TOWARD A COMMON GOAL:
FORGING WATER QUALITY PARTNERSHIPS
NOVEMBER NEW MEXICO WATER RESOURCES RESEARCH INSTITUTE 1990

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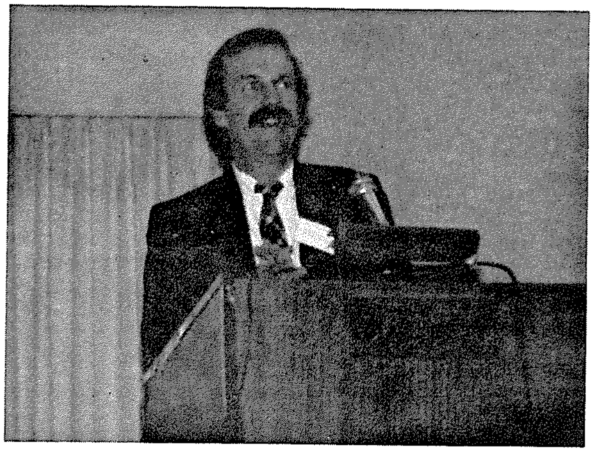

DRINKING WATER PROTECTION STRATEGIES

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INTRODUCTION

Development of management strategies and engineering technologies for providing safe drinking water to the public is arguably one of the greatest public works achievements of the 20th century in the United States. This success is so complete that it is usually only recognized when one travels abroad and is constantly aware of the potential hazards presented by local water supplies.

The first federal standards for drinking water were promulgated in 1914 and principally addressed bacteriological water quality; microorganisms being the causative agents of most acute water borne problems. With improved understanding of potential problems associated with drinking water came increasingly stringent standards in 1925, 1942, 1946, and 1962 (Cotruvo and Vogt 1990).

National Interim Primary Drinking Water standards were promulgated in 1975 based in large part on the 1962 U.S. Public Health Service standards, and established under authority granted to the Environmental Protection Agency (EPA) by the 1974 Safe Drinking Water Act. The 1986 amendments to the Safe Drinking Water Act identified 83 contaminants, most already regulated, which must be addressed by the EPA in its regulatory process. Current regulations are presented in Tables 1 and 2. These standards apply to all public water supply systems, which are defined as systems with 15 or more connections, or those serving at least 25 individuals. The development of these standards has progressed from the relatively straightforward objective of preventing immediate threats of water borne diseases, to providing a water supply, which if consumed for a lifetime (approximately 70 years), would have a vanishingly small probability of causing any excess mortality due to any water associated cause. It is equally clear that procedures to measure these benefits, the treatment technology needed to provide this level of quality, and the analytical methods needed to validate water quality are all taxing current levels of technology.

Groundwater is the source of over 90 percent of public drinking water supplies in New Mexico. Communities relying entirely or in part on

TABLE 1. U.S. ENVIRONMENTAL PROTECTION AGENCY NATIONAL PRIMARY DRINKING WATER STANDARDS (1989)

Primary Standards

Constituents	Maximum Contaminant Level
Physical Parameters	
Turbidity	1 (Turbidity Unit)
Inorganic Chemicals	
Arsenic	50 (μg/L)
Barium	1000 (μg/L)
Cadmium	10 (μg/L)
Chromium	50 (μg/L)
Fluoride	4 (mg/L)
Lead	50 (μg/L)
Mercury	2 (μg/L)
Nitrate	10 (mg N/L)
Selenium	10 (μg/L)
Silver	50 (μg/L)
Organic Chemicals (Pesticides & Herbicides)	
Endrin	0.2 (μg/L)
Lindane	4 (μg/L)
Methoxychlor	100 (μg/L)
Toxaphene	5 (μg/L)
2,4-D	100 (μg/L)
2,4,5-TP Silvex	10 (μg/L)
Organic Chemicals (Volatile Organic Compounds)	
Trichloroethylene	5 (μg/L)
Carbon tetrachloride	5 (μg/L)
Vinyl chloride	2 (μg/L)
1,2-Dichloroethane	5 (μg/L)
Benzene	5 (μg/L)
1,1-Dichloroethylene	7 (μg/L)
1,1,1-Trichloroethane	200 (μg/L)
p -Dichlorobenzene	75 (μg/L)
Bacteriological Factors	
Coliform bacteria	Presence/Absence
Radioactivity	
Gross Alpha	15 (pCi/L)
Radium-226 and 228	5 (pCi/L)
Tritium	20,000 (pCi/L)
Strontium-90	8 (pCi/L)

TABLE 2. U.S. ENVIRONMENTAL PROTECTION AGENCY NATIONAL PRIMARY DRINKING WATER STANDARDS (1989)
Secondary Standards (nonenforceable)

Constituents	Maximum Contaminant Level	Effect On Water Quality
Chloride	250 mg/L	Salty taste
Color	15 color units	Objectionable appearance
Copper	1 mg/L	Undesirable taste
Corrosivity	Noncorrosive	Stains, corrosion
Fluoride	2 mg/L	Stains teeth
Foaming agents	0.5 mg/L	Objectionable appearance
Iron	0.3 mg/L	Taste, stains
Manganese	.05 mg/L	Taste, stains
Odor	3 threshold odor number	Undesirable smell
pH	6.5 - 8.5	Corrosion, taste
Sulfate	250 mg/L	Taste, laxative effect
Total Dissolved Solids (TDS)	500 mg/L	Taste, appearance
Zinc	5 mg/L	Taste, milky appearance

surface water for its drinking supplies include Aztec, Bloomfield, Shiprock, Santa Fe, Las Vegas, Ruidoso, Tularosa, and Chama. There are several advantages with using groundwater as a public water supply.

- Groundwater does not require large storage facilities (reservoirs) to provide supplies during seasonal variations in water availability. Generally only a few weeks' capacity is sufficient.
- Trunk lines in a community's water distribution system can be much smaller compared to those for a single surface water source due to the fact that the aquifer, and therefore the source of water, is distributed over a much larger area.
- Groundwater almost never requires surface treatment. Traditional treatment is limited to chlorination and occasionally, fluoridation. Recognition of groundwater systems contamination is recent, due in part to the very long travel times before a pollutant may be detected in a water supply well.
- There is little or no variability in the quality of uncontaminated groundwater supplies. Surface water sources on the other hand may have diurnal fluctuations in temperature, seasonal variations in water chemistry, hourly changes in suspended solids concentrations during storm events, and are vulnerable to pollutants resulting from upstream spills and discharges.
- Groundwater sources are almost always less expensive to develop because there is no need for large surface storage facilities, no treatment needs, and the ability to develop the distribution system as the community grows.

Groundwater's principal disadvantages as a source of public water supply are:

- Groundwater resources are extremely difficult to quantify.
- Once a groundwater system is polluted, it is extremely difficult to restore it to its original quality.

In contrast to New Mexico's almost total reliance on groundwater resources, communities in the northeastern U.S. depend almost entirely upon surface water sources for public water supply. This contrast is relevant to the present discussion because most federal policy and regulatory decisions regarding water supply and wastewater treatment are initiated in Washington D.C. It is perceived that decisions made in this environment do not fully recognize and account for the technical and institutional constraints experienced by managers of water systems relying upon groundwater. Indeed, formal incorporation of groundwater considerations into policy developed by the EPA did not occur until 1984 (USEPA 1990), and even now regulations pertaining to groundwater quality are entirely within the purview of the individual states.

This paper addresses three areas:

- groundwater protection programs;
- groundwater quality problems and technologies available for meeting programs; and
- consideration of possible future problems which may face groundwater resource managers.

GROUNDWATER PROTECTION PROGRAMS

Wellhead Protection Areas

Until recently there has been little institutional recognition of the relationship between surface development and threats to underlying groundwater resources. This has been true at the federal, state and local levels, although public health agencies have attempted to protect shallow groundwater supplies from contamination by onsite wastewater disposal systems (for example, septic tank systems) for decades. Although limitations on the type and extent of surface development in many communities were possible through zoning ordinances, possible impacts on groundwater quality were not considered.

Furthermore, until passage of the Resource Conservation and Recovery Act (1976), there was little regulation of hazardous materials discharge to groundwater. To its credit, New Mexico was one of the first states to develop regulations pertaining to groundwater discharges, and the standards are nearly identical to federal drinking water criteria.

The 1986 Safe Drinking Water Act Amendments provide states with federal assistance to develop Wellhead Protection (WHP) programs. WHPs address problems associated with surface development in areas dependent upon groundwater for public supply. The program philosophy is to place realistic controls on most surface sources of contaminants. The EPA (1990) notes that 11 European countries have some form of WHP program at present. It is interesting to note that although the law requires all states to participate, no sanctions are provided for states which do not. The objective of the WHP program is to protect areas surrounding public wells or well fields from activities which may pose a threat to the underlying water quality. In developing a WHP program, seven elements must be addressed (USEPA 1987):

- The WHP program must specify the duties of appropriate state and local water and health agencies which will be involved in program implementation.
- Procedures must be developed for defining the extent of the Wellhead Protection Area (WHPA). WHPA's are defined as the surface and subsurface area surrounding a water well or wellfield.
- Procedures must be developed for determining the anthropogenic contaminants which may be present in the WHPA.
- The WHP program must describe procedures which might be implemented to protect water supplies.
- Contingency plans must be developed for an alternative water supply in the event contamination forces closure or abandonment of the current supply.
- The WHP program must require that potential sources of contamination within the WHPA of new wells be considered prior to their construction.
- Procedures to ensure public participation in the WHP program must be developed.

One major element of the WHP program is determination of WHPAs. These are defined as the surface and subsurface area surrounding a water well or wellfield supplying a public water system through which contaminants are reasonably likely to reach the well. An important concept in determining the WHPA is the Zone of Contribution (ZOC), which is distinct from the more familiar Zone of Influence (ZOI), both illustrated in Figure 1. The ZOI is that portion of the aquifer in which drawdown occurs due to stress from the pumping well. The ZOC is the entire area which contributes water to a well or wellfield. These concepts are important as they likely must be considered in delineating a WHPA.

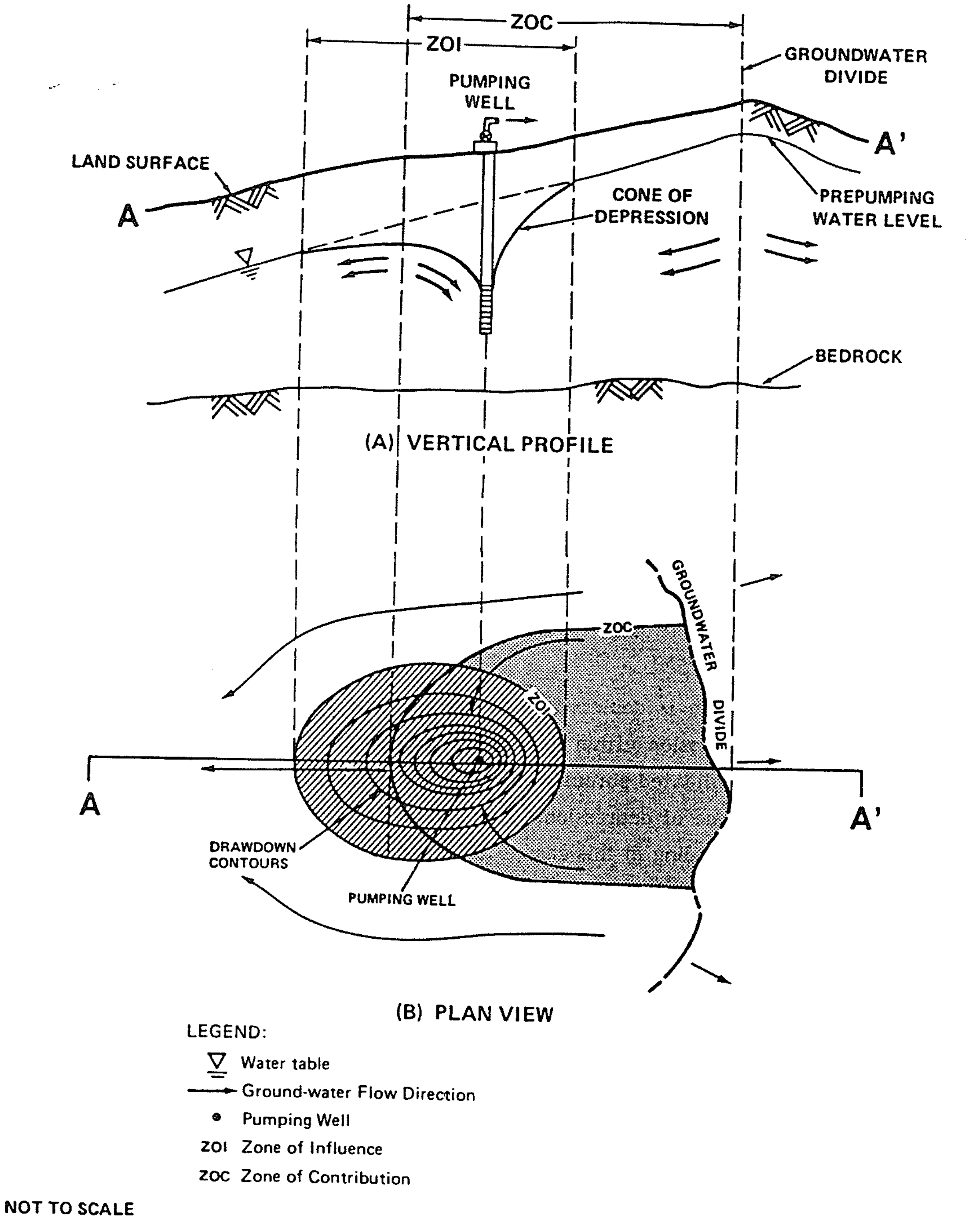

Figure 1. Terminology for Wellhead Protection Area delineation (hypothetical pumping well in porous media) (EPA 1990).

Delineation of a WHPA may be designated using the following criteria, which are generally in order of increasing cost and technical sophistication:

- arbitrarily select the WHPA
- calculate a fixed radius from each well or wellfield
- use simple geometric shapes which account for regional flow patterns to determine the WHPA
- use analytical solutions of groundwater flow patterns
- base the WHPA on hydrogeologic mapping
- develop numerical groundwater flow and contaminant transport models to justify the WHPA

Most likely a combination of two or more of these approaches will be practical. The relationship between each of these approaches is presented in Figure 2. Factors considered in determining which approaches to take include groundwater flow velocities, flow boundaries, and the capacity of the subsurface environment to stabilize, dilute, or degrade possible pollutants.

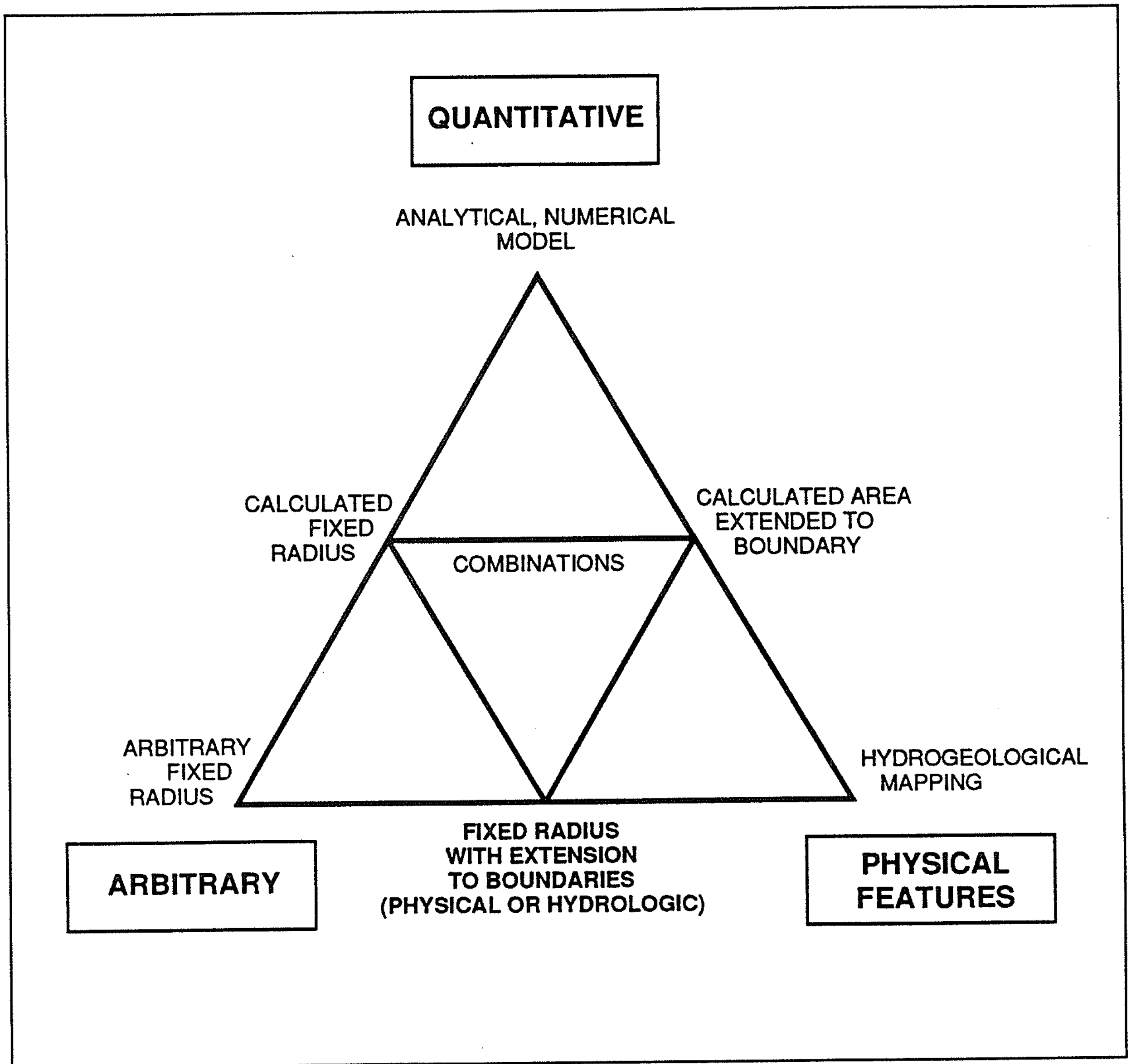

Figure 2. Interrelationships of Wellhead Protection Area delineation methods (EPA 1990).

Three possible management objectives in a WHPA are:

- Establish a remediation zone as protection from unexpected contaminant release. Once pollutants have escaped into the soil, adequate time and distance must be designated for a remediation program, before the contamination affects the water supply.
- Identify an attenuation zone which will reduce contaminants to acceptable levels through degradation, stabilization, or dilution before it reaches the water supply.
- Provide a wellfield management zone in which development and land use are regulated to control potential groundwater threats.

It is possible that a WHPA will be subject to future redelineation as additional information on aquifer characteristics is developed through monitoring programs (Meyer 1990).

Groundwater Protection Policy and Action Plan

In 1988, an independent approach was initiated whereby the city of Albuquerque and Bernalillo County formally recognized the importance of high quality groundwater to the community's continued development. They funded a major three-year study to develop a comprehensive groundwater protection policy (CH2M-Hill 1989). This plan will be known as the Groundwater Protection Policy and Action Plan (GPAP). A very important component of this planning effort is the development of a Hazardous Materials and Waste Storage (HMWS) policy.

The GPAP begins by characterizing the threats to groundwater resources in the Albuquerque basin. This has been accomplished in part through a geographic information system (GIS) compilation of known sources of contamination, and potential sources of pollutants, together with a semi-quantitative ranking process for assigning threat potentials (Aller, et al. 1987). Subsequently, possible aquifer protection strategies will be identified. Finally, a policy will be developed, with considerable emphasis on public involvement, which identifies strategies for minimizing contamination risks to the region's groundwater resources. The planning program is expected to be complete in early 1992.

The HMWS' objectives are to identify appropriate measures which the city and county might implement to minimize the threats to the community from activities which generate or store hazardous materials. This is being accomplished by characterizing all HMWS activities in the area, assessing the vulnerability of groundwater resources to these activities, and reviewing other HMWS programs around the country. The final product will be the HMWS Policy, together with an Action Plan proposing how this policy might be implemented by the local governments.

Two comments regarding this program are relevant here. First, by virtue of the effort's magnitude, the program is producing a large amount of information regarding the basin's groundwater resources that otherwise never would have been compiled. Much of the raw data is cataloged onto the GIS, thus making it readily available in graphic form to assist in this and future planning efforts. This facilitates the use of this information in other projects. Also, the enabling ordinances mandated formation of a Groundwater Protection Advisory Committee consisting of approximately 20 citizens representing various institutional, environmental and citizen groups within the community. This group has worked very closely with governmental agencies and consultants to facilitate development of plans and policies acceptable to the public and the business community. Including the public in the planning process from its inception is unique and in marked contrast to more normal procedures in which the public is simply given an opportunity to comment on a final draft policy.

Groundwater Remediation

A technology still very much in a primitive stage of development is that used to clean up contaminated groundwater. Once an aquifer has become contaminated, two objectives of a remediation program must be achieved to assure protection of a community's potable water supply. First, the pollutant's source must be located immediately and stopped, contaminant migration must be halted, and if necessary, an alternate source of water provided to the community. Once the community's health and safety have been assured, the second objective is to remove or stabilize the contaminants from the subsurface environment. Conventional aquifer restoration alternatives can be broken into four categories:

- containment of the aquifer contaminants
- removal of mobile pollutants, followed by surface treatment of contaminated water or recovery of free product, and subsequent disposal or reuse of treated water
- removal of contaminated soil, followed by treatment and/or disposal
- in situ stabilization of aquifer contaminants

Frequently a combination of these methods is used to maximize the performance of the treatment process. These alternatives are described briefly below.

Pollutant containment is the most immediate concern following determination of a groundwater contamination problem. It can be achieved either by using a physical barrier such as a grout curtain, slurry cutoff wall or sheet piles, or by creating a hydraulic barrier resulting from pumping and injection wells. Containment technology is reviewed by Spooner, et al. (1985) and Keely (1984).

Mobile contaminant removal from the groundwater system is achieved by directing pollutant migration toward wells or trenches from which it can be recovered or removed. A schematic of a traditional pump-and-treat process using combined pumping and injection wells to bring contaminants to the surface is presented in Figure 3. Variations of this process include free product recovery of petroleum products floating on a water table, vacuum extraction of volatile organic compounds, and pump-and-treat processes for soluble constituents. These processes are limited to volatile, liquid, or soluble pollutants; insoluble compounds remain attached to soil particles in the aquifer or vadose zone. Bouwer, et al. (1988), Wagner, et al. (1987) and Guswa et al. (1984) have prepared reviews of processes for management and treatment of groundwater contamination problems involving mobile contaminants.

In situ stabilization of hazardous wastes is a relatively new treatment process which shows considerable promise as an alternative to conventional

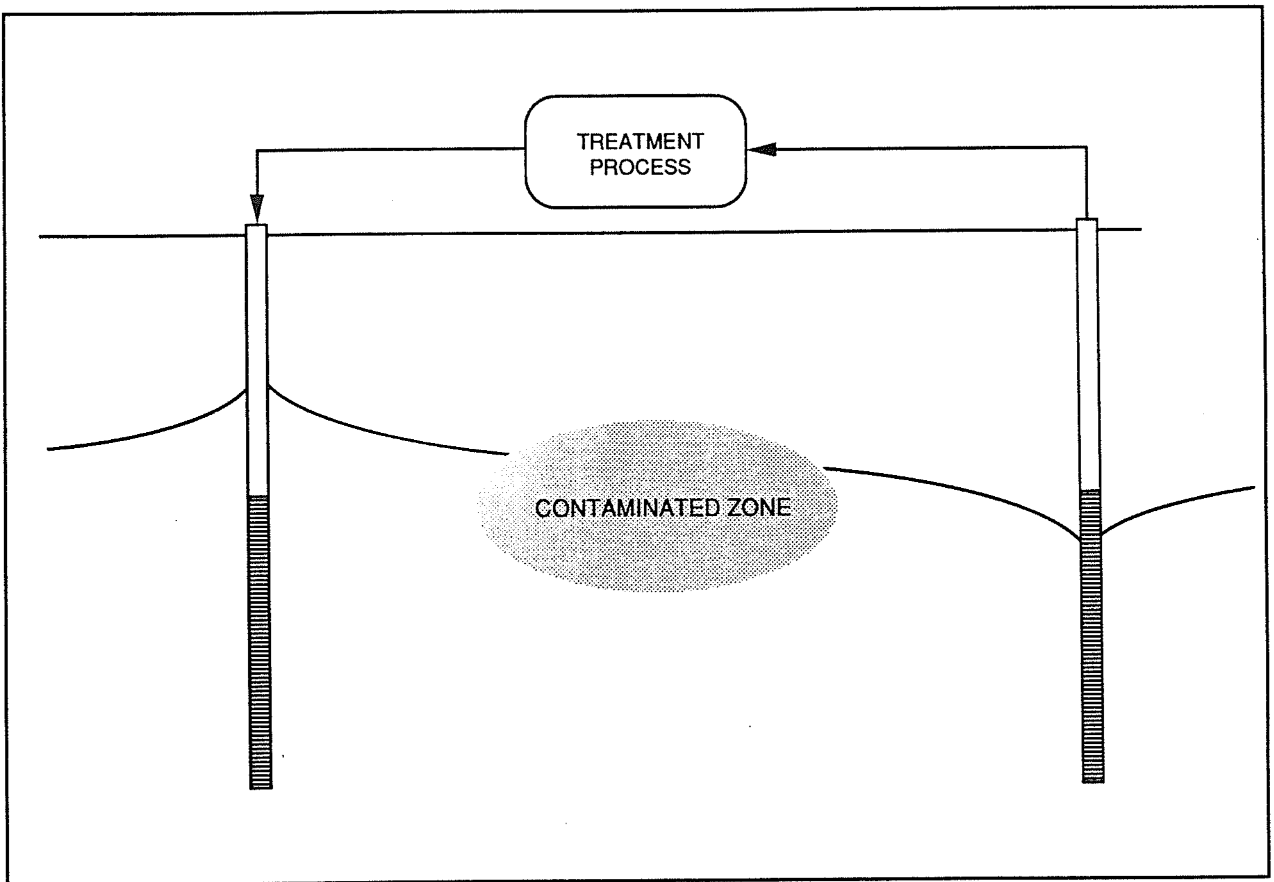

Figure 3. Diagram of conventional pump-and-treat groundwater restoration process.

pump-and-treat methods. Its principal application to date has been in groundwater systems contaminated with biodegradable organic materials. In situ treatment is accomplished by stimulating the growth of naturally occurring soil microorganisms by introducing essential nutrients (for example, nitrogen and phosphorous) and appropriate electron acceptors (for example, oxygen or hydrogen peroxide) required for the organism's growth. Lee, et al. (1988), Wilson, et al. (1986), Borden, et al. (1989), and Amdurer, et al. (1986) have prepared reports and reviews of in situ biological waste stabilization technology, while Sims, et al. (1984) discussed in-place remediation of contaminated soils. In situ technology is limited to applications in which the contaminants are degradable.

Although conventional groundwater restoration programs when properly designed and implemented are generally effective, they have numerous problems which include:

- requiring management of large volumes of water which generally are contaminated at very low levels
- frequently producing difficult to manage by-products, like sludges
- conventional pump-and-treat alternatives requiring large surface disruptions for long periods
- conventional alternatives may affect hydraulic characteristics in uncontaminated parts of the aquifer
- methods which remove mobile contaminants, such as vapors, free liquids, or those which are soluble, may not work in aquifers with low hydraulic conductivity
- surface disposal of large volumes of treated groundwater may pose institutional obstacles such as requirements for ground or surface water discharge permits and possible purchase of groundwater rights

From a drinking water perspective, groundwater restoration operations are enormously expensive. A good rule of thumb is that complete remediation at a leaking underground storage tank site will start at close to $100,000 and may exceed this value by a factor of 10 or more if complicating factors arise. Also, remedial actions take a very long time to complete. For example, in the 1970s, chlorinated solvents were detected in Albuquerque's San Jose Number 6 municipal well, New Mexico's oldest Superfund site. The Remedial Investigation and Feasibility Study (RIFS) was completed in 1989. Remediation activities may take an additional 20 years, and even then it is unlikely that all contaminants will ever be removed from the subsurface environment. This last example, admittedly a worst case study, illustrates the enormous challenges facing the manager of a water utility dealing with a polluted aquifer.

DRINKING WATER TREATMENT

As stated previously, one of groundwater's most important advantages as a source of public supply is that no treatment is traditionally required. However, the combination of more stringent regulations governing drinking water quality, and increasing anthropogenic abuse of groundwater systems has forced some water utility managers to consider the possibility that treatment may be required. Conventional water treatment technology consists of physical and chemical processes. A brief summary of the capabilities of these processes is presented. The reader is referred to a recent treatise on the subject for detailed information (ASCE and AWWA 1990).

Physical treatment processes are those which rely on physical phenomena to achieve treatment. Sedimentation and filtration are processes which remove particulates, down to and including colloidal-sized material if used in conjunction with appropriate chemical addition. Aeration may be used to remove volatile constituents, such as chlorinated solvents or hydrocarbons. One of the most common groundwater treatment technologies is use of packed column air stripping to remove volatile organic compounds (VOCs). In most applications, this process involves exchanging a groundwater pollution problem for a less objectionable air pollution problem.

Chemical treatment processes utilize chemical principles to provide removal of soluble constituents, or in the case of colloids, to achieve destabilization of particulates prior to physical removal. Chemical disinfection using gaseous chlorine or one of its aqueous salts is practiced by virtually all public water utilities in the U.S. It is cheap and very effective at destroying pathogenic organisms. Adding coagulants and flocculating agents is perhaps the second most common process, and precedes either sedimentation or filtration operations.

Chemical precipitation is closely related to flocculation, and relies upon altering the source water chemistry to effect precipitation of otherwise soluble parameters, most commonly metals, which are subsequently removed by sedimentation.

Two other common treatment processes, which are relatively expensive and thus have applications limited to waters with special problems, are activated carbon adsorption and ion exchange. Activated carbon adsorption is a very effective process for removal of most soluble hazardous organic pollutants as well as tastes, odors, and color from organic compounds. Activated carbon is used widely in home water treatment devices. Ion exchange is used for selective removal of ionic constituents, almost always at the water's point of use. The two most common applications are home water softening and demineralization applications where very high purity water is needed for industrial utilization. It is unlikely that either treatment process will ever be used for treating public water supplies except in very unusual circumstances due to their high capital and operating costs.

A block diagram illustrating the treatment sequence for a generic surface-water treatment plant is presented in Figure 4. Pretreatment consists of screening to remove sticks and rags, and also includes pumping the raw water up to the treatment plant. Coagulating and flocculating chemicals are added to improve the sedimentation and filtration process. An implicit assumption in this diagram is that no water quality problems exist which might require special treatment processes such as softening or removal of VOCs. Finally the water is chlorinated and possibly fluoridated, and enters the storage and distribution system. The treatment scheme for a water system using groundwater as its supply is presented in Figure 5 for contrast.

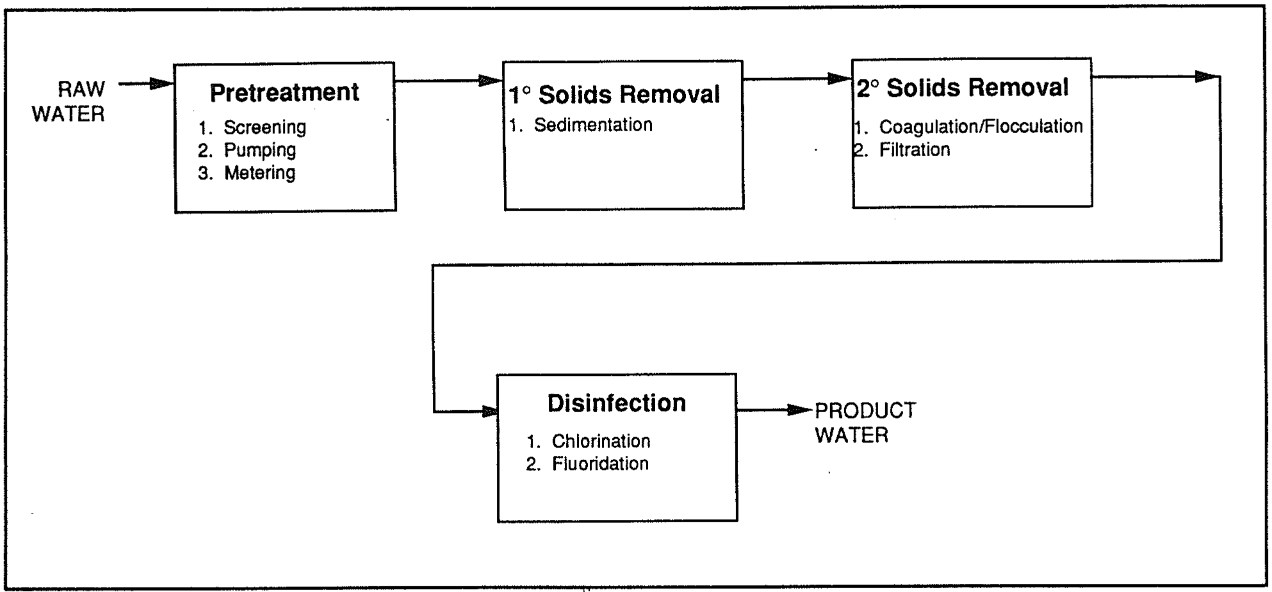

Figure 4. Diagram of common drinking water treatment process for treating surface water.

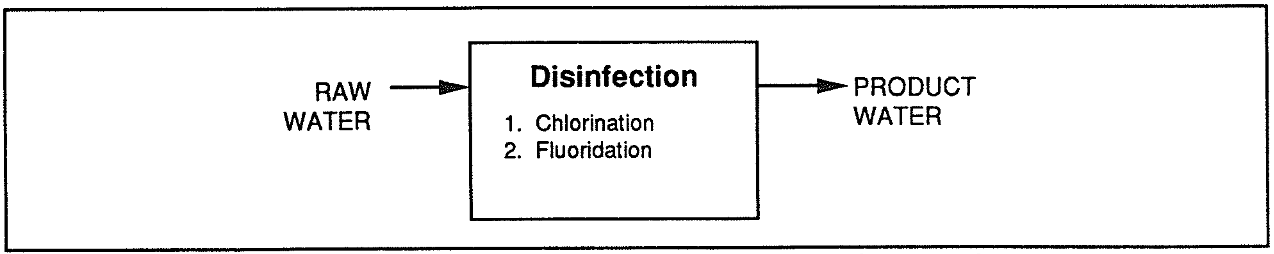

Figure 5. Diagram of common drinking water treatment process for treating groundwater.

Drinking Water Regulations: Gazing Into The Future

Current Safe Drinking Water Act regulations (Table 1) can be readily met by nearly all water utilities using groundwater for supply, provided no anthropogenic contaminants are present. This is because water utility managers historically have not considered groundwater resources which are not of sufficiently high quality to meet Safe Drinking Water standards as possible sources of potable water. Therefore, an aquifer with total dissolved solids (TDS) concentrations greater than 1,000 mg/L, or with elevated arsenic levels, or other naturally occurring constituents present above drinking water standards have not been developed for public water supply. Several New Mexico communities have faced this problem when seeking new water resources for community growth; nearby groundwater resources are available, but water quality considerations preclude their use for potable supply.

New more stringent standards (Table 3), however, are increasing the possibility that many New Mexico communities will have to consider some type of treatment in the near future. These new standards will present three types of problems to water utility managers.

First, new standards consist of ever lower Maximum Contaminant Levels (MCLs). For example, reducing the arsenic standard from 0.5 mg/L to .03 mg/L (Cotruvo and Vogt 1990) will place several major Albuquerque wells out of compliance with primary drinking water standards (Summers 1990). It is interesting to note that not all proposed changes are more stringent; proposed MCLs for barium, chromium, and selenium are higher than present.

The second problem involves establishing regulations for constituents not currently regulated. Parameters which fall into this category include many new VOCs and synthetic organic chemicals, four new microbiological characteristics including viruses, and the radionuclides uranium and radon. Several New Mexico communities, particularly in the northwest, use groundwater supplies with relatively high concentrations of uranium. Radon levels in the state's groundwaters are not well characterized. It is interesting to note, however, that the drinking water standard for radium-226 is 3 pCi/L, while radon which is not regulated, is commonly present at concentrations exceeding 1,000 pCi/L. Another consideration is the cost of monitoring. Sample collection and analysis for the entire suite of organic compounds identified in the proposed regulations may exceed $500 per sample.

TABLE 3. POSSIBLE NEW STANDARDS WHICH MAY AFFECT WATER UTILITIES USING GROUNDWATER AS THEIR SOURCE OF SUPPLY

Parameter	Nature of Standard	Possible Implications
Arsenic	Reduced MCL	May place source out of compliance
Synthetic & volatile organics, uranium, radon, microbial characteristics	New standards	May place source out of compliance Expensive monitoring costs
Lead	Reduced MCL & new application	May force treatment Monitoring uncertainties
Disinfection by-products	New standards	May force treatment

The last problem facing water utility managers as a result of continued regulatory development is that new regulations may change the point of compliance from water quality in the distribution system, to water quality at the tap. This is exemplified by proposed lead and copper regulations which seek to address high lead levels in tapwater resulting from corrosion of lead services, lead solder, and brass fittings (USEPA 1988). The regulations propose a more stringent standard than the current 0.5 mg/L (the exact value has not yet been decided). The point of enforcement will be at the customer's tap, not at the distribution system. The implications of this regulatory approach are enormous in that utilities will have to develop strategies to insure that their water will not accumulate lead regardless of the construction practices used by its customers. Furthermore, a monitoring program that provides proof will have to be developed. This in itself is a significant challenge because in the worst cases, a sample of water standing overnight in a household tap must be drawn. This sample must be collected early in the morning before any water has been drawn. The American Water Works Association Research Foundation has published an extensive monograph on the technologies available (Economic and Engineering Services, Inc. 1990). The EPA's official position is that lead corrosion control is relatively easily controlled at the utility's treatment plant, a position that is not particularly relevant to Albuquerque which operates over 80 wells, 40 reservoirs, and no treatment plants.

CONCLUSIONS

The above example of a more stringent lead standard, coupled with a change in the point of enforcement, illustrates a very important difference between surface water and groundwater as a source of supply. A community relying upon surface water will have only one or two water treatment plants, thus quality control of the product water is relatively straightforward, and as problems appear they can be readily addressed. On the other hand, a community utilizing groundwater must monitor the quality at numerous wells and/or reservoirs, and will have few if any options for addressing water quality problems. Yet groundwater resources have provided high quality drinking water for nearly half the U.S. population for decades with very few problems.

The traditional drinking water regulatory approach is not particularly responsive to utilities which rely upon groundwater resources. However, there is no denial that the subsurface environment is becoming increasingly contaminated by man's surface activities. It is likely that the most effective drinking water protection strategies will include a combination of wellhead protection programs and possibly innovative treatment methods. Hopefully, the regulatory environment will also include some flexibility to allow utilities using groundwater sufficient options to continue to provide high quality water on a cost-effective basis.

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