Ground Water and Surface Water Contamination Issues of Oil and Gas Development in Ohio

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Potential impacts of gas well construction and hydraulic fracturing process on ground water—theory and practice

Ohio has a long history of oil and gas development, with its first oil well (near Macksburg in Washington County) put into production in 1860 (shortly after Drake's well in Pennsylvania, developed in 1859). The nature of the long geologic history of the land that would become Ohio destined it to have both abundant hydrocarbon-rich source rocks and reservoirs and traps to serve as exploration targets. These same reservoir rock units are productive injection zones. As a continental margin over long periods, thick layers of carbonate rock and shale were deposited in shallower or deeper seas, and sandstone and sandy shale in deltas and as a result of the erosion of mountains to the east. Tectonic action resulted in mountain-building episodes, associated deep layers of sandstone and sandy shales, and prominent fault zones.

Social, commercial, and industrial development in Ohio provide the stage on which oil and gas development occurred early in the industry's technical formation – just years after we were lighting lamps with whale oil and firing steam engines with wood. By the 1860s, and especially by the 1880s, tubular iron and steel pipe and the cable tool drilling rig, powered by steam engines, and later internal combustion engines, made developing Ohio's rather shallow oil and gas deposits technically feasible. The Trenton is only about 1,100 ft (300 m) deep in northwestern Ohio, well within the depth capability of cable tool well drilling rigs currently in use. The development of fuels, power generation, and engine-powered vehicles all occurred within Ohio and surrounding states late in the 19th and early 20th Centuries. Cities like Lima, Findlay, and Toledo and their industries grew and prospered due to the oil and gas wealth.

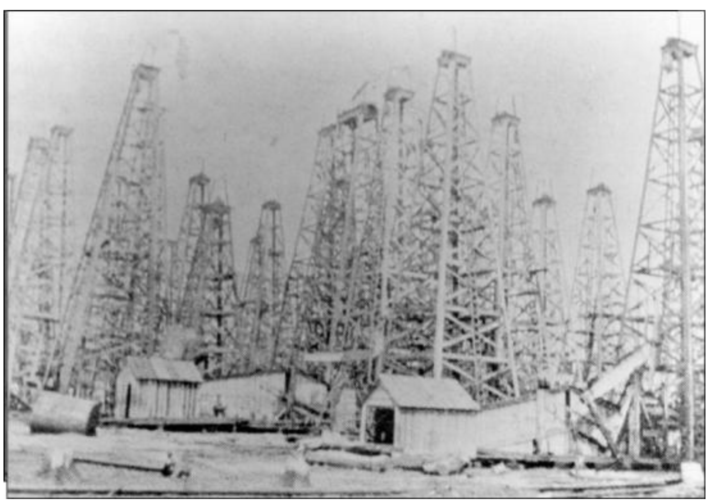


Fig. 1. Oil wells, 1880s, near North Baltimore, Ohio. Ohio Dept. of Natural Resources

The Trenton fields, extending across Northwest Ohio and into Indiana, and the Clinton Sandstone, developed beginning in the 1880s, were the largest oil and gas developments in North America until the development of Spindletop in Texas, and remained major producers for decades, with the Trenton mostly depleted by 1936.

As Figure 1 illustrates (like similar photos from the era), there was virtually no management of the oil and gas resource at that time (the Division of Oil and Gas was not formed until 1965). There (were/was) no:

- Well spacing control to prevent local depletion of pressure – probably 100,000 wells tapped the Trenton.
- No blowout preventers (on the market starting about 1924) so that when wells tapped pressurized liquids, they had to run as gushers (like in the movies) until manageable, depleting pressure.
- Gas was virtually unmanageable and typically flared or run through city light systems as in Findlay.
- No effective well plugging systems – boulders, cannon balls, trees…
- Casing pipe (often seamed and early on riveted) was prone to leaking.
- No effective annular grouting.

Consequently, estimates are that 1 trillion cubic feet of gas in the Trenton gas cap was wasted by 1891 in Ohio. The reservoir pressure was depleted prematurely (perhaps 90 % of the oil is left but no pressure to move it toward wells). Probably millions of barrels ran down ditches and into local drainage and streams. Unknown numbers of abandoned wells and boreholes from this period are potential conduits for contamination.

In the 1960s, with improved exploration and development techniques, including the advent of large rotary drilling rigs (precursors to those used today to drill the Utica-Pt. Pleasant) which could drill 3000 ft, a new field developed in Morrow County in the Trempealeau formation (Cambrian age). However, there was still no orderly management of drilling until the chaos prompted the 1965 legislation, and this oil pool was also depressurized and depleted by "close-ology" development (reports of 11 wells on an 80-acre farm). Further drilling in Ohio, until the "shale boom," has largely consisted of gas drilling and some small-scale oil development. Dr. Jeffrey Dick describes the geologic and technical history of oil and gas development elsewhere in this seminar, and we will mostly leave the history at this point.

While construction and spacing issues were improved by the 1965 regulations and also improved technology (the blowout preventer had been standard equipment for decades), produced brine remained a problem, often stored in unlined "evaporation" pits or allowed to escape to surface water. Subsequent legislation through the 1970s and 1980s resulted in the current brine control program.

"Conventional" oil and gas – collected from traps – and ground water

There is naturally much interest in and concern about the new large-scale shale development, but Ohio's ground water (or groundwater) issues possibly associated with the shale wells are probably dwarfed by problems associated with shallower "conventional" oil and gas, that is, oil and gas developed from reservoir and trap systems. According to Ohio Department of Natural Resources histories, early settlers contended with oil contamination of drilled salt and water wells.

Oily systems and sulfide: Across the Northwestern Ohio range of the Trenton system, and extending into the Devonian lands, sulfide and high levels of iron degrade the quality of ground water. The reasons may include spilled hydrocarbons during development, affecting recharge, or contact with fluids from formerly producing formations. In ambient temperatures, sulfides in water are produced by sulfate-reducing bacteria (SRB), which are ubiquitous in aquifer and hydrocarbon reservoirs. SRBs readily utilize hydrocarbons as a source of carbon, and produce sulfide as a product of respiration. SRBs are probably spread throughout the Devonian-Silurian-Ordovician system. Where physical-chemically (redox) reduced conditions remain, SRB thrive and produce sulfides. Trenton oil was “sour” (undesirable sulfide content), so its fluids harbored SRB.

As a fuel problem, sulfide in “sour” oil was solved by Standard Oil refining innovations, but whether fueled by recharge of spilled fluids rich in hydrocarbons or from hydrocarbons working up into the aquifer zone, SRB-generated sulfides in the hydrocarbon fluid column could affect shallow ground water.

Fig. 2. Testing limestone rock for gas production

Other native rock issues: Native rock as Mother Geology gives it to us also affects ground water quality. For example, in addition to producing formations and reservoirs, low-grade hydrocarbon stringers are sometimes found in more shale-rich zones of the Silurian aquifer system. We have drilled into these in western Ohio. These hydrocarbons readily support SRB. The Devonian carbonates above the Silurian in Ohio’s sedimentary sequence likewise contain abundant hydrocarbons, even where shales are too “immature” to be productive source rock. Figure 2 illustrates a gas meter test – positive – of cooked (200 F) shallow quarried limestone collected near Sandusky that was used as fill under a restaurant that experienced explosive gas atmospheres in a banquet room (solved by venting). We include a safety note about potential for “gas kicks” in specifications for water wells to be developed in north central Ohio. Anecdotal comments from colleagues mention the fun of lighting ponds in northern Ohio, indicating natural hydrocarbon accumulations.

The presence of thick shale sequences, such as the Ohio shale (Devonian) – see Figure 3 – is a problem for both ground water quality and quantity. The rock itself yields poorly, and black color is always bad for quality – carbon, pyrites, and sulfide. These rocks also have a high radioactivity signature in geophysical logs in Ohio due to relatively abundant uranium. The presence of Ohio shale sequences in otherwise productive Devonian carbonates can produce water with radionuclide levels that are above the U.S. EPA Safe Drinking Water Act standard if the sequences are not cased off (isolated from the well).

Fig. 3. Ohio shale core from Crawford County, Ohio (236 ft, OGS core collection)

Brine: “Brine” under Ohio oil and gas law is not always the same as brine as defined geochemically. Brine is saline fluid that is produced in oil and gas operations, and indeed it usually is technical brine, often ten times as salty as sea water. Ohio permits two legal ways to dispose of oilfield brine (ORC 1509:22): deep well injection in Class II injection wells administered by the Ohio Department of Natural Resources (ODNR) under the Federal Underground Injection Control (UIC) program, or (with restrictions) spread as road deicing salt (ORC 1509:266).

Brine is a historic problem as well as resource (brine seeps were important sources of salt for livestock, preservation, and seasoning). Wells were drilled to gain better access, some also encountering oil. Historic drilling, up through the Morrow County oil boom, resulted in numerous cases of salt-contaminated wells and water ways. Studies of the ineffectiveness of "evaporation" pits in Morrow County – saline water simply seeping into the soil and ground water – supported the subsequent ban on this method of disposal under 1985 Ohio oil and gas reform. The Village of Cardington was forced to abandon a shallow sand-and-gravel wellfield due to pit seepage. Two pits studied by Ohio State University graduate students infiltrated an estimated 225,000 bbl of brine. Some brine was also trucked away and dumped in streams, which along with seepage to streams from pits, caused surface water contamination. Similar occurrences were documented and studied in Medina County. At this time, prior to the development of Alum Creek Reservoir, the City of Westerville used Alum Creek (which extends into Morrow County) as its raw water supply directly. Reportedly, contamination from brine pits drove salt levels in the creek well above MCLs for chloride. As the reservoir filled, buffering reduced chloride levels. Prior to reservoir filling, Westerville city water at this time was not suitable for plant watering due to the salt content.

Despite the potential (see following), documented chloride-contaminated wells with problems traceable to oil and gas activities, including brine injection, number in the dozens in Ohio. The emphasis is on documented. Water quality in Morrow County (like yield in the rock) is uneven, however, shale sequences themselves are problematic, without blaming brine contamination. Surface storage of salt for road deicing or industrial processes certainly rivals brine as a problem cause. The literature includes a number of occurrences. Even recently, the Village of Camden, Ohio, had to relocate a wellfield because of identified but unremediated improper storage of salt, and the Ohio EPA has investigated salinity problems in public water supply wells in a number of communities where the source apparently is an unprotected salt pile. With the human sensitivity to chloride threshold at about 300 mg/L, a rise in salinity from a background of 50 to 250 mg/L may be undetected, so that occurrences of salt contact may go unreported.

Scale of conventional oil and gas development: The dominant component of conventional oil and gas in Ohio as a potential water contamination problem is its sheer scale, both in numbers and time. Perhaps 210,000 wells have been drilled for oil and gas in Ohio, and over 60,000 are in active production. As discussed, oil development goes back into the mid-19th Century. A large fraction of these were constructed prior to the current oil and gas regulations were in force. Early Ohio oil and gas rules were concerned about keeping water out of oil zones and not interfering with coal mining, and not at all about protecting water.

Fig. 4. Gas well, Meander Creek watershed, Mahoning County

Where are these wells? While not everywhere, in oil and gas producing regions, they are abundant. Growing up in Ashland County, every farm I knew was drilled or had active wells. Figure 5 illustrates the abundance of oil and gas wells in a producing region. Each dot is a well. Figure 6 shows the occurrence of wells in the vicinity of Figure 4, adjacent to the highly protected Meander Reservoir in Mahoning and Trumbull counties.

Fig. 5. Screen shot of a search of oil and gas wells in the vicinity of three major reservoirs in Portage, Trumbull and Mahoning counties

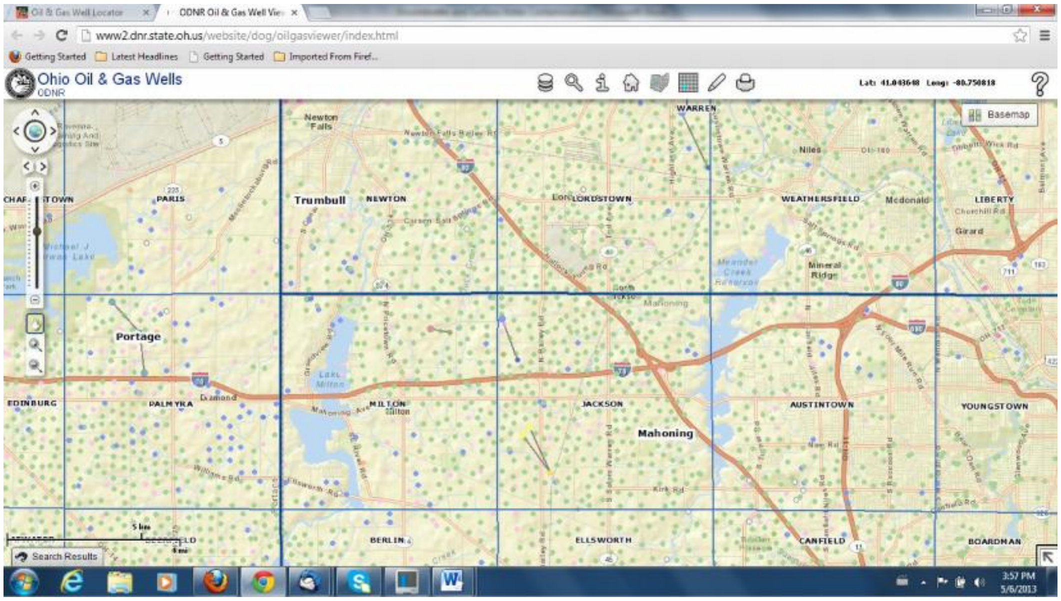
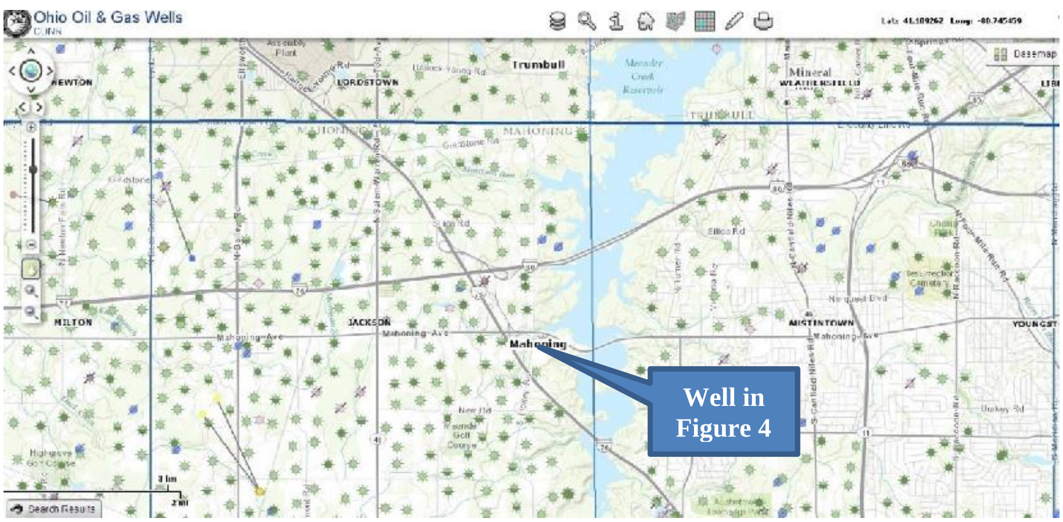


Fig. 6. Oil and gas wells in the vicinity of Meander Reservoir (screen shot of ODNR search results)



Brine spill potential: Given that many thousands of wells have water separators and storage, and shale development will dramatically increase the brine that must be handled, the potential for problems is there. Much of the brine hauling is conducted using trucks, which travel on highways to Class II injection wells. The Division of Oil and Gas Resources Management (DOGRM) regulates the hauling and spreading of oil-field brine. Brine haulers in Ohio are required to be registered, bonded, and insured with the Division. According to DOGRM, approximately 98 percent of all brine is disposed of by injection back into brine-bearing or depleted oil and gas formations. Nearly two percent is spread for dust and ice control subject to local government approval and requirements.

The ODNR asserts that no ground water contamination has resulted from Class II injection activities. However, spills do not seem to be uncommon and case histories do exist, including one in Ashtabula County in the early 1980s (J. Weatherington-Rice, pers. comm.) in which a line from storage tanks to the well ruptured, flooding a pasture. The neighbor's well eventually became saline, until the sand-and-gravel aquifer flushed out. Irritating hydrocarbons were found to be present in the soil as well. A search of information and news sources failed to turn up incidents of trucking accidents resulting in spills.

A recent case occurring in Youngstown, Ohio, and involving the same people responsible for an earthquake caused by Class II injection, resulted in a massive, deliberate spill of oilfield waste into the Mahoning River. This case is being vigorously prosecuted at the Federal level, and seems to be unusual under the current regulatory environment. More recently, a Lowellville (near Youngstown) company, Soil Remediation, Inc. has been charged with illegal dumping (burial) of drilling wastewater and cuttings. The potential for problems and old-style bad behavior remain.

The new thing – shale drilling and hydraulic fracturing and ground water

Description of the geology and technology involved in developing shale source rocks, are described elsewhere in this seminar.

Fig. 7. Utica-Point Pleasant well under way in 2013 in Poland Township, Mahoning County on the Carbon Limestone landfill property

These shales are, in the case of Ohio, the Utica-Point Pleasant (Ordovician age) that underlies the lower Devonian Marcellus. These units are the hydrocarbon source rock that supplied the conventional reservoirs. The new technology has made tapping these units technically and (apparently) economically feasible. Several features of "Utica" development make these projects very different from "conventional" oil and gas as we have known it for 50 years:

- They are comparatively deep (4000-8000 ft deep in the probable mature zones of the Utica in Ohio).
- Utica development is conducted using horizontal drilling, with laterals extending upwards of one mile from the vertical well bore location.
- Multiple wells are developed from a smaller number of large well pads, thus surface activity is concentrated. The pattern in Figures 5 and 6 will not be repeated.
- The laterals are hydraulically fractured to open the tight shale.
- The well systems are large and involve multiple casing and cementing strings.

Hydraulic fracturing has been practiced routinely for decades, although techniques are evolving. Large horizontal "fracks" in Utica and Marcellus shales involve dramatically more water than is typical in vertical conventional wells. Recent studies have indicated that 10 times the wastewater will be produced from a shale well, compared to a vertical well. However, shale wells are estimated to produce 30 times the gas and liquids, at least for a while. Regardless of the benefits of this efficiency, a very large volume of wastewater (many billions of gallons) will be produced (an estimated 4000 shale wells will be drilled by 2015), requiring management and disposal. In addition to Ohio's own wastewater, a large volume of Pennsylvania brine and drilling waste comes to Ohio.

As with conventional wells, there are some potential risks:

- Surface contamination (pit, tank, and hose leaks; brine transport: improper dumping).
- Casing and cementing failures
- Improperly plugged nearby oil and gas wells that may provide conduits for fluids.

George King, global technology consultant for Apache Corporation, developed a diagram of risk assessment probabilities, available at http://www.epmag.com/Production-Field-Development/Studied-Approach-Needed-Cracking-Open-Shales_95211 (accessed May 2013). As in the case with many other activities, shale development involves risks that range from minor to catastrophic, and from exceedingly rare to common. The matrix charts probabilities of these events. In general, catastrophic event probabilities are exceedingly low.

King discusses mitigating factors in shale development that sets it apart from earlier Ohio oil and gas booms: Improved exploration technology that more reliably focuses drilling on good targets, 3-D seismic imaging that can be used to steer lateral development, and improvements in construction technology. There are unknowns, among these are:

- Aging due to corrosion of long, deep, directional wells.
- Fracture propagation in association with formation structure and the current stress field.

According to the Society of Petroleum Engineers, "Although more than 1 million wells have been fracced, no accidents relating to well integrity during the fraccing process were identified. Wells may have sporadic, minor leaks, but they are not related to hydraulic fracturing. Further, no cases of harm to drinking water aquifers caused specifically by hydraulic fracturing have been found."

An emerging potential risk (discussed at length later in the seminar) is the radioactivity of the produced fluids and large volumes of shale drilling cuttings. Fluids reportedly have radioactivity levels many times that of SDWA standards for radionuclides. Cuttings, if improperly stored and disposed of (such as in construction landfills), can leach soluble radium and uranium. At present, the question of the radioactive cuttings and fluids is the central, practical environmental unknown.

In general, the potential long-term impacts are largely unknown. The regulatory climate is very different from that of past oil and gas booms. The economics of oil in particular is such that there is less pressure to cut corners environmentally, while greater scrutiny provides checks on how matters are actually working out.

Interlude: We have other things to worry about – the neighbors, failed on site wastewater systems, agriculture...

Fig. 8. Public water supply well with neighbors accused of ground water contamination off-site and downgradient

The new, large-scale oil and gas development is spectacular. It is large, employing innovative technology that applies high pressures and massive quantities of fluids. The infrastructure being developed to service the new oil and gas fields is likewise massive. It is important to keep focus on other high-priority issues, including:

- Contamination by agricultural activities, including confined animal operations that produce abundant manure and transport it elsewhere for disposal, especially by land spreading of untreated wastes.
- Unregulated personal activities, including nonagricultural use of fertilizers and pesticides.
- Inadequate and failed on-site wastewater systems.
- Numerous abandoned water wells and orphan oil and gas wells.
- Protecting source water protection areas – especially removing state rules that interfere with the ability of water suppliers to protect their sources.

Hydrology Rules

An often-forgotten factor in the discussion of risk potential in water contamination (whatever the source) is that physics rules, specifically the physics of hydrology. We will not provide a text book on hydrology here, but refer the reader to the abundant references on the subject. However, a bottom line is that for an aqueous contaminant to reach an aquifer, well, or other source of fresh water supply, there has to be 1) an available pathway (permeable porous media or fracture channels) and 2) hydraulic head (kinetic potential) sufficient to move the contaminant from the source to the target. There are well-defined procedures for determining the probability and rate of flow along a flow path. Given necessary information, a hydrogeologist can determine what could (or did) happen.

Fracture propagation as a result of hydraulic fracturing and its risks follow the same principles. A sequence of rock has certain rock mechanics properties (elasticity, hardness, etc.) and occurs in a tectonic stress field that can be analyzed. If subject to fracturing action, the rock will behave in a certain way. A fracture will propagate so far depending on a combination of rock mechanics and stress, and the force applied on this system. In all fractured permeable rocks with horizontal bedding, horizontal permeability is much higher than vertical permeability. If a propagating vertical fracture encounters a horizontal bedding plane (common in shale), they stall out, as force also dissipates along the bedding planes. The likelihood of engineered fractures reaching aquifers of potential interest as water supplies is remote, particularly assuming that hydraulic fracturing engineers are competent. Note: The industry doesn’t want fractures to extent into other porous zones adjacent to the producing zone because it would: 1) allow valuable product to leak out, and 2) allow water to leak in. Neither is profitable, so there is incentive to develop precise fracturing technique.

As summarized by the Groundwater Protection Council: “Ultimately, if the pressure difference between a hydraulically fractured zone and a fresh water aquifer is not great, the distance between the zones is relatively large, and there are rocks with low vertical permeabilities in between the deeper and the shallower zones, flow between the zones is unlikely to occur. The exception to this is where there is a separate flow pathway such as an open borehole or a series of faults or joints that intersect both the fractured zone and the fresh water aquifer. Under either of these circumstances, the pressure difference and distance will be the determining factors as to whether fluid can migrate from the lower to the upper zone.”

The point of the exception is important.

1) The region has experienced extensive tectonic fracturing, with major vertical components.
2) Recall the 150-year history of oil and gas development. While Ohio has been diligent about sealing abandoned and orphan wells, for many years, resources have been insufficient to fulfill the task, and we may never know the location of older wildcat wells.

Even without the head necessary to move aqueous fluids toward aquifers, methane and liquid hydrocarbons, with specific gravities much lower than water, can migrate upwards through available openings. Pennsylvania’s geologic setting is a good example, with methane seeps associated with fracture sets and valleys (developed in fracture zones). Undiscovered fracture sets and unsealed well bores (either oil/gas or water) can act as pathways for blowouts near the surface during the construction phase. It is important that well developers (and their regulatory reviewers) do thorough due diligence. In recent presentations in Pennsylvania, Shell described its policy of mapping and avoiding fracture zones that extend from the producing zone to the aquifer zone.

Other relevant aquifer-hydrocarbon settings with lessons to offer

Two other systems where “oil and water mix” are offered for comparison and contrast in problems, characteristics, and lessons to be learned.

Fig. 9. View of brine pit with oil pump jack, Patagonia (city of Caleta Olivia wellfield over the hill)

Patagonia, Argentina: During a visit to consult on a water wellfield in southern Argentina in 1994, we learned about its hydrogeologic setting, which was virtually continuous and hydraulically connected sand and silt from the surface to > 2000 m. This material is derived from erosion from the relatively recent uplift of the Andes.

Water was developed in the top, and hydrocarbons from deeper in the sequence. Ground water conductivity in the aquifer zone was routinely > 2000 µS/cm and saline. SRBs were common and abundant. Consequently, corrosion of water well equipment in wellfields was severe. This is an example of a combination of geology unfavorable for separation of oil and water, poor administrative and technical control, and a resulting undesirable water quality outcome.

Wind River Basin, Wyoming: The Wind River Basin in Wyoming is another case where water is developed in shallow zones and oil and gas developed from deeper sequences. This basin has been the subject of U.S. EPA “Pavillion” studies intended to document a relationship between hydraulic fracturing and poor ground water quality. Well water quality is typically poor (gassy, mineral-rich, sulfides) and yields are low. Oil zone produced water is relatively low in TDS (not much different from “aquifer” zones). Hydrocarbon and water zones are poorly separated, with water developed in discontinuous sands, and hydrocarbon traps also discontinuous. There is little to no barrier to natural hydrocarbon movement into the water zones. There is also known pollution from old waste pits, which (along with poor-quality shales in the “aquifer” zones) confuses attempts to correlate oil and gas activity with water quality issues.

These two situations are in contrast with the Appalachian Basin, where aquifers are shallow (< 1000 ft, typically < 600 ft), and separated from the much deeper hydrocarbon zones both by depth and also significant confining zones (traps for conventional deposits). There is significant fluid quality contrast (hydrocarbon zone fluids are brines). The fluid contrast is important in designing a monitoring program. However, due to structure, hydrocarbon producing zones may also be close to the surface, hence burning springs, etc., so separation is not absolute.

Surface Water Issues

Fig. 10. Meander Reservoir, a highly protected water resource of the Mahoning Valley Sanitation District

Surface water is logically, and historically, more vulnerable to contamination activity, including that resulting from oil and gas development. Referring to the historic discussion at the beginning of this paper, most water abuse was suffered by surface water bodies. This continues to the present with the dumping incidents in Youngstown and Lowellville that affected the Mahoning River, and public water supply intakes downstream in Pennsylvania. “Midnight dumping,” spills from accidents, and spills from impoundments that affect surface water streams are probably the highest probability, highest risk contamination issues with oil and gas development.

While there are many surface water systems of interest in the shale boom regions, including the Tuscarawas and Muskingum watersheds and aquifers, the Meander Reservoir operated by the Mahoning Valley Sanitation District (MVSD) is an illustrative case. It is protected from development, and largely from any human contact (there is no waterfront development or recreational use, and only occasional, limited fishing access). Past requests to drill on MVSD land around Meander have been rebuffed, although directional wells extend under the reservoir. Meander also has one of the first fully endorsed surface water Source Water Protection Plans for the resource.

However, as illustrated in Figures 5 and 6, Meander (like other critical surface water sources in the region) is largely surrounded by oil and gas development. As illustrated in Figures 4 and 6, these are often in close proximity to the reservoir and water-handling facilities. However, the reservoir is also traversed by several highway bridges carrying heavy traffic and everything imaginable.

The State of Ohio has provided the mayor of Youngstown and the MVSD board specific assurances of attention to protection for this reservoir that serves 200,000 people. The dumping incidents demonstrate that surface water body protection requires participants in the waste-handling process to be ethical, or at least afraid of the consequences. The “fear factor” and success in prevention and mitigation also requires public diligence.

While oil and gas waste activities pose a measurable risk to surface water bodies, experience illustrates that these are part of a larger mix of risks to be managed, including agriculture, urban storm water runoff, construction site runoff, poorly performing wastewater systems (including overflows from combined storm/sanitary sewers), and leakage from landfills and industrial activities. However, the experiences in Morrow and Delaware County (and elsewhere prior to improved oil and gas fluid regulation) indicate the potential or problems and need for vigilance.

Regulations to protect ground water and surface water in Ohio

As professional hydrogeologists, it is important that we understand and apply law, rules, and administrative decisions that protect water resources and water supplies in the state. However, I leave an exhausting recitation of chapter and verse to others. The overall structure of relevant water regulation in the State of Ohio is:

- ODNR regulates water resources in general (surface and ground water), in coordination with water districts such as the Muskingum Water Conservancy District, and Federal agencies such as the U.S. Army Corps of Engineers, and the Ohio EPA with its jurisdiction over the Clean Water Act. ODNR adjudicates water rights disputes as developed through a body of case law (a modified riparian system). ODNR also is the repository for hydrologic and geologic information such as water well construction logs, and is home of the Ohio Geological Survey.
- ODNR also administers the Underground Injection Control program as the state primacy agency under the U.S. EPA, and houses the DOGRM, and so has responsibility for management of water supplies and management of oil and gas – both production and protection from harm it could cause. Similar programs regulate coal and other mining.
- The Ohio Department of Health (ODH) has the portfolio for the private water supply program (mostly individual domestic water supplies) and on-site wastewater systems. It provides and enforces rules for private well construction and on-site wastewater system construction, and licenses contractors and installers. Through its requirements for sealing abandoned water wells and the on-site wastewater program, ODH also serves to protect shallow ground water quality. ODH interfaces with local health districts, some of which conduct testing for landfills and other Ohio EPA-regulated assets.
- The Ohio EPA oversees public water supplies and public wastewater systems, both sewered and on-site wastewater treatment serving public facilities. Ohio EPA has charge of surface and ground water quality assurance in the state, and interfaces with the U.S. EPA and its Region 5 office.
- The Ohio Department of Agriculture manages the state’s large-scale confined animal operations, along with management and disposal of large amounts of manure. This also places ODA also something in the ODNR position of both promoting an activity (confined animal operations) and protection from the activity’s effects. As something of a balance, Ohio’s county Soil and Water Conservation Districts, which promote soil conservation and mitigate agriculture effects on water, are administered by the ODNR.

As is evident, Ohio has ground water and surface water protection responsibilities distributed over several agencies. ODNR is also somewhat in the business of promoting extractive activities such as coal mining, stone quarrying, and oil and gas. Despite this situation, Ohio has a number of effective legal and regulatory tools to protect water resources and supplies:

- Water well construction regulations – Ohio has robust well construction rules for both private and public water supplies, as well as enforced requirements for abandoned well sealing. Ohio lacks strong well contractor licensing.
- Ohio's water rights structure is not firmly defined, but built on case law. It does serve to mitigate harm from overdrafting and interference with public and private water supplies. Unfortunately mitigation often requires litigation or intervention from overwhelmed state officials, and short-term harm (e.g., dried up wells or streams) can be severe, even if the problem is mitigated over time. Quality citizen and local authority data collection and vigilance are essential to make a case. Ohio could really be more diligent in this department.
- Ohio's current oil and gas law is widely documented as being both stringent and effective by reviewing bodies. As related above, it is built on the experience of carelessness in the past, and we are watching it being adapted "on the fly" in the present. There is a robust but experience-challenged inspecting program. Ohio also has an Orphan Well program to reduce the incidents of vulnerability from open boreholes.

Monitoring ground and surface water related to potential oil and gas effects

No matter how effective and far-seeing the regulation, the goodwill and stewardship (and bottom-line sense) of the oil and gas sector, and diligence of service providers such as fluid haulers and fluid injection and treatment systems, problems will happen. A large (and increasing) amount of fluid is being handled. Effective and enforced regulations reduce the circle of potential problems, as do a safety-engineering focus at the well site. Despite these controls, an occurrence outside of experience, a construction flaw, accident, or bad behavior can still result in a spill or leak in the subsurface. Monitoring can detect such occurrences to permit rapid mitigation and to lay down a basis for responsibility.

Framework: ODNR promotes water testing that includes baseline (before development) and periodic water testing with best practice lists of constituents. For legal purposes, such testing should be conducted by sampling by an impartial "credible person" (can take a sample and not mess it up) and analysis by a certified laboratory. ODH and county health labs and commercial labs have such analytical programs, including sampling. The exploration and producing (E&P) companies conduct their own testing upwards of a mile from well pads. This work is somewhat in its beginnings in Ohio, but has produced 100,000s of records in Pennsylvania that are providing significant data sets for analysis.

There is also some "citizen monitoring" promoted by the Sierra Club and other activist groups. Curiously, landowner groups who negotiate leases with E&P have shown little interest in conducting independent testing of their own. Public water supplies are increasingly conducting baseline monitoring of their water supply assets.

An important, but underappreciated, framework for protecting water supplies is the Ohio EPA's Source Water Protection Program (SWAP). Another tool is the Sole-Source Aquifer program, also administered by the EPA. Under SWAP, contributing watersheds and ground-water capture zones are defined (ideally, if not always) scientifically, risks to water quality assessed, and plans to prevent contamination drafted. These risks are then to be administered. This latter task is easier in theory than practice, as public water supplies seldom can control their entire zones of interest. In relation to oil and gas:

- Having a defined Source Water Protection Plan (SWPP) endorsed by the state gives a water supplier "a leg to stand on" when negotiating with E&P and ODNR to keep drilling influences out of SWAP zones. And don't forget Ohio Department of Agriculture – keeping manure out of SWAP – although ODA seems to feel free to ignore SWAP.

- Under a SWPP, a monitoring program can be established and used in enforcement.

It is important that SWAP delineation be rigorously, professionally scientific and the SWPP program technically defensible. Unfortunately, Ohio EPA has often performed SWAP delineation internally without valid site-specific data, and these are vulnerable to technical challenge. SWAP delineations should be updated technically if water suppliers expect to be interfacing with E&P, who can hire hydrogeologists who would be happy to cast doubt on the validity of a SWAP.

Monitoring: Baseline and periodic testing is described briefly above and also at ODNR (http://oilandgas.ohiodnr.gov/industry/best-management-practices) and other credible sources provided by interested parties such as http://www.groundwaterscience.com/resources/stuarts-blog/104-enlightened-self-interest-well-water-testing-.html. This sample-and-analyze process has the advantage of technical rigor (if performed properly), ability to provide detailed analyses, and legal status. Its disadvantages include cost and low frequency of performance (due to cost and logistical issues). Water suppliers seldom perform frequent formal testing, and can lose interest if nothing seems to be happening. Water supplies and surface water bodies around Class II injection well installations are not routinely tested.

An alternative approach suitable for long-term and regional monitoring is an instrument-based system that can detect evidence of disturbance and easily detectable change in water quality. Remember that oilfield fluids in the region are easily distinguished from fresh ground water and surface water, specifically by total dissolved solids (TDS) and salinity (presence of Na or Cl). Fresh Ohio waters tend to be alkaline and carbonate-bicarbonate waters, with relatively modest TDS (2000 µS/cm is very high for ground water). If an instrument can detect 1) pressure or head changes, 2) TDS/pH/temperature, 3) turbidity, and 4) dissolved oxygen, it can detect an intrusion of oilfield fluids and accident events such as impoundments giving way.

The Susquehanna River Basin Commission administers this large watershed in Pennsylvania and discharging into the Chesapeake Bay in Maryland (http://www.srbc.net/atlas/index.asp). SRBC has interfaced with the shale boom since early in the Marcellus development, while also managing a watershed in an otherwise busy human environment. SRBC administers an innovative instrument-based monitoring program (http://mdw.srbc.net/remotewaterquality/) that has served to detect transient spills typically undetectable by sample and analysis. SRBC's data are publicly accessible by the interested public.

Individual well pads could be instrumented to detect overpressurization and leaks with similar instrumentation. Figure 11 illustrates a hypothetical well pad monitoring arrangement.

Fig. 11. Instrument-based real-time water quality and pressure monitoring at a drill pad site. Courtesy of Brian Kahl, Groundswell Technologies, Inc., Santa Barbara, CA, used with permission.

On the “defensive” side (as with the SRBC program), a reservoir or wellfield could be instrumented in a similar way. The array would resemble Figure 11, transferred to the water management setting, and designed to be hydrogeologically relevant. In a situation where a shale drill pad is within a 5-year time of travel zone of a wellfield SWAP, this approach should be adopted, as it permits time to initiate action, such as further water testing to confirm problems. The five years gives time for litigation and installation of mitigative measures.

Interestingly, Brian Kahl, cited above, reports the ability of sensitive pressure and gas sensors (methane sensors can also be deployed) to detect the “breathing” of the earth associated with changes in water levels and atmospheric pressure. These data can be used to design methane-ethane monitoring programs. Such systems could be adapted for other purposes, such as identifying soluble phosphorus “hot spots” in a watershed (along with associated data – e.g., temperature, water altitude, velocity, TSS), or storm water “hot spots” in urban areas.

A quality assurance/quality control program would be essential. Sensor calibration and maintenance does factor in. There is also the matter of change in institutional paradigm from one based on discrete water sampling in a legal (chain of custody, certified lab, and expert sampler) mode to this “sentinel" paradigm. The USGS and State of Ohio have been demonstrating live monitoring of river stages and ground water levels for years and many people rely on that timely (live) data.

A game changer for sensors is broadband internet. Large volumes of data can be transferred for analysis. It can be geo-located and displayed, for example using Google Earth. A key component is the ability to analyze and interpret findings. We all experience data overload. What does that pressure change mean? If we detect methane, what does that mean?

Some Recommendations

- “The best advice I think was given by Douglas Adams (author of The Hitchhiker’s Guide to the Galaxy): ‘Don’t panic,’" (Arthur C. Clarke). Citing Midwestern stoicism: “It could be worse”. Dealing with potential oil and gas problems (even of the massive shale development) is not served by ideological opposition and faith in immediately adopting alternative energy supplies, attempts to demonize the E&P sector, nor by bad science.
- “Trust, but Verify” (Ronald Reagan). This is not the 1985, or 1885, oil industry. While profit-driven, it is populated by people educated under 40 years of ecology ethic. They also realize that if they massively fail (a Deepwater Horizon-type disaster), the cost will be very high to fatal. We encounter very capable, ethical people in E&P. That said, collect your own data! We see excessive trust in data collected by the leasing companies, because it does not cost anything. Invest in self-protection.
- All water supplies (and watersheds and aquifers) should be instrumented for routine, automatic water quality monitoring, similar to current water level monitoring. These networks can be designed (with available signal-to-web capability) to be sentient (i.e., self-aware) sentinel systems that can detect and flag an anomaly (e.g., pressure surge, chloride increase, or instrument down) and call for follow up, much as your knee twinge says “look into that.”
- Meter all hydraulic fracturing withdrawals, and encourage use of less-than-fresh water where possible. There are saline aquifers and mine water that can be used. There should be an extraction cost for fresh water lost from the fresh water biosphere permanently (or until continental plates recycle).
- Continue to monitor the situation and incrementally improve the rules and professionalism in state oversight – and provide the necessary funding and resources.

- Update over 40-year-old water resources studies conducted under Governor Rhodes – what water do we actually have and how is it used these days?

This contribution is intended to be educational, but it is not exhaustive. It is intended to prompt thinking and informed action.

References

DeBrosse, T.A. and L.L. Goodwin. A Legacy of Stewardship, Chapter 15, Division of Oil and Gas, Ohio Department of Natural Resources. Accessed April 2013 at http://www.ohiodnr.com/portals/0/publications/stewardship/chapt_15_oilgas.pdf.

DiGiulio, D.C., R.T. Wilkin, C. Miller, G. Oberley, 2012. Draft Investigation of Ground Water Contamination Near Pavillion, Wyoming, U.S. EPA, Ada, OK.

Lehr, J.H. 1969. A Study of Groundwater Contamination due to Saline Water Disposal in the Morrow County Oil Fields. State of Ohio Water Resources Center, The Ohio State University, Columbus, Ohio. Accessed May 2013 at https://kb.osu.edu/dspace/bitstream/handle/1811/36429/OH_WRC_A004OHIO.pdf?sequence=1

Ohio Department of Natural Resources, Division of Oil and Gas Website http://oilandgas.ohiodnr.gov/ Accessed April 2013.

Ohio EPA. 2012. An Overview of Ground Water Quality in Ohio, Ohio EPA, Columbus, Ohio. Accessed May 2013 at http://epa.ohio.gov/portals/35/tmdl/2012IntReport/IR12SectionMfinal.pdf

Pettyjohn, W.A. 1971. Water pollution by oil-field brines and related industrial wastes in Ohio. Ohio Journal of Science 71(5):257-269.

Rau, J.L. 1970. Ground Water Hydrology for Water Well Contractors, National Water Well Association, Columbus (now Westerville), Ohio.

Ryder, R.T. 1995. Cincinnati Arch Province (066). http://certmapper.cr.usgs.gov/data/noga95/prov66/text/prov66.pdf (accessed April 2013).

Schwietering, J.F. 1979. Devonian Shales of Ohio and Their Eastern and Southern Equivalents, METC/CR-79/2. West Virginia Geological and Economic Survey, Morgantown, WV for U.S. Department of Energy, http://www.netl.doe.gov/kmd/cds/disk7/disk1/EGS\Devonian Shales of Ohio and Their Eastern and Southern Equiv.pdf (April 2013).

Society of Petroleum Engineers, 2011. White Paper on SPE Summit on HydraulicFracturing, Woodlands, TX. http://www.spe.org/industry/docs/HFsummitwhitepaper.pdf (May 2013).

Wickstrom, L. H., Gray, J.D., and Stieglitz, R.D., 1992, Stratigraphy, structure, and production history of the Trenton Limestone (Ordovician) and adjacent strata in northwestern Ohio: Ohio Division of Geological Survey Report of Investigations 143, Ohio Department of Natural Resources, Columbus, OH.

Wright, P.R., P.B. McMahon, D. K. Mueller, and M.L. Clark, 2012. “Groundwater-Quality and Quality-Control Data for Two Monitoring Wells near Pavillion, Wyoming, April and May 2012,” Data Series 718, U.S. Geological Survey, Reston, VA.