PROCEEDINGS

of the

2001 Ground Water Protection Council Annual Forum

Safe Drinking Water Act / Clean Water Act Program Integration



The Ground Water Protection Council and the US Environmental Protection Agency, in cooperation with State and Federal Agencies, Tribal and Local Governments, citizen groups, and industry will co-sponsor this event scheduled for September 22 - 26, 2001 in Reno, Nevada. This year's conference will focus on aspects related to integration of the Safe Drinking Water Act and the Clean Water Act programs. The conference will include presentations, panel discussions, posters and exhibits related to technical advancements and practical approaches to underground injection practices, ground water - source water protection, as well as ground water monitoring and remediation

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The GWPC Organizational Profile

MISSION STATEMENT AND GOALS

The mission of the GWPC is to promote the protection of water resources for all beneficial uses and to provide independent research and objective information related to potential sources of ground water contamination and pollution prevention practices.

1. To prevent ground water contamination and protect vulnerable aquifers by promoting the development and implementation of adequate protective measures including underground injection, waste water discharge and land application practices.

2. To promote the utilization of appropriate ground water remediation technology.

3. To promote the conservation of ground water resources.

4. To influence regional, national and international policy on ground water resource issues.

5. To provide leadership in providing forums, educational opportunities and open communication and active participation by local, state and federal governments, industry academia and other parties interested in responsible protection and management of ground water resources.

6. To provide research into tools, methodologies and technologies to protect clean ground water and remediate contaminated ground water.

Policy Statement

Ground water provides approximately fifty percent of the population with drinking water while also supplying needs of industry and agriculture. Due to hydrogeological interconnection, the quality of ground water may directly influence the quality of surface water. The Ground Water Protection Council (GWPC) recognizes the vital importance of preserving abundant, high-quality ground-water supplies. Therefore, the Ground Water Protection Council adopts as its policy the following:

1. To prevent ground water contamination through education and by promoting the development and implementation of adequate protective measures. To promote the safe and responsible use of underground injection as a viable means of waste disposal.

2. To promote ground water as a valuable resource requiring protection based on current and future use and vulnerability to contamination.

3. To promote participation in the Ground Water Protection Council by local governments, state government, federal government, industry and others as groups primarily responsible for protection and management of ground water resources.

4. To utilize every available asset from academia, industry and government for technical, educational, financial and research support as appropriate.

To achieve these policies, the Ground Water Protection Council will promote and support:

1. Education of government officials, industries and the public regarding ground water protection.

2. Research into methodologies to protect clean ground water and to remediate contaminated ground water.

3. Implementation of local, state and federal programs focused on the protection and remediation of ground water.

The goal of the Ground Water Protection Council is to foster ground-water protection efforts and to support state and local ground-water protection programs.

The History of GWPC

The Ground Water Protection Council (GWPC), formerly the Underground Injection Practices Council, was incorporated as a non-profit national association, headquartered in the State of Oklahoma, in November, 1983. This national association of state ground water and underground injection control agencies was initially incorporated by five states who wanted to form an organization that would serve as a forum bringing together technical and regulatory experts to discuss underground injection control (UIC) issues related to oil and gas production, as well as liquid waste disposal using deep injection wells, and shallow, onsite waste disposal. The founders also sought to develop a strong public outreach/ education program to inform the public about the safety of the national UIC program and to develop information that could be used by the states to enhance this effort. Since then the Board of Directors has changed the organizational name to the Ground Water Protection Council to better reflect the overall commitment by the members to broader environmental issues and as a recognition that the UIC program is one piece of a much larger effort to protect ground water.

The GWPC has evolved into a unique organization whose Board of Directors is comprised of State's Underground Injection Control (UIC) and Ground Water Directors representing each of the USEPA's ten regions. Board members are elected by their peers. Among the GWPC core supporters are representatives of state and federal regulatory agencies responsible for oil and gas production, underground injection activity, and ground water and source water protection. Also active in GWPC discussions are stakeholders from the regulated community, environmental groups, and other concerned citizens, all of whom mutually work toward the protection of the nation's ground water supplies. The purpose of the GWPC is to promote the safest methods and most effective regulations regarding comprehensive ground water protection procedures and underground injection techniques. GWPC's affiliated foundation, the Ground Water Protection Research Foundation (GWPRF), provides independent research and review of underground injection control related matters in an effort to improve technologies and assist State regulatory agencies and industries using injection for waste disposal. GWPC and its foundation have been credited with carrying out many successful projects that have had significant outcomes regarding best management practices and fair but effective laws regarding comprehensive ground water protection.

The GWPC has been successful in a world of constantly changing public perception of ground water protection, inevitable political reaction, and new rules and regulations. In 1983 the founding state administrators realized that if the states were going to have an impact on national policy and be able to do so effectively, they needed to form an organization that included all affected groups, or in today's terminology, all stakeholders. By contrast it was common then for national associations to be somewhat parochial in their membership and to deal with issues from a singular focus. Not so with the GWPC. The original charter and organizational structure sought out participation by the various state agencies and impacted industries affected by various regulations related to ground water protection. The principle of inclusion is unique because of the commitment to hear all view points on issues from industries that the states were charged with regulating.

The GWPC has matured into a respected national association of state ground water and UIC agencies. Along the way, GWPC has had a significant impact in affecting national policy in underground injection and ground water protection. The reason for this is that the GWPC was founded upon a sound principal from which it has not wavered.

The Purpose of the GWPC

The GWPC is a national non-profit organization whose members are interested in the protection of the nations's ground water supplies. The purpose of the GWPC

is to promote the safest methods and most effective regulations regarding comprehensive ground water protection and underground injection techniques. GWPC's meetings, workshops, seminars and symposia provide forums, educational opportunities and open communication and active participation by local, state and federal governments, industry, academia and other parties interested in responsible protection and management of ground water resources.

The Membership of GWPC

The Ground Water Protection Council, a national association of state ground water and underground injection control agencies, provides a forum of state and federal ground water and underground injection control regulators, industry representatives, environmental representatives and concerned citizens who are interested in the protection of the nation's ground water supplies. Examples of GWPC participants include: Geologists/ Hydrogeologists; Engineers; Ground Water Scientists; Local, State and Federal Regulatory Officials; Educators; Environmental Advocates; Waste Managers; and Community Drinking Water Managers.

Coal Bed Methane In the Powder River Basin of Montana

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ABSTRACT

During the second half of the 1990s, coal bed methane (CBM) production increased dramatically nationwide to represent a significant new source of natural gas to meet ever-growing energy demands. One area that has the potential to see significant increases in CBM development in the near future is the Powder River Basin (PRB) in Montana. The PRB contains significant coal deposits with methane gas at relatively shallow depths that would allow for the economic recovery of CBM. The development of CBM in the PRB is expected to increase significantly in the coming years and with this development there is the potential for significant environmental impacts. Although significant impacts to resources will occur from surface disturbing activities during the construction phase of CBM development, these impacts can be minimized through active reclamation and following the legal guidance designed to protect resources. The primary considerations of this paper are the impacts from groundwater that is extracted to facilitate the production of methane from the coal seams. Since significant quantities of varying quality groundwater must be extracted during CBM production, the impacts of this produced water on soil, agriculture and water resources are a principle concern. The impacts from CBM produced water can be mitigated through conservation, proper disposal methods, and beneficial use. The proper management of produced water will prevent some impacts to other resources such as soil, agriculture and groundwater, and may provide beneficial uses such as dust suppression, irrigation and livestock watering.

INTRODUCTION

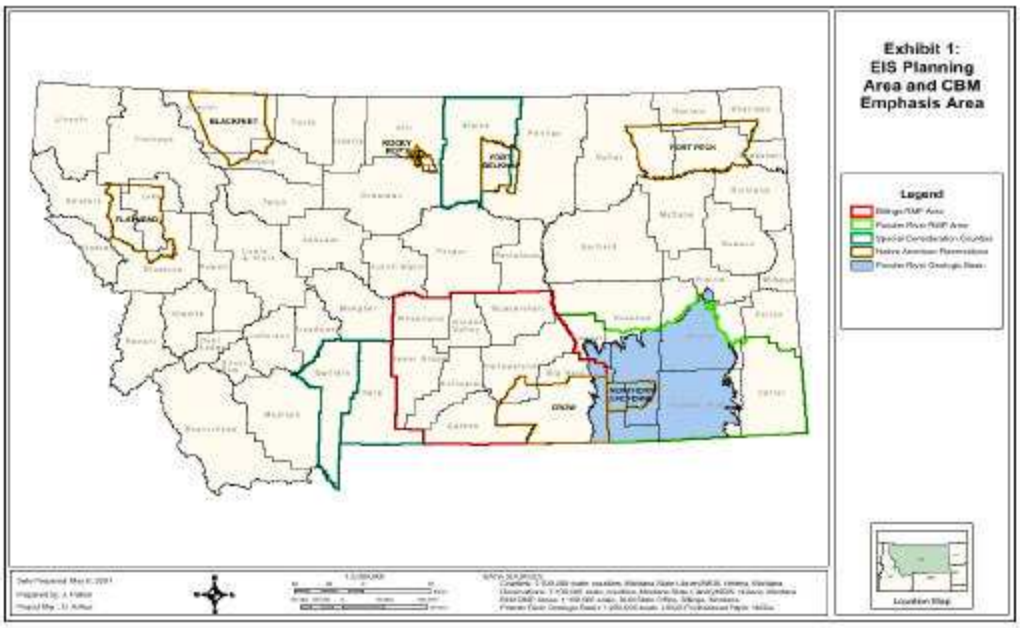
Coal bed methane is a carbon-based gas that occurs naturally in large quantities in the seams in unmined coalbeds. The coal bed methane is typically contained within the micropores of the coal and is retained in place by the pressure created by the presence of water. During production, this water is pumped to the ground surface to lower the pressure in the coalbed reservoir and to stimulate the release of methane from the coal. Methane from unmined coalbeds has been produced on a minor scale since the early 1900s when a rancher in the Powder River Basin (Wyoming) drilled a water well into a coalbed and started heating the buildings with the produced gas. Until the 1980s, coal seams generally were not considered to be a reservoir target, even though producers often drilled through coal seams when going to deeper horizons.

During the second half of the 1990s, coal bed methane (CBM) production increased dramatically nationwide to represent a significant new source of natural gas to meet ever-growing energy demands. In Montana, oil & gas development has been growing since the first oil wells were drilled in the early 20th century. Today, Montana's oil and gas industry exceeds 300 million dollars per year and is a significant aspect of the state's economic livelihood. Recent oil and gas exploration and development in the state has included a focus on CBM exploration and development. There are currently more than 200 commercially producing CBM wells in the state of Montana, all of which are located in the Powder River Basin near the town of Decker. CBM development in the Montana portion of the Powder River Basin (PRB) is in part a result of successful development in the Wyoming portion of the basin where CBM activity started as early as 1993 (Flores et al, 2001).

A primary consideration for this report is the impacts from CBM produced water on soils, agriculture and water resources. Due to the extraction methods and subsequent disposal of produced water required for CBM production, impacts can potentially result from CBM development. The purpose of this technical paper is to present the impacts from CBM.

Study Area

Although a CBM emphasis area has been identified for other purposes, the primary area of concern identified for this report is the PRB of Montana. The Montana PRB is also the area where CBM development is expected to be most intense. For the purposes of this paper, analyses will primarily focus on the Montana portion of the PRB. Exhibit 1 is a map showing the entire state of Montana, the CBM emphasis area, and other points of interest for reference throughout the remainder of this paper.



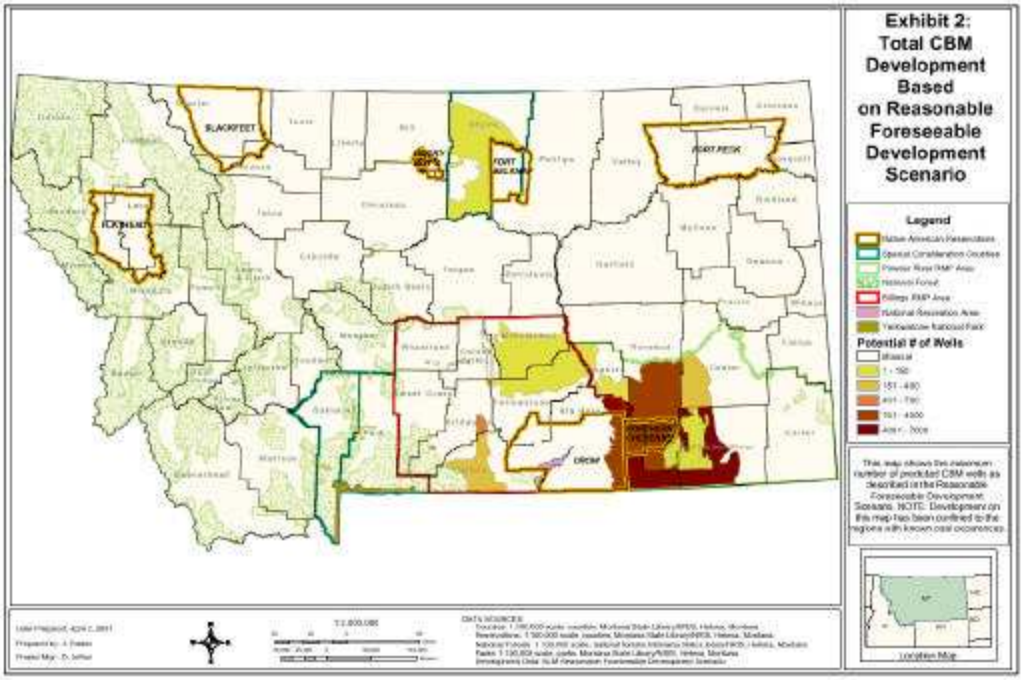
Reasonable Foreseeable Development Scenario

To facilitate planning and the determination of potential environmental consequences, the BLM prepared a Reasonable Foreseeable Development (RFD) scenario. The RFD predicts oil and gas development in five areas: the Powder River RMP area, the Billings RMP area, and in Blaine, Gallatin, and Park counties of Montana. The RFD projects drilling of both conventional and CBM wells, numbers of pipelines, and compressors needed for production of CBM wells.

For CBM exploration and development, the areal extent of certain coals and the rank of coals in the study areas were considered. Areas of sub-bituminous to bituminous coals were considered as most likely to be explored and developed in Montana, although exploration and development has occurred mainly in sub-bituminous coal in the Wyoming portion of the Powder River Basin. The USGS produced a map showing the areas of coal, by rank, for the United States. This information indicates sub-bituminous and bituminous coals in many parts of the study area. Powder River, Rosebud, Custer, and Big Horn counties contain sub-bituminous coals in the northern part of the Basin, which extends north from Wyoming. Blaine and Musselshell counties have mostly sub-bituminous coal. Carbon County has an extension of the Big Horn Basin coal, which is ranked as bituminous coal. Gallatin and Park counties have scattered areas of bituminous to sub-bituminous coals. The projection of methane gas to be produced from coal beds in Montana range from a low of 1 TCF (Fred Crockett-PRB est-RMG, Casper) to a high of 17.7 TCF (estimated based on figures from Nelson, 2000). This and other information for Montana was used to predict where CBM exploration is most likely to occur in the emphasis area. The RFD predicts the number of CBM wells that would be drilled and completed during the next 10 to 20 years. For CBM, potential development in the RFD was estimated to be as much as approximately 26,000 wells in the next 20 years.

Exhibit 2 shows the total RFD for the CBM emphasis area, which includes the Montana portion of the PRB. Also shown on this exhibit are Native American Reservations, National Forests, National Parks, and National Recreation Areas. Review of this exhibit shows potential CBM development throughout the majority of the Montana PRB.

Estimates are based on full-field development by county and shaded areas represent occurrences of sub-bituminous coals within the counties where development is likely to take place.



Analysis of the RFD with respect to the Montana portion of the PRB, suggests that approximately 4,095,000 acres of the total 5,984,000 acres that make up the PRB are expected to have CBM development. The total RFD for this area (including federal, state, and private mineral ownership) amounts to approximately 24,875 total CBM wells. Exhibit 3 illustrates the maximum potential well development as described in the RFD by watershed, shaded for coal occurrences within the basin. This exhibit shows how the predicted CBM development from the RFD intersects watersheds in the PRB of Montana. The development scenario presented in this exhibit represents total drilled wells. It is expected that about 10 percent of these wells will be dry holes.

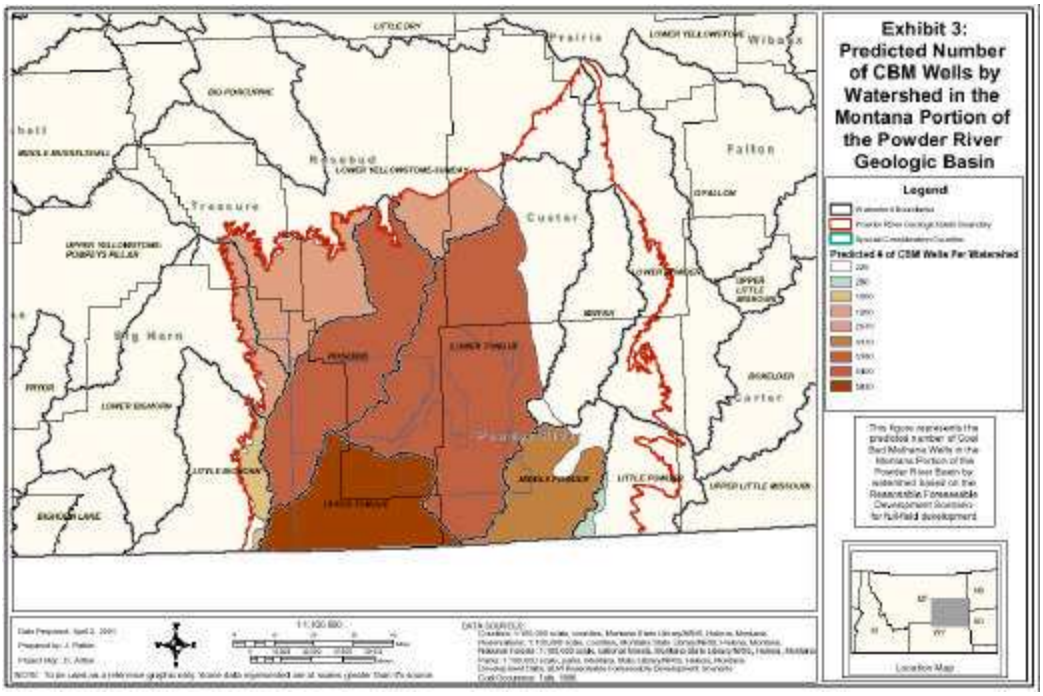


Exhibit 4 indicates the surface area of each watershed within the PRB overlying the known coal occurrences and the predicted number of maximum wells per watershed. This exhibit shows that the potential total area within each watershed that may be impacted by CBM development ranges from 24,000 acres (Mizpah watershed) to approximately 1.3 million acres (lower Tongue watershed). Similarly, CBM development ranges from high concentrations of approximately 5,809 and 5,397 in the upper Tongue and Rosebud watersheds, respectively to only 224 CBM wells in the Mizpah watershed. Considering the total RFD for the state, this exhibit shows that the vast majority of CBM development is expected to occur in the Montana portion of the PRB.

Exhibit 4 - Watershed Acreage and Maximum potential CBM Wells in the PRB

This table indicates the surface area of each watershed within the PRB overlying known coal occurrences and the predicted number of maximum potential wells per watershed.

WATERSHED	SURFACE ACREAGE OF IMPACTED WATERSHED	POTENTIAL WELLS DRILLED
LITTLE BIGHORN	87,000	1,050
LITTLE POWDER	29,500	278
LOWER BIGHORN	121,500	1,200
LOWER TONGUE	1,374,000	5,183
LOWER YELLOWSTONE-SUNDAY	687,500	2,568
MIDDLE POWDER	368,500	3,167
MIZPAH	24,000	224
ROSEBUD	814,000	5,397

UPPER TONGUE	589,000	5,806
TOTAL	**4,095,000**	**24,875**

Coal Bed Methane Operational Summary

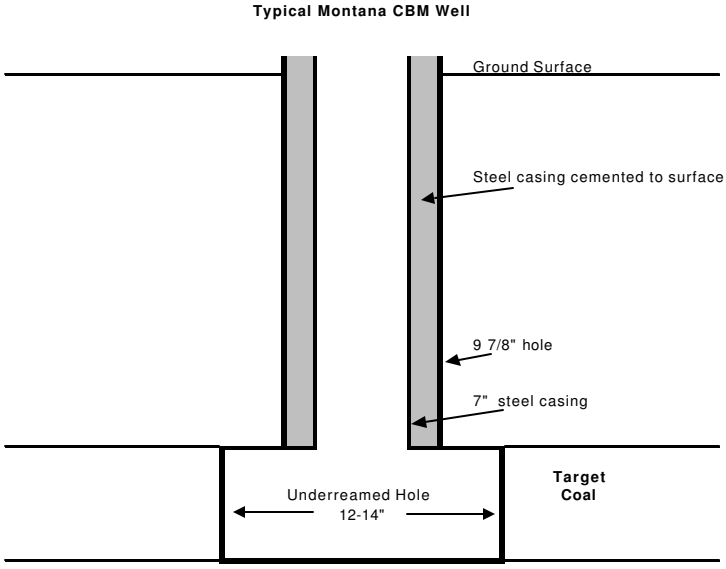
CBM has been produced in the Powder River Basin of Montana since April 1999. The first exploration wells were drilled in 1990 in both the Big Horn and Powder River Basins. The bulk of the producing data has, however, less history than that. In the CX field, operated by Fidelity Exploration & Production Company, approximately 20 months of production data have been submitted to the MBOGC.

Well Drilling and Completion

Exhibit 5 is a schematic view of a typical CBM well from the CX Ranch. This exhibit shows the more common well completion scenario where conductor casing is not used. Although there are variations in this drilling and completion methodology, the approach is generally common for current practices. However, future practices could vary from this method depending on the depth of targeted coal seams, advances in drilling technologies, or changes in drilling philosophies. Potential changes could include, but may not be limited to, completing wells in more than one coal seam or drilling directional or horizontal wells.

Exhibit 5 - Typical CBM Well in the Montana Portion of the PRB

This exhibit diagrams a CBM well as they are typically drilled in the CX Ranch Field. In addition to the elements shown, there may be local variations.



To date, drilling has been done with fresh water drilling fluids to protect the aquifers and the coals being drilled. Water supply during the drilling phases is most often from produced water, although ponds can also be utilized. The bore-hole will finally be cleaned with a slug of formation water pumped at a high rate to flush the coalface. The wells are not artificially fractured during completion activity, although this technique may be used in other parts of the PRB or in other areas of Montana where natural fracturing (cleat) may

not be developed. An electric submersible pump (ESP) is installed near the base of the coal on the end of fiberglass tubing. To help monitor the water level in the well, a 1/4-inch capillary tube may be installed for data collection purposes.

CBM Production Operations

During production, water is pumped up a tubing string to be filtered, metered, and put into a water flow-line for handling or discharge. Many water uses and disposal methods have been suggested and could be used if CBM development continues to increase, current water handling practices are limited.

Immediately after the well is drilled, the water level stands at some elevation above the level of the coalbed, an expression of the virgin reservoir pressure. At this pressure, methane will not flow into the wellbore (Williams 2001). After initial pumping, the water level is reduced, allowing methane to flow out of the coal seam into the borehole up to the surface. The gas comes up the casing-tubing annulus and runs into a low-pressure (approximately 5 pounds per square inch [psi]) flowline. The natural gas consists of approximately 96 percent methane, 3.5 percent nitrogen, and trace amounts of carbon dioxide (CO_2). The flow-line connects to a metering manifold that knocks out the last of the water and connects to an approximately 400-horsepower (hp) field compressor that increases pressure to approximately 40 psi in a gathering pipeline. The gathering lines are connected to a large sales compressor station that builds pressure to approximately 1,000 psi in the regional sales pipeline.

Produced water is piped away from the wellsite and managed in several ways. Currently, the majority of the produced water is discharged. The discharges are permitted by the state to limit the volume of flow and specify certain discharge points, in order to control the dilution of the produced water. The permits also require that the water be discharged via a pipeline rather than a ditch, so that suspended sediments are not incorporated and do not impact the river. Part of the produced water is currently delivered to several ponds that are unlined and supply water to livestock as well as wildlife in the area.

CBM wells must pump water from the reservoir to lower pressure within the coal, to augment the formation of cleat, and to allow the natural gas to break out as a discrete phase. The amount of water that must be pumped off appears to vary not only from reservoir to reservoir, but also during the history of each individual producing well according to the specific coalbed reservoir it is producing from and its proximity to other producing wells. Exhibit 6 presents a list of the average water production rates for approximately 200 wells in the CX field normalized to the age of each well (MBOGC oil and gas database). This data was compiled by averaging the water production rates from active CBM wells from the date of first production. For example, the average for month zero was determined by averaging the water production from all wells reporting for the first time that month, regardless of the calendar date production was initiated. A similar approach was used for each consecutive month. Results from this analysis show that water production rates declined steadily at the CX Field from approximately 12 gpm to slightly less than 8 gpm over a period of 20 months.

The data provided in Exhibit 6 was used to perform a water production decline analysis. Exhibit 7 shows the combined water production data and decline analysis to show a semi-log plot of normalized average CBM water production rates combined with the long-term exponential decline of the data analyzed. The projected average water production rate over a 20-year period as determined from the exponential decline analysis is approximately 2.5

gpm. The actual average water production rates for individual CBM wells may vary from this average based on location, coal seam thickness, well completion type, coal reservoir properties, and other factors. This projected average production value represents a more realistic rate calculated from historical decline rates in CBM water production.

Exhibit 6 - Average Production Rates in the CX Field, Normalized to Age of Each Well

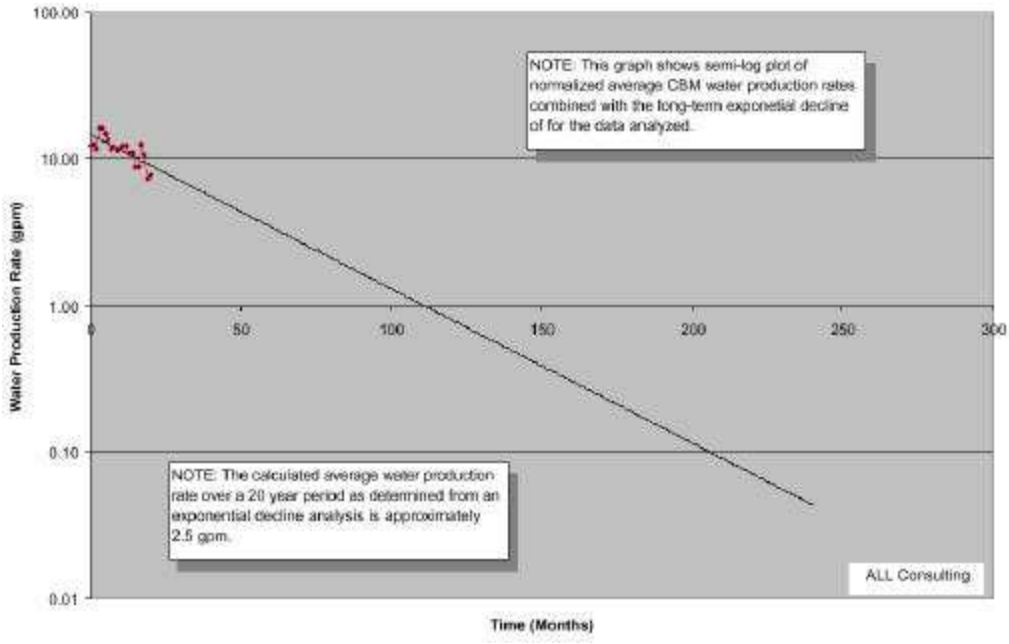
Historical water production rates in the 200 CBM wells in the CX Field, Montana (MBOGC, April 2001).

AGE IN MONTHS SINCE FIRST PRODUCTION	AVERAGE WATER PRODUCTION (BWPD)	AVERAGE WATER PRODUCTION (GPM)
0	418	12.2
1	428	12.5
2	398	11.6
3	553	16.1
4	556	16.2
5	503	14.7
6	460	13.4
7	398	11.6
8	412	12.0
9	394	11.5
10	411	12.0
11	427	12.4
12	419	12.2
13	375	10.9
14	376	11.0
15	303	8.8
16	305	8.9
17	430	12.5
18	367	10.7
19	253	7.4
20	267	7.8

(Notes: gpm = gallons per minute, barrel = 42 gallons, BWPD = barrels of water per day)

FIGURE 7 – PLOT OF THE COMBINED CBM PRODUCTION AND DECLINE ANALYSIS

This graph shows the average production rates at CX Ranch plotted with the decline analysis to show the average production of a CBM well over a 20-year period.



Geology and Hydrology

Introduction

Montana is the site of the juxtaposition of the Great Plains with the Rocky Mountains. The rocks at the surface vary from the ancient metamorphic and igneous complexes forming the cores of some mountains to recent sediments in the major river valleys of the state. Geology of Montana plays an indispensable role in forming the mineral resources, visual resources, and water resources of the state. The geologic history of the state has been a series of major structural events in the tectonics, or continent building of North America.

Montana's basins have accumulated sediments several miles in thickness; these sands, shales, and limestones form the source and reservoirs of Montana's fossil energy reserves – crude oil, natural gas, coal, and coal bed methane (CBM). In these basins, ancient sediments were buried to great depths within the earth where heating and increased pressure formed the fuels from the raw plant materials trapped in the sediments. The sedimentary basins also hold a significant portion of the water resources of the state; in the deep parts of these basins the water is generally salty while the shallower parts of these basins there is fresh water of meteoric origin.

Exhibit 8 presents a map of the statewide outcrop geology. The map emphasizes broad basin features underlying the Great Plains in contrast to the intensely contorted structures under the many mountain areas. These basins, such as the PRB are likely to contain CBM resources that can be seen as broad expanses of similar outcrop. In the case of the PRB, rocks at the surface are all coal-bearing Tertiary formations except for the scattered Quaternary age Alluvium in stream and river valleys. Other basins contain coal-bearing sediments of Cretaceous age. The presence of large volumes of suitable coal is vital for predicting CBM development.

CBM is the focus of this paper and it is important to recognize that the resource is intimately associated with coal deposits. The methane gas is generated by the coal deposit both under thermogenic (heat-driven) and biogenic (microbe-driven) conditions. At the same time, the methane is trapped in the coal seams by the pressure of groundwater.

Releasing the pressure of groundwater from the coal aquifers liberates methane, allowing it to be produced and sold. The magnitude of the CBM resource is determined by coal type and volume; the location of coal reserves will predict the location of Montana's CBM resources.

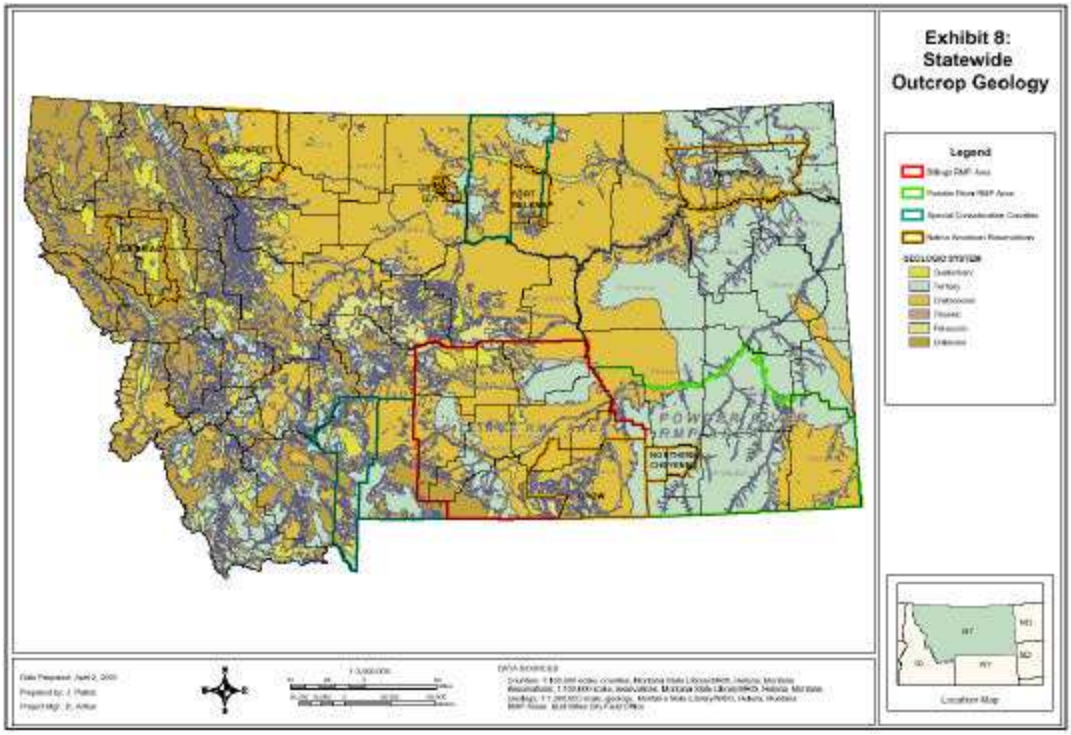
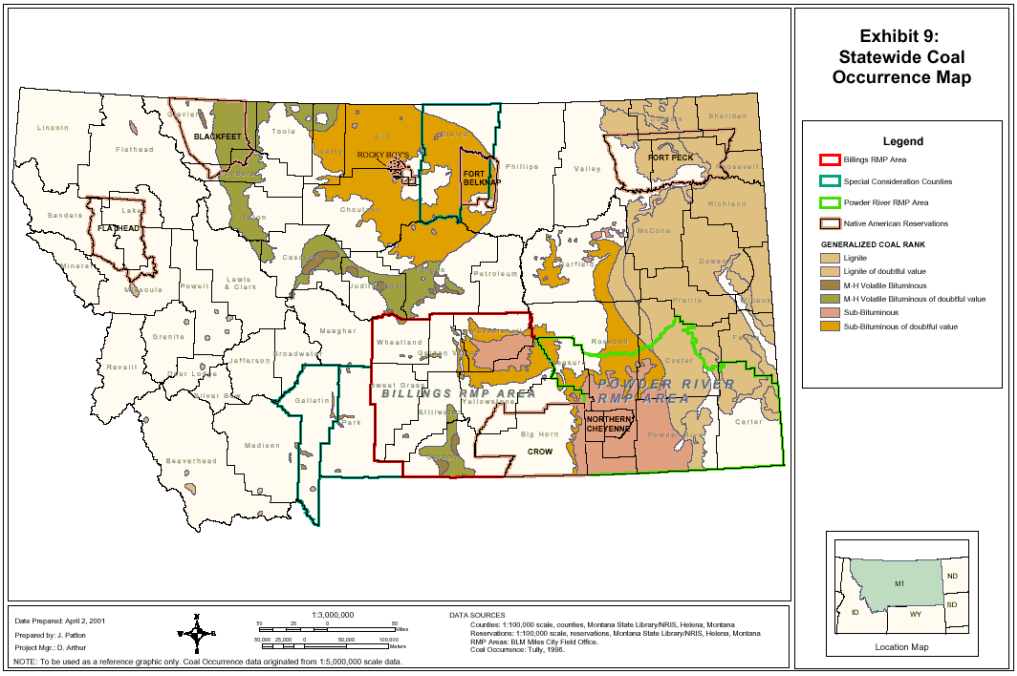


Exhibit 9 is the statewide coal occurrence map. The map displays the extent of coal deposits that support mines and are expected to support projected CBM development. The geology of Montana has given rise to several different kinds of coal; the most important differentiator is coal rank or thermal maturity. As coal is buried or otherwise heated, the raw plant material is gradually converted from complex carbon compounds to simple compounds and elemental carbon. Exhibit 9 highlights coal rank or maturation ranging from lignite, sub-bituminous, high-volatile bituminous, medium-volatile bituminous, low-volatile bituminous, and anthracite coals (Leythaeuser and Welte, 1969). The area of interest is the PRB, which contain mostly sub-bituminous coal that has not reached a high degree of maturation. Also of interest for CBM are the Big Horn Basin and the counties of Park and Gallatin that contain medium and high volatile bituminous coal of slightly higher maturity.



According to the Montana Board of Oil and Gas Conservation (MBOGC) records, CBM has been produced only in the CX Ranch field in the Montana portion of the PRB since April 1999. Exploration solely for CBM first happened in the Montana PRB in December 1990 in the area of CX Ranch. However, the first CBM exploration in the state was in August 1990 in the Big Horn Basin where CBM was tested but never sold. In many parts of the state, coals are aquifers that contain significant amounts of groundwater and are used by residents for water needs. In order to produce the methane in the Montana part of the PRB, groundwater must be drawnoff the coal aquifer. Unless groundwater is produced from the coals, methane will not be produced; water production cannot be avoided during CBM development. This is the central conflict between CBM and traditional uses of the land; when CBM is produced, local coal aquifers are partially depleted. Depending on the area, this depletion may extend beyond the CBM producing field boundaries.

Regional Geology

The focus area of this paper centers on the Powder River Basin. The basin was formerly a broad shelf area until Laramide tectonics caused uplift in the surrounding features and this uplift contributed to sedimentary subsidence within the basins during the Late Cretaceous and Early Tertiary. The PRB in its entirety covers approximately 12,000 square miles with the smaller portion in Montana (Ellis et al. 1998). The PRB is bounded to the west by the Bighorn Uplift, to the southwest and south by the Casper Arch, Laramie Mountains, and Hartville Uplift; and to the east by the Black Hills Uplift. The Miles City Arch and the Cedar Creek Anticline to the north essentially separate the PRB from the Williston Basin. Coal has been mined in the PRB since 1865 and large-scale strip-mining has been underway since the mid-1960s when demand increased for relatively clean-burning coals (Flores and Bader 1999). Conventional oil and gas have been exploited in the PRB for more than 50 years while CBM has been only lately developed with major activity beginning in 1997 (Rice et al. 2000).

Exhibit 10 (formerly 11) depicts the outcrop geology of the Montana portion of the PRB. The map illustrates the broad geometry of the basin with the youngest Tertiary strata (Wasatch Formation) preserved in the deepest part of the basin just north of the Wyoming-

Montana state line. The broad bands of the Tongue River and Lebo/Tullock members throughout most of the basin attest to the shallow dips to the east and north edges of the basin. The narrow outcrop bands on the west limb of the basin indicate that the basin is somewhat asymmetrical with steeper dips on the western side. Exhibit 10 also illustrates the scattered distribution of the Alluvium that fills the valleys of the basin.

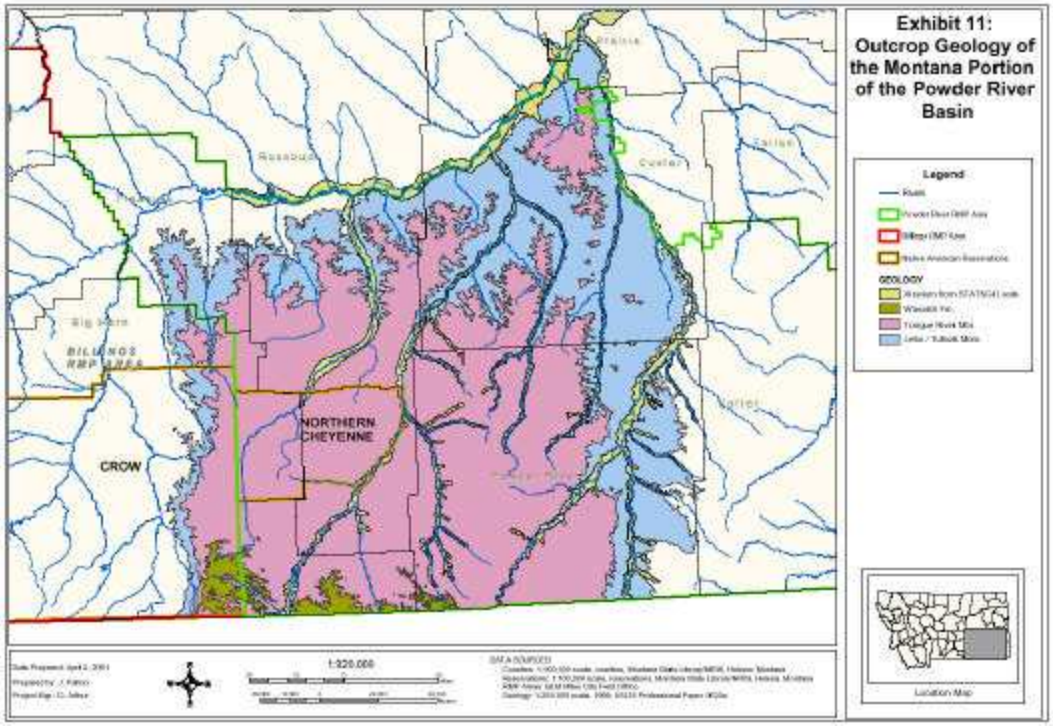
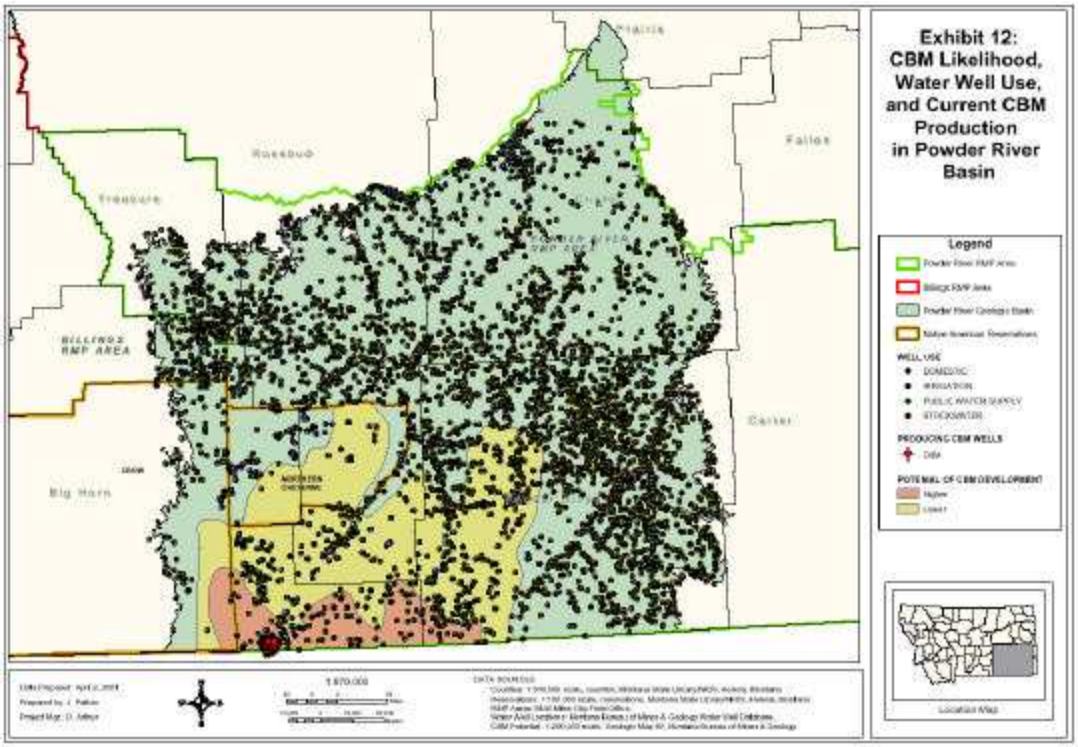


Exhibit 11 (formerly 12) portrays the distribution of water wells, the prospective CBM areas, and existing CBM production within the Montana portion of the PRB. The map was constructed from information in the MBMG Map 60 (Van Voast and Thale, 2001) and emphasizes those areas with thick, sub-bituminous and bituminous coal reserves. Coals are both water reservoirs and gas reservoirs and as such CBM production will affect local aquifers and even surface water. CBM development is expected to be concentrated in the southern portion of the Montana PRB although coals exist over most of the basin and CBM coverage could prove to be greater. The water wells shown in the exhibit could be at risk to drawdown impact from CBM development, especially those water wells completed in coal aquifers. Those aquifers at risk to CBM impact are described in the Hydrology section below.



Stratigraphy

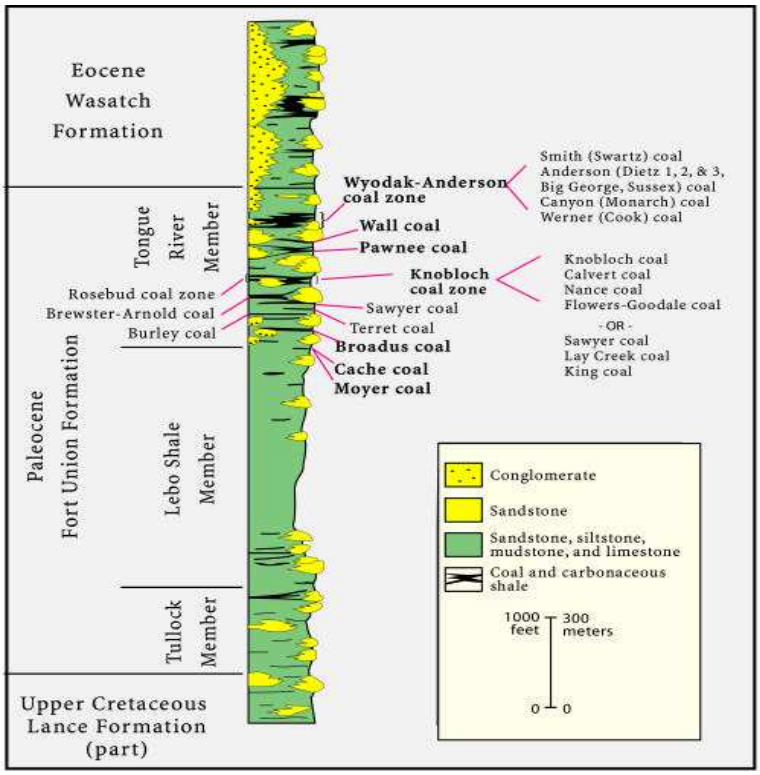
The sedimentary strata of the area extend backward in time from recent age alluvium found in stream valleys, to strata at the surface that is largely Tertiary and Cretaceous. These older sediments correspond to the Laramide tectonism that gave rise to most of the uplifted areas in Montana. Though the area contains significant regional thicknesses of older stratigraphic units, the Tertiary basin fills are of particular interest for coal, CBM, and groundwater production (Ellis et al. 1998). Conventional oil and natural gas occur in the older, pre-Laramide section but coals in the PRB are confined to the Early Tertiary units.

Exhibit 12 is a stratigraphic column of Upper Cretaceous and Lower Tertiary sediments in the Montana PRB. The stratigraphic column shows the continuous development of several thousand feet of sediments that include widespread sands, coals and fluvial, fine-grained sediments. The major formations are named along with major coal seams. The basin's surface consists largely of the several members of the Paleocene Fort Union Formation, as well as the overlying Wasatch Formation in a small corner of the basin (Rice et al. 2000).

The Fort Union Formation encloses the various coal seams within the Montana portion of the PRB; these coals function as the source of the CBM, as well as aquifers carrying groundwater of varying quantity and quality. In the PRB coals range in depth from the surface to approximately 900 feet deep. Coals vary in thickness from over 50 feet and can form aggregate thicknesses over 100 feet. Coal seams in the Fort Union do not have significant matrix porosity and permeability (Gray 1987); they can act as aquifers because fluids such as water and methane are contained within the coal's fracture system, known as cleat (Montgomery et al. 2001). The fractures accumulate the fluids and allow the fluids to move horizontally and vertically.

EXHIBIT 12 - STRATIGRAPHIC COLUMN OF UPPER CRETACEOUS AND LOWER TERTIARY SEDIMENTS IN THE POWDER RIVER BASIN

Bedrock units that fill the PRB include the Lance, Fort Union, and Wasatch Formations (Rice et al. 2000).



Paleocene Fort Union Formation

The Fort Union forms most of the sedimentary fill within the Montana PRB. It consists of approximately 3,500 feet of non-marine silty and shaley clastics and coal beds whose individual thicknesses can be as much as 37 feet near the Decker mine (Roberts et al, 1999a). The Fort Union also contains clinker deposits, formed by the natural burning of coal beds and the resultant baking or fusing of clayey strata overlying the burning coal, which are present throughout much of the area and can be more than 125 feet thick (Tudor, 1975). Stratigraphically the clinker bodies are part of the Fort Union but the clinker is a lithological unit composed of baked and fused siltstone, clay, and sandstone units that have undergone diagenetic changes during the combustion of the coal within the past 3.0 million years (**Heffern et al, 1993**).

Individual units within the Fort Union that were formed as fluvial deposits could be expected to have lithological flow-units oriented in a dip-wise fashion. This preferred direction of porosity and permeability could be exhibited by directional variations in groundwater drawdown levels. The coals, however, appear to have been deposited in mires situated above or below drainage levels within erosional channel features or perched above these channels in raised bogs (Ellis et al 1998). Some of the coals, therefore, could exhibit linear permeability phenomena while other accumulations may be isolated lenses unconnected with other coal seams. In developing CBM fields, it will be valuable to identify these different coal bodies, but such research is beyond the scope of this report.

The Fort Union is split into three stratigraphic members: the lowest being the Tullock Member, overlain by the Lebo Shale Member, overlain by the Tongue River Member (McLellan et al. 1990). In the Montana portion of the PRB, the bulk of the coals are confined to the Tongue River Member, while the Lebo and Tullock Members are predominantly shale and shaley sand (McLellan et al. 1990). The Members are discussed in detail below:

The Tullock Member:

This is the stratigraphically lowest part of the Fort Union, consisting of approximately 300 feet to more than 500 feet of interbedded sands and shales with minor coals near the base (Tudor 1975). The Tullock rests unconformably upon the Upper Cretaceous Hell Creek Formation throughout the PRB. While generally sandier, the Tullock is difficult to separate in outcrop and in the subsurface from the overlying Lebo Member.

The Lebo Member:

This middle member ranges from 75 feet to more than 200 feet of claystones, limestones, and mudstones with the Big Dirty coal (3 to 13 feet of thickness) at the very base (Tudor 1975). The Lebo is, in part, stratigraphically equivalent with the overlying Tongue River (McLellan et al. 1990).

The Tongue River Member:

The thickness of the Tongue River varies from 750 feet at the outcrop edge near the fringe of the basin to 3,000 feet near the axis of the basin (Williams 2001). Total coal isopach ranges up to approximately 150 feet (Ellis et al. 1999). The Tongue River Member is divided into three units. The lower unit includes that portion below the Sawyer coal seam. The Middle unit includes the Sawyer through the Wall coal seam. The Upper unit includes that portion above the Wall coal seam (Ellis et al. 1999).

The Lower Tongue River unit is present across most of the Montana portion of the basin. It includes, from the base up, the Stag, Terret, Witham, Robinson, Rosebud-McKay, Flowers-Goodale, Nance, Calvert, and Knoblach coals. In the Ashland coalfield, the Lower Tongue River unit is up to 1,660 feet in thickness, and individual coals can be up to 71 feet thick (Roberts et al. 1999b).

The Middle Tongue River unit is present over a large part of the Montana portion of the PRB. It includes, from the base up, the Sawyer, Mackin-Walker, Cache, Odell, Brewster-Arnold, Pawnee, and Wall coals.

The Upper Tongue River unit is present only in the southern part of the Montana portion of the PRB. It includes, from the base up, the Otter, Cook, Carney, Canyon, Dietz, Anderson, and Smith coals. At the Decker mine, the Upper Tongue River is up to 1,500 feet thick; coals can attain an individual thickness of 57 feet and an aggregate thickness up to 111 feet (Roberts et al. 1999a).

Although coals are the most economically significant part of the Tongue River Member, they form a small portion of the sedimentary volume. They are also extremely variable stratigraphically. Coal aquifers can be seen to have local continuity but lack regional continuity. A local coal seam such as Dietz 1 can persist for several miles but the entire Anderson-Dietz package is eroded from the Colstrip area. The stratigraphic complications documented Roberts et al (1999a) suggest that even thinly separated coal seams may be very dissimilar. These seams exhibit pinch-outs, bifurcation, and erosional cut-off by Paleocene and recent stream erosion. All of these factors can play a role in complicating the production of water and methane from the Fort Union Formation.

Fort Union coals are also present in the Big Horn Basin, the Bull Mountain Basin, and Park and Gallatin counties where they are prospective for CBM resources.

Hydrology

Hydrology identifies aquifers (porous units containing water) and aquitards (non-porous strata that serve to confine and separate aquifers) in a geographic and vertical sense. Aquifers can contain drinkable water, brackish water of limited usability, or salt water. In the PRB, several formations contain drinking water but show variable reservoir quality and water quality. The Montana portion of the PRB includes many aquifers that represent different hydrologic flow regimes. The basin includes unconfined aquifers as well as confined, bedrock aquifers. Aquifers range from the unconfined Quaternary alluvium in the streambeds of rivers and creeks to the Mississippian Age Madison Formation in excess of 10,000 feet below the surface. The water quality within these aquifers ranges from less than 300 mg/L TDS to more than 30,000 mg/L TDS (Bergantino 1980). The aquifers also vary in depth from the basin center to the margin. Coal aquifers are widespread, supply large numbers of water wells, and will be impacted most by CBM production.

Exhibit 13 lists the significant aquifers in the Montana portion of the PRB. The wells are almost exclusively completed in the shallow aquifers (< 500 ft depth) with the Tongue River Coals being the major aquifers. Wells completed in the major aquifers are limited in geographic distribution – Alluvium wells are distributed along principle rivers and streams, coal wells are arrayed in two principal bands corresponding to two stratigraphic packages, and Cretaceous sand wells are largely limited to the rim of the PRB. Only a very few wells utilize the Wasatch Formation, an aquifer that is more widespread and more important in the southern part of the PRB. A small number of wells near the edges of the PRB use the Cretaceous aquifers. A few wells utilize the sands in the Lebo and Tullock Members. The majority of water wells are completed in the Tongue River coals.

The coal aquifers are the most important to this report since they hold the CBM resource and production of the gas will directly impact coal seam aquifers. CBM production inevitably impacts coal seam aquifers within and around CBM producing fields. CBM production may also impact Alluvium aquifers where they intersect impacted coal seams.

EXHIBIT 13 - AQUIFERS IN THE MONTANA PORTION OF THE PRB

Summary of Montana PRB aquifers and associated data for approximate depth and number of current wells listed in the MBMG database.

AGE	AQUIFER	APPROXIMATE DEPTH	NUMBER OF WELLS IN THE MBMG DATABASE
Quaternary and Recent	Quaternary Alluvium	Surface to 90 feet	198
Tertiary	Wasatch	100 feet	6
	Tongue River Coals	50 to 400 feet	957
	Lebo/Tulloch	100 to 400 feet	306
Cretaceous	Hell Creek/Fox Hills	100 to 500 feet	199
	Judith River	2500 feet	1
	Eagle	2700 to 5700 feet	0
	Dakota/Lakota	5600 to 8600 feet	0

Note: MBMG = Montana Bureau of Mines and Geology

Dakota/Lakota Formation

This formation is present at approximately 5,600 feet bgs in the northern part of the PRB and at approximately 8,900 feet bgs at the southern Montana state line. The Dakota is present across the basin and commonly contains more than 50 feet of sand.

Eagle Formation

This sand zone is present at the south edge of the Montana portion of the PRB at approximately 5,700 feet bgs and at approximately 2,700 feet bgs on the northern edge of the basin. The Eagle exhibits scattered sand development. In Gallatin, Park, and Blaine counties, the Eagle Formation contains coal seams; in these counties CBM production may impact the Eagle sand aquifers.

Judith River Formation

This formation shows in excess of 40 feet of total sand at a depth of approximately 2,150 feet bgs near the Ashland coal area at the northern edge of the PRB. Sand in this formation is not present everywhere and produces water of only moderate quality; water of this quality could not be used for drinking or irrigation without treatment.

Fox Hills—Hell Creek Formations

These Cretaceous sands combine to form the principal aquifer in southeastern Montana (Miller 1981). Water wells into the joined sands can yield as much as 40 gpm. Municipal supply wells can yield more than 200 gpm (Miller 1981). Water quality is generally lower than in either the Fort Union or Quaternary Alluvium. The Fox Hills/Hell Creek aquifer is separated from the coal aquifers in the Fort Union by over 500 feet of fine-grained sediments in the Tullock and Lebo Members; these aquitards are not penetrated by CBM development wells and will, therefore, maintain their integrity. CBM production and drawdown of coal aquifers will not impact water wells using these Cretaceous or deeper aquifers.

Fort Union Formation

The Fort Union Formation contains minor sands and all of the water producing coal beds in the Montana PRB. Coal beds are the most-used aquifers in the Montana PRB (MBMG 2001) where they are largely used for stock watering. Yields can be as high as 150 gpm but average approximately 10 gpm (Bergantino 1980). Within the PRB, coalbed water wells are often less than 100 feet deep but can be as deep as approximately 400 feet (MBMG 2001). Coal reservoir parameters are listed in Exhibit 14 below. The thickness information provided appears to be highly variable but this may not be the truth; previous analysis may have combined thinner coal seams that are separated by thin shale layers that form local aquitards, but appear to be minor lenses in cores or wire-line logs. Porosity data is largely a measure of fracture porosity that is notoriously difficult to measure. The other parameters listed are also dependent upon fracture or cleat density. A more basic uncertainty is the unknown influence of coal bed methane on reservoir characteristics – is there a genetic connection between reservoir parameters and the presence of significant quantities of methane? Do the same coal seams, in a non-producing condition, have significantly different characteristics? There is insufficient data in the Montana portion of the PRB to provide answers. CBM produced water will be discussed in more detail within the impacts chapter of this Technical Report.

EXHIBIT 14 - PUBLISHED RESERVOIR PARAMETERS FOR ACTUAL AND POTENTIAL CBM RESERVOIRS

Reservoir parameters for several coal bed aquifers throughout the Montana portion of the PRB as compared to the Wyodak-Anderson Wyoming EIS data.

COAL SEAM	THICKNESS	TRANS-MISSIVITY	HYDR. COND.	POROSITY (%)	STORAGE COEFF.
Anderson – Dietz (CX Ranch) Redstone 1999	70'	300 ft^2/day	3.37 ft/day	2.0	2.18E-5
Knobloch (Montco Mine, permitted but not opened) (MDSL, 1982)	44'	58 ft^2/day	2.3 ft/ day	2.0	1.2E-4
Knobloch (Ashland Mine, not permitted) (Woessner, et al, 1981. EPA-600-7-81-004a.)	54'	100 ft^2/day	2 ft/day	2.0	5.0E-5
Wyodak-Anderson (BLM, 1999a) For comparison only	Variable		2.0E-5 m/sec (5.67 ft/day)	1.0	1.0E-4

Groundwater conditions described for the Montana Portion of the PRB Resource Management Area (RMA) also exist within the Bull Mountains Basin in the Billings RMP area (Noble et al. 1982). In this basin, Quaternary Alluvium and shallow Fort Union Formation coal and sand aquifers are important sources of water. Coals in the Billings RMP area are adjacent to sand aquifers and are aquifers themselves; water production from Bull Mountains Basin coals is likely to cause drawdown to nearby water wells similar to the Montana portion of the PRB in addition to possibly impacting vertically adjacent aquifers.

Wasatch Formation

Only a very small portion of the Montana PRB contains Wasatch bedrock; the formation has been either eroded or was not deposited over most of the area except within the very center of the basin. In the Wyoming portion of the PRB, Wasatch sands are significant aquifers that can support wells that yield in excess of 500 gpm (BLM 1999b).

Quaternary Alluvium and Associated Terrace Deposits

These clastic sediments are unconfined and in connection with permanent or significant ephemeral rivers and streams. Thickness can exceed 90 feet, but most average less than 30 feet (Bergantino 1980). Water yields average 25 gpm, but can be considerably higher (Bergantino 1980). Quaternary alluvium is the most-used aquifer in the Great Plains portion of Montana (Noble et al. 1982). In the Montana PRB, a total of 198 wells are identified as being screened in the Quaternary Alluvium (MBMG 2001). These wells are largely used for domestic supply, but are also used for publicly owned water systems, livestock, and irrigation. In the Montana PRB, Fort Union Formation coals outcrop in the valleys of streams and are in contact with alluvium. At the edge of the basin, Lebo and Tullock aquifers, as well as Cretaceous aquifers, outcrop in streambeds.

The coal aquifers are of special interest since they hold the CBM resource and production of the gas will directly impact coal seam aquifers. CBM production inevitably impacts coal seam aquifers. CBM production may also impact Alluvium aquifers where they intersect coal seams. The most important groundwater-surface water interaction concerning the effects of CBM production is the exchange of water between coal seams and surface water via Alluvium. Several bands of coal seam development – Anderson, Knoblock, and Colstrip – outcrop as clinker in the watersheds of major streams. These

clinkers often give rise to springs that feed into rivers and alluvium. During periods of little run off, such as late winter when streams and rivers are at baseflow, streams are particularly vulnerable to impact from surface recharge by low quality coal aquifer water. At times of high run off, rivers and streams often have sufficient flow to dilute the coal aquifer water coming via clinker-fed springs.

Watersheds

Watersheds are important to predicting the impacts from CBM development in Montana. Water resource factors such as water quality, water use, and potential impacts will be discussed throughout this report in terms of watersheds. Each watershed is drained by a single stream or river and each is bounded by a no-flow topographic boundary. Streams and rivers are profoundly influenced by their watersheds; in particular water volume and water quality vary from base flow conditions to high-flow conditions under the control of runoff from land surfaces and recharge to rivers by aquifers. Exhibit 3 highlights the watersheds in the PRB along with potential CBM areas. The areas of highest potential for CBM development fall within the northern portion of the Upper Tongue River Watershed, the southern section of the Lower Tongue River Watershed, the western section of the Middle Powder River Watershed, and the eastern section of the Rosebud Watershed. The current CBM production area in the Montana PRB lies within the Upper Tongue River Watershed. It should be noted that the watersheds along the southern boundary of the Montana PRB drain to the north and may already be impacted by CBM development in Wyoming.

IMpacts From CBM

Introduction

This chapter presents an overview of the environmental impacts from CBM production in the Powder River Basin. The descriptions of predicted effects that would result from the exploration, construction, operation and maintenance, and abandonment activities associated with CBM are compared to the pre-project environment. The method of recognizing impacts and accomplishing a systematic impact analysis are in accordance with the Council on Environmental Quality guidelines, which institutes procedures on applying NEPA. The duration of the impacts are analyzed and described as either short-term (up to 5 years) or long-term (life of the project and beyond). Mitigation measures that are not already included as part of the project are described and evaluated, and the residual impacts are determined. Physical impacts to landscapes from development disturbances can easily be quantified, however, effects to watersheds or wildlife can not easily be distinguished and therefore are discussed in conjunction.

impacts and environmental consequences

The development of CBM resources will produce environmental impacts resulting from the exploration, construction, and operations and maintenance activities associated with CBM when compared to the current environment. Areas of concern such as water, air quality, soil, cultural, paleontological, geologic and mineral, and agricultural resources were identified during public scoping as being potentially impacted. There were also concerns that impacts to areas such as the socio-economics of the region, the climate, Indian Trust Assets, Recreation areas, visual resources, wilderness study areas, and the land use and realty would occur. The impacts to these resources may be either positive, negative, or in some cases both, with some areas experiencing more impact than others.

The areas of particular interest are those with the highest potential impacts from CBM development such as water resources, soil, and agriculture. These areas will be discussed in greater detail than other areas where less impact is expected.

The level of disturbance for installation and production of a single CBM was determined in order to facilitate some uniformity in impact analysis. A breakdown of the level of disturbance was calculated for a single CBM well for exploration, construction and operation, these disturbances would be 1, 3.25, and 2.0 acres/well respectively. The level of disturbance is less for exploration wells since no permanent structures will be constructed. The operation disturbance is less than the construction disturbance since areas will be immediately restored as they become unnecessary. Although quantitative impacts can be determined for some resources, qualitative impacts were determined for others. A brief discussion of the impacts to all resources will be discussed later in this report.

Resource Specific Impacts

Air quality

Air emissions would be caused by short-term activities such as construction-generated dust, vehicle and exhaust emissions, natural gas venting during drilling and testing of the well, and accidental releases of gas during drilling and pipeline transport. Air quality issues would also arise from long term activities such as the operation of large central compressor stations used to transport methane gas from production areas and from diesel generator operations used to power the well stations.

Cultural and paleontological Resources

Cultural and paleontolgical resources are potentially impacted by surface and subsurface disturbing activities. Activities that involve the use of heavy equipment (road construction, well drilling, pad construction, pipeline and utility placement, etc.) and which result in changes to the natural landscape cause the most disturbance and have the greatest effect on cultural and paleontological resources. Other activities, such as increased travel and vandalism resulting from access improvements, and increased erosion resulting from surface disturbances, can also impact these resources. These activities can also produce indirect impacts to the resources such as fires; hazardous waste spills and cleanups; changes in livestock grazing patterns; and wildlife habitats.

Environmental justice and indian trust

Environmental justice is a measure to ensure that there is fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income with respect to the development of environmental regulations and policies. Environmental justice is important to CBM development in the PRB of Montana because the development area includes three Indian reservations with substantial minority (Native American) populations. The development area also includes several counties with elevated poverty rates. The level of CBM development will determine to some extent the degree to which environmental justice will be impacted. Impacts to groundwater resources from drawdown, air quality from emissions, and surface water quality for discharge would be widespread and would affect the Indian reservations and poverty stricken counties.

geology and mineral resources

The production or drainage of oil and gas including CBM results in the irreversible and irretrievable loss of these resources. One such loss would result from mineral drainage to adjacent leases from the production of hydrocarbons including the drainage of CBM

resources in Montana from production in Wyoming**.** Wells placed in proximity to mineral lease boundaries would drain neighboring mineral leases. Other activities such as venting or flaring natural gas beyond emergencies, well evaluation, or initial testing would also represent drainage and waste of mineral resources. Another drainage issue results from produced water associated with CBM production that may or may not be an irreversible or irretrievable loss of resources depending on the water quality and aquifer from which it is drawn.

Other impacts of CBM development include the prevention of conventional oil and gas development, coal mining, and surface mineral mining because of surface facilities and producing wells on CBM sites. Other impacts to coal mining include CBM production dewatering at nearby coal seams, which can cause underground coal fires, methane seeps, and the liberation of methane to water wells.

lands and realty

Potential land use impacts would primarily consist of conflicts between CBM activities and other uses of property, such as agriculture and residences. New realty authorizations for gathering lines and power lines, for example, would impact rights-of-way (ROWs) and land segmenting. The development of CBM resources impacts agricultural production by taking land out of production and by soil contamination from drilling and production activities.

Short-term impacts of land uses during construction would consist of the physical intrusion by CBM crews and equipment, the local generation of dust and noise, and the limited obstruction of traffic. Long-term impacts include loss of existing land use, increased access from roads, and loss of land value.

Some surface landowners are unaware of the severed mineral rights, and even though compensated, they would be displeased with the possibility of having well facilities located near dwellings. Placement of roads and well pads near residential, business, and community dwellings may cause direct reductions of property values. Impacts from placement of roads, utility lines, and well pads around communities may cause loss of future community development opportunities.

Social and Economic Values

Impacts on social conditions would include changes in employment and population; changes in the services provided by local governments; the effects of drilling and related activities on rural lifestyles in the project area; the effects of changes in employment opportunities on communities; and the effects of population change on local housing and services.

Direct economic impacts of the project would include changes in personal income resulting from new employment of CBM workers; purchases of equipment, supplies, and services from local area vendors; lease, royalty, and production payments; taxes and other government levies; and related changes in the fiscal health of local governments. Indirect impacts would include induced economic activity from local purchases of equipment, supplies, and services; induced economic activity from purchases of goods and services by project workers; and changes in the sources of income for local governments.

Wildlife

CBM exploration and production includes development of roads, pads, power lines, utility corridors, and facilities as well as human activities and regular human presence. Much of this activity would occur in the relatively undisturbed native short grass prairie of eastern

Montana, resulting in both direct and indirect impacts on wildlife. Those impacts would be localized around CBM exploration and production sites and proportional to the level of activity at a particular location.

Direct habitat loss and direct and indirect impacts because of habitat disruption and wildlife disturbance caused by roads and utility corridors would cause the bulk of the impacts on wildlife. Direct impacts on wildlife would also include mortality as relatively less mobile small mammals, reptiles, and amphibians are killed during road and other site construction during development of CBM facilities. Additional direct impacts that may occur on private lands include greater potential loss of riparian vegetation and other floodplain habitats valuable for wildlife, abandonment of raptor nests because of direct habitat loss and disturbance, and habitat loss for a wide range of species in prairie dog towns larger than 80 acres.

Indirect impacts of road development and use during exploration and production on wildlife and wildlife habitat include biological effects, such as displacement and stress, habitat fragmentation, abandonment of habitat features, physiological penalties from unnecessary energy expenditure in response to vehicles, and other effects related to changes in hunting opportunity (Bury 1980; Trombulak and Frissell 2000, USDI and USDA 2001).

Overhead power lines constructed for production wells pose problems for a variety of wildlife species. Raptors and other species of birds occasionally collide with power lines, especially during periods of relatively poor visibility. Another wildlife disturbance factor associated with CBM exploration, development, and operation is noise. Noise effects would likely be greatest during exploration and development, but would continue through production and abandonment.

WATER RESOURCES IMPACT ISSUES

Introduction

The production of coal bed methane (CBM) has the potential to impact water resources in a variety of ways. Drawdown of coal seam aquifers is an unavoidable impact because the de-pressurization of coal seams is inherent to the process of CBM production. Once brought to the surface during production operations, produced water is essentially a waste bi-product that must be disposed of. Options for disposal include discharge to land or surface water bodies, re-injection, or one of many beneficial use options (e.g., stock watering, controlled irrigation, dust control, storage impoundments, etc.).

The combination of potentially substantial water volumes combined with relatively poor to moderate water quality characteristics emphasizes the needs to closely evaluate and monitor CBM development and production. Depending on the area, groundwater and/or surface waters may vary in potential vulnerability. To fully understand these potential vulnerabilities and impacts, analysis of both groundwater and surface water is required.

GROUNDWATER DRAWDOWN

Groundwater drawdown from CBM production has been documented inside and adjacent to existing production in Montana. CBM production in the PRB requires drawdown of coal aquifers within the producing field in order to liberate methane. Water wells adjacent to but outside of a producing CBM field may also be adversely impacted. Drawdown can be documented by way of dedicated monitoring wells or by gauging private water wells. In Montana's CX Ranch CBM field, the MBMG has installed monitoring wells designed to track drawdown due to the coal mines in the area as well as CBM development.

Exhibit 15 (formerly 21) is a location map of monitoring wells, CBM wells, and coal mines near Decker, Montana. This exhibit shows the spatial relationship between monitoring stations and both coal mine development and active CBM production at the CX Ranch field. Both water level and water quality data have been collected at the monitoring wells identified, although some are currently inoperative. Some of these monitoring wells are periodically checked and sampled. Monitoring data for these wells were obtained from the Montana Bureau of Mines and Geology.

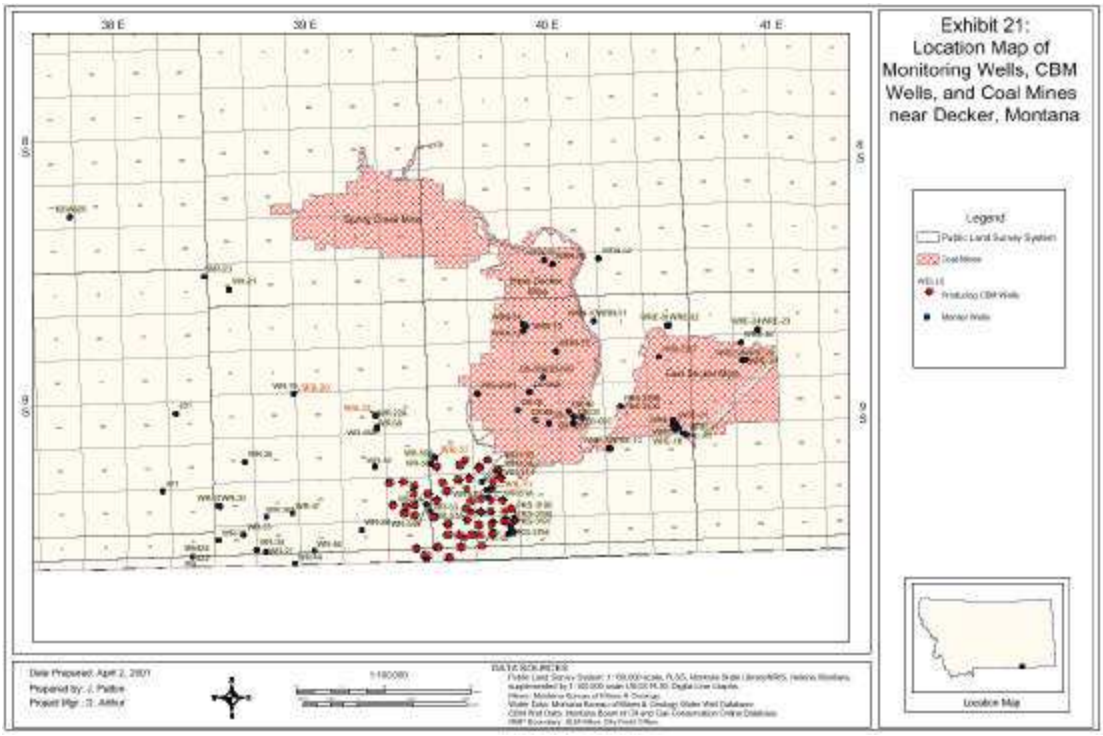


Exhibit 16 summarizes the water level data of 14 monitoring wells in or adjacent to the CX field for which coal aquifer data is available. Those wells closest to the center of CBM development tend to show drawdown at the earliest date, however there are exceptions. The degree of draw-down recorded appears to be due to water production from the nearly 200 CBM wells now on-line at the CX field as summarized above; production began with the drilling of the first CBM wells in March 1998 and first pumping in December 1998 (Williams 2001).

It is unclear what the limit of drawdown will be as the field continues to produce CBM. It may be that as pumping rates drop in the CX Ranch Field, the drawdown radius of impact may cease spreading and may stabilize.

The CX Ranch is still being developed and producing wells are being added. Full extent of CBM development and full extent of offsite aquifer drawdown cannot be estimated at the present time. It is possible that if further development doesn't take place, the WR-22 well may not be drawn down beyond its present point. It is also possible that if more CBM wells are drilled, then WR-22 may be surrounded by CBM wells and drawdown will likely increase more rapidly.

Groundwater drawdown can result in wide-ranging methane migration phenomena under adjacent leases including methane liberation into in nearby water wells, coal fires, etc. have been observed in other coal basins. The PRB is sufficiently different from the San Juan Basin (SJB); however, it may not support methane migration away from aquifer drawdown. Methane liberation into non-

produced water wells has been demonstrated at CX Ranch, the extent of the phenomenon is unknown at the present time.

EXHIBIT 16 - SUMMARY OF WATER LEVEL DATA FROM CX FIELD MONITORING WELLS

STATISTICS ON THE13 HYDROGRAPHS IN THE VICINITY OF CX RANCH CBM FIELD

MONITORING WELL	DISTANCE FROM NEAREST CBM WELL	DATE OF ONSET OF DRAW-DOWN	TIME FOR DRAW-DOWN TO REACH WELL	MAXIMUM DRAW-DOWN
WR-17	0.0 miles	10/1999	11 months	21 feet
WR-51	0.0 miles	1/1999	1 month	111 feet
WR-53	0.0 miles	10/1999	11 months	74 feet
WR-53A	0.0 miles	11/2000	24 months	2.0 feet
WR-54	0.0 miles	10/1999	11 months	38 feet
WR-55	0.2 miles	11/1999	12 months	51 feet
WR-28	0.92 miles	None	-	0.0 feet
WR-22	1.8 miles	3/2000	16 months	10 feet
DS-05A	2.40 miles	None	-	0.0 feet
WR-27	3.12 miles	None	-	0.0 feet
WR-19	3.68 miles	None	-	0.0 feet
WR-20	3.68 miles	None	-	0.0 feet
WRE-10	4.20 miles	None	-	0.0 feet

The San Juan Basin (SJB) has experienced gas seeps and coal fires that appear to be increasing in number in concert with increasing CBM production (BLM, 2000b). It is hypothesized that nearby CBM production has intensified seep activity. Specifically, lowering of the water table in the monocline by downdip dewatering of coal beds is postulated to allow CBM to desorb from coal beds near the outcrop. The desorbed gas could then migrate buoyantly updip to the outcrop and seep. The details of this potential process are not well understood at this time.

Heffern (1999), as quoted in the WYODAK Draft EIS (BLM, 1999c), compares the characteristics of the SJB of southwest Colorado and northwest New Mexico, with its coal fires, methane seeps, and high temperatures that have killed vegetation, with the PRB to evaluate the potential for coal fires and methane migration or seepage within the PRB. Although some similarities exist between the two basins, there are significant differences.

Basin pressurization and regional groundwater flow – the PRB is not an overpressured basin, as is the SJB. Groundwater flow in the PRB coal aquifer is downdip, toward the center of the basin (USGS, 1986b), rather than updip toward the outcrop.

Recharge from clinker - Unlike the SJB where there is little groundwater recharge or clinker at the coal outcrop, extensive deposits of porous clinker occurring in the PRB near the coal mines trap rainfall and snowmelt and recharge the coal aquifers (USGS, 1988; Peacock et al 1997).

Coal characteristics - The bituminous coal in the SJB, while having less volatile matter, has developed better cleat and fractures than the sub-bituminous coal in the PRB. Due to its cleat, the SJB coal must be completely dewatered to achieve maximum production. The methane in the SJB is largely thermogenic, generated at depth from the high temperatures and pressures associated with burial. In the PRB, the methane is biogenic, and water is retained in the cell structure of the coal. In the PRB, overpumping of water from the coal could shut off methane flow if the cell structure collapses, rather than releasing methane (Selvig and Olde, 1953).

Basin structure - In the SJB outcrop area, where methane seepage occurs, it is confined to a much smaller area. Therefore, methane seepage may be more concentrated in the SJB than in the PRB. The SJB also is more highly deformed than the PRB and contains more faults and fractures that could serve as conduits for methane migration. Aubrey, et al. (1998) also notes the lack of substantial caprock in the SJB that would limit the flow of groundwater or methane migration.

Experience in existing mines - Mine fires are common in piles of coal fines and along the highwall in PRB mines, and are regularly extinguished. Since CBM development began, mine inspectors have not noted a significant increase or decrease in the number of fires in coal pits located east of the Marquiss and Lighthouse CBM projects where, to date, groundwater drawdown due to CBM development has been greatest. Moreover, the frequency of coal fires in these pits is similar to that for coal pits located some distance from CBM development.

Methane seepage can occur naturally in the vicinity of near-surface coal seams (Glass et al., 1987 and Jones et al., 1987). The potential for methane migration within the PRB is not limited to areas containing near-surface coal seams or areas where CBM drawdown has occurred. Methane migration potentially could occur at widespread locations within the PRB, as methane can migrate long distances along naturally occurring joints or fractures in rocks. Whether methane migration occurs in the PRB and whether methane seepage could accelerate the natural process of coal combustion is an unresolved question.

Groundwater Balance

Groundwater resources can be balanced against current groundwater production and projected CBM water production within watersheds of the PRB. Exhibit 17 represents a calculated estimate of the water resources that exist in the coal seams of the Montana portion of the PRB. The estimate utilizes the acres within each watershed that have known coal occurrences that could be utilized for CBM development from Exhibit 3. Each acreage figure is multiplied by an average coal thickness of 70 feet from USGS Prof. Paper 1625-A. This is a volume figure that can be used with a porosity estimate (2%) to derive a total in-place groundwater volume for each watershed. These figures add up to an estimated 249.73 billion cu ft of groundwater for the projected CBM area of the PRB. This total does not include the volume of all the coal seams in the PRB, instead only those coals in the CBM potential development area. This total does not include waters held in non-coal aquifers.

EXHIBIT 17 - TOTAL GROUNDWATER RESOURCES IN THE COAL SEAMS OF THE MONTANA PRB WATERSHEDS

Calculated estimate of the water resources that exist in the coal seams of the Montana PRB

WATERSHED	TOTAL ACRES OF WATERSHED	TOTAL GROUNDWATER RESOURCE OF WATERSHED (Billion cu ft)	WATERSHED	TOTAL ACRES OF WATERSHED	TOTAL GROUNDWATER RESOURCE OF WATERSHED (Billion cu ft)
Little Big Horn	87,000	5	Middle Powder	368,500	22.5
Little Powder	29,500	2	Mizpah	24,000	1.5
Lower Bighorn	121,500	7.5	Rosebud	81,4000	49.5
Lower Tongue	1,374,000	84	Upper Tongue	589,000	34
Lower Yellowstone-Sunday	687,500	42	**TOTAL**	**4,095,000**	**248**

EXHIBIT 18 SHOWS A CALCULATION OF THE POTENTIAL WATER PRODUCTION RESULTING FROM THE MAXIMUM NUMBER OF CBM WELLS (FROM THE RFD) FOR

each PRB watershed per year. The average water production rate was calculated from an exponential trend analysis and the details can be seen in Figure 7. The table illustrates that the watersheds with the greatest water production are those with the most wells, i.e. Lower Tongue River, Upper Tongue River and Rosebud. The total water production for all CBM wells in all the watersheds is 4.4 billion cu. ft. per year or approximately 1.75 percent of the water in the coal seems of the Montana PRB Watersheds.

EXHIBIT 18 - MAXIMUM POTENTIAL PRODUCED CBM WATER BY MT PRB WATERSHEDS

Calculation of the potential water production resulting from the maximum number of CBM wells from the RFD full-field scenario for each PRB watershed per year.

WATERSHED	EFFECTIVE ACRES (Acres)	MAX POTENTIAL PRODUCING WELLS	AVERAGE WATER PRODUCTION RATE PER WELL (gpm)	MAX POTENTIAL PRODUCED CBM WATER PER YEAR (Billion cu ft)
Little Big Horn	87,179	1,050	2.5	0.184
Little Powder	29,605	278	2.5	0.049
Lower Bighorn	121,538	1,200	2.5	0.211
Lower Tongue	1,374,159	5,183	2.5	0.910
Lower Yellowstone- Sunday	687,303	2,568	2.5	0.451
Middle Powder	368,349	3,167	2.5	0.556
Mizpah	23,941	224	2.5	0.039
Rosebud	813951	5397	2.5	0.948
Upper Tongue	589009	5806	2.5	1.020
TOTAL	**4,095,034**	**24,873**	**2.5**	**4.4**

Surface Water Impact from Discharge

Impacts to surface water from discharge of CBM water can be severe depending upon the quality of the CBM water. Some watersheds may be able to absorb the discharged water while others are sensitive to large amounts of low-quality CBM water. Water quality data is from stream gauging points maintained by the USGS. These multi-year collections of water quality data illustrate changes within the stream from times of high run-off (typically June for the PRB) when the river is the highest and water is mostly the result of precipitation from spring rains and melting snow. During periods of high flow the streams and rivers contain higher quality water. The USGS data also contains data on base-flow conditions (typically winter in the PRB) when streams are at their lowest flow and water quality is the lowest since much of the water is recharge from alluvial and bedrock aquifers where groundwater is often of low quality. Water quality data consisting of stream flow and SAR is analyzed for a number of USGS gauging points to worst case conditions for CBM water discharge. In addition to surface water information, projected CBM water discharge data is analyzed for comparison; the quality of discharge water is estimated to be the same as produced water from the CX Ranch field, SAR = 47. It is likely however that some of the coal aquifers contain water that differs from the CX Ranch produced waters.

Produced CBM water can have impacts on surface water if it is discharged directly to streams and rivers. In a highest impact scenario, all the water produced in the projected CBM wells would be discharged to the primary drainage in each watershed. The results of this scenario are tabulated in Exhibit 19. In this table, the existing drainage way conditions are compared to the worst case conditions for CBM discharge. If the worst-case scenario would develop – 100% of the CBM produced water would be discharged at the gauging point during the average base-flow conditions. The resultant SAR values are a weighted average of the maximum CBM discharge and the average base-flow. Again

for this scenario water quality was assumed to match that of CX Ranch. The biggest impacts would be those streams with low flow volumes and low SAR values such as Rosebud (near Kirby) that have a substantial increase in flow from the CBM discharge waters. In the case of Rosebud (near Kirby) the SAR increases from 0.8 to 44.4 and has an increase in flow from 1.78 cfs to 31.78 cfs.

EXHIBIT 19 - WORST-CASE DISCHARGE SCENARIO – BY WATERSHED – USING CX RANCH WATER QUALITY

Highest impact scenario for Montana PRB as tabulated from CX Ranch quality water for primary drainage in each watershed.

WATERSHED	BASE FLOW (CFS)		SAR		HIGH FLOW (CFS)	
	EXISTING	POTENTIAL	EXISTING	POTENTIAL	EXISTING	POTENTIAL
Little Big Horn (Near Wyola)	61.8	67.6	1.2	5.1	526	531.8
Little Big Horn (near Crow Agency)	123	128.8	NA	NA	782	787.8
Little Big Horn (near Hardin)	138	144.8	2.0	3.8	851	856.8
Little Yellowstone-Sunday (Myers)	4200	4214.3	1.7	1.9	42,000	42,014.3
Little Yellowstone-Sunday (Hysham)	0.01	14.31	8.5	47	280	294.3
Little Yellowstone-Sunday (Colstrip)	0.6	14.9	4.5	45	65	79.3
Little Powder (near Broadus)	0.35	1.90	NA	NA	69	70.55
Lower Bighorn (near St Xavier)	1750	1756.7	2.5	2.7	10,300	10,306.7
Lower Bighorn (near Big Horn)	640	646.7	3.7	4.1	21,500	21,506.7
Mizpah (near Mizpah)	26	27.25	21.0	21.4	60.1	61.35
Middle Powder (near Moorhead)	153	179.5	5.2	6.1	1433	1450.5
Middle Powder (near Broadus)	198	224.5	NA	NA	1077	1094.5
Rosebud (at Reservation Boundary near Kirby)	1.78	31.78	0.8	44.4	15.7	45.7
Rosebud (near Colstrip)	7.5	37.5	1.5	37.9	56.5	86.5
Rosebud (at mouth near Rosebud)	9.02	39.02	3.7	37	77.0	107
Upper Tongue (at state line)	181	213.3	NA	NA	1724	1746.3
Upper Tongue (at Tongue R. Dam near Decker)	175	207.3	1.1	8.25	1467	1489.3
Lower Tongue (near Birney Day School)	185	213.9	1.4	7.6	1202	1230.9
Lower Tongue (near Ashland)	206	234.9	NA	NA	2073	2101.9
Lower Tongue (at Miles City)	194	222.9	2.4	7.1	1305	1333.9

Except for the Little Big Horn and the Mizpah watersheds, the worst-case discharge would have unacceptable impacts on stream conditions. For both the Little Big Horn and Mizpah, the number of wells is expected to be so small that discharge volumes are also expected to be small and dilution will be sufficient to avoid any significant degradation to water in terms of SAR. Other streams and rivers cannot withstand the maximum discharge of CBM water; the calculated resultant water would be unusable for irrigation. This statement is based upon the maximum number of CBM wells as computed by the RFD and the potential CBM map as well as the assumption that produced water will be the same quality as CX Ranch water. If CBM produced water is less sodic than the CX Ranch water and closer to river water in quality, watersheds will be able to accept more CBM discharge. As discharge waters increase in volume, however, there is the potential to impact riparian areas via increased erosion and sediment transport. Exhibit 19 also casts watershed flow rates against worst-case discharge rates at each potential discharge point. Increases caused by discharge range from approximately 0.1% if all 5,183 CBM wells discharge into the Lower Tongue near Ashland, Montana up to 191% if all 1250 CBM wells discharge into the Rosebud near Kirby, Montana. For the former, little erosion would be expected while for the latter, significant impact could be expected if riparian areas were prone to erosion**.**

AGRICULTURAL IMPACTS

Impacts to agricultural systems, and to other aspects of the land resource, are evaluated in this section. It should be noted that for this analysis it has been conservatively assumed that undiluted CBM water will be used year-round. The low rates of flow from most CBM wells would likely

permit the blended or intermittent use of CBM water, which could reduce or eliminate the level of impacts suggested in this analysis. The use of CBM water for irrigation will also be limited to the growing season for the intended crops, which usually ranges from 100 to 150 days per year.

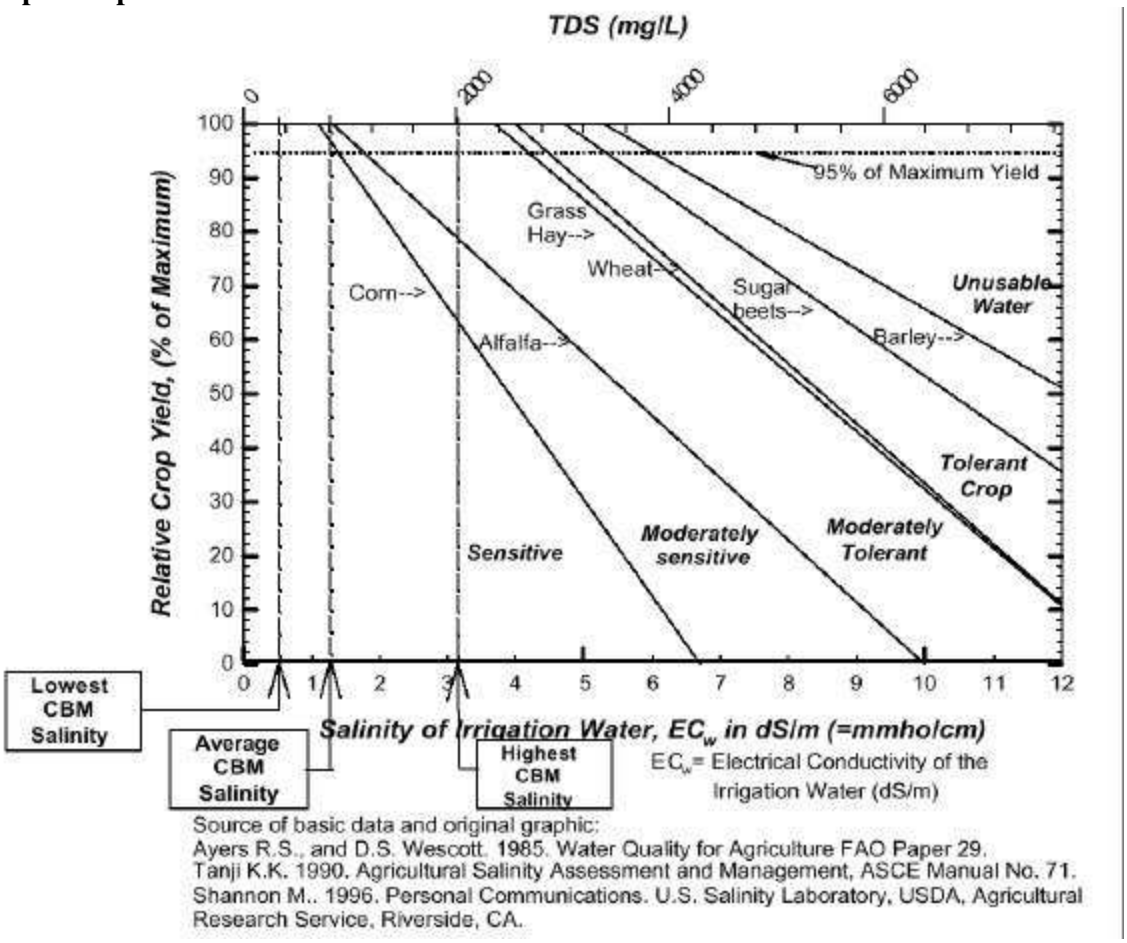
Agricultural Irrigation

Potential impacts from agricultural irrigation with CBM water are related to the quality of the water. To determine these impacts, the quality characteristics of the CBM water can be compared to generally accepted irrigation water quality requirements (Ayers and Westcot 1985). The quality categories are discussed and compared to the previously presented CBM water quality characteristics as follows:

> **Salinity** *(affects crop water availability*): The principal measure of salinity of irrigation water is EC expressed in deciSiemens per meter (dS/m). (Note: 1 dS/m = 1 mmhos/cm). Crops vary in their response to irrigation water salinity as follows:
>
> ?? < 0.7 dS/m provides no restrictions to crop growth
>
> ?? 0.7 – 3.0 dS/m provides slight to moderate restrictions to crop growth
>
> ?? > 3.0 dS/m provides severe restrictions to crop growth
>
> The lowest, mean (average), median, and highest salinities of the CBM water are 0.47, 1.3, 1.13, and 3.02 dS/m, respectively. From Exhibit 3, the average salinity of the CBM water from the 19 Decker wells is 2.39 dS/m. Based on these values, CBM water with salinities equal to those of the indicated lowest and average salinities would pose no significant problem even for most sensitive crops. CBM water with the highest indicated salinity may pose problems only to some moderately sensitive to moderately tolerant crops.

The tolerances to salinity of six example crops grown in the study area are shown in Exhibit 22. In developing the basic data used for Exhibit 22, Ayers and Wescott (1985) assumed a leaching fraction of 15 percent to 20 percent. The line indicating 95 percent of potential yield is also shown. Since the basic data are somewhat empirical, and since many other elements of the crop environment can also affect yield, it is considered reasonable that comparisons can, from a practical standpoint, be made using this indicated level of yield as a no-impact point. It is doubtful that such a yield decrement could be detected as attributed only to the level of salinity in the soil. Also from a practical standpoint, it is likely that farmers will alter their management practices (i.e., ensuring adequate leaching or selecting appropriate crop cultivars) to fit the specific conditions that occur to maximize the crop yield.

Exhibit 22. Relationship Between Relative Crop Yield and Irrigation Water Salinity for Six Sample Crops

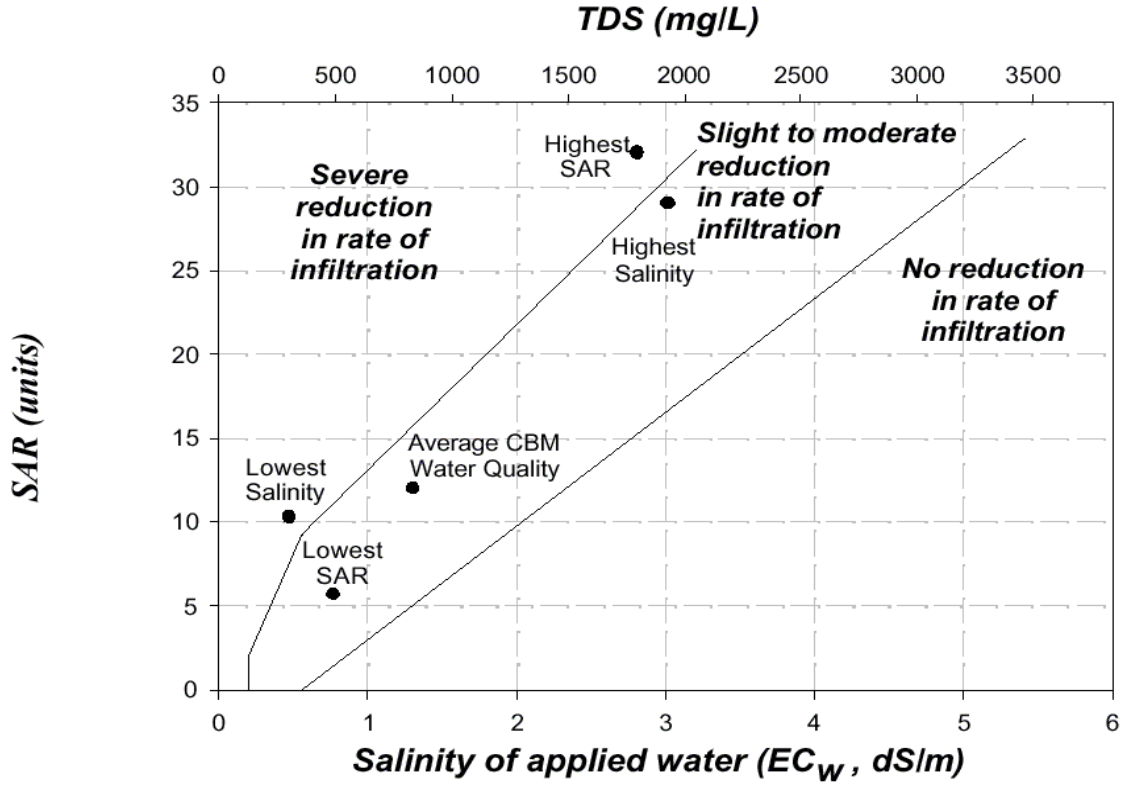


With normally accepted management practices, the lowest CBM water salinity would have no adverse effect on the example crops. For the more salinity-sensitive of the example crops, such as alfalfa and corn, the salinity level of the average CBM water is near the threshold of causing yield reduction, and care would have to be taken to ensure adequate leaching. Also, a portion of the irrigation water supply may have to come from other sources, probably current irrigation water sources. From the standpoint of salinity, the other example crops should do well with any of the indicated CBM water as a sole source for irrigation, provided the soil has good internal drainage and normally acceptable management practices are followed. Prospective irrigators should be provided with this information in order for them to make the decision if they can accept a possible yield reduction, or possible increase in the case where a crop goes from dryland to irrigated.

SAR (Sodicity) *(affects infiltration rate of water)*: Generally, increasing levels of SAR create an increasing hazard for infiltration problems. However, if the irrigation water contains higher levels of salinity, the SAR can increase without greatly increasing the infiltration hazard. Therefore, both the SAR and the EC of the irrigation water are used to evaluate potential infiltration problems. Usually, SAR values below 3.0 are not considered to be a threat to crops and native plants; however, SAR values above 12.0 are considered sodic and may affect soils and vegetation.

Exhibit 23 shows the potential infiltration hazard of the average CBM water quality. Such water may cause a slight to moderate reduction of the rate of infiltration of water into the soil. Also shown in Exhibit 23 are the individual CBM waters (Rice et al, 2000) with the lowest and highest salinity (EC) with their corresponding SAR, and those with the lowest and highest SAR and their corresponding EC. The individual waters with the highest SAR and lowest EC could cause a significant reduction in the infiltration rate if the waters were used continuously as the only water supply. The individual waters with the lowest SAR and the highest EC would likely cause only a slight to moderate reduction in the infiltration rate of the soil.

Exhibit 23. General CBM Water Quality Relative to the Potential for Dispersion of Soil Aggregates and Reductions in Soil Rate of Infiltration (Based on data from Ayers and Westcot 1985)



Trace Elements *(affects crop toxicity*): Certain trace elements in the irrigation water can cause toxicity in certain crops. Ayers and Westcot (1985) present recommended maximum concentrations of trace elements in irrigation water. A comparison of these recommended maximum concentrations to the highest concentrations presented in Exhibit 24 showed that, in every case, the highest concentrations of the CBM waters were considerably lower, in most instances by one to three orders of magnitude, than the recommended maximums.

Livestock Watering

As with plants, certain trace elements in drinking water can be toxic to livestock. Ayers and Westcot (1985) present water quality guidelines for livestock. A comparison of these water quality guidelines to the highest concentrations of the CBM waters and the average concentrations of the CBM water indicated that all of the CBM waters would be very satisfactory to excellent for use as livestock drinking water. In some cases, the water could cause temporary diarrhea in livestock not

accustomed to such water, but this problem should rapidly disappear as animals adapt to the new water supply.

OTHER IMPACTS

In addition to supplying water to plants or livestock, landspreading or surface discharge of the CBM water can cause undesirable impacts. Where irrigation water is otherwise unavailable or not supplied, discharge of CBM water to land would have the benefit of providing water for plant growth. With the higher salinity CBM waters shown in Exhibit 23, long-term landspreading would likely increase the salinity and sodicity of the affected surface soils and hence adversely affect the native vegetation and wildlife habitat. This could lead to an increase in primary productivity of plant communities adapted to this new hydrologic condition or changes in the existing plant community in response to the new hydrologic regime. Resulting communities and habitat would necessarily be adapted to the quality of water from the specific CBM source wells. This could lead to subsequent changes in the wildlife community to one adapted to salt-tolerant plant communities. Accumulation of evaporated salts could also occur in any closed depressions, which would destroy vegetation in these depressions. Such long-term discharge to the land surface could also cause excessive erosion of the soil and gullying, which could intensify over time if high SAR water reduced infiltration. With long-term discharge of high salt CBM water to constructed evaporation ponds, removal and disposal of the accumulated salts would likely be required.

With discharge of the CBM water to surface drainageways and streams, serious erosion could occur damaging or destroying instream vegetation (Bauder 1999). The erosion can result in increased sediment loads, which along with the potential high salinity and sodicity, can significantly degrade the stream and receiving water quality. This degraded quality could also affect the biological aspects of the stream. It is also important to note that, depending on the quantity and level of quality of the discharged CBM water, the receiving waters could significantly dilute the concentrations of the constituents in the CBM water, resulting in potentially minimal impact from salinity on the receiving waters. Of course this would depend on the amount of CBM water released in relation to the flow in the receiving water bodies. Bauder (1999) presented a scenario based on the assumption that 100 CBM wells producing 10 gallons per minute (gpm) each for a total of 2.2 cubic feet per second (cfs) were discharging into the Tongue River near Decker, Montana. The mean flow of the river at the lowest period is about 180 cfs, and during the high flow it is about 1,680 cfs. In terms of volume of water, the CBM water discharges are likely to be insignificant compared to the normal flows of the Tongue River. On the other extreme, the RFD produced by the Miles City, Montana BLM in 2001 gives the full field development of a maximum of 26,000 wells in the next 20 years. At an average flow of 10 gpm per CBM well, this would be approximately 580 cfs (1,150 ac-ft/day), which could make a significant impact on the environment.

The construction and continued use of the CBM wells and gas production facilities, the network of roads and pipelines, and storage ponds can cause significant impacts to the local resources. The actual surface disturbances and use of the facilities can cause erosion of the soils and introduction of noxious weeds to the surrounding area. The existence of the facilities reduces the forage base for livestock and wildlife. The activities during use of the facilities can also adversely affect the activities of the various native wildlife species.

LONG TERM EFFECTS

The long-term impacts of using CBM water or diluted discharge water for agricultural purposes include crop effects, farming practice changes, irrigation management, and direct effects to soils. However, with proper crop selection and appropriate irrigation management, economic yields can be sustained under low to moderate saline conditions.

The use of high salinity/sodium CBM water may have long-term effects on crops. There may be limitations on which crops species can viably be grown. More salt tolerant crops may have to be grown where higher salinity irrigation water is used, such as barley and sugar beets, as well as hays such as Bermuda, wheatgrass and wildrye, instead of the more salt sensitive plants like wheat, alfalfa, corn, and clover hay. Some crops may show toxic effects of salts accumulating in the leaves or rootstock over time. This is most common in trees and other woody perennials.

Another long-term effect of using high salinity CBM water may lead to the modification of cropping practices. This may include such practices as modifying seed placement (e.g., planting on furrow sides, double-row raised beds, increasing seeding rates, etc.) to achieve better germination and stands; new or modified equipment for crop sowing; growing different crops; soil profile modification for better drainage and water penetration; and the use of amendments such as gypsum or sulfur to soils to improve water permeability lost to excess sodium in the soil.

Soils do not usually become excessively saline from use of saline water in a single irrigation season, depending on the quality of water used. It may even take several irrigation seasons to affect the level of salt in the soil solution. The maximum soil salinity in the root zone that results from continuous irrigation with saline water does not occur when salty water is used only a fraction of the time. Changes may need to be made to irrigation water management techniques required to use CBM water. The method of application of irrigation water may need to change. A real application with sprinkler irrigation can cause concentrated salt accumulations near the soil surface and cause foliar damage to certain plants. Other types of application such as drip and furrow irrigation have less salt accumulation at the soil surface in the shorter term, but still may result in salt accumulations in deeper soils over the longer term. Additional irrigation water will be required for leaching to ensure salts are moved out of root zone. Increasing the frequency of irrigation may also need to be implemented to maintain soil water content and decrease the effects of applying saline water (less water holding capacity and higher salinity levels). These increases in irrigation water amounts may lead to producers having to file for additional water rights or finding other sources of lower salinity water for leaching, and a potential for more saline seeps in areas irrigated with CBM water.

The cumulative effects of the application of high SAR CBM water to the soil and the build up of sodium will have an affect on the physical characteristics of the soils -which in turn affect the chemical characteristics – and then the biological characteristics. It is possible to create a site through sodium saturation which will not support the production of very many plant species. This is not so much a consequence of the sodium as it is a consequence of the externalities, i.e., the things that come about when the soil is saturates with sodic water and it disperses (deflocculates). This includes a shut down of the water and gas exchange processes. The soil is likely to go from and aerobic situation to an anaerobic (oxygen devoid) system. High SAR/sodic water should not be applied to fine textured, slow infiltration, poorly drained soils. This would include silts, clays, silt loams, silty clay loams, clay loams, sandy clays. These soils are dependent on good structure for infiltration. If sodic water is applied to these soils, the probability of soil dispersion

(deflocculation) is high. Once the soil disperses, infiltration and drainage decrease. The long-term consequence is an anaerobic, waterlogged, saline/sodic soil. These soils can be reclaimed, but the requirement is engineered drainage and the application of excessive amounts of gypsum, sulfur, and good quality water - and the discharge of the sodium laden drainage water.

Because of its lack of structure and vegetation, dispersed soil is very susceptible to erosion. Depending on the location of the CBM water discharge and the drainage course, a normal rain or storm event could easily provide the flow rate and runoff necessary for erosion on a large scale of the already dispersed, saturated, sodic soils. The soil's dispersion takes place through out the profile. So, the erosion will continue to a point where the profile has not been exposed to the sodic water or it reaches a basement pavement structure that cannot be dispersed or eroded, like coarse gravels or bedrock. In any single drainage, the above scenario could take place repeatedly with down cutting and erosion that would continue until the soil profile is completely eroded away and what is left behind is a "V" shaped cut with bedrock in the bottom. Water will also infiltrate within the ephemeral channels and streambanks, which will contribute to increased erosion in the drainages over time. Another long-term effect includes saline seeps that may appear on lower terraces, river banks, and below impoundments where high SAR water flows or is stored. This may result in varying degrees of adverse effects on vegetation, consumers of that vegetation, the soil, and water quality of any streams receiving salts from such seeps. The native species composition in these effected areas will also change. CBM water discharge will have the cumulative effect of encouraging the establishment and proliferation of non-native and noxious weed species like Salt Cedar that thrive and dominate under high sodic/salt conditions.

Development of a sodium hazard usually takes time. Soil tests for SAR or percent exchangeable sodium can detect changes before permanent damage occurs. Proper management can maintain SAR and salinity values at a steady state below threshold levels.

Best Management Practices and Mitigation

Impacts to resources can be reduced through the use of mitigation technologies. Mitigation may include project-scale permitting, active mitigation during construction, protection of water rights, produced water management, and monitoring techniques.

Mitigation

The impacts to resources that result from surface disturbances can be mitigated by active restoration once construction activities end. There are also laws and regulations designed to protect some resources such as cultural and paleontological resources, Indian Trust Management, wildlife, and lands and realty. Other impacts can be mitigated through technology such as air quality and noise.

CBM production in the Montana PRB will certainly impact a variety of resources including groundwater, surface water, soils, and agriculture. Impacts to groundwater resources may, however, be mitigated through the use of water well agreements, limits placed on discharge and monitoring programs. Furthermore, a predictive model may be helpful as an approximation of future impacts. Groundwater rights will be protected through the use of spring/water well mitigation agreements and an approved monitoring plan to aid in the identification of potentially significant drawdown impacts. Surface water resources can be protected by limiting discharge through alternative management techniques.

Project planning will include protection of adjacent water rights and CBM rights through mitigation agreements and monitoring. Administration of CBM projects is the jurisdiction of the MBOGC with guidance from the MDNRC and the CBM Technical Advisory

Committee. A monitoring plan will be required that may involve dedicated monitoring wells or systematic gauging of private water wells.

Water Mitigation Agreements

Water rights and mitigation agreements can be used to protect groundwater wells and springs. Both the MDNRC and the MBOGC advocate the use of agreements in areas surrounding CBM development as a way of protecting surrounding ranchers and farmers from damage from the inevitable drawdown. Water well mitigation agreements will be the cornerstones of CBM development in Montana. The contract simplifies relief for the aggrieved party (usually the landowner) to file claims without need for counsel. The contract further allows the operator to proceed with aquifer pump-down that is necessary for CBM development. If and when groundwater supplies are impacted, the operator will be required to deliver the same quality of water as that being impacted. The operator can then choose the water replacement option that bests suits his operating plan. Currently, CBM operators are required to offer mitigation agreements to residents within at least one-half mile of the edge of development. If any of these wells or springs are impacted, agreements will be offered to land owners one-half mile beyond.

Water Rights

Water rights in Montana are guided by the prior appropriation doctrine, that is, first in time is first in right. A person's right to use a specific quantity of water depends on when the use of water began. The first person to use water from a source established the first right; the second person could establish a right to the water that was left, and so on. During dry years, the person with the first right has the first chance to use the available water to fulfill their right. The holder of the second right has the next chance. Water users are limited to the amount of water that can be beneficially used. Water rights in Montana are managed by three entities: the Department of Natural Resources and Conservation (DNRC), the Montana Water Court, and the district courts. DNRC administers the portions of the Montana Water Use Act that relates to water uses after June 30, 1973. DNRC trains water commissioners and teaches water-measuring techniques. They also provides technical information and assistance to the Water Court, which is responsible for adjudicating water rights that existed before July 1, 1973. The Water Court decides any legal issues certified to it by DNRC that may arise in connection with permit or change applications, or in disputes filed in the district courts. The district courts can issue injunctive relief while it certifies water right issues to the Water Court for decision. DNRC maintains a central records system for all permits, changes, and certificates issued after June 30, 1973, and for all existing water rights filed as part of the statewide adjudication.

Specific to CBM development in the PRB, the Montana Department of Natural Resources issued a Final Order: “In the Matter of the Designation of the Powder River Basin Controlled Groundwater Area”. The order establishes that a CBM well does not require a MDNR Permit to appropriate water but the order sets out requirements for CBM wells and developments.

Produced Water Management

CBM water production will vary considerably in volume and quality and must be effectively managed during development. As has been seen in the CX Ranch field, water production rates can be expected to fall during the life of a new CBM field but the applicability of this data to other producing areas of the PRB is unknown. Produced water regulations must allow management alternatives so that costs will be kept low to promote wide CBM development. On the other hand, water management options must protect the

full range of environmental resources. The choice of alternatives can depend on economics, regulatory burden, produced water quality, and local geographic conditions. The following are typical produced water management alternatives that are used in other CBM basins and in conventional oil and gas production:

Discharge to impoundments. As is done in parts of the PRB in Wyoming, produced water can be discharged directly to ponds and tanks. In Montana these ponds require MBOGC permits and if the water is in excess of 15,000 mg/l TDS the pond or impoundment must be lined with an impermeable liner (ARM 36.22.1227). Such discharges will require a general produced water discharge MPDES permit from the MDEQ (ARM 17.30.1341).

Discharge to surface water. Produced water can be discharged to waters of the state with an appropriate permit from the MDEQ. New discharges are subject to Non-degradation Rules (ARM 17.30.700). These rules prohibit increases in the discharge of toxic and deleterious materials to state waters, unless it is affirmatively demonstrated to the MDEQ that a change is justifiable as a result of necessary economic or social development and will not preclude present and anticipated use of these waters. Discharge rates will be calculated on the basis of the quality of the produced water and quantity and quality of the receiving water.

Disposal to shallow aquifers. It is possible to dispose of produced CBM water into shallow, drinking water aquifers. For example, produced water could be pipelined to a nearby area where coal aquifers do not produce methane and are not connected to productive coal seams. The produced water could be injected with the required permit from the US EPA Region 8. Injection wells would be described as Class V aquifer recharge wells permitted under 40 CFR 146 Subpart F. If the injectate (CBM water) exceeds primary drinking water standards, the permit may require an aquifer exemption petition to the EPA. Shallow injection has the advantage of preserving the CBM water resource at the same time that surface waters and surface soil is protected.

Disposal into deep zones. Operators can inject CBM produced water into deeper reservoirs that are not classified as USDWs. Montana contains many of these reservoirs scattered across the state. The reservoirs' ability to accept large volumes of injected water and their depths are highly variable. Deep injection requires a permit from the MOBGC and could require a permit from the US EPA if Indian Tribal Land is involved. Deep injection can be limited by economics if suitable injection zones are too deep or cannot accept sufficient fluid relative to the volume of water produced by CBM development. Deep injection has the advantage of protecting surface water resources but the CBM water resource is lost. In addition, injection wells are dedicated facilities that can be extremely expensive to drill and operate.

Industrial beneficial uses. Oil and gas and CBM development will require large quantities of water during drilling, completion, and testing. Coal mining can require large volumes of water for dust control, slurry mining, and slurry pipelining. Other industries such as manufacturing and meat processing may have uses that are compatible with CBM produced water.

Agricultural beneficial uses. Montana ranchers and farmers require large volumes of water to irrigate crops and water livestock. Irrigation uses have a narrow range of acceptable water quality depending upon soil type and crop selection but some reported coal aquifers contain suitable water. Soils and crops have a particular sensitivity to sodium and its concentration relative to calcium and magnesium in the water. Livestock

have a somewhat wider range of quality acceptance depending upon the types of animal being raised. Livestock also has sensitivity to other contaminants in the water. Within the planning period, agricultural uses of the produced water from CBM operations may become more prevalent across the state.

Pre-Disposal treatment. Produced water can be treated prior to being discharged or disposed. Treatment such as reverse osmosis (RO) can be targeted at a single ion such as sodium, rendering the processed water more compatible for a beneficial use. Skid-mounted RO units can be installed near "pod" manifolds or at single high-delivery wells. RO units can be powered by natural gas or electricity including wind turbines. Economics will vary on a site by site basis.

Conclusions

Development of CBM in the Montana portion of PRB has many complexities that must be analyzed in order to determine how to best manage this resource. The environmental impacts from full development of this resource could potentially pose great risk to the existing environment. These impacts can be limited and controlled through the use of mitigation measures and best management practices. Impacts resulting from activities that cause surface disturbances can be mitigated by active restoration once construction activities end. There are also laws and regulations designed to protect some resources that must be followed. The greatest impact from CBM development results from the production of groundwater that accompanies methane gas production. This produced water will be produced in large quantities to allow for the production of methane and will likely vary in quality depending on the source. The impacts from CBM produced water can be mitigated through conservation, proper disposal methods, and beneficial use. The proper management of produced water will prevent some impacts to other resources such as soil, agriculture and groundwater, and may provide beneficial uses such as dust suppression, irrigation and livestock watering.

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LAND TRUSTS: ADDING VALUE TO LOCALLY-LED SOURCE WATER PROTECTION

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ABSTRACT

Protection of public drinking water sources should incorporate the participation of local land trusts and the use of conservation easements to permanently protect contributing areas to reservoirs and municipal well fields. A land trust can add substantial value to source water protection through a strategic and cost-effective collaboration with a municipal water authority by engaging the cooperation of landowners, negotiating provisions of easements to prohibit and restrict undesired land uses and by monitoring and enforcing those conservation easements in perpetuity. Sample easement provisions will be provided along with an overview of potential activities regarding the role of land trusts in source water protection.

Does the Current Knowledge of ASR

Answer All the Necessary Questions?

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Abstract

Aquifer Storage and Recovery (ASR) is a concept that will play a role in the solution to the water supply concerns throughout the world, not only for urban users, but also for agricultural and environmental users. ASR may be a viable method of increasing water treatment plant efficiency and promoting energy conservation because ASR projects permit conservation of water during critical times, while utilizing excess resources in plentiful periods. However, the process has been used to a limited extent to date, with only partial success. The major remaining question is how well ASR will work during drought conditions where the water may be withdrawn up to 2 years after it was injected, what changes must be addressed in design to correct for the bubble changes, and what are the full geologic conditions that must be met to insure the program will be successful. Finally, what is the definition of "success?"

It is generally understood that each ASR well should be designed, constructed, and tested with the unique goals of the project in mind (e.g. injection rate, storage volume, storage period, recovery rate, water quality of recharge, water quality of native, and water quality of intended recovered use). The proper peer review, and multi-jurisdictional input, in an effort to maximize the information gained, will serve to help clarify the magnitude of ASR's future in a regional water supply picture. This is typically lacking on most projects. The reliance on large scale, regional ASR projects are of concern to many utility systems because there are no successful, large-scale demonstration ASR projects, and many of those projects purported to be successful have many questions.

Since geology and water quality play such a significant role in the success of ASR projects, before moving toward the assumption that ASR should be as significant a component for an area's water supply needs, consideration must be given to how ASR is perceived to be successful and where the data gaps in our understanding really are, since modeling of ASR systems has occurred only in a rudimentary manner.

Introduction

Aquifer storage and recovery (ASR) has often been touted as the panacea to solve all water supply issues. But is it really? How much do we really know, versus what we think will happen? Or are all of our efforts and resources being spent on a technology that has yet to be fully proven? This paper is intended to address philosophical and theoretical issues that should be investigated in an effort to measure "success" and to better define the conditions that must exist for "success" to be declared, given the anticipated dependence by water managers in drought-prone areas of the world.

The Concept

ASR is a relatively new concept in the management of water supplies in both potable and nonpotable water systems. There are nearly 30 utilities in the United States that have either utilized or investigated the concept of aquifer storage and recovery (ASR), each with the goal of storing water for later use. Most are potable water systems, employing ASR technology can increase the efficiency of system operation. During a wet or low-demand portion of the year, some or all of the unused water treatment plant capacity can be used to treat water and inject the treated water into an aquifer lying below the ground surface for future recovery and use. When the full treatment plant capacity is required by system demands, injection is discontinued. As demand increases beyond plant treatment capacity, freshwater is withdrawn from the aquifer (recovery), disinfected, and blended with newly-treated water. In theory, the excess water can be left in storage as an emergency supply to be used during a severe drought or during an equipment breakdown. The water to be stored is pumped under pressure into the aquifer of choice.

Figure 1 shows the concept behind ASR graphically. The injected water displaces the native groundwater occurring in the aquifer. In this situation, the idea is to completely displace all of the native water since in most cases the native water is brackish and therefore less buoyant. Where a brackish aquifer is used, the density difference between the treated freshwater and saline sources causes a "bubble" of freshwater to form. A large mixing area, or transition zone will also result outside of the bubble. In the transition zone, the water is permanently lost. Long-term storage is an issue as the buoyancy differences of the fresh and native waters will cause the bubble to float to the top of the formation, reducing ASR well efficiency. This is especially problematic when the injection zone is thick.

Most of these projects have similar protocols for development - injection of significant quantities of water followed by withdrawal of that water almost immediately, until a given water quality parameter (typically chlorides) is exceeded. Long-term storage has not been a component of development of ASR projects. Collier County, Florida is among those who have tested the concept. They injected potable water (with chloride levels of 50 mg/L) into the brackish Hawthorn Aquifer zone (with chlorides of over 2000 mg/L) and withdrawing water until the 200 mg/L chloride level is reached. The aquifer is confined on the top and bottom, averages about 50 feet thick, and has a transmissivity value averaging 80,000 gpd/ft. Water was stored for up to 6 months. Six (6) cycles were completed indicating that the concept is viable at the site and that the retrieved water will only require disinfection prior to mixing with potable water in the on-site tank and pumping into the distribution system. Initial cycles showed low freshwater recovery amounts due to the small amount of water injected. Later cycles showed higher percentage return as the total quantity injected water increased, with an anticipated efficiency of 85 percent.

As a result of the protocol employed in this process, the length of time water was stored, field monitoring and some preliminary modeling, the following issues arose:

- Buoyancy seems to begin within a few months of injection and within 6 months, buoyancy forces cause much of the water to move toward the top of the formation, even in this thin formation with ideal transmissivity;
- The geometry of the fresh water bubble (a cylinder or half sphere inside a larger cylinder or half sphere) demonstrates that 100% recovery of the injected "stored" water at any point in time is not possible because as the fresh water bubble expands, the transition zone volume will also expand (see Figure 2);
- Reduced withdrawal percentages may result from buoyancy causing saltwater to move back into the lower part of the formation (see Figure 3);
- Over 300 million gallons of water are estimated to be necessary to create and maintain the saltwater-to-potable water transition zone in the formation sufficient to recover water suitable to supply the system in a given well (see Figure 4). High recovery from the brackish injection zone does not appear to occur until 300 to 500 million gallons of potable water have been injected.

These findings indicate that the traditional ASR graph (see Figure 5), which is found throughout the literature, should be revisited. This graph purports to compare the amount of water injected and withdrawn over time and shows a general increase in the amount of water being stored. What is not readily discernable with this type of graphical information is the actual quantity of water in storage and available for withdrawal, compared to quantity of water stored that is not recoverable without exceeding the water quality parameter guidelines. The result does not correctly depict the factual situation as it creates the impression of having significantly more water for withdrawal in an ASR system than is truly available. This depiction is one of the problems in assessing "successful" ASR systems, as they have been perceived to date; the line between recoverable and unrecoverable water has not been defined. The graph should be revised to indicate the increasing trend of storage as well as an increasing trend of non-recoverable water because the recoverable quantity of water in storage is only a fraction of the total water stored. The curved line shown on Figure 6 represents the volume of water that is not recoverable without exceeding the water quality parameter.

However, defining the line requires field verification (pumping tests) and modeling. Modeling using the traditional groundwater modeling efforts (MODFLOW), has not been successful since it does not appropriately depict the dynamics of the injection into native waters due to density differentials between the injected, freshwater and native, brackish waters.

Other Theoretical Issues

The literature identifies a number of issues associated with modeling using vortex theory conducted in the Netherlands, which coincide with the Collier findings, that need to be addressed in order to yield a successful project: aquifer thickness, aquifer dip and aquifer hydraulic conductivity. The theory indicates that as the thickness of the aquifer becomes greater, the buoyancy effects of the injected water in respect to the native water will create a bubble faster, thereby limiting the percent of recovery. As a result, the percent of recovery declines as thickness of the aquifer increases (Figure 7).

It has been theorized that if one is able to remove all of the water injected into the injection horizon, the bubble phenomenon will be mitigated, and the recovery system would then be unencumbered by the differential density problem. The work in the Netherlands indicates that the limit of the aquifer system thickness to achieve this result is less than 50 feet, depending on the quantity injected and the hydraulic conductivity of the aquifer system. In injection horizons over

100 feet in thickness, it is difficult to displace the native water in a cylindrical function without injection of billions of gallons of water that is not recoverable in the future; the size and geometry of the transition zone size simply makes it so.

The conductivity of the aquifer system is important. This is the ability of the water to move within the aquifer formation. Vortex theory and modeling indicates the hydraulic conductivity needs to be within a certain range to facilitate injection and recovery, and that as the hydraulic conductivity of the aquifer system increases, recovery begins to decrease due to the ease with which the native water returns over time, thereby displacing the injectate and accelerating the bubble collapse. The models indicate that transmissivity (hydraulic conductivity aquifer thickness) between 50,000 and 200,000 gpd/ft are appropriate for the use of aquifer storage and recovery systems in which significant recovery is desired (see Figure 8). The amount of water that can be recovered with time, will be lost as a result of higher conductivity of the formation as a result of either lateral movement of the injectate or the bubble effect since as hydraulic conductivity increases, the buoyancy forces can create faster movement if the aquifer incline is favorable for such movement;

The incline of the aquifer system is of importance in recovery, especially if the conductivity of the aquifer system is high, or the thickness of the aquifer is great. Either of these will accelerate the problem of movement of the bubble along the top of the formation out of the range of the aquifer storage and recovery well, thereby quickly reducing the recovery from the same well. The only time when the angle of dip/slope/incline is of significant help is if a second, downstream well is utilized for recovery and then, one must assume that the appropriate modeling is developed and calibrated that will measure the amount of time that must exist between injection and recovery.

This leads to perhaps the most difficult terms to define in the use of an aquifer storage and recovery system: what exactly is "recovery?" The transition zone that will occur between the native and injected water is not recoverable. As a result, an aquifer storage and recovery system will **never** recover 100 percent of the water (unless it is freshwater pumped into a freshwater system, which makes it difficult to tell exactly what percentage is recovered). With injection of freshwater into a brackish water system, there is a certain point in time at which recovery may stabilize. As noted earlier, traditional evaluation of the systems' "recovered" water potential has been based on the last water in, versus the water returned; that is recovery at a certain point in time; therefore, recovery could conceivably be 100%. In practice, the recovery cycle occurs almost immediately after the injection is completed, so the all-important time variable between injection and withdrawal recovery is indeterminate.

A more appropriate protocol to evaluate the volume of water injected that is either un-recoverable or recoverable, would be as shown in Figure 9. This graph depicts a series of injection cycles, followed by a storage period and a withdrawal cycle similar to what was done in the Collier County example. At a given point in time, the chloride parameter will be exceeded and the recovery cycle will be terminated. This could be done for successive periods. Each storage injection period should be a minimum of three (3) months, and preferably, six months or longer. As the steps are completed, a line could be drawn to indicate the curve that would be shown as non-recoverable water with each injection cycle. The graph depicts that in cycle No. 4, approximately 70% of the water that is injected within that cycle is recoverable.

Other Issues

Other factors affecting recovery of the water include: the quantity of injection fluid; porosity; diffusive characteristics of the aquifer formation; flow velocity and differential density. In looking at large injection projects, it is hard to describe what the effects of the quantity of injected water is in comparison the amount of recovery, because of the differences in aquifer formations. However, it is reasonable to assume that:

Injection into higher salinity aquifer systems will increase vertical movement potential as a result of increased buoyancy forces;
As porosity increases, pressure build-up slows;
The quantity injected over a given period of time could have a significant impact on the pressure buildup in the aquifer system. In a highly hydraulically-conductive aquifer system, this pressure rise may be minimal, but in a tighter formation, this pressure increase may be significant and grows exponentially. The problem is what happens to the formation, when the pressure increases as the volume of water is increased, and then is suddenly withdrawn? Highly favorable injection formations may suffer significant hydraulic fracturing, and as a result could lead to collapse of the formation over the long-term.

The final issue that has not been studied extensively is the reaction of the aquifer system to the growth of microbiological organisms or other chemical reactions. Figure 10 shows anticipated or theorized bacterial response of chlorinated versus non-chlorinated water. The actual curves for a given well would be dependent on the amount of total organic carbon (TOC) injected in the water. Chlorinated water would reduce background bacteriological growth in the aquifer system, but could create far field increases as a result of increased TOC in the aquifer system. Non-chlorinated effluent would increase the biological activity almost immediately, which could lead to long-term clogging near the well. The absorption coefficient, bacterial growth coefficient, and chlorine residual would be important factors to evaluate.

Projections should be made for chemical reactions, where the chemical characteristics and ion forms with the aquifer system versus the injected water, could have significant effects on precipitation or in a suspension of sand and silt.

Revisiting The Goals Of ASR

If the goal of an aquifer storage and recovery system is to store water for future use, the ability to store water for a given length of time must be measured. Time becomes **the** critical variable. Time has generally been ignored in past testing programs. One agency that has attempted to define the "success" of an ASR program is the South Florida Water Management District ("SFWMD"). The SFWMD believes that recovery of 40% of the water injected into an aquifer storage and recovery well, after the period of time when the well is up and running and the transition zone has generally been formed, will be the break-even point for ASR projects. To meet the goals of the United States Army Corps of Engineers' Comprehensive Everglades Restoration Project, co-written by the South Florida Water Management District, ASR is a necessary tool to recoup water during drought periods, which tend to occur in two-year cycles. Using this logic, a successful

ASR system should be able to retrieve 40 percent of the injected water for up to two years after its initial injection cycle. To this end, Figure 11 has been developed. For purposes of discussion, this figure assumes the 40% recovery applies to a point two years from the point of injection; however, after almost immediate injection, a much higher percentage of this water should be recovered.

The other idea that has arisen to improve ASR performance on the large scale is the cluster concept (Figure 12). The idea here is that injection begins in the center well, and continues until it reaches the next ring of wells. In turn hose wells and the center well are pumped until the next set, and so on. This causes the bubble to be homogenous and ever-expanding, thereby minimizing the transition zone. Withdrawal occurs from the center wells only. Long term maintenance of the bubble should be accomplished via this process.

Summary

There are nearly 30 sites nationwide that have either utilized or investigated the concept of aquifer storage and recovery. Each results found from each project has identified a series of issues specific to that project, but a series of general questions remain in order to define the long-term usefulness of ASR as a water management tool. This paper was intended to raise philosophical and theoretical issues that should be investigated in an effort to measure "success" and to better define the conditions that must exist for success to occur.

Parameters that are important in identifying this recovery percentage potential are:

Time;
Water quality;
Size of the transition zone;
Hydraulic conductivity;
Dispersion within the aquifer;
Buoyancy forces created by the density differentials;
Quantity of water injected;
Porosity;
Absorption and desorption; and
Change in the density of water that is stored or injected after the bubble has been formed.

Future ASR projects should focus on answering these questions and verifying the theoretical expectations of the current models, or providing data sufficient to modify same. A revised testing protocol should be employed in future projects to evaluate these factors, with the understanding that determining whether or not an ASR project can be successful may take 3 to 5 years of field testing (given the need for storage periods to measure what the bubble does over time), which is often difficult for public entities.

Because of the long-term water supply ramifications of the investigation, it is worth spending the time to model and calibrate the system with SEAWAT or similar density – driven program, to determine:

- The size and expansion of the transition zone depending on volume injected;
- The recoverable percentages after extended periods of time;
- The bubble characteristics, including its collapse characteristics during storage and withdrawal;
- Impact of large volumes of injectate on the aquifer system, and the associated impact of large injection horizons on the success of the program;
- Optimizing parameters; and
- Water quality estimates.

Careful collection of data and answering long-term storage questions will provide useful knowledge for the construction and/or modification of current ASR models, and for quantifying long-term injection needs for regional as well as individual utility ASR projects.

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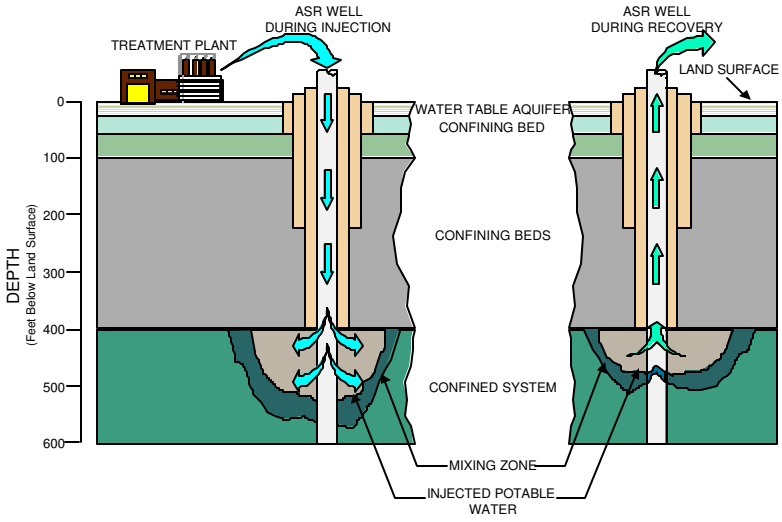


Figure 1 Aquifer Storage and Recovery Conceptual Diagram for Brackish Water Aquifers

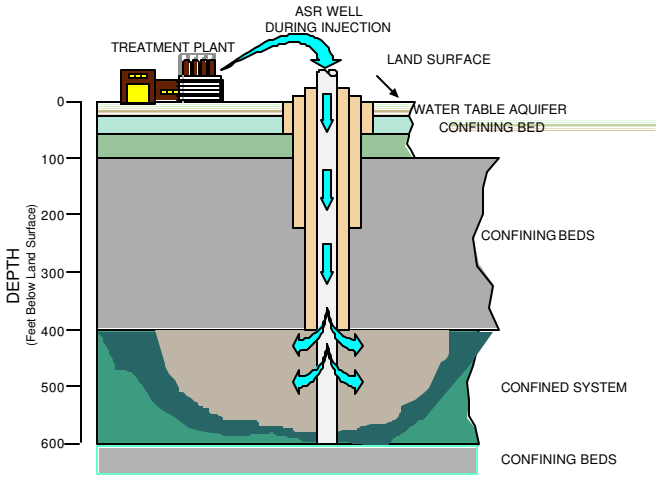


Figure 2 ASR as Water is Pumped into the Injection Zone

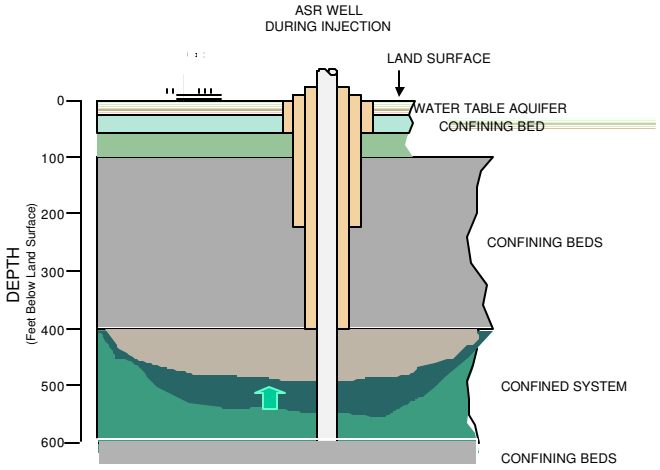


Figure 3 ASR as Buoyancy Effects Occur in the Injection Zone

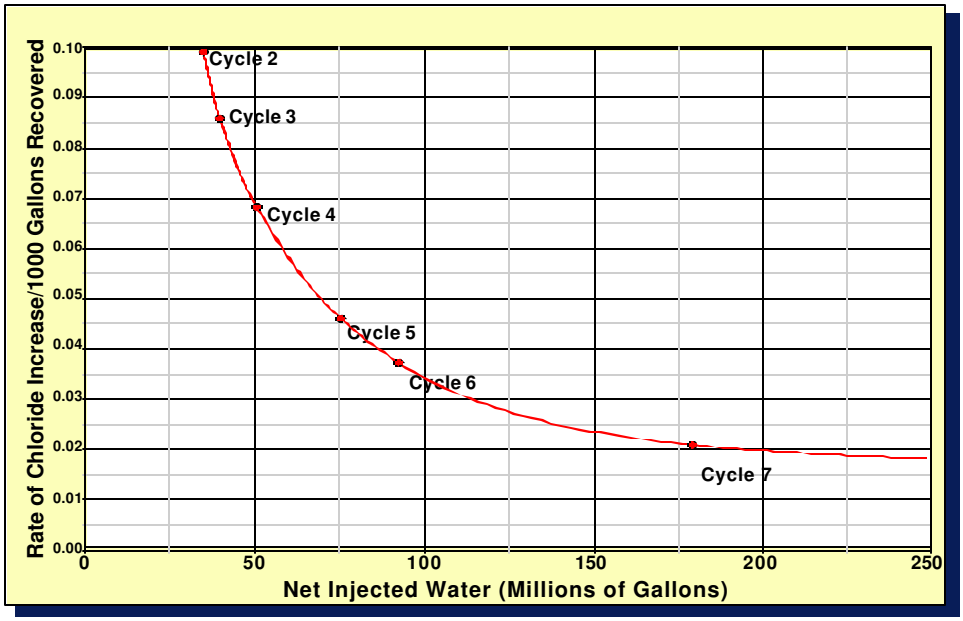


Figure 4 Collier County ASR Project Graph showing recovery efficiency improvement for each succeeding cycle

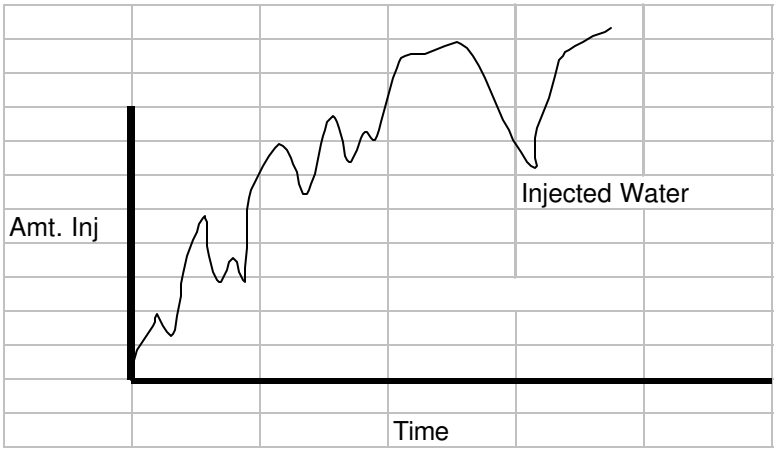


Figure 5 Total Injected Water

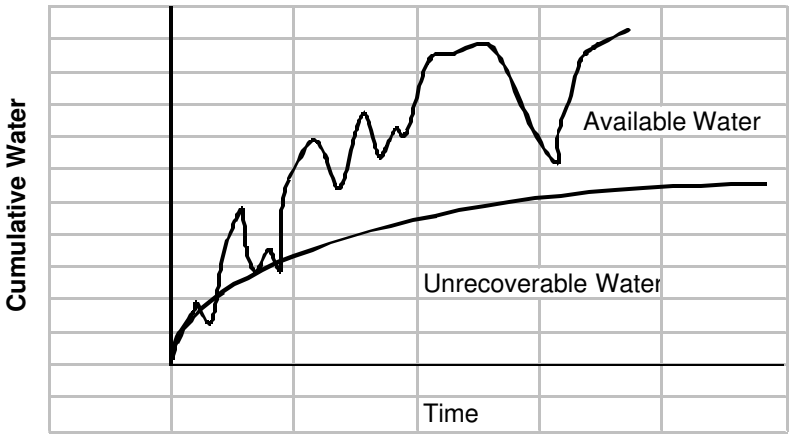


Figure 6 Comparison of Available Water and Injected Water

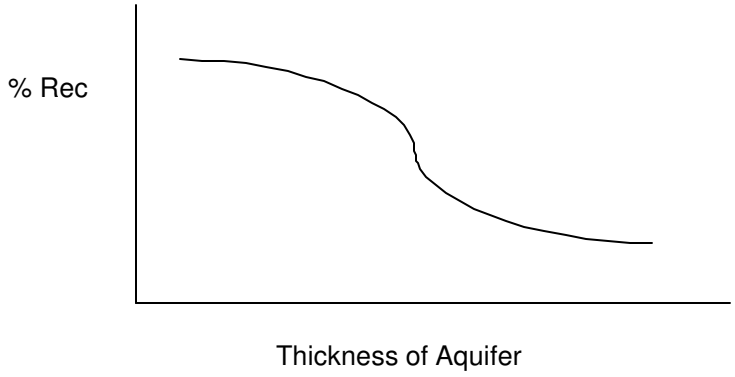


Figure 7 Recovery Versus Aquifer Thickness

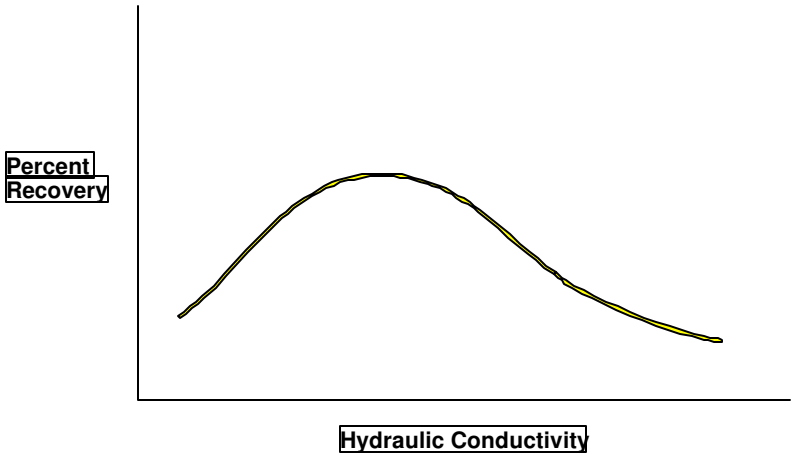


Figure 8 Anticipated Recovery vs. Hydraulic Conductivity

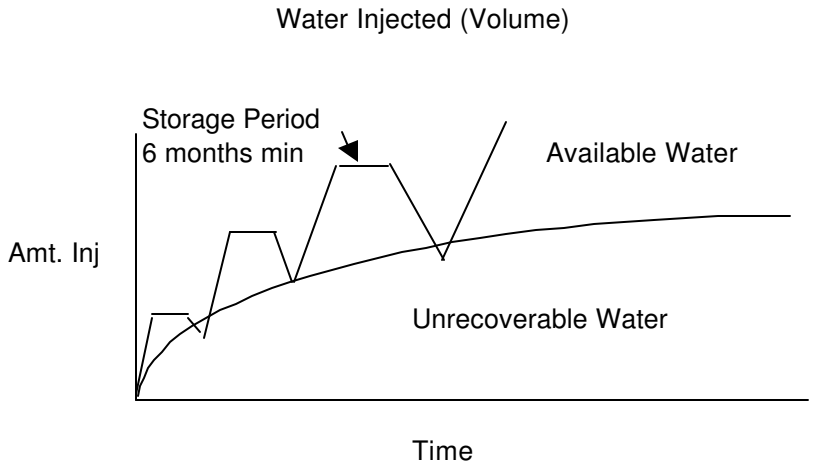


Figure 9 Improved ASR Test Protocol

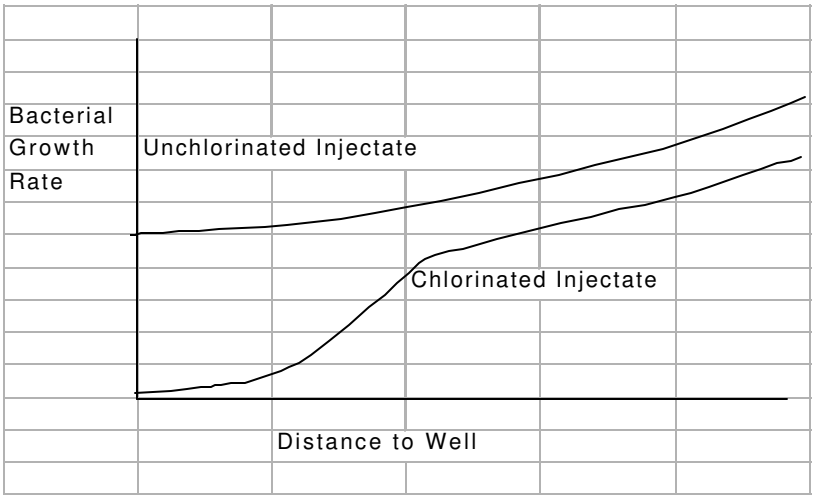


Figure 10 Comparison of Conceptual Effects of Chlorinated and Unchlorinated Injectate on Bacterial Growth Rates in Injection Horizon

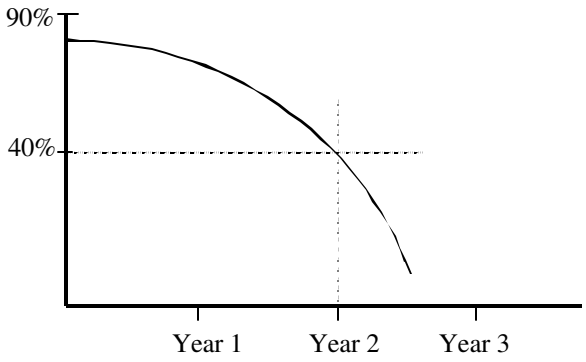


Figure 11 Proposed Definition of “Success”

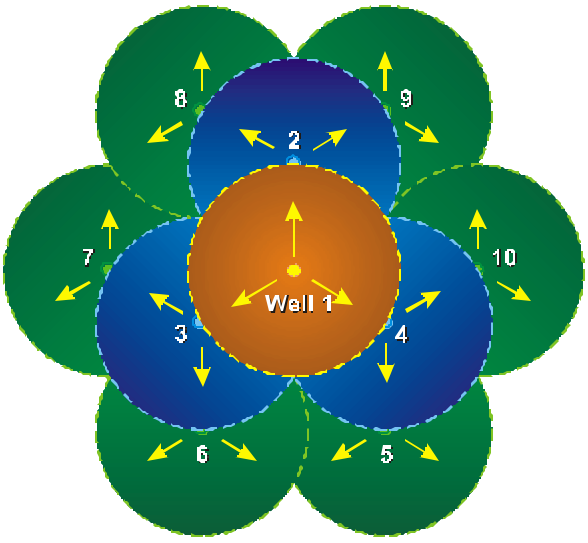


Figure 12 – The Cluster Effect

Microbial Risk Assessment In Aquifer Recharge Applications

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Bios: Dr. Bloetscher is currently the President of Public Utility Management and Planning Services, Inc., which he started in 2000. The firm provides services to help plan, manage and set-up water and sewer service to the public, including permitting and groundwater resource and risk projects. Prior to starting his own firm, he was Director of Engineering, Operations and Planning for the Florida Governmental Utility Authority for two years, Deputy Public Utilities Director for the City of Hollywood, Florida for four and a half years, and Assistant Utilities Administrator for the Collier County Water-Sewer District for five and one-half years.

Abstract: Proposals to use waters of impaired quality for artificial recharge projects have met with limited success and/or significant resistance. Resistance is caused by the concern, expressed by the public and the regulatory community, about the risk of effects to the public should these impaired waters be recovered in water supply wells at a later point in time. The reasonable assurance criteria is designed to define the risks to the public health and environment of proposed programs. Specific risks involve microbiological constituents, heavy metals, and organics, solvents and synthetic compounds

Heavy metals are not perceived by the regulators as being able to move very far in the aquifer system, while the movement of organics varies considerably depending on the weight of the substance and the activity that naturally occurring ground water microorganisms in the aquifer will exert towards organic decay. The small quantities of organics (such as would be injected) generally serve as a food source in the aquifer for the naturally occurring bacteria, and thus would decrease with time and distance.

Therefore the regulatory community perceives the biggest risk to be the possibility of contamination of potable aquifer systems with potentially pathogenic organisms found in treated wastewater. In part this concern is because ground water has traditionally been considered safe for consumption without treatment. Separating the wastewater treatment-oriented organisms and those naturally occurring would be impossible since most are not unique to either environment. Viruses are a different matter. Viruses that have been found in USEPA studies as well as in disease outbreaks from human excretions and wastewater. No dose-response curves are available for viruses (or other pathogens either), so conducting a risk assessment for pathogens assumes that some form of dose-response function, and an indicator organism to model, can be selected. For this investigation predictive Bayesian methods were used to create a dose-response model that yielded useful information on the response of organisms to micro-organisms, while at the same time remaining conservative. Rotavirus was determined to be a useful indicator organism to use in modeling sub-surface conditions due to its persistence, low threshold dose and significant numbers in wastewater sources.

Application of the dose-response function was applied to a salinity barrier project proposed for a drinking water aquifer. For the purposes of the investigation, risk was defined as the probability of the withdrawal of a given number of rotaviruses over a one year period. Most injection sites operate constantly, which can be shown to be a conservative assumption: the wells will not physically be able to operate at all times due to injectate availability and mechanical problems, and the quantity of water may vary. However the assumption makes modeling the wellfield easier as the wells are usually designed for a steady flow, not a peaking flow.

Introduction

Growth and development has been rapid in warm environments, which are often those most prone to drought conditions. Where water supply demands generally exceed availability, at least for certain portions of the year, groundwater injection projects can provide a mechanism that negates the need for inter-basin water transfers and construction of large pipelines to transfer water from one location to another, or impoundment areas where much of the water may evaporate.

Because of limited water supplies, there is move toward using waters of impaired (or less than pristine) quality. The use of reclaimed wastewater has become an attractive and economically viable choice in some areas. This approach may contribute toward the beneficial reuse of wastewater, while contributing to sustainable development of water supplies. However, proposals to use reclaimed wastewaters have met with significant resistance resulting from concerns expressed by the public and the regulatory community about the risk of health effects to the public should these impaired waters be recovered in water supply wells at a later point in time. The "risks" of such reuse projects generally involve heavy metals, organic products like pesticides and solvents, and microbiological contaminants.

Risk Objectives

In discussing the issue with State regulators in Florida, it is their opinion that the regulatory community perceives the biggest risk to be the possibility of contamination of potable aquifer systems with potentially pathogenic organisms found in domestic wastewater effluent. In part, this concern is because groundwater has traditionally been considered safe for consumption without treatment, a belief that may not be justified given current knowledge of groundwater quality.

A risk assessment of the hazards posed by these organisms is a valuable tool for evaluating the potential for impact to the public from waters that contain, or may contain such organisms. The risk assessment can then be used by decision-makers in the development of standards of practice and protocols for injection well usage, as well as the public benefit of using potentially contaminated waters for public purposes. However, risk assessment has only been used to a limited extent for judging risks of waterborne pathogens, despite their presence. *Shigella* and *Salmonella* are the two bacteria of greatest health concern among health professionals. However, the significant number of waterborne *rotavirus* health impacts, as well as the prevalence of the organisms, cause it to be of concern, and as a result of its prevalence and low infectious dose, it can be used as a surrogate to model the risks.

For the purposes of this investigation, risk was defined as the probability of occurrence of an event – in this case the withdrawal of a contaminant introduced into the aquifer by an injection project. However, defining a number for risk leads only to more questions by the public as to what risk is acceptable and what is not. The US Environmental Protection Agency has defined acceptable risk for drinking water purposes as 10^{-4} per year. The intent of this investigation was to develop a mechanism whereby the distances required to reach the desired risk factor for these projects can be defined. It was assumed that any distance in excess of that required to obtain the defined risk level does not pose a concern that would prevent its installation and operation.

Evaluation Of Existing Data

The first necessary step in any investigation of data is to assess the nature and degree of uncertainty associated with it. Unorganized or scattered data is not easily assimilated.

However, there are a number of methods to address this problem. The cumulative density function (CDF) is a useful representation of data as it sums successive partial frequencies on an interval basis up to the maximum recorded value. When evaluating intervals, care should be exercised to avoid the arbitrariness of interval widths that may distort the true underlying distribution function. The cumulative frequency is 1.0, assuming at some point 100 percent response was noted. A CDF is how dose response data is provided in the literature, although the goal of 100 percent response is not always met.

The range of the data set provides information on the minimum and maximum values of the data. The range also helps eliminate certain types of distribution types. For instance, for a range of values that are only greater than 0, Normal distributions generally do not qualify. The underlying distribution characterized as *f(x)*. Without knowing the underlying distribution, but knowing the mean and/or variance and some idea about skewness, as well as the range of *X*, can point the investigator can identify an appropriate underlying distribution.

The coefficient of skewness is the third moment about the mean and provides further indication on the type of distribution that should be considered. There are a number of highly skewed distribution functions. Table 1 outlines the probability models which form the possible descriptions of a given set of observations, given information known about the observations, such as the mean, variance and skewness. The limits of known information is defined as the information content within the context of information theory.

Information theory is branch of mathematical theory within probability and statistics, and can be applied to a variety fields. The roots of information theory is found within the concepts of disorder or entropy in thermodynamics and statistical mechanics. Since the turn of the century, significant literature has been devoted to the studying the mathematical form of information entropy. The literature assumes a samples space *S*, with a series of events *i*, characterized by individual probabilities p_i. Shannon (1949) developed a measure to indicate the information content of a probability distribution in the form of the negative of the information content of the data set:

$$H = -\sum_i p_i \ln p_i$$

Because the field of statistics is concerned with uncertainty, definitive observations do not play an important part in entropy theory since once the definitive observation is made, the underlying uncertainty is greatly reduced or eliminated.

By maximizing information entropy, one can solve for the most conservative, or broadest distribution consistent with the available information (such as the mean, variance and range). In general then, the mean or expected value of any function *F(X)* is known, the entropy can be maximized subject to:

$$\sum_i p_i = 1$$

And

$$\sum_i F(X) p_i = E(F(X)) \; for\ all\ functions\ of\ F$$

The most common prior distribution encountered under the assumption of maximum entropy is the exponential distribution, when only the mean is known. The exponential distribution is a special case of the gamma distribution. The gamma distribution can approach the normal distribution and high mean values. With range or variance data, gamma, normal or log normal distributions may be encountered. Thus, the principle of maximizing entropy can be used to find unknown distributions and estimate their parameters.

To develop a risk assessment from a public health perspective, a relationship between the exposure amount and probability of infection must be constructed. This is a dose-response curve, which is a CDF. A comparison of organisms indicates that different organisms have widely varying exposure risks. *Shigella* for example may create infection with just one organism, whereas other bacteria, such as the *Salmonella* species, may require a million organisms. This threshold is termed the minimum infectious dose. In studies conducted by Ward et al (1986), the infectious dose for *rotavirus* was found to be less than one cultured cell.

Generally higher dosages yield higher infection rates. The resulting data is simply a summary of the number of infections that occur by dosage administered. However, since the resistance of individuals may be different and only a small number of people is included in the study population, one should use caution in evaluating each study on its own without comparing it to similar species studies.

Given a set of data on infectivity of a particular organism, there are several questions that must be answered:

- What distribution best fits the data
- What are the parameters of that distribution
- What is the goodness of fit
- How are uncertainties or spurious data dealt with
- Threshold (or minimum infectious) doses

Because there is very limited data, and a great degree of uncertainty, the use of Bayesian methods has value. However, since the dose response data summary is a CDF, the underlying probability density function (pdf) must be determined. The particular dose-response fit may be selected from a visual comparison of a series of possible distributions, plotted on a log-log scale. The best fit is then refined to determine the most appropriate parameters for future use.

With a continuous distribution then the probability that a simple event lies within $f(x)$ is:

$$\int_{-\infty}^{\infty} f(x)dx = 1$$

Such a distribution is termed a density function which indicates that all values of X lie within S. The absolute or unconditional probability density function $p(x)$ on X is the underlying distribution found through curve-fitting. The Bayesian approach is:

$$p(x) = \int p(x \mid \theta)\, p(\theta)\, d\theta$$

where $p(x)$ and $p(\theta)$ are completely different, and independent functions and the function $p(\theta)$ is the prior distribution. The Bayesian approach is to assume that while the true value of θ is unknown, there are probabilities that can be assigned for a series of possible values of θ. More precisely, it is assumed that $p(\theta)$ is a density function.

The posterior distribution incorporates observations from x into the sample space S. The outcome of the observations conveys additional information about the true content of S through a series of informed assumptions. The basis for the information obtain is the influence of the proper distribution, and the attachment of same to the possible distributions for x. Updating the plausibility in light of the observations of the prior, using Bayes notation leads to the posterior probability function:

$$p(\theta \mid x) = \frac{p(\theta)\, p(x \mid \theta)}{p(x)}$$

Where $p(x)$ can shown to be equal to 1.

The information so far derived permits a plausible assessment on the outcome of the future observations. The interest is in these outcomes is a result of the prior information so that as new information is gathered, the predictive function can be refined. This is the benefit of the Bayesian approach: given uncertainty about a density function $p(y \mid \theta)$, some data can be deduced from the assessment of $p(\theta \mid x)$ over θ when the experimental results of x are known. This function is:

$$p(y \mid x) = \int_{\theta} p(y \mid \theta)\, p(\theta \mid x)\, d\theta$$

Where the function $p(y \mid x)$ is the predictive density function. The problem is that often a very limited amount of prior information is known. This requires the use of information theory to develop useful prior data so that the predictive function can be developed. The integral of the predictive function is the desired CDF.

For rotavirus, is was found that a Pareto I distribution, which includes a threshold dose that was defined as a power function, would adequately replicate the dose-response function conservatively, when compared to other equations (see Figure 1).

Application To A Groundwater Injection Project

Most of the utilities located in southeast Florida rely on the Biscayne Aquifer System for their raw water supplies since the surficial aquifer is the only freshwater supply in most of the region. Fortunately, it is one of the most a prolific surficial aquifer systems in the world. The quality of the water along the coast is relatively good, although is diminishes inland and at the saltwater interface near the coast (due to higher total organic carbon and higher chlorides, respectively). Recharge occurs primarily via rainfall, with some lateral movement from the Everglades and canal systems from Lake Okeechobee 100 miles north.

The City of Hollywood was one of first communities to be developed in Broward County. Like many southeast Florida communities, it was carved out of a coastal mangrove swamp to take advantage of the surf and warm weather of the subtropics. The result is that topography in the City is very flat, with elevations only slightly higher than sea level. Canal systems are necessary to lower the water table to limit flooding; in some cases there may be as much as four feet of difference from historical levels. These same canals siphon off much of the summer rainfalls, which historically replenished the aquifer system.

The lowering of the water table reduces the surficial aquifer water supply, creating the potential for water supply deficits during the dry season and accompanying high demand period. The lowered water table also encourages saltwater intrusion, which threatens coastal wellfields. In some areas, saltwater intrusion has been measured over a mile inland.

The City operates a 42 MGD regional wastewater treatment plant that serves the City and six neighboring jurisdictions. The City originally entered the reclaimed water business when the City experienced high flows during a particularly rainy period of 1992. The high flows required the City to increase plant capacity. While the plant itself was easily re-rated, the City's ocean outfall was not. Since the existing state and federal regulations did not permit prompt regulatory response to the issue, the City pursued the first slow rate land application reuse system in Broward County, targeting golf course users, where large quantities of reclaimed water could be disposed of easily. These slow rate systems utilize secondary effluent that is filtered and superchlorinated. The reclaimed water cannot have a TSS level higher than 5 mg/L, with zero fecal coliforms 75 percent of the time.

Pursuit of the reclaimed water program initially focused golf courses, large industrial and commercial customers, and open space. Six golf courses targeted for reclaimed water all had consumptive use permits to withdraw water within the cone of influence of the City's wellfield. The City's potable water system benefited from this decision because the ponds acted as large "sinks" that evaporated large amounts of water and lowered aquifer levels in the area. Keeping the ponds filled with reclaimed water, the aquifer levels stabilized in the vicinity of the ponds, and throughout the City's cone of influence. Meeting the irrigation needs of the golf courses with reclaimed water also removed their competition with the City for raw water, which will hopefully stabilize the amount that can safely be withdrawn for human consumption.

However, as the City continues to grow, additional reuse customers are needed. Potential customers include cemeteries, ballfields, an international airport and the local Florida Power and Light power plant for reverse osmosis feed water to their cooling system, but these are limited. Therefore, the City has attempted to address this problem by investigating the use of a hydrodynamic barrier to retard or reverse the saltwater intrusion, using reclaimed water as the injectate.

The City pursued the salinity barrier pilot program with the idea that by injecting excess reclaimed water into the Biscayne Aquifer to mitigate saltwater intrusion problems, vast quantities of fresh water in the Biscayne Aquifer that are currently at risk to saltwater intrusion, would be protected. A successful long-term program may also restore some old wells to viable status. In addition, the disposal of reclaimed water via a salinity barrier is a significantly less expensive alternative than the installation of retail/residential reuse irrigation; requiring far fewer pipelines, less engineering and much less disruption to area residents.

The intent is not to recover any of the water injected, as this would be counter to the salinity barrier stability. Therefore, the City does not intend to provide the significant, and often duplicative treatment provided at Water Factory 21. In Florida, the resources are not yet so scarce that this amount of money spent on treatment is acceptable, especially since many utilities are moving to membranes for potable treatment. This need for lesser treatment is further suggested since the flow of water under the City is southeastward, preliminary modeling indicated that 12 inches of head would be created at the coastal injection wells, and that water would not migrate to the water supply wells, 4 miles to the west.

Given this finding, two series of monitoring wells and two injection wells were constructed. The intent of the first set of monitoring wells was to better define the location of the saltwater front and to obtain core samples. The significant finding was that the profile was very clear and consistent, and that the vertical distance between the 3,000 and 10,000 mg/L TDS lines was less than 10 feet in all cases. As a result, the team decided that injection into the 10,000-mg/L TDS water would accomplish the objectives easily, lessen the regulatory burden on the City, and allow the natural buoyancy of the reclaimed water to exert pressure on the saltwater front.

The second set of monitoring wells were drilled at the same time as the two 12 inch injection wells. Two zones were monitored: 165-200 ft., and about 90 ft. The injection horizon has been established at 135 to 160 ft. below land surface, in 10,000 plus mg/L TDS water. The wells were logged and used to define geologic parameters. Injection tests indicated transmissivities are very high, and that injection of over 1.5 MGD was possible.

Upon completion of the injection testing, groundwater modeling was conducted. The groundwater model yielded contours of the movement of the injectate. Solving contaminant transport equations for this concentration should yielded a three-dimensional ellipsoid of concentrations of the constituent of interest. Once the contours were applied to the predictive CDF for rotavirus, it was determined that there was minimal risk to the City's wellfields form the injection program. Figure 2 is a graph of the risk derived from this method for *rotavirus*. The result is readily transferable to any type of injection well application.

CONCLUSIONS

In many areas of the world, utilities have pursued projects that utilize current water resources to plan for future droughts, to protect water resources, to recharge wellfields and/or to store water for use at a later point in time. The common thread of all of these technologies is the injection of vast amounts of treated or treatable water beneath the surface, rather than discharging it to rivers, reservoirs, oceans or other sources.

Because waters may remain limited, in some areas the use of alternative groundwater injection programs have been proposed or pursued to address these needs using waters of less than pristine (or impaired) quality, and mostly with limited success or significant resistance. The resistance is caused by the risk of effects to the public should these waters be recovered in water supply wells at a later point in time.

This investigation was undertaken to develop a mechanism whereby the distances required to reach a defined risk factor for these projects can be defined. It is assumed that any distance in excess of that required to obtain the defined risk number does not pose a concern that would prevent its installation and operation. The groundwater modeling yields contours of the movement of the injected fluids. Assuming conservative tracers (no

decay), the contours can be applied to a risk model as defined above. The contours will provide a relative risk probability from the contour.

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TABLE 1

SUMMARY OF PROBABILITY DISTRIBUTIONS

Distribution	Range	Shape	Skewness	Distr. Type	Theory
Poisson	0 to inf.	Skewed Bell	Right	Discrete	Rate distribution (ocurrances over a period of time) Developed from Binomial Counting probability, low mean Chance of unlikely events Related to exponential distribution Number of events indep of other intervals
Exponential	0 to inf.	Concave Curve	Right	Continuous	Special case of Gamma & Weibull Distributions where α=1 so all issues with Gamma and Wiebull generally apply Describes random phenomena occurring @ constant rate which is equivilent to the Poisson Distr. Does not match gradual rise & fall of most data distributions
Gamma	0 to inf.	Skewed Bell	Right	Continuous	At large mean it approximates Normal Sum of squares of dependent Normal variables & Chi Sq statistics used for test of fit Fits data well at low end of spectrum Shape flexibility with α,β, which can be modified to fit data Erlang version of Gamma =Poisson counting process Requires estimate of mean
Normal	neg inf to ir	Bell	None	Continuous	Symetrical Bell shape about the mean Assumes that the realizations of many independent random causes add up to x, where the central Limit theorem ensures that the measurments cluster around central value Deviations from mean equally likely in both directions Describe central statistics well Inappropriate if data is skewed right, which is very common
Log Normal	0 to inf.	Skewed Bell	Right	Continuous	Uses logs of Normal probability Follows theory of Normal Distribution Log deviations from mean equally likely in both directions Competes with Gamma & Weibull Distributions Follows exact inference of Normal Distribution
Pareto I	Thresh. to	Concave Curve	Right	Continuous	Relates incident size (exposure) to cumulative frequency Threshold value required for Pareto I Range ot infinity, but can have truncated value (upper limit) Can approximate exponential distribution If a<2, high tail which matches dose response cdf Measures low probability, high consequence events Straight line on log scale
Binomial	0 to inf.	Skewed Bell	Right	Discrete	Large population Normal cdf approaches BN cdf @ high pop. Rate distribution, counting probability

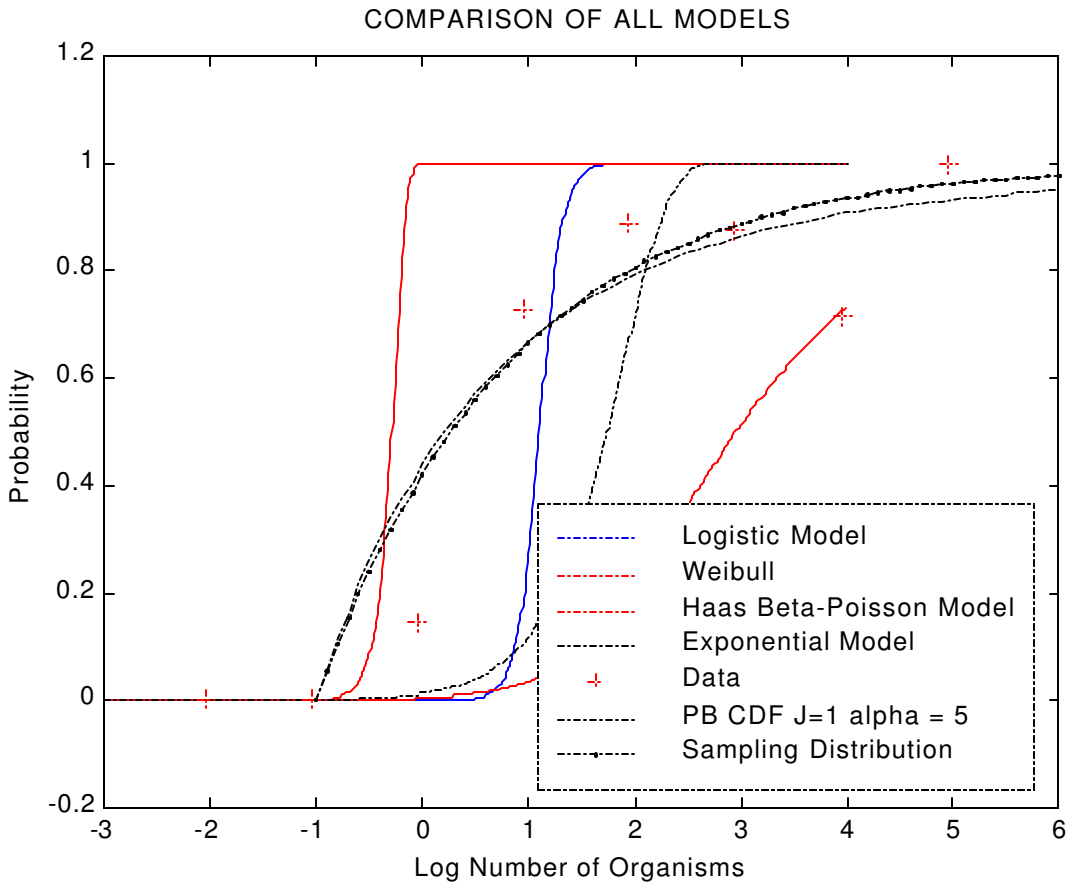
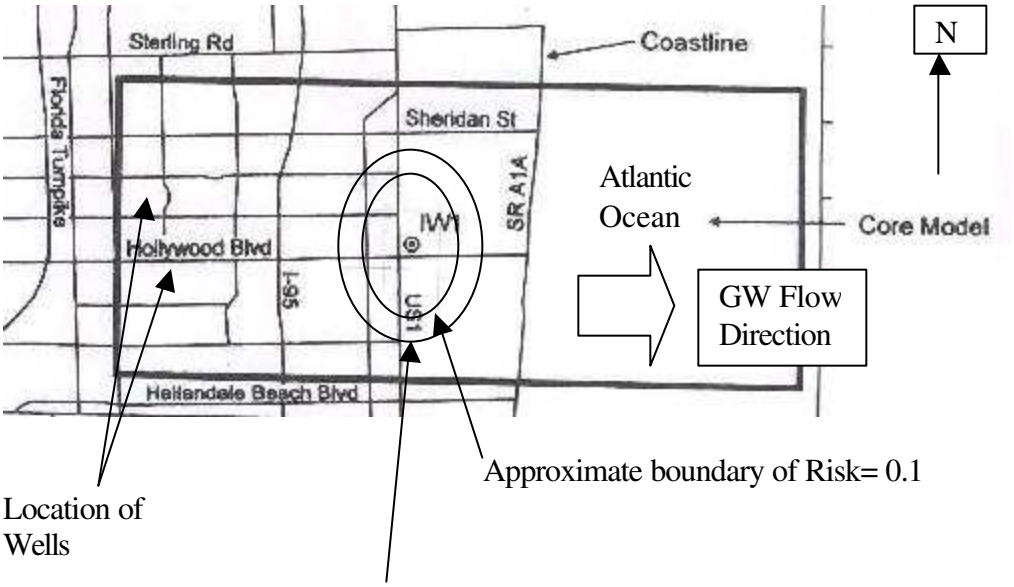


Figure 1 – Comparison of Haas Models and Predictive Bayesian Model



Approximate Boundary Where no further risk occurs – Maximum, with no dispersion is 78 days as calculated by a decay rate of -.25 percent of the organisms/day

Scale: one mile:

FIGURE 2. *ROTAVIRUS* RISK CONTOURS FOR HOLLYWOOD SALINITY BARRIER PROJECT

Comparative Assessment of Human and Ecological Impacts from Municipal Wastewater Disposal Methods in Southeast Florida: Deep Wells, Ocean Outfalls and Canal Discharges

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Abstract : The goal of this investigation was to develop relative risks of three effluent disposal mechanisms available to wastewater system in south Florida: deep well injection, ocean outfalls and canal discharges. Based on water quality, relative to disposal of wastewater treatment plant effluent was gathered, along with water quality data on the receiving waters from utilities, initial comparisons and conclusions regarding potential health concerns associated with disposal of treated wastewater effluent to injection wells were drawn.

The relative risk analysis was developed using several tracer constituents and comparing the relative likelihood of those indicators showing up in quantities that exceed the receiving water, or drinking water standards (depending on which was more applicable). To select appropriate constituents that could be used to measure health risks, the following were evaluated:

- Presence in wastewater
- Concentration higher in wastewater than ambient receiving waters
- Potential for health impacts

Health concerns, if any, would be expected to be associated with migration of effluent out of the injection zone, onto the shore from the ocean outfalls or into drinking water supplies from surface waters. In general, the collected data did not indicate significant health concerns associated with the injection of treated effluent. Of the measured constituents with specific toxicity or infectivity, only antimony and total coliforms were higher in the effluent with respect to both ambient water and regulatory drinking water standards.

Indicators of human health risk included arsenic (the target of significant regulatory activity at the current time, n-nitrosodimethylamine (NDMA – which is highly carcinogenic and has been raised as a public health issue in California), and *Crytposporidium* or rotavirus. Total Kjeldahl Nitrogen was used as an indicator of ecological risk. A modified Delphi Method was used to solicit expert opinion form a series of outside experts. The respondent group was given multiple opportunities to reevaluate their original answers based on reviewing results of the group response. Because a predictive Bayesian approach was adapted for development of the model, the formal Delphi method was modified to reflect the variation in responses , rather than the consensus, of the experts. The range and confidence of the experts' opinions were used to develop the distributions. The confidences were used as prior information for alpha values for Predictive Pareto distribution that describes the event size distribution. The confidence levels for event number distribution were used to determine the standard deviation for the lognormal distribution used to sample mean in order to be used as prior information for the Predictive Negative Binomial distribution.

The three disposal alternatives were compared to one another. The results indicated that health risks associated with deep wells were generally a lower risk than the other two alternatives. Urban ecological risks were also indicated lower, though impacts of urban water use/reuse to the Everglades were not studied. Confidence bands were wide, and it was recommended that additional data collection and analysis be conducted. In particular,

it was recommended that statistical monitoring of effluents for nitrosamines and pharmaceutically active substances be implemented on a broad scale.

Introduction

Injection to deep wells is currently one alternative for disposing municipal wastewater effluent in Southeast Florida. In the past several years, elevated concentrations of ammonia and total Kjeldahl nitrogen, and depressed salinity, relative to native water in the Floridan Aquifer, have been reported in monitoring wells in zones overlying the injection zone in Miami-Dade County. This finding has raised concerns of the U.S. EPA and others regarding the extent of migration of injected water.

In this research, indicators of the human health and ecological risks of available alternatives for disposal of treated municipal wastewater effluent in Southeast Florida were evaluated on a relative basis. Prior to the study, little was known regarding the relative risks of such alternatives. Municipal wastewater effluent disposal alternatives considered in this proposal include (a) injection wells, (b) ocean outfalls, and (c) aquifer recharge via canals. Assessment of risks of reuse of treated effluent for irrigation of golf courses, residential lawns, and parks was outside of the scope of this study. Because of the seasonal nature of rainfall and water levels in South Florida, such reuse is not always possible, and therefore a backup disposal system of similar capacity is required. Therefore, wastewater utilities utilizing reclaimed water for irrigation still require one of the effluent disposal alternatives listed above, for use during wet periods.

Objectives

Objectives of the research were to:

1. Compile and summarize water quality data on treated wastewater effluents and ground waters, related to or in proximity with large deep well injection systems and other disposal systems in Southeast Florida;
2. Develop a conceptual model of the operating environment for each disposal option, including regulatory constraints, hydrogeological and hydrological considerations, and potential pathways of health and ecological exposure;
3. Develop a probabilistic assessment of risks of injection well disposal, based on (a) published literature, (b) available data, and (c) expert opinion, relative to those of ocean outfall and canal aquifer recharge methods of treated-effluent disposal;
4. Prepare a report addressing the relative risks of the three wastewater treatment disposal alternatives; and
5. Recommend additional data and research needs, if appropriate, to refine conclusions reached in the project report.

Because of the complexity of potential exposure paths, time scales, and population characteristics, and the need to avoid site-specificity in the assessment, a predictive Bayesian assessment of relative risks of the various alternatives was undertaken. Bayesian methods allow the explicit and rigorous integration of expert opinion and numeric data, in contrast with resampling methods (which have no subjective capability), and fuzzy logic methods (having limited numeric data capability). The generalized quantitative assessment presented was made possible through the use of a further extension of the approach termed predictive Bayesian methods, involving the use of unconditional, believed probability distributions for potential human health and ecological losses. Such distributions represent both uncertainty (due to information limitations) and variability (due to natural random variation). Resulting unconditional distributions become broader with

decreasing levels of available information, giving estimates of risk directly, and avoiding the arbitrary assumption of confidence limits. Because the distributions are broader in general, their means are typically larger than the corresponding mean frequencies of occurrence. Therefore, these probabilities are termed *believed probabilities*, and are not interpreted as frequencies.

Methodology

The project comprised two phases, data collection and relative risk assessment. The data collection step included review of data on the quality of wastewater effluents from different levels of treatment, and the quality of ground water at depths to approximately 3000 feet. The data was collected from participating utilities and regulatory agencies, summarized, and analyzed. In addition, local and regional geologic data were collected. Data for effluents and ground waters were compared to drinking water standards. The majority of constituents were found in low concentration in the effluent in comparison to the receiving waters. Constituents found in higher concentrations in effluent included cyanide, nitrogen, phosphorous, color, odor, foaming agents, total trihalomethanes (THMs), biochemical oxygen demand (BOD), and total coliform count. In addition, treated effluents were somewhat higher in temperature and lower in pH, on average. Based on wastewater effluent analyses obtained, on average, treated effluents met both primary and secondary standards for drinking water, with the exceptions of primary standards for antimony and total coliform, and secondary standards for color, odor, TDS, and foaming agents.

Three meetings of the Research Team were convened over the course of the project. At the first meeting, a conceptual model of the technological and environmental setting for wastewater disposal in Southeast Florida was constructed, including available wastewater treatment technologies, water quality regulations, hydrologic characteristics, and conventional and emerging wastewater constituents of concern. At the second meeting, the analysis of collected water quality data was presented, along with tree diagrams describing potential exposure pathways, and the conceptual model for the risk analysis was developed. Risk was defined for the assessment as the probability of violating a water quality standard. A modified Delphi elicitation of expert judgment concerning risks associated with the three disposal alternatives was then conducted electronically, based on data collected for the region, applicable published literature information, and the experience of the Research Team.

The Delphi method is a technique for achieving consensus among a group systematically. The method was developed in the early 1950s for the purpose of estimating the probable effects of an atomic bomb attack on the United States, and has since been used in technological forecasting and many other applications (Linstone and Turoff, 1975). The approach involves iterative questionnaires, which protect the anonymity of respondents. Analysis of responses after each iteration involves successive elimination of opinions at the extremes, to achieve convergence of opinion. At the end of the procedure consensus among experts is attained (Sackman, 1975).

The traditional Delphi process involves a group of expert respondents in the field of study. The principal investigator designs a questionnaire and sends it to the larger respondent group. After the questionnaire is returned, the principal investigator summarizes the results and sends the questionnaire back to the respondents, preserving anonymity. The respondent group is given multiple opportunities to reevaluate their original answers based on their review of the group response (Linstone and Turoff, 1975). In a true Delphi process, responses outside the range of the central 50 percent of responses are eliminated prior to each iteration, with the ultimate goal of reaching a consensus likelihood of the group response. Significant commitment of time from the response group, and extensive study review, may be required. Modification of the full Delphi process is common.

The Delphi method avoids some of the pitfalls of group polarization, by preserving anonymity in the process. Group polarization describes the shifting of group opinion in response to the interactive dynamics of the group (El-Shinnawy and Vinze 1998). Group decisions have been found to shift in either the direction of lower or higher risk, and can tend to coalesce around the opinions of dominant members or otherwise change without a corresponding change in the underlying facts. While polarization can be a positive force for agreement when value or preference-based choices are made, it can have a negative influence on the reduction of uncertainty.

Because of the generalized nature of the assessment, there was an inherent uncertainty associated with all modes of effluent discharge. That is, different disposal methods have different risks in different settings, given different loadings, population distributions, and geology, for example. In addition, uncertainty was increased due to the lack of data available regarding some of the alternatives. Thus, the Bayesian approach was used to account for these uncertainties, and consensus was not a prime objective. Therefore, the Delphi method was modified as follows.

A modified Delphi questionnaire was prepared as a Microsoft Excel© Workbook, consisting of three sheets. Each sheet was dedicated to a method of disposal, corresponding to the three modified tree diagrams. The questionnaire posed a series of questions that followed exposure pathways from the point of discharge through to each point in the environment or water management system where a water quality standard existed. Each of these points represented a point of potential water quality violation due to the discharge alternative, and was represented by a node in the corresponding decision tree. For each node and each discharge alternative, the Team was asked four principal questions, worded as follows:

1. How many times in 30 years will the regulatory standard be exceeded at the receiving node? (One such exceedance event may last any number of days.)
2. What is your confidence in the numbers of exceedance events you entered? Please select low (L), medium (M) or high (H).
3. How many days will exceedance events last (minimum, mean, maximum)?
4. What is your confidence in the event sizes you entered? Please select from low (L), medium (M) or high (H).

For each node, the following three types of information were provided to the team members, for use in answering the questions posed:

1. Applicable effluent concentrations found in Southeast Florida effluent, as collected during the project and presented in Section 2,
2. Applicable actual or assumed regulatory standard, and
3. Relevant assumptions and supporting information were provided in the questionnaire.

The questionnaire set was circulated electronically three times to develop input for the initial assessment presented at Meeting 3. A final iteration was conducted to refine input based on group discussion at Meeting 3, to develop input for the final assessment. After each iterative circulation of the questionnaires, results were analyzed. After each iteration, geometric mean, weighted geometric mean, maximum, and minimum answers were tabulated and reported to the group for each question anonymously, along with reasons

given for individual answers, if any. Reasons were particularly requested for answers outside the range of the group in general. Team members were asked to review and refine their individual opinions, based on the opinions and reasons of other members. Extreme answers were not removed, and differences in opinion were allowed.

A probabilistic computer model was developed using the programming software package Matlab©, for computation of believed days of violation in 30 years. These initial results were presented at a third meeting of the team, and discussed for revision of both input and model form. Final input was then collected, and results computed for review by Team members. All Team members were interviewed regarding the final results, which were included in the final report and circulated all members for final review.

Predictive Bayesian Assessment Model

A predictive Bayesian model of health risks associated with injection well, ocean outfall, and canal aquifer recharge disposal alternatives was constructed, based on available data and other information, including expert opinion assembled by the Research Team. The approach involved the assignment of probability distributions, termed *sampling distributions*, to (a) the number of water quality standard violations expected in 30 years due to a discharge alternative, and (b) the expected magnitude (number of days) of individual violations. The Poisson distribution can be theoretically and empirically shown to predict the number of incidents, or infrequent events, over a period, and is widely used for this purpose. Therefore, the Poisson distribution was chosen as the sampling distribution for the number of violations in 30 years. The Pareto distribution is known to predict the size of individual incidents (Englehardt, 1995).

Sampling distributions describe the natural variability in, for example, the number of violations. That is, they describe the variability in the number of violations experienced among several imagined, repeated 30-year periods. The parameters of these distributions determine the location and scale (roughly, the mean and standard deviation) of the distributions. When little or no data are available to specify the parameters of these distributions, probability distributions, termed *prior distributions*, can then be assigned to the parameters themselves. Priors can be determined based on any combination of subjective or numeric information using Bayes Theorem. Because data was not available, model input consisted of professional judgment based on available data (e.g., effluent and water quality, hydraulic conductivity, and dispersion data collected during SEFLOE) and other local knowledge.

An extension of Bayesian methods was applied in this project, termed predictive Bayesian assessment. Predictive methods involve finding the unconditional probability of the numbers and sizes of violations, given the forms of the sampling distributions, and the specified distributions for sampling distribution parameters. That is, uncertainty in the parameters was integrated into the sampling distributions, resulting in *predictive distributions* for the numbers and sizes of violations. Predictive Bayesian distributions evolve in shape systematically in response to information content. As predicted by information theory, predictive distributions are broader when less is known, becoming narrower as information increases, converging on the underlying sampling distribution of variability. The increased breadth of a predictive distribution given limited information accounts for uncertainty due to information limitations. For example, because an ocean outfall in one location may have one expected number of violations and the same outfall in another setting may have another, the distribution in the number of violations is broader for the alternative to account for this range (essentially, uncertainty in location).

Predictive distributions were then used to compute distributions for total losses over the period. The model used to compute cumulative risks over a planning period is the compound Poisson model, in which the number of incidents over the period are described by a Poisson distribution, and the severity of individual incidents is described by a Pareto distribution.
Resulting probability distributions give mean impacts, as well as variability around the mean. For example, the levels of total loss having a 5% exceedance probability for the planning period, are indicated.

Estimation of Parameters for Incident Number

Because no data, inherently site-specific, were used explicitly in the analysis, the predictive Bayesian distributions used for incident number and incident size were equivalent to what are termed second-order probability distributions. For incident number, the distribution was based on the Poisson distribution of the number of incidents over a period, which can be written:

$$f_n(n) = \frac{\lambda^x}{n!} e^{-\lambda} \quad , \; n = 0, 1, 2, \ldots \tag{1}$$

in which λ is the mean number of incidents over the period (and may be a fraction).

Team members were asked not to assess the expected number of occurrences in 30 years at zero for events considered highly unlikely, but rather to estimate such a mean in terms of small fractions. In a few cases where team members felt this to be impossible, a default value of 10^{-12} was used. For incident number, estimates of incident number varied over several orders of magnitude. An analytical predictive Bayesian distribution with a gamma prior could not be used to account for this range of variability, due to computational demands. Instead, a normal distribution of orders of magnitude of mean incident numbers was assumed. That is, mean incident number was assumed lognormally distributed, and the predictive Bayesian version with no available data (second order distribution) was computed numerically.

Estimation of Parameters for Incident Size

For incident size, a predictive Bayesian version of the Pareto distribution due to Englehardt (1995), that assumes a gamma prior distribution for the scale parameter, was used in the analysis. The Pareto distribution can be written:

$$f_z(z \mid a) = \frac{a Z_o^a}{z^{a+1}} \tag{2}$$

in which Z_0 is the location parameter equal to the minimum event size of interest, a is the scale parameter equal to the slope of the log-log plot of the CDF, and z is a realization of the size of an incident measured, in this case, in days of violation. The Pareto I distribution is very highly skewed, so much so that it is not distinguishable from the axes on linear plots. Therefore it is generally plotted on log-log scale. The parameter a largely determines the risk of large losses, and was considered uncertain. The conjugate prior for a is the gamma distribution, which can be written as follows:

$$f_a(a \mid \alpha, \beta) = \frac{\beta^{\alpha} a^{\alpha-1} e^{-a\beta}}{\Gamma(\alpha)}, \quad a \geq 0 \tag{3}$$

in which α and β are greater than zero. The predictive Bayesian version of the Pareto distribution with gamma prior is then as follows (Englehardt 1995):

$$f_z(z \mid Z_0, \alpha, \beta, J, \overline{\ln z_j}) = \frac{(\beta + J\overline{\ln z_j} - J \ln Z_0)^{J+\alpha} (J+\alpha)}{z\left[\ln z + \beta + J\overline{\ln z_j} - (J+1)\ln Z_0\right]^{J+\alpha+1}} \tag{4}$$

The corresponding cumulative distribution function (CDF) is:

$$F_z(z) = 1 - \left(\frac{\beta + J\overline{\ln z_j} - J \ln Z_0}{\ln z + \beta + J\overline{\ln z_j} - (J+1)\ln Z_0} \right)^{J+\alpha} \tag{5}$$

For the assessment, the levels of confidence reported by individual Team members were assigned values of 1, 5, and 20, for low, medium and high confidence, respectively. These values represented increasingly narrow prior distributions for the mean incident size, as confidence increased. The value of the parameter α in Equation 4 was then specified as the average of the individual values. Weighted geometric means were then used to specify β using the relationship for the gamma prior that the (estimated) mean is equal to α/β. Because no numeric data was available for the generalized risk events assessed, the number of data points, *J*, was set equal to zero. Therefore, the remaining term representing the logarithmic mean of the data dropped out. These values were used to compute distributions of believed probability for the total number of days of violation in 30 years for each node indicated by Team responses to have significant risk. Arsenic, NDMA, and *Cryptosporidium parvum* (for surface water) or rotavirus (for ground water) were used as indicators of human health risk, and were therefore computed at drinking water nodes. In the case of ocean outfall disposal, the drinking water node assumed RO treatment and therefore was considered to have negligible risk. Therefore, human health risk for ocean outfall disposal was based on violation of surface water standards at the beach, assuming accidental ingestion of ocean water by bathers at the beach. TKN was used as an indicator of ecological risk, and was computed at surface water nodes. Where more than one node contributed significantly to either health or ecological risk for a discharge alternative, a distribution for the total believed violation days was computed by Monte Carlo simulation. Distributions for the number of violations, and for the total violation days, were truncated at 10,950, the total number of days in 30 years. That is, a violation day was defined as a day during which one or more water quality violations occurred.

Output of the probabilistic analysis included the believed number of days during which one or more violations of existing or assumed water quality standards for arsenic, microbes, n-nitrosodimethylamine (NDMA), and total Kjeldahl nitrogen (TKN) would occur, for comparative purposes. Arsenic, microbes (*Cryptosporidium parvum* for surface water, rotavirus for ground water), and NDMA were used as indicators of human health risks, and TKN was used as an ecological risk indicator. The compound NDMA was selected to represent nitrosamines, an emerging class of toxins that has been found in wastewater effluent. NDMA is considered carcinogenic at extremely low doses. Believed violation days are shown in Table 1 and 2. These numbers were larger than the expected number of days on which violations would be expected to occur, because they reflected uncertainty in addition to inherent variability. In addition, they were based upon multiple assumptions. In particular, the following assumptions were considered important to the results obtained:

1. Rapid vertical migration to the Upper Floridan Aquifer from deep injection wells in the Lower Floridan Aquifer was assumed, although evidence of effluent in the Upper Floridan near injection wells in Miami-Dade County could have been related to construction problems. This assumption is equivalent to assuming that the Floridan Aquifer will be "impacted" with water of generally much lower dissolved solids and inorganics, yet higher organics and nutrients, than native water of the aquifer;

2. ASR wells were assumed located one mile from effluent injection wells. This is a conservative assumption since ASR wells are unlikely to be located closer than 5 miles from injection wells;

3. As water is withdrawn from potable and non-potable ASR wells, salinity would be monitored, and withdrawals would stop if elevated levels were detected;

4. Because marine raw water for drinking was assumed to receive RO treatment, human consumption risks were driven by accidental ocean water ingestion by bathers at the beach, as indicated by the probability of violating marine surface water standards at the beach. In general, surface water standards are comparable to drinking water standards, though consumption of surface water in South Florida is probably three orders of magnitude less than consumption of drinking water.

5. Because specific surface water standards do not exist in Florida for NDMA and *Cryptosporidium parvum*, standards were assumed based on California action levels (NDMA) and published dose-response data (*Cryptosporidium parvum*). Assumed standards were adjusted by a factor of 1000, to account for the fact that ocean water is ingested only accidentally in small quantities, relative to drinking water. Because a specific surface water standard does exist for arsenic in Florida, this standard was not adjusted (in keeping with the definition of risk assumed for the project). Therefore, results for arsenic may be less indicative of actual human health risks.

6. Levels of treatment assumed to be received by discharged effluent and treated drinking water varied according to regulatory requirements; only effluent released to surficial aquifers was assumed to receive AWT. Surficial aquifer recharge by canal was assessed at lower risk than ocean outfalls for *Cryptosporidium parvum*, because (a) the filtration step included in AWT treatment preceding canal discharge provides efficient removal of *cryptosporidium parvum*, and (b) persistent onshore winds could result in inadequate dilution of ocean outfall plumes at the shore. Thus, these assessed risks, and others evaluated in the study, depended upon the level of treatment assumed.

7. Consideration of cost, including those of treatment, was outside the scope of this study.

Conclusions

In light of the assumptions used, generalized scenarios represented, and uncertainties reflected, risk assessment results shown in Tables 1 and 2 can be evaluated only on a relative basis. Relative, or comparative, risks were defined as the ratio of believed violation days (that is, the mean of the believed probability distribution for violation days) for injection well disposal to those for each of the alternatives, and are shown in Table 1. Results are considered significant in terms of orders of magnitude only. In addition, results should not be compared among constituents. For example, arsenic risks are expected to be lower than other risks, because average arsenic concentrations in the effluent samples analyzed were lower than either existing or proposed

surface and drinking water standards, in contrast with other constituents selected for assessment. While the results of Tables 1 and 2 do not reflect the lower arsenic risk, the relative risks of arsenic are shown to be comparable among discharge alternatives in Table 3, as expected.

In general, injection wells were assessed to represent lower health risks, assuming potential changes in Floridan Aquifer water quality in the vicinity of injection wells. Further, while there are no zero-risk options, all discharge alternatives evaluated are permitted under current regulations (though revised rules have been proposed for injection well disposal). In particular, risks of injection well disposal were considered associated with potential migration of effluent to ASR wells in the vicinity of injection. Assessed risks were low because of the geologic isolation and lack of ecological features within the aquifer, and because it was assumed that any contamination of ASR wells would be detected during operational withdrawals and that withdrawals would then stop. Ecological risks within the three urban counties studied were also lower. However, impacts to the Everglades system associated with urban water use/reuse were not evaluated as part of this study.

It was not possible to conduct a quantitative assessment of risks associated with pharmaceutically active substances (PASs), because such compounds are still being identified chemically, concentrations in treated and natural waters are largely unknown, and environmental fates are uncertain. Currently these substances are not monitored. However, such chemicals are being found in concentrations not recognized previously. Because of the widespread use of birth control and other hormonally active drugs, and the lack of removal of PASs in conventional wastewater treatment, the potential risks associated with these compounds require significant further study. Most direct evidence of toxicity is in the form of animal data; evidence in humans is limited at the present time. Additional data regarding effects of exposure in animals and humans are needed. Statistical pilot monitoring programs should be implemented on a broad scale as a basis for future policy development. Further questions include treatment technologies for removal, and the effects of natural processes including microbial degradation, adsorption, dilution, and photochemical reactivity on the fate of PASs in the surface and subsurface environment. Estrogens may be useful as an indicator in future risk assessments, because the compounds and their health effects are measurable.

In addition to PASs, the Team felt that potential risks of blue-green algae and their toxins related to the discharge of treated wastewater effluent, also outside the scope of the current project, also deserve further study. Information on blue-green algae toxicity in Florida is limited at present. However, several species of freshwater or freshwater-estuarine cyanobacteria, or blue-green algae, that produce cyanotoxins occur in Florida waters. Of samples collected in recent monitoring studies of recreational and surface drinking water supplies in Florida with algal blooms, approximately half showed significant levels of blue green algae, all of which were positively identified to contain blue green algal toxins found lethal in mice. Because such algae are nitrogen-fixing, growth rate is independent of TKN levels. However, growth is enhanced with phosphorus concentration. Even following AWT treatment, concentrations of phosphorus in wastewater effluent are two orders of magnitude greater than in natural South Florida surface waters. Further, cyanotoxins are not well removed in conventional flocculation and filtration. Therefore, blue-green algae may be a factor in the risks associated with choice of wastewater discharge alternative that was not evaluated in this study.

In general, flows of human and ecological emissions affect the ecosystem in many ways. Large-scale regional treatment facilities in Miami-Dade, Broward and Palm Beach Counties, and a number of smaller plants, routinely dispose in excess of several hundred million gallons per day. Risk indicators evaluated in this study were lower, in general, for injection well disposal, due to

natural barriers between the injection point and population centers. However, all wastewater discharges of this magnitude impact hydrologic and chemical cycling. In particular, flows of water, carbon, oxygen, nutrients, and many life-sensitive constituents of lesser concentration through the ecosphere are affected, and should be considered in further studies. For example, indirect and direct effects on freshwater and chemical releases to estuarine environments should be considered, in the context of previous substantial alterations in such flows through large scale drainage in South Florida, and in the context of the current Everglades restoration. It is also conceivable that in Southeast Florida, where outfalls lie within the influence of the Gulfstream, ocean outfall disposal contributes positively to the marine environment through the return of nutrients and organic matter. For example, it can be noted that no evidence of benthic accumulation of secondary effluent particles has been detected in the vicinity of the Southeast Florida outfalls.

There are important limitations to the results presented in this report. Some of these are related to the broad scope and generalized nature of the assessment, the currently limited implementation and regulation of ASR technology, uncertainties associated with emerging wastewater constituents of concern such as NDMA and PASs, and associated assumptions for the assessment. Further, the assessment was based on professional judgment, using current data for the region, applicable published literature information, and the experience of the Research Team.

Health and ecological risks represent only one aspect of the sustainability of wastewater effluent discharge alternatives. Costs, and ecological impacts to the drainage basin at large, are also important considerations. As population pressures increase, reuse will be increasingly important part of an integrated wastewater management strategy. Therefore, treatment plant design will be driven by the need to remove non-conventional and emerging wastewater constituents, and research is needed now as a basis for future design. The results reported represent the first quantitative assessment of wastewater discharge risks of such scope, and are therefore considered a starting point rather than an end. Nevertheless, the results are considered important for water management planning and as a basis for further studies.

Table 1. Comparison of Human Health Risk Indicators for three Discharge Alternatives Not Considering Violation of the USDW

Alternative Disposal Methods	**Mean Believed Violation Days In 30 Years**[1]		
	Arsenic	**Microbial**[2]	**NDMA**
Deep Well Injection	1	0.1	0.5
Ocean Outfall	10	50	30
Canal Aquifer Recharge	0.3	5	40

[1] *Results reflect input developed on a relative basis, and should not be evaluated individually.*
[2] *rotavirus for ground water nodes; Cryptosporidium parvum for surface water nodes*

Table 2. Comparison of an Ecological Risk Indicator for three Discharge Alternatives Not Considering Violation of the USDW

Alternative Disposal Methods	**Mean Believed Violation Days In 30 Years**[1]
	TKN
Deep Well Injection	10
Ocean Outfall	40
Canal Aquifer Recharge	100
[1]*Results reflect input developed on a relative basis, and should not be evaluated individually.*	

Table 3. Relative Risk Indicators for Three Disposal Alternatives Not Considering Violation of the USDW

Alternative Disposal Methods	**Relative Mean Believed Violation Days In 30 Years**[1] **(days/days)**			
	Arsenic	**Microbial (rotavirus or *Cryptosporidium parvum***	**NDMA**	**TKN**
Injection Well/Ocean Outfall	10^{-1}	10^{-3}	10^{-2}	10^{-1}
Injection Well/Canal Aquifer Recharge	10^{0}	10^{-2}	10^{-2}	10^{-1}
[1]*Higher values represent higher potential frequency of, and/or higher uncertainty in the probability of, violating surface and drinking water standards given current treatment requirements, for a generalized scenario in Southeast Florida. Values less than one indicate a lower believed risk of violating standards for injection well disposal relative to the alternative.*				

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EVIDENCE OF AEROBIC PCE BREAKDOWN DEMONSTRATED WITH USE OF SHALLOW INJECTION WELLS AND BIOREMEDIATION

Michelle Broyles, Cl Solutions, Cincinnati, Ohio, USA

I have received a B.S. and M.S. degree from Wright State University and I have been with Cl Solutions since 2000. I have experience in environmental consulting with responsibilities in implementing and coordinating field activities for application of bioremediation products provided by Cl Solutions. These responsibilities include technical support for initial site assessments to determine site compatibility to bioremediation and compiling a conceptual budget for the site. I also have experience isolating and identifying the bioremediation microbes from ground water, using traditional microbial plate count methods.
Other interests include wastewater wetlands and mitigation wetlands. I have experience as a wetland consultant, which includes identifying wetland boundaries based on hydrology, plant species, and soil type.

Anaerobic breakdown of tetrachloroethylene (PCE) has been well documented in the past. We have now found that aerobic break down of PCE and other chlorinated aliphatic hydrocarbons is possible, making aerobic in-situ treatment possible, which was demonstrated by the following case studies. Soil and groundwater PCE concentrations from a 50-year old dry cleaning facility was reduced by 90 to 99% in less than one year and within two years the concentrations decreased to the drinking water standard (0.005 mg/L). Groundwater volatile organic compound (VOC) concentrations from a former self-service dry cleaner in southwestern Ohio were reduced by 99.89% in three months. Bioremediation in combination with air sparing decreased PCE concentrations in soil and ground water from a chemical manufacturing facility, by 90 to 99% in two months. Each of these sites were inoculated with bioremediation agents through shallow injection wells that were installed directly within the contaminate plume. In these cases the environmental stigma was removed from the property, restoring the value of the property in a few months. The accelerated approach may be used to complete site remediation much faster than traditional techniques and in a time frame that facilitates a property transfer.

UPDATE – World's Deepest Class V Disposal Well In Its 15TH Year

By: Jim Bundy
Subsurface Technology, Inc

BIOGRAPHY

Jim Bundy is a 1968 graduate of the Colorado School of Mines with a Professional Engineer's Degree in Petroleum Engineering. He has 33 years experience in engineering design, research, planning, logistics, acquisition, optimization and management. During the last 15 years, Jim's previous oilfield expertise has been refined and redirected to permitting, design, installation, maintenance and repair of industrial waste injection wells. He was Project Manager and Technical Advisor to the Federal Government for the world's deepest Class V saltwater disposal well. He has been actively involved in development of mechanical integrity testing procedures, including wireline diagnostics, testing procedures, and various logging techniques. He has conducted numerous Class I Well Operator Training Seminars; health, safety, and environmental seminars; and specialized operational seminars, both domestically and internationally. Jim is currently Director of Engineering and Technical Services for Subsurface Technology, Inc.

ABSTRACT

IN 1986, THE LOWER COLORADO RIVER BASIN SALINITY CONTROL PROGRAM OF THE UNITED STATES BUREAU OF RECLAMATION BEGAN THE INSTALLATION OF A UIC CLASS V INJECTION WELL TO BE CONSTRUCTED TO CLASS I STANDARDS. THE WELL WAS DRILLED THROUGH THE CAMBRIAN AGE ROCKS TO A TOTAL DEPTH OF 15,900 FEET AND COMPLETED IN THE MISSISSIPPIAN LEADVILLE FORMATION BELOW 14,000 FEET.

The well was constructed to dispose of naturally occurring, sodium chloride brine water that infiltrates the Dolores River. The brine is captured with a series of shallow recovery wells along the river where it crosses the floor of the Paradox Valley of Southwestern Colorado. After treatment and filtration, the brine is transferred from the treatment station to the brine injection facility. There, it is diluted with fresh water and injected by a series of quintuplex plunger pumps into the Leadville fracture system below the massive salt dome that forms the Paradox Valley. Injection rates of 200 to 300 gallons of water per minute produce a maximum of 5000-psi surface injection pressure. The Bureau of Reclamation monitors the growth of the natural formation fractures using a series of seismic monitors placed strategically around the area. Fracture growth and the resulting effects on injection pressure have been correlated for the past five years.

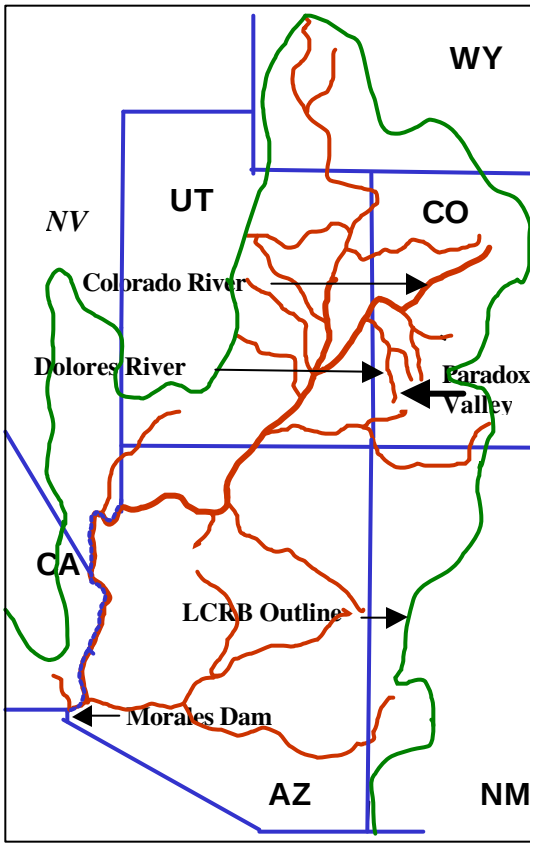
This paper is an update of the project after nearly 15 years since installation began. A similar project of lesser scale was patterned after the Paradox project and installed in New Mexico in 1999.

Introduction

River systems normally begin high in the mountains from melting snow, springs, and natural runoff. Initially the water is (or used to be) nearly pure. As the systems progress downstream, the contaminants (particularly salt) in the water increase due to the natural influx from leaching, mineral springs, floods, etc., and man-made products resulting from fertilizers, pesticides, and irrigation runoff. Studies have indicated that the downstream damages, resulting from salinity in the Colorado River Basin of the southwestern United States, range from $500 million to $750 million annually. Beyond the border of the United States, damages in the Republic of Mexico, although not quantified, are estimated to exceed $100 million per year.

In the United States more than 23 million people derive municipal and industrial water from the Colorado River Basin. Nearly 4 million acres of land are irrigated with water from the Colorado River.

Figure 1: Lower Colorado River Basin



The Federal Water Pollution Control Act was initially passed by Congress in 1948. It was amended several times and in 1966 it became known as the Clean Water Act. As a result of the provisions of the 1972 amendments to the Clean Water Act, a joint Federal and State conference initiated formal efforts to control the salinity of the Colorado River. In 1973, the seven basin states created the Colorado River Basin Salinity Control Forum for interstate cooperation. The Governors of the member states appoint the representatives to the Forum.

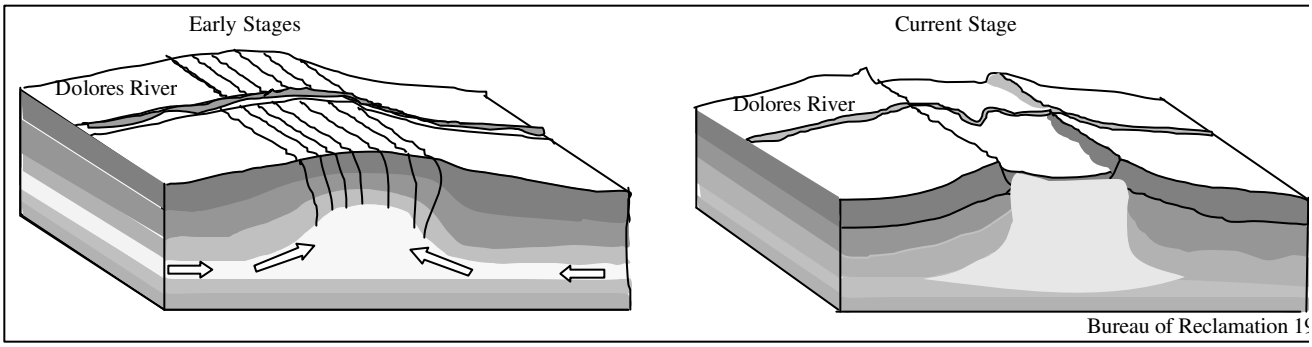
In 1973, the United States approved Minute No. 242 of the International Boundary and Water Commission Agreement between the United States and Mexico. In this agreement between the two countries, the United States committed, among other things, to adopt measures to control the salinity of the 1.36 million acre-feet of water delivered annually to Mexico upstream of the Morelos Dam. In 1974, the Colorado River Basin Salinity Control Act, Public Law 93-320, authorized the investigation and construction of facilities to control the salinity of the water delivered to Mexico.

Eighteen (18) specific projects were investigated in Colorado, Nevada, Utah, Wyoming, New Mexico, California, and Arizona. Of the 18 projects, 10 were determined to be economically unfeasible and eight projects were implemented. The Paradox Valley Unit of Montrose County, Colorado, under the direction of the United States Bureau of Reclamation (USBR), is one of the eight projects.

The Concept

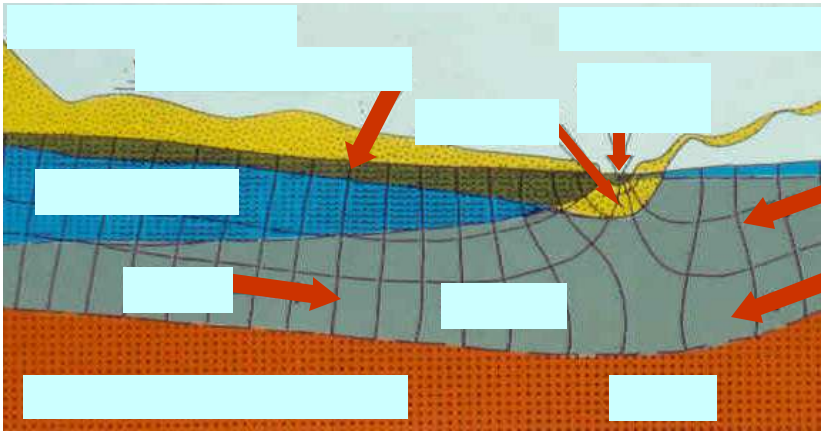
A. C. Peale, of the Hayden Surveys, originally named the Paradox Valley in the 1870s. The Dolores River, an upstream tributary of the Colorado River, crosses the valley perpendicular to the axis of the valley. Most streams follow the axis of the valley they create; thus, the name Paradox.

The valley was formed by the collapse of a salt anticline that began approximately 250 million years ago. Five to eight thousand feet of salt was deposited in a restricted marine basin during the middle Pennsylvanian time. During late Pennsylvanian and early Jurassic time, the salt was buried with the clastic sediments derived from the mountains to the north. The deeply bedded salt layer flowed to the southwest and was extruded upward to form several salt-cored diapirs. One (1) of the diapirs created the Paradox Valley Anticline. As the anticline grew, the Dolores River maintained its original course, transverse to the axis of the anticline. The salt diapir underlying the valley is nearly 14,000 feet thick (Baars and Stevenson, 1982) and is buried by only a few hundred feet of sediments.



An aquifer of saturated saltwater overlays the salt dome across the entire valley. Fresh water overlies the brine on the west side of the Dolores River while little, if any, fresh water exists on the east side of the river. The dissolution of the salt by the ground water, that created the collapse of the anticline, is still an active process. The resulting brine water enters the bottom of the Dolores river channel through springs and seeps. The brine has a total dissolved solids content of nearly 260,000 milligrams per liter. Approximately 93 percent of the dissolved solids is sodium chloride. The rate of influx into the river is estimated to range from 0.2 to 2.1 cubic feet per second (90 to 942 gallons per minute). The influx rate is influenced by aquifer recharge and snow melt, among other things. On the average, it is estimated that the Paradox Valley contributes nearly 200,000 ton of salt annually to the Dolores River and, subsequently to the Lower Colorado River Basin.

Figure 3: Salt Dissolution



Jensen and Leach believe that the formation of sodium chloride brine occurs near the contact between the residual cap (gypsum breccia) and the underlying halite. Recharge farthest from the Dolores River tends to

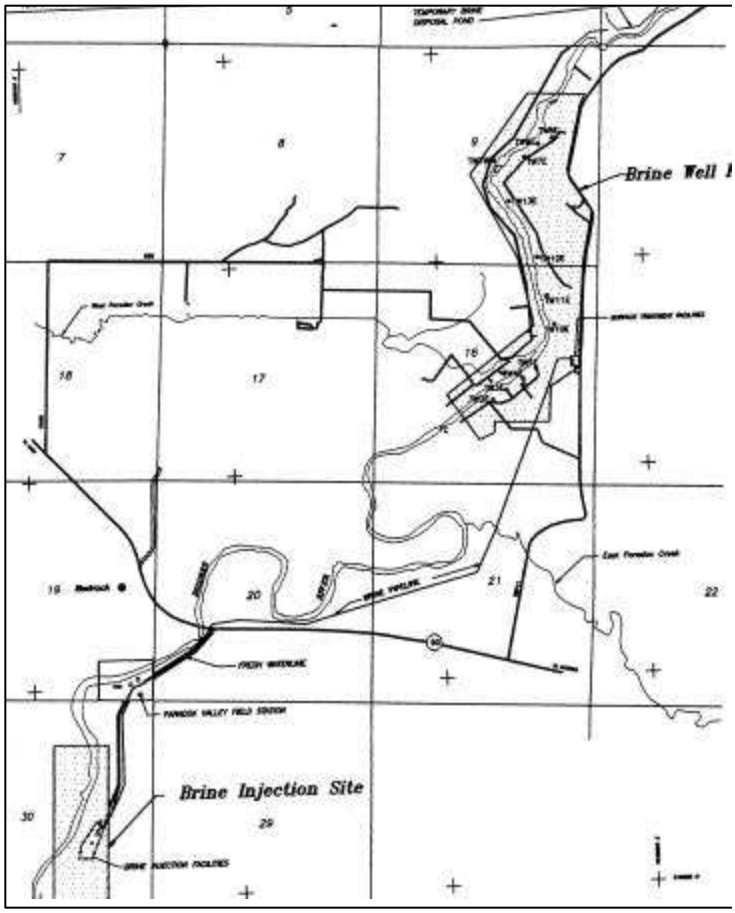
follow flow lines to the deepest part of the aquifer. They believe that it is this part of the aquifer that needs to be controlled to reduce brine influx into the river.

Confirmation

To confirm the theory, the USBR installed a series of shallow water wells along both the east and west banks of the Dolores River. It was learned that the freshwater-brine water interface could be lowered below the bottom of the river by producing the brine from the wells. It was further learned that the interface could be controlled by producing only the wells on the east side of the river at a combined rate of approximately 700 gallons per minute. The produced brine was stored in a temporary evaporation pond.

During the testing of the brine wells, the recovered brine was tested in the field and the laboratory for consistency of composition, corrosive characteristics, and chemical stability. Three (3) characteristics were defined. First, the presence of small amounts of hydrogen sulfide in the salt saturated brine made it extremely corrosive to carbon steel materials. Second, the hydrogen sulfide and naturally occurring iron created suspended iron sulfide solids. And third, under certain conditions of pressure and temperature with an abundance of limestone, the brine tends to precipitate calcium sulfate solids. The calcium sulfate question has been a source of much speculation, discussion, and argumentation over the years. It has also greatly affected the operation, the economics, and the overall environmental benefit of the project.

Figure 4: Brine Recovery Map



The question then was what to do with 700 gallons per minute of corrosive, saturated, brine water containing various dissolved solids. Merely isolating the river channel from the brine was not the solution since the brine would still surface and eventually flood the valley if not removed from the system.

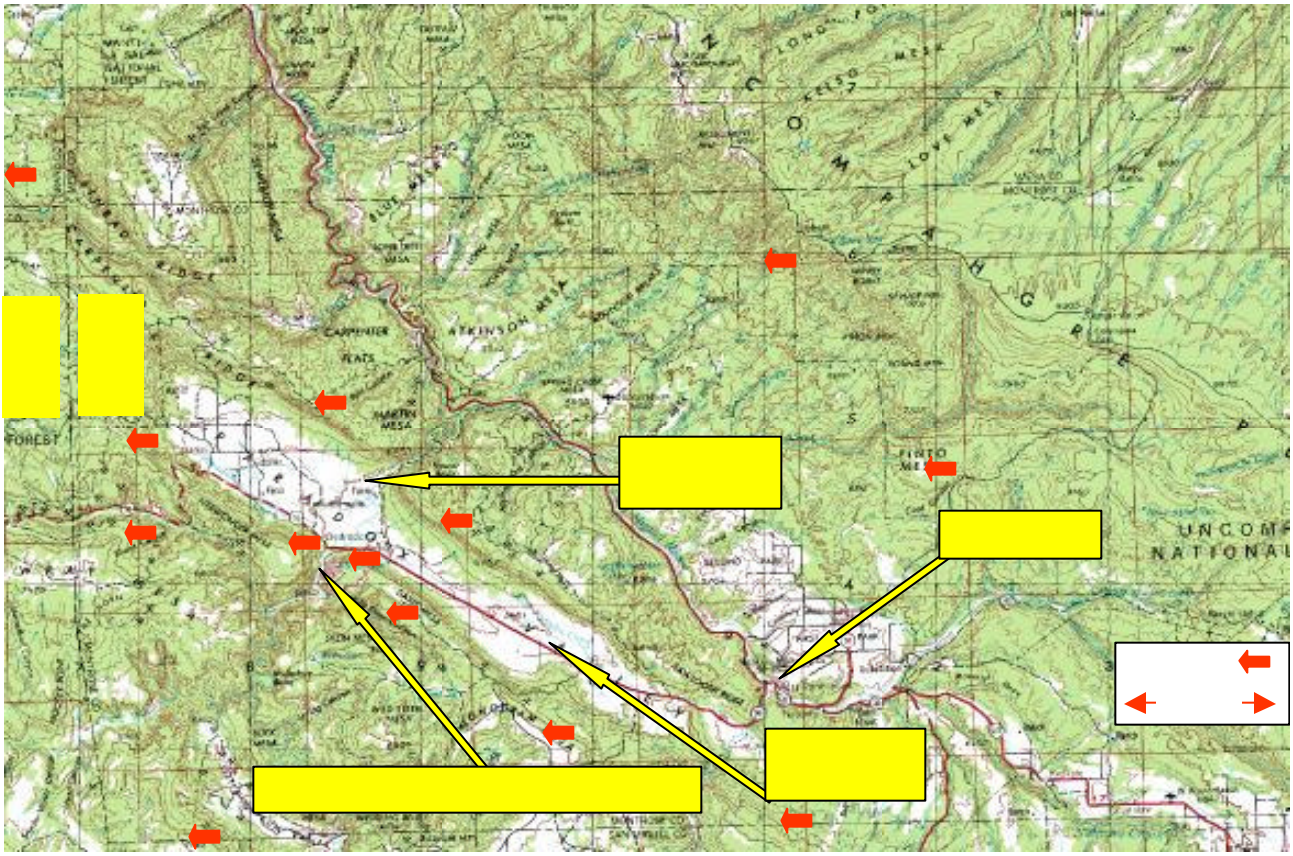
The Plan

A plan was developed to construct 21 miles of pipeline to Dry Creek Basin and allow the brine to evaporate in the 3700-surface acre Radium Evaporation Reservoir. An environmental impact statement was drafted and made public in May 1978 and finalized with the Environmental Protection Agency (EPA) in March 1979. Disposal by deepwell injection was mentioned in the statement, but the idea was discarded because the proposed 5 cubic feet per second (2244 gallons per minute) rate was deemed unfeasible for the available underground geologic reservoirs. The EPA recommended further evaluation of underground injection and the USBR contracted a private consulting firm to investigate the feasibility. It was finally concluded that underground injection could be technically, economically, and environmentally feasible.

Ken E. Davis Associates was contracted to design the well and assist the USBR in obtaining an Underground Injection Control (UIC) permit for the injection of the brine. The targeted injection formations were defined from existing oil and gas exploratory information in the region. The Mississippian Age, Leadville Formation beneath the salt was given the most likely chance of accepting large quantities of brine. This formation was known to be naturally fractured as a result of the faulting that occurred during the evolution of the anticline (Barr and Stevenson, 1981). The Devonian, Silurian, Pre-Cambrian, and Cambrian age formations below the Leadville were thought to be secondary targets as well (Harr and Bremkamp, 1982).

In conjunction with EPA Region 8 and EPA Headquarters, a permit was generated for the well. Since the well would dispose of naturally occurring brine water, and not industrial waste, it did not meet the definition of a UIC Class I well. It was also anticipated that the well would eventually operate at pressures exceeding fracture propagation pressure and UIC Class I wells are not allowed to operate at, or above, fracture pressures. Since the environmental and economic benefit of the project overshadowed other considerations, the well was permitted as a UIC Class V injection well, to be constructed to Class I standards.

The operation of the well at injection pressures greater than fracture propagation pressure necessitated the installation of an elaborate seismic monitoring system. Eleven (11) seismic monitors were initially installed in the area to measure the minute earthquakes that would be associated with fracture propagation. By the summer of 2001, the number has increased to 16. Of the 16 monitors, 13 monitors are indicated by the red arrows in Figure 5.



Well Design and Construction

Conoco Oil Company had drilled a well near the center of the valley and encountered nearly 14,000 feet of salt. Union Oil Company had drilled a well near the Dolores River just south of the southern valley wall and encountered only 400 feet of salt. These two wells affirmed the southern boundary of the diapir. It was decided to drill the injection test well near the Union well to avoid the mechanical problems associated with drilling the very thick salt diapir.

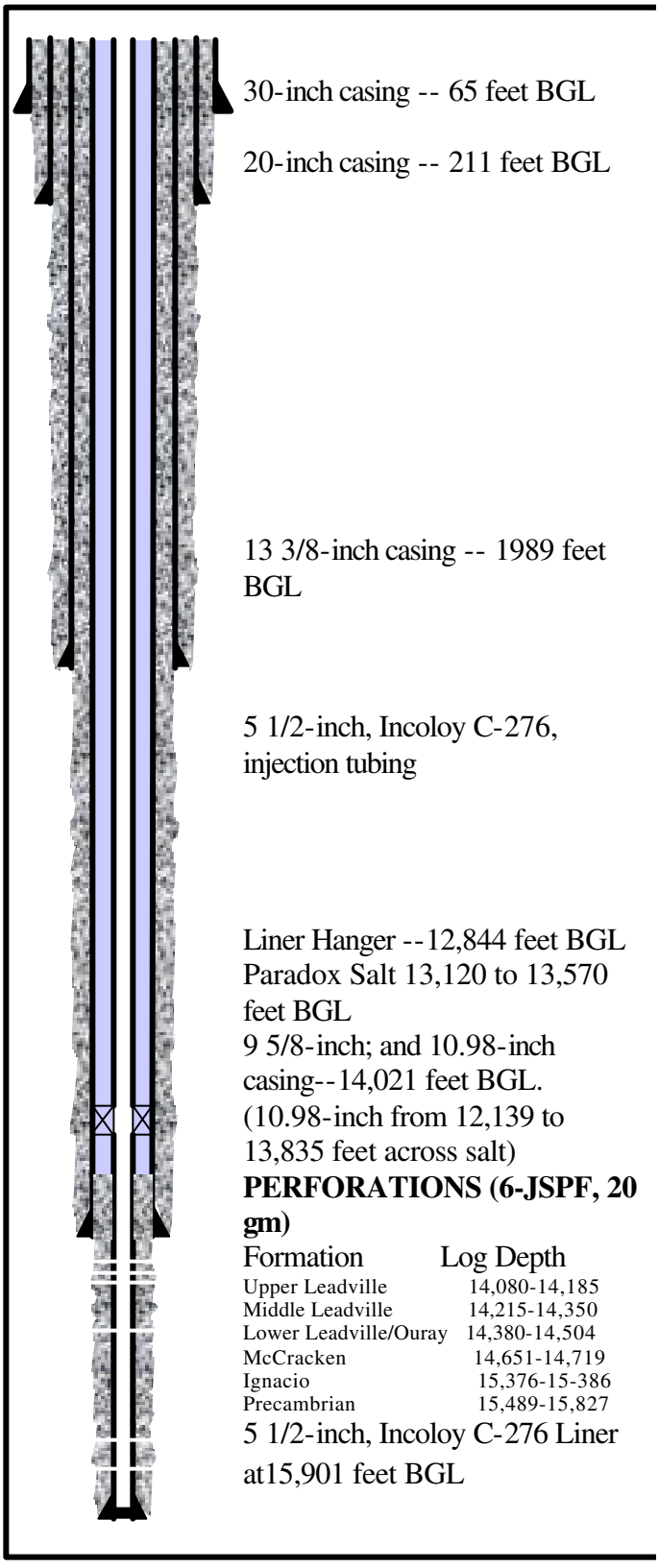
The well design was unique for its time and remains unique some 15 years later. Some of the parameters that were considered were:

- a life expectancy of 100 years;
- an injection rate of 1100 gallons per minute;
- the existence of 300 to 400 feet of pure salt at a depth greater than 13,000 feet;

- the corrosivity of the brine due to the presence of hydrogen sulfide; and
- the anticipation of surface injection pressures approaching 5000 psig.

The project was considered to be a test that would be converted to a permanent installation if the test results were favorable. The underground components of the well need to last for 100 years. For that reason, the acceptable rate of degradation of the components due to corrosion, erosion, and normal deterioration is essentially zero. The presence of hydrogen sulfide in the brine necessitates the use of non-ferrous material for all components in contact with the brine. This includes casing, injection tubing, wellhead, flow lines, pump discharges, metering equipment, storage tanks, surge vessels, and monitoring equipment. Everything downstream of the injection pumps is designed to contain the anticipated 5000-psi injection pressure. The materials chosen for the high-pressure application were Alloy C-276, (approximately 57% nickel, 16% molybdenum, 16% chrome, 5% iron, and 4% tungsten) and Alloy 625 (approximately 61% nickel, 22% chrome, 9% molybdenum, 3.6% niobium, and 2.5% iron). The materials chosen for non-expendable, upstream or low-pressure application were primarily high-density polyethylene (HDPE), polyvinylchloride (PVC), and other non-metallic material.

Well and surface facility components that do not contact the brine are designed of carbon steel. The halite (salt) formation anticipated to exist below 13,000 feet presented another design problem. Salt, under extreme pressure, exhibits plastic properties. After salt is drilled and casing is installed, it will slowly transfer the overburden pressure laterally to create extreme collapse pressures. The overburden pressure can be approximated by assuming an average specific gravity of 2.3 for the rocks that overly the salt. The weight of one cubic foot of material of specific gravity 2.3 is 144 pounds, which results in



a pressure of 1 psi per foot of depth. For the Paradox Valley well, the casing to be run through the salt required a collapse resistance in excess of 13,000 psi, plus a safety factor of 1.125.

A final design for the injection test well was completed in August 1985. Details of the design are presented in the "As-built" Well Schematic (Figure 6). The construction project was offered for competitive bid and a contract awarded. Installation of the well began in November 1986. A 36-inch diameter hole was augured to a depth of 65 feet below ground level and 30-inch diameter conductor casing was installed with the annulus grouted to the surface. A 26-inch hole was rotary drilled to 211 feet below ground level and 20-inch diameter steel casing was installed with cement circulated through the annulus to the surface. A 17-1/2 inch hole was drilled to 1989 feet and 13-3/8 inch diameter steel casing was installed and cemented to surface. A 12-1/2 inch hole was then drilled through the overlying Jurassic, Triassic, and Permian Formations, the Paradox Salt, and the basal Pennsylvanian sediments to the top of the Mississippian Leadville Formation at a depth of 14,021 feet below ground level. The well was cased with a 9-5/8 inch diameter carbon steel casing with 11-inch diameter, 1-inch wall, casing through the salt section from 13,120 feet to 13,570 feet. The heavy-wall casing provides a collapse resistance in excess of 16,000 psi through the salt section.

The final hole was drilled and cored through the injection interval sediments into the top of the Pre-Cambrian granite. The interval is severely fractured and numerous drilling problems were encountered. Full-hole coring was discontinued because of poor recovery, extremely slow coring rates, and excessive cost. Geophysical logs were pieced together as a result of wellbore rugosity and the associated mechanical problems encountered while conducting the logging operations.

The data gathered from drill-cutting samples, recovered full-hole cores, geophysical logs, and open-hole drill stem testing were evaluated prior to the decision to continue. The natural porosity of the formations drilled was less than expected. Throughout the sub-salt formations, rock porosity rarely exceeded 4%. This was a disappointing development, since the porosity was expected to be 10% or greater. The extent of natural fracturing was, however, greater than expected. It was concluded that the void space created by the natural fractures might, in fact, provide the reservoir capacity necessary to accept the Paradox Valley Brine.

The open hole was cased with a 5-1/2 inch diameter, Alloy C-276, corrosion resistant liner from total depth to 12,844 feet. The overlap of the liner into the long-string casing was designed to provide additional collapse resistance through the salt formation. The annulus was cemented through the open hole into the overlap area.

Only enough Alloy C-276 material for the liner had been manufactured prior to drilling the well. Because of the extreme cost of the material, it had been decided that the injection tubing would not be manufactured until it was determined that it would be used. Consequently the drilling equipment was removed from the site and the well was secured in August 1987 to await the delivery of the injection tubing. Construction of the surface treatment facility and the brine injection facility was begun while awaiting completion of the well.

The completion phase of the well construction began on November 1, 1988. The rig was moved back on the site and, beginning at the bottom of the well, selected intervals were perforated. Each interval was tested by injection and pressure transient analysis to determine the potential reservoir capacity. The zones below the Mississippian Age rocks were somewhat disappointing in their reservoir quality, but the test results confirmed the evaluation of the geophysical and geological data.

The Leadville Formation was perforated, fluid samples were recovered, and the zone was injection tested. The Alloy C-276 injection tubing was installed in the well and the annulus between the carbon steel casing and the injection tubing was filled with diesel fuel to minimize corrosion of the casing. The well was secured on December 17, 1988, while preparations were made to conduct the long-term test program.

Comprehensive Wastewater Management Planning and Wastewater Re-Use/Re-Charge in Massachusetts

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Biographical Sketch of Presenter:

Douglas E. Fine currently manages the Massachusetts Department of Environmental Protection's wastewater, drinking water, and wetlands regulatory programs for Central Massachusetts. Mr. Fine has worked at DEP, the state's 1100-person environmental regulatory agency, for twelve years. His prior duties at DEP included management of pollution prevention programs for the industrial waste program, and public involvement and policy within the waste site cleanup program. Prior to coming to DEP, Mr. Fine spent four years at the Massachusetts Audubon Society, the state's largest private non-profit conservation and environmental advocacy organization. Mr. Fine obtained a B.S. in Environmental Science from Antioch College in 1983.

Abstract:

In the last 10 years, increasingly convincing data has shown that many of the watersheds and sub-watersheds in Massachusetts are becoming "stressed" -- in large part by depleted groundwater and the resulting impact on river base flow. River flows, particularly in the headwater areas, are showing higher highs in the spring and lower lows in the dry months, and an increasing number of communities are experiencing difficulty locating adequate groundwater for public water supplies. In some cases, rivers that are receiving discharges from municipal wastewater treatment facilities are more than 80% effluent in the summer, and one river that used to flow year round now runs dry most summers. This had lead DEP to re-think our prior approach to municipal wastewater management, under which we had typically encouraged extending sewers into un-sewered areas, collecting the wastewater for centralized treatment, and sending the water out of the watershed by discharging the treated effluent to a river.

This presentation will provide an overview of DEP's current approach to wastewater and water resource management. This approach includes encouraging communities to conduct comprehensive long-term (20-year) wastewater management planning, and an emphasis on communities evaluating "keeping the water local" via small on-site wastewater disposal systems or centralized treatment with groundwater discharge. DEP's wastewater management approach also encourages wastewater minimization via water conservation and wastewater re-use. The presentation will cover some of the state's recent experiences implementing this approach (including successes, challenges, and public reaction), and

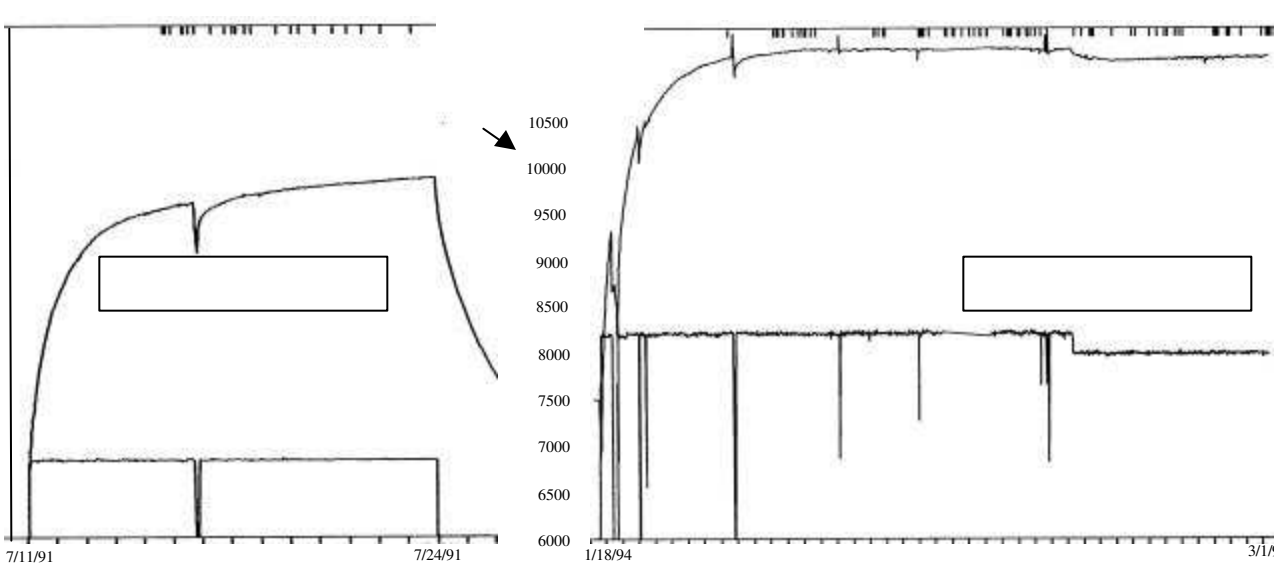
also a look at DEP's requirements for discharge of treated effluent within the Zone II of a public water supply and guidelines on the re-use of treated wastewater (for toilet flushing, irrigation, etc.).

Well Testing

Since the project was intended to be a permanent facility, extensive reservoir testing was required to accumulate data and create a computerized reservoir simulation model. An ambitious, two-year test schedule was planned for the facility. Seven (7) injection periods of increasing length were planned. Each injection period would be followed by a shutin period of sufficient length to observe the pressure falloff curve. Data were gathered electronically with the facility monitoring equipment and stored electronically. Data from each injection and falloff period were evaluated for parameters to be included in the computer simulation.

Fracture stimulation simulators were commercially available, but none were designed to accommodate continuous fracture injection over long periods of time. Envirocorp Services & Technology, Inc. (now Subsurface Technology, Inc.) prepared two computer models. The primary model was created using the SWIFT 486 flow and transport simulator. The SWIFT model utilized data from each of the seven injection periods to create a history match, then predicted performance for 10 years. A commercial fracture simulator was created to verify the SWIFT results. The commercial simulator used only data from the seventh (and longest) injection test period. The predictions of both models, for 10 years of injection, were consistent.

During the construction of the model, a multitude of pressure increases and decreases were noted on the rate-pressure curves. Seismic data are obtained from the USBR Technical Service Center in Denver, Colorado. Seismic events recorded by the monitors placed in the area were integrated into the pressure and rate data. Subtle pressure changes and trends were correlated to seismic events, thus indicating fracture growth. Figure 7 is a representation of the injection rate, bottom-hole

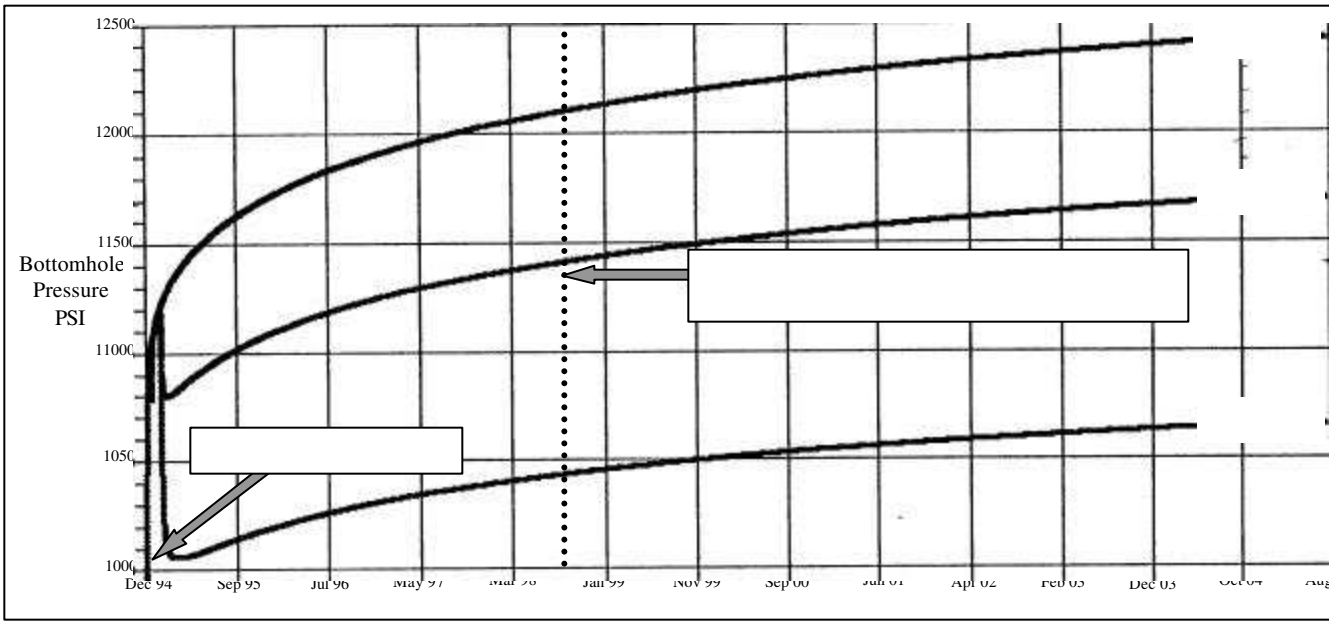


pressure, and seismic record for the first and the sixth test period.

In the SWIFT simulator, the ability to predict the pressure buildup in the reservoir, as a result of injection, is influenced by the ability to accurately predict when and where a fracture will occur. The predicted behavior of the reservoir is shown in Figure 8. The current flowing injection pressure is less than predicted pressure because fracture growth, and frequency, was not forecasted

in the predictive modeling curves. When the model is updated with the last 4 years of actual injection, and seismic data, it will be refined for prediction of future pressure.

Actual injection rate and pressure data since 1996 are illustrated in Figure 11 and are presented later in the text.



Surface Facilities

A total of 23 brine production wells were drilled initially to depths ranging from 48 to 77 feet below ground level. One (1) additional well was drilled into the gypsum cap approximately 155 feet deep. The production wells vary in diameter from 8 to 12 inches, with 15 to 40 feet of gravel packed screen on the bottom. The wells are completed with submersible pumps and fluid level monitors. Operation is controlled with process logic control from the surface treatment facility.

After defining the brine influx to be from the east side of the river, 13 of the wells were plugged and abandoned. Ten (10) wells were completed for long-term brine production and one well was left as standby for future considerations. Production capacity is approximately 1.5 cubic feet per second (673 gallons per minute) which is well in excess of the present disposal capacity.

There are 68 monitoring wells of varying depth along both sides of the river. The wells are completed so as to monitor fluid levels, piezometric surfaces, conductivity changes, and the general effect that brine production has on the freshwater and saltwater aquifers.

The produced brine is transported by pipeline to a nearby treatment facility (Figure 4). The brine is commingled, filtered, and transferred to two, 25,000-gallon underground storage tanks. It is then transferred to the injection facility through 3.5 miles of buried, 10-inch diameter, high-density polyethylene pipeline.

At the brine injection facility, the brine is diluted by 30% with fresh water (a measure designed to minimize the possibility of calcium sulfate precipitation), then placed in two 25,000-gallon pressurized storage tanks. The fresh water is taken from the Dolores River, allowed to settle, filtered, then mixed with the brine.

The necessary injection pressure is provided by a series of four Wheatley, positive displacement, plunger pumps. The pumps are capable of sustaining 5000-psi output pressure at 115 gallons per

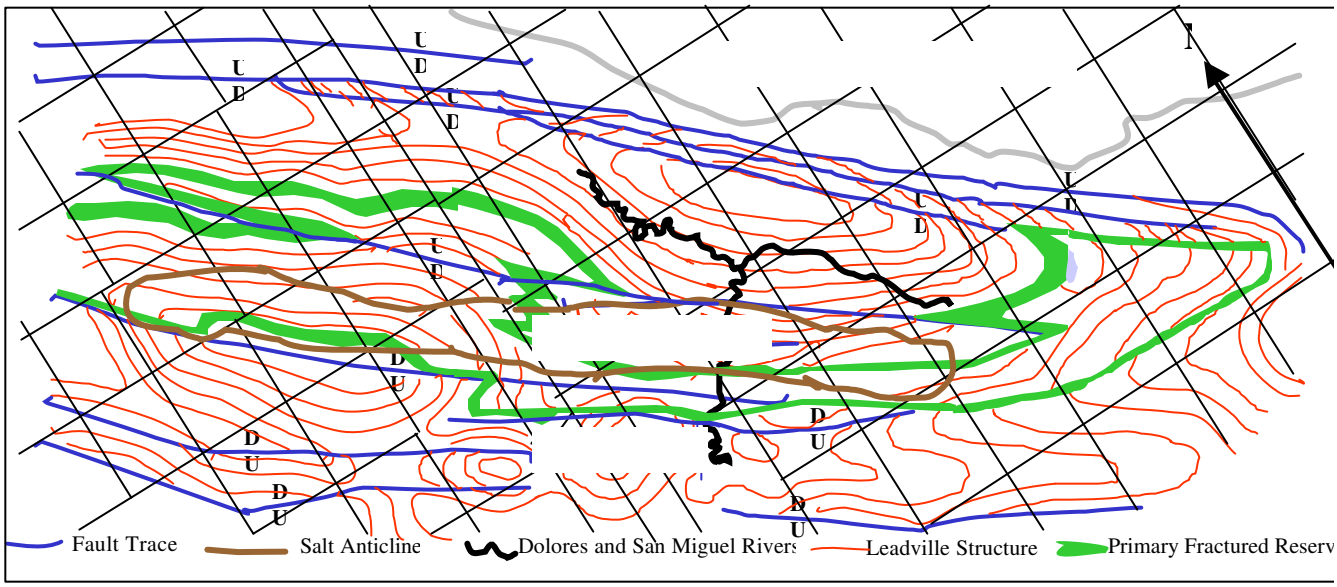


minute each. Each pump is powered by a single, 400-horsepower, 460-volt, 3-phase electric motor. The pumps are capable of being run individually or collectively, providing over 600 gallons per minute of potential injection rate. Using three pumps, the facility can dispose 345 gallons per minute, with one standby to be alternated during repair and maintenance.

Fracture Propagation and Seismic Events

As mentioned previously in this paper, the targeted formations for the injection of Paradox Valley Brine were located primarily in the naturally fractured regions of the Mississippian Age rocks. The reservoir is confined from vertical migration of injectate by more than 300 feet of halite and anhydrite. The majority of void spaces in the reservoir result from fracturing that occurred during the formation of the salt diapir. Karsting of the limestone created minimal amounts of primary, inter-crystalline porosity. Injection capacity is achieved by the hydraulic separation of existing, natural fractures and the extension, or propagation, of fractures within the fracture network. Figure 10 is a structure map of the Leadville Formation, indicating the anticipated fractured reservoir zone and its associated fault blocks.

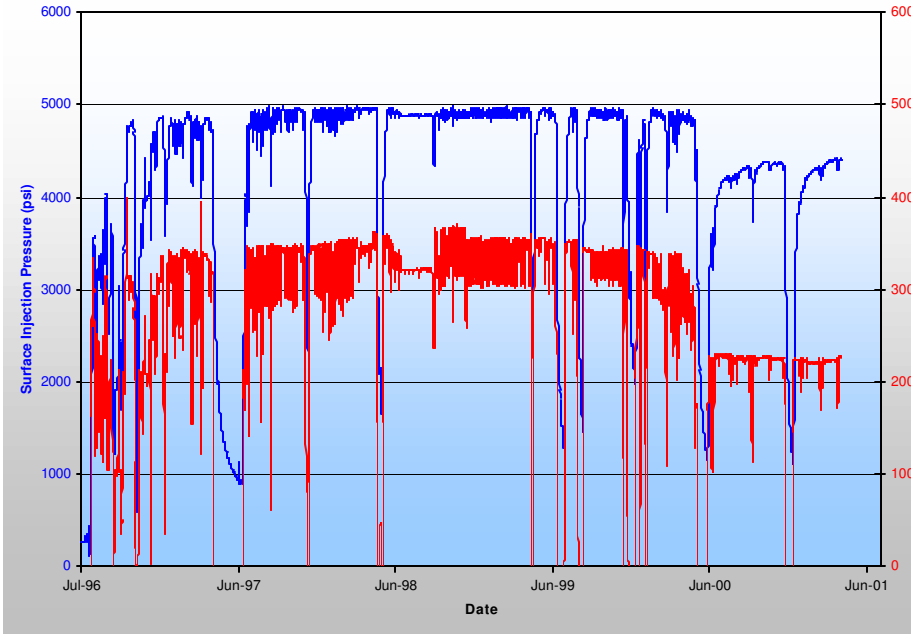
Figure 10: Structure Map of Leadville Formation (after Harr 1988)



Prior to the Paradox Valley Salinity Control Project, the nearest seismic monitoring stations were more than 100 miles away. The National Oceanic and Atmospheric Administration recorded a total of 24 earthquakes within a 100-mile radius of the well from 1850 to 1983. Earthquakes of magnitude less than 3.4 to 4.0 were probably not detected because of the technology available and the focus at the time. The largest recorded earthquake was a magnitude 5.5 that occurred in 1960, approximately 70 miles east of the site.

When injection into the well began in 1991, minute seismic activity was detected within one week (see Figure 7). From 1991 through 2000, more than 3700 events have been attributed to injection into the well. In order for an event to be felt by persons at the surface, the duration magnitude must be greater than 2.6. Of the 3700 events, persons in the area have felt only 12.

The long-term injection of Paradox Valley Brine began on July 22, 1996, at a rate of 250 to 300 gallon per minute. The brine was diluted by 30% with Dolores River water to reduce the potential for calcium sulfate precipitation at the anticipated reservoir conditions of temperature and pressure. Figure 11 is a graphic presentation of the injection rate and surface injection pressure from July 1996 through April 2001. For the first six months, operational problems prevented lengthy, uninterrupted injection periods. By the end of



1996, an operational routine had been established and the rate stabilized at 300 to 350 gallons per minute, utilizing three of the four available pumps. From July 1991 through May 2000, the facility injected approximately 708 million gallons of dilute brine water, resulting in a disposal of 70% or 495.6 million gallons of Paradox Valley Brine. At that time, the installation had prevented 545,160 tons of salt from entering the Dolores River.

On May 27, 2000, a magnitude 4.3 seismic event occurred approximately 1.6 miles south and 1.25 miles west of the wellbore at a depth below 13,500 feet. The event was within the area of expected fluid movement in the Leadville fracture system and was the largest event recorded since operations began. Immediately, injection was stopped and the well was shut in for 26 days while the event was evaluated. During the shutin period, alternative operational practices were evaluated. Those practices included the reduction of the injection rate to approximately 230 gallons per minute by operating only two of the injection pumps at a time. The reduction in injection rate would result in a reduction of surface and bottom-hole injection pressure and should reduce the number and magnitude of seismic events. Programmed pressure falloff periods of 20 days, twice yearly, had been implemented previously, following two magnitude 3.5 seismic events that occurred in June and July of 1999.

Figure 12 is a chronological plot of seismic events, their distance from the wellbore, and the operating pressure at the time of their occurrence. The plot was prepared by the USBR Technical Service Center and clearly defines the relationship between injection pressure (and rate) and fracturing that is occurring in the near-wellbore region. The grouping of the event markers clearly shows that most of the fracturing events occur within two km of the well. A few events were recorded at distances of seven to nine km from the well between July 1988 and July 2000. Most significant is the reduction in the number of events that have occurred since the injection rate was reduced in June 2000.

Figure 13 is a plan view of events that have been recorded since 1998. The plot again shows that the vast majority of fracture events have occurred within two km of the wellbore. Equally as important is the orientation of the fracture events. The axis of the Wray Mesa Fault System, as defined by Harr and Bremkamp, is overlain on the epicenter plot. It is apparent that the fracturing is aligning with the fault system, especially considering the small group of events located five to six km to the northwest.

1.1.1.1.1.1.1 **FIGURE 12:**

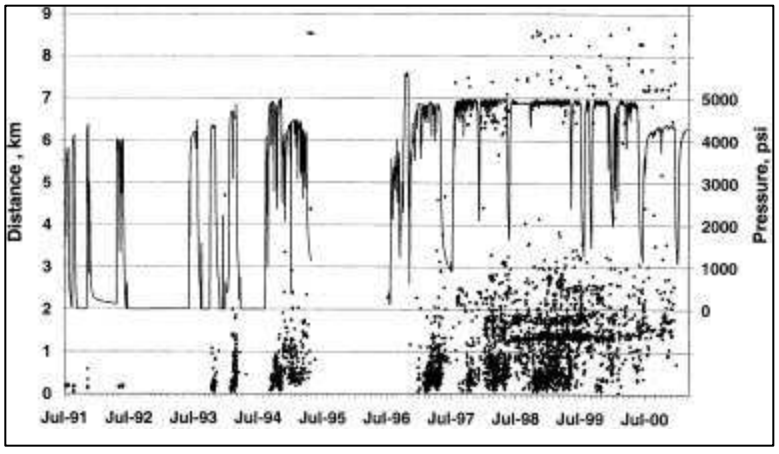
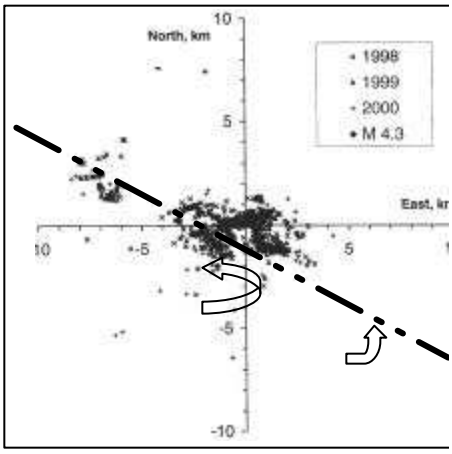


Figure 13: Epicenter Plan Vie



Salinity Control

The stated purpose of the project is the reduction of the amount of salt that flows into the Dolores River and eventually into the Lower Colorado River Basin. This paper has touched on the major features of the project dating back more than 15 years. The magnitude of the success of the project can only be estimated through the calculations of brine chemistry, measurements of brine produced from the valley floor, and the quantity of treated and diluted brine that is disposed into the sub-salt fracture system more than 2-1/2 miles below the surface. There are very few sources of instant gratification to be visualized from the project. One of those sources is presented as

Figure 14: Dolores River Flow Rate, Specific Conductance, and Brine Injection Rate

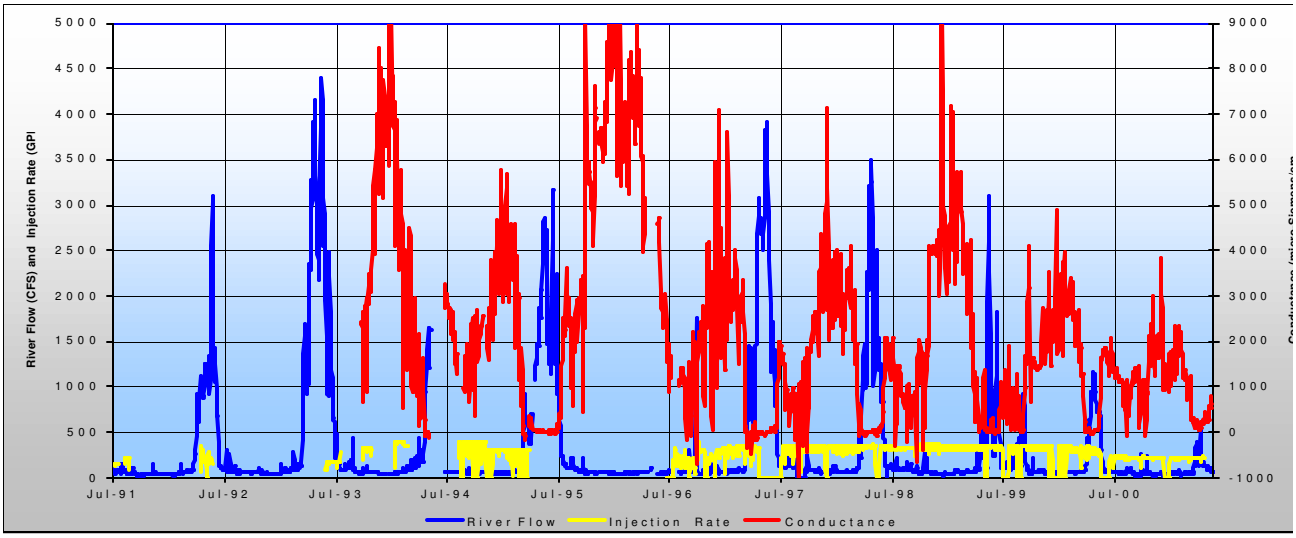


Figure 14 that was generated from a spreadsheet provided by the USBR.

River flow rates have been recorded daily since 1971. In 1993, monitoring and recording equipment was installed to measure the specific conductance of the water on the north side of the Paradox Valley. Brine withdrawal and injection began in 1996. The flow of the river is cyclical with the seasons. Peak flow occurs during April through June, as a result of the runoff from snow. Specific conductance of the water is understandably lower, as a result of the dilution by high river flow rates. Conversely, the conductance is elevated when the river flow rates are at their yearly low during the last half of each year.

The effect of brine recovery and injection can be seen as early as the fall and winter of 1993. The two injection test periods correspond to a reduction of the conductance before and after the peak. More apparent, is the effect of the longer Injection Test Period Number 7, during late 1994 and early 1995. Injection began at 400 gallons per minute (70% brine) in mid-August and continued for three months. At that time, surface injection pressure was approaching 5000 psi and reaching the working pressure limits of the injection facility. The rate was reduced to 300 gallons per minute to lower the injection pressure, and injection continued until April 1995. This also corresponds to a period of low, but consistent, river flow. The specific conductance nearly doubled when the injection rate was reduced. There was no injection from June 1995 to July 1996 while the facility was shut down to replace the temporary injection pumps with the permanent Wheatley pumps. During that period, Figure 14 shows that the specific conductance of the river returned to the much higher values. The effect of the resumption of injection, from July 1996 to July 2001, is again illustrated by Figure 14.

Economic Benefit

The current benefits to the economy of the Lower Colorado River Basin have recently been estimated at $122.00 per ton of salt removed. Through April 2001, over 800 million gallons of dilute brine have been injected at Paradox. This equates to 560 million gallons of Paradox Valley Brine containing approximately 2.2 pounds of salt per gallon or 616,000 tons of salt. At $122.00 per ton, the economic benefit derived from the project so far is in excess of $75 million. The capital cost of the completed facility was calculated to be $68.7 million (USBR 1996) and annual operating costs are approximately $3.3 million.

The current operating level is 230 gallons per minute of dilute brine, or 161 gallons of brine per minute. The facility is scheduled to operate 325 days per year, allowing for two maintenance shutdowns per year. The resulting disposal of brine is then 75,348,000 gallons of brine or 82,882 tons of salt per year. The economic benefit, at this disposal rate, is $10,111,701.00 per year.

Prior to the seismic event of May 2000, the disposal rate was 345 gallons per minute or 124,324 tons of salt per year. If the addition of the dilution water could be eliminated, the disposal of salt could be returned to 118,404 tons per year, operating at the current 230 gallon per minute injection rate.

Objectives and Results

The prime objective of the project was the prevention of 180,000 to 200,000 tons of salt from entering the Dolores River at Paradox, Colorado. The objective was to be achieved by recovering and injecting the raw brine from the saline aquifer below the river into fractured geological formations more than 2 1/2 miles below ground level. On the way to achieving these results, several milestones are noteworthy:

- Pumping brine from the saline aquifer can significantly reduce salinity of the river, before it enters the river channel. The hypotheses of Jensen and Leach were confirmed.
- The disposal well design was both technically and operationally feasible. The well was constructed as designed.
- The disposal intervals anticipated by Harr and Bremkamp and Others are present. The primary porosity of the rock was lower than anticipated, but the fracture network below the salt diapir exists as anticipated.
- The fracture propagation pressure is higher than originally anticipated, and the resulting injection pressure is higher than planned.
- Using the reservoir test data from 1991 to 1994, a predictive, computerized simulation of the reservoir was prepared. When actual reservoir performance is compared to the computer simulation prediction, the results are quite close.
- The economic benefit of the project is being realized, and the cost of disposal is far below the benefits derived.

Future Plans

THE PROJECT IS A SUCCESS. FOR THE SHORT TERM, THE FACILITY WILL CONTINUE TO OPERATE AS IT CURRENTLY OPERATES. ALTERNATIVE PLANS ARE BEING INVESTIGATED TO ALLEVIATE THE CALCIUM SULFATE PRECIPITATION PROBLEM AND INCREASE THE TONNAGE OF SALT REMOVAL. CONSIDERATIONS ARE ALSO BEING GIVEN TO THE

INSTALLATION OF A SECOND WELL, DRILLED INTO A DIFFERENT SECTION OF THE FAULT SYSTEM, THAT COULD POTENTIALLY DOUBLE THE DISPOSAL VOLUME.

Acknowledgements

The author has been actively involved in the project since November 1986. The information archived in the files evolving from Ken E. Davis Associates to Envirocorp Services & Technology, Inc. and Subsurface Technology, Inc., have been crucial to the preparation of this history. Thanks to Ken E. Davis for his written and oral recollections of events during the inception of the project. Thanks also to the personnel from the USBR, specifically Andy Nicholas and Brad Dodd of the Durango Projects Office, Jon Ake and Ken Mahrer of the Denver Technical Service Center and others who provided vast quantities of data and answered many questions.

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WATERS, EPA's New Internet Tool for Geospatial Analysis of Water Resources

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Abstract:

EPA's Office of Water (OW) has a number of geospatial initiatives in place and planned that will provide integrated access, query, and analysis capability for water and water-related data for specific geographical areas. On May 14, 2001, OW released a *new interactive website* called Watershed Assessment, Tracking, and Environmental Results (or WATERS). WATERS unifies specific geographic water quality information that, in the past, could only be found on individual state homepages and at several different EPA program websites. WATERS uses EPA's standard mapping application, Enviromapper, to display the information and integrates USGS's National Hydrography Dataset (NHD) as the common language to connect and display surface water information. The new website address is: www.epa.gov/waters.

WATERS is a valuable Internet tool for communities and citizen groups involved in drinking water source water protection or related watershed initiatives. Although currently focused on surface water quality, the application allows easy geographic access to contamination and source information in the watershed useful to ground water protection activities as well. EPA plans to expand WATERS to include source water protection areas around both surface water intakes and wells.

WATERS is a *work-in-progress*. The presentation will demonstrate the Internet data and mapping features of WATERS, illustrate with examples how it may be used by local communities involved in source water protection activities, and solicit ideas on how the application can be made more useful to communities involved in groundwater protection.

CLASS I UIC SALINE AQUIFERS AND NON-CONTAMINATION

by

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Biography

James E. Clark holds a Bachelor's Degree in geology (1972) from Auburn University and a Master's' Degree in geophysical sciences (1977) from Georgia Institute of Technology. James' undergraduate bachelor's research involved mapping the geology of Shelby County, Alabama. Master's work was in geohydrology and his thesis involved remote sensing of the major streams and rivers in the Coastal Plain of South Georgia. This study confirmed that underlying the coastal plain sediments are the remnants of the continent first splitting apart (plate tectonics). As Chief Geologist for the Georgia Department of Transportation, he conducted studies and investigations involving geotechnical, geohydrological, environmental, and mineral law suits. As a geohydrologist with Law Engineering Testing Co., he worked on numerous consulting projects within the United States and has four (4) years experience on suitability studies of salt domes as repositories for high level nuclear waste isolation. For the past twenty (20) years, James has been a consultant with DuPont and is a member of the Corporate Remediation Group. James has published numerous papers associated with flow and containment of deep saline aquifers, permitting, and evaluation of injection wells.

Abstract

In a recent trial by jury, the plaintiffs made allegations that injectate saline aquifers had been polluted and contaminated by Class I UIC wells permitted by the State and the Environmental Protection Agency (EPA). These permitted Class I wells injectate into saline aquifers that are not usable and contain total dissolved solids (TDS) higher than 10,000 mg/l. Since the EPA has determined that these saline aquifers are not usable or have any potential to supply water, there cannot be any pollution or contamination, as alleged by the plaintiffs. The jury found in DuPont's favor on all three liability issues - trespass, unlawful use and occupancy, and intentional discharge of pollutants, and, thereby, rejected a $174 million damage request.

Regulated Recharge Area Proposal for the Pleasant Valley Public Water District (PWD)

By

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ABSTRACT

Numerous states have developed groundwater protection management programs through statutory and regulatory authority. The Illinois Groundwater Protection Act (IGPA) adopted in 1987 required the Illinois Environmental Protection Agency (EPA) to develop: groundwater standards; Class III: Special Resource Groundwater designation for groundwater contributing to dedicated nature preserve(s); technology control regulations for certain existing and new activities within the setback zone or regulated recharge areas of potable water supply wells; maximum setback rules; and minimal hazard certification rules for potential sources of groundwater contamination. The IGPA required the Illinois Pollution Control Board (Board) to adopt these regulations. Illinois has a rigorous regulatory development system whereby the legal burden of proof is on the proponent of an environmental regulation (see the Board's procedural rules at: http://www.ipcb.state.il.us/rules/procedural/procedural.htm). Further, the IGPA provided the Board with the authority to adopt regulated recharge area regulations. Additionally, the IGPA authorized counties and municipalities served by community water supply wells to conduct groundwater protection needs assessments, and required the Illinois EPA to conduct well site surveys. The IGPA also required the Illinois State Water and Geological Surveys to develop a Potential for Aquifer Recharge Map to be used by the Interagency Coordinating Committee on Groundwater (ICCG) to designate Priority Groundwater Protection Planning Regions. In addition, the IGPA provided the authority to the Director of Illinois EPA to designate priority groundwater protection planning committees. These committees have the authority to petition the Illinois EPA to propose regulated recharge areas to the Board after a local public meeting. The groundwater standards; technology control regulations; minimal hazard certification rules; and maximum setback rules have all been developed and adopted. These finalized rules and regulations can be accessed at the Board's homepage at: http://www.ipcb.state.il.us/ under Subtitle F. As a result of a petition from the Central Groundwater Protection Planning Committee to develop a regulated recharge area for the Pleasant Valley Public Water District the Illinois EPA developed a proposal to establish a prevention-oriented regulation to apply within the contributing recharge area of Pleasant Valley's community water supply. The Board has published this proposal at Second Notice. This proposal, statement of reasons, pre-filed testimony and transcripts can be accessed at: http://www.ipcb.state.il.us/rules/proposal.htm#R00-

017. The purpose of this paper is to describe the groundwater management provisions of this proposal.

(Key Words: Groundwater protection management, source water protection, regulated recharge areas)

REGULATED RECHARGE AREA PROPOSAL FOR THE PLEASANT VALLEY PWD

Introduction

Section 3 of the Illinois Groundwater Protection Act ("IGPA") of 1987 established a definition of a regulated recharge area that describes "…a compact geographic area, as determined by the Board, the geology of which renders a potable resource groundwater particularly susceptible to contamination." The regional groundwater protection program that emerged after intensive negotiations on the development of the IGPA can be summed up in five general principals:

- Local involvement;
- Responsible partnership;
- Differential protection;
- Sound technical information; and
- Preference for prevention.

GROUNDWATER PROTECTION NEEDS ASSESSMENT AND THE CENTRAL GROUNDWATER PROTECTION PLANNING COMMITTEE

In 1992 a groundwater protection needs assessment ("needs assessment") was completed for the Pleasant Valley Public Water District ("District"). (see Figure 1) The needs assessment first delineated the recharge area for the District, and secondly determined that it was susceptible to groundwater contamination due to the nature of the hydrogeologic conditions, existing potential sources of groundwater contamination and land-use. The needs assessment recommended that a recharge area protection program be established. Following completion of the assessment the District worked with Peoria County to develop a local recharge area protection program. This effort led to utilizing the regulated recharge area provisions under the Act.

The District's Board of Trustees adopted a formal resolution on November 4, 1994 to seek the establishment of a regulated recharge area. The District Board sent this resolution, and requested the Central Groundwater Protection Planning Committee ("Committee") to petition the Illinois EPA to develop a regulated recharge proposal through their authority under the Illinois Environmental Protection Act ("Act").

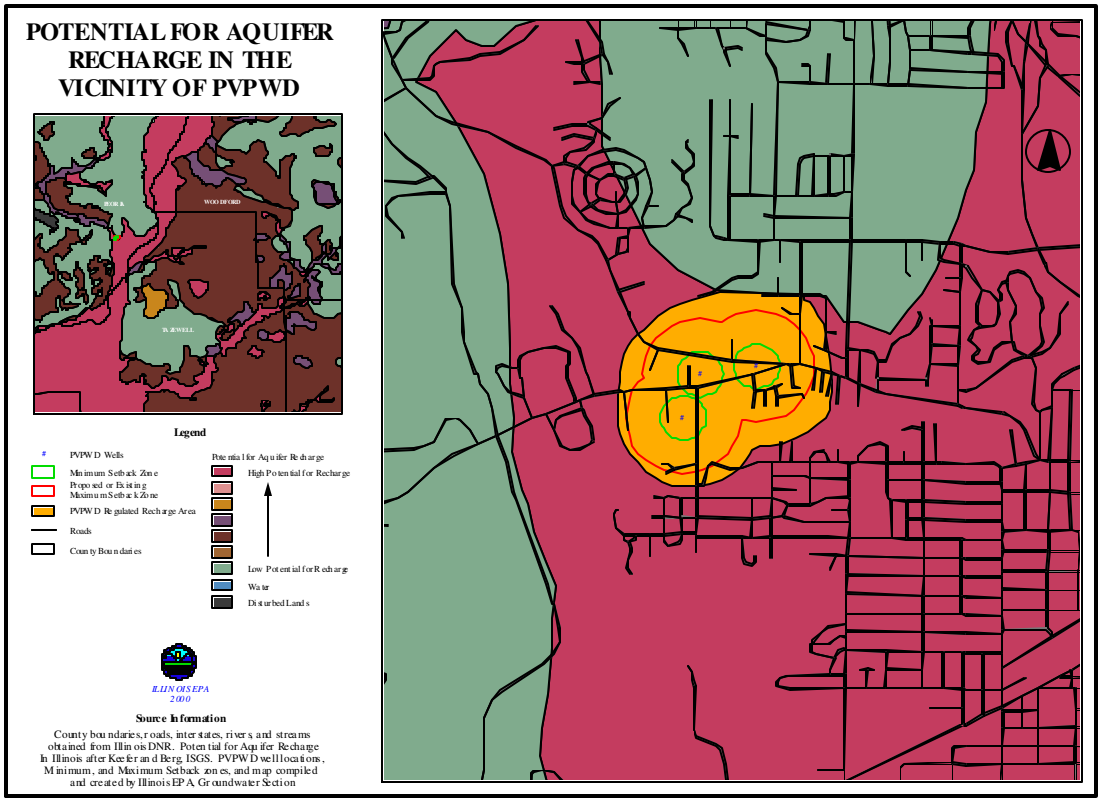


Figure 1. Potential for Aquifer recharge in the Vicinity of the Pleasant Valley PWD

The Committee reviewed the request and voted unanimously On October 19, 1994 to proceed with making such a recommendation. However, before proceeding the Act requires that the Committee hold a public meeting in the area potentially affected by the proposal. A notice was placed in the Peoria Journal Star on December 27, 1994 announcing the public meeting. The meeting was held in Pleasant Valley on January 1995. The Illinois EPA's hearing officer conducted the public meeting and a transcript was taken. No objections were made during the public meeting. The Committee determined that the record supported the motion of October 19, 1994. The Committee then proceeded with petitioning the Illinois EPA on March 28, 1995 to develop a regulated recharge area proposal to submit to the Illinois Pollution Control Board ("Board") for the District.

Illinois EPA Evaluation of The Groundwater Protection Needs Assessment

After receipt of the petition the Illinois EPA began evaluation of the needs assessment as required in Section 17.3(b)(2) of the Act. The Illinois EPA had reviewed the assessment prior to and after its completion in 1992. The Illinois EPA found the needs assessment to be technically adequate in response to the petition received from the Committee on March 28, 1995. The Illinois EPA further evaluated the modeling conducted by Clark Engineers through additional work done in conjunction with the Graduate Geohydrology Program at Illinois State University ("ISU Geohydrology") and the Committee. To assist with the on-going groundwater protection efforts in the Central Planning Region the Illinois EPA, and the Committee initiated a project with ISU Geohydrology to develop a regional groundwater flow model for the entire Peoria area. This

modeling was completed in 1998. Illinois EPA has evaluated, and run this model subsequently to take into account multiple pumping wells and new wells that have gone on-line, since 1992, in the vicinity of the District. The modeling was performed in accordance with the methodology described in a "Guidance Document for Conducting Groundwater Protection Needs Assessments" prepared by the Illinois EPA, Illinois State Water Survey and the Illinois State Geological Survey,

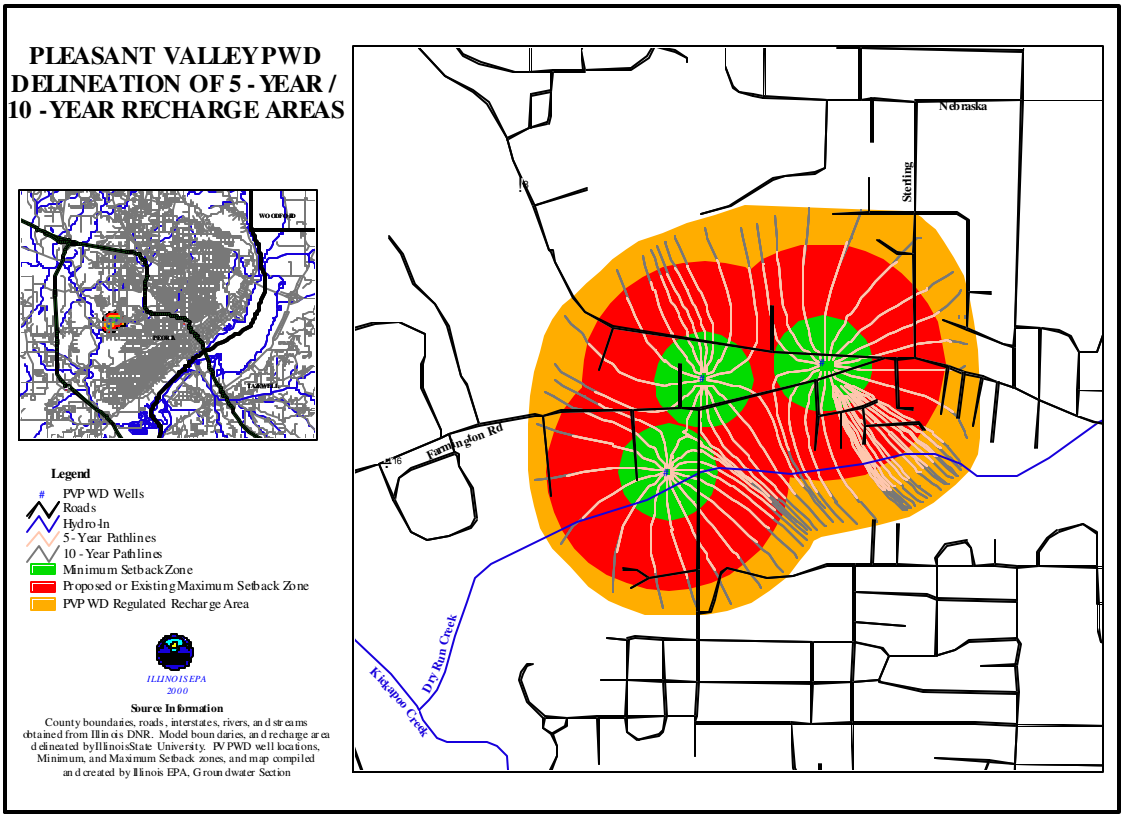


Figure 2. Delineated Contributing Recharge Areas for the Pleasant Valley PWD

and according to the methods prescribed in "APPLIED GROUNDWATER MODELING Simulation of Flow and Advective Transport, prepared by Anderson and Woessner, 1992.

The groundwater modeling in the needs assessment conducted by Clark Engineers and the new modeling conducted by the Illinois EPA with assistance from ISU Geohydrology both used the United States Geological Survey ("USGS") public domain groundwater flow models known as MODFLOW (A modular three-dimensional finite-difference ground-water flow model, Techniques of Water-Resources Investigations 06-A1, USGS McDonald and Harbaugh, 1988), and the particle tracking program referred to as MODPATH (Documentation of computer programs to complete and display pathlines using results from the U.S. Geological Survey modular three-dimensional finite-difference ground-water model, USGS, Open File Report 89-381, Pollack, 1989). The numerical, block-centered, three- dimensional finite difference approach is utilized in MODFLOW to approximate a solution to the "governing equation" of groundwater

flow as a boundary value problem. Once the groundwater head elevations are simulated and calibrated according to observed mass water level measurements, pumping stresses associated with community water supply wells were induced in the model. MODPATH is then utilized to back track the advective movement of groundwater perpendicular to the groundwater head elevations water table map simulated from MODFLOW to the pumping community water supply wells. These water particles are then mapped to show the portion of the aquifer that is actually recharging groundwater to the wells.

Groundwater Modeling

The basic assumption of groundwater modeling is Darcy's Law, which states that the flow of water through a porous material is proportional to the gradient of the hydraulic head. The hydraulic head is the level to which water would rise in a non-pumping well. Darcy's Law combined with the water balance equation (inflow – outflow = change in storage) yields a governing equation that must be satisfied by the hydraulic head everywhere within the water-saturated porous medium. The solution to this equation satisfies the governing equation not only within the model domain but also along the various boundaries of the model. Once the hydraulic head values throughout the system are known, flowlines and capture zones for water flowing through the system can be delineated.

Except for a few very simple hydrogeologic systems, exact solutions to boundary value problems cannot be found. However, numerical modeling techniques such as the finite difference method can be used to find approximate solutions. In the finite difference method, the model domain is separated into an assemblage of cells. The solution consists of single values of hydraulic head that best characterize each cell.

Geology

The study area consists of Pennsylvanian-aged bedrock covered by glacial drift of up to 300 feet. Much of this glacial drift within the study area consists of the Sankoty Sand, which varies in thickness from 50-150 feet. Bedrock highs exist along the western edge of the Illinois River, while the Pekin-Sankoty Bedrock Valley, about two to three miles wide, is filled with deposits of the Sankoty Sand. The Sankoty Sand, of which the aquifer from which the Pleasant Valley wells pump is made, is fine- to medium-grained quartz grains. The Sankoty Sand is missing along portions of the Illinois River near Peoria and East Peoria and along the bedrock uplands within the study area.

Conceptual Groundwater Flow Model

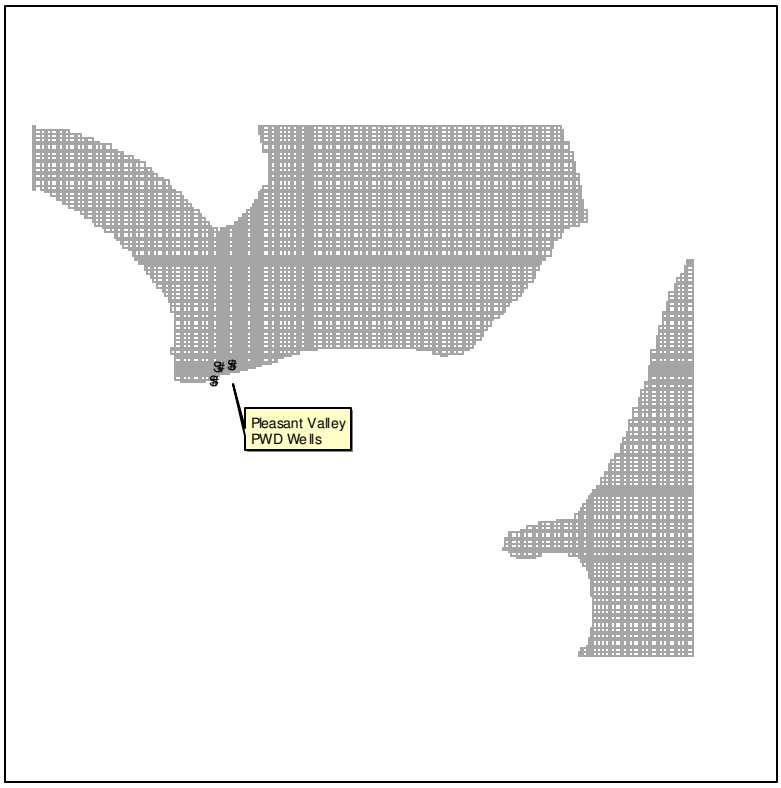
The modeling grid and subsequent recharge area delineations for the community water supply wells were based on digitizing the well locations off USGS (1:24,000 or 1 inch equals 2,000 feet) topographic quadrangle maps. Thus, the modeling grid was tied to real world coordinates. The wells were located and mapped in the field using 1 inch equal 400 foot aerial photographic maps. The aerial photos were used to locate the wells on the USGS maps. Thus, the locations of the wells and the associated recharge area delineations have a locational accuracy that complies with the United States National Map Accuracy Standards.

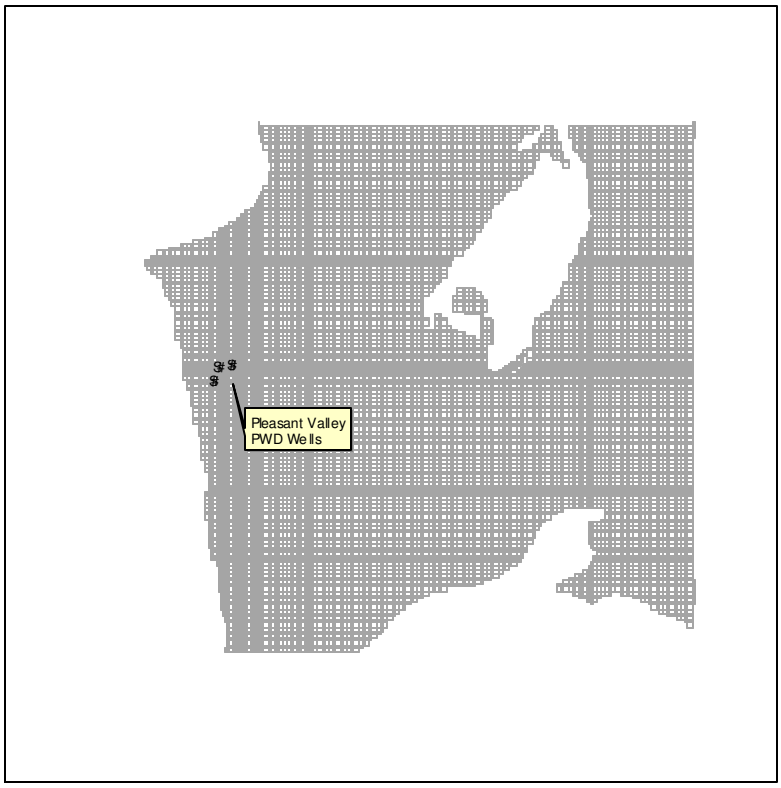
The lambert x and y coordinates for the southeast corner of the model are 2948072 and 2774340 respectively. In order to incorporate all of the municipal wells and any boundary conditions that may affect the results of the modeling, the model area extends 45,000 feet to the east and 36,000 feet to the north, approximately 58 square miles. Input for the model consists of an initial grid of

169 rows and 210 columns representing the study area. Layer one of the model consists of an unconfined aquifer of glacial till with low hydraulic conductivity. Cells where glacial till is thin or absent are made inactive in layer one (Figure 3). Layer one overlies the Sankoty Sand, the aquifer forming layer two. In layer two, the bottom glacial outwash along the Illinois River is modeled as part of the Sankoty Aquifer also. Cells not containing the Sankoty Sand or this glacial outwash are designated as inactive in layer two (Figure 4).

Due to its relative impermeability compared to the above layers, Pennsylvanian bedrock represents the no-flow base of the model. Bedrock highs along the western and southeastern edges of the model are assigned as no-flow boundaries also as they are considered to have no hydraulic connection with the Sankoty. The eastern, northwestern, and southwestern edges of the model are designated as general head boundaries, which allow some flow through the boundary. Kickapoo Creek is simulated in the top layer using the river package. The Illinois River, impounded by a dam south of the study area, is modeled as a general head boundary in the top aquifer with a constant head value of 440 feet and a lake bottom elevation of 435 feet. All of the municipal wells are conceptualized as being screened in the bottom Sankoty Aquifer. All of the wells are also located in separate cells of the grid. Hydraulic conductivity values were developed for the Sankoty Aquifer from values presented by Schicht in a publication entitled "Ground-water Investigation at Peoria, Illinois: Central Well-Field Area. Illinois State Water Survey Contract Report 537". These values are extrapolated from the nearest data point in areas where data is scarce (Boateng, 1998, Well head protection area delineation for Pleasant Valley/Peoria/West Peoria community water supply facilities, Illinois State University report for Illinois Environmental Protection Agency. (unpublished)). The value for layer one is 20 feet per day, while values for layer two range from 38 to 3300 feet per day in one location. Recharge to the top layer of the system is 0.00055 feet per day.

Model calibration was conducted to field-measured data from a previous study conducted by Burch and Kelly, prepared in 1993 and entitled "Peoria-Pekin ground-water quality assessment, Illinois State Geological Survey, Research Report 124". Results of a sensitivity analysis show the average hydraulic head values to be the same with an increase or a decrease of 0.5 feet per day in the hydraulic conductivity. This shows that the model is not overly sensitive to changes in the conductivity values. After model calibration was completed MODPATH was used to generate water particle pathlines, travel times, and capture zones. The porosity for layer one is set at 0.2 and for layer two 0.25.





Figures 3 and 4. Layer one of the model cells are inactive where glacial till is thin or absent. Layer two of the model, the Sankoty Aquifer, cells not containing the Sankoty Sand or glacial outwash are designated as inactive.

Regulatory Evaluation

Further, the Illinois EPA considered the types of potential sources that are present in the Pleasant Valley PWD to develop this proposal. The potential sources were evaluated in relation to:

- Statewide definitions of potential sources and potential routes of groundwater contamination;
- Setback prohibitions;
- Data from 1,200 well site survey reports from community water supply wells;
- Part 255 agrichemical containment rules;
- Part 257 cooperative groundwater program rules for agrichemical facilities;
- Board's technology control regulation for existing and new activities in setback zones and regulated recharge areas;
- Resource Conservation and Recovery Act; and
- Illinois Chemical Safety Act.

This analyses of existing regulatory programs in relation to the types of potential sources located in the District's well field determined that there are gaps at the site specific level to protect Pleasant Valley's well-field recharge area.

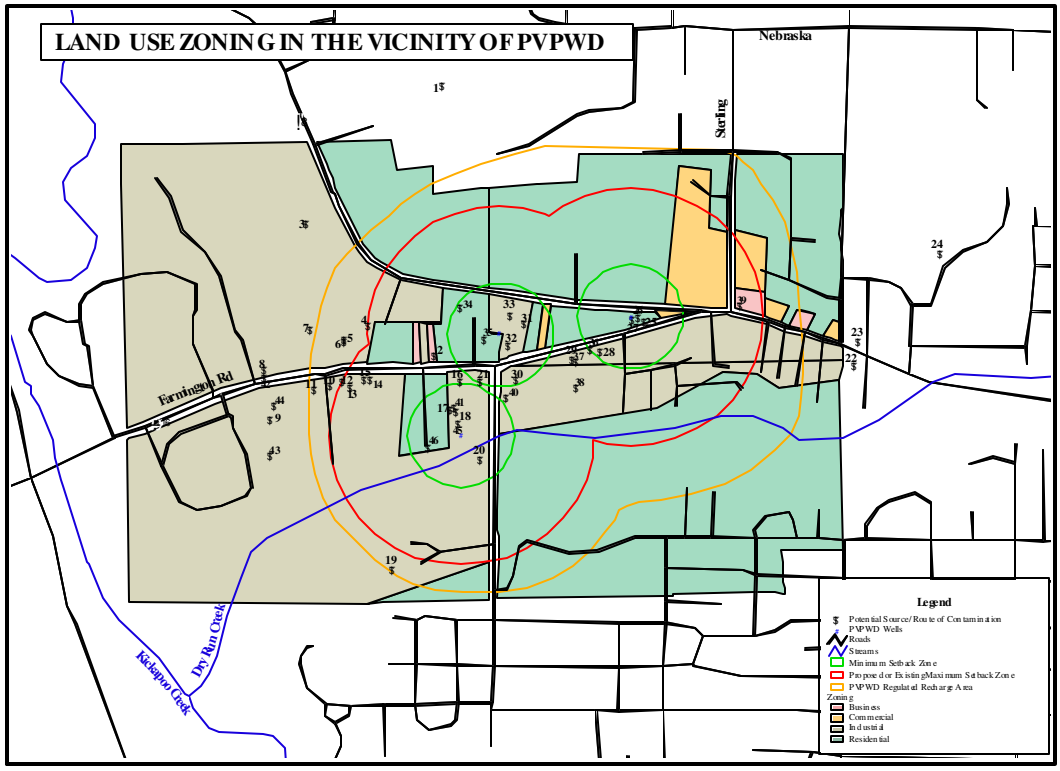


Figure 5. Existing Potential Sources of Groundwater Contamination and Land-Use Zoning

Regulatory Development

Following the technical evaluation the Illinois EPA began developing a draft discussion document for the purpose of getting public input on the proposed regulatory management options. A draft discussion document was developed to obtain input from the Groundwater Advisory Council ("GAC") and the regional groundwater protection planning committees established by the IGPA. The nine member GAC is designated by the Governor, and is comprised of nine members who represent different statewide interests including: environmental, business, agricultural, regional planning, water well drilling, public water supplies, and local government. The regional planning committees have a similar composition but are comprised of seventy five local stakeholders who are designated by the Director of Illinois EPA. The Illinois EPA worked with these groups to sponsor a public workshop that was held in Peoria on June 7, 1996. Good input was obtained at this workshop that helped move from discussion document options toward a draft regulatory proposal.

Numerous draft regulatory proposals were developed and provided to the GAC, the Interagency Coordinating Council on Groundwater ("ICCG"), and the Regional Planning Committees for comment and input. Following these efforts a second public workshop was held on August 6, 1998 to obtain input on the draft regulatory proposal that had been developed since the workshop held in Peoria Illinois on June 7, 1996. The input received at the workshop indicated that this was a sound proposal.

On September 14, 1998 the ICCG and GAC held a joint meeting and discussed the results of the public workshop. The GAC and members of the ICCG including: the Illinois Department of Agriculture; Illinois
Department of Natural Resources; Illinois Emergency Management Agency; Office of the State Fire Marshall; Illinois Department of Nuclear Safety; and Illinois Department of Commerce and Community Affairs were provided with two more weeks to review and provide input on the draft. No comments were received.

Pursuant to Section 17.3(c) of the Act the Illinois EPA then proceeded on November 14, 1998 to publish a press release, and to notify each affected county, municipality, township and soil and water conservation district of the intent of proposing a regulated recharge area for the District. Sixty days notice was provided to the stakeholders described above before this proposal was submitted to the Board.

Regulated Recharge Area Proposal

The Illinois EPA's regulated recharge area proposal is broken out into two sections. Subpart A contains general provisions that we are proposing apply in any delineated recharge area adopted by the Board. Subpart B contains proposed requirements that only apply in the District's delineated recharge area.

SUBPART A

Definitions -There are three key definitions that have been developed for this proposal, as follows: chemical substance; potential tertiary source (existing/new); and major potential source. The definition of "chemical substance" incorporates a 100 pound threshold, and includes extremely hazardous and hazardous substances. The chemical substance definition also clearly excludes these chemical substances if they are utilized exclusively for personal, family or household use.

Potential tertiary sources are defined in this proposal as existing or new units at a facility or site that store or accumulate chemical substances. In addition, the third key definition is a "major potential source". Major potential source is defined in this proposal as a unit at a facility or site that stores, accumulates, landfills or land treats waste. This definition further specifies that the waste be generated on the site, and that it has the potential of contaminating groundwater.

Prohibitions - After careful evaluation, the Illinois EPA believes that there are certain types of new potential sources that should not be located in the regulated recharge area of a community water supply. The Illinois EPA is proposing to prohibit the following new potential sources from locating within a regulated recharge area adopted by the Board:

- Low level radioactive waste site;
- Class V underground injection wells;
- Municipal waste landfills; and
- Special or hazardous waste landfills.

Recharge Area Suitability Assessment - The purpose of the recharge area suitability assessment ("RASA") is to establish a means of assessing the risk of a new "major potential source" before commencing construction. Additionally, the intent of this section is to provide an incentive for implementing best management practices before locating in a regulated recharge area adopted by the Board. The RASA process evaluates the protective measures and management systems being proposed by any new major potential source, and further analyzes the potential environmental impacts. Public input is also part of this proposed process.

Technology Control Regulations -This proposal expands the area of applicability of the Board's existing regulations (35 Ill. Adm. Code 615and 616) that apply to existing and new activities located within setback zones and regulated recharge areas. Additionally, this proposed section also expands the area of applicability to any exiting or new agrichemical facility subject to (8 Ill. Adm. Code 257 or 77 Illinois Adm. Code 830).

Abandoned and Improperly Plugged Well Assistance Program - This section of the proposed regulation was developed with the intent of implementing an improperly abandoned well education and assistance program within highly sensitive delineated regulated recharge area(s). Improperly abandoned wells can provide a direct conduit for contamination of the groundwater. The public input received through the development of this proposal has emphasized the need for this provision to help protect the groundwater used by the community water supplies.

Road Sign Posting - Signage is an approach that has been used by local governments and European countries as a form of education. Use of signs along roadways or at public facilities increases awareness of where recharge protection areas or watersheds are located. Signs also serve to educate individuals, and also provides a mechanism for notification in cases of an accidental contaminant release. Therefore, signage may lessen or prevent impacts associated with contaminant spills. This Section of the proposal before the Board is intended to demarcate the entrance and exit of state and interstate roads that cross recharge areas delineated by the Board.

SUBPART B

Subpart B of the proposed regulation is being proposed specifically for the District and it contains four specific provisions, as follows:

- Registration procedure for potential sources and potential routes of groundwater contamination;

- Information and registration meeting;
- Management systems for existing and new potential tertiary sources; and
- Training program for potential tertiary sources.

Subpart B also includes two appendices. Appendix I illustrates the recharge area delineated for the District, and appendix II contains the proposed potential source and potential route registration form. Additionally, the map in appendix I shows the delineated recharge areas with respect to: county boundaries; township, range and section boundaries; and the USGS digital line graph ("DLG") roads coverage. The DLG roads coverage are at a scale of 1:100,000.

Registration -This proposed provision requires a registration process for all categories of potential sources and routes of groundwater contamination. The registration process will assist the Illinois EPA with the proposed informational and training program. In addition, this will assist with determining compliance with the adopted regulation in-lieu of a complex permit system that Illinois EPA does not believe is appropriate for the types of businesses in the District.

Information and Registration Meeting -Illinois EPA is proposing that we hold an informational and registration meeting within the District to assist persons with meeting the registration and other regulatory requirements in this proposal. The intent of the meeting is to assist the small businesses with protecting the groundwater within the delineated area in the District.

Management Systems - Management system requirements are being proposed for potential tertiary sources located with the District's delineated recharge area to prevent contamination from chemical substances. The Illinois EPA is proposing performance based requirements for existing and new potential tertiary sources, and secondary containment provisions for new potential tertiary sources. These provisions have been developed specifically with small businesses in mind. The requirements also make provisions for acknowledging where management systems are being used, and also accepts that pre-fabricated containment structures can be used for new potential tertiary sources.

Training Program - Subpart B is proposing a training program to by offered by the Illinois EPA to provide technical assistance to the small businesses in the District's delineated recharge area. Further, this training program is intended to provide for awareness regarding the sensitivity of the recharge area, meeting the requirements in the regulation, and assistance with pollution prevention and Small Business Program opportunities.

Pollution Prevention Technical Assistance

Starting in July an Illinois EPA Pollution Prevention (P2) intern was placed at the Tazewell County Health Department to assist with facilitation of groundwater protection activities within the Central Groundwater Protection Planning Region (see http://www.dpc.net/~crgw/). The Planning Region encompasses the counties of Mason, Peoria, Tazewell, and Woodford. The Tazewell County Health Department has always taken an active leadership role on the Central Groundwater Protection Planning Committee. The intern's activities included conducting waste minimization reassessments, new assessments, creating and distributing a business recycling poster, and creating brochures for the residents and businesses of the Pleasant Valley PWD. Businesses located within the source water protection area of the Pleasant Valley PWD were assessed by the P2 intern and provided with numerous recommendations to reduce the risk to the source water.

The following provides a summary of the types of recommendations made by the summer 2000 P2 intern to assist the businesses:

- Place drip pans under equipment on lots to prevent groundwater contamination;

- Storage tanks and barrels should be stored on a surface that does not allow fluids to seep through, such as cement or asphalt or remove barrels that are not needed by contacting a local waste hauler;

- It is recommended to use longer lasting synthetic oils to minimize the amount of used oil and used oil filters generated. The used oil and filters can then be recycled. After oil filters are drained for at least 12 hours, they can be recycled. The waste oil and filter paper from recycled filters are used as an energy source and the scrap metal from recycled filters can be reused;

- It is recommended that scrap metal and lumber be recycled. Contact a local waste hauler about recycling these materials;

- Perform regular preventive maintenance of machinery, equipment, containers, and tanks, such as tightening and replacing leaky seals, gaskets, and dispensers;

- Chemicals should not be disposed of down the drain. Contact the Peoria County Solid Waste Management (309-672-6932) or the call the Illinois EPA Office of Small Business Helpline at (888-EPA-1996) for proper disposal of chemicals;

- Office and break rooms provide many waste reduction opportunities. This may include encouraging the use of washable mugs, plates, and utensils. Reusing scrap paper for note pads, recycle office paper, store ads, cardboard, cans, and glass are other waste reduction recommendations. Making double-sided copies will also save on paper;

- The Industrial Materials Exchange Service (IMES) is a free service that provides a mechanism to recycle and reuse unwanted materials. Placing a listing and description of the pallet over-wrap in this publication will determine if any company is interested in the material. The IMES publication is mailed out to over 18,000 companies nationwide. For more information contact IMES by phone;

- It is recommended that the paper and cardboard be recycled. Arrangements can be made by contacting a local waste hauler;

- If not already implemented, it is recommended that all chemicals be stored inside to prevent ground contamination;

- It is recommended to buy in bulk quantities when appropriate;

- Secondary containment underneath and around all storage tanks and barrels would safeguard against groundwater contamination;

- If not already implemented, it is recommended that secondary containment be placed underneath used batteries being stored for disposal. This will prevent groundwater contamination;

- It is recommended that partially used absorbent material be stored in closed, labeled containers for reuse;

- To reduce the amount of solvent being used, paint cups should be scraped of residual paint before being placed in the spray gun cleaner;

- Cleanable, styrofoam filters are recommended because they can be blown clean with compressed air and reused several times. When they are no longer reusable, they can be dissolved in waste thinner. It should be noted that paint blown out of the filter still needs to be collected if it contains lead or chromium compounds, since it is a hazardous waste. Also, make sure that the thinner recycler would not have a problem with receiving waste thinner with dissolved styrofoam before starting to use cleanable styrofoam filters;

- A computerized inventory making note of the date and amount of paint may be useful in minimizing waste of raw materials;

- It is recommended that an oil waste hauler with a lower or no minimum pickup amount be contacted for disposing the used oil. With less oil on-site, this will reduce the potential for groundwater contamination. Shop space will be saved since the number of barrels needed for storage will be reduced. Two such haulers are Oil Waste Services, that requires a minimum of 55-gallons, and Safety-Kleen, which does not require a minimum amount of used oil for pickup;

- To reduce the loss of cleaning solution, it is recommended that the parts be drained thoroughly over the parts washer;

- It is recommended to use dry pre-cleaning methods, such as wire brushing, whenever possible to reduce the load on the parts washer;

- By substituting water-borne paint for solvent-based paint, VOC emissions from painting operations can be minimized. Other advantages are the reduction of the hazardous nature of the paint residues, the reduced personnel safety hazard, and the ability to clean equipment with water;

- It is recommended that Waste Management be contacted about recycling the tires.

- A self-contained, recirculating solvent sink, is recommended to incorporate solvent reuse.

- Keep parts washer closed and away from heat to minimize product loss and air emissions from evaporation.

- It is recommended that a wash solution not be changed on a scheduled basis. Cleaning solution should only be changed when it no longer adequately cleans parts will save on solvents;

- If available, it is recommended that area washdown wastewater be discharged to a publicly owned treatment works (POTW) or industrial sewer instead of the storm drain;

- It is recommended to provide consumer initiatives for waste reduction. This can include selling canvas or other reusable bags or boxes. This will reduce the number of bags used by the store. Also, selling returnables and bulk food reduces waste. Provide collection of recyclables at the store for plastic bags and aluminum cans. Again, arrangements for recycling pickup can be made by contacting a local waste hauler;

- Rigid control over inventory can be useful in minimizing waste of raw materials; and

- An employee training and incentive program would preferably include pollution prevention training. Such training would include training on spill prevention and proper cleanup techniques.

Conclusion

States have significant experience with developing groundwater protection management programs. This experience provides a strong foundation for evaluating the level of source water protection management that is occurring across a state.

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PERFORMANCE EVALUATION OF A MARSHLAND UPWELLING SYSTEM FOR THE TREATMENT OF DOMESTIC WASTEWATER FROM COASTAL DWELLINGS

Robert E. Watson, Jr., Stephen D. Richardson, Jeremy P. Fontenot, Kelly A. Rusch, Ph.D., P.E.

Abstract

Currently approved on-site treatment techniques (i.e. septic systems and adsorption fields) are severely impaired in the saturated, tidally influenced soils of coastal regions and can contribute to water quality problems. The Marshland Upwelling System (MUS) is a decentralized treatment strategy designed specifically for the unique hydrogeological conditions of coastal zones. The MUS uses the soil's natural filtration properties and density differences between the wastewater and saline subsurface to provide cost-effective, low-maintenance treatment. Costs are limited to operation of an injection pump that intermittently delivers wastewater down a shallow (12-15 ft), Class V well. Upon injection, the waste percolates upwards through the media in the direction of decreasing density prompting waste stabilization prior to reaching the ground surface.

The nine-year, on-going study has focused primarily on system's efficacy in removing fecal pathogens from settled and secondary domestic wastewater sources. The MUS has reduced coliform bacteria concentrations to below standards for shellfishing and recreational waters in the Scatlake soils and salinity regime found at the Port Fourchon, LA experimental site. Optimal performance was achieved at a flowrate of 1.9 L/min when injected intermittently for 30 minutes every 3 hours. Informal results also revealed extreme reductions in influent BOD.

An additional pilot system has been installed along Bayou Cumbest in Moss Point, MS to evaluate its ability to provide total treatment under different soil types and salinity profiles. Nutrient, organic, and bacterial removal is largely dependent on the wastewater plume dynamics. Thus, evaluation of the fundamental mechanisms responsible for plume development is a primary concern. Preliminary data concerning the fate and transport of fecal coliform bacteria and organic matter ($CBOD_5$) will be presented. The ultimate goal of the MUS project is to develop operational criteria, based upon economical and ecological concerns, in hopes of providing an approved, effective treatment alternative for coastal dwellings.

Biographical Sketch

The Institute for Ecological Infrastructure Engineering's (EiEL) is a research institute within the College of Engineering at Louisiana State University. EiEL is dedicated to fully integrating science into the existing engineering infrastructure in the pursuit of ecologically sustainable solutions to environmental and infrastructure problems.

Rob Watson received a B.S. in mechanical engineering from USC in 1997. He received a M.S. in civil engineering from LSU in 2000 and is currently a Ph.D. candidate in the Department of Civil and Environmental Engineering. His research focuses upon using wetlands as a decentralized wastewater treatment option for coastal dwellings.

Geologic Control of Water Quality in the Michigan Basin

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BIO

Gary Dannemiller has been a Senior Project Consultant with Soil and Materials Engineers, Inc. in Lansing, Michigan for the past six years performing numerous surface and groundwater investigations that involve flooding, water supply, waste water discharge permits and contamination. He was previously employed by the United States Geological Survey as a hydrologist conducting a Regional Aquifer-System Analysis of the Michigan Basin and by the United States Environmental Protection Agency in Region VI (Dallas) in the Technical Section of RCRA.

Abstract

The lower peninsula of Michigan consists of bedrock that forms a structural basin that is overlain by glacial Pleistocene age deposits of variable thickness. The overlying glacial deposits cause the present ground water flow direction in the bedrock aquifers. The ground water flow direction through the bedrock imparts a ground water quality that is reflective of the composition of the bedrock. Ground water flows in bedrock aquifers from upland areas in the northern and southern parts of the basin to lowland areas that discharge into Lakes Michigan, Huron and Erie. Areas of thick clay deposits in the lowland areas impart differences in quality of ground water by retarding ground water movement in discharge areas. The major freshwater aquifers in the Michigan basin are the Marshall sandstone of Mississippian age, the Grand River-Saginaw formation of Pennsylvanian age and the glacial deposits.

Analysis of 290 ground water samples from bedrock aquifers and 180 samples from the glacial aquifer collected across the basin were used to identify ground water quality changes along flow paths. Major ion chemistry of ground water in recharge areas approximates a calcium-bicarbonate type, and discharging ground water is a sodium chloride type. Ground water in areas where the two water types mix is a calcium sulfate to sodium sulfate type. The ground water is saline to brine in the deeper parts of the basin and in areas defined as regional discharge areas. In addition to major ion chemistry, isotopic analysis of carbon 14/13 and del deuterium/oxygen-18 were used to define ground water recharge, discharge and flow paths.

A Demonstration of Two New RBDMS Add-ons: Multilateral Construction and Wellbore Schematic Utility Phase 2

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VES will discuss two new add-ons for RBDMS. The first is the Multilateral Construction add-on, which is now available for testing and demonstration. The other is the Wellbore Schematic Utility (WSU) Phase 2.

The Multilateral Construction add-on tracks downhole locations (e.g., bottom hole location, entering production zone, and surface location), perforations, and casing and other features. It is available at http://VirtualES.com/Downloads/RBDMS_Multi.zip. The zip file contains an Access 2000 database for the front end and your choice of back end: either an Access 2000 database or a SQL script you can use to create the back end.

The WSU Phase 2 works with the Multilateral Construction add-on to render scaled diagrams of multilateral and directionally drilled wellbores instantly. Like Phase 1 of the WSU, which is in use in Colorado, New York, and the Osage Nation, Phase 2 uses object linking and embedding (OLE) automation deployed through a Visual Basic interface to link Visio drawing capabilities with a Level 2 ODBC environmental data source such as RBDMS.

The application also includes other enhancements, such as the ability to show downhole locations (up to 50 x, y, and z coordinates), and lithology and other zone information related to water-bearing and oil- and gas-producing zones and geological formations. The following four locations will be typical:

- Surface location (top of vertical hole)
- The point at which the lateral branches from the main hole
- The point at which the lateral enters the producing zone
- The end of the multilateral branch

Both SQL Server stored procedures and Access 2000 queries have been developed for querying the data needed to create the schematic. The WSU was designed so that users can use either Access or SQL Server as the database.

To maintain a common code base for the well schematic, the program will work with both the core RBDMS and the Multilateral Construction add-on. Administrators can set up the WSU Phase 2 to run in two ways: either from a form within RBDMS or from an automated script that creates .gif files for a Web server.

A Demonstration of Oil and Gas Production Reporting with XML

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A utility that oil and gas owners and operators can use to report production data directly to state agency databases is now available for beta testing. VES will demonstrate this utility, which accepts XML-formatted data via either an attachment to an e-mail transmission to a POP3 mail server or an online Web application. The three primary components of this system of production reporting are as follows:

- ***An XML schema,*** which defines the format required for commonly reported production data and was developed through a review of the Petroleum Industry Data Dictionary and W3C standards.

- ***An Access 2000 mde*** program for production data entry and creation of an XML file that conforms to the OilGasProductionReg XML schema. Owners and operators can create XML files with either the ProdXML.mde Access database or with a custom export program linked to their data.

- ***An online Web application,*** which for testing purposes, is at either of these addresses: mailto:ProdXML@VirtualES.com or http://VirtualES.com/ProdXML.

For e-mail, an automated response is sent to indicate if the data was accepted. The Web site reports data status directly to the user's browser. The program now validates the XML against the production schema and performs the following validation checks:

- Valid Facility.FacType code
- Valid tblOil.WaterDisp code
- Valid tblTank.TankFluid code
- Valid tblInjection.InjectionFluidType code
- Valid tblTank.TankType code
- Valid tblTank.TankConstr code
- Valid tblTank.TankBase code
- Valid tblWellCurrentWellActivityType code

Such database validation checks as ensuring a valid API number can be added easily via stored procedures.

As discussed in the **Proceedings of the GWPC 2000 Annual Forum** (*Using XML to Share Data Resources*), such a reporting system can be of significant benefit to both industry and state agencies in leveraging exploration efforts and reducing costs through increased efficiency in data management. The utility is anticipated for testing by BP Amoco and the Colorado Oil & Gas Conservation Commission this fall. A zip file with the Access 2000 mde and the final draft of the XML schema can be downloaded from http://VirtualES.com/downloads/ProdXML_010524.zip.

Clarifying Federal Regulatory Requirements for

In Situ Bioremediation

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ABSTRACT

In 1998 the Interstate Technology and Regulatory Cooperation (ITRC) Work Group published a report titled "Technical and Regulatory Requirements for Enhanced In Situ Bioremediation of Chlorinated Solvents in Ground Water." That report identified areas of uncertainty in the Resource Conservation and Recovery Act (RCRA) as well as in the Underground Injection Control (UIC) Program regarding injection and reinjection processes associated with in situ bioremediation technologies.

Following publication of the Enhanced In Situ Bioremediation Report, the ITRC Work Group worked with other interested parties to approach US EPA on RCRA 3020(b) - a passage in federal statute that specifically deals with reinjection of contaminated ground water. In a pair of letters issued by the Office of Solid Waste and Emergency Response in December of 1999 and December of 2000, the US EPA removed all uncertainty surrounding RCRA requirements and policy associated with in situ bioremediation and other in situ remediation technologies.

The still-unresolved issues identified in the ITRC's 1998 report on in situ bioremediation are those found in state and federal UIC Programs. Those remaining issues include procedural and policy differences between state and federal UIC programs, uncertainty about the appropriate classification for remediation wells, and the fee structure for permitting multiple injection wells necessary for implementing some in situ remedies. It will be a significant accomplishment when the regulatory uncertainty associated with the role of UIC Programs in permitting injection and reinjection wells associated with site remediation has been removed, as has already been accomplished for RCRA requirements.

Introduction

In 1998 the Interstate Technology and Regulatory Cooperation (ITRC) Work Group published a report titled Technical and Regulatory Requirements for Enhanced In Situ Bioremediation of Chlorinated Solvents in Ground Water. That report identified areas of uncertainty in the Resource Conservation and Recovery Act (RCRA) as well as in the Underground Injection Control (UIC) Program regarding injection and reinjection processes associated with in situ bioremediation technologies.

Following publication of the Enhanced In Situ Bioremediation Report, the ITRC worked with other interested parties to approach US EPA on RCRA 3020(b) - a passage in federal statute that specifically deals with reinjection of contaminated ground water. In a pair of letters issued by the Office of Solid Waste and Emergency Response in December of 1999 and December of 2000, the US EPA removed all uncertainty surrounding RCRA requirements and policy associated with in situ bioremediation and other in situ remediation technologies.

The still-unresolved issues identified in the ITRC's 1998 report on in situ bioremediation are those found in state and federal UIC Programs. Those remaining issues or differences between state and federal UIC programs include uncertainty about the appropriate UIC classification for remediation wells, and the fee structure for permitting multiple injection wells necessary for implementing some in situ remedies. It will be a significant accomplishment when the regulatory uncertainty associated with the role of UIC Programs in permitting injection and reinjection wells associated with site remediation has been removed, as has already been accomplished for RCRA requirements.

Barriers to Deployment

The 1998 ITRC document Technical & Regulatory Requirements for Enhanced In Situ Bioremediation of Chlorinated Solvents in Ground water identified regulatory barriers that were preventing consistent deployment of enhanced in situ bioremediation at chlorinated solvent sites. Since 1998 solutions to some of these barriers have been obtained, but still others remain unchanged.

The major barriers identified in the ITRC's 1998 document on enhanced in situ bioremediation were:

1. Reinjection Under RCRA 3020 (b) - This passage of RCRA states that contaminated ground water must be treated to substantially reduce hazardous constituents prior to reinjection. It was unclear if this passage required both treatment and a reduction of contaminant levels prior to reinjection of extracted ground water, or just substantial treatment prior to injection, with the ultimate result being a reduction in contaminant levels within the aquifer.

2. Class IV UIC Wells - When extracted ground water is considered to be contaminated by a hazardous waste, reinjection of the contaminated ground water into an aquifer to enhance bioremediation may be considered a Class IV injection well (40 CFR Part 144). This determination would, in some cases, require inappropriate treatment of amended ground water prior to reinjection, which could likely result in diminished if not unacceptable performance for an in situ bioremediation project.

Resource Conservation and Recovery Act (RCRA)

The ITRC document, Technical and Regulatory Requirements for Enhanced In Situ Bioremediation of Chlorinated Solvents in Ground water[1], identified the challenges inherent in using such a technology in light of the uncertainty of how RCRA 3020(b) might be interpreted. By design an in situ bioremediation project typically involves extraction of ground water that is amended by the addition of organic carbon, nutrients, electron acceptors, and/or microbial cultures prior to reinjection. This type of process can achieve a remarkable reduction of contaminant concentration, but such reduction occurs in the aquifer and only after reinjection.

While researching these issues the ITRC In Situ Bioremediation Work Team identified case studies throughout the United States[2] to evaluate the use of various amendments to promote in situ bioremediation of contaminants in ground water. These case studies identified the need in many instances to (1) extract ground water to control plume migration and (2) to mix additives with the contaminated ground water and reinject it into the plume to enhance the bioremediation of the contaminant. It was scientifically sound and clearly preferred to use the contaminated ground water as the reinjection material due to its inherent similarity to the actual plume. Using the contaminated ground water as the host for the additives for injection and dispersal into the plume clearly lowers the cost of the project and most effectively promotes a chemical and biological environment to substantially reduce the contaminant in ground water.

Relationship to ITRC

Prior to 1998 several states and EPA offices had interpreted RCRA 3020(b) to mean that in situ bioremediation technologies couldn't be deployed and maintain full compliance with the literal language of RCRA 3020 (a) and (b). ITRC raised the issue among its membership, and in the fall of 1999 achieved a consensus among 15 states to issue a letter from ITRC to the EPA seeking clarification of the issue of reinjection of amended contaminated ground water to encourage in situ remediation. Agencies in California worked independently yet in parallel with ITRC to encourage this clarification from EPA.

On December 10, 1999, EPA's Office of Solid Waste sent a letter to the State of California providing the following clarification:

> "*As you know, RCRA section 3020(a) bans hazardous waste disposal by underground injection into or above an underground source of drinking water (within one-quarter mile of the well). However, section 3020(b) exempts from the ban the reinjection of contaminated ground water under a Superfund section 104 or 106 response action or as part of a RCRA corrective action?assuming certain conditions are met.*
>
> *Your letter specifically addresses the condition in section 3020(b)(2) that the contaminated ground water be treated to substantially reduce hazardous constituents prior to such injection. In the biotreatment system you describe, ground water contaminated with hazardous waste is withdrawn from an aquifer, amended by the addition of nutrients or other products designed to promote in-*

[1] *Technical and Regulatory Requirements for Enhanced In Situ Bioremediation of Chlorinated Solvents in Ground water*, Final December 23, 1998, prepared by the Interstate Technology and Regulatory Cooperation Workgroup In Situ Bioremediation Work Team.

[2] Appendix D, *Technical and Regulatory Requirements for Enhanced In Situ Bioremediation of Chlorinated Solvents in Groundwater*, December 23, 1998

situ bioremediation, and then reinjected. This approach is consistent with section 3020(b)(2), as long as the hazardous constituents are substantially reduced, either before reinjection or as a result of subsequent in-situ bioremediation.

EPA interprets section 3020(b)(2) to require treatment of the contaminated ground water prior to reinjection, but the substantial reduction of hazardous constituents in the ground water may occur either before or after reinjection. Thus, the extracted ground water is amended at the surface (i.e. treated) before reinjection, and the subsequent in situ bioremediation achieves a substantial reduction of hazardous constituents, the remedy would satisfy section 3020(b)(2). Please note that to qualify for an exemption, the remedy would also have to meet the other conditions specified in section 3020(b) (i.e., the reinjection is a CERCLA section 104 or 106 response action or part of a RCRA corrective action intended to cleanup the contamination, and the response action or corrective action is sufficient to protect human heath and the environment upon completion).

I trust this clarification will facilitate the use of in-situ bioremediation and other in-situ treatments that substantially reduce the hazardous constituents at sites where ground water is contaminated with RCRA hazardous waste."

In April 2000, EPA incorporated similar language into the Handbook of Ground water Policies for RCRA Corrective Action updated April 20, 2000 (EPA 530-D-00-001). On December 27, 2001, EPA's Office of Solid Waste issued an EPA Guidance Memorandum finalizing this clarification. This December 27, 2000 memo reinforced the previous clarification of December 10, 1999, and also went beyond the injection and reinjection issues associated with in situ bioremediation but also applied it more broadly to most in situ remediation technologies. Both of these clarification documents from EPA can be viewed on the Guidance Document page at http://www.itrcweb.org.

SDWA Underground Injection Control

Established through the Safe Drinking Water Act, the Underground Injection Control (UIC) Program includes requirements to protect the nation's drinking water sources when fluids are injected into the subsurface. Five classification categories (I through V) are used for identifying and regulating injection wells under the UIC Program. Each category represents a particular function and similar design. Class V wells are wells which do not fit into the other classifications of UIC wells.

The ITRC's Bioremediation team, during development of the Technical and Regulatory Guidance for In Situ Bioremediation of Chlorinated Solvents in Ground Water determined that under the UIC program, injection of any fluid into a well is prohibited except as authorized by a permit or rule. If the injected fluid contains a non-RCRA contaminant, the injection wells used for remediation may be designated as Class V (40 CFR 144.80(e)) under the UIC program. However, the use of otherwise-regulated chemicals as a product is not categorically prohibited by federal and (most) state regulations when these additives are being used as a product to accomplish cleanup.

Normally Class V wells require no permit as they are authorized by rule according to 40 CFR 144.24. However, 40 CFR 144.12 and 144.82 state:

> "...your injection activity cannot allow the movement of fluid containing any contaminant into USDWs if the presence of that contaminant may cause a violation of the primary drinking water standards under 40 CFR Part 141, other

> health based standards, or may otherwise adversely affect the health of persons. This prohibition applies to your well construction, operation, and maintenance, conversion, plugging closure other injection activity."

This may cause you to obtain a permit and exclude your well from the permit by rule provision. All of the States surveyed by the ITRC during 1996 & 1997 (Or, Ks, Ca, TX, NJ, NM) indicated that injection well permits, or substantial compliance with class V permit requirements, would have to be obtained/approved for an enhanced in situ bioremediation project involving injection (or reinjection) for remediation purposes. Additional states contacted in 1998 concurred with the findings of the previous survey.

Reinjecting Contaminated Ground Water

If the injected fluid contains a hazardous waste, and the fluid is being injected into an aquifer, the well is defined as a Class IV injection well (40 CFR Part 144.6). 40 CFR Part 144.13 specifically prohibits construction of Class IV wells, with some exceptions. One of these exceptions is injection of treated ground water for CERCLA and RCRA cleanups. 40 CFR 144.13 (c) states:

> "Wells used to inject contaminated ground water that has been treated and is being reinjected into the same formation from which it is drawn are not prohibited by this section if such injection is approved by EPA pursuant to provisions for cleanup of releases under the Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA), 42 U.S.C. 9601 ? 9657, or pursuant to requirements and provisions under the Resources Conservation and Recovery Act (RCRA), 42 U.S.C. 6901 through 6987."

Other exceptions from Class IV prohibition include:

1. Injections into aquifers, which underlie the lowermost formation containing a drinking water supply (40 CFR 144.13 (d)(1)).
2. Wells used to inject hazardous waste into aquifers where no underground source of drinking water exists within on quarter miles of the injection point (40 CFR 144/13(d)(2))

In both instances, the injection wells must comply with Class I UIC criteria (40 CFR 146 Subpart B).

Prohibition of underground reinjection of contaminated ground water at non-CERCLA and non-RCRA sites can represent a significant regulatory obstacle. This obstacle may force the use of less-effective means of reinjection of amended ground water, such as horizontal drilling and trickle injection nests.

Certain technical requirements would likely be imposed as part of the injection well permit. These include the establishment of a containment area of extraction and/or monitoring wells near the site perimeter to monitor the effectiveness of the treatment technique. At least two states (KS & OR) indicated in the 1997 survey that they would require some demonstrated evidence of containment through approved hydrologic modeling. It is likely that the material added to the batch injection would have to be analyzed by a state-approved laboratory prior to mixing. It is also likely the regular monitoring and reporting of results to the UIC approval authority would be required.

State Solutions

Due to the effectiveness of enhanced in situ bioremediation, and the regularity of applications choosing it as a cleanup alternative, authorized states are developing their own approaches to the issues of reinjection related to remediation of contaminated ground water. Several examples follow.

Massachusetts Department of Environmental Protection[3]

Massachusetts General Law Chapter 21E (M.G.L. c. 21E) provides the statutory authority for DEP to develop the regulations and performance standards for cleanup. These are contained in the Massachusetts Contingency Plan, 310 CMR 40.0000 (the MCP).

In 1995, regulations were written into the MCP to allow for remedial additives, 310 CMR 40.0040-49. The MCP defines a remedial additive as any aqueous, gaseous, or solid phase agent that is designed to treat or enhance the treatment of, or assessment of, soil and/or ground water. The term shall include oxidizing agents, encapsulates, sequestering agents, non-pathogenic microbes, enzymes, nutrients, surfactants, and anti-fouling agents used to inhibit microbial growth in remedial treatment systems and monitoring wells.

It is under these regulations, for example, that Massachusetts DEP's Northeast Regional Office is currently overseeing the injection of butane to treat TCA at one of their high priority sites. These regulations also provide comprehensive protective measures (e.g., down gradient monitoring, protection of near water supplies, and several other provisions), and they also provide for exemptions from the Massachusetts ground water discharge program (314 CMR 5.05).

New Jersey[4]

"New Jersey DEP is in the preliminary stages of developing a New Jersey Pollutant Discharge Elimination System (NJPDES) general discharge to ground water (DGW) permit for discharges required to implement various in situ ground water and/soil remediation technologies. NJDEP's current plan for the scope of this general DGW permit would include wells used for injecting amendments into the aquifer during In Situ Bioremediation projects as well as other methods of releasing such amendments to the ground. This general permit would not include discharges to the ground of recovered ground water that are part of a site remediation project. Such discharges must obtain individual NJPDES DGW permits and there are no current plans for a general permit for them.

The NJDEP's NJPDES rules also allow certain discharges that are part of a site remediation to proceed through a permit-by-rule approval if the discharge will not contravene New Jersey's Ground Water Quality Standards or violate the Surface Water Quality Standards (see N.J.A.C. 7:14A-7.5). Most of these discharges are limited to a 30 to 180 day time frame.

New York[5]

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[3] Taken from a verbal discussion during the Regulatory Discussion Section of the Accelerated In Situ Bioremediation Course Waltham, Ma - Sept. 20, 2000

[4] New Jersey Department of Environmental Protection, verbal communication with, August 2001

[5] Taken from a verbal discussion during the Regulatory Discussion Section of the Accelerated In Situ Bioremediation Course Waltham, Ma - Sept. 20, 2000

New York State Department of Environmental Conservation, in a 1987 Guidance from the Department's Division of Water (DOW), states that a NY National Pollutions Discharge Elimination System permit is not required for discharges to ground water involving recirculation if the remedial action is conducted under a consent order and meets the substantive technical requirements of an NPDES permit. It also contains a requirement that "hydraulic containment" be demonstrated before approval of a technology involving injection of amendments or partially treated ground water.

Florida[6]

Florida has promulgated rules under their General Provisions for Ground Water Permitting and Monitoring to automatically approve (permit-by-rule) Underground Injection Control wells when used as part of an approved aquifer remediation project. The rules went into effect august 23, 2001 regarding variances for exceedance of primary or secondary standards but not the minimum ground water criteria (due to toxicology considerations with the latter, with chemicals not included in the standards). No longer is a zone of discharge variance required in those cases. Instead, the Corrective Action Plan is to indicate (1) the size of the zone, (2) the amount of time needed, and (3) appropriate monitoring. The change also allows the use of closed-loop reinjection type systems, which were heretofore only permitted at RCRA and CERCLA sites. However a variance will still be needed if the (1) injected substance contains chemicals if they are of toxicological concern. In this case, a minimum groundwater criteria concentration must be suggested by the manufacturer, and then be validated by FDEP through the University of Florida Center for Environmental and Human Toxicology. The rule change is willing to allow a zone of discharge for the primaries if the prime reagents of the remediation product happen to be a primary drinking water contaminant (as opposed to incidental contaminants such as metals from ore derived reagents.

Louisiana[7]

Department of Natural Resources has **proposed** changes to State Wide Order No. 29-N-1 to clarify the application and approval of reinjection wells for use in in situ bioremediation projects. Section D.-E.1.b.ii states Notwithstanding the requirements of clauses (i) and (ii) above, wells used to inject contaminated ground water that has been treated and is being injected into the same formation from which is was drawn are authorized by rule for the life of the well if such subsurface emplacement of fluids is approved by appropriate state or federal agencies pursuant to provisions of cleanup of releases under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) or pursuant to requirements and provisions under the Resource Conservation and Recovery Act (RCRA).

Idaho[8]

Idaho Department of Water Resources has **proposed** a rule change as follows.
IDAPA 37, Title 03, Chapter 03, Rule 025.03 Authorizations Prohibitions and Exemptions Part a. These rules prohibit the permitting construction or use of any Class I, II, III or IV Injection Well except that wells used to inject contaminated ground water that has been treated and is being

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[6] Florida Department of environmental protection Personal communication regarding the proposed changes to F.A.C. 62-522.300 General Provisions for Ground Water Permitting and Monitoring, August 2001

[7] Louisiana Department of Environmental Quality, Personal Communication regarding proposed changes to LAC 43:XVII.Chapter 1 (Notice of Intent to Amend Statewide Order No. 29-1), August 2001.

[8] Taken from the State of Idaho Website http://www.idwr.state.id.us/ August 2001

injected into the same formation from which is was drawn are authorized by rule for the life of the well if such subsurface emplacement is approved by the United States Environmental Protection Agency (EPA) or an authorized State Agency pursuant to provisions for cleanup of releases under the Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA) 42 U.S.C. 9601 ? 9675 or pursuant to requirements and provisions under the Resource Conservation and Recovery Act (RCRA) 42 U.S.C. 6901-6992k.

Recommendations

In situ remediation of contaminated sites has passed the research and development phase for many technologies. Recent federal clarification of RCRA 3020 (b) has made more certain the path to deployment in remediation programs; however, uncertainty still lingers around the requirements associated with UIC Programs. As a result it appears that a number of approaches to regulation of in situ remedies are being pursued by various states.

The Ground Water Protection Council is an organization that is uniquely capable of helping identify and clarify UIC requirements associated with in situ remediation technologies. The ITRC Work Group enjoys the membership of (currently) thirty-nine states whose representatives come primarily from remediation programs. The remediation world is developing in situ cleanup technologies that can move forward most efficiently with a clear understanding of all the regulatory requirements associated with deployment. One example of developing a clear understanding of regulatory requirements is the ITRC Work Group's participation in obtaining clarification of RCRA 3020(b) from EPA.

Given the shared interest of both the ITRC Work Group and the GWPC in our nation's ground water, there is a logical set of opportunities for increased communication, information exchange, education, and collaboration on matters of mutual interest. Such a cooperative effort would help ensure that a range of state programs would benefit from the collective body of knowledge resident in these two organizations.

Acknowledgements

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Disclaimer

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Similarly, the views expressed herein are those of the authors alone, and should not be construed to represent the views or positions of the California Department of Toxic Substances Control.

Sparks Solvent/Fuel Site
Case Study
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Eric Noack is a Hydrogeologist and Project Manager with the Nevada Division of Environmental Protection providing regulatory oversight for the groundwater contamination resulting from underground nuclear testing on the Nevada Test Site. The Underground Test Area (UGTA) Project is one of the federal government's most comprehensive groundwater study programs designed to identify risks resulting from underground nuclear testing, predict groundwater movement, determine whether radionuclides resulting from nuclear testing have moved appreciable distances from original test locations, and define boundaries for safe water use. He received a B.S. degree in Geology in 1983 from the University of Nevada, Las Vegas and a M.S. degree in Hydrogeology in 1988 through the Water Resource Center of the Desert Research Institute, University of Nevada, Las Vegas. From 1988 to 1998 he held positions ranging from Staff Hydrogeologist through Reno Office Manager for two consulting engineering firms in Nevada. He has been with the Nevada Division of Environmental Protection since April 1998.

ABSTRACT

The Sparks Solvent/Fuel Site (SSFS) is a railyard and fuel terminal tank farm in Sparks, Nevada. Activities over the past century have resulted in the contamination of groundwater and soils by solvents, gasoline, diesel fuels and other petroleum products.

The Nevada Division of Environmental Protection (NDEP) issued a clean-up order in 1987 to the first of 10 responsible parties to commence the on-site contaminant investigation. NDEP issued clean-up orders to the remaining 9 companies at the railyard and fuel terminal in February 1990.

In January of 1991 NDEP filed a civil action against all 10 companies at the railyard and fuel terminal, which assured full collaboration of the companies' clean-up efforts. This action was integrated with similar actions from other municipal and private parties. In August 1991, congressional hearings were held and EPA issued an administrative Order requiring additional investigations and remediation. Consequently, environmental assessments, hydrogeologic characterizations, and groundwater modeling were conducted to evaluate the full extent of the contamination.

To date, clean-up efforts have involved the design, installation, and operation of a groundwater extraction and treatment system, soil vapor extraction and treatment systems as well as other aggressive remedial technologies. Technologies that have been used or are currently in use include recirculation of treated groundwater to enhance biodegradation, soil vapor extraction at hot spot locations, air sparging and phytoremediation. The phytoremediation demonstration area was constructed to evaluate the effectiveness of trees and other vegetation in biological removal of contaminants from groundwater.

The contamination is currently contained and consequently, the remaining contamination does not pose a threat to the Truckee River, the Sparks Marina Park Lake, area groundwater supplies or local water sources. Monthly testing is conducted on the treated groundwater to ensure contaminants are not being discharged to the Truckee River. The remediation system will continue to operate until clean-up is accomplished.

PROJECT OVERVIEW

The Sparks Solvent/Fuel Site (SSFS) is a railyard and fuel terminal tank farm in Sparks, Nevada. Activities over the past century have led to contamination of groundwater and soil by gasoline, solvents, diesel fuels and other products. The site has been used as a refueling and service area for Southern Pacific Railroad since approximately 1907 and has been a fuel storage and distribution facility since 1957. Fuel is transported to the Sparks facility from the San Francisco bay area refineries via a pipeline traversing over the Sierra Nevada Mountains.

The railyard has served as a major east/west thoroughfare for railroad traffic since its construction. Before the 1950's, the railyard was the largest industry in Sparks with a roundhouse, powerhouse, machine and locomotive shops, crew lodging and commissary. Current and past railyard operations include maintenance, cleaning, refueling and storage of railroad engines and other rolling stock.

The fuel terminal tank farm is the central storage and distribution point for most vehicle and heating fuels supplied to the northern Nevada and eastern California region from Bishop to Alturas, California and from the Lake Tahoe area to Ely, Nevada. The terminal also supplies fuels to the Fallon Naval Air Station, Nevada Air Guard, Army National Guard, Sierra Army Depot in Herlong, California, and the Oregon National Guard in Klamath Falls, Oregon. With the exception of the Fallon Naval Air Station, which receives fuel via a dedicated pipeline stemming from the terminal, military fuels are trucked directly from the terminal to their intended destination. Current and past operations at the terminal tank farm include the storage, distribution, and loading of gasoline, heating oil, diesel fuels, military fuels, and fuel additives.

In 1967, a gravel pit operation was initiated less than one mile east of the railyard and fuel terminal tank farm. This operation, known as the "Helms Gravel Pit," had the same characteristic high groundwater levels as present at the railyard and fuel terminal tank farm. The Helms Gravel Pit operation extended into the groundwater and consequently required dewatering to maintain quarry activities. Approximately 6 to 7 million gallons of water per day was pumped from the pit and discharged to the Truckee River via a ditch named "Peoples Ditch." The dewatering/pumping activities had a significant influence on ground water movement and flow in the Sparks area and resulted with the groundwater gradient being controlled by the pit rather than the natural flow, which would have been towards the Truckee River.

In 1987, during construction and excavation activities at the fuel terminal tank farm, free and dissolved petroleum products were found in the underlying soils and groundwater. The Nevada Division of Environmental Protection (NDEP) was informed of the contamination present at the site. The primary contaminant of concern was determined to be petroleum hydrocarbons. NDEP issued an order to Santa Fe Pacific Pipeline Partners (now known as Kinder Morgan Energy Partners) to investigate contamination in December 1987. Santa Fe began an investigation into the cause of the contamination and its extent. In November 1988, separate from Santa Fe Pacific's investigation, diesel fuel was discovered to be seeping from the south wall of the Helms Gravel

Pit. It was determined that the product seeping into the gravel pit originated at the terminal tank farm. Due to the pit dewatering activities controlling the groundwater gradient in the Sparks area, and consequently the contamination plume, it became apparent that pit dewatering activities would have to be continued, regardless of gravel operations, to ensure that the plume's course would be maintained in the direction of the gravel pit and not the Truckee River. Fortuitously, the mechanism utilized to dewater the pit simultaneously, and inadvertently, provided treatment to the water by acting as an oil/water separator and a mechanism for contaminant volatilization prior to discharging into the Truckee River.

A groundwater recovery system was installed at the terminal and began operation in 1989 to capture and contain free product on the terminal property.

The railyard began a site assessment in 1989 that resulted in the discovery of not only hydrocarbons, but also chlorinated solvents present in the underlying soil and groundwater.

From 1989 through 1990, nine additional parties who owned or leased property at the site were ordered by NDEP to participate in the investigation and clean up. The additional parties included Southern Pacific Railroad, Golden Gate Petroleum, Shell Oil, Texaco Refining and Marketing, Inc., BP Air, Berry-Hinkley Terminal, Unocal, Chevron and Time Oil.

A recovery system to capture free product was designed and installed at the railyard in early 1991.

A significant amount of investigation occurred on the actual property of the railyard and fuel terminal facility. There was reluctance, however, on the part of the companies to conduct an off-site investigation. As a result, NDEP filed a civil action against all 10 companies in January 1991. This action was later integrated with similar actions from other municipal and private parties.

Because chlorinated solvents were determined to be present and co-mingled in the plume, the Federal EPA responded with Administrative Order 91-22 (Order) to the 10 companies under Section 106 of the Comprehensive Environmental Response Compensation and Liability Act (CERCLA). In response to the Order, a Removal Action Plan was completed in 1992, summarizing site assessment activities and presenting proposed removal actions. Eleven actions for source control, free product removal, aquifer protection, and surface water protection were outlined in the plan. Following county, state and federal acceptance of the plan, implementation commenced.

The site became officially known as the Sparks Solvent/Fuel Site (SSFS) and extended from the Railyard to the east side of the pit where a series of extraction wells are located.

A groundwater flow model was completed in 1993 to facilitate in the development of a site-wide removal system to control and eventually eliminate the migration of contaminants and impacted groundwater at the SSFS.

In 1994, the Helms Gravel Pit quarry activities were permanently terminated. The Responsible Parties took over the responsibility for the dewatering activities associated with the pit and were held accountable for maintaining the groundwater gradient towards the pit as opposed to the Truckee River. The City of Sparks' ultimate goal, however, was to expedite remediation efforts and eventually fill the pit with groundwater and convert it into a recreational water body.

In 1995, a site-wide groundwater and soil vapor extraction and treatment system and a mobile free product recovery unit were constructed and began operation.

The Division settled its legal action with the Responsible Parties in July 1995. The other parties to this action settled soon after. All companies involved with the settlement

owned, operated or leased operations at the site. The responsible parties formed agroup called the "Vista Canyon Group" to maintain coordinated remediation and monitoring efforts. Per the conditions of the settlement, the financial portion that each company is responsible for, as negotiated amongst themselves, has never been revealed to outside parties, including NDEP.

The terms of the agreement included the payment of over ten million dollars to the State of Nevada over a ten-year period and the clean up of impacted soil and groundwater to state standards, at the settling companies' expense. This settlement was the largest environmental settlement ever reached in Nevada and will ensure the protection of the groundwater and drinking water resources of the Truckee Meadows and the City of Sparks, protect the water quality of the Truckee River and Pyramid Lake and provide an incentive for individuals and corporations to act in an environmentally responsible manner.

In January of 1997, Northern Nevada experienced a major flood event. The Helms Gravel Pit filled up with flood water and consequently formed what is now the Sparks Marina Park Lake. The regional flood of January 1997 significantly impacted the remediation system by causing a rise in groundwater levels across the area. This caused the site-wide soil vapor extraction system to be shut down due to the screened intervals within the wells being submerged by water. The remediation system monitoring data indicated that the total petroleum hydrocarbon concentrations in vapors removed from the unsaturated zone above the pre-flood water table decreased by more than 97 percent across the site prior to the flood.

The shallow groundwater affected by activities at the railyard and terminal tank farm would ultimately discharge into the Sparks Marina Lake unless intercepted. Protection of the lake from impacted groundwater underlying the SSFS is one of the primary objectives for the SSFS remediation system. Another primary objective for the remediation system is to contain impacted groundwater near the terminal and to aggressively remediate areas that have residual petroleum products in the soils underlying the SSFS.

Current activities at the SSFS include extensive quarterly monitoring at the site, which has been on-going since 1992, maintenance of groundwater containment, removal of free product, treatment of impacted groundwater using two fluidized bio-reactors (FBRs) in-series, and aggressive remediation. Prior to discharging to the Truckee River, nitrate is removed from the treated groundwater. Monthly testing is conducted on the treated groundwater to ensure efficient treatment whereby contaminants are not discharged to the Truckee River.

Groundwater containment (groundwater extraction) is focused in two essential areas, the first being just upgradient of the Sparks Marina Park Lake, to minimize contamination from entering the lake, and the second area being near McCarran Boulevard, to eliminate migration of impacted groundwater stemming from the terminal and railyard area towards the Lake. Aggressive remediation activities have included the following:

- Recirculation of treated, aerated groundwater to enhance flushing of residual product from soils and to enhance biodegradation of sorbed and dissolved constituents of concern;

- Phytoremediation to enhance groundwater capture and remediation of dissolved volatile organic compounds and nitrates;

- Soil vapor extraction in the remaining areas of the terminal and railyard with significant concentrations in soils;

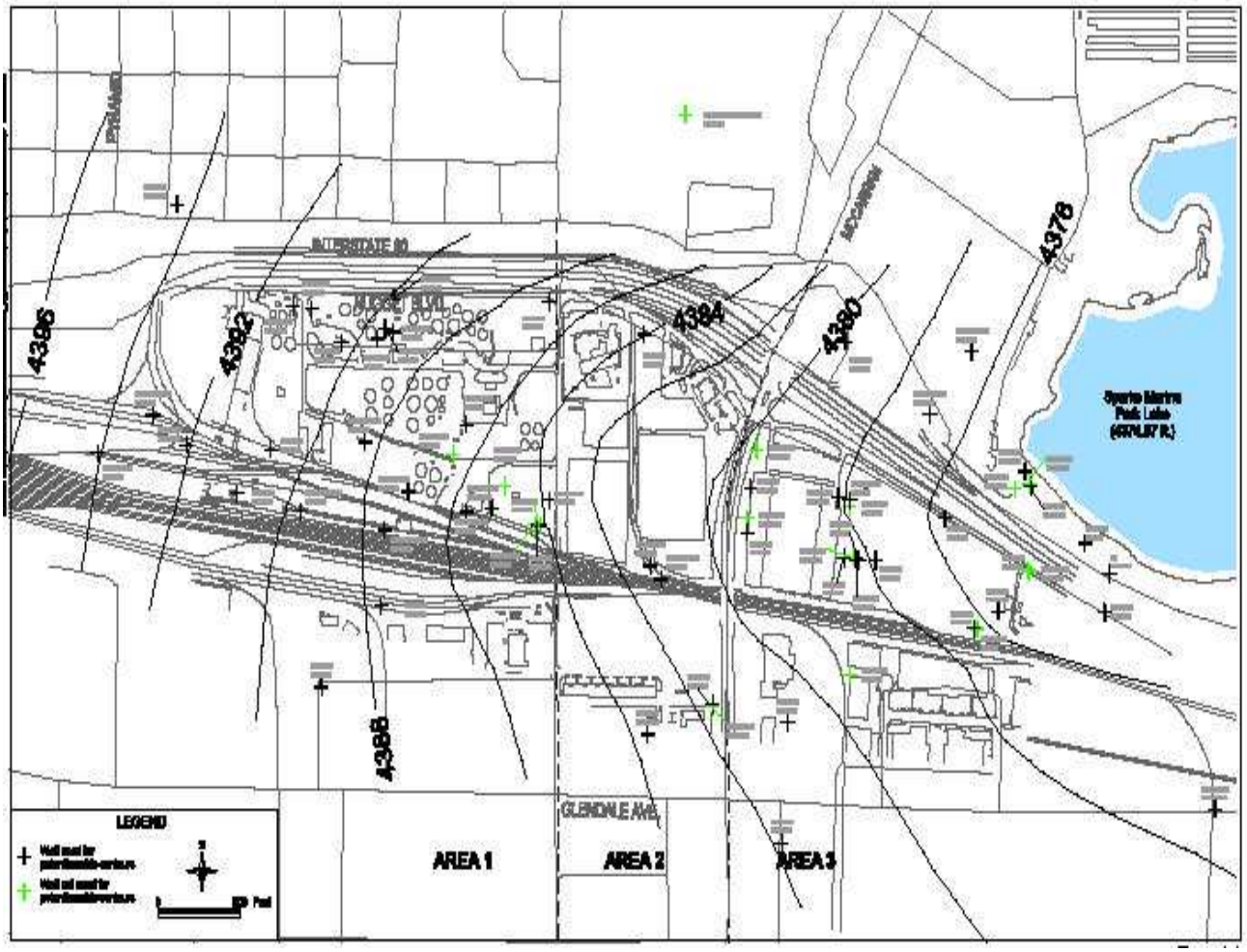
- An air sparging pilot study to determine the effectiveness of remediation by the addition of oxygen to the subsurface; and

- Extraction and treatment using high pressure oxidation of groundwater from wells with the highest levels of MTBE.

In 2000, an Underground Injection Control permit was issued for a "hot-spot" treatment strategy. This strategy includes the extraction, treatment and subsequent reinjection of groundwater that remains impervious to existing remediation efforts. This technique has not yet been employed due to current efforts of maintaining capture.

Since start up of the site-wide remediation system, approximately 400,000 gallons of petroleum hydrocarbons have been removed from the subsurface. Clean-up and capture efforts will continue at the site until the approved clean-up requirements established by NDEP are met.

This site has proven to be one of the most colorful and successful remediation efforts in Nevada. From a regulatory perspective, what may have been a disastrous situation was instead, carefully managed and allowed to be transformed into an environmentally safe community recreational area. The Sparks Marina Lake is the crown jewel of the City of Sparks Parks & Recreation Department and is now the site of fishing derbies, triathlons and scuba diving activities.



Working with Regional Planning Agencies, Watershed Teams, Environmental Non Profit Organizations and Business Associations to Promote Source Water Protection in Coordination with the release of the SWAP Reports

Kenneth A. Pelletier - SWAP & UIC Coordinator - MA DEP – Drinking Water Program

INTRODUCTION: Unfortunately many people outside of the SWAP program both staff inside MA DEP and the various publics the program is attempting to inform look on the SWAP as program whose end product is a series of reports and maps. It is obvious that our early emphasis on meeting the criteria of EPA's SWAP program: Delineation of water supply protection areas (WSPA), Inventory of potential sources of contamination (PSC); Assessment of the WSPA with respect to the potential threats identified and publicizing the results has given the impression that the programs goals are limited to the reports. Through planned outreach efforts we will demonstrate that the reports/maps are tools to assist with ultimate goal of promoting protection and the implementation of prevention measures.

In Massachusetts we have spent our initial efforts on improving the delineation for all public water supplies (PWS); searching databases and conducting assessments on Non-Community systems (TNC and NTNC). While conducting these assessments our SWAP field staff have been able to provide technical assistance directly to the water supplier as issues (PSC) are identified. Additionally we have been directed them to additional resources on the web and to our partners within DEP and at the other state agencies that oversee various environmental programs.

Issues have arisen during these assessments that we have been tracking that will be more prevalent as we now are conducting the assessments for the community water supplies. Many of these issues are out of the control of the smaller PWS to address and need to be acted upon at the community or regional level. This frequently will mean involving parties representing various land uses including government, business, agriculture and recreation. Over the last year as we have been preparing to conduct the community assessments and produce the reports both for a community water supply and community maps showing all water supply protection areas within each community we have been conducting outreach. This has included outreach to the programs within state government that may be affected by the release of the reports and to various groups outside DEP that will either use the reports and/or that me listed in the report as potential sources of contamination.

PLANNING AND INPUT FOR OUTREACH TO THE COMMUNITIES: We have been meeting with the program staff, advisory groups, business groups and citizen groups and in addition to presenting our current efforts and draft template reports and maps we have been soliciting input from them. We have outlined our plans to sponsor outreach meetings throughout the state to groups of communities to discuss the SWAP reports, maps and attachments and how they with assistance from DEP Drinking Water Program (DWP) staff and our various partners can implement measures to protect their water supplies. We have emphasized in all these meetings that

the reports are only the first step in this process and that they are tools to be used by the community along with other tools we reference in the reports to assist them in their efforts.

We received a lot of positive input at these meetings, which we have used to modify the template for the SWAP reports, maps and attachments. Additionally out of these meetings we received commitments from a number of statewide groups (who work with local entities) to both cosponsor and participate in the outreach meetings and lend their various expertise. These include regional planning agencies (RPA), watershed teams and associations,

business associations and chambers of commerce (CoC), statewide and local environmental groups and the state and regional associations representing public water suppliers (NEWWA and MWWA). In addition the support of
the coordinators of state programs overseeing issues that will be addressed in the reports have committed their assistance to this effort. These include the non-point source program (NPS), the storm water program, the TURA/P2 program, the Environmental Results Program (ERP), the Pesticide Program (DFA), state emergency response program (SERC) and many others.

In addition to the support pledged by these groups to assist with the outreach meetings planned to start later this year many of them have committed their assistance to work with the public water suppliers (PWS), local officials, community groups and various sectors that may be identified as potential sources of contamination (PSC) including businesses, farmers, developers and recreational facilities. In many cases they are already working with some or all of the parties and in some cases on the specific issues that will be addressed in the reports. The regional planning agencies, watershed teams and associations and farm bureaus are currently working with the communities on many issues that cross political boundaries (town and state). Many of our water supply protection areas (WSPA) cross political boundaries and in these situations the water suppliers will need assistance implementing many of the recommendations within the SWAP reports.

INPUT FROM NON-COMMUNITY ASSESSMENTS AND PILOT COMMUNITYASSESSMENTS:

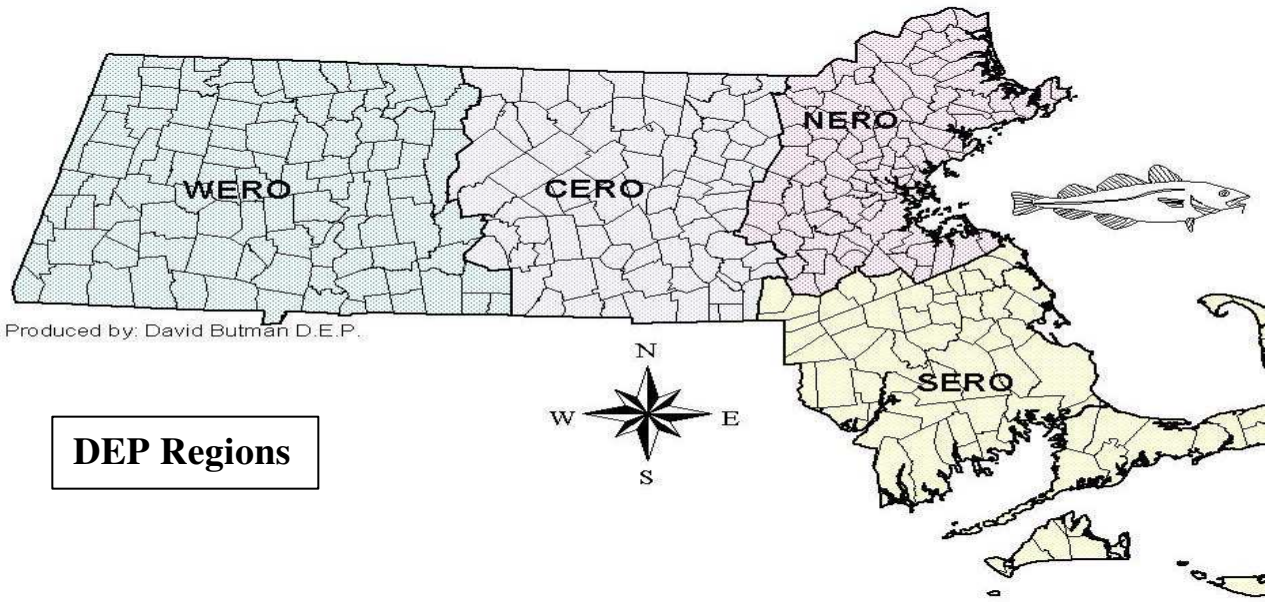
Over the past two years as we have been developing the tools (GIS, databases, technical assistance material, etc.) to conduct assessments, prepare reports and offer technical assistance we have conducted pilot assessments on several community systems. This has given us the opportunity to hear feedback from local officials on methods used to include them in the assessment report review phases of our efforts. Additionally as we discussed the draft reports with the communities and the recommendations in the reports issues came up with respect to assistance (technical and funding) needed to implement many of the recommended protection measures.

The need for the public water supplier and other local officials (health, planning, conservation and elected officials) to coordinate their efforts with all sectors in the community (business, residents, agriculture, transportation) came up very early in the discussions with each community. In addition to the SWAP reports and maps the local officials expressed additional needs to us including: material that could be used to promote best management practices to the various sectors in their community [See - Source Water BMP Outreach Workshop on 9/22 at GWPC Annual Forum for more information on efforts in this area]; assistance in dealing cross-jurisdictional issues, assistance in dealing with regional transportation and utility authorities and assistance in helping them set up collaborative efforts in their communities so that all parties can work together to achieve the goals of water supply source protection.

While conducting the assessments for the Non-Community systems and Small Community systems (defined for the purpose of conducting SWAP assessments as Pop. Of <500) a number of items identified as potential sources of contamination will require the PWS to involve others (local officials, businesses, neighboring communities, etc.) in order to implement recommended prevention strategies. For communities that do not have a community public water supply (PWS) or for communities that have a mix of community and non-community public water supplies DEP will be looking to the Board of Health to take the lead to organize efforts to implement protection measures. DEP Drinking Water Program strongly encourages communities to form a water supply protection committee that should include representation from all stakeholders.

COORDINATING EFFORTS WITH OUTSIDE GROUPS TO ASSIST PROMOTING PROTECTION:

MA DEP is divided into four regions. Each region implements the media programs for the communities within its jurisdiction. SWAP has two staff members in each region one is responsible for conducting assessments, writing up reports and providing technical assistance to non-community and community PWS and communities and the other SWAP staff person works within the GIS program and is responsible to GPS water supply and PSC data and produces draft and final SWAP maps. The Boston SWAP staff are responsible for program development provide support to the regional staff; prepare the SWAP reports for the transient non-community systems (TNC) and will be preparing the SWAP report for the MA Water Resource Authority (MWRA) which provides water to 40+ communities.



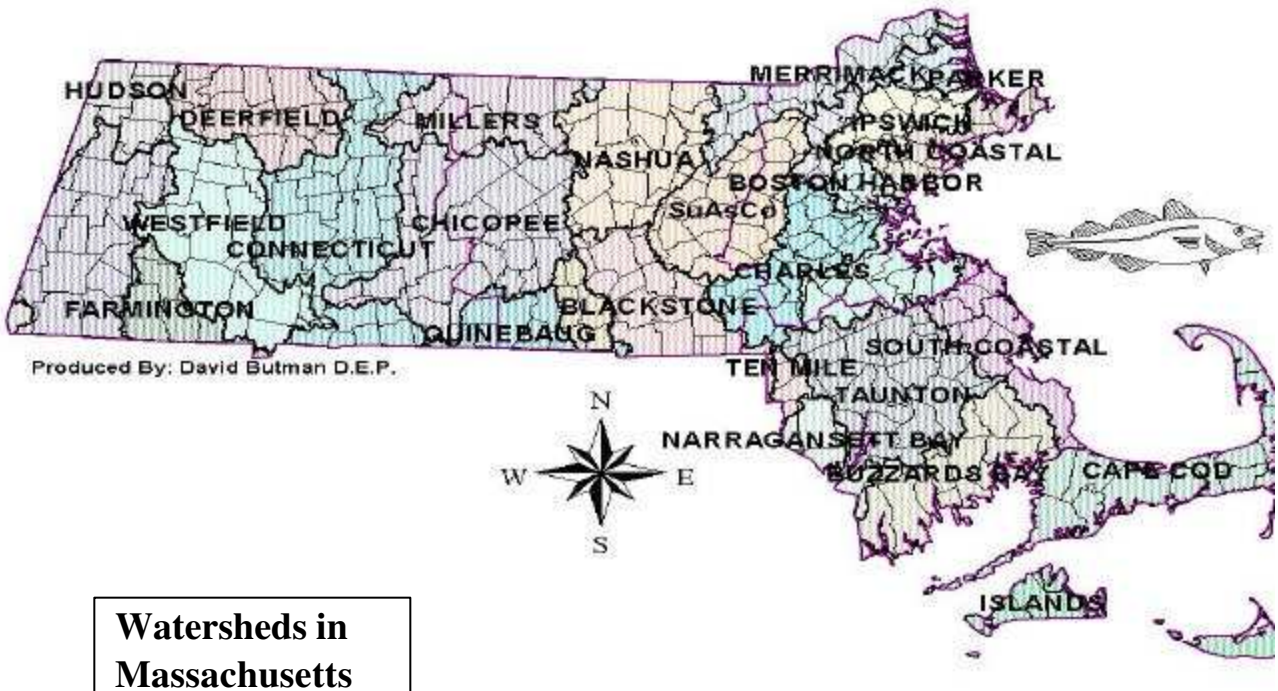
In early discussions with the groups that we will be partnering with we examined both their current roles with respect to water supply protection; current efforts to assist communities with issues being addressed in the SWAP reports; their efforts in dealing with cross-jurisdictional issues and how there "regions" matched up with the DEP regions. We found that in many cases their "regions" overlapped our DEP regions and determined that we will set up our outreach for the most part in "sub-regions" of the DEP regions. WE will use the watersheds, regional planning agency (RPA) regions and chambers of commerce areas of representation as guidelines in assisting us in defining the "sub-regions". Where it make sense based on a watershed or RPAs we will set up outreach meetings that may involve communities in two DEP regions.

WATERSHEDS: In MA DEP's parent agency the Executive Office of Environmental Affairs (EOEA) oversees the Massachusetts Watershed Initiative. It is a broad partnership of state and federal agencies, conservation organizations, businesses, municipal officials

and individuals. The Watershed Initiative is an innovative, results-oriented program that protects and restores natural resources and ecosystems on a watershed basis by:

- Finding the sources of pollution and taking cooperative action to clean them up;
- Teaching and helping groups and communities to protect and restore their local waters;
- Expanding communication among local, private and public partners so everyone works together to solve water resource problems;
- Improving coordination among government agencies, and,
- Directing resources to critical needs so our limited dollars go further to resolving the most important problems.

Watershed teams, made up of representatives of governmental agencies and community partners (non-profit organizations, municipal boards, and businesses), coordinate the watershed protection efforts in each of the 27 major watersheds of Massachusetts. The primary goals of the Watershed Initiative are to:
improve water quality; restore natural flows to rivers; protect and restore habitats; improve public access and balanced resource use; improve local capacity to protect water resources; and, promote shared responsibility for watershed protection and management.



Watersheds in Massachusetts

DEP within its regional offices has set up watershed teams made up of staff from the various media groups to assist with coordination of inspections, outreach and technical assistance, enforcement and planning. DEP's watershed teams coordinate activities with

the EOEA team and SWAP has been coordinating efforts with the DEP teams and keeping the Team Leaders for the EOEA abreast of our progress.

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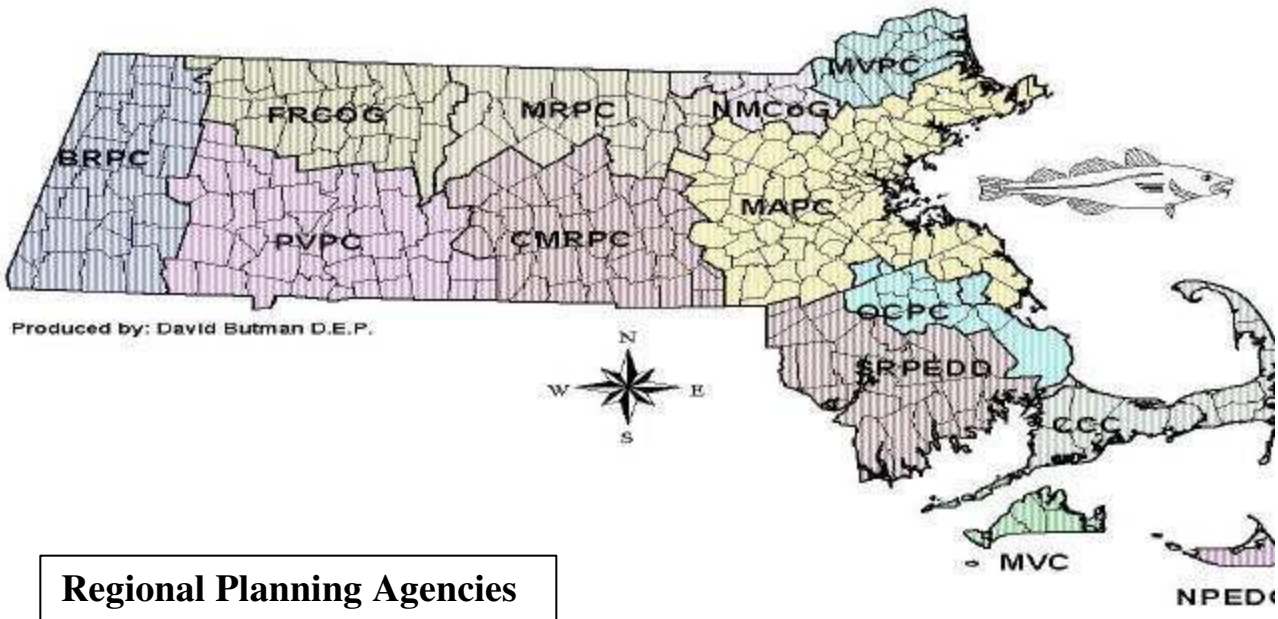
Additionally most of the watersheds have active non-profit associations working to assess the condition of the watersheds and promote protection. These associations are actively involved in the EOEA watershed teams and DEP also works closely with them on many projects (an Executive Director of one of the watershed associations serves on the SWAP Citizen Advisory Committee). Severally of these associations have already approached us and are currently involved in the process.

The Massachusetts Watershed Coalition is another partner of DEPs and has representative on the Advisory committee. The Coalition is a network of local organizations that are committed to the protection, sound management and enhancement of Massachusetts's rivers and watershed ecosystems.

To strengthen the work of watershed associations and allied groups
To raise awareness of actions to sustain and enhance the vitality of our rivers and watershed ecosystems To advocate for policies and decisions that protects our valuable water supplies and natural heritage

REGIONAL PLANNING AGENCIES: DEP is coordinating its efforts with the regional planning agencies (RPA) through the Massachusetts Association of Regional Planning Agencies (MARPA). A representative MAPRA serves on the SWAP Citizen Advisory committee. MARPA is a statewide organization of the commonwealth's 13 regional planning agencies (RPAs). Each RPA, in turn, comprises representatives of the member cities and towns constituting its geographic region. Although RPAs in MA are public service agencies, they are not direct arms of the federal or state governments. Rather, they are consortia of local governments that have banded together under the provisions of state law to address problems and opportunities that are regional in scope. The regional planning areas delineated for each of Massachusetts' 13 RPAs are designated by state enabling legislation as special state districts.

Each RPA is governed by a board formed of representatives from its member communities. Planning professionals on RPA staffs work with their boards and with many public agencies and officials to define and direct solutions to area-wide problems that cannot be solved by member communities working alone.



Regional Planning Agencies

What they do: The regional planning agencies in Massachusetts are public organizations that encompass a multi-jurisdictional regional community. These RPAs serve the local governments and citizens within their planning districts by dealing with issues and needs that cross city, town, county, and even state boundaries through planning, policymaking, communication coordination, advocacy, education, analysis, and technic al assistance.

The 13 regional planning agencies that form MARPA are advisory bodies to member communities, private business groups, and state and federal governments, providing research and analysis services and helping to implement planning in areas such as economic development, community and rural development, infrastructure development and maintenance, environment and land use, regional and municipal services, solid waste manage-ment and recycling, historic preservation, transportation and transit, GIS mapping and graphics services, technical assistance to member communities, housing, bikeway planning and development, and regional information.

RPAs are frequently partners with DEP on various projects and on behalf of their member towns they solicit grants from DEP to address environmental issues in the communities they represent. The SWAP program will be working with various RPAs on regional issues and to assist communities that have water supply protection areas that are partially or wholly in other communities negotiate the implementation of protection strategies in the neighboring communities.

BUSINESS ASSOCIATIONS: The SWAP program has been working with several association representing commercial interests in MA. Two members of the SWAP Citizen Advisory Committee represent different business interests: Associated Industries of Massachusetts (AIM) and a representative of real estate developers
In addition SWAP is currently working with several Chambers of Commerce, which represent the interest on commercial enterprises in the communities. DEP and AIM through their Environmental Health and Safety committee and in concert local chambers of commerce will be coordinating participation of the business in the outreach meetings throughout the state.

Associated Industries of Massachusetts is the voice of 5,900 Massachusetts employers from all industries on legislative and regulatory issues in Boston and Washington, D.C. A.I.M. works on behalf of employers to improve the Massachusetts business economy. A.I.M. is also the Employer's Resource, providing services to member companies in the areas of human-resource management, employment law, environmental compliance, employee training and education, and energy.

The Environmental Health and Safety (EHS) Council (AIM) was formed to educate the business community about environmental health and safety matters. To achieve this goal, the council acts as a convenient one stop location for peer-to-peer information networking among EHS professionals, consultants and attorneys and schedules bimonthly meetings to discuss emerging EHS issues, new regulations, industry trends, and to meet government regulators and policy makers. In addition, members of the Council serve on numerous task forces with the Department of Environmental Protection and the Environmental Protection Agency as A.I.M. representatives. Finally, the Council sponsors half-day seminars and early morning briefings on single topics, such as inspection protocols and disaster preparation.

PUBLIC WATER SUPPLY ADVOCACY GROUPSS: The Drinking Water Program at DEP has a strong relationship with several PWS advocacy groups. Several serve on the SWAP Advisory committee and they are already assisting with technical assistance and training to PWS, boards of health and local officials on source protection issues and will be participating in the outreach meeting
.
New England Water Works Association (NEWWA) is the leading authority on education, training opportunities and public outreach to protect and improve drinking water and water utility operations. NEWWA continues to be an instrument of change to advance the knowledge, science, government awareness and public trust of the water works field.

Mission Statement The primary purpose of NEWWA is to promote public health, safety and welfare through the advancement and dissemination of knowledge for improvement of the

planning, design, construction, operation, management and regulation of water works relating to the production and distribution of safe, potable drinking water.

The Massachusetts Water Works Association (MWWA), inc. Is a membership organization dedicated to the advancement of the drinking water profession through education and advocacy and committed to protecting public health and providing a safe and sufficient supply of drinking water to Massachusetts consumers

Northeast Rural Waterworks Association (NeRWA) is a nonprofit association of small water and wastewater systems in Massachusetts, New Hampshire, and Vermont. Among its many services, NeRWA offers free training and technical assistance via its highly experienced staff. NeRWA's mission is to provide active support for safe, clean, affordable water in rural New England. NeRWA provides free on-site technical assistance to small water and wastewater systems in Massachusetts.

ENVIRONMENTAL ADVOCACY GROUP: The SWAP program is currently working with several statewide and local environmental groups. There are representatives from four groups currently serving on the SWAP Advisory committee. We will be working with several statewide organizations to assist in obtaining the involvement of the local environmental groups in outreach meetings and with implementation of source protection measures.

The Environmental League of Massachusetts is dedicated to protecting the air, water, and land for the people of the commonwealth. We do this by voicing citizens' concerns, educating the public, advocating for strong environmental laws, and ensuring that our laws are implemented and enforced.

Clean Water Action (CWA of MA) is a national citizens' organization working for clean, safe and affordable water, prevention of health-threatening pollution, creation of environmentally safe jobs and businesses, and empowerment of people to make democracy work. Clean Water Action organizes strong grassroots groups, coalitions and campaigns to protect our environment, health, economic well-being and community quality of life.

Massachusetts Audubon Society is the largest conservation organization in New England, concentrating its efforts on protecting the nature of Massachusetts for people and wildlife. The Society protects nearly 29,000 acres of conservation land, conducts nature education programs for over 175,000 schoolchildren annually, and advocates for sound environmental policies.

AGRICULTURE ISSUES / STATE AGENCIES & ADVOCACY GROUPS: The SWAP program is currently

Working with the two state agencies Dept. of Food & Agriculture and the Metropolitan District Commission (Forestry issues) and several advocacy groups on source protection issues. Currently there are four represent-atives representing these issues on the SWAP Advisory Committee. Input from these groups has been very helpful as we have developed the SWAP program and they have participated in the production of several fact sheets being used by the SWAP staff as attachments to the reports (pesticides, fertilizer and other agricultural BMPs).

The Massachusetts Department of Food and Agriculture's mission is to support, promote and enhance the long-term viability of Massachusetts agriculture with the aim of helping this state's agricultural businesses become as economically and environmentally sound as possible.

- The Massachusetts Department of Food and Agriculture's - Agricultural Environmental Enhancement Program (AEEP) provides funding to farmers to install a variety of water quality protection practices. Eligible practices include the installation of buffers, animal waste systems, pesticide storage faculties, fencing, culverts, seed and gutters.
- The Pesticide Bureau in the Division of Regulatory Services of the Department of Food and Agriculture carries out the day to day responsibilities of regulating pesticides.

Massachusetts Farm Bureau develops comprehensive programs designed to educate and build support from their legislators and the public. Through the strength of its membership, Farm Bureau continues its efforts for the very existence of agriculture in Massachusetts.

- MA agriculture is still dairies and vegetable farms, fruit, horticulture, nursery, cranberry bogs, and sugar maple farms. It is also the commercial cultivation of mushrooms on logs, growing and harvesting timber, high tech hydroponics and bio-agricultural farms, exotic vegetables, edible flowers and the art of bonsai.
- Farm Bureau regularly advocates for our members before Department of Environmental Protection, Department of Environmental Management, Department of Public Health, and the Department of Food & Agriculture, among many others.

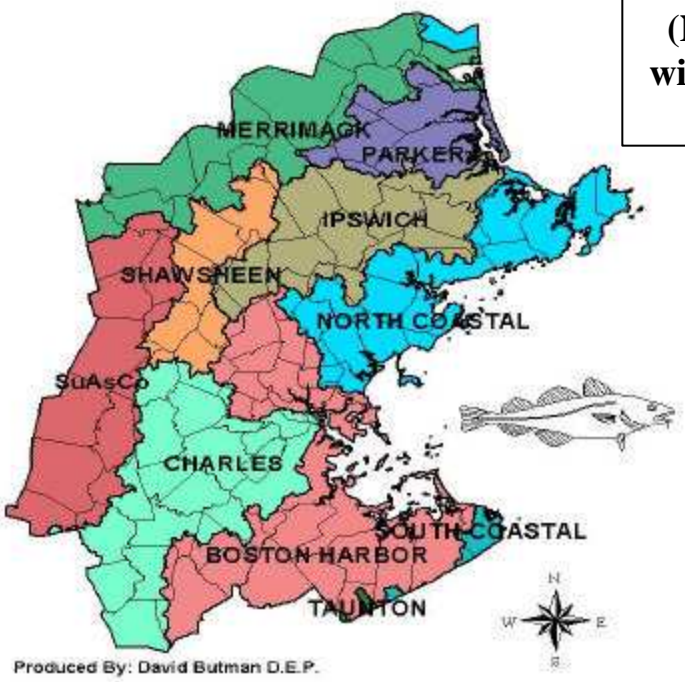
The mission of the Department of Environmental Management is to exercise care and oversight for the natural, cultural, and historic resources of the Commonwealth and to provide quality public recreational opportunities, which are environmentally, sound, affordable, and accessible to all citizens.

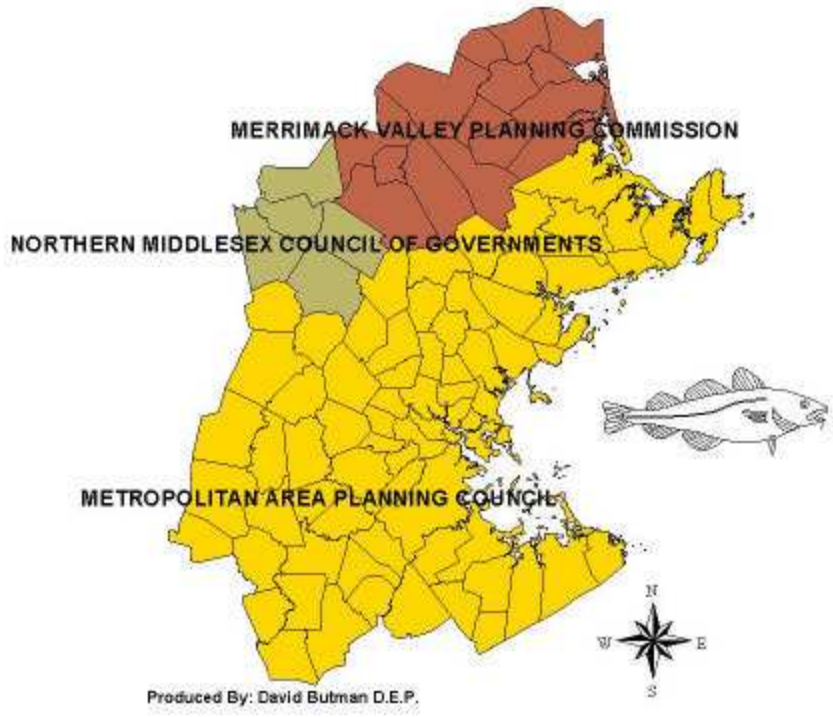
Although it is one of the smallest states in terms of size, Massachusetts has the ninth largest state forest and park system in the country. The Massachusetts Department of Environmental Management (DEM), the state's primary land management and natural resource planning agency, oversees the state forest and park system.

DEM is the largest landholder in Massachusetts, managing over 285,000 acres or five percent of the state, and it helps maintain three million more acres of public and private forests. DEM's landholdings range from Mt. Greylock, the state's highest peak, to the beaches of Cape Cod. In between lie vast tracts of forests, lakes, and ponds where swimming, fishing, hiking, sightseeing, and picnicking are popular

OUTREACH MEETINGS STRATEGY: Along with our partners listed above the SWAP program will be designating sub-regions within the DEP regions. Below find the map of the North East region of DEP with the watersheds and regional planning agency regions delineated.

North East Region (NERO) of MA DEP with Watershed Basins delineated

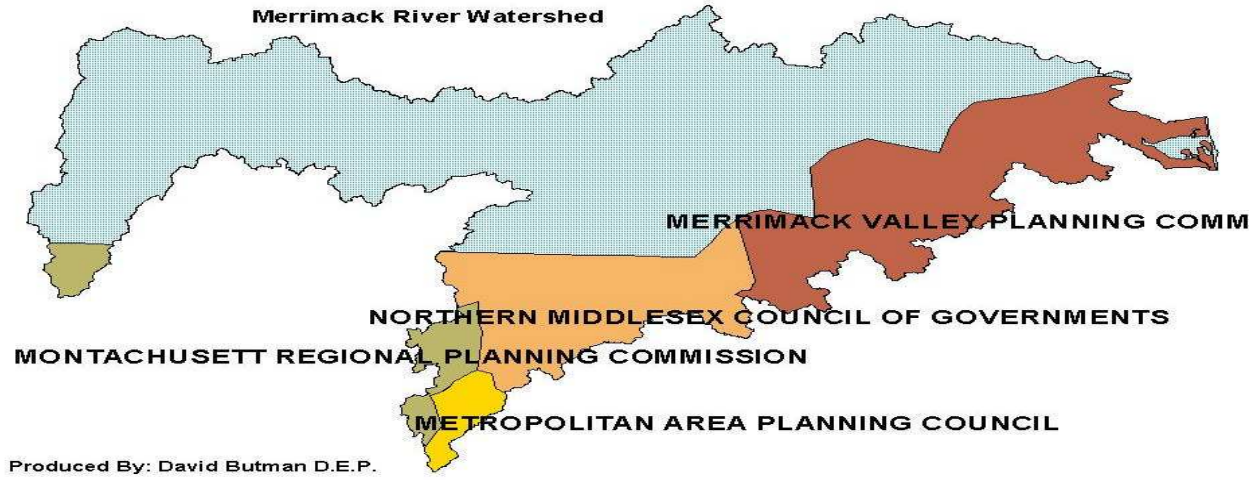




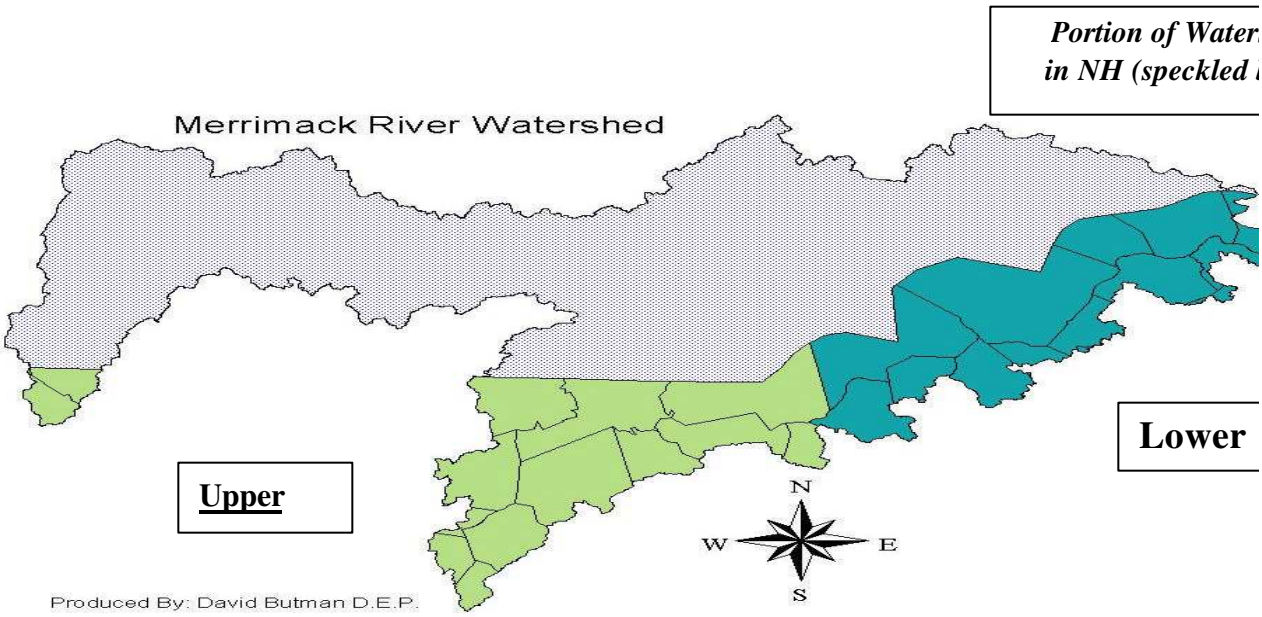
North East Region (NERO) of MA DEP with Regional Planning Agencies (RPA) delineated

Using the Merrimac Valley as an example DEP will coordinate with other groups within the area to delineate
out sub-regions with an area such as the Merrimac Valley located within the North East Region of DEP. These will be used to identify partners that will participate in the Regional SWAP forums, select meeting location; assist us in addressing regional SWAP issues and will be used as one factor in determining the order that we conduct the SWAP assessments.

***Portion of Watershed* in NH (blue)**



Merrimac River Watershed – with Regional Planning Agencies delineated



Merrimac River Watershed – with two proposed sub-regions delineated
Upper & Lowe Merrimac River Watershed
for the purpose of the proposed Outreach meetings

Once the sub-regions are selected DEP will work with its partners to involve the PWS, local officials, the affected chambers of commerce and local environmental groups as well as appropriate state wide organizations, the watershed teams and associations and the appropriate regional planning agency(ies).

We have listed below a few of the organizations that might be involved with proposed Lower Merrimac Valley sub-region for source protection outreach. These are in addition to the Regional Planning Agencies listed on the map.

The Greater Newburyport Chamber of Commerce & Industry is a leading organization in the port region that advocates for sound, balanced economic development. As a vital organization that represents the diverse interests of our members who are from many different business sectors and locations, the Chamber speaks as a collective voice on issues that impact business, the economy, and the community at large. Our goal is to represent the entire business community as effectively as possible so that not only businesses thrive, but also the region as a whole, and we may continue to experience improvements in our overall quality of life.

Through collaboration, education, legislative forums, informational meetings and networking opportunities, we provide our members with the information and resources they need to succeed in today's economy and make key decisions about issues impacting the future of the region's character, growth and business climate. We are recognized as a strong, respected business organization known for our abilities to lead, inform, promote, manage, unify and satisfy the needs of more than 825 members doing business in the Greater Newburyport region.
Now and into the future, the Chamber is committed to being actively involved with:

- future waterfront and economic development issues
- city, state and national government
- addressing industrial concerns and seeking workable solutions
- merchants, financial institutions, professionals, services, non-profits, consultants
- community initiatives and legislation that could impact members, residents, and the environment
- stimulating future infrastructure enhancements
- advocating for sensible use and development of our cultural and natural resources

Merrimack Valley Planning Commission's planning region includes five cities and 10 towns in northeastern
Massachusetts. The region, which includes the lower Merrimack River and several coastal communities, is
bounded on the north by New Hampshire and on the south by the Boston metropolitan area. Nearly 312,000
CITIZENS LIVE IN THE AREA, WHICH CONTAINS SOME OF THE EARLIEST SETTLEMENTS AND INDUSTRIAL DEVELOPMENTS IN THE US.

Member Cities and Towns:: Amesbury/ Georgetown/ Lawrence/ Newbury/ Rowley/ Andover/ Groveland
Merrimac/ Newburyport/ Salisbury/ Boxford/ Haverhill/ Methuen/
North Andover/ West Newbury

The Commission: The Merrimack Valley Planning Commission is an independent public agency composed of
one commissioner from each member city or town and one at-large commissioner representing the region's
minority population. Commissioners generally are elected members of local planning boards and meet monthly.

The Merrimack Valley Planning Commission performs many services directly for communities and regional
agencies in a broad scope of planning areas—transportation and transit, environmental protection, economic
development, housing, growth management, coastal resource management, emergency response, data manage-ment and community outreach and involvement. Specific services provided include water supply protection
plans, economic forecasts, Geographic Information System mapping and graphics, bus and commuter rail plan-ning, aquaculture, pavement management, traffic counts, permit streamlining, business financing, and workshops
and training.

MRWC is a non-for-profit membership organization with a growing constituency of individuals, businesses, municipalities and community groups seeking to protect the natural resources of the watershed. Working in partnership with these diverse interests, MRWC acts as a catalyst to improve the watershed environment through planning, advocacy, education, science, and protection of watershed lands. We combine watershed science and land use planning as a framework for decision-making. Our Board of Directors representing varied interests in the watershed carries out governance, while work is coordinated and implemented by a professional staff and many volunteers.

The Merrimac River Watershed Coalition (MRWC) is a non-for-profit membership organization with a growing constituency of individuals, businesses, municipalities and community groups seeking to protect the natural resources of the watershed. Working in partnership with these diverse interests, MRWC acts as a catalyst to improve the watershed environment through planning, advocacy, education, science, and protection of watershed lands. We combine watershed science and land use planning as a framework for decision-making. Our Board of Directors representing varied interests in the watershed carries out governance, while work is coordinated and implemented by a professional staff and many volunteers.

Other environmental groups that have expressed an interest in the program are:

Lawrence Environmental Action Group,
The Haverhill Environmental League

People for the Environment from North Andover

EPA NEW ENGLAND AND THE NEW ENGLAND

WATER WORKS ASSOCIATION'S DRINKING WATER PROTECTION BUSINESSES HONORS PROGRAM:

A Program to Encourage Businesses to Protect Drinking Water Supplies

Ted Lavery, U.S. Environmental Protection Agency, EPA New England

Biographical Sketch:
Ted Lavery, EPA New England, Office of Ecosystem Protection, Maine Unit, Source Water Protection Coordinator

Education
B.A. History, Middlebury College, Middlebury, Vermont,
Certificate in Management- Harvard University, Cambridge, Massachusetts

Ted serves as a co-coordinator for the Drinking Water Protection Business Program along with Ray Raposa, President of the New England Water Works Association, chapter of the American Water Works Association. Ted also serves as a source water coordinator with the Maine Unit at EPA New England.

Abstract
The U.S. EPA and the New England Water Works Association, a chapter of the American Water Works Association, formed an honorary recognition program for businesses that have voluntarily protected drinking water supplies. Each year both organizations recognize businesses and drinking water suppliers who have partnered to mitigate impacts to drinking water supplies through improved stormwater treatment, land conservation, pesticide reduction management, and pollution prevention efforts. Information on these productive partnerships will be distributed to local drinking water suppliers, business associations and municipal officials through an accompanying video and workbook.

Background
EPA New England and the New England Water Works Association (NEWWA) promote voluntary drinking water protection activities through a cooperative education and awards program. Since 1997, this cooperative program with the New England Water Works Association, a section of the American Water Works Association, has recognized twenty-five (25) businesses such as golf courses, farms, real estate developers, telecommunications companies. Each businesses took voluntarily measures which resulted in the prevention, reduction and elimination of pollution to public drinking water supplies.

Each year the EPA-NEWWA program recognizes efforts by businesses to protect public drinking water supplies by installing safeguards at their facilities and by working cooperatively with their local water suppliers. Many businesses have improved their facilities' impact by treating storm water run-off, reducing pesticide applications and practicing erosion control. Other businesses have set aside land for buffers, and worked with local public water suppliers on spill response measures.

Education and Outreach Activities

The program's second component includes producing a video and distributing a workbook to business associations and individual businesses. The video and workbook illustrate successful cases where businesses voluntarily installed management practices or changed operations to protect drinking water supplies.

Video - "Everybody's Business! - A Team Approach to Drinking Water Supply Protection"
The video, to be completed during the Fall of 2001, includes case studies on different practices that can mitigate impacts to drinking water supplies: storm water treatment, land conservation, pest reduction management, pollution prevention.

Some of these businesses took these extra protection measures by working with their local water suppliers, other took measures on their own. Companies such as Verizon Laboratories, a small Massachusetts vegetable farm, a Maine nursery owner and a small automobile repair station owner explain their incentives to protect drinking water.

The video will be distributed to business associations, public water suppliers and interested individual businesses. Additional marketing for the video will include presentations at conferences and local business association meetings in New England.

Business Workbook for Drinking Water Supply Protection
The workbook to accompany the program, due to be completed in the Fall of 2001, will include case studies, example best management practices (BMPs) and self evaluation modules for four categories of businesses: agriculture, auto repair, construction/land development, and light industry /manufacturing.

The workbook will then be distributed to business associations, public water suppliers and interested individual businesses through mailing and presentations at business association meetings. Businesses will be invited to contribute to the workbook's production through participating in case study development, steering committees, and pilot workshops to review and comment on the drafts of materials.

Drinking Water Protection Business Honors Protection Program
Each nominee for the business honors program is screened for any compliance problems at that particular facility for the past five (5) years. Compliance screening includes checks with the state environmental agencies, state attorney generals and local health boards.

Applications were evaluated based on the criteria listed below. ***(Only one criteria is required to be considered for an award).*** Business efforts drinking water supplies, both surface and ground water through the following activities were considered. Cooperative projects between businesses and water suppliers were recognized as business-drinking water supplier partnerships. Activities protecting future drinking water supplies were also considered. No quota or limit on the number of projects recognized was imposed.

Criteria

- Non-point source pollution prevention for drinking water supplies (Includes erosion control, stormwater treatment, forestry management, innovative septic systems, sludge management)

- Land preservation, conservation and protection

- Innovative agricultural operations (integrated pest management, nutrient management)
- Environmental education for students, customers, and businesses on drinking water protection
- Pollution prevention by reducing or eliminating pollution at its source (Includes substitution of non-toxic for hazardous materials, product reformulation, process modification, and improved operation and maintenance)
- Partnerships with public drinking water suppliers to protect existing and future drinking water supplies
- Use of Best Management Practices or innovative techniques to reduce risk of contamination or demonstrate a commitment to drinking water protection

Program Participants:
Here are some examples of honors program winners that have voluntarily protected drinking water supplies:

Stormwater Treatment
Wolman Construction and Groton Utilities, Connecticut - Real estate development company installed advanced storm water treatment system and erosion controls in its construction of a Marriot Hotel in Groton, CT. Wolman Construction worked closely with local drinking water supplier, Groton Utilities, to design vegetated buffers, install erosion controls and design a storm water collection and treatment system to lessen impacts on nearby Poheganut Reservoir.

FUSCO, New Haven, Connecticut- Real estate development company installed detention basins to treat stormwater run-off from redeveloped shopping center. Storm water treatment system intercepted flows before discharge to tributary of nearby surface water supply, Lake Whitney, a water supply for New Haven, Connecticut.

Verizon Laboratories, Waltham, Massachusetts - Company installed an advances stormwater treatment system and vegetated swales to treat parking-lot runoff which drained into the public drinking water supply for Cambridge Massachusetts. Facility also sponsored spill prevention and clean-up practices with Cambridge Water Department and other area businesses.

Anheuser-Busch Inc., Merrimack Brewery, Merrimack, New Hampshire - Large consumer products company installed advanced stormwater treatment and spill prevention system near a large surface drinking water source for Massachusetts and New Hampshire communities, the Merrimack River.

Vegetated Buffers
O'Donnals Nursery - Gorham, Maine (Sebago Lake Watershed) - Nursery owner assisted local land owners in designing vegetated buffers for installation in the shoreline zone of surface water supplies such as Sebago Lake, water supply for Portland, Maine. Business volunteers time in teaching workshops in conjunction with the county Soil and Water Conservation District.

Agriculture
Marini Farms, Ipswich, Massachusetts - Local farmer who maintains 30 acres within a Massachusetts Zone II water supply protection area implements integrated pesticide management techniques and plants cover crops to limit impacts on nearby public drinking water supply well

and tributaries to nearby reservoirs. Farmer works with local board of health, conservation commission and water supplier on planning and farming practices.

Land Protection Near Supplies

Bovenzi Inc., Leominster, Massachusetts - Real estate development company created local land trust and donated property near drinking water finishing reservoir to newly established land trust. Company worked with local water department and watershed association to identify other properties eligible for state land grants to protect nearby surface water supplies.

Summary

During the Fall of 2001 the video and workbook will be distributed to business associations, public water suppliers and interested individual businesses. Additional marketing for both products and the continued honors program will include presentations at New England business association, water utility association and municipal association meetings. The honors program will accept nominations during the Spring of 2002.

The program's goals are to increase awareness by businesses of potential drinking water protection projects they could tackle. The video and workbook provide real case studies of small and large businesses which volunteered their time, resources and effort to protect drinking water supplies.

Copies of the video and workbook are available by contacting Ted Lavery at Lavery.Ted@EPA.GOV

Electronic Interchange of Data Between Operators, State Regulatory Bodies, the U.S. EPA, and the Public: Where are we at and where are we headed?

Mark A. Layne, Ph.D., P.E.

BIOGRAPHICAL SKETCH

Mark A. Layne, Ph.D., P.E. is one of the founding members of ALL Consulting, an environmental engineering and information technology specialist consulting firm located in Tulsa, Oklahoma. Dr. Layne received his Ph.D. from the University of Missouri-Rolla in Petroleum Engineering. Dr. Layne is the lead technical specialist for information technology at ALL Consulting and is the director of the IT department. One of the main duties Dr. Layne performs is the support of data management direction that is being taken by many State Oil & Gas Regulatory bodies across the U.S.

ABSTRACT

This paper explores the methods of electronic data interchange between various stakeholders in the Class II Underground Injection arena. A review of the in- place exchange technologies currently being utilized by the industry has been performed to provide a baseline of the current status of electronic data exchange. Along with the review of the current situation is a review of the emerging technologies that are being put into place in the industry to facilitate the ease and the need of expanded electronic data interchange. These technologies include the use of personal data assistants, Internet technologies, data management techniques (XML), and GIS capabilities. An analysis is presented that characterizes the benefits and drawbacks of the existing technology with what are being presented as the next steps in the Oil & Gas Industry's Electronic Data Interchange.

Analysis of Injectate Location at DU Pont Beaumont Works

James W. Mercer[1], Charles R. Faust[1], Clay Brown[2] and James E. Clark[3]

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James W. Mercer

Dr. Mercer's degrees, including his Ph.D., are in geology. In 1979, after eight years of research with the USGS, Dr. Mercer co-founded GeoTrans, Inc. In 1985, he received the Wesley W. Horner Award of the American Society of Civil Engineers for work at the Love Canal hazardous waste site. In 1994, Dr. Mercer received the American Institute of Hydrology's Theis Award for contributions to groundwater hydrology. Dr. Mercer has served on the National Research Council's Water Science and Technology Board and was a member of the U.S. EPA Science Advisory Board. He is also co-author of the book, *DNAPL Site Evaluation*.

Abstract

For worst-case regulatory modeling, U.S. EPA requires that injectate be contained for as long as the injectate is hazardous. For this reason, no-migration petitions are required to track injectate or define injectate plumes using health-based limits (HBLs) used for drinking water. This helps insure that overlying underground sources of drinking water (USDWs) are protected. Whereas using HBLs to define an injectate plume is appropriate for worst-case regulatory modeling, in reality, HBLs do not apply to injectate in a brine, which is not drinkable. EPA does not consider water with total dissolved solids (TDS) higher than 10,000 mg/l even a potential water supply. HBLs are based on an assumption of a 70 kg person drinking 2 liters per day of water with the designated concentration of the substance 350 days per year for 30 years. Such an analysis has no meaning when no one is drinking even 1 liter of the brine waters far below the surface of the earth. In addition to the TDS being higher than allowed drinking water limits, these brines often contain naturally occurring chemicals (e.g., arsenic) that are above regulatory risk levels. A more realistic injectate plume definition in a brine environment can be developed using several different methods. The acrylonitrile injectate in the Oakville sand at DuPont's Beaumont Works is used to illustrate this approach. This injectate is composed of approximately 95 percent water. The worst-case regulatory approach has determined that the injectate plume be defined using the 10^{-6} contour. Three different methods are used to define a realistic injectate plume: (1) mass-in-place calculations, (2) HBL approach adjusted for brine, and (3) use of detection limits. Injectate modeling was performed for the Oakville sand, and plume contours were determined. This modeling utilized recent seismic data, as well as other information, that aided in characterization of nearby faults. The three independent approaches lead to the same conclusion that a realistic injectate plume definition in a brine environment is achieved using the 10^{-4} contour. If chemical fate (degradation and sorption) is considered, the contour will be greater (10^{-3} or higher).

INTRODUCTION

Beaumont Works (**Figure 1**) is located adjacent to the Neches River, approximately five miles south of Beaumont, Texas. Approximately two miles west of the centroid of the injection wells is the Spindletop Dome. The plant site encompasses approximately 728 acres. Three wells, located in the north-central portion of the plant property, have been used for the injection into deep strata (**Figure 2**) below the Beaumont Works facility. Injection Well No. 1 has been used for injection, first, into the Catahoula sand, later into the upper Oakville sand, and then (and currently) into the lower Oakville sand since it was completed in 1972. Injection Well No. 2, also completed in 1972, was first used for injection into the Catahoula sand and later (and currently) for injection into the lower Oakville sand. Injection Well No. 3 was completed in 1987 and has been used for injection into the Frio sand only.

The Beaumont Works manufactures acrylonitrile, aniline and other speciality chemicals. The wastewater streams that are injected are composed of approximately 95 percent water. Thus, the vast majority of the injectate is water. The remainder is primarily dissolved salts with traces of organic chemicals. The wastewater stream from the acrylonitrile plant is currently injected into Injection Wells No. 1 and 2. The wastewater stream from the aniline system is currently injected into Injection Well No. 3. As of the end of 1999, a total of approximately 6648 million gallons (mgal) of injectate had been injected into the three wells at the site (approximately 2252 mgal into Injection Well No. 1, approximately 3657 mgal into Injection Well No. 2, and approximately 740 mgal into Injection Well No. 3). The lower Oakville sand has received the most fluid (approximately 3666 mgal, starting in 1980). Injection into the Catahoula sand from 1972 to 1982 totaled approximately 1370 mgal and injection into the upper Oakville sand from 1982 to 1991 totaled approximately 872 mgal. Total injection into the Frio sand is approximately 740 mgal, starting in 1987.

The analysis presented in this paper focuses on the Oakville sands. The SWIFT code (Reeves et al., 1986) is used to determine the present-day (beginning of year 2000) extent of injectate in these sands. DuPont (2000) has performed extensive modeling of the Oakville sands, providing calibration and predictive simulations. The modeling performed here takes advantage of the existing knowledge base developed as part of the regulatory modeling. However, in the regulatory no-migration demonstration modeling performed by DuPont, conservative data and assumptions were used to show that the deep wells are safe and protective of human health and the environment even under worst-case assumptions. The modeling performed in this analysis is based primarily on most likely data and assumptions to determine where the injectate is actually located. Even in this analysis some conservative assumptions are still made.

GEOLOGY

The following discussion is summarized from DuPont (2000). DuPont Beaumont Works is located in the Gulf Coast geosyncline, a thick wedge of interlayered sands and shales/clays (confining beds). The confining beds are composed of clay. The general stratigraphy including the injection sands is shown in **Figure 2**. In descending order of depth, the injection sands historically used at the site are upper Oakville sand, lower Oakville sand, Catahoula sand, and Frio sand. The top of the upper Oakville sand is at a depth of about 4200 feet; and it is approximately 3200 feet below the base of the underground sources of drinking water (USDW), which is less than 1000 feet deep. Between the base of the USDW and the injection sands are over 2000 feet of clay confining beds, including the Lagarto shale, and buffer aquifers. The vertical distance between the Oakville sands and the deeper Frio sand is more than 3000 feet, which includes additional confining clays (e.g., Anahuac shale).

The Oakville sands are laterally continuous across the area and have sufficient permeability, porosity, and thickness to prevent migration of fluids into USDWs. The confining zone for injection into the Beaumont Works injection wells is the interval located approximately 3200 feet to

approximately 3800 feet subsurface. This interval includes part of the Lagarto Formation shales. The Lagarto shale is also laterally continuous and free of transmissive faults or fractures over an area sufficient to prevent the movement of fluids into an USDW. The confining zone is separated from the base of the lowermost USDW by multiple saline aquifers occurring in the interval from 1000 to 3200 feet subsurface. These saline aquifers are buffers and offer additional protection against potential vertical migration of injectate by providing a bleed-off area for any pressure or upward flowing fluids that would ever reach them.

The clay strata between injection sands provide an effective barrier to vertical migration between injection intervals. The upper and lower Oakville sands are separated by a 10-ft clay based on electric logs. In 1987, during the drilling of Injection Well No. 3, samples were collected using Schlumberger's Repeat Formation Tester (RFT) from both the upper Oakville sand (4085 feet depth) and the lower Oakville sand (4133 feet depth). Injectate reaction products were recovered from the lower Oakville sand, whereas no injectate reaction products were recovered from the upper Oakville sand, indicating that the 10-ft clay at this location is an effective barrier to upward migration. The confining zone for the Beaumont Works Injection Wells Nos. 1 and 2 is 600 feet thick, providing a thick barrier to upward migration. As indicated, additional clays are present above the confining zone, providing further protection.

The injection site is between two large salt domes: Spindletop Dome to the west and Port Neches Dome to the east. The salt at the top of Spindletop Dome is approximately 1000 feet deep; whereas, the Port Neches Dome is deeper seated (approximately 7000 feet deep). The Spindletop Dome is a barrier to flow. A radial fault (Fault A) originating from Spindletop Dome passes through the subsurface in an east-west trending direction and passes near the north side of the injection site at the Oakville injection sand level, where approximately 850 feet of offset occurs at the injection level. The same fault passes near the south side of the injection site at the Frio and Catahoula levels. The high side of Fault A is on the north side, i.e., it is a down-to-the-south fault. Fault H, also originating at Spindletop Dome, is a minor down-to-the-north fault, with approximately 70 feet of vertical separation in the Oakville that formed as an antithetic fault to the larger regional Fault A. The location and extent of Fault H has been determined by recent seismic data.

In terms of the potential for vertical fluid migration, Fault A has been determined to be non-transmissive, i.e., the fault does not transmit pressure or fluid vertically. The same lack of injectate reaction products in the upper Oakville sand when Injection Well No. 3 was drilled is consistent with the lack of communication between the two Oakville sands and the non-transmissive nature of Fault A, Fault H, or other local faults.

The impact of Fault A on horizontal fluid flow depends upon the juxtaposition of sediments across the fault. Fault A is a sealing fault (no-flow horizontal boundary with a non-communicating nature) in the Catahoula and Frio sands, based on the contact of sand abutting against clay and/or the available clay for clay smear, DuPont model calibration, and reservoir test results. This sealing nature in the Catahoula sand was further supported during the drilling of Injection Well No. 3 in 1987 when a sample was collected from the Catahoula sand (4712 feet depth). No injectate reaction products were recovered from the Catahoula sand.

Injectate migration to the south in Frio sand and Catahoula sand is limited by Fault A, which, as indicated, is a sealing fault at the depths of these sands. Therefore, injectate placed into the Frio sand through Injection Well No. 3 is limited to migration north of Fault A. Likewise, migration of injectate in the Catahoula sand also is limited to north of Fault A.

The throw on Fault A at the Oakville level is approximately 850 ft. This amount of throw juxtaposes the lower Oakville sand against sands and clays of the Catahoula on the opposite (north) side of the fault in the vicinity of the injection wells. A review of the geology and reservoir test analysis

indicates that Fault A is a communicating fault in the portion of the lower Oakville sand nearest the site where the lower Oakville sand abuts sand across the fault; Fault A is non-communicating away from the site where the lower Oakville sand abuts clay across the fault. This interpretation is supported by the small pressure buildup in Wells No. 1 and 2 (if Faults A and H were both sealed, the observed pressure buildup would be much greater).

Fault H is another fault with a west to east orientation from Spindletop Dome, sub-parallel to Fault A. Like Fault A, Fault H is non-transmissive (i.e., does not allow vertical fluid flow). This is supported by the lack of injectate reaction products in the upper Oakville sand when Injection Well No. 3 was drilled that is consistent with a lack of communication between the two Oakville sands and the non-transmissive nature of Fault H. The sealing nature of Fault H is supported by annual injection/fall-off tests in the Oakville sands that identify a no-flow boundary at the approximate location of Fault H. These test results and analysis of the stratigraphy across the fault indicate that Fault H is non-communicating (i.e., it is a sealed fault and a no-flow boundary) in the lower Oakville in the vicinity of the deep wells.

ANALYSIS

The approach used to determine the extent of injectate migration consisted of groundwater modeling using the Sandia Waste-Isolation Flow and Transport Model (SWIFT). SWIFT is a fully transient, three-dimensional model that simulates the flow and transport of fluid, heat and solutes in geological media (Reeves et al., 1986). The primary equations are coupled by fluid density, fluid viscosity, and porosity. SWIFT was preceded by the code, Survey Waste Injection Program (SWIP), which was designed specifically to evaluate deep-well injection (Intercomp, 1976).

The injection sands at the Beaumont Works are all greater than 4000 feet deep. Vertical containment, including the impact of faults, and oil and gas wells referred to as artificial penetrations (APs), was evaluated by DuPont (2000). The conclusion was reached that the injectate would be contained. The lack of transmissive faults is consistent with Gulf Coast clays, known to exhibit viscoelastic deformation behavior, which causes any natural fractures to close and heal very rapidly under the action of the in-situ compressive stresses. The lack of vertical migration is supported by: (1) sample results from Injection Well No. 3 at the time it was drilled showing injection reaction products in the lower Oakville sand and no injection reaction products in the upper Oakville sand; (2) over 2000 feet of clay confining beds overlying the injection sands; (3) Core Laboratories performed brine flow-through permeability tests on cores from Injection Well No. 3 of the Anahuac shale (depth range 6687-7356 feet) that established an average permeability to liquid of 5.2×10^{-6} md; vertically-oriented core plugs from the Lagarto shales (depth range 3602-4055 feet) that established an average permeability of 1.1×10^{-5} md; and (4) modeling by DuPont that showed only a few feet of vertical permeation distance into the overlying aquitards. Therefore, vertical migration is not considered in this analysis.

As indicated, the acrylonitrile wastewater is injected into the Oakville sands via Injection Wells No. 1 and 2. The hazardous components for this injectate are cyanide, acetonitrile, acrylonitrile, and acrylamide. These chemicals hydrolyze, and their decomposition rate is affected by the pH (the higher the pH, the faster the decomposition) and temperature (the higher the temperature of the injection formation, the faster the decomposition). Independent field evidence, based on an acrylonitrile waste sample collected at a depth of 4133 feet when Injection Well 3 was drilled, supports attenuation. Injection Well 3 is approximately 860 and 1400 feet away from Injection Wells No. 2 and 1, respectively. It was estimated that the encountered injectate was injected in late 1984 and was approximately 2.5 years old. Observations based on the injectate sample that indicated decomposition included the following: (1) the acrylonitrile concentration had decreased to below the detection limit (20 ppm) compared to an average of 222 ppm in the injected wastewater, and (2) the cyanide concentration

had dropped to 22 ppm down from 542 ppm. Although this degradation is occurring, it is not included in this modeling.

Input Data

An important geological consideration for the lower Oakville sand model is the faulting. In plan view, the lower Oakville sand is south of Fault A and the juxtaposed sand (Catahoula sand) is north of Fault A. All of Fault H is sealed whereas, a portion of Fault A is open where the lower Oakville sand is in contact with the juxtaposed sand on the north side of the fault in the area of the three deep wells. The basis for Fault H being sealed is: (1) geology where shale is on the opposite side of the fault; and, (2) reservoir test results indicating a barrier near the Fault H location. The basis for Fault A being open is: (1) geology where sand is on the opposite side of the fault; and, (2) low measured pressure buildup at injection wells (if the fault were sealed, higher pressure buildup would occur). At the Oakville level, Fault A is within approximately 400-500 ft of Injection Wells Nos. 1 and 2; whereas Fault H is approximately 4000 ft away from these wells.

The lower Oakville sand has received only injectate from the acrylonitrile plant via injection from Injection Wells No. 1 and 2. Injection Well No. 2 began injection into the lower Oakville in April 1980 and by December 1999 had injected approximately 2915 mgal into the lower Oakville sand. Injection Well No. 1 began injection into the lower Oakville in February 1992 and by December 1999 had injected approximately 751 mgal into the lower Oakville sand. The total injectate in the lower Oakville sand is approximately 3666 mgal. Injection histories for these wells were used in the model.

The modeling treated the lower Oakville sand as a single layer, confined above and below. This is a conservative assumption with respect to lateral migration and is consistent with analysis showing little or no (1-2 ft) vertical migration of the injectate into the overlying confining bed. The top of the lower Oakville sand is located at a depth of approximately 4250 feet near the injection wells. Near the injection wells, the net sand thickness is between 75 - 100 feet. Unlike DuPont's regulatory modeling that assumed a uniform thickness, the modeling here uses actual thickness that varies spatially. According to temperature logs and other data, DuPont (2000), the entire thickness of the lower Oakville sand receives the injectate. The parameters used in the model are similar to those used by DuPont and are listed in **Table 1**. Formation density and viscosity were computed by DuPont as functions of depth, determined from observed variations of temperature and total dissolved solids (TDS). Injectate density is measured prior to injection. The natural background velocity is on the order of only inches/year. This parameter does not have a significant effect during the injection time period. Sorption effects would retard migration, and were not taken into account. This is a conservative assumption; that is, given the clay content of the sand, some sorption likely occurs that would reduce injectate constituent migration. The porosity was determined from core samples (the average of 17 measurements that ranged from 0.274 to 0.339). The compressibility values are based on literature estimates and reservoir test analysis. Hydrodynamic dispersion is a process that occurs at the leading edge of dissolved plumes. The values of dispersivity are based on other field studies. The values for dispersivity used in this modeling are larger than those determined from smaller-scale field experiments because the scale of the injectate plume at the Beaumont Works is larger than the field experiments. This is a conservative assumption and results in a larger predicted plume. The pressure of 1920.29 psia is based on a measured value from Injection Well No. 2 made on May 24, 1994 for a depth of 4261 ft KB. This is the lowest measured pressure for the lower Oakville. Adjusting the reference depth to ground surface yields 4234.8 ft below ground surface (bgs). Degradation through hydrolysis is not incorporated in the model. This is a conservative assumption given that hydrolysis occurs and reduces injectate constituent concentrations. In addition, injectate in the upper Oakville sand also was modeled. The same parameters were used, and a reference pressure of 1891 psia at a reference depth of 4,184 ft was used.

The permeability estimate is based on reservoir tests. The reservoir data is summarized in DuPont (2000). The lower Oakville has a transmissibility of 1,209,677 md-ft/cp and a storativity of 0.000136 ft/psi. In addition, the reservoir test data indicate a single no-flow boundary at 2700 ft. Using the porosity and viscosity values in **Table 1** and thicknesses determined from seismic surveys and wells, yields permeability and compressibility values similar to those used in the model and listed in **Table 1**. The single no-flow boundary indicated from the reservoir tests corresponds approximately to Fault H. The actual distance of Fault H from Injection Wells No. 1 and 2 is greater than 2700 ft. The smaller distance was estimated from the reservoir tests using a uniform thickness for the lower Oakville. The thickness of the lower Oakville thins toward Fault H. Not accounting for this thinning has resulted in an underestimate of the distance to the no-flow (Fault H) boundary.

Table 1. Model parameters.

PARAMETER	VALUE
Compressibility (fluid)	3.035E-06/psi
Compressibility (sand)	2.81E-06/psi
Formation Fluid Density	65.83 lb/ft^3 (1.055)
Injectate Fluid Density	65.83 lb/ft^3 (1.055)
Fluid Viscosity	0.62 cp
Porosity	0.31
Permeability	11 darcies
Reference Pressure	1920.29 psia
Reference Depth	4248.6 ft bgs
Longitudinal Dispersivity	50 ft
Transverse Dispersivity	5 ft

The finite-difference grid used for the lower Oakville sand model is 320 nodes by 320 nodes. The grid is uniform, consisting of cells 100 feet by 100 feet horizontally, with variable thickness and variable elevation. Fault H is treated in the model as sealed, whereas Fault A is treated as open near the injection wells, and sealed away from the injection wells (based on the geology). The initial conditions for the model consist of the initial relative concentration (0.0) and the initial pressure (1920.29 psia at datum). The boundary conditions are shown in **Figure 3** and are no-flow conditions at Spindletop Dome; the boundaries at the edge of the grid blocks are treated as infinite aquifer using the Carter-Tracy method (using a thickness of 30 ft, radius of 15,000 ft and 360 degrees). The Carter-Tracy method is a boundary condition that allows the effects of the injection sand to be extended beyond the grid. Fault A and Fault H are shown, where the black-and-white portions of the faults indicate sand against shale across the fault, and therefore, that portion of the fault is sealed. The injection rates are used in the

model and the injectate relative concentration is assumed to be 1.0. For the numerical solution, centered-in-time and centered-in-space was selected and the matrix solution technique of L2SOR was used.

Simulation Results

The maximum pressure buildup in the lower Oakville sand occurs in the first quarter of 1998 at Injection Well No. 1 and is an increase of only 37.75 psi or a 1.97 percent increase over the initial pressure (datum of 4248.6 ft). This pressure declines rapidly once injection ceases based on fall-off reservoir tests. This small computed pressure build up is consistent with the observed measured pressure buildup. This is consistent with the conclusion that both Faults A and H can not be sealed.

The predicted extent of injectate migration is shown in **Figure 4**. The present-day (beginning of year 2000) extent of injectate migration is displayed using five contours. The mass of injectate contained within each plume contour was calculated. The results were as follows: the 0.5 contour (50 % injectate/50 % brine by volume) contained 91.81 % of the injectate mass; the 0.1 contour (10 % injectate/90 % brine by volume) contained 99.08 % of the injectate mass; the 10^{-2} contour (1 % injectate/99 % brine by volume) contained 99.94 % of the injectate mass; the 10^{-3} contour (0.1 % injectate/99.9 % brine by volume) contained 99.99 % of the injectate mass; and the 10^{-4} contour (0.01 % injectate/99.99 % brine by volume) contained 99.999 % of the injectate. Therefore, the 10^{-4} contour contains almost all of the injectate mass and volume. If chemical fate (sorption and degradation) were considered, the contour that contains the plume would be even larger (10^{-3} or larger). If instead, a health-based approach is used, then the following steps should be taken to account for the brine. First, chemical fate should be considered when selecting the appropriate injectate chemical, that is, a persistent chemical should be selected that has the lowest HBL. This leads to the selection of acrylonitrile, which has a HBL of 0.00006 mg/l. A concentration reduction factor (CRF) can be calculated by dividing the HBL by the injection concentration. The actual yearly average concentration of acrylonitrile in the injectate for 1980 (the first year the lower Oakville was used for injection) was 83.6 mg/l. Performing this division yields a CRF of 7.18×10^{-7}. The final adjustment to the CRF is needed based on the recognition that HBLs apply to water that is drinkable, whereas, the Oakville brine is not drinkable, even before any injectate is added. Water in sands of the Oakville, as measured in DuPont Injection Well No. 3 at a depth of 4,085 feet, contains 73,000 to 85,000 mg/l TDS. In contrast, the EPA-recommended secondary drinking water standard for TDS is 500 mg/l. Therefore, to make Oakville brine drinkable, it would have to be diluted by a factor of 146 to 170. For computational purposes, a factor of 150 is used. Diluting the brine in its native state to make it drinkable water would also dilute any injectate contained in the brine. Applying the factor of 150 to convert the Oakville brine to a drinking-water equivalent, the CRF (ignoring chemical fate) becomes 1.08×10^{-4}, which is consistent with the contour determined using mass-in-place calculations. Finally, adjusting detection limits based on the brine concentrations leads to the conclusion that the organic chemicals contained in the injectate only can be detected inside the 10^{-4} contour. A similar plot is provided for the upper Oakville sand in **Figure 5**. As may be seen, the plume for the upper Oakville sand is smaller than that for the lower Oakville sand because less injectate was placed in the upper Oakville sand.

Grid cell sizes and time steps were selected using standard Courant and Peclet number criteria to control numerical dispersion (Anderson and Woessner, 1992). Because a uniform grid was used, cell aspect ratio was not an issue. The Peclet number is 2; the Courant number ranged to as high as 0.7. These are within acceptable limits (Spitz and Moreno, 1996; Woessner and Anderson, 1992).

The extent of injectate migration depends primarily on the volume of injectate, amount of dispersion, amount of hydrolysis and sorption, sand thickness, and sand porosity. Of these parameters, volume of injectate is measured during injection, porosity is measured from core samples, and thickness

is determined from well logs and geophysical surveys. Thus, the estimates for these parameters have a high degree of confidence. Reasonable and conservative values for dispersion have been used, and hydrolysis and sorption, which would limit migration, have not been simulated. In addition, the injectate migration is influenced by the presence and behavior of local faults, which have been studied through a variety of logs, seismic surveys, and hydraulic testing. Although changes in permeability affect computed pressure, the extent of injectate migration is not very sensitive to changes in permeability.

Verification

A comparison of simulated pressure falloff compared to measured pressure falloff from the 1992 interference test with the gauge in Well 2 is shown in **Figure 6**. Pressure was monitored in Well No. 2 while an injection and falloff test was conducted in Well No. 1. The data used in this simulation is contained in DuPont (2000) . As shown in **Figure 6**, the model predicted pressures closely track the measured pressures. A comparison is also made with the 1996 falloff test, which was conducted in Well No. 1 and is shown in **Figure 7**. Again, the comparison is good, providing confidence that the conceptual model, that is the basis for the numerical model, is correct.

Data used to verify the simulated results include the measurements of injectate at the Injection Well No. 3 location in 1987 when that well was drilled. As shown in **Figure 8**, the model predicted the presence of injectate in the lower Oakville sand at that location in 1987, and injectate was detected in samples collected when Injection Well No. 3 was drilled in 1987. At the time that Injection Well No. 3 was drilled, a sample also was collected from the upper Oakville sand. This sample indicates no injectate at this location at that time. A time-series plot for injectate concentration in the upper Oakville for the Well No. 3 location is shown in **Figure 9**. Consistent with the observed data, the model predicted that no injectate was present in the upper Oakville at the time that Well No. 3 was drilled. Simulations with Fault A sealed (not shown) force injectate to migrate south of Fault A, and for this simulation, injectate was present at the Well No. 3 location in April 1987. These observations support the conceptualization that Fault A is open in the vicinity of the injection wells.

CONCLUSIONS

Based on borehole information and seismic data, there are two nearly parallel faults (Faults A and H) in the Oakville formation in the vicinity of Injection Wells Nos. 1 and 2, with Fault A being the closer fault. Based on reservoir tests, a no-flow boundary is present near the vicinity of Fault H. Therefore, based on the reservoir test results, Fault H is considered a sealed fault. The best evidence that Fault A is not sealed in the vicinity of the injection wells is the small observed pressure buildup. This conceptualization was used in the SWIFT modeling performed in this paper, resulting in a small computed pressure increase that is consistent with observed data. The conceptual model of Fault A being open is further supported by injectate data collected at Injection Well No. 3 when it was drilled in 1987. The SWIFT model computed the injectate location that is consistent with observed injectate data; whereas treatment of Fault A as sealed would have caused injectate to migrate further south in the upper Oakville sand than was observed.

The present-day location of the injectate plume in the Oakville sands has been determined using SWIFT. A realistic injectate plume definition in a brine environment was developed using several different methods. Three different methods were used to define a realistic injectate plume: (1) mass-in-place calculations, (2) HBL approach adjusted for brine, and (3) use of detection limits. The three independent approaches lead to the same conclusion that a realistic injectate plume definition in a brine environment is achieved using the 10^{-4} contour or larger if chemical fate is considered.

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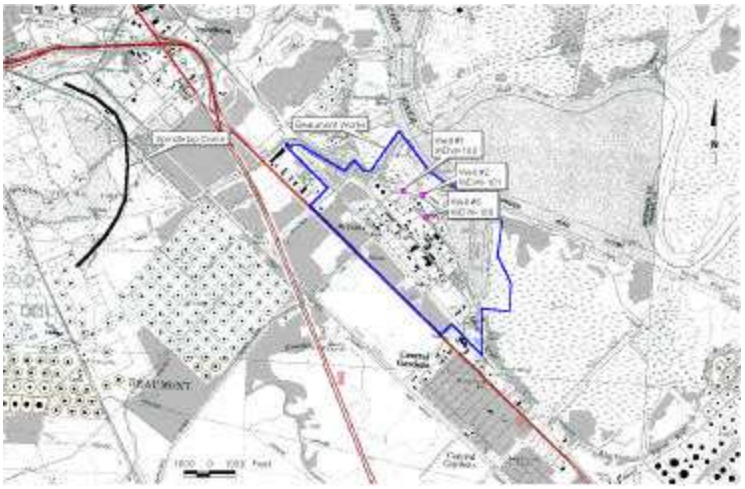
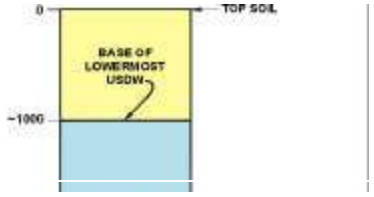


Figure 1. Beaumont Works.



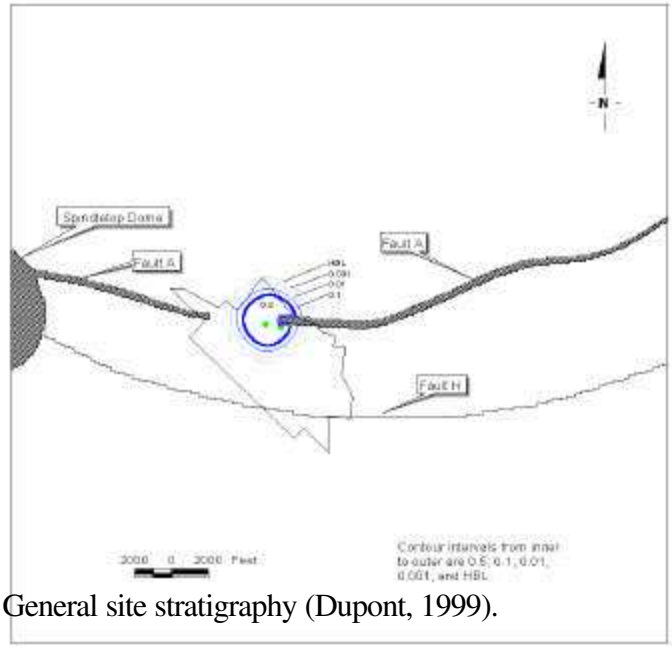


Figure 2. General site stratigraphy (Dupont, 1999).

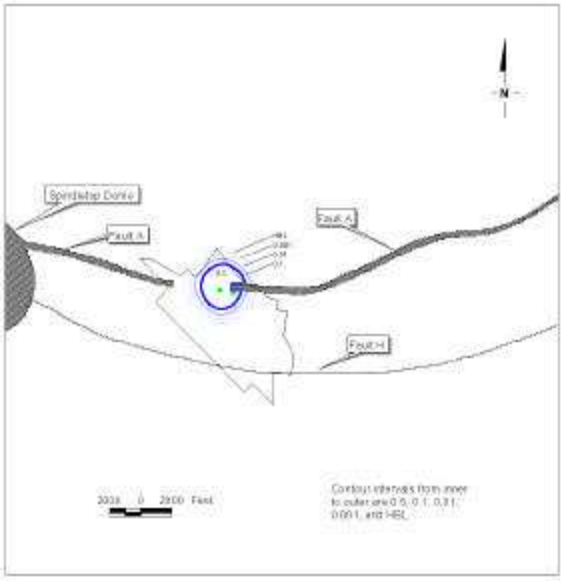


Figure 3. Boundary conditions for the lower Oakville sand model.

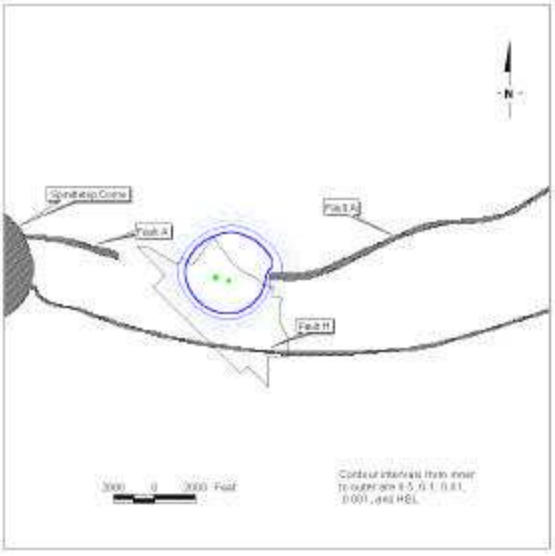


Figure 4. Plume for the lower Oakville sand.

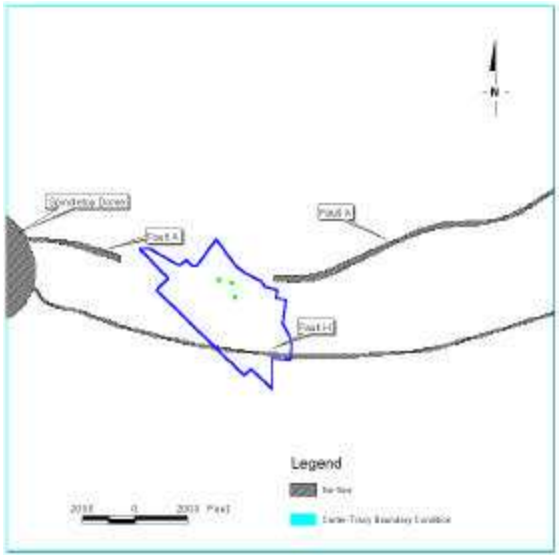


Figure 5. Plume for the upper Oakville sand.

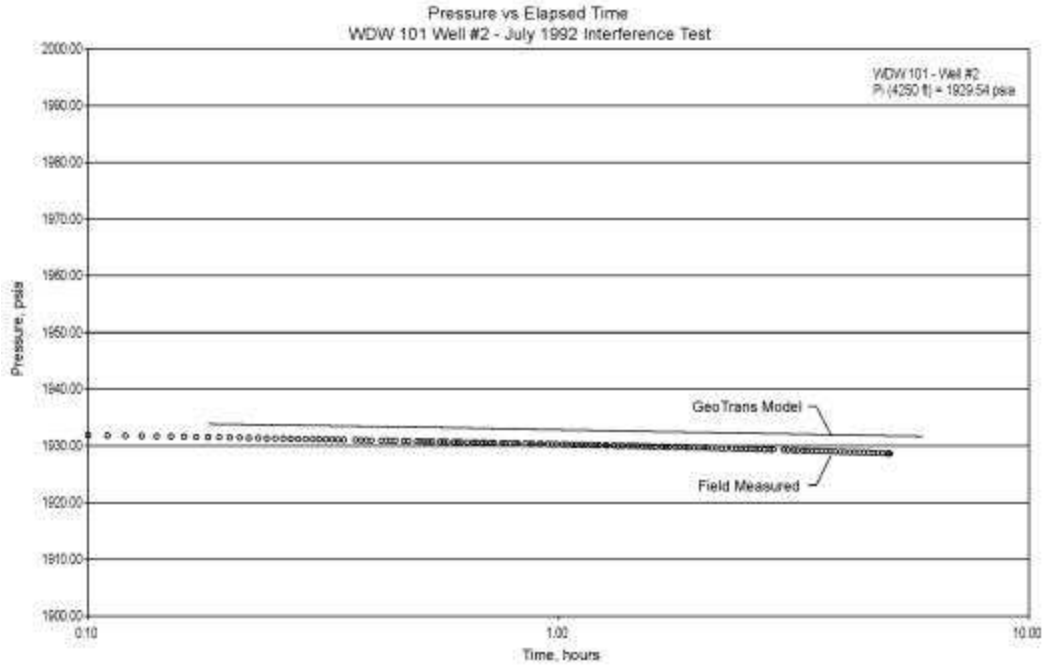


Figure 6. Falloff pressure versus elapsed time at well #2 for the 1992 interference test where the solid line is simulated result and the circles are measured pressure.

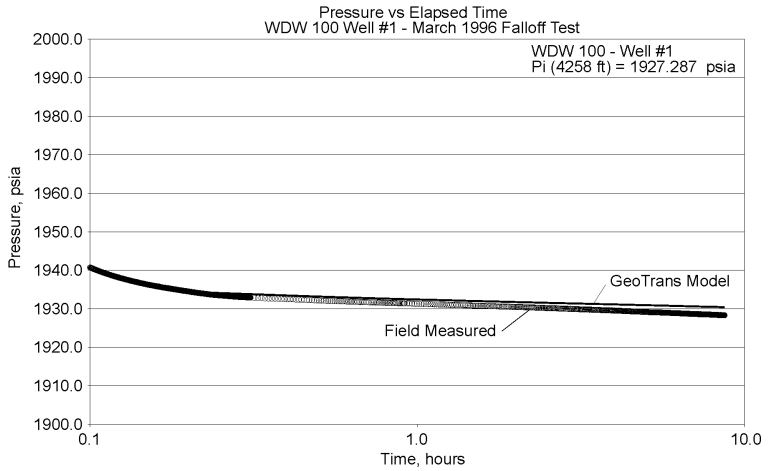


Figure 7. Falloff pressure versus elapsed time at well #1 for the 1996 falloff test.

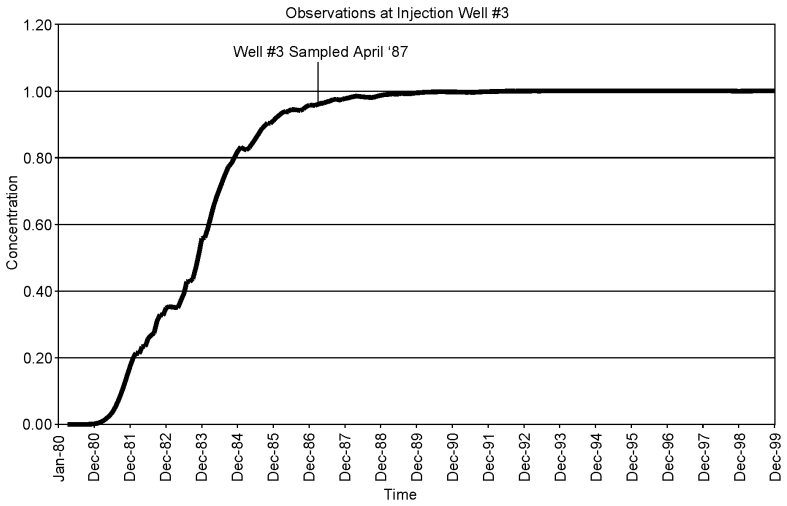


Figure 8. Concentration increase in the lower Oakville sand at the Injection Well No. 3 location.

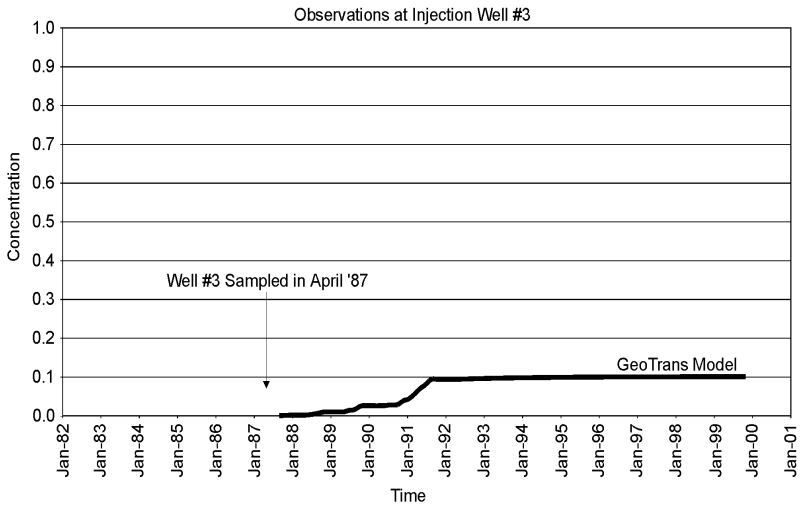


Figure 9. Concentration increase in the Upper Oakville sand at Injection Well #3 location.

ATRAZINE MONITORING of the HIGH PLAINS AQUIFER by IMMUNOASSAY

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ABSTRACT

The member agencies and entities of the Texas Groundwater Protection Committee, with the Texas Natural Resource Conservation Commission (TNRCC) serving as the lead agency, have prepared the state's Generic Pesticide Management Plan (PMP) for the prevention of pesticide contamination of groundwater. Texas received EPA concurrence for its PMP on June 6, 2000. TNRCC continues development and testing of the PMP's various components, especially groundwater monitoring.

Initially the most essential PMP component is ambient groundwater monitoring, since knowledge of areas and concentrations of pesticide contamination is prerequisite to carrying out many of the other components. Groundwater monitoring is being performed in three different ways. (1) Vulnerable area monitoring is being carried out in areas that have been determined to be vulnerable to pesticide contamination. (2) Review of Public Water Supply (PWS) system monitoring with confirmed pesticide detects. (3) Cooperative monitoring is being carried out to determine general ambient conditions.

Vulnerable area and PWS monitoring is carried out by TNRCC personnel. The groundwater samples are analyzed using immunoassay techniques for atrazine and metolachlor. Samples are then selected for laboratory confirmation based on immunoassay results. Wells with first time detections of atrazine or metolachlor are resampled at a later date for verification. Wells with significant confirmed detections are sampled on a routine basis under PWS monitoring. Cooperative monitoring is carried out by the cooperating entity, who send samples to the TNRCC for immunoassay analysis. Wells with atrazine detections >0.3 ppb under cooperative monitoring are resampled at a later date for verification.

Although other areas of the state have undergone some vulnerability area monitoring, the focus for PWS and cooperative monitoring has been on the Texas Panhandle because of the large number of confirmed atrazine detections in wells of several PWS systems. This project is the state's first large scale pesticide monitoring effort. This paper presents the highlights of ambient monitoring of the High Plains aquifer and the results of analyses for atrazine.

1. INTRODUCTION

The TNRCC is the State's lead agency in the protection of groundwater resources in Texas. The TNRCC has the responsibility of chairing the Agricultural Chemicals Subcommittee and its parent Groundwater Protection Committee, the multi-agency body that develops the State's strategy for protection of State groundwater resources. The Interagency Committee has responsibility for the development of the generic PMP and pesticide-specific PMPs, conducting groundwater monitoring in areas vulnerable to groundwater contamination by pesticides, and the investigation of areas with detects of pesticides in groundwater. The monitoring and investigative activities for a fully-implemented PMP under an EPA Final Rule are anticipated to require considerable funding to cover the entire State.

Texas has aggressively sought to make their PMP both effective and efficient, as groundwater resources are irreplaceable, and agriculture is a major part of the State's overall economy. Texas has more acres in farm lands than any state in the U. S., and is second in agricultural production revenue (Reference 1). Atrazine is one of the most popular pesticides used for controlling weeds in corn, sorghum, and several other important crops. Atrazine has a relatively high water solubility, relatively long half-life, a relatively low soil sorption index, and has been identified in ground and surface water in a number of states. As analytical methods with increasingly lower detection levels are employed, an increasing number of detections are occurring in both surface water and groundwater in Texas.

One pilot site investigation in the Texas Panhandle expended nearly the entire annual lab analysis budget, leaving little funding for routine monitoring activities during the final quarter of the 1999 Fiscal Year. Texas has 22 major/minor aquifers covering about 276,300 square miles (Reference 2). Cost of lab analytical work for such a large area is prohibitive. Texas PMP employs low cost immunoassay along with vulnerable area ranking and cooperative efforts to lower sampling and analytical costs. Immunoassay analysis is easier, faster, less expensive than lab analysis, and routinely detects analytes at lower concentrations because of the following; only one analyte at a time is analyzed; a smaller sample volume is required; it can be conducted in a hotel room or office/lab location; and there are less stringent/ time intensive Quality Assurance/Quality Control (QA/QC) requirements. Immunoassay screening and "high-grading" of samples reduces the number of more costly lab analyses, and also serves as a good check on lab analyses. Additionally, EPA promulgated the IA method for triazine herbicides as atrazine analysis in 1999, as EPA Method 4670 (Reference 4).

2. PROJECT DESCRIPTION

a. Background

The Texas Generic Pesticide Management Plan (PMP) for Prevention of Pesticide Contamination of Groundwater, provides for ambient monitoring focusing on vulnerable areas and a monitoring and investigative response to pesticide detections. Vulnerable areas are ranked for monitoring based on estimates of pesticide use in an area, modeling of pesticide movement through soils, and connectivity with the occurrence of usable quality groundwater. Groundwater-based PWS system data is also reviewed for pesticide detects. Monitoring is conducted at PWS sites experiencing detects for atrazine to verify Point-of-Entry (POE) detects, determine specific contributing wells, and to assess the area for extent of the pesticide detected.

b. Project Origin

The Texas Panhandle Region containing the High Plains aquifer was identified as having the most vulnerable areas, and some of the highest atrazine use in the state. The area has substantial amounts of corn and sorghum production, the main croplands on which atrazine is typically applied. In previous sampling by various agencies, atrazine has been detected in the region's groundwater and found in significant concentrations in area surface water bodies. Limited sampling and review of POE monitoring for PWS systems in the region identified six PWS systems with atrazine detects. A verification and investigative monitoring project at five PWS sites confirmed detects in individual PWS wells for these systems.

Reporting of the monitoring data to the interagency ACS and Texas Groundwater Protection Committee drew attention to possible quality impacts to a major aquifer and the need for additional sampling. Atrazine sampling could be coordinated with the TWDB's 5-year cycle of state groundwater quality monitoring, beginning with the Panhandle region in 1999. The High Plains Underground Water Conservation District #1 (HPUWCD#1), the largest of such organizations in the state, was also coordinating their routine water quality monitoring activities with the TWDB, and volunteered to provide additional samples, preferably in areas the TWDB had limited sample coverage. These combined efforts, coordinated through the ACS, enabled the efficient screening of an important regional aquifer for atrazine.

c. Project Objectives and Structure

The Panhandle Cooperative Project's (PCP) primary objective was to screen groundwater samples for atrazine from as much of the Texas High Plains aquifer as possible. Sample areas with atrazine concentrations at or greater than 0.3 ppb would be recommended for follow-up verification sampling, as TNRCC's experience indicates samples with concentrations below this will come back as non-detects by lab analyses. This approach would address the PMP monitoring component and the fostering of cooperation of state and local agencies and entities.

Project sampling was primarily conducted by the TWDB, with additional sampling by the HPUWCD #1. Field notations and well records were the responsibility of the sampling entity, while analysis, compilation of the data, map and report generation were TNRCC's responsibilities. All immunoassay analyses for atrazine were conducted by TNRCC.

A major aspect of the program is the Quality Assurance Project Plan (QAPP), which includes Standard Operating Procedures (SOP). The QAPP is the multi-part document that specifies groundwater sampling protocol and guidelines, acceptable analysis methods, and program standards. TNRCC's QAPP includes pesticide analysis by immunoassay method for screening and investigative (delineation) efforts. Other entities are allowed to conduct sampling for the program, as long as they are trained to follow sampling and shipping protocol. Both TWDB and HPUWCD#1 sampling personnel received TNRCC training, to ensure adequate QA/QC measures were maintained. These included;

- collecting 1 duplicate sample for every 20 samples,
- 1 field blank for every 20 samples,
- Collection of sample in 40-ml glass vials, leaving no headspace (bubbles),
- keeping samples cooled from 2°-4°Celsius, in a secured place until delivered for immunoassay analysis, and accompanied by chain-of-custody documentation

Analyses of samples were conducted with SDI/Ohmicron kits and an instrument for magnetic-particle-based **e**nzyme-**l**inked **i**mmuno**s**orbant **a**ssay (ELISA) method of analysis of atrazine in water samples. Analyses were done using two SDI/Ohmicron RaPID Analyzer spectrophotometers. The RaPID Assay

kits for atrazine have a Least Detectable Dose (LDD, which is similar to the method reporting limits) of 0.05 ppb, and an upper limit of 5.0 ppb after which dilution is required, with the optimal range for the method being in the 0.3 to 1.0 ppb area (most accurate and precise values are in this range). False positive results for atrazine are typically attributed to the method also detecting structurally related compounds (triazines for atrazine), and metabolites. Lab analysis is specific for atrazine and concentrations are usually less than the IA concentrations for the sample. Most samples indicating concentrations of pesticides >0.3 ppb by the IA method are recommended for verification by lab analysis, while those <0.3 ppb have resulted in non-detection by lab analysis and are not typically sent for lab analysis.

DATA COLLECTION AND ANALYSES

Sampling was conducted between March 18 and November 11, 2000. A total of 721 wells and 61 QA/QC samples were analyzed for atrazine by IA method. This essentially covered most of the High Plains aquifer in the Texas Panhandle. Sampling and analysis were completed within 8 months, with about 1-2 months additional time for data reduction, analysis, mapping, and reporting of results. The attached map (Figure 1) provides a view of the locations of wells sampled. Upon completion of the analyses, the database totals were cross-checked to Chains-of-Custody and immunoassay analysis sheets to confirm totals and numbers of QA/QC samples. The sampling is summarized in Table 1 below, followed by the data QA/QC summary.

Sample Summary Table

Agency/Entity	# Wells Sampled	# QA/QC Samples
TWDB	634	
HPUWCD#1	87	
TOTALS	721	61

Immunoassay data sheets were maintained for each analytical run, documenting which staff did the analysis, date and time analyzed, instrument number, calibration data, sample ID, concentration, date and time of sample collection, and other important notes. A total of 20 separate analytical runs were conducted to complete all the samples. The field and lab blanks were all non-detects, and the duplicate samples were either the same concentration or well within the 0.5 ppb method limit.

Of the 20 runs, four runs (172 samples, or 22%) had one of several calibration factors out of acceptable range. Three of these four were reading slightly more atrazine for the control than they should (0.09, 0.13 and 0.54 ppb), and one had a lower correlation factor reading than was acceptable (off by 0.011). These minor failures on these four calibration runs were the result of instrument age (~6 years), and a need to replace the lamp and/or filter. This resulted in these samples indicating slightly higher atrazine concentrations than were actually present, and showing numerous detects when no atrazine would have been detected by a newer instrument. This was proven true when a new spectrophotometer was purchased and utilized from 8/21/00, for the last seven analytical runs. Considerably fewer detects near the 0.05 ppb LDD were observed, and noticeably more non-detects resulted.

RESULTS

Of the 721 well samples analyzed for atrazine, 206 had atrazine detects (mostly low concentrations), and 553 did not have atrazine detected. Five well samples had atrazine detects greater than 1.0 ppb, 21 samples detected between 1.0 and 0.3 ppb atrazine. Of these 26 wells, four are PWS system wells with confirmed atrazine detects, while the remaining 22 wells are first time detects. There were a total of six counties with more than one well with an atrazine detect above 0.3 ppb atrazine, which centers roughly around Castro County.

Summary of Atrazine Analyses

Total # of Wells Analyzed	# of Non-Detects (ND is <0.05ppb)	# of Detects ≥0.05<0.1ppb	# of Detects ≥0.1<0.3ppb	# of Detects ≥0.3<1.0ppb	# of Detects ≥1.0ppb
721	515	117	63	21	5

Figure 1 shows the well sample and atrazine detect locations greater than 0.3 ppb. The most notable trend is the cluster of detects stretching from Deaf Smith County to Hale County, in the central area of the Panhandle region. These results correspond best with the high usage area, and north of the vulnerable area indicated on the assessment map (Figure 2). This also corresponds with the cluster of Public Water Supply systems (Figure 3) having relatively high atrazine detects in specific wells, currently targeted for ongoing monitoring by the Agricultural Chemicals Subcommittee of the Texas Groundwater Protection Committee. Only one of the wells sampled and analyzed by immunoassay method during the cooperative monitoring project had a detect above the 3.0 ppb Maximum Contaminant Level (MCL). This concentration was 3.31 ppb, near enough to the MCL that it will likely result in a concentration considerably below the MCL by lab analysis.

CONCLUSIONS

This cooperative project indicates a pattern (Figure 1) of atrazine detects in the central area of the Texas Panhandle. Such region-wide groundwater monitoring supports earlier indications in the PWS systems that a regional groundwater contamination concern exists for atrazine in the Texas Panhandle.

Additionally, the cost estimate comparison further confirmed the program's efficiency. The estimated cost for TNRCC to conduct a non-cooperative sampling & laboratory analysis program of this magnitude would require about 50 man-weeks of sampling staff salaries ($27,000) plus expenses ($17,000). Lab analyses for 782 total samples X ~$240/EPA Method 525 analysis = about $190,000, for a total sampling & analytical cost of about $230,000.

By contrast, estimates for the cooperative project immunoassay analysis for atrazine and follow-up work for the 782 samples, or 10 reagent kits + pipette tips X $430 = $4,300, plus $5,700 for test equipment, and TNRCC analysis staff time of about 160 man-hours X $770/40 hours = $3077, for a total analytical cost estimate of $13,077 (the added cost for other sampling entities to collect one vial for this analysis is minimal). This estimate indicates an approximate total savings to the State of nearly $217,000.

The cooperative atrazine groundwater monitoring by immunoassay method as conducted by the TWDB, HPUWCD#1, and TNRCC enabled a large area of the state to be screened for potential atrazine contamination. Conducting the monitoring through coordination between state agencies and other water resource entities has enabled this work to be conducted quickly and efficiently, saving the state considerable resources.

RECOMMENDATIONS

The following recommendations are based on project results, and the authors' experiences with Immunoassay for atrazine:

a. Continue to coordinate IA screening with other agency subdivisions, agencies, and local entities, to share in related efforts and expenses and eventually cover the entire state; One group may not be able to afford the equipment or use it enough to justify the purchase, but several can share in the expenses and benefits (The ACS is continuing to coordinate cooperative efforts in the present year, which will enable monitoring in other vulnerable and high pesticide use areas across the state at a substantial savings to taxpayers, and in a more timely manner.

b. Expand program, secure funding to screen for additional pesticides (completed analyses for both atrazine and metolachlor for the Gulf Coast aquifer and several minor aquifers in 2001)

c. Spin-off project to determine source(s) of contamination and migration pathways in both playa and non-playa lake areas

d. Secure funding to conduct sampling of well fields for larger cities, where entry points are only sampled and individual wells are seldom or never sampled and analyzed for pesticides

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4) USEPA Method 4670, Triazine Herbicides as Atrazine by Immunoassay, SW-846, Chapter 4.4, or 540/R94-509, 1999.

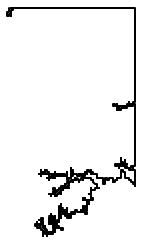
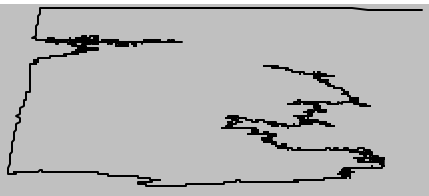


Figure 1



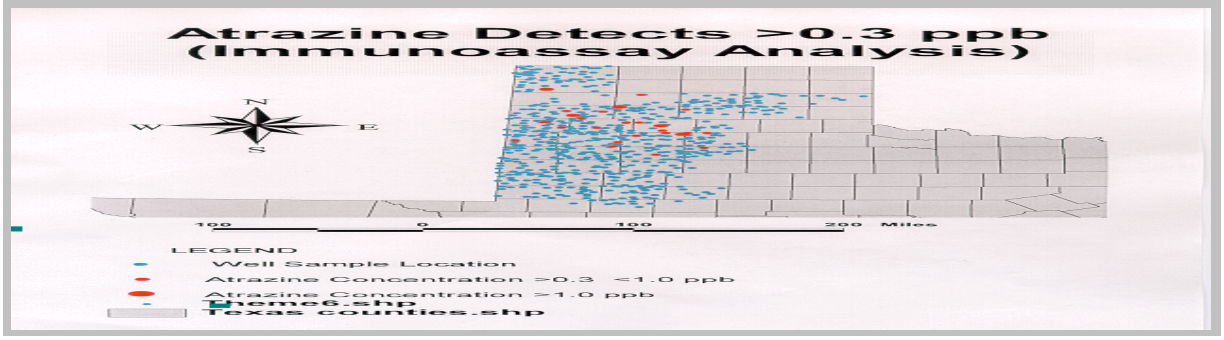

Atrazine Detects >0.3 ppb
(Immunoassay Analysis)
N
W
E
S
100
0
100
200
Miles
LEGEND
Well Sample Location
Atrazine Concentration >0.3 <1.0 ppb
Atrazine Concentration >1.0 ppb
Hwnm6.shp
Texas counties.shp

Figure 2

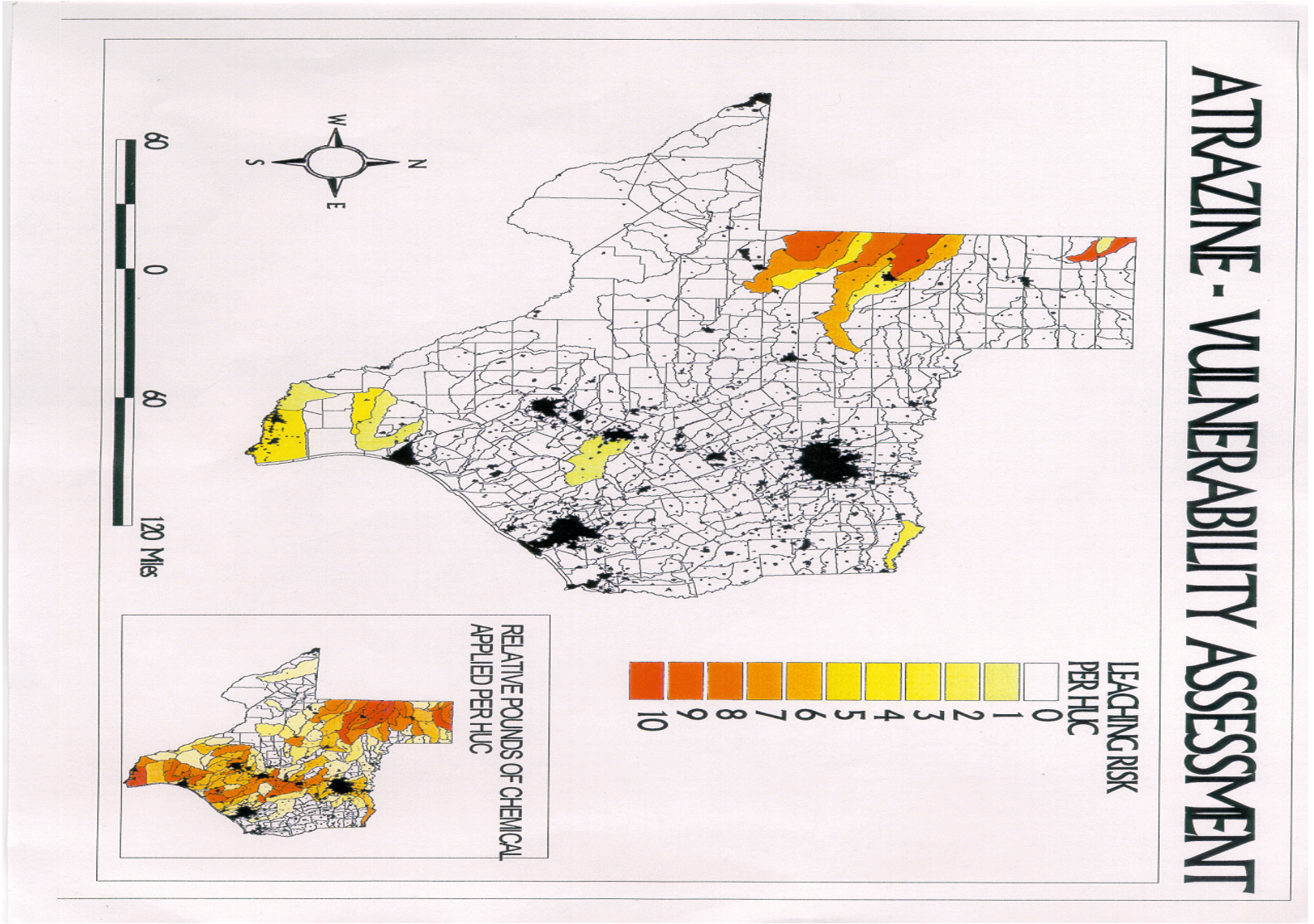
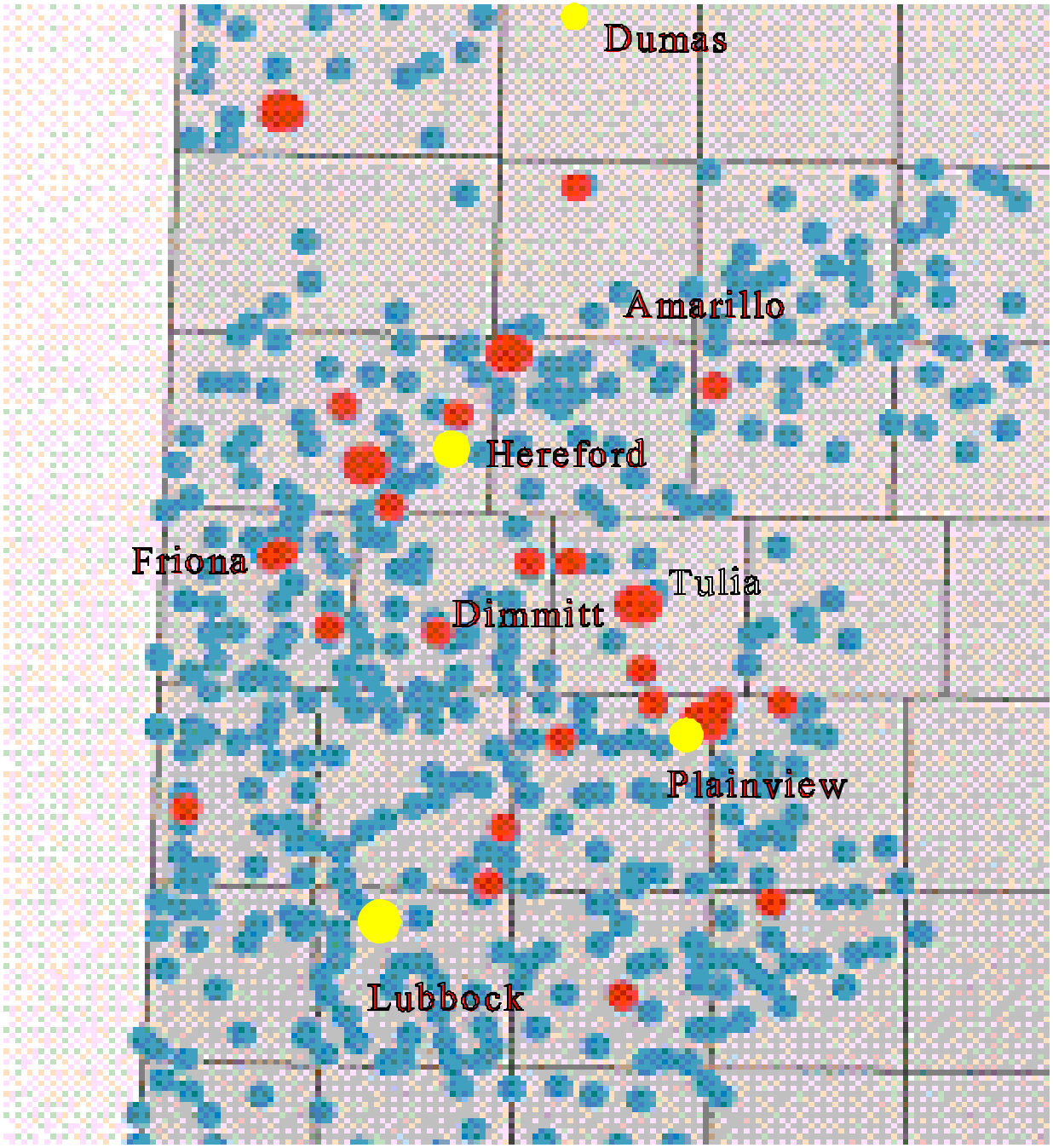

ATRAZINE - VULNERABILITY ASSESSMENT
LEACHING RISK PER HUC
0
1
2
3
4
5
6
7
8
9
10
N
W
E
S
60
0
60
120 Miles
RELATIVE POUNDS OF CHEMICAL APPLIED PER HUC

Figure 3
Wells with Atrazine Detects >0.3 ppb and
PWS with Atrazine Detects
(excluding city of Amarillo, no Atrazine detects to date,
and City of Lubbock detect not verified as of June 2001)



Brookhaven National Laboratory

Source Water Assessment for Drinking Water Supply Wells

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Abstract:

The water supply for Brookhaven National Laboratory is obtained exclusively from six onsite wells that draw water from a shallow, highly permeable glacial sand and gravel aquifer. These wells pump approximately 2.2-million gallons of water per day to meet the site's need for drinking water, process cooling water and fire protection. Because this shallow aquifer is very susceptible to contamination from legacy and ongoing facility operations, water quality is being protected through (1) a comprehensive program of engineered and operational controls of existing aquifer contamination and potential sources of new contamination, (2) groundwater monitoring, and (3) potable water treatment.

Source water areas for the potable water supply wells were determined using the Laboratory's regional groundwater model, which was used to simulate the groundwater flow regime under several water supply operating scenarios. Flow paths to each well were delineated using reverse particle tracking, whereby particles were introduced into the modeled supply well and tracked

backwards along flow path lines. Two-year and five-year travel time zones were delineated using this time-of-travel approach.

The two and five-year travel time zones were compared to an inventory of known and potential sources of contamination (e.g., existing volatile organic compound and radionuclide plumes, contaminated soils, underground and above ground storage tanks, and sanitary lines). The existing engineered and operational controls on those potential threats were then evaluated to determine whether the water supply is adequately protected.

1.0 INTRODUCTION

Because groundwater is the primary source of drinking water on Long Island, New York, there has been a long history of local, state and federal agency involvement in the development of groundwater management programs designed to protect this valuable resource. The Long Island 208 Study (Koppelman, 1978) was the first comprehensive attempt at water quality management. The 208 Study delineated eight major hydrogeologic zones based on groundwater flow patterns and determined the areas that contribute recharge to the Upper Glacial, Magothy and Lloyd aquifers. The Upper Glacial and Magothy aquifers are extensively used as sources of public drinking water. The Long Island Comprehensive Special Groundwater Protection Area Plan (SCDHS, 1992) established nine special groundwater protection areas that are deemed critical for the maintenance of good water quality in the Upper Glacial and Magothy aquifers.

The 1996 amendments to the Safe Drinking Water Act (SDWA) require the preparation of Source Water Assessments for all sources of water that are used to supply public drinking water. The Brookhaven National Laboratory (BNL) *Source Water Assessment for Drinking Water Supply Wells* was prepared to satisfy this requirement (Bennett *et al.*, 2000). Together with BNL's Environmental Management System, this Source Water Assessment is designed as a management tool to further protect the sole source aquifer system underlying the BNL site. The content of the BNL source water assessment is consistent with the requirements outlined in the *NYS Source Water Assessment Program Plan* (NYSDOH, 1999), and with Nassau and Suffolk County's proposed plan for conducting source water assessments for public water supply wells on Long Island (*Long Island Source Water Assessment Program – Technical Work Plan*, 1999).

2.0 GROUNDWATER RESOURCES AT BNL

There are three distinct water-bearing units underlying the BNL site: the Upper Glacial aquifer, Magothy aquifer, and the Lloyd aquifer. Detailed descriptions on the hydrogeology of the BNL site can be found in deLaguna (1963); Warren *et al.* (1968); and Scorca *et al.* (1999). The water supply for Brookhaven National Laboratory is obtained exclusively from six onsite wells that draw water from the Upper Glacial aquifer. These wells pump approximately 2.2-million gallons of water per day (MGD) to meet the site's need for drinking water, process cooling water and fire protection. The Upper Glacial aquifer is composed of Pleistocene-aged deposits that extend from land surface to 130 feet to 200 feet below land surface. The broadly stratified, glacio-fluvial outwash deposits are composed primarily of silica-rich medium to coarse-grained sand and gravel. Thin layers of silt and clay have been observed within the outwash deposits, but do not represent significant barriers to groundwater flow. The water table is normally encountered within 30 feet of the land surface. The hydraulic conductivity of the outwash deposits range from 80 to 200 ft/day.

2.1 Classification of Groundwater Quality

The Nassau/Suffolk Aquifer System has been designated by the U.S. Environmental Protection Agency (EPA) as a Sole Source aquifer system, pursuant to Section 1424(e) of the Safe Drinking Water Act (SDWA). Groundwater in the sole source aquifers underlying the BNL site is classified as "Class GA Fresh Groundwater" by the State of New York (6 NYCRR Parts 700-705). The best usage of Class GA groundwater is as a source of potable water supply. As such, federal drinking water standards, NYS Drinking Water Standards (NYSDWS), and NYS Ambient Water Quality Standards (NYSAWQS) for Class GA groundwater are used as groundwater protection and remediation goals. BNL evaluates the potential impact of radiological and nonradiological levels of contamination by comparing analytical results to NYS and DOE reference levels. Nonradiological data from groundwater samples collected from surveillance wells are usually compared to NYSAWQS [6 NYCRR Part 703.5]. Radiological data are compared to the NYSDWS (for tritium, strontium-90, and gross beta), NYSAWQS (for gross alpha, radium-226, and radium-228), and 40 CFR 141/Department of Energy Derived Concentration Guides (for determining the 4 mrem/yr dose for other beta-/gamma-emitting radionuclides).

2.2 Water Supply System

The six drinking water supply wells at BNL are located in two geographical areas. Potable water Supply Wells 4, 6, and 7 comprise BNL's Western Well Field, and Wells 10, 11 and 12 comprise the Eastern Well Field. Figure 1 shows the locations of the BNL potable supply wells. Historically, BNL has operated a number of large capacity process water supply wells used to provide water for heating and cooling purposes (Wells 101, 102, 103 and 105). The use of these wells was discontinued in 1999, and water for all cooling and heating is now being provided using the drinking water supply system. The BNL supply wells are operated under New York State Department of Environmental Conservation (NYSDEC) Long Island Well Permit 1-4722-00032/00113 granted to the U.S. Department of Energy on September 14, 1998. BNL submits an annual Water Pumpage Report to the NYSDEC that summarizes total pumpage for all BNL potable supply wells.

Each BNL potable supply well is capable of delivering up to 1,200 gallons per minute (gpm) to the potable water system. The six potable wells are used in rotation to meet the daily water supply requirements for the site. During 1999, the average water usage at BNL was 2.2 MGD. Most of the water (approximately 75 percent) is returned to the aquifer by way of onsite recharge basins and permitted discharges to the Peconic River. Under normal hydrologic conditions most of the water discharged to the Peconic River recharges to the Upper Glacial aquifer before leaving the BNL site.

2.3 Water Supply Management

Managing groundwater consumption at BNL and understanding the effects of groundwater withdrawals on the regional hydrogeological regime are important components of the BNL Groundwater Protection Program. The Upper Glacial aquifer is highly permeable, and yields significant quantities of water throughout the BNL area. The present rate of groundwater pumpage at BNL, coupled with significant recharge after use, results in only a minor net loss in the quantity of water stored in the Upper Glacial aquifer. However, since pumping of supply wells and subsequent recharge of this water does cause significant changes in groundwater (and possibly contaminant) flow directions and velocities, conservation of water by minimizing pumping is important. Since the early 1990s, total pumpage from the potable wells has been reduced from approximately 3.5 MGD to 2.2 MGD. This reduction has been realized by the implementation of water conservation projects, which have included distribution system upgrades to prevent water loss and the identification and correction of wasteful water use practices.

In the late 1980s, BNL developed a *Water Utility Master Plan* which provided an assessment of needed water supply system upgrades (e.g., new distribution lines, treatment and storage facilities, and well

modifications and replacements), daily water demands, fire fighting capabilities, and predicted growth (BNL, 1989). Based upon this plan, and more recent assessments of predicted growth in employee population and potential water demands for planned future research and support facilities, the current supply well network is capable of providing adequate supply of both potable and non-contact cooling water for the site. However, to maintain proper flow and pressure conditions, modifications to the existing distribution system may be required.

2.4 Locations of Future Water Supply Wells

Although BNL's water supply infrastructure is capable of meeting current and projected usage demand, if the water quality in the existing source water areas is unexpectedly and significantly degraded, a new source of water supply may be required. Identifying potential installation locations for a future water supply well or well field is a complex task. In general, some of the important siting criteria include:

- New supply wells can be easily connected to existing water distribution and power systems.
- Wells can be completed (screened) in aquifer material that provides good production (or yield) and good water quality (i.e., low in naturally occurring metals such as iron).
- Groundwater withdrawals would not adversely impact current or planned remedial activities (i.e., divert plume away from an existing or planned treatment system).
- Low risk of being impacted by existing or potential contaminant sources and the need for new treatment systems.
- No impact to surface water hydrology (e.g., Peconic River or associated wetlands).

Based on these criteria, several areas of the BNL site were identified as potential installation sites for new water supply wells (Bennett et al., 2000). The preferred location is to the east-northeast of the Eastern Well Field. Use of groundwater in this area would be the preferred alternative because the water has naturally low levels of iron and has not been impacted by site operations.

3.0 POTABLE WATER MONITORING PROGRAM

The SDWA requirements pertaining to the distribution and monitoring of public water supplies are applicable to any water supply that has at least five service connections or regularly serves at least 25 individuals. The Laboratory supplies water to a population of approximately 3,500 employees and visitors and must, therefore, comply with these regulations. The Suffolk County Department of Health Services (SCDHS) - Bureau of Drinking Water specifies the annual minimum monitoring requirements for all potable-water suppliers. If a contaminant were to be detected in a supply well sample at concentrations exceeding applicable drinking water standards, the well is immediately shutdown and an investigation into the source of the contamination is conducted. Follow-up actions, including the collection of additional samples for confirmatory analyses and communications with water users and regulatory agencies is described in the *BNL Groundwater Protection Contingency Plan* (BNL, 2000).

For drinking water supplies, the federal maximum contaminant levels (MCLs) set forth in 40 CFR 141 (primary MCLs) and 40 CFR 143 (secondary MCLs) apply. In addition, DOE Order 5400.5, Radiation Protection of the Public and Environment, establishes Derived Concentration Guides for radionuclides not covered by existing federal or state regulations. On an annual basis, BNL prepares a *Potable Water System Sampling and Analysis Plan* that outlines sampling procedures and schedules for monitoring the BNL's potable water supply system. Routine monitoring of the potable wells and the potable-water distribution system by BNL exceeds the prescribed minimum monitoring requirements. The monitoring program consists of: monthly bacteriological analyses; quarterly analyses for Principal Organic Compounds; annual analysis for Synthetic Organic Compounds and pesticides; semi-annual inorganic

chemicals analyses; and annual analyses of micro-extractables and asbestos. Potable water samples are collected by BNL personnel, and are analyzed by New York State Department of Health (NYSDOH) certified contractor laboratories using standard USEPA methods. BNL prepares monthly *Water System Operations Reports* that are submitted to the SCDHS - Bureau of Drinking Water. These reports include a summary of all analytical data. In addition to the SCDHS requirements, BNL maintains a supplemental sampling and analysis program for the BNL potable well system that includes more frequent analyses for radionuclides.

4.0 SOURCE WATER ASSESSMENT

The delineation policies of the Wellhead Protection Program established a "baseline" two-zone wellhead protection area for all public systems using groundwater supplies and allow flexibility for locally initiated refinements or revisions (NYSDOH, 1999). This policy emphasized regional aquifer management for wells in unconsolidated aquifers like those found on Long Island. Most source water assessments use an intermediate fixed radius (e.g., one mile) delineation approach or a more sophisticated computer modeling approach.

4.1 BNL Groundwater Model

Source water areas for BNL's potable water wells were determined using the BNL Regional Groundwater Model. The calibrated groundwater flow model (which is based on the computer code MODFLOW, and was developed for BNL by Arcadis Geraghty & Miller, Inc. [1996, 1999]) was used to simulate the groundwater flow regime under two water supply operating scenarios. A particle track analysis was then performed to trace the groundwater flow paths in the study area. The analysis code of the groundwater flow path used was a semi-analytical particle-tracking scheme known as MODPATH (Pollack 1994). The flow path was delineated using reverse particle tracking, whereby particles were introduced into the modeled supply well and tracked backwards along flow path lines. Two-year and five-year travel time zones were delineated using this time-of-travel approach. This method is consistent with the USEPA guidance on Wellhead Protection (USEPA, 1987). Because of BNL's extensive environmental protection and monitoring programs, the two and five year travel time zones are considered adequate for source water protection planning at BNL.

Groundwater models are a simplified representation of the complex groundwater system. Particle-tracking codes simulate advective transport only (the dominant contaminant transport mechanism at BNL) and neglect contaminant attenuation processes (e.g., dispersion, sorption, chemical reactions, and dilution), which can slow the rate of migration. Because particle tracking does not simulate dispersion (which can cause low levels of contamination to migrate ahead of its center of mass), it needs to be applied cautiously to compute the first arrival of measurable contamination. Nevertheless, particle tracking is recognized as a suitable planning technique if applied carefully.

4.2 Water Pumping Scenarios

The groundwater flow direction and rate in the Upper Glacial aquifer at BNL is strongly influenced by water supply and remediation pumping and recharge. In 1999, the average BNL potable water demand was approximately 2.2 MGD. Given variations in water use demands throughout the year due to fluctuations in seasonal temperatures, experiment run times, and worker and guest population, predicting future water demand is challenging. However, the 1999 potable water pumpage volume is considered a reasonable estimate for future water consumption needs, and was therefore used as representative volume

for this source water evaluation. If this demand were to change significantly in the future, then the source water assessment would have to be updated.

While all six of BNL's potable supply wells are in use each year, they are cycled on and off during any given period. Operationally, either the Western or Eastern Well Field is the primary source of water at any one time. Based on forecasts for 2000-2005, it is anticipated that Wells 4, 6, and 7 (the Western Well Field) will be operated in the "lead" position, and supply approximately 85% of the annual demand. Wells 10, 11, & 12 (the Eastern Well Field) will supply about 15% of annual demand. The modeled pumping rates are based on average annual demand for a particular well field and assume that the pumpage is divided equally among wells in that well field. For the purposes of the source water assessment, two pumping scenarios were evaluated. Under Scenario 1, the Western Well Field pumpage is 85% of demand (1.8 MGD), whereas the Eastern Well Field pumpage provides 15% of demand (0.32 MGD). Conversely, under Scenario 2 the Western Well Field pumpage provides 15% of demand (0.32 MGD), whereas the Eastern Well Field provides 85% of demand (1.8 MGD). These results indicate that during periods of "lead position" withdrawals (i.e., when a well field is supplying 85% or more of the average demand) the two-year source water areas extend approximately 1,000 feet away from each supply well, whereas the five-year source water areas typically extend up to 1,700 feet from each well.

5.0 SUSCEPTABILITY OF SUPPLY WELLS TO CONTAMINATION

Historically, the operations of a number of BNL potable and process supply wells were impacted by groundwater contamination. In the late 1980s and early 1990s, the operations of six of BNL's drinking water supply wells were severely impacted by VOC contamination (primarily due to the solvent 1,1,1-trichloroethane). As a result, three older wells (Wells 1, 2 and 3) were permanently decommissioned, and large capacity carbon filters were installed on the remaining three impacted wells (Eastern Areas Wells 10, 11 and 12). Although trace amounts of VOCs were detected in samples from Western area Well 4 (primarily 1,1,1-trichloroethane at concentrations <5 µg/L), the operation of this well was not impacted. Over the past several years, BNL's drinking water was in full compliance with all county, state, and federal regulations, and no (untreated) water samples collected at the supply wells were found to have contaminant concentrations that exceeded New York Sate Drinking Water Standards. This strongly indicates that the operational and engineered controls that were put in place during the 1990s have effectively protected the quality of the drinking water supply.

The extent of the modeled source areas was compared to the inventory of known and potential sources of contamination identified as part of BNL's Environmental Restoration and Environmental Surveillance programs. The existing engineered and operational controls on those potential threats were then evaluated to determine whether the water supply is adequately protected. This process was used to identify any activities that may need additional operational and/or engineered controls to increase the level of protection.

Figures 1 and 2 show the projected source areas under pumping Scenarios 1 and 2 with a geographical inventory of existing contaminant plumes, wastewater discharge outfalls permitted under BNL's State Pollutant Discharge Elimination System (SPDES) permit, and Class V injection wells (e.g. dry wells and cesspools). Figure 3 shows the geographical inventory of bulk chemical/waste storage areas, underground storage tanks and above ground storage tanks, and Figure 4 shows the distribution of the BNL sanitary line system. Figure 5 shows the source water areas (Scenario 1) with a geographical inventory of existing activated soil shielding areas and activated cooling water systems. Tables 1 and 2 list the potential threats to water quality and what groundwater protection controls are in place to address these potential threats.

This evaluation concluded that the source water for BNL's Western Well Field (comprised of Supply Wells 4, 6, and 7) has relatively few threats of contamination and that identified potential sources are

already being carefully managed. The source water for BNL's Eastern Well Field (comprised of Supply Wells 10, 11, and 12) has moderate threats to water quality, primarily from several existing volatile organic compound and tritium plumes. The Laboratory has been carefully monitoring plume migration, and has made adjustments to water supply operations. Although a number of BNL's water supply wells were impacted by VOC contamination in the late 1980s, recent routine analysis of water samples from BNL's supply wells indicate that no drinking water standards have been reached or exceeded. The high quality of the water supply indicates that the operational and engineered controls implemented over the past ten years have effectively protected the quality of the water supply. These programs need to be maintained to provide adequate water supply protection.

6.0 CONCLUSIONS

The BNL water supply system meets all water quality standards and has sufficient pumping and storage capacity to meet current and anticipated future operational demands. Because BNL's water supply is drawn from the shallow Upper Glacial aquifer, BNL's source water is susceptible to contamination. The quality of the water supply is being protected through (1) a comprehensive program of engineered and operational controls of existing aquifer contamination and potential sources of new contamination, (2) groundwater monitoring, and (3) potable water treatment.

The BNL Source Water Assessment found that the source water for BNL's Western Well Field (comprised of Supply Wells 4, 6, and 7) has relatively few threats of contamination and identified potential sources are already being carefully managed. The source water for BNL's Eastern Well Field (comprised of Supply Wells 10, 11, and 12) has a moderate number of threats to water quality, primarily from several existing volatile organic compound and tritium plumes. Although a number of BNL's water supply wells were impacted by VOC contamination in the late 1980s, the detection of only low-levels of contaminants in recent years indicates that the operational and engineered controls implemented over the past ten years have effectively protected the quality of the water supply.

A COPY OF THE COMPLETE REPORT CAN BE FOUND ON THE BNL WEBSITE AT HTTP://WWW.BNL.GOV/ESD/GW.HTM.

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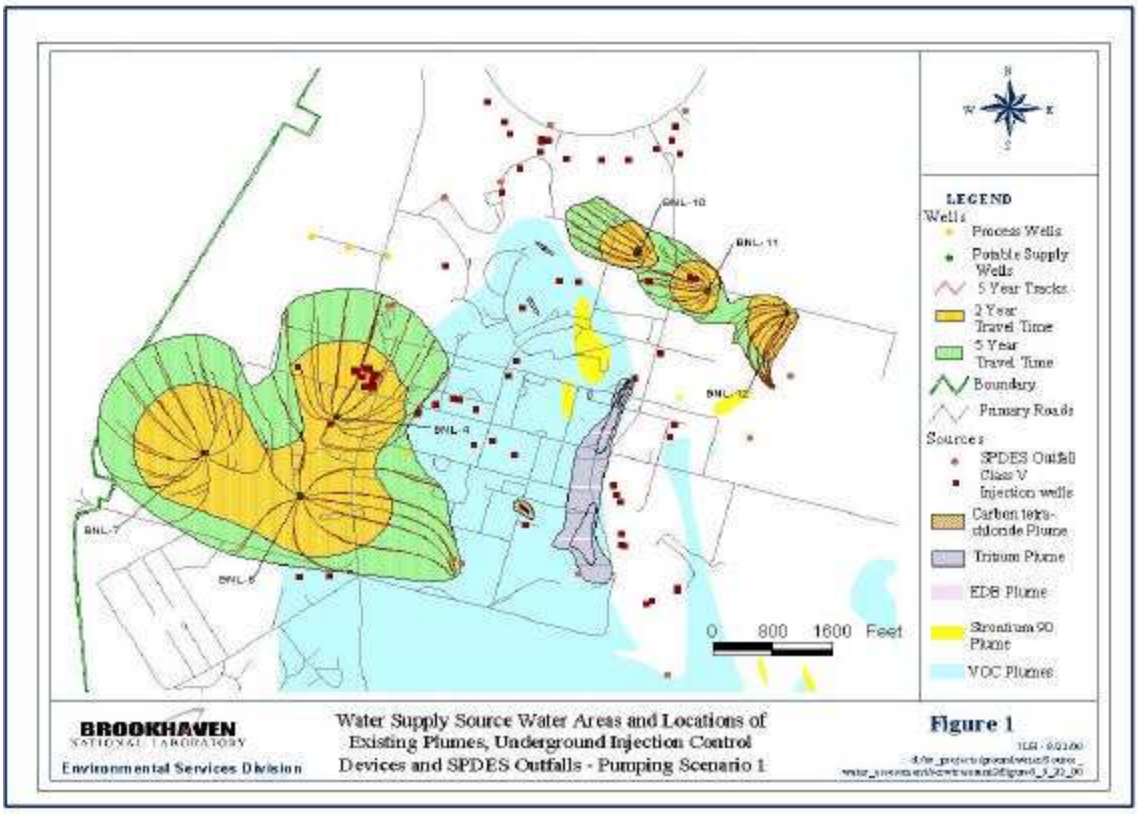
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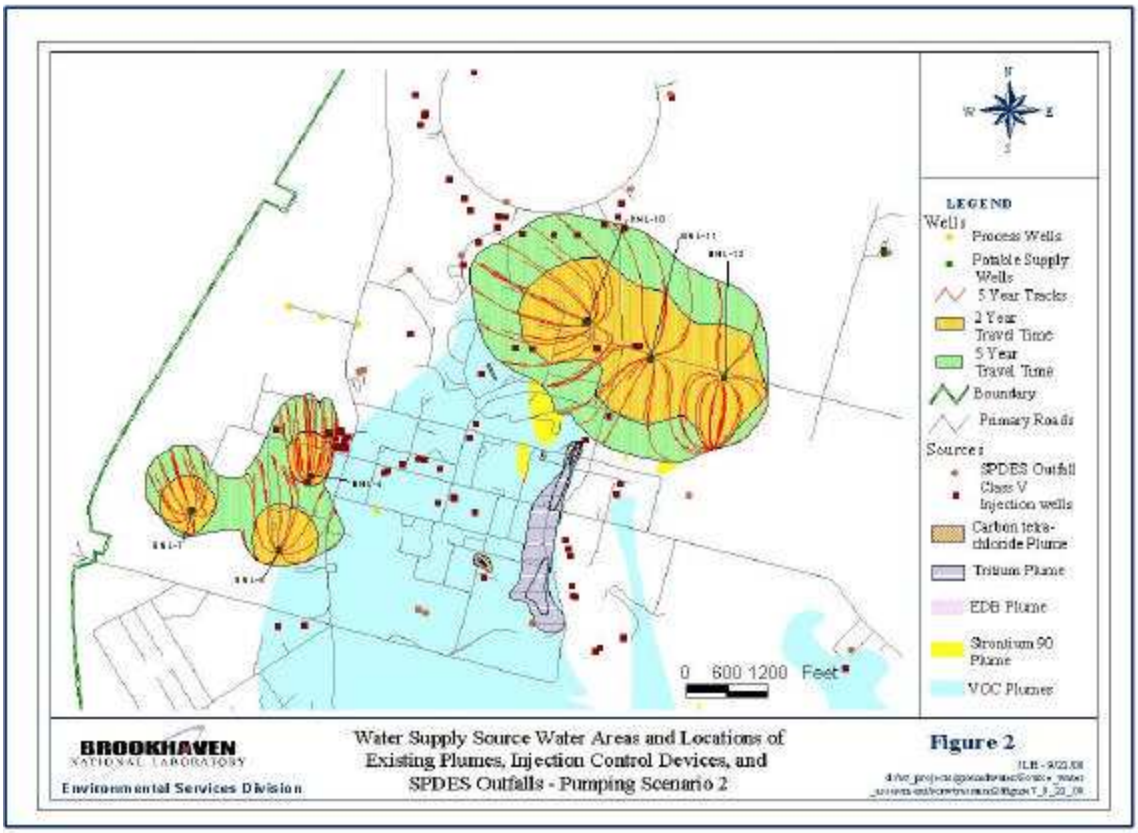
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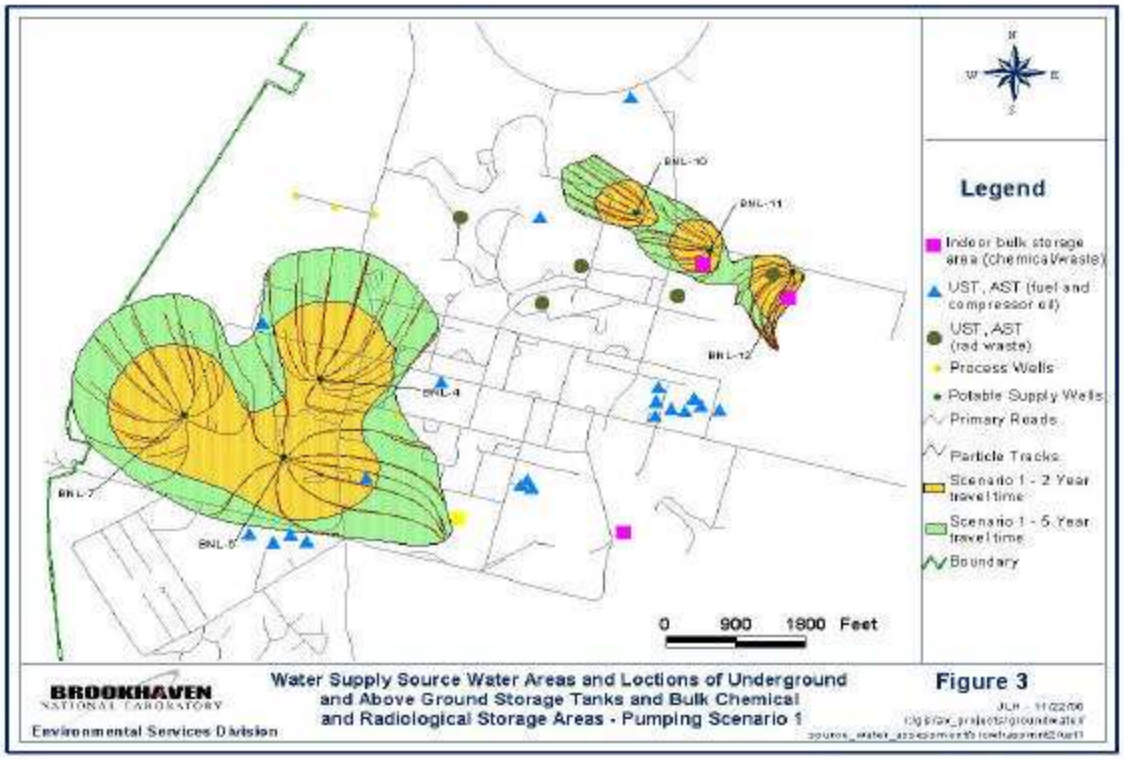
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N
W
E
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LEGEND
Wells
Process Wells
Potable Supply Wells
5 Year Tracks
2 Year Travel Time
5 Year Travel Time
Boundary
Primary Roads
Sources
SPDES Outfall
Class V Injection wells
Carbon tetrachloride Plume
Tritium Plume
EDB Plume
Strontium 90 Plume
VOC Plumes
BNL-10
BNL-11
BNL-12
BNL-4
BNL-7
BNL-8
0 800 1600 Feet
BROOKHAVEN
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Environmental Services Division
Water Supply Source Water Areas and Locations of Existing Plumes, Underground Injection Control Devices and SPDES Outfalls - Pumping Scenario 1
Figure 1


N
W
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S
LEGEND
Wells
Process Wells
Potable Supply Wells
5 Year Tracks
2 Year Travel Time
5 Year Travel Time
Boundary
Primary Roads
Sources
SPDES Outfall
Class V Injection wells
Carbon tetrachloride Plume
Tritium Plume
EDB Plume
Strontium 90 Plume
VOC Plumes
BNL-10
BNL-11
BNL-12
BNL-4
BNL-7
BNL-8
0 600 1200 Feet
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Water Supply Source Water Areas and Locations of Existing Plumes, Injection Control Devices, and SPDES Outfalls - Pumping Scenario 2
Figure 2

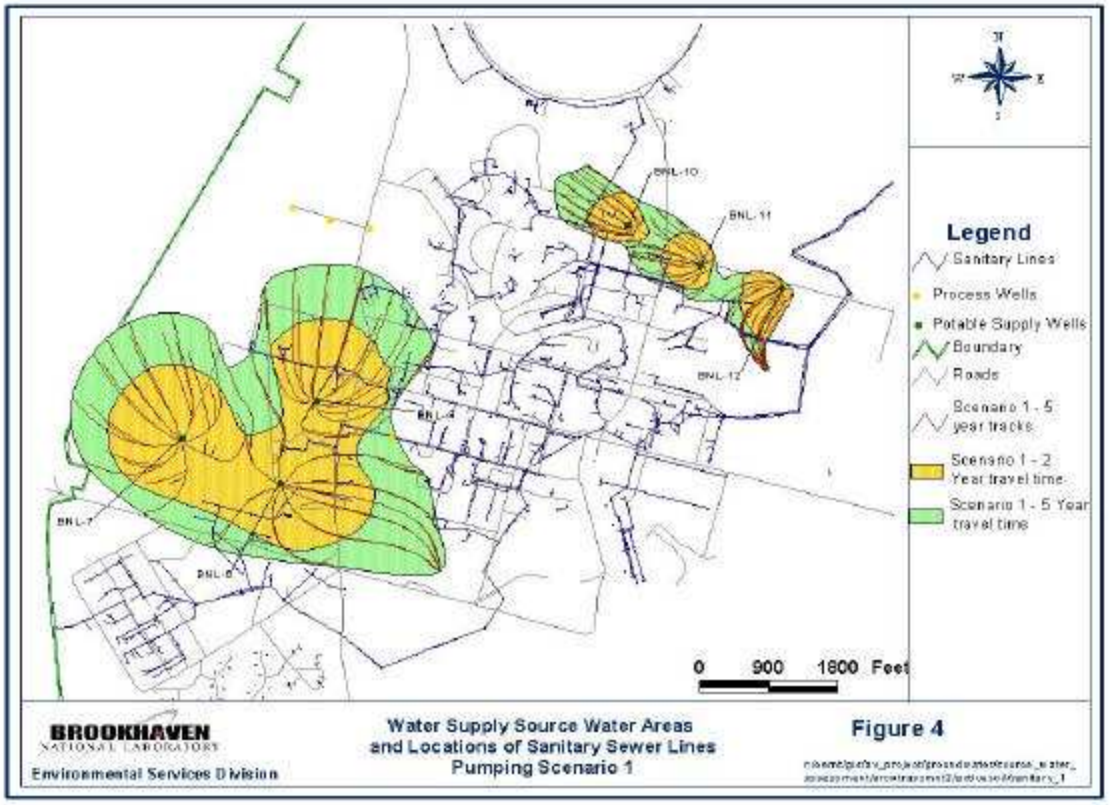


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Water Supply Source Water Areas and Loctions of Underground and Above Ground Storage Tanks and Bulk Chemical and Radiological Storage Areas - Pumping Scenario 1

Figure 3

JLH - 11/22/06


BNL-10
BNL-11
BNL-12
BNL-4
BNL-7
BNL-8
0 900 1800 Feet
Legend
Sanitary Lines
Process Wells
Potable Supply Wells
Boundary
Roads
Scenario 1 - 5 year tracks
Scenario 1 - 2 Year travel time
Scenario 1 - 5 Year travel time
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Water Supply Source Water Areas and Locations of Sanitary Sewer Lines Pumping Scenario 1
Figure 4

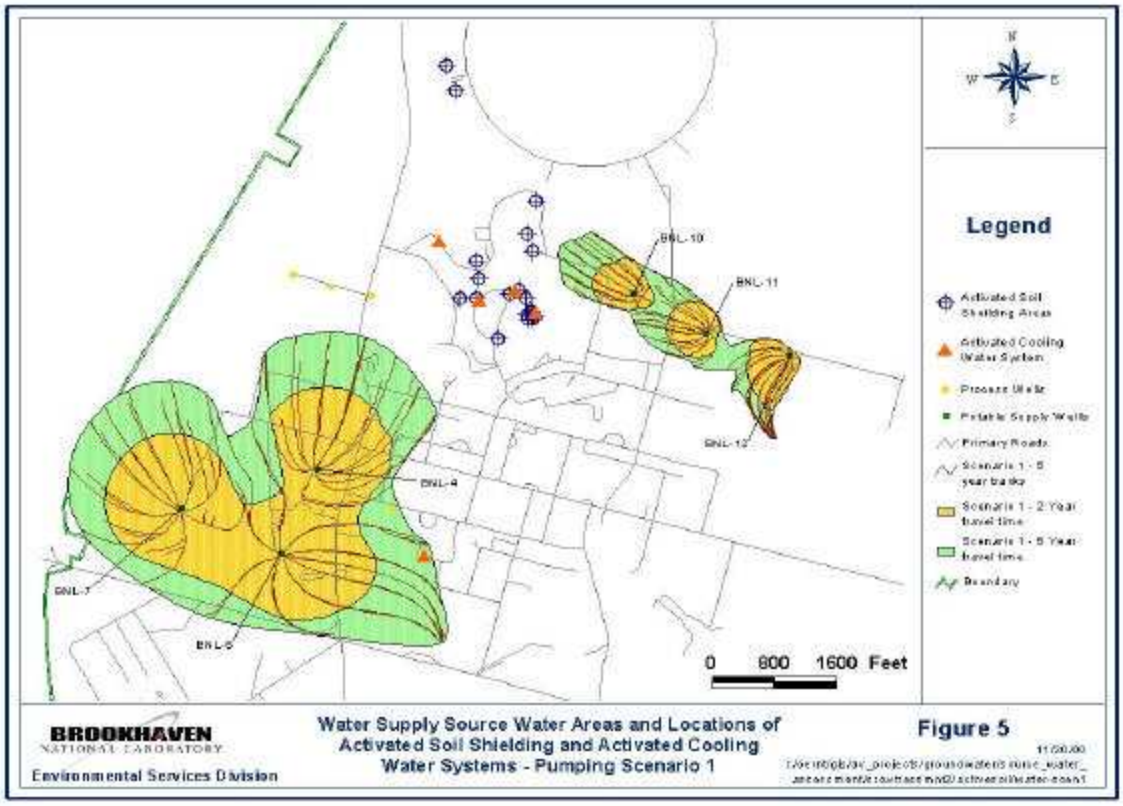

BNL-10
BNL-11
BNL-12
BNL-4
BNL-7
BNL-8
0 800 1600 Feet
Legend
Activated Soil Shielding Areas
Activated Cooling Water System
Process Wells
Potable Supply Wells
Primary Roads
Scenario 1 - 5 year tracks
Scenario 1 - 2 Year travel time
Scenario 1 - 5 Year travel time
Boundary
BROOKHAVEN
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Water Supply Source Water Areas and Locations of Activated Soil Shielding and Activated Cooling Water Systems - Pumping Scenario 1
Figure 5

Table 1

BNL Source Water Assessment for Drinking Water Supply Wells
Contaminant Source Inventory for Western Well Field

Source Type	*Facility/Plume*	*Threat*	*Current Groundwater Quality*	*Controls*
Operating Facility	Water Treatment Plant Recharge Basin	Backwash from iron filters.	No identifiable impacts from WTP operations.	• Outfall monitoring (SPDES Program) • Groundwater monitoring (Environmental Surveillance Program).
	Basin HP/ OU III Groundwater Treatment system recharge basin	• Liquid polyphospate (anti-foulant) in BMRR non-contact cooling water, • OU III Groundwater treatment system is designed to meet DWS before discharge, but could be a threat if fail safes do not operate as designed.	No identifiable impacts from Basin HP/OU III Treatment Plant operations.	• Groundwater monitoring (Environmental Restoration Program). • Fail-safe engineered controls to shut OU III system down, if operational parameters are off-normal (Environmental Restoration Program)
	Class V Injection wells (multiple locations)	Accidental discharges or spills to these recharge features.	No identifiable impacts from Class V injection wells located in this source water area.	• Some UIC targeted for closure (EPA Phase II Agreement). • Connection of facilities to BNL Sanitary System. • Proper control, storage, and transportation of chemical and radioactive materials (RCRA regulations, DOT regulations, and BNL standard operating procedures) • BNL Spill Response Program
	Accidental Spills	Petroleum products (e.g., gasoline, hydraulic fluids)	Shallow soils have been impacted by historical and recent spills. No identifiable impacts to groundwater quality.	• BNL Spill Response Program – most heavily contaminated soils were removed.
	BMRR	Primary cooling water contains high levels of tritium	Groundwater has been impacted by low level tritium contamination (concentrations < NYSDWS)	• Groundwater monitoring (Environmental Surveillance Program). • All piping systems conform with SC Article 12 requirements. All floor drains are properly sealed. • Operating procedures are in place for the proper handling and storage of primary water.
	Motor Pool Area	Petroleum storage and dispensing	Groundwater has been impacted by historical use of solvents. 1,1,1-trichloroethane is detected at concentrations above NYSDWS. Low level MTBE detected, but below NYSDWS.	• Groundwater monitoring (Environmental Surveillance Program) . • Product inventory (BNL standard operating procedures) • Double-walled storage tanks with leak detection (conform with SC Article 12 requirements). • Paved work areas.

Table 1 (Continued)

BNL Source Water Assessment for Drinking Water Supply Wells
Contaminant Source Inventory for Western Well Field

Source Type	*Facility/Plume*	*Threat*	*Current Groundwater Quality*	*Controls*
Operating Facility	Biology Greenhouse Area	Use of pesticides and heavy metals.	No identifiable impacts from greenhouse operations.	• Groundwater monitoring (Environmental Surveillance Program). • Procedures are in place for the proper use and storage of pesticides and herbicides. • Applicators are NYS Licensed.
	Paint Shop	Use of solvents	Historical spillage of solvents impacted soils near shop. Are suspected to have contributed to historical low level VOC contamination detected in Well 4.	• Contaminated soils were removed. • Groundwater monitoring (Environmental Restoration program). • Procedures are in place for the proper use, storage and disposal of paints and paint thinners.
	Sanitary Lines	Sanitary Line Leakage – possible release of bacteria and low level VOCs and radionuclides.	There are no indications that releases from sanitary lines located within the Source Water Areas are impacting groundwater quality.	• Laboratory-wide procedures prohibit the unauthorized disposal of chemical or radioactive waste to the sanitary system. • Supply Well water is routinely tested for chemical, radioactive and bacteriologic contaminants. • Drinking water is treated by chlorination.
Existing Groundwater Plumes	Western edge off the OU III VOC plume.	Historical discharge of solvents to land surface and cesspools in the AGS operations areas.	TVOC (primarily 1,1,1-trichloroethane) detected in monitoring wells at concentrations less than 50 µg/L. Low level 1,1,1-trichloroethane (< NYSDWS) is occasionally detected in Supply Well 4	• Groundwater monitoring (Environmental Surveillance and Restoration Programs). • Active remediation systems to improve groundwater quality. • Proper control, storage, and transportation of chemical and radioactive materials (RCRA regulations, DOT regulations, and BNL standard operating procedures).

Table 2

BNL Source Water Assessment for Drinking Water Supply Wells
Contaminant Source Inventory for Eastern Well Field

Source Type	*Facility/Plume*	*Threat*	*Current Groundwater Quality*	*Controls*
Operating Facility	Waste Management Facility	VOCs and low level radioactive waste are stored at this facility	No identifiable impacts from WMF operations.	• State-of-the-Art-Storage facility • Facility operated in accordance with NYSDEC RCRA permit • Groundwater monitoring (Environmental Surveillance Program)
	Recharge Basin HO	Non-contact cooling water from AGS Stormwater runoff	No identifiable impacts from Basin HO operations.	• Operational controls to minimize accidental chemical releases (BNL Procedures). • Effluent monitoring (SPDES Permit).
	AGS Beam Stops and Target Areas	Activated soil shielding – potential rainwater leaching of tritium and Na-22 to groundwater.	Three tritium plumes with concentrations above drinking water standards have been identified within this source water area (e.g., g-2/VQ12 Magnet area, Former E-20 Catcher area, and Former U-Line Stop area)	• Impermeable caps have been installed to prevent leachate generation (BNL procedures) • Operational controls to minimize soil activation (BNL Procedures) • Groundwater monitoring (Environmental Surveillance Program)
	Class V Injection wells (multiple locations)	Historical discharge of solvents to land surface and cesspools in the AGS operations areas.	TVOC (primarily 1,1,1-trichloroethane) detected in nearby monitoring wells at concentrations less than 50 µg/L. Low level 1,1,1-trichloroethane	• Some contaminated UICs were remediated and closed (Environmental Restoration Program). • Some UIC targeted for closure (EPA Phase II Agreement). • Connection of facilities to BNL Sanitary System. • Proper control, storage, and transportation of chemical and radioactive materials (RCRA regulations, DOT regulations, and BNL standard operating procedures) • BNL Spill Response Program
	Accidental Spills	Petroleum products (e.g., gasoline, hydraulic fluids)	Shallow soils have been impacted by historical and recent spills. No identifiable impacts to groundwater quality.	• BNL Spill Response Program – most heavily contaminated soils were removed.

Table 2 (Continued)
BNL Source Water Assessment for Drinking Water Supply Wells
Contaminant Source Inventory for Eastern Well Field

Source Type	*Facility/Plume*	*Threat*	*Current Groundwater Quality*	*Controls*
Operating Facility	Sanitary Lines	Sanitary Line Leakage – possible release of bacteria and low level VOCs and radionuclides.	There are no indications that releases from sanitary lines located within the Source Water Areas are impacting groundwater quality.	• Laboratory-wide procedures prohibit the unauthorized disposal of chemical or radioactive waste to the sanitary system. • Supply Well water is routinely tested for chemical, radioactive and bacteriologic contaminants. • Drinking water is treated by chlorination.
	Shotgun Range	Potential lead (Pb) contamination	Recent monitoring of nearby surveillance and water supply wells has not identified lead in groundwater.	• Groundwater monitoring (Environmental Surveillance Program). • Although lead does not readily leach out of soils, current operational restrictions prohibit the use of lead shot at the range.
Existing Groundwater Plumes	Brookhaven Graphite Research Reactor	Historical operations at BGRR have release Sr-90 to soils and groundwater	Sr-90 has been detected at concentrations above drinking water standards in monitoring wells located downgradient of BGRR.	• Decontamination and decommissioning of facility, groundwater monitoring, and active remediation of soils and groundwater (Environmental Restoration Program). • Retardation of Sr-90 in aquifer.
	Waste Concentration Facility	Historical operations at WCF have release Sr-90 to soils and groundwater	Sr-90 has been detected at concentrations above drinking water standards in monitoring wells located downgradient of the WCF.	• Active remediation of soils and groundwater, and groundwater monitoring (Environmental Restoration Program). • Retardation of Sr-90 in aquifer. • Storage facilities meet SC Article 12 requirements. • Operational controls.
	Building 650 Sump and Sump Outfall	Historical operations at Building 650 have release Sr-90 to soils and groundwater	Sr-90 has been detected at concentrations above drinking water standards in monitoring wells located downgradient of these release points.	• Active remediation of soils and groundwater , and groundwater monitoring (Environmental Restoration Program). • Retardation of Sr-90 in aquifer.
	Low-level area of the OU III VOC plume.	Historical discharge of solvents to land surface and cesspools in the AGS operations areas.	TVOC (primarily 1,1,1-trichloroethane) detected in monitoring wells at concentrations less than 50 µg/L. Low level 1,1,1-trichloroethane (< NYSDWS) is occasionally detected in Supply Well 4.	• Groundwater monitoring (Environmental Surveillance and Restoration programs). • Proper control, storage, and transportation of chemical and radioactive materials (RCRA regulations, DOT regulations, and BNL standard operating procedures).

Tides of Federalism — The Potential Implications of *Bragg v. West Virginia Coal Association* for the Balance between the Federal Government and the States under Selected Regulatory Environmental Laws

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ABSTRACT
This paper discusses a recent decision by the U.S. Court of Appeals for the Fourth Circuit (*Bragg v. Robertson*) that raises potential implications for the balance between the federal government and the states under environmental laws. Although the case involves the Surface Mining Control and Reclamation Act it can also affect other laws, especially the Safe Drinking Water Act and Clean Water Act. The paper summarizes the decision in plain language. It further discusses important questions raised by the decision, including the following. What is the precedential value of the judgment? Does the decision reflect a general trend in the courts? What are the implications for other federally approved state environmental programs? Does the ruling bolster the authority of the states to make environmental decisions?

INTRODUCTION

On April 24, 2001, a three-judge panel of the U.S. Court of Appeals for the Fourth Circuit held that a citizen suit under the Surface Mining Control and Reclamation Act (SMCRA) against a West Virginia regulatory agency allowing mountaintop removal (MTR) coal mining was barred. The court decided that the Eleventh Amendment to the U.S. Constitution gave the state sovereign immunity from suit in federal court and that the case did not involve an exception to the sovereign immunity clause.

The practice of MTR coal mining exposes horizontal seams of coal layered in mountains for extraction through blasting off entire hilltops and placing the resulting residue—leftover rocks and dirt—in adjacent valleys and streams. The extent of the loss and degradation of West Virginia streams resulting from the construction of excess spoil fills associated with surface mining activities (MTR, steep slope, and multiple-seam mining operations) is in dispute.

HISTORY

In 1977, Congress passed SMCRA to regulate strip mining. SMCRA created the Office of Surface Mining Reclamation and Enforcement (OSM) in the U.S. Department of the Interior and entrusted it with writing nationwide mining rules. SMCRA also gave OSM the authority to delegate the program to the states. In 1981, OSM approved the strip mine rules of West Virginia.

On July 16, 1998, Patricia Bragg and others (collectively "Bragg") filed a federal lawsuit against the West Virginia Department of Environmental Protection (DEP) to curb MTR coal-mining operations. The plaintiff alleged that the DEP had unlawfully approved numerous MTR permits that did not require the operators to protect streams and reclaim mined land.

On October 20, 1999, the U.S. District Court for the Southern District of West Virginia ruled in favor of the citizens. Judge Charles H. Haden II blocked the DEP from issuing any permit that allowed placement of excess spoil from surface mining operations in intermittent and perennial streams (i.e., those that flow all or part of the year). Judge Haden reasoned that the practice violated federal and state surface mining laws, including the "buffer-zone rule" that requires 100-foot buffer zones between mining activities and streams. However, he stayed the injunction pending the appeal of the case.

On February 17, 2000, Judge Haden approved a consent decree that formalized the settlement of other issues in the MTR case.

The DEP appealed to the Fourth Circuit arguing that Bragg was barred from suit under the Eleventh Amendment to the U.S. Constitution, which gives the states sovereign immunity from being sued in federal court. Because the litigation involved the enforcement of state law rather than federal law, the DEP argued, no exception to the sovereign immunity clause was triggered. Therefore, the case belonged in state court, not before a federal judge.

The citizens asserted that Congress authorized citizen suits against state officials who have the responsibility to comply with SMCRA and approved state programs. Moreover, the litigation involved enforcement of federal law that authorized states to run their own federally approved programs. Finally, the citizens contended that West Virginia had waived its sovereign immunity through its participation in the federal SMCRA program.

HOLDING

The appeals court panel overturned Judge Haden's ruling to limit MTR coal mining, holding that the State of West Virginia could not be sued in federal court over lax enforcement of strip-mine

regulations. The 41-page opinion focused exclusively on the question of federal court jurisdiction. Judge Paul V. Niemeyer, joined by Judges J. Michael Luttig and Karen J. Williams, wrote that the principle of state sovereign immunity, protected by the Eleventh Amendment to the U.S. Constitution, barred Judge Haden from hearing the case. The panel did not discuss the merits of efforts to use the buffer-zone rule to curb the size of valley fills. The judges declined to throw out the consent decree. In conclusion, the appeals court sent the case back to Judge Haden and instructed him to dismiss it so that it could be filed in state court instead.

DRIVER

Since 1970, Congress has included citizen suit provisions in almost every federal environmental statute. Members of the public are granted the power to compel adherence to the law. Prior to including citizens in the administrative and judicial process compliance with environmental laws was mostly a matter between regulators and polluters. Citizen suits are designed to supplement not supplant governmental prerogatives. They empower local people to enforce the law around local problems. Citizen suits provide a compliance incentive to private firms and deter governmental agencies from capricious implementation and enforcement of environmental laws. While their language may vary somewhat, most citizen suit provisions exhibit an analogous structure and procedure. When levied against a government official to carry out a nondiscretionary duty, the citizen actions are described as "mandatory" suits. Individual citizens and groups have brought thousands of successful lawsuits that have forced both polluters and the government to comply with the law on the books.

The citizen suit provision of SMCRA reads:

> "…any person having an interest which is or may be adversely affected may commence a civil action on his own behalf to compel compliance with this chapter… against the Secretary or the appropriate State regulatory authority to the extent permitted by the eleventh amendment to the Constitution where there is alleged a failure of the Secretary or the appropriate State regulatory authority to perform any act or duty under this chapter which is not discretionary with the Secretary or with the appropriate State regulatory authority" (30 USC §1270(a)(2)).

REASONING

The appeals court emphasized that the Eleventh Amendment to the U.S. Constitution barred citizens from bringing suits in federal court against their own states and that in the absence of a federal law violation or a state waiver, no exception to state sovereign immunity was triggered.

The appeals court first examined an exception to state sovereign immunity known as the *Ex parte Young* doctrine. The exception provides for federal jurisdiction over a suit against a state officer to enjoin official actions that violate federal law (emphasis added), even if the state itself is immune from suit under the Eleventh Amendment. The appeals court found that no infringement of federal law could have occurred because West Virginia had gained primacy and exclusive jurisdiction under SMCRA. The court explained that SMCRA provided for either state regulation of surface coal mining within its borders or federal regulation, but not both. Once a state enacted statutes and regulations that were approved by OSM, these statutes and regulations became operative, while the federal law and regulations dropped out. Individual state regulations, once approved by OSM, could only be revoked if OSM decided to throw out a state's entire set of mining rules. The court concluded that allowing citizens to sue the state in federal court would circumvent the carefully designed statutory balance between the federal government and the states. The federal interest in maintaining the state's compliance with its own program would be safeguarded through litigation in the state courts.

The appeals court then analyzed another exception to state sovereign immunity known as the "constructive waiver." This exception construes the state's submittal of its regulatory program for federal approval as a waiver of the state's immunity. The court rejected such an interpretation, because West Virginia had not explicitly consented and Congress had not provided an "unequivocal" warning that state delegation of a federal program necessarily meant the state's surrender of its immunity under the Eleventh Amendment.

In the final part of the decision, the appeals court upheld Judge Haden's consent decree. In this respect, the panel held that the citizen suit provision of SMCRA confers on federal district courts subject-matter jurisdiction over at least some types of strip mine claims.

FEDERAL OR STATE JURISDICTION

General Judicial Trends. Courts have been divided with respect to the onset of federal jurisdiction over citizen litigation involving federally approved state regulations. Some federal courts have rejected suits when the state laws or regulations were more stringent than federal law or regulations (*Atlantic States Legal Found. v. Eastman Kodak*). Similarly, federal jurisdiction was denied when no federal blueprint for the state regulation existed (*Chemical Weapons Working Group, Inc. v. United States Dep't of the Army*). Other courts held that state standards may be enforced in federal courts when they have "become effective pursuant to" federal law (*Ashoff v. City of Ukiah*). A particularly interesting split involves decisions of two circuit courts interpreting the damage remedy provision of SMCRA

SMCRA gives a private damage remedy to "any person" suffering personal or property damage from violations of "any rule, regulation, order or permit issued pursuant to" SMCRA (30 USC §1270(f)). While this language, unlike the mandatory citizen suit provision of SMCRA (30 USC §1270(a)), does not speak to federal jurisdiction, the cause of action is couched in identical terms. The decision of the Court of Appeals for the Third Circuit (*Haydo v. Amerikohl Mining Co.*) declined federal jurisdiction, finding that SMCRA granted states "exclusive" jurisdiction. The judgment handed down by the Court of Appeals for the Fourth Circuit (*Molinary v. Powell Mtn. Coal Co.*) rejected that position and held that a federally created cause of action, in the absence of a specific grant of jurisdiction, was cognizable in federal court. Federal judicial procedure, the court reasoned, explicitly gave the district courts original jurisdiction of all civil actions arising under the laws of the United States (28 USC §1331). Interestingly, Judge Niemeyer sat on the panel that decided the *Molinary* case.

Prospects. Some have advanced that the *Bragg* and *Molinari* holdings could not coexist and that this conflict could make the case ripe for review by the full Fourth Circuit. Others have added that state sovereign immunity was extended beyond the envelope of U.S. Supreme Court decisions on the Eleventh Amendment. Judges Niemeyer, Luttig, and Williams are considered the most conservative judges on the Fourth Circuit, which ranks among the most conservative appeals courts in the country. No decision by the citizen groups has been reported with respect to a potential appeal to the U.S. Supreme Court. The citizens could also ask the full appeals court to reconsider the case before petitioning the U.S. Supreme Court.

IMPLICATIONS FOR OTHER FEDERALLY APPROVED STATE ENVIRONMENTAL PROGRAMS

Types of Federal-State Relationships. Federal-state relationships may not only vary from statute to statute, but also within individual laws. The relationship between federal and state authorities

can be organized pursuant to three forms, including state delegation, federal direction, and voluntary arrangements.

The regulation of surface coal-mining operations under SMCRA and the underground injection control (UIC) program under the SDWA provide examples of the first category—statutory delegation schemes. Laws with delegation provisions have generally authorized a federal agency to establish national environmental standards but delegate much of the authority for program implementation and enforcement to the states. States generally receive primacy when they apply standards "at least as stringent as" the federal standards. States with approved programs enjoy certain flexibility with respect to the daily operation of their programs and receive federal grants to defray their costs. The initiation of a federal enforcement action, either administrative or civil, following state enforcement, is known as overfiling. In addition to this potential for overlap, primacy remains subject to revocation and subsequent direct implementation by the federal authorities. The withdrawal proceedings of Alabama's Class II UIC program in the wake of litigation involving hydraulic fracturing of coalbed methane gas wells in Alabama (*Legal Envtl. Assistance Found. v. EPA*) provide an illustrative example of this federal prerogative under the SDWA. As an alternative to seeking primacy, states may opt not to run particular environmental programs or they may choose to assume only a portion. For example, as of August 2001, 44 states have the authority to operate the National Pollutant Discharge Elimination System under Section 402 of the CWA, while only two (Michigan and New Jersey) have the authority to operate the wetlands permitting program under Section 404 of the CWA.

Under a second type of federal-state arrangement federal law gives a direct order to states. Examples of this arrangement include the Clean Air Act requirement for state implementation plans and the SDWA provision for state wellhead protection (WHP) programs. WHP is protection of all or part of the area surrounding a groundwater well. The law specifies certain minimum components for the WHP programs. The federal government is responsible for approving state WHP programs and for providing technical support. State governments must develop and implement WHP programs that meet SDWA requirements.

The third form of federal-state relationship involves voluntary arrangements that provide funding incentives to the states, but do not authorize a federal agency to operate a program within state borders. Such an approach can be found in the Indoor Radon Abatement Act. This law authorizes the U.S. Environmental Protection Agency (EPA) to assist states in the development and implementation of programs and projects that reduce radon risks.

Again, the type of federal-state arrangement may vary within individual statutory regimes. For example, the SDWA required the EPA to establish national standards for underground injection control programs that were subject to delegation for implementation and enforcement by approved states. However, in the 1986 amendments to the SDWA, Congress used the technique of directing the states to create WHP programs, shifting the burden from the federal to the state level. Finally, occurrences of overfiling have resulted in federal enforcement separate from previous state action.

Language in Bragg. *Bragg* contains two interesting references to environmental laws other than SMCRA. The appeals court found that "the statutory federalism of SMCRA is quite unlike the cooperative regime under the Clean Water Act." The panel further referred to language in a Supreme Court decision that "…one of the Clean Water Act's regulations 'effectively *incorporate[d]*' State law into the federal enforcement scheme, making State law, in certain circumstances, federal law." Finally, the appeals court paraphrased a 1999 decision by the Second Circuit Court of Appeals with "…concluding that similar language in the Clean Water Act, the

Resource Conservation and Recovery Act, and the Comprehensive Environmental Response, Compensation and Liability Act did not evidence Congress' intent to abrogate state immunity."

Potential Significance. While these remarks represent *dictum* (i.e., judicial opinion on a point other than the precise issue involved in determining a case) they suggest distinctions among environmental statutes with respect to their arrangement of federal-state relationships. *Bragg* illustrates that the array of potential federal-state relationships within and across environmental regulatory statutes has led to a complicated mosaic of environmental protection efforts. The patterns of program implementation and enforcement of the law range widely. As evidenced by the onslaught of litigation, contention has dominated over cooperation.

The *Bragg* judgment confirms this trend. While the decision addresses a specific case under a specific statute, the appeals court panel almost hastens to insulate its decision by emphasizing that the mechanics of other environmental regulatory statutes provide for stronger federal strings within the federal-state relationship. The panel uses the phrase "statutory federalism" for the federal-state relationship under SMCRA and immediately distinguishes it from the "cooperative federalism" embraced by other regulatory environmental laws. According to the appeals court, the former arrangement represents an exclusive relationship of either federal or state program operation, whereas under the latter federal and state responsibilities coexist.

It is noteworthy that the term "cooperative federalism" is generally used with respect to the environmental regulatory statutes enacted by Congress since 1970, including SMCRA, the CWA, and the SDWA. SMCRA differs from other federal environmental regulatory statutes because it focuses solely on one industry, whereas other federal environmental laws, including the CWA and the SDWA, address specific environmental problems attendant to all industries. This more limited statutory scope may affect stakeholder activism and general political attention. In this regard, the CWA and the SDWA seem to affect larger regulated communities than SMCRA.

Yet, SMCRA shares the delegation feature with important environmental protection programs under the CWA and the SDWA. Other courts may feel encouraged by the *Bragg* decision to discover these parallels and curtail citizen suits in federal court. Such a development could possibly affect cases that involve approved state UIC programs.

GREATER ROLES FOR STATES IN ENVIRONMENTAL DECISIONMAKING

Bragg falls into the context of the evolving relationship between the states and the federal government, which is based on sharing, overlapping, and competing powers. Federalism and state rights represent the broader themes of the decision. The decision bolsters the position of states by curtailing citizen suits in federal courts. The outcome in *Bragg* coincides with the present political tide that seems to favor stronger state roles in environmental decisionmaking. State (and local) authorities, it is argued, are positioned closer to the problems that may arise and often are better equipped to deal with regional concerns. In this vein, the Bush Administration is developing an Executive Order (EO) on federalism. The EO is said to increase the role of the states in environmental regulation. States are expected to gain greater freedom with respect to fashioning compliance with existing water, waste, and air laws. Several sources note that a stronger emphasis on federalism may lead to more programs that have the federal government set the target and the states design programs for meeting the targets. Supporters of the forthcoming EO argue that states will be enabled to experiment and develop innovative pollution reduction strategies. Recently, EPA Administrator Christine Todd Whitman told the Environmental Council of States (ECOS) that EPA would give states more freedom to pursue their own programs and "to renew the relationship that binds Washington with our state partners." Environmentalists express the concern that these initiatives could remove the "safety net," arguing that the states may not do enough to

safeguard the environment without the threat of federal enforcement. New initiatives that set a more positive tone within the federal-state relationship are emerging. The National Environmental Performance Partnership System (NEPPS) was developed jointly by EPA and ECOS to revitalize environmental protection by establishing new federal-state partnerships that will strengthen public health and environmental protection through management for environmental results. This approach, borrowed from the Government Performance and Results Act, involves the use of goals and indicators as measures of progress. If initiatives like NEPPS prove successful, the environmental policy agenda for change in intergovernmental relationships will feature the concept of cooperation in bold letters.

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ASSESSING THE REGULATORY ENVIRONMENT FOR THE GEOLOGICAL SEQUESTRATION OF CO_2

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Elizabeth J. Wilson is a graduate student in Engineering and Public Policy at Carnegie Mellon University and an employee at EPA's Office of Research and Development National Risk Management Research Lab. Her current research focuses on potential regulatory contexts for geologic carbon sequestration.

David W. Keith: Professor Keith's policy work addresses the uncertainty in climate change predictions, geoengineering and carbon management. He has been a collaborator in research on climate related public policy at Carnegie Mellon since 1991, and an investigator in the Center for the Integrated Study of the Human Dimensions of Global Change since its inception.

His current research involves an analysis of the use of fossil fuels without atmospheric emissions of carbon dioxide by means of carbon sequestration. This research aims to understand the economic and regulatory implications of this rapidly evolving technology. Questions range from near term technology-based cost estimations, to attempts to understand the path dependency of technical evolution.

Abstract:
Carbon sequestration is becoming an increasingly important topic, yet little has been written on the potential regulatory context within which it would operate. Different types of carbon sequestration are briefly mentioned and the rationale behind them explained. This paper focuses on geologic carbon sequestration and reviews operational details and legal frameworks of current UIC activities. We assess current underground injection activities and evaluate how their cumulative experience provides relevant insights for possible future CO2 sequestration activities. Small, medium and large-scale CO2 sequestration scenarios will be developed and compared with: CO2 miscible floods for Enhanced Oil Recovery in the Permian Basin, Hazardous Waste Disposal, Florida Municipal Waste Disposal, Acid Gas Disposal Wells in Texas, and Brine Disposal Wells. An analysis of how initial geologic CO2 sequestration activities could be shaped by existing regulation and project definitions is presented and future research needs identified.

CLASS III OPERATOR TRAINING:

This workshop is an entry-level course designed for operators that have no or limited experience with the construction, operation, and maintenance of UIC Class III wells. The course is generally directed to people having direct responsibility for operating UIC Class III wells. However, other support personnel should find the course informative.

Students will be presented information on the techniques, concepts, equipment, and machinery used to drill and complete, operate and maintain solution mining wells. Particular attention is given to the type of mineral deposit the technology is applicable to, typical construction standards, well operation and construction hydraulics, mechanical integrity testing, and well repair.

The course materials have been organized into seven chapters, which outline the primary issues operators, supervisors, and service personnel should be aware of. The case histories presented are both informative and interesting; plus, they provide examples of solutions that have been used successfully in the past.

Various types of mineral deposits have been successfully mined utilizing in-situ solution mining techniques. They include minerals such as copper, trona, colemanite, sodium chloride salts (halite), uranium, sulphur, potash, salt, and others. The solution mining process consists of dissolving a mineral in-situ and then recrystallizing or purifying the mineral for commercial use. For the purpose of this training manual, we will only address solution mining, copper, trona, colemanite, uranium, and halite. The subsequent use of salt (halite) caverns for hydrocarbon storage will also be discussed briefly.

BMP Workshop

Chi Ho Sham

The 1996 Safe Drinking Water Act Amendments called for assessing drinking water sources and encouraging protection of drinking water supplies. To design and implement an effective local source water protection program, local entities need information on specific protective measures that are available to prevent contamination of their drinking water supplies. The materials for this workshop have been developed for EPA's Drinking Water Academy to provide introductory-level training materials on best management practices (BMPs) and other preventive measures for about a dozen different sources of contamination that threaten source water.

Review of Class I Injection Wells – North Slope of Alaska

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Abstract: Class I injection capability is critical to the exploitation and development of oil and gas resources located in the North Slope of Alaska. With no year-round connecting roads, waste transport is prohibitively expensive and introduces the added potential for surface spills on the surface of the Arctic tundra. There are currently six (6) active Class I wells located at : BPXA's Pad 3 facility (three wells), BPXA's Badami facility (one well), BPXA's offshore Northstar facility (one well), and PAI's Colville River Field facility (one well). These Class I wells are a key component of the overall waste management operations and goal of zero surface discharge of wastes in the North Slope, and is consistent with the concept of assessing the overall environmental impact of an industry rather than from an individual pollutant.

The North Slope operators have combined mechanical grinding and deep well injection to dispose of waste streams from oil and gas drilling and production activities. This in turn eliminates the traditional use of reserve pits for storage or disposal of drilling wastes, and provides an integrated approach to managing wastes from drilling, production, maintenance operations, and the camp sewage system.

This paper reviews the current state of the art for design, construction, and operation as referenced to the six (6) active Class I wells located on the North Slope. Discussion of design characteristics to incorporate the presence of an approximately 1500 - 2000 foot thick permafrost layer, the use of special cements for casing purposes, and operating above the fracture pressure in order to dispose of solids and drill cuttings is reviewed in this paper. Mechanical integrity testing procedures, both internal (SAPT) and external (RTS, Borax PNL, and OA/WFL logs) are also reviewed.

The success of Class I wells demonstrates that deep well injection is a cost-effective and environmentally sound method for safe disposal of waste streams, in areas that are not only environmentally sensitive but are also harsh, isolated, and remote such as the Arctic North Slope of Alaska.

1.0 Introduction

Oil production from the North Slope of Alaska is playing an increasingly important role in meeting the energy needs of the U.S. domestic economy. Anticipated production of natural gas and potential coal-bed methane resources in Alaska, are also expected to play an important role in meeting our domestic energy needs in the years to come. Alaska's total liquid hydrocarbon production in 1998 was 463 million barrels (429 million barrels – oil and 34.8 million barrels – natural gas liquids), a 9.0 % decline from 1997. Total dry and casing-head gas produced was nearly 3.4 trillion cubic feet, of which approximately 2.92 trillion cubic feet of casing-head gas was re-injected to support enhanced oil recovery (EOR) operations. Water injection for enhanced oil recovery totaled nearly 931 million barrels or nearly 2.6 million barrels/day.

Class I injection capability is critical in the exploitation and development of oil and gas resources located in the North Slope of Alaska. With no year-round connecting roads, waste transport is prohibitively expensive and introduces the added potential for surface spills on the surface of the Arctic tundra. These Class I wells are a key component of the overall waste management option and goal of zero surface discharge of wastes in the North Slope, and is consistent with the concept of assessing the overall environmental impact of an industry rather than from an individual pollutant.

The North Slope operators have combined mechanical grinding and deep well injection (utilizing both Class I and II wells) to dispose of waste streams from oil and gas drilling and production activities. This in turn has eliminated the traditional use of reserve pits for storage or disposal of drilling wastes, and provides an integrated approach to managing wastes from drilling, production, maintenance operations, and the camp sewage system.

There are currently six (6) active Class I wells in the North Slope located at : Pad 3 Facility (three wells), Badami (one well), Northstar (one well), and Colville River Field (one well).This paper provides an update on the current state of the art for design, construction, and operation as referenced to the six (6) Class I wells located in the North Slope. Discussion of design characteristics to incorporate the presence of a 1000 – 2000 foot permafrost thick layer, the use of special cements for casing purposes, and operating above the fracture pressure in order to dispose of solids and drill cuttings is included in this review. Mechanical integrity testing procedures, both internal (standard annulus pressure test - SAPT) and external – Temperature, Radio-active Tracer (RTS), Borax PNL (Pulsed Neutron Log), and Oxygen Activation/Water Flow Logs (OA/WFL) are also reviewed.

2.0 Review of BPXA's Pad 3 Class I Wells

A general project location map of the North Slope and the Northstar, Badami, Pad 3, and Colville River Units are shown in Exhibits 2-1and 2-2.

Pad 3 wells were originally drilled in the late 1970s to test the thaw characteristics of the permafrost. Of the five (5) wells that were originally drilled, three (3) wells were converted as Class I (non-hazardous) industrial waste injection wells in the mid-1980s, while the remaining two

(2) wells – Center well has never been completed, while the North East well was plugged and abandoned in March 1978.

The wells were drilled as vertical holes with wellhead separations of 32 feet. The injection zone is the Sagavanirktok Formation which extends from near the surface to a depth of approx. 4500' subsea (SS) in the area. The base of the permafrost is at 1835' MD-BGL (measured depth – below ground level). Injection is through perforated intervals opposite the 5 ½" casing from 1978' MD in the SE well to 2093' MD in the NW well. The maximum permitted wellhead injection pressure is 1400 psi (which is above the fracture pressure). Maximum injection rates at each active well are about 3500 to 4000 bbls/day at maximum injection pressures of 900 to 1100 psi (maximum permitted monthly volume for all three wells is 285,720 barrels).

The injection zone is confined on the top by a sequence of inter-bedded sands, silts and shaly mudstones (gross thickness of 132 feet made up of a 54 foot thick upper confining zone and a 78 foot thick arresting zone at the NW well). Below the Sagavanirktok Formation, approx. 2000 feet of inter-bedded sands and shales comprise the Ugnu and West Sak Formations. The massive Seabee and Kingak shales then extend to, and form a trap for, the main hydrocarbon producing reservoir.

The original 10 year Class I permit was issued by EPA on 8/20/89 and renewed in 1999. The maximum authorized injection pressure is 1400 psi (which is above the fracture pressure) and the monthly injection volume must not exceed 285,720 bbls (for all three wells located at Pad 3). The injected waste fluids include: sea water and brine, fresh water, drilling mud, gel (generally a bentonite and water mixture), crude oil, produced water, stimulation fluids, cement contaminate, diesel, contaminated snow, methanol, line pigging material, and boiler water.

A generalized stratigraphic column for the North Slope of Alaska (Kuparak and Prudhoe Bay Fields) is shown in Exhibit 2-3 (AOGCC, 1998).

A Type Log for the Pad 3 NW well is shown in Exhibit 2-4.

Disposal Well OWDW-NW Details (Inactive Class I Well – Shut-In)

First Placed in Service	1/76
Completion Date w/tbg.	1/7/85
Injection Zone Perfs:	1980-2005' (25') with 4 SPF
	2032-2052' (20') with 4 SPF
	2052-2062' (10') with 2 SPF
	2073-2093' (20') with 6 SPF
	Total perfs – 86 feet

Additional details including a downhole schematic of Well OWDW-NW are given in Exhibit 2-5.

Note: The Pad 3 NW failed to demonstrate a stabilizing tendency of the annulus pressure during the annual SAPT test conducted on March 12-13, 2001, as required under the UIC

permit. The well has been shut-in pending diagnosis of the leak point and repair of the well.

Disposal Well OWDW-SE Details (Active Class I Well)

First Placed in Service	3/78
Completion Date w/tbg.	4/22/85
Injection Zone Perfs	1978-2003' (25 feet) with 4 SPF

Additional details including a downhole schematic of Well OWDW-SE are given in Exhibit 2-6.

Disposal Well OWDW-SW Details (Active Class I Well)

Completion Date:	1/1/85 (First placed in service).
Injection Zone Perfs:	1980-2005' (25 feet – 4 SPF).

Additional details including a downhole schematic of Well OWDW-SW are given in Exhibit 2-7.

Disposal Well OWDW-NE Details (P&A'd in 1988)

Pad 3 Well OWDW-C Details (Never completed with tubing).

3.0 Review of BPXA's Badami Class I Well B1-01

The Badami Unit is located about 27 miles northeast of the main infrastructure at Prudhoe Bay, and the isolated oil development is not served by an all-weather road. EPA granted BPXA the UIC Permit on 8/22/97 and is valid for a period of 10 years.

The Badami Class I well injects permitted wastes into the Ugnu Formation, approx. 7000 feet below the ground surface. Wastes are confined in the injection zone by impermeable rock layers and permafrost. There are no reported USDWs in the area.

BPXA extimates that the typical injection stream at Badami will consist of: Sea water, produced brine, fresh water gel (49 %), Camp sewage and other domestic wastewater (23 %), Workover fluids, crude oil, spent acid, vessel sludge/sand, methanol, frac sand, cement, snow melt, and
misc. (15 %), Water-based drilling mud (11 %) and Water –based drill cuttings (2 %).

Most of the waste stream will be in liquid form. The solid portion of the waste stream is pulverized in an on-site ball mill and mixed with liquid waste to form a thin slurry (Grind and Inject facility – G&I). In order to prevent formation plugging, injection pressures have to be high enough to propagate fractures within the injection zone. The amount of slurried material to be injected is expected to decline over time because drill cuttings, drilling mud,

and frac sand are mostly generated during the early drilling and completion phase of production.

The maximum permitted surface injection pressure is 3000 psi. Average injection pressures are in the range of 1350-1450 psi with a maximum recorded pressure of 2150 psi. Average injection rates are 600 bbls/day well below the maximum permitted of 65,000 bbls/month volume. The low volumes are due to the marginal oil production from the Badami field, which are well below initial estimates.

The injection zone is the Ugnu Formation through perforations opposite the 9 5/8" casing in the interval 8390'-8420' MD. The well is completed with a 2 7/8" velocity string, a 4 ½" tubing and permanent packers set at 7941' and 8055' MD. The Ugnu Formation is overlain by an almost 2000 foot thick impermeable interval composed mostly of shale and siltsone. The top of the upper confining zone (which is an approx. 500 foot thick impermeable shale sequence) is about 4000 feet below land surface (bls).

Additional details are given in the downhole schematic of Badami Well B1-01in Exhibit 3-1.

4.0 Review of PAI's Colville River Field Class I Well WD-02

The Alpine project area of the Colville River Field (CRF) is located approx. 250 miles north of the Arctic Circle on Alaska's North Slope – about 60 miles west of Deadhorse, Alaska and about 25 miles west of the westernmost part of the Prudhoe Bay all-weather road network.

The CRF Project is a stand-alone, self-contained, oil field drilling and production facility. There will be 92 oil development wells drilled from two gravel pads located in the Colville River delta. The wells will be directionally drilled to a depth of 6,800 feet.

Development costs of $ 700-800 million will yield estimated reserves of 365 million barrels. Production began in late 2000 and will reach a nominal rate of 70,000 barrels/day. Project life is estimated to be 20 years.

PAI/AAI obtained an approved UIC area permit from EPA Region 10 on 2/3/1999 (10 year Permit No. AK-1I003-A) for the drilling, construction, and operation of up to three (3) Class I (non-hazardous) industrial waste injection wells. To date, one (1) Class I well No. WD-02 has been drilled and completed and was first placed on injection on May 15, 1999.

The waste disposal system is designed to provide an integrated approach to managing wastes generated from oil production, maintenance operations, the camp sewage system, and some minor liquids from the drilling rig. With a project life of 20 years, the estimated Class I disposal volume will consist of 1.7 million barrels of domestic waste water, 3.2 million barrels of exempt production wastes, up to 50,000 bbls of Class I non-hazardous wastes, and potentially 14 million bbls of produced water from the reservoir.

The upper injection zone is the Triassic Sag River Formation in the interval 8937'-8979' (42') consisting of fine-grained, glauconitic sandstones with good reservoir properties and an average permeability of 120 millidarcies (md). The lower injection zone is the Permo-Triassic Ivishak Formation in the interval 9446'-10132' (656 feet) and consists of thick-bedded conglomerates, siltstones and mudstones of moderate reservoir quality. The perforated injection intervals are from 9459' to 10047'(selectively) opposite the 7" casing (total perfs – 191 feet). Maximum permitted surface injection pressure is 3200 psi. Monthly injection volumes are about 15,000 bbls/month at injection pressures of 1450-1800 psi.

The Triassic Shublik (consists of shale and siltstones in its lower part and limestones in its upper part – 400 feet thick) acts as a barrier between the upper and lower injection zones. The Lower Jurassic Kingak Formation in the interval 8187'-8938' (751 feet thick and mostly shales) serves as the Upper Arresting Zone, while the Upper Jurassic Kingak present in the interval 7680'-8187' (507 feet thick and mostly interbedded shales and siltsones) overlies the arresting zone and serves as the Upper Confining Zone.

There are no reported USDWs at this area and the base of the permafrost is at 900' TVD.

For additional details and downhole schematic of PAI's Well WD-02 see Exhibit 4-1.

5.0 Review of BPXA's Northstar Class I Well NS 10

The Northstar project area is located approximately 250 miles north of the Arctic Circle on Alaska's North Slope. Surface production facilities are situated on an existing gravel island six miles offshore in the Beaufort Sea. Development will involve anticipated high rate wells (7000 bbls/day/well) and a high quality crude oil (42 degree API). Anticipated peak production is 65,000 bbls/day. Northstar is the first joint (State and Federal) offshore Arctic development. The Class I well was the first well drilled when drilling rig activities began in late 2000 and Class I injection capability is critical to Northstar development because it is remote and isolated from other North Slope infrastructure. As such, an integrated approach to managing wastes from drilling rig activities, production operations, and maintenance work has been developed.

If project life lasts 20 years, total waste disposal will consist of 900,000 bbls of Class II exempt drilling and production wastes, 600,000 bbls of Class I camp domestic waste waters, 40,000 bbls of Class I non-hazardous industrial wastes, and 60-118 million bbls of produced water from the oil reservoir.

The permitted injection zone includes an upper zone of Upper Brookian age (734' MD/ 420' TVDss thickness) consisting of sandstone and shale at a depth of 5007' MD (top). The lower injection zone is completed open hole to TD and is of Middle Brookian age at a depth of 6140' MD (top) and has a thickness of 2106' MD/1753' TVDss. Porosity for the upper zone and lower zones are in the range of 29-34 % and 26-32 % respectively, while

permeability values range from 250-4500 md and 150-2500 md for the upper and lower zones.

At the present time injection is into the lower injection zone in the 6 ¾"open hole interval (8029'-8246' MD – Schrader Bluff). The upper zone may be opened at a later time if necessary. Maximum permitted wellhead injection pressure is 3000 psig. The tubing/casing annulus must be filled with a non-freezing corrosion inhibited fluid and a positive annulus pressure up to 500 psig is authorized.

Additional details on the injection, confining, and aquifer units are given in Table 5-1. There are no reported USDWs at this location with the aquifer units having TDS concentrations in the range of 27,000 – 55,000 mg/l in the various aquifer units. The base of the permafrost is at 1512' MD (1449 TVDss).

A downhole schematic of the Northstar Well NS10 is given in Exhibit 5-1.

The 10 ¾" surface casing was cemented in two stages. The casing was reciprocated during the first stage and cement was observed to have circulated during the second stage based on fluid appearance, fluid density and pH. There were no operational problems during cementing. A Schlumberger USIT (Ultrasonic Imaging Tool) log was run with less than 500 psi on the well. The log showed excellent bond above 1600 feet and several intervals with acceptable compressive strength below the permafrost at 1512' MD.

The 7 5/8" casing was cemented in three stages. The casing was reciprocated during the first stage and cement was observed to circulate to the surface during the third stage. There were no operational problems during cementing. The USIT log showed excellent cement bond from 6245' to 7965' MD, near the casing shoe, good to excellent bond across most of the shale barrier separating the upper and lower injection zones, and good to excellent bonding in several intervals from the surface casing shoe at 3726' to 3909' MD, the base of the confining zone. Finally, the log also verified the cement top to be more than 500 feet above the surface casing shoe.

6.0 MECHANICAL INTEGRITY TESTING PROCEDURES FOR CLASS I WELLS – NORTH SLOPE

The UIC permits issued by EPA for all Class I wells located in the North Slope of Alaska require that the wells demonstrate both internal and external mechanical integrity on an annual basis.

6.1 DEMONSTRATION OF INTERNAL MECHANICAL INTEGRITY

The EPA UIC Class I Permits require that each Class I well demonstrate on an annual basis that there is no significant leak in the casing, tubing or packer **(internal mechanical integrity),** generally with the Standard Annulus Pressure Test (SAPT). The permit requirements generally read as follows:

In order to demonstrate that there is no significant leak in the casing, tubing or packer, the tubing/casing annulus must be pressure tested to at least the maximum permitted injection pressure for not less than 30 minutes. Pressure shall show a stabilizing tendency. That is, the pressure may not decline more than 10 % during the test period and shall experience less than one-third of its total loss in the last half of the test period. If the total loss exceeds 5 % or if the loss during the second 15 minute period is equal to or greater than one half the loss during the first 15 minutes, the permittee may extend the test period for an additional 30 minutes to demonstrate stabilization.

RESULTS FROM A SAPT RUN ON PAI'S CLASS I WELL WD-2 ON APRIL 11-12, 1999, ARE SHOWN AS AN ILLUSTRATIVE EXAMPLE.

Upon completion of the Step-Rate test, RTS, and spinner surveys, the well was secured and freeze protected with approx. 12 bbls of diesel. At that time the 4 ½"x 7" annulus pressure was increased to 3513 psi (permit authorized maximum is 3200 psi for normal operations) and held for 30 minutes. Pressure declined as follows:

Time, minutes	Ann. Pressure, psig	Pressure Drop, psi	Decline, %
Initial	3513	0	0
5	3455	58	1.7
10	3418	95	2.7
15	3391	122	3.5
20	3367	146	4.2
25	3345	168	4.8
30	3323	190	5.4

The annulus pressure decline was within the 10 % stipulated in the permit. However, the pressures were not fully stable during the test period as required by EPA, although the allowable loss of 68 psi over the final 15 minutes was within the approved one third total loss of the permit condition.

The reasons for the pressure decline are believed to be the result of the wellbore being thermally unstable, resulting from the just completed injection of approx. 1000 bbls of both warm and cold fluids (RTS, Spinner and Step-Rate tests), and tubing pressures were not fully recovered from the logging program.

The SAPT was repeated the next day (4/12/99). Overnight, the wellbore was allowed to reach both thermal and pressure equilibrium. Details are given below:

Time, minutes	Annulus Pressure, psig	Pressure Drop, psi	Decline, %	Tubing Pressure, psig
Initial	3500	0	0	650
10	3500	0	0	
20	3475	25	0.7	
30	3450	50	1.4	620

THE SAPT CONFIRMED THE INTERNAL MIT (NO LEAKS ON THE BACKSIDE OF THE ANNULUS ABOVE THE PACKER) OF PAI'S CLASS I WELL WD-2. SOME OF THE DATA

HAD TO BE MANUALLY RECORDED AS THE HOT OIL TRUCK CHART RECORDER FROZE AND FAILED IN THE –5 DEGREE F, AMBIENT TEMPERATURES.

6.2 External Mechanical Integrity Procedures

The EPA UIC Class I Permits also require that each well demonstrate on an annual basis that it has **external mechanical integrity.** The external tests are required to detect the movement of fluids behind the casing through vertical channels adjacent to the injection wellbore and to determine that the confining zone is not fractured. Approved fluid movement tests currently utilized in the North Slope include: Radioactive Tracer Surveys (RTS), Temperature , Oxygen Activation/Water Flow Logs, and Borax – PNL logs. In addition to these logs, the operator must also demonstrate from cementing records and cementing logs that the injection zone is isolated from zones above with a good quality cement job – usually with a log showing good bonding and isolation such as a CBL/CET (Cement Bond Log/Cement Evaluation Log) or a USIT(Ultrasonic Imaging Tool) log. The theory and application of these logging procedures are briefly summarized in this section.

Cement Evaluation with the Ultrasonic Imaging Tool (USIT)

The main purpose of cement over the production or injection interval is to provide isolation between neighboring zones. Hydraulic isolation allows the well operator to selectively complete certain zones and assures that fluids will not move into or from neighboring zones through the borehole behind casing, including contamination of freshwater sands. The only remedy in cases of cement seal failure may be a costly cement squeeze job with only a marginal potential for success with perhaps damage to the well integrity.

Conventional cement bond logging techniques provide a Bond Index (BI) indication. This measurement, when compressive strength is constant, is an indication of annular fill. For example a BI of 70 % would indicate a channel occupying 30 % of the annular space. Unfortunately, this is not necessarily so since the BI measurement is also affected by cement compressive strength. A BI less than 100 % can be caused by a channel or by a reduction of cement compressive strength. This factor is particularly important for "Arctic Type Lite" cements opposite the permafrost intervals which may only develop a compressive strength of 500 psi or less , as opposed to the conventional Class G type cements which may reach a final compressive strength of 3000 psi.
While conventional bond logs offer no way to resolve this issue, the development of the pulse echo bond log tools provide an estimate of cement coverage, and a direct measurement of the cement compressive strength.

Currently available pulse echo tools available from the industry include:

Schlumberger:	Cement Evaluation Tool (CET)
	Ultrasonic Imaging Tool (USIT)
Halliburton:	Pulse Echo Tool (PET)

The CET and PET use fixed transducers and are not discussed in this paper. The USIT widely used in the North Slope uses a single rotating transducer and is discussed below.

The Ultrasonic Imaging Tool (USIT) introduced by Schlumberger in 1991, is basically a continuously rotating pulse echo type tool, and is an improvement over the CET with nearly 100 % coverage of the casing wall. The processing of the echo is, however, quite different from the CET. The USIT is shown schematically in Exhibit 6-1(a). The main working element is the rotating transducer indicated as "sensor" on the bottom of the tool string. The transducer rotates, emitting and receiving signals reflected back from the casing wall. Sampling can be done in a number of modes, as frequently as each 5 degrees of rotation and 1.5 inch of depth, and more frequently if only corrosion information is desired.

The USIT can only be run on the Schlumberger Maxus 500 surface system. The USIT is 3 3/8" in diameter. By changing the rotating transducer subassemblies the tool can operate in casing sizes from 4.5" to 13 3/8". Borehole mud densities are limited to less than 16 lb/gal for water based muds and 11.6 lb/gal for oil based muds. The minimum channel size detectable is 1.2 inches. The rotating transducer is shown in Exhibit 6-1 (b). In the measurement position it is aimed toward the wall and in the fluid properties it is aimed toward the target plate. The fluid properties are measured when going in the hole.

Acoustic impedance, Z, is defined as the product of the density (kg/m*3) and acoustic velocity (m/sec) of a medium and is expressed in MRayl (10*6kg/m*2sec). A list of acoustic impedance values for common downhole materials is given in Table 6-1.

Table 6-1 Acoustic Properties of Materials (Smolen, 1996)

Material	**Density**	**Acoustic Velocity**	**Acoustic Impedance**
	Kg/m*3	**m/sec**	**MRayl**
Air (1-100 bar)	1.3 – 130	330	0.0004-0.04
Water	1000	1500	1.5
Drilling Fluids	1000-2000	1300-1800	1.5-3.0
Cement Slurries	1000-2000	1800-1500	1.8-3.0
Cement (Litefil)	1400	2200-2600	3.1-3.6
Cement (Class G)	1900	2700-3700	5.0-7.0
Limestone	2700	5500	17
Steel	7800	5900	46

A SECTION OF A USIT LOG RUN ON A NORTH SLOPE WELL IS SHOWN IN EXHIBIT 6-2 (BPXA'S NORTHSTAR CLASS I WELL NS-10).

The log is highly colored and computer processed. Tracks 1 through 7 relate primarily to casing condition. The left hand track, track 1, usually contains the geometrical parameters and the gamma ray. Track 2 shows diagnostic signals for the field engineer, track 3 measures the A1 amplitude, with a high value indicating that the signal is reflecting strongly. Tracks 4,5,6, and 7 show inner radius and wall thickness traces and maps. The conditions outside of casing are shown in Tracks 8-10. Track 8 is a color coded map of acoustic impedance with no interpretation. Track 10 is exactly the same as Track 8 except that values of Z less than 0.3 MRayl are specially shaded to indicate gas. Values greater than 0.3 but less than 2.6 MRayl are shaded to indicate liquid behind pipe. Track 9 shows the fractional coverage of the casing with cement, liquid, and gas. Track 11 can be used as a gas flag indicator (not shown in this example).

The log was run after the 7 5/8" casing was cemented in 3 stages from 7865' MD to the surface with an acoustic impedance threshold set at 2.6 MRayl. The log in track 10 shows the excellent bonding (colored yellow) from the casing shoe depth to 7500' and above.

External Mechanical Integrity – Temperature Surveys

Temperature surveys are run in injection wells to locate zones of injection and to highlight channelling behind pipe. For the most part, interpretations of temperature logs are qualitative in nature.

Temperature in a well increases with depth, the actual rate of increase depending upon the type of formation and its thermal conductivity. This temperature profile is assumed to be linear and called the geothermal gradient. Geothermal gradients are typically in the range of 0.5 to 2.0 degree F/ft. The most common temperature survey is the continuously run log of temperature in a well with depth. Differential temperature surveys are measurements of the temperature gradient, dT/dZ, along the wellbore. This log is measured by memorizing the temperature, say 10 feet earlier, and recording the difference between that and the current reading. Such a rolling difference may be based on any vertical distance selected for dZ, typically between 1 and 10 feet.

The temperature log is usually run with other production logs (sensors) in a combination string. Therefore, the best temperature log is taken during the first run down into the hole, at a relatively slow logging speed of about 30 ft/min or less, and the full interval should be logged.

Time Lapse Temperature Logs to Locate Zones of Injection

The technique of locating an injection zone by time lapse temperature logging is shown in Exhibit 6-3. This method is used extensively in Class I wells in Alaska. On the left of this schematic is shown an injection well with a mean surface temperature of 80 degree with isotherms increasing in increments with depth. If the injection fluid is water, the water is seen to heat up on its way downhole and causes distortions of the isotherms around the well. The zone of injection is located between the 105 and 110 degree isotherms. Below the injection interval, the isotherms return to their normal geothermal gradient indicated by their horizontal shape. Notice that the water enters the injection zone at a temperature substantially lower than the geothermal temperature.

If a temperature log is run during injection, the log will look like that shown on the right of Exhibit 6-3 and labeled "injecting". The temperature increases with depth and abruptly returns toward the geothermal (Static) profile below the zone of injection. When the well is shut-in, the wellbore fluid is heated up by the adjacent formations and tries to return to the geothermal profile. The wellbore volume is small and this return to the geothermal profile is relatively rapid. Over the zone of injection, however, the volume of injected water is very large. This region of injection returns to the geothermal profile much more slowly. Temperature logs run after shut-in will detect a " bump on the log" over the zones of injection due to this effect. The shut-in runs are shown at times t_1, t_2, and t_3 after shut-in.

A copy of time lapse temperature logs run on BPXA's Northstar Class I Well NS-10 on 6/1/01 is shown in Exhibit 6-4.

On 6/1/01, approx. 743 bbls of cold seawater were pumped into well NS-10 at 5 bpm at injection pressures upto 1250 psi.

After this injection period, Schlumberger ran a series of three temperature passes, each about 2 hours apart, from about 4860' MD (about 155' above the packer) to near the tubing tail (8006' MD). Based on the general character and uniform warming over time, as shown on the overlay of the three shut-in temperature passes, there is no evidence for any significant upward fluid movement outside the casing. The cooling trends at the base of each pass indicate possible fluid movement behind pipe could be as high as 7965' MD, about 65 feet above the casing shoe. These results were very similar to the initial SI temperature logs run in January 2001. The top of the approved injection interval in this well is at 6140' MD.

External Mechanical Integrity – Radioactive Tracer Surveys (RTS)

Radioactive Tracer Surveys (RTS) are usually used to monitor fluid movement downhole by detecting radioactive (RA) tracer materials released into in the flowing stream by the tool. These techniques are effective and quantitative, especially in single phase flow.

The basic tracer techniques are used for detection of either fluid movement or locating RA tagged materials downhole. The applications for fluid movement include:
Measure the injection (production) profile quantitatively.
Locate channels behind casing while injecting into a well.

The applications for tagging materials include:
Cement top or squeeze placement by tagging cement with RA materials.
Gravel pack quality by tagging gravel with RA materials.
Detect RA tagged acid.
Measure fracture or propped height with tagged frac fluid or proppant.
Locate RA tags placed downhole with shaped charge or bullet perforators

RA Tracer Tools and Isotopes

Exhibit 6-5 shows a common RA tracer tool configuration (1 3/8" diameter tool) used in Class I wells in the North Slope of Alaska with two GR detectors positioned below the ejector port and a GR sonde above the ejector port to obtain a base GR log before ejecting any RA slug downhole. The Casing Collar Locator (CCL) is used for depth control. The ejector portion of the tool is comprised of a chamber containing a RA tagged fluid compatible with the fluid being injected into the well and an ejector port. When activated at command from the surface, the tool ejects a small cloud or slug of RA fluid into the injection stream. This slug then passes the GR detectors where it is detected both in terms of position and time (Smolen, 1996).

RA Detectors

The detectors used in most tracer surveys are either Geiger-Mueller or Scintillation detectors. Of the two, scintillation detectors are far more effective in counting gamma rays. In a typical downhole scenario with casing and cement, the G-M detector loses its sensitivity after about 6 inches, whereas the scintillation detector can discriminate the signal from background out to about 12 inches (with an Iodine 131 GR source). The major service companies primarily use scintillation counters today.

A list of common isotopes used in oilfield tracer work is available in the literature (Smolen, 1996). The most common isotope used in injection wells, is Iodine 131 in the form of NaI dissolved in water. It has a convenient half life of 8.04 days, which means that it can be shipped to the wellsite and retain enough strength to be usable with the usual delays in operations. Most service companies are avoiding the handling of RA materials. As a result, the procurement and handling of the tracers is usually done by companies specially qualified to handle such materials.

The distance and material between the tracer and detector have significant effects on the intensity of the radiation at the detector. In general, the intensity is related to the distance from a point source by the inverse square law, i.e., by doubling the distance from the radiation source to the detector, the intensity is reduced to one fourth its original value.

RA Tracer Techniques for Fluid Movement- Illustrative Example of Sequential Passes for Channel Detection

The example of Exhibit 6-6 shows a water injection well in which the open hole below the casing shoe is the injection zone. Tracer was injected into the injection stream, and a number of up passes were made to monitor the movement of the large RA slug. Run # 1 begins at time 0:00, run # 2 at time 1:17, run # 3 at time 2:25, and so on. Runs # 1-4 show downward movement with a reduction of height and increase of base dimensions, and approximately constant area. Runs # 5 and # 6 show a rapid decrease in amplitude and area, as well as a second bump above the casing shoe. Run # 6 has been drawn heavy to aid in seeing this second bump which has moved up to about 4,110 feet behind casing. The slug in run # 6 which began only 7 minutes and 40 seconds into the program, was monitored for over an hour and showed the slug moving to a place at least 150 feet uphole from the casing shoe (Smolen, 1996).

Exhibit 6-7 shows a copy of a RTS log run on PAI's Class I well WD-02 on April 11, 1999.
A base GR was run before any RA slug was ejected into the well. Also low and high background GR checks were made prior to the RA passes. The logs shows clearly no upward channel above the perforations (top @ 9459') or above the packer @ 7865'.

External Mechanical Integrity – OA/WFL

Oxygen Activation/Water Flow Logs are used to detect water flow or channels behind casing in injection wells.

The background curves of a Pulsed Neutron Log (PNL) survey may be affected by upward water flow in or around the borehole. When the neutron burst occurs, the oxygen associated with the up flowing water is activated to an unstable nitrogen isotope having a half-life of 7.35 seconds (oxygen activation effect). When the nitrogen isotope returns to its native oxygen, gamma rays are emitted which may be detected by the near or far background count rate measurement.
At present , there are two tools available for the standing oxygen activation measurement. These are:

Western Atlas:	Hydrolog
Schlumberger:	Water Flow Log (WFL)

The Atlas Hydrolog tool is a special tool with the near (SS) and far (LS) detectors optimally spaced for best detection of water movement. The Hydrolog pulses continually for 28 milliseconds after which it is turned off for 8 ms, then the cycle is repeated every 36 ms. When the pulsing is turned off, the first 1 ms will be dominated by capture events. The count rate during the following 7 ms stabilizes at a value consistent with the formation activation background counts caused by activated water flowing past the detector. By comparison of these measured near (SS) and far (LS) count rates with those which one would get if no flow was present, then a water velocity can be calculated (Smolen, 1996).

The lowest reasonably certain velocity measurable with this technique is about 3 ft/min. Each stationary reading takes about 5 minutes per station. The main problem, especially at low rates, with this technique is that the background counts measurement must be taken at a depth different from that of the test, since simply shutting in an injection well does not assure no flow at the tested interval.

The Schlumberger Water Flow Log approach is quite different and much more like conventional tracer techniques. The WFL is a dual burst TDT (thermal decay time) with a modified pulse sequence, so that the conventional TDT is also available while downhole. Unlike a conventional TDT log however, the WFL is run centralized.

The operation of the WFL technique is shown in Exhibit 6-8. The neutron generator is turned on for either 2 or 10 seconds, then turned off. If no water flow is present, the count rate decays as shown, reaching background after about one minute. If water flow is present, then the count rate decays as before, until the activated water moves adjacent to the detector. When that occurs, excess counts are observed. After the cloud of activated water passes, the counts return to the background decay curve.

The data are recorded on three detectors, typically the near (N), far (F), and gamma ray (GR). Only one will be typically optimized to provide good data. While each burst and decay sequence takes about one minute, the data collected may be highly statistical, and therefore the burst and decay sequence will typically be repeated up to about 15 times (about 15 minutes). This technique has a minimum velocity detectable of about 3 ft/min and each station reading may take up to 15 minutes.

WFL measurements, in a water-filled wellbore, may give a false indication of fluid movement due to the effects of natural convection currents. When slow flows are detected (range of 2-4 ft/min), such flows may be due to convection in a standing water column, and this effect is much worse in deviated wells.

Exhibit 6-9 shows a WFL run on PAI's Class I Well WD-02 on 3/2/01.

Station # 1 Test shot while RIH at 100 fpm cable speed.
Station # 2 Minitron depth @ 9431.1', injection rate 2.5 bpm.
Station # 11 Minitron depth @ 9431.1', injection rate ¾ bpm

External Mechanical Integrity – Borax-PNL Logs

Channel detection using temperature or noise logs is often ambiguous. In certain areas, RA tracers cannot be used either due to safety, environmental, or political reasons. As a result, a technique based on the high capture cross section of boron has been developed in Alaska to locate channels.

The technique uses a solution of a borax compound. These may include borax, boric acid, or sodium tetraborate pentahydrate dissolved in water. The latter, whose chemical formula is $Na_2B_4O_7$, offers the greatest increase in capture cross section per pound. The mix rate used in Alaska is 7 lbs/bbl of seawater. The technique is a log-inject-log technique where before and after boron injection runs are compared. Saturated brine or other less common salts may be used instead of a boron solution. Advantages of boron compounds include high capture cross section, low cost, and ready availability.

The Borax-PNL technique involves comparing pulsed neutron log (PNL) passes run before and after pumping a solution of borax dissolved in warm water as a tracer. A PNL indicates a significantly higher Sigma value when boron is present, so an overlay of log passes quickly indicates those areas within and adjacent to the wellbore where boron accumulates due to injection of the tracer. This technique is commonly used for channel detection in development wells on the North Slope of Alaska.

Schlumberger's RST (Reservoir Saturation Tool) is commonly used for these surveys due to its availability at Prudhoe Bay and because it has been proven capable to detect the presence of boron laden fluids within and external to the wellbore.

A typical Borax-PNL procedure used at BPXA's Pad 3 Class I wells in the North Slope is outlined below:

Run baseline temperature log
Pump 100 bbls hot seawater, high rate
Run two baseline RST passes, minimum rate (to minimize frictional drag on the logging tool due to high velocities and small clearance between the tool and the tubing ID
Pump 25 bbls hot borax-seawater solution, high rate
Run RST passes, minimum rate
Pump 50 bbls hot borax-seawater solution, high rate
Run RST passes, minimum rate
Pump 50 bbls hot borax-seawater solution, high rate
Run RST passes, minimum rate
Pump 15 bbls hot seawater to flush wellbore
Run final RST pass, minimum rate

A copy of the Borax-PNL log run on BPXA's Pad 3 Class I well OWDW-SW on 3/14/01 is shown in Exhibit 6-10.

Seawater Pass 2 and Borax Pass 2 Overlay

This overlay shows the change in tool response between a baseline pass and a pass run after pumping the first stage of borax solution. Below the tubing tail at 1918' MD, there is a significant increase in wellbore sigma due to the borax solution in the wellbore. Above the tubing tail, there is no significant shift in wellbore sigma due to the very small volume of borax solution surrounding the tool while it is in the tubing (Tubing ID = 1.995", RST OD = 1.6875"). There is no significant increase in formation sigma due to an accumulation of borax solution exterior to the casing. The small decrease of 1 chart division could be due to the processing algorithm, as normally the increase in formation sigma due to the displacement of formation fluids adjacent to the wellbore with borax solution is 2 ½ - 6 chart divisions or 5-12 capture units (Mike Bill, BPXA Report, 2001). The absence of any increase in formation sigma due to pumping a large amount of boron laden solution indicates no evidence of uphole movement of injected fluids above the injection interval (top of perfs at 1980' MD at this well).

Concluding Remarks

Class I injection wells play a critical role in the exploitation and development of oil and gas resources located in the North Slope of Alaska. The harsh and remote operating conditions in the Arctic coupled with the absence of year-round connecting roads, render waste transport prohibitively expensive and introduces the added risk of surface spills. The Class I wells are a key component of the overall integrated waste management option and goal of zero surface discharge of wastes in the North Slope, and is consistent with the concept of assessing the overall environmental impact of an industry rather than from an individual pollutant.

Although, there are no reported underground sources of fresh water – USDWs (based on available data) and there is a 1000-2000 foot thick permafrost layer (the deepest section is in the Prudhoe Bay Unit), present in most areas of the North Slope, the federal UIC requirements imposed on Class I operators are stringent. This paper presents a review of the Class I wells and the UIC permit requirements, including the various tests required to demonstrate that these wells maintain their mechanical integrity (both internal as well as external) on an annual basis. The operational history of Class I wells over the past two decades, has successfully demonstrated that the Class I waste management option is a safe and viable option, particularly in areas such as the North Slope that are harsh and remote with limited logistics capabilities, but are also sensitive to impacts from oil and gas production activities.

Disclaimer

The views expressed in this paper are strictly the authors and not those of their employers or the EPA. Also, brand names used are not to be considered endorsement of these products.

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****SEE FOLDER {SYED ATTACHMENTS} FOR ACCOMPANYING GRAPHICS***.

THE COORDINATION BETWEEN STATE/LOCAL PROGRAMS NECESSARY FOR A SUCCESSFUL ENFORCEMENT ACTION INVOLVING A CLASS V UIC WELL.

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Abstract
Successfully resolving a Class V Underground Injection Control (UIC) enforcement action often requires effective coordination with numerous state and local government programs. When addressing Class V injection well regulatory requirements, especially when implementing enforcement against an owner/operator, many complications and cross-programmatic issues can arise. This includes program priorities and requirements established in and for the Clean Water Act, Safe Drinking Water Act, Resource Conservation and Recovery Act, U.S. EPA annual work plans, and any state initiative or strategic plan.

As an example, the closure or modification of a Class V UIC well usually involves the installation of a new waste water treatment system. In Ohio, permits for the installation and operation of such systems require a permit to install issued under the Ohio Clean Water Act and interaction with the program or agency that issues those permits. The timely resolution of an enforcement action against the owner/operator of a Class V injection well could involve the cooperation of a local licensing or certification bureau concerning the license of a business or the certification for occupancy of a residence. Class V injection wells used as part of a waste water treatment process at a mobile home park could not just be closed as people reside at the facility and condemnation and eviction procedures including revocation of the occupancy license must be carried out prior to closure of the Class V injection well.

All the above complications to a Class V UIC enforcement case necessitate the coordination between UIC staff and other state and local officials. The various relevant issues concerning the enforcement process at the facility must be identified during the initial stages of enforcement and the various state and local programs that need to be involved must be contacted and barriers to successful coordination identified and resolved. The permits/licenses that need to be issued/revoked and the requirements for acting on the permits/licenses must be identified and the appropriate entities made aware of their obligations in the process. Funding issues also must be identified and any coordination necessary involving the clean water act state revolving fund must be explored. Benefits of cross-programmatic coordination to the UIC program include quicker resolution of the violations and less commitment of UIC program funds to each enforcement action.

Introduction
Successfully resolving a Class V Underground Injection Control (UIC) enforcement action requires effective coordination with numerous state and local government programs. Many complications and cross-programmatic issues can arise when approaching enforcement against the owner or operator of a Class V injection well. These complications can include requirements for the Clean Water Act, Safe Drinking Water Act, Resource Conservation and Recovery Act, U.S. EPA annual work plans, and any state initiative or strategic plan. The closure or modification of a Class V injection well can involve the issuance or modification of permits under the Clean Water Act. The timely resolution of an enforcement action involving a Class V injection well could involve the cooperation of a local licensing or certification bureau concerning the license of a business or the certification for occupancy of a residence.

All the above issues pertaining to a Class V UIC enforcement case necessitate the coordination between UIC staff and other state and local officials. This paper will examine the coordination effort with state, and local government programs that a UIC inspector and enforcement officer should be pursuing during a regulatory action against the owner or operator of a Class V injection well.

Why Coordinate?
The UIC program needs to coordinate with other state and local government agencies for several reasons. The most important of which is the issue of overlapping authorities concerning the treatment or disposal of a particular waste stream. This is especially true concerning an enforcement action related to the discharge of septage or non-hazardous industrial waste into a Class V injection well. In Ohio, this discharge is regulated under the UIC regulations for multifamily residences, and commercial or industrial facilities, but the discharge is also regulated, depending on the number of people and families using the Class V injection well, by either the Ohio Environmental Protection Agency (Ohio EPA) Division of Surface Water (DSW) or the local health department (LHD).

By coordinating with their regulatory counterparts, UIC inspectors can educate their counterparts concerning the UIC requirements and become familiar with the requirements of the other programs. This will allow all parties to avoid making contradictory statements to the regulated entity. This education about the other agencies and programs also includes becoming familiar with the staff of the other agencies and programs and building a good working relationship with that staff.

The quick and efficient resolution of the enforcement action is also more likely if all parties know their roles and responsibilities in regard to the enforcement action. While the UIC inspector may have the authority to enforce closure of the Class V injection well, the UIC inspector may be relying on another program to permit the system that will replace the Class V injection well. Since in many cases the Class V injection well cannot be easily closed prior to the wells replacement, the length of the enforcement case and the amount of time spent by the UIC inspector on the enforcement case can be dependent on the cooperation of the other regulatory agency.

Initial Inspection
Initial contact of the UIC inspector with the owner or operator of a Class V injection well is usually an inspection visit. During the inspection, the UIC inspector will need to determine not only UIC compliance activities with regard to the injection well, but other activities at the facility that may impact any resulting enforcement action. Information should be collected that could indicate which other regulatory entities are involved with the facility. This information could include:

- The type of facility where the Class V injection well is located. Is the facility a multi-residential building, a campground, mobile home park, commercial establishment or industrial site?;

- What kind of hazardous chemicals or wastes are stored, used or generated at the facility. If there is such activity at the facility, then what kinds of chemicals are present and where are they stored and used should be determined; and

- If they are a commercial or industrial business, it should be noted what kind of business the facility is and does the owner or operator have licenses or certifications posted. If the business does have licenses or certifications posted, then the regulatory agency that issued the licenses or certifications should be noted.

This information will allow the UIC inspector to determine what other regulatory programs are involved with the facility and the possible coordination that may have to occur to bring the Class V injection well into compliance with the rules.

Inspection Follow Up

Upon completing the inspection and prior to documenting the results of the inspection to the owner or operator of the Class V injection well, the UIC inspector should conduct research using available files and the internet to determine which state and local government agencies do regulate the facility and what their involvement in any UIC action may be. The state and local government programs could vary depending on the activities at the facility and the state and local laws regulating those activities. Examples of a few types of UIC wells and the Ohio state and local agencies potentially involved include:

- Septic systems including a Class V injection well: As mentioned above, regulation of these systems could be shared with the Ohio EPA DSW or the LHD depending on the type of facility and the number of people/families served by the system; and

- Agricultural drainage wells: Interaction concerning this type of well could be with the Ohio EPA DSW, National Resources Conservation Service (NRCS), Ohio Department of Natural Resources Division of Soil and Water Conservation and/or the Ohio Department of Agriculture (ODA). If the owner or operator of the farm is allowing the spreading of municipal sewage sludge on the farm field adjacent to the agricultural drainage well, the Ohio EPA DSW is involved through the sludge management plan required in the waste water treatment plant permit issued to the provider of the sewage sludge. If the farm has more than 1000 animal units as defined by U.S. EPA, then ODA permits the activities at the farm including the spreading of manure on the farm fields. Farms less than 1000 animal units are not regulated by ODA, but the NRCS and the local soil and water conservation districts advise the farmer on best management practice activities; and

- Industrial wells: Ohio EPA DSW may be involved with any action the UIC program may take against the facility owner or operator.

In addition to regulatory aspects that directly effect the management of the Class V well, other regulatory aspects of the facility must be considered. If the facility is a permitted/licensed business such as a beauty parlor, gas station food mart, fast food service, mobile home park or apartment building, the agency responsible for issuance of the permit or license should be ascertained by the UIC inspector. The information provides not only a contact person, but also the terms and conditions of the license or permit that may need to be considered if the Class V injection well is closed. Coordination and notifying the regulatory agency that issued the license or permit of the potential action against the owner or operator of the Class V injection well may prevent misunderstandings later on between the regulatory programs.

The UIC inspector should also determine if any other regulatory program has an outstanding enforcement case pending against the facility. If there is an outstanding enforcement case, then the UIC inspector should contact the appropriate regulatory program and determining how to coordinate any UIC enforcement action against the owner or operator of the facility with the already pending enforcement action.

Any other regulatory agencies or programs that will need to be directly involved with any potential enforcement action should be contacted. The UIC inspector should notify and discuss any UIC concerns about the regulated facility with the appropriate staff at the regulatory agency or program. The possible actions that may occur and what involvement or assistance may be need from the other regulatory agency or program should be discussed.

The above coordination ensures that all potential regulatory agencies that may be involved are fully aware of the UIC inspector's action. It may also allow the regulatory agencies to determine before hand which of them will be the lead agency in the resulting enforcement case. Allowing another agency to take the lead in an enforcement case that includes UIC rule violations may save the UIC program time and effort and allow the UIC staff to more efficiently use the resources available to them.

Notice of Violation and Meeting with Facility Owner

All identified regulatory agencies directly involved or potentially involved with any potential enforcement action against the owner or operator of the Class V injection well should receive a copy of the letter/notice of violation sent to the facility owner or operator documenting the results of the inspection. Even though no apparent assistance may be necessary from the regulatory agency, it allows them the opportunity to become aware of the UIC issues and evaluate for themselves if there are cross-programmatic concerns. This allows other regulatory entities to inform the UIC inspector of these concerns and have them considered early in the enforcement process.

Any agency or program that may be able to provide assistance to the owner or operator of the Class V injection well in returning to compliance should be identified in the letter with an appropriate phone number or e-mail address. This allows the owner or operator to independently contact the other agency or program and solicit any needed assistance including beginning discussions on any permits or licenses that may be needed or may have to be modified to address the UIC issues.

The owner or operator may request a meeting with the UIC inspector upon receiving the enforcement letter. At this point, the UIC inspector needs to evaluate who should be at the meeting and who should be informed about the results of the meeting. The appropriate people will have to be contacted and their availability determined. At the vary least, the UIC inspector will have to discuss the situation with the appropriate regulatory agency staff and determine what action they are willing to take in support of the UIC enforcement.

In Ohio, if the UIC Class V injection well is being used as part of the septic system for the facility, then a new septic disposal system may need to be approved prior to abandonment of the Class V injection well. This could require, depending on the size of the system, that either a representative from the LHD or Ohio EPA DSW be present at the meeting. The UIC inspector prior to the meeting with the owner or operator will need to discuss with the LHD/ Ohio EPA DSW inspector what permits/licenses will have to be issued and the process for obtaining them. At this time, the UIC inspector will get some indication of the possible alternatives to the Class V injection wells and the limitations and benefits of each one, the time necessary to implement those alternatives and the possible cost of replacing the Class V injection well.

There are three general options for replacing a Class V injection well disposing of sewage in Ohio: a surface water discharge system; another UIC Class V well system; or a land application system. The advantages and limitations concerning each type of discharge must be considered including the limitations related to the availability of land to build a system and the local ground and surface water bodies that could be impacted. While a land application system may solve the concerns of both the surface water regulator and the UIC inspector, the facility owner may need to purchase additional land at considerable expense to be able to implement such a solution. The lack of a viable receiving stream and available property for land application may limit the choice to another Class V injection well. The presence of a sole source aquifer or a source water protection area may rule out the use of a Class V well system. Any of these situations could make negotiations very long and difficult between the regulators and the facility owner and should be discussed between the regulators early in the enforcement process.

The UIC inspector should continue to evaluate the agencies and programs that could become involved and continue to keep them appraised of the results of the meeting. If the site is a mobile home park or campground in Ohio, then the LHD issues a license to operate to the owner or operator. In this case, the LHD should be kept appraised of the developments incase the license needs to be revoked. If cost is an issue then the UIC inspector may want to contact the staff administering the clean water act state revolving fund to see what options are available for financing a new system.

Administrative Orders/ Consent Agreements

If the facility owner or operator is recalcitrant in responding to notice of violation issued by the UIC inspector and is taking very little or no action to resolve the compliance situation at the facility, then, in Ohio, the owner or operator of the Class V injection well will be requested to negotiate and sign a consent agreement that will contain stipulated penalties if the entity fails to comply with the signed agreement. The consent agreement is a legal document and will need to contain a list of all actions that will need to be taken by the owner or operator of the Class V injection well and a schedule for completing those actions. At this time, all regulatory agencies involved with the facility will have to be informed of the action and will have to be consulted as to the license/permits or license/permit modifications that will need to be issued in order to bring the facility into compliance with the UIC rules. Should the facility owner be required to apply for permits and license modifications, then the consent agreement will have to include a schedule for applying for those permits and licenses and a schedule for implementing them once the permits or licenses are issued. The regulatory entities that are responsible for issuing the necessary permits and licenses will need to be part of the negotiations and will need to contribute to the consent agreement so that realistic time frames and actions can be included.

In the case of a farm with agricultural drainage wells, an example of this cooperation would include having requirements within the consent agreement for separation distances between manure or sludge handling areas and the drainage wells. To make this requirement most effective the agency or program permitting the manure or sludge handling would have to modify the permit allowing the sludge or manure handling to include the same restrictions as the consent agreement. The UIC enforcement staff will have to consult and coordinate with the appropriate agency or program to determine how this will be done and on what timetable.

Another example may be coordinating with the regulatory agency that licenses a business to condition the license so that the business license is revoked should the consent agreement be violated by the facility owner or operator.

Consent Agreement Follow up

Once a consent agreement is signed, the coordination needs to continue between the agencies or programs involved to ensure that the agreed upon actions occur within the time frames contained within the consent agreement. Any necessary deviations from the consent agreement need to be properly documented. If non-compliance with the agreement occurs then coordination with the agencies or programs involved will need to occur to ensure that the punitive actions stipulated in the consent agreement are implemented. For a successful enforcement action to occur there must be agreement between all regulators that the action needs to occur.

For example, the UIC enforcement officer refers the facility for non-compliance with the consent agreement, but the local agency or program refuses to concur and revoke the operating permit for the business. As a result of this, the facility owner or operator may be able to continue to operate the Class V injection well for several years while the case is being resolved in the courts.

In Conclusion

The UIC inspector must identify and coordinate with other regulatory agencies at every step in the compliance and enforcement process in order to successfully resolve most UIC violations concerning a Class V injection well. This coordination is necessary to ensure that all regulatory aspects of the facility are adequately addressed and that no contradictory information is being provided by the various regulatory agencies concerning the UIC enforcement action. The cooperation of other regulatory agencies includes not only regulatory agencies that enforce environmental statutes but will include agencies that issue business or occupational licenses and certifications. This cooperation will allow for the regulatory agencies to understand their roles and responsibilities in regard to the enforcement action, develop a good working relationship, and ensure the quick and efficient resolution of the enforcement action.

The Public Water Supplier as an Abutter in Local Land Use Decisions

by

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Abstract

Like many states, Maine was unpleasantly surprised to find MTBE in a number of their water supplies several years ago. After a statewide assessment of the extent of water supply contamination, the Governor banned RFG containing MTBE, and the Legislature and state agencies convened a series of Task Forces to improve the protection of public water supplies. The last Task Force recommended that public water suppliers be designated as abutters for local land use decisions within their Source Water Protection Areas. The Legislature enacted this requirement in PL 761, subject to the Drinking Water Program providing each municipality with maps showing the locations of the water supplies and their source water protection areas.

PL 761 represents an important step forward in Maine Law. First, it acknowledges, for the first time, the special importance of public water supply sources. Second, it defines the concept of source water protection area, and gives the Drinking Water Program the authority to delineate those areas. Most importantly, it gives public water suppliers notice of locally-regulated activities contemplated within their source water protection areas, and gives them an opportunity to participate in the local decision making process. How effective it will be depends on the commitment of both the supplier and local government to making good land use decisions.

The Drinking Water Program has produced municipal maps for about 400 towns. We expect the maps to have a secondary effect of raising municipal awareness of public water supplies, and providing opportunities for communication and coordination between Towns and water suppliers.

The most recent legislature expanded the protection of groundwater supplies by prohibiting new underground tanks within the source water protection areas of public water supplies, as well as within 300 feet of private wells. The mapping of source water protection areas was a key in obtaining passage of this legislation.

Biographies

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Background

In 1988, a high-capacity well field operated by Portland Water District was threatened with contamination by MTBE. While this was not a unique event, its effects were felt far beyond the borders of the town of Windham, were the wells were located. The PWD had expended significant time, effort, and resources in assessing the contributing area for these wells, and had worked closely with the town to develop a wellhead protection ordinance. Several generations of ground water models had been applied to refine the boundaries, which were then modified to fit existing lotting patterns.

One particular lot was located at the edge of the WHPA, and had been proposed for a gasoline station several times. The Water District, their consultants, and the Planning Board had all worked to keep petroleum products out of the WHPA. After some turnover in the town government, the station was approved. Eight months after the convenience store was opened, it detected MTBE in an onsite monitoring well at concentrations in excess of 500 ug/l. The store, complete with new state-of-the-art tanks and piping, leak detection, and groundwater monitoring, was approved in 1997 by the town of Windham just 700 feet from two surficial wells used by the Portland Water District to serve water to the North Windham section of the town.

During the review process representatives of the Portland Water District voiced serious concerns about the proposed location of this store. A delineation of the 2,500-day time of travel (TOT) distance for these wells completed for the District showed the store site to be within this protection area. Earlier, a political decision had been made by the Town of Windham to move the "line" defining the protection area for these wells from the 2,500-day TOT to the property line at this location. This was done to answer the concerns of the property owner who was actively marketing the property as a good location for a convenience store that likely would have been prohibited if the property were included inside the protection area.

Within days of the Windham contamination discovery, the well that serves the Whitefield School in central Maine was found to have more than 500 ug/l MTBE. There are no gasoline stations or fuel storage facilities near the school's well. The school had to discontinue use of the well and supply bottled water to students and staff. The MeDEP began to look for a new water supply for the school and initiated remediation activities at the site. The discovery became immediate news and intensified the now renewed debate over the RFG program and the use of MTBE in Maine. A MeDEP investigation identified run-off from a nearby parking lot as the likely source of MTBE in the well. A new well was drilled in August 1998 to replace the contaminated well. Unfortunately, the new well tested extremely high for Radon and Gross Alpha, and will likely require significant treatment prior to being placed online as a source of drinking water for the students and staff of the Whitefield School.

Task Forces and Commissions

The Governor and state agencies responded forcefully to these occurrences. An interagency task force was formed, and, with an unusual degree of governmental cooperation, a statewide random sampling of private wells initiated. This was coupled with sampling of public water supplies. Within 90 days, the sampling was completed, and MTBE had been detected in 16% of private water supplies and 15.8% of public water supplies. Based on this information, Maine withdrew from its agreement to use RFG, and substituted "Southern Fuel", which has a much lower MTBE content. The task force also identified some more long-term problems, but was unable to create a solution in the time before the next legislative session.

The Legislature met and created a Commission to look at structural solutions to the problems identified by the task force. The commission included representatives from municipal government, water suppliers, environmental groups, business and industry, and the petroleum sales industry, as well as state and federal agencies. This group identified water suppliers' lack of standing in land use decisions as a key problem. They also noted that public water supplies had not had effective advocacy either from the suppliers or from the state. A number of solutions were proposed and discussed, including giving suppliers veto power over land use decisions in their source water protection areas. The group, after some discussion, determined that veto power could probably not be legally extended to PWS's, who may not be governmental agencies. They decided that providing water suppliers with standing as abutters for proposed land use activities within their source protection areas represented a significant step forward.

The Law

In 2000, the Legislature received the Commission's report and passed PL 761, which, among other things, provided that water suppliers would be considered abutters for the purposes of local land use decisions within their source water protection areas. This provides PWS's with notice and standing to participate in town government decisions. The law does not guarantee that the PWS will be successful in persuading the town. It provides a forum where the PWS and the Town planners can discuss the merits of a proposal, and its potential effect on water supplies.

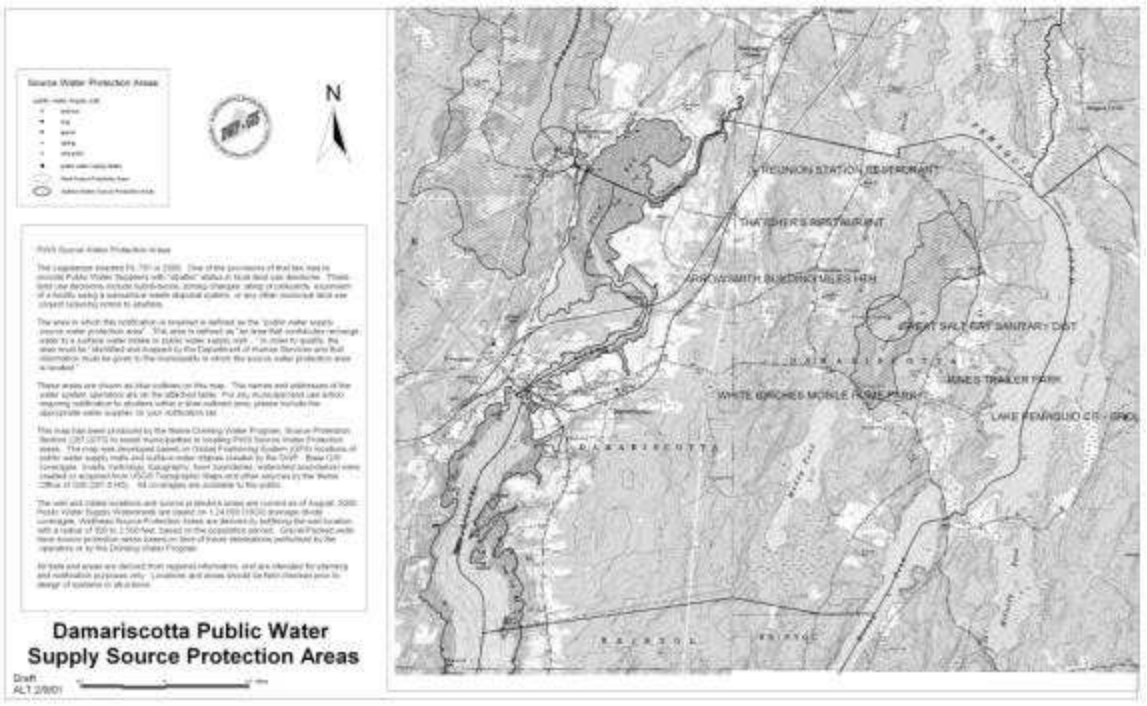
The law defined Source Water Protection Areas as those areas mapped by the Drinking Water Program as contributing water to public water supplies. Under current practice, these include a mix of time-of-travel ground water delineations, variable fixed radius circles based on population, and direct watersheds as mapped from 1:24,000 topographic maps. For management and assessment purposes, the watersheds of rivers are arbitrarily terminated one half mile above the intake.

Standing is especially useful for water suppliers where the source protection area is located in another town or towns. Often, the town where the source is located is outside PWS service area, and has no obvious reason to assist in protection of the quality of that source. Land use decisions offer a forum for public and civic education about the water quality consequences of development.

The Maps

Implementation of the new law was contingent on the Towns' receiving "information" about the location of source water protection areas from the Drinking Water Program. The DWP had volunteered that it would not be a problem to perform this task. Once the actual number of maps was tallied, the project looked a little more formidable. First, a series of prototype maps were prepared and sent to the Maine Municipal Association, the State Planning Office, and several water suppliers. With feedback from those groups, a series of pilot towns were selected, and maps made for distribution and comment.

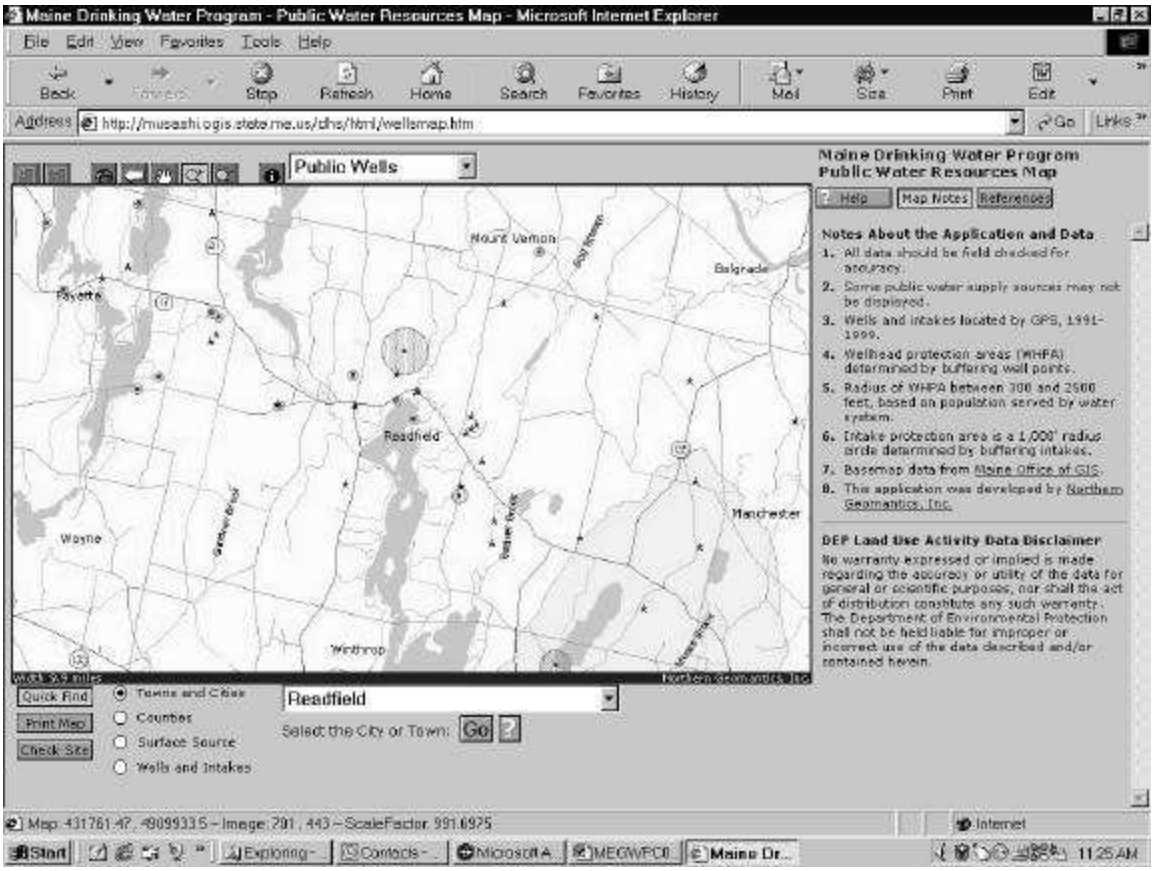
We received some limited feedback from the pilot towns: generally they seemed happy with the maps, although they (and we) would have preferred them on a tax-map base. Unfortunately, most of the state does not have digital tax map coverage, and where it does exist, the quality and projection is variable. We used a USGS 7.5 minute topographic map base. This proved to be more recognizable that coverage-based road networks, because the culture on the topographic base provided better reference points for the lay reader. Each map includes a table with the name, address, and phone number for a contact at each public water supply.



With the basic design decisions made, the problem of actually producing maps for about 400 towns with limited staff and time loomed larger. The draft maps required about an hour of composition time, and another hour to plot. We enlisted technology to speed up the process. The Maine Geological Survey used their expertise in Arc Macro Language to semi-automate map compilation and annotation. With the help of a new and faster plotter and a couple of interns, we were able to generate maps for al the towns in about five weeks.

The Web Site

We are currently working on the fourth generation of our PWS mapping web site. The site shows essentially the same information as the maps. It allows interactive searches, and provides a tool to locate sites and buffers them using UTM or point and click coordinates. The site also can provide a page-sized printed map. We are encouraging use of the web site, because it is possible to update it much more easily than a paper map set.



The "site mapping" facility on the web site is also very useful. It can be activated either by typing in UTM coordinates, or by selecting and clicking on a location on the screen. Once the site is mapped, its location relative to source water protection areas can be easily determined. It can also be used to 'reverse engineer' extract UTM locations of wells. The next generation web site will allow for downloads of well and source protection area data for use in development planning. The names and addresses of public water suppliers are also available by clicking on their source location. As more towns and agencie s have and use internet access, these tools help to provide the information needed to kink PWS's to the towns' decision making processes.

The Towns

Preliminary reactions from towns have been positive. Numbers of responses to the initial mailings have been modest, but interested and enthusiastic. The most frequent is a request for more maps, so that Planning Boards, CEO's and other bodies can each have their own copy. Next most frequently is a request for the shapefiles of the sources and their protection areas from the Towns with GIS capability. The third most frequent is a bug report. We know that our data has some inconsistencies, and that we never have all the new and renamed transients geo-located.

A number of town planners have been excited to receive the maps. They are also looking forward to using the shapefiles, which we're providing through the State Planning Office to towns where comprehensive planning is about to start or is early in the process. The availability of easy to use locational data for public water supplies appears to be an important factor in both the Legislature's and the Town's willingness to work towards their protection.

The Public Water Suppliers

A number of suppliers have been interested in this process, and are working to take advantage of the opportunity to participate in town decision-making. However, most of the PWS's have limited technical resources, and have difficulty finding the time to collect, review, and analyze permit applications. Even if they do find that time, they then need skills and abilities in order to advocate effectively for the protection of their sources. This is not usually one of the selection criteria for water operators, although there are some individuals who are very good advocates for their sources.

This last legislative session, the Department of Environmental Protection, with assistance form the Drinking Water Program and the Maine Water Utilities Association, advocated for a new law to prohibit the location of new underground storage tanks within Source Water Protection Areas for ground water sources. The Legislature adopted this new law, which also will protect sand and gravel aquifers that may serve as future public water supplies. One of the factors that made passage feasible was the existence of maps and tools for locating source water protection areas quickly and accurately.

Next Steps

We are working with the Maine Rural Water Association and the University of Maine to provide technical assistance and training to both municipal officials and water suppliers in implementing the law. At the same time, we're working to complete the Source Water Assessments. These are scheduled for release in mid-2002, and we hope to use them to build on the initial success of the protection area mapping project.

One of the major risks we've found to PWS's is the lack of knowledge about their location, or even existence. By repeatedly providing towns with information about water supplies, the likelihood of making an impression is increased.

We are also working with the Department of Environmental Protection to help them implement their new laws. They are required to verify the location of all proposed UST's, to assure that they are outside the source protection areas of public water supplies. We are training their field staff to use our Internet mapping site to locate tank sites relative to public water supplies. The town maps also allow individuals to screen potential UST sites to avoid conflict with public water supplies.

While providing Public Water Suppliers with abutter status was a welcome step forward, it does not "solve" any source protection problems by itself. By creating an opportunity for interaction and education, it offers the potential for improved local land use decisions. The cumulative effect of these interactions can increase understanding and cooperation between the PWS and town decision makers. Whether this actually happens depends on the efforts of many individuals, as well as on the political climate of the town and the difficulty of the land use decisions being made.

NATURAL GAS CAVERN STORAGE AND THE ISSUE OF DISPOSAL OF THE FLUIDS

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Abstract

With the increase in the demand for natural gas in this country, the value of Market Area Storage has become a critical issue that needs to be examined. In many areas in the United States, bedded and domal salt caverns are being used for high-deliverability storage and salt-cavern storage will continue to be an important component of the natural gas supply industry. Successful commercialization of this type of storage project depends upon the following factors: 1) sufficient thickness of the salt; 2) depth of the salt; 3) location of the facility; 4) availability of a freshwater supply for the dissolution process; and 5) an acceptable method of fluid disposal.

One of the most important issues in dealing with this type of project is finding an acceptable, cost-effective method for the disposal of the fluids generated during the salt-dissolution process. Current interpretation of the Federal Regulations regarding this issue varies widely among U.S. EPA Regional Offices and Primacy States. Some of these agencies allow for disposal of the start-up or excess fluids into Class II injection wells, while others require disposal of these types of fluids into Class I non-hazardous injection wells. The lack of consensus on this issue of disposal needs to be resolved. This can be accomplished through: 1) greater communication between U.S. EPA, Primacy States, and the industry; 2) a detailed study of existing cavern storage facilities where fluids are being disposed into Class II wells; 3) an evaluation of the Federal Regulations to see if a national consensus can be reached; and 4) if a consensus cannot be reached then what changes need to be made in the regulations to make this an acceptable Class II disposal practice.

Introduction

The National Petroleum Council projects that United States demand for natural gas will grow by 42 percent from the 1998 levels to 31.3 tcf (trillion cubic feet) in 2015. However, Rick Daniel of AEC Storage and Hub Services, Inc., expresses concern that peak-day demand is expected to grow 37 percent to 152 bcfd (billion cubic feet per day), while storage capacity is only projected to increase by 25 percent to 4 tcf during the same period (Fletcher, 2001). According to Daniel, industry will need to add several new natural gas storage facilities each year to keep up with the projected demand (Fletcher, 2001).

Most of the storage facilities in the United States are owned and operated by utilities and interstate pipeline companies that may not have the economic incentives to fully develop their capacity (Fletcher, 2001). Based upon conversations with utility storage operators, Daniel concludes that operators are not moving on development opportunities for regulatory reasons (Fletcher, 2001). He predicts, " Over regulation will continue to discourage investors."

Natural Gas Cavern Storage

Storage of liquids and gases in salt caverns was reportedly first conceived in Canada in the early 1940s, during World War II (Bays, 1963). The storage of liquid petroleum gas (LPG) and other light hydrocarbons spread rapidly in North America and in several European countries during the early 1950s (Thoms and Gehle, 2000). By the 1960s, storage of natural gas in solution-mined salt caverns had commenced in the U.S. and Canada (Thoms and Gehle, 2000). The first reported storage of natural gas in salt caverns in the U.S. occurred in Michigan and Kansas in the early 1960s (Gentry, 1963; Vance, 1963).

With the increase in the demand for natural gas in this country, the value of Market Area Storage has become a critical issue that needs to be examined. In many areas in the United States, bedded and domal salt caverns are being used for high-deliverability storage and salt-cavern storage will continue to be an important component of the natural gas supply industry. Successful commercialization of this type of storage project depends upon the following factors: 1) sufficient thickness of the salt; 2) depth of the salt; 3) location of the facility; 4) availability of a freshwater supply for the dissolution process; and 5) an acceptable method of fluid disposal.

Currently in the United States, eight states have existing or proposed natural gas storage projects in solution-mined salt caverns. These states include: Alabama, Kansas, Michigan, Mississippi, New York, Louisiana, Texas, and Virginia. Based on the AGA 1998 Survey, Texas is the leader, with over 100 bcf (billion cubic feet) of storage capacity.

Issue of Disposal

One of the most important issues in developing this type of natural gas storage project is finding an acceptable, cost-effective method for the disposal of the start-up fluids generated during the salt-dissolution process or the excess fluids produced during storage operations. Current

interpretation of the Federal Regulations regarding this issue varies widely among both U.S. EPA Regional Offices and Primacy States. Some of these agencies allow disposal of these start-up fluids or excess fluids from storage operations into Class II injection wells, while others require disposal in Class I non-hazardous injection wells. The following table gives a breakdown of which states and U.S. EPA Regional Offices allow for Class II disposal.

U.S. EPA Regional Office	**States**	**Class II Authorized Disposal**
Region 2	New York	Yes
Region 4	Alabama, Mississippi	Yes
Region 6	Louisiana, Texas	Yes
Region 3	Virginia	No
Region 5	Michigan	No
Region 7	Kansas	No

Conclusions and Recommendations

The lack of consensus by U.S. EPA on the issue of disposal of fluids associated with natural gas storage in salt caverns needs to be resolved. This can be accomplished through: 1) greater communication between U.S. EPA, Direct Implementation and Primacy States, and the industry; 2) a detailed study of existing cavern storage facilities where fluids are being disposed into Class II wells; and 3) a thorough evaluation of the Federal Regulations. If a national consensus can be reached on this issue and it is considered an acceptable Class II disposal practice, then changes in the Federal Regulations should be considered.

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Evaluation of Slurry Fracture Injection Technology for Disposal of Oil Field Wastes

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Biographical Sketch of Authors

John Veil is the manager of the Water Policy Program for Argonne National Laboratory's Environmental Assessment Division (EAD). He analyzes a variety of oil and gas and electric power industry water and waste issues for the U.S. Department of Energy. He has a B.A. in Earth and Planetary Science from Johns Hopkins University, and two M.S. degrees -- in Zoology and Civil Engineering -- from the University of Maryland. Before joining Argonne, he managed programs for industrial wastewater discharge, underground injection, and oil control for the State of Maryland and was on the faculty of the University of Maryland.

Markus Puder is a policy analyst for EAD. His legal education in the Federal Republic of Germany includes the First and Second Legal State Examinations (German equivalent of U.S. JD and multi-jurisdictional bar certification) and a Ph.D. in Law from the *Ludwig-Maximilans* University in Munich. After earning an LL.M. from the Georgetown University Law Center, he became a member of the New York State Bar and the U.S. Supreme Court Bar. He also is an adjunct professor of law at the Georgetown University Law Center where he teaches European Union law.

John Gasper is the manager of Environmental Policy Analysis and Planning for EAD. He has a B.S. in Environmental Geography and an M.S. in both Environmental Health Science and Public Health. He has more than 25 years of experience in environmental assessment activities related to energy technologies and development. His areas of expertise include environmental and energy policy, legislation and regulation, solid and hazardous waste management, and occupational and public health risk.

Abstract: Argonne National Laboratory has recently commenced a study to evaluate the technical feasibility, regulatory status, and economics of slurry fracture injection (SFI)[9] technology. The evaluation will assess several injection technologies used for disposing of solid oil field wastes, including SFI, annular injection, and subfracture pressure slurry injection, with an emphasis on SFI. The project will:

1. Characterize the equipment and operational requirements for SFI.
2. Inventory sites where SFI has been applied in the United States and document application characteristics such as volume of waste injected and operational problems encountered.

[9] The authors understand that the terms "Slurry Fracture Injection" and "SFI" may be copyrighted by Terralog Technologies. Use of those terms in this paper does not refer to the specific process licensed by Terralog Technologies, but rather to the generic process of grinding solid wastes into small particle size, mixing them with a carrier fluid to create a slurry, and then pumping the slurry into an underground formation at pressures high enough to fracture the rock.

3. Compile state, federal, and, where possible, international regulatory requirements applicable to SFI, and identify

potential related limitations to the use of SFI technology.

4. Characterize and assess the costs of SFI, comparing them with other disposal technologies. The analysis will attempt to capture both actual and avoided costs from the use of SFI.

Introduction

The oil and gas industry has used several different practices for managing solid oil field wastes, including:

- landspreading and landfarming,
- evaporation and burial onsite,
- incineration and other thermal treatment,
- bioremediation and composting,
- discharge to the ocean,
- reuse and recycling, and
- underground injection.

Most of these waste management practices place waste materials on or near the earth's surface, which means that some potential exists for interaction with the biosphere. Underground injection offers an alternative that moves waste below the biosphere. As long as wastes do not escape during or following injection, environmental or health impacts from underground waste management are less likely. Marinello et al. (2001) describe several forms of injection practices used for oil field wastes. Slurry fracture injection (SFI) has been applied in a wide range of geographic settings, including Canada (Sipple-Srinivasan et al. 1997; Dusseault and Bilak 1998), Alaska (Schmidt et al. 1999), California (Sipple-Srinivasan et al. 1998), Louisiana (Baker et al. 1999; Reed et al. 2001), the North Sea (Moschovidis et al. 1993), and the Gulf of Mexico. A commercial waste disposal company practices subfracture pressure slurry injection[10] at several facilities in eastern Texas. According to Marinello et al. (2001), more than 80% of the commercially disposed drilling wastes from offshore and transition oil and gas operations in the Gulf of Mexico and more than 90% of oil field wastes containing naturally occurring radioactive material have been injected through subfracture pressure slurry fracture injection. Salt caverns in Texas and western Canada have also been used for disposing of various types of oil field wastes (Veil et al. 1996, 1998).

The U.S. Department of Energy's (DOE's) Office of Fossil Energy and National Petroleum Technology Office have supported studies to evaluate the technical feasibility, legality, and cost-effectiveness of various innovative waste management methods. The salt cavern research noted above (Veil et al. 1996, 1998) and an evaluation of downhole oil/water separators (Veil et al. 1999) are examples of this type of evaluation. Earlier this year, DOE agreed to fund Argonne National Laboratory to conduct a similar study of SFI technology. This study will be conducted in conjunction with the Petroleum Environmental Research Forum (PERF). Because the project has just begun, no results or conclusions are presented at this time. Rather, the paper describes the framework for the study and the types of information to be collected. One goal of this paper is to solicit input from state and federal regulators and industry representatives about SFI.

[10] In this method, a slurry of wastes is injected into a porous formation at a pressure lower than fracture pressure. The Texas facilities noted in the text inject the slurry into naturally fractured cap rock above salt domes at very low pressures.

Study Design

The study is based on the four main components described in the following sections.

A. Description of SFI Technology:

Argonne will review and describe the various types of injection technologies used to dispose of solid exploration and production (E&P) wastes. The technologies to be characterized will include but not limited to SFI, annular disposal, subfracture pressure slurry injection, and salt caverns, but the primary focus will be on SFI. The information will be obtained through literature review and interviews with oil and gas operators, service companies, state and federal (Environmental Protection Agency, Bureau of Land Management, Minerals Management Service) officials, and industry contacts. The information needed for the technology description section includes:

1. Technology, equipment, and process requirements
    - capital equipment
    - operational and maintenance requirements
    - support services

2. Operational parameters
    - geological conditions needed for successful injection
    - applicable well types and configurations (e.g., single wells, dedicated disposal wells, multiple wells)

3. Technology availability
    - contractors and service companies that currently offer SFI services

B. Inventory of SFI Sites:

Argonne will develop a database of wells where SFI has been used. Although the database will focus on the United States, it will also include international data, where available. The information for the database will be obtained from literature reviews and interviews with commercial SFI companies, state and federal agencies, oil and gas operators, and service companies. The types of information sought for the database will include, at a minimum:

- name of operator
- name of injecting company, if different from operator
- site name and location
- site geology
- depth of injection formation (top, bottom)
- geology of injection formation (type of rock, porosity, permeability)
- top and bottom of perforated zone
- dates and duration of injection
- injection rate (range, average)
- bottom hole pressure (range, average)
- types of materials injected
- volume of materials injected
- nature of slurry (fluid used for slurry, density)
- preinjection treatment or processing (solids processing, injection of water before slurry injection, etc.)
- problems experienced
- costs
- other comments.

C. Legal and Regulatory Requirements for SFI:

Argonne will develop a compendium of state and federal legal regulatory requirements regarding injection of solid oil field wastes, with a focus on SFI. To the extent possible, international requirements will also be included. This information will be obtained through interviews with state and federal agencies, oil and gas operators, and service companies, and where appropriate, foreign government agencies. The types of information that will be sought for the legal and regulatory section includes:

1. Regulatory authority
    - laws, regulations, and policies
    - existing limitations or prohibitions
    - responsible agency and contact information

2. Permitting history
    - historic use of SFI within jurisdiction
    - geologic or other limitations that curtail use of the technology in certain areas

3. Permitting process
    - coverage of permits (one or multiple jobs)
    - permit requirements
    - testing and monitoring (e.g., mechanical integrity testing, waste characterization, pressure testing)
    - use of alternative regulatory processes (e.g., case-by-case administrative decisions)

D. Economics:

Argonne will develop information on the current and projected costs of SFI and compare them with more conventional methods of disposal of oil field wastes. Argonne will also develop information actual and avoided cost estimated. These estimates will be developed on a typical-well and a per-barrel basis. Sources of information will include literature reviews and interviews with oil and gas industry contacts. Examples of information sought for the economics section includes:

1. Actual costs
    - injection costs
    - service company charges
    - equipment rental
    - liability
    - drilling stoppages resulting from inability of SFI equipment to keep pace with drilling waste production

2. Avoided costs
    - transportation
    - offsite disposal facility tipping fees

<u>The Project Team</u>

The Argonne team includes John Veil (project manager), Markus Puder, John Gasper, Bill Bryson, Maurice Dusseault, and Bob Ayers.

<u>Where Do We Go from Here?</u>

The project team will collect information throughout the remainder of 2001. A draft report and database, be prepared during the first part of 2002, will be made available to interested persons for review.

The team members will give a series of conference presentations on the project during the next six months that will be updated as new information is developed. The schedule of presentations to date includes:

Ground Water Protection Council (GWPC) Annual Meeting - Reno, NV - September 25, 2001
GWPC West Coast Injection Meeting - Long Beach, CA - October 25, 2001
Interstate Oil and Gas Compact Commission (IOGCC) Winter Meeting - Santa Fe, NM - December 10, 2001
GWPC Injection Meeting - Houston, TX - January 2002.

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INJECTION OF CHEMICAL OXIDIZERS INTO A SEMI-CONFINED AQUIFER FOR GROUNDWATER REMEDIATION – SOME LESSONS LEARNED

BY
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Abstract
In situ chemical oxidation has gained great attention over the past few years as a technology for remediating groundwater contaminated with hydrocarbons and chlorinated solvents. The process involves subsurface injection of oxidizers, stabilizers, and catalysts via groundwater monitoring wells for the oxidative destruction of subsurface contamination. It has successfully achieved contaminant reduction of more than 90 percent in both laboratory and field studies. Effective chemical oxidation depends on the nearly simultaneous mixing of oxidizers, catalysts, and contaminants. Estimates for predicting chemical oxidation radius of influence and injection volumes are typically based on models for predicting groundwater transport and flow in an unconfined homogeneous isotropic aquifer. These estimates proved to be greatly inaccurate at a site in southern California, where the effectiveness of chemical oxidation in cleaning up groundwater contaminated with benzene and 1,2-dichloroethane was tested. While the technology had not previously been tested in a fine-grained semi-confined water-bearing zone, the site was considered a good candidate for chemical oxidation because it met the vendor's minimum requirements for hydraulic conductivity. However, during the test, the estimated 20-foot radius of influence was not achieved, contaminant reduction was only minimal, and numerous undesired effects resulted. These effects, which had not been observed at previous test sites, included injected chemicals coming back to ground surface and injected chemicals remaining in the injection wells. It is believed that the semi-confined water-bearing zone was responsible for many of these adverse effects. Subsequent evaluation of the test design revealed additional steps that could have been implemented to more accurately measure the effectiveness of the process. While this study did not meet the remediation goals, lessons were learned regarding well design and

placement, injection techniques, and effectiveness measurement. These lessons can be applied at similar sites to enhance the potential for successful remediation.

Introduction

In situ chemical oxidation by Fenton's chemistry has gained great attention over the past few years as a technology for remediating groundwater contaminated with hydrocarbons and chlorinated solvents. Fenton's chemistry is the process of combining hydrogen peroxide and a ferrous iron catalyst to generate the hydroxyl radical. The hydroxyl radical is an oxidizer second only to fluorine in oxidation power (Table 1) and is capable of oxidizing most organic contaminants with typical end products of carbon dioxide, water, and mineral salts. Hydroxyl radicals have half-lives on the order of nanoseconds. Therefore, effective Fenton's chemistry depends on the nearly simultaneous mixing of the hydrogen peroxide, the ferrous catalyst and the organic contaminants. Two types of Fenton's chemistry, low pH (4 to 6) and circum neutral pH (5 to 8), are most commonly used commercially.

Table 1
Relative Oxidation Power
(Chlorine = 1.0)

Fluorine	2.23
Hydroxyl Radical	2.06
Atomic Oxygen (singlet)	1.78
Ozone	1.50
Hydrogen Peroxide	1.31
Perhydroxyl Radical	1.25
Potassium Permanganate	1.24
Chlorine Dioxide	1.15
Bromine	0.80
Iodine	0.54

Low pH Fenton's chemistry typically uses ferrous sulfate as the source of the ferrous iron catalyst and hydrogen peroxide concentrations between 20 and 50 percent. The reagents are injected via specially designed steel injection wells. However, this method is only suitable for groundwater with pH less than 6. When pH is greater than 6, the ferrous iron in the catalyst is precipitated out and converted to ferric iron which reacts with hydrogen peroxide to form the perhydroxyl radical, a much less powerful oxidizer (Table 1). Vendors using low pH Fenton's chemistry typically pretreat the aquifer with acid to lower the pH to an acceptable range.

Circum neutral pH Fenton's chemistry uses a chelated iron matrix as the source of the ferrous iron catalyst and hydrogen peroxide between 6 and 18 percent. Reagents are injected via standard polyvinyl chloride monitoring wells. The chelated ferrous iron is not converted to ferric iron at neutral pH and, therefore, for this method, it is not necessary to adjust the pH of most aquifers. Both methods of Fenton's chemistry have been reported to achieve contaminant reduction of more than 90 percent in both laboratory and field studies (Greenberg et al. 1998, Nyer et al. 1999, and Geo-Cleanse International, Inc. 2001). As such, this technology quickly gained popularity over traditional remediation technologies, such as vapor extraction and air sparging, because success is achieved in a much shorter time period, requires very limited equipment, and it produces little, if any, waste products.

Circum neutral Fenton's chemistry had never been used in California or in a semi-confined aquifer. However, this technology was thought to be an outstanding process

option to remediate a groundwater plume adjacent to an active runway in southern California. Land-use restrictions required that the area adjacent to the runway remain free of surface structures, thereby precluding traditional remediation technologies such as vapor extraction and air sparging. In addition, circum neutral pH Fenton's chemistry had the following advantages over low pH Fenton's chemistry:

- It required no acidification: groundwater at the site has a pH near 7 and high buffering capacity due to high TDS and alkalinity.
- The vendor recommended hydrogen peroxide concentrations of 8 percent: lower hydrogen peroxide concentrations met the requirements of the safety evaluation.
- The probability of soil eruption, excessive gas venting, and creation of sinkholes was believed to be low due to lower hydrogen peroxide concentration.

Based on these advantages, it was decided to go forward with a bench-scale test and, if successful, conduct a pilot test at the site. A chemical oxidation vendor, with historical success in implementing circum neutral pH Fenton's chemistry, was selected. The vendor was provided with site historical and hydrogeologic information and contracted to perform an initial bench-scale test prior to the field pilot testing. Based on the results of the bench scale-testing and the vendor's assessment of the hydrogeologic information, the vendor concluded that circum neutral pH Fenton's chemistry would be well suited for use at the site.

Site Conditions

The project site (Figure 1) was a fuel farm that operated between 1942 and 1955. It consisted of 23 underground storage tanks (USTs) ranging in size from 25,000 to 50,000 gallons. Most of the tanks stored aviation fuel. The fuel farm was relocated when a nearby runway was expanded in the mid-1950s. At that time, most of the piping was removed and the tanks were drained, cleaned, and filled with sand. Fourteen of the tanks were subsequently removed in the mid-1980s. In the early 1990s, a site investigation identified groundwater contamination in the vicinity of the former tanks. Subsequent investigations identified a groundwater plume that covers almost 80 acres, with the runway bisecting the area of highest groundwater contamination (Figure 1). Contamination in soil above the water table is generally absent except in the locations of the former USTs, and free product has not been reported in any of the groundwater wells.

The remedial alternatives focused on reduction of dissolved phase contaminants in groundwater, predominantly total petroleum hydrocarbons measured as gasoline (TPH-g), benzene, and 1,2-dichloroethane (DCA) with maximum reported concentrations of 33,000, 16,000, and 1,690 micrograms per liter, respectively. Other petroleum-related compounds and chlorinated solvents are also present in groundwater but at much lower concentrations. TPH-g, benzene, and 1,2-DCA were selected as the site indicator compounds because they occur at the greatest concentrations and pose the greatest health risk at the site.

Lithology in the upper 15 feet consists of interbedded mixtures of sand, silt, and clay. Stratigraphic layers vary in thickness from a few inches to about 5 feet (Figure 2). The interbedded soils overlie a massive clay layer that ranges from 15 to 25 feet thick. Groundwater is present in a silty sand unit between 10 and 15 feet below grade. Large desiccation cracks have formed as a result of hot summer temperatures that commonly exceed 110 degrees Fahrenheit between May and September. Some of the cracks are as wide as two inches at the ground surface and extend to the top of the water table.

Slug tests and short-term pump tests indicate that the water-bearing zone is semi-confined. Hydraulic conductivity ranged from 10^{-5} to 10^{-3} centimeter per second and transmissivity ranged from 10^{-4} to 10^{-2}. Groundwater flow is to the north at an average rate of 10 feet per year with a gradient of approximately 0.004 feet per foot.

Bench Testing

A bench-scale laboratory test was conducted to assess how effective the process was for site contaminants and to determine the optimum catalyst mixture. The bench test consisted of injecting catalyst and hydrogen peroxide mixtures into vials containing samples of contaminated groundwater or soil and groundwater slurries (comprised of a 1:1 mixture of soil to groundwater) collected from the site. The selected catalyst/hydrogen peroxide mixture reduced VOC concentrations in groundwater by 97 percent and in the soil slurry by 91 percent, meeting the pilot study design goal of 90 percent contaminant reduction.

Four control samples were also evaluated. The control samples were produced by injecting known volumes of distilled water into one groundwater vial and one slurry jar and injecting hydrogen peroxide and catalase into one groundwater vial and one slurry jar. (Catalase is a naturally occurring enzyme catalyst that promotes the decomposition of hydrogen peroxide to water and oxygen without formation of the hydroxyl radical.) Control samples were evaluated to assess:

- contaminant reduction due to sample dilution by reagent volumes,
- contaminant reduction due to volatilization caused by room temperature test conditions,
- contaminant reduction from volatilization caused by gases generated during the reaction, and
- contaminant reduction due to hydrogen peroxide oxidation.

Contaminant reduction was not observed in any of the control samples. Therefore, it was determined that contaminant reductions of the bench-test samples were due to the interactions between the catalyst/hydrogen peroxide mixtures and the contaminants.

Pilot Study

The pilot study was designed to determine if the groundwater concentrations of the target contaminants (TPH-g, benzene, and 1,2-DCA) could be reduced by 90 percent over a 20-foot radius of influence (ROI) in three injection events. The test array (Figure 3) consisted of six injection wells (IW1 through IW6) arranged in a triangular pattern and seven monitoring wells (MW 7 through MW13) with one in the center of the injection triangle and the others in groups of two offset from each vertex. The wells were screened across the silty sand water-bearing unit approximately 15 to 20 feet below ground surface (Figure 2). Downhole instruments were installed in each of the exterior monitoring wells (MW7 through MW12) to monitor temperature, pH, conductivity, pressure, dissolved oxygen, and oxidation/reduction potential.

The chemical oxidation vendor specified the triangular injection well array surrounding a central monitoring well. Prior to the test, the well array was modified by adding the exterior monitoring wells (MW7 through MW12) to assess the effects of gradient and preferential flow of the injected chemicals on contaminant reduction. It also allowed for calculation of separate estimates of the ROI based on monitoring parameters (hydrogen peroxide and Fe^{2+}). The design of the triangular array also allowed these wells to be converted to injection wells in the future if full-scale remediation was performed.

The pilot study was scheduled to take place over 3 months with 1 injection event each month. The following process was proposed:

- Gravity inject catalyst through three of the injection wells (IW2, IW4, and IW6).
    - Inject catalyst and allow it to spread along the top of and slowly disperse through the water-bearing unit.
    - Measure iron concentrations at the central monitoring well to determine when the catalyst had saturated the area within the injection array.

- Gravity inject hydrogen peroxide through the injection wells that had previously received catalyst (IW2, IW4, and IW6).
  - Inject hydrogen peroxide and allow it to spread along the top of and slowly disperse through the water-bearing unit.
  - Contact between hydrogen peroxide and catalyst generates hydroxyl radicals.
  - Hydroxyl radicals oxidize react with the contaminants to generate carbon dioxide, water, and mineral salts.

Following the injection, weekly groundwater samples were collected and analyzed for target contaminants.

Significant Observations and Difficulties

Numerous difficulties were encountered during testing. Many of these were minor and are not unexpected during a pilot study. However, several unexpected difficulties occurred that, separately, could have been managed. However, in combination, they eventually led to the early termination of the pilot test. Each of these problems is described below, by injection event.

First Injection Event

The purpose of the initial injection event was to determine the site injection rate and how quickly the reagents would reach the central monitoring well. Injection rates between 0.5 and 3 gallons per minute (gpm) per well were anticipated. Reagents were injected into wells IW2, IW4, and IW6. Concurrently, field monitoring for hydrogen peroxide, total iron, pH, conductivity, and temperature was performed at the central monitoring well (MW13) and adjacent injection wells (IW1, IW3, and IW5).

- Observation: Injection rates were lower than expected (as low as 0.1 gpm), and no changes in field monitoring parameters were observed in the central monitoring well or the adjacent injection wells.
- Conclusion: Reagents are not sufficiently mobile in the subsurface, using the current method of injection, to achieve a measurable change in monitored parameters 20 feet from injection wells. Based on poor reagent mobility, it was anticipated that this process would be unable to achieve a 20-foot ROI.

Because of the slow injection rates, the vendor applied low pressure (less than 10 pounds per square inch) in an effort to increase rate of chemical injection and to increase the horizontal displacement of the injected chemicals.

- Observation: Liquid was observed seeping to the ground surface near one of the monitoring wells. It was determined that the liquid had traveled to the surface between the well grout seal and soil.
- Conclusion: The cause of the well failure was initially undetermined. However, it was later found out that the vendor had applied low pressure rather than gravity feed (as outlined in the work plan). It was also thought that a poor grout seal or backpressure from chemical reaction could be possible causes. Therefore, this well was redrilled and replaced prior to the second injection event.

Second Injection Event

While the work plan specified the maximum hydrogen peroxide concentration of 10 percent, the chemical oxidation vendor injected 17.5 percent hydrogen peroxide into three wells during the first phase of the second event. The goal was to destroy soil organic carbon, thereby eliminating interference with preferred reaction between reagents and site contaminants. This was performed without knowledge or permission of the customer or the primary contractor.

- Observation: The injection of 17 percent hydrogen peroxide was discovered during an informal conversation between a vendor employee and one of the participating environmental consultants.

- Conclusion: This was considered a major deviation from the approved work plan and resulted in a stop-work order and an incident investigation. Mitigation measures were implemented to ensure that similar incidents would not occur. Additionally, injection of high concentrations of hydrogen peroxide to destroy soil organic carbon directly contradicts the belief that hydroxyl radical generation results in more efficient chemical oxidation reactions than using high concentration hydrogen peroxide alone.

Low-pressure injection (less than 10 pounds per square inch) was applied to the six injection wells in an attempt to increase the rate of chemical injection and to increase the horizontal displacement of the injected chemicals.

- Observation: Liquid was observed seeping to the ground surface at five of the six injection wells as well as between the wells. In one instance, the point where the fluids were initially discharged was more than 7 feet from the injection well. Additionally, no evidence of contaminant mixing or the creation of the hydroxyl radicals was observed in the monitoring wells.
- Conclusion: The liquid seeping to the ground surface was a result of a combination of injection pressure applied to the wells and pressure buildup in the semi-confined aquifer from the chemical reaction. The pressure created by the reaction alone is believed to have been sufficient to force liquids up to the ground surface via desiccation fractures and weakness in the grout/soil interface. The addition of injection pressure compounded the problems.

In an effort to increase reagent horizontal displacement and mixing, a vacuum was applied to three of the monitoring wells (MW9, MW11, and MW13) during injection. It was hoped that this would create a flow path along the top of the water-bearing zone and increase the horizontal displacement of the reagents.

- Observation: Drawdown measurements of 2 to 3 inches were recorded in monitoring wells 35 feet away, and measurements of total iron nearly doubled at well MW13 where the vacuum was applied.
- Conclusion: The observed drawdown and increase in total iron at the pumping well indicated increased horizontal displacement of the reagents during the pumping. However, there was little to indicate whether or not mixing of the reagents occurred in the subsurface. This combined method, while promising, would require further testing and development before conclusions regarding effectiveness and implementability could be drawn.

Third Injection Event

Initially, the third injection event was postponed while an evaluation of the events took place and groundwater samples were collected. It was later decided to cancel the third injection period for the following reasons:

- Contaminant concentrations did not significantly decrease (discussed below).
- The injection wells required replacement and perhaps pressure grouting to prevent subsequent seepage of reagents to the ground surface.
- The vendor had made numerous unauthorized changes to the injection strategy outlined in the work plan.

Test Results

Table 2 presents groundwater contaminant concentrations measured at the conclusion of injection the second injection event and 3 months after test conclusion for MW 7, MW9, MW11, and MW13. No significant reduction in target contaminant concentrations was measured. The reported groundwater concentrations were within the normal historical variability observed at well MW13.

Table 2
Groundwater Contaminant Reductions
(results in micrograms per kilogram)

SAMPLING PERFORMED AT TEST CONCLUSION									
	TPH-g			**Benzene**			**1,2-DCA**		
Well ID	Initial	Final	Percent Decrease	Initial	Final	Percent Decrease	Initial	Final	Percent Decrease
MW7	4,300	3,200	26	300	230	23	270	330	-22
MW9	24,000	23,000	4	14,000	11,000	21	1,100	880	20
MW11	3,500	2,400	31	1,500	1,200	20	640	540	16
MW13	31,000	19,000	39	11,000	10,000	9	1,400	950	32
SAMPLING PERFORMED THREE MONTHS AFTER TEST CONCLUSION									
	TPH-g			**Benzene**			**1,2-DCA**		
Well ID	Initial	Final	Percent Decrease	Initial	Final	Percent Decrease	Initial	Final	Percent Decrease
MW7	4,300	3,800	12	300	160	47	270	310	-15
MW9	24,000	24,000	0	14,000	12,000	14	1,100	1,000	9
MW11	3,500	3,900	-11	1,500	970	35	640	460	28
MW13	31,000	25,000	19	11,000	12,000	-9	1,400	1,100	21

The injection wells were not sampled before or during pilot testing. However, because of the lack of significant contaminant reduction, in the specified monitoring wells, the injection wells were sampled 3 months after the final injection to determine if the process had worked at ground zero. High concentrations of TPH-g, benzene, and 1,2-DCA (16,000, 6,000, 560 micrograms per liter, respectively) were reported in the injection wells.

Significant concentrations of residual chelating agent were also measured in the injection wells following test completion. It was expected that chelating agent concentrations would be minimal because the agent is consumed in the Fenton chemistry process. Presence of chelating agent in the injection wells is evidence of poor mixing of hydrogen peroxide and chelated iron catalyst and subsequent minimal production of hydroxyl radicals.

Lessons Learned

THE PILOT TEST WAS CONDUCTED TO DETERMINE THE SUITABILITY OF GRAVITY INJECTION OF CHEMICAL REAGENTS THOUGH STANDARD MONITORING WELLS FOR THE CIRCUM NEUTRAL CHEMICAL OXIDATION OF GROUNDWATER CONTAMINATION AT THE SITE. BASED ON THE DIFFICULTIES ENCOUNTERED, IT WAS CONCLUDED THAT THE TECHNOLOGY WAS NOT READILY IMPLEMENTABLE AS DESIGNED (GRAVITY INJECTION OF REAGENTS THROUGH STANDARD MONITORING WELLS). THEREFORE, IT WAS DECIDED NOT TO CONTINUE WITH CHEMICAL OXIDATION AT THIS SITE. LESSONS LEARNED FROM THE PILOT STUDY THAT CAN BE APPLIED TO THE DESIGN OF FUTURE PILOT TESTS ARE DISCUSSED BELOW.

Hydrogeology Controls Reagent Flow

Regardless of the injection method (gravity feed, low pressure, or high pressure), the aquifer parameters control the flow rates, horizontal displacement, and mixing of injected reagents. The fact that this technology had never been used in semi-confined conditions was a concern from the beginning. However, it was discussed, and the vendor was confident that the site hydraulic

conductivity and transmissivity values would allow for successful circum neutral Fenton's chemistry. This proved to be a fatal error in the design of the pilot study.

Figure 4 depicts the ideal flow path of reagents in an unconfined aquifer and the likely flow path of reagents in a semi-confined aquifer. In an unconfined aquifer, the catalyst forms a mound above the water table and then slowly mixes downward under the force of gravity. Once the catalyst is mixed into the aquifer, the hydrogen peroxide is injected. The hydrogen peroxide forms a mound above the groundwater/catalyst mixture and then slowly mixes downward under the force of gravity. As the hydrogen peroxide contacts the catalyst/contaminated groundwater mixture, hydroxyl radicals are formed and oxidize the contamination. Therefore, the top levels of the water-bearing unit are treated first, then the middle, and finally the bottom. In a semi-confined aquifer, there is no vertical pathway for the catalyst or hydrogen peroxide to mound up and spread out along the top of the water-bearing unit. Instead, the reagents are pushed out in donut-shaped slugs at whatever rate the aquifer can accept additional liquids. Each successive slug of reagent pushes out the previous slug, with the only mixing occurring at the interface between the slugs. The result is rings of unreacted reagents.

One possible option to overcome this problem would be to combine *in situ* chemical oxidation with groundwater extraction. The resultant drawdown of the water table from the groundwater extraction could create space for reagent mounding. A last-ditch effort was made to combine these technologies, using a vacuum truck to draw down the water table. This resulted in a significant buildup in iron levels at MW13 indicative of effective reagent mounding.

Pressure Injection Increases Injection Rate, not Horizontal Displacement of Reagents

Because iron and hydrogen peroxide readings collected at MW13 did not increase during the first injection event, the vendor concluded that horizontal displacement of reagents in the water-bearing unit was minimal. Therefore, the vendor concluded that pressure injection was necessary to increase the displacement distance. However, due to the semi-confined conditions, the reagents were being pushed out in donut-shaped slugs. Because of the upper confining layer, there was no headspace available for reagent mounding and subsequent gravity dispersion. Therefore, pressure injection could only increase reagent injection rate (donuts were displaced faster) but could not increase horizontal displacement. The end result of the pressure injection was increased pressure in the aquifer followed by subsequent migration of reagents and groundwater to the surface via desiccation cracks in the confining layer and gaps between the grout seal of the wells and the soil. Therefore, pressure injection in semi-confined conditions should only be used to increase injection rate and only if mechanism is in place to prevent migration of reagents and groundwater to the surface. Pressure injection in a semi-confined aquifer should not be used to increase lateral displacement of process reagents.

Significant Contamination Can Be Trapped in Saturated Soil Pore Spaces and Adsorbed to Soil Particles

Previous investigations at the site had concluded that soil above the water table did not contain significant contaminant mass, that there was no free product, and that the majority of the contamination was in the dissolved phase. However, these previous investigations did not include sampling of saturated soil in the water-bearing zone. In fine-grained aquifers, significant contamination can be trapped in the pore space and adsorbed to the soil particles. *In situ* chemical oxidation is a nearly instantaneous process (hydroxyl radicals have half-lives on the order of nanoseconds), as compared to traditional methods that operate for years. This long duration of traditional methods allows for groundwater contamination to remain in equilibrium, with the contamination adsorbed to the saturated soil. Groundwater samples taken soon after a chemical oxidation treatment are not in equilibrium with contaminants adsorbed to the saturated soil. Displacement of dissolved-phase contamination, dilution of dissolved-phase contamination, and preferential destruction of dissolved-phase contamination result in measured groundwater concentrations that are well below equilibrium levels for the saturated soil contamination. As

indicated in Table 2, rebound concentrations were as high or higher than the original concentrations.

It is recommended that saturated soil samples be collected before and after treatment to assess the reduction in concentration of trapped contaminants. It is also recommended that groundwater monitoring be continued until conditions return to equilibrium. For sites with fine-grained soils, injection intervals of more than 1 month may be required to allow groundwater to return to equilibrium with soil conditions.

Gas Venting Should Be Accounted for in the Design of* In Situ *Chemical Oxidation Systems

Injection of hydrogen peroxide into a water-bearing unit results in the release of gases. If the chemical oxidation process is successful, the primary gas released is carbon dioxide. If the chemical oxidation process is unsuccessful, the primary gas released is oxygen. This gas will rise until it reaches a confining layer. Then it will migrate horizontally along the confining layer until it reaches a conduit to the surface. The rate of gas generation is predominantly dependent on the rate of hydrogen peroxide injection and the concentration and amount of organic matter. If there are no readily available conduits to the surface (monitoring wells, other injection wells, desiccation cracks, etc.), the process gases will accumulate and build up pressure until they are released. This is cause for concern, particularly in shallow water-bearing zones, because of the following:

- Excessive oxygen release can result in an explosive atmosphere.
- Pressures of reaction have blown sealed wells out of the ground and chunks of concrete into the air.
- Release of gas is typically accompanied by entrained groundwater and could result in surface contamination.

Pressure grouting wells may degrease the likelihood of well failures. Pressure gauges can also be put on observation wells in the injection area to monitor for gas buildup. A means for pressure relief should be incorporated in the design of injection systems for shallow groundwater

Monitoring Programs Should Be as Flexible as Possible

The injection and monitoring array originally proposed by the vendor consisted of the six injection wells (IW1 through IW6) and a central monitoring well (MW13). The vendor proposed sampling all of the injection wells and the monitoring well before and after each round of treatment to evaluate the process effectiveness. The participating environmental consultants were of the opinion, that if the treatment did not work at ground zero (injection wells), then it was completely ineffective. Therefore, the injection wells were dismissed as suitable monitoring points for process effectiveness. However, post test sampling of the injection wells reported high concentrations of site contaminants. This indicated that not only did the process fail to achieve significant contaminant reduction at a 20-foot ROI but also that the process was ineffective at treating contaminants in the area immediately surrounding the injection wells.

Based on this, it was concluded that there was minimal successful mixing of process reagents with contaminated groundwater. Additional standard monitoring wells could not be installed within the injection array because they would present routes for reagent short-circuiting back to ground surface. Therefore, six monitoring wells were installed outside of the injection array to evaluate process effectiveness and the impact of preferential pathways. Had the process been completely effective, this probably would have been sufficient for process evaluation. However, because the process was not effective, it became readily apparent that the monitoring scheme was insufficient to fully evaluate the process.

Additional measures could have been taken to improve the monitoring program are as follows:

- Installation of monitoring wells to evaluate the process at spacings closer than the estimated process 20-foot ROI. These wells could have been installed with internal packers or sealed well caps to prevent them from becoming conduits for reagents to ground surface.
- Collection of saturated soil samples throughout the injection array before and after the pilot study. These samples could have been used to perform a mass balance on total contaminant levels and would have provided a more accurate evaluation of process effectiveness than groundwater monitoring.
- Inclusion of the injection wells in the monitoring program. This would have given more information on the effectiveness or lack of effectiveness of the process at ground zero.

Effective Communication Between Vendors and Team Members Is Key to Successful Pilot Testing

By far one of the greatest failures of the test was a breakdown in communication among the vendor and other team members, including environmental consultants, the contracting entity, and regulatory agencies. The vendor's process was proprietary; therefore, limited information was shared with the team. This led to an immediate suspicion on the part of regulatory personnel because they needed to know the chemical makeup of the reagents injected into the groundwater. It took some time, but this issue was finally resolved, and the test was allowed to go forward as outlined in the approved work plan.

Many of the adverse effects were the result of the site lithology and aquifer characteristics. While the vendor had an outstanding understanding of the chemical oxidation process, they did not have a good understanding of groundwater flow mechanics. This was the strength of the participating consultants, however, they were not informed of problems early on. Additionally, when things did not go as planned, the vendor began to make changes without approval or documentation. The lack of documentation of the changes made it difficult to separate successes from failures. Distrust soon began to build, allowing emotions to take precedent over science and ultimately leading to the cancellation of the project. As in any area of business, communication is a key to success. From the beginning, the team needs to identify the strength of each of the contributing members. It is believed that many of the problems identified in the pilot study could have been overcome if identified early.

Conclusion

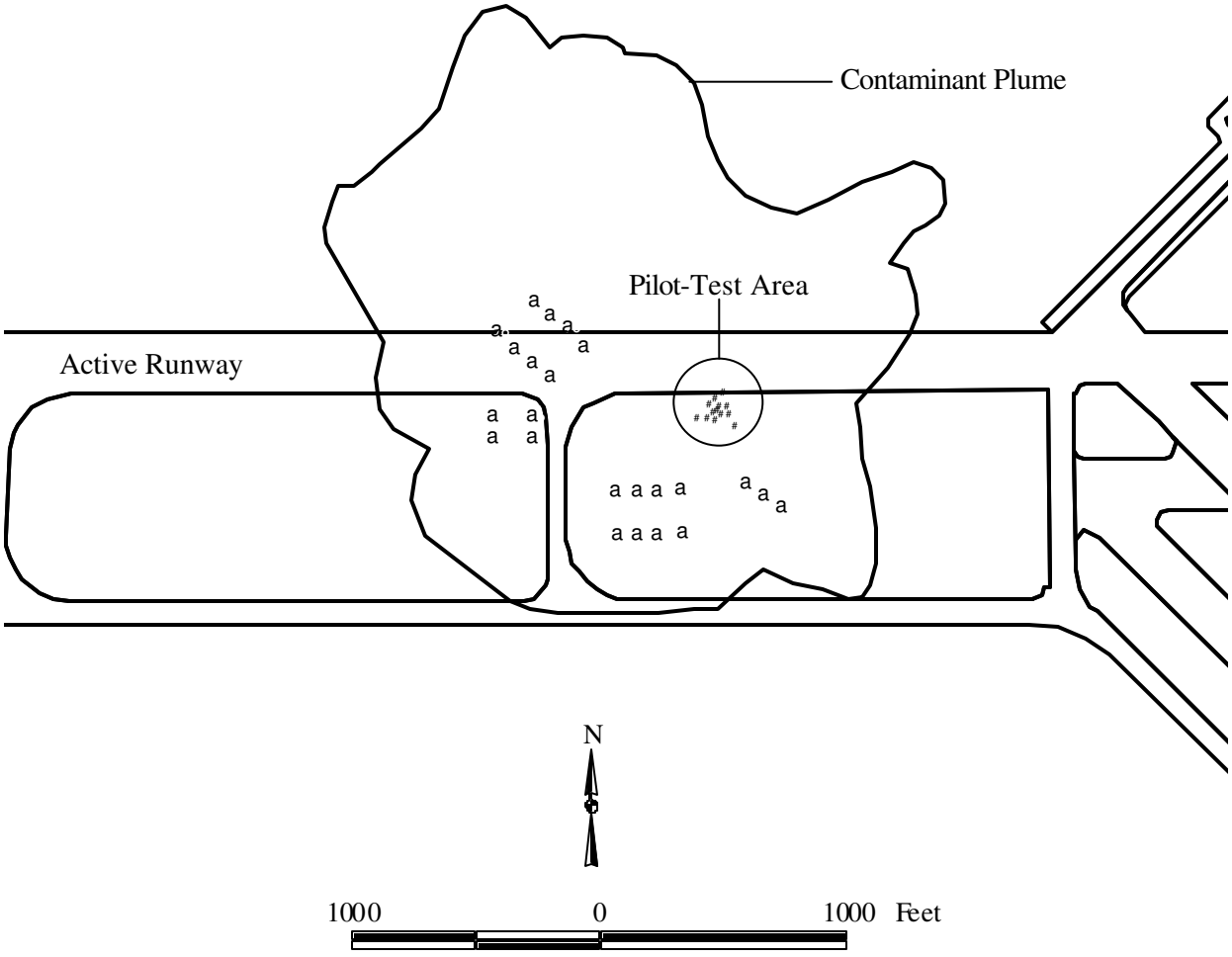
The pilot study was cancelled due to minimal contaminant reductions, poor communication between the vendor and team, and injection difficulties. However, *in situ* chemical oxidation has proven to be a successful groundwater remediation technique at other sites with organic contaminants. Successful implementation of *in situ* chemical oxidation (particularly in a semi-confined environment) requires a greater understanding of the interactions between the site hydrogeology, geochemistry, and the technology than necessary for most traditional remediation methods. However, with careful planning, the problems encountered during this test can likely be overcome to produce successful site remediation.

Appendix 1 – References

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Nyer, Evan K. and David Vance, 1999. "Hydrogen peroxide treatment: The good, the bad, the ugly". *Groundwater Monitoring and Remediation.* Summer 1999.

Geo-Cleanse International, Inc. 2001. Website, http://www.geocleanse.com.



a Former Underground Storage Tank Location

FIGURE 1 – SITE MAP

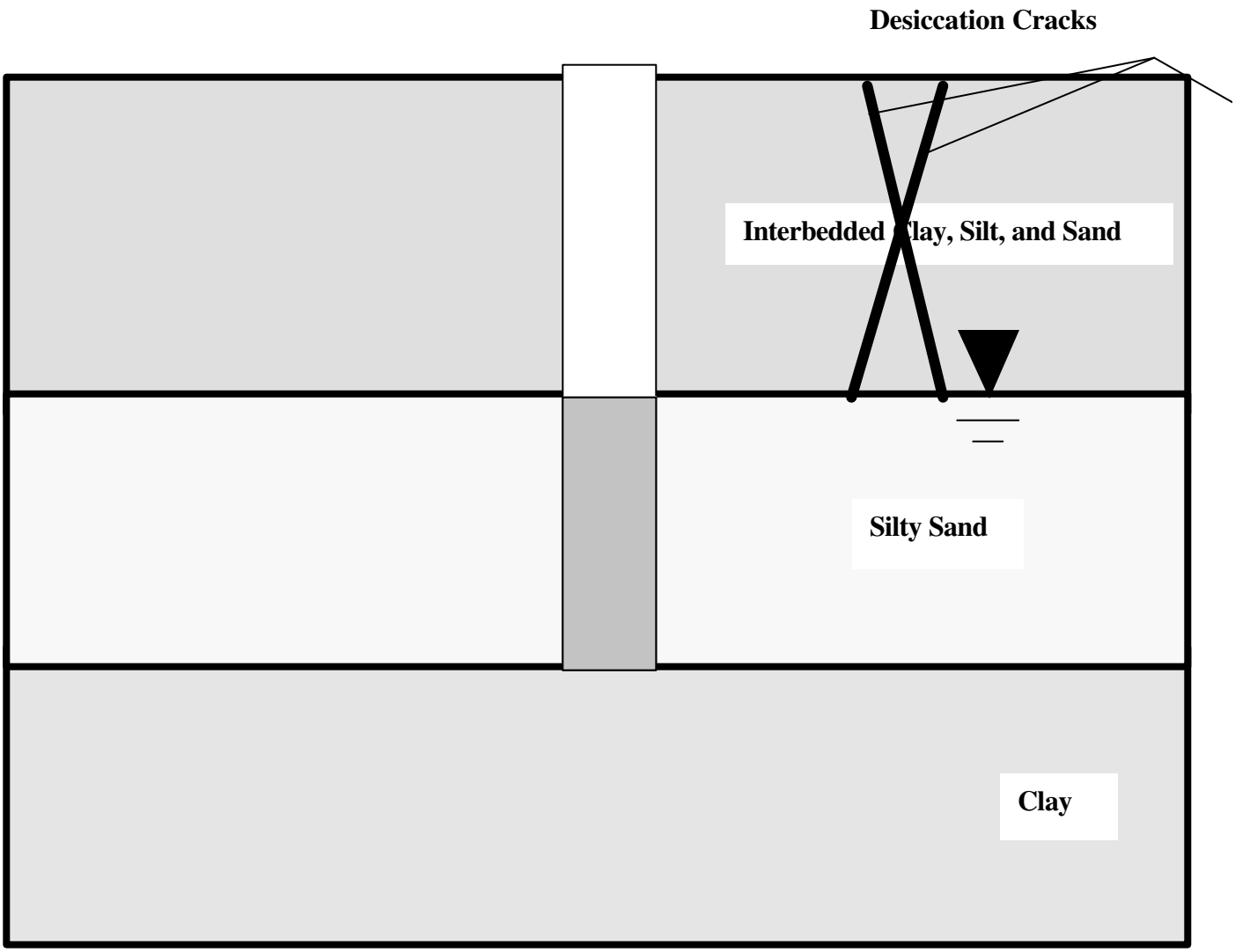


FIGURE 2 – SITE LITHOLOGY AND WELL CONSTRUCTION

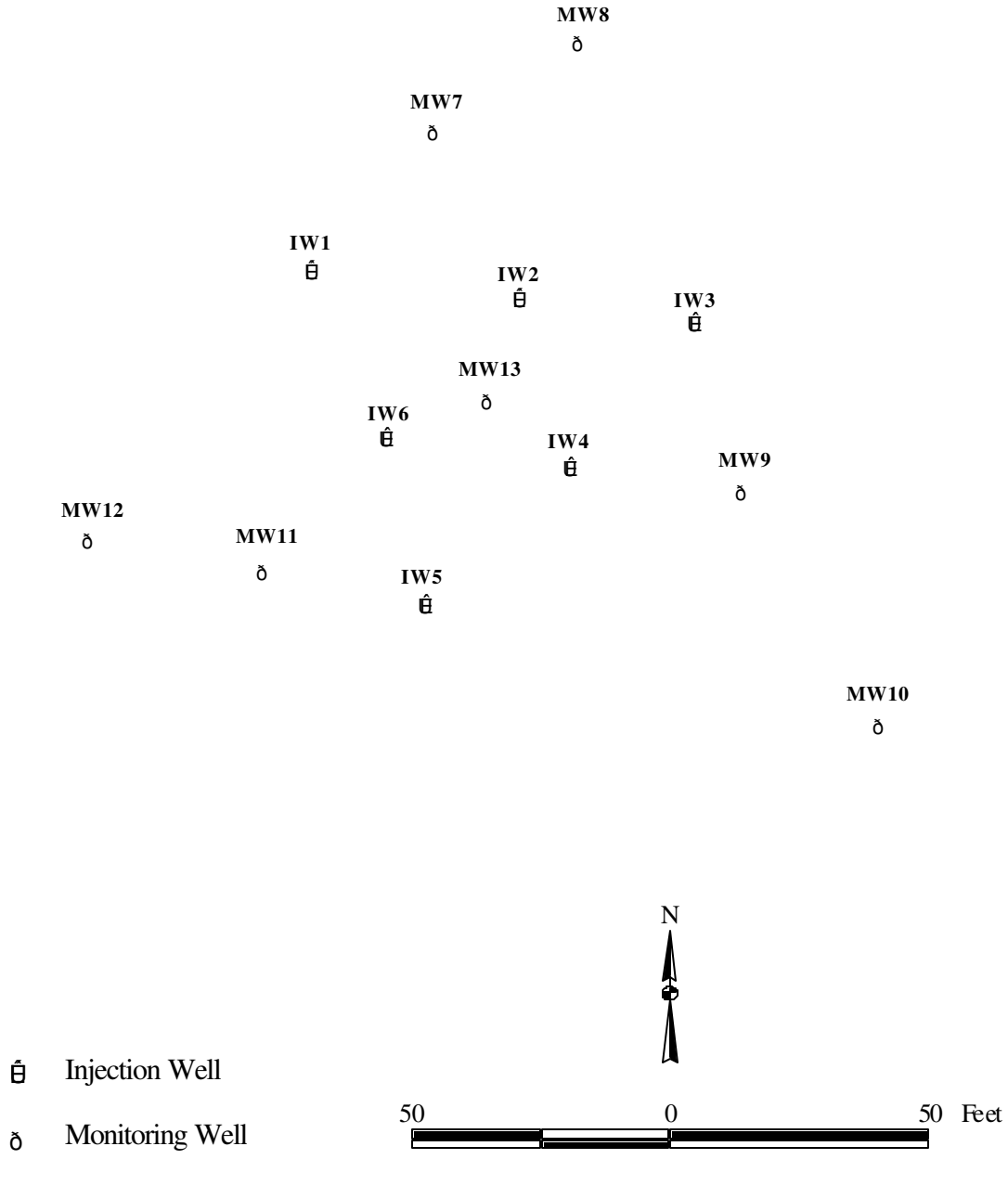


FIGURE 3 – INJECTION ARRAY

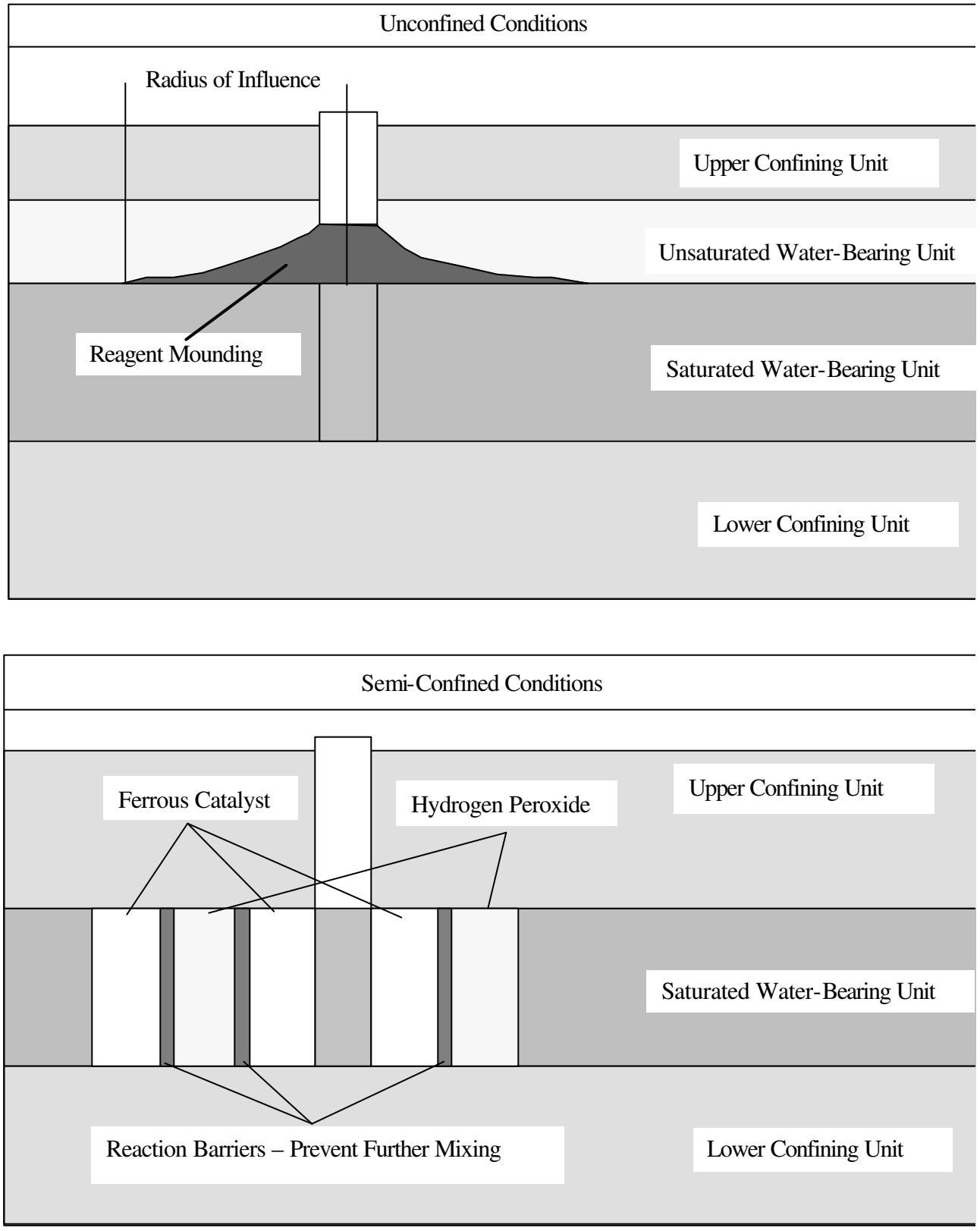


FIGURE 4 – CONCEPTUAL INJECTION SCENARIOS

GROUND WATER & SOURCE WATER PROTECTION: STRUCTURAL & NON-STRUCTURAL CONTROLS FOR EFFECTIVE MANAGEMENT OF SALT STORAGE PILES

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ABSTRACT: The use of roadway deicing salt is necessary to maintain high levels of winter safety and mobility on streets and highways throughout the North American snowbelt. Because its use is restricted to the winter months, large salt storage piles must be maintained by salt producers at distribution sites. Such distribution piles vary in size and may contain more than 100,000 tons of salt. The distribution piles provide public and private winter maintenance agencies with the salt inventory necessary to supplement their limited storage capabilities. Public and private winter maintenance agency piles vary in size from 100 tons up to 15,000 tons.

Strategically located salt storage facilities with adequate capacity ensure prompt and reliable delivery of salt for roadway application during periods of high demand created by unpredictable and severe winter weather conditions. Salt storage pile size and location raise environmental concerns, particularly for storm water runoff that may impact ground water and local surface waters. This presentation/paper provides a comprehensive review of structural and non-structural measures for effective management of salt storage piles.

Structural measures are engineered systems and controls that include fixed and permanent enclosures, impermeable storage pads, waterproof covers, berms or curbing for containment and drainage, discharge systems, etc. Non-structural measures are best management practices or

procedural controls for pile construction, pile configuration, pile shaping, pile covering, cover maintenance, housekeeping, salt reclamation, storm water runoff management, etc.

For the Forum presentation, the authors shall provide a comprehensive review of acceptable controls observed during a collective 43 years of experience in the salt industry. The presentation will be in a PowerPoint format and include pictorial examples of controls from various salt storage sites. In addition, a brief review of applicable federal and state regulatory requirements will be provided along with a substantial amount of resource materials for effective management of salt storage piles. This paper is the text that will be used as the basis for the presentation.

INTRODUCTION

The use of roadway deicing salt is necessary to maintain high levels of winter safety and mobility on streets and highways throughout the North American snowbelt. Deicing salt is produced from underground halite deposits through conventional underground mining techniques, and by solar evaporation of seawater or natural brine.

A significant percentage of the deicing salt produced in North America is shipped from the production sites to distribution locations using water transportation - lake vessels and river barges. Shipment activity occurs in the spring, summer, and autumn. Water access becomes severely restricted in the winter months due to freezing conditions. Consequently, large distribution stockpiles of salt are placed at port and terminal facilities along the Great Lakes and navigable inland river waterways. These stockpiles range in size from 2000 tons up to 350,000 tons. The average size for a typical distribution pile is 40,000 tons.

Smaller local stockpiles are constructed with salt shipped from the distribution stockpiles by truck or from the production sites by truck or rail. These smaller stockpiles are located "inland" and closer to the points of use. They range in size from 20 tons up to 20,000 tons. The average size for a typical pile of this type is 2000-3000 tons.

POTENTIAL FOR ADVERSE ENVIRONMENTAL IMPACT

In the absence of appropriate controls, the handling and storage of deicing salt present the potential for adverse environmental impact. The larger distribution stockpiles have the potential to adversely impact adjacent surface water bodies. The smaller inland stockpiles have the potential to adversely impact local ground water. The primary means for such impact is through fugitive particulate matter releases and storm water runoff.

Use of an empirical relationship for material drop operations[1] allows one to estimate the fugitive particulate matter emissions associated with stockpile construction. For example, for roadway deicing salt conforming to established standards,[2] fugitive particulate matter generated from vessel unloading activities when constructing a 40,000-ton distribution stockpile is approximately 320 pounds. Salt particulate matter tends to be on the upper end of the particle size range and consequently has a parabolic fallout pattern with minimal drift. In addition to localized air quality impact, such salt dustfall impacts surface and ground water through storm water runoff and percolation.

To demonstrate the potential impact to surface and ground water, consider a 40,000-ton distribution stockpile having no control measures. A typical 40,000-ton stockpile located along a navigable river and constructed by barge shipments will have a footprint of approximately 80,000 sq.ft. A 1" rainfall event on this area will generate about 49,900 gallons of water. In utilizing assumptions based on worst case conditions,[3] the 1" rainfall event may dissolve up to 46 tons of salt and generate runoff having a chloride (Cl) concentration of up to 134,000 mg/l. In addition to chloride, other pollutants associated with salt dissolution and runoff include sodium (Na) and total dissolved solids (TDS).

CONTROLS

The selection and implementation of appropriate controls are critical for the effective management of salt storage piles. Such controls eliminate, reduce, and/or limit the potential for adverse environmental impact.

Salt stockpiles contained within fully enclosed, permanent structural cover provide a best case scenario. Specialty structures such as domes provide optimal protection from precipitation and eliminate runoff issues. These structures are costly. For example, a typical structural cover with a 10,000-ton capacity has a capital cost of $450,000, and a similar structure with a 100,000-ton capacity has a capital cost of $1 million to $2 million.[4] Consequently, large capacity structures are not feasible for large distribution stockpiles and are often not feasible for smaller stockpiles owned and operated by public and private entities on limited budgets.

Salt stockpiles contained within specially-built sheds or buildings provide a "next" best case scenario. Such structures provide ample protection from precipitation and eliminate runoff issues. These structures are less costly than domes. For example, a salt storage shed or building having an innovative construction design with a 10,000-ton capacity has a capital cost of $50,000 to $100,000.[5] Specially built, open end sheds or buildings are often feasible for such smaller stockpiles.

Public and private agencies often employ alternate methods of "creative" storage in lieu of constructed enclosures. Such alternate methods are subject to local resources and often have restrictions that present disadvantages. For example, limestone caves that once served as borrow areas for construction materials and aggregate are sometimes used for salt storage.[6] These spaces also provide optimal protection from precipitation and eliminate runoff issues. However, logistics, vehicular access and mobility, and other physical restrictions present disadvantages that compromise the non-existent or limited capital cost.

An economic alternative to structural cover and specially-built sheds or buildings is an impermeable salt storage pad with a non-permanent, flexible stockpile cover consisting of a waterproof tarp. These limited but adequate structural controls require implementation and maintenance of complementary non-structural controls, or best management practices (BMPs). For example and as a comparison to estimates provided earlier, a 10,000-ton capacity storage pad would require an initial capital cost of $25,000 to $35,000 and an annual cost of $2500 for cover installation and disposal.[7]

Table I below provides a summary of the comparative costs for salt stockpile storage facilities.

Table I

Salt Stockpile Storage Facility Comparison
(Basis: 10,000-ton capacity, excl. cost of land)

STRUCTURE TYPE	CAPITAL COST	ANNUAL OPERATING COST
Permanent Structural Cover	$450,000	$0
Open End Shed or Building	$50,000 - $100,000	$0
Pad with Temporary Cover	$25,000 - $35,000	$2500

BEST MANAGEMENT PRACTICES (BMPs)

Best management practices, or BMPs, are standard operating procedures, schedules of activities, and prohibitions of unfavorable practices that are implemented and maintained. Salt handling and storage BMPs are designed to minimize potential adverse impact to the environment by the elimination, reduction or control of: dust, contaminated runoff, leaks, spillage, and drainage from material handling and storage areas. These BMPs include product transfer, pile construction, pile configuration, pile shaping, pile covering, cover maintenance, housekeeping, salt reclamation, and storm water runoff management.

Various published and unpublished documents relative to BMPs for deicing salt handling and storage have been generated by industry and regulatory agencies. A partial and non-exhaustive list is provided below:

- "The Salt Storage Handbook," Salt Institute - Alexandria, VA, rev. 1997.
- "Salt Institute Voluntary Salt Storage Guidelines for Distribution Stockpiles," Salt Institute - Alexandria, VA, rev. 1998.
- "Proper Bulk Salt Storage Training Manual (Based on the Salt Institute Voluntary Salt Storage Guidelines for Distribution Stockpiles)," Salt Institute - Alexandria, VA, rev. 2000.
- "Guidelines for Environmental Management of Depot Stockpiles," IMC Salt - Overland Park, KS, rev. 1999.
- "Storage Pile Best Management Practices," Wisconsin Department of Natural Resources - Bureau of Watershed Management, Publication # WT-468-96, November 1996.
- "Stockpiling Safety," U.S. Department of Labor, Mine Safety & Health Administration, National Mine Health & Safety Academy - Manual No. 30, 1994.
- "Storm Water Management for Industrial Activities," U.S. EPA - Office of Water, EPA 832-R-92-006, September 1992.

SALT STORAGE PAD

Recommended structural criteria for a salt storage pad should incorporate design, construction, impermeability, site drainage, pad elevation, and slope. Evaluation of a proposed

salt storage pad location must include an examination of conditions such as topography, hydrology, and soils to determine potential environmental impact on ground and surface waters.

Design and construction of an asphalt storage area require an adequate pad sub-grade thickness to ensure pad integrity and stability. The pad base and sub-base must be constructed to achieve the highest durability consistent with asphalt construction techniques. This is achieved using a base and/or sub-base composition having an appropriate mixture of coarse aggregate, fine aggregate, and bitumen. Design and construction of an asphalt storage area also require an adequate surface or wear layer thickness to ensure pad impermeability and proper drainage. The pad surface must be constructed to achieve the lowest permeability consistent with asphalt construction techniques. This is achieved using a wear layer composition having an appropriate mixture of fine aggregate and bitumen.

The pad elevation should be sufficient so that storm water runoff from the adjacent terrain will not run onto the pad. This is typically accomplished by topographic elevation differences, curbs or berms along the edge of the pad, or drainage ditches around the pad perimeter.

The salt storage pad should have a minimum slope of 0.5% to allow proper drainage of precipitation. This slope may be from end-to-end of the pad. Or, the slope may be along the longitudinal axis of the pad so as to create a "crown," i.e., sloping away from the centerline in opposite directions. The pad slope must be consistent with site-specific salt storage and handling BMPs.

Recommended non-structural criteria or BMPs for a salt storage pad should incorporate provisions for capacity, working face, and prevailing wind direction. The structural criteria for the salt storage pad require consideration of these BMPs.

The storage pad size must be adequate to contain the quantity of salt that will be placed at the site. The pad size must also be sufficient to provide for the maneuvering of trucks, loaders, and other equipment.

The storage pad should be configured so that the working face of the salt stockpile is downwind of the prevailing wind direction. For example, if the prevailing wind direction is from the northwest, the pad should be configured so that the working face is at the southeast end of the stockpile. In addition, and equally important, the working face must be consistent with the pad slope and prevailing wind direction. For the example just cited, the up-gradient pad end would be to the northwest; the down-gradient end would be to the southeast.

Other BMPs relative to the salt storage area include periodic inspection, maintenance, and repair of the asphalt pad. These activities may include asphalt patching, crack sealing, etc.

SALT UNLOADING AND STOCKPILE CONSTRUCTION

Recommended structural criteria for salt unloading and stockpile construction should incorporate systems for the control of fugitive particulate matter emissions. Salt stockpiles may be constructed by self-unloading vessels, crane/clam-shell transfer into a hopper/conveyor system, truck transfer, or similar type methods. Dust suppression controls should be employed for such methods. Suggested dust controls include telescopic chutes or elongated trunks for salt discharge/unloading, enclosure of transfer points, and controlled water spray/mist systems for rapid transfer activities.

Recommended non-structural criteria or BMPs for salt unloading and stockpile construction should incorporate procedural activities and stockpile configuration. A minimum feasible vertical distance between the salt drop point (e.g., end of conveyor) and the ground or stockpile should be maintained to reduce the potential for generation of excessive salt dust. Pile construction should begin at the up-gradient end of the pad and proceed to the down-gradient end of the pad. There should be established parameters for suspension of unloading activities. Such parameters should include excessive wind, excessive precipitation, spillage of salt beyond the storage pad area, etc. Operators constructing salt stockpiles from multiple vessels, barges, rail cars, and/or trucks should minimize the delivery time between transport vehicles. The stockpile configuration should be in conformance with the pad configuration while preserving salt's natural angle of repose (32 deg.) and maintaining a constant pile width. The crown, or the top of the stockpile, should be graded so that the slope of the planar surface is consistent with the slope of the pad, i.e., sloping toward the working face of the stockpile and toward the down-gradient end of the pad.

STOCKPILE COVER

The recommended structural criterion for a salt stockpile within an unenclosed area is the installation of a waterproof tarp or cover to protect the salt from contact with precipitation. The tarp should have sufficient thickness and composition for durability purposes - it should be capable of withstanding elevated wind speed, abrasion, ultraviolet light degradation, etc. The cover should be secured to the pile using an appropriate tie-down system. The cover should extend beyond the edge of the stockpile and this cover "apron" should be secured to the ground using a suitable anchor system.

Recommended non-structural criteria or BMPs for stockpile covers should incorporate federal and local requirements. For instance, EPA has identified the following covering requirement for salt stockpiles:[8] "Storage piles of salt used for deicing or other commercial or industrial purposes and which generate a storm water discharge associated with industrial activity which is discharged to waters of the United States shall be enclosed or covered to prevent exposure to precipitation, except for exposure resulting from adding or removing materials from the pile." Because of this, large salt stockpiles should be constructed in stages and likewise covered in stages. Other BMPs relative to stockpile covering activities include periodic inspection, maintenance, and repair of the cover system. The covers are sometimes damaged by abatement of tie-down or anchor systems, excessive winds, wear and tear, vandalism, etc. Prompt corrective action ensures the integrity of the stockpile cover.

OUTBOUND SALT SHIPPING FROM THE PILE

Controls relative to reclamation of salt from the stockpile are largely non-structural as opposed to structural. These are essentially procedural "do's" and "don'ts" for equipment operators conducting outbound salt shipment activities. Initiation of salt reclamation from the stockpile should occur at the down-gradient end of the pile/pad. The removal of the stockpile cover at the working face should be limited to accommodate the anticipated daily shipment tonnage. The working face should be maintained perpendicular to the long axis of the pile by loading alternately left to right and right to left. The distance between the working face and the outbound vehicles during loading activities should be minimized. Housekeeping exercises should be conducted on a

frequent basis and should include crushing and blending of any salt chunks back into the pile, sweeping of tailings back toward the working face, etc.

PERMIT(S) AND POLLUTION PREVENTION PLAN

An operator of a salt storage site should review federal and local environmental regulations to determine potential permit applicability and comply accordingly with any such requirements. Regardless of permit applicability, the operator should implement and maintain a written pollution prevention plan for the salt storage and handling activities. This plan should be based on the protection of ground water, surface water, and air quality. The plan should include structural controls and BMPs.

ENVIRONMENTAL REGULATION

The U.S. Environmental Protection Agency and some State agencies have developed regulations or requirements for salt handling and storage. As noted above, an operator of a salt storage site should review federal and local environmental regulations to determine potential permit applicability and comply accordingly with any such requirements.

The EPA requirements for salt storage have been promulgated under the Clean Water Act (CWA).[9] The CWA regulations contain programs for storm water management.[10] Within these programs, EPA has identified storm water provisions for salt storage piles in the *General Permit Program for Storm Water Discharges Associated with Industrial Activity*[11] and in the *Storm Water Multi-Sector General Permit Program.*[12] Both of these permit programs require implementation of select BMPs and development and maintenance of a Storm Water Pollution Prevention Plan.

Among the State agencies that have developed requirements relative to salt handling and storage are, for example, Michigan[13] and Wisconsin.[14] These two States have promulgated regulations that are more extensive than EPA's minimum requirements under the CWA storm water program. In the absence of specific regulatory requirements, salt industry voluntary guidelines provide the basis for environmentally sound salt storage and handling with minimum potential for environmental impact. Operators of salt handling and storage sites are encouraged to implement and maintain site-specific structural controls and BMPs that provide protection for ground water, surface water, and air quality.

SALT INSTITUTE RESOURCES

The Salt Institute (Alexandria, VA) is the association of the major North American and international salt producers. IMC Salt is one such member of the Salt Institute. Many member companies produce rock salt and solar salt for deicing roadways during the winter months. The Salt Institute has developed a number of programs for salt producers and end users to ensure environmentally responsible management of salt handling, storage and use. The Salt Institute has also amassed numerous resources developed by other public and private groups. All information is available on the Salt Institute's web page at www.saltinstitute.org.

CONCLUSIONS

There are a variety of structural controls for effective management of salt storage piles. Costs associated with such structural controls are highly variable. Salt producers and public and private salt storage operators often construct and maintain salt storage areas with limited but adequate structural controls in conjunction with complementary non-structural controls, or BMPs. Storage facilities of this type present an economic alternative to permanent structural cover and open-end storage sheds and buildings while still affording protection for ground water and source water.

BMPs include procedures, activities, and practices for the elimination, reduction or control of: dust, contaminated runoff, leaks, spillage, and drainage from material handling and storage areas. Operators of salt handling and storage sites are encouraged to implement and maintain site-specific structural controls and BMPs that provide protection for ground water, surface water, and air quality. Ineffective implementation and maintenance of controls by the industry and deicing salt end users may result in increased regulatory requirements for salt handling and storage. There is an abundance of literature, training publications, and audio/visual materials, etc. relative to salt storage structural controls and BMPs. A good starting point for a comprehensive review of such resources is the Salt Institute - Alexandria, VA.

Footnotes

[1] Compilation of Air Pollutant Emission Factors - Volume 1: Stationary Point & Area Sources (AP-42), U.S. Environmental Protection Agency, EPA-454/C-95-001, 5th ed., Section 13.2.4.3 - Predictive Emission Factor Equations.

[2] ASTM (American Society for Testing and Materials) D-632-00 or AASHTO (American Association of State Highway and Transportation Officials) M-143-86.

[3] The stockpile was not enclosed or covered. Rainfall on the stockpile was assumed to become saturated with salt. All rainfall was reported as runoff.

[4] Salt Institute (2001).

[5] Ibid.

[6] Example: EcoSpace Business Park, Louisville Underground, Inc. - Louisville, Kentucky.

[7] IMC Salt (2001).

[8] 57 FR 41311 (9/9/92): EPA General Permit for Storm Water Discharges Associated with Industrial Activity - Guidance for Developing Pollution Prevention Plans and Best Management Practices.

[9] PL 92-500, 33 USC 1251 et seq.

[10] 40 CFR Part 122.26.

[11] 57 FR 41236 (9/9/92).

[12] 60 FR 50804 (9/9/95).

[13] Michigan Surface Water Quality Division, Water Resources Protection - General Rules, Part 5: R323.1157 through R323.1169.

[14] Wisconsin Department of Transportation - Chapter Trans 277.

Managing On-Site Wastewater Treatment Systems in the New Millenium

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Biography: Mr. Hogye is with EPA's Office of Wastewater Management in Washington, D.C. He is project officer for several EPA grant projects, including the National Small Flows Clearinghouse and the National Onsite Demonstration Project. He has also been a key player in the development of voluntary national guidelines for the management of onsite and decentralized wastewater treatment facilities. Prior to his employment at EPA, Mr. Hogye worked for the Virginia Water Control Board, where he managed numerous water resources and water quality programs in Northern Virginia.

Abstract: Onsite and decentralized systems treat wastewater from one fourth of the households in the United States. These systems include individual home systems as well as small facilities serving clusters of homes or individual businesses. The majority of these systems consist of conventional septic tanks with drainfield dispersal to soil, and more than half of the systems are 20 years old or more. Indications are that up to 30% of these systems are malfunctioning to some extent, and that 10% of all systems are experiencing a major malfunction at any given time, including sewage backing up into homes or breaking out on the ground surface. Many other malfunctions are not apparent to the homeowner, but can impact the quality of drinking water and other ground water resources. Septic systems have been reported by States as being the third most important source of ground water contamination.

With proper management, however, onsite and cluster systems can function as a reliable, cost-effective and permanent component of a community wastewater program. When properly designed, located, installed and maintained, even conventional systems can provide adequate treatment of wastewater to protect ground and surface waters and public health. New technologies and management systems have been developed in the last 15 to 20 years which can greatly increase the level of treatment, treatment reliability, and can serve sites which are not appropriate for conventional systems, such as areas of shallow or poor soils, high ground water, and steep slopes.

The U.S. Environmental Protection Agency has developed voluntary national guidelines to assist communities and States in developing programs to properly manage onsite and decentralized wastewater systems and protect water quality. The guidelines cover a number of elements and activities such as planning, siting, design, installation, operation, maintenance, monitoring and enforcement. Five "model" management programs are presented as a progressive series in which management becomes more rigorous as system technologies become more complex or as the sensitivity of the environment increases. Models range from a basic inventory of systems and awareness of maintenance needs, to a program in which all systems are owned and maintained by a central management entity. A guidance manual is being prepared to assist in implementing programs, and an onsite system design manual is also being finalized, which will complement the management program guidance.

For more information, visit EPA's web site on decentralized wastewater treatment at www.epa.gov/owm/decent.

DELINEATION OF HYDROLOGIC AREAS OF CONCERN FOR NEW HAMPSHIRE WATER SUPPLY RIVERS USING DYE TRACER STUDIES AND OTHER METHODS

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Mr. Smith received an Sc.B. in Geological Sciences from Brown University and an M.S. in Hydrology from the University of New Hampshire. He has worked for the U.S. Bureau of Reclamation in Colorado, as an environmental geologist in California, and participated in acid-precipitation and small-watershed process studies in New York and Vermont. As a hydrologist with the USGS, Mr. Smith conducts water-resource investigations in conjunction with other state and federal agencies.

ABSTRACT

As part of the Drinking Water Source Assessment Program in New Hampshire, the NH Department of Environmental Services (DES) delineated a "hydrologic area of concern" (HAC) for 57 surface sources of public drinking water. The goal of HAC delineation was to focus the inventory of potential contaminant sources in those areas that are likely to have the greatest influence on water quality at the water supply intake. A number of methods were used to delineate the HACs, depending on the type of source (stream or reservoir), size of the watershed, degree of development, presence of dams, and river velocity.

For 13 rivers with large watersheds, DES and the U.S. Geological Survey (USGS) designed and conducted dye tracer tests to estimate the travel times and dispersion of soluble contaminants hypothetically released upstream of each water-supply intake. The USGS measured river discharge and injected rhodamine WT dye during annual low and mean flows on each study river. Rivers were sampled downstream of the dye-injection

sites to measure the concentrations and arrival times of the dye cloud. Results of the dye tests were used to construct graphs for estimating the travel times and concentrations of soluble contaminants over a range of river discharges and transport distances. Estimated travel times during flow conditions equal to the mean annual flood were extrapolated from these graphs.

DES used the estimated distance traveled by a dye cloud peak in 6 hours at mean annual flood to delineate the HAC. Where the 6-hour HAC was too large, DES based the HAC delineation on the presence of large impoundments, or on a 1-mile buffer along each side of the river. The results of the dye tracer tests are also expected to be useful in planning emergency response to a contaminant spill in the studied rivers.

DELINEATION OF HYDROLOGIC AREAS OF CONCERN FOR NEW HAMPSHIRE WATER SUPPLY RIVERS USING DYE TRACER STUDIES AND OTHER METHODS

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The dye tracer studies upon which this paper is based were designed and conducted, and the results interpreted, by the U.S. Geological Survey. The DETERMINING TIME OF TRAVEL and METHODS OF DYE TRACING sections of this paper are based on written communication from T.E. Smith, U.S. Geological Survey, September 5, 2001. Laura Hayes and Jeffrey Blecharczyk of N.H. Department of Environmental Services assisted with the field and lab work. The work was funded by New Hampshire's Drinking Water State Revolving Fund grant from U.S. Environmental Protection Agency and by U.S. Geological Survey.

BACKGROUND

The Safe Drinking Water Act Amendments of 1996 are credited with strengthening source protection, public involvement, and the public's right to know about their community water systems. The Amendments require all states with primacy for federal drinking water programs to develop Source Water Assessment Programs (SWAPs). The purpose of this mandate is to provide water suppliers and the public with information about where their drinking water comes from and the actual and potential threats to which their drinking water is vulnerable, thereby stimulating improved source protection efforts. There are four parts to a SWAP: delineation of contributing areas, inventory of potential sources of contaminants within those areas, assessment of each drinking water source's vulnerability, and communicating the assessment results to the public.

This paper focuses on New Hampshire's approach to delineating contributing areas for surface sources of public drinking water for its SWAP. (In New Hampshire, the SWAP is known as the Drinking Water Source Assessment Program, or DWSAP.) New Hampshire's DWSAP also covers approximately 3,000 groundwater sources for public water systems.

In developing the DWSAP Plan (NHDES 1999), the delineation, inventory, and assessment approaches were seen not only as sequential steps; they were integrated into an overall approach. Specifically, the delineation methodology took into account the inventory and assessment methodologies. Because DES already had a well-developed geographic information system (GIS), DES chose to use the available federal SWAP funds to conduct drive-through ("windshield") surveys to inventory and locate (using global

positioning technology) potential contaminant sources within the contributing areas to public water supply sources. Whereas the level of effort required for windshield surveys in wellhead protection areas is not unreasonable, surface sources present a different picture. In New Hampshire, water supply watershed areas cover approximately 80% of the state. Therefore, DES took a two-tiered approach to delineating contributing areas for the DWSAP. DES would use its GIS to inventory some types of potential contaminant sources in the entire watershed area, but it needed to narrow the geographic scope of the windshield surveys.

USEPA's guidance to the states in developing SWAPs (USEPA, 1997) recognized the need to narrow the scope of inventory activities within large water-supply watershed areas. EPA terms these high-priority areas hydrologic areas of concern (HACs). The HAC delineation methods discussed in Appendix C to the federal guidance are buffer strips, time of travel, and modeling. DES uses all three of these methods in its DWSAP – the first two for delineation of HACs, and the last for assessing the potential impact of changing land use on water supply lakes and reservoirs. This paper focuses primarily on DES's development and use of time-of-travel information, and to a lesser extent on the use of buffers.

An analysis of New Hampshire's approximately 30 surface water supply sources found that these sources could be divided into four groups, each group being amenable to a different approach for delineating HACs:

1. Small (5,000 acres or less) or undeveloped watershed areas – windshield surveys would be conducted in the entire watershed area.
2. Special studies – where the water supplier had already conducted or was under contract to conduct studies that would identify critical watershed segments, windshield surveys would be conducted in those identified areas.
3. Impoundments, lakes, ponds with large, developed watersheds – DES would delineate a "direct watershed," as the HAC, excluding portions of the watershed area which drain to large wetlands or impoundments before reaching the sources. The windshield survey would be conducted only in the direct watershed, under the assumption that detention and some degree of natural treatment takes place in the intervening wetlands or impoundments.
4. Rivers with large watershed areas not falling into the previous categories – the delineation of the HAC would begin with time-of-travel (TOT) information.

As explained in the federal guidance (USEPA 1997, Appendix C), "It is the streamflow TOT between the intake and the upstream point of interest that provides the opportunity for managers to enhance protection management of long-term potential contaminant sources and to respond to a contamination event." After surveying the water suppliers who use the rivers in this category, and consulting with its DWSAP advisory committee, DES decided to use the 6-hour travel zone during high flow as the starting point in delineating the HACs. The rationale for choosing 6 hours was that if a hazardous materials spill were to occur 6 hours or more from the water supply intake, the water supplier would have adequate time to receive notification, assess the situation, and make a

decision regarding whether and when to shut down its intake. If a spill were to occur less than 6 hours from the intake, the water supplier might not have enough time to react. Therefore, efforts to inventory and manage potential contamination sources within that 6-hour zone should receive extra attention.

After consulting with the USGS, DES determined that existing data on river discharges, coupled with the available streamflow models, would not be adequate for the purposes of developing travel-time and dilution data that would be of use both in the DWSAP and in emergency response planning. DES then entered into a cost-sharing agreement with the USGS to develop travel-time and dilution information for the large water supply rivers.

DETERMINING TIME OF TRAVEL

The USGS determined that the most appropriate method for estimating the limits of the 6-hour travel zone on water-supply rivers was by dye tracing. A less labor-intensive method would have been to use empirical equations that were developed by regression analysis on previous dye studies. However, the best equation for river velocity developed by Jobson (1996) has $R^2 = 0.70$, indicating that considerable variability in the data remains unexplained by the equation. Better accuracy was needed for delineating New Hampshire HACs; therefore, dye travel times were measured in each river that required a 6-hour delineation (Smith, 2001) .

The river distance that a contaminant would travel in 6 hours is a function of stream velocity and discharge; thus a standard discharge had to be selected for which the 6-hour distance would be determined on each river. NHDES decided upon a conservative approach, drawing the HAC boundary at the maximum 6-hour distance from which a concentrated contaminant cloud would travel. This 6-hour distance is at approximately bankfull flow conditions, when discharge and velocity are at their highest for within-bank flows. Whereas higher channel velocities may be reached at higher discharges, the storage in over-bank flow areas would disperse and slow the contaminant mass enough that a lower peak concentration would likely reach the drinking-water intake than at bankfull discharge. The discharge at bankfull stage was assumed to be equal to the mean annual flood (MAF) discharge (Kilpatrick and Barnes, 1964).

Measuring dye velocity during bankfull discharge is impractical for several reasons: 1) these flows occur infrequently and somewhat unpredictably, 2) discharge is generally unsteady at high flows, and 3) a large quantity of dye would be required because of dilution by the large volume of water. Therefore, measurements were made at lower discharges and used to estimate bankfull velocity. For discharges in the same flow regime (for example, within-bank, friction-slope control), the logarithms of velocity and discharge are linearly related (Jobson, 1996). Bankfull velocity can thus be extrapolated from two dye velocity measurements made at different discharges (Figure 1).

Discharge varies through a study reach due to inflows; therefore an index site was chosen on each river from where the reference discharge would be measured. These index sites were usually USGS stream-gaging stations. One river did not have a streamflow gage. Dye studies generally were conducted on each river when the index discharge was near mean flow and again when discharge was near the 90-percent exceedance value. Higher discharges were not targeted for dye tracing to avoid unsteady flow conditions that would create uncertainty in the discharge-velocity relation.

METHODS OF DYE TRACING

Rhodamine WT dye was selected as the tracer because of its suitable properties. This red dye is fluorescent and easily measured at low concentrations (less than 0.1 microgram per liter), and it is highly soluble, relatively stable and conservative, and considered safe by the USEPA for use as a tracer in natural waters. A dye concentration of 2 µg/L was targeted for the final sampling sites at the drinking-water intakes to remain safely below the 10 µg/L maximum acceptable under USGS policy. Because the red dye is highly visible in the river for several miles downstream of the injection site, local officials (city, town, police and fire departments) were notified of each impending dye injection.

A carefully measured mass of dye was injected instantaneously into the center of river flow at the head of each study reach, and sampling began downstream before the earliest anticipated arrival time of the dye. The first sampling site was located far enough downstream from the injection site that the dye had become completely dispersed in the river, and the second sampling site was located at the water-supply intake. On some rivers, where large tributaries merged in the study reach or where there were two water-supply intakes, the study was divided into two reaches and three sampling sites were used. Streamwater samples were collected, manually or by autosamplers, over the duration of dye-cloud passage and analyzed later for dye concentrations by fluorometry.

The resulting time-concentration plots from each sampling site could then be used to determine 1) the peak dye concentration, 2) the travel time of the dye cloud (peak concentration) between consecutive sampling sites, 3) the duration of the dye-cloud passage, and 4) the approximate mass of the dye cloud passing each sampling site. Mean river velocity was determined from the travel time between sampling sites (Table 1), and plotted against the index discharge to estimate the velocity at MAF discharge (Figure 1). From the MAF velocity, the 6-hour travel distance was then calculated for each drinking-water intake (Table 2).

Several additional plots of the dye-tracing data were made to help water-supply managers estimate the travel and dispersion rates of a potential contaminant spill. The velocity-discharge relation was used to plot a family of curves for each of the river reaches studied (Figure 2) from which the travel time of a spilled contaminant can quickly be estimated from two pieces of information; 1) the upstream distance of the spill, and 2) the discharge at the index gage (or site).

The duration of dye-cloud passage was plotted for all sample sites, and found to have a tight correlation with dye-peak travel times (Figure 3). Thus the expected duration of a contaminant cloud can quickly be estimated from this plot for any river if travel time is known.

For emergency planning it is also useful to know the conservative peak concentration of a contaminant cloud, because this is the upper-limit concentration that can be expected following a spill. The peak dye concentration measured at each sample site can be converted to a conservative peak concentration by calculating the dye recovery. A conservative concentration would be the concentration observed if the entire mass of dye that was injected passed by the sampling site in the dye cloud – i.e. no dye was lost to adsorption, degradation, diversions, or other processes.

Dye recovery is the mass of the dye cloud passing a sampling site, expressed as a percent of the mass of dye injected (Table 1). The dye-cloud mass can be calculated from the time-concentration plots and discharge hydrographs of the index gage. Dividing the dye recovery into

the measured peak concentration gives the conservative peak concentration (Table 1). This value can further be normalized by river discharge and the injection mass to compute a unit concentration value.

The unit concentration value represents the peak concentration of a conservative solute predicted to occur at the sampling site, per kilogram of solute injected at a discharge of 1 cubic meter per second. Like dye-cloud duration, unit concentration has a close correlation with travel time on a plot of all sample sites (Figure 4). In the event of a contaminant release into one of these water supply rivers, the unit concentration value can be used to predict conservative concentrations for any of the studied New Hampshire rivers. With figures 1 through 4, the USGS is developing a report containing step-by-step instructions on how to estimate the arrival time and peak concentration of spilled materials at water supply intakes that can be used by emergency planners and responders.

APPLYING THE DYE-TRACING DATA TO HAC DELINEATION

As envisioned in the NH DWSAP Plan, delineation of the HACs began with the time-of-travel data. The first step was to draw an arc within the watershed area, centered on the intake. The radius of the arc was the estimated 6-hour travel time of the dye peak concentration during mean annual flood. However, in most cases, it was necessary to further limit the scope of the HAC to limit the time required for a windshield survey to one or two days for each source. If the HAC needed to be reduced, DES looked first for active dams with large impoundments along the main stem of the river. Next, DES considered the direct/indirect watershed approach. As a last resort (for the Merrimack and Connecticut rivers), DES used a one-mile buffer along the rivers to define the HACs. All of the HAC and windshield survey area delineations are based on 1:24,000 hydrography.

In many cases, instead of or in addition to reducing the size of the HAC, DES designated a "windshield survey area" within each HAC (a 500 foot buffer around surface water, not including intermittent streams, and 1,000 feet around the intake), resulting in a three-tiered delineation. In these cases, the windshield survey area was smaller than the HAC in order to balance the information needs of the assessment with the time it would take to do the survey. In practice, DES has found that these 500/1,000 foot windshield survey areas provide sufficient information to complete the vulnerability assessment protocol, which essentially involves answering a number of questions about land uses and potential threats in the watershed area, in the HAC, and within 500 feet of the source water and 1,000 feet of the intake. DES is using its Geographic Information System to provide information about land uses and potential threats outside the windshield survey areas.

Once the preliminary HACs and windshield survey areas were delineated, DES consulted each water supplier affected, provided them with a map of the preliminary delineation and a blank assessment report form, and offered to meet with them to discuss the delineation. These meetings, some of which were conducted by phone, covered the DWSAP, the rationale for the delineations, and the procedure DES would follow to complete the assessments and make the information available. A description of the rationale for each delineation follows. While the Androscoggin and Mascoma Rivers were included in the dye tracer studies, their HACs were delineated on the basis of "special studies" (see BACKGROUND, above) initiated by the water suppliers, rather than on the basis of time of travel.

1. Ammonoosuc River (Woodsville Water and Light)

Watershed area for the intake: 399 square miles
Estimated velocity in the reach above the intake at mean annual flood: 7.95 feet per second
6-hour time-of-travel radius: 32.5 miles, encompassing 380 square miles, or 95% of the entire watershed area.
To narrow the focus of the windshield survey, DES designated the 48 square mile portion of the watershed area lying within 7 miles of the intake as the HAC. The rationale was that there is an active dam with a 24-acre impoundment approximately 4.75 miles up-river from the intake and another active dam with a 64-acre impoundment located approximately 4 miles up-river from the previous dam. This second dam is located approximately 7 miles (as the crow flies) from the intake, and was the basis for the 7-mile limit. It is likely that a substantial amount of natural treatment takes place in these two impoundments. Within the HAC, DES conducted a windshield survey within the 500/1,000 foot buffer area. (Figure 5)

2. Connecticut River (Cheshire County Home)
Watershed area: 5,586 square miles
Estimated velocity: 9.23 feet per second
6-hour time-of-travel zone: 37.8 miles - 997 square miles (18% of watershed area)
Since this area is too large in which to conduct a windshield survey in a reasonable amount of time, a first step was to set the upstream boundary for the HAC at the Bellows Falls Dam, located 13.8 miles up-river (11.3 miles as the crow flies) from the intake. This is the nearest impoundment on the river. An arc with a radius of 11.3 miles encompasses a 129 square-mile portion of the watershed area, which is still too large for a windshield survey. Alternatively, a buffer encompassing an area lying within one mile of the river between the Bellows Falls Dam and the intake is approximately 27 square miles. DES designated this buffer area as the HAC, and conducted a windshield survey within the 500/1,000 foot buffer area.

3. Contoocook River (City of Concord)
Watershed area: 271 square miles
Estimated velocity: 2.29 fps immediately above intake, 2.09 fps in the reach above that
6-hour time-of-travel zone: 9 miles - 77.5 square miles (29% of watershed area)
Since this area is too large for a windshield survey area, the first step was to set the upstream boundary for the HAC at the Contoocook Village Dam (an active dam with an impoundment of 110 acres), located 8.6 miles up-river (5.0 miles as the crow flies) from the intake. This is the nearest impoundment on the river. An arc with a radius of 5 miles encompasses a 27.4 square mile portion of the watershed area. DES designated this area as the HAC, and conducted a windshield survey within 500 feet of surface waters connected to the Contoocook River in this area, and within 1,000 feet of the intake.

4. Exeter River (Exeter Water Department)
Watershed area: 91 square miles
Estimated velocity: 1.82 feet per second.
6-hour time-of-travel zone: 7.45 miles - 30 square miles (33% of watershed area)
DES designated this area as the HAC, and conducted a windshield survey within the 500/1,000 foot buffer area.

5. Lamprey River, Piscassic River, and Follett's Brook (Newmarket Water Works)
Newmarket's three river sources are unique in that their intakes are all located close to one another and their watersheds are nested (The Follett's watershed is part of the Piscassic watershed, which is part of the Lamprey watershed). While DES is assessing each source individually, the HAC delineations are interdependent.

- The Follett's Brook watershed is relatively small (1.6 square miles), so DES has designated the entire watershed area as the HAC, which in this case is also the windshield survey area.
- Piscassic River watershed area: 23.6 square miles. Estimated velocity: 1.74 feet per second. 6-hour time-of-travel zone: 7.1 miles - 16.3 square miles (69% of watershed area). However, because the Piscassic River follows a meandering route, a more reasonable approach is to measure along the river to a point that lies 7.1 miles up-river from the intake. DES used this point to define the HAC, with an area of roughly 11.8 square miles, and conducted a windshield survey of this area.
- Lamprey River watershed area: 213 square miles. Estimated velocity immediately above intake: 0.7 feet per second, 2.05 fps in the reach above that. 6-hour time-of-travel zone: 2.86 miles - 9.3 square miles in the Lamprey watershed, including nearly all of that portion of the Lamprey watershed downstream from the UNH/Durham intake (see below). The 6-hour zone for Newmarket's Lamprey River intake is not too large an area in which to conduct a windshield survey. Because the Follett's Brook and Piscassic River watersheds are nested within the Lamprey watershed, the Lamprey HAC includes the HACs for those two streams.

6. Lamprey River (UNH/Durham Water Systems)
Watershed area: 184 square miles
Estimated velocity: 2.05 feet per second
6-hour time-of-travel zone: 8.4 miles - 62 square miles (34% of watershed area)
Since this area is too large for a windshield survey, DES eliminated "indirect watershed areas." This approach results in an area of 36 square miles. DES designated this area as the HAC, and conducted a windshield survey within the 500/1,000 foot buffer area.

7. Merrimack River (Pennichuck Water Works)
Watershed area: 3,425 square miles
Estimated velocity: 5.37 feet per second
6-hour time-of-travel zone: 17 miles - 350 square miles (10% of watershed area)
Since this area is too large and developed for a windshield survey area, the upstream boundary for the HAC was set at the Amoskeag Dam, located 14 miles up-river (13 miles as the crow flies) from the intake. This is the nearest impoundment on the river. An arc with a radius of 13 miles encompasses a 209 square mile portion of the watershed area, which is still too large for a windshield survey area. Accordingly, DES used a buffer encompassing an area lying within one mile of the river between the Amoskeag Dam and the intake. This area is approximately 30 square miles. DES designated this area as the HAC, and conducted a windshield survey within the 500/1,000 foot buffer area. (Figure 6)

8. Oyster River (UNH/Durham Water Systems)
Watershed area: 17 square miles
Estimated velocity: 1.8 feet per second
6-hour time-of-travel zone: 7.36 miles - entire watershed area
Because the Oyster River follows a meandering route, a more reasonable approach is to measure along the river to a point that lies 7.36 miles up-river from the intake. DES proposed to use this point to define the HAC, with an area of roughly 8.9 square miles, and to conduct a windshield survey of this area. However, at the water supplier's request, we have included the entire watershed area in the HAC and conducted a windshield survey within the 500/1,000 foot buffer area. (Figure 7)

9. East Branch, Pemigewasset River (Lincoln Water Works)
Watershed area: 116 square miles
Estimated velocity: 10.3 feet per second
6-hour time-of-travel zone: 42 miles
Since the entire watershed area is no more than 14 miles from the intake, the time-of-travel information was not useful in defining the HAC (although it will be useful in emergency response planning). Given the fast-moving nature of this river, DES designated the entire watershed as the HAC and conducted a windshield survey within the 500/1,000 foot buffer area.

10. Salmon Falls River (Somersworth Water Works)
Watershed area: 222 square miles
Estimated velocity: 1.31 feet per second
6-hour time-of-travel zone: 5.36 miles - 30 square miles (13% of watershed area)
DES designated this area as the HAC and conducted a windshield survey within the 500/1,000 foot buffer area.

11. Sugar River (Claremont Water Department)
Watershed area: 253 square miles
Estimated velocity: 5.99 feet per second
6-hour time-of-travel zone: 24.5 miles
Since the entire watershed area is no more than 20 miles from the intake, the time-of-travel information was not useful in defining the HAC (although it will be useful in emergency response planning). Given the fast-moving nature of this river and the absence of dams with significant impoundments, DES delineated the HAC on the basis of lakes, ponds, and wetlands in the watershed area, designating the "direct watershed" as the HAC. DES conducted a windshield survey in the 500/1,000 foot buffer area within the HAC. (Figure 8)

CONCLUSION

Time of travel (based on dye tracer tests) was a useful factor to employ in identifying critical portions (Hydrologic Areas of Concern, or HACs) of water supply watersheds for the purposes of New Hampshire's Drinking Water Source Assessment Program. Other factors that were considered in delineating HACs included the level of development and locations of impoundments. The information derived from dye tracer tests, when presented in an easy-to-use format, is also expected to be of great value in emergency response planning.

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Smith, T.E., U.S. Geological Survey, New Hampshire-Vermont District, written communication, September 5, 2001

US Environmental Protection Agency, August 1997, State Source Water Assessment and Protection Programs Guidance (EPA 816-R-97-009)
http://www.epa.gov/safewater/source/swpguid.html

Table 1. Results of New Hampshire travel-time studies including travel times and concentrations of dye (Smith, 2001)

[Discharge measurements made at sampling sites are listed in downstream order. Travel times listed for the dye-cloud leading edge, peak, and trailing edge are times between the arrivals at sequential sampling sites. (A), upstream river reach on rivers where study reach was divided into two parts; (B), downstream river reach; T_l, travel time to the dye-cloud leading edge; T_p, travel time to the dye-cloud peak; T_t, travel time to the dye-cloud trailing edge; M, missing data; --, no data; e, estimated values due to incomplete sampling of dye cloud; ft^3/s, cubic feet per second; ft/s, feet per second; µg/L, micrograms per liter; <, less than]

River	Date	Discharge		Reach	Reach length (miles)	Travel time			Ratio T_l/T_p mean	Dye pk. velocity (ft/sec)	Dye concentration		Dye recovery (percent)
		at gage (ft^3/s)	at sample site (ft^3/s)			Tl (hours)	Tp (hours)	Tt (hours)			Peak measured (µg/L)	Peak conservative (µg/L)	
Ammonoosuc	1-June-00	151	450; 544	A	6.97	6.83	8.10	12.72	0.82	1.26	1.37	1.54	89
	29-Aug-00	47	101; 102	A	6.97	20.50	25.83	M	--	0.40	0.87	1.50	58 e
Androscoggin	9-Sept-00	1,510	--	A	8.75	16.75	18.08	23.42	0.93	0.71	1.13	1.35	84
Connecticut	15-June-00	10,326	--	A	9.68	7.78	9.28	12.72	0.83	1.53	1.00	1.19	84
	30-Sept-00	1,744	--	A	9.68	39.25	47.50	M	--	0.30	0.51	0.57	89
Contoocook	30-May-00	579	--	A	3.33	5.50	5.50	5.50	0.89	0.89	--	--	--
		--	--	B	5.34	13.33	15.00	19.33	--	0.52	0.85	1.23	69
	19-Dec-00	3,242	--	A	3.33	M	2.65 e	M	--	1.84 e	--	--	--
		--	--	B	5.34	M	4.26 e	M	--	1.84 e	<4.29	M	M
East Branch Pemigewasset	4-May-00	468	428	A	2.80	1.52	1.70	2.27	0.88	2.42	2.25	2.92	77
	3-Aug-00	104	84	A	2.80	3.28	3.82	4.77	--	1.08	0.65	1.08	60
Exeter	20-Apr-00	106	--	A	2.31	8.00	11.33	16.17	0.84	0.30	0.97	1.11	87
	13-Sept-00	16	--	A	2.31	42.00	43.32 e	M	--	0.08 e	0.34	0.51	67
Lamprey	12-May-00	408	--	A	6.40	9.58	11.20	15.87	0.89	0.84	2.00	2.00	112
		--	--	B	2.99	11.17	12.08	14.83	--	0.36	1.01	1.11	91
	6-Sept-00	21	--	A	6.40	54.17	>54.17	M	--	<0.17	M	M	M
		--	--	B	3.11	M	>40.67	M	--	<0.11	M	M	M
Mascoma	19-May-00	334	--	A	2.68	1.43	1.68	2.33	0.85	2.34	2.01	2.05	98
	15-Aug-00	42	--	A	2.68	4.20	4.95	M	--	0.80	0.69	1.01	68 e
Merrimack	9-June-00	7,693	--	A	5.49	4.00	5.00	6.83 e	0.76	1.61	--	--	--
		--	--	B	4.89	2.17	3.83	6.17	--	1.87	0.95	1.46	65
	4-Oct-00	1,249	--	A	5.49	13.00	15.75	M	--	0.51	--	--	--
		--	--	B	4.89	12.00	16.00	18.00	--	0.45	0.89	0.94	95
Oyster	2-May-00	33	40.3	A	3.10	8.50	8.83	11.00	0.96	0.51	2.74	2.77	99
	30-Aug-00	0.9	--	A	3.10	M	>45.75	M	--	<0.10	M	M	M
Piscassic	19-Apr-00	--	24	A	2.01	12.92	15.00	M	0.86	0.20	1.05	1.42	74 e
	28-Sept-00	--	3.6	A	2.01	84.25	97.75	143.75	--	0.03	0.48	0.75	64
Salmon Falls	15-May-00	243	322; 500	A	5.40	15.92	21.08	27.42	0.75	0.38	1.64	1.64	138
	12-Sept-00	30	33; 32	A	5.40	81.73	109.00 e	M	--	0.09 e	M	M	M
Sugar	22-May-00	392	168	A	12.71	10.02	10.75	13.08	0.93	1.73	2.02	2.02	102
	25-Sept-00	84	58	A	12.71	23.00	25.00	31.00	--	0.75	3.17	3.64	87

Table 2. Estimated travel velocities at mean annual flood discharge and associated 6-hour travel distances for New Hampshire rivers in travel-time studies (Smith, 2001)

[Q1, measured discharge and velocity during the low-flow dye run; Q2, measured discharge and velocity during the mean-flow dye run; MAF, estimated values at mean annual flood discharge; (A), upstream river reach on rivers where study reach was divided into two parts; (B), downstream river reach; NA, not applicable because no drinking-water intake on river reach; --, no data; *, MAF velocity was estimated by flow area approximation rather than graphical extrapolation; e, estimated value; ft^3/s, cubic feet per second; ft/s, feet per second; <, less than]

River	Discharge (ft3/s)			Velocity (ft/s)			6-hour travel (miles)
	Q1	Q2	MAF	Q1	Q2	MAF	
Ammonoosuc	102	544	10,909	0.40	1.26	9.84	40.25
Androscoggin	1,510	--	10,619	0.71	--	2.74 *	11.21
Connecticut	1,744	10,326	62,806	0.30	1.53	8.00	32.73
Contoocook (A)	579	3,242	4,313	0.89	1.84 e	2.08	NA
Contoocook (B)	579	3,242	4,313	0.52	1.84 e	2.27	8.96
East Branch Pemigewasset	104	468	6,279	1.08	2.42	9.74	39.85
Exeter	16	106	1,220	0.08 e	0.30	1.66	6.79
Lamprey (A)	21	408	2,151	< 0.17	0.84	2.13 *	8.71
Lamprey (B)	21	408	2,151	< 0.11	0.36	1.30 *	6.80
Mascoma	42	334	1,928	0.80	2.34	5.80	23.73
Merrimack (A)	1,249	7,693	31,203	0.51	1.61	3.90	NA
Merrimack (B)	1,249	7,693	31,203	0.45	1.87	5.60	17.44
Oyster	0.9	33	303	< 0.10	0.51	1.78 *	7.28
Piscassic	3.6	24	481	0.03	0.20	1.74 *	7.12
Salmon Falls	30	243	1,436	0.09 e	0.38	1.29	5.28
Sugar	84	392	4,722	0.75	1.73	6.68	27.33

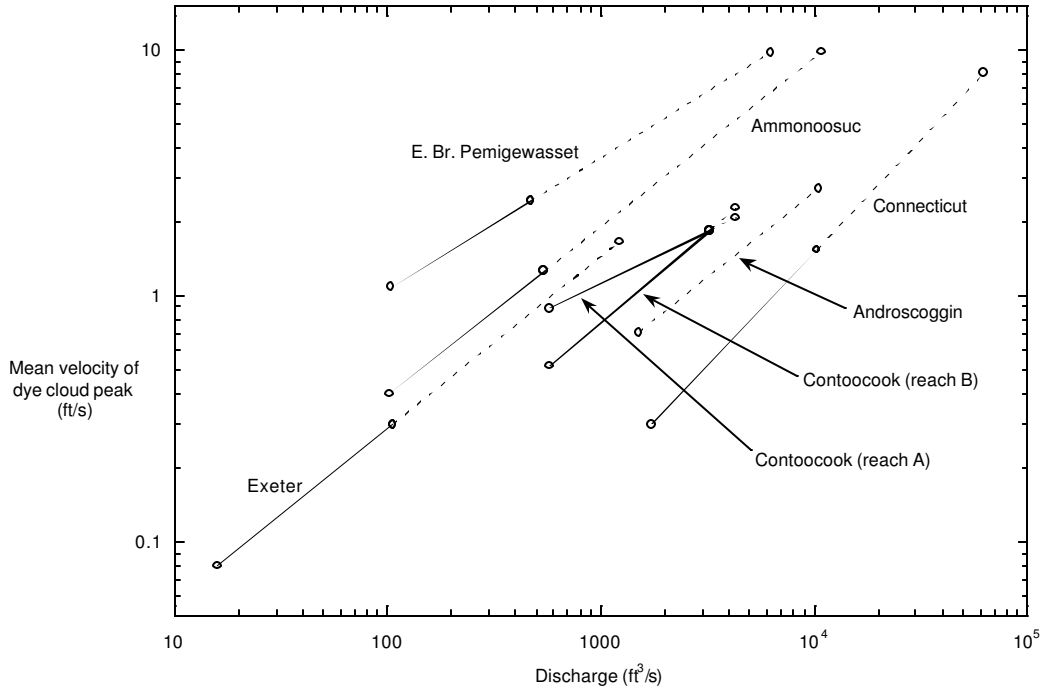


Figure 1. Plot of dye velocity (cloud peak) in relation to discharge for the Ammonoosuc, Androscoggin, Connecticut, Contoocook, East Branch Pemigewasset, and Exeter Rivers. [Measured data points are connected with a solid line, and the

extrapolation to MAF discharge is shown with a dashed line. Discharge is measured at index gage or index site.] (Smith, 2001)

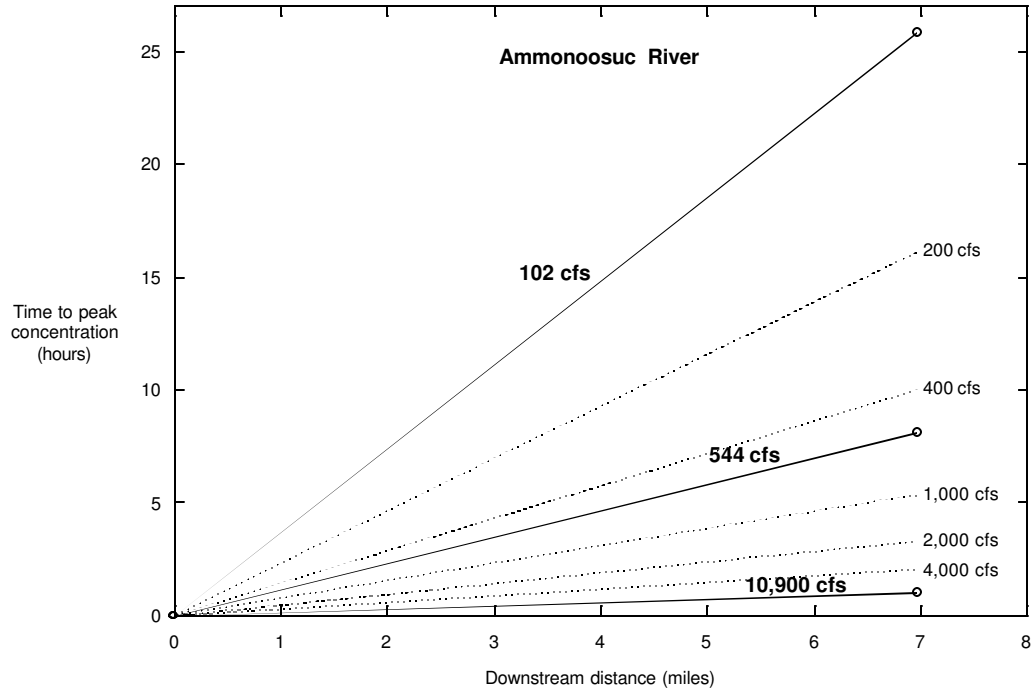


Figure 2. Travel time for dye-cloud peak in relation to downstream distance on the Ammonoosuc River, as a function of discharge at index site. [Solid lines indicate time-distance relation at discharge values measured during dye runs, and at estimated MAF discharge. Dashed lines are interpolated and extrapolated, assuming a log-linear correlation between discharge and velocity.] (Smith, 2001)

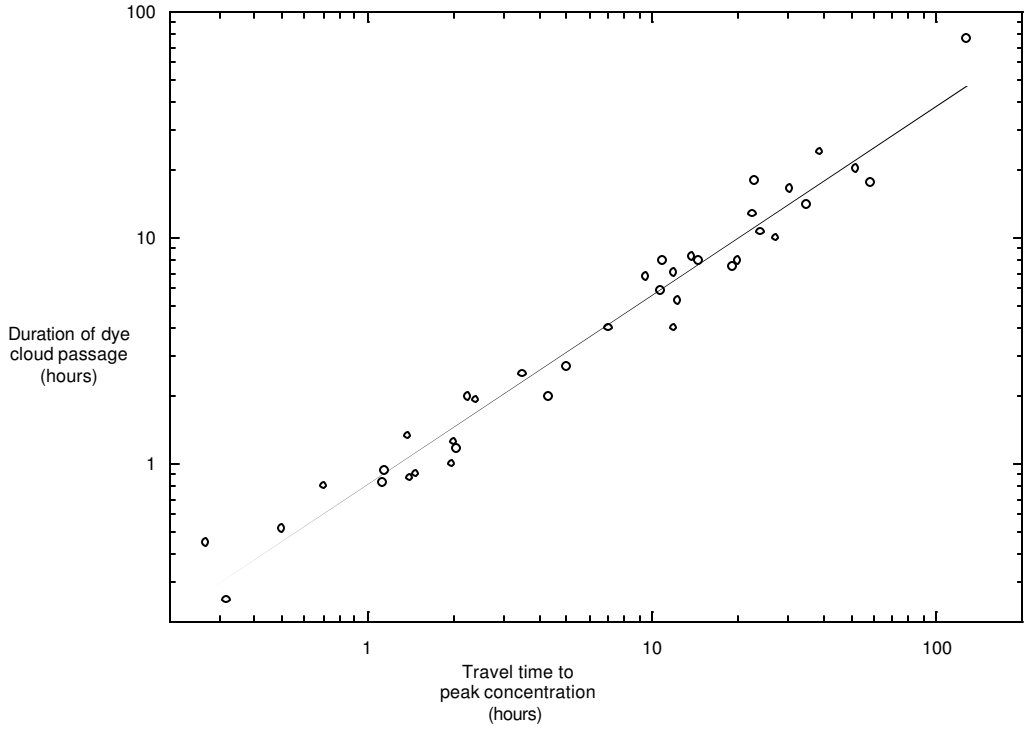


Figure 3. Duration of dye-cloud passage in relation to travel time to peak concentration. [Dye-cloud passage duration is defined as the time from arrival of the leading edge of the dye cloud (first detection) at a sampling site to trailing edge (the time at which the dye concentration has receded to 10 percent of its peak value). Data from all sampling sites in the dye studies are plotted. $R^2 = 0.96$.] (Smith, 2001)

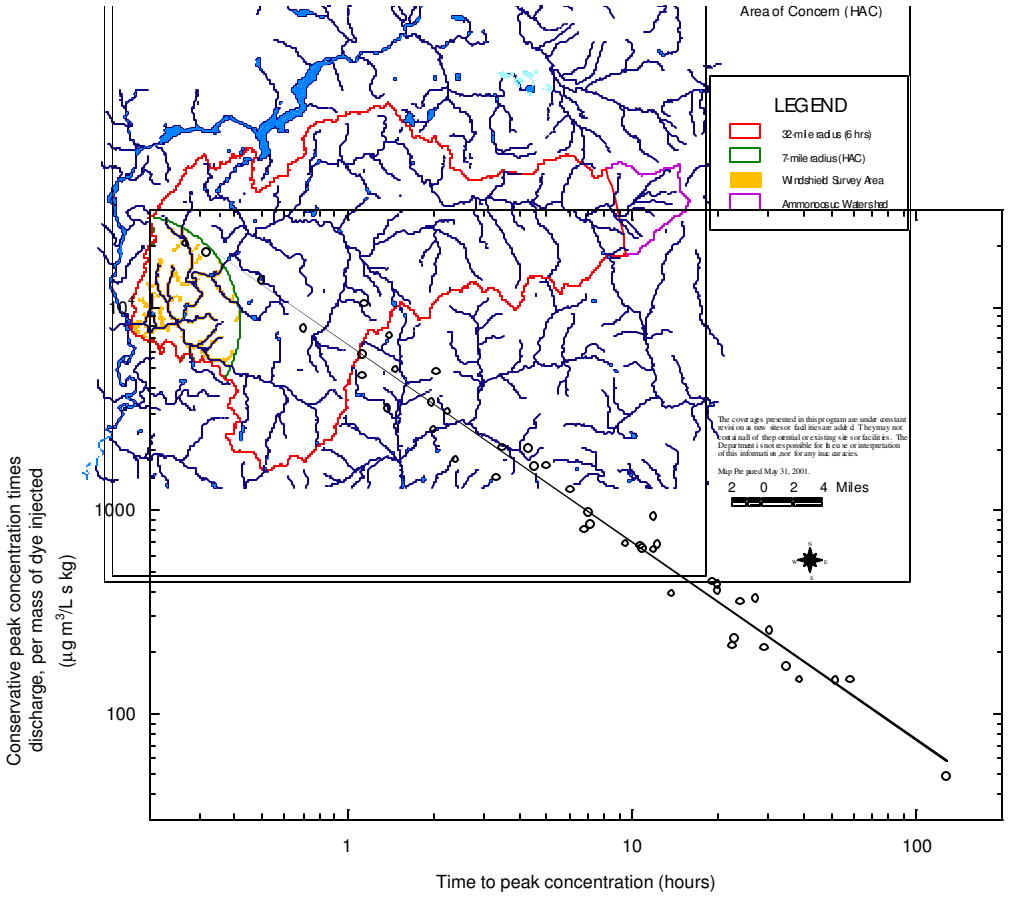


Figure 4. Unit concentration in relation to travel time to peak concentration. [Unit concentration is defined as the peak concentration (micrograms per liter) of a conservative solute, per unit mass (1 kilogram) of solute instantaneously injected into the river at unit discharge (1 cubic meter per second). Data from all sampling sites in the dye studies are plotted. R^2 = 0.97.] (Smith, 2001)

FIG. 5

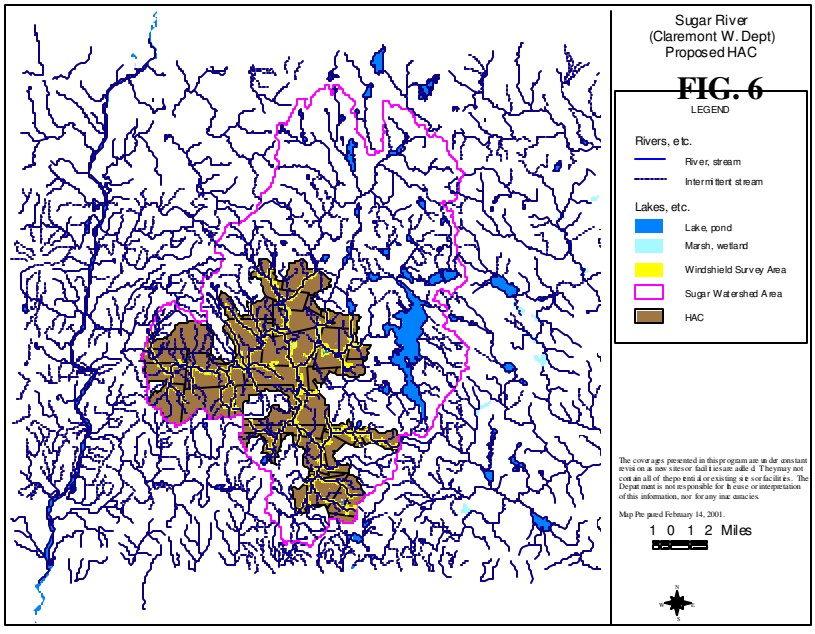
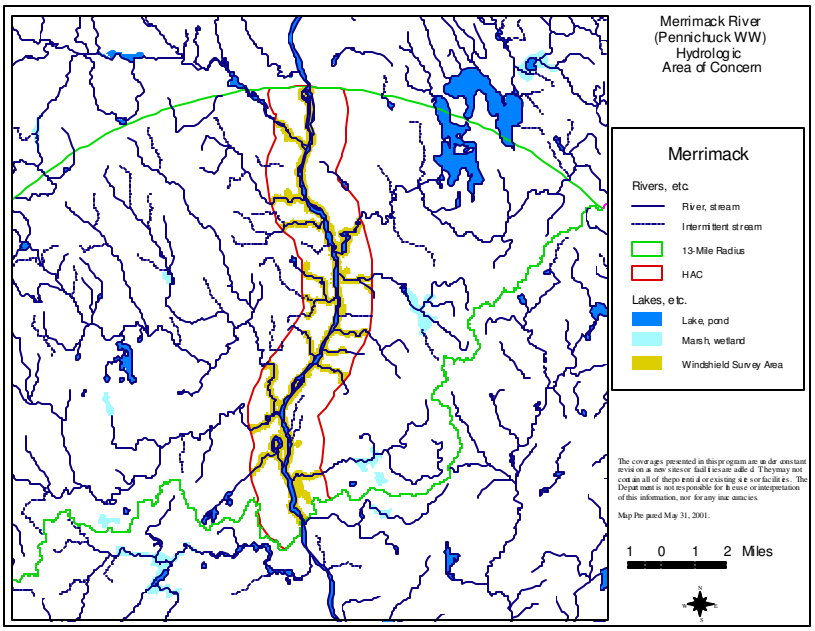
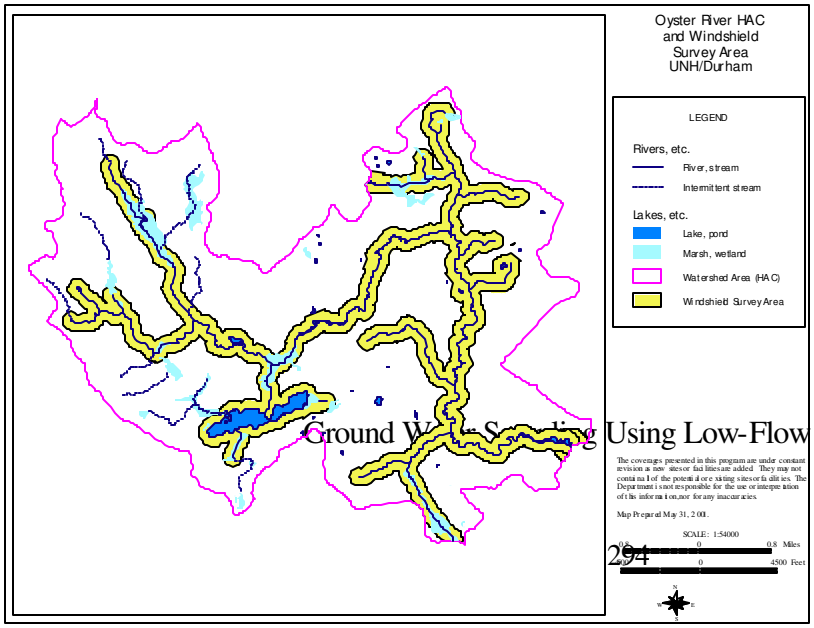


FIG. 6


Merrimack River
(Pennichuck WW)
Hydrologic
Area of Concern
Merrimack
Rivers, etc.
River, stream
Intermittent stream
13-Mile Radius
HAC
Lakes, etc.
Lake, pond
Marsh, wetland
Windshield Survey Area
The coverages presented in this program are under constant
revision as new sites or facilities are added. They may not
contain all of the potential or existing site or facilities. The
Department is not responsible for the use or interpretation
of this information, nor for any inaccuracies.
Map Prepared May 31, 2001.
1 0 1 2 Miles


Oyster River HAC
and Windshield
Survey Area
UNH/Durham
LEGEND
Rivers, etc.
River, stream
Intermittent stream
Lakes, etc.
Lake, pond
Marsh, wetland
Watershed Area (HAC)
Windshield Survey Area
The coverages presented in this program are under constant
revision as new sites or facilities are added. They may not
contain all of the potential or existing sites or facilities. The
Department is not responsible for the use or interpretation
of this information, nor for any inaccuracies.
Map Prepared May 31, 2001.
SCALE: 1:54000
0 0.8 Miles
0 4500 Feet

Cynthia J. Paul and Robert W. Puls

Paul.Cindy@epamail.gov

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U.S. Environmental Protection Agency, Office of Research and Development,
National Risk Management Research Laboratory (NRMRL)
919 Kerr Lab Drive
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ABSTRACT: *Obtaining representative ground water samples is important for site assessment and remedial performance monitoring objectives. The sampling device or method used to collect samples from monitoring or compliance well can significantly impact data quality and reliability. Low-flow or minimal draw-down purging and sampling techniques is an alternative method for obtaining representative samples from conventional monitoring or compliance wells or from low permeability formations and fractured rock. Use of low-flow techniques can minimize purge volumes and decrease monitoring costs as well as provide representative and reproducible ground water samples. The use of dedicated sampling devices in conjunction with low-flow purging and sampling can eliminate initial disturbance into the formation caused by pump insertion and further minimize purge time. Periodic monitoring of the water level within the well should be conducted throughout purging and sampling in order to measure draw-down. The flow rate of the pump should be adjusted to match the ground water entrance velocity into the well screen. Water quality indicator parameters (pH, redox, specific conductance, DO, turbidity, temperature) should be monitored during purging to determine when adjacent formation water has entered the well screen and sampling can be initiated. Stabilization criteria for water quality indicators is defined as three successive readings, at three minute intervals, within ± 0.05 for pH, ± 5 mV for redox, ± 3% for specific conductance, ± 10% for DO, and ± 10% for turbidity. However, some parameters are more sensitive than others (e.g., redox, DO) and should be evaluated with time over several sampling events before establishing a sampling protocol.*

Biographical Sketches: **Cynthia J. Paul** has a B.S. in Biology from East Central University in Ada, OK and a Masters of Environmental Science from the University of Oklahoma. She is an Environmental Scientist at the R.S. Kerr Environmental Research Center, of the National Risk Management Research Laboratory of the USEPA in Ada, Oklahoma. Research interests include permeable reactive barriers, natural attenuation of chromium, arsenic, and other contaminants, transport and fate of metals in the subsurface, and ground water sampling issues.

Faruque A. Khan received his M.S. in soil science and Ph.D. in soil science and water resources from Iowa State University. While at Iowa State, he conducted basic and applied research on the fundamental geochemical processes and properties of soils as they relate to critical problems and opportunities of natural resources management within the state of Iowa. In addition to his research, Dr. Khan supervised the Soil Survey Characterization Laboratory at the Iowa State University. He has most recently been a research soil scientist, working in the Subsurface remediation Branch of the Subsurface Protection and Remediation Division of U.S. EPA in Ada, OK.

Robert W. Puls has a B.S. in Soil Science and Natural Resources from the University of Wisconsin, a Masters from the University of Washington, and a Ph.D. in Soil and Water Science from the University of Arizona. He has worked as a Research Soil Scientist at the R.S. Kerr Environmental Research Center, of the National Risk Management Research Laboratory of USEPA in Ada, Oklahoma since 1987 and is currently Chief of the Subsurface Remediation Branch. He has more than 20 years experience working in the environmental science field. Dr. Puls is Co-Chair of the USEPA's Permeable Reactive Barrier Action Team , one of seven Action Teams comprising EPA's Remedial Technology Development Forum (RTDF). He has been actively involved in research related to permeable reactive barriers since

1991. His recent publications have covered a range of topics including ground water sampling, the development and evaluation of in situ remediation techniques for soils and ground water, and metal reactions governing subsurface contaminant transport and transformation processes.

Groundwater Guardian Workshop:
Today's Technology Protecting Tomorrow's Ground Water

This Groundwater Guardian Workshop, "Today's Technology Protecting Tomorrow's Ground Water", has been designed to educate workshop participants about:

I. The Groundwater Foundation and Its Mission
II. Groundwater Guardian and Its Value to Communities
III. Groundwater Protection Tools for a Variety of Needs and Audiences
   A. Applying Community Technology Today
   B. Source Water Assessment and Protection
   C. Groundwater Foundation Fall Conference and Groundwater Guardian Designation – "Today's Technology Protecting Tomorrow's Ground Water"

A variety of Groundwater Foundation publications will be made available during this workshop at no cost. Get your copies and learn how to use them at this workshop!

Who Should Attend?

Anyone who works with individuals and/or groups on the local level to protect groundwater, surface water, and drinking water quality should attend.

Why Attend?

Learn how groundwater enthusiasts from all walks of life are using information and technology to educate the public and protect groundwater. Also learn how the programs and processes to use information and technology can work in your state and/or community.

For more information, please contact:

Rachael Herpel
The Groundwater Foundation
Phone: 402-434-2740
FAX: 402-434-2742
Email: rachael@groundwater.org
www.groundwater.org

Groundwater Ambient Monitoring and Assessment Program

Angela V. Schroeter [1]

Biographical Sketch:
Angela V. Schroeter is Chief of the Groundwater Special Studies Unit at the California Water Resources Control Board – Division of Clean Water Programs and leads the Groundwater Ambient Monitoring and Assessment (GAMA) Program. She has several years experience in water quality and environmental remediation. Prior to her work at the Water Board, she was a Technical Team Leader with the U.S Army Corps of Engineers – Environmental Engineering Branch. Ms. Schroeter earned bachelor's degrees in Geology and Environmental Policy, Analysis and Planning from the University of California, Davis and a master's degree in Hydrogeology from the University of Nevada, Reno.

Abstract:
The California Legislature, and Governor, as well as private citizens have become increasingly concerned about the recent public supply well closures due to the detection of chemicals, such as MTBE from gasoline and various solvents from industrial sources. As a result of the increased awareness toward groundwater quality, the Supplemental Report of the 1999 Budget Act required the State Water Resources Control Board (SWRCB) to develop a comprehensive ambient groundwater monitoring plan. To meet this mandate, the SWRCB created the Groundwater Ambient Monitoring and Assessment (GAMA) Program. The primary goal of the GAMA Program is to assess the water quality and relative susceptibility of groundwater resources in California, especially those used as a drinking water supply. In addition to coordinating with other groundwater agencies and collecting existing groundwater data, the GAMA Program has two main components: the California Aquifer Susceptibility (CAS) Assessment which addresses public drinking water wells and the Voluntary Domestic Well Assessment Project which addresses private domestic drinking water wells.

The CAS Assessment employs groundwater age-dating techniques and low-level analyses for volatile organic compounds (VOCs) as a guide for assessing aquifers in terms of susceptibility. The assessment is designed to sample the approximately 16,000 public supply wells statewide, starting with three focus areas: Santa Clara Valley, Livermore Valley, and Orange County. The Voluntary Domestic Well Assessment Project will sample domestic wells for various constituents commonly found in domestic well water and provide that information to the domestic well owners. This project will be conducted on a voluntary basis in various focus areas based upon existing knowledge of water quality and land use, in coordination with local environmental agencies. Finally, both the CAS Assessment and the Voluntary Domestic Well Assessment Project include a public education component to aid the public in understanding water quality data and water quality issues affecting groundwater.

[1]California Water Resources Control Board, Division of Clean Water Programs, 1001 'I' Street, Sacramento, CA 95814; email schroeta@cwp.swrcb.ca.gov.

DEVELOPING A NEW WATER RESOURCE FROM OILFIELD PRODUCED WATER

Roger Funston and Lawrence Y.C. Leong

Abstract
The presentation would include a discussion of the opportunities and challenges associated with converting an "unusable by-product" of hydrocarbon production into a valuable water resource. The presentation would analyze the quantity and quality of California oil field produced water in relation to the location and needs of potential users, and evaluate the economics of treating produced water for use by industrial, municipal and agricultural entities.

Oil production generates a significant by-product, commonly known as "produced water". As the oil is produced from an oil field, produced water can reach $\geq$ 90 percent or more of the fluids pumped from an oil well. In 1999, approximately 204 AF/day was generated in the Los Angeles Basin (Los Angeles and Orange counties), 80 AF/day generated in the Coastal Basin (Monterey to Ventura along the Pacific Ocean), and 303 AF/day generated in the Kern County oil fields. The most prevalent method of handling oil field produced water is through deep well injection. The disposal cost for produced water at the Placerita oil field in Santa Clarita, California was equivalent to $775/AF in 1996 dollars and energy costs.

THE FOLLOWING FACTORS MAKE CONSIDERATION OF NON-TRADITIONAL SOURCES OF RECLAIMED WATER MORE ATTRACTIVE:

- THE RELIABILITY OF EXISTING WATER SUPPLIES HAS DECREASED AND MANY PUBLIC WATER AGENCIES ARE ACTIVELY SEEKING NEW SOURCES OF WATER.
- New drinking water regulations are increasing water costs and are creating viable private water markets.
- "Water wheeling" statues (Water Code Section 1810 et seq.) establish a framework for water exchange agreements.
- Treatment technologies (particularly membranes) have advanced significantly over the past several years.

The ideal scenario is when a water purveyor is looking for a new source of reclaimed water that can supply the needs of non-potable users freeing up the potable water resources. Collaborative public/private sector approaches appears to be the best strategy for identifying and delivering this new reclaimed water resource. Government funding may be available to assist public agencies for developing this resource.

COMPELLING ECONOMIC DRIVERS ARE NEEDED AS INCENTIVES FOR OIL COMPANIES TO CONSIDER RECLAMATION OF PRODUCED WATER. TYPICALLY, THERE WILL NOT BE A POSITIVE RATE OF RETURN ASSOCIATED WITH THE SALE OF RECLAIMED PRODUCED WATER. THESE DRIVERS CAN INCLUDE:

1. Improved crude oil recoveries and reserves by de-watering the oil production reservoir.
2. The lack of disposal capacity for produced water disposal using current practices.
3. Avoided costs associated with current disposal practices.

The water use must be determined before selecting treatment technologies to convert produce water into a useable water resource. The water use dictates the water quality requirements and these requirements determine the appropriate treatment technologies. Treatment technologies may include membrane or thermal processes. Membrane technologies are generally preferable for water with a TDS $\leq$10,000 mg/L, and thermal technologies are generally more viable at higher TDS levels.

The key water quality issues of converting produced water to a useable water resource appear to be total dissolved solids (TDS), hardness, organics, ammonia, silica, borate, and water temperature. Other critical factors include regulatory and institutional risks, uncertainties of developing water exchange agreements, potential permitting, regulatory, jurisdictional issues, and the public acceptance of reuse of treated oilfield produced water.

IMPROVING B2G WORK PROCESSES IN THE OIL AND GAS INDUSTRY THROUGH INTERNET TECHNOLOGY

Martin D. Wittstrom
Project Manager
Chevron eBusiness Development Company

M. D. (Marty) Wittstrom is currently the Project Manager for Chevron – UpstreamInfo.com Pilot Projects. He has 25 years experience with Chevron and has held numerous positions in North America, where he has lead exploration, reservoir management and knowledge management efforts. He is a graduate of the Colorado School of Mines (Master of Science, Geology) and lives with his family in Calgary, Alberta, Canada.

Abstract

Chevron believes that digital business and internet technology is a rich environment for continued performance improvement at all points along the petroleum value chain and will be a significant advantage in maintaining competitiveness and in meeting its goal for environmental and safety performance. Numerous projects are underway where Internet technology is enabling faster, better decisions within asset teams and in joint venture operations through virtual integration of data, regardless of data location or format, and by providing anywhere, anytime access to that information.

The real-time information sharing and collaboration enabled by Internet technology is redefining work processes and performance expectations in the exploration, production, refining and marketing sectors. This same technology can be utilized to enable similar improvements in the B2G (Business to Government) sector, where access to data and the exchange of information are essential to regulatory processes. The timelines and quality of decisions that result from regulatory processes ultimately determine how well business and government fulfill their respective missions. Existing technology can be utilized now to achieve improvements in B2G areas such as: permitting, compliance reporting, production reporting, project oversight, monitoring, and collaborative research.

Key elements for implementing changes in processes such as these include: access to the necessary technology for data access and virtual data integration, participants who are willing to take active roles in managing the necessary change, and a data storage and security solution that will build and maintain the trust of the public trust and industry shareholders. Chevron is looking to partner with government to redefine processes using Internet technology to improve communication, public trust, and create value for all involved.

DRAFT SELF-PACED COMPUTER COURSE

Managing Shallow Class V Injection Wells

Elizabeth Janes, USEPA Region 9

Elizabeth Janes is an Environmental Protection Specialist, employed at EPA, Region 9 San Francisco. She is responsible for direct implementation of the Class V program in California.

Region 9 has drafted a self-paced Class V training course for distribution to local governments and tribes. With national, regional and state participation, it could be a valuable reference tool for UIC programs and communities wanting to move forward with source water protection. Today's presentation will include some of the highlights of the training course. Any state or EPA UIC staff interested in participating in the peer review, or submitting attachments, are invited to email janes.elizabeth@epa.gov by 11/30/01.

DRAFT SELF-PACED COMPUTER COURSE

Managing Shallow Class V Injection Wells

The delineation of source water areas is alerting local governments to the need for more proactive control of contaminant sources. Shallow injection wells discharging hazardous fluids can be a significant source of water pollution. UIC resources can be expanded by educating local health, environment, utility, and public works agencies (and anyone else interested) to recognize shallow injection wells.

EPA Region 9 developed a self-paced training module, which is being distributed in draft form to the EPA Class V workgroup and to any state UIC Class V staff for peer review through November, 2001. The draft CD-Rom contains the Lotus Freelance course, and many attachments from UIC programs around the country that exemplify the points covered in the training. The course itself covers these areas:

1. An overview of ground water pollutants and the federal regulations applicable to various discharge activites, focusing on the Safe Drinking Water Act and Underground Injection Control regulations

2. Liquid waste generation and disposal, introducing concepts of hazard, toxic, dilution, pretreatment, waste minimization, and best management practices

3. Types of shallow injection wells, covering all types, then focusing on those most likely to endanger, those prohibited (Class Ivs, motor vehicle waste disposal wells, and large capacity cesspools); common construction methods

4. Class V regulations and program implementation: basic requirements for all wells, tools for managing high-risk wells, delegation of authority to states, data management, and reporting

5. Inspection, investigation, compliance assistance and enforcement: practical advice for the inspector, how to assess risk, when to require closure, what federal enforcement tools exist.

The course is designed for the beginner and presumes no hydrogeologic, engineering or otherwise technical background. Its focus is gravity-fed drains, generally constructed for stormwater or sewage disposal, that sometimes are used for agricultural and industrial wastes in unsewered areas.

A full outline follows. Course can be adapted for use with groups. We would appreciate your feedback on the training course and the usefulness of the attachments by November 30, 2001.

PLUS... We need your attachments! Compact Disks are large - there is significant room to include outreach documents from other states. **Electronic** copies of Best Management Practices, permit samples, inspection forms, and any documents which could be used by another UIC program would enhance the value of the CD.

Following the review by EPA Regions and State UIC programs, the EPA Drinking Water Academy will consider adapting the material for an approved training course. EPA Region 9 will seek assistance from HQ to refine navigability and publish copies for national distribution.

A limited number of disks will be available at GWPC. If you do not receive one and would like to participate in the review, please call (415) 744-1834 or email janes.elizabeth@epa.gov.

OUTLINE

0. Introduction

... What is a shallow injection well?
... Examples of Class V injection wells
... Why Regulate? Groundwater Foundation/USGS statisticsCause for Concern
... Shallow Injection wells are everywhere
... This course covers...

1. Ground Water Contamination and Regulatory Controls

... In this Section
1.1 Examples of ground water contaminants (drawing)
... Naturally occurring contamination and PWSS role
1.2 Overview of applicable federal statutes: SuperfundPrevention/control:
RCRA, FIFRA, CWA, SDWA ... SDWA 1974 UIC
... Timeline: UIC/SWP
... Key UIC Terms: Well, injection, USDW, aquifer
1.3 What is an Underground Source of Drinking Water? (HQ diagram)
... Ohio EPA diagram
1.4 UIC Basics: 5 classes
... 5 Classes of injection wells (diagram)
... Class V is the "all other" category (animation)
... Class V wells can also affect surface water
... To consider as you proceed - 3 questions about your drinking water

2. Liquid Waste Generation and Disposal

... In this Section
... Ideal/Real
2.1 Liquid Waste Sources and disposal
... Each disposal option has an impact
... explanation of regs re: containment, surface water discharge, gw discharge
... Onsite disposal = injection well
2.2 What's in the waste? (list)
... Class IV prohibition
... What is hazardous?
... What is toxic? (MCLs)
2.3 Compounding Factors: dilution, pretreatment
... Keeping stormwater clean
... compounding factor: pretreatment
... Pretreatment method 1: oil/water separator
... Pretreatment method 2: surface impoundment
... Pretreatment: no certification or licensing on national basis of alt techs (SEE REGS FOR TREATMENT FACILITIES IN RCRA)
2.4. Waste Minimization - what it is.
... Pollution prevention
... Example of bad/better/best mps
... Protecting ground water from contaminated runoff (animation)
... For More Information

3. Types of Shallow Injection Wells

... In this Section
3.1. Categorizing the Universe of Class V wells (diagram)

... what makes up each waste stream?
... 1987 RTC list of 32 types
... 32 types into 7 categories - CLICK TO 32TYPES.PDF
... Anyone working with shallow injection wells will find sites that defy the list
3.2. Characterizing the risk to ground water: factors influencing endangerment
... beneficial uses of injection wells
... Range of risk: baseball field vs. industrial stormwater drywell
... answers to question
... Hazardous waste disposal: Class IV wells "Hang up and Dial 911"
3.3. Common construction methods (need better graphics) -
... Common terms used to describe shallow injection wells (graphic)
... Less common Class Vs (diagram)
... A drain on the floor may be the only clue (animation of disappearing drain)
3.4. Function of Shallow Injection Wells... what makes them fail to perk
... What enhances/prolongs percolation
... Potentially contaminating injection wells
3.5 Banned shallow injection wells
... Motor vehicle waste disposal wells
... Large Capacity cesspools
... Risky Business: worst case scenario
... For More information

4. The federal UIC regulations and program
... In this Section
4.1 Two basic requirements
... Not endanger
... Submit inventory information: to open or close a well
... Authorization by Rule
4.2 Federal tools for managing high-risk wells
... Guidelines for Rule Authorization
... Information Request
... Requiring a Permit
... Requiring Closure
... Flow chart of regulatory options based on risk
4.3.Delegation of authority to States (w/map)
... Primacy and Direct Implementation
... EPA's need for local participation
4.4. Data Management
... Shallow injection well universe graphic
... Managing inventory data
... GIS
... Related Data Sources
... Reporting
... Reporting: value and link to 7520s
... Suggested report elements for general use

5. Inspection, Investigation, Compliance Assistance and Enforcement
... In this Section
5.1. Planning and conducting inspections
... tools for inspections
... Health and safety for inspectors
... What to look for/questions to ask yourself

... Legal Entry: Notice of Inspection form
... questionable management practices (photo)
... ID destination of all drains on site
5.2 Recording what you see
... inspection photos: depict flow
... inspection photos: depict drains
... Sampling without a Lab: using your nose/ears
... Can the Facility Show you (documentation)
... inspection reports
5.3 Compliance assistance
... O&M training example
5.4. Where is compliance assessed? (sampling)
... Permits and Compliance Monitoring
5.5. Site characterization and Closure
... Closure - reg definition
... physical destruction
5.6. Federal Enforcement Options
... Civil: NOV, AO, APO

BIBLIOGRAPHY/ATTACHMENTS

32typesGWPC.pdf: the list of 32 types of Class V injection wells, originally published by the Ground Water Protection Council, retyped.

Azoilwaterseparators.pdf: Arizona Department of Environmental Quality, Best Management Practice (BMP) guidelines on oil/water separators.

designsCV.PRZ: lowest-technology Class V well configurations summarized. Septic tank, drywell, and leachfield. Explanations of function and risks associated with use.

DraftGuideRuleAuthorization.wpd: draft guidelines for rule authorization of industrial disposal and industrial drainage shallow injection wells

Gauicapp.pdf: Georgia's Class V permit application.

GenpermADEQ5D4.pdf: Arizona Department of Environmental Quality's general permit for drywells receiving stormwater runoff in industrial areas.

GwfloExYuccaMtn.pdf: article explaining ground water flow at Yucca Mountain, a proposed nuclear waste repository.

Industrialdrains.pdf: Region 9 outreach material on industrial and motor vehicle waste disposal wells.

Lithouse.gif: graphic depicting residential septic system and leachfield.

Mobiless.exe: Lotus Freelance file viewing software.

MoVeSelfAudit.pdf: Reigon 9 self-audit checklist for motor vehicle facilities that attempts to integrate RCRA and stormwater issues.
NoticeofInspection.PDF: Region 9 form used to acknowledge approval to inspect by inspectee.

NOV.wpd: Notice of Violation for a sump at an automotive salvage yard (see SiteXinspectionreport.wpd.)

Nvautomotive.wpd: Nevada Division of Environmental Protection outreach material for motor vehicle waste disposal wells.

REG7APO.wpd: a sample administrative penalty order for an agricultural drainage well.

restankinstall.jpg: photograph of two-compartment septic tank being installed at a new residence; shows access risers and size of excavation needed.

SBREFAbmplinks.wpd: Official OECA language for small business owners, includes links to many EPA and industry-provided hotlines and websites.

SiteXinspectionreport.wpd: inspection report from automotive salvage yard (see NOV.wpd.)

Soilsguide.pdf: USDA Natural Resources Conservation Service primer on soils.

Supplementalinv.wpd: same as UIC144-27form.pdf, in WordPerfect format for editing.

UIC144-27formR9.pdf: Region 9 form used to obtain additional information about well(s) suspected of endangerment.

USTClosure2001.pdf: EPA Region 10 closure guidance for Underground Storage Tanks.

Weblinks (NOTE: Not all of the Weblinks within the presentation are activated.)

es.epa.gov/oeca/main/compasst/compcenters.htm
ga.water.usgs.gov/edu/mwater.html
gwpc.site.net
map3.epa.gov/enviromapper/index.html.
www.dhs.cahwnet.gov/ps/ddwem/dwsap/dwsapdoc/dwsap07.htm
www.epa.gov/region09/cross_pr/p2/autofleet/index.html
www.epa.gov/owm/sw/toolbox/
www.epa.gov/etv
www.epa.gov/safewater/uic/cl5study.html
www.epa.gov/safewater/uic/primacy.gif
www.epa.gov/epaoswer/osw/hazwaste.htm
www.epa.gov/safewater/uic/7520s.html
www.epa.gov/safewater/
www.epa.gov/ogwdw/dwa/electronic.html
www.groundwater.org/index.htm
www.nesc.wvu.edu/nsfc/
www1.umn.edu/mntap/P2/DRYCL/fs54-r17.htm

NEED TO ADD: copy of 40 CFR 144 (anyone recommend a good source in a searchable format?), other regions/state's outreach materials, photographs within presentation, closure guidance documents.

MANAGEMENT OF PRODUCED WATER IN OIL & GAS OPERATIONS: PRODUCED WATER TREATMENT AND RE-USE IN FIELD DEMONSTRATIONS OF NATURAL HABITAT RESTORATION

PRESENTED BY: D. B. BURNETT, DEPARTMENT OF PETROLEUM ENGINEERING, TEXAS A&M UNIVERSITY AND THE GLOBAL PETROLEUM RESEARCH INSTITUTE (BURNETT@GPRI.ORG)

DESCRIPTION OF PROJECT

The Texas Water Resources Institute (TWRI) at Texas A&M University has formed an interdisciplinary faculty team to study the re-use of water resources in the oil and gas industry. With the support of TWRI, the Department of Petroleum Engineering at A&M has partnered with the Chemical Engineering Department and the International Agriculture Department to bring new technology to treatment of produced water produced from oil and gas operations. This effort is part of an effort to bring the concepts of sustainable development to oil and gas producing activity.

The industry-sponsored portion of the work is being managed by the Global Petroleum Research Institute (GPRI). The goals of the GPRI project are:

(1) To design and construct prototype portable units to use in oil field operations,
(2) To measure the performance of the unit in field tests.

The GPRI project would be a part of the larger A&M multidisciplinary study;

(3) To prove that on site water treatment is technically possible and economically justifiable at the current time in oil & gas production operations,
(4) To measure the impact of treated water in the creation of habitat and rangeland restoration,
(5) To create a program to effect change in the regulations governing the reuse of treated oilfield brine for use as a resource to the public
(5) To create a program promoting the technology to broader markets and areas of application.

Experimental work on treatment of produced brines is being performed at the Separation Sciences Laboratory at A&M (www.tamu.edu/food-protein/divisions/separ_sc/) under the supervision of Dr. S Sefa Koseoglu, Department of Chemical Engineering, Separator Technology (s-koseoglu@tamu.edu). The process design of the field units is being developed by Dr. Maria Barrufet of the Department of Petroleum Engineering (Barrufet@spindletop.tamu.edu). The effort to address the environmental and regulatory issues related to the re-use of produced brine is being led by Mr. David Burnett (burnett@gpri.org). The impact of treated produced brine on rangeland and habitat restoration is being coordinated by Linda. S. Cleboski, International Agriculture Department, Texas A&M University (l-cleboski@tamu.edu).

For more information about GPRI and this project go to http://www.gpri.org and select "Facilities and Processes Projects" (http://pumpjack.tamu.edu/gpri/index.html)

A Presentation of the Region 8 Underground Injection Control Program Database

Valois Shea

Valois Shea, geologist (B.A. and M.S.), is a five year member of the Region 8 Underground Injection Control (UIC) Program Class V Team. For 13 years previously, Valois conducted environmental and health and safety mining research at the former US Bureau of Mines. Valois just completed a three year project developing the Region 8 UIC program database designed to track all UIC program activities. Having survived the past three years, Valois is now tasked with fostering the survival and improvement of this database, as well as running the Class V Direct Implementation program in Colorado and selected Region 8 Tribal Lands.

Abstract: The Region 8 Underground Injection Control Database tracks all UIC program activities including mass mailouts to identify Class V facilities, permitting for all UIC well classes, compliance activities, enforcement activities, and all activities that a UIC well can experience from its discovery or birth through its closure or conversion. The database is an Access2000 runtime application, but also has the query, sorting and filtering capabilities that are usually not available with Access2000 runtime applications. These functions have been customized and programmed into the runtime application. The database has on-line help and some administrative functions available. The database is not yet fully populated. All planned reports are not yet fully functional. The UIC database is integrated with CATS, the Compliance Activity Tracking System database, developed in Region 8 and adopted by a few other EPA Regions. The UIC database is designed to fully integrate with FRS, the Facility Registry System, a database designed to house all EPA regulated facilities.

Professor Charles R. Goldman

Environmental Science & Policy

University of California

Davis, California 95616

Charles R. Goldman, Professor of Limnology in the Department of Environmental Science and Policy, has been with the University of California, Davis, since 1958. He developed the first courses in limnology and oceanography at UCD, served as Chair of the Division of Environmental Studies from 1988-1992, and was founding Director of the Institute of Ecology, serving from 1966-1969 and again in 1990-92. Prior to his 42-year tenure at UC Davis, he earned Bachelor and Masters degrees from the University of Illinois and a Ph.D. in Limnology-Fisheries from the University of Michigan. He has supervised 88 graduate students and 30 postdoctorals during his four decades at UC Davis. Professor Goldman's many prestigious awards include an NSF Senior postdoctoral Fellowship in 1964 for limnological research in the Arctic (Lapland), a Guggenheim Fellowship in northern Italy in 1965, the "Goldman Glacier" in Antarctica named in 1967, served as President of the American Society of Limnology and Oceanography in 1967-68, awarded the Antarctic Service Medal by Congress in 1968, and elected a Fellow by the California Academy of Sciences in 1969.

In 1973-74, he was elected Vice President of the Ecological Society of America, and accepted a Fulbright Distinguished Professorship to Yugoslavia in 1985. He was awarded the Vollenweider Lectureship in Canada in 1989, the Chevron Conservation Award and Culver Man-of-the Year in 1991, the Earle A. Chiles Award in 1992, and the UC Davis Distinguished Public Service & Research Lecturer awards in 1993. He was elected Vice President of the International Society of Limnology (SIL) for 1992-98, and presented the prestigious Baldi Lecture at the triennial SIL Congress in Ireland in August 1998. Dr. Goldman has published four books and over 400 scientific articles, and has produced four documentary films which are in worldwide distribution. He has served

on many national and international committees and is frequently sought for consultation and research missions to foreign countries on major environmental problems. In 1990 he was a member of a UNESCO team to qualify Lake Baikal as an International Heritage Lake and Senior Scientist for the National Geographic Baikal project. His single most important and sustained contribution is the 40 years of research on Lake Tahoe. P

Professor Goldman is Director of the Tahoe Research Group and has pursued long-term ecological research simultaneously at Lake Tahoe and Castle Lake, California, since 1958. He successfully combined effective research and social action with his pioneering studies of lake eutrophication. These have been directly applied to engineering solutions, social needs, and legal decisions. This work has recently included the development of artificial wetlands and research on alternatives to conventional road

salt for deicing highways. This relationship of basic science to political change has been of particular importance to the Lake Tahoe basin. During the summer of 1997, Dr. Go ldman hosted President Clinton and Vice President Gore aboard the UC Davis research vessel *John Le Conte* during the Lake Tahoe Presidential Forum. Similar studies have extended Dr. Goldman's research-social action efforts to analysis of lakes like Baikal in Russia and hydroelectric impoundments throughout the world. Thus, while aggressively pursuing basic research on lake dynamics, he has also been able to translate the findings directly to state, national and international policy decisions, contributing decisively to the conservation and judicious use of aquatic resources from the Antarctic to the lakes and wetlands of South and Central America, New Guinea, Africa, Asia, Europe and the United States. Professor Goldman’s career work has

now been honored with his most prestigious award yet: he received the 1998 Albert Einstein World Award of Science in a formal ceremony held in New Zealand. The Einstein Award, bestowed annually to a single individual by a council of eminent scientists which includes 25 Nobel laureates, recognizes those who have accomplished scientific and technological achievements that have advanced scientific understanding and benefited humanity.

Geothermal Field Trip Summary

The Geothermal Field Trip will be visiting the Steamboat Hot Springs Known Geothermal Resource Area at the southern end of the Truckee Meadows, approximately 10 miles south of Reno. Two scheduled stops are planned, one at an overlook of the project area from the Virginia Hills (road to Virginia City) to include an overview of the geology, hydrology, and discussion of the two geothermal projects in the Steamboat Springs area. The second stop will be at the Steamboat Geothermal Power Project operated by SB Geo, Inc., one of two geothermal projects in the area. This stop will include a tour of the power plant, production and injection wells. This facility has four "power plants", run as two separate operating entities - SB 1/1A, and SB 2/3. The plants were completed in 1986 and 1992, respectively. The approximate power output of each set units is SB1/1A - 7 megawatts and SB2/3 - 28 megawatts.

For more information on the Steamboat Springs area, visit the following websites:

Steamboat Geothermal, Inc. (SB Geo, Inc.) has a website with a brief facility overview at http://home.nvbell.net/sbgeo/steamboat.html

DOE website with overview of Nevada geothermal projects
http://www.eren.doe.gov/geothermal/nevada.html

Sparks Solvent/Fuel Site
GWPC Field Trip

The Sparks Solvent/Fuel Site (SSFS) is a railyard and fuel terminal tank farm in Sparks, Nevada, which is approximately 5 minutes from the hotel which GWPC will be hosting the 2001 Annual Forum. Activities over the past century have resulted in the contamination of groundwater and soils by solvents, gasoline, diesel fuels and other petroleum products.

The Nevada Division of Environmental Protection (NDEP) issued clean-up orders in 1990 to all of the 19 responsible parties that required an on-site contaminant investigation to commence. After congressional hearings were held in 1991, EPA also issued an Administrative Order requiring even further site investigations.

To date, clean-up efforts have involved the design, installation, and operation of a groundwater extraction and treatment system, soil vapor extraction and treatment systems as well as other aggressive remedial technologies. Technologies that have been used or are currently in use include recirculation of treated groundwater to enhance biodegradation, soil vapor extraction at hot spot locations, air sparging and phytoremediation.

This field trip will provide a look at the source and migration of a plume that originated from common practices in the early 1900's and also the extensive remediation activities implemented to address the plume.

Re-decommissioning of the La Goleta Gas Field, Santa Barbara County, California: A case study

By
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Jerry M. Menesez, ExxonMobil Production Company, Goleta, CA

Biographical Sketch of Authors

Al Robb has over 10 years domestic and international experience with upstream oil industry safety, health and environmental issues, and is currently responsible for environmental/risk assessment and remediation activities for ExxonMobil. Al received a B.S. in Earth Sciences (Geology) with distinction from Penn State and a M.S. in Geology from the University of Kansas. Al served as Chair of the API Ground Water Issues Group (GWIG) from 1996 to 1999, and in conjunction with those duties was an ex-officio board member of the GWPC. He served as the industry Co-Chair of the GWPC Class II Division from 1997 to 2000. He is also an Environmental Associate of the Academy of Natural Sciences.

Jerry Menesez has over 35 years experience with oil and gas production operations in California and is currently a facilities engineering technician at coastal California assets for ExxonMobil. Jerry has particular expertise in the various aspects of well work, along with a strong familiarity with safety, health and environmental compliance issues.

Abstract

This paper briefly describes the successful voluntary "re-decommissioning" of historic (1929-1931) oilfield operations in California. Extraordinary shoreface erosion of coastal Santa Barbara County, along Goleta Beach and the mouth of the Goleta Slough, during the 1997-1998 El Nino storm events exposed the remains of wood, steel and concrete drilling and production structures of five historic well sites that had been previously decommissioned. These remnants remained exposed, and posed safety hazards as well as potential health and environmental issues, requiring an immediate response. An innovative re-decommissioning approach was implemented that included a unique coil tubing unit application to plug one of the wells due to concerns with complex safety and environmental issues associated with the location of the well. The described project was conducted without a single OSHA-recordable injury, and no discharges to the environment of any kind occurred as a result of this project. The overall response, conducted under emergency circumstances, required a positive working relationship between the regulatory agencies and the operator, utilization of innovative approaches, and the cost-effective management of complex coordination and logistics issues.

Introduction

The decommissioning, including well plugging and abandonment (P&A), of historic oilfield assets (wellbores / equipment / structures) continues to be an important concern for regulators, environmental groups, and the regulated community. At least twelve oil and gas wells were drilled between 1929 and 1931 from wood and steel-reinforced concrete pier structures as part of the La Goleta Gas Field along coastal Santa Barbara County, California, and were plugged according to regulatory guidelines shortly after drilling (Figure 1). This historic lease comprised a total of approximately 2 square miles of coastline, including the adjacent beach and State Tidelands, and is located approximately one mile west-northwest of the City of Santa Barbara, along a sensitive stretch of coastal Santa Barbara County (Figure 2). The coastline in the vicinity of the former well sites on this lease is a steep cliff face with a sandy shore that faces south and is fully exposed to ocean swells. The center of the closest residential community, Goleta, is located approximately 1.5 miles to the north of the leases.

Extraordinary shoreface erosion during the 1997-1998 El Nino storm events exposed the wood, steel and concrete remnants of the drilling and production structures of five of the previously abandoned La Goleta Gas Field wells along Goleta Beach and the mouth of Goleta Slough (Figure 2). These remnants remained exposed after the storm events, posing potential safety, health and environmental hazards that required an immediate response. The exposed well sites and potential hazards that required remediation were as follows:

- Chase #134-1 - unplugged well and exposed wood pile,
- James #136-1 - exposed steel-reinforced concrete caissons and steel H-pile,
- Sands #137-1 - exposed steel-reinforced concrete caissons and steel H-pile,
- Crandall #138-1 - exposed steel-reinforced concrete caissons and steel H-pile, and
- Parker #139-1 - exposed steel-reinforced concrete caissons, wood and steel H-pile.

This paper briefly describes the successful voluntary "re-decommissioning" of five previously decommissioned historic oil and gas well sites. The overall response, conducted under emergency circumstances, required a positive working relationship between the regulatory agencies and the operator, utilization of innovative approaches, and the cost-effective management of complex coordination and logistics issues.

Historical Background

The south-central California coast has been the site of hydrocarbon extraction and utilization for hundreds of years, in part due to the attention brought about by naturally-occurring oil and gas seeps along the coastline. The natives of the Chumash culture caulked their woven baskets and canoes with the naturally seeping oil and asphaltum to make them water-resistant. Beginning in the 1890's, the Alcatraz Asphaltum Company mined pure asphalt from a network of vertical and horizontal shafts just west of Goleta Point and at Carpinteria (Griggs, 1993). Onshore and coastal drilling also began in this region in the 1890's in the Summerland area, just east of Goleta. Natural gas was first to be produced, and commercial oil was produced shortly thereafter (Kallman & Wheeler, 1984). Regionally, oil and gas production originates from the Miocene age Rincon Anticline Complex that extends approximately 30 miles from the offshore Dos Cuadros Field (approximately 13 miles to the south-southwest of the project site) to the onshore Ventura Field (approximately 17 miles to the southeast).

Twelve oil and gas wells are known to have been drilled from wood and steel-reinforced concrete pier structures as part of the La Goleta Gas Field under State Prospecting Permits along coastal

Santa Barbara County, California between 1929 and 1931 (Figure 1). At least seven companies were involved with the drilling and held operator status for these wells. The More #1 well was drilled just east of the Goleta Slough by the General Petroleum Corporation of California in 1929 (exact location of this well is unknown). The Chase #134-1 was spudded by the Altadena Oil Company, but was subsequently acquired and drilled deeper by General Petroleum. The Bank #133-1, James #136-1, Sand #137-1, Crandall #138-1, and the Parker #139-1 were all subsequently drilled by General Petroleum. The operators of record for later wells were: the Robert Bowles Oil Company for the Tidelands Well #140, the U.S. Petroleum Company for Well #141-1, R.C. Foerster and C.C. Kreis for Well #142-1, J.F. Schuman for Well #143-1, and the El Camino Oil Company for Well #149-1.

Records indicate that all of the La Goleta Gas Field wells, except for the Chase #134-1, were found to be noncommercial and were abandoned according to regulatory guidelines shortly after drilling. The Chase #134-1 well was quitclaimed by General Petroleum back to Altadena, and was later classified as deserted by the California Department of Conservation, Division of Oil and Gas (DOG). In 1983 the DOG transferred ownership to Mobil Oil Corporation, who had acquired General Petroleum.

The La Goleta Gas Field wells were drilled, completed, and were intended to be produced from wood and steel-reinforced concrete pier structures. These wells never produced commercially; therefore no onshore production facilities beyond the pier structures existed. In general, these wells appear to have had pier structures consisting of a steel-reinforced concrete caisson set composed of one approximately 12-foot diameter well caisson surrounded by four 8-foot diameter derrick foundations (Figure 3). A pier and wharf structure was constructed from the inshore bluff to the wells. The pier consisted of wooden decking mounted on a wood and steel H-pile foundation. This type of construction was typical of coastal oil and gas development projects in California during the early 1900's. Agency and company records indicate that the La Goleta Gas Field pier structures were removed by severing the foundations (wood and steel pile and steel-reinforced caissons) below the ground surface shortly after the wells were plugged (early 1930's). Agency records indicate that cleanup work may have been performed at the lease after the initial decommissioning. Observations at the site in 1998, including flailed and mangled steel, suggest that explosives were utilized during the initial or subsequent decommissioning projects.

Regulatory Approvals

The re-decommissioning of the La Goleta wells posed several interesting challenges to both the regulators and the operator associated with the project. The regulators were challenged to identify the appropriate responsible party, or parties, and subsequently provide the necessary approvals to accomplish the desired results in a timely manner. The operator(s) was required to react quickly to the many coordination, logistics, and permitting issues raised during the project implementation. Teamwork, compromise, and sharing of innovative ideas between the operator and regulatory agencies was key in assuring a safe and successful re-decommissioning project.

The voluntary participation and unusual circumstances surrounding this project allowed the operator to obtain timely approval for results-oriented permit conditions. In contrast to most oil and gas-related projects in coastal California, regulatory approvals and public relations issues were not controversial components of this effort. The California State Lands Commission (SLC) acted as the lead agency for this project (except for well plugging activities). The SLC determined that this project was conducted in response to the severe El Nino conditions, and that it involved *"a project undertaken, carried out, or approved by a public agency to maintain, repair, restore, demolish, or replace property or facilities damaged or destroyed as a result of a disaster in a*

disaster stricken area, in which a state of emergency had been proclaimed by the Governor... " (SLC, 1998). As a result, all work was performed with appropriate agency approvals, but was statutorily exempt from California Environmental Quality Act (CEQA) requirements.

Table 1 summarizes the key regulatory agencies directly involved with this project and the approvals provided. The SLC provided approval of the Work Program and the Approval to Plug for the Chase #134-1 well. The California Coastal Commission (CCC) approved a Coastal Development Permit. The U.S. Army Corps. of Engineers determined that the proposed work complied with the terms and conditions of the Regional General Permit (Sections 10 and 404 Permit requirements). The California Division of Oil, Gas and Geothermal Resources (CA DOGGR) as well as the County of Santa Barbara Energy Division provided approvals concerning the P&A of the Chase #134 well and well site. Site access was granted from Southern California Gas Company (SCG). Project documentation and follow-up reports were provided to all involved agencies.

Wildlife Surveys and Environmental Compliance

In accordance with the permit conditions of the U.S. Army Corps. of Engineers Regional General Permit Authorization and Coastal Commission Coastal Development Permit, a grunion survey was conducted of the beach area to be potentially affected by project activities prior to starting project activities. Grunions are protected marine fish who spawn by depositing their eggs in the beach sand at or above the high tide line. A total of 70 trenches were installed and sampled from four study sites at the work location for evidence of grunion activity. No grunion eggs were found as a result of the survey. The survey report further noted that three of the four survey locations were generally not suitable for grunion spawning (Tenera Environmental, 1998).

An analysis of threatened and endangered fauna and flora was also conducted. Surveys of protected or sensitive avian and their habitat, including for example the Great Blue Heron and their nests, as well as various other shore birds, were performed. It was determined that there was no adverse effect on the use of the beach by shorebirds in the proximity to the project.

To ensure that project activities complied with permit conditions and that no adverse impacts occurred to biological resources or recreational activities in the project area, Mobil provided an onsite environmental monitor. The monitor provided direct guidance to field personnel regarding impact avoidance and interfaced with any individuals that approached the work site. Such an approach provided direct assurance to the resource agencies that the project was being conducted in accordance with the approved procedures and permit conditions without assigning an agency staff person to oversee the activities.

Project Implementation

Regulatory approvals, as previously discussed, were efficiently and expeditiously secured. Due to the emergency nature of this project, only limited planned public outreach was involved. Access agreements were obtained by the operator from the landowner, Southern California Gas Company (SCG), enabling efficient site access. Project notifications were provided to adjacent landowners

and company public affairs personnel were available to assist with inquiries. Safety was an important component of this project; daily safety meetings and Job Safety Analysis (JSA's) were performed on critical tasks. The work did not interfere with normal public access to coastal areas. Work areas on and around the beach were identified by yellow caution tape; few people came near the project area (typically one or two per day).

Facility Decommissioning Activities

The storm erosion exposed steel pile, sheet steel wrapped around concrete caissons, and/or concrete at the following well locations: James #136-1, Sands #137-1, Crandall #138-1, and Parker #139-1. The steel pile requiring removal occurred on the beach and extended into a mean average water depth of 6 feet. Only wood piling was observed at the Chase #134-1 well site.

The Goleta Slough mouth to the west, a steep bluff to the north, and a rocky point to the east (see Figure 2) restricts access to the beach. Pedestrian access is available through a gate and informal walkway from the SCG property located north of the site, at the top of the bluff. This access served as the entry point for workers, equipment and materials to be transported from the staging area to the work area on the beach. Equipment, materials, and personnel were staged from the SCG property located on the bluff overlooking the project site and access corridor. This area is generally used by SCG as an employee barbecue and recreational area. During the project, this area was also used for worker safety/orientation meetings; equipment, materials and debris storage; and vehicle parking.

Materials and equipment were initially transferred to the beach from the staging area by hand, which was labor-intensive, slow, and difficult. To assist with the movement of the equipment and materials to and from the beach, an innovative temporary track system, constructed of bolted prefabricated steel track, was installed along the existing pedestrian walkway. This track system operated by means of a cable winched flatbed railcar.

Workers removed most of the exposed steel by digging around the H pile and other protruding metal with hand shovels and cutting the exposed metal with an oxygen torch at approximately 1 foot below the maximum sand scour line. No excavation was performed in cases where the metal was in super-saturated (liquefied) sands or under water; pile was cut at just below sand line in these circumstances. Torches were also used to remove or smooth down any rough edges of potentially hazardous metal within the caissons (e.g., piping, reinforcement steel, etc.) or sheet steel surrounding the concrete caissons. The removed steel was collected on the beach and then transported to the bluff in a cart and winched up the bluff on the track system to the project staging area. The scrap steel was loaded into metal storage bins at the staging area and was subsequently shipped to a recycling facility. Exposed concrete was smoothed to remove any sharp edges with the use of sledgehammers. Concrete debris was removed to the project staging area for subsequent recycling.

A total of 72 steel pile sections were removed from well sites during this project; none at the Chase #134-1, none at the James #136-1, 57 at the Sands #137-1, 14 at the Crandall #138-1, and 1 at the Parker #139-1. Additional scrap steel (e.g., piping and sheet steel) and concrete was recovered. It is estimated that the project involved an area of approximately 1 acre on the beach (including material transport and excavation work area) and resulted in the excavation and subsequent back fill of about 19 cubic yards of sand (based upon 72 excavations with a radius of 1.5 feet to a depth of an average of 1 foot).

Well Plugging Activities

According to DOGGR records, all of the wells exposed during this event, except the Chase #134-1, had been properly plugged in accordance with the Departments guidelines. Well plugging records for the Chase #134-1 could not be located in either the Department's well files or company files. As a result, verification of the well completion status was required. A hole in the steel plate welded over the casing stub measuring approximately 3/4" in diameter was discovered during an inspection of the well site. A weighted tag line was dropped through the hole into the wellbore to a depth of 80 feet. The lack of a surface plug at 80 feet indicated that the well had not been appropriately plugged and subsequent plugging activities would be required. No hydrocarbon odor or gas bubbles were detected at the surface during periodic inspections.

In 1998, the Chase #134-1 well was located on a mudflat immediately adjacent to the Goleta Slough just north of its discharge at Goleta Beach. According to DOGGR Regulations, this well is considered a "critical well" due to its location within 100 feet of a navigable body of water or watercourse perennially covered by water. However, also due to its coastal location, no freshwater sands requiring special protection were recognized by the DOGGR in the subsurface at this location. Well plugging activities commenced immediately upon development of an approved Well Plugging Procedure, DOGGR-approved Permit to Conduct Well Operations, and an SLC Approval to Plug.

The well was plugged utilizing a $1^{1/2}$ inch Halliburton coil tubing unit (CTU). The closed-system coil tubing entry was made through a specially fabricated horizontally-mounted $2^{7/8}$ inch piping apparatus (with a horizontally-mounted injection head) with a 4 inch by 72 inch sweep elbow to vertically enter the well (Figure 4). This made it possible to stage the coil tubing truck and other equipment from an existing adjacent pad area approximately 50 meters away, therefore avoiding rigging up the coil tubing unit close to a water body and beneath overhead power lines. Records indicate that the Chase #134-1 well intended to target a production interval at 3750 feet, but was only drilled to a total depth of 2053 feet (Figure 5). The well has 24 inch casing cemented to 20 feet, 20 inch casing cemented to 57 feet, $13^{3/4}$ inch casing cemented to its shoe at 1484 feet, and had an uncased 16 inch hole from 1484 to 2053 feet (no modern documentation of open hole OD exists).

The coiled tubing was run into the hole and encountered refusal at a depth of 1481 feet. It was presumed that refusal was the result of sloughing of the uncased hole bottom. With DOGGR approval, an approximately 400-foot cement plug was placed beginning at the 1481 foot depth at the base of the $13^{3/8}$ inch casing shoe. The DOGGR witnessed the top of cement tagging (@ 1080') and approved a variance (with SLC concurrence) from the approved Plugging Procedure eliminating the requirement for a mud plug above the cement. A 291 foot thick cement plug was placed between 1080 and 789 feet immediately above the first cement plug. Mud was circulated into the well above the second cement plug and a 100 foot cement plug was placed at the top of the casing (Figure 5). Liquid wastes (excess muds, well fluids, etc.) generated during the procedure were stored in a mobile frac tank and disposed of offsite at an approved facility. A half inch thick steel plate was welded to the top of the well casing stub with the following information: 1) name of company, 2) well name and number, and 3) date cap was welded to casing.

All critical activities were witnessed and confirmed by the appropriate regulatory agencies. All drilling, production and appurtenant equipment, except some wood piling stubs, appear to have been previously removed. The Santa Barbara County Petroleum Office provided authorization for the wood piling stubs at the Chase #134-1 well site adjacent to the Goleta Slough to be left in-place to deter further erosion.

Conclusions

Considerable attention has been given by the regulatory agencies and public in California regarding decommissioning of idle oil and gas structures and facilities in State Tidelands ever since the first large scale project removed platform Harry (operated by Philips Petroleum) from offshore Santa Barbara County in 1974 (County of Santa Barbara, Planning and Development Department, Energy Division, 2000). From an operator perspective, the La Goleta Field well site "re-decommissioning" project posed somewhat different challenges due to the unique issues associated with this project. Regulatory and public support for this project was obtained with no objection. Timing and logistical issues were paramount. Considerable effort was directed towards achieving flawless performance from a safety, environmental, and compliance perspective; the described project was conducted without a single OSHA-recordable injury and no discharges to the environment of any kind occurred.

The successful outcome of this project is attributed to several key factors including:

1. a positive working relationship between regulatory agencies and operator,
2. utilization of innovative approaches, and
3. cost-effective management of complex coordination and logistics issues.

Acknowledgements - We thank the following people for helpful review and comment to this paper: Michael Cannon (ExxonMobil), Mike Parker (ExxonMobil), Tobe Plough (Management & Public Relations Consultant), Simon Poulter (Padre Associates), and Buck Steingraber (ExxonMobil). Padre Associates drafted figures 1, 2, & 3; Marka Risley assisted with figures 4 & 5; ExxonMobil granted permission to publish this paper.

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Tenera Environmental, 1998. Report on grunion egg survey conducted for the Mobil piling removal project, Goleta Beach, California (letter report dated March 27, 1998).

Agency	Permits/Approvals

California State Lands Commission (SLC)	CEQA Determination Work Permit Approval Approval to Plug Chase #134-1 well
California Coastal Commission (CCC)	Emergency Coastal Development Permit
California Division of Oil, Gas and Geothermal Resources (DOGGR)	Permit to conduct well operations Witness plugging activities Approval of Chase #134-1 well plugging Well site clearance
County of Santa Barbara Energy Division	Approval to Plug Chase #134-1 well Witness plugging activities Approval of Chase #134-1 well plugging Well site clearance
U.S. Army Corps. of Engineers	Regional General Permit Authorization (Section 10 & Section 404)

TABLE 1. Summary of key regulatory agencies and permits/approvals provided.

(Figures are contained in the separate files indicated in parenthesis)

FIGURE 1. Historic lease map indicating location of wells. (Robb & Menesez Fig 1.ppt)
FIGURE 2. Project site location map. (Robb & Menesez Fig 2.ppt)
FIGURE 3. Typical caisson construction diagram. (Robb & Menesez Fig 3.ppt)
FIGURE 4. Coil tubing unit configuration. (Robb & Menesez Fig 4.ppt)
FIGURE 5. Wellbore construction. (Robb & Menesez Fig 5.ppt)

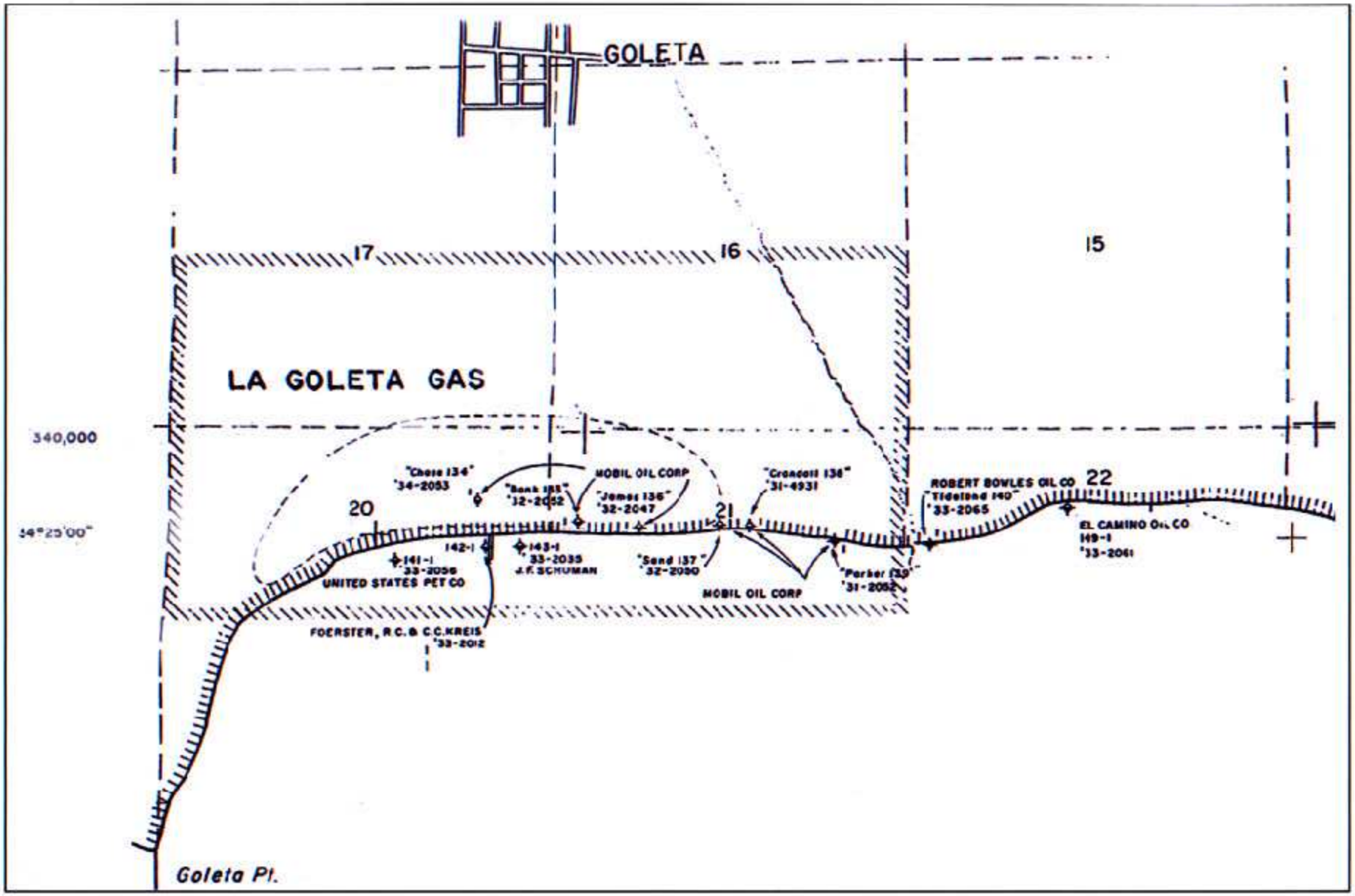


FIGURE 1 - HISTORIC LEASE MAP INDICATING LOCATION OF WELLS

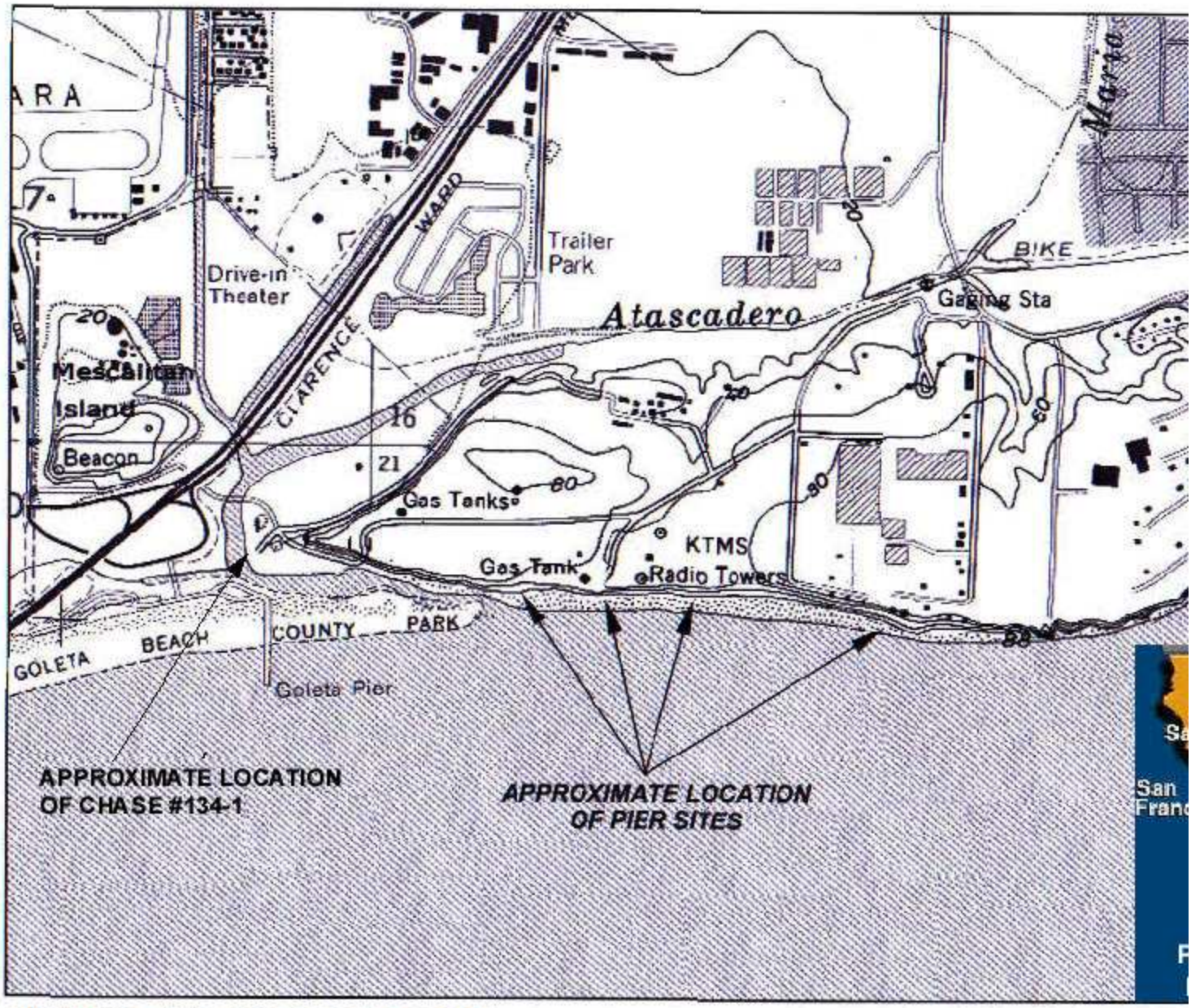


FIGURE 2 - PROJECT LOCATION MAP

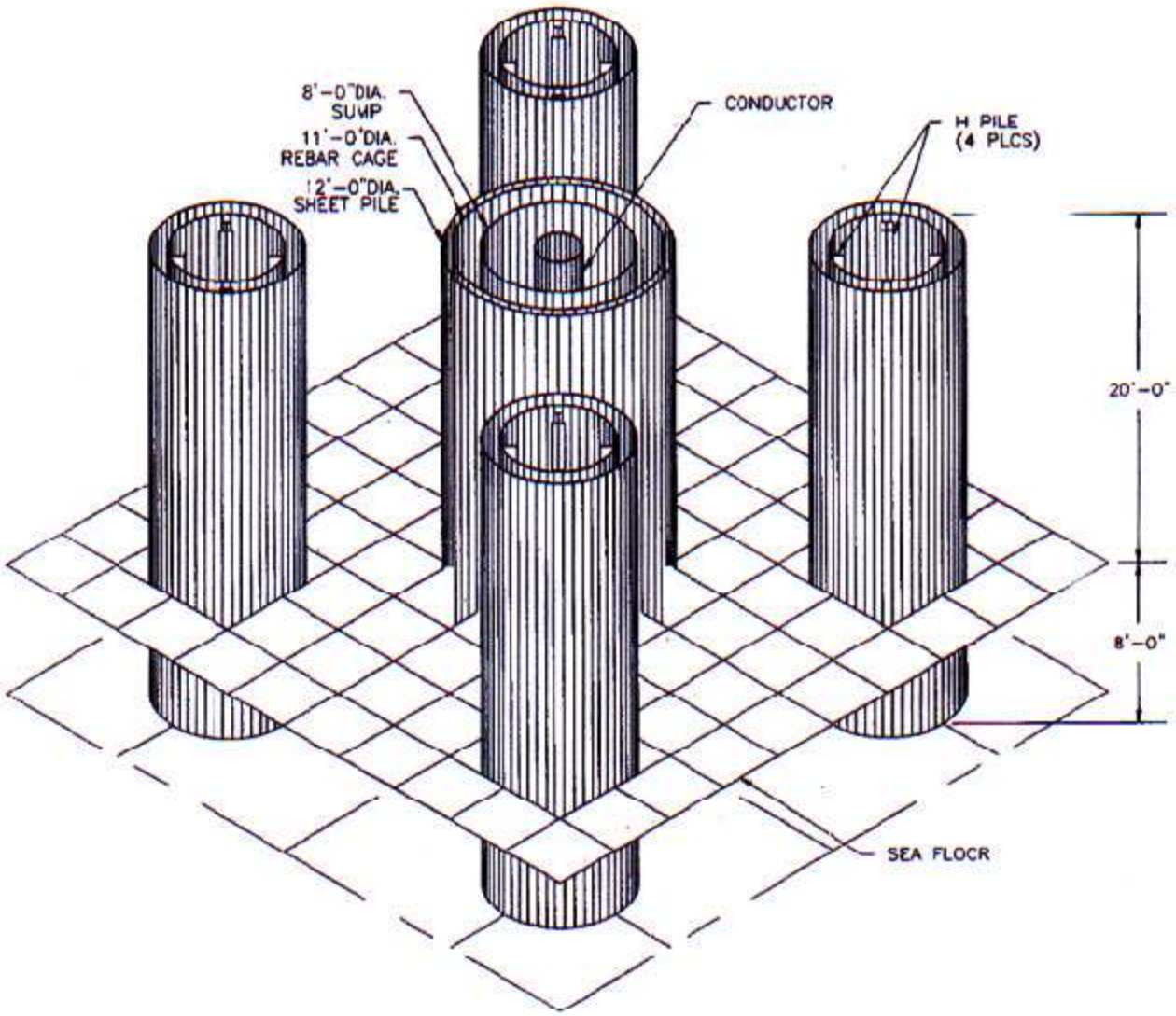
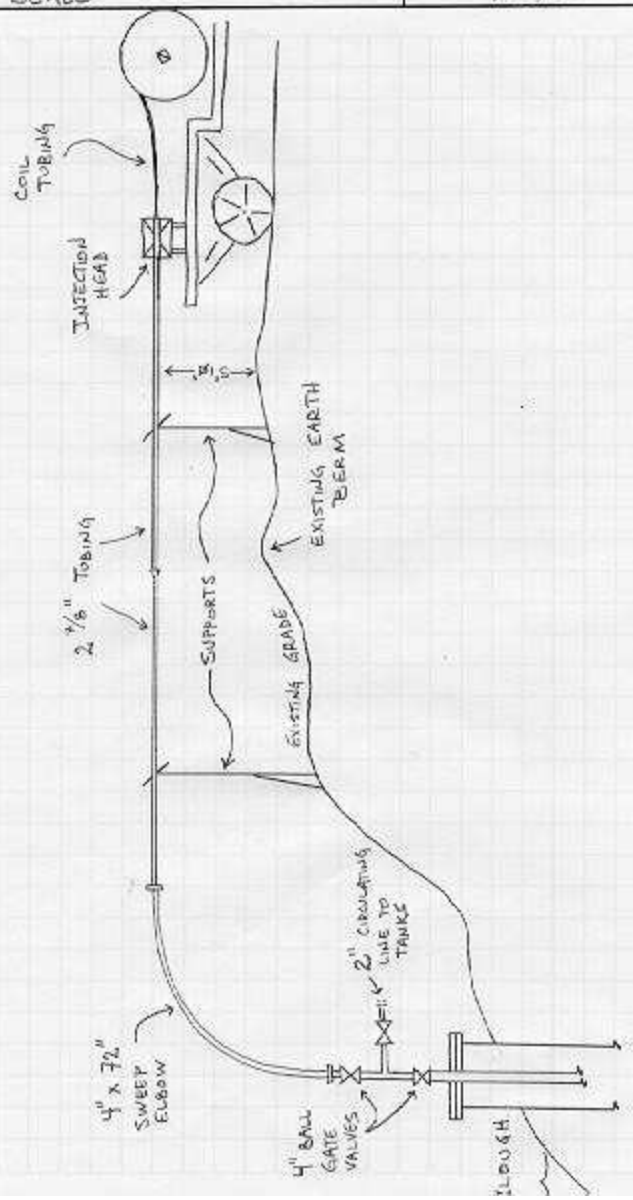


FIGURE 3 - TYPICAL CAISSON CONSTRUCTION

MOBIL

engineers calculation sheet

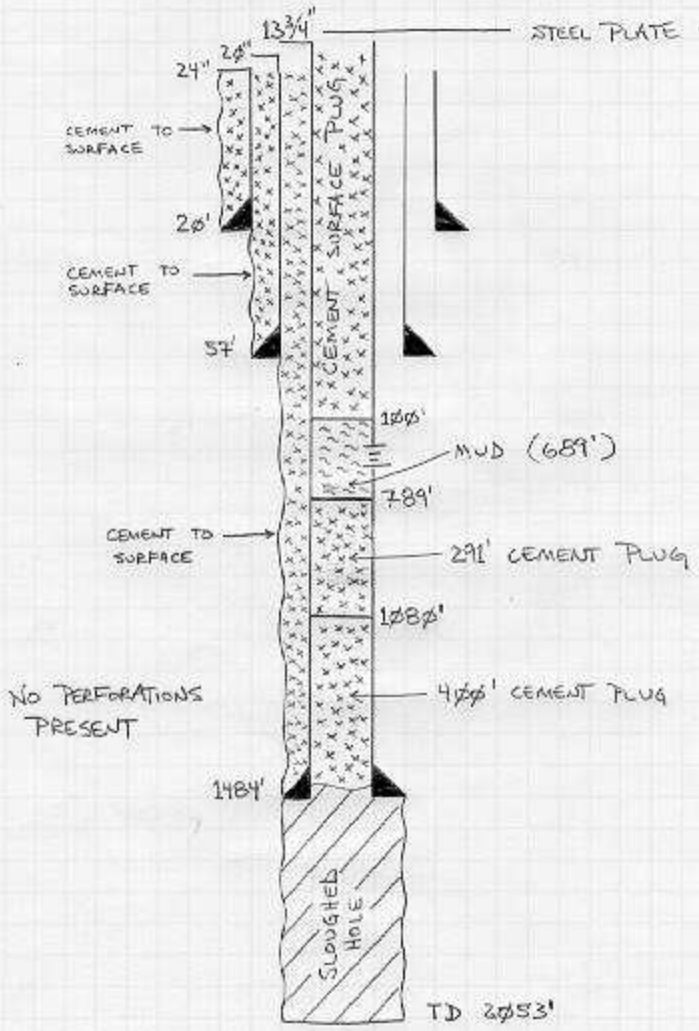
FOR P&A PROCEDURE	JOB OR AUTH. NO.
LOCATION CHASE #134-1, SANTA BARBARA CO., CA.	PAGE 1/1
SUBJECT COIL TUBING CONNECTION	DATE 29 AUG 01
NO SCALE	BY AJR



MOBIL

engineers calculation sheet

FOR P&A PROCEDURE	JOB OR AUTH. NO.
LOCATION CHASE #134-1 SANTA BARBARA CO, CA	PAGE 1/1
SUBJECT WELLBORE CONSTRUCTION (POST-P&A)	DATE 29 AUG 91
NOT TO SCALE	BY AJR



Ground Water Sampling Using Low-Flow Techniques

Cynthia J. Paul and Robert W. Puls

Obtaining representative ground water samples is important for site assessment and remedial performance monitoring objectives. The sampling device or method used to collect samples from monitoring or compliance well can significantly impact data quality and reliability. Low-flow or minimal draw-down purging and sampling techniques is an alternative method for obtaining representative samples from conventional monitoring or compliance wells or from low permeability formations and fractured rock. Use of low-flow techniques can minimize purge volumes and decrease monitoring costs as well as provide representative and reproducible ground water samples. The use of dedicated sampling devices in conjunction with low-flow purging and sampling can eliminate initial disturbance into the formation caused by pump insertion and further minimize purge time. Periodic monitoring of the water level within the well should be conducted throughout purging and sampling in order to measure draw-down. The flow rate of the pump should be adjusted to match the ground water entrance velocity into the well screen. Water quality indicator parameters (pH, redox, specific conductance, DO, turbidity, temperature) should be monitored during purging to determine when adjacent formation water has entered the well screen and sampling can be initiated. Stabilization criteria for water quality indicators is defined as three successive readings, at three minute intervals, within ± 0.05 for pH, ± 5 mV for redox, ± 3% for specific conductance, ± 10% for DO, and ± 10% for turbidity. However, some parameters are more sensitive than others (e.g., redox, DO) and should be evaluated with time over several sampling events before establishing a sampling protocol.

This is an abstract of a proposed presentation and does not necessarily reflect EPA policy.

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REPORTING PROGRESS TOWARDS
SOURCE WATER ASSESSMENT AND PROTECTION

Questions by Bruce Olsen
Minnesota Department of Health
August 29, 2001

Part 1 - National Reporting Issues

1. What questions has Congress asked EPA regarding the status of state wellhead protection programs and the preparation of source water assessments? How effective are current state reporting efforts towards answering these questions? To what degree has EPA involved the states in answering Congressional questions beyond asking for data?

2. Has Congress asked questions of other federal agencies regarding source water protection and are they sharing their findings with EPA?

3. What is the responsibility of the states to report data to EPA that would support the Agency's internal goals developed to meet requirements of the federal Government Performance Results Act (GPRA)? How will state reporting be affected by potential differences in the GPRA goals prepared by individual EPA regions versus Headquarters?

4. What existing federal statutes or rules require reporting and on whom is the reporting burden placed?

5. What uses for state-generated information have been identified within EPA? To what extent has EPA been able to generate answers internally with existing data versus asking states to report additional data or to provide different programs within EPA with the same information?

6. With what other federal agencies does EPA share reporting data relating to the status of state wellhead protection programs?

7. Given the lack of direction nationally regarding the content of protection plans for surface water intakes, what process will EPA use to determine the data elements it needs to track state progress in this area? What legal basis is there for states to report progress towards protecting surface water sources of drinking water?

8. What pending federal rules will require data reporting that can be used by EPA to track progress towards source water protection?

9. How will EPA solicit data from state agencies other than the state primacy agency for administering federal wellhead protection and source water assessment programs? How will EPA coordinate reporting under the Clean Water Act that is needed to report progress towards implementing wellhead protection or completing source water assessments under the Safe Drinking Water Act?

10. How will EPA track federal efforts such as environmental review, permitting, and enforcement actions that are used to protect sources of public drinking water? Will EPA report these actions to the state primacy agency that administers the wellhead protection program?

11. Will the Safe Drinking Water Reporting System be used by EPA as the central data base for housing state reported data?

12. How will EPA address differences in the wellhead protection delineations or source water assessment area delineations along state borders? How will states report progress if there is a dispute between them regarding the status of protection efforts?

13. Will EPA recognize the source water protection area for a surface water intake if the area designated by a water utility differs from that designated by the state? What future legal issues may arise because there is no national or state process for approving the delineation of a source water protection area for a surface water supply?

Part 2 - State specific reporting issues

14. What additional data management capabilities will be needed to 1) meet future reporting required by federal statutes and rules or 2) serve data out in a format that EPA can use to develop a national overview of source water assessment and wellhead protection efforts?

15. How much time will states have to meet federal standards regarding the locational accuracy of sources of drinking water or the locations of potential contamination sources?

16. How will the results of future source water assessment updates be reported to EPA? Will EPA accept these updates if the state changes its approach to preparing source water assessment updates? Does EPA have authority to re-approve a state source water assessment program after the time period for completing assessments has passed?

17. Should different criteria be used to assess state progress towards protecting sources of drinking water based on factors such as 1) whether wellhead protection is required or voluntary, 2) the number of public water supply systems, or 3) goals specified in EPA-approved state wellhead protection program descriptions?

18. Why should states report the geographic coordinates of drinking water sources to EPA if the Agency cannot make this information available to the public? Why should states report the boundaries of wellhead protection areas or source water assessment areas if EPA determines that this data cannot be made publically available? Can't EPA just access this information from a state's web site rather than ask it be reported directly to a federal

data base? How often will EPA need updates if a state is continually adding locational information such as for newly constructed wells?

19. What quality assurance procedures are in place at the state level to ensure that data reported to EPA are not altered during incorporation into national data sets? What QA/QC documentation will states have to provide EPA to meet federal data reporting requirements for wellhead protection or source water assessment programs?

20. How long will states have to keep the results of source water assessments available on a web site if they indicated they will do this in their EPA-approved source water assessment program description? What was the intent of Congress regarding keeping the results available to the public over time? Did Congress consider this when determining the mechanism for funding source water assessment work?

Part 3 - Determining What to Report

21. What are the aspects of protecting a source of drinking water that need to be reported so that Congressional questions are accurately and effectively answered?

22. How do states report the differences between a source water assessment and the implementation of measures to protect a source of drinking water?

23. Does reporting the "steps" reached toward developing a protection plan provide the information needed to assess the status and effectiveness of drinking water protection efforts?

24. What are measures that can be used to demonstrate coordination between local, state, and federal efforts to protect a source of drinking water?

25. Are some elements of drinking water protection simply not reportable because they are not enough resources available to track them? For example, how is the effectiveness of implementing BMPs by land owners measured if there is no one to compile results? How does this impact state and federal abilities to measure success of protection efforts?

26. Source management strategies may be implemented in stages to reflect state and local resource and legal issues. How should staged implementation of plans be reported?

27. When do the costs of reporting results stand in the way of using available resources to implement protection measures? When do the states get to the point of diminishing returns for the time and expense invested in reporting versus working with local wellhead protection teams?