GROUNDWATER ISSUES

WELLHEAD PROTECTION UNDER THE SAFE DRINKING WATER ACT

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Introduction

Groundwater protection and management is primarily a state responsibility in the United States. The Environmental Protection Agency has been directed by Congress through legislation to primarily focus on specific waste sources and the regulation of those sources to protect groundwater quality. For instance, the Federal Insecticide, Fungicide and Rodentice Act (FIFRA) regulates which pesticides are safe for use in the U.S. and places restrictions on its use through label requirements. Many of these label requirements take into consideration the potential for groundwater contamination.

Another federal statute, the Resource Conservation and Recovery Act (RCRA) has three major components: Subtitle C, regulation of hazardous waste; Subtitle D, regulation of solid wastes; and Subtitle I, regulation of underground storage tanks.

The list of additional federal efforts in groundwater protection is brief (Table 1). Federal-state relationships are shaped in the primary process of state assumption of the federal program requirements. Congress authorizes EPA the lead role for developing the necessary technical data, technical standards, and regulatory framework, while the states have the opportunity to establish their own programs, modeled after the federal requirements. States are usually provided with federal financial assistance to establish and implement their programs. EPA then provides an overview function.

As explained below, the Wellhead Protection Program authorized under the Safe Drinking Water Act, is an anomaly to the typical federal-state environmental regulatory relationship.

Wellhead Protection Overview

Section 1428 of the amendments to the Safe Drinking Water Act (SD WA) requires states to develop Wellhead Protection programs and prepare submissions to EPA by June 19, 1989. The purpose of the program is to protect the public water supply wells from sources of contamination. Unlike most EPA programs which are regulatory in nature and address specific sources of contamination, the WHP program is designed to assist state and local governments in focusing on the resource itself rather than on controlling a limited set of contamination sources via State or federal regulations. The program is established to provide for comprehensive analysis of geology, hydrology, land uses, and institutional arrangements impacting public water supply wells. The focus is to target management controls to the area around the well that affects

Table 1. Existing Federal Ground-Water Protection Programs

Program	Regulations	Activities
Safe Drinking Water Act Underground Injection Control	40 CFR Parts 144 –14 6	Control of injection to groundwater
Safe Drinking Water act UIV Class V	40 CFR Part 148	Control over shallow well injections to aquifers
Safe Drinking Water Act Public Water Supply Program	40 CFR Part	Regulation of State Public Water Supply Programs
Resource Conservation and Recovery Act	40 CFR Part 300	Hazard Ranking System for Uncontrolled Hazardous Substance Releases
RCRA (Subtitle D)	40 CFR Parts 257, 258	Regulations of Solid Waste Disposal Facilities
Toxic Substances Control Act	40 CFR Part 761	Regulation and permitting of Toxic Substances
Federal Insecticide, Fungicide, and Rodenticide Act		Development of State Pesticide Management Strategies
Comprehensive Environment Response, Compensation, and Liability Act	40 CFR Part 300	National Contingency Plan

public water supply wells. All potential sources of groundwater contamination are to be addressed, whether there is a state or federal regulatory requirement for that source or not.

A comprehensive Welihead Protection program comprises several distinct and essential elements. At a minimum, each state’s WHP program must:

Specify roles and duties of state agencies, local government entities, and public water suppliers, with respect to the development and implementation of WHP programs;

Delineate the welihead protection area (WHPA) for each welihead, as defined in subsection 1428(e), based on reasonably available hydrogeologic information on groundwater flow, recharge and discharge, and other information the state deems necessary to adequately determine the WHPA;

Identify sources of contaminants within each WHPA including all potential anthropogenic sources that may have any adverse effect on health;

Develop management approaches which include, as appropriate, technical assistance, financial assistance, implementation of control measures, education, training, and demonstration projects that are used to protect the water supply within WHPAs from such contaminants;

Develop contingency plans for each public water supply system indicating the location and provision of alternate drinking water supplies in the event of well or well-field contamination;

Site new wells properly to maximize yield and minimize potential contamination; and

Ensure public participation by incorporating processes for appropriate involvement in WHP program elements.

Status of State WHP Efforts

Figure 1 identifies those states that have

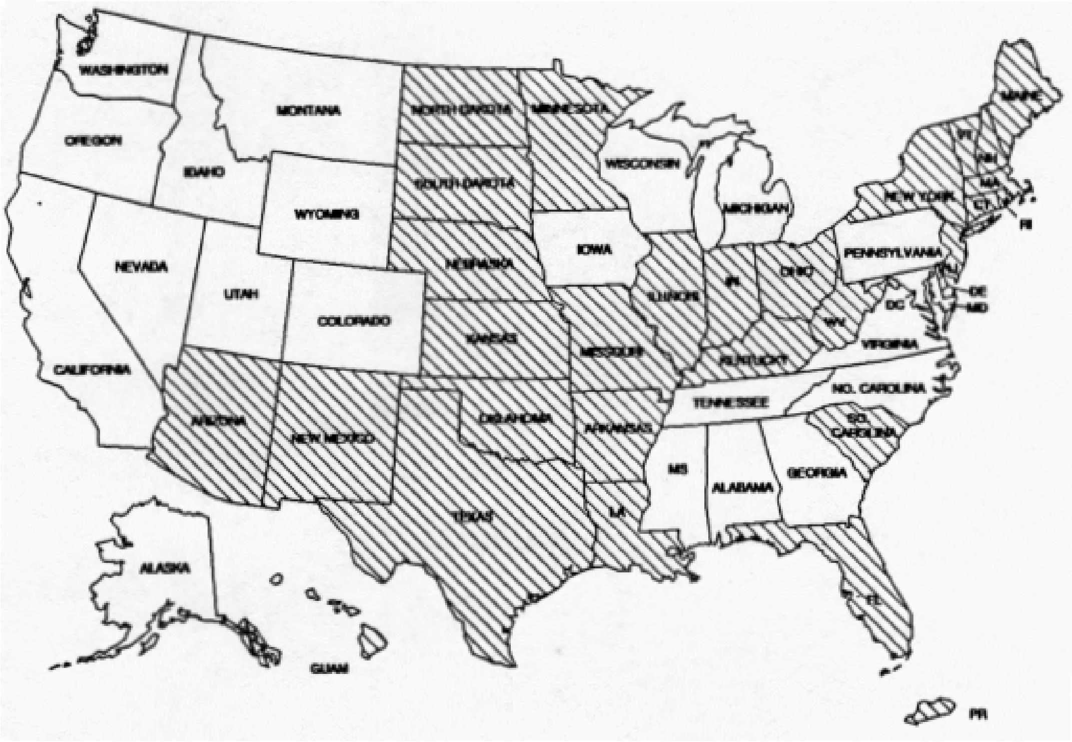

FIGURE 1

submitted a WHP program or work plan to EPA for review and approval. EPA is currently working with the states on final adjustments to the submissions prior to approval. The WHP program recognizes the many different approaches that could be employed to protect public water supply wells. Also the diverse nature of hydrogeologic settings across the county is recognized, and site specific delineation approaches and management controls of sources of contamination are encouraged.

The findings to date, based upon an initial review of the programs submitted, *is* very encouraging. Most states are linking existing source management programs and requiring higher levels of protection, enforcement, and compliance within Welihead Protection areas. Coordination mechanisms such as memorandum of agreements and interagency steering committees are being formed to organize and direct state WHP efforts.

A number of states are proposing or have recently adopted legislation and regulatory actions for Welihead Protection. For example, Minnesota's 1989 Groundwater Protection Act mandates the State Department of Health to develop WHP rules for public water supply wells. Massachusetts is in the process of promulgating revisions to their Drinking Water regulations to require local water suppliers to conduct groundwater monitoring, delineate WHP areas, perform land use surveys, develop local water resources management plans, and ensure that contingency measures are in effect.

The Future of Welihead Protection

EPA is very encouraged by the enthusiasm with which the states are undertaking WHP. Over the next year state and local governments will be moving forward on finalizing and implementing their WHP efforts. The protection of the public water supply resource through WHP should provide greater safety and less public health threats from sources of groundwater contamination. The flexibility to design a state WHP program to fit the specific institutional and hydrogeologic setting is producing WHP programs that will effectively manage WHP areas from sources of contamination.

TOXICOLOGIC RISK ASSESSMENT FOR GROUNDWATER CONSTITUENTS

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Introduction

Groundwater throughout the United States contains both inorganic and organic nonwater chemicals (constituents). Many constituents occur in groundwater naturally, sometimes enhancing the aesthetic or nutritive properties of the resource. In some cases, however, natural constituents and those which result from human activities occur at excessive concentrations. Excessive concentrations of constituents may present a risk to the health of people who consume (or otherwise use) the groundwater. Comparison of constituent concentrations to such regulatory standards as federal Maximum Contaminant Levels (MCLs) or Maximum Contaminant Level Goals (MCLGs) or to state groundwater standards is not an adequate representation of human health risk, since these standards may not be directly tied to human health risk; standards may also consider environmental risk, aesthetic factors (e.g., taste), or feasibility and cost of treatment. Further, a generic standard cannot consider actual exposure patterns. Instead, the potential for groundwater constituents to cause adverse health effects can be evaluated using toxicologic risk assessment tools. Some basic concepts in toxicology will be reviewed and potential pathways for exposure to groundwater will be discussed.

Risk is a function of exposure to a constituent and that constituent's inherent hazard. I aspire not to explain how to evaluate human health risks associated with constituents present in groundwater, but rather to familiarize the reader with general approaches and major sources of uncertainty. Thus, the reader will be in a better position to understand the implications of toxicologic risk assessments and to make informed decisions about use or remediation of affected groundwater. This paper will address hazard first, and then exposure.

Hazard: Concepts in Toxicology

The basic premise of toxicology is the centuries-old adage that "the dose makes the poison." For each chemical, there is a dose (an exposure level) below which no harm (or no discernible harm) will occur. For instance, arsenic, that quintessential poison, may be a required nutrient at low doses. Even water, an absolute requirement for survival, can kill: although we drink an average of 1.4 liters of water each day (USEPA 1989), inhalation of only a relatively small amount of water can cause death (drowning).

In addition to illustrating that "the dose makes the poison," water demonstrates the importance of route of administration. The three environmentally relevant routes of administration are oral (ingestion), inhalation (respiratory), and dermal (skin). Each may be important for constituents in groundwater: (1) When we drink affected water we are also ingesting the constituents. Similarly, we may consume produce which contains constituents from affected irrigation water.
(2) Constituents can also volatilize (evaporate), thus moving into air which may be inhaled. (3) Constituents can be absorbed from affected water which comes into contact with the skin.

Another underlying concept in toxicology is that there are numerous different and independent toxicologic endpoints (different types of adverse health effects). Any given chemical may cause several different adverse effects at different exposure levels or by different routes of administration. One such adverse effect is cancer. While all chemicals cause noncancer adverse health effects, only some, carcinogens, cause cancer. Other adverse health effects include skin rashes, organ damage (e.g., liver, kidney, or central nervous system), reproductive effects, blindness, birth defects, and death. Adverse health effects are typically evaluated in two groups: cancer effects and noncancer adverse health effects. This division was originally based on a belief that cancer is caused by a wholly different biological mechanism than other adverse health effects. More recent research has demonstrated that chemicals can induce cancer by a variety of means, many of them similar to mechanisms which cause noncancer adverse health effects. Retention of differential treatment of cancer and noncancer health effects probably results from habit and society's perception of cancer as a particularly bad, severe or deadly effect.

In general, many cells in a given tissue all perform the same function. Therefore injury to, or death of one or a few, cells is not biologically relevant — other cells are able to compensate. However, when enough cells of one type are damaged or killed, the organ or system may cease to function properly, or the compensatory efforts may become pathological. These are adverse effects, but they occur only after a large number of similar cells are damaged or killed. Hence, we have the concept of a "threshold" level of exposure (or damage) below which no biologically relevant adverse health effect occurs. At and above this threshold there is an adverse health effect. In practice, we cannot pinpoint the threshold, either for a population or an individual, but this concept of a threshold is basic to risk assessment for noncarcinogens.

Cancer is thought to result from damage to the genetic material of a single cell which then reproduces in an uncontrolled manner, perhaps metastasizing to other organ systems. In theory, a dose as low as a single molecule could cause cancer — it must only cause the necessary damage to the genetic material of one cell. Hence, there is no threshold below which biologically relevant damage will not occur, and cancer is known as a "<u>nonthreshold</u>" effect. The body, of course, has many protective mechanisms which make this one-molecule, "one-hit" scenario unlikely. For instance, the single molecule could interact with biologically irrelevant cellular molecules, or be metabolized, or cause genetic damage which kills the cell or is irrelevant, or cause genetic damage which is repaired. Also, we have learned that many chemicals cause cancer through a mechanism which does not involve direct genetic damage. Rather, these chemicals bring about an increased rate of cell production which decreases the likelihood that naturally occurring genetic damage will be properly repaired. For these "nongenotoxic" carcinogens, there is a threshold level of exposure below which the rate of cell production will not be affected.

Although the ability to cause specific adverse health effects is an inherent property of each chemical, many <u>individual factors</u> also affect the toxicity of chemicals. Some of these factors can be controlled, but others cannot. Among those which cannot be controlled are genetic background, previous illness, and general state of health. Other individual factors such as diet, lifestyle, exposure to pharmaceuticals, and smoking can be controlled. There is no way to account for these factors in a risk assessment except to be very conservative (risk overestimating) in risk evaluation.

There are two primary <u>sources</u> <u>of</u> <u>informa</u>tion elucidating the toxic effects of environmental chemicals: studies of humans and studies of laboratory animals. There are two types of studies which provide direct information about health effects in humans. The first type, <u>clinical studies</u>, involves intentional exposure of humans to chemicals, typically pharmaceuticals. These are seldom an important source of information exposed population is small, (2) the exposed population is often special (requiring some sort of medical treatment), (3) therapeutic doses are much higher than environmental exposures, and (4) most environmentally important constituents have not been used as pharmaceuticals (notable exceptions include chloroform and similar chemicals which have been used as anesthetics).

The other type of studies of humans is epidemiologic studies, which evaluate human populations that had accidental, occupational, or environmental exposure to chemicals. These are useful because they provide information about effects in humans who may have been exposed at environmentally relevant concentrations. (Of course, some accidents and some occupations result in exposure levels higher than those generally associated with environmental exposures.) However, there are many factors which make epidemiologic studies difficult to interpret. For instance, study populations are usually small, so that the frequency of an effect would have to be very high in order to be noticed. Populations can also be very difficult to follow over the course of the several decades that may be required for some effects to become noticeable. Further, the route of exposure may be different from the route of interest, and humans are constantly exposed to other chemicals (e.g., tobacco smoke, occupational constituents) which may mask the effects of the chemical of interest or make it impossible to determine the cause of a particular effect. Another concern is that the exposure dose is seldom quantified in epidemiologic studies, so a dose-response relationship cannot be established. Finally, it can be difficult to identify appropriate control (unexposed) populations.

Thus, data for use in toxicologic risk assessment most often come from studies performed in laboratory animals. In these studies, the route of administration and the dose level can be controlled, and genetically homogeneous animal populations can be used. Further, exposure to other constituents can be minimized, and it is treated animals live in the same environment. Unfortunately, in order to recognize rare effects, animal studies typically use extremely high doses of chemicals. Interpretation of these studies in light of effects that would occur at the lower levels to which humans might be exposed is complicated and uncertain. And, of course, laboratory animals are not humans.

Exposure

People can be exposed to constituents in groundwater by all three exposure routes (ingestion, inhalation, and dermal) and via many different exposure pathways. Several of these exposure pathways occur indoors (e.g., ingestion of drinking water, bathing/showering, and exposure to indoor air which is affected by groundwater constituents). Other pathways include ingestion of homegrown produce which is affected because it was irrigated with affected groundwater, ingestion of food which is prepared in affected groundwater, and dermal and inhalation exposure related to irrigation. Traditionally, toxicologic risk assessment has considered only the ingestion (drinking) pathway of exposure to water, but other pathways can also be important. This section will discuss some of the salient factors associated with evaluation of the drinking-water exposure pathway and others. The goals in evaluating exposure pathways are to identify those which are important in a particular case and to obtain estimates of constituent intake or dose. This information is then combined with hazard-related information to obtain both qualitative and quantitative evaluations of risk.

People can also be exposed to constituents present in groundwater following discharge of the groundwater to surface water. Important human health-related factors under this scenario would include dilution, attenuation of constituent concentrations, direct exposure to surface water, other uses of surface water, effects on and exposure to sediment, and resultant constituent concentrations in fish which may be consumed.

These indirect pathways of exposure to affected groundwater will not be discussed here.]

The first factor which must be considered when evaluating an exposure pathway is constituent concentration at the point of exposure. For exposure pathways which involve direct exposure to groundwater (e.g., drinking, dermal contact during bathing/showering), the concentrations which were found in the groundwater itself are typically used as exposure point concentrations. These concentrations may not perfectly represent actual concentrations at the point of exposure. For instance, constituent concentrations may be affected by beverage preparation methods (e.g., boiling of tea water increases volatilization and so decreases the concentration of volatile constituents in the water; by decreasing the amount of water without affecting the amount of metals, boiling could increase the concentration of metals in the water). Such alterations in constituent concentrations are not usually considered in exposure evaluations. When the medium of interest is not water itself (e.g., when the pathway involves exposure to air that may contain constituents which volatilized from water, as in the cases of both irrigation water and showering), we typically face additional uncertainties. For instance, unlike the concentration in groundwater (which is usually measured), concentrations in the air are seldom known because air is seldom monitored. Even if air were monitored inside or outside of representative homes, there would be no way to account for nonwater sources of constituents, such as carpet glue or the gas station down the block. In the absence of actual monitoring data, constituent concentrations in air are typically estimated using equations which include constituent concentration in groundwater as an input parameter. This contributes uncertainty. These equations generally overestimate exposure concentration, often by orders of magnitude. Available equations for estimating concentrations in irrigated produce (or livestock which consume affected groundwater or crops) contribute so much uncertainty that expensive chemical analysis of the food product is almost a necessity.

It is also important to remember that, although exposure equations typically assume that constituent concentrations remain static over time, this is not likely to be true. Rather, constituent concentrations in groundwater (and so, in other media) will change over the course of time. This is particularly true for concentrations in affected homegrown produce, because over several seasons irrigation can contribute to increased constituent concentrations in soil which may also be taken up by plants.

Another important factor is the rate of exposure to the affected medium — the amount of affected groundwater which is consumed or which comes into direct contact with the body, the amount of affected air which is inhaled or the quantity of affected produce consumed. Traditionally, it has been assumed that a person drinks 2 liters of affected water per day (USEPA 1986). A more recent estimate of daily water consumption is 1.4 liters. This includes not only water but water-based beverages (juice concentrate, coffee, tea, etc.) and represents daily consumption from all sources (e.g., at home, at work). Exposure estimates typically assume that all of the 1.4 liters of water come from the same affected source. This overestimates exposure (and so, risk). An individual's activity level greatly affects the quantity of water which is consumed.

For affected air, 23 cubic meters per day is an estimated breathing rate for an adult (*53* F.R. 148). More detailed estimates of breathing rate by gender, age, and activity levels are available (USEPA 1989). Most adults do not spend all day every day in the affected building or area (e.g., at home), and this is an important consideration in exposure estimation. In some cases it may be most effective to consider showering as a separate inhalation exposure, since concentrations during showering are higher than concentrations in general indoor air.

Dermal exposure to affected groundwater is difficult to estimate because it occurs during so many activities (bathing/showering, hand washing, dishwashing by hand, household cleaning). The key factor here is the surface area of the exposed skin. The total skin surface areas of adult males and females are about 1.94 and 1.69 square meters, respectively (USEPA 1989). Surface area estimates are also available for body parts (e.g., hands) and for children.

The quantity of affected produce consumed can be estimated based on intimate knowledge of the exposed population or can be derived from other studies (USEPA 1989). Estimates of consumption of homegrown beef and dairy products are also available and can be considered when livestock consume affected groundwater or crops irrigated with affected groundwater.

There are compilations of information about daily activities which can facilitate estimation of the duration of exposure. For instance, most Americans bathe or shower once each day, and the median duration of a shower is about 17 minutes (USEPA 1989).

Exposure estimates are typically in units of milligrams of constituent per kilogram body weight per day (mg/kg/d), thus the body weight of the exposed person has an integral role in exposure estimates. Typical assumptions include a 70-kilogram man, a 60-kilogram woman, and a 10-kilogram child.

The duration of exposure to affected groundwater or air is also an important factor. Traditionally, 70 years has been used as the life-span (USEPA 1986), but more recent evaluation of relevant data suggests that 75 years would be more appropriate (USEPA 1989). If the affected supply is to a residence, 9 to 30 years may be appropriate, since most people move from one home to another (USEPA 1989). If the affected groundwater or air is in a workplace, it might be more reasonable to consider 40 years (the entire working lifetime), but only 5 days each week.

Appropriate use and interpretation of risk assessments for groundwater which contains constituents rests on an understanding of the basic concepts of toxicology and of exposure estimation. Considerable uncertainty is inherent in the “hazard” component of risk. Data must often be extrapolated from animals to humans and from high doses to low doses. Further, there is currently no way to address chemical or biological interactions among the many constituents which may occur together in groundwater. Many other assumptions and conventions also affect the interpretation of hazard-related information.

The exposure component of risk is also fraught with uncertainty. Actual constituent concentrations in the groundwater are not static over time, and resultant concentrations in air or food are not known with certainty. It can be difficult to include all relevant exposure pathways (e.g., drinking water, indoor air, affected produce) in the risk evaluation, and, in fact, this is typically not attempted.

The assessment of toxicologic risk associated with constituents in groundwater should be undertaken with an appreciation of the science of toxicology and with respect for the many sources of uncertainty associated with both hazard and exposure. Responsible risk assessors produce meaningful risk estimates which are well documented so that the informed reader can identify and appreciate major sources of uncertainty. These uncertainties, which are typically addressed by using conservative assumptions and methods, do not detract from the usefulness of the risk evaluation. Rather, toxicologic risk assessment is a powerful tool which, when put into proper perspective, contributes to effective decision making about the use, value, or remediation of groundwater which contains constituents.

References

Federal Register.1988. Hazardous Waste Management System; Identification and Listing of Hazardous Waste; Exclusion “53(148): 29038-43.

U.S. Environmental Protection Agency. 1988. Superfund Public Health Evaluation Manual. Office of Emergency and Remedial Response. OSWER Directive 9285.4-1. Washington, DC.

U.S. Environmental Protection Agency. 1989. Exposure Factors Handbook.
Office of Health and Environmental Assessment, EPA/600/8-89043.
Washington, DC.

GROUNDWATER MANAGEMENT AREAS: AN EXAMPLE OF THE MANAGEMENT DOCTRINE

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Introduction

Laws governing groundwater withdrawals started out as property-based rules of capture giving rights of unlimited use. As demand for groundwater increased and it became apparent that some control over withdrawals might be necessary, court decisions began to shift from rules of capture to rules favoring proportional sharing of groundwater as a public resource. Along with this shift, many state legislatures began taking a more proactive role in establishing groundwater management programs. Some of the goals of these management programs have been to minimize competition, protect groundwater resources, help ensure wise development of groundwater resources, help maintain regional economic stability, and diminish the historic reliance on courts to settle groundwater disputes.

This emphasis on managing groundwater as a shared public resource has been termed the emergence of a “management doctrine” for groundwater. One aspect of that has been the decision in 27 states to pass specific legislation allowing for the designation of special groundwater management areas where withdrawals are managed differently than they are in the rest of the state. Such management areas are often (but not always) designated in areas that have severe or recurring groundwater supply problems, where groundwater demand routinely exceeds supply. Regulations in groundwater management areas are normally tailored to the hydrogeologic conditions of the area and to the specific management needs. For this reason, groundwater management area programs are very diverse from state to state and within states. They are often used in conjunction with statewide groundwater regulations. They’re one example of the increased tendency for local, regional, and state governments to attempt to manage groundwater resources rather than simply react to competition and conflict over the resource.

In Search of a Groundwater Management Paradigm

American courts and legislatures have experimented over the last hundred years or so with methods for governing groundwater withdrawals and for resolving competition where groundwater shortages are a problem. At one time, groundwater was regarded as private property; rules governing its use were property-based rules of “capture” giving rights of unlimited use. Rules of capture for groundwater are roughly equivalent to saying “if you can pump it, you own it.” In a preindustrialized society, this was not an unreasonable way to “manage” groundwater resources; demands on the resource were limited and scattered so as to minimize possibilities for well interference. It didn’t take long, though, for growth and the associated expansion in groundwater use to exert challenging new pressures on the courts’ early inclination to abide by rules of unrestricted pumpage, which they often did even when that pumpage impeded a neighbor from obtaining his own fair share of groundwater. Cities, industries, agricultural irrigation — all meant more demand for groundwater, which led to more competition for groundwater in some places. Given that groundwater resources are limited, free-for-all competition for them is clearly not in the best interests of the users as a whole. The problem, as with most common pool resources, is this: no one wants to be cheated out of his share. Rather than risk reducing pumpage to save for the future and having another user pump the water for present use anyway, most users will use as much water as they can for as long as they can. This presents obvious problems when the demand exceeds the supply; when more water is being extracted than is being replenished over the same time period, the total quantity of water available to all users is diminished. So, the idea that groundwater can be used without liability to other users gradually came under increased scrutiny. Eventually the rules governing groundwater withdrawals began shifting from simple rules of capture to rules requiring proportional sharing (Bowman and Clark, 1989; Gould, 1986; Goldfarb, 1988; Tarlock, 1985). Today there is general recognition in many courts and legislatures of the common pool nature of groundwater; there is a reciprocal dependency in which one pumper's rights can affect and be affected by all pumpers' rights (Bowman and Clark, 1989). A landowner's pumpage rights are qualified in that they are exercised in consonance with the similar rights of other landowners over the same groundwater supply (Clark, 1967).

As the search for an adequate groundwater management paradigm rages on, groundwater laws are evolving from property-based rules of capture to an assortment of rules requiring conservation and sharing among claimants of groundwater as a public resource (Tarlock, 1985). This is evident in most parts of the country in both the courts and in state legislatures. First, in court decisions, the original common (case) laws of groundwater ownership have been replaced in many cases by the concept of shared allocation of limited groundwater resources. These changes have emphasized conservation and proportional sharing of limited groundwater. Second, there has been a heightened role by legislatures toward comprehensive groundwater management through statutes, also emphasizing conservation and sharing of groundwater as a public resource. These shifts have led to the emergence of what has been called a "management doctrine" for groundwater, which (1) acknowledges groundwater as a shared resource, and (2) allows flexibility to regulate withdrawals suitable for a particular aquifer (Bowman and Clark, 1989; Goldfarb, 1988; Gould, 1986).

Groundwater Management Areas—a Management Doctrine Model

At one time, groundwater users competing with each other over a limited supply found themselves with little recourse but to battle it out in court. Today, states are much more likely to have some kind of groundwater management program in place that works to prevent such competition whenever possible, and minimize reliance on courts to settle groundwater disputes. These programs normally address two main types of groundwater problems: well interference and supply interruption, and the broader problem of long-term aquifer depletion. This is accomplished with use permit requirements, water use monitoring and reporting, well construction standards, prioritized allocations, restricted usage in times of shortage, and other similar management mechanisms.

Some states employ groundwater use restrictions statewide. Others limit groundwater management to specific groundwater management areas rather than imposing statewide regulations. Portions of states suffering from severe or recurring groundwater supply or quality problems are designated as special or critical groundwater areas and managed differently than the rest of the state. Such areas may be established in addition to statewide permitting systems and other regulatory measures, or they may be the only areas in a state where groundwater use is regulated. Programs like these clearly represent a significant departure from the original laws of groundwater ownership; they are examples of the proactive stance many states are taking in protecting groundwater resources.

A recent survey shows that 27 states have groundwater management area (GWMA) programs (see Table 1). Bear in mind that some of these states also have statewide groundwater management regulations, and, of course, many of the states that do not have GWMA programs do have other groundwater management regulations. GWMA programs are one example of the expanding roles by state, regional, and local governments in management of groundwater resources; they are an example of management that bears closer examination because of their diversity and widespread nature.


Table 1. States with Groundwater Management Area Legislation

State	GWMA Legisl. Used	GWMA Legisl. Pending	No Active Areas*
Alaska		X	
Arizona	X		
Colorado	X		
Connecticut		X	
Delaware			X
Florida	X		
Hawaii	X		
Idaho	X		
Illinois	X		
Indiana			X
Iowa			X
Kansas	X		
Louisiana	X		
Mississippi	X		
Montana	X		
Nebraska	X		
Nevada	X		
New Jersey	X		
New York	X		
New Mexico	X		
North Carolina	X		
Ohio		X	
Oregon	X		
South Carolina	X		
South Dakota			X
Texas	X		
Utah	X		
Virginia	X		
Washington	X		
Wyoming	X		

*GWMA legislation exists, but no management areas designated

Groundwater management area programs are mainly used to control groundwater withdrawals in parts of states where groundwater demand normally exceeds supply. In some states they are also used to address problems of subsidence and groundwater pollution. GWMA programs got their main start in the 1950s, ‘60s, and ‘70s in the High Plains for controlling regional irrigation water use and expansion. Since then many states have adopted GWMA programs, often because of stresses from heavy localized groundwater use for agricultural irrigation. Although not all irrigated states have GWMA programs, the GWMA approach has seen its greatest development in states most heavily irrigated from groundwater, where economic and groundwater management concerns have often clashed (Aiken, 1980; Keller et al., 1982).

Regional groundwater use is controlled in GWMAs through issuance of water use permits, water rights or allocations, pumpage fees, well-spacing requirements, emergency water use restriction powers, and so on. Often, regulations also include mandatory irrigation scheduling, water use metering and reporting, well production limits, and others. These are the same types of regulations imposed in statewide groundwater management programs; limiting them to specific areas within a state allows for the regulations to be tailored to each localized groundwater problem and helps avoid unnecessary regulation. This flexibility is one of the clear benefits of the GWMA approach; it is also partly responsible for the vast diversity in GWMA programs across the country.

Most groundwater management area programs have been motivated by an overpumpage problem or some other type of groundwater quantity problem. Some have been motivated by a groundwater pollution or contamination problem. At least 13 states have GWMA programs that allow for special regulations to be imposed within the designated areas to address both quantity and quality problems. In most states with GWMA programs, the individual management areas are designated by a central state agency of water or natural resources. That is, hydrologists from an agency identify the problem area, initiate a process to designate it as a GWMA, and define its boundaries. In most cases, this initial formation process allows for some level of input by local interests. There are a number of states in which the local interests hold the balance of authority for initiating GWMA formation; the High Plains states of Colorado, Kansas, Nebraska, and Texas stand out in this regard. Most states, including the four High Plains states mentioned, have more than one process for initiating and forming a management area.

Management area boundaries are defined along surface watershed lines, groundwater basin lines, and political lines such as townships and counties. Most states report using political boundaries only as a last resort for administrative convenience. The administration of management areas is carried out in most states by a central state agency; that, agency develops a management plan (usually with input from local interests), oversees the implementation of the plan, and pays for administrative costs out of general state revenues. Some states give considerable formal authority to the local management districts themselves to develop and implement management plans and pay for administrative costs with local property taxes, pumpage fees, permit application fees, and so on. Again, the four High Plains states stand out in this regard.

There is a great deal of diversity in GWMA programs. The heavily irrigated High Plains states with GWMAs (Colorado, Kansas, Nebraska, and Texas) have allowed the groundwater users to administratively impose controls on themselves by forming management areas and restricting withdrawals. Most of the other states have GWMA programs that are controlled by a central state agency. Presumably, in the four High Plains states, groundwater is so closely tied to the local irrigation economies that maintaining control over its regulation is a jealously guarded tradition among local groundwater users (Aiken and Supalla, 1979; McCleskey, 1972).

Conclusions

Comprehensive groundwater management programs are being developed in many states as the laws governing groundwater withdrawals shift from property-based rules of capture to rules requiring proportional sharing of groundwater as a public resource. One aspect of this new “management doctrine” for groundwater is the designation of special groundwater management areas. While the programs vary in their specifics, their basic form is fairly standard: areas that have severe and recurring groundwater supply problems and/or groundwater quality problems are designated as a special or critical management area. Groundwater withdrawals in those areas are then regulated differently than in the rest of the state. Specific regulations (including everything from well spacing to drilling moratoria, from emergency water use restrictions to transfer of water rights) are tailored to the specific needs of the area. In some cases, the management areas are used in conjunction with statewide groundwater management regulations, and in some cases they are the only places where groundwater use is managed. They are an example of the increased efforts toward managing groundwater as a public resource.

References

Aiken, J.D. 1980. Nebraska Ground Water Law and Administration. Nebraska Law Review 59:917-1000.

Aiken, J.D., and RJ. Supalla. 1979. Ground Water Management in Nebraska. Proceedings: Legal, Institutional, and Social Aspects of Irrigation and Drainage and Water Resources Planning and Management, ASCE. Blacksburg. VA, July 26-28.

Bowman, J.A., and G.R. Clark. 1989. Transitions in Midwestem Groundwater Law. Water Resources Bulletin 25(2):413-20.

Clark,R.E. 1967.Waters and Water Rights .Vol. 1. Indianapolis, IN Allan Smith Co.

Goldfarb, W. 1988. Water Law. *24* ed.. Chelsea, MI.: Lewis Publishers.

Gould, G.A. 1986. Water Law in 1986: Selected Issues. In Water Resources Law, Proceedings of the National Symposium on Water Resources Law. American Society of Agricultural Engineers, St. Joseph, MI
2-18.

McCleskey. G. W. 1972. Problems and Benefits in Ground-Water Management (guest editorial). Ground Water 10(2):2-5.

Tarlock, A.D. 1985. An Overview of the Law of Groundwater Management. Water Resources Research 21(11):1751-66.

AGRICULTURE AND GROUNDWATER QUALITY

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Introduction

Intensive row-crop agriculture in the corn belt area of the Midwest United States is the foundation of the region's economy. Major increases in agricultural production in this region have occurred in the past thirty years due in part to extensive use of pesticides (herein, the term pesticide is used to include herbicides and insecticides) and inorganic fertilizers. In Iowa, inorganic nitrogen fertilizer use has increased from an average of 13 lbs/acre in 1955 to 139 lbs/acre in 1988. Similar increases have been seen in the other corn belt states. Nitrogen used on corn averaged *158*, 146, 163, 139, and 132 lb/acre in 1988 in Ohio, Indiana, Illinois, Iowa, and Missouri, respectively. In this same five state region, 98% of the corn acreage received herbicide treatment and 34% insecticide treatment in 1988. Depending on the actual pesticide compounds used, the rates for herbicides and insecticides would be about 3 and llb/acre, respectively. Use of this ag-chemical technology has resulted in increased production at lower per-unit costs. Ag-chemical use does represent cost to the producer. On a typical Iowa farm, total fertilizer costs for corn represented about 14% (8% for nitrogen fertilizer only) and pesticides represented 8% of the total $344/acre production costs in 1989. However, these inputs normally provide significant increases in crop yield and subsequent income. For example, addition of nitrogen fertilizer to continuous corn often more than doubles yield compared to no nitrogen added.

In the past, considering only economic costs, there was little difference between an "economically optimum yield" and maximum yield. Hence, if one was to error on inputs, it was good insurance to error on the side of higher chemical use. Now with the water quality concerns arising from the detection of pesticides and nutrients in groundwater (primarily herbicides and nitrates) and the increasing desire to design alternative agricultural systems that are more sustainable, there is a need to reevaluate and modify current farming practices, taking into account costs beyond simply the dollar value of inputs.

Nitrate nitrogen levels above the existing drinking water standards and detectable levels of pesticides have been reported in most of the corn belt states. As an example of pesticide contamination, a one-time sampling of all public water supplies in Iowa (Iowa DNR, 1988) found 16% of the 217 wells that were less than 100 feet deep contained detectable levels of pesticides. For wells of 100-1000' depth, 6% of the 413 wells tested contained detectable levels of pesticides. None of the *105* wells tested that were deeper than 1000' were found to contain pesticides. For comparison, 61% of the 41 public water supplies using surface water sources were found to contain pesticides, and the concentrations of pesticides were generally higher in surface water than in groundwater supplies. In 1987, the Illinois Public Health Department sampled wells at 80 of 1500 agricultural chemical facilities statewide.

Results showed that two-thirds of the wells sampled were contaminated (Illinois Farm Bureau, 1989). A more recent sampling of 160 private rural water supply wells in four counties in north-central Iowa revealed detectable levels of pesticides in water from only 1 well.

Research Issues

Further research on the determination of the main source of pesticide contamination is needed. Whether the pesticides are leaching through the soil as nonpoint source contamination (i.e., pesticide-treated fields) or coming from “point sources,” such as areas of chemical spills or improper disposal that may exist around places where pesticides are handled, is not known. It is known that atrazine, a longer-lived herbicide, can leach through the root zone, although usually at concentrations less than 1 micro gram / liter (ppb); however, when a number of different pesticides are detected and at significantly higher concentrations, the question has to be raised as to point sources in the vicinity. This type of research is critically needed in order to develop cost-effective management methods to prevent further groundwater degradation.

Another issue that needs and is getting further attention is the role that macropores, or preferential flow paths, play in the transport and fate of ag-chemicals in the environment. Macro-pores or channels or cracks certainly have the potential to allow surface-applied chemicals to move deeper into the soil more quickly than if water had to flow through the soil matrix as “plug flow.” However, these macropores also have the potential of allowing water from the soil surface to move through the soil, bypassing chemicals that may be within the peds or soil aggregates, and therefore actually decrease chemical leaching. The role that conservation tillage plays in the formation of macropores is very important and needs to be resolved in order to be able to continue to promote conservation tillage as an environmentally sound soil conservation practice.

Relative to the fate and transport of ag-chemicals in the soil/groundwater system, little is known about the potential existence of various attenuation processes. The rate of attenuation reactions for both nitrate and pesticides is not completely understood. Are the trends of decreasing concentrations of contaminates with depth that are often observed in well sampling simply the result of the chemicals not having had enough time to move deeper, or are attenuation processes such as denitrification, pesticide degradation, and adsorption significant factors also?

Much of the current research on transport of ag-chemicals has focused on the shallow “rooting zone.” For corn, this is assumed to be the first five feet of soil. The processes of transport in the vadose zone below the rooting depth until the water table is reached and the processes of transport within the groundwater zone have received much less research. In the groundwater system, for example, an improved understanding of the effects of the small-scale anisotropic conditions found in many unconsolidated aquifers on contaminant transport is critical for the prediction of the transport of ag-chemicals. Adsorption and biological degradation of pesticides with the low organic matter aquifers is not fully understood.

The issue of “best management practices” to control nonpoint source pollution has already received a lot of attention in the research community. However, the word “best” is an overstatement because it implies we know more than we actually do about the impact of various “best management practices” on groundwater quality. Certainly there is still need for further field verification of the effectiveness of currently recommended practices under varying field conditions. Furthermore, there is room for development of improved farming practices or agricultural systems. Significant new research is being initiated in this area of concern under the banner of sustainable agriculture. While sustainable agriculture is much broader than agricultural chemical impacts on groundwater, changes in farming practices will be necessary to answer the chemical concerns.

The design of new agricultural practices or systems is affected by the performance standards that are applied. For water quality impacts, the major question is what are the appropriate water quality standards for use in developing new practices. Most agricultural chemicals do not have established drinking water standards or maximum contaminant levels. Some of the chemicals have health advisory levels established. How should these various standards be applied to design of new practices? For example, will health advisories that are being established for the more modern pesticides be the criteria against which to measure best management practices, or will agricultural drainage be required to meet the drinking water standard? Should concentration standards be applied to individual grab samples collected or to longer-term average concentrations? These are important questions that will require interdisciplinary research teams in several disciplines including engineering, economics, health professions, political science, and others.

Research Initiatives

To meet the need for additional groundwater quality research, there are two new research activities on the horizon. They are the USDA Midwest Water Quality Initiative and the USGS Mid-Continent Herbicide Initiative. These major new programs are related in that significant cooperation between the two lead agencies and US EPA is taking place. In the USDA initiative, emphasis is being placed in four areas:

- An assessment of the effects of existing management systems (with respect to pesticides, nitrogen, cultural practices, crop and livestock systems, and water management) on the water quality of agricultural drainage;

- The development of new management systems, chemical application technology, and diagnostic tools (such as a soil-nitrate test), resulting in improved water quality;

- The development of fundamental information useful in further improved practices and systems for water quality control (e.g., data on mass accountability, preferential water flow and chemical transport, and biological pest control); and

- Model development and utilization for making policy and management decisions.

For the USGS Mid-Continent Herbicide Initiative, studies have been planned to investigate the effects of agriculture on the occurrence of herbicides in ground and surface water. The herbicide atrazine has been chosen as the focus chemical because of its widespread continuous use and the frequency with which it has been detected in groundwater. The objective is to answer the key question: What happens to atrazine after its application? The studies are considering physical, chemical, and biological processes that can affect the transformation, transportation, and storage of atrazine. Included are various environmental factors, which can vary over time and space, such as soil pH, atrazine application rate, depth to water. A research matrix has been developed that uses a mass-balance concept to account for the distribution of atrazine in the environment and to identify additional research needed. Information gained is to be used to provide the scientific basis to guide institutional decisions to mitigate water contamination.

The purpose of this paper has been to outline some of the concerns with the proper use and management of agricultural chemicals. Additional research is needed in order to assist the farmers in facing the critical issues of improved management in the future. University researchers have an important role in finding solutions to the issues discussed above.

References

USDA Economic Research Service. 1989. Agricultural Resources/Situation and Outlook Report, No. AR-13.

Iowa Cooperative Extension Service. 1989**.** Estimated Costs of Crop Production in Iowa - 1989**,** Report No. FM-1712.
Iowa DNR. 1988. Pesticide and Synthetic Organic Compound Survey. Report to Iowa General `Assembly` Required by House File 2303.

Illinois Farm Bureau. 1989. Farmweek. 17 (34) August 28.

Jeffrey Lorimor. Personal communication. Soil and Water Engineering Specialist, Cooperative Extension Service, Mason City, IA.

HAWAIIAN ISLANDS GROUNDWATER: A NEW BALL GAME

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Without groundwater sources, the Hawaiian Islands would not have been as vital as they are today—a very popular vacation destination for millions of global visitors, a booming commercial hub of the Pacific, a strong agricultural producer, and an important national defense base.

The beginning of a changing era was the year 1879 when James Campbell sponsored the drilling of a well that struck artesian water on Oahu. That copious groundwater source was the impetus at that time for sugarcane cultivation as a large scale mechanized agricultural industry. More important, it is the high quality of groundwater—potable without treatment—that makes it the premier and most economical source for Hawaii's drinking water supply. Groundwater provides 99+% of the drinking water for Honolulu with its present population of 838,000 and 90% of all water uses including irrigated agriculture. Although it is self-evident, ocean imposes freshwater self-sufficiency for each island.

As a part of Hawaii's artesian water centennial (1879-1979), the University of Hawaii Water Resources Research Center documented in a book a century of progress in exploration, discovery, and study of Hawaii's remarkable aquifers. That book provides a benchmark of the state of the Hawaii groundwater resources.

Now, a century plus ten years later, a new ball game is being played regarding allocation of water for use and contamination of water sources. Three major issues are the talk of the town and preoccupy the water professionals in Hawaii today.

(1) Water Allocation

Hawaii finally got its first state water code in 1987 to manage the state's water resources by regulation of the uses of water. The code spells out who may develop water from what sources, at what quantity, for what purpose, and for how long. A state water commission is vested with the authority to allocate water by a permit system. Are the great expectations fulfilled by a document that is perfect or a disaster? The answer is neither. Perhaps to the surprise of no one, the legislation is generally regarded as a masterpiece of compromise. It is a compromise between two traditional opposing water resources management approaches—free market and regulation— and a compromise among strong, vested interests in Hawaii. The water commission needs to provide fairness and wisdom to make an imperfect legislation work.

(2) Organic Contamination of Groundwater

While the water code addresses primarily water resources management, water quality management was not really regarded compelling until a time bomb exploded about 1983. The prolonged transport of organics since their first use many decades ago has surfaced in trace amounts in potable groundwater sources on the island of Oahu. The immediate response was immense public concern. Evidence of pesticides used in pineapple cultivation and pipeline spills of aviation fuels in groundwater caused several essential wells to become unusable. Federal and state officials took immediate action to address public health concerns. The state legislature mandated closer monitoring on the sale and distribution of pesticides and the strengthening of the authority of state officials. From this unprecedented experience, the several measures outlined can be used by other water utilities to forecast or to meet similar contingencies. The Hawaii experience is a landmark because the action level of the pesticides concerned was set at an unprecedented low level—20 ng/l or parts per trillion—the laboratory detection limit and many times lower than all other states.

(3) Aquifer Protection Policy Dilemma

How can we protect aquifer and groundwater sources from contamination and yet, at the same time, not unduly restrict land use when we know that its development can cause aquifer depletion and contamination? In this regard, Hawaii faces more problems than continents because of the shortage of land for development on a small island. Then, too, much land suitable for development and those areas already developed overlie potable groundwater sources. Hawaii’s groundwater protection policy actually dates back to the 1920s when any development in the groundwater recharge areas—high rainfall mountain regions—was prohibited. The water and forest conservation zones are marked by a circumisland “no-pass” line. More recently, a second line was added for each island, the UIC (underground injection control) line that delineates the areas in which no waste injection into groundwater is permitted. The current policy debate appears to be wavering somewhere between antidegradation and differential protection rather than the outright nondegradation.

By request, the University of Hawaii Water Resources Research Center is immersed in research to develop options for policy and regulations. For instance, a two year modeling project now nearing completion deals with potential groundwater contamination by urban use of pesticides. In a long-term project, all aquifers in Hawaii are being mapped and classified by their vulnerability to pollution. In progress is an interagency planning effort of large-scale use of primary effluent for replenishment of nonpotable groundwater source by wastewater irrigation. The scientific basis for planning is a recently completed three year demonstration project by UH-WRRC. The innovativeness of this facility is the use of primary, rather than secondary, effluent and the consequent result in tremendous savings from constructing and operating a secondaiy wastewater treatment plant.

In looking to the year 2001 concerning Hawaii’s groundwater resources and quality management, extraordinary measures will be required to supplement conventional strategies. Above all is education in the broadest sense to enable formulation of rational policies. This means education of the public and the policy makers. As the only publicly funded university in the state, the University of Hawaii must assume principal responsibility for this special education. Close coordination with action agencies will pinpoint the selection of this particular audience to ensure every chance of success. Educating the public about relative health risks is especially important because an informed public is less prone to emotional reaction and more apt to be able to sift truth from untruths. Hawaii’s experience may benefit other Pacific island countries because of similarities in environment and Hawaii’s scoreboard of successes in economic development. Technology transfer is one key to this ball game of special education; social acceptance is the other key.

PACIFIC ISLANDS GROUNDWATER: LEARNING THE GAME

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In the immensity of the central Pacific Ocean, island groups starting with the Hawaiian Archipelago on the east stretch westward to the Philippines on the rim of Asia. Hawaii has a teeming economy and in political and social behavior resembles its sister states, but the islands on its western horizon are relatively small and many are still emerging from subsistence economies. Others like Guam and Saipan have quickly evolved into modern societies because of their strategic importance.

The succession of islands in the north central Pacific Ocean in which the United States has played a guiding role since World War II starts with the low-lying atolls of the Marshall Islands. Farther west are the East and West Caroline Islands, which include rugged volcanic terrains as well as atolls, then the Mariana Islands of mixed volcanic and limestone composition. These islands were once governed under the U.S. Trust Territory Administration but in the last decade have become or are in the process of becoming sovereign entities associated with the U.S. The Marshall group is now called the Republic of the Marshall Islands; the Caroline Islands have divided into two nations, the Federated States of Micronesia and the Republic of Palau; and the Marianas consist of the Territory of Guam, which has existed since the turn of the century, and the Commonwealth of the Northern Mariana Islands, of which Saipan is the capital.

In many social and cultural aspects the islands have connecting similarities, but environmentally each may differ profoundly from the others. Everywhere, however, the fundamental concern is the availability of freshwater. Depending on local environments, water is obtained from rain catch, diverted from streams or extracted from the ground.

Reliable water sources are vital if the expectations of the emerging island economies are to be met. Before the period of modern intervention in island affairs, freshwater was obtained as rain catch and from shallow-dug pits, streams, and springs. The sources were adequate, but once a water system is constructed to solve a specific problem, the old means of securing a supply suffer by comparison and are soon abandoned where possible. Turning a tap is more convenient than diverting a trickle from a stream. It is also more sanitary.

The most modern water system west of Hawaii serves Guam. It is based on groundwater in limestone aquifers covering the northern half of the island. The Water Resources Research Center at the University of Guam has played an important role in the success of the system. Saipan also has a central distribution network based on groundwater in limestone, but problems of salinity plague the delivered water supply. In Yap and Palau a core system exists, but only for the small urban areas serving the government centers. Small capacity wells, on the order of 10 to 20 gpm, have successfully exploited the low permeability volcanics of these arc islands, but surface water remains an essential component of supply where limestone aquifers are absent.

In the mid-ocean islands both surface and groundwaters serve urban centers, but efforts are being made to convert solely to groundwater wherever possible to eliminate sanitation problems. The Water Resources Research Center at the University of Hawaii and Guam has been engaged in performing research to assist the long-term goals of the island governments.

Water supply unreliability afflicts some islands of the central north Pacific, but sanitation is a worrisome concern in all. The problem of waste disposal is acute in those islands not yet far removed from their subsistence past. For some urban areas small sewage treatment plants have been constructed and sometimes work, while in rural and wild areas human and animal wastes are not treated and rarely collected. Carelessness threatens surface and shallow groundwater supplies.

The University of Hawaii Water Resources Research Center first sent a sanitation survey team to the islands more than 20 years ago. Its most recent effort was in 1988-89 when a census of waste disposal practices was taken in Truk and Palau to assess contamination potential.

The conjunction of water supply and sanitation practices is inseparable in islands. Carelessness either in water development or disposal of wastes escalates quickly to disaster because the resource base is too small to allow for much error. The largest island in the American sphere of concern west of Hawaii is Guam, embracing 212 square miles. Most atoll islands are less than 1 square mile in area.

The problems of supply and disposal are bound to intensify. It is a new ball game, indeed, in the islands of the north central Pacific, and learning the game is the first order of priority.