal of wellhead protection is to prepare a master wellhead protection area map that shows all existing contaminant sources and identifies potential threats. This map will focus your team's protective strategy and land management activities.

Evaluate the Degree of Threat Each Source Poses

To formulate a effective management strategy, it is important to evaluate the immediacy and degree of the risk associated with each potential source of contamination. Values of risk can be assigned to sources of contamination based upon their proximity to ground water supply, contaminant toxicity, the intended use of the ground water, the degree of local regulatory authority over the source, or other considerations. Table 4-5 lists general categories of land uses and ranks them in order of their risk to ground water. State and federal agencies might be able to guide your planning team in prioritizing contaminant sources according to the degree of threat they pose to ground water. By assigning risk values like those in Table 4-5 to the land uses you have identified in your wellhead protection areas, it will be possible to prepare a map showing the location and magnitude of potential threats to your groundwater supply. This map will help you determine which areas of your community require immediate attention to prevent contamination. It will also help you create a long-term defensive planning strategy for your most vulnerable recharge zones.

Table 4-5. Land Uses and Their Relative Risk to Ground Water

LEAST RISK	A.	1.	Land surrounding a well or reservoir, owned by a water company.
		2.	Permanent open space dedicated to passive recreation.
		3.	Federal, state, municipal, and private parks.
		4.	Woodlands managed for forest products.
		5.	Permanent open space dedicated to active recreation.
	B.	1.	Field crops: pasture, hay, grains, vegetables.
		2.	Low density residential: lots larger than 2 acres.
		3.	Churches, municipal offices.
	C.	1.	Agricultural production: dairy, livestock, poultry, nurseries, orchards, berries.
		2.	Golf course, quarries.
		3.	Medium density residential: lots from 1/2 to 1 acre.
	D.	1.	Institutional uses: schools, hospitals, nursing homes, prisons, garages, salt storage, sewage treatment facilities.
		2.	High density housing: lots smaller than 1/2 acre.
		3.	Commercial uses: limited hazardous material storage and only sewage disposal.
	E.	1.	Retail commercial: gasoline, farm equipment, automotive, sales and services; dry cleaners; photo processor; medical arts; furniture strippers; machine shops; radiator repair; printers; fuel oil distributors.
		2.	Industrial: all forms of manufacturing and processing, research facilities.
		3.	Underground storage of chemicals, petroleum.
GREATEST RISK		4.	Waste disposal: pits, ponds, lagoons, injection wells used for waste disposal; bulky waste and domestic garbage landfills; hazardous waste treatment, storage and disposal sites.

Source: Adapted from U.S. EPA, 1989a.

STEP FOUR—Manage the Wellhead Protection Area[5]

Many wellhead protection area management programs can be implemented easily and at a low cost to the community. Several ideas for such programs are presented below; your planning team, however, should institute strategies appropriate to the specific needs of your community. An important place to start is with your most urgent ground water problems. Immediate threats to the community's water supplies should be addressed first; then your team can concentrate on the prevention of potential contamination and the protection of future water supplies. Table 4-6 summarizes the major non-regulatory and regulatory tools available for wellhead protection.

Non-regulatory Management Strategies

These management strategies are intended to reach as broad a spectrum of the community as possible. Ground water protection is a real possibility only if the whole community cooperates to achieve this end. The following programs do not necessarily involve spending a lot of money or staff time.

Public Education

The major aim of public education is to increase awareness of the threats of ground water contamination, encourage voluntary ground water protection (such as conservation measures and environmentally sound waste management), and create support for protective regulatory initiatives (such as industrial controls and zoning changes).

To circulate your message throughout the community, you can use many means, including newspaper articles, local radio programs, pamphlets, brochures, community meetings, and seminars. A good method of distributing pamphlets and other literature is to include them with water or tax bills. Your committee can develop slide shows or videos and use them at educational programs or workshops. Schools and universities can bring the message of wellhead protection to all age groups in the community. School outings to water treatment facilities or to the wellhead area can allow students to look for potential threats while encouraging them to be aware of how their own activities can affect drinking water quality. Your community should provide alternatives for disposing of potential contaminant substances (such as by providing a central location point where waste oil and other materials can be collected and recycled). Another method of reaching a large portion of the community is the use of road signs indicating the most vulnerable areas in your wellhead protection zone.

[5]For more detailed information on management techniques for wellhead protection areas, see *Wellhead Protection Programs: Tools for Local Governments* (EPA 440/6-89-002).

Your message to the community should include:

- An explanation of what ground water is and the effects of ground water contamination on public health.
- Information on how each business and each individual contributes to ground water pollution.
- Information on how to take good care of a septic system.
- Information on the proper disposal of pesticides, solvents, used oil, and other contaminants.
- Water conservation techniques for all activities, whether commercial, industrial, residential, or agricultural.
- A description of your community's wellhead protection program, listing your team's accomplishments to date and goals for the future.

Acquisition of Lands within the Wellhead Protection Area

The most effective control over susceptible recharge areas occurs when that land is directly owned or controlled by the community. In this case, the community can establish park land, recreation facilities, or other community-based land uses. (Alternatively, public access can be restricted, depending on the nature of the land area.) Before your community purchases land for the purpose of wellhead protection, it is important to ensure that the land is within the aquifer's zone of contribution.

Large-scale land acquisition is extremely expensive and usually impractical for most small communities. Some states, however, offer grants to encourage appropriating vulnerable lands for protection. Some non-profit organizations, such as local or regional land trusts, work to acquire environmentally sensitive land areas. Often a public water supplier controls the land directly surrounding its water supply wells.

Some alternatives to ownership of land still allow some control over vulnerable recharge zones. These include acquisition of "conservation easements" and "restrictive covenants." Conservation easements are voluntary arrangements restricting a landowner from performing certain activities (such as using hazardous materials or installing septic systems) on the land covered by the easement. The landowners may continue to conduct non-threatening land use activities in this area. The property may change hands, but the land restrictions are attached to the deed. Restrictive covenants are similar to easements in that they are attached to the deed and apply to subsequent land owners. Easements are held by another party who can enforce restrictions, however, whereas restrictive covenants can only be enforced by other property owners similarly restricted. Restrictive covenants may also prohibit dangerous land practices and restrict development densities.

Table 4-6. Summary of Wellhead Protection Tools

	Applicability to Wellhead Protection	Land Use Practice	Legal Considerations	Administrative Considerations
Regulatory: Zoning				
Overlay GW Protection Districts	Used to map wellhead protection areas (WHPAs). Provides for identification of sensitive areas for protection. Used in conjunction with other tools that follow.	Community identifies WHPAs on practical base/zoning map.	Well-accepted method of identifying sensitive areas. May face legal challenges if WHPA boundaries are based solely on arbitrary delineation.	Requires staff to develop overlay map. Inherent nature of zoning provides "grandfather" protection to pre-existing uses and structures.
Prohibition of Various Land Uses	Used within mapped WHPAs to prohibit ground-water contaminants and uses that generate contaminants.	Community adopts prohibited uses list within their zoning ordinance.	Well-organized function of zoning. Appropriate techniques to protect natural resources from contamination.	Requires amendment to zoning ordinance. Requires enforcement by both visual inspection and onsite investigations.
Special Permitting	Used to restrict uses within WHPAs that may cause ground water contamination if left unregulated.	Community adopts special permit "thresholds" for various uses and structures within WHPAs. Community grants special permits for "threshold" uses only if ground water quality will not be compromised.	Well-organized method of segregating land uses within critical resource areas such as WHPAs. Requires case-by-case analysis to ensure equal treatment of applicants.	Requires detailed understanding of WHPA sensitivity by local permit granting authority. Requires enforcement of special permit requirements and onsite investigations.
Large-Lot Zoning	Used to reduce impacts of residential development by limiting numbers of units within WHPAs.	Community "down zones" to increase minimum acreage needed for residential development.	Well-recognized prerogative of local government. Requires rational connection between minimum lot size selected and resource protection goals. Arbitrary large lot zones have been struck down without logical connection to Master Plan or WHPA program.	Requires amendment to zoning ordinance.
Transfer of Development Rights	Used to transfer development from WHPAs to locations outside WHPAs.	Community offers transfer option within zoning ordinance. Community identifies areas where development is to be transferred "from" and "to."	Accepted land use planning tool.	Cumbersome administrative requirements. Not well suited for small communities without significant administrative resources.
Cluster/PUD Design	Used to guide residential development outside of WHPAs. Allows for "point source" discharges that are more easily monitored.	Community offers cluster/PUD as development option within zoning ordinance. Community identifies areas where cluster/PUD is allowed (i.e., within WHPAs).	Well-accepted option for residential land development.	Slightly more complicated to administer than traditional "grid" subdivision. Enforcement/inspection requirements are similar to "grid" subdivision.
Growth Controls/ Timing	Used to time the occurrence of development within WHPAs. Allows communities the opportunity to plan for wellhead delineation and protection.	Community imposes growth controls in the form of building caps, subdivision phasing, or other limitation tied to planning concerns.	Well-accepted option for communities facing development pressures within sensitive resource areas. Growth controls may be challenged if they are imposed without a rational connection to the resource being protected.	Generally complicated administrative process. Requires administrative staff to issue permits and enforcement growth control ordinances.

Table 4-6. Summary of Wellhead Protection Tools (Continued)

	Applicability to Wellhead Protection	Land Use Practice	Legal Considerations	Administrative Considerations
Performance Standards	Used to regulate development within WHPAs by enforcing predetermined standards for water quality. Allows for aggressive protection of WHPAs by limiting development within WHPAs to an accepted level.	Community identifies WHPAs and established "thresholds" for water quality.	Adoption of specific WHPA performance standards requires sound technical support. Performance standards must be enforced on a case-by-case basis.	Complex administrative requirements to evaluate impacts of land development within WHPAs.
Regulatory: Subdivision Control				
Drainage Requirements	Used to ensure that subdivision road drainage is directed outside of WHPAs. Used to employ advanced engineering designs of subdivision roads within WHPAs.	Community adopts stringent subdivision rules and regulations to regulate road drainage/runoff in subdivisions within WHPAs.	Well-accepted purpose of subdivision control.	Requires moderate level of inspection and enforcement by administrative staff.
Regulatory: Health Regulations				
Underground Fuel Storage Systems	Used to prohibit underground fuel storage systems (USTs) within WHPAs. Used to regulate USTs within WHPAs.	Community adopts health/zoning ordinance prohibiting USTs within WHPAs. Community adopts special permit or performance standards for use of USTs within WHPAs.	Well-accepted regulatory option for local government.	Prohibition of USTs require little administrative support. Regulating USTs requires moderate amounts of administrative support for inspection followup and enforcement.
Privately Owned Wastewater Treatment Plants (Small Sewage Treatment Plants)	Used to prohibit small sewage treatment plants (SSTP) within WHPAs.	Community adopts health/zoning ordinance within WHPAs. Community adopts special permit or performance standards for use of SSTPs within WHPAs.	Well-accepted regulatory option for local government.	Prohibition of SSTPs require little administrative support. Regulating SSTPs requires moderate amount of administrative support of inspection followup and enforcement.
Septic Cleaner Ban	Used to prohibit the application of certain solvent septic cleaners, a known ground water contaminant, within WHPAs.	Community adopts health/zoning ordinance prohibiting the use of septic cleaners containing 1,1,1-trichloroethane or other solvent compounds within WHPAs.	Well-accepted method of protecting ground water quality.	Difficult to enforce even with sufficient administrative support.
Septic System Upgrades	Used to require periodic inspection and upgrading of septic systems.	Community adopts health/zoning ordinance requiring inspection and, if necessary, upgrading of septic systems on a time basis (e.g., every 2 years) or upon title/property transfer.	Well-accepted purview of government to ensure protection of ground water.	Significant administrative resources required for this option.

Table 4-6. Summary of Wellhead Protection Tools (Continued)

	Applicability to Wellhead Protection	Land Use Practice	Legal Considerations	Administrative Considerations
Toxic and Hazardous Materials Handling Regulations	Used to ensure proper handling and disposal of toxic materials/waste.	Community adopts health/zoning ordinance requiring registration and inspection of all businesses within WHPA using toxic/hazardous materials above certain quantities.	Well accepted as within purview of government to ensure protection of ground water.	Requires administrative support and onsite inspections.
Private Well Protection	Used to protect private onsite water supply wells.	Community adopts health/zoning ordinance to require permits for new private wells and to ensure appropriate well-to-septic-system setbacks. Also requires pump and water quality testing.	Well accepted as within purview of government to ensure protection of ground water.	Requires administrative support and review of applications.
Non-regulatory: Land Transfer and Voluntary Restrictions				
Sale/Donation	Land acquired by a community with WHPAs, either by purchase or donation. Provides broad protection to the ground-water supply.	As non-regulatory technique, communities generally work in partnership with non-profit land conservation organizations.	There are many legal consequences of accepting land for donation or sale from the private sector, mostly involving liability.	There are few administrative requirements involved in accepting donations or sales of land from the private sector. Administrative requirements for maintenance of land accepted or purchased may be substantial, particularly if the community does not have a program for open space management.
Conservation Easements	Can be used to limit development within WHPAs.	Similar to sales/donations, conservation easements are generally obtained with the assistance of non-profit land conservation organization.	Same as above.	Same as above.
Limited Development	As the title implies, this technique limits development to portions of a land parcel outside of WHPAs.	Land developers work with community as part of a cluster/PUD to develop limited portions of a site and restrict other portions, particularly those within WHPAs.	Similar to those noted in cluster/PUD under zoning.	Similar to those noted in cluster/PUD under zoning.
Non-regulatory: Other				
Monitoring	Used to monitor ground water quality within WHPAs.	Communities establish ground water monitoring program within WHPA. Communities require developers within WHPAs to monitor ground water quality downgradient from their development.	Accepted method of ensuring ground water quality.	Requires moderate administrative staffing to ensure routine sampling and response if sampling indicates contamination.
Contingency Plans	Used to ensure appropriate response in cases of contaminant release or other emergencies within WHPA.	Community prepares a contingency plan involving wide range of municipal/county officials.	None.	Requires significant up-front planning to anticipate and be prepared for emergencies.

Table 4-6. Summary of Wellhead Protection Tools (Continued)

	Applicability to Wellhead Protection	Land Use Practice	Legal Considerations	Administrative Considerations
Hazardous Waste Collection	Used to reduce accumulation of hazardous materials within WHPAs and the community at large.	Communities, in cooperation with the state, regional planning commission, or other entity, sponsor a "hazardous waste collection day" several times per year.	There are several legal issues raised by the collection, transport, and disposal of hazardous waste.	Hazardous waste collection programs are generally sponsored by government agencies, but administered by a private contractor.
Public Education	Used to inform community residents of the connection between land use within WHPAs and drinking water quality.	Communities can employ a variety of public education techniques ranging from brochures detailing their WHPA program, to seminars, to involvement in events such as hazardous waste collection days.	No outstanding legal considerations.	Requires some degree of administrative support for programs such as brochure mailing to more intensive support for seminars and hazardous waste collection days.
Legislative:				
Regional WHPA Districts	Used to protect regional aquifer systems by establishing new legislative districts that often transcend existing corporate boundaries.	Requires state legislative action to create a new legislative authority.	Well-accepted method of protecting regional ground water resources.	Administrative requirements will vary depending on the goal of the regional district. Mapping of the regional WHPAs requires moderate administrative support, while creating land use controls within the WHPA will require significant administrative personnel and support.
Land Banking	Used to acquire and protect land within WHPAs.	Land banks are usually accomplished with a transfer tax established by state government empowering local government to impose a tax on the transfer of land from one party to another.	Land banks can be subject to legal challenge as an unjust tax, but have been accepted as a legitimate method of raising revenue for resource protection.	Land banks require significant administrative support if they are to function effectively.

Source: Horsley and Witten, 1989.

Using Monitoring Wells to Detect Pollution

Ground water monitoring programs around pumping wells and high-risk sources of contamination can detect potential pollutants before they infiltrate the public water supply. A good ground water monitoring program consists of taking a number of ground water samples on a regular basis, performing laboratory tests to detect various contaminants, and following good quality control/quality assurance procedures. Regular testing will allow your committee to identify problems quickly and initiate early remediation procedures. Your success in dealing with contamination problems depends on the position of the monitoring wells. The farther these wells are from your active wells, the more time will be available to rectify the situation or provide adequate substitute water supplies should contamination occur. Monitoring might also allow your team to investigate the effectiveness of source controls (such as limitations on underground storage tanks) within the wellhead protection area.

Your planning team should do the following before implementing any monitoring program (U.S. EPA, 1989b):

- Collect all of the available existing data pertaining to your aquifer's water quality. These data can be obtained from your State Department of Environmental Protection, your State Department of Water Resources, regional agencies, water treatment plants, hazardous waste facilities, underground injection wells, consulting engineers, and well-drilling firms.
- Define the overall limits of your ground water monitoring program. This program should be adapted to suit your community's specific needs with respect to wellhead protection. Your team should decide what geo-

graphic area the program should cover and what contaminants to test for during the laboratory analysis.

- Determine the specifics of the sampling program, including sampling frequency, the specific chemical tests required, and onsite sampling techniques. Your team could require private well owners to submit samples for testing to ensure a comprehensive monitoring program.
- Investigate the expense of a ground water monitoring program. Such a program may prove expensive for small communities because of the costs of drilling new wells, the need for hydrogeologic expertise to correctly place the wells, and the costs of using analytical testing laboratories. Industries should be encouraged to conduct self-monitoring.

Monitoring Local Situations

Many potential polluting activities might already be monitored in your community by state and federal authorities. These include underground injection wells, solid waste landfills, underground commercial storage tanks, and facilities that handle hazardous materials. Your team should identify these activities and, if possible, obtain information about them from the responsible state agency. Some facilities, however, might be too small to be inspected by the state on a regular basis. These should be closely monitored by your team. Many states grant authority to local groups to perform inspections. Your team may decide to regularly inspect facilities that are presently unregulated or to conduct more extensive inspections of facilities presently monitored. Inspections should be conducted by trained personnel who can determine what materials are being used, how they are transported, where they are stored, what the waste products are, how they are disposed of, and the safety precautions that should be taken in the case of a spill (Paly and Steppacher, n.d.). This form of local monitoring can also be implemented at construction sites, which might be a source of contamination.

Water Conservation

Encouraging water conservation is a crucial element of any management campaign. This action facilitates your goal of wellhead protection in two ways: first, by reducing water withdrawals from your wells, thereby conserving your primary water source and, second, by protecting your aquifer from contaminant intrusion by reducing the rate of contaminant transportation (which is increased by high pumping rates). Excessive pumping in coastal areas can result in drawing salt water into the aquifer, causing poor quality/unpotable water. Where contaminated plumes exist, conservation might delay contamination at the wellhead and allow time for remediation work. It is important to educate the public about the need to conserve ground water resources; voluntary efforts might help the community avoid mandatory controls in the future.

Encouraging Best Management Practices

Best management practices (BMPs) are standard operating procedures for a particular industry or commercial activity that can limit the threat to the environment posed by ongoing practices, such as pesticide application or storage and use of hazardous substances (U.S. EPA, 1989b). BMPs prevent the release of toxic substances into the environment or control these releases in an environmentally sound manner. BMPs also encourage operating and design standards to ensure the safety of plant operators and the public.

Facilities in the wellhead protection area that store or handle hazardous substances—heavy industrial plants, dry cleaners, gas stations, auto repair workshops, and transportation facilities such as trucking, railroad, bus depots, and airports—should consider implementing BMPs. Examples of BMPs include restricting and carefully monitoring hazardous materials storage and disposal, and limiting or introducing collection systems for roadway deicing chemicals. For agriculture, BMPs include minimal chemical application, chemical application only during dry periods when infiltration is slow, and erosion and sedimentation controls (U.S. EPA, 1989b).

Your community may choose to enforce mandatory BMPs or encourage voluntary use through incentives or educational programs.

Regulatory Management Strategies

Regulatory controls can be adopted by communities to protect water supplies pursuant to state enabling legislation. These controls vary in their ability to manage land uses and activities.

Zoning the Wellhead Protection Area

Communities traditionally have used zoning ordinances to control and direct development within the community. Zoning has become a popular process for communities to safeguard flood plains and wetlands. A community can consider creating a zoning district to protect aquifers, recharge areas, and areas of influence by modifying existing zoning ordinances or creating new ones. Zoning generally divides communities into specific land use districts while specifying a set of applicable regulations for each district. A ground water zoning ordinance could prohibit specific land uses while requiring special permitting or performance criteria for less hazardous activities.

Zoning options can provide a variety of opportunities to prevent high-risk development or activities within your wellhead protection area. These options depend on the intensity of development in the areas surrounding the wells. It is easiest to zone an area that is undeveloped and "unzoned" (if the community has zoning authority). Such an area can be zoned for low-density residential use. This use limits potential contaminant sources in addition to limiting the amount of impervious material within the aquifer's recharge zone. Impervious areas do not allow precipitation to percolate down to ground water; therefore, they limit an aquifer's recharge capacity.

Down-zoning consists of changing a zone that has already been designated for a specific land use to a zone that is more compatible with your protection goals. This approach generally involves reducing allowable development densities. If an area has been zoned and is partially developed, it may be possible to "phase-in" zoning requirements over a period of time. For example, a community can restrict any future construction of high-risk industrial plants and prohibit the expansion of existing facilities.

Large-lot zoning of single-family residences is another method of reducing source contamination through reducing the number of septic systems. This form of zoning also protects the permeable acreage of your aquifer's recharge area by restricting the amount of impervious material. Large-lot zoning may be less effective in areas experiencing rapid expansion. **Conditional zoning** allows certain low-risk land uses, while high-risk uses are allowed only under strict conditions. This approach can be used where zones have not been clearly defined. **Cluster zoning** is another alternative to controlling residential development. The aim of this type of development is to increase the density of a small section of the zone (cluster of residential units), while maximizing the open space acreage throughout the zone.

Overlay zoning can be used to define environmentally sensitive areas over a pre-existing zoning map. The boundaries of your delineated wellhead protection area are unlikely to agree with established land-use boundary zones. An overlay map can help your community implement management regulations only in those portions of existing land-use zones that fall within your wellhead protection area.

It is important to consider the legal aspects of zoning changes prior to their implementation. Zoning changes are often sensitive community issues and must not appear overly restrictive or discriminatory, or court action could result. Your community's counsel or solicitor should be able to offer you guidance in this regard. Business representation on your planning team can help avert potential concerns about zoning changes.

Implementing Subdivision Controls to Minimize Ground Water Impacts

Subdivision ordinances are most effective in controlling future land development. They are only applicable when land is subdivided for sale or development purposes. Depending on state enabling legislation, a locality may have the authority to impose subdivision regulations that control development. Subdivision ordinances provide guidelines for development rather than alter existing land-use patterns.

The major impetus for subdivision control has been to protect a community's infrastructure from sudden growth, and subdivision ordinances to date have reflected this goal. Subdivision ordinances may also be used, however, to apply measures for wellhead protection. Such measures can include requiring low-leakage sewers to inhibit contamination transportation and requiring the use of environmentally sound design and construction standards (such as standards for road and parking lot runoff collection systems, stream or ditch channels, and road salt storage areas).

Subdivision control ordinances and zoning ordinances can be used in combination with site plan reviews and design and construction standards to formulate an effective management strategy for wellhead protection. As with zoning issues, the legitimacy of subdivision control regulations might be challenged in court. It is therefore important to seek the advice of your community counsel or solicitor prior to any enactment of subdivision amendments.

Implementing Health Regulations to Minimize Risks to Ground Water

A community can play a significant role in implementing health regulations to minimize risks to ground water. Many communities have the authority to adopt regulations governing any activity that might degrade the quality of their public water supply. These regulations can include administering standards for the location, construction, and operation of septic tanks and leaching fields, and for regulating solid waste disposal in sanitary landfills. These duties may be carried out by the Board of Health.

It might be possible to regulate the movement of hazardous materials within your community by limiting the use of agricultural chemicals over sensitive recharge areas or restricting and monitoring the use of underground storage tanks.

Restricting the Storage and Use of Toxic and Hazardous Materials

Your community might have the authority to regulate hazardous materials, and this can be particularly significant with respect to commercial and industrial operations in your wellhead protection area. Many communities require that any facility handling hazardous materials inform the local Board of Health about how it uses, stores, transports, and disposes of these materials. Other regulatory approaches to controlling the use and storage of hazardous chemicals in your wellhead protection area include requirements for periodic testing and replacement of underground fuel tanks, permit requirements and corrosion protection for new tanks, and limitations on herbicide and pesticide applications.

An approach that has proved successful for a number of communities is the selection of a hazardous waste coordinator. This coordinator may be a health, fire, or police official, or a concerned citizen. The coordinator can help the community identify and control hazardous substances, organize hazardous waste committees to provide advice and support, identify potential sources of contamination, develop emergency procedures to respond to accidental spills, and educate citizens about hazardous materials issues.

Requiring Wellhead Monitoring

Ground water monitoring at the wellhead (discussed under Non-Regulatory Strategies above) is essential to assess the quality of the resource and to ensure early warning of contamination. Many communities require facilities performing high-risk activities within sensitive recharge zones to have monitoring programs and submit periodic reports to the community.

STEP FIVE—Plan for the Future

Review the Wellhead Protection Plan Yearly

To ensure the long-term success of any wellhead protection program, it is essential to review and update your protection plan regularly, perhaps annually. This review will allow your planning team to improve management strategies, and it also will give you time to act on any new information about contaminant sources. Regular review will help your team deal constructively with new trends and activities in your community.

Identify Future Problems and Develop Solutions

A critical aspect of your wellhead protection plan is the identification of future hazards that threaten your wellhead protection areas. One method of identifying potential future problems is to analyze your community's "Development Plan" or "Master Plan." This plan generally gives some idea of the direction that land development in the community will take. The plan is usually based on local zoning maps and zoning regulations. Your team can use these maps to identify land areas that have been zoned for commercial and industrial use and that might prove to be trouble spots. The plan should be carefully evaluated by your team; it might prove inconsistent with your overall goals of wellhead protection. Often a development plan is only advisory in nature and therefore may be relatively easy to amend.

In addition to local master development plans, regional long-term development plans and statewide infrastructure plans should be reviewed to determine their possible impacts on your community's wellfields. These plans might indicate highway and major earthworks proposals, new prison or hospital facilities, and dams or dredging activities. Major expansion or maintenance plans of local water and power utilities should also be reviewed. The objective here is for your team to be aware of forthcoming changes to your ground water recharge zone so that you can pursue adequate protection measures.

Another method of determining future risks to your ground water is to conduct a "build-out analysis" of your community's zoning map. This is done by using your land-use overlay map and existing zoning and subdivision regulations to determine the development potential of each land-use zone within your wellhead protection area. This allows you to assess the implications to your aquifer if every section of developable land within your recharge zone was built upon. This "saturation analysis" allows your team to investigate whether your community's zoning and development plans are compatible with its current and/or long-term need for ground water protection.

One important aspect of a build-out analysis is that it can be used to help your team anticipate your community's future water supply needs. It can show the need for new wells (which should be located to minimize potential contamination). New wells offer your team the opportunity to implement wellhead protection practices that may have been difficult to carry out in established wellhead areas. Your community should consider purchasing land for the purpose of managing the wellhead protection area for a future well. Alternatively, you can establish an ordinance to protect the area around the site for a future well. These actions will help ensure that the area does not have a contamination history when the new well is needed.

Develop a Contingency Plan for Alternate Water Supplies

A vital aspect of a wellhead protection program is the development of a contingency plan. This ensures that your community has an alternative water supply in the event of contamination of your primary source. If possible, your team should develop both short-term emergency response alternatives and long-term or permanent water supply alternatives.

Your team's contingency plan should contain emergency response procedures to be implemented as soon as possible following a release of contaminants into the environment. These procedures should identify the appropriate personnel to contact at the state and federal level, the appropriate equipment to have on hand, and a structured plan of action to respond as quickly and effectively as possible, to mitigate any environmental damage resulting from such a release. Your contingency plan will benefit from good coordination mechanisms, such as an emergency response team, when reacting to emergency spill situations.

Contact your State Department of Water Resources to see if it has already developed contingency plans for public water systems throughout your state, and to gain information and guidance on contingency planning for your community's water supply. Your team can adapt emergency response frameworks and state contingency plans for your own community.

Conclusion

The five-step process for wellhead protection can be an effective way for small communities to prevent contamination of their drinking water sources. This process offers communities with little or no experience in hydrogeologic methods a simple, structured approach to establishing a comprehensive wellhead protection program. Community planning teams can approach the seemingly daunting task of ground water protection one step at a time. The potential rewards of wellhead protection are substantial, and are well worth the time and effort needed to develop a successful program. The case studies in Chapter Five provide a description of how four communities successfully tailored elements of this process to their own situations. Chapter Six lists many of the organizations and publications that are available to help you develop and implement a wellhead protection program in your community.

A wellhead protection plan will help your community avoid the high costs of cleaning up contaminated ground water or finding a new source of water.

Chapter 5

Case Studies

CASE STUDY ONE: Hill, New Hampshire, Water Works

Description of Hill

Hill, New Hampshire, is a small town located in the central Lakes Region of the state, 21 mi north of Concord, the state capital. The village district has a population of 325; the greater town population is 814. The region was originally a farming and logging area; today, most residents of Hill make their livelihood as factory workers in the nearby towns of Bristol and Franklin, or as workers in the service industry. The village experienced moderate growth in the 1980s, which has now tapered off. No more lot development or building is expected in the village and slow growth is expected to continue in the region.

The town's village district has a 40-ft-deep, gravel-pack well drilled in 1941. It supplies water to the village's 125 households. The well has a maximum pumping rate of 36,575 ft^3/day with a yield of 190 gallons per minute (gpm). The drawdown is 0.1 ft, observed during a 3-hr pump test. Water is used primarily for residential purposes.

The well is located between three mountains to the north, northwest, and southeast on a shallow slope just upgradient from Needle Shop Brook and a wet meadow. The well lies about 1,000 ft southwest from the intersection of a local and a state road. Upgradient from the well, slopes are predominantly 8 to 15 percent, although some land is even steeper (up to 25 percent slope). Closer to the well, the slope gradient ranges from 3 to 5 percent. Because of the well's location near the stream and wet meadow, the water table is assumed to be near the surface, and the saturated thickness is assumed to be 40 ft, the depth of the well.

The soils upgradient of the well are of the Monadnock and Lyman series, Monadnock being predominant. The U.S. Soil Conservation Service (SCS) describes Monadnock soils as very deep, well-drained soils on uplands, formed in a loamy mantle and underlain by sandy glacial till. They were derived mainly from granite and gneiss and typically consist of sandy loam to 23 in. deep and gravelly sand from 23 to 65 in. deep (the substratum). The permeability of Monadnock substratum is 2 to 6 in./hr, which is equivalent to 4 to 12 ft/day. Lyman soils are relatively shallow (i.e., they reach bedrock at only 17 in.), somewhat excessively drained, and located on uplands. They were formed in glacial till and typically consist of a stony loam surface layer 2 in. deep and a fine sandy loam subsurface layer from 2 to 4 in. deep. The subsoils are loamy and range from 4 to 17 in. deep. Lyman soils have the same permeability as the gravelly sand (2 to 6 in./hr or 4 to 12 ft/day). Flatter land surrounding the well consists of loamy sands and sandy loams with permeabilities between 6 and 20 in./hr (12 to 40 ft/day). The hydraulic gradient is 0.03 (3 percent).

Overview of Wellhead Protection Issues

Water quality in Hill is considered to be good. To date, Hill has not experienced problems with contamination of the water source. When considering the establishment of a wellhead protection program, the water commissioners were most concerned about an area immediately surrounding the well, an old farm with very high development potential. The commissioners and the town selectmen also were concerned about the way in which a wellhead protection program would be initiated in the community. They stressed the need for clear communication and alleviation of property owners' fears—both about the quality of their ground water and control of their properties.

Approach Used to Form a Community Planning Team

Hill's Water Commissioner Dean Wheeler initially contacted the New Hampshire Department of Environmental Services to get information about ground water protection. He was referred to John Lukin, the Northeast Rural Water Association (NeRWA) ground water technician for the states of Massachusetts, New Hampshire, and Vermont.

After a phone conversation in August 1991, the two set up an exploratory meeting that also included several selectmen, another commissioner, and the farmer and owner of the lot immediately surrounding the well. Lukin wrote of his visits with Hill and other New England communities: "Initial visits to systems were never canned presentations. NeRWA assistance was explained in detail, including the funding source and program objectives. However, the sessions generally were exchanges with local officials or the system manager/operator that obtained information about the system and community, while building rapport." At the end of their meeting, participants agreed that a ground water protection program for Hill was a sound idea. A community planning team was created, with the two commissioners, the NeRWA technician, and one of the selectmen as its members. As their first task, team members agreed to research pump test data on Hill's well.

Approach Used to Delineate the Wellhead Protection Area

Fairly good site-specific information on well construction, soil type, and ground water flow was available for Hill. The technician used guidance from the New Hampshire Department of Environmental Services (NHDES) to delineate the area. The guidelines propose a phased approach that utilizes maximum pump rate data, transmissivity, hydraulic gradient, and U.S. Geological Survey (USGS) topographic information to delineate the wellhead protection area. The wellhead protection area boundary upgradient of a well is drawn at any ground water divide (i.e., watershed boundary) or at 4,000 ft, whichever is encountered first. The topographic upgradient of the well is also assumed to be the well upgradient. The boundary of the wellhead protection area down and side gradient is calculated using transmissivity, pump rate, and hydraulic gradient information in the uniform flow equation.

The major topographic features to the north, northwest, and southeast determine the upgradient boundary of the Hill wellhead protection area. The wellhead protection area is delineated at 4,000 ft to the northwest and southwest, and extends about 2,000 ft southwest to the top of Huses Mountain. The maximum downgradient distance of the wellhead protection area, running to the northeast along Needle Shop Brook, is approximately 400 ft. Because the down and side gradient area around the well consists of loamy sand and sandy loam soils, and the drawdown is 0.1 ft, the transmissivity (T) of the area is considered representative of the highest permeability (40 ft/day) and is equivalent to 1,600 ft^2/day (40 ft/day x 40-ft-deep well). The technician used the 0.03 (3 percent) gradient for the relatively flat area nearest the well to build the equation, resulting in a more conservative delineation (see Figures 5-1 and 5-2 for delineation work).

The wellhead protection area was first mapped on a USGS topographic map (Figure 5-3) and transferred to a local property tax map (Figure 5-4). To transfer the information, the technician enlarged the topographic map to match the scale of the tax map and then traced the wellhead protection area onto the tax map. Although this procedure distorts somewhat the accuracy of the wellhead protection area, it is adequate for identifying the properties affected by the wellhead protection area. The technician submitted the Hill wellhead protection area to the state hydrologist for review before going on with the next step of the program.

Approach Used to Identify and Locate Potential Sources of Contamination

Two other planning committee members carried out the inventory for potential sources of contamination. They used their own knowledge and town records to establish ownership and use of the wellhead protection area and conducted limited fieldwork.

According to their findings, the wellhead protection area lies over 30 separate parcels. Ten of the parcels are in residential use, 15 lie over woodland areas, and 5 lie over open meadows. In addition, the wellhead protection area incorporates the town solid waste transfer station, State Highway 3A and town roads, a small engine repair shop, and the town cemetery. All of these are considered potential sources of contamination. The team used the NHDES list and other resources to prioritize potential contaminant sources. By far the area of greatest concern was the transfer station on Lot R6-40. Although not a current threat to ground water, farm lot R6-46 to 49 remained a concern to the team.

Approach Used to Manage the Wellhead Protection Area

The team chose low-cost, attainable measures to manage its wellhead protection area. Hill will rely on voluntary compliance to protect its ground water system. The board of selectmen will notify landowners and municipal agencies and ask them to incorporate the following practices into their activities:

Transfer Station—The transfer station will operate in accordance with New Hampshire regulations governing such facilities and use Best Management Practices (BMPs) to guard against ground water contamination. BMPs include the use of impervious surfaces—such as metal or concrete—to transfer waste and operating practices that prevent leakage of contaminants into water and soil. Hazardous wastes are not to be stored at the site.

State Highway 3A and Town Roads—The Town of Hill will notify the New Hampshire Department of Transportation (NHDOT) in writing of State Route 3A's passage through Hill's wellhead protection area and send the transportation department a copy of the wellhead protection area map. The notification will request that the NHDOT apply minimal road salt to the affected section of the highway. Hill will deice the local roads in the wellhead protection area using a sand/salt mixture that minimizes the use of salt. The town also will post signs along the roadways to

12/8/91 HILL, NH DELINEATION WORK

Gradient: W along Needle Shop Brook $= \frac{200'}{4000'} = 0.05$

NW along small tributary stream $= \frac{120'}{4000'} = 0.03$

Pumping Rate: = 190 gpm from USGS information
= 36575 ft^3/day

Transmissivity

Upgradient of well, dominant soils are of the Monadnock Series. SCS Soil Interpretation Records identify the substratum (23" to 65") as "gravelly sand." Permeability at this depth is noted as 2.0 to 6.0 in./h = 4.0 to 12 ft/day. These soils (Ca, Ch, Hm) are also labeled Lyman Series, which are shallow to bedrock (17"). Permeability is the same. Slope is predominantly 8 to 15% with some 15 to 25%.

The flatter land close to the well is loamy sands and sandy loams with permeabilities between 6 and 20 in./h (12 to 40 ft/day).

Well depth is 40′ (USGS, town system generator) and recorded drawdown is 0.1 ft (USGS). Since well is adjacent to stream and with a wet meadow just downgradient, the water table is assumed to be near the surface. Therefore 40′ = saturated thickness.

T = hydraulic conductivity x saturated thickness

T = 4 ft/day x 40′ = 160 ft^2/day
= 12 ft/day x 40′ = 480 ft^2/day
= 40 ft/day x 40′ = 1600 ft^2/day

Since down and side gradient soils are the loamy sand/sandy loams, and observed drawdown during a 3 h pump test was 0.1 ft, the uniform flow equation T will be the greatest value of 1600 ft^2/day.

$$X = \frac{36{,}575}{(6.2832)\,(0.05)\,(1600)} = \frac{36{,}575}{502.656} = 73' = \text{downgradient limit of ZOI}$$

$$Y = \frac{36{,}575}{(0.05)\,(1600)} = 457' = \text{maximum width of ZOC – not used here}$$

or

$$X = \frac{36{,}575}{(6.2832)\,(0.03)\,(1600)} = \frac{36{,}575}{301.6} = 121.3',\ \text{say } 125'$$

$$Y = \frac{36{,}575}{48} = 762',\ \text{say } 765'$$

Since land closest to well is relatively flat, the 0.03 gradient is proposed for determining the Phase I recharge area. The result is a more conservative delineation.

Conversion to 1:24,000 scale for mapping on topo sheet:

$\frac{1}{24{,}000} = \frac{X}{125'}$ | $\frac{1}{24{,}000} = \frac{Y}{765'}$ | @T = 480

X = 0.0625″ | Y = 0.3825″ | X = 404′ = 0.202″

Figure 5-1. Calculations for delineation of the Hill wellhead protection area.

WORKSHEET TO ACCOMPANY A PHASE I WHPA DELINEATION

Town: Hill, NH Well Name: ______ EPA ID # 1131010-001

Well Type: Overburden ✓ Bedrock ___ / Drilled ___ Dug ___ Other(specify) ______

Population Served: 325 people; Town(s) of Hill, NH

Well Owner Information: Name Town of Hill
Address PO Box 236
Hill, NH
Phone # 934-3055

Contact Information: Name Board of Selectmen
Address same as above
Phone # ______

Street Address of Well Location (attach locus map): Hill Center Road

I. Information obtained to perform delineation:(please check on left if found)

___ USGS map: Quadrangle name(s) Bristol Dated 1987

___ Surficial geology map: name(s) ______ Dated ______

___ USGS stratified drift aquifer map: name(s) ______ Dated ______

✓ SCS map: survey name not published page(s) ______ Dated ______
obtained photocopies of maps and Soils Interpretations records from SCS in Concord

___ WSPCD/WSEB files:
- ___ well log(s)
- ___ pump test: date ______ duration ______
- ___ maximum yield ______ (gpm)

___ Owner/Operators files:
- ___ well log(s)
- ___ pump test: date ______ duration ______
- ___ maximum yield ______ (gpm)

___ WRD/WMB boring logs:

✓ Other (please list): USGS Well Schedule Form 9-1642B

(continued on reverse)

Figure 5.2. Worksheet on delineation of the Hill wellhead protection area.

II. Describe hydrogeologic mapping for upgradient boundary (attach sheet(s) if necessary).

Information Utilized:

See attached explanation

Narrative:

III. Complete the following chart and show calculation using the Uniform Flow Equation to derive the WHPA boundary down and side gradient of the well. Identify all flow boundaries encountered before the calculated distance (attach sheet(s) if necessary).

Parameter	Value and Units	Source of Information
Maximum Pumping Rate	Q = 36,575 ft³/day	USGS
Transmissivity*	T = 1600 ft²/day	SCS data
Hydraulic Gradient	i = .03	Topo sheet

*Specify Hydraulic Conductivity and saturated thickness used if T is calculated

Show the calculation performed using the Uniform Flow Equation:

Downgradient stagnation (x) $= \frac{36575}{(6.2832)(.03)(1600)} = \frac{36575}{301.6} = 121.3$ ft

maximum width (y) $= \frac{36575}{(1600)(.03)} = \frac{36575}{48} = 762$ ft

Describe any flow boundary identified within the calculated boundary:

Comments:

IV. Attach the delineation and a copy of all information gathered and utilized. Provide a listing of all information submitted.

Figure 5.2. Worksheet on delineation of the Hill wellhead protection area (continued).

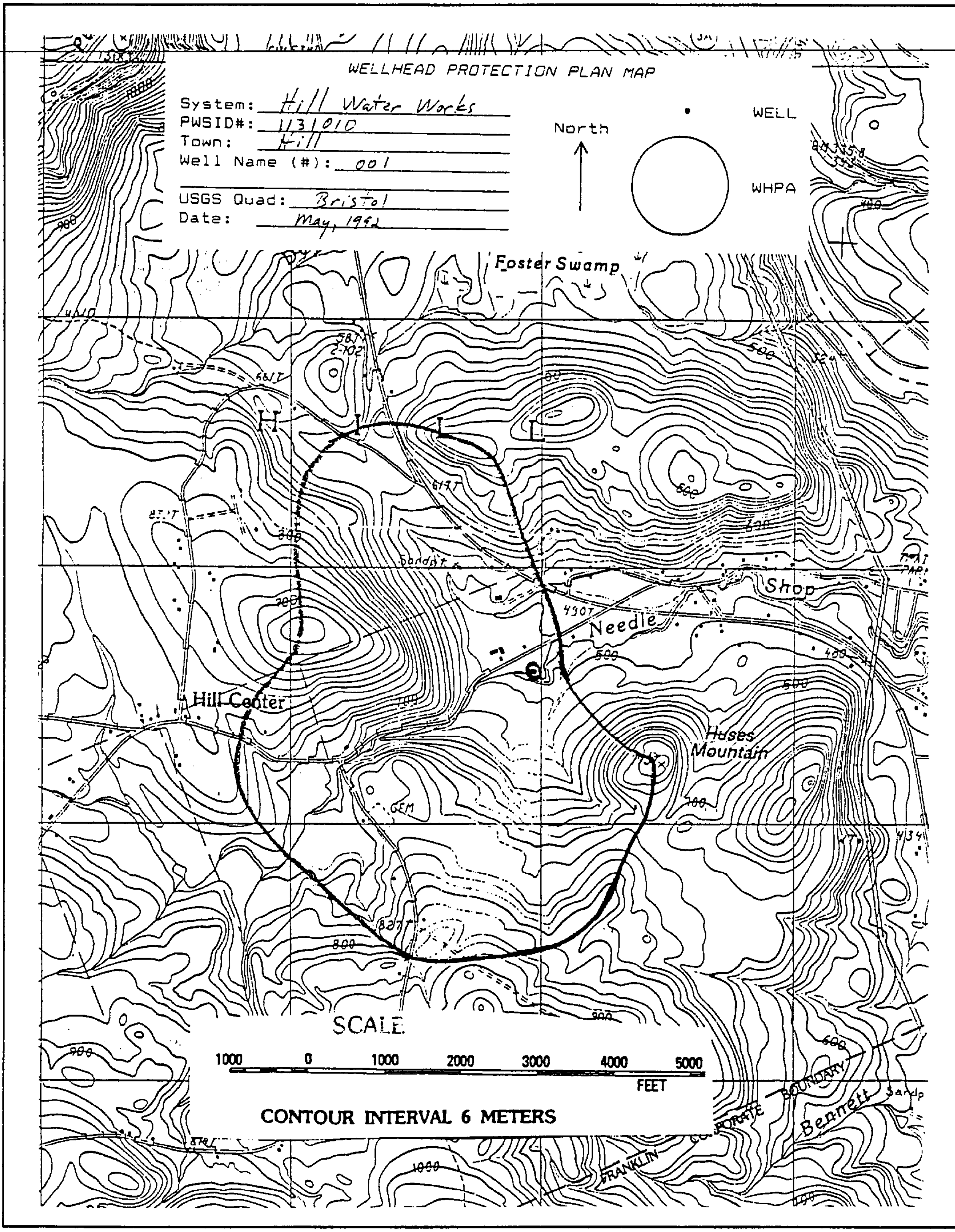

Figure 5-3. Delineated wellhead protection area on topographic base.

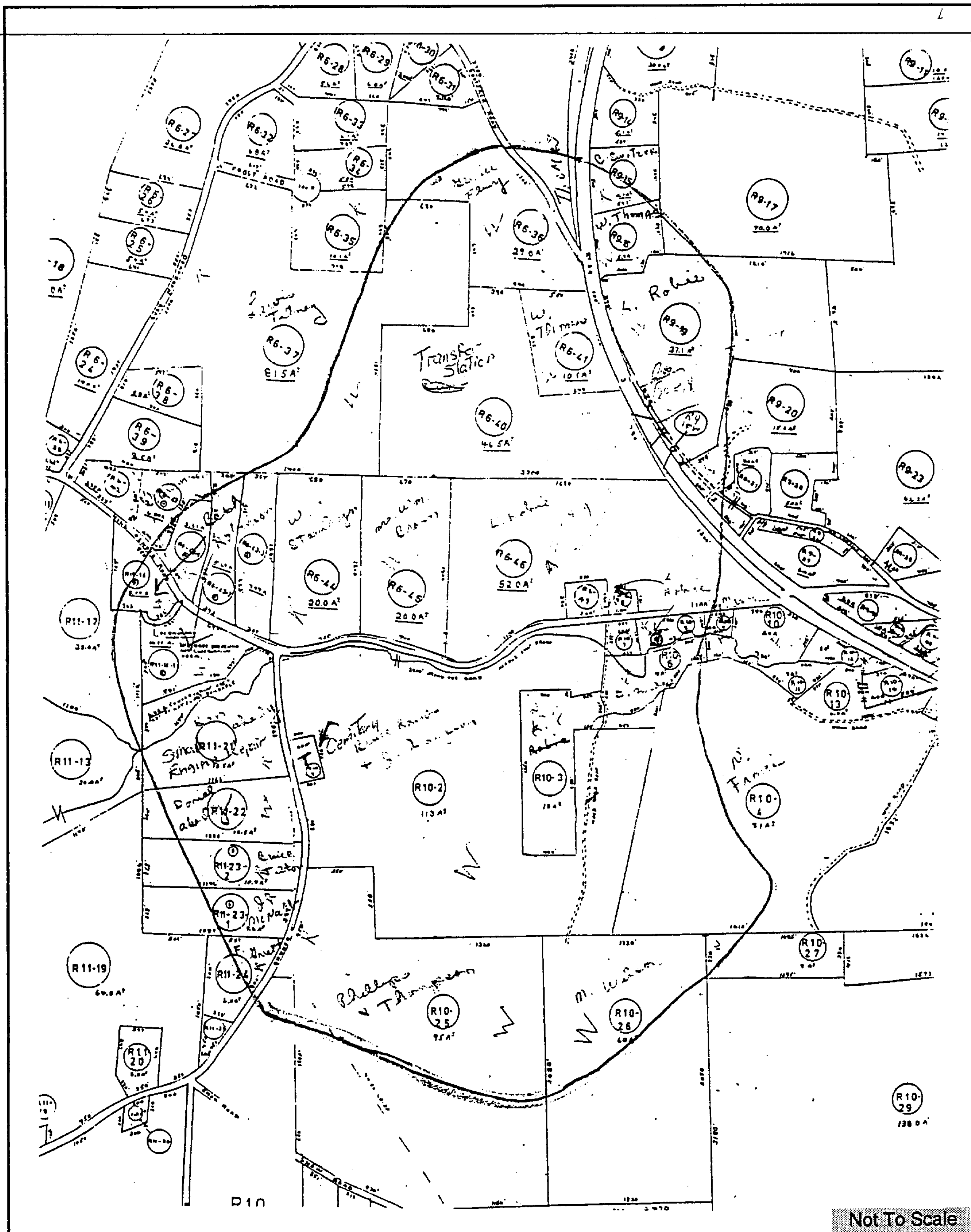

Figure 5-4. Wellhead protection area transferred to village tax map.

indicate to motorists that they are driving through a public water supply recharge area.

Small Engine Repair Shop—Hill will notify the land owner of the extent to which his property is situated in the wellhead protection area and ask him to cooperate by using BMPs to run his shop. BMP information will be provided to the land owner. BMPs include proper storage and disposal of potentially hazardous products like waste oil, antifreeze, solvents, used filters, paint, and batteries, as well as practices that minimize leakage. NHDES also encourages use of alternative products and technologies, such as aqueous cleaners and high-pressure water washes for cleaning, and recycling of products such as solvents, antifreeze, and engine oil.

Residential Properties—Hill zoning allows for "rural residential uses" within the recharge area. Minimum lot size is 3 acres. To better protect the public water supply, the town will seek classification of the ground water in the recharge area according to the state of New Hampshire's Ground Water Protection Act (RSA 485-C). In addition, the town will explore the creation of a ground water protection overlay district to conform with the wellhead protection area and promote closer scrutiny of proposed land use activities within the wellhead protection area.

Hill will notify property owners in writing of the location of their properties within the wellhead protection area and will ask them to cooperate by properly operating and maintaining their septic systems and properly using, storing, and disposing of household hazardous materials. The property owners will be provided with information on these practices.

Woodland—Much of the woodland in the wellhead protection area is in the New Hampshire Current Use Program, which provides tax liability reductions for maintaining open space. Financial penalties are assessed to change the use. Hill will notify landowners that their land falls within the wellhead protection area and will ask them to cooperate by using BMPs during any logging operations and ensuring that their contractors use BMPs as well, especially when using gasoline and oil.

Fields—Currently, no chemical fertilizers, pesticides, or herbicides are used on the fields. Hill will ask field landowners to continue to refrain from using chemicals on their properties.

Cemetery—The town will refrain from using herbicides, pesticides, or fertilizers on the town-owned cemetery grounds, and the town will ask the owners of the private cemeteries to do the same.

Approach Used to Plan for the Future

The team felt that the geologic setting of the Town of Hill Village District well should promote relatively rapid flushing of any contamination of the aquifer adjacent to the well. Hill's short-term solution to any unanticipated loss of water from the well will be to supply bottled water. If Hill permanently loses its present source of water, the town will continue to implement the short-term solution until another water source is developed and brought on line.

Conclusion

The planning team members successfully carried through the first four steps of the five-step wellhead protection process: they formed a planning team; with the technician's assistance, they delineated the wellhead protection area; they identified potential sources of contamination; and they created an approach for managing potential contamination sources. They are now on Step Five, having developed a plan for the future, including some contingency plans.

The planning team attributed the success of the program to date, in part, to meeting the challenges of explaining the program to the community and thus alleviating potential concerns. Technician John Lukin has provided educational materials to the selectmen for use in the wellhead protection program.

CASE STUDY TWO: Village of Cottage Grove, Wisconsin

Description of Cottage Grove

The village of Cottage Grove is located in south central Wisconsin, 15 mi west of the capital city of Madison. Once a small farming community, the village is now part of the broad suburban ring that surrounds Madison. Many of its 1,200 residents work in the capital for the state or for the University of Wisconsin. Several small industries also support the village. They include Avganic Industries, Inc.; Hydrite Chemical; the Dane County Farmers Union Cooperative; Badger Lumber; and a handful of service industries. A new highway between Madison and Cottage Grove and the recent sale of public land to developers have spurred village growth exponentially. The population grew from 900 to 1,200 between 1989 and 1992, and the village clerk estimates that 800 dwelling units have been approved or are about to be approved for construction.

Cottage Grove lies in a region of rolling hills, on a base of sandstone, mostly of the Wonewoc formation. The sandstone aquifer under the village wells is approximately 725 ft deep, with an average hydraulic conductivity of 5.5 x 10^{-5} cm/sec. There are no bodies of water or surface streams in the area. Like 95 percent of Wisconsin's communities, Cottage Grove relies solely on ground water wells for its water supply. Two wells serve the village area. They are located generally in the central district of the village, surrounded by residences and small businesses. Well #1 is located on Main Street, the village's north-south artery, near the intersection of Taylor Street. Well #2 lies in the midst of a residential development framed by Cottage Grove Road to the north and Main Street to the east (see Figure 5-5).

Overview of Wellhead Protection Issues

The village was actively involved in surveying and protecting its ground water when it contacted the Wisconsin Rural Water Association (WRWA) for technical assistance. The location of Avganic Industries and the adjacent Hydrite Chemical Company, just 0.5 mi from Well #1 (and 1 mi from Well #2), caused concern about wellwater contamination. Drums containing a multitude of chemicals had been discovered on the Avganic site, owned and operated by North Central Chemical in the 1950s. The drums were found to have leached into the soil through their cement pad and contaminated much of the site. Avganic was defining the plumes and preparing for remediation under the Resource Conservation and Recovery Act (RCRA). The village was also conducting its own study of the Avganic facility. In addition, serious ground water contamination problems from atrazine use were identified in the southern portion of the village near the Dane County Farmers Union Cooperative.

Approach Used to Form a Community Planning Team

Village utility director Christine Diebels met the WRWA ground water technician, Jill Jonas, at a state wellhead protection conference in May 1991. In early July, the village president contacted Jonas to request help with developing the village's wellhead protection program. Specifically, the village was interested in assistance with delineating wellhead protection areas for Wells #1 and #2 and a proposed well (Well #3) (see Figure 5-5) in the northern area of the village to replace the threatened Well #1. The WRWA technician agreed to assist the village with its program.

In mid July, the technician met with the utility director to discuss the program. They constituted the core of the team that would take the program through the delineation phase and provide the impetus for completing the program. One distinct advantage that this core team had was its level of expertise—the village's utility director also is a trained hydrogeologist. They immediately began work on delineating the protected areas. As the wellhead protection program developed, they would bring the village clerk, the village attorney, the utility board, and area citizens and businesses into the planning process.

Approach Used to Delineate the Wellhead Protection Area

An abundance of geologic data on Well #1 was available from the RCRA study. Several documents existed on the solvent remediation program alone. The team's challenge was to determine which information would be most useful in delineating the wellhead protection areas. In addition, Avganic Industries offered to provide information for simple calculations of ground water travel time. Research of existing materials proved to be extensive. Among the most useful pieces of data was the Geological Survey Water-Supply Paper 1779-4 developed for the USGS. It provided essential hydrogeologic information, including a potentiometric map with a ground water divide. The technician cross-referenced these data with information from the remediation project.

Initially the technician used the uniform flow equation (see Chapter Four) to delineate areas for all three wells. Figure 5-6 shows her delineation of the wellhead protection areas for all three wells using this method. No guidance or state oversight on delineation was available from the state of Wisconsin, which is still in the process of developing a wellhead protection program for public water supplies. The technician requested a review of the initial delineation from a hydrogeologist for the Wisconsin Geological and Natural History Survey. He recommended using a more complex delineation approach to account for interference between the wells. He suggested using the EPA computerized WHPA Code semianalytic model (see Chapter Four) and provided training.

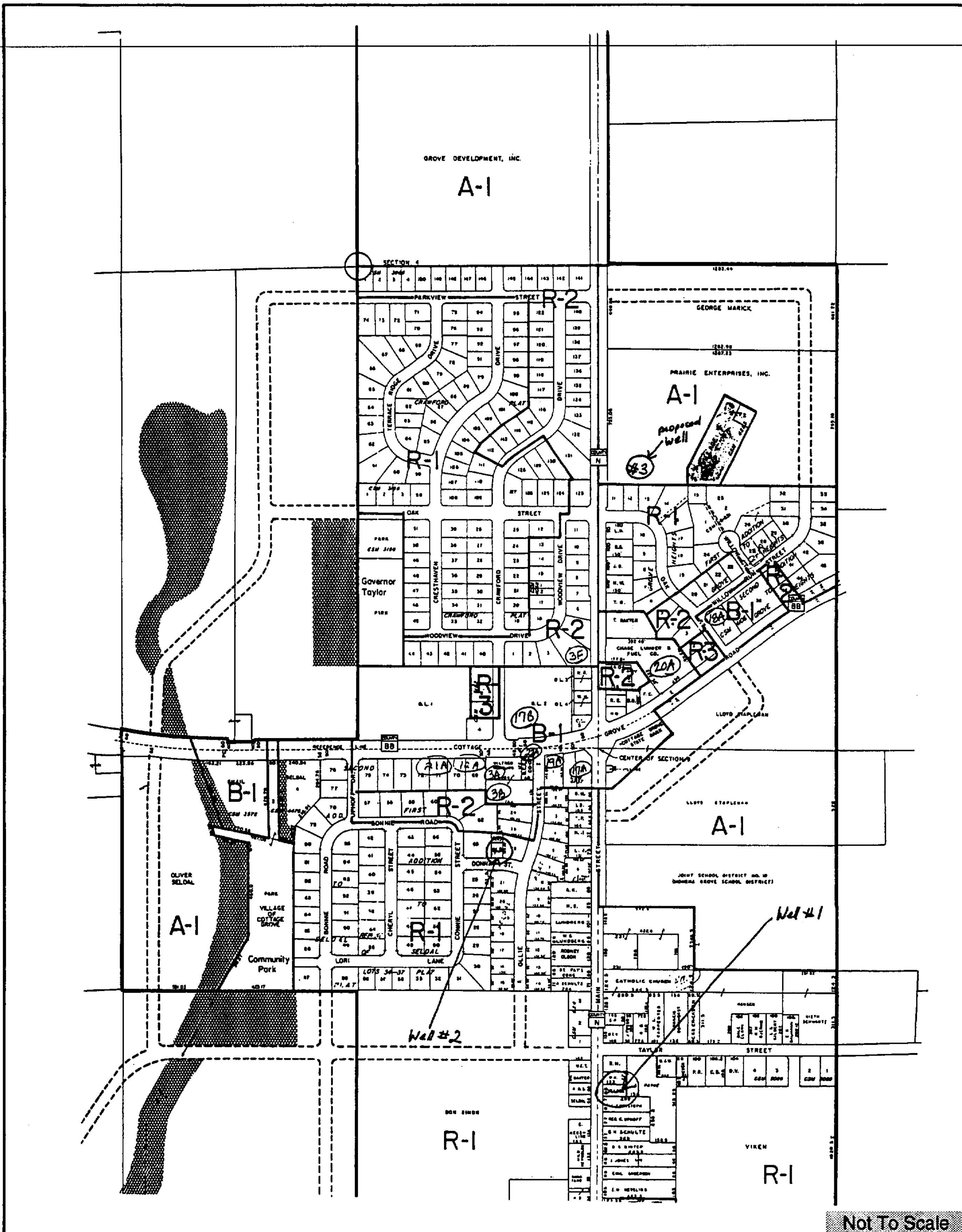

Figure 5-5. Zoning map of Cottage Grove with well locations.

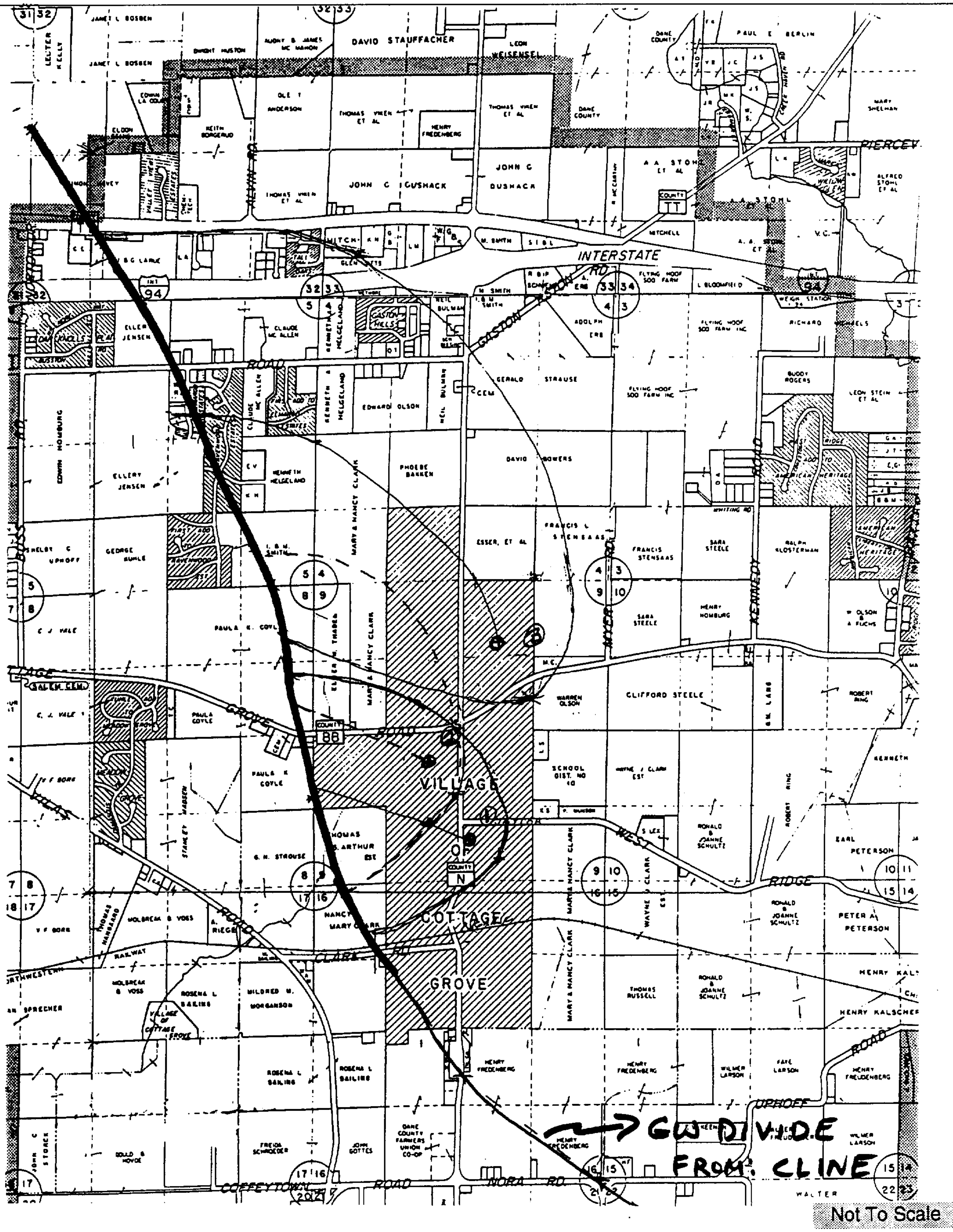

Figure 5-6. Delineation of Cottage Grove wellhead protection areas using uniform flow equation.

In the meantime, the village decided to abandon Well #1. They asked that the technician delineate wellhead protection areas for Well #2 and proposed Well #3. The wellhead protection areas for these wells were delineated using the WHPA Code program, incorporating zones of contribution for times of travel (TOTs) of 1, 5, 50, and 100 years into the model. The resulting wellhead protection areas are shown in Figure 5-7. The ground water contributing to Cottage Grove's wells comes from the northwest and runs southeasterly. The wells are delineated to the west by the ground water divide based on the USGS data. The zone of contribution for 50 years extends approximately 8,000 ft northwest to Interstate 94, incorporating several major developments that lie outside the village jurisdiction in Cottage Grove. To the southeast, the downgradient zone of contribution extends approximately 600 ft for both wells. The wellhead protection areas based on these zones lies beyond the ground water flow affected by Avganic Industries, Hydrite, and Dane County Farmers Union Cooperative. It incorporates the northern half of the village dominated by residential zones and small businesses.

Approach Used to Identify and Locate Potential Sources of Contamination

The technician worked closely with the village clerk to identify potential sources of contamination. Together they matched maps of the village with ownership and address information on file to identify owners and uses of lots. Because they were concerned with managing ground water contaminants in the entire village, they considered all lots within the village jurisdiction. They simplified a cumbersome process of identifying all possible contaminant sources from among the 51 lots by using an inventory format developed by the WRWA (similar to Figure 4-15 in Chapter Four). Each known use from the clerk's list was matched against the established list of "potential contaminant sources" identified on the inventory sheet and assigned a reference number. Locations of repeated use, such as the three cemeteries in Cottage Grove, were differentiated by letter. Using this method, the clerk and technician located 48 potential sources of contamination from among 24 different uses (see Figure 5-8). Twelve of these were located within the designated wellhead protection areas. Members of the Cottage Grove Historical Society also helped with the inventory. The members of the society, most of them elderly, used their knowledge of the community and research skills to locate old cisterns and gas pumps. Of the list of 20 they provided, the team eliminated 17 (tanks that had already been removed) and incorporated 3 into its list of potential contamination sources. Although the wellhead protection areas did include fuel stations and small repair shops, retailers, a general store, laundry, and lumber retailer, these potential sources were not considered major threats to the wellhead protection areas.

Approach Used to Manage the Wellhead Protection Area

Once the inventory process was complete, the planning team, with the village clerk, set up a meeting with the utility board, the parks program, and the planning department. Using the comments from this meeting, the utility board then went to work on drafting a resolution and ordinance to manage the village's ground water. The board called on the various skills available in the village community to draft the document language. The utility director, in conjunction with the technician, provided technical guidance, the village attorney provided legal expertise, and village residents provided the "common sense" that made the ordinance a readable public document. The ground water ordinance was meant to be a sweeping long-term plan to include all areas of the village and ensure safe drinking water into the next century.

Three public hearings were held on the ground water protection ordinance between November 1991 and April 1992. To encourage public participation, the village clerk posted announcements of the meetings in seven public locations, placed notices in the local papers, and issued a memo to sectors of the community that had a special interest in the ordinance. The clerk's November 8, 1991, memo (see Figure 5-9) invited the village board, the utility commission, the village attorney, the village engineer, the director of public works, committee chairpersons, and personnel from Avganic Industries, Dane County Coop, Hydrite Chemical, and Kessenich General Store to the public hearing held on December 2, 1991.

Citizens and village businesses were very active in the hearings. Avganic Industries in particular requested clarification of the technician's methods and suggested a number of useful modifications. The company's suggestion to use a numerical model to redefine the wellhead protection areas was considered over a subsequent 30-day period, but was rejected because of the cost. The utility director estimates that using such a model would have cost the village several hundred thousand dollars. Numerous meetings also were held between the village attorney, the technician, and the utility director.

On April 20, 1992, the Village Board of Cottage Grove adopted a resolution (see Figure 5-10) requesting that "Dane County, the Town of Cottage Grove, and the Wisconsin Department of Natural Resources . . . consider wellhead and ground water protection in making permits, zoning, subdivision, and other related land use ordinances, regulations, or decisions for areas possibly affecting the wells of the Village of Cottage Grove."

The Board also added a Wellhead Protection Ordinance (Figure 5-10) to the Municipal Code "to institute land use regulations and restrictions to protect the village's municipal water supply and well fields, and to promote the public health, safety and general welfare of the residents of the

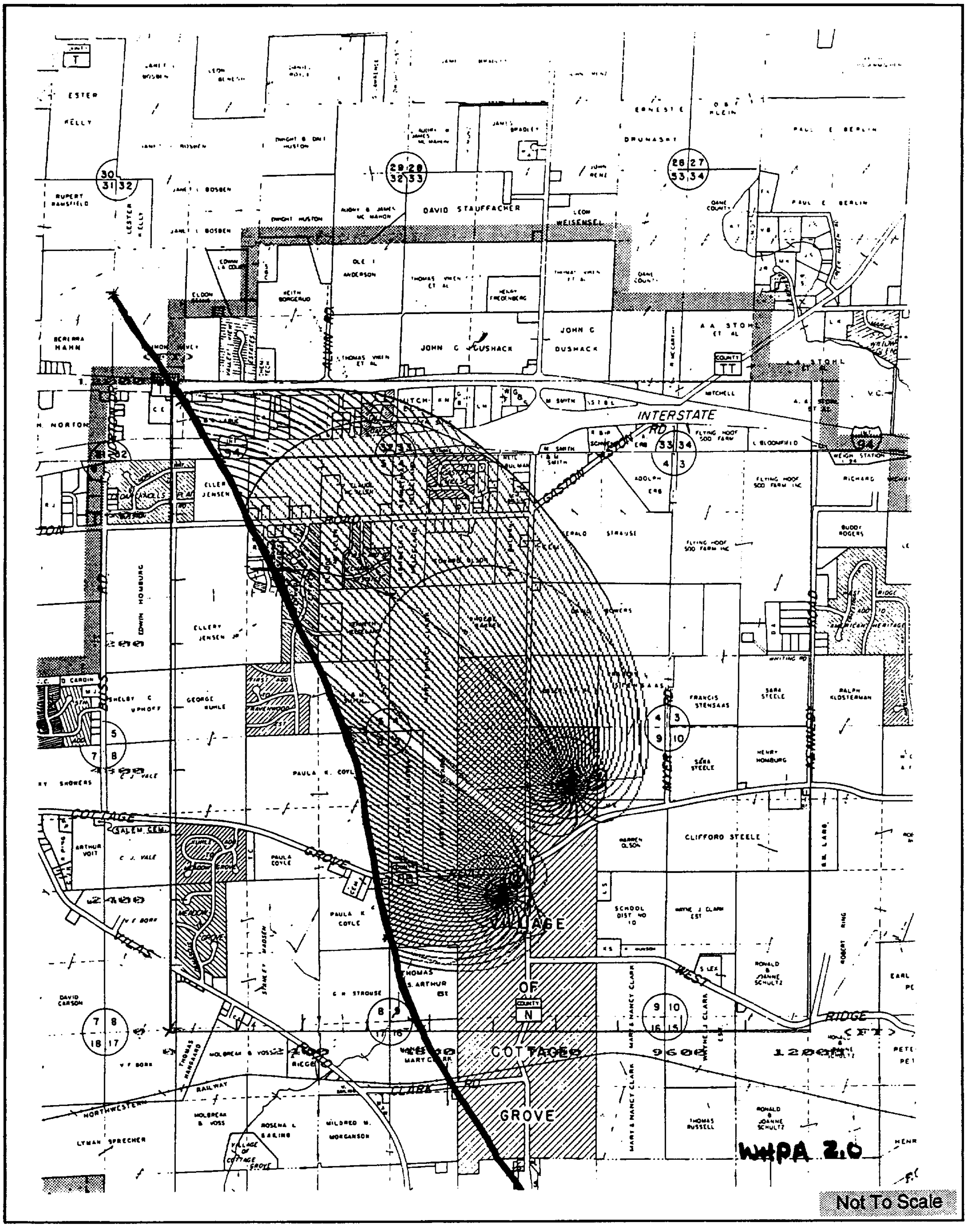

Figure 5-7. Delineation of Cottage Grove wellhead protection areas using WHPA Code computer program.

Reference: Wellhead Protection Ordinance
Village of Cottage Grove

01A) Blackhawk Airport, Kennedy Rd.
02A) Fredenberg property (inactive silage pit), CTH N north of Natvig Rd.
03A) Two Buck Automotive Rebuilders & Service, 212 W. Cottage Grove Rd.
03B) " " " " " , 212A W. Cottage Grove Rd.
03C) Village of Cottage Grove (truck and eqpt. storage), 117 Reynolds St.
03D) Village of Cottage Grove (garage), 300 S. Main St.
03E) K & S Automotive and Grove Machine & Tool, 351 S. Main St.
03F) Michael Schraufnagel residence (restored old cars in large garage) 132 B Woodview Dr.
03G) Ron Mueller's Service (auto service, UST), CTH TT and CTH N
03H) Larson's Automotive (UST), CTH TT and CTH N
03I) Town of Cottage Grove (garage, truck and automotive supplies storage), 4091 CTH N
04A) Cemetery, CTH N south of Gaston Rd.
04B) Cemetery, W. Cottage Grove Rd.
04C) St. Patrick's Church (cemetery), 434 N. Main St.
05A) Hydrite Chemical Co. (chemical packaging company), 150 Donkle St.
06A) Town & Village of Cottage Grove (closed landfill), Natvig Rd. & CTH N
07A) Dane County Farmers' Union Co-operative (feed mill), 241 Clark St.
07B) Dane County Farmers' Union Co-operative (grain bins, automotive repair, pesticide truck cleaning, agri-chemical storage), CTH N and Coffeytown Rd.
07C) Garst Seed Co. (Agri-chemical), 2560 Nora Rd.
08A) Huston Bros. Garden Center, CTH N and Coffeytown Rd.
09A) Dane County Farmers' Union Co-operative (fertilizer plant), 251 Clark St.
09B) Gus Paraskevoulakos (restaurant eqpt. storage - former Dane County Farmers' Union feed mill), 356 S. Main St.
10A) Gerald Strouse property (sludge lagoons), Vilas Rd.
11A) " " " (sludge spreading), Vilas Rd.
12A) Mall - Suds Your Duds (laundry), 214 W. Cottage Grove Rd.
13A) Chicago & Northwestern Transportation Co. (railroad), division of N & S Main Sts.
13B) Interstate 94 (gas station) I94 & CTH N
14A) Irving Smith property (former gravel pit filled with highway construction debris) CTH N & Gaston Rd.
14B) Gerald Strouse property (active mineral extraction site) CTH N south of Gaston Rd.
14C) Dean & Barb Everett, d/b/a Viking Stone (active mineral extraction site), Gaston Rd north of CTH N
15A) Town of Cottage Grove (salt storage), CTH N south of Village limit
16A) Eugene Fredenberg residence (unsewered), 357 S. Grove St.
16B) Theron Uphoff residence (unsewered), 377 S. Grove St.
16C) Lisa Vitense & Rick Hatton residence (unsewered), 362 S. Grove St.
16D) Nondahl Heights subdivision (failing septic systems), Vilas Rd.
17A) Kessenich's General Store, 585 N. Main St.
17B) Dane County Farmers' Union Co-operative (car wash, diesel & gasoline UST, LP tanks, hardware store), 205 W. Cottage Grove Rd.
18A) Dick's Market c/o Jerry Stoddard, 205 E. Cottage Grove Rd. locker plant
18B) Hollywood Dressed Beef (slaughterhouse), Pieper Rd.
19A) LSJ Enterprises (now vacant), 202 W. Cottage Grove Rd.
19B) J. R. Fritz (miscellaneous storage), 127 Reynolds St.
19C) Village of Cottage Grove (storage shed), 116 Reynolds St.
20A) Chase Lumber, 123 E. Cottage Grove Rd.
20B) Badger Lumber (wholesaler), 120 N. Main St.
21A) Universal Hair Design (beauty shop), 214 W. Cottage Grove Rd.
22A) Conklin Electric, 204 W. Cottage Grove Rd.
23A) Avganic Industries (hazardous waste recyclers), 114 N. Main St.
24A) Robert Hartwig (buried railroad tanker for fuel oil), 712 Willow Run Ct.

Figure 5-8. List of potential contaminant sources for Cottage Grove.

Village of Cottage Grove

116 Reynolds Street
Phone: 839-4704

Post Office Box 156
Cottage Grove, WI 53527

M E M O

To: Village Board
Utility Commission
Village Attorney
Village Engineer
Director of Public Works
Commission/Committee Chairpersons
Avganic Industries
Dane County Farmers' Union Co-op
Hydrite Chemical
Kessenich General Store

From: Village Clerk

Date: November 8, 1991

Re: Proposed Wellhead Protection Ordinance

The Water & Sewer Commission is proposing that the attached wellhead protection ordinance be adopted by the Village. A public hearing has been scheduled for December 2, 1991 at Flynn Hall.

The ordinance would place some restrictions on land use within the village in an effort to protect the municipal water supply. If you have any questions about the ordinance or the hearing, please call me at 839 - 4704.

Figure 5-9. Village clerk's memo announcing proposed wellhead protection ordinance and public hearing.

Village of Cottage Grove

116 Reynolds Street
Phone: 839-4704

Post Office Box 156
Cottage Grove, WI 53527

RESOLUTION NO. 92-03

VILLAGE OF COTTAGE GROVE
DANE COUNTY, WISCONSIN

A RESOLUTION OF THE VILLAGE OF COTTAGE GROVE TO DANE COUNTY, THE TOWN OF COTTAGE GROVE AND TO THE WISCONSIN DEPARTMENT OF NATURAL RESOURCES, REQUESTING THAT WELLHEAD PROTECTION AND GROUNDWATER PROTECTION CONSIDERATIONS BE WEIGHED IN MAKING PERMITS AND ZONING, SUBDIVISION, AND OTHER RELATED LAND USE ORDINANCES, REGULATIONS, OR DECISIONS.

WHEREAS, it is within the responsibility of the Village of Cottage Grove, as a public water supplier, to consider the health, safety, and welfare of it's customer; and
WHEREAS, groundwater contamination can and does occur as a consequence of a variety of land use activities; and

WHEREAS, it is desirable to preserve and protect the quantity and quality of our groundwater resources to assure a continued safe, adequate, and usable supply, now and in the future; and

WHEREAS, protection of current and potential future sources of groundwater is worthwhile from the standpoint of resource protection;

NOW, THEREFORE, BE IT RESOLVED by the Village Board of Cottage Grove, that we do respectfully ask that Dane County, the Town of Cottage Grove, and the Wisconsin Department of Natural Resources to consider wellhead and groundwater protection in making permits, zoning, subdivision, and other related land use ordinances, regulations, or decisions for areas possibly affecting the wells of the Village of Cottage Grove.

ADOPTED this 20th day of April, 1992, by the Village Board of Cottage Grove, by unanimous vote.

Village of Cottage Grove
Official Signature

Rhonda Kazda, President

ATTEST:

Linda S. Kettinger, Clerk

Figure 5-10. Cottage Grove wellhead protection resolution and ordinance.

AN ORDINANCE CREATING
CHAPTER 18 OF THE MUNICIPAL CODE
FOR THE VILLAGE OF COTTAGE GROVE

The Village Board for the Village of Cottage Grove, Dane County, Wisconsin, does hereby ordain as follows:

SECTION I: Chapter 18 of the MUNICIPAL CODE FOR THE VILLAGE OF COTTAGE GROVE is hereby created to read as follows:

SECTION 18.1. CONSTRUCTION OF ORDINANCE

(a) TITLE

This Chapter shall be known, cited and referred to as the "Wellhead Protection Ordinance" (hereafter **WHP ORDINANCE**).

(b) PURPOSE AND AUTHORITY

1. The residents of the Village of Cottage Grove (hereafter **VILLAGE**) depend exclusively on groundwater for a safe drinking water supply. Certain land use practices and activities can seriously threaten or degrade groundwater quality. The purpose of the **WHP ORDINANCE** is to institute land use regulations and restrictions to protect the **VILLAGE'S** municipal water supply and well fields, and to promote the public health, safety and general welfare of the residents of the **VILLAGE**.

2. These regulations are established pursuant to the authority granted by the Wisconsin Legislature in 1983, Wisconsin Act 410 (effective May 11, 1984), which specifically added groundwater protection to the statutory authorization for municipal planning and zoning in order to protect the public health, safety and welfare.

(c) APPLICABILITY

The regulations specified in the **WHP ORDINANCE** shall apply within the **VILLAGE'S** corporate limits.

SECTION 18.2. DEFINITIONS

(a) Existing Facilities Which May Cause Or Threaten To Cause Environmental Pollution - Existing facilities which may cause or threaten to cause environmental pollution within the corporate limits of the **VILLAGE'S** well fields' recharge areas which include but are not limited to the Wisconsin Department of Natural Resources' draft list of "Inventory of Sites or Facilities Which May Cause or Threaten to Cause Environmental Pollution," "Department of Industry, Labor and Human Relations (hereafter D.I.L.H.R.) list of Underground Storage Tanks (hereafter UST's) and list of facilities with hazardous, solid waste permits, all of which are incorporated herein as if fully set forth.

Figure 5-10. Cottage Grove wellhead protection resolution and ordinance (continued).

(b) Groundwater Divide - Ridge in the water table, or potentiometric surface, from which ground water moves away at right angles in both directions. Line of highest hydraulic head in the water table or potentiometric surface.

(c) Groundwater Protection Overlay District - Shall be defined as that area contained in the map attached as Exhibit A and incorporated herein as if fully set forth.

(d) Recharge Area - Area in which water reaches the zone of saturation by surface infiltration and encompasses all areas or features that supply groundwater recharge to a well.

(e) Well Field - A piece of land used primarily for the purpose of supplying a location for construction of wells to supply a municipal water system.

SECTION 18.3. GROUNDWATER PROTECTION OVERLAY DISTRICT (hereafter **DISTRICT**)

(a) INTENT. The area to be protected is the Cottage Grove well fields' recharge areas extending to the groundwater divide (as determined by the UNITED STATES GEOLOGICAL SURVEY WATER SUPPLY PAPER 1779-U, incorporated herein as if fully set forth) contained within the **VILLAGE** boundary limits. These lands are subject to land use and development restrictions because of their close proximity to the well fields and the corresponding high threat of contamination.

(b) PERMITTED USES. Subject to the exemptions listed in Section 18.4, the following are the only permitted uses within the **DISTRICT**. Uses not listed are to be considered prohibited uses.

1. Parks, provided there is no on-site waste disposal or fuel storage tank facilities associated within this use.

2. Playgrounds.

3. Wildlife areas.

4. Non-motorized trails, such as biking, skiing, nature and fitness trails.

5. Residential municipally sewered, free of flammable and combustible liquid underground storage tanks.

(c) REQUIREMENTS FOR EXISTING FACILITIES.

1. Facilities shall provide copies of all federal, state and local facility operation approvals or certificate and on-going environmental monitoring results to the **VILLAGE**.

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Figure 5-10. Cottage Grove wellhead protection resolution and ordinance (continued).

2. Facilities shall provide additional environmental or safety structures/monitoring as deemed necessary by the **VILLAGE**, which may include but are not limited to stormwater runoff management and monitoring.

3. Facilities shall replace equipment or expand in a manner that improves the existing environmental and safety technologies already in existence.

4. Facilities shall have the responsibility of devising and filing with the **VILLAGE** a contingency plan satisfactory to the **VILLAGE** for the immediate notification of **VILLAGE** officials in the event of an emergency.

<u>SECTION 18.4</u>. <u>PERMITTED USES</u>

(a) Individuals and/or Facilities may request the **VILLAGE** to permit additional land uses in the **DISTRICT**.

(b) All requests shall be in writing either on or in substantial compliance with forms to be provided by the **VILLAGE** and shall include an environmental assessment report prepared by a licensed environmental engineer.

Said report shall be forwarded to the **VILLAGE ENGINEER** and/or designee(s) for recommendation and final decision by the **VILLAGE BOARD**.

(c) The Individual/Facility shall reimburse the **VILLAGE** for all consultant fees associated with this review at the invoiced amount plus administrative costs.

(d) Any permitted uses shall be conditional and may include required environmental and safety monitoring consistent with local, state and federal requirements, and/or bonds and/or sureties satisfactory to the **VILLAGE**.

<u>SECTION 18.5</u>. ENFORCEMENT

(a) In the event the individual and/or facility causes the release of any contaminants which endanger the **DISTRICT**, the activity causing said release shall immediately cease and a cleanup satisfactory to the **VILLAGE** shall occur.

(b) The individual/facility shall be responsible for all costs of cleanup, **VILLAGE** consultant fees at the invoice amount plus administrative costs for oversight, review and documentation.

1. The cost of **VILLAGE** employees' time associated in any way with the cleanup based on the hourly rate paid to the employee multiplied by a factor determined by the

-3-

Figure 5-10. Cottage Grove wellhead protection resolution and ordinance (continued).

VILLAGE representing the VILLAGE'S cost for expenses, benefits, insurance, sick leave, holidays, overtime, vacation, and similar benefits.

2. The cost of VILLAGE equipment employed.

3. The cost of mileage reimbursed to VILLAGE employees attributed to the cleanup.

(c) Following any such discharge the VILLAGE may require additional test monitoring and/or bonds/sureties as outlined in Section 184.4(d)

(d) Enforcement shall be provided pursuant to Section 25.04 of the Code.

SECTION II. CONFLICT AND SEVERABILITY. Section 25.02 of the Municipal Code of the Village of Cottage grove applies to this ordinance.

SECTION III. EFFECTIVE DATE. This ordinance shall take effect upon passage and posting as provided by law.

Adopted this 20th day of APRIL, 1992.

BY ORDER OF THE VILLAGE BOARD
VILLAGE OF COTTAGE GROVE

Rhonda Kazda, President

Attest: Linda A Rittenger

Requested By: ______________________

Drafted By: Leighton W. Boushea, Village Attorney

Approved As to Form By: Leighton W. Boushea, Village Attorney

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Figure 5-10. Cottage Grove wellhead protection resolution and ordinance (continued).

village." The ordinance was drawn up in accordance with authority granted by the Wisconsin Legislature in 1983, Wisconsin Act 410, specifically adding ground water protection to the statutory authority of municipal planning bodies. The ordinance determined that lands within the Wellhead Protection District be subject to land use and development restrictions, with use limited to parks, playgrounds, wildlife areas, nonmotorized trails, and municipally sewered residences. Existing uses of developed lots are required to meet all local, state, and federal safety and environmental requirements, and the owners are required to devise and file an emergency contingency plan with the village. Additional land uses in the district are subject to a permitting process. Actions in the case of release of contaminants endangering the district are determined at the cost of the individual/facility causing the release, and enforcement is provided pursuant to Section 25.04 of the Village Code.

Approach Used to Plan for the Future

The village ordinance extends management of the village ground water into the distant future. In the short term, remediation efforts continue at the two sites where ground water has been compromised by contaminants. Well #1, still active as of July 1992, will be shut down as soon as construction of Well #3 is complete. It will be kept as a test well. It is expected that Wells #2 and #3 will serve the growing population of the village. To ensure that future needs are met, the technician would like to see the village develop a contingency plan in the event of contamination of either of these wells.

Education continues to be an important piece of Cottage Grove's current and future management plan. Believing that preventive action is more effective than remediation, the utility director is gathering materials to educate homeowners on residential contamination sources. Because the village asked that surrounding communities and the state take voluntary measures to prevent ground water contamination that may affect Cottage Grove, the utility director is taking steps to encourage as much education and voluntary participation as possible within the village community. She feels that the village will need to rely as much on voluntary action as legal compliance to protect its water. She also foresees that the Wisconsin State Groundwater Protection Program will require an education initiative as part of local ground water protection programs and views the education program as part of the village's compliance.

Conclusion

The village of Cottage Grove was unusually active in the development of a ground water protection program. Its proactive approach was in part a response to the tangible threats to its drinking water supply. The village benefited greatly from the expertise and leadership of its utility director and the WRWA technician. The WRWA program enabled the village to tap expertise that would otherwise have been beyond its means. "We were considered either too small or too affluent to qualify for most grant programs," noted Village Clerk Sue Kettinger. The utility director estimates that the services provided by the technician would have cost the community between $25,000 and $30,000 if they had hired an engineering consultant.

The success of the Cottage Grove initiative can also be linked to the open lines of communication established in the village from the beginning. The planning team actively sought input from the business and residential sectors of the community and incorporated suggestions into the final document. In addition, the team tapped the network of knowledge and experience from other communities and state resources such as the University of Wisconsin Extension Service and the Wisconsin Department of Natural Resources. The willingness of local businesses, in particular Hydrite and Avganic, to participate in the establishment of a ground water protection program was also an essential part of Cottage Grove's success.

CASE STUDY THREE: Enid, Oklahoma

Description of Enid

Located 85 mi northwest of Oklahoma City, Enid is the largest ground water user in the state. The city's water supply serves about 60,000 people, including a metropolitan population of approximately 46,000 (which includes Vance Air Force Base and Phillips University) as well as citizens in neighboring rural communities. Enid's drinking water is supplied by 153 wells located in five wellfields drawing from two aquifers. The wellfields are located in four counties, with the Cimarron River crossing one of the wellfields. The Cimarron River Terrace Aquifer provides 80 percent of the water supply, and the Enid Isolated Terrace Aquifer provides 20 percent. Water quality in the two aquifers is considered to be very high. Average water usage is 11 million gallons per day (mgd), with peak demand at 18 mgd; the water supply system capacity is 27 mgd. Well water treatment includes chlorination and fluoridation.

Enid's economy is based primarily on agriculture, oil and gas activities, and manufacturing. In addition, the city serves as a center of trade, health care, and retirement for the surrounding rural area. Several railroad lines and two highways pass through Enid.

Approach Used to Form a Community Planning Team

The wellhead protection planning team is composed of members of several city departments, including the Director of Public Works, who has an engineering background in ground water resources and geology; members of the Engineering Department; and staff from the Water Production Department with geotechnical expertise. The Oklahoma Water Resources Board provides useful technical assistance for the wellhead protection program. The planning team spent 6 months preparing a "total aquifer management plan," which was completed and approved by the City Council in March 1990.

Mechanisms also were developed for public participation in wellhead protection planning and program review. Interested citizens and civic and environmental organizations in the area reviewed and critiqued proposed program elements. City Council public meetings served as a forum for this review process.

Approach Used to Delineate the Wellhead Protection Area

The wellhead protection planning team reviewed existing data, including water quality test results, water production records, drillers' logs, test hole data, geologic and hydrologic reports and maps, and potential contaminant source inventories. Field surveys were then conducted to obtain missing information. The team mapped the data as overlays onto a digital base map and developed a geographic information system (GIS) to organize the data.

The area consists of alluvium (fine-grained, unconsolidated soils deposited by a stream or other body of running water), terrace deposits (coarse-grained, unconsolidated soils, including sand dunes), and consolidated shale and sandstone. The hydraulic conductivities and specific yields of these soils are given in Table 5-1. Figure 5-11 shows the aquifers and recharge areas for the Enid, Oklahoma, area. Figure 5-12 illustrates ground water flow and elevations in Enid's Cleo Springs wellfield area.

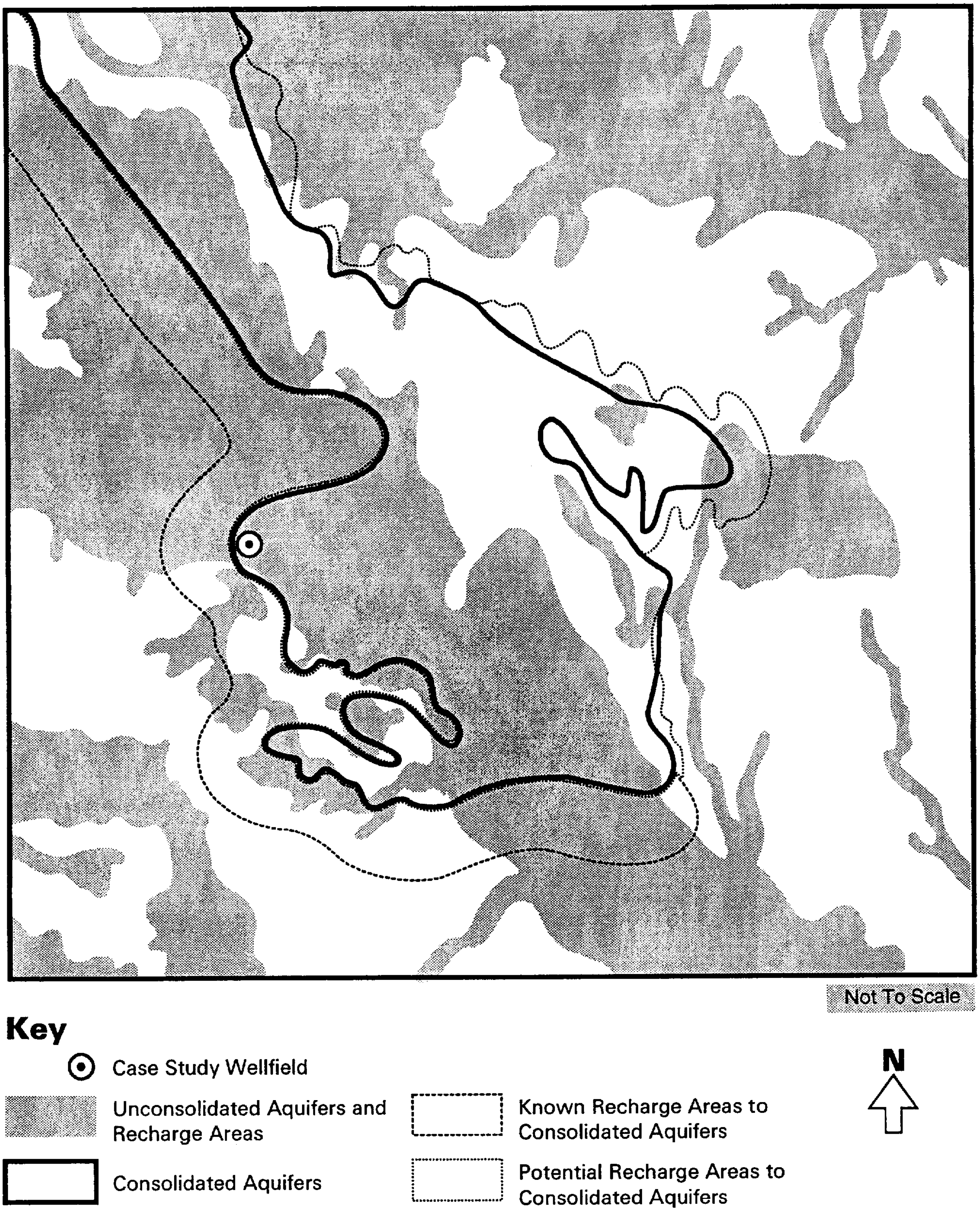
Initially, the project team used semianalytical methods developed by the Oklahoma Water Resources Board to delineate the five wellfield boundaries. Team members then refined these delineations by using the U.S. Geological Survey (USGS) computer programs MODPATH and MODFLOW, which allowed aquifer conditions, such as ground water head and velocity and the area of influence for each well, to be modeled.

One- and 10-year time of travel criteria were used. The 10-year wellhead protection area was used to include ground water protection from oil injection wells in the area. (These wells were used by local oil companies to recover additional oil from old oil fields that were not yielding enough oil.) The wellhead protection team stipulated to the oil companies that within the 10-year wellhead delineation area, only fresh water could be used in the injection wells; outside of the 10-year delineation area, the oil companies could use salt water in their injection wells. Figure 5-13 shows wellhead protection area delineations for several wells in Enid's Cleo Springs wellfield.

Table 5-1. Hydraulic Conductivity and Specific Yield Values for Soil Types in Enid's Cleo Springs Wellfield

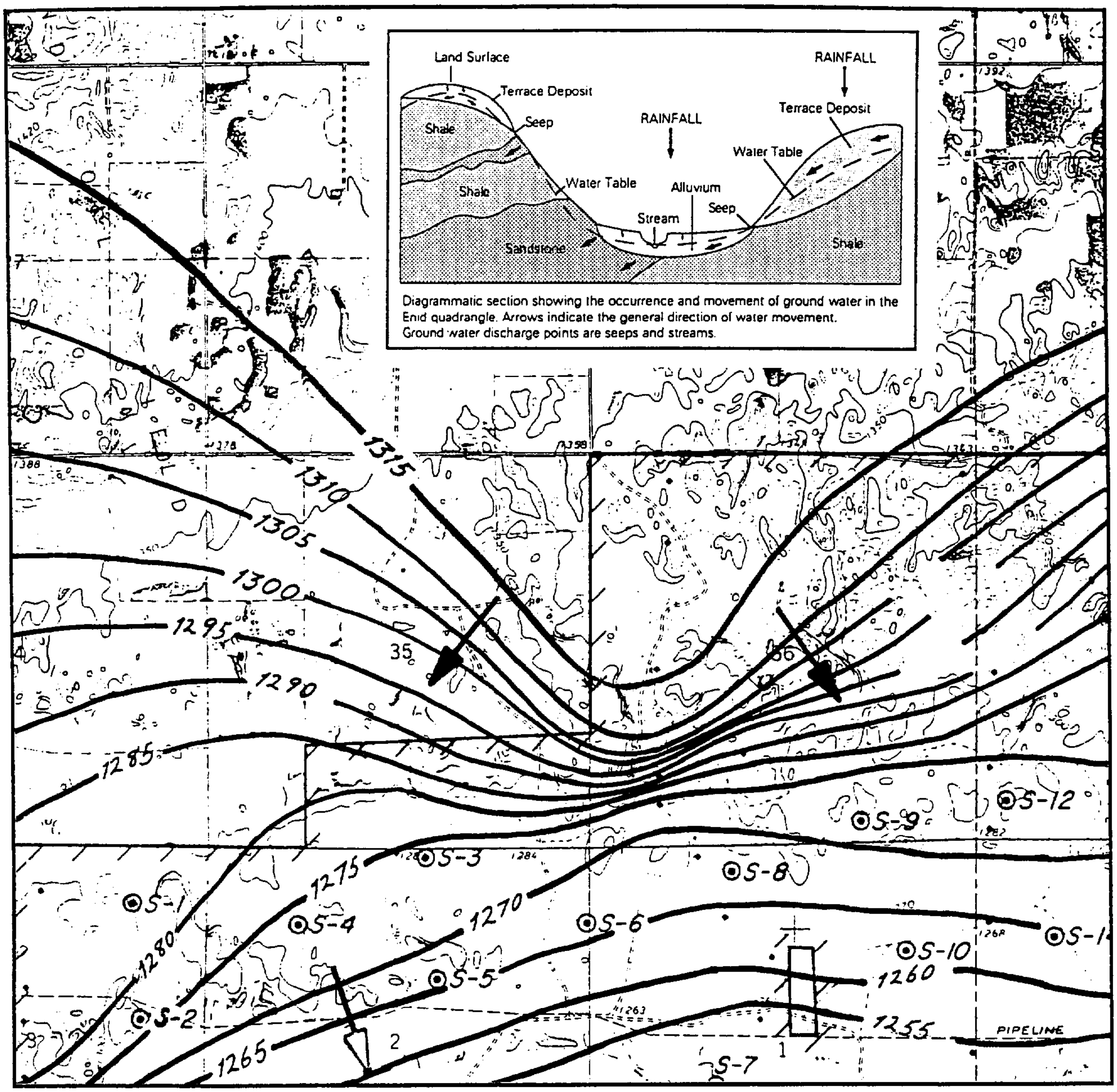
	Hydraulic Conductivity (gal/d-ft^2)		Specific Yield	
Lithology	**Range**	**Average**	**Range**	**Average**
Shale	5×10^{-3} - 5×10^{-7}	—	—	—
Sandstone	1×10^{1} - 8×10^{-4}	—	—	—
Alluvial deposits	5.1×10^{3} - 1.3×10^{2}	1.6×10^{3}	1.3×10^{-1} - 1.8×10^{-2}	6.4×10^{-2}
Alluvial deposits	4.0×10^{3} - 1.1×10^{3}	2.7×10^{3}	2.2×10^{-1} - 4.8×10^{-3}	1.1×10^{-1}

Source: Enid Municipal Authority. *Well Field Analysis.* November 1982.



Source: Maps Showing Principal Ground-Water Resources and Recharge Areas in Oklahoma
Sheet 1 — Unconsolidated Alluvium and Terrace Deposits; Sheet 2 — Bedrock Aquifers and Recharge Areas. Oklahoma Geological Survey.

Figure 5-11. Aquifer and recharge areas for the Cleo Springs Wellfield.



Key

1315	Ground Water Contours
	Direction of Ground Water Flow
⊙	Existing Water Production Wells

N

Not To Scale

Figure 5-12. Map showing ground water flow and elevations in Enid's Cleo Springs Wellfield.

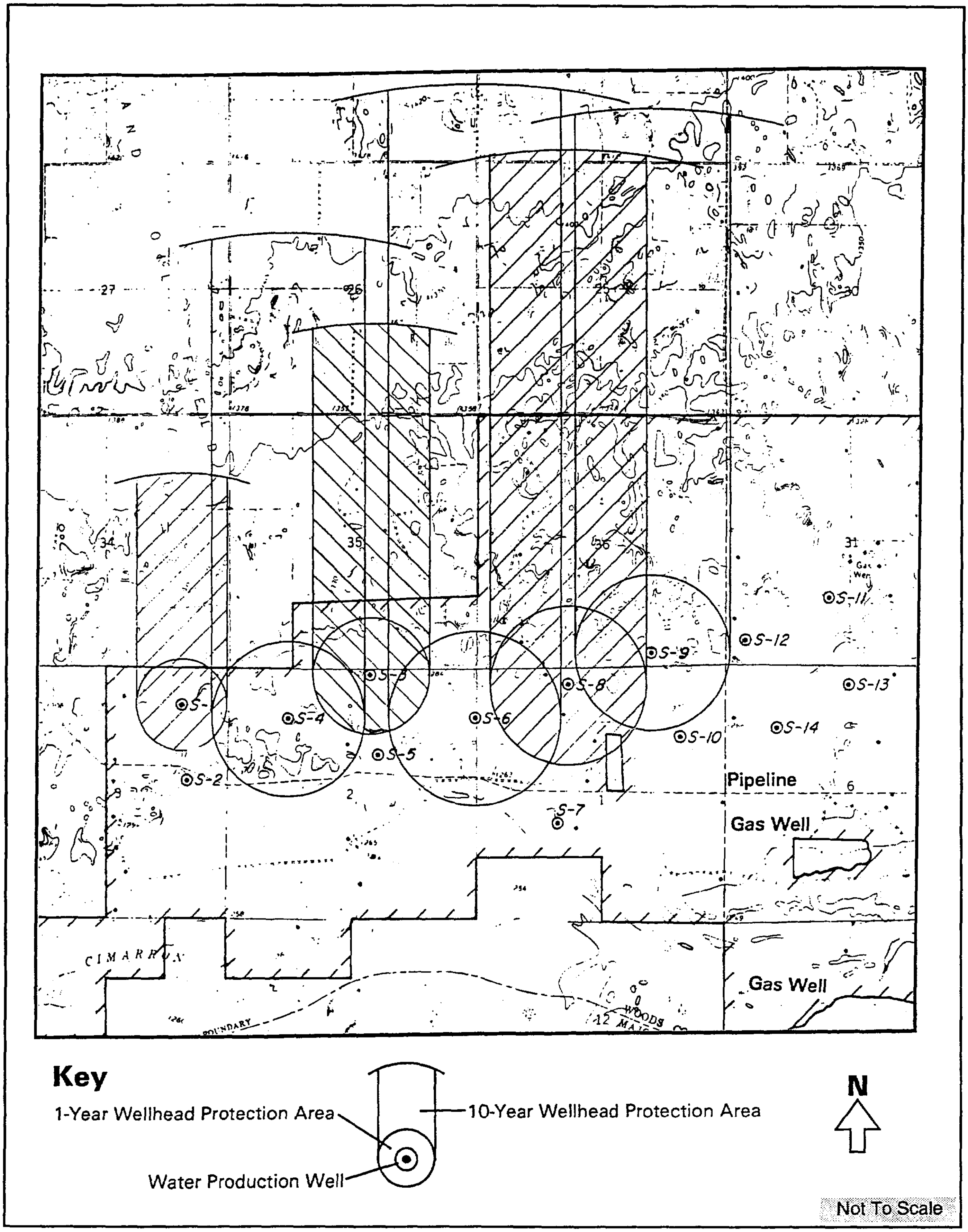


Figure 5-13. Wellhead delineations for selected wells in Enid's Cleo Springs Wellfield.

Approach Used to Identify and Locate Potential Sources of Contamination

The program team began with existing data bases from federal and state agencies that provided information on sources such as underground storage tanks and on local soil conditions. This information was augmented with field surveys of sources within each wellfield boundary to provide a comprehensive data base of potential contamination sources. Figure 5-14 presents a Source Vulnerability Survey form developed by the State of Oklahoma and used by Enid to help identify potential contamination sources.

The team also has developed an aquifer vulnerability index using EPA's DRASTIC methodology to determine susceptibility of ground water to contamination from leaks or spills. The index includes parameters such as depth to water table, soil type, recharge rate, topography, and land uses. The team plans to incorporate this index into a broader risk assessment system that could be integrated with other federal and state programs, such as SARA Title III and state ground water standards.

Potential sources of ground water contamination to Enid's wells include oil and gas drilling activities, such as production, storage, and transport through pipelines and trucks; injection wells; herbicide and fertilizer use; irrigation wells; livestock wastes; surface waters; septic systems; municipal wastewater disposal lagoons; active and inactive municipal and private landfills; wastewater treatment and land application facilities; a RCRA-approved hazardous waste disposal facility; underground and aboveground storage tanks; cemeteries; and vehicle and rail spills.

Approach Used to Manage the Wellhead Protection Area

Enid's aquifer management program involves a 10-phase plan:

- Compilation and review of existing data.
- Development of base mapping.
- Data acquisition.
- Development of a hydrologic model.
- Delineation of wellhead protection areas.
- Development of a data base of potential contamination sources.
- Review of existing practices of potential polluters and of relevant federal, state, and local regulations.
- Public education and public participation in policy and regulation review.
- Initiation of changes, if required.
- Implementation of a wellfield management system and wellhead protection program.

Public education is a key element in Enid's wellhead protection program. The program emphasizes public awareness in part because Enid and surrounding rural communities do not have regulatory authority—most of the wellfields are located in rural areas outside of Enid, and no zoning statutes exist in these rural areas. The project team has found the public awareness approach to be effective.

The public education component consists of both structured and informal strategies. The project team meets in groups and individually with targeted populations such as individual landowners, farmers, and oil and gas field personnel. Farmers in the area are already well educated about environmental transport and fate of contaminants in the subsurface and have been receptive to the importance of wellhead protection. Oil and gas fields share the same geographic area as the wellfields; discussing wellhead protection with oil and gas field personnel is important, since they maintain equipment and are the first to respond to problems (e.g., leaks). Wellhead project team members met with oil and gas staff to discuss the wellhead protection program, including what to do if a leak occurs and whom to contact. A successful informal network continues between wellhead protection and oil and gas personnel.

Potential surface water contamination of the wells from the Cimarron River prompted the team to expand ground water monitoring as part of its wellhead protection program. A RCRA-authorized hazardous waste disposal unit exists 15 miles from one of Enid's wellfields. The wellhead protection team has since determined that the hazardous waste disposal site is a minimal threat, since it is not connected hydrologically to the aquifer that serves the drinking water wells. The Cimarron River, however, is a gaining stream—that is, ground water discharges to the river. Changes in hydrogeologic conditions (e.g., climatic changes or pumping) could reverse the water flow gradient, resulting in the river recharging ground water. If this were to occur, the river would become a potential source of contamination if any substances from the hazardous waste site found their way into the river. Therefore, the wellhead protection team decided that, although it is unlikely that reverse water flow between the Cimarron River and ground water will ever occur, monitoring of ground water elevation is important in this situation to protect ground water quality because of the hydrologic relationship between the Cimarron River and the area's ground water.

Previously, ground water monitoring included quarterly measurements of ground water elevation and measurements of ground water quality every 5 years. The expanded ground water monitoring program now includes monthly measurements of ground water elevation in 175

SOURCE VULNERABILITY SURVEY

(Complete for Every Source)

SYSTEM:______________________________ ID__________

CNTY: __________________ DATE: __________ CONTACT PERSON: __________

SOURCE NAME OR WELL#: ____________________ WELL DEPTH: __________

LEGAL LOCATION:_______ 4 ____4 ____4 ____ Sec __________ TWP ______ RGE ______M

FINDING LOCATION: ______________________________

LOCAL FEATURES: Check all local features that may have affected source water quality within the last 25 years within each approximate distance range from the referenced source.

FEATURE	LESS THAN 100 FT	100 FT to 1/4 MILE	COMMENTS
Residential Features			
Septic field			
Garden			
School			
City Park			*Please complete Ag Chemical Usage form
Golf Course			*Please complete Ag Chemical Usage form
Commercial Features			
Gas Station			
Dry Cleaner			
Car Wash			
Road			
Industrial Features			
Chemical Plant			
Refinery			
Chemical Storage			
Airport			
Railroad			
Military Base			
Pipeline			
Fuel Storage			
Waste Disposal Pond			
Landfill			
Oil Well			
Injection Well			

Figure 5-14. State survey used by Enid to identify potential sources of contamination.

SOURCE VULNERABILITY SURVEY

LOCAL FEATURES (continued): Check all local features that may affect groundwater quality which occur within each approximate distance range from the referenced well.

FEATURE	LESS THAN 100 FT	100 FT to 1/4 MILE	COMMENTS
Agricultural Features			
Irrigated Cropland			*Please complete Ag Chemical Usage form
Non-irrigated Cropland			*Please complete Ag Chemical Usage form
Pasture			*Please complete Ag Chemical Usage form
Orchard/Nursery			*Please complete Ag Chemical Usage form
Feedlot (confined animals)			*Please complete Ag Chemical Usage form
Rangeland			*Please complete Ag Chemical Usage form
Forestland			*Please complete Ag Chemical Usage form
Surface Water Features			
River, Stream (Perennial/Ephemeral)			
Irrigation Canal (Lined/Unlined)			*Please complete Ag Chemical Usage form
Drainage Ditch			*Please complete Ag Chemical Usage form
Lake/Pond			
Salt Flat			
Mine/Quarry			
Electrical substation/ transformer storage			

Estimate the percentage of each general class of land use within each distance range from the well.

FEATURE	LESS THAN 100 FT	100 FT to 1/4 MILE	COMMENTS
Residential			
Commercial			
Industrial			
Agricultural			
Other (Explain)			

Comments: ______________________________

____

____

Source Vulnerability Survey Completed by: ______________________________

Title: ______________________________ Date: __________

Figure 5-14. State survey used by Enid to identify potential sources of contamination (continued).

observation and production wells with 17 continuously recording electronic water level meters and three continuously recording precipitation gauges. The elevation readings let the wellhead protection team know whether the water flow gradient is steady or is being reversed.

The Enid League of Women Voters also played an important role in the municipality's public education program. The local league produced and distributed information on wellhead protection through newspapers, newsletters, radio, and television. Some of these materials were financed through a grant the local league received from the League of Women Voters Education Fund and the U.S. Environmental Protection Agency; other publicity was free (e.g., public service announcements).

Approach Used to Plan for the Future

A contingency plan has been conceptualized and is being developed. The contingency plan is a geological-based risk analysis for each wellfield based on all the data acquired through the wellhead protection program. Contingency plans for different levels of risks will be developed. In the unlikely event that the water flow gradient between the Cimarron River and ground water ever reversed, the city would take wells nearest the river out of service. Since Enid now has 60 percent more production capacity than is currently used, alternative wells already exist within the system if they are needed. If necessary, the city has sufficient water rights to develop new wells.

Conclusion

Enid was fortunate to have municipal personnel with expertise in hydrogeology to develop a sophisticated wellhead protection program for its 153 drinking water wells. The wellhead protection planning team also drew upon federal, state, and local resources (e.g., data bases, technical assistance, and citizen organizations). The city also established detailed management and contingency plans to successfully implement its wellhead protection program.

CASE STUDY FOUR: Descanso Community Water District, San Diego County, California

Description of the Descanso Community Water District

The Descanso area is located along the Descanso and Sweetwater Rivers in the south central region of San Diego County in California (see Figure 5-15). The Sweetwater is the major river in the area and provides an important source of recharge for the area's aquifers. Descanso covers an area of approximately 8 square miles in the upper Sweetwater River Basin. Most of the ground water pumped from the upper basin occurs in this area. The northern portion of the Descanso area consists of Cuyamaca State Park and is protected from development (see Figure 5-16). The Descanso area remains mostly undeveloped, while existing development is largely residential. Its population was estimated in 1988 at 1,400 full-time residents. These residents depend completely on privately owned or public wells to satisfy their water supply needs.

Because a large portion of the land in Descanso remains undeveloped, the potential for increased residential development is high. Further development will place additional burdens on the district's ground water in two ways: first, through increased potable water demands and, second, through increased risk of ground water contamination, because the primary method of sewage disposal in the area is through the use of septic systems.

The Descanso Community Water District (DCWD) serves the water supply needs of the Descanso area and is responsible for the development and implementation of a wellhead protection program for the area. DCWD maintains seven public supply wells in the area and provides water to approximately 900 residents.

The area's aquifers consisted of a thin layer (averaging 50 ft) of weathered bedrock or regolith overlying metamorphic and granitic bedrock. Most of the ground water pumped from existing wells is recovered from the regolith layer. Ground water within the area generally flows toward the rivers that run through the area. In 1988, ground water storage in the regolith layer was estimated in the range of 800 to 2,000 acre-ft, and 300 to 3,000 acre-ft in the underlying bedrock (USGS, 1990). These estimates do not account for the physical limitations that inhibit recovering ground water; the actual recoverable ground water is much less. Surface altitude ranges from 3,300 to 4,100 ft above sea level.

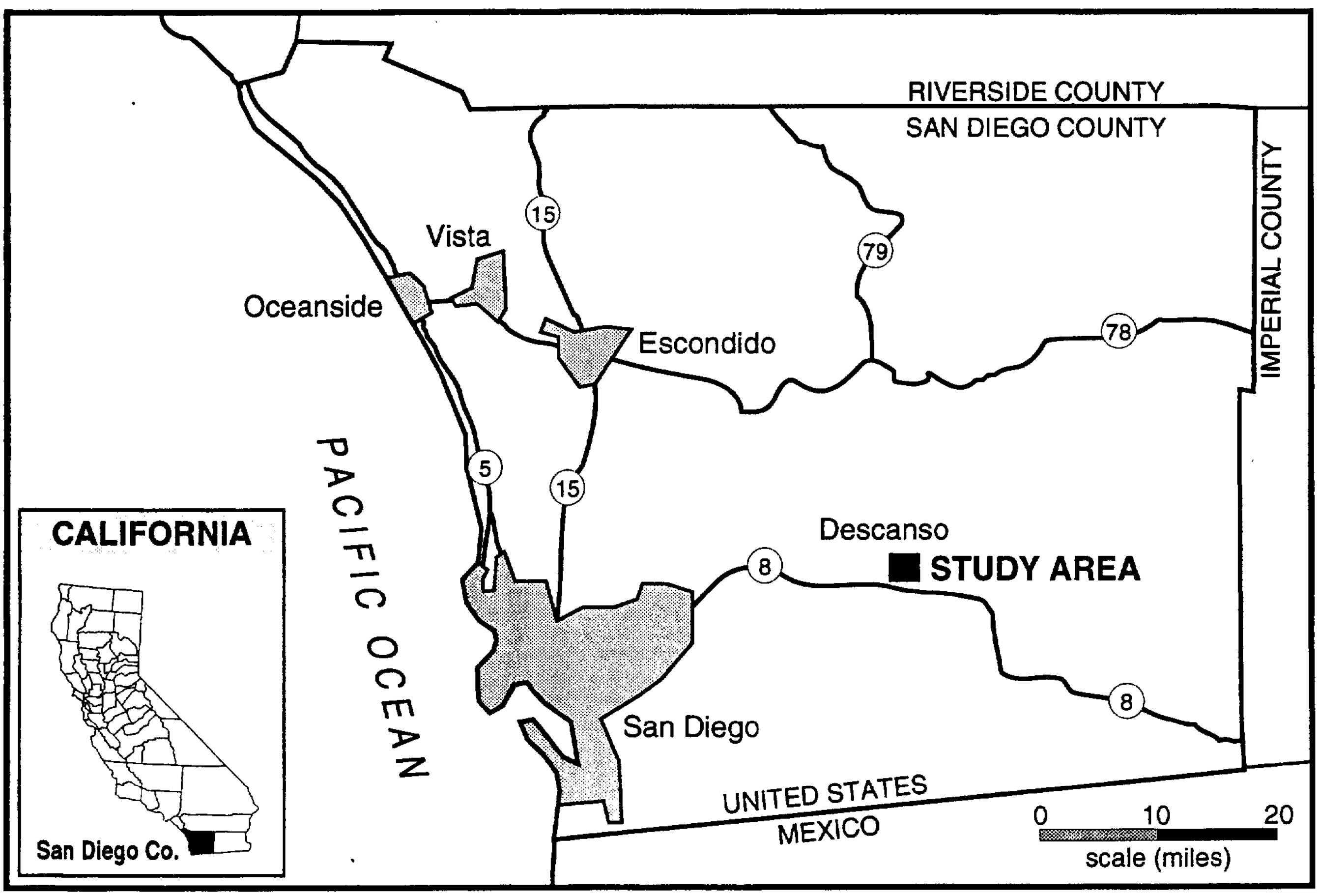


Figure 5-15. Locus map of the Descanso area, San Diego County, California. Prepared by Horsley & Witten, Inc.

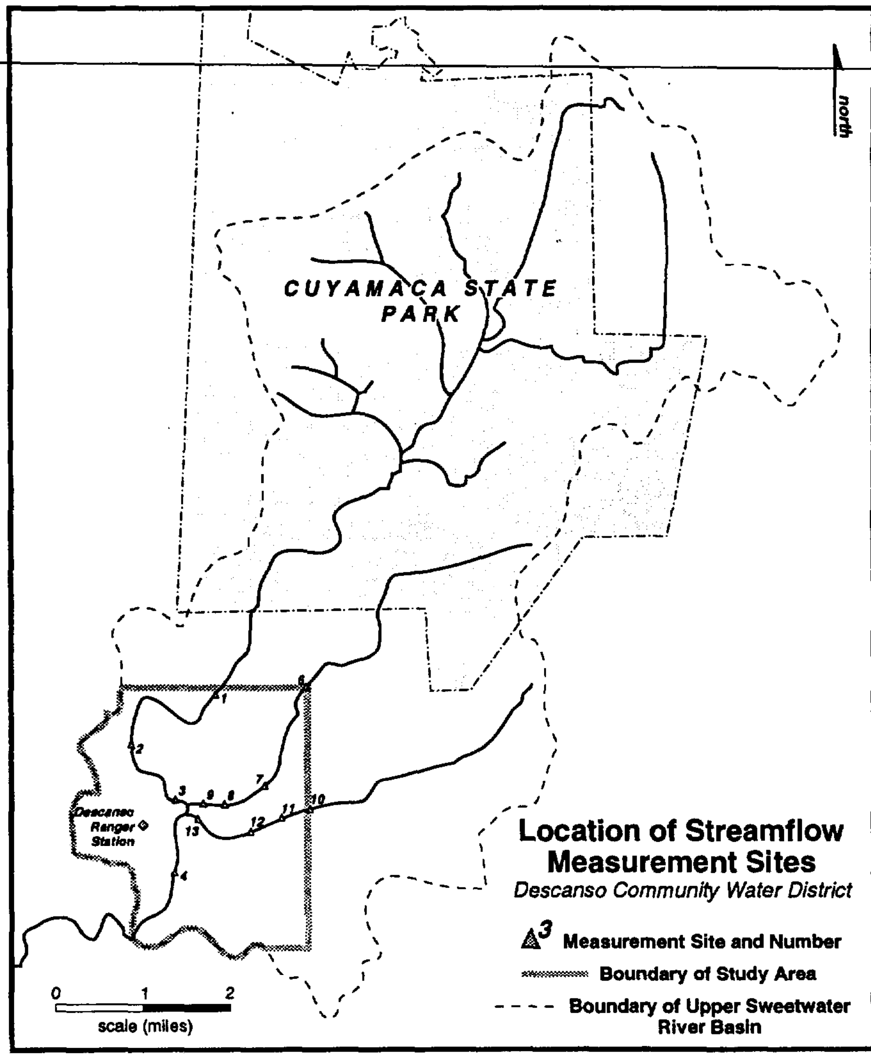


Figure 5-16. Descanso area, Upper Sweetwater River Basin, and location of streamflow measurement sites. Prepared by Horsley & Witten, Inc.

There are several types of wells in the DCWD, including shallow wells in sand, gravel, and decomposed granite, and deep bedrock wells. The yield from metamorphic and granitic bedrock is a function of fracturing (Merriam, 1951). Most of the bedrock wells in the Descanso area are less than 500 ft deep, which probably indicates the depth of open and hydraulically connected fractures (USGS, 1990). The depth to ground water and water table altitude was investigated in several of Descanso's wells during a 1988 water resource investigation of the area by the United States Geological Survey. This study revealed that the water level depth in the study wells ranged from 2 ft below ground level in river valleys to around 46 ft below ground level on hillsides (USGS, 1990).

This investigation also estimated that ground water recharge from precipitation and streamflow in the Descanso area was approximately 1,000 acre-ft in 1988, while well pumpage was approximately 170 acre-ft in the same year.

Overview of Wellhead Protection Issues

In general, the water quality from Descanso's seven wells is acceptable for domestic consumption, although some wells have yielded water samples with concentrations of iron and manganese exceeding California maximum contaminant levels; however, these levels are based on aesthetic criteria and are not toxic levels. Table 5-2 presents Descanso's annual water quality report.

At this time, there is no known contamination in any of the DCWD wells. Several potential sources of contamination exist, however, particularly septic system leachate. Because there are no wastewater treatment sewers in the area, all residential dwellings use septic systems to handle wastewater. Pollutants that are released into the septic systems (primarily nitrogen, nitrates, and household cleaning products) ultimately can migrate into surrounding aquifers. A preliminary evaluation of the septic

Table 5-2. Concentrations of Selected Constituents in 10 Samples from Wells in and near the Descanso Area, 1988, and California Maximum Contaminant Levels (MCLs) for Domestic Drinking Water

Constituent	Median	Range	MCL
	Microsiemens per centimeter at 25°C		
Electrical conductivity	522	384-685	900-1,600
	Standard units		
pH	7.6	7.3-8.1	NA
	Milligrams per liter		
Calcium, dissolved	50	32-82	NA
Magnesium, dissolved	14	8-27	NA
Sodium, dissolved	30	16-40	NA
Potassium, dissolved	3.8	1.5-5.9	NA
Alkalinity, total field	142	90-235	NA
Sulfate, dissolved	33	12-91	240-500[1]
Chloride, dissolved	42	27-100	250-500[1]
Fluoride, dissolved	.30	0.10-0.40	1.4-2.4[2]
Silica, dissolved	42	28-76	NA
Dissolved solids sum of constituents	322	247-424	500-1,000[1]
Nitrite plus nitrate, dissolved as nitrogen	.20	<0.10-6.6	10
Boron, dissolved	30	<10-60	NA
Iron, dissolved	37	4-2,800	300
Manganese, dissolved	62	<1-280	50

[1]No fixed consumer acceptance contaminant level has been established. The lower constituent concentrations are recommended, and the higher levels are acceptable if it is neither reasonable nor feasible to provide more suitable waters.

[2]Depends on annual average of maximum daily air temperature.

Source: U.S. Geological Survey, 1990.

system impacts was conducted in the area using a nitrogen loading model (U.S. EPA, 1991e). It found that current average nitrate-nitrogen concentrations in the ground water are 2.1 to 3.8 mg/liter. Under drought conditions, based on the existing level of development, concentrations would be well below EPA's 10 mg/liter maximum contaminant level (MCL). These concentrations indicate that septic systems are not having a critical impact on area ground water quality at this time. An analysis of the existing zoning ordinance demonstrated that future potential development could result in nitrate-nitrogen concentrations in excess of the MCL at one well and near the MCL at another well. Proposed zoning changes were also evaluated using the nitrogen loading model.

Approach Used to Form a Community Planning Team

As part of EPA's Wellhead Protection Program, EPA Region 9 initiated local training in rural communities to assist in the design and implementation of wellhead protection plans. Region 9 obtained assistance from the California Rural Water Association (CRWA) to identify localities to participate in the project. Descanso and two other communities were selected for participation. EPA Region 9 funded the research and other project support work necessary for developing wellhead protection plans in these communities.

In the case of Descanso, establishing a community planning team was not the first step of the wellhead protection process. Representatives from EPA Region 9 and Horsley Witten Hegemann, Inc. (HWH), the consulting firm hired by Region 9 to assist in the development of the wellhead protection plan, developed a preliminary wellhead protection plan for Descanso. The plan delineated the wellhead protection areas, identified potential sources of contamination, and outlined strategies for wellhead protection. This preliminary plan was presented at a meeting of the DCWD Board of Directors in July 1991. Although EPA and CRWA played a vital role in the design of a wellhead protection program, the DCWD Board of Directors had primary responsibility for determining what type of action, if any, would be taken within the water district to protect ground water quality.

Participants in the July meeting included a hydrologist from HWH, a representative from San Diego County, a hydrogeologist, the Local Planning Group (which is an advisory group to the County Board of Supervisors), and the DCWD Board of Directors. Although this group of participants included people who were not members of the local community, the group did act as the "community planning team" in that it included the people who developed the plan, as well as the people who decided whether to implement the plan.

The individuals on the community planning team had the following responsibilities: the representatives from HWH acted as expert consultants to Descanso; the representative from San Diego County served as a liaison between the team and the county government and assisted the team by providing advice when possible; the hydrogeologist provided the team with expert advice on issues related to delineation of the wellhead protection area and potential sources of ground water contamination; the Local Planning Group functioned as an advisory group to the County Board of Supervisors and also represented the citizens of Descanso in the decision-making process; and the DCWD Board of Directors had the final authority to decide if and/or how the proposed plan would be implemented.

Approach Used to Delineate the Wellhead Protection Area

HWH contacted Town of Descanso and DCWD officials to obtain any existing information that could be used to delineate the wellhead protection area. The information made available to HWH included water well drillers' reports showing the soils and rock features of the Descanso wells, well pump tests, a 1990 USGS-Water Resources Investigations Report giving information on the hydrogeologic setting of the area, land use maps, and DCWD water quality reports. HWH used this information to delineate the wellhead protection area of two major wells currently in operation in Descanso. This was accomplished by using the Theis (1935) solution, a set of equations allowing calculation of the drawdowns on a water table that occur due to a pumping well, and by using flow net analysis and darcian ground water velocity calculations.

The 1990 USGS report described the water levels in 21 wells measured periodically in 1988. From information obtained from the Town of Descanso and USGS, HWH developed a regional water table showing ground water flow directions throughout the community (Figure 5-17). A pumping rate of 75 gal/min was selected for both of the wells in the study, and values of 360 ft^2/day for transmissivity and 0.02 for storage capacity (storativity) were chosen from the USGS report for input into the Theis equation.

This set of equations yielded drawdown values that were subtracted from the regional water table map to determine the configuration of the pumped water table. Table 5-3 shows the drawdown calculations for different pumping periods. This analysis examined the drawdown that would occur within the water table during a 1- and 5-year drought period, under zero recharge conditions, with continuous pumping from storage within the aquifer.

Wellhead protection area boundaries were defined using time of travel criteria thresholds. The chosen thresholds were the 1- and 5-year time of travel zones. These were

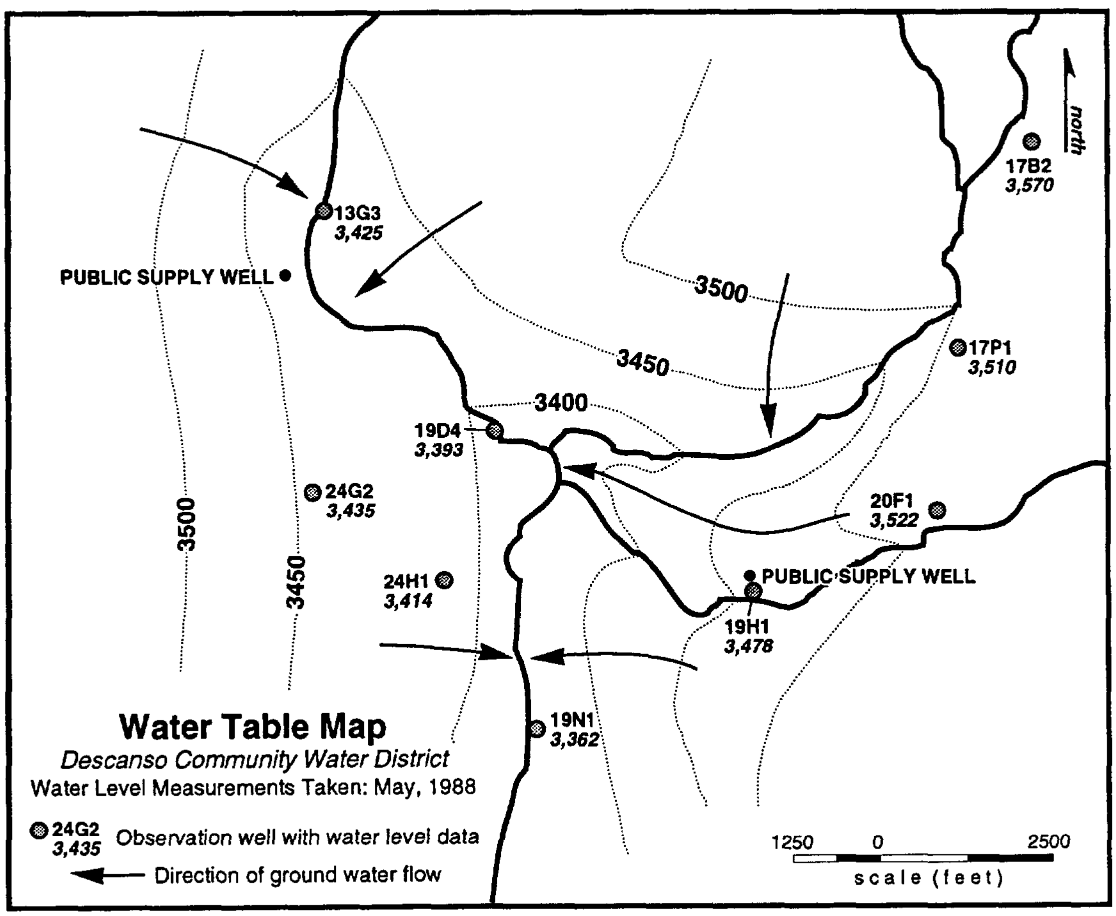


Figure 5-17. Descanso water table map showing flow directions. Prepared by Horsley & Witten, Inc.

Table 5-3. Theis Equation Calculations for Descanso Valley

Q = well discharge (ft^3/day)	14438		u = (r)(r)(S)/4(T)(t)
T = transmissivity (ft^2/day)	360		s + Q(W)(u)/4Tπ
t = time pumping (days)	*365*		
S = storativity	0.02		
r = distance to well (ft)	**u**	**Wu**	**s = drawdown (ft)**
100	0.000380518	7.25	23.15
200	0.00152207	6	19.16
300	0.003424658	5.09	16.25
500	0.009512938	4	12.77
1000	0.03805175	2.75	8.78
2000	0.152207002	1.52	4.85
Q = well discharge (ft^3/day)	14438		
T = transmissivity (ft^2/day)	360		
t = time pumping (days)	*120*		
S = storativity	0.02		
r = distance to well (ft)	**u**	**Wu**	**s = drawdown (ft)**
100	0.001157407	6.2	19.80
200	0.00462963	4.83	15.42
300	0.010416667	4.04	12.90
500	0.028935185	3	9.58
1000	0.115740741	1.7	5.43
2000	0.462962963	0.56	1.79
Q = well discharge (ft^3/day)	14438		
T = transmissivity (ft^2/day)	360		
t = time pumping (days)	*1825*		
S = storativity	0.02		
r = distance to well (ft)	**u**	**Wu**	**s = drawdown (ft)**
100	7.61035E-05	8.93	28.51
200	0.000304414	7.53	24.04
300	0.000684932	6.75	21.55
500	0.001902588	5.7	18.20
1000	0.00761035	4.32	13.79
2000	0.0304414	2.96	9.45

Source: U.S. EPA , 1991e.

calculated using flow net analysis and darcian ground water velocity calculations. The 1- and 5-year time of travel zones for each of the wells examined in the study were delineated on a topographic map of Descanso. Figure 5-18 shows the wellhead protection areas delineated for the two public supply wells in the Descanso area.

Approach Used to Identify and Locate Potential Sources of Contamination

To determine existing and potential sources of contamination a survey of the Descanso area was undertaken. Survey activities included studying USGS topographic maps, driving through the local neighborhood to identify high-risk activities, and interviewing members of the DCWD Board of Directors and their staff. The survey confirmed that the predominant sources of potential ground water contamination in the Descanso area are residential septic systems. Given the absence of a local sewer network and the potential for further residential development in Descanso, septic system impacts needed to be closely evaluated.

A preliminary estimation of septic system impacts based on a 1990 USGS hydrologic budget of the area concluded that Descanso's average nitrate-nitrogen ground water concentrations are currently below the federal drinking water standard. This situation could change, however, if Descanso's ground water recharge zones are developed to their existing allowable development densities according to the zoning ordinance.

At the time of this study, the San Diego County Department of Planning and Land Use was proposing an amendment to the existing zoning ordinance. This change proposed down-zoning existing residential zones within Descanso to reduce allowable development densities. Figure 5-19 was prepared by overlaying Descanso's zoning district map over the wellhead protection areas of the study wells. This map allowed HWH to determine the development potential of the land within the delineated wellhead protection areas. HWH used a nitrogen loading model (Nelson et al., 1988) to investigate the effects of potential development under the existing zoning in the wellhead protection areas, as opposed to that under the proposed zoning in the wellhead protection areas, on nitrate-nitrogen concentrations within the study wells. The results of this analysis suggest that the proposed zoning changes would result in lower nitrate-nitrogen concentrations in the study wells than if the existing zoning is upheld (see Table 5-4).

Approach Used to Manage the Wellhead Protection Area

Following the presentation of the proposed wellhead protection plan for Descanso at the July meeting of the DCWD Board of Directors, the community took formal

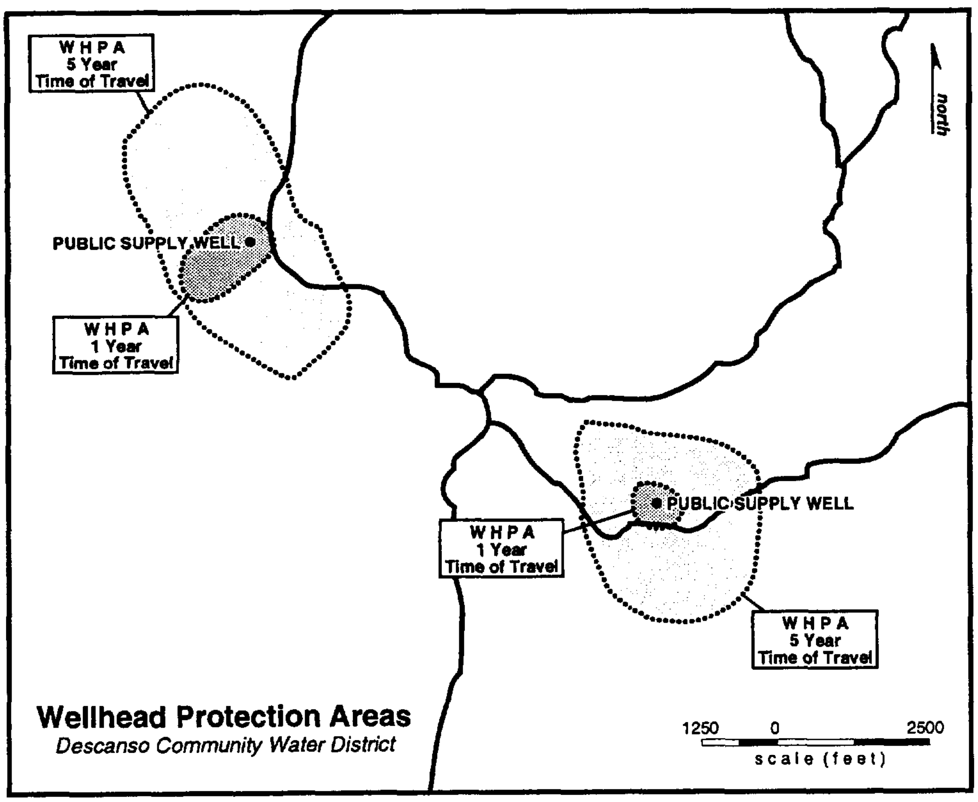


Figure 5-18. Wellhead protection areas delineated for Descanso's drinking water. Prepared by Horsley & Witten, Inc.

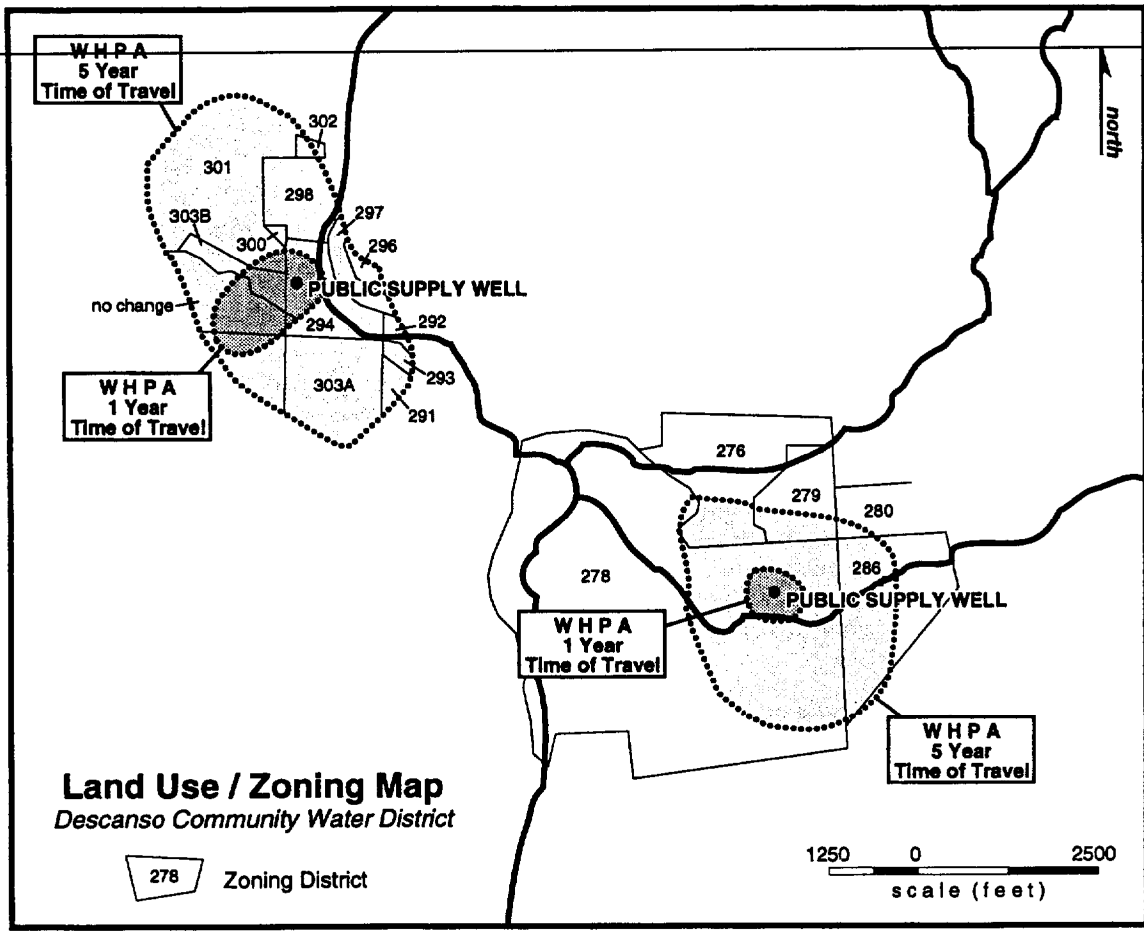


Figure 5-19. Descanso's land use/zoning map overlaid on the map of Descanso's wellhead protection area. Prepared by Horsley & Witten, Inc.

action to set up a wellhead protection program and set out to be a pilot program for the State of California. To get the program started, a committee was established to help implement wellhead protection measures within Descanso. Figure 5-20 presents an article that appeared in a local community newspaper explaining the process of wellhead protection to the public and inviting interested members of the community to serve on the wellhead protection committee. This committee held regular public meetings to discuss issues related to wellhead protection. This public forum was used to educate Descanso residents about the aims of a wellhead protection program and to allay community fears that the committee might implement severely restrictive land use regulations.

Table 5-4. Results of Nitrogen Loading Analysis for Descanso Area

Well #1		
Existing conditions	73 dwellings	6.2-7.9 mg/liter
Current zoning	150 dwellings	11-13 mg/liter
Proposed zoning	99 dwellings	7.8-9.5 mg/liter
Well #2		
Existing conditions	27 dwellings	3.4-5.1 mg/liter
Current zoning	107 dwellings	8.3-10 mg/liter
Proposed zoning	104 dwellings	8.1-9.7 mg/liter

Source: U.S. EPA, 1991e.

Educating the Descanso community about the threat of contamination to its wells is an important issue for the Descanso wellhead protection committee. Informational and educational materials on wellhead protection and water conservation are available in the DCWD office. The DCWD annual newsletter regularly contains articles on water conservation and how to properly dispose of household toxic materials. In the future, the DCWD will hold education workshops where hydrogeologists and sanitary engineers can give detailed information to the community on the geology of the public supply wells, the threats of ground water contamination, and the implications of household toxic waste mismanagement. In addition, the committee is obtaining signs to inform individuals when they enter wellhead protection areas. This will encourage environmental awareness and familiarity with the concept of wellhead protection.

Descanso takes part in U.S. pilot project to protect groundwater

Diana Saenger
Alpine Sun Writer

The community of Descanso has been chosen to participate in a federal "Well Head Protection Plan" project, and the water district has agreed to implement the pilot program.

Representatives of the U.S. Environmental Protection Agency came to a Descanso Community Water District board meeting to explain what the project was and how it would work. An EPA study of all existing wells and well sites in the Descanso area revealed how much ground surrounding each well would be needed to provide a five-year buffer zone from pollution. That is, it would take five years for pollution to penetrate from the boundaries of the buffer zone to the well head.

Gale Ruffin, general manager of the Descanso Water District, said the district became aware of the project through Harry Brown from the EPA. The Descanso district had been working with Brown on improving its well sites and reservoir. "Mr. Brown wants other districts to see what effect the pilot program will have on Descanso," said Ruffin. Ruffin was extremely pleased the study was done by the EPA because it is very expensive and saved the community a great deal of money.

The program consists of seven steps: 1) organize a staff for the program; 2) delineate the Well Head Protection Area; 3) identify anything hazardous in the ground such as septic or fuel storage and identify proposed new developments; 4) develop a contingency plan in case of hazards; 5) management of testing and looking at new well sites; 6) continue education; 7) make the public participants and placing of signs designating this is a "Well Head Protection Area."

The next step for the district is to organize a committee to get things going. Ruffin has been in touch with a community in Texas that has the program already working. If anyone is interested in working on this committee, please call the Water District at 445-2330.

Figure 5-20. This article appeared in the Alpine Sun, a Descanso local newspaper on August 21, 1991. Source: U.S. EPA, 1991e.

The San Diego County Department of Planning and Land Use was updating the Central Mountain Sub-Regional Plan, which regulates zoning in the Descanso area, during the time period of this case study. The EPA wellhead protection study of the area indicated that the proposed zoning changes would enhance wellhead protection in Descanso by limiting potential development in the area. The DCWD decided to take an active role in the public hearing process regarding the proposed zoning changes; members recognized that this was an ideal opportunity to help regulate wellhead protection in the locality. They submitted letters and supporting documentation to the San Diego County Department of Planning and Land Use, requesting that a special clause be incorporated into the updated zoning ordinance to ensure that no source of potential contamination be permitted in a wellhead protection area. They were successful in this endeavor and the updated regulations will contain such a clause.

Approach Used to Plan for the Future

As a result of a statewide depressed economic climate, Descanso is not faced with the prospect of heavy development that seemed imminent a couple of years ago. However, DCWD has continued to expand and develop its wellhead protection program and is committed to protecting Descanso's ground water from contamination.

The DCWD has applied for federal assistance under EPA's Wellhead Protection Demonstration Project to further develop and implement Descanso's wellhead protection program. If the application is successful, DCWD will use the allocated funds to delineate the WHPA of its major well, site another well, and perform a nitrogen loading analysis of an area where a major development is proposed. These funds will also allow the DCWD committee to continue its efforts to educate the Descanso community about the daily threat of ground water contamination.

In regard to contingency planning, Descanso is fortunate to have wells pumping from two different aquifer systems, the Sweetwater and Descanso river valleys. If major contamination of one aquifer occurs, the community can fall back on the other.

Conclusion

Wellhead protection in Descanso followed an unusual path in that the U.S. EPA Region 9 initiated the program, with the help of consultants and the California Rural Water Association, by providing "hands on" training in applying the five-step process to wellhead protection. However, the main impetus in developing and implementing the area's wellhead protection program came from the DCWD. EPA and its consultants developed a preliminary plan delineating wellhead protection areas for two of the area's main wells, investigated potential sources of contamination, and suggested possible management strategies. DCWD then organized a committee to implement wellhead protection strategies and began the process of protecting Descanso's ground water in earnest at the local level.

The DCWD committee recognizes the need for wellhead protection and is committed to establishing a comprehensive, effective program to protect the community's valuable ground water resource.

Chapter 6

Resources for Additional Information

1. Publications

Many documents are available on the subjects of ground water and wellhead protection. The following publications (in addition to those listed under "References") may be useful to your community in establishing a wellhead protection program.

Technical Guides to Ground Water Contamination and Wellhead Protection (including STEP ONE—Forming a Community Planning Team)

The following publications provide relatively nontechnical overviews of ground water and wellhead protection.

Born, S.M., D.A. Yanggen, and A. Zaporozec. 1987. *A Guide to Groundwater Quality Planning and Management for Local Governments.* Special Report 9, 92 pp. Wisconsin Geological and Natural History Survey, 3817 Mineral Point Rd., Madison, WI.

Central Connecticut Regional Planning Agency. 1981. *Guide to Groundwater and Aquifer Protection.* Bristol, CT.

Community Resource Group, Inc. 1992. *The Local Decision-Makers' Guide to Groundwater and Wellhead Protection.* 16 pp. Available from Rural Community Assistance Program offices.

Concern, Inc. 1989. *Groundwater: A Community Action Guide.* Washington, DC, 22 pp.

Gordon, W. 1984. *A Citizen's Handbook for Groundwater Protection.* Natural Resources Defense Council, New York, NY.

Hall and Associates and R. Dight. 1986. *Ground Water Resource Protection: A Handbook for Local Planners and Decision Makers in Washington State.* Prepared for King County Resource Planning and Washington Department of Ecology, Olympia, WA.

Harrison, E.Z. and M.A. Dickinson. 1984. *Protecting Connecticut's Groundwater: A Handbook for Local Government Officials.* Connecticut Department of Environmental Protection, Hartford, CT.

Hrezo, M. and P. Nickinson. 1986. *Protecting Virginia's Groundwater: A Handbook for Local Government Officials.* Virginia Water Resources Research Center, Virginia Polytechnic Institute and State University, Blacksburg, VA.

Massachusetts Audubon Society. 1984-1987. Ground Water Information Flyer Series. *Groundwater and Contamination: From Watershed into the Well* (#2, 1984); *Mapping Aquifers and Recharge Areas* (#3, 1985); *Underground Storage Tanks and Groundwater Protection* (#5, 1985); *Local Authority for Groundwater Protection* (#4, 1985); *Protecting and Maintaining Private Wells* (#6, 1985); *Landfills and Groundwater Protection* (#8, 1986); *Road Salt and Groundwater Protection* (#9, 1987). Public Information Office, Lincoln, MA.

Massachusetts Department of Environmental Quality Engineering. 1985. *Groundwater Quality and Protection: A Guide for Local Officials.* Boston, MA.

Mullikin, E.B. 1984. *An Ounce of Prevention: A Ground Water Protection Handbook for Local Officials.* Vermont Departments of Water Resources and Environmental Engineering, Health, and Agriculture, Montpelier, VT.

Murphy, J. n.d. *Groundwater and Your Town: What Your Town Can Do Right Now.* Connecticut Department of Environmental Protection, Hartford, CT.

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Texas Water Commission. 1989. *The Underground Subject: An Introduction to Ground Water Issues in Texas.* Austin, TX.

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U.S. Environmental Protection Agency. 1987. *An Annotated Bibliography on Wellhead Protection Programs.* Office of Ground Water Protection, Washington, DC.

U.S. Environmental Protection Agency. 1990. *Citizen's Guide to Ground Water Protection.* EPA/440/6-90-004, 33 pp. Available from EPA's Safe Drinking Water Hotline.

U.S. Environmental Protection Agency. 1991. *Protecting Local Ground Water Supplies Through Wellhead Protection.* EPA/570/09-91-007, 18 pp. Available from EPA's Safe Drinking Water Hotline.

U.S. Environmental Protection Agency. 1991. *Why Do Wellhead Protection? Issues and Answers in Protecting Public Drinking Water Supply Systems.* EPA/570/9-91-014, 19 pp. Available from EPA's Safe Drinking Water Hotline.

U.S. Environmental Protection Agency. 1992. *Ground Water Protection: A Citizen's Action Checklist.* EPA/810-F-91-002, 2 pp. Available from EPA's Safe Drinking Water Hotline.

U.S. Geological Survey. 1976. *A Primer on Ground Water.* Washington, DC.

Waller, R.M. 1988. *Ground Water and the Rural Homeowner.* U.S. Geological Survey, Reston, VA.

STEP TWO—Delineating the Wellhead Protection Area

The following publications provide technical information on basic hydrogeology, methods for hydrogeologic characterization, and wellhead protection area delineation.

Aller, L., T. Bennett, J.H. Lehr, and R.J. Petty. 1987. *DRASTIC: A Standardized System for Evaluating Ground Water Pollution Potential Using Hydrogeologic Settings.* (NTIS PB87-213914), 641 pp. [Earlier version EPA/600/2-85/018 published in 1985]. Also published by National Water Well Association, Dublin, OH.

Berg, R.C., J.P. Kempton, and K. Cartwright. 1984. *Potential for Contamination of Shallow Aquifers in Illinois.* Circular 532. Illinois State Geological Survey, Champaign, IL.

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Heath, R.C. 1984. *Ground-Water Regions of the United States.* 1984. U.S. Geological Survey, Water Supply Paper 2242. U.S. Government Printing Office. For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, DC.

Heath, R.C. 1987. *Basic Ground-Water Hydrology.* U.S. Geological Survey Water-Supply Paper 2220. 84 pp. For sale by the Books and Open-File Reports Section, U.S. Geological Survey, Federal Center, Box 25425, Denver, CO.

Horsley, S. and M. Frimpler. In Press. Delineation of Wellhead Protection Areas. Lewis Publishers, Chelsea, MI.

Kreitler, C.W. and R.K. Senger. 1991. *Wellhead Protection Strategies for Confined-Aquifer Settings.* EPA/570/9-91-008, 168 pp. Available from EPA's Safe Drinking Water Hotline.

National Rural Water Association. 1990. *Hiring an Engineer.* Rural and Small Water Systems Technical Bulletin, Duncan, OK.

Quinlin, J.F., P.L. Smart, G.M. Schindel, E.C. Alexander, Jr., A.J. Edwards, and A.R. Smith. 1991. *Recommended Administrative/Regulatory Definition of Karst Aquifer, Principles for Classification of Carbonate Aquifers, Practical Evaluation of Vulnerability of Karst Aquifers,* and *Determination of Optimum Sampling Frequency at Springs.* Ground Water Management 10:573-635 (Proc. 3rd Conf. on Hydrogeology, Ecology, Monitoring and Management of Ground Water in Karst Terranes). Available from the National Ground Water Information Center (1-800-332-2104).

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U.S. Environmental Protection Agency. 1987. *Guidelines for Delineation of Wellhead Protection Areas.* EPA/440/6-87-010. Available from EPA's Safe Drinking Water Hotline.

U.S. Environmental Protection Agency. 1988. *Model Assessment for Delineating Wellhead Protection Areas.* Office of Ground Water Protection, Washington, DC. EPA/440/6-88-002 (NTIS PB88-238449), 267 pp.

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U.S. Environmental Protection Agency. 1991. *Delineation of Wellhead Protection Areas in Fractured Rocks.* Office of Ground Water and Drinking Water. EPA/570/9-91-009, 144 pp.

U.S. Environmental Protection Agency. 1991. *A Modular Semi-Analytical Model for the Delineation of Wellhead Protection Areas, Version 2.0.* Office of Ground Water Protection, Washington, DC.

U.S. Environmental Protection Agency. 1991. *Wellhead Protection Strategies for Confined-Aquifer Settings.* Office of Ground Water and Drinking Water and Bureau of Economic Geology, University of Texas at Austin. EPA 570/9-91-008.

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Ground Water and Drinking Water and Wisconsin Geological and Natural History Survey. EPA/570/9-91-009, 144 pp.

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Walton, W.C. 1984. *Practical Aspects of Ground Water Modeling.* National Water Well Association, Worthington, OH.

STEP THREE—Identifying Sources of Contamination

The following publications may be useful for identifying potential contaminant sources.

Cape Cod Aquifer Management Project (CCAMP). 1988. *Guide to Contaminant Sources for Wellhead Protection.* Available from EPA Region 1 (617-565-3600), or National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, VA.

Conservation Law Foundation of New England Inc. 1984. *Underground Petroleum Storage Tanks: Local Regulation of a Ground-Water Hazard.* Boston, MA.

D'Itri, F.M. and L.G. Wolfson (eds.). 1987. *Rural Groundwater Contamination.* Lewis Publishers, Chelsea, MI.

Lukin, J. 1992. *Understanding Septic Systems.* Northeast Rural Water Association, Williston, VT, 18 pp.

Miller, D.W. 1982. *Groundwater Contamination: A Special Report.* Geraghty & Miller, Inc., Syosset, NY.

National Small Flows Clearinghouse. An EPA clearinghouse for information about onsite disposal systems; monthly newsletter and extensive publications list. 258 Stewart Street, P.O. Box 6064, Morgantown, WV. 1-800-624-8301.

Pye, V.I., R. Patrick, and J. Quarles. 1983. *Groundwater Contamination in the United States.* University of Pennsylvania Press, Philadelphia, PA.

U.S. Environmental Protection Agency. 1986. *Pesticides in Ground Water: Background Document.* EPA/440/6-86-002 (NTIS PB88-111976).

U.S. Environmental Protection Agency. 1987. *EPA Activities Related to Sources of Ground Water Contamination.* EPA/440/6-87/002 (NTIS PB88-111901), 125 pp.

U.S. Environmental Protection Agency. 1990. *Ground Water Handbook, Vol I: Ground Water and Contamination.* EPA/625/6-90/016a.

U.S. Environmental Protection Agency. 1991. *A Review of Sources of Ground-Water Contamination from Light Industry.* EPA/440/6-90-005 (NTIS PB91-145938).

STEPS FOUR AND FIVE—Managing the Wellhead Protection Area and Planning for the Future

The following publications may prove useful for developing approaches for controlling and preventing contamination in wellhead protection areas.

Born, S.M., D.A. Yanggen, A.R. Czecholinksi, R.J. Tierney, and R.G. Henning. 1988. *Wellhead Protection Districts in Wisconsin: An Analysis and Test Applications.* Special Report 10. Wisconsin Geological and Natural History Survey, Madison, WI, 75 pp.

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Cantor, L.W., R.C. Knox, and D.M. Fairchild. 1987. *Ground Water Quality Protection.* Lewis Publishers, Chelsea, MI.

Conservation Foundation. 1987. *Groundwater Protection.* Washington, DC, 240 pp.

Curtis, C. and T. Anderson. 1984. *A Guidebook for Organizing a Community Collection Event: Household Hazardous Waste.* Pioneer Valley Planning Commission and Western Massachusetts Coalition for Site Waste Management, West Springfield, MA.

Curtis, C., C. Walsh, and M. Przybyla. 1986. *The Road Salt Management Handbook: Introducing a Reliable Strategy to Safeguard People and Water Resources.* Pioneer Valley Planning Commission, West Springfield, MA.

DiNovo, F. and M. Jaffe. 1984. *Local Groundwater Protection: Midwest Region.* American Planning Association, 1313 E. 60th Street, Chicago, IL, 327 pp.

Freund, E.C. and W.I. Goodman. 1968. *Principles and Practices of Urban Planning.* International City Managers Association, Washington, DC.

Getzels, J. and C. Thurow (eds.). 1979. *Rural and Small Town Planning.* American Planning Association, Washington, DC.

Horsely, S. and J. Witten. 1992. *Ground Water Protection.* Lewis Publishers, Chelsea, MI.

Jaffe, M. and F.K. DiNovo. 1987. *Local Groundwater Protection.* American Planning Association, Washington, DC, 262 pp.

Kemp, L. and J. Erickson. 1989. *Protecting Groundwater Through Sustainable Agriculture.* The Minnesota Project, Preston, MN, 41 pp.

Massey, D.T. 1984. *Land Use Regulatory Powers of Conservation Districts in the Midwestern States for Controlling Nonpoint Source Pollution.* Drake Law Review 33:36-11.

Moss, E. (ed.). 1977. *Land Use Controls in the United States: A Handbook on the Legal Rights of Citizens.* Natural Resources Defense Council/The Dial Press, New York, NY.

National Research Council. 1986. *Ground Water Quality Protection: State and Local Strategies.* National Academy Press, Washington, DC, 309 pp.

Page, W.G. (ed.). 1987. *Planning for Groundwater Protection.* Academic Press, Orlando, FL.

Potter, J. 1984. *Local Ground-Water Protection: A Sampler of Approaches Used by Local Governments.* Misc. Paper 84-2. Wisconsin Geological and Natural History Survey, Madison, WI, 17 pp.

Redlich, S. 1988. *Summary of Municipal Actions for Groundwater Protection in the New England/New York Region.* New England Interstate Water Pollution Control Commission, Boston, MA.

University of Oklahoma. 1986. *Proceedings of a National Symposium on Local Government Options for Ground Water Pollution Control.* Norman, OK.

U.S. Environmental Protection Agency. 1985. *Protection of Public Water Supplies from Ground-Water Contamination.* EPA/625/4-85/016, 181 pp.

U.S. Environmental Protection Agency. 1988. *Household Hazardous Waste: Bibliography of Useful References and List of State Experts.* EPA/530/SW-88-014, 37 pp.

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U.S. Environmental Protection Agency. 1988. *Sole Source Aquifer Designation Petitioners Guidance.* EPA/440/6-87-003 (NTIS PB88-111992).

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Western Michigan University. 1988. *Policy Planning and Resource Protection: A Groundwater Conference for the Midwest.* Institute for Water Sciences, Kalamazoo, MI.

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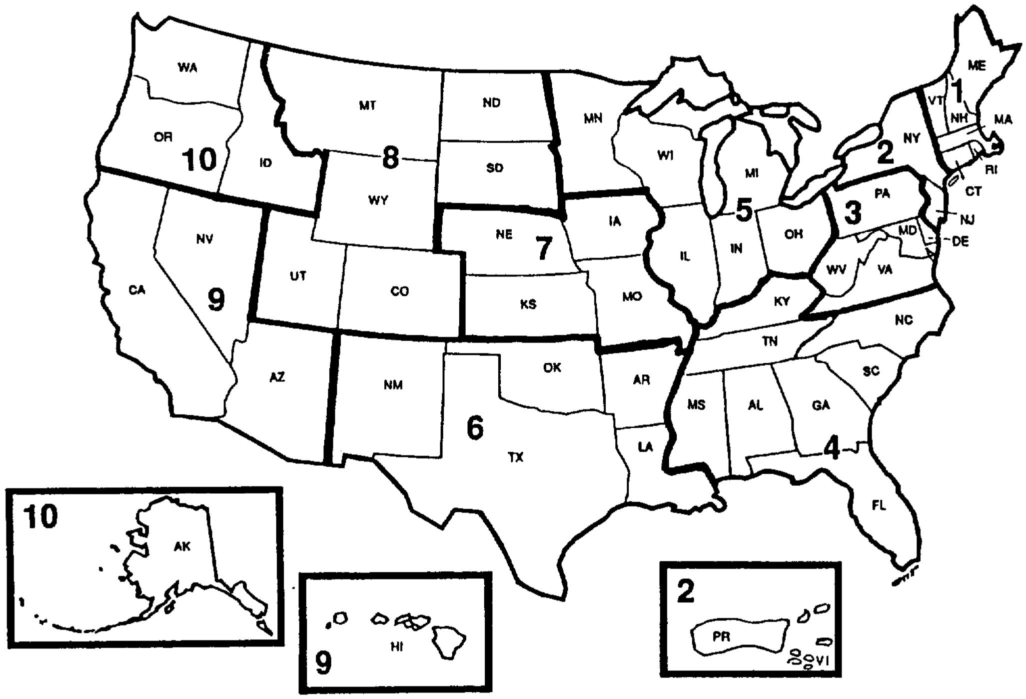
EPA Regions



2. FEDERAL, STATE, AND LOCAL AGENCIES

Federal Agencies

U.S. Environmental Protection Agency

Tom Belk
Office of Ground Water and Drinking Water (WH 550G)
U.S. Environmental Protection Agency
401 M Street, SW
Washington, DC 20460
Tel (202) 260-7593
Fax (202) 260-4383

U.S. EPA Regional Offices and Ground Water Representatives

Robert Adler
Office of Ground Water
Water Management Division
U.S. EPA, Region 1
JFK Federal Building
Boston, MA 02203-2211
Tel (617) 565-3601
Fax (617) 565-4940

Dore LaPosta
Ground Water Management Section
Water Management Division
U.S. EPA, Region 2
26 Federal Plaza
New York, NY 10278
Tel (212) 264-5635
Fax (212) 264-2194

Jerri-Anne Garl
Ground Water Protection Branch
Water Management Division
U.S. EPA, Region 5
77 West Jackson Boulevard (WG-16J)
Chicago, IL 60604
Tel (312) 353-1441
Fax (312) 886-7804

Erlece Allen
Office of Ground Water
Water Management Division
U.S. EPA, Region 6
1445 Ross Avenue
Dallas, TX 75202-2733
Tel (214) 655-6446
Fax (214) 655-6490

Virginia Thompson
Office of Ground Water
Water Management Division
U.S. EPA, Region 3
841 Chestnut Street
Philadelphia, PA 19106
Tel (215) 597-2786
Fax (215) 597-8241

Beverly Houston
Office of Ground Water
Water Management Division
U.S. EPA, Region 4
345 Courtland Street, NE
Atlanta, GA 30365
Tel (404) 347-3866
Fax (404) 347-1799

Robert Fenemore
Office of Ground Water
Water Management Division
U.S. EPA, Region 7
726 Minnesota Avenue
Kansas City, KS 66101
Tel (913) 551-7745
Fax (913) 551-7765

James Dunn
Office of Ground Water
Water Management Division
U.S. EPA, Region 8
999 18th Street
Denver, CO 80202-2405
Tel (303) 294-1135
Fax (303) 294-1424

Doris Betuel
Office of Ground Water (W-6-3)
Water Management Division
U.S. EPA, Region 9
75 Hawthorne Street
San Francisco, CA 94103
Tel (415) 744-1831
Fax (415) 744-1235

William Mullen
Office of Ground Water
Water Management Division
U.S. EPA, Region 10
1200 6th Avenue
Seattle, WA 98101
Tel (206) 553-1216
Fax (206) 559-0165

SAFE DRINKING WATER HOTLINE:
1-800-426-4791
8:30 a.m. to 5:00 p.m. Eastern Time
Monday through Friday

Provides assistance and information to the regulated community (public water systems) and the public on the regulations and programs developed in response to the Safe Drinking Water Act Amendments of 1986.

To order publications from EPA's Office of Ground Water and Drinking Water, call (202) 260-7779.

Other Federal Agencies

Agency	***Information Available***
Department of Agriculture (202/447-7590)—Soil Conservation Service (SCS), Agricultural Stabilization and Conservation Service (ASCS), U.S. Forest Service (USFS)	*SCS:* Soil surveys, aerial photography, hydrologic data (generally limited to areas where SCS has conducted watershed planning). Each state has county-level (District), multi-county (Area), and state offices. *ASCS*: County-level aerial photography. *USFS*: Aerial photography, soil surveys, hydrologic data, other resource data for areas within National Forests.
Department of the Interior—U.S. Geological Survey (USGS) (703/648-4000)	*USGS:* Circular 777 *A Guide to Obtaining Information from the USGS* (available from USGS Branch of Distribution, 604 S. Pickett St., Alexandria, VA 22304) provides a good overview. *Topographic Maps:* Often available from state geological surveys. Otherwise, USGS Map Sales, Box 25286, Federal Center, Denver, CO 80225 (303/236-7477). *Hydrologic Data*: District Offices of Water Resources Division located in each state are the primary source of information. Water Resource Investigation summary reports, available for each state, list publications by USGS and cooperating agencies. *Remote Sensing Data*: The EROS Data Center (Sioux Falls, SD 57198; 605/594-6151) provides access for NASA's Landsat satellite multispectral imagery and aerial photography.
Department of the Interior (Other Agencies) (202/208-3100)—Bureau of Land Management (BLM), Bureau of Reclamation (USBR).	*BLM*: Aerial photographs, hydrologic and other data on lands administered by BLM in 11 western states. Resource Management Plans developed by District offices provide good summaries of geologic, hydrologic, and other resource data. *USBR*: Geologic and hydrologic data in areas of western states where Bureau of Reclamation projects have been conducted.
Department of Commerce—National Oceanic and Atmospheric Administration (301/606-4237)	*Photogrammetry Division* (6001 Executive Blvd., Rockville, MD 20852) maintains file of aerial photographs of the tidal zone of the Atlantic, Gulf, and Pacific Coasts. *National Climatic Center* (NCC) (Federal Building, Asheville, NC 28801; 704/259-0682) is the primary source for information on climatic data. Annual summaries of data from local climatic stations and a wide variety of other data. The 1988 *Selective Guide to Climatic Data Sources,* available from NCC, provides a more detailed description of available information.

State Agencies

State ground water protection contacts are listed below.

Alabama
Department of Environmental Management*†
Ground Water Branch
1751 Federal Drive
Montgomery, AL 36130

Alaska
Department of Environmental Conservation*†
P.O. Box O
Juneau, AK 99811-1800

American Samoa
EPA, Office of The Governor*†
Pago Pago, American Samoa 96799

Arizona
Ground Water Hydrology Section*†
Department of Environmental Quality
2005 N. Central Avenue
Phoenix, AZ 85004

Arkansas
Department of Health*
Division of Engineering
4815 West Markham Street
Little Rock, AR 72205-3867

Department of Pollution Control & Ecology†
P.O. Box 9583
Little Rock, AR 72219

California
State Water Resources Control Board*†
P.O. Box 100
Sacramento, CA 95801

Colorado
Ground Water & Standards Section*†
Department of Health
4210 East 11th Avenue
Denver, CO 80220

Connecticut
Department of Environmental Protection*†
Room 177, State Office Building
165 Capital Avenue
Hartford, CT 06106

Delaware
~~Division of Water Resources*†~~
Ground Water Management Section
Department of Natural Resources & Environmental Control
P.O. Box 1401
Dover, DE 19903

District of Columbia
Department of Consumer & Regulatory Affairs†
614 H Street, N.W.
Washington, DC 20001

Florida
Department of Environmental Regulation*†
Bureau of Drinking Water & Ground Water Resources
2600 Blair Stone Road
Tallahassee, FL 32399-2400

Georgia
Department of Natural Resources*†
Floyd Towers East, Suit 1252
205 Butler Street, S.E.
Atlanta, GA 30334

Guam
EPA*†
P.O. Box 2999
Agana, GU 96910

Hawaii
Department of Health*†
Ground Water Protection Program
500 Alamoana Boulevard
5 Waterfront, Suite 250
Honolulu, HI 96813

Idaho*†
Water Quality Bureau
Division of Environmental Quality
Department of Health & Welfare
450 West State Street
Boise, ID 83720

Illinois
EPA*†
2200 Churchill Road
Springfield, IL 62706

*Wellhead Protection Programs
†State Ground Water Strategies

Indiana
Department of Environmental Management*†
105 South Meridian
P.O. Box 6015
Indianapolis, IN 46206

Iowa
Surface & Ground Water Protection Bureau*†
Department of Natural Resources
Wallace State Office Building
900 East Grand Street
Des Moines, IA 50319

Kansas
Department of Health and Environment*†
Bureau of Water Protection
Landon State Office Building
9th Floor, 900 S.W. Jackson
Topeka, KS 66612-1290

Bureau of Water Protection*
Department of Health & Environment
Building 740
Forbes Field
Topeka, KS 66620

Kentucky
Division of Water*†
Natural Resources & Environmental Protection Cabinet
18 Reilly Road
Frankfort, KY 40601

Louisiana
Department of Environmental Quality*†
P.O. Box 44066
Baton Rouge, LA 70804

Maine
Department of Human Services*
State House Station 10
Augusta, ME 04333

Department of Environmental Protection†
State House #17
Augusta, ME 04333

Marshall Islands
EPA, Office of the President†
Republic of Marshall Islands
Majuro, Marshall Islands 96960

*Wellhead Protection Programs
†State Ground Water Strategies

Maryland
Department of the Environment*†
Room 8L
2500 Broening Highway
Baltimore, MD 21224

Massachusetts
Division of Water Supply*
Department of Environmental Quality Engineering
1 Winter Street
Boston, MA 02108

Executive Office of Environmental Affairs†
100 Cambridge Street
Boston, MA 02202

Michigan
Department of Public Health*
P.O. Box 30035
Lansing, MI 48909

Office of Water Resources*†
Department of Natural Resources
P.O. Box 30028
Lansing, MI 48909

Minnesota
Department of Health*
P.O. Box 59040
Minneapolis, MN 55459

Pollution Control Agency†
520 Lafayette Road N, 6th Floor
St. Paul, MN 55155

Mississippi
Ground Water Quality Branch*†
Bureau of Pollution Control
P.O. Box 10385
Jackson, MS 39289-0385

Missouri
Department of Natural Resources*†
P.O Box 176
Jefferson City, MO 65102

Montana
Water Quality Bureau*†
Department of Health & Environmental Sciences
Cogswell Building, Room A206
Helena, MT 59620

Nebraska
Department of Environmental Control*†
State House Station
P.O. Box 98922
Lincoln, NE 68509-4877

Nevada
Division of Environmental Protection*†
201 South Fall St., Room 221
Carson City, NV 89710

New Hampshire
Ground Water Protection Bureau*†
Department of Environmental Services
6 Hazen Drive
Concord, NH 03301

New Jersey
Division of Water Resources*†
Department of Environmental Protection
CN029
Trenton, NJ 08625-0029

New Mexico
Environmental Improvement Division*†
1190 St. Francis Drive
Santa Fe, NM 87504

New York
Bureau of Water Quality Management*†
Department of Environmental Conservation
50 Wolf Road
Albany, NY 12233-3500

North Carolina
Ground Water Section*†
Department of Environment, Health & Natural Resources
P.O. Box 27687
Raleigh, NC 27611

North Dakota
Division of Water Supply & Pollution Control*†
Department of Health
P.O Box 5520
Bismarck, ND 58502-5520

Northern Mariana Islands
Division of Environmental Quality*
P.O. Box 1304
Saipan, Mariana 96950

Ohio
Division of Ground Water*†
Ohio Environmental Protection Agency
Box 1049
Columbus, OH 43266-0149

Oklahoma
Department of Pollution Control*†
P.O. Box 53504
Oklahoma City, OK 73152

Oregon
Department of Environmental Quality*†
811 SW 6th Avenue
Portland, OR 97204-1334

Pennsylvania
Office of Environmental Management*†
Department of Environmental Resources
P.O Box 2063
Harrisburg, PA 17120

Division of Water Supplies*
Department of Environmental Resources
P.O Box 2357
Harrisburg, PA 17120

Puerto Rico
Water Quality Area*†
Environmental Quality Board
Box 11488
Santurce, PR 00910

Rhode Island
Department of Environmental Management*†
9 Hayes Street
Providence, RI 02903

South Carolina
Bureau of Water Supply & Special Programs*†
Department of Health & Environmental Control
2600 Bull Street
Columbia, SC 29201

South Dakota
Division of Environmental Regulation*†
Department of Water & Natural Resources
Joe Foss Building
Pierre, SD 57501-3181

*Wellhead Protection Programs
†State Ground Water Strategies

Tennessee
Department of Health and Environment*†
Division of Water Supply
150 Ninth Avenue, North
Nashville, TN 37219-5404

Texas
Texas Department of Health*
1100 West 49th Street
Austin, TX 78756

Texas Water Commission*†
P.O Box 13087
Austin, TX 78711-3087

Utah
Bureau of Drinking Water/Sanitation*
Division of Environmental Health
288 North 1460 West
Salt Lake City, UT 84116-0690

Bureau of Water Pollution Control†
Division of Environmental Health
288 North 1460 West
Salt Lake City, UT 84114-0700

Vermont
Division of Environmental Health*†
Department of Health
60 Main Street
Burlington, VT 05401

Agency of Natural Resources†
1 South Building
103 Main Street
Waterbury, VT 05676

Virginia
Water Control Board*†
P.O. Box 11143
Richmond, VA 23230-1143

Virgin Islands
Department of Planning & Natural Resources*†
179 Altona & Welgunst
St. Thomas, VI 00820

Washington
Department of Social and Health Services*
Olympia, WA 98504

Department of Ecology†
Mail Stop PV 11
Olympia, WA 98504

West Virginia
Office of Environmental Health Services*
1800 Washington Street, East, Room 554
Charleston, WV 25305

Department of Natural Resources†
1800 Washington Street, East
Charleston, WV 25305

Wisconsin
Division of Environmental Standards*†
Department of Natural Resources
P.O. Box 7921
Madison, WI 53707

Wyoming
Department of Environmental Quality*†
Water Quality Division
Herschler Building, 4th Floor
122 West 25th
Cheyenne, WY 82002

Other Organizations

American Planning Association (Headquarters)
1776 Massachusetts Avenue, N.W.
Washington, DC 20036
(202) 872-0611

American Planning Association Research Department (Technical Support)
1313 E. 60th St.
Chicago, IL 60637
(312) 955-9100

American Society of Civil Engineers (ASCE)
345 E. 47th St.
New York, NY 10017-2398
(212) 705-7496
(800) 548-ASCE

American Water Works Association
6666 West Quincy Avenue
Denver, CO 80235
(303) 794-7711

National Ground Water Association
6375 Riverside Drive
Dublin, OH 43017
(800) 551-7379

*Wellhead Protection Programs
†State Ground Water Strategies

National Rural Water Association
~~P.O. Box 1428~~
2915 South 13th Street
Duncan, OK 73534
(405) 252-0629
(Also see list of Rural Water State Associations below)

National Society of Professional Engineers
1420 King St.
Alexandria, VA 22314
(703) 684-2810

Rural Water State Associations

Alabama Rural Water Association
4556 South Court Street
Montgomery, AL 36105
(205) 284-1489

Arizona Small Utilities Association
1955 W. Grant Road, Suite 125
Tucson, AZ 85745
(602) 620-0230

Arkansas Rural Water Association
P.O. Box 192118
Little Rock, AR 72219
(501) 568-5252

California Rural Water Association
216 W. Perkins Street, Suite 204
Ukiah, CA 95482
(707) 462-1730

Colorado Rural Water Association
2648 Santa Fe Drive, #10
Pueblo, CO 81006
(719) 545-6748

Connecticut & Rhode Island Rural Water Association
11 Richmond Lane
Willimantic, CT 06226-3825
(203) 423-6737

Delaware Rural Water Association
P.O. Box 118
Harrington, DE 19952-0118
(302) 398-9633

Florida Rural Water Association
1391 Timberlane Road, Suite 104
Tallahassee, FL 32312
(904) 668-2746

Georgia Rural Water Association
~~P.O. Box 383~~
Barnesville, GA 30204
(404) 358-0221

Idaho Rural Water Association
P.O. Box 303
Lewiston, ID 83501
(208) 743-6142

Illinois Rural Water Association
401 South Vine
Mt. Pulaski, IL 62548
(217) 792-5011

Indiana Water Association
P.O. Box 103
Sellersburg, IN 47172
(812) 246-4148

Iowa Rural Water Association
1300 S.E. Cummins Road, Suite 103
Des Moines, IA 50315
(515) 287-1765

Kansas Rural Water Association
P.O. Box 226
Seneca, KS 66538
(913) 336-3760

Kentucky Rural Water Association
P.O. Box 1424
Bowling Green, KY 42102-1424
(502) 843-2291

Louisiana Rural Water Association
P.O. Box 180
Kinder, LA 70648
(318) 738-2896

Maine Rural Water Association
14 Maine Street, Suite 407
Brunswick, ME 04011
(207) 729-6569

Maryland Rural Water Association
P.O. Box 207
Delmar, MD 21875
Salisbury, MD 21801
(301) 749-9474

Michigan Rural Water Association
P.O. Box 17
Auburn, MI 48611
(517) 662-2655

Minnesota Rural Water Association
RR 2, Box 29
Elbow Lake, MN 56531
(218) 685-5197

Mississippi Rural Water Association
P.O. Box 1995
Hattiesburg, MS 39403-1995
(601) 544-2735

Missouri Rural Water Association
P.O. Box 309
Grandview, MO 64030
(816) 966-1522

Montana Rural Water Systems Association
925 7th Avenue South
Great Falls, MT 59405
(406) 454-1151

Nebraska Rural Water Association
P.O. Box 186
Wahoo, NE 68066
(402) 443-5216

Nevada Rural Water Association
P.O. Box 837
Overton, NV 89040
(702) 397-8985

New Jersey Association of Rural
Water & Wastewater Utilities
703 Mill Creek Road, Suite D4
Manahawkin, NJ 08050
(609) 597-4000

New Mexico Rural Water Users Association
3218 Silver, SE
Albuquerque, NM 87106
(505) 255-2242

New York State Rural Water Association
P.O. Box 487
Claverack, NY 12513
(518) 851-7644

North Carolina Rural Water Association
P.O. Box 540
Welcome, NC 27374
(704) 731-6963

North Dakota Rural Water Systems Association
Route 1, Box 34C
Bismarck, ND 58501
(710) 258-9249

Northeast Rural Water Association
512 St. George Road
Williston, VT 05495
(802) 878-3276

Ohio Association of Rural Water Systems
P.O. Box 397
Grove City, OH 43123
(614) 871-2725

Oklahoma Rural Water Association
1410 Southeast 15th
Oklahoma City, OK 73129
(405) 672-8925

Oregon Association of Water Utilities
1290 Capitol Street, NE
Salem, OR 97303
(503) 364-8269

Pennsylvania Rural Water Association
138 West Bishop Street
Bellefonte, PA 16823
(814) 353-9302

South Carolina Rural Water Association
P.O. Box 479
Clinton, SC 29325
(813) 833-5566

South Dakota Association of Rural Water Systems
5009 West 125th Street, Suite 5
Sioux Falls, SD 57106
(605) 336-7219

Tennessee Association of Utility Districts
P.O. Box 2529
Murfreesboro, TN 37133-2529
(615) 896-9022

Texas Rural Water Association
1616 Rio Grande Street
Austin, TX 78701
(512) 472-8591

Rural Water Association of Utah
P.O. Box 661
Spanish Fork, UT 84660
(801) 798-3518

Virginia Rural Water Association
133 West 21st Street
Buena Vista, VA 24416
(703) 261-7178

Washington Rural Water Association
P.O. Box 141588
Spokane, WA 99214-1588
(509) 924-5568

West Virginia Rural Water Association
P.O. Box 225
Teays, WV 25569
(304) 757-0985

Wisconsin Rural Water Association
2715 Post Road (Whiting)
Stevens Point, WI 54481
(715) 344-7778

Wyoming Association of Rural Water Systems
P.O. Box 1750
Glenrock, WY 82637
(307) 436-8636

3. Financing Wellhead Protection

The cost of wellhead protection varies from community to community, depending on factors such as the complexity of your aquifer's geology, the number of wells in your town, and the amount of hydrogeologic data available. Although the problem of financing a wellhead protection program may appear daunting to small communities at first, there is a variety of avenues to explore to raise the necessary revenues. After all, the cost of cleaning up a contamination plume or finding an alternative water supply far outweighs the cost of preventive strategies such as wellhead protection.

The information below is a brief summary of two EPA publications on financing for wellhead protection programs: *Local Financing for Wellhead Protection* and *Guidance for Applicants for State Wellhead Protection Program Assistance Funds under the Safe Drinking Water Act.* These and other publications listed below can be consulted for detailed financial information.

Three main sources of funds exist at the local level:

- Local taxes or fees
- Private expenditures
- Intergovernmental assistance in the form of grants and loans

These sources of revenue can be used for major wellhead protection initiatives such as land acquisition; capital facilities; regulatory measures; and broad-based management efforts including information gathering, wellhead protection area delineation, public education, and contingency planning.

Taxes

The principal taxes that have been used by towns to generate funds for wellhead protection include personal property, ad valorem, real estate transfer, and sales taxes.

Fees

The following is a list of fees that can be used to generate income for wellhead protection:

- *Impact Fees.* These are paid by developers to local governments to finance the public facilities servicing their developments. These fees can be used to pay for utilities, such as sewer networks, water treatment facilities, and ground water monitoring, and for corrective action if necessary.
- *Permit and Inspection Fees.* These fees cover the costs of permit processing and inspection monitoring and testing. They are used to cover the administrative costs of regulatory management efforts in wellhead protection. The advantage of such fees is that the potential polluter, rather than the public, pays the administrative control costs.
- *Fines and Penalties.* This form of fee is designed to change undesirable existing practices rather than raise funds.
- *Unit Charges and Access Fees.* Unit charges include water consumption charges on water and sewer bills. Many wellhead protection programs are financed largely through these types of unit charges. This form of revenue can be used for land acquisition, utility infrastructure, ground water monitoring, and management techniques. Access fees include connection fees for water and sewer lines and general facilities charges for capital costs.
- *Service Fees.* These fees are charged when services are difficult to price on a unit basis and users cannot be charged according to their level of use. This type of fee was first used to finance storm water drainage improvements but more recently has been used for wellhead protection measures.

Private Expenditures

Many towns have chosen to place the costs of wellhead protection on the private sector. This can serve the dual purpose of limiting the town's financial burden while encouraging the private sector to minimize the cost of implementing wellhead protection management initiatives. Private-sector financing of wellhead protection can take the form of a water supply company purchasing lands to protect them from contamination or a local developer being required to install monitoring wells in sensitive recharge areas if development is proposed in that locality.

Intergovernmental Assistance

- *Bonds and Loans.* Tax exempt bonds and bank loans are the most common types of long-term debt available for public infrastructure programs. As with any loan, the borrower repays the principal plus interest charges.
- *Grants.* Grants may be obtained from your state or from the federal government for assistance in wellhead

protection. The Safe Drinking Water Act established requirements for the development and implementation of state wellhead protection programs and the authority for federal grants. EPA awards these development and implementation grants for 1-year budget periods. States must apply for assistance funds annually during the application period that EPA designates. For more information on this program, see EPA's *Guidance for Application for State Wellhead Protection Program Assistance Funds under the Safe Drinking Water Act.* Local communities can apply for federal assistance under EPA's Wellhead Protection Demonstration Project.

Table 6-1 summarizes the protection activities and funding sources for a number of wellhead protection programs.

Publications on Financing Wellhead Protection

Allee, D.J. 1986. *Local Finance and Policy for Ground Water Protection.* The Environmental Professional, Vol. 8, No. 3.

Jakubiak, S. and R. Mudge. 1987. *Financing Infrastructure: Innovations at the Local Level.* National League of Cities.

Litvak, L. and B. Daniels. 1979. *Innovations in Development Finance.* Council of State Planning Agencies.

Mushkin, S. 1972. *Public Prices for Public Products.* The Urban Institute.

Petersen, J.E. and W.C. Hough. 1983. *Creative Capital Financing for State and Local Governments.* Government Finance Research Center, Municipal Finance Officers Association.

Stroman, M. 1987. *The Aquifer Land Acquisition Program: An Approach for Protecting Ground Water Resources in Massachusetts.*

U.S. Environmental Protection Agency. 1987. *Guidance for Applicants for State Wellhead Protection Program Assistance Funds under the Safe Drinking Water Act.* EPA/440/6-87-011.

U.S. Environmental Protection Agency. 1988. *Developing a State Wellhead Protection Program, A User's Guide to Assist State Agencies under the Safe Drinking Water Act.* EPA/440/6-88-003 (NTIS PB89-173751).

U.S. Environmental Protection Agency. 1989. *Funding Ground Water Protection: A Quick Reference to Grants Available Under the Clean Water Act.* EPA/440/6-89-004 (NTIS PB92-190255).

U.S. Environmental Protection Agency. 1989. Local Financing for Wellhead Protection. EPA/440/6-89-001 (NTIS PB92-188705).

Watson, R. 1982. *How States Can Assist Local Governments with Debt Financing for Infrastructure.* National Conference of State Legislatures.

Williams, P.C. 1982. *Creative Financing Techniques for Water Utilities.* Journal of the American Water Works Association.

4. Computer Modeling

Several computer programs have been developed by EPA that may be useful in delineating wellhead protection areas.

- U.S. Environmental Protection Agency. 1991. *WHPA: Modular Semi-Analytical Model for the Delineation of Wellhead Protection Areas. Version 2.0.* Office of Ground Water Protection, Washington, DC. Available from the International Ground Water Modeling Center, 1500 Illinois Street, Golden, CO 80401. 303-273-3103. This model calculates time of travel contours for a wide range of aquifer conditions. The most recent version [2.1] allows consideration of recharge and vertical leakage within the wellhead area.

- McDonald, M.G. and A.W. Harbaugh. 1988. *A Modular Three-Dimensional Finite-Difference Ground Water Flow Model.* U.S. Geological Survey Techniques of Water Resource Investigations, Book 6, Chapter A1, 575 pp. A very versatile model that can address anisotropic, layered, heterogeneous aquifer systems.

- Newell, C.J. J.F. Haasbeek, L.P. Hopkins, S.E. Alder-Schaller, H.S. Rifai, P.B. Bedient, and G.A. Gorry. 1990. *OASIS: Parameter Estimation System for Aquifer Restoration Models—User's Manual Version 2.0.* EPA/600/8-90/039 (NTIS PB90-181314). This a software package for estimating parameters required for modeling transport of contaminants in ground water. It contains data on hydrogeology of major ground water regions in the United States and data on properties of common contaminants in ground water. It includes a simple analytical solute transport model and is designed to be used in conjunction with EPA's BIOPLUME model for analyzing the potential for biodegradation of organic contaminants.

- Schafer, J.M. *GWPASS: Interactive Ground-Water Flow Path Analysis.* Illinois State Water Survey, Bulletin 69. Champaign, IL. 42 pp. A reverse path numerical model that allows calculation of time of travel contours.

A number of more complex computer models have been developed for analyzing the flow of ground water and transport of contaminants. EPA's *Model Assessment for Delineating Wellhead Protection Areas* (EPA/440/6-88-002; NTIS PB88-238449), provides information on 64 models with potential value for wellhead delineation. These models were screened from a data base maintained by the International Ground Water Modeling Center on more than 600 models. Most of these models require extensive data about an area and specialized expertise in the selection and use of computer models.

Table 6-1. Examples of Funding for Wellhead Protection and Ground Water Protection

Location/Agency	Activity	Funding Source
State of Arizona Dept. Environmental Qual. (602) 257-2300	Performance controls on discharges	Permit fees (proposed)
Town of Easton, MA Public Water Company (508) 238-3641	Land-use and performance controls	Unit charges, access fees
Commonwealth of Massachusetts Dept. Env. Qual. Eng. (617) 292-5526	Aquifer land acquisition	General obligation bonds
Town of Harwich, MA Water Department (508) 432-0304	Land-use controls	General revenues, general obligation bonds
County of San Bernardino, CA Health Department (714) 387-4646	Monitoring, new well permits	Impact fees, permit fees
State of Vermont, Dept. Devel. & Commun. Affairs (802) 828-3231	Land acquisition, planning, studies	Real estate transfer excise tax
State of Nebraska Natural Resource Commission (402) 471-2081	Performance controls	Special assessments
State of New York, Dept. of Environmental Conservation (518) 457-8681	Land acquisition	General obligation bonds
City of Tacoma, WA Planning Commission (206) 591-5377	Land-use and performance controls (proposed)	Permit fees, service fees (proposed)
City of Collier, FL Dept. Environmental Sci. & Pollution Control (813) 774-8904	Land-use and performance controls	General revenues
County of Ocean, NJ Health Department (201) 341-9700	Land-use and performance controls, new well	Permit fees, penalties, permits, monitoring
County of Suffolk, NY Dept. Health Services (516) 348-2703	Land acquisition	Dedicated sales tax
Edwards Undergrd. Water Conserv. District, TX (512) 222-2204	Performance controls (proposed)	General revenues
South Ctrl.. Connecticut Regional Water Auth. (203) 624-6671	Land acquisition, management	Unit charges
Town of Nantucket, MA Land Bank Commission (508) 228-7240	Land acquisition	Real estate transfer excise tax
South Florida Water Management District (407) 686-8800	Use and well permits, recharge	Ad valorem property tax rationing

Table 6-1. Examples of Funding for Wellhead Protection and Ground Water Protection (continued)

Location/Agency	Activity	Funding Source
Bourne Water District, MA (508) 563-2294	Land acquisition	Property tax, dedicated tax bonds
Town of Littleton, MA Dept. Light & Water (508) 486-3104	Well installation and monitoring Performance controls	Mandatory private, unit charges Permit fees, unit charges Taxes
Metro. Dade County, FL Dept. Env. Resource Mgmt. (305) 375-3303	Studies, enforcement, monitoring, and planning Operating permits Plan approval	Service fees (utility surcharge) Permit fees Permit fees
Santa Clara Valley Water District, CA (408) 265-2600	Surface and ground water supply	Surface water charges, treated water sales, property taxes, ground water pumping service fees
LOTT Operating Agency and County of Thurston, WA Department of Health (206) 786-5439	Sewer interceptors	Septic tank use fees, access fees (general facilities charge), sewer use service fees
	Models, monitoring, public education, planning	Grants, sewer use service fees, septic tank fees
County of Spokane, WA Dept. Public Works (509) 456-3600	Interceptor sewers	Pumping service fees, septic tank use fees, access fees, dedicated sales tax, real estate transfer excise tax
	Monitoring, public education, regulatory coordination	Pumping service fees, septic tank service fee planning

Note: Table excludes grants.

Source: U.S. Environmental Protection Agency. 1989. *Local Financing for Wellhead Protection.* Office of Water, Washington DC. EPA/440/6-89/001.

Appendix A

Regional Distribution of Ground Water in the United States

Researchers have identified 15 geographical ground water regions within the United States, Puerto Rico, and the Virgin Islands (Figures A-1 and A-2). These regions have similar rock and soil structures and aquifer characteristics (Heath, 1984; U.S. EPA, 1990a; U.S. EPA, 1990b). The discussion below provides an overview of hydrogeological conditions in these regions. For a more detailed discussion of ground water regions, see *Ground-Water Regions of the United States*, by R. Heath, available from the U.S. Geological Survey.

Western Mountain Ranges

Tall mountains and narrow, steep valleys characterize this region, which includes the Rocky, Sierra Nevada, Coast, Cascade, Bighorn, Wasatch, Unita, San Juan, and Black Hills mountain ranges. Although precipitation in the mountains is abundant, much of it runs off into surface waters in the valleys, and aquifers in these mountain areas are limited to fractures in crystalline rocks with small storage capacity. The valleys contain thick deposits of **alluvium** (transported sand, gravel, etc. that have been washed away and deposited by flowing water) that serve as aquifers supplying moderate to large well yields. The alluvial aquifers often are connected hydrologically to underlying bedrock.

Alluvial Basins

The alluvial basins include the Basin and Range area of the Southwest and the Puget Sound/Willamette Valley Area of the Pacific Northwest. Both areas consist of thick

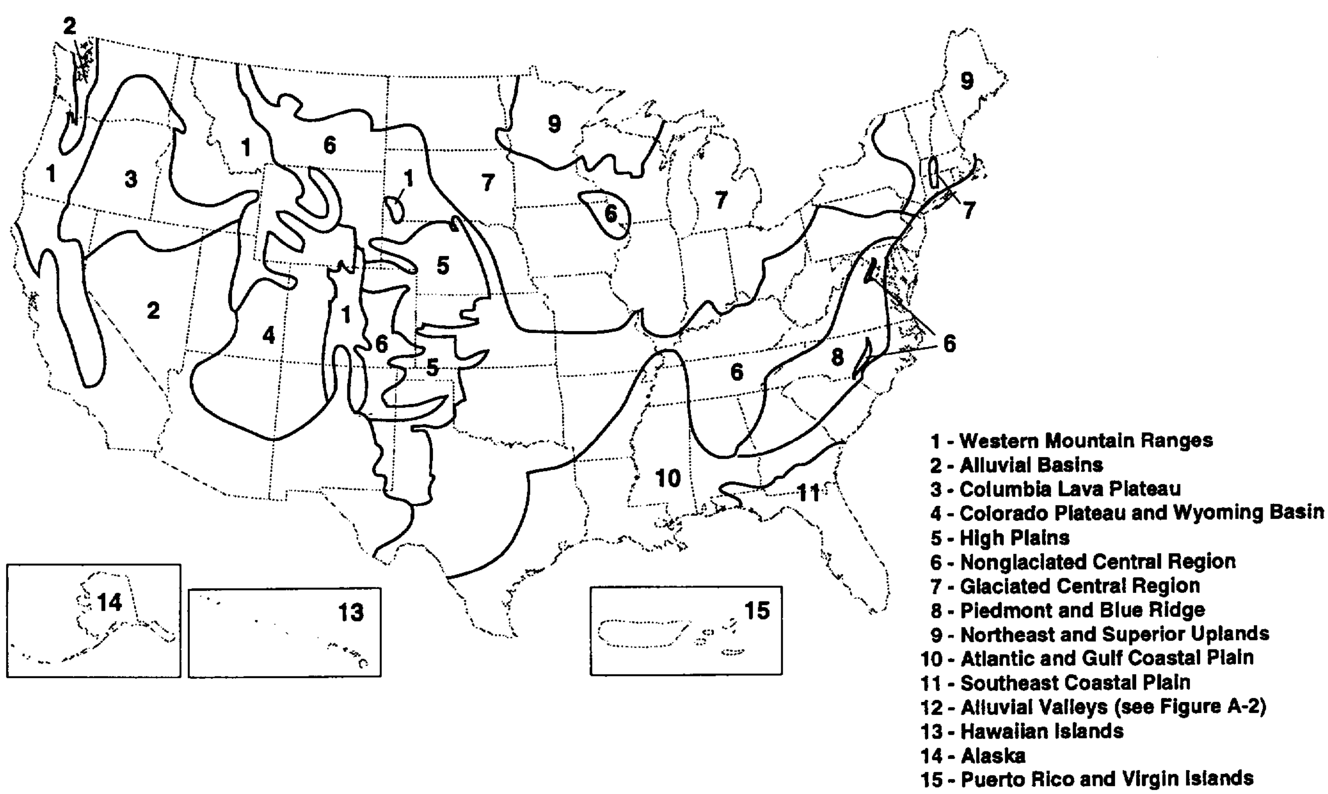


Figure A-1. Ground water regions of the United States. Source: Heath, 1984.

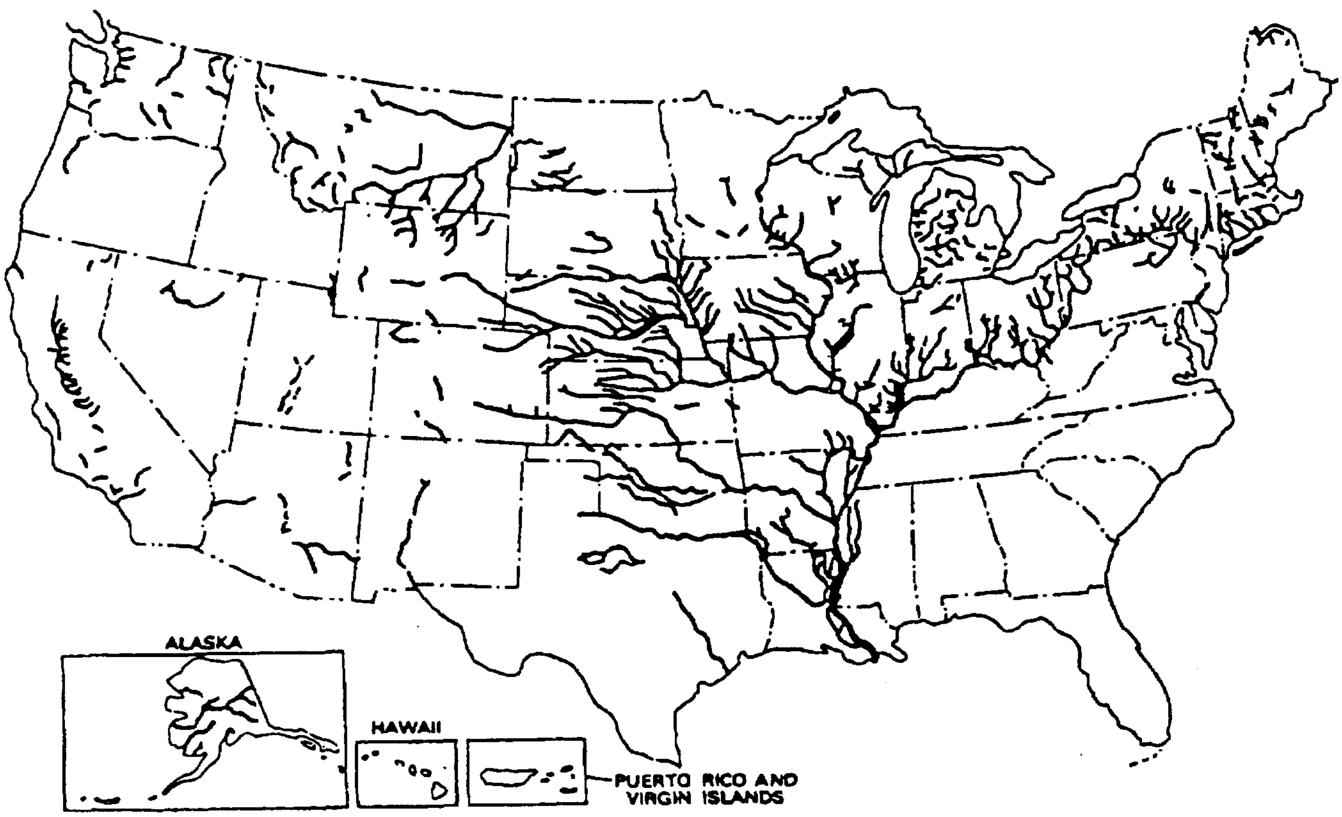


Figure A-2. Alluvial valleys ground water region. Source: Heath, 1984.

alluvial deposits in basins or valleys alternating with rocky mountain ranges. The Alluvial Basins are the driest areas in the United States, and ground water is the major water source. The mountainous areas store and transmit limited amounts of water in fractured bedrock. The basins in the Southwest, including the Great Basin, typically are closed systems through which no surface or subsurface water leaves the region. All water arriving from other areas is returned to the atmosphere by evaporation or transpiration. The movement of water through the permeable deposits in the basins often involves complex hydrogeologic relationships. Most ground water in this region is obtained from permeable sand and gravel deposits that are interbedded with layers of saturated silts and clays. In the Puget Sound area, most of the water is provided by thick layers of permeable sands and gravels interbedded with clay layers. In the Willamette Valley, precipitation is the major source of recharge to interbedded sands, silts, and clays.

Columbia Lava Plateau

The lava in this area of south-central Washington and northern Idaho is found in flat-lying sheet-like flows and is the principal waterbearing unit for the region. High permeability occurs between the lava flow layers and in fractured rocks. The area is characterized by interflow zones, made up of a complex series of relatively horizontal aquifers separated by denser layers of rock; these often are connected hydrologically by intersecting fractures and faults within the lava sheets. Recharge is from precipitation and infiltration from streams.

Colorado Plateau and Wyoming Basin

Sandstone with large pore spaces and fractures serves as the primary ground water source in this area. Some areas of alluvium in river valleys also yield small to moderate amounts of ground water. Deeper ground water often contains dissolved minerals and can be saline. Recharge is from precipitation and stream infiltration. Aquifers in this region usually discharge to springs and seepage areas along canyon walls.

High Plains

This region is underlain by the Ogallala formation, a thick deposit of semiconsolidated alluvial materials made up of sands, gravels, silts, and clays. The Ogallala is the primary aquifer; younger alluvial deposits form the aquifer where the Ogallala is absent. Extensive areas of sand dunes also are present in the region. In some areas, the Ogallala is connected hydrologically to underlying consolidated deposits. In other areas, the Ogallala is above rocks that often contain highly mineralized water unusable for drinking water.

Recharge to the Ogallala aquifer is from precipitation, which varies across the region. In permeable areas with sand dunes, recharge increases. A **caliche** (a low-permeability calcium carbonate layer at or near the land surface) is present in some areas, which limits the amount of precipitation that infiltrates to the aquifer. Extensive agricultural irrigation has led to long-term declines in water levels in this region and a decrease in aquifer thickness in some areas.

Nonglaciated Central Region

The Nonglaciated Central region extends from the Appalachian Mountains to the Rocky Mountains, and is underlain in most areas by consolidated rocks including sandstones, shales, carbonates, and conglomerates. Chemical and mechanical weathering of the bedrock in this area has formed a layer of **regolith** (a residual soil formed from weathered bedrock) that varies in thickness and composition. Sandstones and limestones are the major aquifers in the area, with water found primarily in bedrock fractures. Karst formations are fairly common. Mineralized water often is found at deeper levels. Recharge is from precipitation, which varies widely in the region. Small to moderate well yields are typical, with karst areas sometimes providing higher yields.

Glaciated Central Region

In this area, sandstones, shales, and carbonates are covered by glacial drift consisting of poorly sorted glacial till interbedded with sands, gravels, clays, silts, and loess. The glacial drift varies in thickness within the region; where it is thick, sands and gravels form major aquifers with high well yields. Fractured bedrock in the region also often serves as an aquifer. The glacial drift and bedrock often are connected hydrologically in this region, with the drift providing recharge to the bedrock aquifers. Local ground water quality problems have occurred when poor quality water has moved from the bedrock into the glacial drift. Hard water is common because of widespread carbonate rocks. Recharge to the glacial drift is by precipitation and stream infiltration, and varies depending on the type of soil and rock materials encountered.

Piedmont and Blue Ridge

The Piedmont region lies between the coastal plain and the Appalachian and Blue Ridge mountains. It consists of low, rounded hills that gradually increase in height until they become two mountain ranges. The fractured metamorphic bedrock in this region is overlain by regolith that yields small to moderate amounts of water to shallow wells and serves as a storage reservoir to recharge the bedrock aquifer. The fractured bedrock aquifers in this area store a limited amount of water. Well yields in the region are extremely variable. Wells often are placed in both the regolith and the bedrock for maximum yield.

Northeast and Superior Uplands

The Northeast includes most of New England and the Adirondack Mountains, while the Superior Uplands include most of northern Minnesota and Wisconsin. Both areas include bedrock that has been fractured extensively, with unconsolidated glacial deposits, varying in thickness, above the bedrock. The glacial deposits comprise poorly sorted glacial tills, clays, and well-sorted sands and gravels. The sands and gravels serve as important aquifers capable of producing moderate to high yields. Ground water also occurs in bedrock fractures, but the bedrock generally has a low ground water storage capacity. Recharge to the glacial deposits is primarily through precipitation; the glacial deposits provide recharge to the bedrock by slow seepage. Wells often are placed close to streams where they can reverse the hydraulic gradient, cause induced infiltration, and obtain greater yields.

Atlantic and Gulf Coastal Plain

This region extends southward from Cape Cod to the Rio Grande River in Texas. The region consists of semiconsolidated to unconsolidated deposits of sand, silt, and clay. All deposits dip toward the Atlantic coast or the Gulf coast. Limestone and shell beds also occur in some areas and serve as aquifers. Recharge to aquifers is from precipitation and stream infiltration. In some areas, clay deposits limit recharge, and withdrawal can result in declining water levels.

Southeast Coastal Plain

This area includes Florida and southern parts of Alabama and Georgia, and consists of unconsolidated sand, gravel, silt, and shell beds. The **Floridan aquifer** is the primary water source for the entire region and is one of the most productive aquifers in the United States. It consists of thick, semiconsolidated to consolidated limestones and dolomites. The Hawthorn formation, consisting of clay and silt, can be found underneath much of the surface deposits and above the Floridan aquifer, and often acts as a confining layer. In the northern area, the Floridan aquifer is unconfined, and recharge occurs through precipitation; in central and southern Florida, the Floridan is semiconfined by the Hawthorn formation, and surface recharge is limited. The Floridan discharges to numerous springs and streams.

Water in the southern part of the Floridan aquifer is typically saline, and the Biscayne aquifer, made up of semiconsolidated limestone beds, is used for drinking water. The Biscayne aquifer is unconfined and is recharged by precipitation and surface water infiltration. Sands and gravels also serve as aquifers throughout the region, with small to moderate yields.

Alluvial Valleys

These areas consist of thick sand and gravel deposits often interbedded with silts and clays. The sands and gravels, which occur mostly within the flood plain and adjacent terraces, are permeable and can yield moderate to large amounts of water. Ground water and surface water often are connected hydrologically in alluvial valleys; ground water withdrawal might reverse the hydraulic gradient, causing induced infiltration to the ground water from the stream. Recharge in these areas is from streams and precipitation.

Hawaiian Islands

The Hawaiian Islands consist of various types of lavas. Lavas formed above sea level contain permeable interflow zones, while those formed below the sea are relatively impermeable. Ground water on the islands includes dike-impounded water, perched water, and basal ground water. The dike-impounded and basal ground water are partially hydrologically connected. Basal ground water is the principal water source and occurs as a fresh-water lens floating on denser sea water. Recharge, through precipitation, occurs quite readily because the volcanic soils are highly permeable.

Alaska

Much of the bedrock in Alaska is overlain with unconsolidated deposits of gravel, sand, silt, clay, and glacial till. Climate is an important factor in Alaskan hydrology. Surface and subsurface water often is frozen most of the year, forming a permafrost zone of varying depths that is present everywhere but the southern coasts. Ground water can be found beneath the permafrost and in some areas beneath deep lakes and alluvial channels or in sand and gravel deposits. Where no permafrost exists, ground water can be found in soils and bedrock. Permafrost limits recharge to this area's aquifers. Most recharge occurs from stream infiltration.

Puerto Rico and the Virgin Islands

The alluvium, limestone, and volcanic rocks underlying this region are all water bearing. Geologic processes, however, have converted these rocks to hard, dense rocks that now contain interconnected openings only along fractures and faults. The limestones and overlying alluvial deposits make up the most productive aquifer, the most extensive of which underlies the north coastal area of Puerto Rico. This area receives abundant precipitation, which recharges the ground water system throughout the area. However, this and other coastal areas underlain by productive aquifers contain fresh ground water in direct contact with sea water. The higher inland areas have adequate precipitation and are less subject to seawater encroachment, but are underlain by rocks of very low permeability, small storage capacity, and small well yields.

Appendix B

Methods for Delineating Wellhead Protection Areas for Fractured Rock Aquifers[6]

Fractured rock aquifers are less common than unconfined and confined aquifers (see Chapter Two). They are important supplies of drinking water, however, and should be protected from contamination. The following methods are suitable for delineating wellhead protection areas in fractured rocks.

Vulnerability Mapping

Vulnerability mapping involves examining a wide range of geologic and hydrologic maps and aerial photographs to identify areas surrounding wells that are especially susceptible to ground water contamination. These areas include shallow or exposed bedrock, permeable soils, open surface fractures, and sink holes (U.S. EPA, 1991b). The maps discussed under Step Two of the Five-Step Process (Chapter Four) should prove useful when conducting a vulnerability study. The disadvantage of this mapping is that it does not directly delineate a zone of contribution for a well. Instead, once the vulnerable area around the well has been identified, a wellhead protection area can be established using the **arbitrary fixed radius** or the **simplified variable shapes** delineation method (see Chapter Four). (These delineation methods are not particularly suitable for fractured rock aquifers and are best used as first-step approaches.) Figure B-1 illustrates wellhead protection areas delineated from vulnerability studies.

Flow-System Mapping

Flow system mapping is a subset of **hydrogeologic mapping** (see Chapter Four). It uses ground water divides and flow-system boundaries, which can be determined from water table mapping, to delineate the zone of contribution for a well. Ground water divides and flow-system boundaries include physical boundaries to ground water flow and hydrologic features such as rivers, canals, and lakes. This approach to wellhead protection area delineation requires detailed mapping of the study area's water table (see Figure B-2). Ideally, this mapping should be a result of field measurements. If economic and time constraints preclude field measurement, a water table map can be constructed from available well construction logs and existing hydrogeologic studies. To determine the well's approximate zone of contribution in a localized flow system, flow lines are drawn perpendicular to the ground water contours. These flow lines begin at the well and extend upgradient to the ground water divide (U.S. EPA, 1991b). This method tends to produce conservative estimates for zone of contribution boundaries. The following two methods use flow-system mapping to delineate the zone of contribution of a pumping well.

Flow-system mapping is not very suitable for aquifers where water levels fluctuate widely throughout the year, because the method assumes that hydrogeologic boundaries remain relatively stationary through time (U.S. EPA, 1991b). This method also is not applicable to extensive flow systems.

Flow-System Mapping with Time of Travel Calculations

This method uses a water table map to estimate the horizontal hydraulic gradient of a wellfield, and then uses this with other hydraulic parameters to calculate ground water velocity by solving Equation B-1.

Equation B-1:

$$\bar{v} = \frac{K i}{n}$$

Where:

$\bar{v}$ = average linear velocity of ground water (feet/day)
K = horizontal hydraulic conductivity (feet/second x 86,400 [feet/day])
i = horizontal hydraulic gradient (percent)
n = porosity (percent)

Ground water velocity can be used with a particular time of travel to limit the wellhead protection area to that portion of the zone of contribution that will contribute water to the well in a specified time period (U.S. EPA, 1991b). Time of travel contours are delineated based on the assumption that contaminants in ground water will move in the same direction and at the same velocity as ground water (U.S. EPA, 1991b).

[6]Most of this information on delineating wellhead protection areas in fractured rocks is summarized from EPA's *Delineation of Wellhead Protection Areas in Fractured Rocks* (EPA 570/9-91-009). For more detailed technical information on these techniques, please refer to this publication.

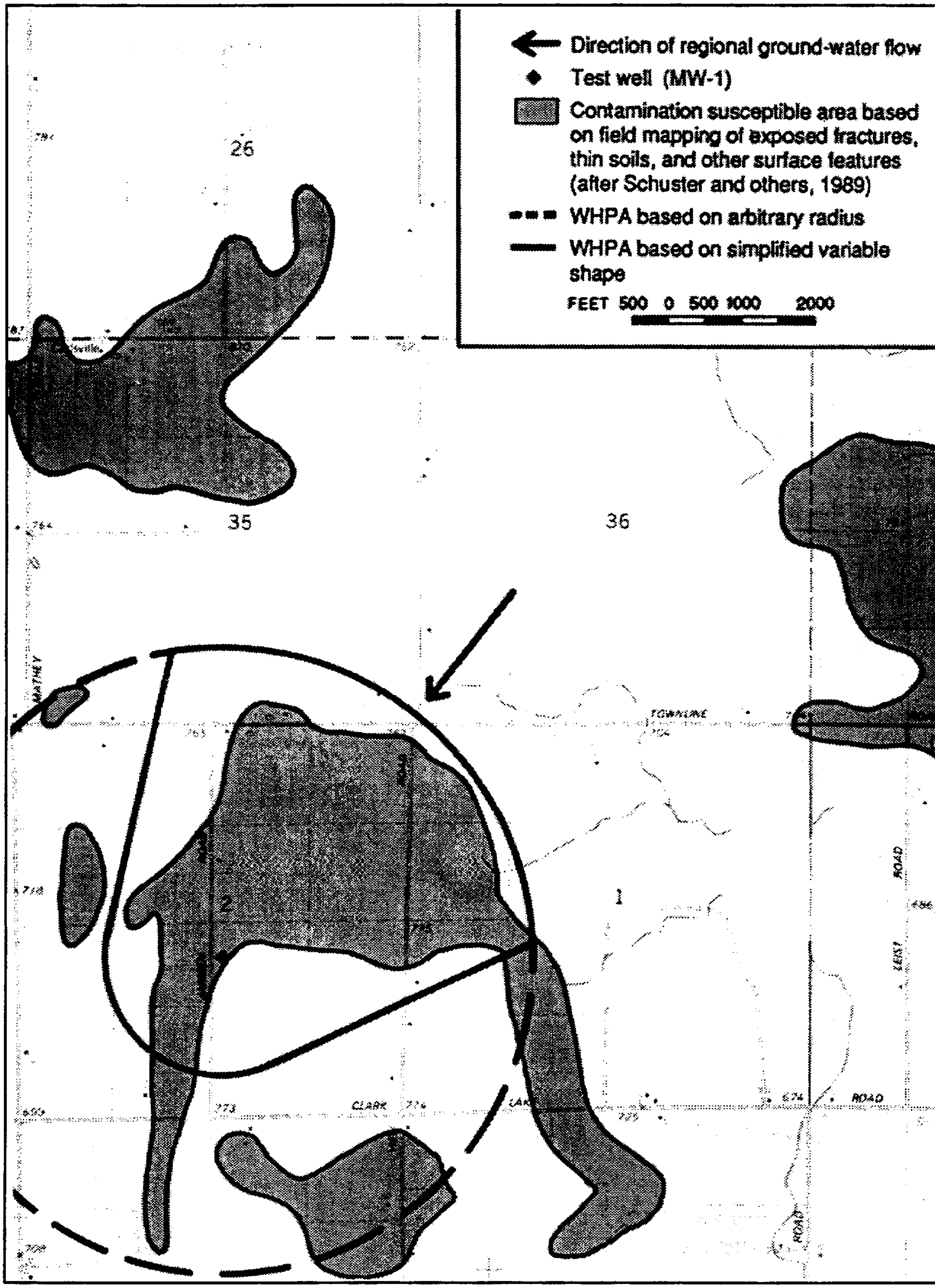


Figure B-1. Shaded areas show wellhead protection areas based on vulnerability mapping for the town of Sevastopol, Wisconsin. Source: U.S. EPA, 1991b.

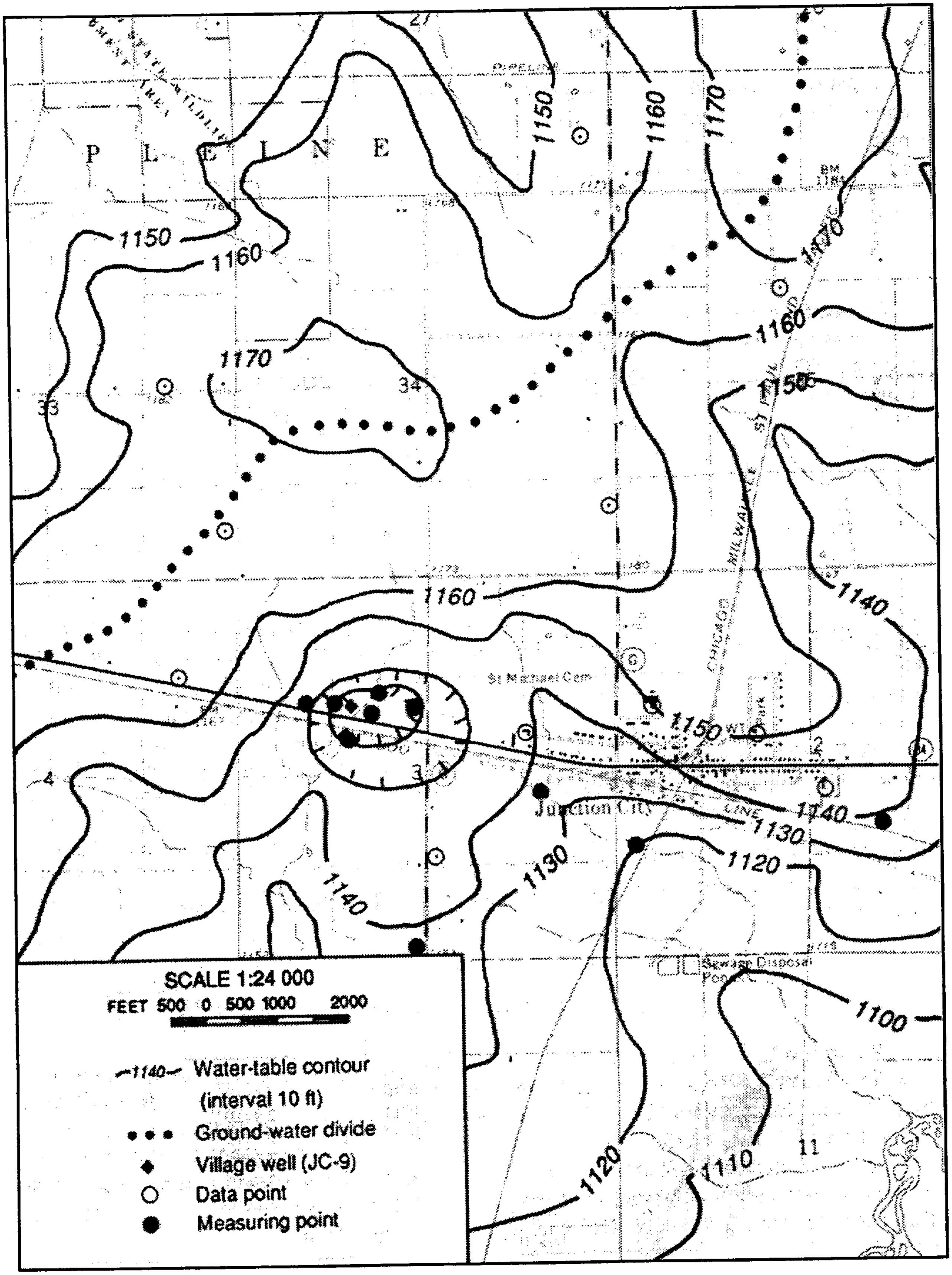


Figure B-2. Portion of the water-table map of Junction City, Wisconsin. Source: U.S. EPA, 1991b.

Time of travel contours can be delineated using the following equation:

Equation B-2: $d = \bar{v}t$

where:

d = the upgradient distance from the well to the time of travel line (feet)

$\bar{v}$ = average linear velocity in feet/year ($\bar{v}$ from Equation B-1 × 365)

t = desired time of travel (years)

The advantage of using time of travel criterion in flow system mapping is that the delineated zone of contribution is more realistically sized. A disadvantage of this method lies in the potential for using incorrect estimates of porosity or hydraulic conductivity in Equation B-1, which can lead to inaccurate wellhead protection area delineations. Figures B-3 and B-4 illustrate zone of contribution delineations in fractured rocks (U.S. EPA, 1991b).

Flow-System Mapping using the Uniform Flow Equation

This method is the same as that discussed under *Analytical Models* for delineating wellhead protection areas for unconfined aquifers in Chapter Four. This method uses data derived from a water-table map to solve the Uniform Flow Equation (Todd, 1980) and delineate the zone of contribution of a well in a sloping water table (see Figure 4-13 and Equations 4-2, 4-3, and 4-4). Figure B-5 illustrates the zone of contribution delineation for a well in crystalline rocks using the Uniform Flow Equation.

Residence-Time Approach

This delineation approach uses water chemistry to identify ground water travel paths and flow rates (U.S. EPA, 1991b). Two isotopes,[7] tritium (a radioactive isotope of hydrogen) and oxygen-18 (an isotope of oxygen), are present in ground water and can be used to estimate the age of water produced by a well. This is applicable to wellhead delineation in the following ways. Determining the age and chemical makeup of ground water allows you to check time of travel calculations, discover the effectiveness of zone of contribution delineation (where ground water is hundreds of years old, a zone of contribution might be too large to be a practical wellhead protection area), and differentiate zones of rapid recharge from zones of less rapid recharge (well water with the same isotopic content as a river adjacent to it might indicate a fracture network connecting the river and the well) (U.S. EPA, 1991b).

Tritium (^3H) is naturally present in the atmosphere, but its concentration increased substantially following atmospheric atomic testing in the 1950s and 1960s. Tritium concentrations increased in ground water that was recharged following this time period. Tritium is a very good indicator of how recently ground water was recharged because of its relatively short half-life, 12.3 years (U.S. EPA, 1991b, citing Egboka et al., 1983; Knott and Olimpio, 1986). Tritium data are used to verify the boundaries of zones of contribution. Oxygen-18 (^{18}O), another naturally occurring isotope, is an indicator of climate when ground water was recharged (U.S. EPA, 1991b). The ratio of ^{18}O to ^{16}O, which is the more common isotope of oxygen present in ground water, is dependent on how cold the climate is during recharge. This ratio becomes lower in colder climates and can indicate the age of ground water. The oxygen isotope ratio is also dependent on season and helps identify water originating from different recharge areas (U.S. EPA, 1991b).

The residence-time approach requires the collection of a large number of high-quality ground water samples that are subjected to extensive chemical testing. Good geochemical and isotopic interpretation skills are required, and the method might, therefore, prove expensive. In addition, this method does not produce a zone of contribution delineation. It is very useful, however, in confirming zone of contributions and time of travels delineated by alternative methods.

Numerical Models

Numerical flow/transport models already have been discussed under methods for mapping wellhead protection areas for unconfined and confined aquifers (see Chapter Four and Appendix C). When attempting to model complex aquifers, numerical models are especially useful. Most of the widely used ground water flow models assume porous-media flow (see Chapter Two under ground water movement), which is the flow associated with granular aquifers rather than fractured rock aquifers. These models can be used to delineate wellhead protection areas in fractured rocks if the aquifer behaves as a porous medium at the scale of the study (U.S. EPA, 1991b). Figure B-6 illustrates the zone of contribution developed for Junction City, Wisconsin, using a USGS modular three-dimensional model (McDonald and Harbaugh, 1988).

Wellhead Protection Area Delineation Methods for Fractured Rocks That Do Not Behave as Porous Media

The wellhead protection area delineation methods outlined above are suitable for fractured rock aquifers that behave as porous media aquifers. Fractured-rock aquifers that do not behave as porous media aquifers usually fall into two categories. The first includes aquifers with numerous interconnected fractures, and the second includes rocks with very sparse and poorly connected fractures in a low-permeability matrix. The wellhead protection area delineation methods that are useful for these aquifers include vulnerability mapping, hydrogeological mapping, residence-time approach, and some numerical modeling (see U.S. EPA, 1991b).

[7] Isotopes of the same element have the same atomic number but different atomic weights.

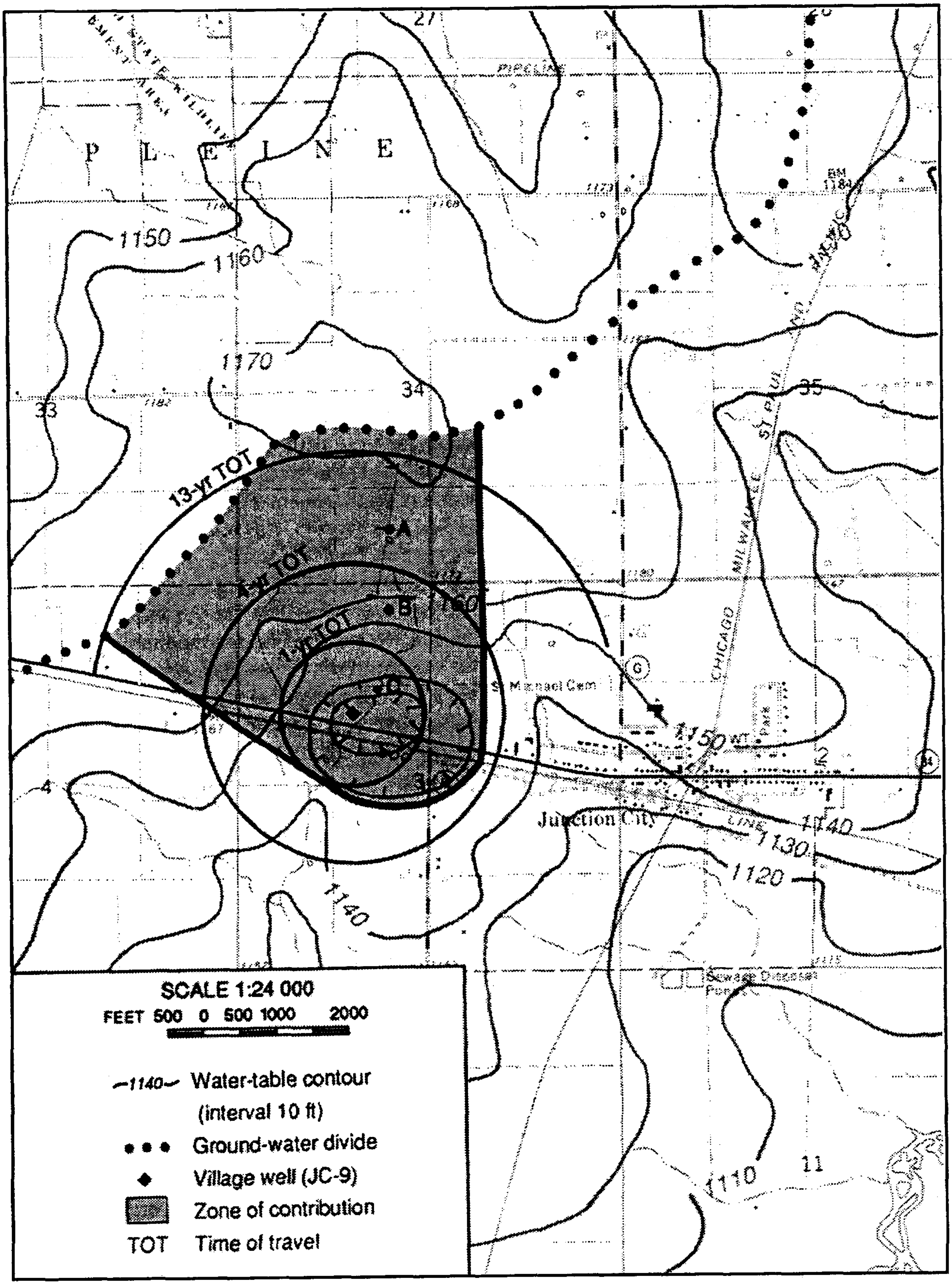


Figure B-3. ZOC delineation in crystalline rocks using a field-measured water-table map. A, B, and C are points where hydraulic gradients and ground water velocities were calculated using the hydraulic conductivity determined from the pumping test. Source: U.S. EPA, 1991b.

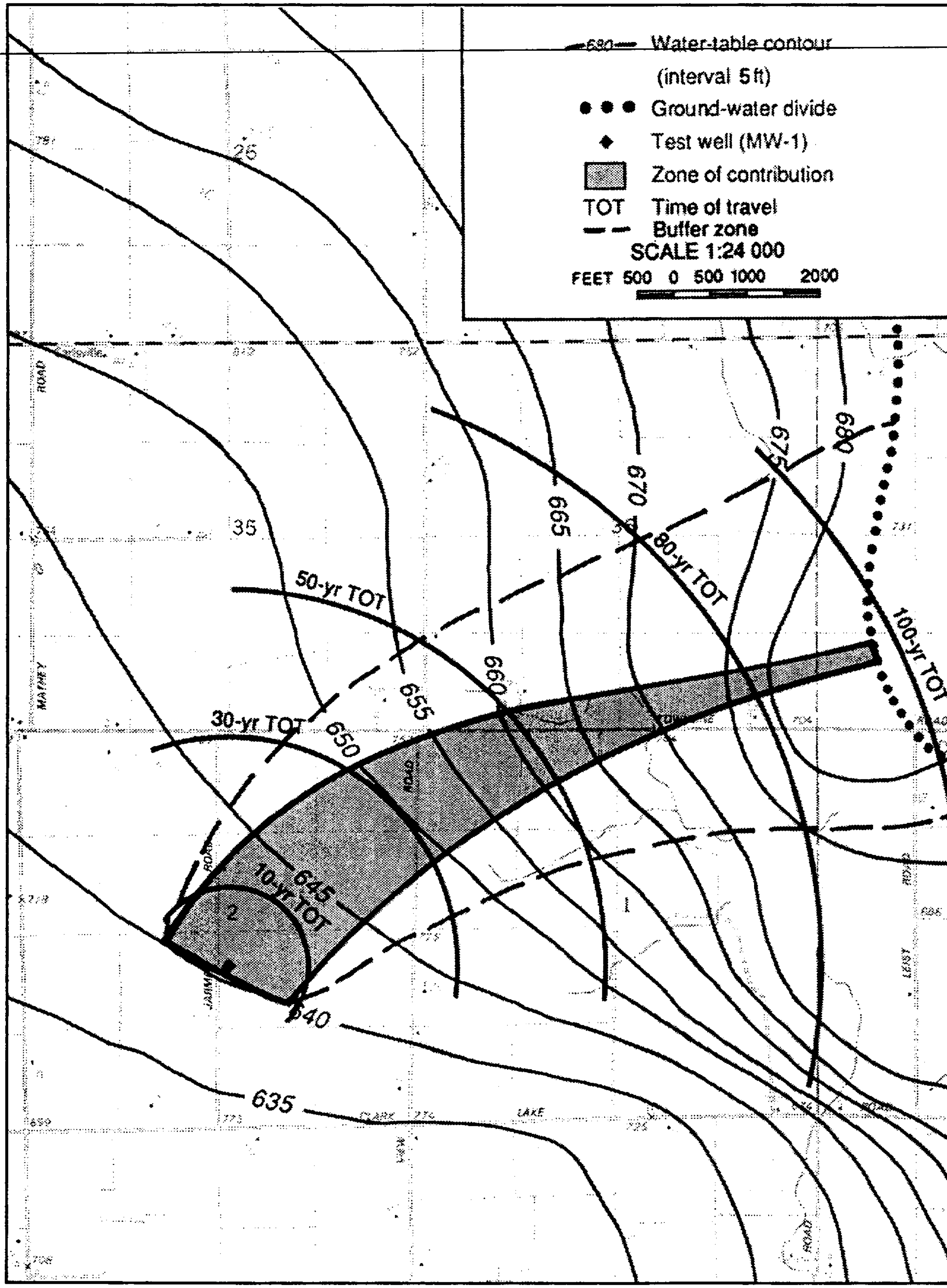


Figure B-4. ZOC delineation in a deep ground water system in dolomite using a potentiometric-surface map. Source: U.S. EPA, 1991b.

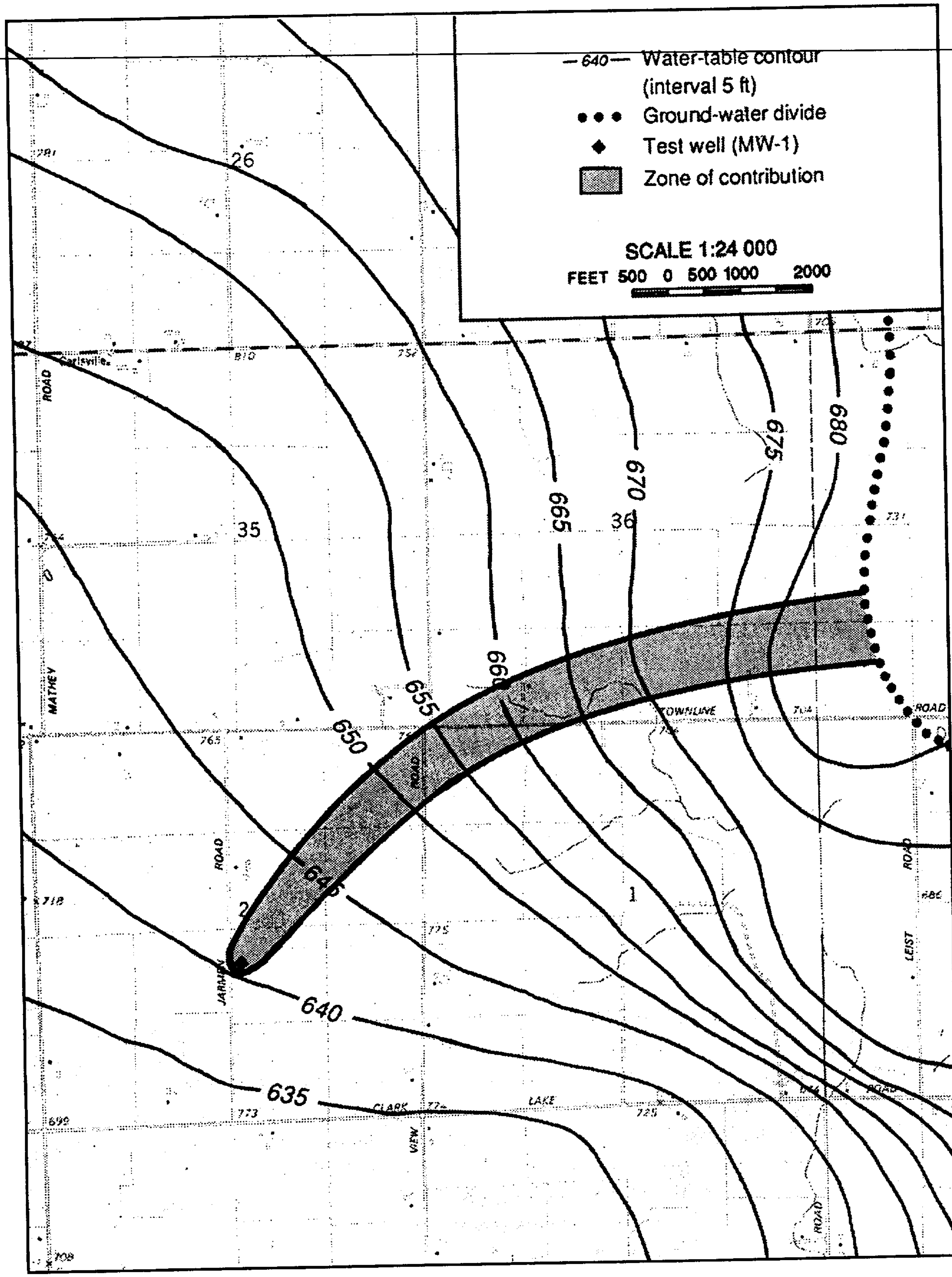


Figure B-5. ZOC delineation in a deep ground water system in dolomite using the uniform flow equation. Source: U.S. EPA, 1991b.

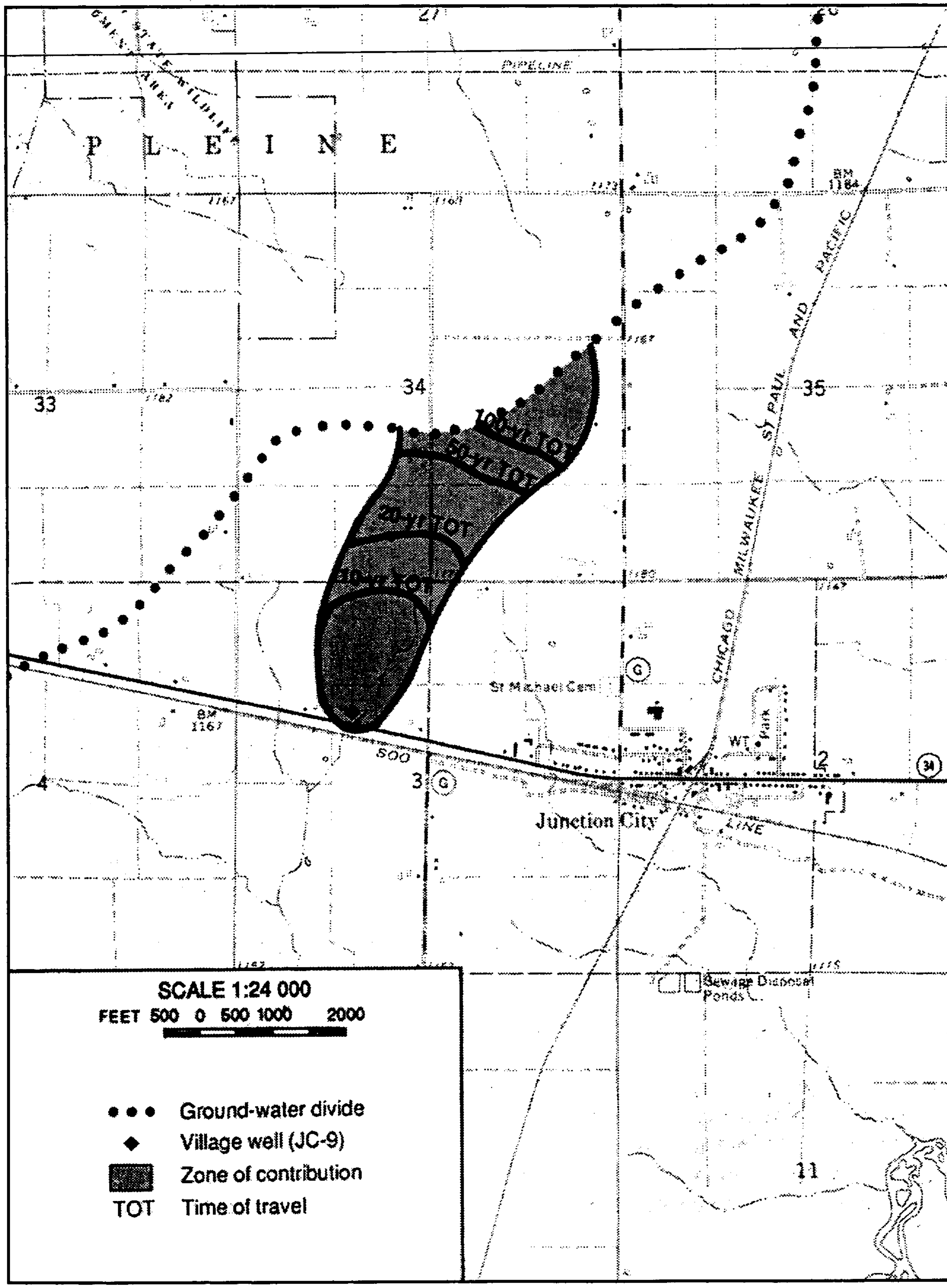


Figure B-6. ZOC predicted by numerical modeling for a well in crystalline rocks. Source: U.S. EPA, 1991b.

Appendix C

Methods for Delineating Wellhead Protection Areas for Confined Aquifers[8]

As discussed in Chapter Two, a **confined aquifer** is overlaid by relatively impermeable soils or rocks (see Figure 2-2). The possibility of contamination is higher for unconfined aquifers than for confined aquifers but contamination can occur in confined aquifers. Therefore, wellhead protection areas for confined aquifers must be delineated.

Confined aquifers can be categorized as **semiconfined** or **highly confined** aquifers. A semiconfined aquifer is subject to leakage of water and possibly contaminants from its confining strata (see Figure C-1). In highly confined aquifers this leakage is negligible. The degree of confinement of an aquifer is an important consideration when choosing delineation methods for confined aquifers, because some methods take vertical leakage into consideration and some do not.

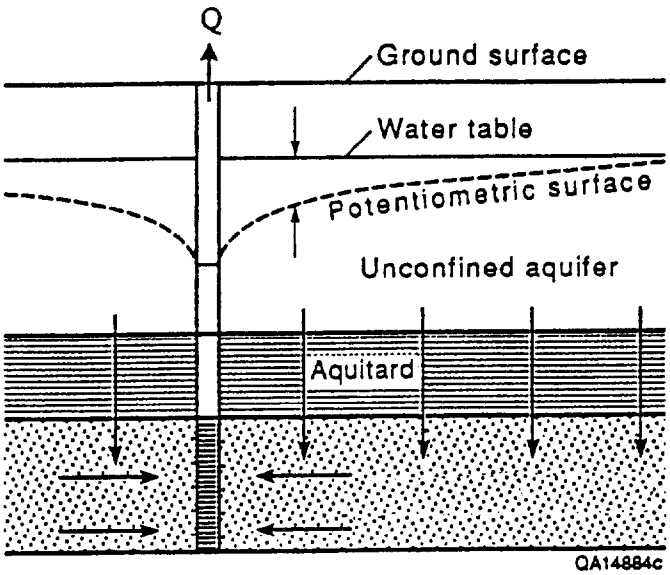


Figure C-1. Schematic of a semiconfined (leaky) aquifer. Source: U.S. EPA, 1991a.

There are many methods for delineating wellhead protection areas for confined aquifers. The following delineation methods take into consideration the gradient of the aquifer's **regional potentiometric surface.** Potentiometric surfaces in confined aquifers typically are characterized by very low gradients (see Figure C-2). Steeper initial gradients can occur within confined aquifers, however, and this affects the shape of the cone of depression of a pumping well (see Figure C-3) (U.S. EPA, 1991a). The following sections describe delineation methods for both confined aquifers with very low gradient potentiometric surfaces and confined aquifers with sloping potentiometric surfaces.

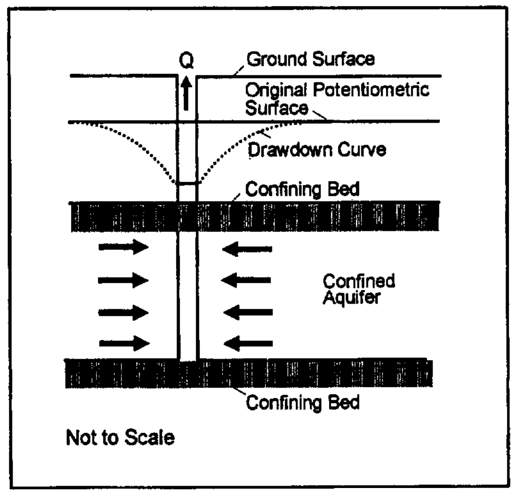


Figure C-2. Ground water flow toward pumping well with a negligible initial potentiometric-surface gradient.

Wellhead Protection Area Delineation Methods for Confined Aquifers with Negligible-Sloping Potentiometric Surfaces

Cone of Depression

This approach to wellhead delineation involves marking out the lateral (areal) extent of a well's cone of depression. The lateral extent of a cone of depression occurs where drawdown because of pumping is less than 1 foot

[8]Most of the information on delineating wellhead protection areas for confined aquifers is summarized from EPA's *Wellhead Protection Strategies for Confined-Aquifer Settings* (EPA 570-9-91-008). For more detailed technical information on these techniques, please refer to this publication.

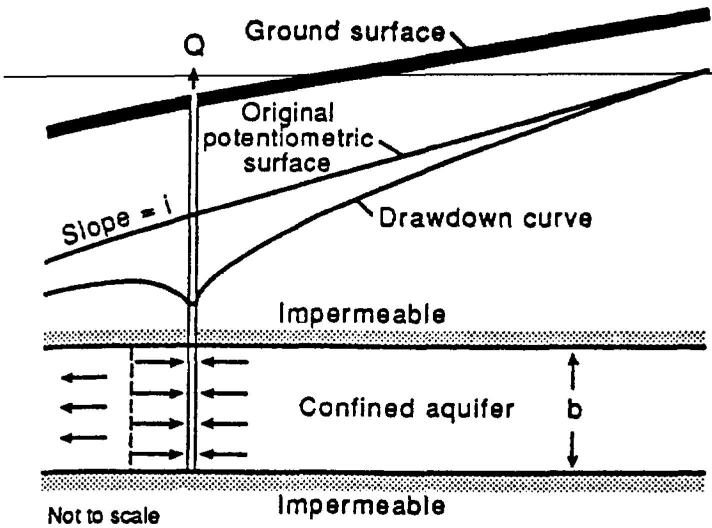


Figure C-3. Ground water flow field for cone of depression of a pumping well with a regional ground water flow gradient. Source: U.S. EPA, 1991a.

(U.S. EPA, 1991a). The three delineation methods described below can be used to determine the lateral extent of the cone of depression. These methods are recommended for semiconfined aquifers. They are less dependable for highly confined aquifers because wellhead protection areas delineated for highly confined aquifers using this approach tend to be very large.

Drawdown Versus Distance Curve

This method involves measuring drawdown in several monitoring wells located at different distances from a pumping well. From these data, it is possible to plot drawdown versus the log of distance to obtain a straight line. The lateral extent of the cone of depression can be estimated by reading the corresponding distance for 0 to 1 foot drawdown from this graph. Figure C-4 illustrates a hypothetical drawdown versus log distance graph generated by a computer modeling technique. Each line refers to an aquifer exhibiting different leakage characteristics P', where P'=0.001 is a highly confined aquifer and P'=10.0 is a semiconfined aquifer.

Drawdown Versus Time

This method uses a "drawdown versus time" curve (see Figure C-5a) for a single well to determine the lateral extent of the cone of depression. Once the drawdown versus time curve has been established for the well in question, the "drawdown versus distance" curve can be obtained (see Figure C-5b). The slope of a semilog plot of drawdown versus distance is twice that of the time versus drawdown curve (Driscoll, 1986).

Drawdown Versus Distance Using Analytical Models and Simple Computer Models

Analytical models can be used to determine the lateral extent of a cone of depression. This involves solving

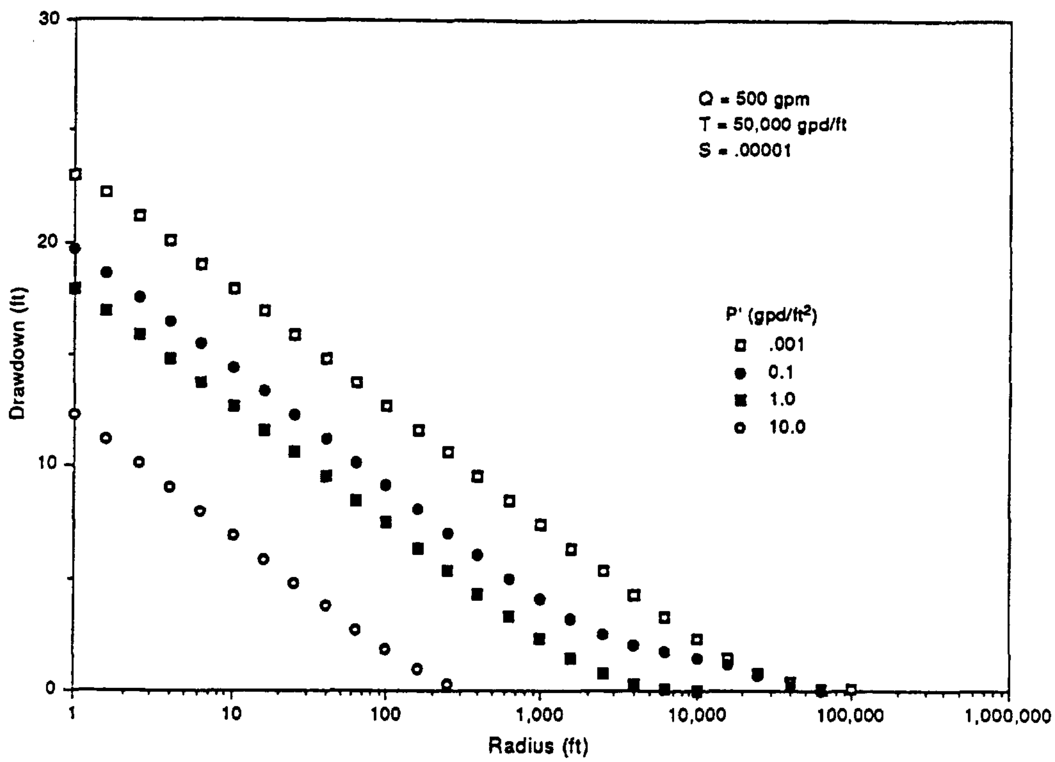


Figure C-4. Simulation of drawdown versus log distance for hypothetical aquifer for different values of leakage using computer code PTIC. Note curves are linear. At the well maximum depth of drawdown can be determined. As drawdown approaches zero, the maximum lateral extent of the code of depression can be estimated. Source: U.S. EPA, 1991a, citing Walton, 1987.

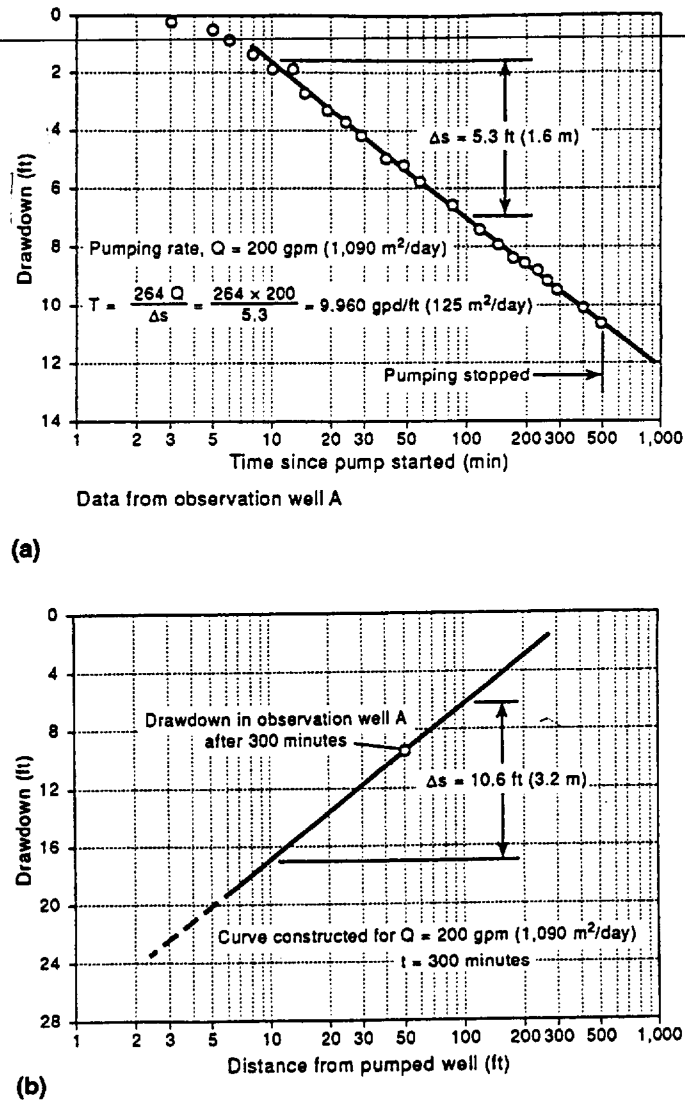


Figure C-5. The lateral extent of a cone of depression of a pumping well can be determined with time versus distance data. The slope of drawdown versus log distance is twice the slope of drawdown versus log time. Used with permission from Driscoll, *Groundwater and Wells*, Edition 2, 1986, Johnson Filtration Systems Inc. Source: U.S. EPA, 1991a.

equations using hydrologic parameters obtained from pump test data or regional data. Two methods are in general use: the Thiem equation (Thiem, 1906) and the Theis equation (Theis, 1935). The first of these, the Thiem equation (see Equation C-1), can be used when a cone of depression has stopped expanding (in other words, has reached equilibrium).

Equation C-1:

$$s = \frac{Q}{2\pi Kb} \log_e \frac{r_e}{r}$$

where:

s = drawdown from the original potentiometric surface
Q = discharge
K = hydraulic conductivity
b = aquifer thickness
r = radial distance at point of drawdown observation
r_e = radial distance of zero drawdown of cone of depression

For a more detailed discussion on the use of this equation the reader is referred to *Ground Water Hydraulics: U.S. Geological Survey Professional Paper* by S.W. Lohman, 1972.

When a well's cone of depression is still expanding, the nonequilibrium Theis equation can be used (see Equation C-2). This equation enables the user to calculate the lateral extent of the cone of depression at different times.

Equation C-2:

$$s = \frac{114.6\, Q\, W(u)}{T}$$

W(u) is the well function of u where

$$u = \frac{1.87\, r^2 S}{Tt}$$

s = drawdown
Q = discharge
T = transmissivity
r = radial distance to point of drawdown observation
S = storativity
t = time

For a more detailed discussion on solving this equation, see *Groundwater and Wells, Second Edition* by F.G. Driscoll (1986).

Cones of depression for equilibrium and nonequilibrium conditions can be delineated using simple computer programs. These computer programs are semianalytical codes with relatively simple boundary conditions that require the input of certain hydraulic parameters including storativity, leakage, and hydraulic conductivity (EPA, 1991a). Information on these computer programs may be obtained from *Groundwater Pumping Tests: Design and Analysis* by W.C. Walton (1987). More complex computer programs exist that calculate drawdown versus distance using numerical models rather than analytical solutions; these programs, however, require more detailed input data. These computer programs can be used in towns that have multiple wells with interfering cones of depression. For a list of existing computer models see *Model Assessment for Delineating Wellhead Protection Areas* (U.S. EPA, 1988).

Time of Travel

Under this delineation approach, the time of travel for a given distance of flow or the distance of flow for a given period of time is calculated using known hydraulic parameters, including transmissivity, porosity, hydraulic gradient, and pump discharge (U.S. EPA, 1991a). A widely used time period in time of travel calculations is 40 years. This time period is chosen because waters recharged in the last 40 years have the distinguishing characteristic of containing tritium, whereas older waters do not. Tritium only was released into the atmosphere in the last 40 years. If ground water does not contain tritium, it can be inferred that it will take at least 40 years for it to be recharged. The following discussion outlines three time of travel approaches to wellhead delineation.

The first method discussed under this approach, Cone of Depression/Time of Travel, is considered the most accurate of the methods outlined here for confined aquifers with negligible sloping potentiometric surfaces. This is the most adaptable method because it provides an accurate delineation for confined and semiconfined aquifers. Vertical leakage is taken into consideration and the time of travel calculation ensures that the lateral extent of the wellhead protection area will be limited to a realistic size.

Cone of Depression/Time of Travel

This delineation method calculates time of travel based on the hydraulic gradient of a well's cone of depression. The hydraulic gradient (slope of water table or potentiometric surface) decreases very quickly as you move away from a well (see Figure C-1). Therefore, the hydraulic gradient is dependent on the distance away from the well. Time of travel contours can be established through solving analytical equations or through computer modeling that takes into consideration the value of the hydraulic gradient.

Analytical Methods

~~Equation C-3 can be used to calculate time of travel.~~

Equation C-3:

$$TOT = (\Delta 1)^* \, \Theta / K^* \, i$$

where:

TOT = time of travel threshold

Δ1 = distance of travel for a given time period

K = hydraulic conductivity

Θ = porosity

i = h/1 is the hydraulic gradient of the cone of depression between two points of measurement. **Δh is the difference in hydraulic head between two points of measurement on a flow line (Δ1).**

This equation can be arranged in order to calculate time of travel contours:

Equation C-4:

$$\Delta l = (TOT^* \, K^* \, i)/\Theta$$

The time of travel is estimated for various incremental distances away from the well using Equation C-3 and the appropriate input variables, which can be obtained from pumping data. These incremental TOTs then are added to obtain the total time of travel. The log of total time of travel is plotted against the log of distance to yield a straight line (see Figure C-6). From this graph, distances for different TOTs can be read easily. It then is

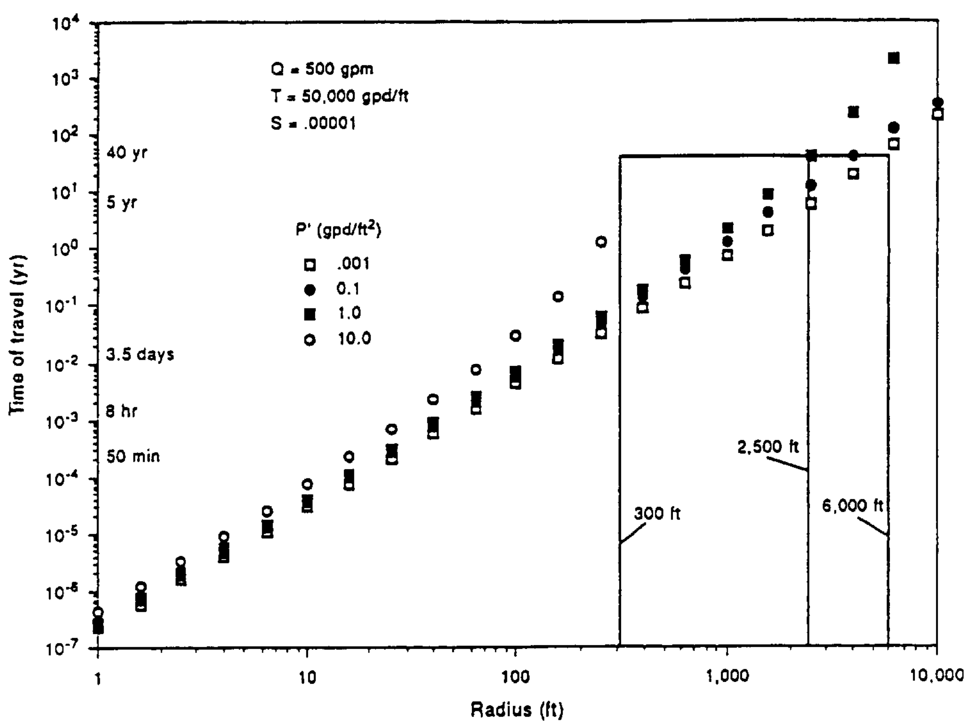


Figure C-6. Simulation of time of travel (in years) for hypothetical aquifer for different values of leakage using computer code PTIC. Source: U.S. EPA, 1991a, citing Walton, 1987.

possible to mark out time of travel contours from this information.

Reverse Path Computer Modeling

Computer models can be used to calculate the recharge area of a well and time of travel contours. These programs use numerical techniques to map the potentiometric surface and calculate ground water flow paths in a reverse direction. Calculating these flow paths allows the user to determine the recharge area of a well. These computer models include **GWPATH** (Shafer, 1987), and **WHPA** [2.1]. WHPA, an integrated semianalytical model for delineation of wellhead protection areas, is available from EPA's Office of Ground Water Protection. This program calculates wellhead protection areas by calculating time of travel contours for negligible or sloping regional hydraulic gradients (see Figure C-7).

Ground water flow paths in a reverse direction are calculated using either forward or reverse particle tracking ground water flow models. Forward tracking predicts where ground water will flow in the future and is the method used by most ground water flow models to calculate flow paths. This method especially is useful for estimating the movement of contaminants from a pollution site. Reverse tracking is the opposite of forward tracking and calculates where ground water flowed in the past.

Reverse path computer modeling is used for defining wellhead protection areas because it outlines the recharge area of a well and the time of travel for water or contaminants to get to a well. Estimating wellhead protection areas using reverse path modeling requires calculating the water level at the well and the surrounding potentiometric surface and using computer programs such as those discussed above to determine the reverse flow paths (see Figure C-7).

The advantage of using this method lies in the realistic delineations of wellhead protection areas that sophisticated computer programs can produce. These computer programs are highly complex, however, and require a good deal of hydraulic and hydrologic data.

Cylinder Method

This method is the same as the Calculated Fixed Radius method for unconfined aquifers (see Equation 4-1, Chap-

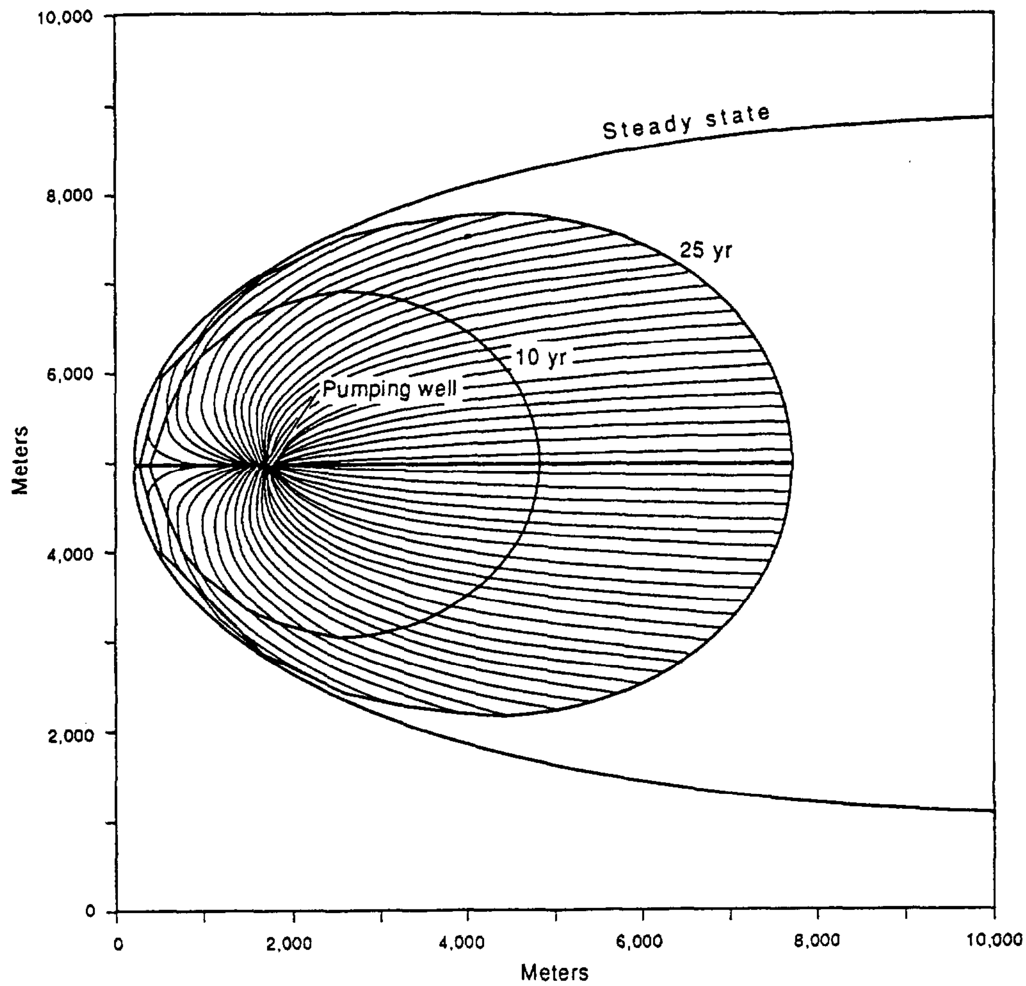


Figure C-7. Example of reverse-path calculation using the WHPA computer program. Source: U.S. EPA, 1991a, citing Blanford and Huyokorn, 1990.

ter Four). This equation assumes that all flow is horizontal. This means that vertical leakage is not taken into consideration and the aquifer is considered highly confined. This can result in unrealistically large radii for certain times of travel.

Wellhead Protection Area Delineation Methods for Confined Aquifers with Regional Sloping Potentiometric Surfaces

Delineation methods that incorporate a sloping regional potentiometric surface should be considered when an aquifer's regional potentiometric gradient lies between 0.0005 and 0.001 or greater (Todd, 1980; Bear and Jacob, 1965; Southern Water Authority, 1985).

Zone of Contribution with Identification of Flow Boundaries Method

This method is the same as that described under *Analytical Models* for delineating wellhead protection areas for unconfined aquifers (Chapter Four). The uniform flow equation (Todd, 1980) is used to define the zone of contribution to a pumping well in a sloping water table (see Figure 4-13, and Equations 4-2, 4-3, and 4-4 in Chapter Four). The Uniform Flow Equation (Equation 4-2) does not consider vertical leakage; therefore, the wellhead protection area using this method will be oversized if there is significant vertical leakage.

Zone of Transport with Time of Travel Contours Approach

The following three methods calculate a zone of transport with time of travel contours.

Analytical Solution

Equation C-5 (modified from Bear and Jacob, 1965) allows the calculation of the time of travel of water along a line parallel to the hydraulic gradient, from a point to a pumping well (U.S. EPA, 1991a).

Equation C-5:

$$T_x = \frac{\Theta}{Ki}\left[X_L - \frac{Q}{2\pi Kbi}\ln\left(1 + \frac{2\pi Kbi}{Q}X_L\right)\right]$$

where:

T_x = travel time from point x to pumping well
Θ = porosity
X_L = distance from pumping well over which ground water travels in T_x (time); X_L is either positive or negative depending on whether point x is upgradient (+) or downgradient (-) of the pumping well
Q = discharge
K = hydraulic conductivity
b = aquifer thickness
i = hydraulic gradient

A trial and error process is used to determine travel distances for specific travel times. These travel distances and travel times only can be calculated along a line through the well parallel to the regional hydraulic gradient (U.S. EPA, 1991a). This equation probably is most helpful for determining the impact of the regional potentiometric gradient on the shape of the wellhead protection area, since this equation cannot delineate the complete wellhead protection area. A computer solution is necessary to completely delineate a wellhead protection area in an aquifer with a sloping potentiometric surface. The ratio of the distance of ground water travel in the downgradient direction to that in the upgradient direction for the same time of travel indicates how noncircular the wellhead protection area will be (U.S. EPA, 1991a).

Equation C-5 does not allow for vertical leakage; therefore, if the aquifer is semiconfined, the calculated wellhead protection area might be more extensive than required.

WHPA [2.1] Model

As discussed in the previous section, WHPA [2.1] is an integrated semianalytical model for delineating wellhead protection areas (see Figure C-7). This computer program can be used to determine time of travel contours for confined aquifers with regionally sloping potentiometric surfaces. This method is better than the two methods outlined above because it produces a complete delineation of the wellhead protection area. Additionally, WHPA [2.1] incorporates vertical leakage in semiconfined aquifers and consequently calculates a more realistic wellhead protection area.

Reverse-Path Calculations

Reverse tracking calculations, as discussed above under time of travel methods, might also be used to determine time of travel contours for confined aquifers with a negligible regional potentiometric gradient. This method is the most accurate of those discussed under this section, but it can be complicated.

Appendix D

Conversion of Units[9]

Units of measurements used in ground water literature are gradually changing from the inch-pound units of gallons, feet, and pounds to the International System of units of meters and kilograms (metric units). It is, therefore, increasingly important that those who use this literature become proficient in converting units of measurement from one system to another. Most conversions involve the fundamental principle that the numerator and denominator of a fraction can be multiplied by the same number (in essence, multiplying the fraction by 1) without changing the value of the fraction. For example, if both the numerator and the denominator of the fraction 1/4 are multiplied by 2, the value of the fraction is not changed. Thus,

$$\frac{1}{4} \times \frac{2}{2} = \frac{2}{8} = \frac{1}{4} \; or \; \frac{1}{4} \times \frac{2}{2} = \frac{1}{4} \times 1 = \frac{1}{4}$$

Similarly, to convert gallons per minute to other units of measurement, such as cubic feet per day, we first must identify fractions that contain both the units of time (minutes and days) and the units of volume (gallons and cubic feet) and that, when they are used as multipliers, do not change the numerical value. Relative to time, a day is 1,440 minutes. Therefore, if any number is multiplied by 1,440 min/d, the result will be in different units, but its numerical value will be unchanged. Relative to volume, a cubic foot is 7.48 gallons. Therefore, to convert gallons per minute to cubic feet per day, we multiply by these "unit" fractions, cancel the units of measurement that appear in both the numerator and denominator, and gather together the units that remain. In other words, to convert gallons per minute to cubic feet per day, we have

$$\frac{\text{gallons}}{\text{minute}} = \frac{\text{gallons}}{\text{minute}} \times \frac{1{,}440 \text{ min}}{\text{d}} \times \frac{\text{cubic feet}}{7.48 \text{ gal}}$$

and, canceling gallons and minutes in the numerators and denominators, we obtain

$$\frac{\text{gallons}}{\text{minute}} = \frac{1{,}440 \text{ ft}^3}{7.48 \text{ d}} = 192.5 \text{ ft}^3 \text{ d}^{-1}$$

which tells us that 1 gal min^{-1} equals 192.5 $\text{ft}^3 \text{ d}^{-1}$.

We follow the same procedure in converting from inch-pound units to metric units. For example, to convert square feet per day to square meters per day, we proceed as follows:

$$\frac{\text{ft}^2}{\text{d}} = \frac{\text{ft}^2}{\text{d}} \times \frac{\text{m}^2}{10.76 \text{ ft}^2} = \frac{\text{m}^2}{10.76 \text{ d}} = 0.0929 \text{ m}^2 \text{ d}^{-1} =$$

$$9.29 \times 10^{-2} \text{ m}^2 \text{ d}^{-1}$$

[9]Heath, R. 1982. *Basic Ground-Water Hydrology.* U.S. Geological Survey. Water Supply Paper 2220. Washington, DC.

RELATION OF UNITS OF HYDRAULIC CONDUCTIVITY, TRANSMISSIVITY, RECHARGE RATES, AND FLOW RATES

Hydraulic conductivity (K)

Meters per day ($m\ d^{-1}$)	Centimeters per second ($cm\ s^{-1}$)	Feet per day ($ft\ d^{-1}$)	Gallons per day per square foot ($gal\ d^{-1}\ ft^{-2}$)
1	$1.16x10^{-3}$	3.28	$2.45x10^{1}$
$8.64x10^{2}$	1	$2.83x10^{3}$	$2.12x10^{4}$
$3.05x10^{-1}$	$3.53x10^{-4}$	1	7.48
$4.1x10^{-2}$	$4.73x10^{-5}$	$1.34x10^{-1}$	1

Transmissivity (T)

Square meters per day ($m^2\ d^{-1}$)	Square feet per day ($ft^2\ d^{-1}$)	Gallons per day per foot ($gal\ d^{-1}\ ft^{-1}$)
1	10.76	80.5
0.0929	1	7.48
0.0124	0.134	1

Recharge Rates

Unit depth per year	Volume		
	($m^3\ d^{-1}\ km^{-2}$)	($ft^3\ d^{-1}\ mi^{-2}$)	($gal\ d^{-1}\ mi^{-2}$)
(In millimeters)	2.7	251	1,874
(In inches)	70	6,365	47,748

Flow rates

($m^3\ s^{-1}$)	($m^3\ min^{-1}$)	($ft^3\ s^{-1}$)	($ft^3\ min^{-1}$)	($gal\ min^{-1}$)
1	60	35.3	2,120	15,800
0.0167	1	0.588	35.3	264
0.0283	1.70	1	60	449
0.000472	0.0283	0.0167	1	7.48
0.000063	0.00379	0.0023	0.134	1

UNITS AND CONVERSIONS (Metric to inch-pound units)

LENGTH
1 millimeter (mm) = 0.001 m = 0.03937 in.
1 centimeter (cm) = 0.01 m = 0.3937 in. = 0.0328 ft
1 meter (m) = 39.37 in = 3.28 ft = 1.09 yd
1 kilometer (km) = 1,000 m = 0.62 mi

AREA
1 cm^2 = 0.155 $in.^2$
1 m^2 = 10.758 ft^2 = 1.196 yd^2
1 km^2 = 247 acres = 0.386 mi^2

VOLUME
1 cm^3 = 0.061 $in.^3$
1 m^3 = 1,000 l = 264 U.S. gal = 35.314 ft^3
1 liter (l) = 1,000 cm^3 = 0.264 U.S. gal

MASS
1 microgram (µg) = 0.000001 g
1 milligram (mg) = 0.001 g
1 gram (g) = 0.03527 oz. = 0.002205 lb
1 kilogram (kg) = 1,000 g = 2.205 lb

LENGTH
1 inch (in.) = 25.4 mm = 2.54 cm = 0.0254 m
1 foot (ft) = 12 in. = 30.48 cm = 0.3048 m
1 yard (yd) = 3 ft = 0.9144 m = 0.0009144 km
1 mile (mi) = 5,280 ft = 1,609 m = 1.609 km

AREA
1 $in.^2$ = 6.4516 cm^2
1 ft^2 = 929 cm^2 = 0.0929 m^2
1 mi^2= 2.59 km^2

VOLUME
1 $in.^3$ = 0.00058 ft^3 = 16.39 cm^3
1 ft^3 = 1,728 $in.^3$ = 0.02832 m^3
1 gallon (gal) = 231 $in.^3$ = 0.13368 ft^3 = 0.00379 m^3

MASS
1 ounce (oz) = 0.0625 lb = 28.35 g
1 pound (lb) = 16 oz = 0.4536 kg

Appendix E

Definitions of Hydrogeologic Terms

Alluvium. A general term for unconsolidated material deposited by a stream or other body of running water.

Aquifer. A water-bearing rock unit that will yield water in a usable quantity to a well or spring.

Aquifer heterogeneity. A term describing those aquifers in which hydraulic conductivity is variable.

Bedrock. A general term for the consolidated (solid) rock that underlies soils or other unconsolidated surficial materials.

Capillarity. The rise in water level because of adhesion of water to solid particles.

Capillary fringe. The zone above the water table in which water is held by surface tension. Water in the capillary fringe is under lower-than-atmospheric pressure.

Cone of depression. The depression of hydraulic heads around a well caused by the withdrawal of water.

Confined aquifer. An aquifer saturated with water and bounded above and below by beds having a distinctly lower hydraulic conductivity than the aquifer itself.

Confining bed. A layer of rock adjacent to an aquifer that hampers the movement of water into or out of the aquifer.

Contaminant plume. An elongated and mobile column or band of a pollutant moving through the subsurface.

Discharge area. An area in which water is lost from the zone of saturation.

Drawdown. The decline in ground water level at a point caused by the withdrawal of water from an aquifer.

Freshwater. Water containing only small quantities (generally less than 1,000 mg/L) of dissolved minerals.

Gaining stream. A stream or reach of a stream that receives water from the zone of saturation.

Glacial drift. A general term for material transported by glaciers and deposited directly on land or in the sea.

Ground water. Water in the saturated zone that is under a pressure equal to or greater than atmospheric pressure.

Ground water divide. A ridge in the water table or potentiometric surface from which ground water moves away at right angles in both directions. The line of highest hydraulic head in the water table or potentiometric surface.

Hydraulic conductivity. The capacity of a rock to transmit water; expressed as the volume of water that will move in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow.

Hydraulic gradient. The slope of the water table or potentiometric surface; that is, the change in water level per unit of distance along the direction of maximum head decrease. Determined by measuring the water level in several wells.

Hydraulic head. In ground water, the height above a datum plane (such as sea level) of a column of water. In a ground water system, it is composed of elevation head and pressure head.

Hydrologic cycle. The exchange of water between the Earth and the atmosphere through evaporation and precipitation.

Igneous rock. A rock that solidified from molten or partly molten material.

Karst. A landscape or region characterized by rock dissolution.

Losing stream. A stream or reach of a stream that contributes water to the zone of saturation.

Metamorphic rock. A rock formed when preexisting rocks undergo mineralogical, chemical, and structural changes caused by high temperature, pressure, and other factors.

Mineralized water. Water containing dissolved minerals in concentrations large enough to affect the use of the water for some purposes. A concentration of

1,000 mg/L of dissolved solids is used commonly as the lower limit for mineralized water.

Permeable. Having a texture that permits water to move through it perceptibly under the head differences ordinarily found in subsurface water.

pH. A number used by chemists to express the acidity of solutions, including water. A pH value lower than 7 indicates an acidic solution, a value of 7 is neutral, and a value higher than 7 indicates an alkaline solution. Most ground waters in the United States have pH values ranging from about 6.0 to 8.5.

Porosity. The volume of openings in a rock. When expressed as a fraction, porosity is the ratio of the volume of openings in the rock to the total volume of the rock.

Potentiometric surface. An imaginary surface representing the level to which water will rise in a well.

Recharge area. The area in which water reaches the saturated zone by surface infiltration.

Saturated zone. The zone (below the unsaturated zone) in which interconnected openings contain only water.

Sedimentary rock. A layered rock formed at or near the Earth's surface (1) from fragments of older rocks, (2) by precipitation from solution, or (3) from the remains of living organisms.

Specific capacity. The rate of discharge of water from a well per unit of drawdown of the water level.

Specific retention. The amount of water that soils or rocks will retain against the pull of gravity to the rock/soil volume.

Specific yield. The amount of water yielded (i.e., from a water-bearing material) under the influence of gravity.

Storativity. The amount of water an aquifer will release from storage.

Till. An unsorted and unstratified mixture of clay, silt, sand, gravel, and boulders deposited directly by glaciers.

Time of travel. The amount of time it takes for water to reach a well from a certain distance.

Total head. The height (usually above sea level) of a column of water; includes elevation head and pressure head. Ground water flows in the direction of decreasing total head.

Transmissivity. The capacity of an aquifer to transmit water; equal to the hydraulic conductivity times the aquifer thickness.

Transpiration. Evaporation of moisture from the pores of the skin or from the surface of leaves and other plant parts.

Unconfined aquifer. An aquifer that contains both an unsaturated and a saturated zone (i.e., an aquifer that is not full of water).

Unsaturated zone. The subsurface zone, usually starting at the land surface, that contains both water and air.

Water table. The level in the saturated zone at which the water is under a pressure equal to the atmospheric pressure.

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