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Hydrogeologic Concerns Regarding

Hydraulic Fracturing within the

Muskingum River Watershed

In Eastern Ohio with

Justification & Recommendations in

Support of a Drilling Moratorium

within Reservoir Watersheds and

Statewide Legislation Banning Hydraulic Fracturing

Prepared for:

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Hydrogeologic Concerns Regarding Hydraulic Fracturing; Muskingum River Watershed, Eastern Ohio
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1.0 Purpose of Study

The overall purpose of this study is to define the deleterious impacts associated with hydraulic fracturing that will adversely impact the health of residents in the Muskingum River Watershed via ingestion and physical contact with contaminated water. The second purpose of this study is to assess existing and future water quality risks within the Muskingum River Watershed in Ohio that stem from past oil and gas drilling operations and modern hydraulic fracturing practices. Characterization of the hydrogeologic setting is necessary to understand water quality impacts associated with drilling and hydraulic fracturing in watersheds containing water supply reservoirs. Assessment of water quality risks requires an understanding of existing methods used to measure water quality parameters and a database designed to document historical, current and future conditions. Identification of the interaction of the hydrogeologic setting with the oil and gas drilling and fracking activity in the subsurface will define potential groundwater movement from drilling targets to surface reservoirs and near surface aquifers. The movement of groundwater and associated gas industry chemicals must be evaluated with respect to its capacity to degrade public and private water supplies in the watershed. As a consequence potential human health impacts must be considered for down-gradient water users.

Another purpose of this study is to encourage the assessment of potential human health impacts by a comparative study between permitted and regulated gas industry practices in eastern Ohio (a worst case scenario) and New York State's efforts to protect New York City's water supplies by banning hydraulic fracturing within reservoir watersheds (sound water quality protection).

An additional purpose of this study is to assess potential water quality risk associated with the sale of reservoir waters for oil and gas activities, focusing on the water requirements for hydraulic fracturing. As a result of these proposed assessments, reasoned recommendations are provided to protect groundwater and surface water quality for future generations.

Timely dissemination of information describing potential hazards of hydraulic fracturing on water quality is critical to the protection of human health. Decision makers, including residents and officials of the watershed, the Muskingum Watershed Conservancy District Board, and state regulators should understand this information and recognize the significant risk to public water supplies.

2.0 HydroQuest Qualifications

HydroQuest is an environmental consulting firm with over three decades of professional hydrologic and geologic experience. This experience includes technical work with attorneys, towns, and environmental groups, affidavit and report preparation, presentations, and extensive litigation support. In recent years, this work has extensively focused on contaminant issues related to gas drilling. This includes groundwater sampling and litigation support in Dimock, PA and Washington County, PA contaminant situations.

HydroQuest has been a leader in developing and providing detailed hydrogeologic and industry-based information that documents the real adverse environmental impacts of gas drilling on present and future water quality. This work has been advanced for environmental groups (e.g., Delaware Riverkeeper Network, Sierra Club, Schoharie Valley Watch, Damascus Citizens for Sustainability, Sullivan Citizens Alliance), a number of law firms and independently. The products have been put forth in press conferences, in public forums, privately before high-up government officials (including Governor Cuomo's Executive staff), and as testimony before county legislatures and the New York State Assembly and Senate.

3.0 Introduction

On behalf of Southeast Ohio Alliance to Save Our Water, HydroQuest has started to examine critical hydrogeologic concerns regarding ongoing and planned horizontal hydraulic fracturing and water withdrawal within the Muskingum River Watershed in eastern Ohio (Figure 1A). This report is a preliminary assessment subject to change and revision as evaluation work continues. **The ultimate result of extensive gas exploitation in the Muskingum River Watershed will be that groundwater and surface water contamination will occur. Such pollution is assured because (1) the durability of well sealant materials available today to effect zonal isolation of freshwater aquifers is poor and short-lived, and (2) toxic hydrofracking fluids injected deeply in the ground will move with groundwater flow systems, eventually moving upward into freshwater aquifers, reservoirs and waterways. Permitting of horizontal gas wells proximal to reservoirs will needlessly jeopardize water quality.**

The hydrogeologic setting is discussed within the context of potential risk of groundwater contamination. Exploitation of gas resources that are present within Ohio fairways poses a direct threat to groundwater and surface water quality. Much of the Muskingum River Watershed is being exploited by the gas industry (Figure 1B). Within the broader Muskingum River Watershed, the Senecaville Lake reservoir (also referred to as Seneca Lake; Figure 1C) and its tributary watershed (118 mi^2) are used within this report as a case example illustrative of an extremely vulnerable hydrologic situation. Considering potential loss of potable water quality, it is difficult to conceive of any worse combination of factors than those proposed for drilling and production of horizontal wells with high pressure and high volume hydrofracturing next to and under public water supply reservoirs (i.e., a combined network of abandoned industry wells with aging cement plugs, many of which may soon be hydraulically connected by lengthy laterals of new gas wells [albeit inadvertently], many adjacent to and under a reservoir – all set within a watershed with other active gas wells). This situation is exactly what major water suppliers elsewhere have fought hard to avoid (e.g., New York City, Syracuse, NY).

New York City's proactive and protective approach that seeks to ban any hydraulic fracturing within any portion of their watersheds acknowledges that groundwater flow follows a roughly arcuate pattern, one that flows from both shallow **and** deep geologic formations down-gradient and then upward to valley bottom aquifers, streams and reservoirs. Toxic, carcinogenic and proprietary gas industry chemicals injected deep underground will follow curved regional flow paths until they surface in finite water supply sources. Regardless of whether they are injected deep underground during the hydraulic fracturing process or as wastewater into relict oil and gas wells, chemical contaminants will reach aquifers and surface waters by natural groundwater circulation. Assured failure of gas well sealant materials used to "*isolate*" and protect freshwater aquifers (i.e., cement and steel), especially when subjected to repeated high hydraulic pressures, seismic motion, and corrosive chemicals, will often speed degradation of freshwater aquifers.

In the physical setting of eastern Ohio watersheds and reservoirs, it is imprudent to permit drilling, hydrofracturing and production of horizontal gas wells, as proposed for the area of Senecaville Lake. If the Ohio Department of Natural Resource (ODNR) allows permitting and well construction to begin, the eyes of the nation should watch closely as such a salient test case proceeds. An uncontrolled experiment involving people's health and water quality will take place next to communities (Senecaville, Kennonsburg, Lakeview, and Lakeland) drawing their water from local reservoirs. One recommendation of this report is to gather and establish critical hydrogeologic and public health information before advancing construction of planned horizontal wells, should Ohio's regulatory authorities and political figures determine that it is in the public's best interest to place residents and their water resources at risk. In addition, development of an emergency response plan is recommended. It is recommended that the Ashokan Reservoir in New York City's water supply system be studied to find policies and regulations in watershed land use to protect public health and water quality.

Four sets of recommendations relative to hydraulic fracturing are provided. The first set identifies immediate actions, for instance, instituting a drilling moratorium within the watersheds of all reservoirs. The second set is a list of items to do prior to and during hydraulic fracturing of planned horizontal wells, should approval be forthcoming. The third set provides recommendations designed to achieve long-term protection of water resources, to the extent possible considering that numerous oil and gas wells are already present. A fourth recommendation seeks to initiate a comprehensive comparative water quality and land use study between that of the Senecaville Lake (Ohio) and Ashokan (NYS) reservoir basins. The overriding goals of these recommendations are to (1) protect the quality of groundwater and surface water throughout the Muskingum River Watershed from degradation that will assuredly occur if horizontal hydraulic fracturing is permitted, and (2) protect the health of people and animals within the watershed (present and future).

Seneca Lake Reservoir

Existing and planned land use exploitation by the gas industry within the watershed and beneath the Seneca Lake reservoir (3,520 acres) provide a **worst case scenario** that will result in both groundwater and reservoir water quality degradation for generations to come. This will become pronounced with time as the cement and steel in boreholes fails and as hydraulic fracturing and earthquakes crack the low-durability cement used to effect zonal isolation of freshwater aquifers. The Seneca Lake reservoir provides an excellent case study location that should be extensively monitored **using tracer additions to all fracking waters**, coupled with extensive chemical testing, to fully document the loss of a non-renewable resource.

Ashokan Reservoir

The Ashokan Reservoir (8,300 acres) in the New York City watershed has no gas wells. NYC has hired experts that have correctly recognized that development of gas wells anywhere within the watershed will needlessly jeopardize the long-term quality of the water supply. Reservoirs and major streams and rivers represent hydrologic low points where deep groundwater flow, including that from gas-rich shales, discharges upward into aquifers and fresh surface waters. Sound land use planning and water quality protection sought throughout NYC watersheds provide the antithesis to that of Ohio's regulatory lack of water quality protection. HydroQuest recommends that this reservoir, its tributary streams and ground-water wells within the watershed be used to contrast water quality through time with those within the Seneca Lake Watershed, the ultimate comparative land use study relative to hydraulic fracturing.

4.0 Water Quality Protection of Reservoirs

The intentional injection of toxic, carcinogenic and proprietary chemicals into deep, but actively flowing, groundwater systems known to discharge upward to freshwater aquifers, reservoirs and waterways is unconscionable. The wisdom of hydrofracking next to reservoirs is even further confounded when considering that well sealant materials available today will degrade in less than 100 years, often far less – thereby providing direct upward contaminant pathways to reservoirs.

Reservoirs and the aquifers and waterways that provide base flow and surface runoff to them require the highest degree of protection. They are physically situated in low valley bottoms to which up-gradient streams and aquifers drain. Reservoirs are constructed to provide high-quality water for large populations that do not have sufficient water availability elsewhere, thus heightened protection is warranted. It is imperative that protective measures take into account the hydrogeologic setting within the context of both local and regional groundwater flow.

Within the broad Muskingum River Watershed, the Senecaville Lake reservoir is used as an example, illustrative of hydrogeologic concerns similar to other reservoirs in the watershed and beyond. The risk to the quality of Senecaville Lake and the integrity of its related infrastructure is a real and serious matter. For comparative purposes, it is valuable to contrast the virtually complete lack of protection afforded to the Senecaville Lake (watershed: 118 mi^2; maximum storage: 88,500 acre-feet; normal storage: 43,500 acre-feet) reservoir of Ohio (Figure 1C) with one of New York City's unspoiled reservoirs: the Ashokan Reservoir (watershed: 255 mi^2; maximum storage: 377,166 acre-feet) in southeastern New York State (Figure 1D). The Senecaville Lake watershed is less than half the size of the Ashokan Reservoir watershed and is riddled with gas wells. The Senecaville Lake reservoir itself is less than half the size and has less than ¼ of the storage volume of the Ashokan Reservoir, making it vulnerable to contaminant loading from up-gradient and adjacent gas wells. The different approach to water quality protection is stark and is worthy of rigorous comparative assessment.

A great misunderstanding on the part of many towns, water district departments, regulating agencies, and the public at large is the concept that hydraulic fracturing chemicals or other contaminants injected deep underground will stay there indefinitely. Regional groundwater flow from deep gas-rich shale formations to freshwater aquifers has not been taken into account (see Attachments A and B to this report). **Gas industry hydrofracking chemicals will first migrate down-gradient and then upward where they will contaminate Muskingum aquifers**, resulting in widespread groundwater contamination of a magnitude worse than that of Love Canal, where Hooker Chemical released vast quantities of hazardous waste into an old canal. Many of the waste materials dissolved with infiltrating groundwater and then migrated outward into the surrounding community. Some of the same toxic and hazardous wastes disposed of by Hooker Chemical are freely used by the gas industry with full regulatory approval. By way of comparison, contaminant dispersal outward from the Love Canal site pales relative to deeper and widespread chemical dispersion from tens of thousands of oil and gas wells. Whereas remedial clean-up was possible at the Love Canal site, the deep-seated nature of contaminant plumes outward from gas wells makes comprehensive monitoring and remediation impossible. Another contrast between the Love Canal hazardous waste site and Ohio gas fields is that the response to the former situation was one of extensive monitoring, litigation, trial and clean-up, while Ohio permits down-hole disposal/injection of toxic chemicals, allowing them to freely enter groundwater flow systems that will discharge to potable aquifers and surface water resources. Thus, on a much broader scale, regulators in the State of Ohio may be the Hooker Chemical of today. Adverse health impacts, already well-documented by toxicologists and doctors in neighboring Pennsylvania, will assuredly occur and then increase as contaminated groundwater reaches major down-gradient aquifers.

Gas industry chemicals injected into gas-rich shale formations (e.g., Marcellus, Utica) will migrate as widespread plumes to Ohio's freshwater aquifers. *"Hydraulic fracturing poses a serious threat to groundwater quality, not only in the vicinity of the drilling site, but also in the entire down-gradient part of the groundwater flow system. Although the main injection of contaminants takes place thousands of feet below the surface, groundwater flow inevitably carries them laterally and then upward into major neighboring river valleys over periods of years to hundreds of years, tailing off for possibly thousands of years. In the Appalachians, the valleys are where most people live. The* ***contaminants*** *are widely dispersed, but they* ***pose a low-level threat to health****, especially when thousands of fracked wells are involved."* (see *Palmer – Long-term Aquifer Contamination by Fracking Chemicals (C)* in files available at http://hydroquest.com/Hydrofracking/ page 8). Palmer provides an excellent example calculation of the potential magnitude of contaminant loading (Attachment B below). **Once contaminated, groundwater cannot be remediated even at unlimited cost**.

An important aspect of the contamination is that it will converge in the valleys, which are the location of major aquifers, town water wells, and reservoirs. The technology does **not** exist to remediate aquifers once they are contaminated (see Attachment A below). As gas well sealant materials degrade and fail, hydrofracking in Ohio will adversely impact precious water supplies for hundreds of generations to come. Earthquakes are likely to increase the potential for well sealant failure (Figures 2 to 6).

4.1 New York City Based Protection of Aquifers and Reservoirs

New York City (NYC) provides an excellent example of a government body that has actively sought to protect the quality of their water supply, as well as the health of those living within the watersheds of their reservoirs. NYC, in taking a precautionary approach, has wisely expended considerable effort to keep any and all hydraulic fracturing activity outside of their watershed areas. In addition, other protective options are being examined. Figure 1D is provided for comparative purposes to contrast with the approach to water quality "*protection*" currently being advocated in the state of Ohio (as exemplified in the Senecaville Lake reservoir watershed, Figure 1C). The most important water quality protective measure being sought for all New York City watersheds is a complete ban of any hydraulic fracturing within reservoir watershed areas. HydroQuest recommends that the State of Ohio immediately adopt this stance with respect to the Muskinghum River Watershed. Figure 1D illustrates two possible additional NYC protective measures that could, if formalized, protect areas adjacent to city watersheds from intrusion of horizontal laterals and from potential damage to the water supply infrastructure. The red cross-hatched area southeast of the Ashokan Reservoir represents a NYC based 4,000 foot buffer area that would enhance protection of the watershed area **if** horizontal laterals are not permitted to intrude within this area. HydroQuest recommends that a one-mile exclusion zone be adopted outward from all Ohio reservoir watershed areas. No gas or oil well laterals should be permitted within this exclusion zone. NYC's DEP originally recommended a seven-mile buffer around all watershed infrastructure to protect their drinking water supply. In part, this would serve as an infrastructure exclusion zone to help protect tunnels and aqueducts. This outward distance is illustrated on Figure 1D. Should this 7-mile exclusion zone be formalized (which is unlikely based on recent DEP information), it would serve to protect much, but not all, of the adjacent Town of Marbletown. Based on hydrogeologic concerns raised in this report and elsewhere, a ban of hydraulic fracturing throughout the State of Ohio is recommended. A key justification for this recommendation lies in industry documentation that well sealant materials do not exist which are capable of effectively sealing off freshwater aquifers beyond a few years to approximately one hundred years.

4.2 Challenge Claiming Safety of Hydraulic Fracturing with Reference to New York State

Business Editor Brenda J. Linert of the "Tribune Chronicle" (Ohio) wrote an article titled: *Drilling commences at Mahoning County well (Opponents decry location)* discussing a new gas well in Mahoning County, Ohio (September 14, 2012). The Meander Reservoir is situated a short distance northeast of the Muskingum River Watershed. In what appears to be commentary on Linert's article by Jim Willis, editor of the Marcellus Drilling News (a daily compilation of articles geared toward landowners and those with an interest in the shale gas drilling industry), a challenge viewpoint relative to gas exploitation in watersheds containing reservoirs used for water supply is put forth:

> "*CNX Gas Starts Utica Well in Meander Reservoir Watershed*
>
> *The third Utica Shale well to be drilled in Mahoning County, Ohio is set to begin any day now. The well is being drilled by CNX Gas (subsidiary of CONSOL Energy). While the fact that a new well is being drilled may not seem like news (it's the third well to be drilled in Mahoning County), where it's being drilled in the county is big news: in the watershed of the Meander Reservoir, which provides drinking water to 300,000 people in the Mahoning Valley.*
>
> ***When completed, this will be a great example of the fact that drilling and fracking is safe—even in watershed areas (pay attention New York*** [emphasis added]**)**:"

Indeed, New York, Ohio and the nation should pay attention. However, to do so cannot be done without detailed geologic, hydrologic, biologic and water quality data. This report recommends a comparative watershed evaluation approach to examine this critical issue in great depth (see recommendation section). Before High Volume Hydraulic Fracturing (HVHF) begins, current water quality conditions must be measured and baseline water quality parameters must be documented. Unfortunately, **the ultimate result of extensive gas exploitation in watersheds <u>will be</u> that groundwater and surface water contamination will occur, this is assured because (1) the durability of sealant materials available today to effect zonal isolation of freshwater aquifers is poor and short-lived, and (2) toxic contaminants injected deeply in the ground will move with groundwater flow systems, eventually moving upward into freshwater aquifers, reservoirs and waterways.** At best, gas companies can hope that massive contaminant and health-related problems do not surface until after they have ceased gas production and have moved to new gas plays. **The importance of requiring tracer additions to ALL fracking fluids cannot be stressed enough** (see discussion below)**.**

5.0 Hydrogeologic Setting

Many possible contaminant pathways are available to degrade water resources in the Muskingum River Watershed should hydraulic fracturing be permitted within the underlying Utica Shale and/or other gas-rich geologic beds. Figure 7 illustrates the assorted contaminant transport pathways possible between gas wells and homeowner wells and surface waters. Natural gas and contaminant transport pathways between deep gas horizons and freshwater aquifers are well documented. They include faults, joints, fracture zones, failed cement sheaths and casing material and poorly or not plugged wells. A key problem is not so much the leakage of contaminants through the shale, but leakage along vertical fractures produced or enlarged by hydraulic fracturing, into adjacent high-permeability beds. From there, groundwater flow follows the path of least resistance and maximum buoyancy. Most fractures remain unidentified.

The process of hydraulic fracturing increases the density and interconnectivity of the network of potential pathways for fluid transmissivity through bedrock. In order to fracture the shale and allow natural gas to flow up the wellbore, the hydraulic fracturing process introduces 4 to 5 million gallons of toxic fluid into thin bedrock openings, thereby exerting forces on the order of 10,000 pounds per square inch on the fluids and rock material. When pressure declines in gas producing wells, another hydraulic fracturing treatment is used to revitalize gas flow. Increasing the pressure inside the wellbore and out into geologic formations forces fluid and gas upward through available pathways of least resistance.

In addition to the fracture, fault and failed borehole flow vectors possible, an additional and highly likely source of contamination stems from chemical spills and sloppy site work associated with drilling operations (e.g., spills and draining of diesel fuels, oil, drilling mud, hydraulic oil, acids and other materials onto the ground). The top of Figure 7 illustrates likely contaminant flow routes with red curving lines. Furthermore, by pumping wells which is the accepted means of operating one's water well, homeowners may induce an inward hydraulic gradient toward their wells thereby increasing contaminant migration to them. An effort should be made to document the presence of potential vertical flow paths such as unplugged wells, plugged wells, vertical production wells, faults, joints, fracture zones, karst strata and water well locations within the Muskingum River Watershed. All such information should be amassed into a database before any HVHF wells are drilled. Gas companies, the Ohio DNR, local well drillers, and structural geologists may have the needed information.

Most of the residual contaminants from hydrofracturing will eventually move laterally and emerge in adjacent deep valleys. This is **not** just a hypothesis. Some may move so slowly that they may take thousands of years to emerge; but with the enhanced permeability of the shale there is bound to be some that is faster-moving – as is documented by hydrogeologists in textbooks and professional publications. Contaminants can also rise directly to the surface through unsealed or poorly sealed wells (possibly including those beneath Senecaville Lake), if the well bottoms are located near valleys where groundwater flow paths are oriented upward (as at "x" in Figure 4 of Dr. Arthur N. Palmer's document which is Attachment B to this report). Figure 1 of Attachment B to this report documents that pressure heads over a mile above the land surface are possible when hydraulic fracturing pressures of only 2500 psi are exerted at gas wells. Hydraulic fracturing pressures far in excess of this value are commonly used.

Myers, through the use of computer simulation, has estimated that pressure after fracking takes about 300 days to return to pre-injection levels (see *Myers Potential Pathways from Hydraulic Fracturing Paper (F).pdf* at http://hydroquest.com/Hydrofracking/. The high pressures and injection of fluid upsets the hydraulic equilibrium of the fluid-gas-rock system and it takes about 3 to 6 years for the system to reach a new equilibrium. During periods of such variable semi-unstable conditions, pressurized fluids not only rise up the wellbore, but they will rise up any other opening in the vicinity of the well (i.e., faults and joints). Again, the risk to water quality from beneath Senecaville Lake will be greatly increased if HVHF is permitted there.

Should HVHF be permitted within the Senecaville Lake watershed, repeated high pressure heads associated with hydraulic fracturing may cause poor well seals and plugs to fail. This may then result in contaminants being forced upward into overlying formations and aquifers via fractures, faults and poorly sealed wellbores. In some cases evidence may be visible, taking the form of oil slicks on a reservoir surface (or in ponds or streams) or as actively bubbling natural gas areas. Bubbling observed on Clendening Reservoir immediately after Gulfport conducted hydraulic fracturing operations nearby (Harper, pers. comm.) may provide evidence of either plug failure beneath the reservoir (if relict gas wells are there) or open fracture pathways extending from great depth to the reservoir and/or ground surface. Either way, this observation may provide proof of interconnectivity between deep and shallow geologic units and the great potential water quality risk to reservoirs, aquifers and waterways if adequately documented. Direct correlation between fracking operations and bubbling (i.e., gas releases or excursions) on reservoir surfaces should provide rationale to immediately stop gas well drilling operations and plug and abandon the well under construction. Furthermore, if there is correlation between well drilling operations and observed surficial gas excursion locations (e.g., similar timing, bubbling during fracking), this should provide rationale to consider discontinuing all drilling operations in the area to avoid potential degradation of water resources.

While it is not prudent to develop horizontal gas wells adjacent to and underneath reservoirs, it would be particularly poor to conduct hydraulic fracturing operations proximal to any reservoir that has abandoned oil and gas wells (whether plugged or not) within its footprint. Apparently, some of these wells beneath reservoirs date prior to the 1930s (e.g., the Senecaville Lake dam was constructed by the Army Corps in 1937). This is an extremely vulnerable situation. The combination of weak and potentially failing plugs, compounded by repeated fracking episodes is likely to provide open upward contaminant transport pathways to reservoirs. **HydroQuest <u>strongly</u> recommends that no gas well permits be given within any watershed with a reservoir, and particularly in settings with relict gas wells beneath reservoirs.**

Figure 1C reveals that a number of relict oil and gas wells are present within the footprint of Senecaville Lake. In addition, the locations of planned horizontal wells are illustrated. Example gas well laterals were added by HydroQuest. In this simplified rendition, only single laterals vs. multiple laterals per well are portrayed, each extending outward some 6,000 feet from vertical boreholes. Lateral distances in Ohio are reported to be as great as 7,974 feet. Lateral direction was arbitrarily selected along an orientation that allows 1,000 feet or more between adjoining laterals, as specified in Ohio drilling regulations.

Figure 1C provides a southeastern Ohio example of placement of oil and gas wells such that aquifer and reservoir water quality will almost certainly be degraded. In addition, the reservoir infrastructure (i.e., dam) lacks protection. This is a highly vulnerable situation. In this figure, only part of watershed area of Senecaville Lake is portrayed. Numerous abandoned wells (black dots) are present, many densely clustered and some beneath the lake. What integrity remains of the plug material is likely to be jeopardized from repeated hydrofracking of numerous laterals. High pressure heads during fracking (to over one mile above the reservoir surface) may drive contaminants upward through fractures and poorly plugged wellbores.

Should excursions be detected within the reservoir (analogous to that of the BP spill in the Gulf of Mexico), immediate actions will be needed to protect the quality of reservoir water and lake ecosystems. One option may be to quickly drain the reservoir for access to failing/leaking wellbores. This may pose a flooding risk to downstream people and their lands. Obviously, this approach is not likely to be practical. There should be a well thought out Emergency Response Plan in place before advancing permits for HVHF wells and their laterals close to or beneath reservoirs. In addition, as seen relative to the enormous expense incurred due to the BP spill, there should also be a formal legal document in place to cover water quality and ecosystem damage and remedial costs prior to permitting gas wells.

A key component of any HVHF permit approvals should be the inclusion of company specific tracers, capable of withstanding dilution, so that responsibility for contaminant excursions can be appropriately applied immediately, or not, to the gas industry. Tracer selection should be made by an independent panel of tracer experts. This measure will protect the public from years of delay and legal costs associated with experts, chemical testing, legal fees, etc. **Failure on the part of the gas industry or regulating agencies to require tracer addition to all fluids injected downhole should be cause to not permit hydraulic fracturing because this would demonstrate an unwillingness to accept responsibility for activities involving great environmental and health risk.** In my professional opinion, permitting and construction of HVHF wells and numerous laterals close to and beneath Senecaville Lake (or any lake or reservoir anywhere) is not prudent and should be avoided.

5.1 Coal Mine beneath Senecaville Lake Reservoir

HydroQuest understands that there is a coal mine situated beneath all or part of the Senecaville Lake reservoir. A map depicting its areal extent was not available for reference. Both this and geologic information will be examined when they become available. The presence of a flooded coal mine beneath the reservoir raises many hydrogeologic and water quality issues that should be fully addressed prior to issuing any additional gas well permits in this reservoir basin, or others in similar settings. A few initial questions include: 1) how thick were the coal beds removed, 2) were there multiple coal bed layers, 3) do abandoned oil and gas wells extend through excavated coal beds, 4) is water within the coal beds highly corrosive to steel casings and cement, 5) which came first – the coal mine or the gas/oil wells, 6) did coal mining remove gas/oil well casings, 7) if one or more old gas/oil wells have failed is the water in the coal mines toxic, 8) are open coal mine areas serving as integrators of contaminants derived from the coal itself and/or from gas/oil wells that extend into it, 9) if so, will failure of poorly plugged gas/oil wells beneath the reservoir surface provide a large contaminant pool/source area that will be forced upward should hydraulic fracturing pressures be exerted through the flooded coal mine, and 10) will the coal mine serve as a receptor of contaminants forced upward through bedrock fractures into the mine. Clearly, there are many unknowns that may potentially contribute to contamination of reservoir water quality should horizontal hydraulic fracturing be permitted adjacent to and under Seneca Lake. These issues should be fully addressed prior to permitting gas wells within the reservoir watershed.

6.0 Hydrogeologic and Geologic Reasons to Ban Hydraulic Fracturing in the Muskingum River Watershed

The high risk of the development of local and regional hazards provides several reasons to ban hydraulic fracturing in the Muskingum River Watershed. These hazards are the result of a combination of the hydrogeologic setting including water and gas bearing formations, regional groundwater flow, limitations of durability and longevity of well construction materials, and characteristics of hydrofracking such as injection of large volumes of fluids containing hazardous materials at pressures as high as 10,000 pounds per square inch (psi). The presence of former producing petroleum wells, the likelihood of local unplugged or poorly wells, and the presence of naturally transmissive planar geologic features (faults, joints, fracture zones) increase the probability of contaminant fluid migration from deep fracking targets to near surface aquifers and reservoirs (used as public and private potable water supplies). The potential for earthquakes within the watershed is evaluated and found to pose additional risk. All of these risk factors explain much of the human health impacts being discovered in areas of recent hydrofracking.

6.1 Hydrogeologic Risk & Concerns

The only viable means of protecting groundwater and surface water resources now and for future generations is to enact legislation which prohibits the use of hydraulic fracturing in the extraction of oil and gas.

Today's gas field technology is not capable of permanently isolating freshwater aquifers from gas field contaminants. Sealant materials do not exist to effectively seal off freshwater aquifers beyond a few to approximately one hundred years. In a short time all gas well sealant materials designed to isolate and protect freshwater aquifers will fail - 100 percent. The durability and mechanical properties of gas well sealant materials (primarily cement and steel) are not sufficiently advanced such that freshwater aquifers will be safely protected for even as long as 100 years, much less the hundreds of thousands of years required, regardless of the number of nested casings used. Aquifer contamination will persist for centuries, far outlasting the technology for prevention of leakage from wells.

Failure of cement sheaths due to shrinkage, debonding, cracking, corrosion, and other mechanisms is well-documented throughout gas industry literature and by HydroQuest (e.g., see *HydroQuest DRBC Draft Regulations Comment Report 4-09-11 (E1).pdf* and *April 9, 2011 DRBC Comment Report Figures (E2)/* at: http://hydroquest.com/Hydrofracking/).

HydroQuest and Mid-Hudson Geosciences have advanced hydrogeologic and other key reasons to ban hydraulic fracturing in New York State. **<u>Two</u> key documents are hereby incorporated by reference for purposes of providing solid rationale to enact legislation in Ohio designed to ban hydraulic fracturing.** The first is a document file titled: *HydroQuest – Mid-Hudson Geosciences NYS Senate Testimony 4-25-12 (H).pdf* that is found at the following URL:

http://hydroquest.com/Hydrofracking/

A second document that provides hydrogeologic rationale for banning hydraulic fracturing in NYS, WV, PA, OH and elsewhere is titled: *Key Reasons to Ban Hydraulic Fracturing in New York State – Submitted to NYSDEC on 8-14-12*. This document, among others, was recently provided to NYS Governor Cuomo’s Executive Staff. It is provided here as Attachment A to this report.

Fox (2012, The Sky is Pink (an 18-minute documentary video revealing facts behind gas well failures: 6-20-12 [http://vimeo.com/44367635]) cites a number of examples which document the significance of these failures, including an industry document published by Schlumberger in Oilfield Review that showed that Sustained Casing Pressure (i.e., casing failure) occurred in 6 percent of wells immediately upon drilling with 50 percent casing failure within 30 years. Of wells drilled in the Gulf of Mexico, 45 percent of 6,650 wells had well integrity (i.e., leakage) issues. Of wells drilled in the North Sea, UK, 34 percent of 1,600 wells had well integrity (i.e., leakage) issues (information from a conference presented by Archer on Better Well Integrity). Recent PA DEP statistics from 2010 to 2012 show well failure/gas leakage rates of between 6.2 and 7.2 percent for newly installed wells. Clearly, these percentages will rise significantly through time as sealant material degrades and both earthquake and repeated episodes of hydraulic fracturing produce ground motion that cracks cement sheaths (see below). Statistics of this nature make it clear that gas and other contaminants will eventually discharge into overlying freshwater aquifers.

As a result of failure of sealant material, degradation of water resources (groundwater and surface water) is assured. The lack of long-term durability of cement sheath and casing material used to isolate freshwater aquifers is the subject of much misinformation from the oil and gas industry. There are no hydrofracking procedures which can assure protection of finite and valuable water resources now or into the future. As a result, toxic and carcinogenic contaminants are already and will continue to move with groundwater flow systems to the most prolific valley bottom aquifers and rivers, as is already occurring in Pennsylvania and elsewhere. The enormous magnitude of planned new gas well installations that could potentially tap the Utica Shale and other gas-rich bedrock formations in Ohio (i.e., thousands) would result in large-scale and widespread water contamination that cannot be remediated. As aptly stated by Cyla Allison, Ph.D. of the Eight Rivers Council, WV: "*The damage may not show up for years, the ruination of our water may at first be invisible and in the end irreparable*." It is imperative that legislation be enacted that comprehensively addresses the

Muskingum River Watershed, designed to protect the quality of water resources and people's health. Long horizontal laterals and repeated high pressures associated with HVHF wells will increase the magnitude of groundwater contamination by hydraulically interconnecting fractures open to preexisting vertical oil and gas wells.

6.2 Five Year Life Expectancy of Casing Material

The basic underlying premise put forth by the gas industry is the erroneous concept that hydraulic fracturing can be conducted safely such that long-term water quality is assured. This is not true, as documented in industry literature and as demonstrated by regional groundwater flow characterizations (HydroQuest; Palmer; Myers – available at http://hydroquest.com/Hydrofracking/). Gas, cement, and steel industry literature provides field and model-based documentation confirming that even under the best of conditions, the cement and steel casing materials used to isolate freshwater aquifers will fail in 100 years or less. Moreover, industry insiders admit that the real situation is significantly more dire. For example, while conducting a tour of the TMK IPSCO facility (TMK IPSCO operates 24 production facilities around the world) in Wilder, KY on June 1, 2012, Plant Manager Jim Truskot specifically addressed the life expectancy of the steel well casing and tubing products, stating directly and definitively to Stephen Gross of Hudson Highlands Environmental Consulting that such products have:

> *"No better than a five year life expectancy when used for fracking because of the highly corrosive nature of the fracking chemicals used. After that, it would need to be replaced."*

(Steve Gross, pers. comm. to Paul Rubin)

Obviously, five years or less is an alarmingly shorter life expectancy than that traditionally cited by the gas industry. Thus, failure of cement sheaths and casing materials used to isolate freshwater aquifers will assuredly occur in less than 100 years, quite possibly in less than the five year life expectancy of steel exposed to corrosive hydraulic fracturing chemicals, and possibly in under a year. When failure does occur, downhole contaminants will be under sufficient upward hydraulic pressure to disperse upward into freshwater aquifers, first via failed sealant materials and then via fractures, faults, and improperly plugged and/or abandoned oil and gas wells. See Figure 7. Palmer (see *Palmer - Upward Leakage through Micro-Annulus of Injection Well (12-10-11) (N).doc* at http://hydroquest.com/Hydrofracking/) presents a sample calculation detailing the operable hydraulic conditions and factors that will drive contaminants upward to the level of freshwater aquifers during hydraulic fracturing operations when sealant failure occurs and provides a way to estimate the rate of upward flow from the bottom of a cased injection well back to the surface along a micro-annulus formed where the casing has separated from the surrounding cement. Palmer's calculations demonstrate that, given the pressures involved, even tiny apertures in a failed cement sheath can yield a very large amount of contaminant leakage upward into freshwater aquifers.

6.3 Evaluation of Post-Production Plugging and Reclamation of Oil and Gas Wells

Before any additional gas well permits are approved and any additional drilling occurs, the status of ALL plugged and abandoned wells in and adjacent to the Muskingum River Watershed should be fully documented and should be determined to be acceptable within applicable state regulations. If all wells are not within full compliance with state regulations, state aquifers and people's health may be at risk. An assessment similar to that conducted by Dr. Ron Bishop to evaluate the success of New York State's regulatory program for the oil and gas industry with respect to post-production plugging and reclamation (see *Bishop – NYS Regulatory Well Plugging Failure (P).pdf* at http://hydroquest.com/Hydrofracking/ is recommended. A serious look at Ohio data should be conducted if this has not already been done, using Dr. Bishop's work as a general template. Dr. Bishop's recommendations should be adopted immediately for Ohio – unless all Ohio well records, files, maps and well closures are complete with no omissions, are well organized for public review AND the locations of all wells can be demonstrated to be known and the wells can be demonstrated to be in full compliance with state plugging and abandonment regulations. Reference to Figure 1C, for example, shows there are active wells within Senecaville Lake, which is not correct. It is likely that there are other examples of incorrectly placed wells, some with questionable plug integrity. Until such time as all wells can be documented to be in full compliance with existing laws, Dr. Bishop's recommendation to prohibit all high-volume, hydraulically-fractured (HVHF) projects in New York State applies equally to Ohio until:

> "*(a) All oil and gas wells in New York State which are known or suspected to require plugging have been added to the priority plugging list, and* [While written for NYS wells, this applies equally to Ohio]
>
> *(b) Every well on that list has been plugged and the area reclaimed.*
>
> *The objective would be to demonstrate oil and gas industry compliance with existing laws before approving any more intensive industry operations in the state*."

An analysis similar to that conducted by Dr. Bishop in New York State, conducted for the Muskingum River Watershed, should be conducted to demonstrate/document that the state of Ohio is or is not in a position to advance new HVHF well applications confident in the knowledge that all old wells are fully located and properly abandoned.

6.4 Seismic Risk

The placement of gas production wells within seismically active regions significantly increases the risk of contaminant dispersal upward into overlying aquifers as ground shaking/motion will damage the integrity of cement seals. Repeated hydrofracking episodes in gas wells will also result in cracking and failure of cement sheaths that are intended to protect freshwater aquifers. Repeated stress from multiple fracking episodes per well, as well as from fracking in nearby wells, has a high likelihood of degrading the integrity of cement sheaths used to isolate freshwater aquifers. Once cracked, cement sheaths will provide a contaminant transport pathway into overlying aquifers. A crack in a cement sheath of only 0.001 inch is sufficient to allow upward gas migration.

Another factor that needs to be considered as sound rationale for enacting legislation to ban hydraulic fracturing in the Muskingum River Watershed is that of seismic risk to the integrity of gas well sealant materials. The risk of earthquakes in the watershed and the surrounding region is both real and great. Because aquifers must be capable of providing potable groundwater for the next 100 years, next 1,000 years and far beyond for future generations, seismic risk to cement sealant material must be evaluated based on the long-term risk to water quality (i.e., the reasonable use aquifers within their expected life of 1,000,000 plus years). Figures 2 through 5 document that the seismic risk within the Muskingum River Watershed, based on USGS-based earthquake probability modeling for 100, 500, 1000 and 10,000 year intervals at Coshocton and Akron, Ohio is unacceptable (i.e., up to 90-100 percent). Figure 6 documents earthquake epicenters in Ohio and adjacent areas. Seismic activity and related ground vibration are highly likely to result in cracking and loss of integrity of cement sheath and plug material very early in the life expectancy of Ohio aquifers. This will then open contaminant vectors illustrated on Figure 7.

A recent earthquake provides a good indication of the likelihood of downhole cement cracking from earthquake induced ground shaking. For example, the 5.8 magnitude earthquake of 8-23-11, with an epicenter 200 miles SW of Philadelphia, impacted Philadelphia structures in 48.8 seconds. Just as ground vibrations can be sufficiently large to cause buildings to vibrate, windows to crack, and structures to crack (e.g., as occurred in Philadelphia), ground shaking associated with earthquakes can cause gas wellbores to shear, opening them as pathways of contamination to the underground geology. Induced lower magnitude earthquakes such as those probably associated with the downhole injection of wastewater from hydraulic fracturing, inclusive of those with epicenters about 2 miles north of Irving, Texas that occurred on September 29, 2012 (3.4 M and 3.1 M), also pose great risk to the integrity of cement sheaths. Another example of earthquakes induced by deep waste fluid disposal/injection occurred at the Rocky Mountain Arsenal in Colorado where multiple earthquakes were recorded in the 1960s, some of 5.3 and 5.2 magnitude. Increased lubrication along fault planes by wastewater reduces the friction, resulting in movement along faults and earthquakes. Ground shaking from earthquakes and aftershocks will almost certainly destroy the integrity of cement and steel sealant materials, thereby opening contaminant pathways that cannot be remediated.

7.0 Reasons to Not Sell Reservoir Water (Possible Impacts of Exploitation)

The extraction of large quantities of reservoir water may increase the flow and recharge of groundwater to them from up-gradient watershed areas. As reservoir water levels fall below spillway elevations, the hydraulic gradients from the surrounding watershed to lowered reservoir levels will steepen, thereby potentially increasing the rate of influx of contaminants present in unconsolidated and bedrock aquifers. This may, in turn, increase the rate of contaminant influx from up-gradient chemical-laden gas wells (existing and new) and fractures, thereby degrading water quality in reservoirs. Thus, a higher percentage of reservoir source water will be groundwater derived than when surface runoff provided more water, especially during dryer and drought conditions. This hydrologic situation should be evaluated through a combination of field data and modeling before further consideration is given to extracting reservoir water. In addition, a reduction in reservoir levels will equate to <u>less surface water dilution</u> of gas field contaminants as reservoir levels are drawn down from water extraction for use in gas well development.

The potential intended sale of reservoir water for hydraulic fracturing use both within reservoir watersheds and beyond will degrade and irreparably harm its high quality and may, in time, adversely impact the health of residents in watersheds where this water is used (e.g., from within the Senecaville Lake watershed). If some of this reservoir water is used for hydraulic fracturing of gas wells in watershed areas up-gradient of reservoirs, alongside reservoirs, or elsewhere, it is certain that toxic additive chemicals will flow with the groundwater flow system and rise upward into down-gradient reservoirs, aquifers, and waterways where water users will then ingest them, potentially leading to the need for a health clinic such as that now operating in Washington County, PA for individuals with toxic gas field chemicals in their blood streams and with related ailments. In essence, Senecaville Lake reservoir water would be extracted, toxic and carcinogenic chemicals would be added and injected downhole in gas wells. This contaminated water would then flow with the regional groundwater flow system, until it would ultimately rise upward into the Senecaville Lake reservoir or, possibly, the Ohio River where it would be extracted and ingested – at which time it could then be extracted and again be circulated though this cycle. In addition, it would not be prudent to sell Seneca Lake water in the absence of a drought management plan. Excessive water withdrawal during times of drought may have the potential of over extending reservoir water availability. Also, before any reservoir water is extracted, a study of water levels required to safeguard existing fisheries and ecosystems should be completed.

It is possible that Ohio has state laws that seek to protect drinking water by seeing that it does not become impaired. This should be evaluated within the context of hydraulic fracturing. Adding toxic chemicals to reservoir water and injecting them underground into flowing aquifers does not preserve, protect and enhance the present and potential value of Ohio's water resources. Similarly, gas field chemicals will rise with groundwater in populated valley bottom settings, thereby also degrading surface river water quality and reservoirs. This planned degradation of reservoir water may result in large and important adverse environmental impacts, some of which may directly impact the health of people situated down-gradient of gas well chemical injection points. A full Environmental Impact Statement that addresses **all** the issues raised in this report should be prepared for public review and comment prior to extracting reservoir water and permitting hydraulic fracturing of gas wells in the Muskingum River Watershed.

7.1 Adverse Health Impacts Associated with Gas Exploitation

The most important reason to ban hydraulic fracturing in the Muskingum River Watershed is that it poses great medical risk to the residents. Gas industry chemicals mixed with groundwater and injected into gas-rich shale formations (e.g., Utica Shale) will migrate as one or more contaminant plumes to freshwater aquifers. Hydraulic fracturing poses a serious threat to groundwater quality, not only in the vicinity of the drilling site, but also in the entire down-gradient part of the groundwater flow system. Because groundwater flow rates are slow, chemical exposure is likely to continue for decades, centuries, or far longer. Although the injection of contaminants would take place thousands of feet below the surface, groundwater flow inevitably carries them laterally and then upward into major neighboring river valleys over periods of years to hundreds of years, tailing off for possibly thousands of years. This is the underlying reason why more and more homeowners and animals in gas fields will experience adverse health impacts in the future. In the broader Muskingum River watershed area, the valleys and areas around reservoirs are where most people live. While contaminants would be widely dispersed, they would pose a threat to health, especially when numerous horizontal fracked wells are involved. Once contaminated, groundwater cannot be remediated even at unlimited cost.

Important insight into the future of southeastern Ohio, if horizontal hydraulic fracturing is permitted, can be gleaned by examining what is occurring now in other active gas field areas. To this end, it is important to recognize that toxic gas industry contaminants, if added to deep groundwater, will move with the groundwater flow system to down-gradient receptors. Unfortunately, many homeowners in gas fields have had their well water contaminated such that it is NOT fit to drink or bathe in. Homeowners in Washington County, PA gas fields, for example, and elsewhere report that assorted medical problems have occurred after installation of horizontal gas wells (e.g., headaches, stomach cramps, blotches on their skin; pers. comm. to HydroQuest). In addition, HydroQuest has firsthand experience with clients that have experienced assorted physical/medical problems from contact exposure with hydraulic fracturing chemicals (e.g., skin rashes, abdominal pains, toxic toluene, benzene and arsenic in people's systems). Some or all of these symptoms are consistent with those impacting residents in Washington County, PA gas field areas (toxicologist Dr. David Brown, pers. comm. to HydroQuest) where a permanent clinic has been set up to treat adversely impacted residents. As per the advice of toxicologists, some of these people have taken their children and moved away from their homes.

Recent research by PhD student Elaine Hill, in an as yet unpublished Dyson School Working Paper tentatively titled *Unconventional Natural Gas Development and Infant Health: Evidence from Pennsylvania,* provides the first evidence that links natural gas development with human health directly. Hill (July 2012) correlated infant health at birth before and after gas field well development from 2003 to 2010 with mothers living within approximately 1.5 miles from gas development. Exploiting this natural experiment to identify the impacts of gas field contaminants on infant health, Hill concludes that "*The results suggest that exposure to natural gas development before birth increases the overall prevalence of low birth rate by 25 percent, increases overall prevalence of small for age by 17 percent and reduces 5 minute APGAR scores, while little impact on premature birth is detected. … This paper provides evidence that exposure within at least 1.5 miles is very detrimental to fetal development.*" Although this work has yet to be peer reviewed, the percentages may change somewhat, and it is subject to change, it provides additional justification to ban hydraulic fracturing in the Muskingum River Watershed – at least until such time as similar medical studies have been conducted in similar pre- and post- gas drilling areas of Ohio. This research should, like the findings of Dr. Brown and other toxicologists, serve as an important warning. These medical studies (i.e., health impacts assessment) should be conducted by independent physicians, toxicologists and health professionals.

A comprehensive Health Impact Assessment (HIA) is needed (Catskill Mountainkeeper 9-28-12). While their comments are directed to New York State regulators and the Governor, they apply equally to Ohio. An HIA is the gold standard used to study health impact. The process insures that the best available science and all relevant perspectives are brought to bear on the analysis. It distinguishes itself from other kinds of public health investigations by being done in advance of any decision to approve or prohibit a proposed activity. It allows for public participation in scoping, hearings, reviews, meetings, and stakeholder consultations, especially with members of targeted communities. An HIA should be completed prior to approval of any HVHF or LVHF within reservoir watersheds. The Catskill Mountainkeeper clarifies that the HIA process would:

> *"Identify the potential effects of shale gas extraction on the health of the people … and describe what its effects will be on our citizens. … Even small increases in the incidence of chronic health problems could potentially impact thousands of people and create ruinous health care costs.*
>
> *Consult independent experts from multiple disciplines to evaluate the complex hazards and exposures created by shale gas extraction.*
>
> *Have special emphasis on vulnerable subpopulations including infants, children, pregnant women and the elderly. For example, an HIA could examine the associated air pollution impacts on birth weight, childhood asthma, heart attack and stroke.*
>
> *Analyze not only the causes of illness but also the conditions that affect health, which include personal behaviors, social and economic factors, the built environment, and the physical environment.*
>
> *Consider the health risks from cumulative impacts and throughout the entire life cycle of shale gas extraction and transport including radon exposure from pipelines, radon in homes and apartments, exposures to lead and toxic chemicals and the potential for exposure to toxins from drilling wastes.*
>
> *Examine occupational health risks to workers.*
>
> *Recommend actions to minimize or eliminate the health effects that it identifies."*

7.2 Ethical Issues

While not strictly hydrologic in nature, an issue related to injecting toxic chemicals underground into actively flowing groundwater systems is that of accepting ethical and moral responsibility for the adverse environmental and health impacts that will result once contaminated publicly-owned reservoir water is ingested by people and animals. Gas field chemicals added to hydraulic fracturing water will move with groundwater within regional groundwater flow systems. This water will then be ingested by both people and animals, thereby raising the question of whether it is legally and morally correct to knowingly sell degraded water for a purpose that is known to create environmental harm. As a professional hydrogeologist, I do not believe that publicly owned and then degraded water sold for profit is in the best interests of the public, especially those situated down-gradient where the public will ingest gas industry chemicals. These issues and hydrologic concepts should be considered prior to selling public water to the gas industry.

Public water sold for purposes of hydraulic fracturing will be irreparably degraded. Water quality protection, water quality degradation, water use, and exposure of the public to contaminated water have long been critical areas addressed by hydrogeologists, as have ethic related issues. Here, it is known that the sale of publicly-owned reservoir water to gas companies is for the explicit purpose of forever degrading its quality for private profit. Typically, and by way of contrast, point source discharge permits are granted after a determination is made that pollutants discharged to waterways will be adequately diluted and assimilated so that downstream communities can reasonably withdraw it for water supply purposes. This is also important from an ecologic standpoint. Thus, the intent of pollutant discharge permit programs is to maintain water quality. The concept behind these permits is to only allow single or multiple point source discharges that will not individually or cumulatively exceed the assimilative capacity of streams and rivers such that the total contaminant load will not degrade or destroy water quality and ecosystems. By analogy, it makes sense that similar efforts should be made to maintain the quality of potable groundwater that will extracted from Muskingum River watersheds. Freshwater is a finite, non-renewable, resource. To contaminate it for private corporate profit may be in direct conflict with state programs designed to protect water quality. A determination should be made to ascertain whether knowing and intentional degradation of aquifer waters is in violation of Ohio water protection statutes. If not, legislation should be enacted to thwart groundwater contamination. Since deep groundwater is known to flow upward to valley bottom aquifers, the only possible means of protecting groundwater quality is by not injecting toxic chemicals downhole under great pressure or by banning hydraulic fracturing. The recommendation section of this report provides guidance to legislative initiatives designed to ban hydraulic fracturing.

Water quality protection should be addressed prior to approving the sale of any reservoir water. Sale of reservoir water to gas companies will be with the knowledge and intent of forever degrading high-quality groundwater (i.e., drinking water) for private profit. Beyond this, once intentionally contaminated by gas companies, this water will move with regional groundwater flow systems to aquifers in municipalities where people will ingest it and become very ill. The hydrogeology and pathways leading to this were discussed above. Based on recent findings of toxicologists, contact with contaminated gas field groundwater has already adversely impacted the health of numerous individuals. Thus, those seeking approval of the sale of reservoir water to gas companies must recognize that this is what will happen with this water. Local reservoir water owners and gas companies will benefit, but at an unacceptable price and risk to public health and without affording any water quality protection.

8.0 Overall Risk Factor Conclusion

Health risk and assured contamination of ground and surface water supplies is the reason to ban hydraulic fracturing in the Muskingum River Watershed and beyond. The use of fracking fluids containing contaminants and the fact that the petroleum industry is exempt from hazardous waste regulations are potential high risk factors contrary to the protection of public health in Ohio. The frequency of natural and pressure-induced fracture networks increases the likelihood of vertical migration of contaminants upward from gas wells into aquifers and reservoirs. Multiple fracking treatments for each well increase the time of pressurization of fluids within bedrock formations and the potential for movement of fracking fluids to higher levels in bedrock. Seismic events (earthquakes) have been documented in injection wells (should these be permitted in the future in the watershed) as induced by over-pressurization, which can also result in additional interconnections between natural and frack-induced fractures. Inherently the fracking process has the potential to damage the cement sheath around well casings and therefore allow leakage of natural gas and well fluids. All these factors indicate that fracking has the capability of creating openings in rock which will help in gas production, but can also conduct contaminants upward with potential discharge to aquifers, reservoirs and surface waters. Toxic chemical-laced fracking fluids that are injected into gas wells known to be within regional groundwater flow systems will eventually flow upward and contaminate aquifers and surface waters. This, in turn, poses great medical risk. This provides rationale to ban hydrofracking in the Muskingum River Watershed and beyond. To allow the petroleum industry to destroy precious water resources is not prudent. Once contamination is discovered and documented, the profits of the industry will be long gone and remediation will be impossible.

9.0 Recommendations

The recommendations below stem from active review of adversely impacted homeowners in PA gas field settings. Furthermore, HydroQuest's research of industry literature and understanding of groundwater flow systems leaves no doubt that well sealant material failure will eventually occur in 100 percent of all gas wells and that the chemicals released will ultimately discharge to aquifers and reservoirs in the Muskingum River Watershed and the Ohio River. Such contamination of fresh waters is likely to jeopardize the health of people who ingest this water. HydroQuest hereby provides four sets of recommendations. The first set of recommendations should, in our professional opinion, be instituted immediately.

The second set of recommendations is designed to protect the interests of both the gas industry and private landowners in the event that the planned horizontal wells are approved for development and groundwater contamination is found.

The third set of recommendations should be considered for incorporation within text of legislation that addresses the entire Muskingum River Watershed and the state of Ohio. These recommendations are designed to protect the water quality and health of all residents throughout the Muskingum River Watershed and beyond.

Until such time as the State of Ohio enacts legislation banning hydraulic fracturing, which is likely to eventually occur as water contamination and adverse health impacts become evident, actions such as that taken on October 1, 2012 by the Yellow Springs Village Council in adopting a Community Bill of Rights ordinance banning shale gas drilling and related activities in the village provide an important step protective of water quality.

The fourth recommendation below seeks to have a comprehensive comparative land use and water quality study conducted using the Senecaville Lake (Ohio) and Ashokan (NYS) reservoirs and watersheds as test cases to assess "*baseline*" water chemistry, changes and trends in water quality through time in locations with and without active gas wells. Detailed assessment and analysis of existing conditions in the Senecaville Lake watershed and reservoir is required, as low level degradation may already be present. For this reason, it is critical that much comparative work be conducted in headwater stream and groundwater portions of the watersheds. This study will chronicle the degradation of water resources in the Senecaville Lake watershed through time. Also, it will address the implication put forth in the September 14, 2012 Marcellus Drilling News that drilling and hydraulic fracturing are safe, even in watershed areas.

9.1 Recommended Immediate Actions

Reservoirs within the Muskingum River Watershed, and elsewhere, are particularly vulnerable to contamination from nearby hydraulic fracturing operations that occur close to or directly underneath them via horizontal laterals. This situation will be greatly exacerbated if old abandoned oil and gas wells are present beneath or close to reservoirs as they will eventually, if not immediately, provide vectors or pathways for contaminants to move rapidly upward from depth. High pressures and repeated hydraulic fracturing episodes pose a great risk of forcing pressurized contaminant-laden frack fluid upward into or adjacent to reservoirs. Palmer provides detailed calculations showing how fracking-related pressures can temporarily raise the pressure head to over a mile above the land surface. This work is incorporated here by reference (Appendix B, below). The following actions are recommended immediately:

- Institute a drilling moratorium on all watershed lands surrounding reservoirs (e.g., Atwood Lake, Charles Mill Lake, Clendening Lake, Leesville Lake, Piedmont Lake, Pleasant Hill Lake, Senecaville Lake, Tappan Lake), pending completion of other recommendations made in this report;

- Should water quality and public health risk concerns not be sufficient to institute a drilling moratorium on all watershed lands surrounding reservoirs then, at the very least, no hydraulic fracturing operations should be permitted proximal to any reservoir that has abandoned oil or gas wells within their footprints;

- Ban the extraction of reservoir water. Lowered reservoir levels will almost certainly result in an increased percentage of reservoir composition due to groundwater influx and a decrease in surface runoff and potential contaminant dilution due to extraction of reservoir water. In addition, pumping of reservoir water will increase the hydraulic gradient close to reservoirs, thereby potentially increasing the contaminant load stemming from failed oil and gas wells either now or in the future. A combination of field data and modeling should be conducted to assess the associated impacts;

- Prepare a full Environmental Impact Statement that addresses all the issues raised in this report for public review and comment prior to extracting reservoir water and permitting hydraulic fracturing of gas wells in the Muskingum River Watershed;

- Before any reservoir water is extracted, a study of reservoir water levels required to safeguard the existing fishery and ecosystem should be completed;

- Before any reservoir water is extracted, drought management plans should be developed and formally adopted that establish thresholds (e.g., reservoir levels, minimum stream inflow, anticipated water demand, nearby groundwater levels) below which reservoir water extraction is not permitted;

- Conduct an assessment of all plugged and abandoned wells to demonstrate oil and gas industry compliance with existing laws before approving any new gas and oil drilling operations in the state (i.e., HVHF and LVHF). Until such time as all oil and gas wells can be documented to be in full compliance with existing laws, prohibit all high-and low volume, hydraulically-fractured projects in Ohio until: (a) All oil and gas wells which are known or suspected to require plugging have been added to a priority plugging list, and (b) Every well on that list has been plugged and the area reclaimed;

- Conduct a geologic, hydrogeologic and water quality assessment of the potential implications of the coal mine situated beneath the Senecaville Lake reservoir, as well as other reservoirs with similar geologic conditions;

- If historic and recent water quality data exists for reservoir water, conduct comprehensive analyses to assess changes in water chemistry through time, if any. These analyses should also include documentation of spills, fish kills, inability to maintain certain fish populations, etc.;

- Conduct similar infant health related medical studies as conducted by Elaine Hill in similar pre- and post- gas drilling areas of Ohio. Toxicologists, health professionals and medical doctors should be part of this important independent study. Consideration should be given to contracting with Elaine Hill to spearhead this study;

- Have toxicologists and medical doctors in Ohio who may have patients exhibiting adverse health impacts from exposure to gas field chemicals prepare an independent report detailing their findings and concerns, if any;

- Conduct and complete a comprehensive Health Impact Assessment (HIA);

- Protect the infrastructure of all reservoirs and their distribution systems (e.g., dams, aqueducts, tunnels) by establishing a minimum setback distance from them of 2 miles;

- Ban all drilling and placement of well laterals within one mile of the outer boundary of all reservoir watersheds in the Muskingum River Watershed (as well as other reservoirs in the state of Ohio). Do not permit well laterals to project into or beneath these protection/buffer/exclusion zones;

- Develop a well thought out Emergency Response Plan before advancing permits for HVHF and LVHF wells and their laterals close to or beneath reservoirs (should permits be approved);

- Develop a formal legal document to guarantee full funding to cover water quality and ecosystem damage and remedial costs should old wells beneath and near Muskingum River Watershed reservoirs fail;

- **Require tracer addition to all waters and fluids that will be injected downhole.** All HVHF and LVHF permit approvals should mandate the inclusion of company specific tracers, capable of withstanding dilution, so that responsibility for contaminant excursions can be appropriately applied immediately, or not, to the gas industry. Tracer selection must be made by an independent panel of tracer experts. There should also be a monitoring component where an independent party oversees tracer additions and then tests for compliance using standard litigation quality chain-of-custody protocols. This measure will protect the public from years of delay and legal costs associated with experts, chemical testing, legal fees, appeals, etc. It may also help other states and federal regulators solidify their positions relative to banning or permitting hydraulic fracturing in the future. **Failure on the part of the gas industry or regulating agencies to require tracer addition to all fluids injected downhole should be cause to not permit hydraulic fracturing because this would demonstrate an unwillingness to accept responsibility for activities involving great environmental and health risk.**

9.2 Recommended Actions in Advance of Completing Horizontal Gas Well Installations (If Permitted)

The following actions are recommended prior to advancing HVHF and LVHF wells should regulating agencies fail to ban hydraulic fracturing before the recommendations above are completed:

- Document the presence of faults within the Muskingum River Watershed. Gas companies, the Ohio DNR, local drillers, and structural geologists may have the needed information;

- If not already mandated by Ohio law, require full disclosure of all chemicals to be injected downhole in gas wells, inclusive of proprietary chemicals. This disclosure should include a detailed listing of all chemicals contained in product listings comprised of multiple chemicals, inclusive of full MSDS information;

- Collect baseline water chemistry information from all groundwater wells within one mile of planned HVHF and LVHF gas wells;

- Collect and assess historical and present water chemistry data from streams and reservoirs within the Muskingum River Watershed;

- If not already in place, establish a water quality monitoring network to assess groundwater, surface water and reservoir quality as hydraulic fracturing of new wells proceeds and as groundwater moves chemical-laced gas industry fluids towards major rivers, homeowner wells, major springs, valley bottom aquifers and reservoirs. Chemical parameters to be monitored should include all major ions, pH, specific conductance, total dissolved solids, heavy metals, all Maximum Contaminant Level parameters associated with gas field chemicals or their byproducts, a suite of gas field chemicals to be determined by independent chemists, and the tracers discussed in Section 9.1 above ;

- Conduct a stepped drawdown, high yield, pumping test on new gas wells once they are drilled to the bottom of the freshwater aquifer, and prior to casing them, while monitoring groundwater wells within ½ mile of them (see related file: *Seismic Hazard Expert Fact Sheet Back 9-4-11(M2).pdf* graphic and text at http://hydroquest.com/Hydrofracking/ hereby incorporated by reference). Transducers and water level indicators should be used to monitor for hydraulic connectivity. If pumped wells cause water levels in groundwater wells to decrease, incipient gas wells should be plugged and abandoned or completed as water wells. Otherwise, once cement sheath failure occurs in the gas well (anytime from minutes to years), an open pathway will be present where natural gas may enter drinking water sources and buildings, resulting in an explosive risk to houses and wells. In addition, depending on the hydrologic setting, groundwater contamination may also occur;

- Install transducers on all groundwater wells within ½ mile of planned HVHF and LVHF gas wells in advance of hydraulic fracturing operations, preset to record water pressure at sufficiently small time intervals to detect hydraulic connectivity during fracking operations. Develop a plan to immediately plug and abandon any and all gas wells that are found to be hydraulically connected to aquifer wells;

- Install a seismic network in advance of hydraulic fracturing. Seismometers locations should include key infrastructure features (e.g., dam);

- Install an air monitoring network for use in health impact assessments;

- **Have an independent panel of tracer experts select one or more tracers and detection and monitoring methodologies for use in all gas industry fluids. The importance of this measure cannot be stressed enough. No additional fluids should be permitted downhole without strict regulation and enforcement of tracer additions**;

- Conduct and complete a comprehensive macro-invertebrate, fish and biodiversity study of species presence and health along streams tributary to the Senecaville Reservoir and within the reservoir itself. In addition, the reservoir outflow stream should be incorporated within this study. Along streams, this assessment should include headwater reaches; and

- Consider requesting that EPA take an active role in the full testing and evaluation process.

9.3 Recommended Statewide Legislative Action

The intentional injection of toxic, carcinogenic and proprietary chemicals into deep, but actively flowing, groundwater systems known to discharge upward to freshwater aquifers, reservoirs and waterways is unconscionable. The wisdom of hydraulic fracking proximal to reservoirs is even further confounded when considering that well sealant materials available today will degrade in less than 100 years, often far less, thereby providing direct upward contaminant pathways to reservoirs. It would be prudent to adopt statewide legislation banning hydraulic fracturing. The following items should be considered and adopted in the legislation:

- Ban both High Volume Hydraulic Fracturing and Low Volume Hydraulic Fracturing throughout all of the Muskingum River Watershed and Ohio. It should be explicitly stated that this ban shall specifically include vertical wells, as well as angled and horizontal wells. Vertical gas and oil wells pose similar environmental and health threats as do horizontal wells. In addition, consideration should be given to banning downhole exploration by gas companies anywhere;

- Ban the extraction of surface and groundwater for sale in use in any aspect of gas and oil exploitation. Water sold to the gas industry will be irreparably degraded by industry chemicals, will then move within groundwater flow systems, and **will** adversely impact down-gradient populations;

- Ban present and future sale of landfill leachate to the petroleum industry, regardless of whether it has been wholly or partially treated;

- Ban the purchase or free acceptance and spreading of any gas industry fluids (e.g., flowback or produced water) for any purpose, inclusive of road deicing. The concept of intentionally dispersing toxic and proprietary pollutants onto pristine landscapes where they will, without fail, infiltrate directly into underlying aquifers and flow to waterways is difficult to comprehend. To not grasp this contaminant flow vector would ignore the empirically based science of groundwater hydrology that has been advanced by hydrogeologists worldwide for over half a century, plus the dire medical concerns raised by toxicologists and doctors treating clients exposed to frack fluid contaminants. Consideration should be given to advancing protective legislation designed to thwart all potential contaminant vectors advocated by the gas industry, inclusive of brine spreading;

- Ban the storage and disposal of any by-products of hydraulic fracturing inclusive of land spreading, downhole injection, and in wastewater treatment plants;

- Ban the installation of gas industry pipelines. These pose a threat to nearby residents and to the many wetlands and waterways that they cross. In addition, they significantly fragment ecosystems and landscapes; and

- Avoid enacting anti-fracking legislation that has any possible loophole or waiver that might one day provide industry access to state and private lands. To enact legislation with a waiver would likely have the impact of rendering it meaningless. Should this topic, for any reason, become an issue - seek to replace it with law section items that specifically address issues that might conceivably be envisioned (e.g., the extraction and sale of spring or groundwater explicitly for beverage and bottled water purposes). The importance of this recommendation cannot be stressed enough.

9.4 Recommended Long-term Comparative Study

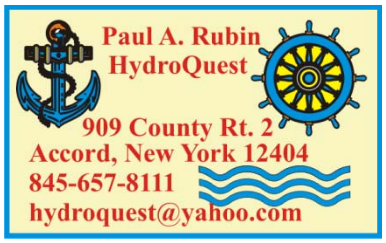
- HydroQuest recommends that New York City's Ashokan Reservoir, the streams tributary to it, and groundwater wells within the watershed be used to contrast water quality through time (**past, present, and future**) with that of the Seneca Lake Reservoir, its tributary streams and groundwater wells. This comparative water quality and land use study relative to hydraulic fracturing will have important ramifications relative to protection of groundwater and surface water resources throughout Ohio, New York State and the nation. The scope of these comparative studies must be well thought out and comprehensive. It is imperative that those conducting this study be independent experts without gas company affiliation. EPA involvement should be considered.

If I can provide additional information, please feel free to contact me.

Sincerely yours,

Paul A. Rubin

Paul A. Rubin
Hydrogeologist
HydroQuest



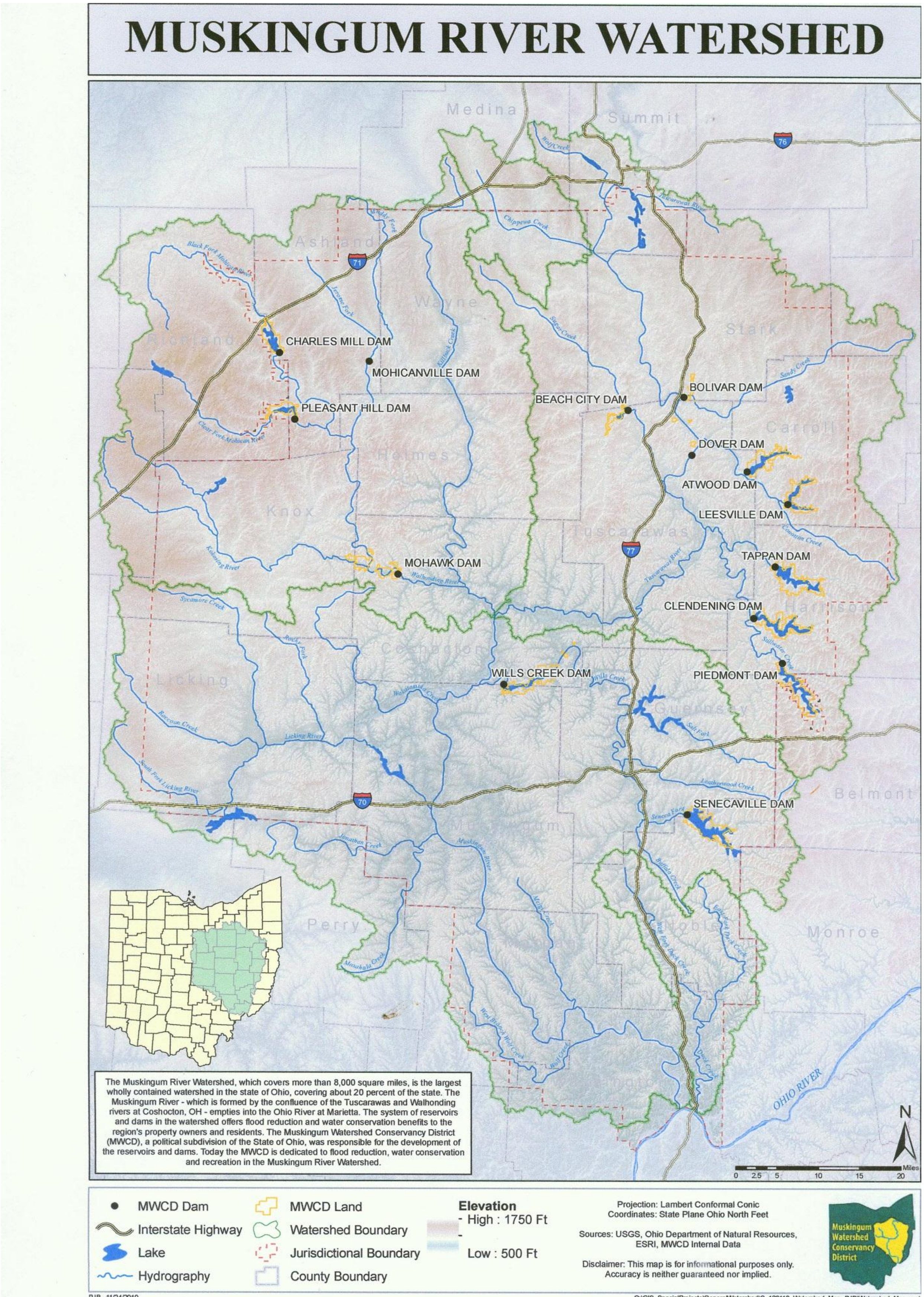


Figure 1A: Muskingum River Watershed. Source: Muskingum Watershed Conservancy District.

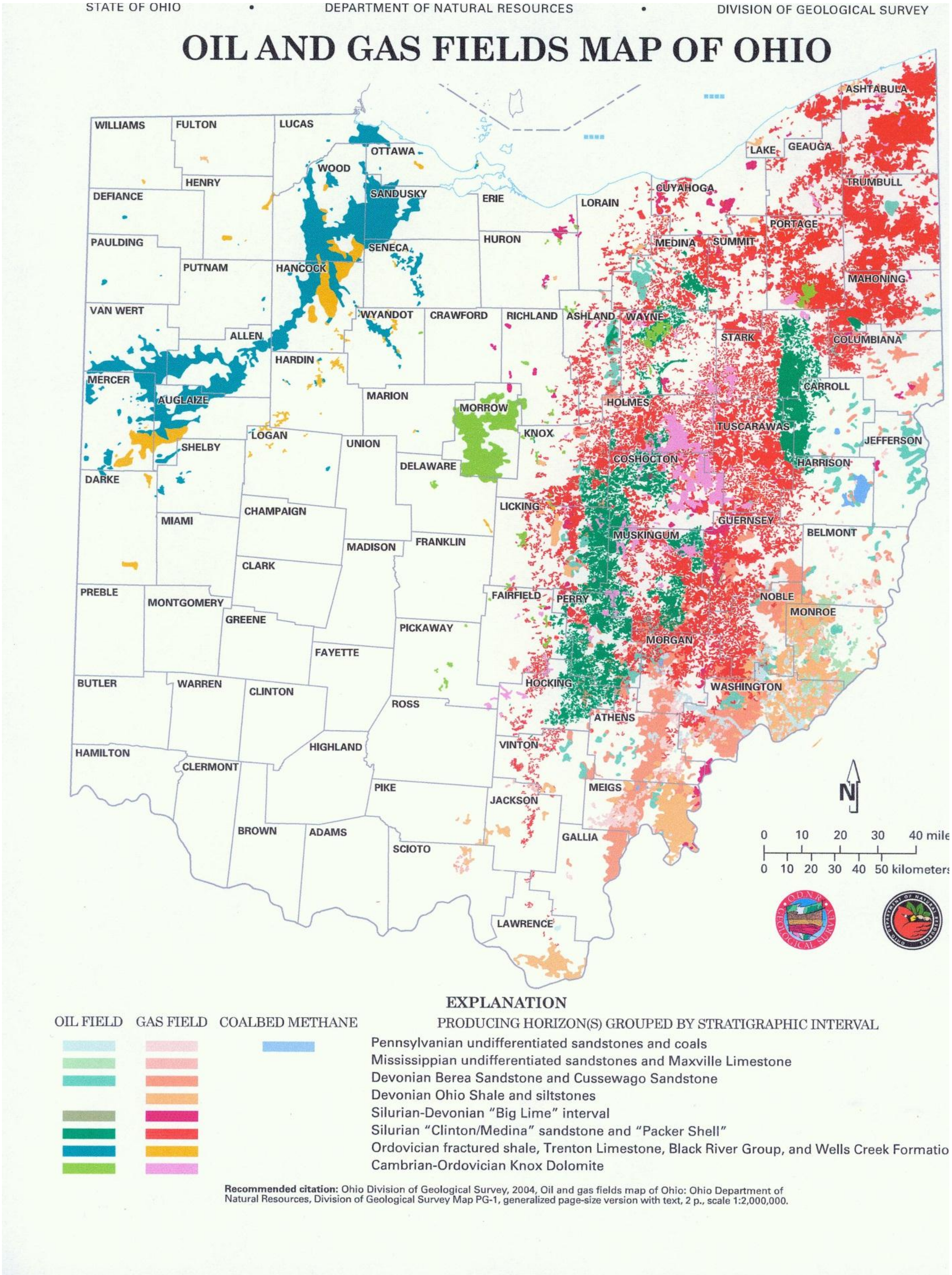
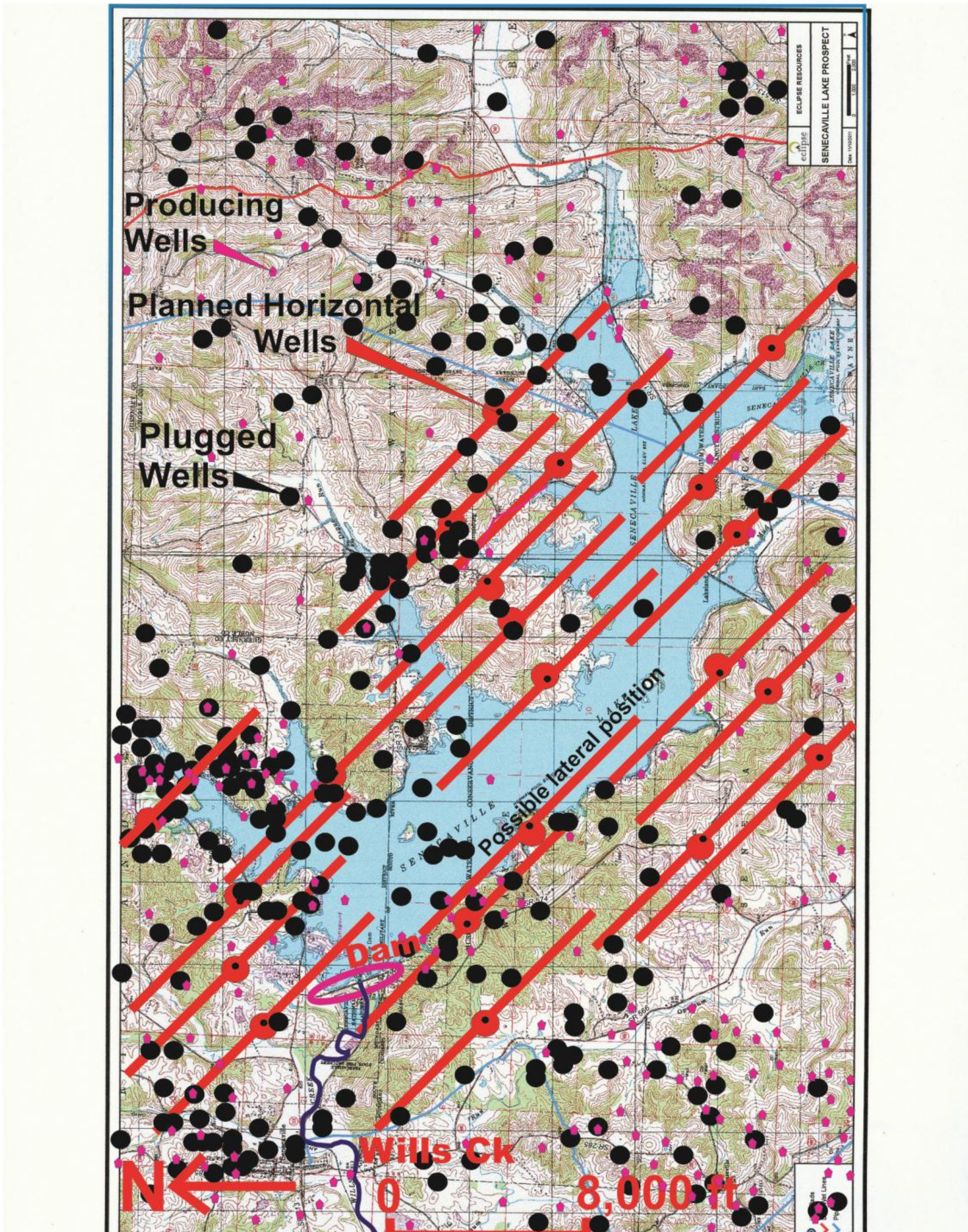


Figure 1B. Oil and Gas Fields Map of Ohio. Source: Ohio Division of Geological Survey, 2004. Comparison of Figures 1A and 1B show the significant overlap of petroleum wells and the Muskingum River Watershed.



Sources: Planned wells- Eclipse Resources; Plugged & Producing wells - ODNR; Graphic design & caption - HydroQuest. Well locations & number may not be exact due to scale of ODNR database.

Figure 1C. A SE Ohio example of placement of oil and gas wells such that aquifer and reservoir water quality will almost certainly be degraded. In addition, the reservoir infrastructure (i.e., dam) lacks protection. This is a highly vulnerable situation. Here, part of the watershed area of Senecaville Lake is portrayed. Many abandoned wells (black dots) are present, many densely clustered and some beneath the lake. What integrity remains of the plug material is likely to be jeopardized from repeated hydrofracking of numerous laterals (arbitrarily portrayed here in a simplified manner outward from planned horizontal wells). High pressure heads during fracking (to over one mile above the reservoir surface) may drive contaminants upward through fractures and poorly plugged wellbores connected by horizontal laterals. Faults are known within 30 miles to the NE, SE & W.

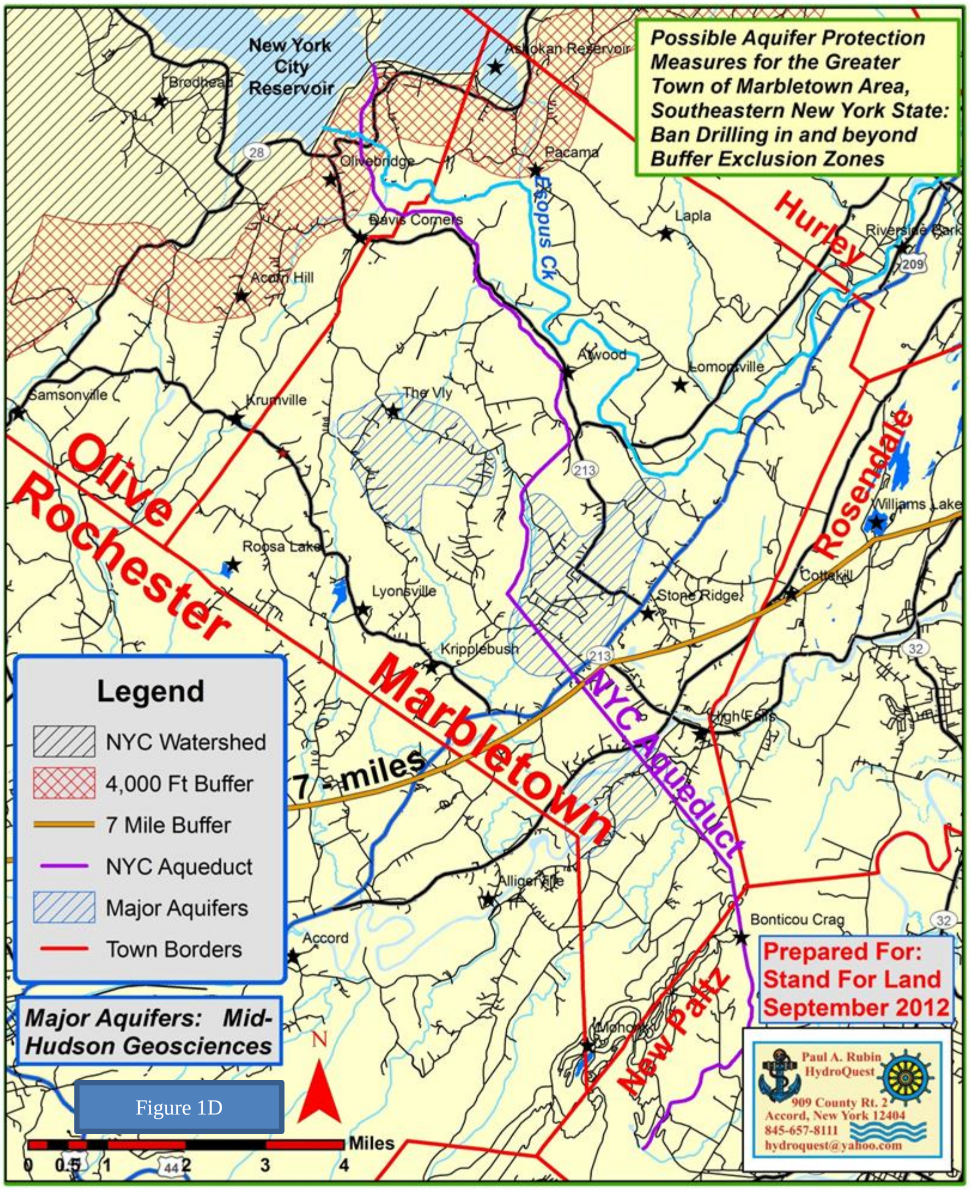


Figure 1D. Protective measures currently being considered to preserve and protect the quality of New York City's reservoirs include different buffer zone distances extending outward from watershed boundaries (e.g., 4,000 foot and 7 mile buffer/exclusion zones; 2 miles outward from major aqueducts) AND **no** drilling within watershed boundaries. This is in stark contrast to that depicted for the Senecaville Lake reservoir in eastern Ohio where many gas wells are permitted within the watershed, with expansion being contemplated to allow horizontal well laterals to extend adjacent to and beneath the reservoir. Laterals are likely to interconnect old wells and fracture zones. High fracking pressures are likely to stress the integrity of aging well plugs and allow upward contaminant migration into the reservoir and waterways.

Muskingum Watershed, Ohio
> 5.0 Magnitude Earthquake
Probability within 100 years

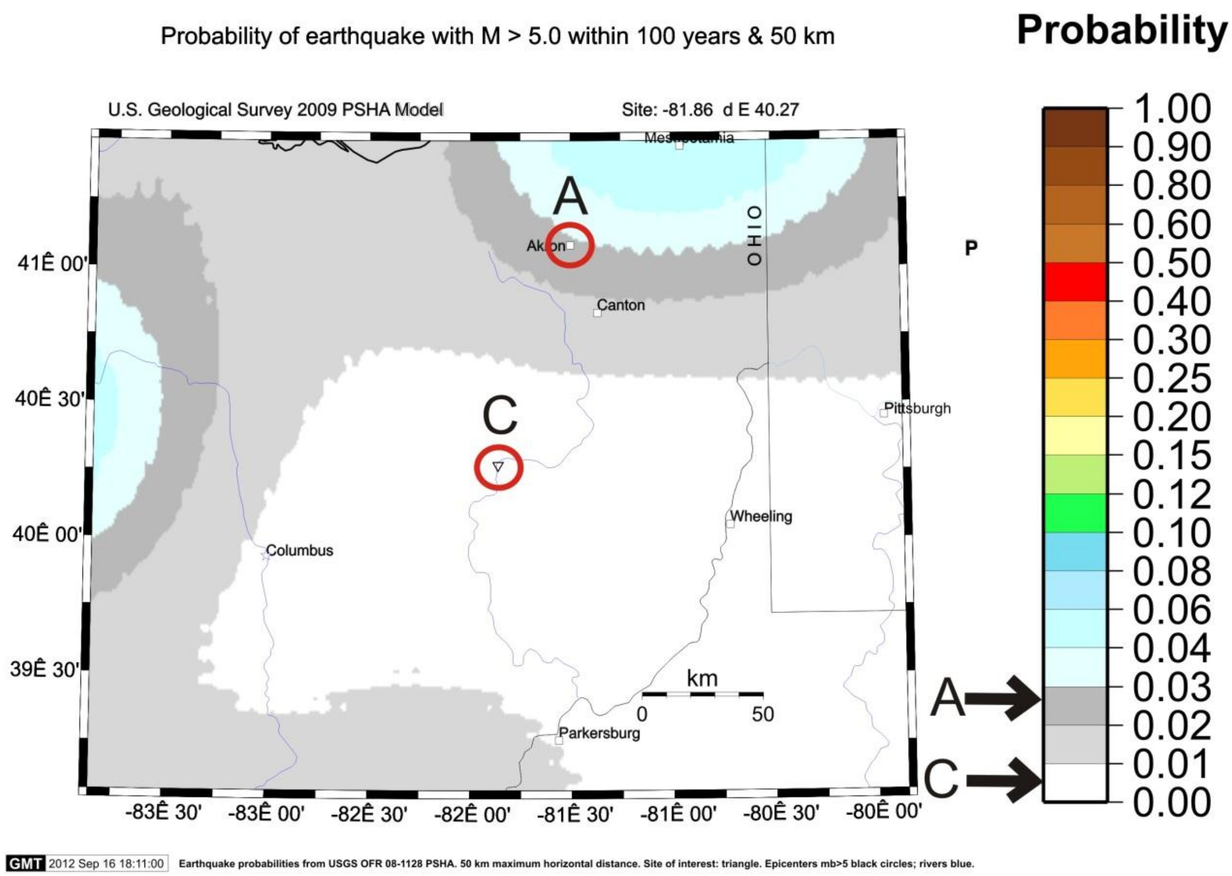


Figure 2. 2009 Earthquake Probability Mapping. USGS Geologic Hazards Science Center. This map displays earthquake probabilities that were computed from the source model of the 2008 USGS-National Seismic Hazard Mapping Project (NSHMP) update for Coshocton, Ohio [**C**] (40.27º N, -81.86º W) and Akron, Ohio [**A**] (41.08º N, -81.52º W). The generated map shows the probability of earthquakes with a magnitude of > 5.0 within a radius of 50 km for a 100-year event is 0 to 1% and 2 to 3%, respectively. USGS web-based model run conducted by HydroQuest.

Muskingum Watershed, Ohio
> 5.0 Magnitude Earthquake
Probability within 500 years

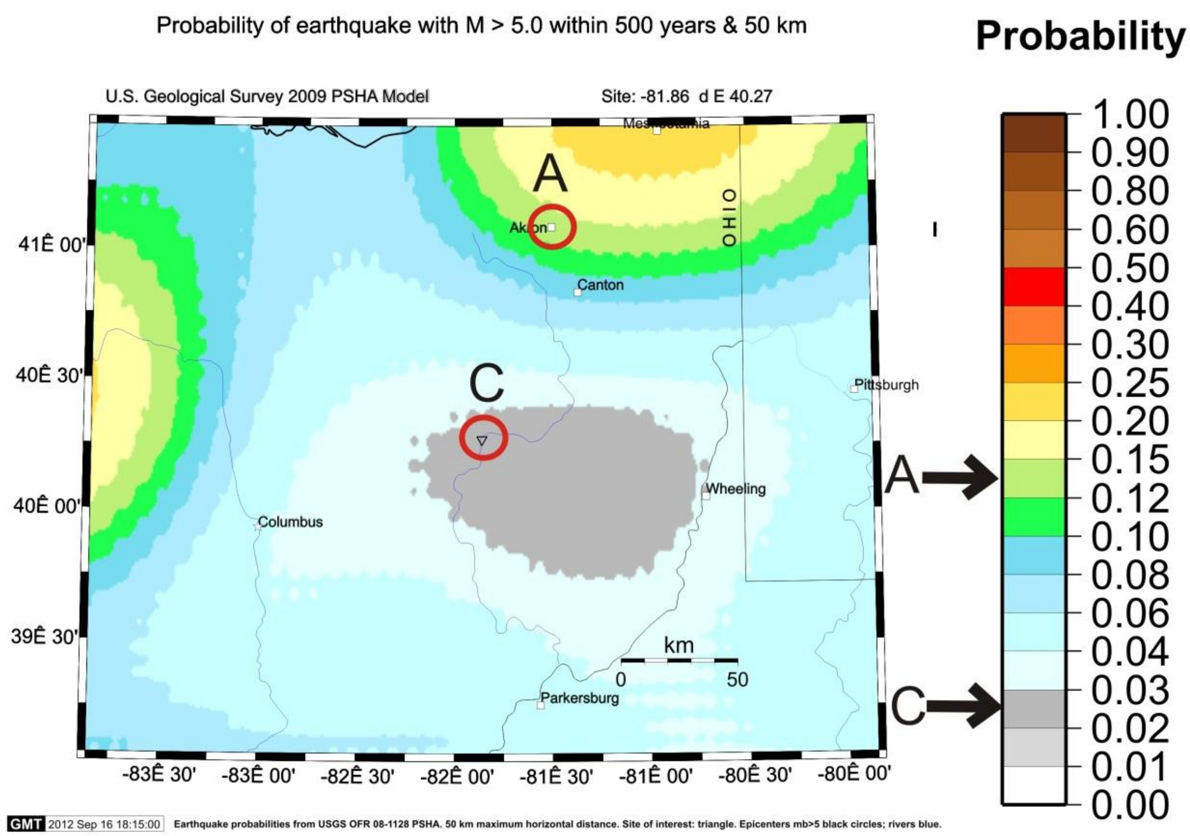


Figure 3. 2009 Earthquake Probability Mapping. USGS Geologic Hazards Science Center. This map displays earthquake probabilities that were computed from the source model of the 2008 USGS-National Seismic Hazard Mapping Project (NSHMP) update for Coshocton, Ohio [**C**] (40.27º N, -81.86º W) and Akron, Ohio [**A**] (41.08º N, -81.52º W). The generated map shows the probability of earthquakes with a magnitude of > 5.0 within a radius of 50 km for a 500-year event is 2 to 3% and 12 to 15%, respectively. USGS web-based model run conducted by HydroQuest.

Muskingum Watershed, Ohio > 5.0 Magnitude Earthquake Probability within 1000 years

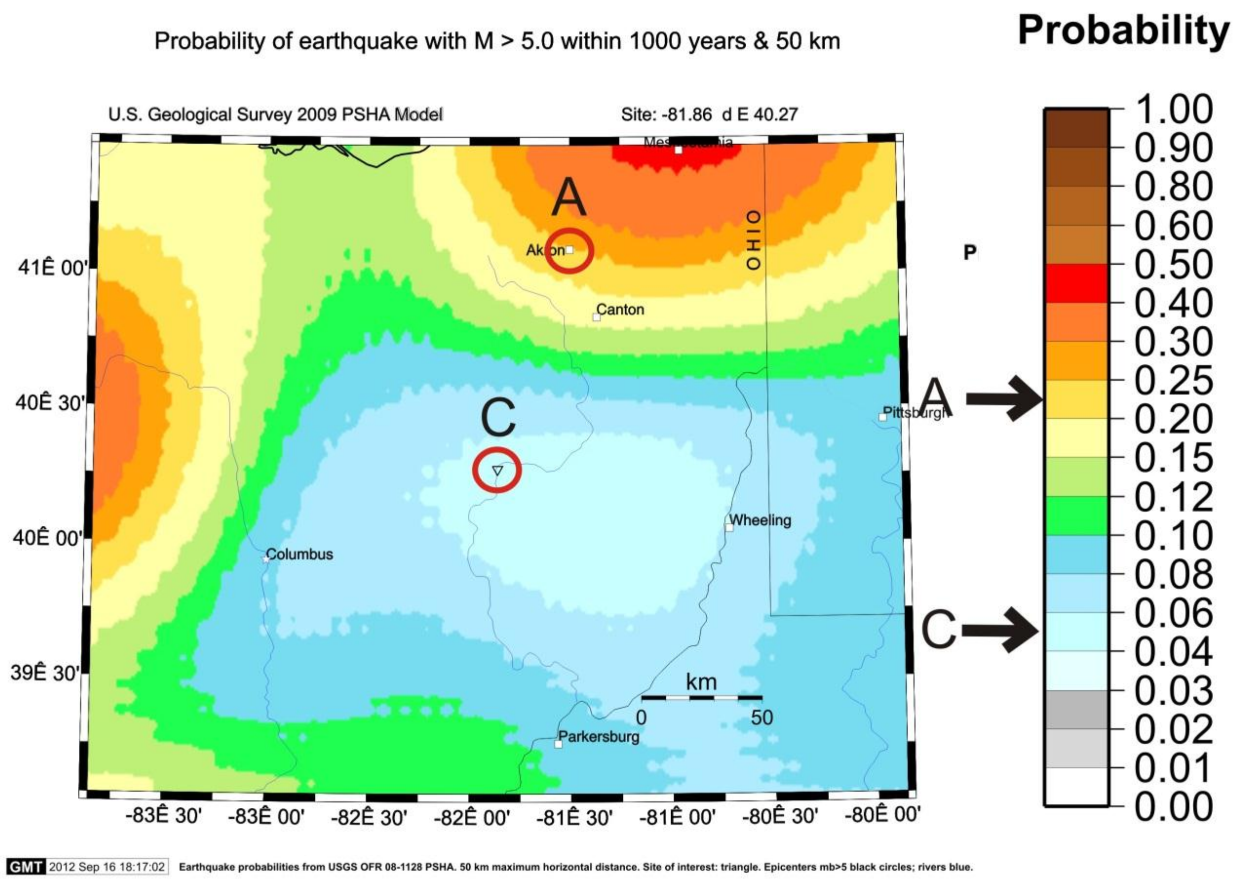


Figure 4. 2009 Earthquake Probability Mapping. USGS Geologic Hazards Science Center. This map displays earthquake probabilities that were computed from the source model of the 2008 USGS-National Seismic Hazard Mapping Project (NSHMP) update for Coshocton, Ohio [**C**] (40.27º N, -81.86º W) and Akron, Ohio [**A**] (41.08º N, -81.52º W). The generated map shows the probability of earthquakes with a magnitude of > 5.0 within a radius of 50 km for a 1000-year event is 4 to 6% and 20 to 25%, respectively. USGS web-based model run conducted by HydroQuest.

Muskingum Watershed, Ohio
> 5.0 Magnitude Earthquake
Probability within 10,000 years

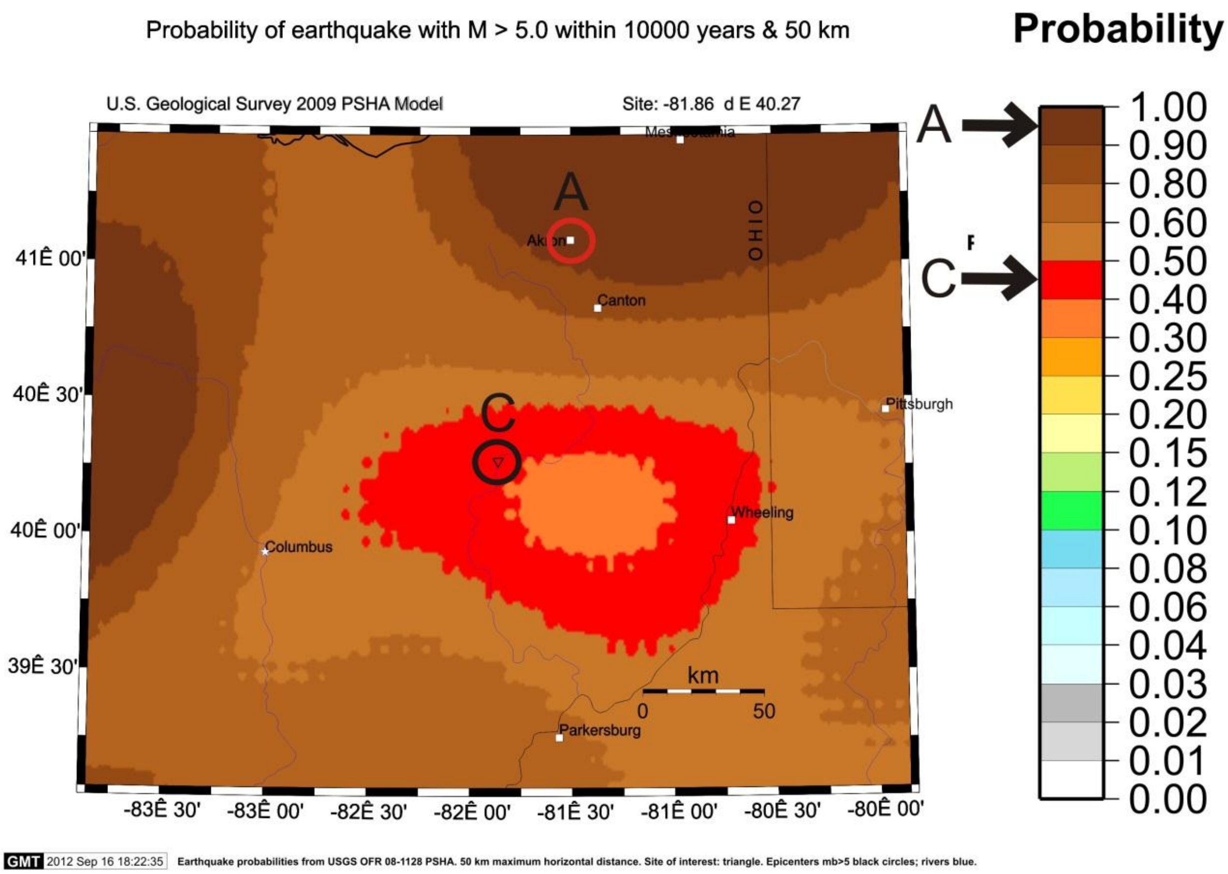


Figure 5. 2009 Earthquake Probability Mapping. USGS Geologic Hazards Science Center. This map displays earthquake probabilities that were computed from the source model of the 2008 USGS-National Seismic Hazard Mapping Project (NSHMP) update for Coshocton, Ohio [**C**] (40.27° N, -81.86° W) and Akron, Ohio [**A**] (41.08° N, -81.52° W). The generated map shows the probability of earthquakes with a magnitude of > 5.0 within a radius of 50 km for a 10,000-year event is 40 to 50% and 90 to 100%, respectively. USGS web-based model run conducted by HydroQuest.

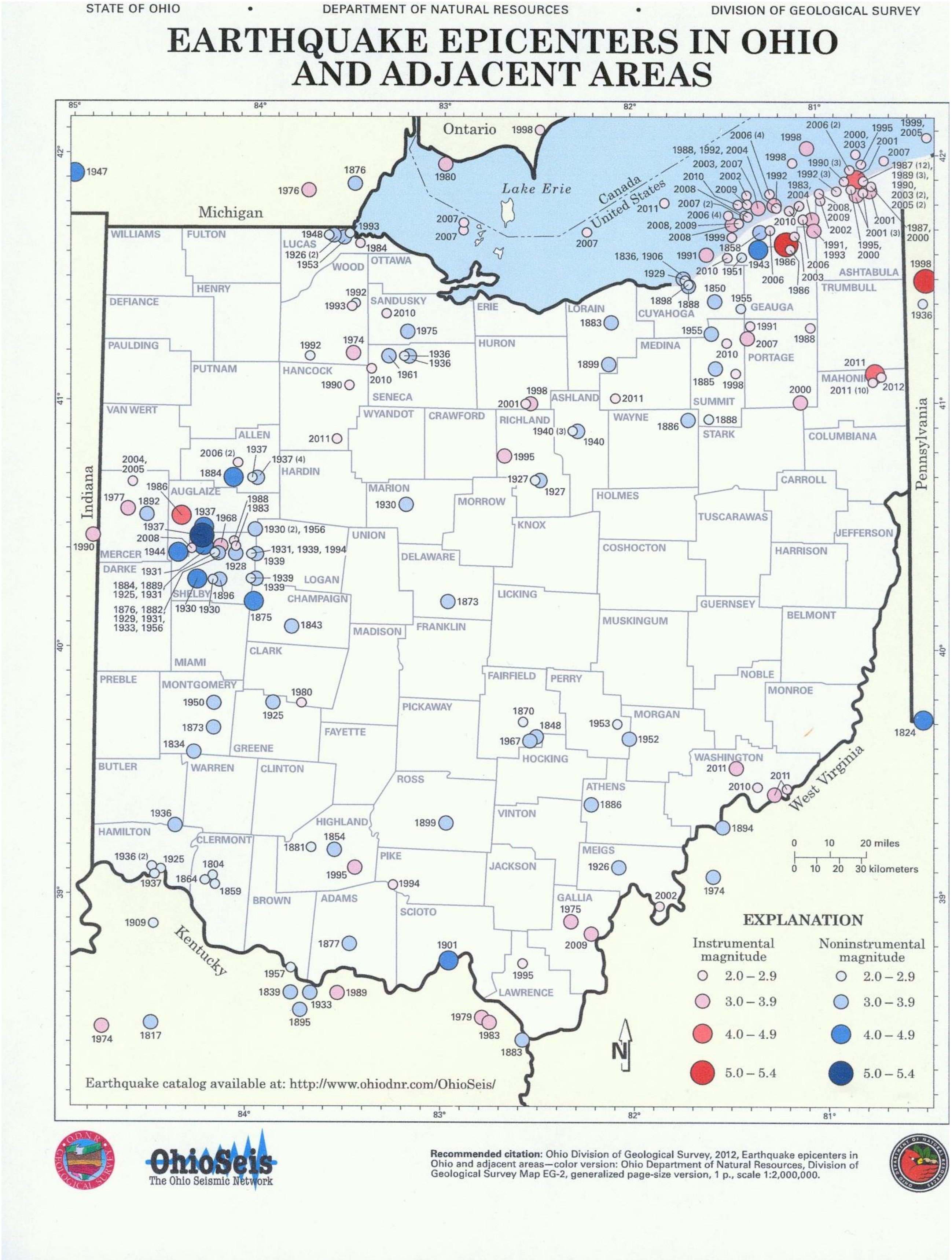


Figure 6. Earthquake Epicenters in Ohio and Adjacent Areas. Source: Ohio Division of Geological Survey, 2012.

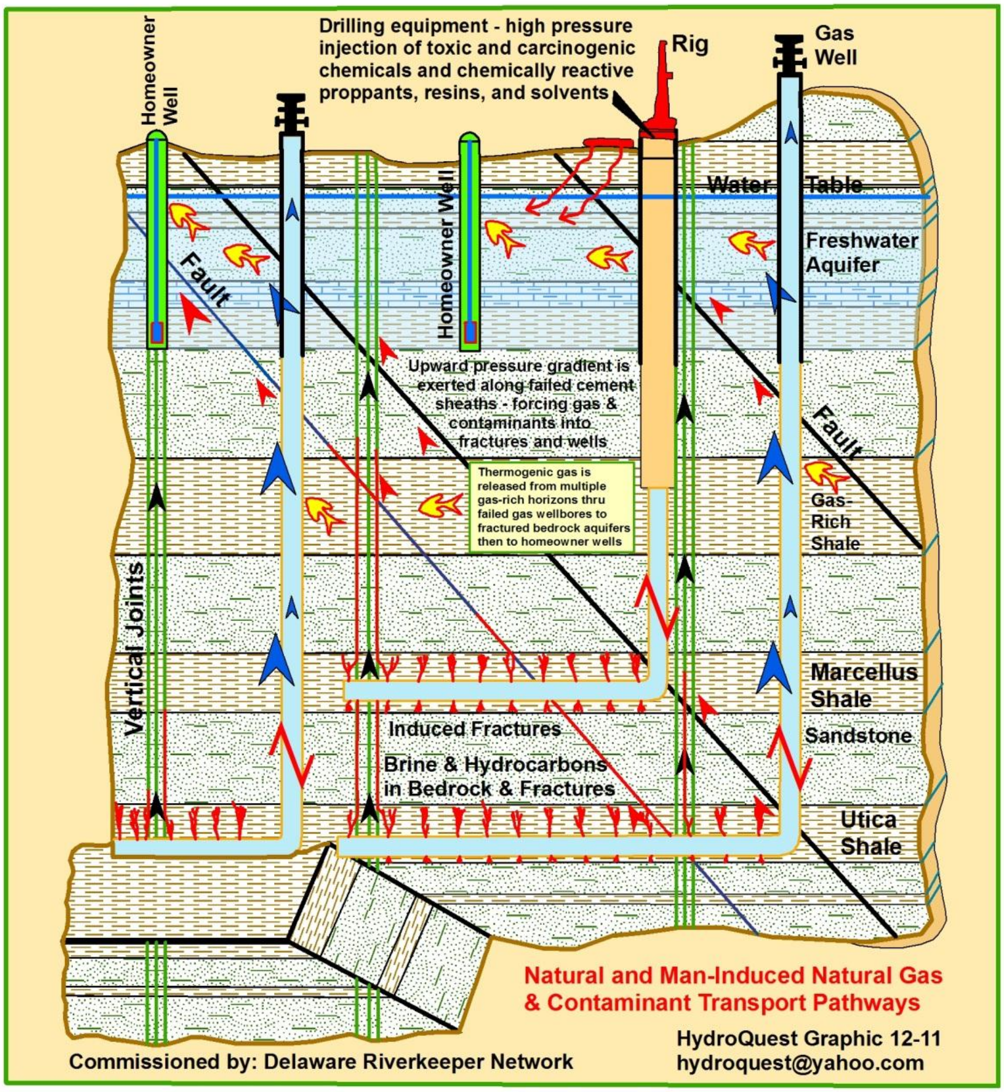


Figure 7. Natural and man-induced natural gas and contaminant transport pathways both within bedrock and from spills on the ground surface. Fractures or joints provide potential contaminant pathways upward from the Utica shale or other gas-rich geologic beds to aquifers and waterways. Faults also provide potential pathways. Faults have been documented within 30 miles of Senecaville Lake. Gas companies may already have documented faults within the Muskingum River Watershed, as may structural geologists who have or are mapping in the area. Information on fault presence, if any, should be obtained and portrayed on a map of the area.

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Key Reasons to Ban Hydraulic Fracturing in New York State – Submitted to NYSDEC on 8-14-12

HydroQuest[A] has over 30 years of professional experience characterizing groundwater and surface water hydrology. Since 2009 this work has included assessing contaminant transport pathways and adverse impacts associated with hydraulic fracturing for environmental groups and law firms and independently. Research and documentation have been presented in report, affidavit, Fact Sheet, press release and presentation format[B] – much of which is available at http://hydroquest.com/Hydrofracking/. Document titles on this web page are identified below with superscripted alpha characters and hereby incorporated by reference.

Regional groundwater flow from deep gas-rich shale formations to freshwater aquifers has not been taken into account[C,D,E,F,G]. Gas industry hydrofracking chemicals will migrate upward and move throughout NYS aquifers, resulting in widespread groundwater contamination of a magnitude worse than that of Love Canal[E]. Adverse health impacts, already well-documented by toxicologists and doctors in neighboring states, will assuredly occur and then increase as contaminated groundwater reaches major down-gradient aquifers[Y].

Gas industry chemicals injected into gas-rich shale formations (e.g., Marcellus, Utica) will migrate as widespread plumes to New York State's freshwater aquifers. "*Hydraulic fracturing poses a serious threat to groundwater quality, not only in the vicinity of the drilling site, but also in the entire down-gradient part of the groundwater flow system. Although the main injection of contaminants takes place thousands of feet below the surface, groundwater flow inevitably carries them laterally and then upward into major neighboring river valleys over periods of years to hundreds of years, tailing off for possibly thousands of years. In the Appalachians, the valleys are where most people live. The **contaminants** are widely dispersed, but they **pose a low-level threat to health**, especially when thousands of fracked wells are involved*." [C (Dr. Arthur N. Palmer, page 8)] Palmer provides an excellent example calculation of the potential magnitude of contaminant loading[D]. **Once contaminated, groundwater cannot be remediated even at unlimited cost[C].**

An important aspect of the contamination is that it will converge in the valleys, which are where the major aquifers, town water wells, and reservoirs are located. The technology does **not** exist to remediate aquifers once they are contaminated[C,D,E,H et al.]. If permitted, hydrofracking in NYS will adversely impact our precious water supplies for hundreds of generations to come[E et al.].

The durability and mechanical properties of gas well sealant materials (primarily cement and steel) are not sufficiently advanced such that freshwater aquifers will be safely protected for even as long as 100 years, much less the hundreds of thousands of years required[E,G,H,I,J,K et al.] – regardless of the number of nested casings used. Aquifer contamination will persist for centuries, far outlasting the technology for prevention of leakage from wells. Failure of cement sheaths due to shrinkage, debonding, cracking, corrosion, and other mechanisms is well documented throughout gas industry literature[E,Z]. A leading casing manufacturer (TMK IPSCO) states that corrosive fracking chemicals result in a pipe life expectancy of no better than 5 years[G]. The gas industry is misinforming the public and governmental agencies. **The construction of properly secured gas wells is beyond the scope of present technology.**

Failure of well sealant material is 100 percent assured. The well sealant technology needed to permanently isolate freshwater aquifers from natural gas and gas industry contaminants does not exist. It is not a question of if, but rather when, well sealant materials will fail. Even without the failure mechanisms mentioned in the paragraph above, much of the Appalachian Basin of NYS is seismically active. Repeated natural and hydrofracking related ground vibrations will degrade cement sheaths and permit upward gas and contaminant movement[D,H,K,L,M,N,V,Z]. Cracks as narrow as 0.001 inch can allow significant escape of gas[H].

Natural gas and contaminant transport pathways between deep gas horizons and freshwater aquifers are well documented[e.g., C,D,E,G,L,M,N,O,U,Z]. They include faults, joints, fracture zones, failed cement sheaths and casing material and poorly or not plugged wells[D,O,P,Q,R,S,V,Z]. A key problem is not so much the leakage of contaminants through the shale, but leakage along vertical fractures produced or enlarged by fracking, into adjacent high-permeability beds. From there, the groundwater flow is concentrated and relatively rapid[C,F,R]. Most fractures remain unidentified[D]. Soluble rocks containing caves (i.e., karst aquifers) are extremely vulnerable to contamination and should be avoided[C,I,L,Z] and expressly prohibited in state regulations.

Ill-conceived "*beneficial uses*" of landfill leachate[G] and waste gas field brines[W,X] pose additional needless threats to NYS waters. Gas industry related regulations must ban these uses.

"*Protective*" setback distances between gas wells and water resources, as proposed in state regulations, do not allow for groundwater flow, the migration of contaminants in groundwater, and ARE NOT based on any empirically-based data. The concept of setback distance is inappropriate hydrologically[D]. To date, HydroQuest has provided the only empirically based value for setback distance[I] (greater than 4,300 feet). Hydraulic fracturing should not be permitted in the absence of empirically-based setback distances from gas well horizontal arrays.

While the contaminant concerns addressed here will result from chemical additions to hydraulic fracturing fluids, it is important to recognize that should alternate (i.e., non water-based) means of fracturing bedrock be used (e.g., gelled propane), upward excursion of naturally-occurring and formerly isolated contaminants (e.g., natural gas, LNAPLs, NORMs) would degrade freshwater aquifers[C,D,N,Z]. Clearly, approval of alternate means of fracturing bedrock should require the full "*hard look*" contemplated in SEQRA laws.

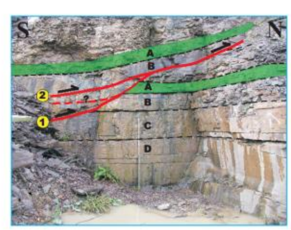
NYS law does not provide for real property recovery costs in excess of market value (*Fisher v. Qualico Contracting Corp., 98 N.Y.2d 534, 539 (2002)*). Thus, gas industry and NY State's failure to reasonably require company specific tracers[H et al.] in drilling fluids places undue financial burden on homeowners for experts, doctors, attorneys and chemical testing with little hope of recovery. Tracer use is imperative for health risk assessments, homeowner protection and to correctly assign responsibility for contamination.

The rigorous science behind hydrofracking, including that of the gas industry, shows that it is not in the best interest of the people of NYS. The only sound, scientifically-based, and rational decision regarding hydrofracking in NYS is to permanently ban it. It simply does not make sense to force toxic and carcinogenic chemicals into groundwater flow systems known to surface in our freshwater aquifers and waterways. If hydrofracking is permitted in NYS, our finite water resources will become contaminated. **Then, how are we going to clean up what we have contaminated–especially our waters?** This is impossible.

Dimock, PA water exceeds MCLs

"The damage may not show up for years, the ruination of our water may at first be invisible and in the end irreparable."

Cyla Allison, Ph.D.
Eight Rivers Council, WV



Faults and joints in bedrock

Potential Contaminant Paths from Hydraulic Fracturing of Shale Gas Reservoirs

Arthur N. Palmer, Professor Emeritus, SUNY Oneonta

3-13-2012

I have worked in the gas and oil industry and am not antagonistic toward it. But my main specialty is bedrock hydrology, and I want to describe, in an unbiased way, some potential water-quality problems related to high-volume hydraulic fracturing for shale gas.

Hydraulic fracturing (hydrofracturing, or "fracking")

Fluids are injected into shale to create and enlarge fractures, which facilitate the withdrawal of gas by increasing the permeability of the rock. This requires high pressures, typically about 2500 pounds per square inch at the injection well. This is enough to raise a column of water **1.09 mile** (Fig. 1). Pressures deeper in the ground are even greater, mainly because of the natural weight of rock and groundwater, but the injection pressure at the well is the only significant factor in fracturing the shale.

Most of the hydrofracturing fluid consists of water and tiny inert spheres of sand or glass designed to keep the fractures open once the pressure is released. Roughly 2% of the injected fluid consists of chemicals that retard clogging of the fractures and enhance gas recovery. Many of these fluids and their by-products are known to be threats to health. Current regulations do not require that they all be identified. See Web references on page 4.

Aquifers

An aquifer is a rock or sediment deposit that is able to transmit enough water to supply water wells – whether for individual homes, a town, city, or industrial plant (Fig. 2). The definition is rather loose. In the plateau region of New York State, the map of major aquifers, prepared by the U.S. Geological Survey, shows only the bodies of thick sand and gravel in large valleys. These were deposited mainly by meltwater from glaciers around 14,000–100,000 years ago, augmented by deposits left by the rivers themselves. These account for nearly all groundwater supplies for towns and cities. Not shown are all the areas of bedrock that have permeabilities ranging from modest (e.g. sandstone) to huge (e.g. limestone; Fig. 3), because they are generally used only for domestic wells.

Most aquifers used for water supply are shallow, because deep water tends to be loaded with dissolved minerals and gases. Also, wells are drilled only as deep as necessary. In bedrock, the chances of obtaining a suitable water supply diminish greatly beyond a few hundred feet. Shales that are targeted for gas lie thousands of feet below the productive aquifers. This is why gas production is considered safe (see Fisher, 2010, in list of references on p. 4).

However, during the periods when hydrofracturing fluids are being injected, the pressure is more than great enough to raise water all the way to the surface, right through the shallowest aquifers. This is likely only where major fractures provide efficient pathways. Abandoned or poorly sealed oil and gas wells also serve as easy paths for gas and fluid migration to the surface. Many of these have been documented in New York State with petroleum and saline fluids still leaking to the surface.

Natural fractures

Natural fractures are widespread and unpredictable. They offer the most likely pathways for rising fluids. Most flow follows major fractures, the way traffic follows interstate highways, and therefore much groundwater, including contaminants, is concentrated in zones of relatively high-velocity flow, moving much faster than average groundwater.

Generally speaking, there are two types of fractures: (1) Most are produced by weathering and erosion at the surface, where the release of confining pressure causes underlying rocks to split. These cracks diminish in width and number downward, where confining pressures are greater. Permeability is highest near the surface and diminishes rapidly downward. (2) Fractures formed by regional stress, such as compression or tension in the Earth's crust, are related to motion of the continents. They form extensive fractures, mainly faults, which involve slipping of one block of rock past another. They are fewer but much more extensive, and many extend to great depth. In general, major fractures feather upward into a myriad of smaller ones toward the surface.

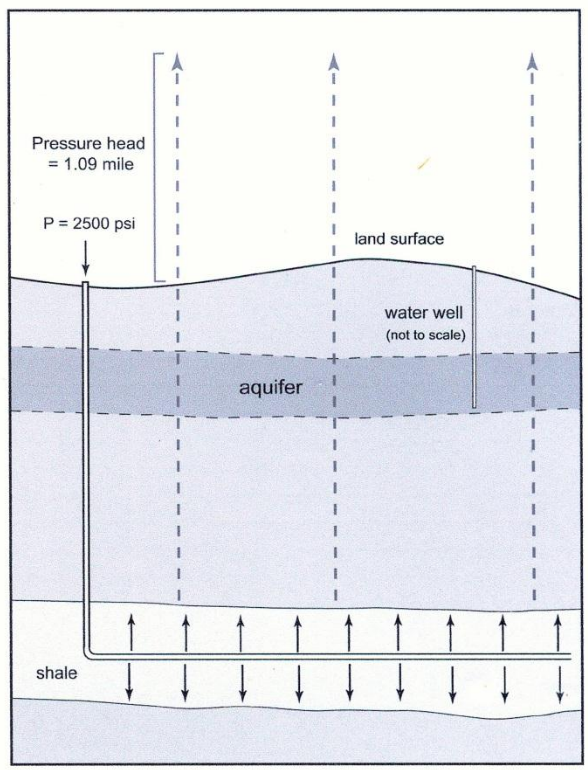


Fig. 1: Distribution of pressure in ground during fracking, with 2500 psi pressure at the well. Pressure head = height to which the pressure can raise a column of water. Pressures are later reversed to remove the fluids, but a large percentage are left behind in the shale and surrounding rocks.

The distribution of major fracture zones in New York has been competently mapped by Jacobi (2002), but most fractures still remain unidentified. Most are almost impossible to detect even with geophysical methods. Large ones are best identified by the presence of natural gas leaks, saline water in wells, hot springs, or highly mineralized springs. They show that water is able to rise thousands of feet naturally. Also, the world's deepest known limestone caves follow intersecting fracture systems to depths greater than a mile (up to 7200 feet to date) and terminate only at the bottom of the limestone, or at sea level.

Seismic events

Small earthquakes often occur in the vicinity of wastewater injection wells. These are caused by the release of natural stresses that have previously developed in the bedrock. Although there are no documented examples of major earthquakes triggered by hydrofracturing, even the small stresses released by the process can be enough to disrupt the seals in injection wells and allow leakage of fracking fluids and gases.

Contaminants

In the hydrofracturing process, up to 5 million gallons of water are injected into each well over its productive life. Usually no more than 2% of the fluid consists of additives that retard clogging and aid in gas recovery. There are more than 700 different components, most of them known or possible carcinogens. More than 200 are unidentified trade secrets. Once hydrofracturing is completed, the flowback of fluids accounts for an average of 20-70% of the total fluid, leaving 30-80% in the ground.

The shale itself contains a variety of materials of concern, including toxic heavy metals and radium. Radium is the source of radon gas; both are radioactive. Ordinarily these materials are not released into groundwater supplies because of the low permeability of shale, but artificial fracturing tends to release them in unnatural quantities, and they are contained in the fluids withdrawn from the gas well. Nearby water supplies and household air should be monitored for increases in these substances.

Evaluating the potential for contamination is difficult, because not enough is known about the fluids involved. Among the most abundant are petroleum distillates, from which benzene is a by-product. The EPA places the minimum drinking-water standard of benzene at only 0.005 ppm.

For example, consider that 50% of the fluids remain in the ground after the fracturing process is completed. If the original volume is 5 million gallons, that leaves 2.5 million gallons, 2% of which is "suspect" material. Petroleum distillates constitute about 17% of the suspect fluid, and their minimum benzene content is 0.8%. Of the 2.5 million gallons remaining in the ground, benzene would conservatively amount to 68 gallons, or about 27 parts per million. This is more than 5000 times the EPA standard. How large an area could this affect? A residual fluid volume of 2.5 million gallons is equivalent to 0.334 million cubic feet. The effective bedrock porosity (capable of transmitting fluid) is about 10%. In the porous bedrock, the fluid would saturate 3.34 million cubic feet of rock, like the water in a sponge. With a benzene content 5000 times the drinking-water standard, a 5000X dilution with normal groundwater would be necessary to bring it down to the standard. That would account for about 17 billion cubic feet of water right at the EPA limit. Imagine a block of ground one mile square. This would be enough to contaminate the entire block over a thickness of 600 feet.

This fluid becomes diluted with time, and the mixture is carried off as part of the regional groundwater flow. However, this scenario considers just a single contaminant in a single well. Additional wells will contribute. This is just a crude example based on reported concentrations, but it is the kind of approach needed if we are to assess the pros and cons of hydrofracturing.

Local contamination related to hydraulic fracturing

At the well site, fracking fluids are likely to cause contamination only in the event of improper well seals and waste-water handling. An exception is where hydrofracturing takes place in valleys, where upward leakage through major fractures or poorly sealed wells can easily reach the surface (Fig. 4). Some migration of gases to the surface is also expected at and around most hydrofracturing sites.

Shale ordinarily has very low permeability – it transmits fluids with great difficulty. That is why natural gas has remained trapped in

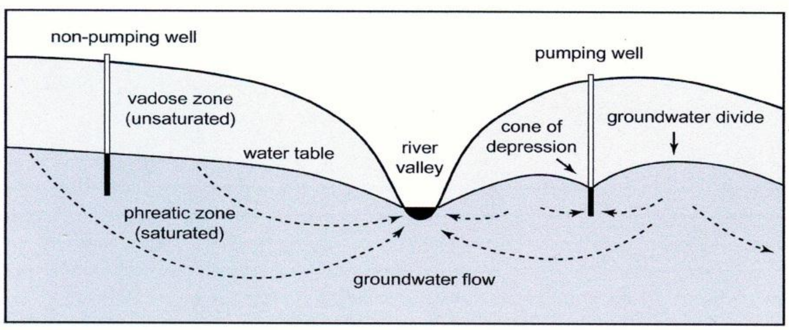


Fig. 2: Natural pattern of groundwater flow in the vicinity of water wells. Note the flow paths toward the valleys, interrupted only locally by pumping of wells. The water table is the level below which all openings are filled with water. In broad terms it is the level to which water stands in a non-pumping well. "Saturated" and "unsaturated" refer to whether or not water fills all available openings.

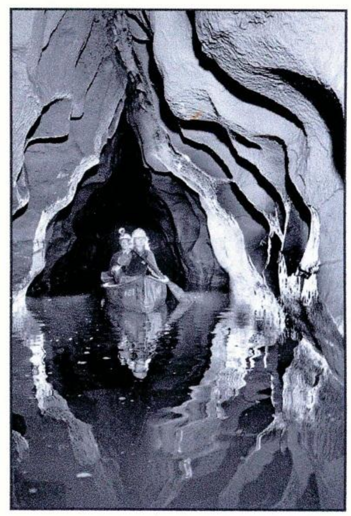


Fig. 3: Underground stream in a limestone cave. Water moves rapidly and with no filtration. Here the lowest flow rate is about 1000 gallons per minute, and the maximum water depth is about 15 feet. This example is in Indiana, but New York's Howe Caverns has a river equally large.

it for millions of years. Hydraulic fracturing greatly increases its permeability. Doubling the width of a fracture allows about 8 times more fluid to pass through (if all other variables remain unchanged). Seismic monitoring during the fracturing process shows a vertical range of fracture development as much as 2000 feet, extending mainly above the injection zone (Fisher, 2010). Because the maximum thickness of Marcellus Shale is about 250 feet, much of the fracture enlargement extends far into surrounding rock layers.

Problems can develop when the injected fluids migrate from the shale (owing to its enhanced permeability) into the more permeable rocks above and below, which include sandstone and limestone. Ordinarily the high pressure of hydrofracturing is not sustained long enough to drive fluids far above the shale. There are rare exceptions. One is where major fractures extend through the entire rock sequence. Another is where unsealed oil or gas wells are present, or where the injection well is inadequately sealed. In these conditions, water, gases, and contaminants can be driven upward all the way into shallow aquifers. Of the potential types of contamination, small gas leaks are most likely. These seem to account for most of the complaints about increased methane in wells and in the atmosphere. Serious contamination is very rare; but the potential is there.

When the pressure is reversed, most of the fluids are sucked back up the well and the danger of upward leakage quickly diminishes. Each hydrofracturing event increases the potential for upward leakage because the fractures become wider and longer, and residual fluids are driven higher. Nevertheless, the chance for contaminants being forced to the surface is less than that of surface spills due to poor handling of drilling wastes.

Long-term regional problems

The ability of shale to transmit fluids (i.e., its permeability) is about 1000 times less than that of the sandstone aquifers that supply most of the water to domestic wells in plateau regions of southern New York State. For this reason it is widely thought that fracking fluids cannot spread into aquifers. Besides, the suitable aquifers overlie the shale by thousands of feet.

But the entire goal of hydrofracturing is to increase the permeability of the shale. This allows fluids to leak out of the shale, mainly into the overlying more-permeable rocks. Fractures provide the most favorable paths for fluid migration, and their distribution is difficult to predict. Poorly sealed (or entirely unsealed) wells also allow much leakage. There are thousands in New York State that are abandoned and mostly undocumented.

When shale-gas production ceases, the groundwater gradually returns to its original flow pattern. It is well known that natural groundwater follows long curving paths that extend deep below the surface and rise into valleys (Figs. 2 & 4). This is easily proved by application of hydraulic laws and by measurements in wells. It has been documented that more than 75% of the flow in nearly all surface rivers is delivered by groundwater.

This is **not** just a hypothesis. Most of the residual contaminants from hydrofracturing will eventually move laterally and emerge in adjacent deep valleys. Some may move so slowly that they may take thousands of years to emerge; but with the enhanced permeability of the shale there is bound to be some that is faster-moving. Contaminants can also rise directly to the surface through unsealed wells, if the well bottoms are located near valleys where groundwater flow paths are oriented upward (as at X in Fig. 4).

Valley aquifers are the greatest sources of groundwater for municipal, domestic, and industrial use, because that's where the greatest population centers are located in the gas-rich plateau regions of the state. That is also where the most productive sand-and-gravel aquifers are located, as well as all reservoirs, including those that supply New York City. The concept of "offset" from water supplies (e.g. 4000 ft) is entirely inappropriate for this kind of contaminant transport.

Levels of contamination in adjacent valleys may be undetectable for many years but will then continue to rise over many more years (typically decades) and subside gradually over a much longer time. The time-line can easily be hundreds of years, depending on the topography and geology of the region.

From a single properly installed gas well, contamination is likely to be so dispersed that it will never cause a problem. But as more wells are developed with hydrofracturing, background contamination will continue to rise and spread undetected at depth throughout the region until it begins to emerge in valleys.

It is possible that contaminant levels will not exceed the limits for drinking water, but the risk of chronic low-level contamination is real. There are many historical examples of low-level contamination eventually being recognized as more serious than predicted. The story of DDT, PCBs, etc. come to mind.

Near-surface contamination is routinely remediated by various methods, but they are expensive and often ineffective. **But if contaminants from hydrofracturing become widely**

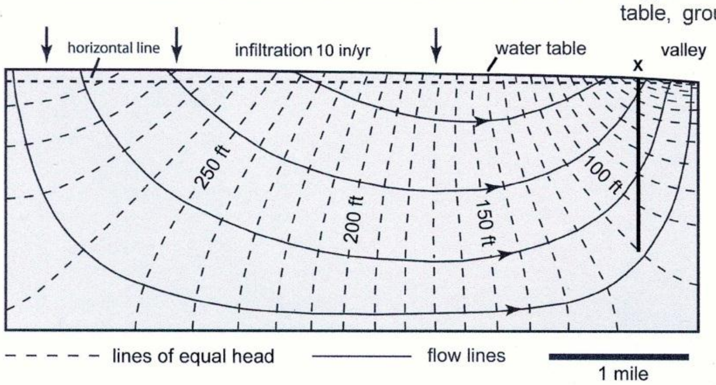


Fig. 4: Regional flow of groundwater from uplands to valleys (from groundwater modeling software of U.S. Geological Survey). Even with very low slopes of the land surface and water table, groundwater flows inevitably toward the valleys. Flow rates are slower at depth because of greater distances and usually lower permeability, but the overall direction of flow is unaffected, except for slight bending at boundaries between different rock types. The hydraulic head is the height to which water will rise in a cased well (in this example, elevation above the valley bottom). Water moves from high to low head, roughly perpendicular to the lines of equal head (deviating only at permeability boundaries).
X = unsealed gas or oil well that can leak contaminants to the surface (to 110 ft above the valley bottom). In areas of rising flow, the head at depth can be higher than the overlying land, allowing water to leak to the surface, just as in artesian conditions.

dispersed, and are found to pose a health problem, remediation will be *impossible*, both physically and economically.

The false security of setback distance

The usual method of protecting water supplies (reservoirs, etc.) is to specify a "setback distance" within which no sources of contamination are allowed. A typical setback for reservoirs is 4000 feet. But arbitrary setback distances do not take into account local conditions. The lateral arms of hydrofractured wells must be included when determining the distance. In some cases the setbacks may be overestimated, but they are more often underestimated. A thorough hydrologic study is necessary to determine a feasible setback distance, but the standard methods are expensive, time-consuming, and often misleading (see Worthington et al., 2002).

Conflicting rights of property owners

Although the threat to local aquifers in the vicinity of a hydrofractured gas well is not great, wherever a problem does occur, local property values plummet. Unfortunately neighboring properties are occasionally affected by leakage, and, even if they are not, their values are diminished too, along with the contaminated site. The concept of private land ownership and mineral rights is often raised, but the problems easily cross boundary lines. No landowner is allowed to contaminate water that flows onto an adjacent property, and yet this happens regularly, out of sight below the surface. Many of the problems caused by hydrofracturing have involved contamination of neighboring wells. Worst of all, contamination affects the entire down-flow part of the groundwater system and is not confined to the fracking site.

Recommendations

1. Many of the potentially harmful aspects of hydrofracturing can be diminished by **waiting** until the technology matures. Less disruptive techniques are being developed that involve less-toxic fluids (for example, liquid nitrogen) and require much smaller water use and less truck transport.
2. Wait until the price of natural gas rises. At present there is a glut of gas, prices are low, and there are plans to ship some gas out of the country.
3. Wait until there is a larger data-base of successful vs. disruptive case histories.
4. Wait for a consensus from state and federal regulators as to how production sites should be monitored.
5. Meanwhile, if hydrofracturing must proceed, limit it to areas of low population density and low topographic relief. Avoid developing gas reservoirs at shallow depth.
6. Do not trust the validity of fixed offset distances to water supplies, but insist upon site-specific hydrologic studies.
7. Avoid limestone areas (noted for caves and sinkholes), because contaminants can spread rapidly over large distances through solution conduits (Fig. 3).

Final notes:

Petroleum products are largely responsible for our high standard of living. Shale-gas production may provide economic benefits and a reprieve from energy shortages while more sustainable sources are developed. However, every gas or oil well involves at least some small contamination, and a small probability of more serious situations. Decisions about hydrofracturing must be based on local geology and fundamental scientific concepts, not just economic, social, and political considerations. Behavior of gas wells may be predicted from past experience, but each new site has the potential for unexpected problems.

A recent $380,000 project funded by University of Texas showed that problems attributed to hydrofracturing tend to occur close to the surface, when gas and drilling fluids escape from poorly lined wells or storage ponds. There was no direct evidence that deep hydrofracturing itself has contaminated groundwater. Methane in water wells in some areas may comes from natural sources. But the report concludes with: **"Gaps remain in understanding, especially in cumulative and long-term impacts. We are hobbled by a lack of baseline information."**

From the American Oil and Gas Reporter: **"Studies conducted by governmental agencies and respected authorities have unanimously concluded that hydraulic fracturing is safe."**

Are these statements reassuring?

Some Web sites, both pro and con:

www.dec.ny.gov/lands/36119.html [aquifer map of New York State]

http://63.134.196.109/documents/RiskAssessmentNaturalGasExtraction.pdf [Report on leaking oil/gas wells in New York]

www.lhup.edu/rmyers3/marcellus.htmhttp://en.wikipedia.org

www.desmogblog.com/fracking-the-future/danger.html

www.earthworksaction.org/issues/detail/hydraulic_fracturing_101

wiki/Hydraulic_fracturing_in_the_United_States#Halliburton.27s_hydraulic_fracturing_operations

http://skeptoid.com/episode.php?id=4275&comments=all#discuss

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Fisher, K., July 2010, Data confirm safety of well fracturing: American Oil and Gas Reporter. [Shows fracturing pattern from fracking.]

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Worthington, S.R.H., Smart, C.C., and Ruland, W.W., 2002, Assessment of groundwater velocities to the municipal wells at Walkerton, Ontario: Proceedings of 2002 conference, Canadian Geotechnical Society and International Association of Hydrogeologists, Niagara Falls, Ontario, p. 1081-1086. [Alarming example of contamination in soluble rock from a remote source that was denied by professionals who relied simply on well tests, but proved by dye tracing.]

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