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The Role of Environmental Technology in Developing, Maintaining, and Protecting Ground-Water Supplies in the 21st Century: An Update*

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Abstract

New methods, procedures, and devices are transforming the way the water-supply industry will do business in the 21st Century. Past practices point the way to improved technological and managerial efficiency in ground-water development, water-well construction, maintenance, and protection from contamination. The cost-benefit of the use of ground water and surface water requires new ways to meet demands involving conjunctive use programs. Past practices have depleted the low-cost, high-quality ground-water resources and as a result water costs will be higher in the future as high-cost, low quality surface water resources are brought on-line. With the aid of the Internet, new developments will be distributed faster than ever before. With the aid of EPA and state regulatory programs, in cooperation with local utility management, the general public will be supplied with relevant, timely information on the quality of drinking water it consumes. The general prognosis is good. The details require attention.

Introduction

Before I discuss the future directions of technology in the ground-water industry, we need to define a few terms. Next, we need to evaluate where we have been in the field before we look into the future. Environmental technology involves the methods, procedures, and devices we use to assess environmental conditions. Developing, maintaining and protecting ground-water supplies over the past century began by drilling a hole in the ground and pumping water to the surface. New technology was neither available nor needed. In the early 1970's, however, early federal legislation mandated that a young U.S. Environmental Protection Agency (EPA) take note that ground water was becoming the primary source of drinking water in the U.S. and take steps to protect that valuable natural resource from growing agricultural and industrial contamination. EPA and other federal agencies funded major studies on water well technology (see reference (2), and developed a set of water well construction standards (6) to provide guidelines for improved well construction technology.

Water well technology consisted of time-tested methods, procedures and devices used for years in the water well and oil industries by companies and consultants in constructing both high capacity municipal and low capacity rural water systems.(3) The technology developed slowly during the early years because of technical isolation in both the water well industry and oil well industry. Technical developments in one field did not find their way into the other field.

Over the past 30 years, however, significant population growth has occurred in the U.S. This growth has encroached into once rural areas as the suburbs continue to expand. The ground-water resources have supported this outstanding growth around the major cities of the U.S. The relatively shallow, easy to recover, cheap ground-water resources have been seriously depleted in areas of high growth along the eastern seaboard, Gulf Coast, California coast, and interior regions. The lay public, however, often misunderstands the term "depletion." In context with ground water, the term means that water levels (and the so-called potentiometric ((pressure)) surface it represents) are declining in elevation as more water is removed than is recharged to the aquifer. Depletion then indicates that the usage of many aquifers in the U.S. is out of balance, water levels are declining and the cost to pump increases as a result and wells must be deepened, if possible, or re-drilled.

This depletion of ground-water resources often involves other consequences beyond increased pumping costs. Land subsidence is caused when the aquifer's water level (potentiometric surface) is lowered over years of decline. Numerous places around the U.S. have experienced significant land subsidence since the early 1970s. Baytown, Texas, for example, southeast of downtown Houston, experienced almost eight feet of subsidence. Areas in California, as well as others around the county, have also experienced similar lowering of surface elevations.

Experiences in the U.S. Indicate that we have now reached the time in this country's history when a change in our usage of water in general, and especially ground water, must be made. A paradigm shift is now required if the rate of population growth is to be maintained without major disruptions in our system. The transition of old ways giving way to new methods involves the need for new attitudes about the value of drinking water. The need to maintain the production and, in some areas, upgrade drinking water quality outweighs the pressure to continue as in the past. It is clear that these programs will cost more to operate because new types of managerial systems are required to implement and optimize the new programs. Quasi-private and local government cooperative programs will be a necessity. The State of California and associated county agencies seem to be leading the way in such programs.

Because of the Internet, technical isolation in the ground-water supply industry is decreasing. Case histories and related issues can now be made available throughout the U.S., and federal and state regulatory agencies are providing important technical and financial assistance via the Internet. This rapid acquisition of information is one of the major reasons we may be able to respond to and meet the pressing need to change our old ways of using water, especially ground water. It is no longer "well" water but water obtained from a common aquifer of great aerial extent deep underground.

With the growing difficulties in ground-water usage, state, county, and city agencies often resort to old engineering thinking, i.e., building dams to supply surface water. Since the early 1970s, we have come to realize that ground water is characteristically a high-quality, low cost resource, while surface water is a low-quality, high cost resource requiring considerable treatment and protection. This is why ground water has been so aggressively developed over the past 30 years and more. However, the old thinking has resurfaced as cities and counties attempt to meet the water demands of the approaching 30 years.

The cost-benefit analysis of ground water vs. surface water strongly favors the former over the latter in most cases. Ground-water supplies are less costly to develop than surface water and are less susceptible to contamination than surface water. In large cities, water usually is supplied by a network of underground pipes from either a surface reservoir or from a system of high-capacity water wells. As suburbs have expanded into rural areas, water wells often must coexist with nearby oil and gas wells as well as with other projects such as landfills, mines, and similar operations.(8) Cooperation and coexistence are only a necessity for society today. Litigation should only be a last-resort solution to disagreements.

The selection process of deciding between a surface-water or ground-water source depends on many factors, i.e., 1) geographic location (topography, climate, precipitation, temperature, and population density), 2) hydrogeologic conditions, (depth to water table and aquifers, suitability of aquifers- water quantity and quality characteristics), 3) engineering controls (cost sensitivity, political preferences), and 4) contamination issues (surface-water vulnerability, ground-water vulnerability, and operator responsibility). Litigation can result from disagreements between the landowner and well contractor, the municipal utility district (MUDs) and the operator and/or residents, and insurance companies over water costs, water quality, causes of well failures, etc. These disagreements should decrease in the future because arbitration and regulatory limitation will serve to decrease these legal disputes.

The Geographic Factors

In regions of the U.S. where the land surface is hilly or has some relief, a surface source of water can be developed by damming a river or large stream, or by sculpturing a reservoir out of lowlands that receive regular runoff. These projects are usually large engineering efforts that require large capital expenditures and multidisciplinary teams involving the U.S. Corp. of Engineers, state and federal wildlife regulatory agencies, and local groups.

The political issues are often major but usually surmountable if the project makes sense to the majority of those interest groups involved. The projects are promoted on the basis of the multiple use of the land involved. The reservoir would not only hold a supply of water but also would be used for fishing, boating, and swimming, as well as serve as a focal point for development of surrounding residential subdivisions.

In the Texas and Oklahoma Panhandles, ground water is used for irrigating crops. Since before the 1960s, withdrawals have exceeded recharge and water levels have dropped to seriously low levels as a result. Only a few years now remain until water supplies are exhausted and the practice of irrigated farming will have to cease. Unless enlightened management intervenes, the Texas Panhandle area, now so dependent on ground water, will soon be without a viable water supply to maintain the present way of life in that region.

The Hydrogeologic Factors

Ground-water supplies are usually available everywhere. Regional variation in water quality depends on the local makeup of the subsurface aquifer produced as a water supply. In high rainfall areas, the depth to water will be minimal, usually less than 20 feet below surface, depending upon the time of the year. The top of the ground-water reservoir is known as the water table. It varies in elevation over the year and adjusts to infiltrating local rainfall. During droughts, the water table declines. During years when rainfall is above normal, the water table will rise, sometimes high enough to create a temporary bog or swampy area. If this happens on a regular basis over the years, a wetland may develop. For all practical matters, the water table is a dynamic surface, in constant change.

Houses do not have basements in the Gulf-Coast area because rainfall is high and the water table too shallow to allow for their construction. If constructed, water would soon erode the cement slab making for rather wet conditions in the basement, even with the best cinder-block sealant. The shallow ground water in these regions is not generally used for drinking water for a variety of reasons, i.e., 1) limited volume is available, 2) shallow water receives runoff from the surface which is often of marginal to even hazardous quality, and 3) regulatory agencies consider the shallow water aquifers as protection for the deeper aquifers of high capacity and good quality. Their thinking goes that by keeping the shallow aquifers free of contamination, pollutants will not reach the deeper aquifers and associated source of local drinking water.

Ground-water taste also varies regionally.(9,10) Many water supplies that develop ground water usually involve minimal engineering and usually involve a relatively small population base.(4,5,7) This source provides water for small groups of residents, which ranges from a few residents in small subdivisions to thousands of residents in the larger suburbs surrounding major cities and towns. Some large municipalities also utilize ground water as opposed to surface water. These projects involve only minimal real estate, few permits, and generally little interference from state and federal agencies and polarized interest groups.

The Engineering Control Factors

The difference in cost between surface-water and ground-water sources is substantial, for obvious reasons. Surface-water sources require large expenditures, ground-water sources require small expenditures. Based on the cost per 1000 gallons of water delivered, surface-water costs run in the range of $ 0.85 to $ 1.35/1000 gallons, while many ground-water sources range from $ 0.30 to $ 0.80/1000 gallons (not including unusual treatment costs for special problems or other cost loading issues). It also should be noted here that the surface-water cost does not account for the other, all-important benefits provided by the presence of a surface-water reservoir, i.e., fishing (less the license, bait and tackle costs), boating (less the jetty fees paid, license, and fuel costs) as well as swimming, camping and other apparent benefits. These benefits, however, have indirect costs as well, such as police coverage, sanitation and garbage collection. The water-quality issues involved in the two sources of water are substantial and make an easy selection difficult.

Surface water is usually soft water which makes good suds for washing and showering, while ground water tends to be hard water and may not provide good suds without additional treatment, which would add a few more cents per thousand gallons to its cost. The iron-stained toilet bowl is an indication of the high-iron content of the supply, often common in ground-water supplies.

The Contamination Factors

Surface water is vulnerable to widespread contamination by accidents involving railroad chemical tank cars or trucks and intentional contamination by a disturbed individual or radical group. It is also subject to bacterial contamination from septic tanks surrounding the reservoir. Some dams are subject to breaching by flooding. Although chances are relatively small, the impact of any such occurrences would be widespread and of catastrophic impact to the local residents.

Ground water is not as vulnerable to widespread, rapid contamination from surface spills or other contamination as surface water, but ground water is subject to subsurface contamination from oil and gas wells (both abandoned fields as well as operating fields, from mining activities, road-salting activities, and nearby gasoline stations).(8) Since 1991, U.S. EPA has required that all drinking water supplies (surface water as well as ground water) be tested on a regular basis for a number of potential contaminants such as benzene and for pesticides and other chemical constituents. The design and construction of water-supply wells and ground-water monitoring wells have been well-based in the technical literature of the field for many years. (2,6)

Ground-water quality will vary naturally from region to region because of differences in the local geology of the aquifers. Taste and odors may, from time to time, become a problem in smaller ground-water supplies where operators are not present on a continuous basis to monitor water treatment systems. Slight changes in regulation of the chlorinating equipment can affect the taste and odor of the produced water.

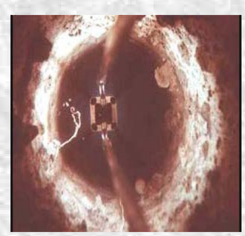
Many wells also develop nonpathogenic iron and manganese bacteria that can affect the water by creating taste and odor anomalies. Sulfate-reducing bacteria, for example, can develop in a supply well, which impart additional taste and odor problems. The familiar "rotten eggs" odor arises when hydrogen sulfide is produced in very small quantities from the sulfate-reducing bacteria living in the anaerobic microcosms under crusts of aerobic iron-oxidizing bacteria. Both problems will tend to give the water a yellow-brown to light orange appearance. Regular monitoring of the water's inorganic chemistry, combined with appropriate water treatment, can control such problems. The cost will depend upon their severity and add an additional $ 0.02 to $ 0.10 per thousand gallons of raw water produced.

Water-well maintenance is a critical factor in controlling water quality. Many individual rural water wells are not maintained appropriately or on a regular basis. In addition, some wells are located down-gradient from the septic tank and leach fields. (4,7) Well maintenance usually consists of regular checkups of the downhole conditions of the well screen or intake, the submersible pump and motor, wiring, and fittings, For all practical purposes, the well should be periodically maintained in a manner similar to the family car. Too often, however, the individual well is forgotten until a problem in quantity or quality develops.

In municipal utility wells, maintenance is usually performed on a regular basis by the operator/contractor. With the EPA monitoring requirements now in place, water quality can be monitored effectively. Before 1991, monitoring small water supply systems was difficult for states to conduct on a regular basis without an indication of a problem with water quality. Some common types of contamination released from leaking underground storage tanks of service stations and other sources have been found to naturally degrade with time with the aid of specialized bacteria that are indigenous in the contaminated aquifer.(1)

The first down-hole, well-screen photograph (left) illustrates a typical, properly-maintained well. The well screens are free of bacterial encrustations although some build-up is expected in wells in some parts of

the U.S. The second photograph (right) shows a well in need of maintenance. The reddish brown color is caused by iron bacteria and, under the iron scale, sulfate-reducing bacteria typically exist in low concentrations. As indicated previously, the former is often responsible for staining of porcelain fixtures and poor taste, while the latter is often responsible for the rotten-egg odor of the water. Both problems can be managed, but, if not controlled, a new well may be required to solve the problem. Problems seem to be involved in any source of drinking water. So to deal with these, the new solution will be to use a combination of ground water and surface water under a so-called conjunctive use program.(14)



The New Paradigm

With the necessity for growth, efficiency, and protection of the resource, conjunctive use programs are beginning to be employed in the U.S. to combine the best of both potential sources of drinking water. Such programs will need to be capable of modifying operations (source switching) in response to fluctuating climatic and environmental conditions, such as draughts or contamination of resources, via managed programs combining the available ground water and surface water resources. The costs to develop and operate these programs will be high, far higher than most citizens have faced to date. This is because we have been using very low-cost, high-quality ground water. Now, with its depletion, no other choice is feasible but to incorporate surface water into the water supply program in many areas where once only ground water was the principal source of drinking water. This does not mean that we will not use ground water but rather we will use it more frugally for emergency recourse, secondary systems, or in some cases, maintain its use after surrounding production pressures have allowed the water levels to recover to conditions where its effect on land subsidence has been considerably reduced. For example, the early signs of water-level recovery have become apparent in parts of the Houston, Texas area where the use of surface water has taken the stress off of the aquifer.

New Ground Water Sources

The new paradigm shift will also involve subtle changes in the ways we develop and maintain ground-water resources, thus raising the standard of care managers and consultants must exercise. The old well-site selection criterion is focused on sites of convenience, both for the well drilling contractor and for the well owner, i.e., MUD or other utility group. The new way will require a supervising hydrogeologist to insure that the well-drilling contractor drills and constructs the well according to the design and needs of the specific program. Well-site selections will be made by the hydrogeologist by considering, for example, potential fault locations or other geotechnical considerations (slump areas, etc), as well as the proximity of other high capacity water wells which may interfere with the regional ground-water production plan. Other activities that have significant impact on developing ground-water resources in certain areas of the U.S. involve the increasing use of surface geophysics to help optimize selection of the well-site locations according to the most favorable hydrogeologic conditions.

To ensure that appropriate studies, plans, and maintenance programs are implemented, the long-standing "turf tussle" between the engineer and hydrogeologist must be settled once and for all, state by state. Because tremendous numbers of engineers have been produced over the past 25 years in the U.S. (compared to hydrogeologists), many of them consider that the water-supply field, in general, is part of their domain, primarily because civil engineers are exposed to basic issues of water supply during their college training days. On the other hand, hydrogeologists, although considerably fewer in numbers, consider that hydrogeologic functions involving regional and local aquifer assessment, short- and long-term well productivity, etc. should be conducted only by those trained in the field of hydrogeology. Historically, hydrogeologists have had the responsibility for such studies, reporting, and planning affecting ground-water resources, with appropriate input from engineers on such issues as metallurgy (or corrosion), electrical, or construction / well-foundation stability provided by the specific type of engineer required. This should be realized soon!

The fact is, as I have come to see it, both are needed in the ground-water-supply field (as well as in the environmental remediation field, and others). Each professional should perform their appropriate type of studies and evaluations. Engineers often overstep and usurp geological functions and investigations. Mistakes, however, causing errors and omissions by such intrusions can have tremendous harmful and economically wasteful effects on human health and on society's water-supply infrastructure. This must be cleared up as soon as possible or more, unnecessary litigation will surely follow.

Drilling New Wells

The standard of care will also be raised by state and local regulations requiring that all wells drilled and constructed are supervised by a professional hydrogeologist assisted by the appropriate engineering consultant. New water-well designs will be developed to allow for subsidence, thus avoiding vertical loading of casing and screens. Although it has become clear that bacteria already exist in dormant stages in the pores of most aquifers, water well completion techniques will be required by regulation and increased standard of care to apply more aggressive programs for reducing bacteria introduced during drilling. Efforts to eliminate excessive bacteria from downhole will be made as a result of improvements in new drilling equipment as well as with new well treatment methods presently under development. Downhole video surveys have been used in the past to establish the "as built" conditions of the new water well. Based on video advances (and lower equipment cost) in this field, such surveys should become widespread and a principal tool of the supervising hydrogeologist to confirm well contractor activities and initial downhole conditions.

New Water Well Maintenance

Regular well maintenance programs have become a standard activity for most MUD and rural water systems. The EPA has recently introduced increased hydrochemical sampling requirements to cover a broader range of potential contaminants. Water system management should not base their sampling program on meeting minimum EPA requirements but on the needs of local conditions as defined by the recommendations of the consulting hydrogeologist. The need may exist to conduct regular hydrochemical sampling to monitor ambient water quality instead of longer-term sampling required by EPA. Subtle changes in hydrochemistry may allow the system management to make treatment adjustments long before changes in bacteria bloom becomes a problem requiring expensive well workovers by the willing well contractor.

The use of downhole geophysics beyond video surveys will also become widespread as the value of ground water increases over the years ahead. These tools will permit an improved level of inspection and assessment of downhole conditions by the supervising hydrogeologist during all phases of the well maintenance program.

New Ground-Water Treatment Programs

Past methods of ground-water treatment, when needed for special reasons, involved some form of chlorination combined with phosphatization, the former to control the presence of any pathogenic bacteria, the latter to control iron and manganese in the water supply. The treatment systems were relatively simple to maintain and effective in controlling harmful bacteria and reducing the impact of porcelain-staining iron minerals, particulates and odors. The storage tanks allowed for particulates to settle out in the tanks, not in the distribution piping, and allowed for increased contact time of chlorinated water before being delivered to the distribution system and end user.

Some rural water supply systems do not have treatment systems. State health department must increase their vigilance to help the public avoid contamination from locally contaminated streams, septic tanks and drain fields, and from animals within human contact, either directly or indirectly. Pathogenic bacteria, such as the recently identified (circa 1980s) E. coli, version O157:H7 and other pathogens, are now more than ever before a real threat to human health. Recent reports of E. coli version O157:H7 have been reported in various news sources (ex. see 11). It's not that the so-called "well water" is bad, it's that we are getting sloppy with our habits of trying to live with farm animals, which are most often the source of the virulent bacteria. (12) We are inadvertently introducing such pathogens to an otherwise good source of drinking water. The problem is a human social one and one that we can eliminate by education. Why has this particular problem appeared now, one might ask? It is reasonably clear that farm cattle, and other animals have been fed antibiotics for years now. Apparently, the bacteria may have finally evolved around this defense. For now, the pathogen is especially virulent when exposed to young children and with people with compromised immune systems (many elder citizens).

In the water chemistry area, the typical chlorination process creates unwanted by-products called THMs (of the trihalomethanes group) and other constituents. New treatment methods are under development and some are in use today. EPA is providing substantial information about these new developments. Methods such as ozonation, radiation from various sources, UV treatments and other approaches will come into use as they prove their way in the water supply field. With the rapid communication offered by the Internet, case histories reporting the successes and the failures will guide their development according to the merits of the method, not solely in response to advertising claims as in the past. In any event, rural water supplies, in areas of definable high risk, should be treated to eliminate bacterial contamination of the drinking water supply. Recent news events regarding isolated *E. coli* contamination of the water supply in New York, Wyoming, and elsewhere indicate the need for such protection. Treatment technology can meet the needs of the rural resident but the rural resident must be also convinced of the need to protect their own drinking water supply.

The New Road

I have covered only a few of the new technologies that we will see in the future. Technology is changing quickly in the water-supply industry where change has been slow over the past 50 years. As the value of drinking water increases, and with continuing assistance in technology development from EPA and in water-resource monitoring from the U.S. Geological Survey, the water-supply industry is making the paradigm shift to a new level of efficiency in bringing a healthy water supply to the America public. And, this transition will involve resources from ground water, surface water, or an optimized combination of both. In any case, the cost to the consumer must increase if progress is to be made in this vital area of human health.

The American universities have begun to show an interest in the practical problems of the water supply industry. Graduate students are now working on research topics involving aquifer modeling and associated subjects. Beginning about 30 years ago(13), there has been a slow increase in students working on water supply-related research projects. Students graduating now have stronger and better training in the field than ever before. EPA and other state and federal agencies have shown strong confidence in the academic community to work out the early research phases of industrial development in the water-supply industry. This trend is expected to escalate.

Probably the most important aspect in the recent improvement in the water-supply industry is the communication now available via the Internet. Change will now be even faster than ever before. This communication allows the local water-supply utility to publish all water analyses and other data concerning the water supply on the utility's web site. This will help to allay feelings by utility customers that the water supply may be unfit to drink. The data will be there for all to see. Even though EPA carries such information in its database, it often is not complete or up-to-date. In any event, the responsibility rests with the local utility to provide real data in real time because the public does have the right to know about the quality of the water that comes out of the tap. One benefit of increased costs to the user is that the public will be getting the information it needs to monitor the quality of the drinking water it consumes. The general prognosis for the water supply-field is good. The problems are in the details of follow-up and enforcement. Who will speak for the water-supply field? EPA, State regulatory agencies, and the people of the U.S. That means local residents should be active in the activities of the local municipal water utilities. In rural areas, where the municipal agency is not responsible for providing the water, the State or County must improve the effectiveness of their present educational programs in the installation and use of both the water well and septic tank systems.

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