Wellhead Protection:
A Guide for Arizona Communities

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Preface

The purpose of this document is to provide a resource for Arizona communities to use in establishing their own wellhead protection programs. The basic elements of wellhead protection are presented as well as a step-by-step process for implementing a program. This document has been written with the intent of giving Arizona's community leaders a guide that is concise and easy to use. It is designed to be useful to those with or without a technical background.

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Table of Contents

Tables

Figures

Chapter 1.
The Need to Protect Groundwater Resources

What is the Wellhead Protection Program, and why is it important to my community?

In the United States, groundwater is the source of drinking water for half of the total population and 95% of the rural population (EPA, 1993). Groundwater is also used for livestock raising, agriculture, and industry. In the arid west, groundwater is a particularly important resource because of the scarcity of surface water. Although groundwater was once thought to be protected by layers of rock and soil, we now know groundwater to be vulnerable to many types of contamination. Contaminants can enter groundwater from landfills, waste storage lagoons, chemical spills, leaking underground storage tanks, improperly managed hazardous waste sites, fertilizers and pesticides, sewage, animal waste, and other sources. Even distant contamination sources can impact a well in time (Figure 1).

Groundwater can be contaminated by microorganisms, metals, and both synthetic and naturally occurring chemical compounds. Serious health effects have been well documented: cancer; liver, kidney and nerve problems; birth defects; and learning disabilities in children. Table 1 shows health risks associated with some major contaminants found in groundwater.

The Wellhead Protection Program

Amendments to the Safe Drinking Water Act (SDWA) were passed in June 1986 establishing the Wellhead Protection (WHP) Program to protect groundwaters that contribute to public water supply systems. Each state must establish its own WHP Program that contains the following elements:

1. Define institutional roles within the program
2. Delineate wellhead protection areas (WHPAs)
3. Identify potential sources of contamination in WHPAs
4. Identify management approaches to prevent pollution
5. Prepare contingency plans
6. Address protection of new wells
7. Encourage public participation in the program

TABLE 1.

Possible Health Risks Associated with Contaminated Groundwater

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, horticulture 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.		

The primary benefits to communities for establishing WHP Programs are two-fold:

- Assurance of reliable sources of high quality drinking water for the future
- Cost-savings

Once a drinking water source becomes contaminated, clean-up is difficult and expensive. In some cases, groundwater contamination has been so severe that groundwater resources have had to be abandoned. In other cases, groundwater resources have been cleaned up, but at great cost. On the other hand, developing new resources is also expensive. Effectively managing the land area around a well to *prevent* groundwater contamination offers an opportunity to preserve drinking water sources and save money.

Results of an EPA survey indicate that, on the average, clean-up of contaminated groundwater supplies may be 30 to 40 times more costly than prevention. The same study further suggests that the ratio of clean-up costs to basic prevention may be as large as 200 times (EPA, 1996a). Local businesses can also save money. Savings to local businesses have been realized through reduction in operating costs and in liability (EPA, 1996a).

WHP in Arizona

Arizona's WHP Program is designed to protect groundwater resources by actively coordinating local pollution prevention efforts with existing state programs. The state program is voluntary and designed to be locally initiated and operated, with ADEQ playing a supporting role. Locally operated programs can accommodate local economic and social issues as well as site-specific hydrogeologic conditions. Support available from ADEQ includes both assistance with program development and technical resources.

Drinking Water Monitoring Waiver Program

The SDWA requires certain regulated public drinking water systems to monitor for inorganic chemicals (IOCs), volatile organic chemicals (VOCs) and synthetic organic chemicals (SOCs). The monitoring frequencies and sampling locations vary by contaminant group making compliance with the drinking water regulations both complex and expensive.

Provisions to the State drinking water rules allow ADEQ to develop a monitoring waiver program designed to set monitoring frequencies based on a system's vulnerability to contamination. ADEQ's waiver program has been developed to allow systems with little or no vulnerability to certain sources of contamination to reduce or eliminate their monitoring and transfer these savings to facility upgrades or improvements. The monitoring waiver program is also intended to increase a system's understanding of where their water comes from, how it can become contaminated, and what measures can be taken to protect it.

The State's monitoring waiver program is predicated upon the fundamental concepts of wellhead protection. Under the monitoring waiver program, a system is required to delineate a ½-mile circular radius around each source and conduct an inventory of the different land use activities occurring within the radius. This ½-mile radius is a very minimal and basic Wellhead Protection Area delineation and the inventory is a very basic identification of potential sources of contamination.

Because the State's monitoring waiver program is based upon the fundamental concepts of wellhead protection, the State will allow public water systems to substitute a Comprehensive Wellhead Protection Program for the waiver application process. For required monitoring to be waived based on a Wellhead protection program, the WHP will have to be evaluated by ADEQ to ensure it meets the minimum requirements of the monitoring waiver program.

Source Water Protection

Source Water Protection (SWP) has become a national priority under the 1996 Amendments to the Safe Drinking Water Act (SDWA). The amendments recognize and further support the fact that much of the authority and responsibility for source water protection resides with the states, municipalities, and water suppliers. SWP programs are intended to build on current programs such as wellhead protection, sole source aquifer, and monitoring waivers. SWP also builds on such key community-based initiatives as the Watershed Approach and the Comprehensive State Groundwater Protection Program.

Resources provided under the 1996 Amendments emphasize new source water protection programs and the opportunity to use funding through state set-asides of the new Drinking

Water State Revolving Fund (DWSRF). The DWSRF can be used to finance a variety of source water protection activities. These include three possible set-asides: (1) up to 10% for a state to administer or provide technical assistance for source water protection programs within the state; (2) up to 15% for more than one of several source water protection activities (i.e., land acquisition/easements, voluntary protection and petition programs, and grants for source water assessments and wellhead protection); and (3) up to 2% for additional technical assistance to rural public water sources. DWSRF funds can also be used for public water system activities that may complement source water protection, such as operator certification and system capacity building.

Each state must have an approved Source Water Assessment Program (SWAP). A state SWAP is required to: (1) delineate the boundaries of the areas providing source waters for public water systems, and (2) identify (to the extent practicable) the origins of regulated and certain unregulated contaminants in the delineated area to determine the susceptibility of public water systems to such contaminants. Assessments are to be completed for all public water systems within the state. To avoid duplication, assessments may make use of sanitary surveys, wellhead protection programs, pesticide management plans, watershed initiatives including efforts under the Surface Water Treatment Rule, and efforts under the Federal Water Pollution Control Act (Clean Water Act). Under a new permanent monitoring relief authority established in the 1996 Amendments, a state must have an EPA-approved SWAP to implement alternative monitoring requirements for public water systems. Any public water system seeking alternative monitoring requirements under a state's permanent monitoring relief authority must have a completed source water assessment.

One of the key purposes of the assessments is to assist states, water systems, and local governments in developing the most efficient and effective SWP programs. States have many options to consider. A voluntary incentive-based approach is the Petition Program. States may establish a petition program to receive, approve, and respond to petitions from public water system operator/owners or local government entities to assist in the development of voluntary local incentive-based partnerships to (1) reduce the presence of contaminants, (2) provide financial or technical assistance requested, and (3) develop recommendations for voluntary, long-term source water protection strategies.

WHP as a Management Tool

A WHP Program can be an effective management tool for managing a community's resources. As part of the overall goal of managing local groundwater resources, community needs are defined, both in the present as well as for the future. Plans for population growth, residential development, and economic and industrial expansion can provide useful information to help community leaders determine areas that need to be protected and managed.

Watershed Management

ADEQ is in the process of developing a framework for managing water quality on a watershed basis. For this purpose, ADEQ has divided the state into 10 major watersheds. The following objectives illustrate the goals of watershed management:

- Empower local communities in setting priorities
- Encourage fair and equitable actions through public involvement
- Coordinate environmental planning and implementation with other agencies and governments
- Align ADEQ resources to achieve more efficient, effective, and responsive customer service
- Provide a sound technical basis to support environmental decisions
- Provide a forum to foster continuous evaluation and improvement of environmental programs and regulations

The three most important components of watershed-based environmental management are a common geographic focus, synchronizing activities within geographic areas, and fostering local interest and involvement in the process. This last component includes establishing partnerships among citizens, business groups, environmental advocates, and government agencies across the various levels, toward the development and implementation of a unified watershed plan. Wellhead protection is a major component of any unified watershed plan. See Chapter 5 for practical tips on how to develop a local wellhead protection program.

Chapter 2. Groundwater Hydrogeology

Where does our water come from?

The Hydrologic Cycle

The term "hydrologic cycle" refers to the movement of water above, on, and below the Earth's surface. The concept of the hydrologic cycle is important to understanding the occurrence of water in the natural environment and to the development and management of water supplies.

The hydrologic cycle involves a number of key elements (see Figure 2). Precipitation occurs as rain, snow, and hail. Precipitation wets vegetation and land surfaces and then infiltrates into the ground. Infiltration rates vary widely, depending on land use, the character and moisture content of the soil, and the intensity and duration of precipitation. Rates can vary from as much as 1 in/hr in mature forests on sandy soils to 0.1 in/hr in clayey and silty soils to zero in paved areas. When and if the rate of precipitation exceeds the rate of infiltration, overland flow or runoff occurs. Water infiltrates slowly through the soil zone to replenish groundwater resources (see Figure 3).

Water from runoff and from groundwater discharge reaches streams and rivers and eventually moves to the oceans. Evaporation from surface water bodies and transpiration from plants completes the cycle by returning water in the form of vapor to the atmosphere where it condenses as clouds. The oceans are the principal source of evaporated water because of their vast areas of exposed water surface. The oceans contain about 94% of the Earth's water (Heath, 1989). (See glossary for further descriptions of hydrogeologic terms.)

Aquifers

An aquifer is a rock unit (which includes unconsolidated sediments) that will yield water in a usable quantity to a well or spring. Water is held in pore spaces in unconsolidated geologic materials and in fractures in consolidated rock (see Figure 4).

An *unconfined aquifer* is directly overlain only by permeable rocks and soil. An unconfined aquifer may be recharged by infiltration over the whole area underlain by the aquifer because there is no barrier to stop the downward flow of water from the surface (Figure 5).

A *confined aquifer* is bounded above and below by low permeability formations. Water in a confined aquifer may be under considerable pressure from overlying rocks. The water level may be held below where it would be if it were unconfined (see Figure 5).

Groundwater Flow

Under natural conditions, groundwater is in a state of dynamic equilibrium. Over time the amount of recharge into the system equals the amount of discharge. Groundwater movement is controlled by differences in hydraulic head from one location to another. Total hydraulic head is composed of elevation head, which is the height of the bottom of a water column above sea level, and pressure head which is the energy exerted by the mass of the water column itself (another term, velocity head, can be ignored due to the low velocities of groundwater). Water moves from areas of high hydraulic head to areas of low hydraulic head to maintain an energy balance.

Fractured Rock and Karst

Changes in stress conditions in consolidated rocks create fractures. Generally such fractures are small (less than 0.05 inches) but can be extensive. The term "karst" refers to limestone terrains where dissolution has created extensive open cavities. Both fractured bedrock and karst aquifers can be confined or unconfined and can have very high flow rates under rapid recharge conditions such as storm events. Transport times across entire fractured bedrock or karst flow systems may be as short as hours to weeks, much briefer than in porous, granular aquifers (Figure 4).

Unsaturated Zone

The unsaturated zone occurs immediately below the land surface and contains both water and air in the spaces within the geologic material. Water in the spaces is at less than atmospheric pressure.

An unsaturated zone can provide a protective buffering layer above an aquifer depending on the hydraulic conductivity and adsorptive capacity of the soil material and the chemical characteristics of the contaminants of concern. Low conductivity soils such as clays and soils with a high fraction of organic carbon provide the best protection. Some contaminants such as nitrate, however, do not readily adsorb onto soil materials and may be transported long distances in soils with a high hydraulic conductivity.

Saturated Zone

In the saturated zone, water completely fills the spaces within the geologic material. The *water table* is the level in the saturated zone at which the water pressure is equal to atmospheric pressure. Below the water table, the water pressure increases with depth. The *capillary fringe* above the water table consists of small pore spaces where saturation is maintained through surface tension at less than atmospheric pressure.

Water in wells penetrating a confined aquifer may rise to levels above the top of the aquifer. Such water levels define a potentiometric or artesian pressure surface (Figure 5).

Recharge of Aquifers

Aquifers are replenished by a process known as recharge. Unconfined aquifers are recharged primarily by infiltration from the surface, either by natural precipitation or by discharges from human activities. Confined aquifers are recharged where the aquifer material is exposed to the surface or where an overlying confining layer is fractured, discontinuous, or punctured by wells.

Surface waters can recharge aquifers in areas where water tables are below the level of the stream. In arid environments in the western United States such as Arizona, many streams flow only in response to flood events during rainy seasons. Runoff from the land surface enters stream basins which are generally filled with unconsolidated alluvial sediments.

Water percolates through the stream sediments and into the unsaturated zone above the water table. From there, downward moving water can accumulate as a mound on top of the existing water table. The mound slowly disperses laterally and the water table eventually reaches a new equilibrium. As the shape of the water table changes, directions and velocities of water movement (*gradients*) can change. These changes can affect the movement of contaminants dissolved in groundwater. The water table can also be lowered due to pumping from nearby wells.

Effects of Groundwater Pumping

Pumping of groundwater alters the state of equilibrium in an aquifer. Withdrawal of water causes a lowering of water levels around the well. In areal view, this area of depressed water levels is known as the “zone of influence” (ZOI) of a well. In three dimensions, this phenomenon can be seen as a cone-shaped area centered on a well called a “cone of depression.”

The area contributing water to a well or well field is defined as the “zone of contribution” (ZOC). The areal extent of the ZOC can increase with time as water is withdrawn from the well (see Figure 6).

Riparian Areas

The Arizona Game and Fish Department inventoried riparian areas in the state and estimated 266,786 acres of riparian vegetation communities are associated with perennial waters in Arizona. This equals only about 0.04% of Arizona’s surface area. Riparian areas are especially vulnerable to fluctuations in water tables. Plant species characteristic of riparian areas rely on a dependable source of water, and their roots must penetrate the water table. If the area-wide water table drops due to pumpage such that stream-side trees and other plant species no longer have a constant water source, then the riparian plant community can no longer be sustained. This condition has already occurred in many stream basins in the state that were formerly classified as riparian. Local WHP strategies may address protection of a community’s riparian resources (ADEQ, 1994).

Chapter 3.
Arizona Hydrogeology

What are the characteristics of the land and water in my community?

Arizona has been divided into three hydrogeologic provinces (see Figure 7):

1. Basin and Range Lowlands, in southern Arizona. The Basin and Range Province is characterized by steep fault-block mountain ranges separated by broad alluvial valleys.

2. Plateau Uplands, in the northern part of the state. The Plateau Uplands Province consists of flat-lying sedimentary rocks punctuated by volcanic mountain peaks rising to over 12,000 feet.

3. Central Highlands. The mountainous Central Highlands contain rock types similar to both adjacent provinces (USGS, 1985).

The climate, physiography, and water quality varies considerably among the three provinces.

Climate

Throughout Arizona, precipitation varies widely with geography and the season. Average annual precipitation can vary from 4 inches in the Basin and Range Province along the Colorado River to over 25 inches at high elevations. In general, two seasons of precipitation are common. During July and August, precipitation occurs as brief but intense localized thunderstorms. The period of December through March is the second rainy season with precipitation occurring as region--wide gentle rains. May and June are the driest months. In the winter, snow accumulates at high altitudes which can contribute to large amounts of spring runoff (USGS, 1985).

The climate is arid to semi-arid in the basins with temperatures often exceeding 100ºF in the summertime. Evaporation is high and more than 95 percent of the precipitation evaporates or is transpired by vegetation. The high evaporation rates have a significant effect on storage reservoirs. Evaporation from Lake Mead, the largest reservoir in the United States, was estimated to be 787,600 acre-feet in 1982 (USGS, 1986).

Physiography

In the Basin and Range Province, mountains have a general north-to-northwest trend and divide the province into many broad alluvial basins. Altitude of the land surface in the basins ranges from less than 150 feet along the Colorado River to over 3,600 feet in the southeastern part of the state. Mountains range from less than 1,500 feet in the southwestern part of the state to over 10,000 feet in the Pinaleno Mountains near Safford (USGS, 1985).

Sediment thicknesses of 6,000 to 10,000 feet can occur in some basins, although other basins contain less than 1,000 feet. Depth to water in the basins can range from near the surface close to perennial streams to over 400 feet. Water levels are declining severely in some areas due to pumping. Figure 8 shows the typical structure and sequence of basin deposits.

In closed basins such as the Wilcox Basin, all ground and surface water is confined to the basin. Playa lakes form and evaporite deposits develop. Many basins that are through-flowing now were closed in the geologic past. Buried evaporite deposits can cause salinity problems in groundwater in some areas.

Thick beds of clay and silt at various depths can have very low conductivities and restrict well yields. Silt and clay layers can also form confining layers and underlying beds can be under artesian pressure. Coarse-grained strata within the alluvial basins may yield several thousand gallons per minute to individual wells. Wells that penetrate fine-grained strata may yield only a few gallons per minute (see Figure 8) (Montgomery and Harshbarger, 1989).

The Plateau Uplands are characterized by diverse rock types. Consolidated sedimentary rocks attain a maximum thickness of more than 10,000 feet. Limestone, dolomite, sandstone, and shale beds are major aquifers in some areas. Alluvial deposits are aquifers only in relatively short reaches of major stream valleys. Volcanic rocks may contain aquifers of local importance (USGS, 1985). Although sandstone and limestone aquifers contain large volumes of groundwater, the yields to individual wells commonly range from a few tens to a few hundred gallons per minute from unfractured rocks. Large yields to wells are obtained from extensively fractured rocks especially along major faults. Individual wells can range from several hundred to more than 1,500 gallons per minute (see Figure 9) (Montgomery and Harshbarger, 1989).

The Central Highlands are similar to the Plateau Uplands in that they contain aquifers in consolidated bedrock of low conductivity which yield water only where fractured or in alluvial deposits of limited extent. The mountain masses consist chiefly of dense igneous and metamorphic rocks. Because the porosity of such rocks is small, groundwater storage is limited to fractures. Yields of up to 1,000 gallons per minute have been obtained from individual wells at selected locations. Wells located in floodplain alluvium may also yield up to 1,000 gallons per minute (see Figure 10) (Montgomery and Harshbarger, 1989)

Water Quality

Chemical quality of water in the Plateau Uplands can range from 90 to 60,000 mg/L of dissolved solids in the sandstone aquifers. In the Basin and Range Lowlands, dissolved-solids concentrations are generally less than 1,000 mg/L. Brackish water, which contains 1,000 to 10,000 mg/l of dissolved solids, is present mainly adjacent to the Gila River, the Colorado River near Yuma, the Wilcox Playa area, and along the Santa Cruz River near Tucson and Casa Grande. Groundwater in the Central Highlands generally contains less than 1,000 mg/L of dissolved solids, although locally springs can yield saline water (USGS, 1985).

Chapter 4.
Groundwater Contamination

How does groundwater become contaminated?

Sources of Contamination

Groundwater can become contaminated from many types of human activities as well as from natural sources. Agricultural, commercial, industrial, and residential development can all contribute to groundwater contamination. Tables 2 and 3 describe common sources of potential groundwater contamination.

Contaminant Properties

Inorganic Chemicals

Inorganic chemicals comprise some of the most common and mobile contaminants in groundwater. Such contaminants include nitrate, ammonia, sodium, chloride, fluoride, and arsenic. Nitrate contamination from sewage and agricultural practices occurs over large areas. Salt in groundwater can be the result of road de-icing and also from upwelling of highly mineralized geothermal waters. In Arizona, buried evaporite deposits can cause groundwater to have high levels of dissolved minerals. Fluoride and arsenic can occur naturally in areas containing sediments derived from igneous rocks. Nitrate and chloride do not adsorb readily onto soil materials and can be transported great distances.

Metals, including heavy metals, are also of environmental concern. The transport of metals is controlled by their solubility. The solubility of metals is dependent on pH. The pH of water can be affected by acid drainage from mining activities. Dissolved metals can also be adsorbed onto large organic molecules in water and be transported by them.

Organic Chemicals

Organic compounds are carbon-based chemicals, some of which occur naturally. However, it is the human-produced chemicals that are of concern. These chemicals include solvents, pesticides, and other industrial chemicals. Organic chemicals are removed from groundwater by chemical reactions and microbial activity. Many organic compounds, however, particularly those containing chlorine, can remain in the subsurface for many years.

Table 2.

Typical Sources of Potential Groundwater Contamination by Land Use Category

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

Source: U.S. EPA, 1991a.

TABLE 3

Potentially Harmful Components of Common Household Products

Products	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 metal, 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 ketone
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
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: EPA, 1993

Bacteria and Viruses

The survival of disease organisms in the subsurface environment has long been a key public health concern. Artificially introduced bacteria will be eliminated more quickly than organic chemicals. However, where oxygen and nutrients are plentiful, bacteria may survive up to 8 months. Under normal conditions, coliform bacteria will reach 99.9 percent elimination in less than 8 days, while *Salmonella typhimurium* can survive up to 230 days. Virus survival is controlled by climate, clay content, clay moisture-holding capacity, and virus type. Viruses can migrate considerable distances underground. Virus migrations to depths of 200 feet and horizontal distances of 1,400 feet have been reported (EPA, 1987).

Effects of Contamination

Contamination of groundwater can result in poor drinking water quality, loss of a community's drinking water supply, high cleanup costs, high costs for providing alternative drinking water supplies, and potential community health problems. Even low levels of contamination can create health problems in especially susceptible members of the community.

The consequences of a contaminated drinking water supply can be serious. In some cases, groundwater contamination has been so severe that groundwater resources have had to be abandoned. In other cases, groundwater resources have been cleaned up, but at great cost. Even after the contamination has been cleaned up to acceptable standards, monitoring may have to continue for many years to ensure that residual contaminants left in the ground do not recontaminate groundwater.

Chapter 5.
Developing a Local Program

Five steps to develop a WHP Program
for your community . . .

A local WHP Program can be implemented by carrying out the following five steps:

1. Form a local planning committee
2. Delineate Wellhead Protection Areas
3. Locate potential sources of contamination
4. Choose appropriate management strategies
5. Provide for ongoing protection

These steps are discussed in the following paragraphs.

Step 1. Form a Local Planning Committee

For a WHP Program to be responsive to the community, a planning committee representing diverse perspectives and interests must be formed. This committee should have clear responsibility for carrying out the planning and implementation phases of the program. The membership of the committee should include local government officials who are in a position to set policy and make funding decisions, as well as community leaders who can explain and promote the program to their constituencies.

Interested parties may include:

- Members of local city and county departments such as water, waste, fire, planning, engineering, public health, and administration
- State and federal government organizations and councils of government (COGs)
- Representatives of agriculture, ranching, and business
- Representatives of neighborhood associations
- Members of local conservation/environmental organizations
- Academic and technical persons

Community service and public interest groups can provide valuable assistance with resource evaluations and contamination source assessments and often provide volunteer labor. The AARP (formerly known as the American Association of Retired Persons) has successfully coordinated with WHP Programs in several states. Designating a committee leader who is familiar with the community and with the regulatory options can add to the effectiveness of the planning committee.

Identifying Goals and Objectives

The purpose of the local planning committee is to identify local needs and to define the goals and objectives of the project. Many factors-- including degree of vulnerability of local groundwater supplies, extent of local industrial and/or farming activities, and current groundwater contamination issues--will combine to determine a community's long-term goals. Reasonable short-term goals should also be established. Initial goals and objectives can be revised and expanded as the program develops.

Step 2. Delineate Wellhead Protection Areas

A major element of a WHP Program is the determination of zones surrounding wells or well fields within which potential contaminant sources are addressed and management strategies are developed. These zones are denoted wellhead protection areas (WHPAs) and are defined by the SDWA as "the surface and subsurface area surrounding a water well or well field, supplying a public water system, through which contaminants are reasonably likely to move toward and reach such water well or well field."

Selecting methods for determining WHPAs depends upon available technical data and local community resources. Methods selected must also address unique local hydrogeologic conditions. Combinations of methods may be selected.

Whole Aquifer Protection

Arizona has designated all aquifers in the state to be drinking water aquifers, thus all aquifers, in their entirety are protected by drinking water standards. Arizona's large alluvial basins constitute whole aquifers. Zones of contribution to wells can be quite large if travel times of many years are taken into consideration. Some areas of contamination in the state extend over many square miles.

Criteria Definition and Characteristics

The U.S. EPA (1993) has recommended five criteria as the technical basis for delineating WHPAs. These criteria are discussed below.

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 method to WHPA delineation. It is only recommended as a preliminary step, however, because it does not include the processes of groundwater flow or contaminant transport.

Drawdown

Drawdown is the decline in water level elevation induced by a pumping well (see Figure 11). 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 (ZOI) or the areal extent of the well's cone of depression. Groundwater 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 WHPA.

Time of Travel

The time of travel criterion is used to represent the time it takes for groundwater 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 WHPA (see Figure 11).

Flow Boundaries

The flow boundary criterion uses determined locations of groundwater divides and/or other physical/hydrologic features that control groundwater flow to define the geographic area that contributes groundwater to a pumping well. This area is the zone of contribution (ZOC) (see Figure 11) of the well and is used as its WHPA. This approach assumes that contaminants entering the ZOC will eventually reach a pumping well. Groundwater divides occur naturally or may be artificial, such as those created by another 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 impact of contaminants before they reach a pumping well through the processes of dilution, dispersion, adsorption, 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.

Selecting the Appropriate Method

The methods for delineating WHPAs range in complexity and cost of implementation. The choice of a particular method depends on available resources, hydrologic conditions, regulatory requirements, and specific community goals and objectives (see Table 4). Data requirements, accuracy, and costs are the primary considerations. Costs associated with various WHPA delineation methods include: staff time, data acquisition costs, lab fees, costs of acquiring computer programs, and consulting services. The more sophisticated techniques involve analytical methods and/or computer modeling. Hydrogeologic field work and mapping may also be required. Private consultants may have to be hired for much of the technical work if local staff do not have the required expertise.

Methods for Delineating a WHPA

Arbitrary Fixed Radius

This approach involves drawing a circle of specified radius around each well. For example, several communities in Georgia have established 1,500 feet as a radius for a wellhead protection area. Louisiana uses a 1-mile radius for confined aquifers and a 2-mile radius for unconfined aquifers (EPA, 1993).

Local hydrogeological conditions should be considered in the choice of radius. A well located in an area with highly conductive soils may require a fairly large radius to ensure adequate protection. ADEQ's monitoring waiver program requires a ½ mile radius for its study area.

Use of a fixed radius as a method has the advantage of being inexpensive and it can be implemented quickly. Choosing a large radius can increase its protective effectiveness. Wells can be protected quickly in case of an imminent contamination threat. A disadvantage is that since the WHPA is not based on specific hydrologic mapping, recharge areas some distance from the well may not be adequately protected (see Figure 12).

TABLE 4.
Advantages and Disadvantages of Wellhead Protection Area Delineation Techniques

Arbitrary fixed radius	Few 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
Analytical methods Simplified variable shapes	Based on relatively few field data Still fairly quick and easy If data are available, low cost In complex setting, not very precise
Hydrogeologic mapping	Based on substantial field data May require professional help Can be highly accurate Moderate to high cost
WHPA code (semianalytic model)	Based on substantial field data May require technical assistance Automatic delineation of capture zones Calculates the efforts 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.	

Calculated Fixed Radius

This approach involves determining a circular boundary around a well based on a specified time of travel. The period of time chosen is estimated to be the time necessary for any potential contamination to be degraded, diluted or dispersed to safe levels before it reaches the well. Calculations can be done in the manner described below where:

Q = Pumping Rate of Well (ft^3/yr)
n = Aquifer Porosity (dimensionless)
H = Length of Well Screen (ft)
t = Travel Time Based on Hydrology and Contaminant Source Locations (years)
π = 3.1416

The advantage of this method is that it requires limited technical expertise and the required data are usually readily available. Although this method offers greater scientific accuracy than the arbitrary fixed radius, some results may be inaccurate because not all hydrogeologic factors influencing contaminant transport (such as contaminant characteristics) are considered (see Figure 13).

Analytical Methods

Sets of analytical equations can be used to calculate zones of contribution to pumping wells based on site-specific hydrogeologic data. This method uses equations that require some technical background. Zones of contribution are calculated by first computing the distance to downgradient and lateral extents of the groundwater flow boundaries around a pumping well using uniform flow equations (see Figure 14), and then using a time of travel equation (see Figure 13) to calculate the upgradient extent. This method can also use known hydrogeologic divides and aquifer boundaries (Figure 15).

More precise site-specific data is required than for the previous methods described; however, hydrologic boundaries and aquifer heterogeneities cannot be taken into account without detailed hydrologic mapping and/or the use of a numerical computer model (see below).

Simplified Variable Shapes

Standardized shapes can be produced using analytical methods and then these shapes can be applied to other wells in aquifers with known similar hydrogeologic characteristics (Figure 16). Caution must be used to ensure their appropriate application.

Hydrogeologic Mapping

This method requires a high degree of site-specific field data which may require the services of a hydrogeologist to perform field investigations, including surface geology, and geophysical data. Flow boundaries conforming to the local hydrogeology are accurately mapped and the resulting WHPA is more accurate than that calculated by the more general methods described above (see Figures 17 and 18). If good mapping of the area is already available, then this method may be relatively simple to apply, although some expertise is still required.

Computer Modeling

WHPAs can be delineated using computer models that approximate groundwater flow and solute transport. A wide variety of models are available both commercially and through public agencies such as the EPA and the U.S. Geological Survey (USGS). Analytical computer models solve standard flow and transport equations with values for hydrogeologic parameters supplied by the user. These types of models are fairly simple to use and many have user-friendly preprocessor programs that guide the user through the use of the model. The limitations of analytical models is that they make many simplifying assumptions, particularly about the existence of homogeneous conditions within the aquifer, that may produce inaccurate results.

Numerical computer models are mathematically more complex. A grid is established that overlays the groundwater system being investigated. Each node on the grid is assigned a unique set of parameter values. The program then predicts time-related changes based on solutions to large systems of equations. These programs are much more difficult to use and may require the assistance of a consultant. Their use is only justified, however, if sufficient data are available to support the data needs of the program. Where large quantities of input data must be estimated, analytical models will provide the same relative level of precision.

Selecting a Model

Models for use in WHPA analyses should be evaluated and selected using the following criteria.

- Be suitable to answer the questions raised concerning local conditions
- Have been thoroughly reviewed for accuracy and consistency
- Provide clear and understandable documentation
- Be relatively user friendly (unless the services of a consultant will be used)

Finding and Using Appropriate Data

The results calculated by the model are only as accurate as the data entered into the model. Care must be taken to use the most accurate data. Where field data are not available, estimates can be used provided valid assumptions are made concerning their application.

Data can be obtained from a variety of sources. Some are listed below:

- Arizona Department of Water Resources well registration reports
- Geologic and hydrologic reports of the USGS or the Arizona Geological Survey
- State universities
- Water Resources Research Center (WRRC) at the University of Arizona in Tucson

- Councils of government (COGs), and county and city government offices
- Public water supply companies
- Arizona Department of Environmental Quality reports and databases

The WRRC has published a booklet entitled "Where to Get Technical Information about Water in Arizona." Contact the WRRC for further information.

The source of the data should be considered with respect to accuracy. Data collected and recorded with appropriate quality assurance procedures are more accurate than unsubstantiated information. Water quality data in particular must be collected according to correct procedures and analyzed within appropriate time limits to ensure results are valid and representative of actual conditions. Also, water level and water quality data that are several years old may not represent current conditions.

Estimation of Values

Often representative data from a site are simply not available and input values to the program must be estimated. Empirical values have been developed for such aquifer characteristics as hydraulic conductivity and porosity (Table 5 and Figure 19). Chemical properties of contaminants have been compiled and are available in several standard references (Appendix B).

Interpretation of Results

The total error (or the extent to which a calculated value differs from observed values) in the model output is the product of the error associated with each of the input values. Therefore, even small amounts of error will be compounded. The output can be no more accurate than the amount of error in the least accurate parameter value. Results in some cases may have only an order of magnitude accuracy and should be viewed as qualitative rather than strictly quantitative. The ability to assess the amount of error in the program output is essential in being able to properly use the model and apply the results.

Table 5. Average Porosity Values for Selected Earth Materials	
Material	**Porosity**
Soil	55
Clay	50
Sand	25
Gravel	20
Limestone	20
Sandstone,	11
Granite	0.1
Basalt, young	11
Source: Health, 1989.	

Useful Computer Models

WHPA

WHPA was developed for the EPA's Office of Groundwater Protection. The model contains four different modules, two semi-analytical capture zone modules, a numerical module usable with flow data supplied by MODFLOW (see below), and a statistical module. The semi-analytical solutions are applicable to homogeneous aquifers exhibiting two-dimensional, steady-state groundwater flow in an areal plane. A particle tracking module traces movement of water from potential sources of contamination. WHPA is user friendly and provides a graphical output of zones of contribution around pumping wells. Figure 20 shows a typical display of a zone of contribution as generated by WHPA.

MODFLOW

MODFLOW is a numerical model developed by the USGS that simulates groundwater flow in three dimensions. The user establishes a grid and assigns a separate set of aquifer parameters to each node of the grid. This allows for much greater accuracy in predicting changes in the contours of the water table over time due to changing conditions. Node values can be entered to simulate streams or aquifer boundaries. Vertical layers with different properties can simulate aquifers and aquitards. MODFLOW can be obtained in a PC version with a pre-processor, however use of the model requires some knowledge of hydrology and computer modeling. The services of a consultant may be required.

CMLS

CMLS is an analytical model developed at the Department of Soil Science at the University of Florida. CMLS allows the user to simulate chemical movement in layered soils and can therefore be used to determine the assimilative capacity of soils. The model estimates the depth of the peak concentration of a non-polar organic chemical (such as TCE) as a function of time after release. CMLS is based on the physical processes involved in water flow, requiring readily accessible information on soils and chemicals. The model is menu-driven with results displayed in graphical form. The model can be useful in determining the capacity of soils in protecting groundwater sources through adsorption and attenuation of contaminants.

VIRALT

VIRALT was developed by the EPA to assess the transport of viruses in the saturated and unsaturated zones. The assumptions implicit in the equations used in the model also allow the program to be used to model chemical solutes. The saturated zone module assumes advection and dispersion along one-dimensional pathlines intercepting a single contaminant source and one or more pumping wells. Contaminant travel distances can be used to determine zones of contribution around wells. The model allows for biodegradation and adsorption of contaminants and therefore can be used to assess the assimilative capacity of both the saturated and unsaturated zones.

Step 3. Locate Potential Sources of Contamination

Preventing future pollution problems requires evaluating both existing and potential sources of contamination. An inventory of local contaminant sources provides the planning committee with an understanding of the degree of potential threat to groundwater as well as basic information to be used in designing management tools.

There are many sources of information about potential contamination sources: local residents, business directories, newspapers, police and fire departments, local, state and federal agencies. A review of local records can be supplemented by a field survey.

The following three steps, discussed below, will help your community locate potential sources of contamination: identify land use categories, plot potential sources on a map, and prioritize sources of contamination.

Identify Land Use Categories

A good first step is to divide the WHPA into land use categories. Land use information can help identify possible locations for specific sources of contamination. Potential sources of groundwater contamination are listed according to land use in Table 6. *Point sources* of contamination discharge waste at a single location and generally consist of pipe outfalls to surface waters. In Arizona, point source discharges are frequently to dry washes. Wastewater treatment plant discharges dominate some stream reaches which would otherwise be dry. All point sources are regulated under the Federal Clean Water Act. *Nonpoint sources* of contamination are spread over a wide area. Examples include septic system discharge, agricultural runoff, urban stormwater runoff, landfill runoff and leakage, and impacts from mining operations. Non-point sources of contamination may or may not all be covered by state and federal permitting programs.

Table 6.

Potential Sources of Groundwater 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; 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 formation	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	Pesticides[5], 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***[1]: 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]

Source	Health, Environmental, or Aesthetic Contaminant[1,2,3]
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]
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 anticorrosive (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 well	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

Source	Health, Environmental, or Aesthetic Contaminant[1,2,3]
Artificial groundwater 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]
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
Campgrounds	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 sludge
Gasoline service 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, florist	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

Source	Health, Environmental, or Aesthetic Contaminant[1,2,3]
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 sludge, cyanide, 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
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 oils; solvents; gasoline and diesel fuel 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; insecticides[17]
Industrial Sources	
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	Brine associated with oil and gas operations
Industrial Processes (Presently Operated or Torn-Down Facilities)[18]	

Source	Health, Environmental, or Aesthetic Contaminant[1,2,3]
Asphalt plants	Petroleum derivatives
Communications equipment manufactures	Nitric, hydrochloric, and sulfuric acid wastes; heavy metal sludge; 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
Furniture and fixtures manufacturers	Paints; solvents; degreasing sludge; solvent recovery sludge
Machine and metalworking shops	Solvents; metals; miscellaneous organics; sludges; oily metal shavings; lubricant and cutting oils; degreasers (tetrachloroethylene); 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 brine (highly mineralized salt solutions)
Industrial pipelines	Corrosive fluids; hydrocarbons; other hazardous and nonhazardous materials and wastes[16]
Photo processing laboratories	Cyanides; biosludges; 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; gylcols; 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

Notes

[1]In general, groundwater 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 agriculture, 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, groundwater contamination is not likely to occur.

[2]Contaminants can reach groundwater 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 groundwater 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 naphthalene, 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 phenols, and cresols.

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Plot Potential Sources on a Map

Once all potential sources of contamination have been identified, each source should be plotted on a map of your WHPA. Many city and county engineering departments have access to Geographical Information Systems (GIS) programs. GIS can be used to create maps and to store and process information about contamination sources. AutoCAD programs for personal computers also provide useful graphical tools. Information can also be plotted on USGS topographical maps or other maps of the community such as city water or sewer system maps.

Prioritizing Sources of Contamination

After an inventory of potential contamination sources has been completed, your community may wish to prioritize the sources based on the degree of threat and the need for controls. Some activities that pose a risk to groundwater may already be covered by existing regulatory controls, however other sources may not be addressed. In addition, communities may wish to use scarce resources to address more significant threats to groundwater immediately and address additional potential sources as resources become available. Table 7 lists land uses and their relative risk to groundwater.

Step 4. Choose Appropriate Management Strategies

Strategies for managing WHPAs should be appropriate to the specific needs of the community. Many WHPA management programs can be implemented easily and at low cost. Enforcement of existing regulatory controls may be adequate to ensure protection. In other cases, additional protection measures may be needed.

Existing Regulatory Programs

Federal Programs

The **Safe Drinking Water Act** (SDWA) provides EPA and states with authority to ensure that drinking water supplied by public water systems meets minimum health standards. In addition, the SDWA regulates the use of certain wells for waste disposal and establishes the WHP Program. The Sole Source Aquifer Program (SSA) provides for EPA review of projects that are financially assisted through federal grants and loan guarantees. These projects are evaluated to determine whether they have the potential to contaminate a SSA. If there is such a potential, the projects must be modified or federal funding can be denied. To date, EPA Region 9 has designated two SSAs in Arizona, the Upper Santa Cruz-Avra Basin Aquifer and the Naco-Bisbee Aquifer. The 1996 Amendments to the SDWA require states to implement Source Water Assessment and Protection measures (see Chapter 1).

The **Resource Conservation and Recovery Act (RCRA)** sets standards for the design, operation. and cleanup of hazardous waste facilities. RCRA also regulates underground storage of petroleum and other hazardous substances, and municipal solid waste landfills.

The **Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA),** also known as Superfund, was established to clean up abandoned hazardous waste sites, including those that threaten drinking water supplies.

Table 7.

Land uses and Their Risk to Groundwater

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.	6.	Field crops: pasture, hay, grains, vegetables
		7.	Low density residential: lots larger than 2 acres
↓		8.	Churches, municipal offices
	C.	9.	Agricultural protection: dairy livestock, poultry, nurseries, orchards, berries
		10.	Golf courses, quarries.
		11.	Medium density residential: lots from ½ to 1 acre
↓	D.	12.	Institutional uses: schools, hospitals, nursing homes, prisons, garages, salt storage, sewage treatment facilities
		13.	High density housing: lots smaller than ½ acre
		14.	Commercial uses: limited hazardous material storage and only sewage disposal
↓	E.	15.	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
		16.	Industrial: all forms of manufacturing and processing, research facilities
Greatest		17.	Underground storage of chemicals, petroleum
Risk		18.	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: Adopted from U.S. EPA, 1989

The **Superfund Amendments and Reauthorization Act (SARA) Title III** requires businesses to notify governments of potentially hazardous substances stored or managed onsite. This information can be useful in identifying potential sources of contamination.

The **Clean Water Act (CWA)** requires states to restore and maintain the chemical, physical, and biological integrity of the nation's waters. States are to establish water quality standards as goals to be achieved for designated uses of navigable waters. The Act is currently limited to surface water and groundwater shown to have a connection with surface water, and sets standards for allowable pollutant discharges. Point source discharges are unlawful except in accordance with the requirements of the National Pollutant Discharge Elimination System (NPDES) permit program. There are currently no regulatory provisions related to nonpoint sources of pollution, making WHP an important management tool for such sources.

The **Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA)** was established to set standards for the registration and use of pesticides. Pesticides are potential contaminants of groundwater supplies, especially in rural areas.

Arizona's Programs

The **Environmental Quality Act (EQA)** of 1986 established ADEQ as the responsible agency for all purposes of the Clean Water Act, Safe Drinking Water Act, and the Resource Conservation and Recovery Act. The state has implemented programs to enforce these acts. The EQA also established additional programs described below.

- Under the **Aquifer Protection Permit (APP) Program,** facilities that discharge pollutants either directly into an aquifer or onto the land surface in a manner that could pollute an aquifer must obtain an APP. Discharging facilities include surface impoundments, solid waste disposal facilities, mining waste piles and pounds, septic tank systems with a capacity greater than 2,000 gallons per day, sewage or sludge ponds, wastewater treatment facilities, and point source discharges to navigable waters. The program also includes agricultural general permits consisting of best management practices for regulated agricultural activities.
- The **Water Quality Assurance Revolving Fund (WQARF)** provides funds for investigation, monitoring, risk assessment, and remediation of hazardous substances which may pose a hazard to waters of Arizona. Investigation and mitigation of non-hazardous substances can also be funded through WQARF.
- The **Underground Storage Tank (UST) Program** is designed to locate and remediate leaking underground storage tanks and to prevent future releases from USTs. The program consists of notification requirements, technical standards for new and existing USTs, leak detection and closure criteria, and financial responsibility demonstrations.
- The **Nonpoint Source (NPS) Water Quality Management Program** seeks to identify and control pollution from NPS discharges. Some of these activities are covered by Aquifer Protection Permits, while others are being addressed through the development of best management practices.

The **Groundwater Management Act (GMA)** was passed in 1980 to prevent overdrafting of groundwater in several critical areas of the state. The GMA requires the Arizona Department of Water Resources to administer safe yield and 100-year assured water supply requirements for the state. The Act covers designation of groundwater basins, restrictions on transporting groundwater, well registration, and requirements of land developers to evaluate and report water availability.

Minimum Well Construction Standards. All wells installed in Arizona since the passage of the GMA in 1980 are subject to minimum well construction standards, which contain safeguards to prevent contaminants from entering wells from surface sources. The Arizona Department of Water Resources (ADWR) administers these standards. ADWR also has the authority to impose special well construction requirements for new or replacement wells in areas of poor quality water. ADWR does not have authority to compel abandonment or modification of existing wells for water quality reasons.

Local Programs

Local management tools may include ordinances that regulate industrial practices, wastewater discharges, household hazardous waste collection, and floodplain and riparian area protection, as well as fire, building, and zoning codes. Local governments can have regulatory authorities delegated to them by the state. A list of wellhead protection tools for local governments (prepared by Horsley and Witten, 1980) is summarized in Table 8.

TABLE 8.

Summary of Local Wellhead Protection Tools

Tools	Applicability to Wellhead Protection	Land Use Practice	Legal Considerations	Administrative Considerations
		Regulatory: Zoning		
Overlay Groundwater 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 in 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 groundwater 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 groundwater 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 groundwater 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.

Tools	Applicability to Wellhead Protection	Land Use Practice	Legal Considerations	Administrative Considerations
Cluster/PUD Design	Used to guide residential development 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., with in 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 enforce growth control ordinances.
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.

Tools	Applicability to Wellhead Protection	Land Use Practice	Legal Considerations	Administrative Considerations
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 Regulation				
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 follow-up 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 follow-up and enforcement.
Septic Cleaner Ban	Used to prohibit the application of certain solvents septic cleaners, a known groundwater containment, 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 groundwater quality.	Difficult to enforce even with sufficient administrative support.

Tools	Applicability to Wellhead Protection	Land Use Practice	Legal Considerations	Administrative Considerations
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 groundwater quality.	Significant administrative resources required for this option.
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 groundwater.	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 groundwater.	Requires administrative support and review of applications.
Non-regulatory: Land Transfer and Voluntary Restrictions				
Sale/Donation	Land acquired by a community within WHPAs, either by purchase or donation. Provides broad protection to the groundwater 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.

Tools	Applicability to Wellhead Protection	Land Use Practice	Legal Considerations	Administrative Considerations
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 with 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 groundwater quality within WHPAs.	Communities establish groundwater monitoring program within WHPAs. Communities require developers within WHPAs to monitor groundwater quality downgradient from their development.	Accepted method of ensuring groundwater 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.
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.

Tools	Applicability to Wellhead Protection	Land Use Practice	Legal Considerations	Administrative Considerations
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 groundwater 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.				

Step 5. Provide for Ongoing Protection

To ensure the long-term success of a WHP Program, the program should be reviewed and updated regularly, probably yearly. This review will allow the planning committee to assess the effectiveness of management strategies and also provide an opportunity to modify the plan based on new information about contaminant sources.

A regular water quality monitoring program can determine the effectiveness of a community's protection plan. This may require additional water quality testing beyond current state drinking water requirements. Monitoring wells may have to be installed between public supply wells and potential contaminant sources. Such monitoring is particularly necessary in tracking the movement of known contaminant plumes. Factors to consider in a monitoring program are the geographical area to be sampled, frequency of sampling, constituents to be tested, and required sampling protocols.

Identify Potential Future Sources of Contamination

An important aspect of the community protection plan is to identify potential future hazards that may threaten your WHPAs. Community and regional master development plans should be checked to determine if future development could potentially impact a community's wellfields. The planning committee can then pursue adequate protection measures. Often such development plans can be modified. A planning committee should also consider statewide infrastructure plans such as highways, canals, and dams.

Site New Wells in Low Risk Areas

Protection of new wells is an important part of a WHP Program. New wells should be located such that the risk of contamination is reduced as much as possible. Well sites should be chosen based on a complete area-wide contamination source assessment and a review of all future development plans.

Develop a Contingency Plan

Another important aspect of a community program is the development of a contingency plan. This ensures that the community has an alternate source of drinking water in case of an emergency, such as an accidental chemical spill. A long-term contingency plan may also be necessary in case a drinking water source becomes permanently impaired.

Public Education

Public support is important for the success of any program. The public can be informed about the program through press releases to newspapers and radio stations, newsletters, brochures included with water bills, public presentations at schools and community organizations, and the development of slide shows and video tapes. Voluntary committees can assist with the implementation of public education and groundwater protection programs.

Funding

The EPA has provided grants to assist communities in developing local WHP projects. Information regarding grant funding can be obtained from:

- Water Division
  U.S. EPA, Region IX
  75 Hawthorne Street
  San Francisco, CA 94105
  415/744-1835

EPA Technical Documents

The EPA's Office of Ground-Water Protection has developed many technical documents to assist local governments interested in developing WHP Programs, including the following:

- WHP Programs: Tools for Local Governments (April 1989)
- Wellhead Protection: A Guide for Small Communities (February 1993)
- Ground Water and Wellhead Protection (September 1994)
- Ground Water Resource Assessment (October 1993)
- Model Assessment for Delineating Wellhead Protection Areas (May 1988)
- Guidelines for Delineation of Wellhead Protection Areas (June 1987)
- Ground Water Volume I: Ground Water and Contamination (September 1990)
- Ground Water Volume II: Methodology (July 1991)
- Wellhead Protection: a Decision Maker's Guide (May 1987)
- Protecting Ground Water: Pesticides and Agricultural Practices (February 1988)
- Septic Systems and Ground Water Protection, A Program Manager's Guide and Reference Book (July 1986)
- Guide to Ground-water Supply Contingency Planning for Local and State Governments--Technical Assistance Document (May 1990)
- Benefits and Costs of Prevention—Case Studies of Community Wellhead Protection—Volumes 1 and 2 (March 1996)
- Business Benefits of Wellhead Protection—Case Studies (March 1996)

Copies of these or other EPA materials can be obtained through the Water Division, U.S. EPA, at the address listed above.

Conclusion

The process of wellhead protection can easily be approached one step at a time. The five-step process outlined above can be an effective method for a community to prevent contamination to its drinking water sources. The whole community will benefit from the assurance of high quality drinking water into the future and the savings of financial resources.

For further information on wellhead protection or to obtain assistance in developing a program for your community, contact state WHP coordinator Moncef Tihami, Drinking Water Section, Arizona Department of Environmental Quality, 3033 North Central Avenue, Phoenix, 602/207-4425 or 1/800/234-5677.

Chapter 6.
Case Studies for WPA Delineation

Tucson, Arizona

The Pima Association of Governments (PAG) in Tucson developed a pilot WHP Program for Tucson Water, the city-owned and operated water department (PAG, 1994). This project, as well as the following case studies, was funded by a grant from the EPA. Tucson Water is a major metropolitan water utility and operates a large distribution system with over 200 wells.

Instead of WHPAs with closed boundaries, PAG chose an approach that determined zones of contribution around wells that were open-ended in the up-gradient direction from the well. The potential contaminant risk to each well was then determined based on the distance from that well to each type of contaminant source within the upgradient zone of contribution. A matrix was then constructed with all the wells in the system versus each type of contaminant source. The distance from the well to the nearest contamination source of each type was entered into the matrix. Each well was then placed into a risk category based on overall risk determined from the matrix.

The matrix contains distances in miles from each well to the nearest upgradient contaminated well, leaking underground storage tank (LUST), landfill, irrigated agricultural area, sludge/effluent disposal site, and industrial area. Distances were measured electronically using CAD software. Upgradient was defined as anywhere above the well within a 45-degree angle oriented along the regional flow direction, as well as anywhere within a 0.3 mile radius around the well to account for lateral dispersion (see Figure 21). Figure 22 demonstrates PAG's approach applied to a specific well. These criteria were based on inspection of the dimensions and orientations of existing plumes.

Each well was assigned to one of five risk categories, based on the distances to upgradient potential pollution sources. The categories can be used to estimate the relative risk of a well exceeding a maximum contaminant level (MCL) in the future. The system does not assign point values to wells in order to avoid misleading comparisons. The categorization is most useful as a summary of the information in the matrix, and as a starting point for more detailed analyses. The criteria used for the categorization relied on the following assumptions:

- The precision of the measurements is adequate for categorizing wells in a general way;
- The closer a well is to a contaminated well or a potential pollution source, the greater its chances of becoming contaminated;
- Previous cases of well contamination can be used to determine what poses a reasonable risk to active wells;
- Potential pollution sources and existing groundwater contamination are not likely to effect upgradient wells;

- Existing groundwater contamination poses a greater risk to a well than potential pollution sources;
- Trihalomethanes (THMs) in samples from drinking water supply wells are disinfection by-products, and do not originate in the surrounding groundwater;
- For purposes of wellhead protection, a general risk categorization can be based on distances alone without consideration of hydrogeologic factors;
- A LUST does not pose a reasonable risk to a well unless it is adjacent to it; this is based on historical data showing that less than one percent of LUSTs have impacted public-supply wells (PAG, 1992); adjacent is defined as being within 0.2 miles, which is the precision of the distances reported;
- Discharges from landfills and industrial areas which have not already been shown to have impacted groundwater quality are not likely to cause MCL exceedences in wells more than one mile downgradient; this is based in part on data from the 1992 WHP study, but, more importantly, on the assumption that recently adopted environmental regulations will prevent activities which could lead to large scale contamination;
- Nitrate sources do not pose a reasonable risk of contamination to wells more than one-half mile downgradient; this is based on data from the 1992 WHP study which reported distances between nitrate sources and contaminated public-supply wells.

Using these assumptions, PAG developed the following criteria for the risk categories. A well was assigned to a category if it met the condition of that category without meeting the condition of a higher risk category. Wells currently containing a contaminant at concentrations greater than an MCL were denoted with an asterisk in the matrix. The categories and criteria, from highest risk (A) to the lowest risk (E) were:

A. Well is within 1 mile of an upgradient contaminated well, and has been confirmed to contain VOCs (other than trihalomethanes) at quantifiable concentrations that are currently below MCLs;

B. Well is within .5 miles of an upgradient contaminated well, but does not contain VOCs; OR well is within .2 miles of an upgradient landfill;

C. Well is within .5 miles of an upgradient landfill or industrial area; OR well is within .2 miles of a LUST;

D. Well is within 1 mile of an upgradient contaminated well, landfill, or industrial area; OR well is within .5 miles of an upgradient agricultural area or wastewater treatment facility.

E. Well is more than 1 mile from the nearest upgradient contaminated well, landfill, or industrial area; AND the well is more than .5 miles from the nearest upgradient agricultural area or wastewater treatment facility.

A representative portion of the supply well/contaminant source matrix is presented in Table 9, which shows the distances between Tucson Water potable supply wells and the nearest upgradient potential pollution sources. The wells are arranged by Township, Range, and

Section. The risk category for each well is listed in the far right column. Table 10 lists wells in the two highest risk categories A and B. Most of these wells are located near one of three known major contaminant plumes. Table 11 shows the numbers and percentages of wells assigned to each category. Overall, the results indicate that Tucson Water's potable supply wells are at a fairly low risk of becoming contaminated, and that the highest risk wells (A & B) supply less than 13% of the potable water delivered to Tucson Water's customers (Table 11).

TABLE 9.

Distances in Miles from Selected Potable Supply Wells to Nearest Upgradient Potential Contaminant Sources

Well Name	Location				Distance To Potential Contaminant Source (Miles)						Category
	T	R	SEC	QQQ	Contamination Well	Landfill	Industry	LUST Site	Agriculture	Effluent Disposal	
W-002 A	11	10	20	DCC					0.0		D
W-001 A	11	11	31	CBC				3.6	0.2		D
1-002 B	11	14	4	BBC	NA	NA	NA	NA	NA	NA	NA
1-001 A	11	14	4	CCB	NA	0.2	NA	0.1	NA	NA	B
W-004 A	12	10	4	ACD					0.0	2.8	D
SC-014 A	16	14	21	DBB	0.0						*
AF-012 A	12	10	12	BCD					0.0		D
Y-001 A	12	12	22	DCD		1.3	2.5	2.1	0.0	0.8	D
C-102 A	12	13	7	DDD							E
C-117 A	12	13	17	BCD							E
SS-020 A	15	13	2	ACA	0.0		0.7	1.7			*
B-106 A	12	13	18	BCC							E
B-109 A	12	13	20	DAD			1.2		1.1		E
C-096 A	12	13	26	CDB			4.4	1.4	1.6		E
Z-017 A	12	13	31	BAA			0.9	1.9	2.8		D
Z-013 A	12	13	31	CCC	2.9	3.0	0.2	0.1	1.8		C
SC-019 A	16	14	25	BBB	0.5						B
SC-026 A	16	14	25	CCC	0.5						B
SC-027 A	16	14	26	CCC	1.4						E
SC-022 A	16	14	28	CCB	3.3				0.3		D
SC-021 A	15	13	2	CAA	0.3		0.3	1.4	0.3		A

	Location				Distance To Potential Contaminant Source (Miles)						Category
SC-018 A	15	14	18	BBB	0.2	4.3	1.4	1.4			A
SC-031 A	17	14	2	BAA							E
SC-024 A	17	14	4	ACA							E
SC-023 A	17	14	4	BCB							E

Notes:

* - Well already contains contaminants at concentrations greater than MCLs.

NA - Data not available; upgradient area is outside of study area

Blank Cell - No source within 5 miles of well

T,R,SEC,QQQ - Township (south), range (east), section, quarter-quarter-quarter section

Source: PAG, 1994.

TABLE 10.
Wells in Categories A and B

Well Category	Well Name	
A	B-085 A	
	C-114 A	
	SC-018 A	
	SS-015 A	
	SS-021 A	
B	B-084 A	SC-019 A
		SC-021 A
	B-103 A	SC-026 A
	C-020 B	SS-001 A
	D-041 A	SS-010 A
	E-008 A	SS-012 A
	I-001 A	SS-018 A
	SC-006 A	SS-023 A
	SC-009 A	Z-002 A
	SC-011 A	
	SC-016 A	

Source: PAG, 1994

TABLE 11.
Numbers and Percentages of Wells in Each Category

Well Category	Number of Wells	Percentage of All Wells
A	5	2.5
B	19	9.5
C	53	26
D	37	18
E	84	42
*	3	1.5

Source: PAG, 1994

Gila River Indian Community, Arizona

The Gila River Indian Community (GRIC) occupies an area of nearly 600 square miles in Central Arizona and is the home of approximately 8,500 members of the Pima and Maricopa Tribes. Community members live primarily in 22 small villages, many of which represent sites occupied by the tribe's ancestors for over 400 years. Climatic conditions of GRIC are characterized by hot summers and mild winters. Daytime summer temperatures exceed 100◦ F. Winter temperatures are in the sixties. Mean annual rainfall for Sacaton, the community's largest population center (1,452 population in 1990), is 8.37 inches. Most of the precipitation falls during two rainy seasons, December to March, and July to September.

The geology of the GRIC is characterized by broad sloping alluvial valleys bounded by generally northwesterly trending mountain ranges. Two principal sedimentary units function as aquifers and include the Upper Alluvial Unit and the Lower Conglomerate Unit. Another unit the Middle Silt and Clay Unit is found in deeper basins and separates the other two units where it is found. The Middle Silt and Clay Unit yields only small amounts of water. Groundwater flows can change magnitude and direction in response to seasonal agricultural pumping and river recharge events.

In delineating WHP areas, the first step was to determine an overall groundwater budget for all areas within the boundaries of the GRIC. Inputs to the groundwater reservoir were considered to be agricultural runoff, irrigation canal leakage, Gila River recharge, mountain front recharge, infiltration from precipitation, and basin groundwater inflow from the southeast. Outflows were considered to be pumpage from agricultural, domestic, industrial, and commercial uses, and basin outflow to the west. Values for each variable were estimated and the total change in storage was estimated to be +87,100 ac-ft/yr for the years 1982-92.

Next, a groundwater flow model, MODFLOW, was used to simulate water level conditions based on the budget estimates and on measured water levels throughout the GRIC. Then, a particle-tracking model, which tracks the movement of potential contaminants, was used in conjunction with MODFLOW to establish zones of influence based on 5 to 40 year times-of-travel around eleven public supply wells (see Figure 23). This program was developed by CH2M HILL and Lee Wilson and Associates (1994) for the GRIC.

Fernley, Nevada

Fernley, Nevada is located in western Nevada, 35 miles east of Reno along Interstate Highway 80 (see Figure 24). The economy of Fernley has been historically dominated by agriculture. Recent development has been primarily residential due to its proximity to the Reno-Sparks area and the arrival of light industrial manufacturing in town. The population of Fernley is approximately 7000 and the town is situated at 4150 feet elevation in a broad alluvial fault-block valley surrounded by mountains. The climate is arid with a average annual precipitation of 4.7 inches, most of which occurs during the winter. The average July temperature is 73.70 F, and the average January temperature is 34.10 F.

The valley fill deposits are composed of alluvium and Pleistocene lake sediments. Much of the valley fill is of low permeability, however buried beach deposits of moderate to high permeability are the primary water production sources. The uppermost aquifers in the area are generally unconfined. Deeper aquifers are generally confined. The nature and extent of these confined aquifers is not well known, but they are an important source of water. Water-table elevations are generally 10 to 20 feet lower in the confined aquifers than in the unconfined aquifers. Water levels in public supply wells range from less than 25 feet to more than 250 feet.

Recharge comes from two sources. Precipitation from high altitude areas of the basin contribute about 600 ac-ft/yr. Second and most significant is water from the Truckee Canal and cropland irrigation. Seepage from the canal and diversions for agriculture total approximately 45,000 ac-ft/yr. Major discharges from the basin are evapotranspiration from croplands and riparian areas, lake evaporation, underflow to other basins, and pumpage for industrial and public water supply.

For delineation of the WHPAs in the Fernley public water supply well system, the computer program, WHPA, developed by the U.S. Environmental Protection Agency was employed. The program was chosen because it is cost effective and enough data were available to justify using the method. The program establishes zones of contribution (ZOCs) based on time-of-travel (TOT). Twenty-five year TOTs were selected. Watersource Consulting Engineers, Inc. (1994) developed this program for the town of Fernley.

Nogales, Arizona

BACKGROUND

Nogales, Arizona is located in the southern part of the state along the international border with Mexico. The estimated 1995 population was 20,700 (Arizona Department of Economic Security). Directly across the border lies Nogales, Sonora whose estimated 1995 population was 133,500 (Mexican National Institute for Statistics, Geography, and Information). Population estimates for Nogales, Sonora that include Acolonias@ or unincorporated areas are 250,000 or higher. Population in unincorporated areas has grown rapidly and the city has not been able to keep up with infrastructure requirements.

The International Waste Water Treatment Plant (IWWTP), located 9 miles north of the international border, treats sewage from the collection systems of both Nogales, Arizona and Nogales, Sonora. The first IWWTP was built in the 1930s to serve both communities. Treated sewage is discharged into the Santa Cruz River just downstream from its confluence with Nogales Wash. Nogales Wash, a major tributary of the Santa Cruz River, originates in Mexico, flows north through Nogales, Sonora, across the border, and through Nogales, Arizona before joining the Santa Cruz River. Almost half of the population of Nogales, Sonora live in unsewered areas. Waste water and raw sewage flow directly into local drainages and then into Nogales Wash. Deficiencies in the Nogales, Sonora sewage collection system result in additional flows of raw sewage and nonpoint runoff into Nogales Wash. Monitoring studies along Nogales Wash have found high fecal coliform bacterial levels, ammonia, heavy metals, and the parasites *Giardia* and *Cryptosporidium* in surface water. Potential for contamination by surface water into the shallow aquifer has been a public concern.

A study by the Arizona Department of Environmental Quality found low levels of volatile organic carbon compounds in groundwater wells along Nogales Wash. A federal RCRA site, United Musical Instruments, is located near public supplies wells in the Potrero Creek basin. Solvents used in metal plating were leaked into groundwater at this site. Industrial facilities or Amaquiladoras@ situated along the Mexican side of the border have often been criticized for poor waste disposal practices. Improperly maintained solid waste dumps in Mexico have also been indicated as possible sources of both air and groundwater pollution

An epidemiological study by the University of Arizona conducted in 1994, found anomalous disease clusters in Nogales, Arizona for lupus and multiple myeloma. Concern that these diseases may have been caused or influenced by environmental contamination prompted the community to implement a wellhead protection program to protect drinking water supplies. A technical committee was formed to determine WHPAs for the City of Nogales/Santa Cruz County Wellhead Protection Program. The committee determined WHPAs for six public supply wells owned by the City of Nogales and seven wells owned by the Valle Verde Water Company, a private water company serving portions of the city (see Figure 25).

GENERAL DESCRIPTION OF METHODS

Zones of contribution for wells in the City of Nogales (1997) program were determined by first using the WHPA computer model developed by the U. S. Environmental Protection Agency (see description of the WHPA model in chapter 5). Starting with the zones of contribution determined by the model, the technical committee then examined other hydrogeologic, topographic, and water quality information available for the area in order to determine more representative hydrogeologic boundaries. This additional information included mapping of Younger and Older Alluvium units, flood plain mapping, and data regarding down-stream impacts of the IWWTP discharge. In general, the committee considered three questions for each WHPA:

1. How far upstream should the WHPA be extended within each valley, based on the results of the WHPA model? All the way to the headwaters, or to some point less distant from the wells?

2. To what degree do the wells seem to be influenced by surface water conditions, such that surface water transport of contaminants may also be improved?

3. From a practical point of view, can the WHPA be successfully managed as a single unit, or is it so large that it needs to be divided into "higher" and "lower" protection areas?

The response to these questions are given below for each WHPA. It is important to emphasize that the WHPA delineations described below have been based on the technical committee's best professional judgment of the available information. Because these data were not sufficient to pinpoint exact boundaries of recharge areas, it is likely that new data collected in the field could demonstrate that the boundaries should be modified. Thus, the WHPA delineations should be considered open to change in the future if better data become available. In addition, the technical committee agreed that the designation of "higher" and "lower" protection areas will refer to a general principle of more stringent protection in the higher protection areas and less stringent protection in the lower protection areas.

Potrero Creek WHPA

Potrero Creek is a tributary of the Nogales Wash. The Potrero Creek basin is a small mountain stream valley of approximately fourteen square miles. The City of Nogales has three public supply wells located in the lower part of the basin. The aquifer in the basin is composed of a layer of partially cemented Tertiary alluvium that overlays a low permeability conglomerate. Data supplied by the ADWR indicate that the water table is approximately 100 feet below the land surface and the saturated thickness averages 100 feet in the lower (downstream) half of the basin. The Older Alluvium (Tertiary to Quaternary) thins out in the upper part of the basin. A narrow, thin layer of Younger Alluvium (Quaternary) overlays the Older Alluvium but lies above the saturated zone and is not a source of water. The three City of Nogales wells pump water from the Older Alluvium.

The following parameters were selected for use with the WHPA model. A transmissivity for the Older Alluvium of 2,674 square feet per day (ft^2/d) was used for calculations based on data from the ADWR. An average hydraulic gradient of 0.015 was determined from a topographic map of the area. The wellfield was treated as a single well with an average discharge (pumping) rate of 1,200 gpm, based on information provided by the City of Nogales. A conservative estimate of 0.25 was used for the average aquifer porosity. The above data were then used to calculate a 50-year zone of contribution.

The resultant zone of contribution calculated by the WHPA model filled much of the basin, including the small wetland in the area. Decreases in aquifer thickness, as well as increases in hydraulic gradient at the margins of the basin, effectively extend the boundaries of the zone of contribution to include the entire basin. Since the Potrero Creek basin is a small, confined area, a potential contaminant source anywhere in the basin would become a threat to the groundwater wells. Thus, the answer to question #1 (above) was that the delineation should be extended as far as the headwaters, which is the topographic limit of the basin. In addition, although these wells are not considered to be directly influenced by surface water, the small size of the basin, the potential for movement of contaminants to the wells from any point, and the fact that the basin is a manageable size all contributed to the technical committee delineating the entire basin as the Potrero Creek WHPA.

Santa Cruz WHPA

In contrast to the Potrero Creek watershed, the Santa Cruz River basin is very large, covering hundreds of square miles and containing several major sub-basins. The Santa Cruz River originates in the United states, flows south into Mexico, and then turns and flows back into the United States just east of Nogales. The City of Nogales, Arizona, has three public supply wells located in the Santa Cruz River basin approximately four linear miles north of the international border. The City of Nogales, Sonora, has a wellfield location in the Santa Cruz River basin at Mascareñas, approximately two linear miles south of the border. The Younger Alluvium layer is much thicker here than in Potrero Creek, averaging 85 feet, with a saturated thickness averaging 70 feet, The Younger Alluvium in the Santa Cruz basin forms a major part of the water-bearing formation.

The City of Nogales, Arizona, has identified two areas near the Santa Cruz River for the development of additional sources of public drinking water: the Guevavi Ranch area, located approximately four linear miles northwest of the present wellfield, and an area of City-owned property west of and adjacent to the Santa Cruz River, and north of and adjacent to the international border. These areas were included in consideration of the Santa Cruz WHPA.

Transmissivities can be very high in the Younger Alluvium, up to 55,000 ft^2/d. Even with a more moderate gradient (relative: to the Potrero Creek basin) of 0.008 along the Santa Cruz River and a greater porosity of 0.35, the 50-year zone of contribution calculated by the WHPA model extended well over 30 miles upstream. In addition, the gradient increases significantly in major sub-basins containing substantial thicknesses of younger alluvium. These steeper gradients, associated with steeper topography, would tend to increase the velocity of both surface flows and groundwater. Thus, in regard to question #1 (above), the technical committee determined that this WHPA should be extended to the topographical limits of the major tributary canyons, which are: Cumero Canyon, Proto Canyon, Yerba Buena Canyon, Cañada de la Paloma, Wild Hog Canyon, and Providencia Canyon.

With regard to how far upstream along the main channel of the Santa Cruz River the WHPA should be extended, the committee reviewed data from the IWWTP showing that the impacts of the, discharge could be detected 7 miles downstream according to a number of water quality parameters, and potentially as far as 14 miles downstream for some water quality parameters. Considering the high transmissivity of the Younger Alluvium in this area, and these data from the IWWTP, the technical committee concluded that, from a strictly technical perspective, this WHPA should extend at least 14 river miles upstream of the Santa Cruz Wells. However, this southern extent of the WHPA is considered to be flexible because of the fact that it goes well into Mexico and encompasses the Mascareñas wellfield. The committee members recognize they have no authority to implement any wellhead protection activities in Mexico; only Mexican representatives could do so, if they are so inclined. The committee members also recognize that, due to the location of the Mascareñas wellfield, Mexican representatives may, in fact, have an interest in conducting their own activities to protect water quality in this area, and possibly in areas even further upstream, as well. Thus, in consideration of Mexican national sovereignty, and of the undetermined potential need for protecting the Mascareñas wellfield, the southern extent of the Santa Cruz WHPA remains flexible.

Finally, the committee considered questions #2 and #3 (above) together. According to information provided by the City of Nogales, the Santa Cruz Wells are likely to be directly influenced by the water quality of instream flows when the river is flowing due to storm events. In addition, because this basin is very large, the committee identified the need to identify higher and lower protection areas to make the area more manageable. Because of the potential influence of surface water flows, the committee delineated the higher protection areas as a one-half mile buffer zone on either side of the main channel and major tributaries listed above, with the lower protection areas encompassing the remainder of the watershed to a point of 14 river miles upstream from the wells.

Valle Verde WHPA

The Valle Verde wells are located along the Nogales Wash at several locations north and south of its confluence with Potrero Creek. The Nogales Wash is a major tributary of the Santa Cruz River and contains a thick layer of Younger Alluvium. Inputs to the WHPA model were chosen to be the same as those used for the Santa Cruz WHPA. The results of this modeling showed that, although this area may be somewhat less transmissive than the Santa Cruz area it is still significantly more transmissive than the Potrero Creek area. For this reason, the committee determined that, from a strictly technical prospective, the WHPA should extend upstream to the headwaters, which is the topographic limit of the watershed. Including the whole watershed as the WHPA made the issue of whether these wells could be influenced by surface water a moot question for delineation purposes. Finally, with regard to whether the area should be divided into higher and lower protection areas, the committee determined that the whole area should be managed at one level, rather than bifurcated, due to factors such as the greater density of development and much longer history of use relative to the other

WHPAs. In addition, the committee members acknowledged that much of the Nogales Wash watershed lies in Mexico, thus raising similar issues as were discussed above for the Santa Cruz WHPA.

Phoenix, Arizona

Background

Approximately one million people live in the Phoenix area. Historically, the City of Phoenix has operated approximately 150 public water supply wells. Many of those wells have been abandoned due to low water yield or contamination. The Phoenix area also has a large number of stormwater drainage wells (Class V injection wells). These drainage wells, along with releases of hazardous substances, leaking underground storage tanks, landfills, septic tanks and agricultural practices have had the potential to contaminate groundwater supplies. Because Phoenix depends on groundwater during serious drought conditions, management of groundwater resources is important.

On July 20, 1992 the City of Phoenix was awarded $30,000 from EPA, under the Wellhead Protection Demonstration Program (City of Phoenix, 1996). The City contributed $5,445 to bring the project total to $35,445. In January 1993 EPA approved a plan to spend these monies primarily on equipment and professional services to accomplish the grant plan's objectives during two years beginning in January, 1993. In addition, after the term of the grant, the City provided an additional $5,000 for consultant services to provide for updates and enhancements to the customized GIS software.

Project Goals

The original goals of the program were: 1) to delineate WHPAs, 2) to consolidate information on potential contamination sources, wells and water quality into an integrated database which is compatible with the statewide project, 3) to develop management control options, 4) to involve the public through public education efforts, 5) to plan for contingency water supplies, future well sites and proper land use planning, and 6) to identify and coordinate divisions within the city and non-city entities which are responsible for decisions affecting WHP objectives.

Workplan Implementation

During the initial stages of the wellhead protection program, staff moved to a location where they could have direct access to the city's GIS network. Computer support personnel recommended that the Wellhead protection program utilize the ARC/INFO UNIX platform instead of the PC/Arc-DBASE software that was originally contemplated. As a result, the city revised its computer hardware and software requirements. UNIX-based software was already being used in the citywide GIS project and provided increased capability over the PC-based product. While this change necessitated obtaining approvals from EPA and caused some delay, the use of this software enhanced the end-product's utility. A UNIX based system allows for the use of Oracle software for database management enhancing compatibility of the system with other agencies and with the city's other databases. Also, quarter-section map conversion was done on the UNIX platform software. Early connection to the city's main GIS project circumvented the need to make adjustments to the databases during uploading procedures that were proposed in the grant implementation plan.

After changing computer platforms the city purchased a Sun SparcStation workstation, ARC/INFO license, ArcView Version 2, a 3.5 inch drive floppy drive, and a CD-ROM drive. Staff attended UNIX training and ArcView Training. The city hired a consultant to assist with the data conversion and to provide custom programming that would allow utilization of flow model outputs. Selection of a contractor was based on the consultant's experience, competency, bid price and M/WBE considerations.

A three dimensional groundwater flow model for Phoenix and the surrounding area, developed by the Arizona Department of Water Resources (ADWR), was combined with WHPA delineation methods to rate those land areas that are more likely to be areas of groundwater recharge. Well location, well use and well construction data were obtained from the city Water Services Department production division. The stormwater NPDES database provided several useful database layers for the WHP GIS for identifying potential pollutant sources and groundwater conduits in industrial site surveys. The data base was structured using Entity-Relationship diagramming. Arc/INFO software was used with some customized programming.

A consultant performed the following tasks essential to the Wellhead Protection Demonstration project's workplan.

Task 1. Importation, Conversion, and Evaluation of Data Sets Necessary to Delineate Wellhead Protection Areas Associated with Drinking Water Well Sites

Basic data conversion and hydrologic evaluation were required as well as consideration of outputs from the "Department of Water Resources Report, A Regional Ground Water Flow Model of the Salt-River Valley, Phase I and Phase II." Data sets required for this task included:

Dataset	Source(s)
City production well locations	City files
Water levels	DWR
Sources of Recharge Incidental irrigation recharge Canal seepage Artificial lakes Effluent flows Flood flows Mountain front recharge	DWR
Catchment Basins and Drywells	Previously converted

Task 2. Importation, Conversion and Evaluation of Data Sets Necessary to Inventory Potential Sources of Groundwater Pollution

This task will include appropriate tools to allow the user to group and view the respective lists of sources associated with the Wellhead Protection Areas identified in Task #1 above.

Dataset	Source(s)
*Drywell Inventory	Previously converted
*Industrial Source Inventory	Previously converted
*Storm Water Outfall and Catchment Areas	Previously converted
*Land use information	Previously converted
*Landfills	Previously converted
*Washes and Canals	Previously converted
*Private wells	DWR, SRP
*Abandoned wells	City files, DWR, SRP
*WQARF and Superfund Sites	ADEQ
*Other drywells	ADEQ and city files

Task 3. Design and Construction of a Well Information Database and User Interface for Viewing and Updating Well Data and Potential Source Data

This included obtaining appropriate public domain software, modifying other appropriate software, or developing required instruction sets as needed.

Data Set	Source(s)
Well Construction Information	City Files
Well Locations	City Files
Geologic Parameters	DWR, SRP, and City Files
Water Quality Information	DWR, SRP, and City Files

On-Site Training for Users of the Wellhead Protection Program Data

This task included installation of the data and the users tools and on site orientation sessions necessary to introduce staff to the use of the data sets and the software interfaces.

The consultant also provided custom programming to allow delineation of WHPAs (see the section on "Delineation" below). Also, because we found areas where lack of data precluded a particle track delineation, the city provided $5,000 to modify the program to allow the users to:

1. Choose a well by number/name,
2. Choose fixed radius or particle trace,
3. Select time of trace,
4. Select fixed radius or radius for trace buffer,
5. Select coefficient of length for use in buffer calculation, (e.g. 0.25),
6. Generate polygon around well,
7. Overlay SIC points,
8. Generate SIC list with attributes (i.e., names, addresses, phone numbers) and print a list,
9. Print map of well zone and SIC coverage with markers, labels and shading.

Modifications allowed for delineation of areas where lack of data precluded a particle track delineation and expanded the program's ability to identify vulnerability zones to be used by the city to apply for groundwater monitoring waivers from the Arizona Department of Environmental Quality (ADEQ). The city also intends to have a consultant periodically update street and SIC code databases.

Delineation

Because of the complexity of the hydrogeology and the number of well locations in the Phoenix area, traditional wellhead delineation techniques such as time-of travel or particle track modeling are difficult to use. The city decided to combine the three-dimensional flow model developed by ADWR with WHPA delineation methods to rate those land areas likely to contribute to groundwater recharge. This approach results in delineation of WHPAs specific to each wellhead.

The final model outputs were delivered to Phoenix in late 1994. Also in late 1994, Environmental Systems Research Inc. (ESRI) released the new ARC/INFO Version 7, which contains some valuable new tools. The city obtained this software and installed it on the GIS network. This program makes use of a Darcy equation to predict the path of flow in static, two-dimensional systems. These tools, Darcyflow and Particletrack, found within the Grid module, were used in combination with the outputs from the ADWR model to delineate the wellhead protection areas for the City of Phoenix production wells. While the WHPAs were delineated only for city wells, the software module is capable of delineating these areas for any well (i.e., private, industrial, or agricultural wells)'that has the appropriate MODFLOW model outputs. In order to facilitate the use of this program, the city's consultant developed a menu/prompt driven program that allows the user to define direction and time duration of the particle tracking. The linear outputs from this program are then transformed to WHPA zones by applying a buffer to form a polygon coverage around each wellhead.

Each of these WHPA zones consists of a buffer of 1000 feet around the wellhead and the particle track identified by the software. Additionally, the buffer is mathematically widened by a factor of 0.25 times the distance from the wellhead to compensate for any error that may exist in the ADWR data sets and for flow anomalies that may exist in the unsaturated zone due to variability in vertical or lateral transport. Depending on the length of the particle track, the resulting WHPA can be fairly large and there is overlap of the WHPAs of wells that are close to each other.

A review of ADWR data sets determined that the most complete data set for use with the MODFLOW model was from 1989. The 1989 data represented changes in the subsurface hydrologic flow conditions that resulted from groundwater withdrawals over the previous several decades. These conditions were assumed to persist, although changes in land use such as urbanization of agricultural land will alter the flow patterns in the future. Newly activated wells are not as accurately represented in the model outputs since the model relies on data that reflect drawdown from past groundwater withdrawals. As new data become available and the flow model generates new outputs, it will be necessary to rerun the particle tracks for each of the city's active wells and determine whether the WHPAs delineated from the 1989 data are still accurate.

As mentioned above, some wells were located in areas which had no data in the ADWR database. The result was that the software could not produce a particle track. As described above, the software was modified to allow the use of a fixed circular radius instead of a particle track zone buffer.

Management Strategies

In May, 1995 WHP program staff presented examples of the GIS outputs and general information about groundwater contamination and management strategies to the city's Water Services Department management. Entities responsible for wellhead protection planning decisions were identified. Meetings with the city's Planning Department were initiated. A slide presentation was developed to educate Planning staff about wellhead protection concerns and provide them with access to the grant plan's GIS outputs. Another presentation was given to the city's Water Services Department management to promote interest and understanding among staff working in wellhead protection program related areas and to initiate public scoping of management strategy alternatives.

Wellhead protection program concerns regarding management strategy alternatives were incorporated into written industrial surveys of industries by conducting meetings with pollution control and pollution prevention planning staff. Inspection forms and data storage procedures were adapted to be compatible with the WHP project's data acquisition requirements. WHP staff reviewed the *Phoenix Water Resources Plan, 1990* and the *City of Phoenix Drought Management Plan* and the *General Plan for Phoenix, 1985-2000.* Future versions of these documents will incorporate the WHPA delineations, management strategies described in the work plan, and guidance from the State and EPA.

Staff limitations restricted public outreach activities. Slides from EPA, a sand tank model on loan from ADEQ, and videos were used for presentations to schools and other groups. The City of Phoenix will continue to refine its wellhead protection program. WHPAs and management strategies will be reevaluated and modified as new data are obtained. WHP will continue to be an integral part of the city's planning and pollution control activities.

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Appendix A: Glossary

Advection	The process by which solutes are transported by the bulk motion of the flowing groundwater.
Alluvium	A general term for clay, silt, sand, gravel, or similar unconsolidated material deposited during comparatively recent geologic time by a stream or other body of running water as a sediment in the bed of a stream or its floodplain or as a fan at the base of a mountain slope.
Aquifer	A water bearing rock unit that will yield water in a usable quantity to a well or spring.
Basin	The major sediment-filled trough that lies between mountains.
Capillary fringe	The zone above the water table in which water is held by surface tension. Pore spaces within the capillary fringe are saturated but the water is under lower-than-atmospheric pressure.
Dispersion	The spreading and mixing of chemical constituents in groundwater caused by diffusion and mixing in microscopic variations in velocities within and between pores.
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 groundwater, the height above sea level of a column of water plus the energy contained in the mass of water in the column.
Percolate	The act of water seeping or filtering through the soil without a definite channel
Permeable	Having a texture that permits water to move through a material under differences in head.
Porosity	The volume of openings in a rock, expressed as the ratio of openings to total volume of rock.
Potentiometric surface	An imaginary surface representing the level to which water will rise in a well.
Recharge	The addition of water to the zone of saturation; also, the amount of water added
Saturated zone	The zone (below the unsaturated zone) in which interconnected openings contain only water.
Transmissivity	The capacity of an aquifer to transmit water; equal to the hydraulic conductivity times the aquifer thickness.
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 pressure equal to the atmospheric pressure.
Well screen	A filtering device used to keep sediment from entering a water well.
Wellhead protection area	"The surface and subsurface area surrounding a water well or wellfield, supplying a public water system, through which contaminants are reasonably likely to move toward and reach such water well or wellfield" (SDWA)

Appendix B: Environmental Fate References

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