Revisions to the draft Supplemental Generic Environmental Impact Statement (dSGEIS) propose many critical measures to help minimize the impact of shale-gas development on the water resources of New York State. However, a number of water-resource characterization and monitoring needs and opportunities related to shale-gas development have not been addressed by the revised dSGEIS. These issues include:

1) Shallow characterization of freshwater, saltwater, and gas;
2) Groundwater monitoring at shale-gas well pads;
3) Principal Aquifer delineation;
4) Sources of recharge to stratified-drift aquifers and groundwater supplies;
5) Microseismic monitoring of hydraulic fracturing;
6) Fractures, faults, and hydraulic-fracture barriers;
7) New York City aqueduct; and
8) Well water-quality sampling and data base.

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Shallow Characterization of Freshwater, Saltwater, and Gas

Protection of freshwater aquifers during shale-gas development is critical. Measures taken to protect the aquifers during gas-well drilling include installation and cementing of steel surface casing set below the base of freshwater. However, only scattered and incomplete information is available on the depth to the base of freshwater, and the character and distribution of deep freshwater and shallow saltwater and gas is not well understood. Freshwater was reportedly produced from two Oriskany gas test wells in Yates County, New York from depths of 1,000 feet below land surface (Kreidler, 1959). Randall (1978) and Williams and others (1998) report the presence of saltwater and gas in water wells completed in Upper Devonian bedrock that were drilled deeper than 200 feet in the glaciated valleys of south-central New York and north-central Pennsylvania. Records of gas wells in Chemung, Tioga, and Broome Counties, New York indicate the presence of freshwater in Upper Devonian bedrock in upland settings at depths of 800 feet below land surface (Williams, 2010).

Methane contamination of domestic water wells has occurred near selected shale-gas development sites in north-central Pennsylvania presumably due to inadequate casing seals (Osborn and others, 2011). Given this methane migration issue, the revised dSGEIS's requirement of the installation and cementing of an intermediate casing, in addition to the surface casing, is prudent. However, the design, installation, and ultimate success of casing and cementing programs are dependent on effective characterization of the shallow geohydrologic system. Two major Marcellus gas-development companies have realized the importance of shallow characterization and are routinely collecting mud logs and geophysical logs (fig. 1) from the surface and intermediate intervals of one topset well at each shale-gas well pad. The revised dSGEIS does not require the detailed mud logging and geophysical logging of the upper part of gas wells needed to determine the distribution of freshwater, saltwater, and gas and to properly design the casing and cementing program.

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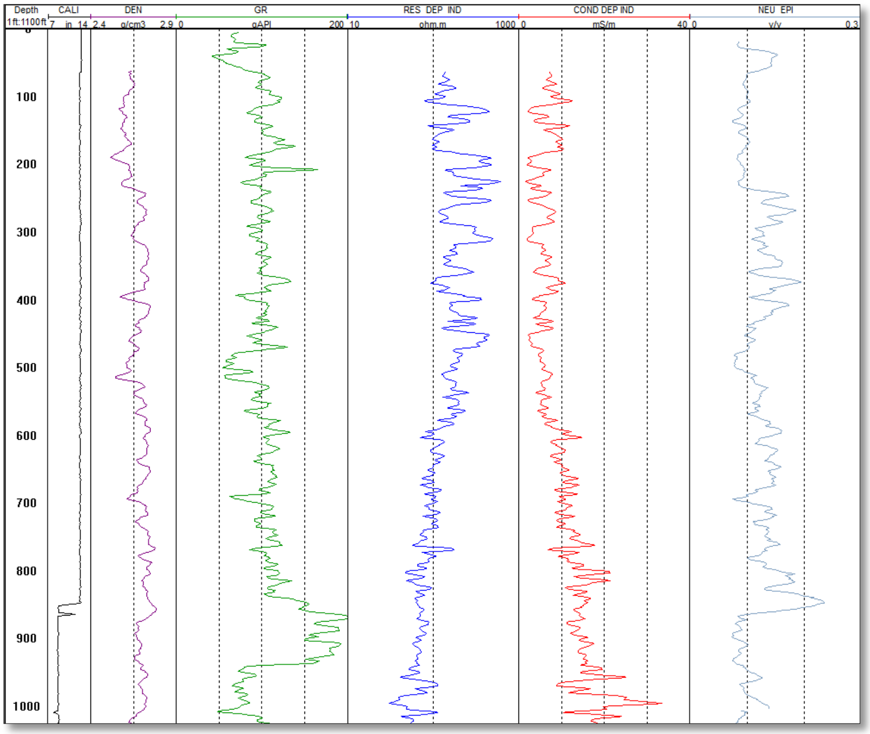

Figure 1. One-arm caliper, gamma, induction resistivity and conductivity, and neutron porosity logs from a Marcellus gas-well topset hole in fractured upper Devonian bedrock; induction resistivity and conductivity logs suggest the base of the freshwater aquifer is at a depth of about 450 ft below land surface

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Groundwater Monitoring at Shale-Gas Well Pads

Contaminant threats to the groundwater resources at shale-gas well pads include: (1) surface spills and leakage of drilling fluids, hydraulic fracturing chemicals, and flow-back fluids; and (2) inadequate or faulty well casing and cement seals that allow for vertical migration of natural gas, injected chemicals, and saline water. Design and implementation of a groundwater network to monitor impacts of these groundwater contamination threats in glaciated, fractured bedrock settings is a technical challenge that will necessitate an integrated multi-method approach to well design and sampling.

If no domestic water-supply wells are present in the designated radius, or if homeowners deny access to their wells, it would appear that under the revised dSGEIS no groundwater quality sampling would be required at a shale-gas well-pad site. In addition, although affording some level of protection, domestic wells are not sited or constructed to serve as monitoring points and interpretation of water-quality samples from them are fraught with issues. During the initial stages of shale-gas development in New York State, it would appear prudent that specifically designed groundwater monitoring programs should be conducted at least at a selected number of well pads. Discrete-zone monitoring wells (fig. 2) could be installed to the base of the freshwater aquifer to monitor hydraulic heads, water quality, and gas before, during, and after drilling and hydraulic fracturing operations, and much of the data provided in a near real-time basis for all to understand the results of this monitoring.

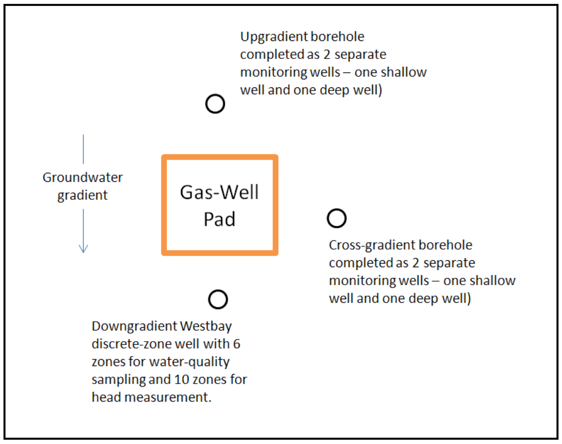

Figure 2. Schematic example layout of monitoring wells in relation to a prospective shale-gas well pad

Principal Aquifer Delineation

Specific measures to protect New York State's drinking water in the revised dSGEIS include prohibiting surface drilling on Principal Aquifers without site-specific reviews. However, unlike the Primary Aquifers, not all Principal Aquifers have been delineated at a mapping scale adequate for well-pad site evaluation. The existing State-wide Geographic Information System (GIS) map showing the Principal Aquifers was compiled and digitized in the 1980s at a scale of 1:250,000. The State-wide map is outdated and highly inaccurate when projected to the 1:24,000 scale (fig. 3). Recently completed GIS coverages of the Primary Aquifers and selected Principal Aquifers mapped at the 1;24,000 scale using consistent delineation criteria are available from the USGS web page at http://ny.water.usgs.gov/projects/gisunit/Upstate_Aquifer_Page.html . Delineation of the remaining Principal-Aquifer boundaries at the 1:24,000 scale using the same mapping criteria is warranted for effective application of this water-resource protection measure.

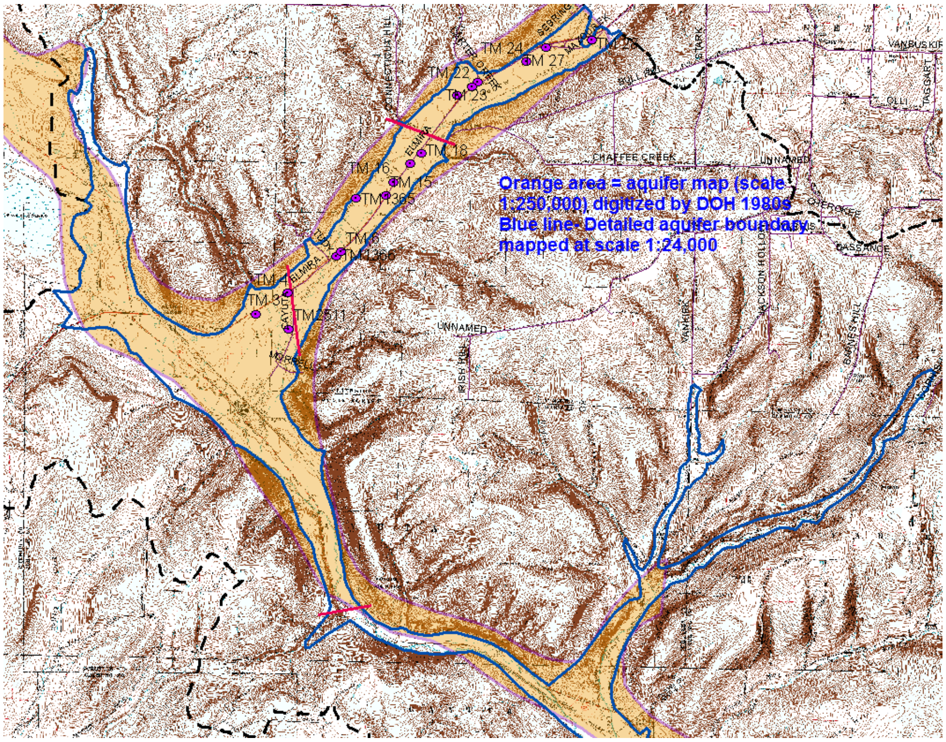

Figure 3. Example of aquifer boundaries compiled and digitized at a scale of 1:250,000 (orange area) compared with a detailed aquifer boundary mapped at a scale of 1:24,000 (outlined in blue line); note that there is more than a 30 percent discrepancy between the aquifer boundaries mapped at the two different scales

Sources of Recharge to Stratified-Drift Aquifers and Groundwater Supplies

The proposed setbacks for stratified-drift aquifers, public-supply wells, and domestic wells provide a broad basis for protection of water resources over a large geographic area, much like the public supply wellhead-protection area delineations under the New York State Department of Health. Detailed analysis of conditions is not possible over this large area, but incorporation of some additional geohydrologic concepts can enhance protection of public and domestic groundwater supplies.

Groundwater-supply protection is complicated because water sources and groundwater flow is not readily observable. Adequate protection of groundwater supplies depends on characterization of the local geohydrologic setting and potential sources of recharge to the stratified-drift aquifers that supply many communities. The importance of upland sources of recharge to stratified-drift aquifers in the glaciated Northeast (fig. 4) has been recognized for more than 40 years (Crain, 1966; M^{ac}Nish and Randall, 1982; Morrissey and others, 1988; Randall, 1978; Williams, 1991; and Williams and Morrisey, 1996).

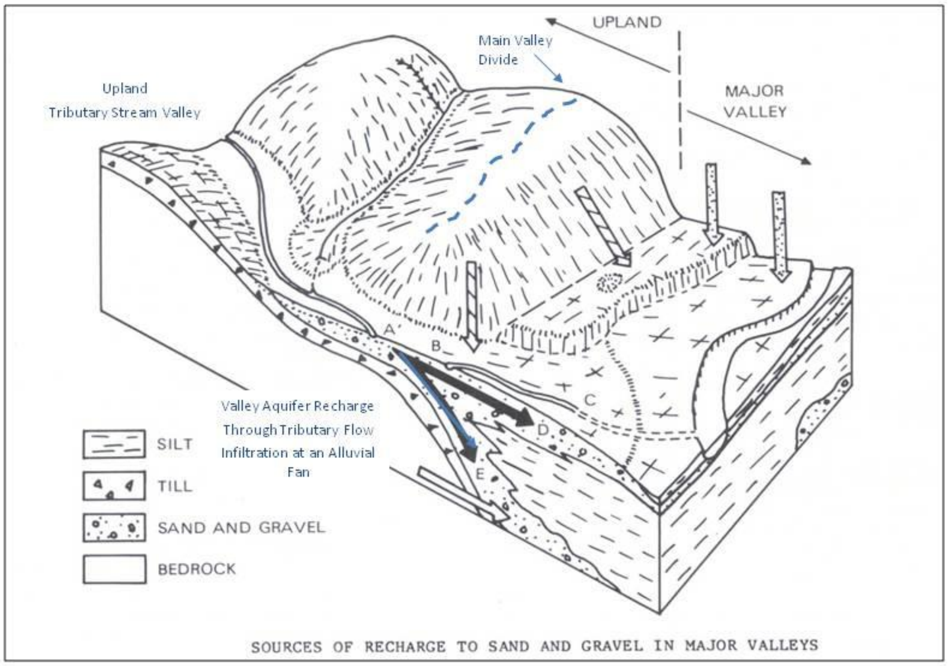

Figure 4. Sources of recharge to stratified drift in valleys in the glaciated Northeast (from Morrissey and others, 1988) and example of divide on adjacent hilltops in unchanneled valley-wall areas

The upland sources of recharge to stratified-drift aquifers and groundwater supplies that should be considered for protection are:

1. *Infiltration of precipitation on adjacent valley hillsides with subsequent down-slope groundwater flow to the valley floor.* Delineation of topographic divides generally defines the areal extent of this contribution. The proposed 500 ft buffer around Primary Aquifers is one-size-fits-all and may provide only partial protection to these aquifers. A more scientifically sound approach is to require delineation of surface-water divides adjacent to the Primary Aquifers. This would not be a significant investment in time using the USGS web application StreamStats (http://water.usgs.gov/osw/streamstats/new_york.html), thus the cost-benefit is potentially great.

2. *Infiltration of water from tributary streams as they flow across alluvial-fan or stratified-drift deposits towards the main-valley stream or river.* This water is derived from the watershed area of the tributary stream. A supply well on an alluvial fan or in adjacent stratified drift may seasonally derive a significant percentage of pumped water from infiltration of stream water derived from an upland source area (fig. 5). Thus, public groundwater supplies in the main valleys that derive water from tributary streams are particularly vulnerable to water-quality degradation in those upland watersheds**.** Additional protection should be considered for these upland watersheds that contribute water directly to public groundwater supplies. Ideally, these watersheds should be afforded the same protection as hillside areas. Exclusion of well pads in contributing tributary watersheds less than 5 mi^2 or the lower 5 mi^2 of larger tributary watersheds would provide a reasonable degree of public-water-supply protection.

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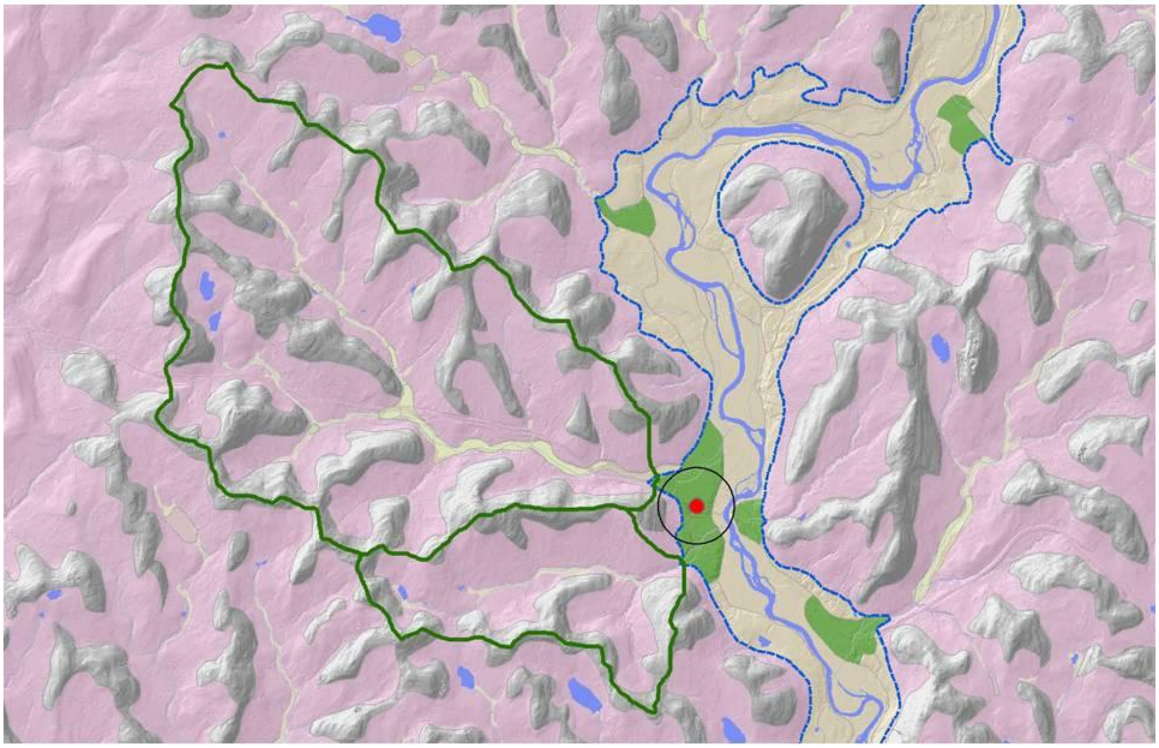

Figure 5. Example area showing main valley aquifer (tan outlined with blue dashed line), uplands with thick till (pink) and thin till (gray), alluvial fans (green), upland watersheds of streams that lose flow as they cross selected alluvial fans (outlined with green solid line), and public-supply well (red dot) with 2,000 ft buffer (gray circle).

The revised dSEIS affords limited protection to domestic well owners with a proposed 500 ft buffer around domestic wells and springs unless waived by the homeowner. The 500 ft buffer around domestic wells does not take local geohydrologic conditions and topographic setting into account. Nearly all domestic wells in upland areas tap the fractured bedrock aquifer. The low storage in these aquifers relative to a sand and gravel aquifer means that changes brought about by drilling, including water quality changes, can be felt rapidly at significant distance from a disturbance –especially if a domestic well is downgradient of a well pad. Upland areas of thick till (fig. 5) provide some level of protection to local domestic wells from drilling related accidents at land surface. <u>Protection of individual wells on a site by site basis is not feasible; however, siting well well pads immediately upslope of domestic wells in bedrock aquifer areas should be avoided and well pads should not be sited (as much as possible) where bedrock is exposed at land surface.</u>

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Microseismic Monitoring of Hydraulic Fractures

Microseismic evaluation of hydraulic fracture development is a geophysical method applied by some gas companies to monitor the horizontal and vertical extent of fracture propagation. Data from the gas industry for Marcellus hydraulic fractures suggests that the upward vertical extent of the fractures decreases with decreasing depth with fracture heights of 2,000 feet at a depth of 8,000 feet and 500 feet at a depth of 5,000 feet (Fisher, 2010). In New York State, the Marcellus shale likely will be hydraulically fractured at depths between 3,000 and 5,000 feet, a depth interval for which virtually no microseismic data has been collected. Although microseismic is a proven industry technique, mapping the extent of hydraulic fractures using this geophysical method is not required by the revised dSGEIS even during the initial stages of shale-gas development in New York State. Provision to supply these data to the State would allow the public to better understand the lateral and vertical extent of fractures created during the hydraulic fracturing process.

Reference

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Fractures, Faults, and Hydraulic-Fracture Barriers

The Marcellus Shale is underlain by the Onondaga Limestone and is overlain by the Tully Limestone and Upper Hamilton shales and limestones. These bedrock units are purported to be barriers to fracture propagation from hydraulic fracturing of the Marcellus Shale. The integrity of the hydraulic-fracture barriers can be investigated through geophysical investigations including well logging, lineament mapping, and seismic surveys. Although geophysical investigations are commonly completed as part of gas exploration, documentation of hydraulic-fracture barrier continuity and integrity is not required by the revised dSGEIS. Provision to supply these data to the State would allow a better understanding of the structural nature of those areas where these investigations take place.

Lineaments observed on remote sensing data have been found to be coincident with zones of fracture concentration (Jacobi, 2002). In the interbedded shale and sandstone bedrock overlying the Marcellus shale-gas play, the fracture frequency within these zones typically is an order of magnitude greater than that in the surrounding area. Zones of fracture concentration have been associated with nearby faults as inferred from outcrops, well logs, and (or) seismic reflection data, and some zones have been associated with methane gas anomalies in the soil (Jacobi, 2002).

As presented below (fig. 6) from a recent aquifer mapping project by the USGS in cooperation with the NYSDEC (Miller and Pitman, in review), zones of fracture concentration and faults commonly underlie valleys that contain important stratified-drift aquifers. It is prudent that that the location of major zones of fracture concentration and faults be considered in shale-gas drilling and hydraulic fracturing operations to help minimize risks to stratified-drift aquifers as well as bedrock aquifers.

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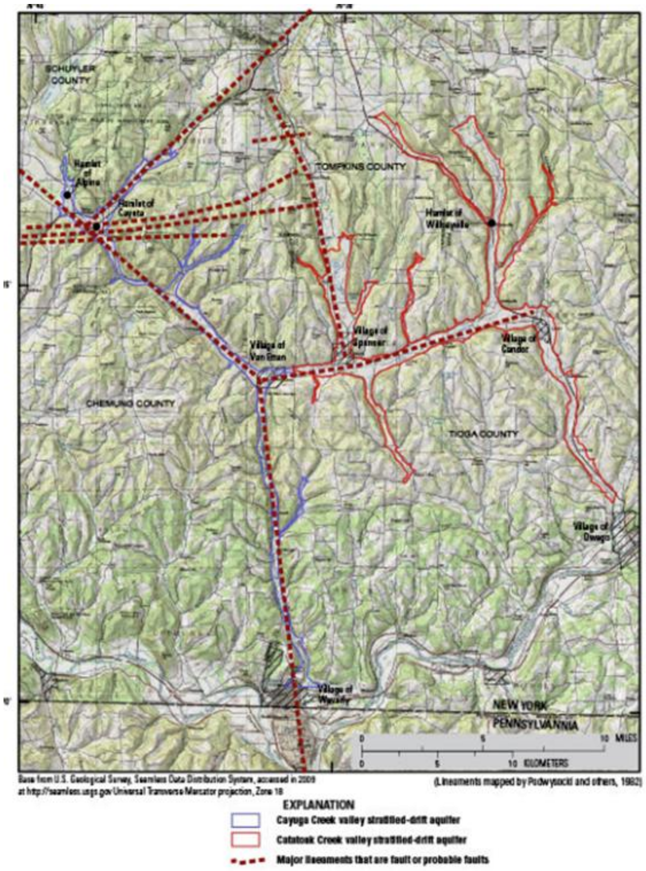


Base from U.S. Geological Survey, Seamless Data Distribution System, accessed in 2009 at http://seamless.usgs.gov Universal Transverse Mercator projection, Zone 18

(Lineaments mapped by Podwysocki and others, 1982)

EXPLANATION

- ▭ Cayuga Creek valley stratified-drift aquifer
- ▭ Catatonk Creek valley stratified-drift aquifer
- ▪▪▪ Major lineaments that are fault or probable faults

Figure 6. Relation of lineaments and selected stratified-drift aquifers (lineaments shown as dashed red lines, Cayuga Creek aquifer outlined in blue, and Catatonk Creek aquifer outlined in orange)

The revised dSGEIS references the State-wide map of faults and lineaments by Isachsen and McKendree (1977). A more detailed mapping of lineaments in New York's Appalachian basin was completed by EarthSat (1997) for the New York Energy Research and Development Authority. Through an integrated analysis of lineament, geologic, geophysical, and seismic epicenter data, Jacobi (2002) concluded that there are more faults in New York's Appalachian Basin than previously suspected, and that many of these faults are seismically active.

The fault map, "Mapped Geologic Faults in New York State", presented as figure 4.13 in the revised dSGEIS (fig. 7), grossly under represents the number and extent of faults in the Appalachian Basin of New York. The fault map is outdated and does not include the results of many publications summarized below that have mapped additional faults and should be considered.

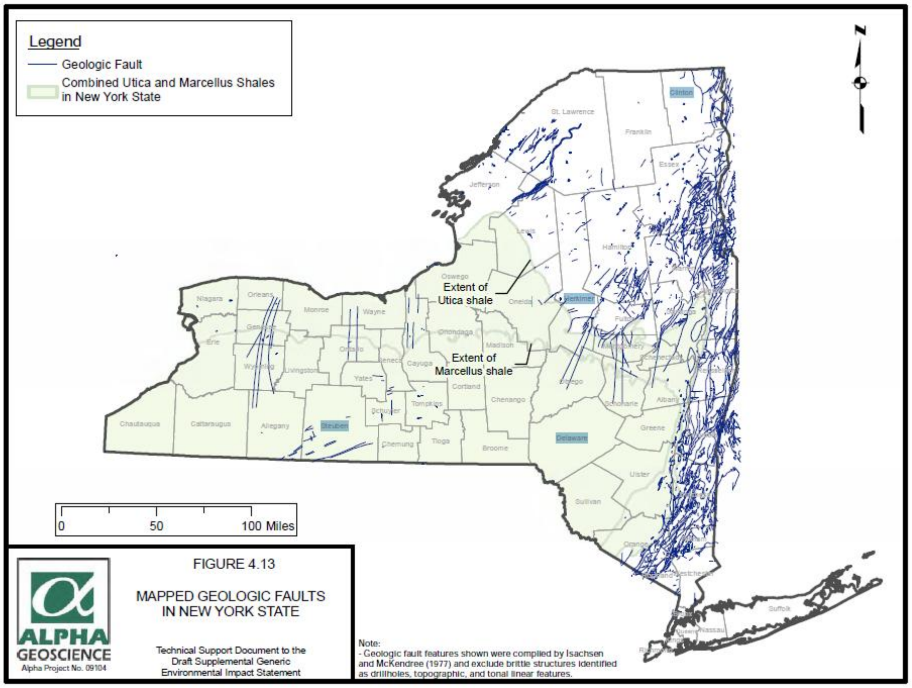
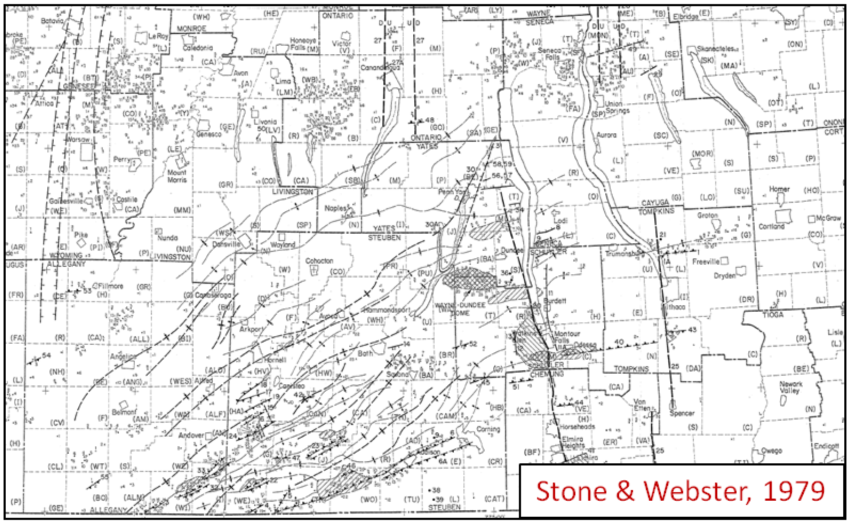


Figure 7. Revised dSGEIS Figure 4.13 showing faults in New York.

Publications over the past 40 years that document the presence of faults in the Appalachian Basin of New York are summarized below in chronological order.

1. Parker (1942) mapped three joint sets in central New York (N10°W, W-E, and N65°E) indicative of the fault/fracture framework.
2. Jacoby (1969) mapped the Retsof fault.
3. Jacoby and Dellwig (1974) mapped the Seneca Lake fault. The fault strikes N5°W and projects southward along the west shore of Seneca Lake and extends from the Himrod mine in the north to Watkins Glen brine field (and continuing southward, the fault trace coincides with a Landsat lineament mapped by Isachsen and McKendree (1977).
4. Stone & Webster geologic and hydrologic reports (1978a, 1978b, and 1979) mapped structures in central NY (fig. 8) as part of an evaluation of the suitability of burying high-level radioactive waste in the Salina Formation. One of the conclusions of the Stone & Webster reports was that “Faulting in the New York study area is more widespread than previously thought”. The Stone & Webster reports also stated in the conclusions that “We believe that the evidence is sufficient at this time (*1978*) to conclude that the salt basin in New York is cut by strike-slip tear faults and other nearly vertical faults which represent potential conduits of groundwater circulation.”



Stone & Webster, 1979

Figure 8. Structures including faults mapped by Stone & Webster (1979)

5. Hutchinson and others (1979) established that the Clarendon-Linden fault extends beneath Lake Ontario.
6. Murphy (1981) built upon the Stone & Webster work and demonstrated that detachment structures are present in south-central New York (fig. 9) based on detailed examination and interpretation of the geologic data gathered to date. The data used in this study consisted of geophysical logs supplemented by descriptions of sample cuttings of all wells drilled as of May 1979. Of note, Murphy (1981) describes the West Seneca Lake fault, the Cayuga Lake fault (which is a right-lateral fault extending south into Cayuta Creek valley and has an en echelon offset along the Catatonk Creek valley), and Keuka Lake faults.

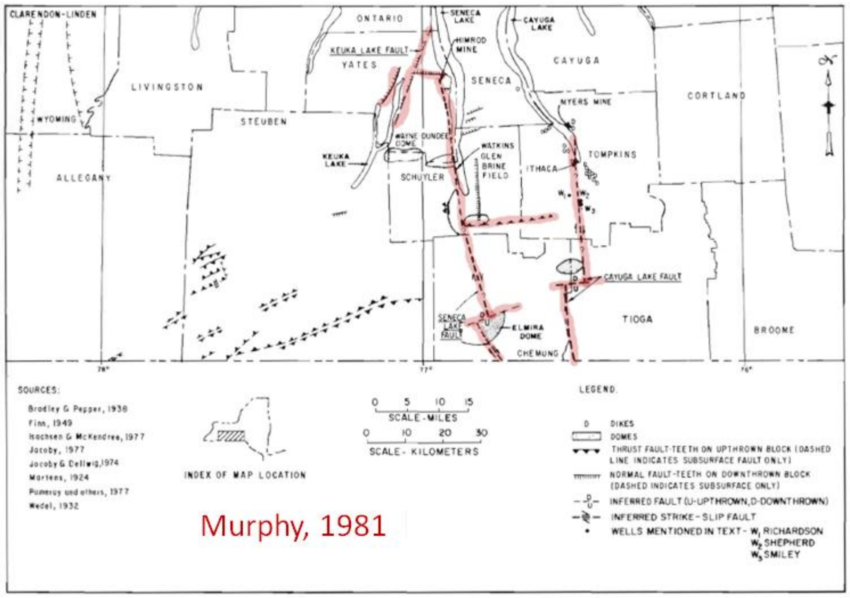


Figure 9. Faults mapped by Murphy (1981)

7. Podwysocki and others (1982) investigated the feasibility of storing high-level radioactive waste in the Salina Salt Formation in south-central NY. In addition to mapping the faults mapped in the Murphy paper (1981), this USGS report mapped other faults and probable faults such as West Danby thrust faults, the Cortland-Ithaca fault, Watkins Glen-Taughannock fault, Corning-Bath fault, Van Etten-Towanda fault, Corning-Bath fault, Endicott-Syracuse fault, and others (fig. 10). Although not confirmed everywhere due to a scarcity of deep well logs, the presence of faults was based on several sources of data including:
    a. digital contrast enhancement of several Landsat multi-spectral scanner images;
    b. analysis of lineament patterns from a Landsat MSS-7 mosaic;
    c. field mapping of bedrock joint patterns;
    d. compilation and analysis of surface and subsurface structure and isopach maps;
    e. collection and digital analysis of aeromagnetic data for southern New York;
    f. compilation and analysis of aeromagnetic and gravity data for much of New York and Pennsylvania; and
    g. analysis of seismic reflection survey lines for selected portions of New York and Pennsylvania.

    The paper summarized the geology of south-central New York as follows: “We believe the data examined show the study area to be structurally complex, having undergone several periods of deformation. The stratigraphic units proposed as potential storage beds for disposal of nuclear wastes appear to be affected by both Pre-Alleghanian extensional (?) deformation as well as Alleghanian compressional and shear tectonism. The general shape of the block and its relation to the Alleghanian folds begs for a thrust sheet interpretation for the block, with the east and west bounding lineament zones acting as tear faults and the northward displacement being taken up along splay faults of the West Danby fault system. We have cited evidence which corroborates this thesis. Two lineaments within the rectilinear block also display thrust or tear fault attributes. Thus, where on a megascopic scale only one large thrust sheet is recognized, more detailed inspection reveals that the block probably consists of many smaller blocks bounded by their own thrusts and tears."

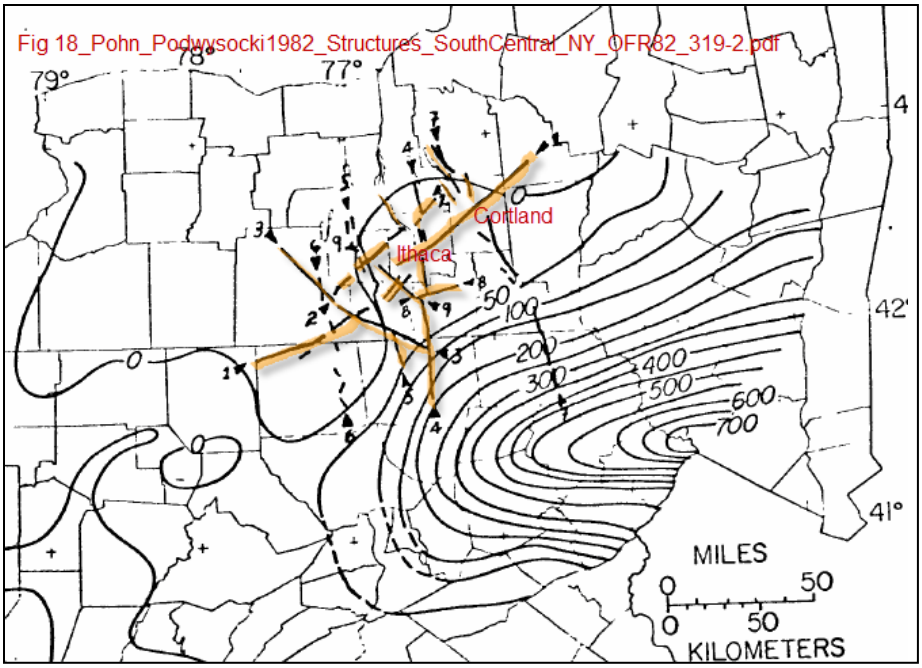


Fig 18_Pohn_Podwysocki1982_Structures_SouthCentral_NY_OFR82_319-2.pdf

Figure 10. Faults mapped by Podwysocki and others (1982)

8. As part of a USGS report on overthrust belts worldwide, Pohn (2000) mapped lineaments and earthquake epicenters in the Appalachians (fig. 11).

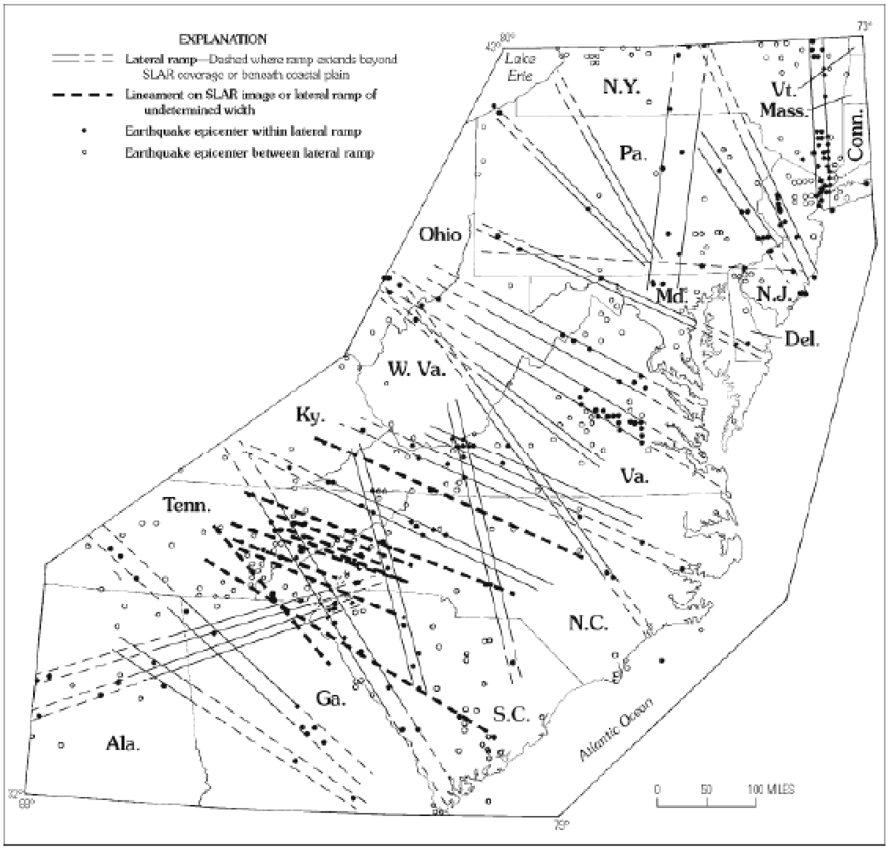


Figure 11. Lineaments and earthquake epicenters mapped by Pohn (2000)

9. Jacobi (2002) documented faults and an extensive array of Fracture Intensification Domains (FIDs) in western and central New York (fig. 12). Jacobi and Fountain (2002) found that FIDS were commonly associated with nearby faults identified on the basis of stratigraphic displacements inferred from outcrops, well logs, or seismic reflection data. Moreover, they found that faults with small offset commonly occur in outcrops within a FID. Thus, by identifying and ground truthing the lineaments, they predicted the location and extent of subtly expressed faults that were previously overlooked. Evidence utilized for recognition of faults in New York included the integration of FIDs, EarthSat (1997) and other lineaments, gradients in gravity and magnetic data, seismic surveys, and geophysical logs.

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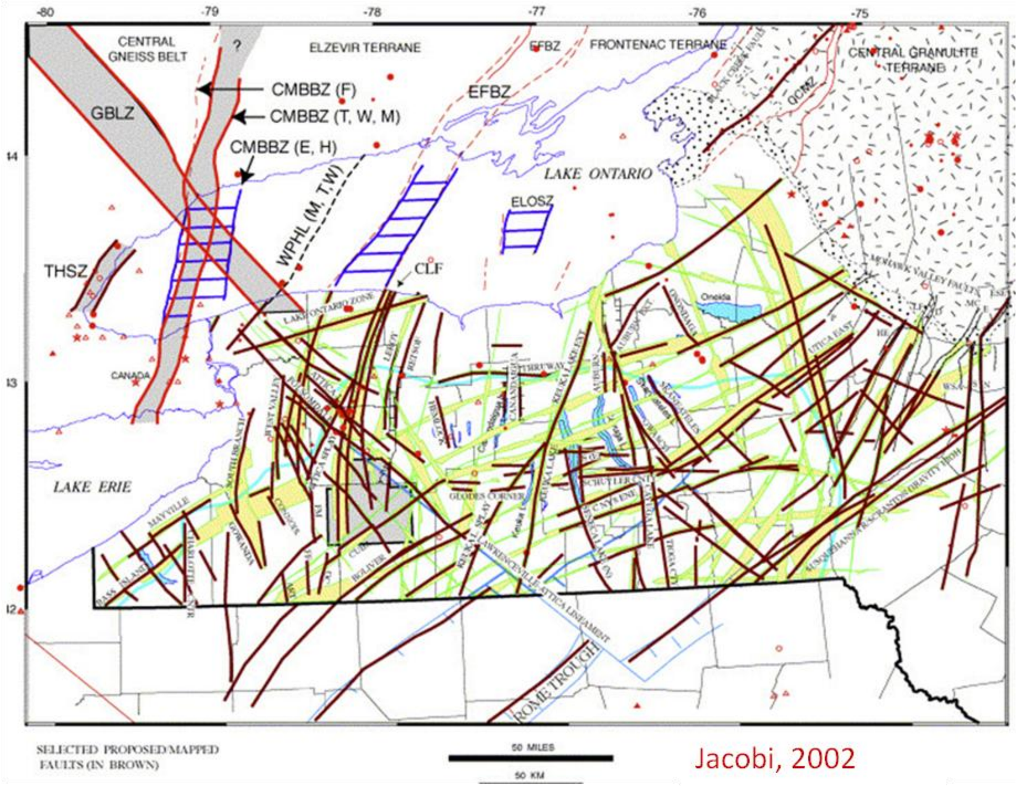

Figure 12. Faults and Fracture Intensification Domains mapped by Jacobi (2002)

10. Using multiple lines of evidence, Ramussen and others (2003) mapped structures (including faults) in the Finger Lakes region of New York (fig. 13). The most direct evidence was from direct mapping of the structural element. Less direct methods utilized offsets in fold features that affected the Lower Devonian Oriskany Sandstone. Linearly aligned zones of en echelon kimberlitic dikes were also used to define potential, northwest-striking, deep-seated fault elements (such as the Ithaca line). Other potential basement structures were indicated by linear breaks between magnetic highs and lows, gravity highs and lows, radiometric highs and lows, as well as troughs. Offsets in the regional outcrop patterns were also related to deep-seated faults. Alignments in the contour lines on the Conodont Alteration Indices (CAI) map were also used.

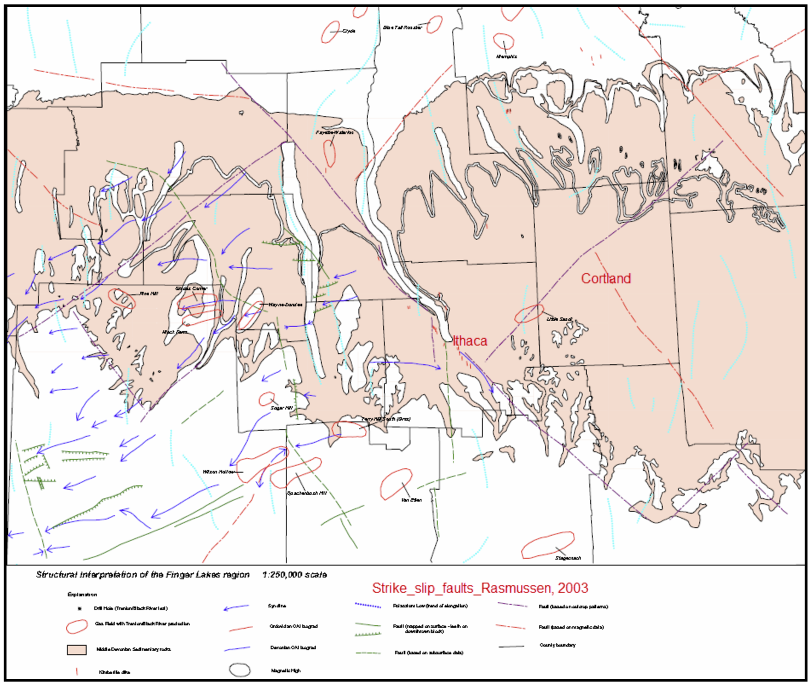

Figure 13. Structures including faults mapped by Ramussen and others (2003)

11. As part of a regional assessment of a hydrothermal dolomite gas play in the Appalachian Basin, the Trenton-Black River Research Consortium (2006) mapped an extensive set of faults that are roughly parallel to regional strike and are offset by a second set of northwest trending faults (figs. 14 and 15).

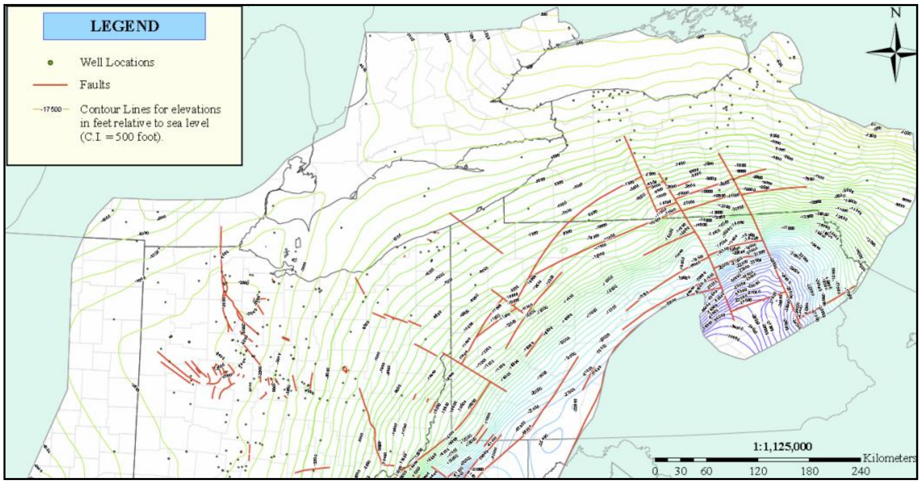

Figure 14. Structure of the top of the Precambrian including faults mapped by the Trenton-Black River Research Consortium (2006)

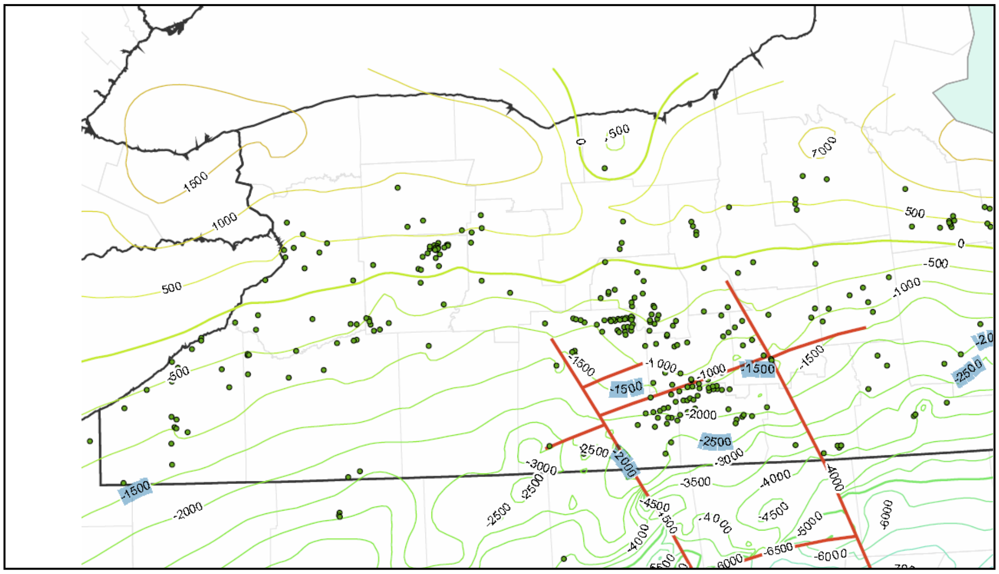

Figure 15. Structure of the base of the Devonian shale including faults mapped by the Trenton-Black River Research Consortium (2006)

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New York City Aqueduct

The Marcellus shale-gas play in southwestern Delaware County is traversed by the West Delaware Aqueduct, an important subsurface connection of the New York City West-of-Hudson water-supply system (fig. 16). The revised dSGEIS proposes a buffer zone for Marcellus shale-gas wells of 1,000 ft around New York water-supply infrastructure including aqueduct tunnels. Fracture zones in the bedrock may potentially provide pathways for the migration of pressurized fluids over significant distances.

Lineaments observed on remote sensing data have been found to be coincident with zones of fracture concentration (Jacobi, 2002). In the interbedded shale and sandstone bedrock overlying the Marcellus shale-gas play, the fracture frequency within these zones typically is an order of magnitude greater than that in the surrounding area. Some of the zones of fracture concentration have been associated with nearby faults as inferred from outcrops, well logs, and(or) seismic reflection data, and some zones have been associated with methane gas anomalies in the soil (Jacobi, 2002). Isachsen and McKendree (1977) published a preliminary brittle-structure map for New York State that included lineaments as well as faults. A more extensive mapping of lineaments in New York's Appalachian basin was completed by EarthSat (1997) for the New York Energy Research and Development Authority.

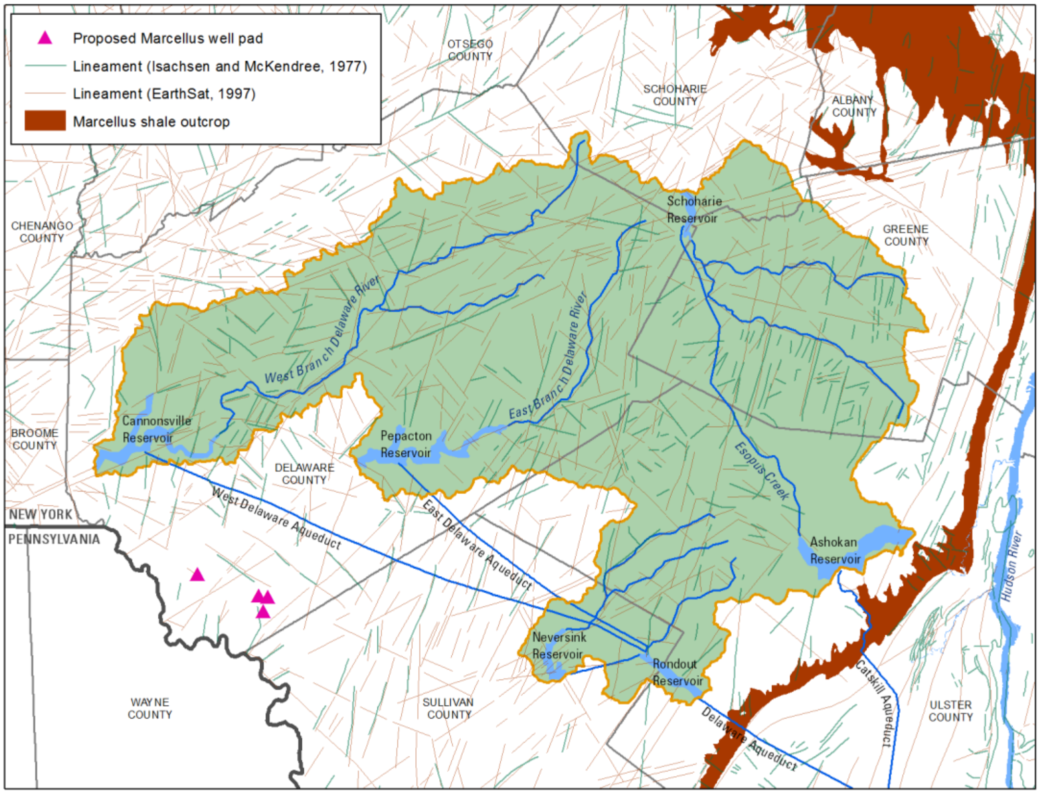

Figure 16. New York City West-of-Hudson water-supply watershed, reservoirs, and aqueducts; Marcellus shale outcrop; proposed Marcellus well pads; and lineaments mapped by Isachsen and McKendree (1977) and EarthSat (1997)

<u>The possibility of damage to the aqueduct from hydraulic-fracturing operations is an issue of concern given the proposed infrastructure buffer zone. Assessment of the spatial relation of proposed Marcellus wells with lineament features that cut across the path of West Delaware Aqueduct would provide important information for the protection of the New York City West-of-Hudson water-supply infrastructure.</u>

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Well water-quality sampling and data base

The water-quality data collected by the gas industry and others during shale-gas development would provide an important database for understanding and protecting the State’s groundwater and surface-water resources if made available to government agencies, academia, and other interested parties. The revised dSGEIS does not propose a mechanism for electronically storing and sharing the potentially large amount of water-quality data collected during shale-gas development. Submittal of domestic-well water-quality sampling results in electronic data base format would allow sharing of that data for scientific purposes. Safeguards could be taken to protect personal information. An example of utility of these data in understanding ambient groundwater quality for constituents of concern such as methane (fig. 17) was demonstrated by Molofsky and others (2011).

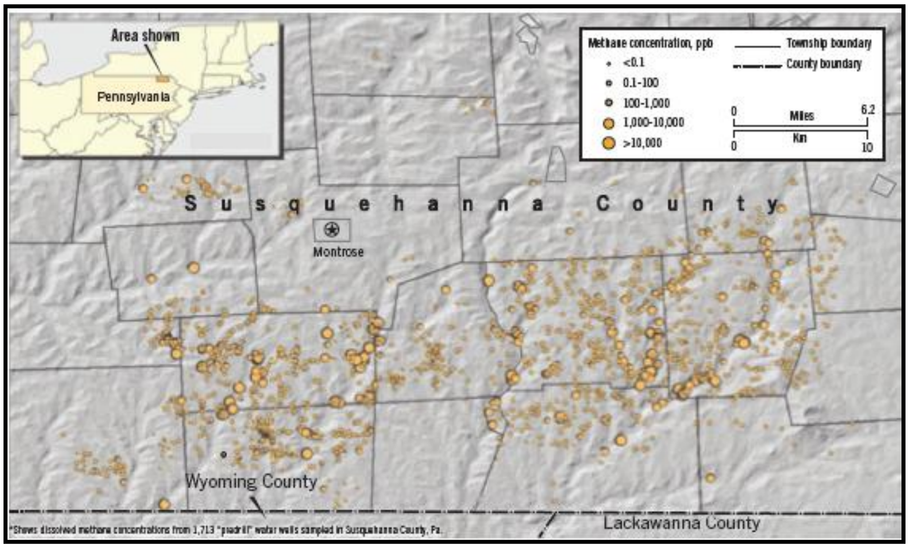

Figure 17. Results of pre-drill survey by gas industry for methane in water wells, Susquehanna County, Pennsylvania (Molofsky and others, 2011)

To improve the consistency, comparability, and utility of the groundwater-quality data, the following is suggested:

1. The final list of water-quality parameters should be a required list rather than a suggested list.
2. If the industry tests for other water-quality parameters, they should provide those results also, but not in lieu of the required list of parameters.
3. The analysis method for each parameter must be specified as to an EPA lab procedure code and type (i.e., dissolved and[or] total for each parameter analyzed).
4. Holding times for time-critical parameters (i.e., gross alpha and beta) should be specified, and the time limit not exceeded. If the limit is exceeded, notification on the laboratory report should be made.
5. Field measurements should also be entered along with the parameter codes and results.
6. The results of all analyses (field and lab) along with QA/QC results should be provided to the New York State Department of Environmental Conservation (Division of Water) and Department of Health in electronic spreadsheet format with all pertinent location information including GPS latitude/longitude coordinates (NAD83 datum).
7. The Division of Water should assign a County well number to any well not identified under the New York State Water Well Driller Registration Law (drilled pre-2000).

Reference

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