faces numerous concerns

Anthony W. Gorody
Universal Geoscience Consulting Inc.
Houston

CBM ENVIRONMENTAL ISSUES—1

Operators contemplating developing coalbed methane gas (CBM) face numerous regulatory, residential, and legal concerns.

At stake are millions of dollars to assess, dispute, and settle claims regarding the impact of production practices.

This expenditure does not include the hidden costs for managing in crisis and redirecting a sparse labor pool to handle environmental issues.

This first article of a two-part series summarizes allegations stemming from these concerns in the San Juan, Black Warrior, and Powder River basins (Fig. 1). The concluding part will discuss how operators can foresee and address in a more cost-effective way these concerns with a marginal amount of environmental base line information.

The most common complaints attributed to CBM practices in the San Juan, Black Warrior, and Powder River basins are as follows:

- Loss of domestic water quantity.
- Progressive deterioration of either surface or groundwater quality.
- Emergence of potentially dangerous concentrations of free and dissolved methane in both water and soils.

These complaints arise from a variety of causes, but this article will discuss information, contained in legal documents or published by regulatory agencies, that attribute these problems to CBM production practices.

Changes in water quantity, water quality, dissolved gas concentrations found in domestic water wells, or the perceived rate of methane seeps at the surface are naturally occurring phenomena, and one easily can attribute these phenomena to numerous factors other than CBM production operations.

CBM operations could not be assailed as easily if supported by data gathered in a base line sampling program conducted prior to and during the onset of CBM production.

Domestic water quantity

Several reasons can explain declining water yields in domestic water wells that might be completed in aquifers hundreds of feet above or below a producing coal horizon. A frequently quoted and widely held popular view is that drawing water from a coalbed aquifer is like drawing water from a glass through a straw. A lower water level in the glass will lower the water level in the straw.

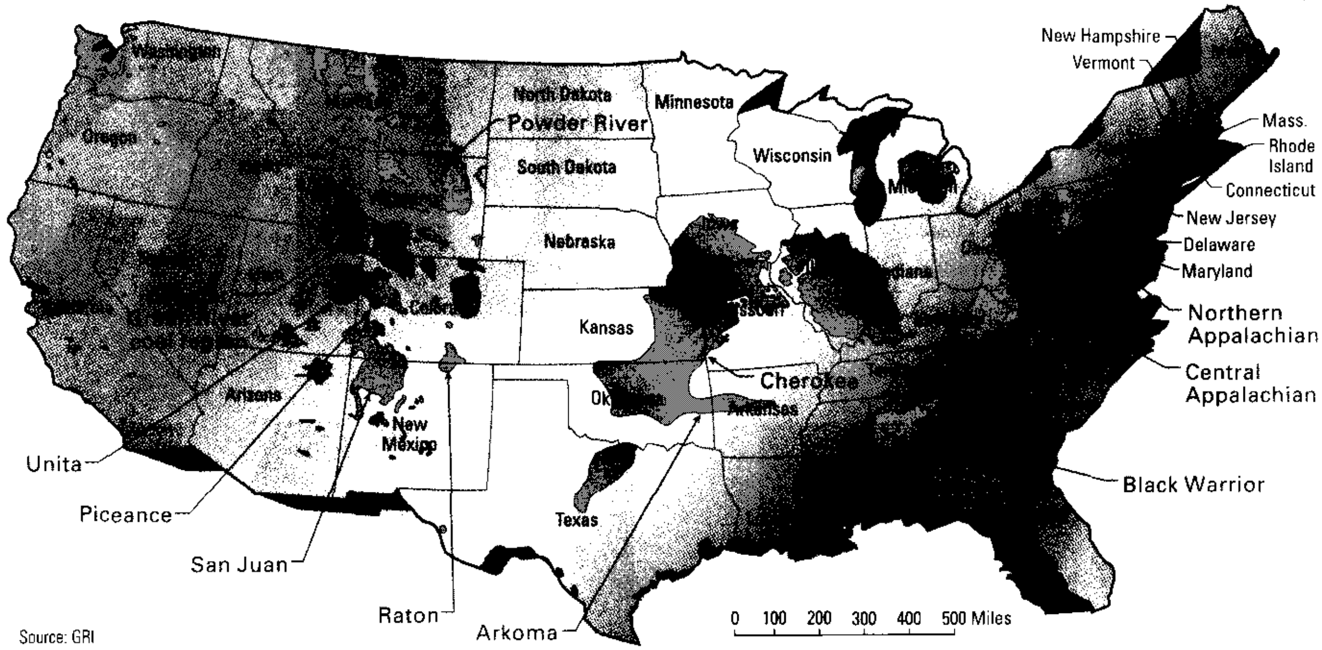
This simplistic view is reinforced by the misconception that local aquifers have a regional extent and that they are both vertically and laterally homogeneous.

A more reasonable claim is that numerous permeable conduits can connect coal seams with overlying and underlying aquifers. These conduits include naturally occurring fractures, fractures induced by either underground mining or hydraulic fracturing, and poorly constructed producing or abandoned oil and gas wells.

The most pressing concerns, expressed by both state and federal regulators, are for CBM production in the proximity of basin

US COAL BASINS

Fig. 1



Source: GRI

margins. It has been asserted that downdip production can lower water levels in domestic water wells completed near or within outcropping CBM producing horizons.

Lowered water levels allegedly also may increase the risk for spontaneous coal combustion.

Surface, groundwater quality

Various sources cite that induced changes in the oxidation state of water in wells may be caused by changes in water quality attributed to CBM practices.

If one assumes that migrating coalbed methane can bubble through a domestic water well, the methane will displace free oxygen or generate conditions favorable for a chemically reducing environment. For example, bacterial consortia can assimilate the carbon in the organic methane molecule by forming simple building blocks for cell growth.[1]

Increased methane concentrations, therefore, can accelerate the activity of bacterial consortia living in water. This can have two effects.

The first effect increases the bacterial waste in water. These increased levels of bacterial cell matter and slime can turn clear water cloudy and cause it to appear unappetizing (Fig. 2).

The second effect lowers free and chemically bound oxygen levels that bacteria consume for respiration. A progressive loss of oxygen can promote the growth of iron-reducing bacteria (IRB) and sulfate-reducing bacteria (SRB).

SRB will strip sulfate ions of their oxygen during respiration. The byproduct of this metabolic process is carbon dioxide (CO_2) and hydrogen sulfide (H_2S) gas. The presence of H_2S is unmistakable. It emanates as an offensive odor usually described as similar to the smell of rotten eggs. Water containing dissolved H_2S is mildly acidic, and can corrode faucets, shower heads, and appliances.

IRB, on the other hand, will allow iron to readily dissolve in water. Dissolved iron and sulfide ions can combine to form suspended particles of iron sulfide that will impart a dark gray color to water. The iron quickly will oxidize and precipitate as an insoluble, rust-colored iron hydroxide when reduced waters rich in dissolved iron are in a home's plumbing system and come in abrupt contact with air. This precipitate can stain porcelain fixtures, faucets, and even discolor laundry (Fig. 2).

Bacteria can also be agents of chemical change in increasingly oxidized waters. If one assumes aquifer water levels fall as a result of CBM production, a water pump operating in progressively shallow water will draw more oxygenated water that is in closer contact with air.

If oxidation occurs in a wellbore containing dissolved iron, then iron-oxidizing bacteria will convert the iron to an iron hydroxide precipitate. This imparts a rusty red color to water and, if present in large concentrations, will render water opaque. The water will also tend to have an unpleasant taste, commonly described as metallic.

Various sources also cite that both chemical reduction and oxidation of domestic aquifers result from chemical reactions induced when produced water, discharged at the surface, infiltrates shallow aquifers.

Surface discharge also can affect surface water chemistry by changing salinity or modifying historic concentrations of metal ions.

Methane seeps

Methane seepage is the third and last type of complaint attributed to CBM production activities. Seeps pose the greatest potential safety hazard and engender the greatest fear among residents.

Methane is an odorless and colorless gas that can lead to spontaneous explosions if allowed to reach concentrations of between 5 and 15% by volume in air. This range is defined by the lower and upper explosive limit of methane, respectively. Such concentrations can be reached in two ways: by an exsolution of dissolved methane that is allowed to collect in an enclosed and unven-

The bucket, left photo, contains black water from the San Juan basin that is typical of water having reduced iron and manganese. This water sample had a sulfide smell. The other bucket, left center photo, contains red water from the Black Warrior basin that is typical of water having oxidized iron from an area affected by historic strip mining.

The stained appliances (two right photos) are from separate households in the Black Warrior basin. This staining is typically produced by the precipitation of insoluble iron oxides (Fig. 2).

tilated space or by the accumulation of free gas seeping to the surface.

Methane seeps can displace normal oxygen levels in soil and kill vegetation, and extensive gas seeps can alter noticeably the vegetative landscape. The seeps also can behave as a carrier gas that transports undesired concentrations of H_2S to the surface.

In sufficiently high concentrations, H_2S irritates skin and eyes and, in the worst scenario, leads to loss of consciousness or death.

Litigators too easily explain the origin of dissolved methane in water wells and methane seeps as being from coalbed methane operations that lower the hydrostatic pressure and cause large quantities of gas to be released into the subsurface. Implied in this explanation is the idea that gas released from a coalbed methane reservoir has easy access to the surface and surrounding aquifers.

Both litigators and regulatory agencies have identified four migration mechanisms to account for methane in domestic aquifers and for methane seeps:

1. Vertical migration through large, natural fractures that extend vertically from the producing reservoir to the surface or domestic aquifer.

2. Gas migration along access paths provided by wellbore conduits. In the San Juan basin, for example, well installation practices conducted prior to the 1950s left the production casing annulus of deep oil and gas wells uncemented across both the shallower Fruitland formation and overlying strata.

Consequently, when CBM operations began in the 1980s, desorbed gas was free to migrate vertically from the Fruitland coal along the wellbore annulus and into shallow aquifer horizons.[2]

Domestic water wells can also provide gas conduits to the surface. For example, gravel packing of wells completed in the Wyodak coal seam was at one time an appropriate completion method for domestic water wells in the Powder River basin. Since CBM operations have begun, however, water yield in several such wells has declined, and the gravel pack has provided a conduit for gas to migrate to the surface.

3. Methane liberated during production could migrate updip until it emanates from the outcrop or shallow subcrop, near basin margins where gas seeps emerge along the outcrop belt of producing coal seams.

4. Alternatively, down-basin production could lower water levels near the outcrop and allow gas to be released at the surface via in situ desorption of gas-saturated coal seams, also near basin margins where gas seeps emerge along the outcrop belt of producing coal seams.

Production-related complaints

It is essential that operators understand the natural plumbing dynamics of regional coalbed aquifers, and both overlying and underlying aquifers within 100 ft of a CBM producing horizon. Otherwise, their drilling, completion, and production methods may cause invasion water from outside the producing formation.

Under the right conditions, significant local cross flow between aquifers can occur both within and outside of the immediate wellbore environment. At best, this results in unnecessary costs for pumping out excess water. At worst, cross flow alters the geochemical properties of a CBM reservoir.

For example, cross flow can introduce dissolved sulfate into a reservoir causing sweet coalbed methane to turn increasingly sour. Operators can incur significant costs for monitoring, controlling, blending, and processing souring gas reserves.

Cross flow also can introduce fluids that promote wellbore scaling or corrosion. To control these effects, operators may have to inject expensive additives repeatedly into wells and reservoirs.

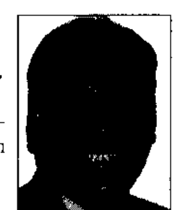
CBM operators continually evaluate their drilling and production strategies. Questions of greatest economic importance relate to issues such as optimum well spacing, and the impact of infill drilling on correlative rights.

Questions of this kind are usually left to the reservoir engineer to answer. Yet few operators realize that base line sampling of the producing reservoir and temporal monitoring techniques provide powerful and useful tools for both constraining and supporting reservoir engineering models. ✦

Reference

1. Erlich, H.L, Geomicrobiology, Marcell Decker Inc., 1996.
2. Beckstrom, J.A., "Aquifer protection considerations of coalbed methane development in the San Juan Basin," SPE Formation Evaluation, 1993, pp. 71-80.

The author



Anthony W. Gorody is an environmental scientist and a principal with Universal Geoscience Consulting Inc., Houston. As an advisor and analyst for oil and gas companies, he has participated in defending major litigation involving coalbed methane operators in the US during the past 15 years. He also assists and trains managers to implement enviromental risk analysis when developing shallow gas plays. Gorody has an MS and a PhD in geology and geochemistry from Rice University, Houston.

CBM ENVIRONMENTAL ISSUES—Conclusion

Base line studies assess regional aquifers

Anthony W. Gorody
Universal Geoscience Consulting Inc.
Houston

Prudent base line measurement and monitoring practices of regional aquifers are relatively easy and inexpensive to implement and can provide data that alleviate controversy and uncertainty about whom to blame for a variety of complaints perceived to result from coalbed methane operations.

Base line methods focus on understanding production practices from a perspective of potential impacts on the physical and geochemical properties of regional aquifers. Base line measurements are best used for assessing risk and targeting areas where health, safety, and quality of life issues are important.

Also, these measurements provide substantial secondary benefits. The right information can help operators to constrain reservoir engineering models, detect reservoir compartmentation and anisotropy, verify the need for infill drilling, assess wellbore integrity, and predict the potential for souring gas reserves.

This concluding article in a two-part series discusses when and how to implement base line studies. The first part (OGJ, July 23, 2001, p. 66) described regulatory, residential, and legal concerns related to coalbed methane (CBM) production.

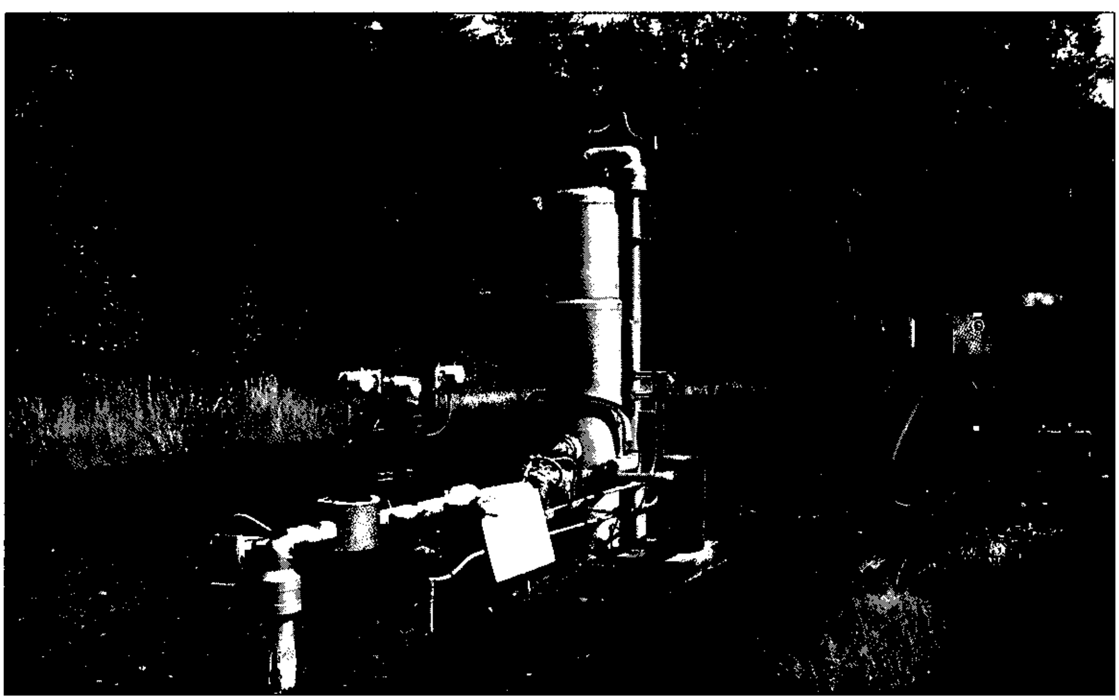
Figs. 1 and 2 illustrate surface equipment found in some coalbed operations.

Base line studies

In view of the environmental controversy and negative popular perceptions that plague CBM development, base line studies are a relatively minor cost of doing business. Operators should consider including the right to perform base line testing of a lessor's water wells in their mineral lease. Such studies should then be carefully planned before and during lease acquisition and implemented before and during production. Table 1 lists components that can be included in a base line monitoring action plan.

At the very least, simple work should be performed that includes testing a lessor's water wells, noting mechanical problems, determining water yield, detecting the presence of methane before production, and noting anecdotal evidence of methane discharges at the surface.

At best, a more detailed sampling and analysis of groundwater chemistry will help operators understand environmental conditions before production.



Some Black Warrior basin wells, such as this one, have downhole progressive-cavity pumps for dewatering the methane producing coalbeds (Fig. 1).

BASE LINE MONITORING ACTION PLAN

Table. 1

Background data	Sampling plan	Monitor well plan	Site investigation
Geology	Outside development plan	Random seasonal sampling	Detailed investigation
Hydrology	Inside development plan	Related to operations	*Remediate*
Prior publications		*Establish trends, and action triggers*	
State and federal agencies	Known problem areas		
Regulatory documents	Critical areas at risk		
Maps	*Establish base line values, and thresholds*		
Imagery			
Visual site inspections			
Local inquiry			
Define risk, environmental parameters, sampling protocols, and cost benefits			

Armed with these studies, operators can better quantify the risks associated with production activities and prioritize the development of acreage positions.

Delaying production in environmentally sensitive areas can provide ample time for establishing monitoring sites that can provide early warning signs of impending problems.

Remediation costs will be minimized when a program is in place to detect early warning signs and when contingency actions have been planned in advance. Operators who are sensitive to changes in the environment surrounding their producing fields are also in the best position to ward off needless litigation.

Local and regional base line analysis of aquifer properties should be conducted in two stages: a sampling and analysis program followed by a monitoring program.

During initial sampling, a minimum amount of data should be collected to help operators define early warning signs of impending problems relevant to the following most common complaints attributed to CBM production:

1. Domestic water well quantity or yield.
2. Domestic water well quality.
3. Occurrence of free or dissolved methane.

Subsequent monitoring should be conducted in sensitive areas to determine if there are statistically meaningful trends in the value of environmentally sensitive parameters that may correlate with CBM activities.

A cost-effective sampling program limits the scope of investigation by identifying three areas of greatest concern:

1. Where the risk of affecting local residents is greatest.
2. Where water well problems unrelated to CBM production operations already are known to exist.
3. Where either the risks of affecting production revenues or the opportunities for maximizing revenues are greatest.

Sampling should proceed with a randomized method for selecting sampling locations that are both within and outside of all three areas of interest. This approach minimizes possible bias and allows objective comparison of geographic and time-varying trends through the use of accepted statistical hypothesis-testing methods.

Sufficient samples should be collected to establish statistically meaningful threshold values of the environmental parameters that are most useful for warning operators of impending problems. These threshold values should be defined and used to establish action triggers.

Examples of actions to be taken might include additional sampling for more thorough analysis, or remediation. Threshold values can also be used to guide operators in establishing protocols to implement consistent drilling, completion, and production practices.

Establishing hierarchy

Advanced planning can minimize the costs for a base line sampling and analysis program. The planning should begin early in the leasing phase of a shallow gas prospect, and it should be designed by a multidisciplinary team, with members having different background training and responsibilities. For example, landmen, geologists, log analysts, reservoir engineers, and hydrologists.

Ideally, the team should be led by an individual who has good leadership skills and is comfortable working with multidisciplinary data. The team leader should be responsible for knowing where and how to retrieve base line information in the event of problems.

A cost-effective base line sampling program consists of a pyramidal hierarchy of tasks performed sequentially. Each task leads to a subsequent and more expensive analysis level that may be required to characterize critical environmental parameters satisfactorily.

Over the long-term, the advantage of a staged program is that additional costs only are incurred if necessary.

Reconnaissance

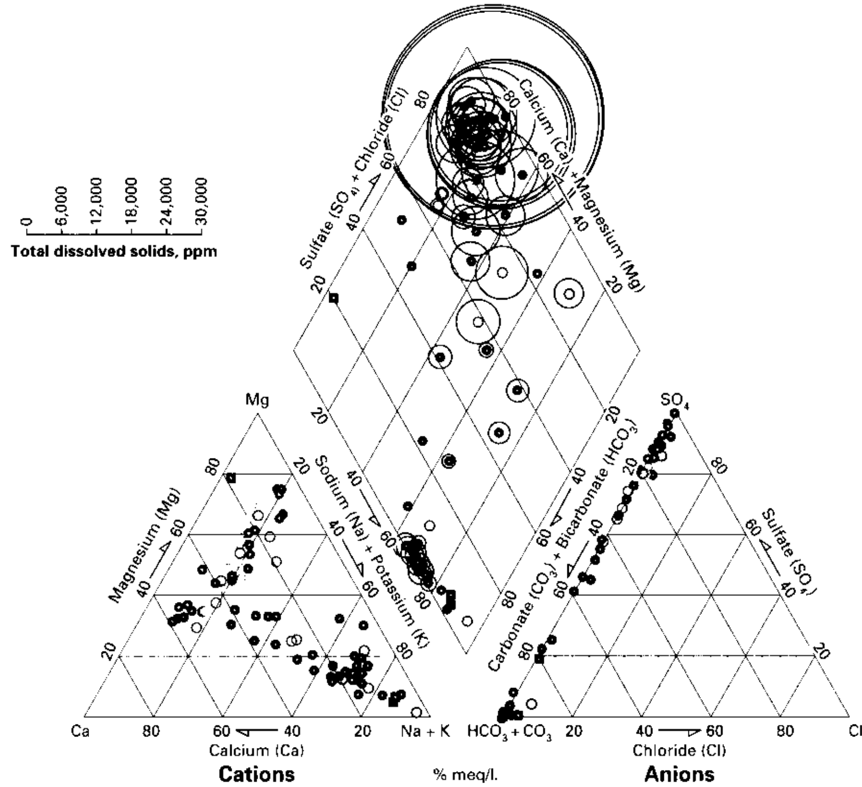
Compiling a variety of hydrologic, historic, and geologic data in a shallow gas basin is important and offers the greatest benefits at the lowest cost. These data can provide 80% of the information for assessing potential environmental impacts and the relative risk associated with shallow gas drilling and development.

This reconnaissance provides operators with:

- Historical context for evaluating water quality and quantity delivered by various aquifers.
- Historical context for known gas seeps.
- Historical context for areas that may be affected by other potentially hazardous anthropogenic activities.
- Regional framework for determining base line sampling areas.
- Regional framework for designating critical areas at risk that should be sampled or monitored.

This evaluation will define specific requirements for spatial and ongoing ten

Fig. 3



water levels. One, therefore, needs to document this variability.

Sampling also should be conducted before soil freezes or after it thaws.

Sampling objectives

After one gathers the information in a reconnaissance study and has differentiated base line areas from critical areas at risk, then it is time to design an aquifer characterization program[3,7] into three components:

1. Documenting and implementing standardized sampling and analysis protocols.
2. Making provisions for quality assurance and control practices in the field and among laboratories used to provide analyses.
3. Designing rigorous statistical tests to evaluate multiple hypotheses.

Operators should be aware, however, that they will inevitably be accused of collecting biased information. Strict adherence to and documentation of objective sampling and analysis practices will help alleviate such concerns.

One should collect both spatial and temporal samples to characterize adequately any site. Spatial sampling defines, compares, and contrasts geographic patterns in data collected from local and regional aquifers. This sampling requires one to design a grid and use a grid spacing that is appropriate for capturing a minimum amount of information at a desired scale.

One can gather samples at random anywhere inside the grid, which is an example of random stratified sampling. The number of samples must be designated if one statistically analyzes the aquifer data. For example, a set of 24 samples is a reasonable estimate, within 20%, of the mean and variance for a single aquifer parameter.

For example, permitting data complying with the Surface Mining Control and Reclamation Act, the Bureau of Mines, the US Geological Service (USGS), and state departments of environmental quality are excellent sources for base line hydrologic and geologic data.

Wireline logs record porous and permeable fairways in shallow aquifers that underlie residential areas. These logs help differentiate aquifer horizons that are trapped by domestic water wells completed at different depths. Wherever possible, one should identify key marker beds and then plot their distribution on structure maps.

Shallow structural and stratigraphic traps could provide local reservoirs for shallow gas to accumulate.[2] To identify these, if shallow wireline logs are not available, one can run gamma ray logs through casing whenever a CBM producing well needs repairs.

Maps and images can indicate the distribution of aquifers and possible natural gas seeps in a regional context. For example, geologic, soil, topographic, and vegetation maps should all be reviewed before designing a sampling program.

Remote sensing images and aerial photography provide valuable synoptic views of an area. For example, color infrared and color photography help identify evidence of current or historic coal burns. Spectral imagery can help identify areas where discharging aquifers (springs) may be transporting dissolved iron that oxidizes at the surface. These are logical places to test for methane and sulfide gas.

Climate data are of great value. Local airports and municipalities often keep accurate climate records for decades and the National Oceanic and Atmospheric Agency compiles data that are available on the internet.

Local and regional precipitation trends will establish the ideal timing required to collect seasonal samples. Local aquifers recharge during rainy seasons, when alluvial deposits are saturated and irrigation ditches are full. In semi-arid to arid environments, melting snow efficiently recharges local aquifers.

This variability will systematically influence analytical results because recharge will significantly affect aquifer

Temporal (repeated) sampling helps establish how the range of values for any given aquifer parameter varies at any location due to changing environmental conditions. One should defer the design specifications for collecting temporal samples until completing spatial surveys.

Spatial and temporal sampling programs can be used to design an aquifer monitoring program. Temporal sampling of producing CBM aquifers also provides a powerful means to assess reservoir continuity and to assess drainage patterns.

A sampling program should quantify parameters that are useful for characterizing the quality of various aquifers identified in the reconnaissance program. A sampling hierarchy should be used to minimize the costs needed fully to quantify environmentally relevant properties of soils and aquifers.

Three cost-based levels to a sampling hierarchy are: field sampling and analysis methods, standard laboratory analyses, and special laboratory analyses.

Field methods

Field sampling methods are screening tools and offer the most cost-effective means to establish the potability, oxidation state, and general chemical properties of water in aquifers over a large area. Only a few hand-held field instruments need to be calibrated daily for these analyses. These instruments measure acidity (pH), redox potential (Eh), temperature, conductivity (used to determine the relative concentration of dissolved chemicals), and dissolved oxygen (dO).

Other useful data pertain to observations made with one's senses such as water color, clarity, and smell. It is relatively easy and inexpensive to collect hundreds of field samples in a single season among a variety of sites that include springs, water wells, CBM production wells, streams, surface reservoirs, irrigation ditches, and other sources of aquifer recharge. This prolific source of information can then be used to selectively target a smaller suite of samples slated for more expensive laboratory analyses.

Sampling ambient air above various soil and outcrop horizons also provides a good means for screening sites where soil gas probes should be installed. Such sampling is usually performed along specified transects where gas seeps have been informally documented or can logically be suspected to occur. These types of analyses are best conducted in areas both far from and within critical areas of potential risk. Outcrops, producing wells, and production facilities are common risk targets.

A variety of hand-held sniffer detectors can analyze ambient air quality. One also can analyze headspace gases of soil samples, gases liberated from water samples collected in springs and streams, or gases liberated when domestic well water is used to fill sinks or buckets.

Of the available organic vapor analyzers (OVA), flame ionization devices (FID) offer the greatest sensitivity to low hydrocarbon concentrations. Many companies offering such services provide trained observers who can detect the surface manifestation of gas seeps. Alternatively, company personnel can be trained quickly to use rental equipment for such activities.

Walking the ground should be considered an important component of field analysis methods. Public education forums can help persuade residents to cooperate with an operator's efforts to randomly conduct sniffer surveys of residential basements and crawl spaces. One should always encourage educating a concerned public before production activities. Any excuse for two-way communication provides valuable clues regarding water quality issues already facing a community.

It is usually difficult to measure static water levels in domestic water wells. Obtaining permission to access properties is a significant problem in western states. Even if access is granted, many operators are leery of disassembling well heads for fear that they may be accused of damaging the well. Some operators may opt to drill and maintain monitoring wells at even higher costs.

At the very least, operators should randomly inspect a specified number of domestic well heads. A surprisingly large number of wells are poorly constructed, lack sanitary seals, or have other obvious problems that can account for poor water quality and quantity.

Numerous plaintiffs who have complained of declining water yields and water quality were unaware that their do-it-yourself maintenance practices allowed them to inoculate their wells with bacteria. As a result, rich bacterial cultures growing in their wells were so prolific that thick slime coated the aquifer, there restricting aquifer yield.

Laboratory analyses

Once an area has been screened with data from field analyses, there are more detailed and expensive analyses which c be conducted on a relatively small numl of targeted samples.

Targeting strategies are most effective when based on statistical analysis of fiel data. Results of such analyses can be use to unambiguously differentiate among aquifers. Each aquifer can then be selectively sampled and analyzed for a variety of specified inorganic and organic constituents.

Wet chemical analyses are standard a relatively inexpensive. A typical suite of analytes includes the major ions as follows: calcium, magnesium, potassium, and sodium (positively charged ions) ar carbonate, bicarbonate, sulfate, and chlo ride (negatively charged ions). Checking the charge balance between positively ar negatively charged major ions is one go way to check quality control.

Other analytes that are typically measured are iron and manganese, dissolved nitrogen compounds, and non-reactive ions such as bromine and fluorine. Some operators also measure the concentration of selected metals listed by the Resource Conservation and Recovery Act as potentially hazardous. It is also customary to measure other properties of water in the laboratory, such as pH, and conductivity.

In the search for potential sources of hydrocarbon contamination, samples should be analyzed for the total concentration of dissolved organic carbon components. Benzene, toluene, ethyl benzene and xylene (BTEX) analyses should be performed routinely as they are the best indicators of migrated petroleum or leaking sources of distillate and gasoline.

Special samples are needed to determine the concentration of dissolved methane in water. Analysis of dissolved g concentrations is particularly important because naturally-occurring bacterial methane is a common and ubiquitous constituent of basin margin aquifers.

Fig. 3 shows a trilinear, Piper diagram from water samples north of Gillette, Wyo., in the Powder River Basin. Blue do are surface and alluvial water samples, re circles are overburden water well sample black circles are coalbed produced waters, and purple squares are deep Fort Union aquifers. This diagram illustrates the distinctly recognizable hydrochemical facies of different aquifers in the area.

Special laboratory analyses

If gaseous hydrocarbons are found to be dissolved in water samples or discovered to be emerging along seeps, it is important to characterize them. Chromatography and isotopic analyses are the best means available to assess the likely source of gas contaminants. These measurements require special laboratory analyses which are reliably performed by only a handful of laboratories in the US and elsewhere.

Stable isotopic analyses of carbon, hydrogen, and oxygen are the most expensive environmental measurements generally made in CBM production-related base line studies. In some areas, the stable carbon isotopic content of methane is sufficient to distinguish between methane of thermogenic and bacteriogenic origin.

In many instances, however, the stable isotopic compositions of carbon and hydrogen in methane, carbon in associated carbon dioxide, and the hydrogen and oxygen of associated water samples are all needed to differentiate adequately among potential gas sources.[8]

The stable isotopic composition of gas samples collected near or at the surface should be compared with stable isotopic analyses of methane collected from a select number of producing wells tapping all producing horizons. ✦

References

1. Gorody, A.W., "The origin of shallow gas in groundwater overlying the Ignacio-Blanco gas field, San Juan Basin, near Bayfield, La Plata County, Colorado," Wyoming Geological Association, 52nd Annual Conference Guidebook, In press, 2001.
2. Wiese, K., and Kvenvolden, K.A., "Introduction to microbial and thermal methane," In: The Future of Energy Gases, USGS Prof. Paper 1570, 1994, pp. 13-20.
3. Koterba, M.T., Wilde, F.D., and Lapham, W.W., "Ground-water data-collection protocols and procedures for the national water-quality assessment program: collection and documentation of water-quality samples and related data," USGS Open File Report 95-399, 1995.
4. Mueller, D.K., Martin, J.D., and Lopes, T.J., "Quality-control design for surface water sampling in the National Water-Quality Assessment program," USGS Open File Report 97-223, 1997.
5. Shelton, L.R., "Field guide for collecting and processing stream-water samples for the National Water-Quality Assessment program," USGS Open File Report 94-455, 1994.
6. Ott, W., Environmental Statistics and Data Analysis, Lewis Pub., 1995.
7. Cothern, R.C., Handbook For Environmental Risk Decision Making: Values, Perceptions, and Ethics, Lewis, Pub., 1996.
8. Clark, I.D., and Fritz, P., Environmental Isotopes In Hydrogeology, Lewis Pub., 1997.