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Bradford and Susquehanna County, Pennsylvania Retrospective Case Study Characterization Report

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EXECUTIVE SUMMARY

The United States Environmental Protection Agency (EPA) is conducting a retrospective case study in Bradford and Susquehanna Counties, Pennsylvania (PA) to determine if there is a relationship between hydraulic fracturing and drinking water. EPA selected this site "in response to complaints about appearance, odors, and possible health impacts associated with water from domestic wells" (EPA, 2012b). To investigate these complaints, EPA is collecting groundwater and surface water quality data

An understanding of background water quality conditions prior to or in the absence of hydraulic fracturing is required to determine if a relationship exists between hydraulic fracturing and drinking water resources. Absence of background water quality necessitates a rigorous investigation of potential sources for any observed impacts prior to source attribution. This report is intended to provide an initial understanding and characterization of water quality conditions in Bradford and Susquehanna Counties based upon publically available information on land use, known surface water impairments, and water quality data from the U.S. Geological Survey (USGS), EPA, and Commonwealth of Pennsylvania. Key findings from this report include:

- Pennsylvania has one of the most rigorous regulatory programs for oil and gas development of any state.
- Groundwater and surface water quality vary throughout Bradford and Susquehanna Counties. This variation is due to natural events (e.g., geologic, seasonal) and anthoprogenic activities. Water quality is largely determined by the composition of the soil and rock through which the water flows and the length of time the water has been in contact with the soil and rock. Many of the water quality parameters evaluated within this report are naturally occurring in groundwater, spring water, and surface waters of the area above screening criteria. A number of pre-shale gas development (primarily before 2007) impairments have been identified and traced back to historical land uses. These historical activities could provide sources for a number of pollutants that may exist in groundwater and/or surface water in the study area. The main causes of water quality impairments in Bradford and Susquehanna Counties are agriculture and road runoff. Other land uses known to impact water quality in the county include habitation modification, septic systems, non-point sources; point sources; and resource extraction from coal and non-coal mineral mining. Land uses and associated parameters include:
    - **Agricultural runoff:** Agricultural runoff includes insecticides, herbicides, fungicides, fertilizers (e.g., nitrogen and phosphorous), metals (e.g., arsenic), and other constituents (e.g., dissolved solids, bromide, selenium). In addition, algal blooms caused by agricultural runoff of nitrogen and phosphorous can be a source of organic carbon that can promote the formation of disinfection byproducts (DBPs) upon chlorination of surface water in water treatment plants (EPA, 2005). Agricultural and livestock activities can also be a source of methane (King, 2012).
    - **Road runoff:** Road salt application to paved roads contains chloride and trace amounts of bromide (with a Cl:Br ratio of 1,000 to 10,000 [USGS, 2009]). It has been well documented that chloride concentrations in surface waters and glacial till aquifers in the northeast have been increasing over time based on statistical studies of historic water quality data (pre-dating hydraulic fracturing activities). In these studies, temporal spikes in concentration were noted especially during winter months from November to April, indicating a likely relationship with winter deicing activities (USGS, 2009). Runoff from impervious roadways can also be a source of heavy metals (e.g., iron, lead, zinc) and volatile organic compounds (VOCs). In addition, runoff from paved and unpaved roads is known to contribute sediment loading and runoff of other road-related substances to nearby surface waters.

- **Septic Systems:** Studies have shown elevated levels of potassium, boron, chloride, dissolved organic carbon, and sulfate concentrations in monitoring and domestic wells in proximity to septic tanks (Katz et al., 2011).
- **Non-point sources, stormwater runoff, and industrial activities:** Constituents associated with these sources may include polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), metals; salts, pH; siltation; suspended solids; and nutrients, depending upon the types of activities in the area. Habitat modification can cause stream bank instability and significant soil erosion and sediment pollution in nearby streams.
- **Non-coal mineral mining:** Groundwater quality and quantity can be impacted by dewatering activities in sand, gravel, and crushed stone quarries. Water quality parameters that may be influenced by these types of activities could include total suspended solids (TSS), turbidity, temperature changes, pH, and oil and grease from runoff and washing operations in the vicinity of mechanical equipment and vehicles.
- **Coal mining and abandoned mine drainage:** Constituents associated with coal mining activities may include metals, sulfate, and general water quality (i.e., total dissolved solids [TDS], pH). A limited amount of coal mining has been conducted in Bradford and Susquehanna Counties, but known impairments to watersheds exist.
- **Conventional oil and gas development:** Constituents associated with this activity may include petroleum hydrocarbons, benzene, toluene, ethyl benzene, xylene (BTEX), and methane. Conventional oil and gas activity has been present in Bradford and Susquehanna Counties since the mid-1800s, but in very limited amounts prior to development of the Marcellus Shale play.
- **Surface water impairments:** Total maximum daily loads (TMDLs) have been established due to known surface water quality impairments for over 231 miles of impaired streams and rivers in Bradford and Susquehanna Counties. The chemicals that have caused these surface water impairments in Bradford and Susquehanna Counties include pH, metals, PCBs, nutrients, siltation, and suspended solids.

- Historical background data on water quality within the study area are extremely limited for the parameters EPA has selected to study. Of the 192 critical and measured parameters that EPA identifies in its quality assurance project plan (QAPP), 38 parameters are included in a sufficient number of historical samples to establish any statistically meaningful background water quality for groundwater, 11 parameters are included for springs, and 23 parameters are included for surface water. These data are limited primarily to inorganic and general water quality parameters.
- Given the reported EPA study design, determining a relationship between a potential source of impact and drinking water will be difficult given both the known impairments and the lack of adequate data to characterize background water quality conditions. Without adequate background water quality, assumed impacts observed as part of the EPA study may in fact be naturally occurring or have been present prior to shale gas development. Background information sufficient to determine natural condition and variations allow for the determination of a potential impact. Once a potential impact is identified, a rigorous investigation is required before attributing it to a source, including hydraulic fracturing.

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ABBREVIATIONS AND ACRONYMS

AMD	abandoned mine drainage
ANOVA	analysis of variance
API	American Petroleum Institute
AST	above ground storage tank
BCCD	Bradford County Conservation District
bgs	below ground surface
BOD	biochemical oxygen demand
BOGM	Bureau of Oil and Gas Management
BTEX	benzene, toluene, ethylbenzene, and xylene
CA	critical analyte
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CWA	Clean Water Act
DBP	disinfection byproduct
DQO	data quality objective
EPA	U.S. Environmental Protection Agency
FSP	Field Sampling Plan
HUC	Hydrologic unit code
IOGCC	Interstate Oil & Gas Compact Commission
M	measured
MCL	maximum contaminant limit
NPDES	National Pollutant Discharge Elimination System
NRC	National Research Council
NURE	National Uranium Evaluation
NWIS	National Water Information System
PA DCNR	Pennsylvania Department of Conservation and Natural Resources
PADEP	Pennsylvania Department of Environmental Protection
PA GWIS	Pennsylvania Groundwater Information System
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl
PENNDOT	Pennsylvania Department of Transportation
PGWA	Pennsylvania Groundwater Association
PPC	Preparedness, Prevention, and Contingency
PSU	Pennsylvania State University
PWS	public water system
QA	quality assurance
QAPP	Quality Assurance Project Plan
QC	quality control

RCRA	Resource Conservation and Recovery Act
RPD	relative percent difference
SDWA	Safe Drinking Water Act
SMCL	secondary maximum contaminant limit
SRBC	Susquehanna River Basin Commission
STORET	EPA STOrage and RETrieval Data Warehouse
STRONGER	State Review of Oil and Natural Gas Environmental Regulations
SVOC	semivolatile organic compound
TDS	total dissolved solids
TMDL	total maximum daily load
TRI	Toxic Releases Inventory
TSS	total suspended solids
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
UST	underground storage tank
VOC	volatile organic compound
WWTP	wastewater treatment plant

1.0: INTRODUCTION

The U.S. Environmental Protection Agency (EPA) has initiated five retrospective case studies as part of the agency's evaluation of the potential relationships between hydraulic fracturing and drinking water resources (EPA, 2011).

One of the retrospective case studies selected by EPA is located in Bradford and Susquehanna Counties in Pennsylvania (EPA, 2011; EPA, 2012a) where groundwater and drinking water wells have been reported to be contaminated, and surface water contamination from a spill is suspected. To investigate these complaints, EPA is collecting samples from domestic wells, springs, and surface water bodies in the study area and analyzing those samplesfor a wide range of water-quality parameters.

To enable evaluation of the EPA case study water sampling and analysis results within the context of regional spatial and temporal variability, American Petroleum Institute (API) and America's Natural Gas Alliance requested Battelle to characterize historical land use, historical groundwater quality, historical spring water quality, and historical surface water quality in Bradford and Susquehanna Counties, using readily available data that predates (prior to 2007) unconventional oil and gas development in the area. This report summarizes historical water- quality data prior to 2007 for use in comparing the future data to be generated as part of EPA's retrospective case study.

Based on information contained in the EPA Quality Assurance Project Plan (QAPP) and through recent discussions with Chesapeake Energy, Inc., EPA collected water samples from 23 wells, two springs, and two surface water bodies in November 2011 and April 2012 in the study area. To date, these data have not been made available to the public.

1.1 Scope of Work

The primary objective of this report is to develop an understanding of and to characterize background groundwater, spring, and surface water quality conditions within the EPA retrospective study area prior to the onset of unconventional oil and gas development and to highlight potential adverse impacts that may have resulted from former land-use activities. This was accomplished by:

- Defining the spatial and temporal boundaries and attributes of the study area.
- Identifying historic and current land use and water-quality data that could be used to provide historical context for characterizing water resources in the defined study area, along with identifying associated analytical parameters that could be used to evaluate potential impact on drinking water resources.
- Developing a list of available chemicals and water-quality parameters analyzed in the study area, and comparing them to EPA QAPP requirements.
- Developing and applying quality assurance (QA) criteria to assess the quality of the historical water-quality data.
- Conducting summary statistical analyses on the water-quality data and comparing the data and results to state and federal water quality screening criteria.

Battelle utilized EPA's data quality objective (DQO) process to help ensure that an appropriate type and quantity of data needed to meet the study objective was collected (EPA, 2006). An in-depth evaluation of water-quality data by individual surface water bodies, springs, aquifers, or wells is beyond the scope of this report.

1.2 Report Organization

Section 2 of this report discusses the technical approach to defining the study area boundaries; identifying, collecting, and organizing the historical water-quality data; QA procedures for data assessment; and a discussion of relevant regulations and water-quality screening criteria applicable to the water-quality parameters of interest. Section 3 provides an analysis of the historical land use, groundwater quality, spring quality, and surface water-quality data evaluated for this report. Key conclusions and findings are presented in Section 4.

1.3 Site Description

Figure 1-1 shows the 40EPA sampling locations in the Bradford and Susquehanna Counties retrospective case study area, comprising 36 groundwater sample locations, two spring sample locations, and two surface water sample locations identified using the EPA Bradford-Susquehanna County QAPP (EPA, 2012b) and coordinate information provided by Chesapeake Energy, Inc. The EPA sampling locations are clustered in five relatively discrete areas:

- East Smithfield, Granville-Summit, Leroy, Troy, and West Burlington Townships in south-central/southwestern Bradford County
- Southeastern portion of Bradford County including Asylum, Monroe, Sugar Run, Terry, Towanda, Wilmot, Wyalusing, and Wysox Townships
- Le Raysville, Stevensville, and Tuscarora Townships in southeastern Bradford County and Auburn and Rush Townships in southwestern Susquehanna County
- South central Susquehanna County including Dimock, Meshoppen, Montrose, Lenox, and Springville Townships
- North-central Susquehanna County including Franklin, Great Bend, Liberty, and Silver Lake Townships.

The locations for the case study were selected by EPA in response to "homeowner complaints regarding appearance, odors and possible health impacts associated with water from domestic water wells" (EPA, 2012b). Although no rationale was provided in the EPA QAPP for selecting the specific sampling locations, Battelle obtained information from the Pennsylvania Department of Environmental Protection (PADEP), the United States Coast Guard National Response Center, news outlets and social media Web sites that identifies numerous homeowner complaints generally corresponding to areas targeted for sampling by EPA. In these areas, PADEP violations including Consent Order and Agreements were identified between the years 2008 and 2011, along with reports to the National Response Center in 2010 and 2011, and individual private or class-action citizen complaints. These various complaints are associated with one or more of the following:

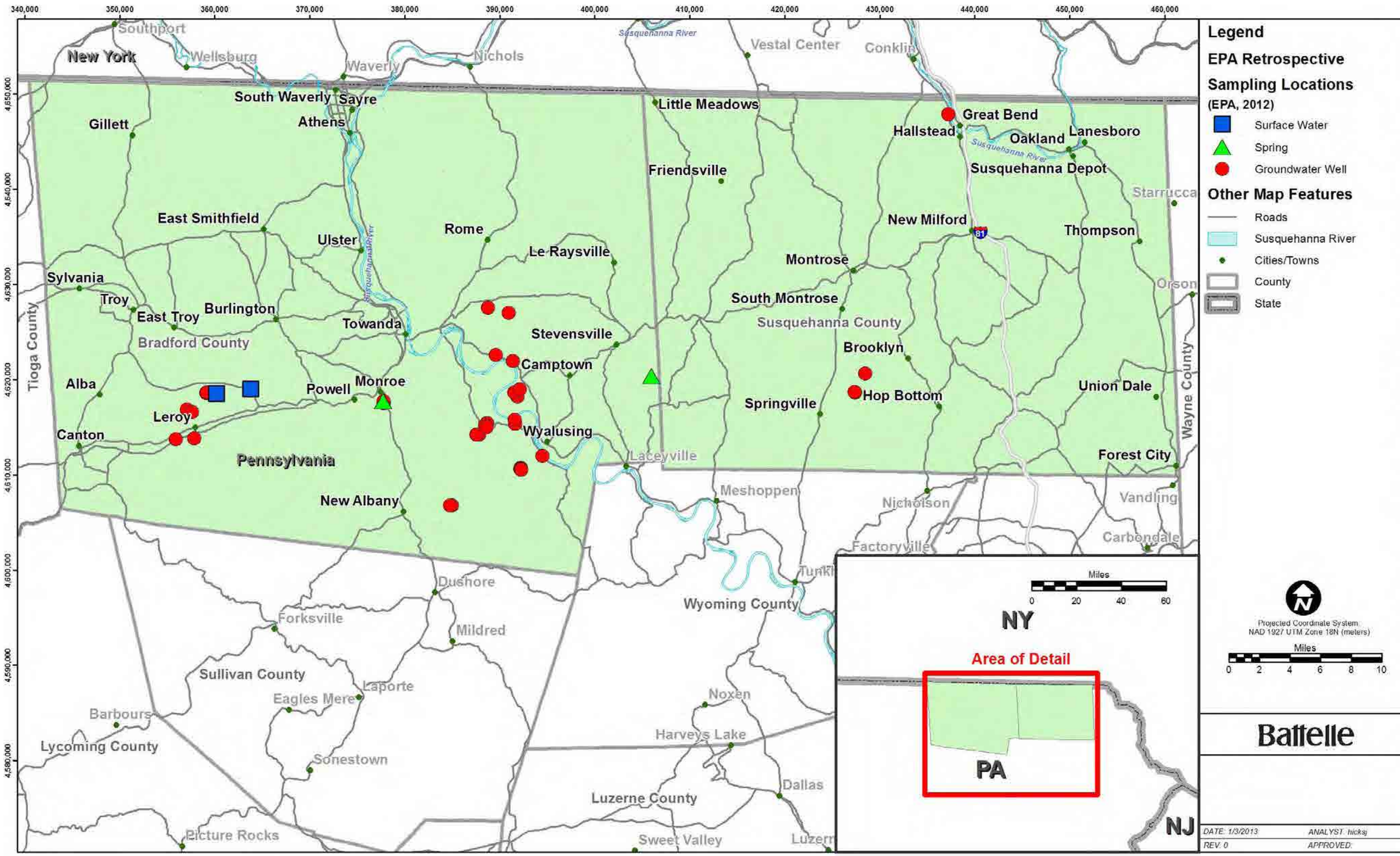

Figure 1-1. EPA Retrospective Sampling Locations in Bradford and Susquehanna Counties, PA

- Possible health effects to livestock,
- Possible distressed or damaged vegetation or other ecosystem impacts,
- Potential human health effects, including blood poisoning, miscarriage, loss of hair, respiratory illness, and suicide,
- Possible discolored, corrosive, or flammable water,
- Possible chemical or fuel spills,
- Possible surface water impairments,
- Possible odors, vapors, or fumes,
- Possible impacts to property value or business operations, and
- Possible physical damage to property from explosive conditions.

Chemicals or materials that were specifically noted in the various complaints to have caused alleged impacts included aluminum, barium, diesel fuel, ethane, fluids associated with unconventional oil and gas development (including specifically BARA KADE), hydrochloric acid, iron, methane and mineral oil. Given the paucity of information regarding specific location and ownership of the EPA sampling sites and the general lack of detailed location information from the homeowner complaints, Battelle was not able to directly associate particular complaints to specific EPA sampling stations.

2.0: TECHNICAL APPROACH

This section provides the technical approach to defining the study area boundaries, data collection, QA processes, and the applicable environmental regulatory framework.

2.1 Retrospective Case Study Area Boundaries

The subject study area comprises Bradford and Susquehanna Counties within the Marceullus Shale play of northeastern Pennsylvania (Figure 1-1). Bradford County encompasses approximately 1,147 square miles and has a current population of approximately 62,622. Susquehanna County encompasses approximately 823 square miles and has a population of approximately 43,356 (U.S. Census Bureau, 2010). Figure 1-1 shows the EPA groundwater, springs and surface water sampling locations in the Bradford and Susquehanna Counties retrospective case study.

Physiographically, Bradford and Susquehanna Counties are located in the Glaciated Low Plateau Section of the Appalachian Plateaus province where the topography is characterized by rounded hills, along with valleys that have been modified by glacial erosion and deposition (PA DCNR, 2012).

From a hydrological standpoint, both counties are located within the Susquehanna River Basin. Figure 2-1 shows the seven subbasins that cross into Bradford and Susquehanna Counties, all of which flow to the Susquehanna River. Surface water bodies considered in Battelle study are those that may be considered drinking water resources or contribute to surface water bodies that may serve as drinking water resources which translates into essentially all rivers and streams in the Bradford and Susquehanna counties.

The study area is vertically constrained by hydrogeologic formations in Bradford and Susquehanna Counties that serve as drinking water resources. Drinking water is typically obtained from surficial or near-surface unconsolidated glacial formations that are generally a few hundreds of feet thick. Drinking water is also obtained from bedrock formations that underlie the unconsolidated glacial deposits and are up to 2,000 feet in thickness, but only the upper portions of these bedrock formations are used for drinking water supply. The average depth to groundwater in northeastern Pennsylvania is approximately 175 feet below ground surface (bgs) but is commonly less than 40 to 50 feet bgs in areas of low topography. Fresh groundwater occurs to depths of approximately 800 feet bgs in upland areas and 200 feet bgs in valleys, below these depths water is commonly saline. However, saline groundwater has been documented to occur at much shallower depths, particularly in the valleys (Williams et al., 1998). The depth to the underlying Marcellus Shale ranges from roughly 4,000 to 7,000 feet bgs beneath Bradford and Susquehanna Counties; the depth and thickness of the Marcellus Shale generally increasing from northwest to southeast.

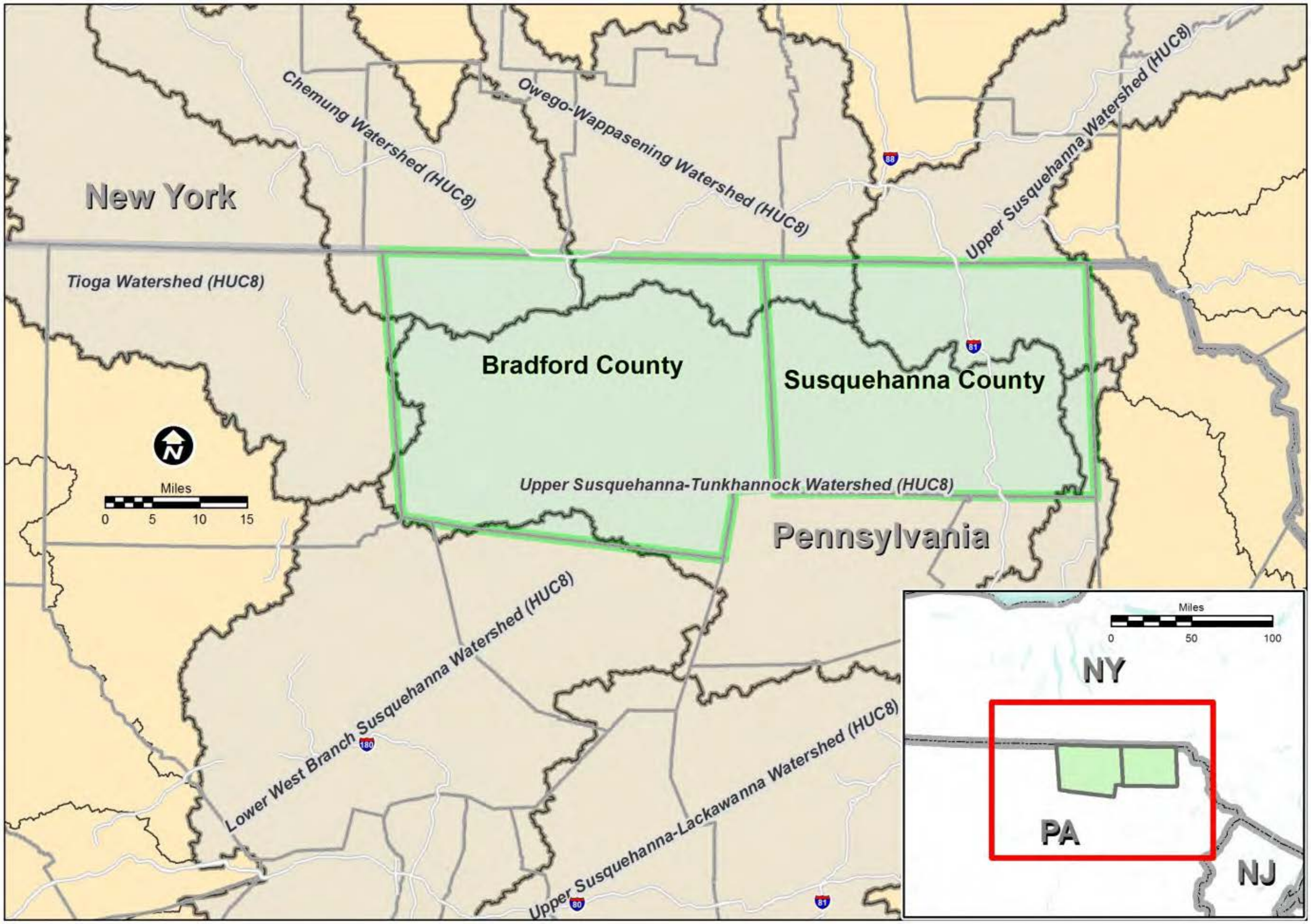

Figure 2-1. Location of Watershed Subbasins within Bradford and Susquehanna Counties

2.2 Data Sources, Collection, and Organization

The data contained in this report are secondary or historical data obtained by Battelle from publically available U.S. federal government and state of Pennsylvania records. Secondary data are defined as “data that were originally collected for another project or purpose” and have been summarized in historical databases. This section also describes the types of historical or current land use and the historical (pre-2007) water quality data. Further, the report describes how the data were collected and managed. The data collected focused on the following:

- Land uses potentially contributing to water-quality conditions;
- Groundwater quality conditions;
- Spring water quality conditions; and
- Surface water quality conditions.

2.2.1 Land Use Data Collection. The land-use data collected are qualitative in nature and rely upon the original quality and documentation of the primary source of the data sets. The primary sources of the land use data are summarized in Table 2-1. Both historic and current land use information was reviewed to evaluate conditions associated with water quality within Bradford and Susquehanna Counties. This information also provides a context within which to evaluate both the water quality for spatial and temporal changes and for future comparison with data collected in the EPA retrospective case study.

Table 2-1. Summary of Land-Use Data Sources

Data Source	Timeframe	Type of Data
PADEP[1]	1991-2012	Storage tank cleanup locations
PA DCNR[2]	2007	Oil and gas fields of Pennsylvania
PASDA/PADEP[2]	2012	Total maximum daily load (TMDL) impaired waters
PASDA/PADEP[2]	2011-2012	Coal mining operations and mineral mining data.
PASDA/PADEP[2]	2012	Land recycling cleanup location divided into sub-facilities categorized: air, contained release or abandoned container, groundwater, sediment, soil, surface water, and waste
USDA[3]	2011	Cropland information
EPA Envirofacts[4]	2012	Recognized pre-existing environmental activities that may affect air, water, and land resources
Bradford County Planning Commission[5]	2004	Comprehensive Plan that includes historic land use, economy, and industries
Susquehanna County Planning Commission	2003	Comprehensive Plan that includes historic land use, economy, and industries
USGS[6]	1986	Land use map

2.2.2 Water Quality Data Review. Data were summarized and reviewed from U.S. federal government and state of Pennsylvania sources to characterize baseline groundwater and surface water

[1] http://www.portal.state.pa.us/portal/server.pt?open=514&objID=589714&mode=2
[2] http://www.dcnr.state.pa.us/topogeo/maps/map10.pdf
[3] http://nassgeodata.gmu.edu/CropScape/
[4] http://www.epa.gov/enviro/index.html
[5] http://www.bradfordcountypa.org/Boards-Committees/Planning-Commission.asp
[6] http://water.usgs.gov/GIS/dsdl/ds240/index.html

quality. The spatial boundaries for the data review were hydrologic unit code (HUC) 8 watershed boundaries for the seven HUC 8 watersheds crossing Bradford and Susquehanna Counties (see Figure 2-1). This larger data set was then reduced to include only data located within Bradford and Susquehanna Counties.

Water quality data were collected from the following sources:

- U.S. Geological Survey (USGS) National Water Information System (NWIS),
- EPA STOrage and RETrieval Data Warehouse (STORET),
- USGS National Uranium Evaluation (NURE), and
- Pennsylvania Department of Environmental Protection (PADEP) Ambient and Fixed Station Network.

Table 2-2 provides an overview of the types of water-quality data that were reviewed. The data were then reduced to those stations within Bradford and Susquehanna Counties and then used to characterize water quality for the retrospective case study area. The selection of the sampling locations and the types of analytes measured were developed to meet specific objectives. Although the data sources listed in Table 2-2 are considered secondary data and by definition were not originally collected for the specific purposes of this report, these databases are commonly used in defining historical background or baseline groundwater, spring, and surface water quality.

Table 2-2. Summary of Water-Quality Data Sources for Bradford and Susquehanna Counties

Data Source	Timeframe	Number of Monitoring Locations	Parameters
USGS National Water Information System (NWIS)[7]	1930 - 2007	249 wells 4 springs 24 surface water	Major Ions, Minor Ions, Nutrients, PAHs, Pesticides, Radionuclides, VOCs, Water Characteristics
EPA STOrage and RETrieval Data Warehouse (STORET)[8]	1982 - 2007	63 surface water	Major Ions, Minor Ions, Nutrients, PAHs, Pesticides, Radionuclides, VOCs, Water Characteristics
USGS National Uranium Resource Evaluation (NURE)[9]	1977	285 wells 90 springs 266 surface water	Major Ions, Minor Ions, Radionuclides, Water Characteristics
USGS report - PADEP – PA Ambient and Fixed Station Network and Others[10]	1979 - 2006	117 wells 2 springs	Major Ions, Minor Ions, Nutrients, Water Characteristics

The frequency of USGS groundwater and surface water analyses and the time period when they were takenvary. There have been a number of academic research studies and citizen monitoring efforts in which data were collected for a short period of time for a specific purpose. These data sources were not

[7] http://waterdata.usgs.gov/nwis/qw
[8] http://www.epa.gov/storet/
[9] http://tin.er.usgs.gov/geochem/doc/nure_analyses.htm
[10] http://pubs.usgs.gov/ds/314/

pursued for the Battelle database due to the general lack of available documentation on QA/quality control (QC) procedures. Field monitoring data for surface water are available from the Susquehanna River Basin Commission (SRBC) Remote Water Quality Monitoring Network from 2010 to present; however, these field monitoring data were not included in the development of background water quality conditions because the data were collected after 2007. Historic SRBC data for surface water is present within EPA STORET.

A reference sheet was used to document the data collected by file name, type of data, data source, date of downloading, hyperlink to the source Web site, storage location on the project network drive, and any relevant comments. The data were subsequently uploaded into a Microsoft® SQL Server database, processed, assessed according to the QA procedures described in Section 2.3 and qualified, as necessary, based on the results of the QA assessment.

2.2.3 Data Management. Groundwater, spring water and surface water sampling analytical data collected before 2007 represent conditions in Bradford and Susquehanna Counties prior to significant development of the Marcellus Shale through hydraulic fracturing and serve to define the background conditions discussed in this report.

Summary tables were prepared for groundwater, spring water and surface water sampling analytical data for a range of parameters. For the purposes of Battelle's evaluation, a minimum of one result from eight discrete locations was selected as the criterion for the minimum number of results needed to characterize water quality for a given parameter. When evaluating the quantity of water quality data, it is noted that EPA's guidance on statistical analysis of Resource Conservation and Recovery Act (RCRA) groundwater monitoring data (EPA, 2009) recommends that a minimum of at least eight to 10 independent background observations be collected before running most statistical analysis methods. Although still a small sample size by statistical standards, these requirements allow for minimally acceptable estimates of variability and evaluation of trend and goodness-of-fit. This approach is not meant to imply that eight sample location results are sufficient to characterize water quality for Bradford and Susquehanna Counties, only to note that this number was selected as the lower bound for the number of results included. Notwithstanding, it should be taken into consideration that larger sample sizes still may not necessarily constitute a representative data set for characterizing background water quality for specific formations or locations. Additional evaluation of spatial and temporal conditions should be performed prior to completing quantitative comparisions with EPA or operator collected water quality data. Water-quality parameters with results at fewer than eight locations were excluded from the summary data tables and associated discussion, but are included in Appendix B.

Two separate sets of summary analytical data tables were produced for groundwater, springs and surface water. One set of data tables includes applicable analytical data from the databases identified in Table 2-2. A second duplicate set of analytical data excludes the STORET data because these data may be indicative of environmental impact monitoring that could potentially skew the data set, and other data with potential usability issues as summarized in Table 2-3.

Within each of the two separate datasets, summary statistics (mean, median, standard deviation) were derived. To ensure that spatial locations receive equal weighting and that locations with multiple results over time are not weighted higher, the average of parameter-specific multiple temporal results was used to represent the specific water-quality parameter at that location. In the event that duplicate sample results exist, the duplicate sample is included as a separate result and included in calculating the average for the sampling location. Two separate sets of summary statistics are calculated in each dataset: one set includes all available data, with non-detect values included in the calculations at half of the detection limit; the second set includes only detected values; non-detect values are excluded.

Groundwater and surface water quality screening criteria were compiled and used for comparison against the available historical water quality characterization data; surface water screening criteria were used for comparison against the spring data. When making these comparisons, only detected values are included when calculating the number of samples above screening criteria; non-detect values were excluded. A summary of the water quality regulations that were utilized to compile selected water-quality screening criteria are summarized in Section 2.4.1.

Table 2-3. Summary of Removed Water Quality Data for Bradford and Susquehanna Counties

Data Source	Initial Number of Monitoring Locations	Reduced Number of Monitoring Locations	Reason for Reduction in Monitoring Locations
NWIS	249 wells 4 springs 24 surface water	248 wells 4 springs 24 surface water	Latitude and/or longitude coordinates were reported with ≤2 decimal places
STORET	63 surface water	0 surface water	Data may be indicative of environmental impact monitoring
NURE	285 wells 90 springs 266 surface water	278 wells 88 springs 262 surface water	Latitude and/or longitude coordinates were reported with ≤2 decimal places
USGS report - PADEP – PA Ambient and Fixed Station Network and Others	117 wells 2 springs	9 wells 0 springs	For groundwater, data may be indicative of environmental impact monitoring. For springs, no coordinate data were reported.

2.3 Quality Assurance Procedures

A systematic approach was used to assess the quality of secondary data in accordance with EPA QA/R-5 which requires that data be reviewed and acceptance criteria and limitation of use be defined (US EPA, 2001). To this end, prior to initiating the site characterization study, Battelle developed overall DQOs to establish the study objective, problem being investigated, study goals, data input, boundaries, analytical approach, a plan for obtaining data, and data acceptance criteria. The DQOs established the following criteria:

- Data were collected by an agency and organization known to have a rigorous quality system.
- Data were collected under an approved QAPP/Field Sampling Plan (FSP).
- Data were produced by laboratories known to implement a rigorous quality system.
- Analytical methods were identified and appropriate.
- For non-detect values, the detection limits were defined and sensitive enough for each parameter.

- If QC data were available, accuracy was demonstrated to be ≥80% and precision was demonstrated to be ±30%. Accuracy is determined using the results of spiked sample analysis where percent recovery can be quantified. Precision is determined using field or laboratory duplicate samples by calculating the relative percent difference (RPD).

Due to the nature of the source Web sites and the lack of available QC data and metadata, many of these criteria could not be directly assessed. An exhaustive review of comment fields was conducted to determine if the comments provided additional information such as sample preservation or processing procedures, holding times or titration endpoints, or other data quality issues. In some cases, Battelle was able to assign the following data qualifiers based on the comments:

- U qualifier was assigned if the comment indicated that the value was less than a specific value inserted as the detection limit (e.g., "<0.05 µg/L").
- J qualifier was assigned if the value was deemed an estimate. Data were classified as estimates if they were less than the reporting limit, if samples did not meet holding time or holding condition requirements, or a QC failure was noted. This is consistent with national validation guidelines.
- S qualifier (suspect) was assigned if the data entry comment indicated that it was suspect; if the parameter was marked as a highly variable compound, if the method high range was exceeded, or if processing errors were noted.

However, the lack of metadata that would enable an assessment of data quality (e.g., analytical laboratories, QC data, and assignment of data qualifiers) left the majority of data without clear "proof" of quality using the DQO criteria. Although the DQOs specified that such data be flagged as estimated values to be used with caution, the study team determined that too much data would be lost using this approach. Therefore, data were evaluated using the approach described in Appendix A.

Based on the data quality assessment, the groundwater, surface water, and spring water data should be used with care for the following reasons: the analytical laboratories, analytical methods, and laboratory quality control data or quality-related qualifiers are unknown or not reported consistently. Quality system elements that support the data include collection organizations with known quality systems and acceptable laboratory detection limits with the following exceptions: arsenic in groundwater and selenium in surface water and spring water; both have screening criteria (described in Section 2.4) that are below laboratory detection limits.

2.4 Applicable Statutory and Regulatory Framework

A brief discussion of federal and state statutes and regulations is relevant because of their role in setting water quality standards and criteria. A chronology of relevant laws and regulations related to groundwater quality, surface water quality, and environmental restoration is provided in Figure 2-2. The statutes and regulations in place in Pennsylvania to regulate oil and gas activities are also discussed. Pennsylvania has no statutes or regulations that apply to the drilling, completion, or operation of private water supply wells.

2.4.1 Relevant Water Quality Statutes, Regulations and Guidance. For comparison purposes, historical data are compared to water quality criteria from various sources. Although these values may not be directly relevant or applicable, they are used in this document as screening values. Results above screening criteria do not indicate that corrective action (e.g., remediation) is required, but may suggest

PENNSYLVANIA OIL AND GAS STATUTES AND REGULATIONS

- **1984**
  - Pennsylvania Coal and Gas Resource Conservation Act
  - Pennsylvania Oil and Gas Act
- **1987 to 2011**
  - Pennsylvania Code 25 § 78 Oil and Gas Wells*
- **2010**
  - Pennsylvania Code 25 § 95.2 and 95.10 (surface water discharge)
- **2012**
  - Act 13 Pennsylvania Statute 58 §§ 23, 25, 27

Note: *PA Chapter 78 regulations were first adopted July 31, 1987; there have been several amendments to these regulations, the most recent being February 5, 2011. Chapter 95 was originally adopted on September 2, 1971; Sections 95.2 and 95.10 were amended effective August 21, 2010.

ENVIRONMENTAL STATUTES AND REGULATIONS

- **1937**
  - Pennsylvania Clean Streams Law
- **1948**
  - United States Water Pollution Control Act
- **1972**
  - Federal Water Pollution Control Act of 1972 (Clean Water Act)
- **1974**
  - United States Safe Drinking Water Act
- **1980**
  - Comprehensive Environmental Response, Compensation and Liability Act
- **1984**
  - Pennsylvania Safe Drinking Water Act
- **1995**
  - Act 2: Land Recycling Program (Voluntary Remediation Program)
- **2007**
  - Pennsylvania Code 25 § 93.7 (Updated Water Quality Requirements)

Figure 2-2. Timeline of Statutes and Regulations Related to Oil and Gas Activities

that water quality is different from what would be expected, possibly due to anthropogenic or natural conditions. A detection above water quality criteria should not be interpreted as indicative of an impact. In order to assess if an impact has occurred, or if corrective action is suggested, a thorough investigation would have to be performed; this is beyond the scope of this study. Relevant water quality statutes, regulations and guidance used to select screening criteria are listed and summarized below.

Pennsylvania Clean Streams Law. Enacted in 1937, the Clean Streams Law regulates the discharge of sewage, industrial waste or any substance which causes or contributes to pollution, into the waters of the Commonwealth of Pennsylvania. It also regulates the impact of mining operations upon water quality, supply and quantity. The law was last amended in 1987 to align with requirements of the U.S. Clean Water Act (CWA). The Clean Streams Law is one of the oldest pieces of legislation in Pennsylvania with provisions regulating discharges from oil and gas well drilling activities. The law requires operators to have a plan to prevent accelerated erosion due to drilling activities.

U.S. Clean Water Act. The CWA is the common name for the Federal Water Pollution Control Act of 1972 [33 U.S.C. §1251 et seq. (1972)]. It established the basic structure for regulating the discharge of pollutants into U.S. waters and setting water quality standards for surface water. It expanded upon the original 1948 law called the United States Water Pollution Control Act. Under the authorities granted by the CWA, the EPA has implemented the National Pollutant Discharge Elimination System (NPDES) permit program. It also established the concept of total maximum daily load (TMDL), which is a calculation of the maximum amount of a pollutant that a water body can receive and still meet designated water quality standards. TMDLs are specific to each impaired water body and regulate the maximum amount of contaminant loading from both point and non-point sources.

U.S. Safe Drinking Water Act. The Safe Drinking Water Act (SDWA) was enacted in 1974 and amended in 1986 and 1996. Under SDWA, EPA established maximum contaminant levels (MCLs) and secondary maximum contaminant levels (SMCLs). MCLs are established to protect public health from contaminants in drinking water by balancing potential health risks and the cost of treatment. An MCL represents the maximum allowable amount of a contaminant that can be delivered to a consumer by a public water system (PWS). An SMCL is a non-enforceable water quality standard for constituents that may cause taste, odor or color concerns in drinking water. These non-mandatory SMCLs are established as guidelines for PWSs to address aesthetic and taste issues and do not represent a health risk.

EPA Region 3 Mid-Atlantic Regional Screening Levels for Chemical Contaminants at Superfund Sites. Under the authority of the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) of 1980, screening levels were established for carcinogenic and non-carcinogenic human health effects in tap water. Although these levels are only guidance values, they are useful benchmarks for compounds that do not have established MCLs or SMCLs.

Other Relevant State Environmental Regulations. Several other environmental laws have been enacted by the state of Pennsylvania which include provisions that set water quality standards and/or screening levels. The Pennsylvania SDWA was passed in 1984 to establish provisions for safe drinking water including drinking water quality standards. Pennsylvania has established surface water quality standards through Title 25 Environmental Protection, Chapter 93, Water Quality Standards (25 Pa.C. § 93.7). Title 25 Pa.C. §§ 93.7-93.8 established state surface water quality standards for the protection of drinking water, wildlife and industrial water. The Land Recycling Program (Voluntary Remediation Program), commonly known as Act 2, is a Pennsylvania program designed to encourage the voluntary remediation of contaminated areas. The Act was passed in 1995 and established uniform cleanup standards, reviews and timetables, as well as financial assistance and the chance for liability relief for property owners who voluntarily remediate. Although Act 2 has not historically been applied to the oil and gas industry, the Act 2 water quality standards are included as reference benchmarks in Battelle's review of background water quality.

2.4.2 Oil and Gas Related Statues, Regulations and Guidance. State laws regulating the oil and gas industry in Pennsylvania have been in place since 1961; those with provisions having to do with environmental protection of water resources are briefly summarized here. Several amendments to the framework of applicable laws and regulations have been passed since the start of unconventional oil and gas development in the Marcellus Shale and further regulations are expected in 2013.

In 2010, PADEP requested to have its oil and gas regulatory program reviewed by the non-profit, multi-stakeholder organization called State Review of Oil and Natural Gas Environmental Regulations (STRONGER). This was the latest of four STRONGER reviews of the PADEP's program and the first to focus on hydraulic fracturing. Overall, the report concluded that the framework in place in Pennsylvania was well-managed, professional and meeting its stated objectives (STRONGER, 2010).

Coal and Gas Resource Coordination Act. Passed in 1984, this act controls potential interference between coal mining and oil and gas activities. The act states that there must be a minimum of 1,000 ft separating gas wells that penetrate a workable coal seam; it also provides recourse for owners of active coal mines to object to proposed gas wells that would penetrate their seam.

Pennsylvania Oil and Gas Act. This act was first passed in 1984 and amended most recently in 2012 (Pennsylvania Statute 58 §§ 601.101-601.607). The chapters of the Oil and Gas Act include Chapter 1 (definitions of commonly used terms in the Act); Chapter 2 (provides general requirements of well permitting and reporting, notification of drilling activities, well location, well site restoration, well casing, well plugging and the use of safety devices); Chapter 3 (confining the activities of underground gas storage); Chapter 4 (defining the conditions of eminent domain); Chapter 5 (elucidating enforcements and remedies); and Chapter 6 (miscellaneous provisions in the Act). A summary of key sections of Chapter 2 and recent amendments are summarized below.

- Chapter 2, Section 205 (Pennsylvania Statute 58 §§ 601.205) of the law provides restrictions on the location of oil and gas wells. The construction of an unconventional well, which includes wells drilled to the Marcellus Shale and other gas shales, within 500 ft of a building or water supply is prohibited without permission from the owner; this was increased from 200 feet for conventional wells by Act 13 (see below). As established by Act 13, unconventional wells may not be constructed within 1,000 feet of a public water supply well, surface water intake, reservoir, or other water intake point without written consent from the water purveyor. An unconventional oil or gas well may not be drilled within 300 ft of a surface water body or wetland greater than 1 acre in size. Impacts to public parks, national or state scenic rivers, national natural landmarks, habitats of rare or endangered species and historical or archaeological sites are also considered by the provisions of this section.
- Chapter 2, Section 206 (Pennsylvania Statute 58 §§ 601.206) provides requirements for site restoration after drilling is completed. The section requires the oil or gas well owner or operator to: (1) restore the land surface within the drilling area, including recontouring to the approximate original condition and restoring the land to support pre-drilling activities (as amended by Act 13); (2) remove all drill pits, drilling supplies and equipment not needed for well operations within 9 months of drilling completion; (3) remove all production and storage facilities and equipment within 9 months of plugging the well; and (4) follow all requirements of the Clean Streams Act of 1937.

- Chapter 2, Sections 207 and 208 (Pennsylvania Statute 58 §§ 601.207-601.208) relates to the protection of water resources. Section 207 establishes requirements for protective casings on wells. Casings meeting regulatory standards provided by the Bureau of Oil and Gas Management (BOGM) must be installed in the vertical distance that a gas well penetrates a freshwater-bearing strata or mined coal seam. This casing must prevent the migration of all gases or fluids into the strata or seam. In locations where a coal seam has not been mined, a casing that prevents the migration of gases or fluids into the seam (except those found to be naturally occurring before drilling activities began) must be installed. Section 208 provides for landowner recourse and compensation in the event of an alleged contamination incident, as well as the process for operator rebuttal to an accusation. If the owner of a water supply located within 2,500 ft of an unconventional well (amended from 1,000 ft for conventional wells by Act 13) makes a contamination complaint within 12 months of completion of the oil or gas well (updated from 6 months for conventional wells by Act 13), the well operator is presumed to be responsible, unless:
  - The pollution existed before drilling as determined by operator commissioned pre-drilling water surveys carried out by an unbiased, accredited laboratory;
  - The landowner or purveyor complaining did not allow operator access for a pre-drilling survey;
  - The complaint does not satisfy the location or temporal requirements above; or the pollution occurred as the result of some other cause.
- Recent provisions of the 2012 amendment to the Oil and Gas Act (Pennsylvania Statute 58 §§ 23, 25, 27) commonly known as Act 13 include:
  - Allowing for the assessment of unconventional oil and gas impact fees.
  - Strengthening the PADEP's authority to deny permit applications to operators in continuing violation
  - Instituting separate standards for unconventional oil and gas development
  - Increasing the setback distance of a vertical wellbore to 300 ft from any surface water body ("solid blue line" stream, spring, wetland, or other body of water) with the potential for additional protective measures on wellbores located closer than 750 ft to a water body
  - Increasing or establishing setback distances to 500 ft for unconventional wells from existing buildings and water supplies (without owner consent)
  - Increasing or establishing setback distances to 1,000 ft for oil and gas wells from existing public water wells, surface water intakes, reservoirs, or other water intake points
  - Establishing requirements for the construction and maintenance of containment pits and requiring the submission of a waste containment plan
  - Requiring unconventional well sites be constructed to prevent spills either onto the ground or off the well site
  - Codifying as law chemical disclosure obligations
  - Requiring notices of well permit applications to be disclosed to nearby municipalities
  - Extending notification of drilling activities to property owners up to 3,000 ft from the vertical well bore

  - Prohibiting drilling in floodplains if the site will have a pit or impoundment
  - Increasing the distance and duration to which the rebuttable presumption of damage to a water supply to 2,500 ft and 12 months of drilling completion
  - Establishing the State Natural Gas Energy Development Program.
- In 2008, PADEP issued a policy requiring an approved Water Management Plan as a condition of drilling permits for shale gas wells. This requirement has been codified in PA Act 13 of 2012. For the Ohio River Basin, PADEP's review of water management plans follows established practices utilized by the SRBC. Water withdrawals from streams are generally approved if they meet either of the following criteria:
  1) withdrawal rate does not exceed 10% of the 10-day, 7-year expected low flow rate, or
  2) withdrawal is regulated to ensure a pass-by flow of not less than 20% of the stream's average daily flow.

Title 25 Environmental Protection, Chapter 78, Oil and Gas Wells (41 Pa.B. 805).

- In 2011, this amendment updated the provisions of the Oil and Gas Act; Pennsylvania Code 25 §§ 78.81-78.89 and § 78.122 were amended as follows:
  - Casing requirements
    - Requires operators to condition a wellbore to enhance bond between cement, casing and formation
    - Requires the use of centralizers to ensure proper placement of casings
    - Requires better quality cement
    - Necessitates an on-site casing and cementing plan
  - Specifies the actions operators will take if gas migration is detected
  - Clarifies how and when blowout prevention equipment is to be installed and operated
  - Requires pressure barriers plan to minimize well control events
  - Requires disclosure of hydraulic fracturing fluids to the PADEP
  - Requires operators to keep a list of emergency numbers at the well site.
- Pennsylvania Code 25 §78.53 requires operators to design, implement and maintain best management practices related to erosion and sediment control. There are also rules requiring a Preparedness, Prevention and Contingency (PPC) Plan (Pennsylvania Code 25 § 78.55) for oil and gas operations and for regulating the application of residual waste of the drilling, production and plugging of an oil or gas well (Pennsylvania Code 25 § 78.63). Pennsylvania 25 §78.89 requires operator or owner to conduct an investigation of potential natural gas migration incidents. The purpose of the investigation is to determine the nature of the incident, assess the potential for hazards to public health and safety and mitigate any hazard posed by the concentrations of stray natural gas.

Title 25 Environmental Protection, Chapter 95, Wastewater Treatment Requirements (40 Pa.B. 4835). In 2010, this amendment updated surface water discharge requirements defined in Pennsylvania Code 25 § 95.2 and 95.10. These provisions apply to new and/or expanded discharges, not those previously permitted. Effluents must comply with the following standards:

- pH: no less than 6 and no more than 9

- Oil: no effluent may have a sheen, no more than 15 mg/L oil as a daily average and no more than 30 mg/L at one time
- Iron: no more than 7 mg/L dissolved iron
- Total dissolved solids (TDS): no more than 500 mg/L (monthly average)
- Chlorides: no more than 250 mg/L (monthly average)
- Barium: no more than 10 mg/L (monthly average)
- Strontium: no more than 10 mg/L (monthly average).

3.0: DATA ANALYSIS

The quality of groundwater, spring water, and surface water is affected by a range of factors including land use patterns, watershed characteristics, hydrology, geology, geohydrology, and water resource management practices. The role of land use is discussed below, along with a review of groundwater, spring water, and surface water quality data in Bradford and Susquehanna Counties.

3.1 Land Use

The total population of Bradford County is approximately 62,622 within 1,147 square miles, which yields a population density of approximately 55 persons per square mile. This represents a 0.2% decrease from the population of 62,761 in 2000. The total population of Susquehanna County is approximately 43,356 within 823 square miles, which yields a population density of approximately 53 persons per square mile. This represents a 2.6% increase from the population of 42,238 in 2000 (U.S. Census Bureau, 2010). Figure 3-1 shows the land cover for Bradford and Susquehanna Counties as of 2006.

Table 3-1 summarizes land use statistics for both counties in 1986 and 2006, reclassified into the corresponding USGS land use categories (USGS, 1986; USGS, 2006). This region has more forest cover than other regions in Pennsylvania, ranging up to 59% and 64% of the land cover in 2006 for Bradford and Susquehanna Counties, respectively. In 1986, farmland (e.g., cropland, pasture, and orchards) was a major land use at 40% and 51% for Bradford and Susquehanna Counties, respectively. However, over time, some agricultural land has reverted to rangeland, forest and transitional land (Table 3-1). The total land use dedicated to higher intensity development comprising residential, urban, industrial, commercial and services, and transportation areas, was less than 2% on a county-wide basis for both Bradford and Susquehanna Counties.

Table 3-1. Summary of Land Use Statistics for Bradford and Susquehanna Counties

Category	Bradford County (1986)	Bradford County (2006)	Susquehanna County (1986)	Susquehanna County (2006)
Agriculture (Crop, Pasture, Orchard)	50.72%	15.76%	39.45%	28.40%
Surface Extraction (Strip Mine, Gravel Pit, Quarry)	0.03%	0.15%	0.03%	0.14%
Industrial, Commercial, and Services	0.16%	0.32%	0.13%	0.14%
Forest Land	47.12%	58.51%	58.44%	64.11%
Rangeland	0.13%	3.62%	0.19%	1.20%
Wetlands	0.08%	1.76%	0.01%	0.69%
Urban	0.04%	0.06%	0.07%	0.03%
Residential	0.71%	1.25%	0.60%	0.39%
Transitional	0.10%	18.02%	N/A	3.70%
Transportation and Communication	0.03%	N/A	0.52%	N/A
Water Bodies	0.88%	0.55%	0.56%	1.20%

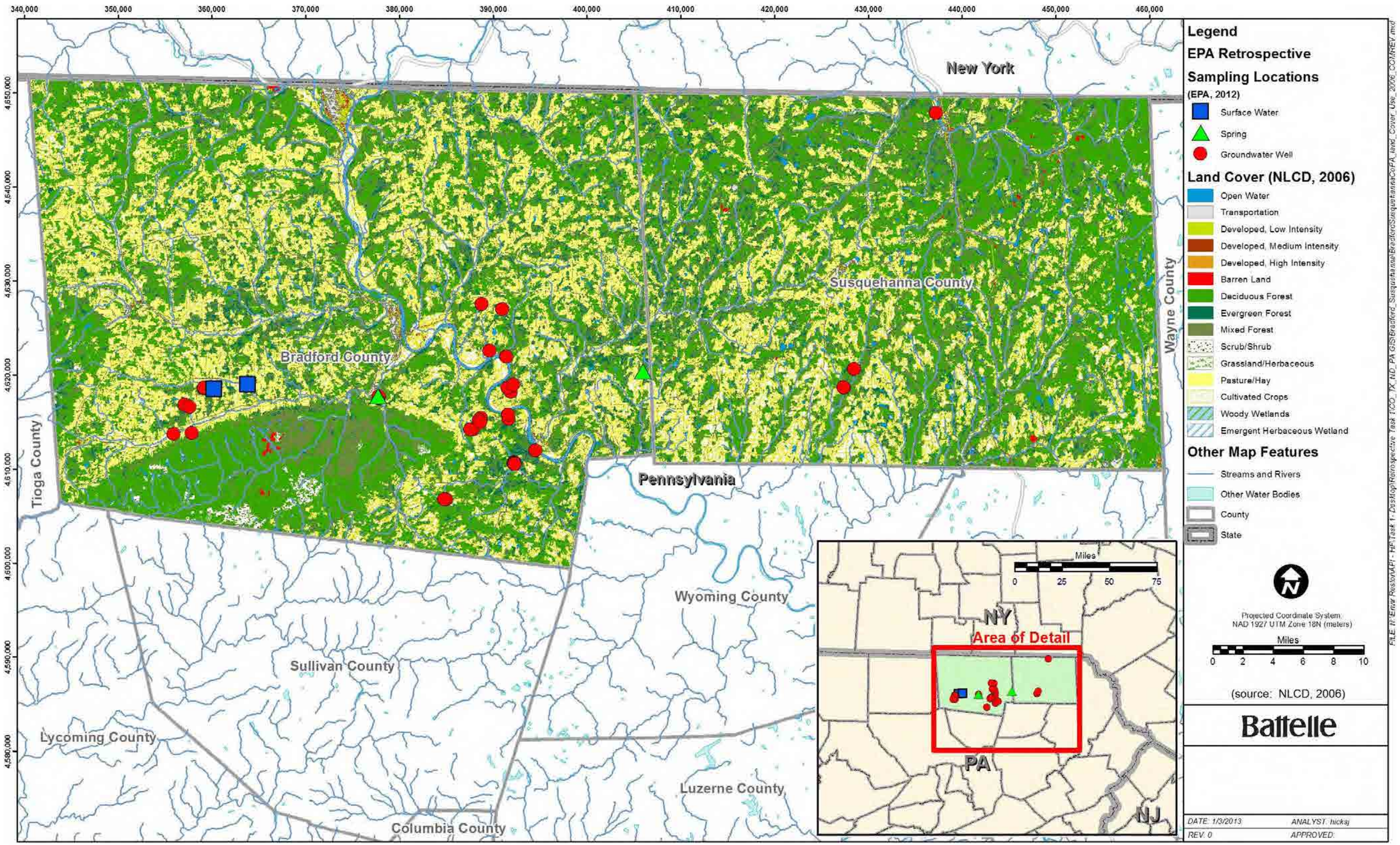

Figure 3-1. Land Cover Map for Bradford and Susquehanna Counties (USGS, 2006)

Historically, agriculture and the timber industry have been important economic drivers in the region, along with resource extraction of minerals such as sand, gravel, and flagstone (Bradford County, 2004; Susquehanna County, 2003). The primary causes of water quality impairment in the region are: agriculture, road runoff (especially from dirt and gravel roads) and other non-point sources, human waste handling, industrial discharges, and resource extraction including coal and other mineral mining activities. These land use activities have influenced water quality as discussed below.

3.1.1 Agriculture. Agriculture, one of the leading industries by revenue in Bradford and Susquehanna Counties, had moved from a largely subsistence to commercial activity by the late nineteenth century (PADEP, 2005a; Susquehanna County, 2003). Over 90% of this revenue comes from livestock sales with the remainder from crop sales (Bradford County, 2004). Over time the total number of farms has decreased with some reverting to rangeland, forest and transitional land, although the average acreage per individual farm has increased (Bradford County, 2004).

Dairy farming is the major agricultural pursuit in the area; livestock production includes primarily cattle, poultry and hogs. The growth in the animal production industry has led to an increase in animal manure handling and associated environmental issues (BCCD, 2005; Susquehanna County, 2003). Manure may serve as a source of nutrients and pathogens to surface water and groundwater. In addition, unrestricted access of livestock to nearby streams can result in trampled stream banks, loss of streamside vegetation, stream bank erosion, and subsequent sedimentation of the stream. For example, soil erosion is a major issue in the Johnson Creek Watershed in Bradford County which has experienced siltation impacts from suboptimal buffer zones and unlimited livestock access to steam banks (PADEP, 2011).

Over 215,605 acres of Bradford County and 110,520 acres of Susquehanna County were dedicated to cropland in 2011 (U.S. Department of Agriculture [USDA], 2011). Crop production in Bradford County is predominately hay, corn, alfalfa and soybean production (USDA, 2011). In Susquehanna County crop production in is predominately hay, corn and alfalfa (USDA, 2011). Land dedicated to crop production may have herbicides, insecticides, fungicides and fertilizers applied on a regular basis. Large areas of row crops, along with the use of conventional tillage, can also leave the top soil vulnerable to erosion into nearby streams (PADEP, 2011). Agricultural nutrient management (e.g., fertilizer and manure applications) and conventional tillage practices are known to have caused water quality impairments in both counties (BCCD, 2005; PADEP, 2005b).

As part of the *2012 Pennsylvania Integrated Water Quality Monitoring and Assessment Report*, PADEP indicated that the largest issue for water quality impacts within the state is agriculture with stressors such as nutrients, suspended solids, organic enrichment and low dissolved oxygen (PADEP, 2012a). Agricultural nutrient management, agricultural tillage, and stream channel and bank stability are known factors contributing to water quality issues within Bradford County (Lovegreen, 2007; BCCD, 2005). Agricultural runoff may include insecticides, herbicides, fungicides, fertilizers (e.g., nitrogen and phosphorous), metals (e.g., arsenic) and other constituents (e.g., dissolved solids, bromide, selenium). Algal blooms caused by agricultural runoff of nitrogen and phosphorous can be a source of organic carbon that promotes the formation of disinfection byproducts (DBPs) upon chlorination of surface water in water treatment plants (EPA, 2005). Agricultural and livestock activities can be a source of methane (King, 2012) and the cause of increased erosion of stream banks and siltation of streams (PADEP, 2011).

3.1.2 Other Non-Point Sources and Stormwater Runoff. Runoff from impervious surfaces and other non-point source discharges can affect the quantity and quality of groundwater recharge and surface water. In the Upper-Susquehanna-Tunkhannock subbasin that crosses both Bradford and Susquehanna Counties, the known causes of stream impairments include road runoff (hydrocarbons and road salts), urban runoff/storm sewers, and erosion from barren land (EPA, 2012c). Habitat modification can cause stream bank instability and significant soil erosion and sediment pollution in nearby streams.

In addition, runoff from dirt and gravel roads is known to directly impact surface waters by contributing sediments and other road-related substances via drainage systems, eroding road banks, and blockages of stream channels and floodplains (BCCD, 2005). Over 1,300 miles of dirt and gravel roads exist in Bradford County with 1,500 sections of these roads in need of repair to reduce their impact on water quality (BCCD, 2005). There are over 1,027 miles of dirt and gravel roads in Susquehanna County so similar issues exist there with over 2,700 sections in need of repair (Susquehanna County Conservation District, 2011). Urban and stormwater runoff may contain suspended solids, nutrients (e.g., phosphorous), heavy metals (e.g., arsenic, cadmium, mercury), organic contaminants (lawn pesticides, chlorinated solvents), salts, and pathogens. Run off from dirt and gravel roads may increase siltation of nearby surface waters.

Road runoff from road salt application to paved roads contains chloride and trace amounts of bromide (Solars et al., 1982). Bradford County hosts seven Pennsylvania Department of Transportation (PENNDOT) salt stockpiles and there are numerous others in local townships and municipalities. In Bradford County, PENNDOT salt usage was 13,435 tons and brine usage was 90,878 gallons in the Winter of 2010 to 2011 (PENNDOT, 2012). Susquehanna County hosts nine Pennsylvania Department of Transportation (PENNDOT) salt stockpiles with numerous others in local townships and municipalities. In Susquehanna County, PENNDOT salt usage was 19,633 tons and brine usage was 121,232 gallons in the winter of 2010 to 2011 (PENNDOT, 2012). Runoff from impervious roadways can also be a source of heavy metals (e.g., iron, lead, zinc) and volatile organic compounds (VOCs) (e.g., benzene, toluene, ethylbenzene and xylene [BTEX]) related to automobile use (EPA, 1995). These inputs occur with rainfall and the concentrations have been found to be dependent on the length of the preceding dry period (Hewitt and Rashed, 1992).

3.1.3 Municipal and Other Wastewater Discharges. Human waste disposal methods include centralized wastewater treatment plants (WWTPs), decentralized small systems and on-site sewage disposal. In rural areas and older homes, on-site sewage treatment and disposal may include septic systems, cesspools, or “wildcat” sewers which are straight pipes that discharge directly to surface water or groundwater. In Bradford County, public water and sewer facilities are provided in the more populated and developed areas, especially along the Susquehanna River, and maintained by local municipalities at the township and borough levels (Figure 3-2). Approximately 35% of the municipalities in Bradford County are serviced by public water and municipal sewer services (PADEP, 2005a). Public water and municipal sewer service coverage was not readily available for Susquehanna County. The majority of residents in the rural townships have on-lot septic systems which are the primary means of sewage treatment in the area (BCCD, 2005). Septic systems and on-site disposal can directly impact downgradient water quality in nearby drinking water wells. Bradford County has recognized the need to develop private well standards related to the placement of on-lot septic systems.

The impact of malfunctioning, inadequately constructed and poorly cited on-lot septic systems is a known problem causing drinking water well and stream water quality impacts in both Bradford and Susquehanna Counties (BCCD, 2005; PADEP, 2005a; and PADEP, 2005b). In eastern glacial deposits, Katz et al. (2011) have shown elevated levels of potassium, boron, chloride, dissolved organic carbon and sulfate concentrations in monitoring and domestic wells in proximity to septic tanks. The extent of the impact was associated with the number of houses using septic tanks, the high permeability of soils, oxic conditions and shallow well depths. In the absence of adequate treatment, all of the wastewater disposal methods listed above may discharge pathogens, household and industrial chemicals, suspended solids, increased biochemical oxygen demand (BOD), water softening chemicals and nutrients into receiving waters. It is estimated that 25% of household and industrial chemicals may pass through in the discharge to receiving waters even after treatment at a WWTP (EPA, 1997).

3.1.4 Industrial, Manufacturing, and Commercial Activities. Early industries in the study area relied upon natural resources such as timber and stone (Susquehanna County, 2003). The wood manufacturing industry still remains a significant employer in the area, along with the meat packing industry and other manufacturing activities (Bradford County, 2004). There are over 549 facilities or locations in Bradford County and more than 558 in Susquehanna County with recognized environmental conditions and/or sites that are subject to applicable federal and state environmental regulations (Figure 3-3). This includes environmental restoration sites such as 88 storage tank incident sites (both aboveground and underground), 77 land recycling cleanup locations, and two Brownfield/CERCLA sites in Bradford County. There are 94 storage tank incident sites, 235 land recycling cleanup locations and one CERCLA site in Susquehanna County.

Figure 3-3 includes facilities that handle wastes subject to Resource Conservation and Recovery Act (RCRA) and the Toxic Releases Inventory (TRI) regulations. The locations of NPDES permits are shown where there are allowable discharges of industrial effluent and stormwater discharges. Although these are permitted discharges, violations of these permits can occur along with accidental releases above regulatory levels. In Bradford County, NPDES permits include 18 WWTPs; multi-family dwellings, nursing homes, mobile home parks, and schools; lumber and wood product facilities; meat packing plants; agricultural production operations (e.g., hogs and dairy farms); oil and gas facilities; and metal working facilities. In Susquehanna County, NPDES permits include16 WWTPs; cut stone and stone product facilities; schools; woodworking facilities; and oil and gas related facilities.

In 2010, 1,430 tons of chemicals regulated under the TRI Program were discharged into the environment in Bradford County through on- and off-site disposal or other releases. This includes metals such as antimony, barium, chromium, cobalt, copper, lead, manganese, molybdenum, nickel, and zinc from metal processing and chemical plants, and ammonia and nitrate compounds from meat packing facilities. A variety of organic chemicals are also discharged from equipment and woodworking manufacturing facilities such as 1,2,4-trimethylbenzene, acetaldehyde, glycol ethers, dioxins, ethylbenzene, formaldehyde, methanol, n-methyl-2-pyrrolidone, phenol, polycyclic aromatic hydrocarbons (PAHs), styrene, toluene, and xylene (EPA, 2012d). There were no discharges large enough to be noted under the TRI Program within Susquehanna County. Leaking underground storage tanks (USTs) and above ground storage tanks (ASTs) may be associated with contamination of soil and groundwater with petroleum hydrocarbons, BTEX and oxygenates. Petroleum hydrocarbons released from storage tanks can degrade to methane, but methane is not routinely included in groundwater investigations at USTs and ASTs. Therefore, methane is typically lacking in the historical data at these sites.

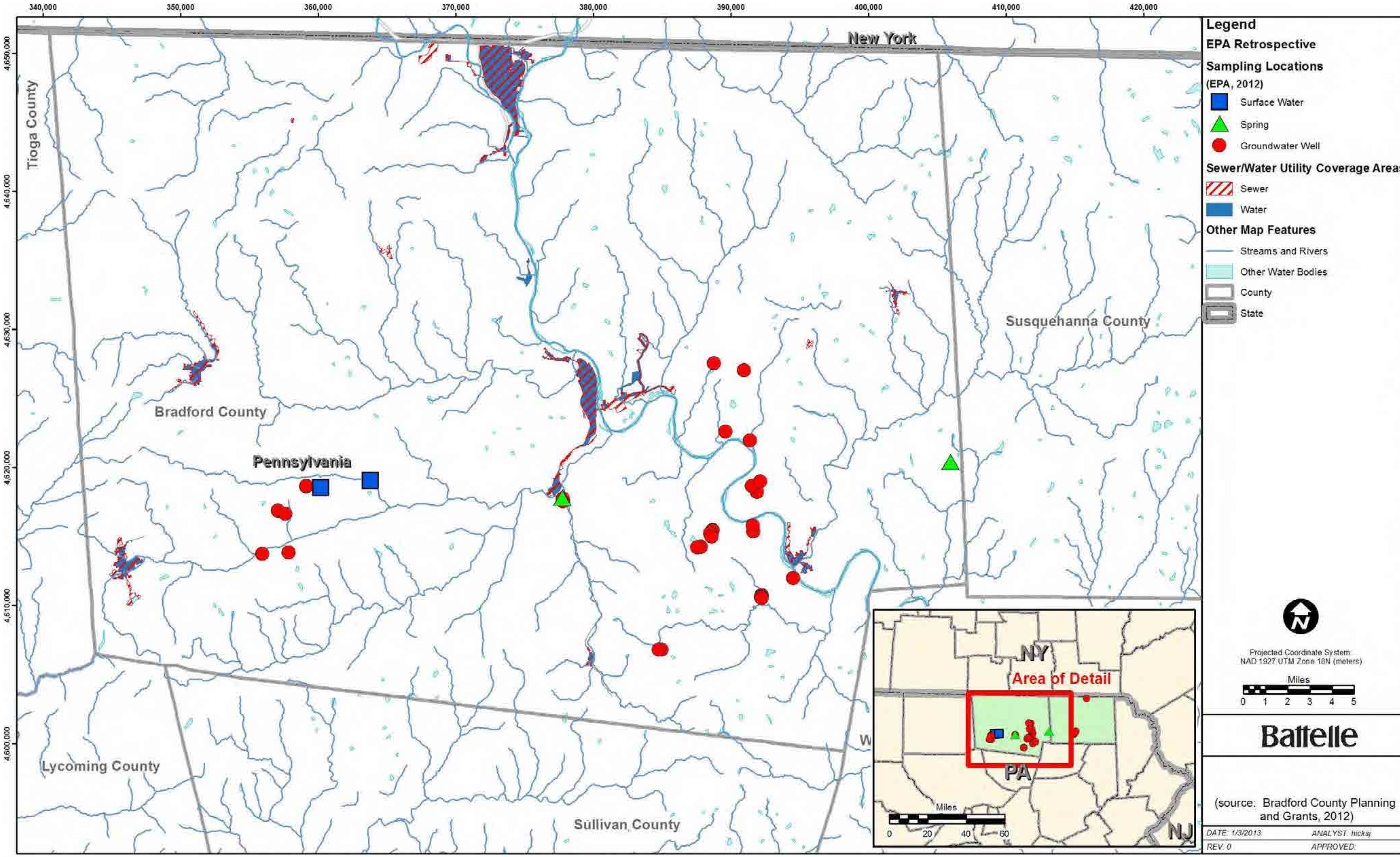

Figure 3-2. Public Water and Sewer Infrastructure Coverage in Bradford County

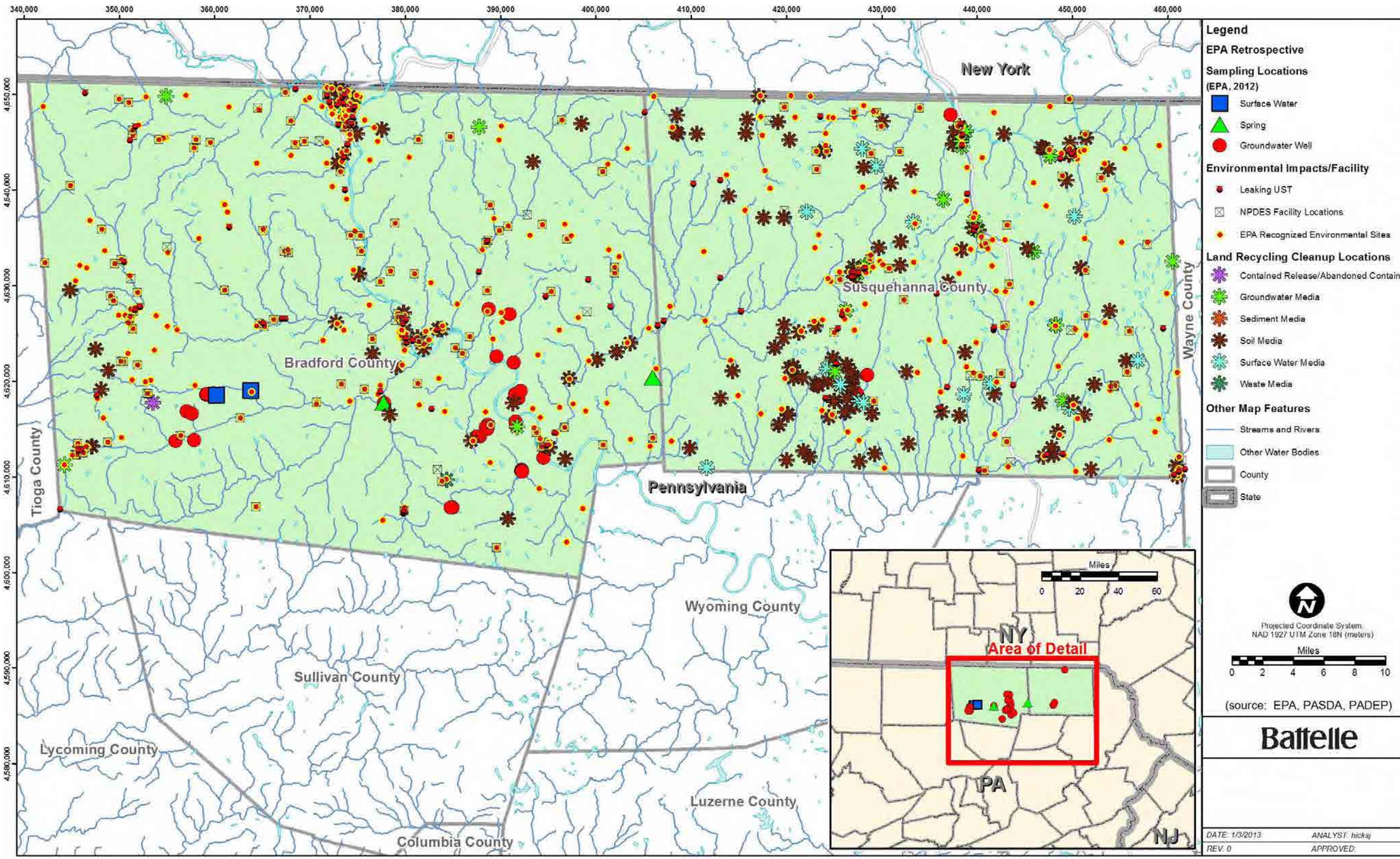

Figure 3-3. Sites with Recognized Environmental Impacts and/or Subject to Environmental Regulations in Bradford and Susquehanna Counties

3.1.5 Resource Extraction. Resource extraction activities that have occurred in Bradford and Susquehanna Counties include aggregate and stone mining; coal mining; and conventional and unconventional oil and gas activities.

In addition to surface sand and gravel mining in Pennsylvania, the state is one of the top ten in the country for producing crushed stone aggregate from limestone/dolomite, sandstone and argillite (PADEP, 2012b). Historically, the largest resource extraction activity in Bradford and Susquehanna Counties has been sand, gravel, and crushed stone quarries. Eastern Bradford County and all of Susquehanna County have been the site of a significant amount of quarrying (Figure 3-4). According to Young (2002), quarrying began in Susquehanna County as early as the 1820s, but became more widespread in the 1870s and 1880s. Sand and gravel quarries occur in areas with thick deposits of glaciated materials. These deposits cover most of Bradford and Susquehanna Counties and are especially thick in valleys (Williams et al., 1998). One of the most commonly mined stones in the area is the Pennsylvania Bluestone, a sandstone named for its bluish hue that can be cut and shaped in varying sizes. Bradford and Susquehanna Counties are the locations of some of the largest concentrations of this stone (PADEP, 2008). Natural aggregate mining is one of the most significant resource conservation issues in Bradford County as a result of small quarries that are “pervasive” throughout the area (BCCD, 2009).

Although natural aggregate and stone mining has significantly less environmental impacts than metal ore mining, the most noticeable impact is the presence of the large open pit that results from quarry development (Drew et al., 2002). The pit itself could have a direct hydraulic connection to the regional aquifer as groundwater levels are drawn down to facilitate quarry operations. This drawdown can result in substantial quantities of groundwater being discharged as surface water reducing the overall availability of groundwater and impacting both groundwater and surface water quality. Sand and gravel deposits are often located near alluvial floodplains formed by streams which can constitute critical recharge areas for groundwater aquifers. Because these deposits have relatively high permeabilities and therefore rapid infiltration rates, activities within and above the granular aggregate can negatively impact groundwater quantity and quality (Minnesota Department of Natural Resources, 2005). Water quality parameters that may be influenced by these type of activities could include total suspended solids (TSS), turbidity, temperature changes, pH, and oil and grease from runoff and washing operations in the vicinity of mechanical equipment and vehicles.

The presence of mineable coal in Bradford and Susquehanna Counties is confined to relatively limited areas (Figure 3-4). Bradford County is underlain by a small, discontinuous tract of bituminous coal that is part of the Pennsylvania North-Central Coal Fields in the southwestern and south-central portions of the county. Abandoned mine drainage (AMD) has impacted the Long Valley Run Watershed near Weston in south-central Bradford County. Water quality impacts include low pH and metals. Underground mining began in the 1820s in this area and, due to the shallow depths of the mines, subsequent subsidence has altered features of the landscape (PADEP, 2004). Susquehanna County lays claim to a portion of the Pennsylvania Northern Anthracite Field in the southeastern corner of the county. Underground mining of the Northern Anthracite Coal Field took place primarily from the 1820s to 1960s. The last underground mine closed in 1966 as most of the underground mines in the area were inadvertently flooded after the 1959 Knox Mine Disaster. Since the 1960s, only minor strip mining and coal reprocessing operations have occurred in the area. High levels of metals (iron, manganese and aluminum), low pH and siltation from AMD have impacted portions of the Lackawanna River Watershed which crosses the southeastern corner of Susquehanna County (PADEP, 2005c).

Conventional oil and natural gas drilling has occurred in a limited way for over a century in Bradford and Susquehanna Counties (Young, 2002). According to McCoy and Schmitt (2007), the only economical conventional sources of gas were small, deep gas fields in northern Bradford County, in contrast to the large shallow and deep oil and gas fields in Western Pennsylvania. Young (2002) describes a number of historic ventures in Susquehanna County from the 1860s to early 1900s that had little to no success in yielding economic quantities of oil or gas. Although economic quantities were not yielded from conventional gas wells in the area, the natural presence of methane gas in natural seeps and water wells has been documented in this region for many decades (Molofsky et al., 2011). Figure 3-5 depicts the locations of historic oil and gas fields in the two counties, and indicates the limited extent of conventional oil and gas drilling in the region. Because of the lack of complete historical records, well numbers and locations have some inherent uncertainty and many historic wells are undocumented. Permitting and registration were not required by the state of Pennsylvania until the 1960s. Little is known about the construction, production and abandonment procedures for these historic oil and gas wells. Permit dates associated with the oil and gas wells shown in Figure 3-5 range from 1991 to 2012.

The oil and gas industry is aware of potential pathways associated with historic oil and gas wells, and has identified several approaches for evaluating these pathways (e.g., using remote sensing technologies and on-the-ground field surveys [e.g., McKee, 2012]). Oil and gas regulatory agencies in producing states proactively manage orphan wells within their jurisdiction, generally evaluating the potential risk posed by each identified well, and mitigating the highest risk wells first. The Interstate Oil & Gas Compact Commission (IOGCC) formed an Orphan Well Task Force to address the requirements in Section 349 of the Energy Policy Act of 2005. This Task Force provides for the establishment of a program to provide technical and financial assistance to oil and gas producing states to deal with environmental issues associated with abandoned or orphan wells. In summary, although the potential for pathways exists, industry and state agencies are well aware of the situation and are taking steps to mitigate those risks.

Figure 3-6 shows the location of unconventional oil and gas drilling in Bradford and Susquehanna Counties. In late 2006, the first unconventional gas wells were completed in the Marcellus Shale in this region. Drilling on the Duffey Unit 1 well (API #37-015-20062) began on September 22, 2006 in Ridgebury, Bradford County. Drilling began on September 27, 2006 for the Teel 1 Well (API #37-115-20007) in Springville Township, Susquehanna County. This well was completed on October 28, 2006 and fractured 13 days later on November 10, 2006 (PADEP, 2012c).

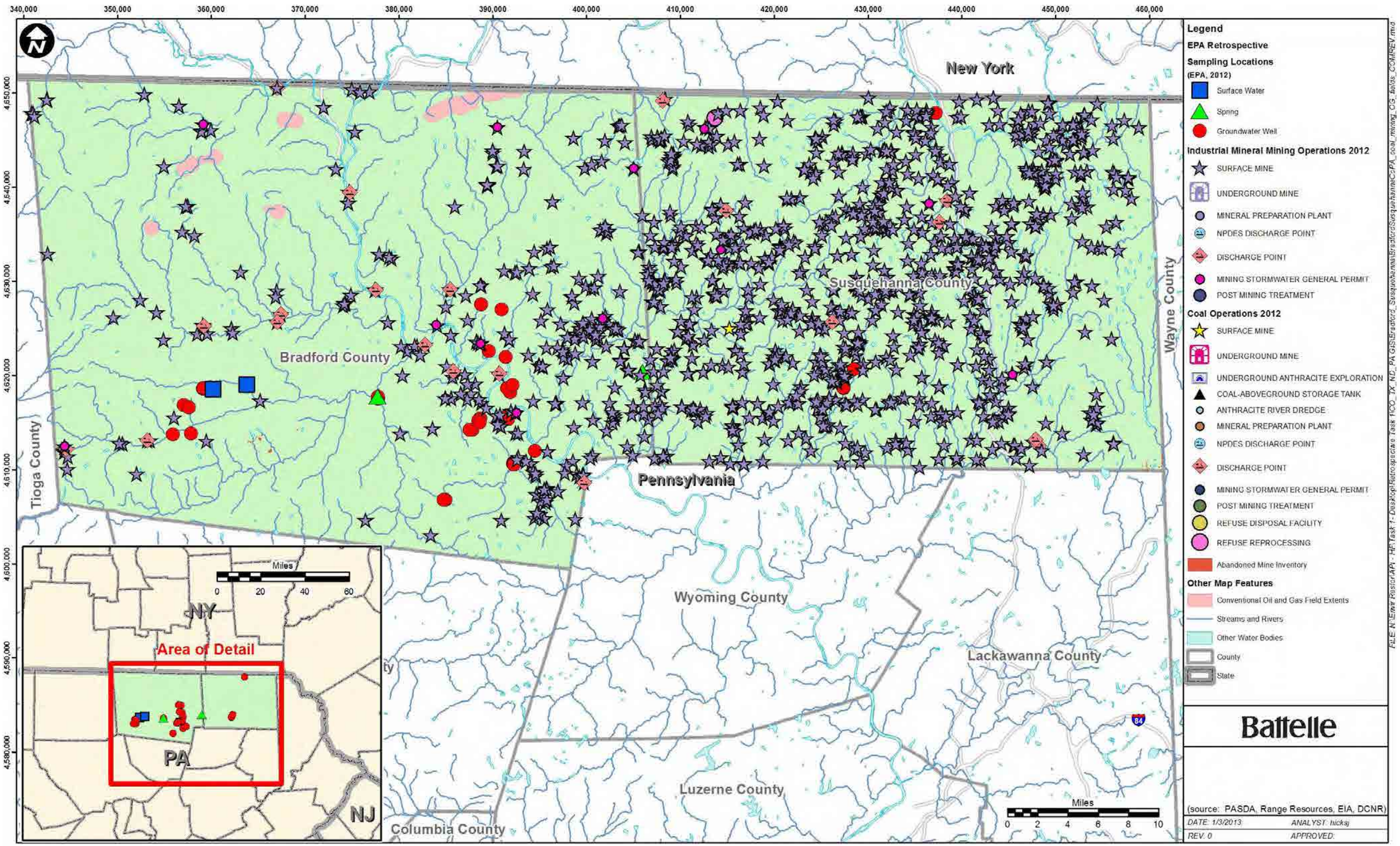

Figure 3-4. Extent of Resource Extraction Activities in Bradford and Susquehanna Counties

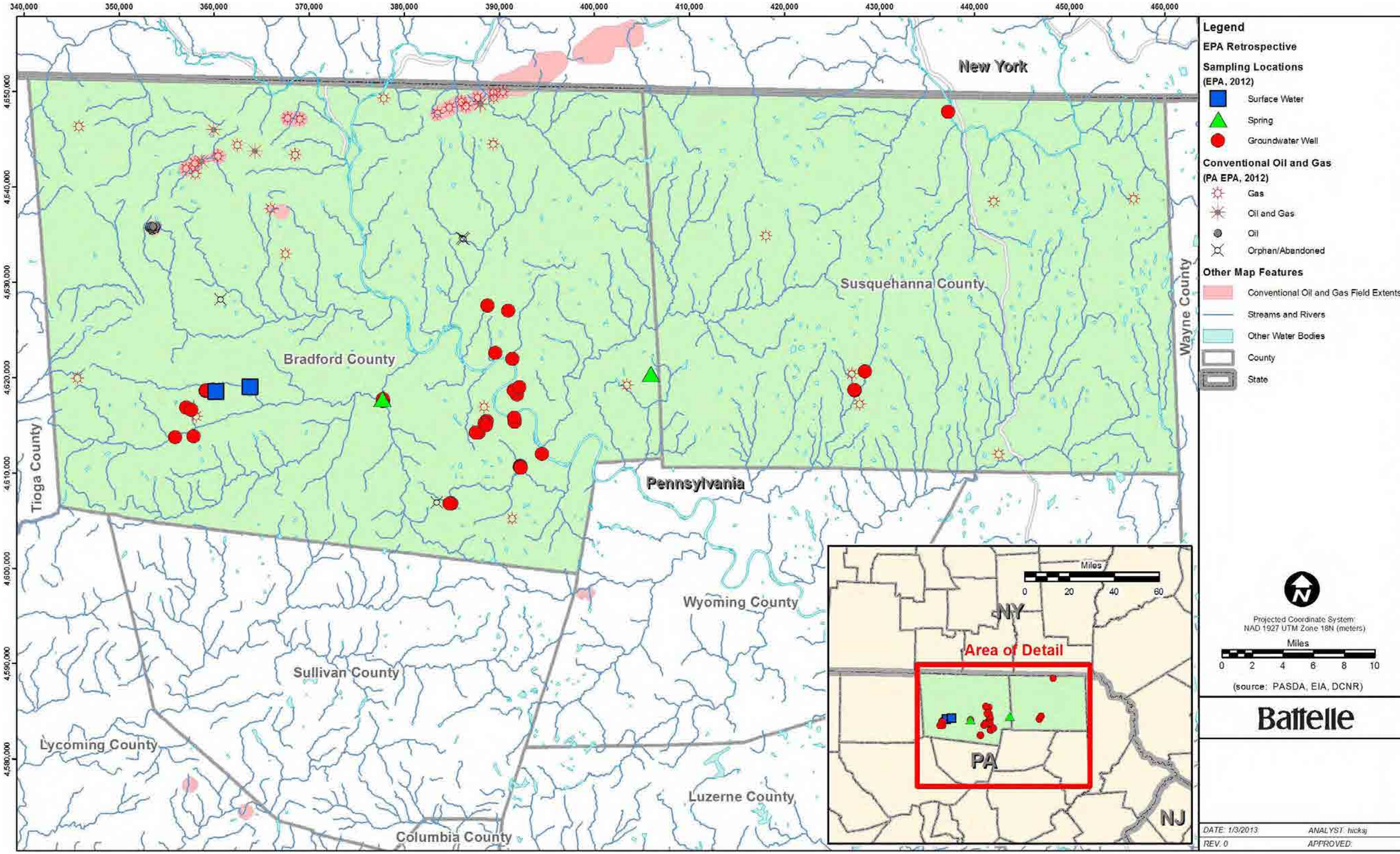

Figure 3-5. Conventional Oil and Gas Fields and Wells in Bradford and Susquehanna Counties

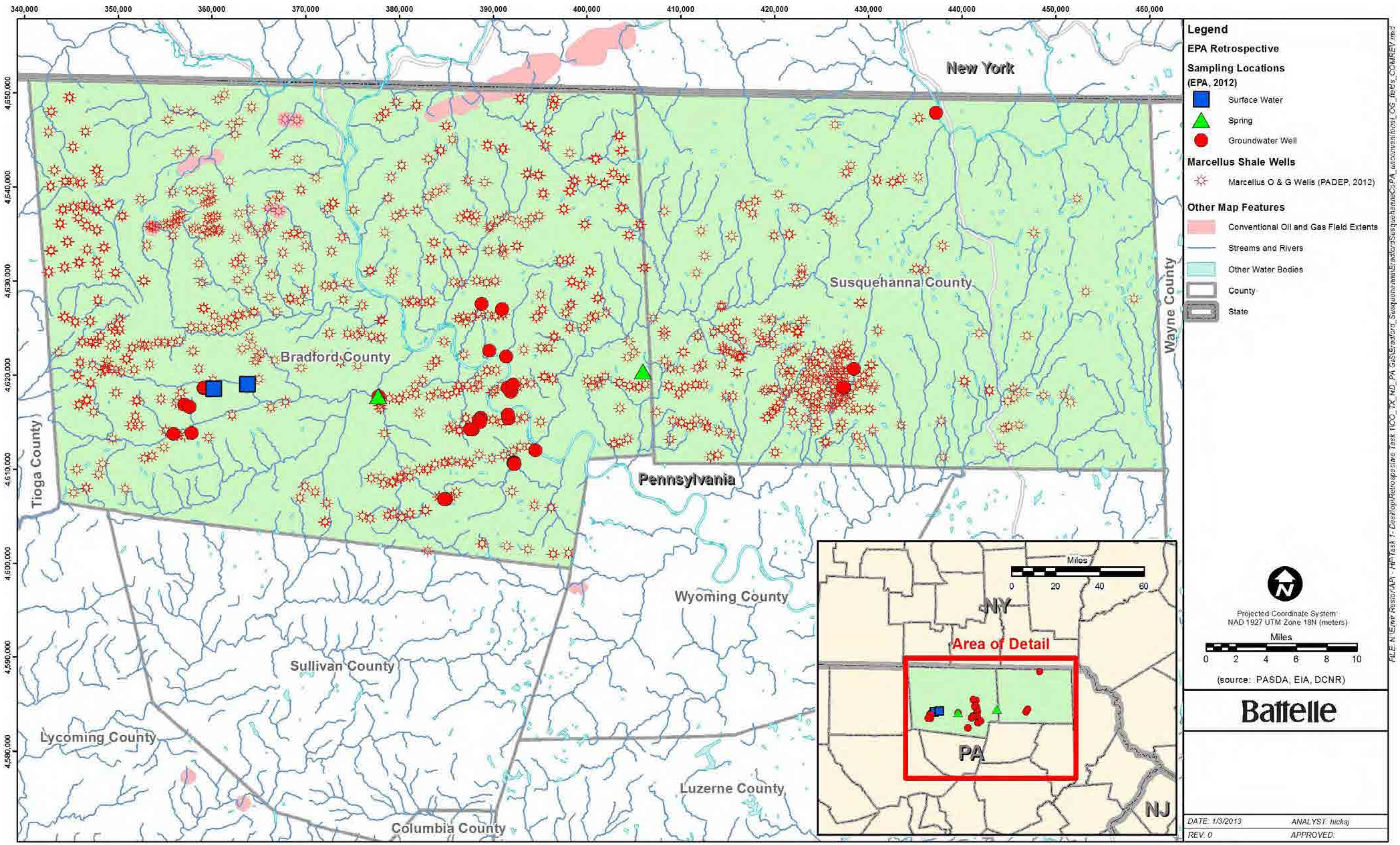

Figure 3-6. Post-2006 Unconventional Oil and Gas Wells in Bradford and Susquehanna Counties

3.2 Groundwater Resources

This section describes the groundwater resources in Bradford and Susquehanna Counties, including the most significant groundwater-bearing units that are typically used for drinking water. This section also includes an analysis of available historical (pre-2007) groundwater quality data in comparison to screening criteria, as well as a statistical assessment of the available groundwater data to identify potential temporal and spatial patterns or trends.

3.2.1 Hydrogeology. In Bradford and Susquehanna Counties, groundwater resources primarily occur within Pleistocene-age unconsolidated sedimentary deposits and consolidated Pennsylvanian, Mississippian, and Devonian age sedimentary rocks.

Alluvial drift and glacial outwash materials are the two primary unconsolidated sedimentary deposits present in northeastern Pennsylvania. Unconsolidated alluvial drift deposits in Bradford and Susquehanna Counties generally follow rivers and streams. The saturated thickness of these deposits is often thin. Although groundwater in alluvial drift is relatively unimportant as a source of drinking water, it can be important in aiding in the recharge of underlying units (Williams et al., 1998). Pleistocene age unconsolidated glacial deposits are more important water-bearing features. Specifically, the glacial outwash and till deposits associated with the Wisconsin Stage are the most important remaining water-bearing deposits associated with past glaciations. These glacial outwash and till deposits are typically between a few feet to hundreds of feet thick. Aquifers in Pleistocene-age glacial materials occur under confined and unconfined conditions. In general in northeastern Pennsylvania, drinking water wells completed in unconsolidated glacial deposits yield a relatively small amount of water, with median specific capacities of 11 gal/min/ft for confined systems and 24 gal/min/ft for unconfined systems (Williams et al., 1998).

Overall, the unconsolidated sedimentary deposits are less important water-bearing features relative to the series of consolidated sedimentary rocks that underlie them. The first few layers of consolidated deposits are relatively unimportant water-bearing features, namely, from youngest to oldest, the Post-Pottsville and Pottsville Formations of Pennsylvanian Age and the Mauch Chunk and the Pocono Formations, both of Mississippian Age. The Post-Pottsville (also known as the Llewellyn) and Pottsville Formations are approximately 200 feet thick, and consist largely of conglomerate and sandstones with some thin margins of slate and coal. In certain areas, the Allegheny Formation, comprising sandstone, shale and some coal, occurs undivided with the Pottsville Formation. The Mauch Chunk Formation is a discontinuous deposit of hard sandstone and reddish shale, varying from very thin to approximately 170 feet thick. The Pocono Formation is comprised of pebbly conglomerate, sandstone, and shale; its thickness in northeastern Pennsylvania is approximately 665 feet. The Huntley Mountain Formation (generally sandstone and shale) and Burgoon Formation (sandstone) are members of the Pocono Formation.

Two formations that underlie the Pocono Formation are important water-bearing features in northeastern Pennsylvania: the Catskill Formation and the Lock Haven Formation. The more important of these, the Catskill Formation, is of Upper Devonian age. This formation consists of shale with cross-bedded sandstone, conglomerate, some siltstone and mudstone, and a few deposits of coal (Berg et al, 1980). The Catskill Formation yields moderate supplies of good quality water and is considered to be the most important water-bearing formation in Susquehanna County. However, saline groundwater has been reported at shallow depths in this formation (Williams et al., 1998). The maximum thickness of the Catskill Formation is estimated to be approximately 1,800 feet.

Augmenting the drinking water production of the Catskill Formation is the less important Lock Haven Formation which is of Devonian age. This formation consists of interbedded mudstone, siltstone, sandstone, and thin conglomerate with embedded marine fossils (Berg et al., 1980). It yields a small to moderate amount of fair to poor quality water in shallow portions of the aquifer, with saline groundwater reported in several wells in Bradford County at depths less than 200 feet (Williams et al., 1998). The maximum thickness of this formation is estimated to be approximately 4,400 feet.

The average depth to groundwater in northeastern Pennsylvania is approximately 175 feet, but is commonly located at depths less than 40 to 50 feet based in areas of low topography. Williams (2010) conducted a study in three New York counties (Chemung, Tioga, and Broome) adjoining Bradford and Susquehanna Counties. The author determined that the average maximum depth of fresh groundwater in the three counties was 800 feet in upland areas and 200 feet in valleys. Water below these depths was commonly saline.

Table 3-2 provides a summary of the maximum thickness, general lithology and several hydrogeologic properties of water-bearing formations in Bradford and Susquehanna Counties. Figure 3-7 shows the shallow groundwater-bearing formations across Bradford and Susquehanna Counties.

Table 3-2. Summary of Water-bearing Formations in Bradford and Susquehanna Counties

Formation/Group[2]	Maximum Thickness[2,3]	Lithology[1]	Hydrogeology[2,3]
Alluvium	Relatively Thin	Unconsolidated clay, silt, sand and gravel	Unimportant water-bearing units, but important in augmenting recharge for underlying units
Pleistocene Glacial Deposits[3]	hundreds of feet	Unconsolidated, heterogeneous glacial till and stratified glacial outwash	Low yields from till and outwash. Unconfined (typically $CaCO_3$-type water) and confined units (typically saline water). Not as important as consolidated water-bearing units
Post-Pottsville and Pottsville	~200 feet	Largely conglomerate and sandstones with some thin margins of slate and coal deposits	Relatively unimportant water bearing features
Mauch Chunk	~170 feet	Hard sandstone and reddish shale	Relatively unimportant water bearing features
Pocono	~665 feet	Pebbly conglomerate, sandstone, and shale	Relatively unimportant water bearing features
Catskill	~1,800 feet	Shale with cross-bedded sandstone, conglomerate, and a few deposits of coal	Principal aquifer unit in Bradford and Susquehanna Counties; typically yields moderate supplies of good water
Lock Haven	~4,400 feet	Interbedded mudstone, siltstone, sandstone, and thin conglomerate	Small to moderate yield of fair quality water in shallow portions of the aquifer; saline water in deeper portions

1. Berg, T. M., Edmunds, W. E., Geyer, A. R., and others, compilers. 1980. Geologic map of Pennsylvania: Pennsylvania Geological Survey, 4th ser., Map 1, 2nd ed., 3 sheets, scale 1:250,000.
2. Lohman, SW. 1937. Groundwater in Northeastern Pennsylvania, PA Topographic and Geological Survey and USGS, Water Resources Report 4.
3. Williams, JH, LE Taylor, and DJ Low. 1998. Hydrogeology and Groundwater Quality of the Glaciated Valleys of Bradford, Tioga, and Potter Counties, Pennsylvania, Pennsylvania, PA Geological Survey and USGS, Water Resources Report 68.

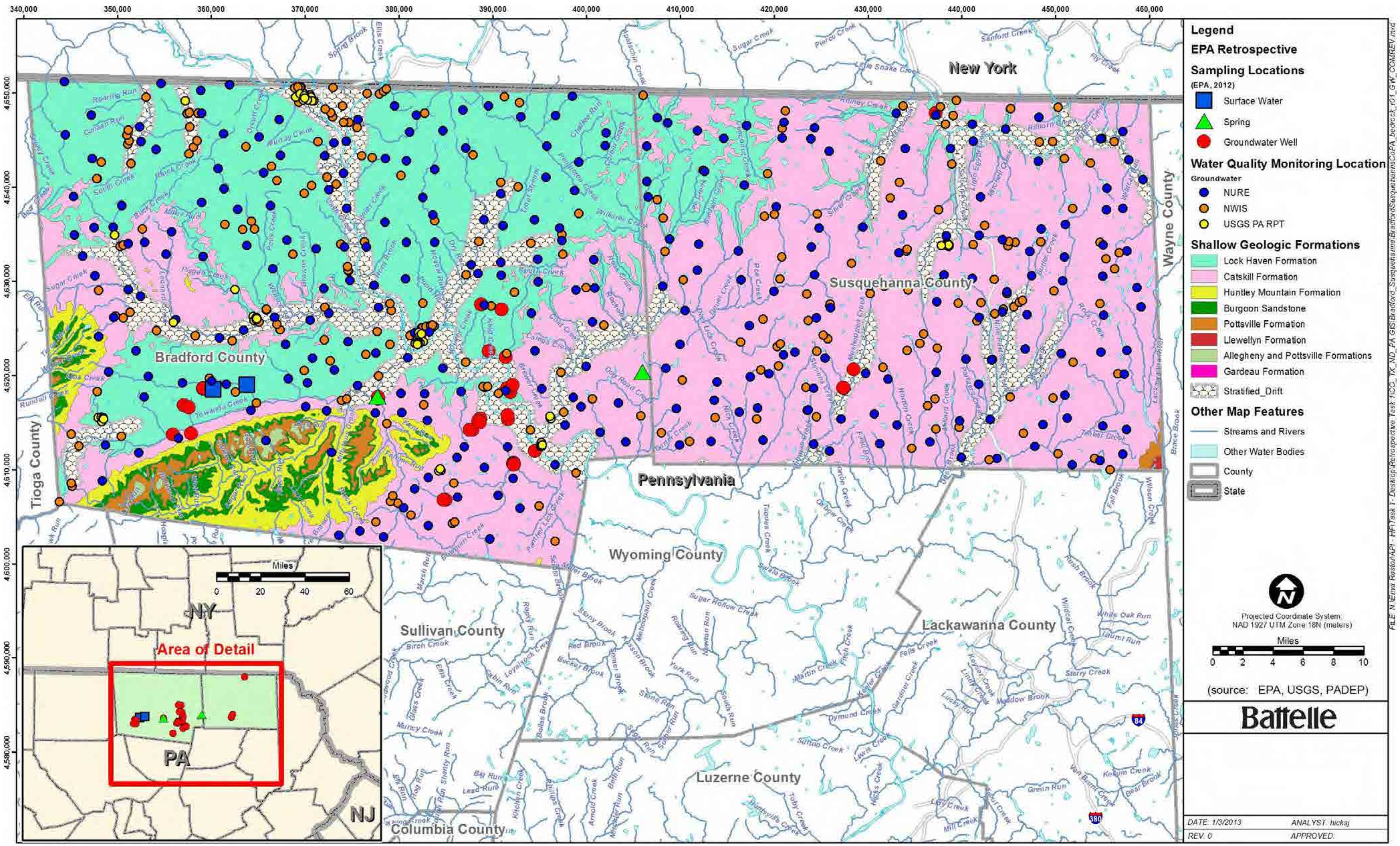

Figure 3-7. Shallow Groundwater-Bearing Formations and HistoricalGroundwater Quality Sampling Locations in Bradford and Susquehanna Counties

Groundwater Quality

Taylor (1984) assessed groundwater resources of the Upper Susquehanna River Basin, which includes Bradford and Susquehanna Counties. He examined water quality data from 245 samples collected from wells and springs in the Appalachian Plateau and 111 samples from the Valley and Ridge Province within the basin and found naturally occurring constituents (e.g., iron and manganese) above SMCLs in more than 36% of the water samples. For iron, approximately 28 percent of the 245 samples in the Taylor (1984) study equal or exceed the EPA SMCL and approximately 36 percent of the manganese samples equal or exceed the EPA SMCL. Taylor (1984) also reported that many wells in the study area have hydrogen sulfide odor. Taylor (1984) noted "the amount and type of dissolved mineral matter found in groundwater are determined largely by the composition of the soil and rock through which the water flows and the length of time the water has been in contact with the soil and rock." Generally, groundwater with shorter residence times (shallow groundwater, relatively short flow paths) will have lower total dissolved solids than groundwater with longer residence times (deeper groundwater, relatively longer flow paths). Carbonate rocks had the highest total dissolved solids while sandstones or shallow flow systems had the lowest total dissolved solids.

Taylor (1984) also noted groundwater impacted by acid mine drainage can be identified by elevated iron, sulfate, TDS, and low pH. In areas of the anthracite region that were deep mined for coal, much of the groundwater was contaminated. However, in other areas (of the anthracite region) where no coal mining has occurred, groundwater naturally has these quality characteristics.

Williams et al. (1998) described two major hydrogeochemical systems within Bradford and Susquehanna Counties. The unrestricted groundwater flow zone is characterized by calcium bicarbonate type water, and is present within the unconfined and confined unconsolidated sedimentary deposits as well as in some areas of underlying shallow bedrock. The restricted groundwater flow zone is characterized by sodium chloride type water, and is found predominantly in bedrock, and occasionally in the overlying glacial till and confined unconsolidated aquifers. Williams et al. (1998) identified 44 drinking water wells that contained naturally-occurring sodium chloride type groundwater in northeastern Pennsylvania. Of these 44 wells (ranging from 37 to 720 feet deep, and with a median depth of 200 feet), 38 were completed in bedrock formations (23 wells in the Lock Haven Formation and 15 wells in the Catskill Formation), and six wells were completed in confined portions of unconsolidated glacial deposit aquifers.

Groundwater in confined aquifers of unconsolidated glacial material is typically characterized by elevated iron and manganese concentrations; this same condition exists in some unconfined aquifer systems in unconsolidated glacial material. In the restricted flow zone, sulfate concentrations are typically low, allowing for naturally elevated concentrations of other constituents, including dissolved barium (Weston, 2012). Williams et al. (1998) observed the presence of hydrogen sulfide and methane in water wells completed within the restricted flow zone.

Recently, PADEP guidance documents and proposed regulations have resulted from growing concerns associated with poor groundwater quality. The Commonwealth of Pennsylvania has provided a Fact Sheet listing guidelines on the location and completion of private wells (PA DCNR, 2010). In 2009, Pennsylvania State University (PSU) released a guidance document (PSU, 2009a) that was designed to assist homeowners with the proper construction, installation and maintenance of private water systems. House Bill 1855 was referred to the Committee on Consumer Affairs on December 7, 2011 with hearings and testimony provided in January 2012 (PGWA, 2012). The goal of this legislation is to establish construction standards for residential wells across the Commonwealth of Pennsylvania.

Recent USGS studies (DeSimone, 2009; Ayotte et al., 2011) examined water quality in principal aquifers across the U.S. from data collected in the 1991-2004 timeframe. While not specific to Bradford and Susquehanna Counties, both studies demonstrate the importance of understanding factors that contribute to observed water quality and identify important considerations for making comparisons between data collected from different locations and times.

DeSimone (2009) assessed contamination in domestic wells, variation among and within aquifers, and the co-occurrence of contaminants. Compounds found most frequently at concentrations greater than human health benchmarks were naturally occurring (radon, fluoride, gross alpha- and beta-particle radioactivity, arsenic, iron, manganese, strontium, boron, and uranium), with the exception of nitrate and fecal indicator bacteria. Patterns of occurrence related to rock type, land use, and geochemical conditions were also noted. The study noted that 23% samples have at least one result above the respective MCL.

Ayotte et al. (2011) provided a comprehensive analysis of trace elements occurrence in groundwater across the U.S. This study illustrates the importance of understanding how climate, well construction, geologic composition of aquifer and aquifer geochemistry affect trace elements detected in water quality. For example, aluminum, copper, iron, lead and manganese were detected in greater concentrations in humid regions (Bradford and Susquehanna Counties are characterized in the humid region in the report) relative to dry regions due most likely to acidic and anoxic conditions. Concentrations of copper, lead, radon, and zinc were significantly greater in drinking water wells than in monitoring wells. Copper, lead, and zinc are found in pumps and pipes used in water well construction and may explain their elevated concentration in drinking water wells. Many trace elements (aluminum, antimony, barium, boron, chromium, cobalt, iron, manganese, molybdenum, nickel, selenium, strontium, and uranium) were all greater in monitoring wells than drinking water wells in humid regions. Land use (e.g., agricultural vs. urban), aquifer composition, and geochemistry were major factors affecting trace element concentrations in groundwater.

Low and Chicester (2006) evaluated groundwater quality data collected from 1979-2004 from 8,012 well with most wells located in southeastern Pennsylvania, near Pittsburgh and in the northwestern Pennsylvania. The data were compared against screening criteria with the percentage of samples above the criteria for the following major analyte groups: 53% of biological, 14% of VOC, 40% of major ions, 17.1% of minor ions, 20% of water characteristics, 0.3% of pesticides, 8.4% of radionuclides, 0% of wastewater compounds and 8.8% of nutrients.

Low and Galeone (2007) reviewed arsenic concentrations in groundwater collected in 2005-2006 from eight northern tier counties including Bradford and Susquehanna counties. Detectable concentrations of total arsenic were identified in wells ranging from 29 to 400 ft deep completed in Lock Haven, Catskill, and glacial aquifers. The median arsenic concentration was 4 ug/L, and the maximum detected concentration was 188 ug/L. Arsenic levels were significantly greater in the Lock Haven. Arsenic concentrations also varied by topography within the Lock Haven and glacial aquifers where higher concentrations occurred within valleys relative to higher elevations. There was no variation in arsenic levels with depth for any aquifer.

In 2010 and 2011, water quality data was collected near gas wells before and after hydraulic fracturing in 20 counties across Pennsylvania including several wells in Bradford County (Boyer et al., 2011). Phase 1 included sampling of 42 wells within 2,500 feet of a gas well and 6 control wells. Phase 2 included 172 wells within 5,000 feet of a gas well and 13 control wells (>25,000 feet from nearest gas well). Phase 1 sampling included both pre and post hydraulic fracturing data; Phase 2 sampling consisted of only post hydraulic fracturing data. Note that for this study, pre and post hydraulic fracturing refer to sampling time relative to nearby gas wells. Findings from Boyer et al. (2011) include:

- 40% of water wells failed at least one SDWA standard before gas drilling commenced with coliform bacteria, turbidity and manganese most common

- 20% of water wells had a detectable level of methane before gas drilling began
- Statistical analyses of pre- and post-drilling did not suggestion any major influences due to gas drilling; there was no significant correlation to distance from drilling, and no statistically significant increase for methane or constituents prominent in drilling waste fluids (e.g., TDS, chloride, sodium, sulfate, barium, and strontium);
- past incidence and ongoing investigations clearly demonstrate the need for a more intensive study focused on the occurrence and sources of methane in water wells.

Boyer et al. (2011) also noted that the results of their study should be used and interpreted with caution due to the short duration of the study. Additional research that include a larger number of study wells and control wells along with numerous pre and post drilling samples are needed to investigate potential for subtle water quality effects between pre and post drilling.

Weston (2012) collected water samples from 14 water wells and 1 spring in conjunction with EPA's Oct/Nov 2011 sampling events in Bradford County. This data was compared with historical (pre 2007 data) from: 1) NWIS (169 wells in Catskill and Lock Haven Formations in Bradford sampled 1935 to 2006); 2) NURE (164 wells sampled in Bradford in 1977, of which 160 were from Catskill or Lock Haven Formation); 3) USGS from Williams et al. (1998; 108 wells in Bradford sampled 1935 to 1986). Chesapeake Energy baseline water quality data, provided by Chesapeake (up to 2,000 samples collected 2009 to 2012) was also used in Weston's (2012) study. In their assessment Weston (2012) focused on TDS, chloride, barium, strontium, sodium, iron, manganese, arsenic coliform bacteria and methane, with chloride, barium, sodium, TDS and methane chosen as key indicators of impacts from natural gas operations. Results noted groundwater quality is largely affected by the composition and residence time within the rock types that make up an aquifer, that there is no significant deviation in water quality from baseline to post drilling, and that the water quality in the 14 wells and one spring sampled in October and November 2011 do not appear to be impacted by natural gas drilling or production activities including hydraulic fracturing.

As a part of the Battelle study, an evaluation of domestic, commercial, industrial, public supply and recreational water wells was completed for Bradford and Susquehanna Counties. Data for this evaluation were obtained from the Pennsylvania Groundwater Information System (PA GWIS). The PA GWIS database has 9,461 records for groundwater wells completed in Bradford and Susquehanna Counties (4,915 in Bradford County and 4,546 in Susquehanna County), although only 4,845 wells include georeferenced coordinates that allow for locating the wells on a base map (3,235 in Bradford County and 1,610 in Susquehanna County). Based on the groundwater well records from PA GWIS, groundwater is present and extracted from relatively shallow depths in Bradford and Susquehanna Counties, with a median well depth of 150 feet and a median depth to groundwater of 45 feet.

Groundwater Wells in Bradford and Susquehanna Counties

In Pennsylvania, over 3 million residents obtain their water from private groundwater wells. A majority of these private wells are completed in bedrock, and derive groundwater from local flow. Wells are commonly completed in consolidated bedrock or co-completed in both unconsolidated and consolidated formations, and are open hole completions with casing pounded to bedrock, often with no seal or grout. The state of Pennsylvania has established groundwater well installation regulations for public water supply wells. However, the state does not regulate the construction of private water wells, and currently there are no requirements regarding the location, construction materials, water quality or yield, of these wells. To operate in the state of Pennsylvania, groundwater well drilling companies are required to have a water well driller's license and valid rig permit. Upon well completion, drillers must provide a copy of the well completion report to the state and the home owner that describes the well location and construction method used (PA DCNR, 2010).

Poor groundwater well location and well construction are key factors resulting in water supply contamination. Several studies have been conducted in an attempt to evaluate whether groundwater quality can be compromised by poor well construction. As part of the National Water Quality Assessment Program, the USGS (Bickford et al., 1996) conducted a study of the Lower Susquehanna River basin and found that “nearly 70% of the [146] wells tested had total coliform present and thus were not suitable for drinking water without treatment.” The majority of the wells sampled in this investigation were not sealed or grouted, and the USGS concluded that poor well construction can allow contaminated surface water or shallow groundwater to enter the well.

A statewide survey of 701 (450 wells in 2006; 251 wells in 2007) private wells conducted by the Pennsylvania Master Well Owner Network in 2009 showed that wells with poor construction had poor water quality and noted that statewide regulations requiring well construction components appeared to be warranted (Swistock et al., 2009). The wells in this study ranged in depth up to 1,000 feet with an average depth of 172 feet. All Pennsylvania counties were included in this study. The study found poor well construction was the most important factor for the elevated levels of coliform bacteria observed in 33% of the wells. Water quality was also found to be strongly tied to aquifer geology and associated with land use.

In response to growing concern regarding poor groundwater quality, several regulations have been proposed and a number of publications have been presented addressing the problem. The state of Pennsylvania has provided a fact sheet listing guidelines on siting and completion of private wells (PA DCNR, 2010). In 2009, Pennsylvania State University (PSU) released a guidance document (PSU, 2009) that was designed to assist homeowners on the proper construction, installation, and maintenance of private water systems. House Bill 1855 has been introduced in the Pennsylvania legislature to set statewide construction standards for residential wells; this bill was referred to Committee on Consumer Affairs in December 7, 2011 with hearings and testimony provided in January 2012 (Pennsylvania Groundwater Association [PGWA], 2012).**3.2.2 Data Summary.** Groundwater quality data (from the sources identified in Section 2.0) were compiled by Battelle into a database to characterize the condition of groundwater resources within Bradford and Susquehanna Counties prior to unconventional oil and gas development (i.e., pre-2007). Summary tables were compiled as noted in Section 2.0 for the complete dataset (includes data potentially associated with environmental impacts) and for a reduced dataset that removed data potentially associated with environmental impacts. Figure 3-7 shows the locations of the groundwater quality sampling stations (including locations potentially associated with environmental impacts) represented in the database overlain on a map of shallow groundwater-bearing formations in Bradford and Susquehanna Counties. Figure 3-7 also shows the known EPA sampling locations for groundwater in the retrospective case study. The dates of the sampling events at these groundwater quality sampling stations range from 1930 to 2007. Groundwater data are available from 651 wells for a number of constituents, including general water-quality parameters, major and minor ions, metals, radionuclides, nutrients and a limited number of organics.

Table 3-3 (the complete dataset that includes data potentially associated with environmental impacts) provides a pre-2007 listing of groundwater parameters detected, number of samples, the minimum, maximum, median, and mean constituent concentration, the standard deviation of the concentration range, the date range for sample collection, and comparison against water quality standards and criteria, including the number of results above each screening criteria. For groundwater, the screening criteria include the MCL, SMCL, Pennsylvania Act 2, EPA Region III carcinogenic and non-carcinogenic criteria. Section 2 provides an explanation of these screening criteria and how summary statistics were calculated. Table 3-3 also identifies those parameters monitored by EPA and includes a designation of whether the parameter is a critical analyte (CA) or a measured (M) parameter per the EPA QAPP (EPA, 2012b). Appendix B includes a listing of all groundwater data collected for Bradford and Susquehanna Counties.

Inorganic Summary. As indicated in Table 3-3, the observed historical (pre-2007) constituent concentration is above one or more of the screening criteria for two general water quality parameters (pH and TDS) and four major ions (chloride, fluoride, sulfate and sodium). Chloride and sulfate were detected above the SMCL, fluoride was detected above the MCL, SMCL, Pennsylvania Act 2 and the EPA Region III non-carcinogenic criteria, and sodium was detected above the EPA Health Advisory level of 20 mg/L. Chloride, sulfate and sodium are identified as EPA CA, whereas fluoride is identified as an EPA M analyte. Two nutrient parameters, nitrate as N and nitrite as N both of which are EPA CA, were detected above the MCL, the Pennsylvania Act 2 criteria, and the EPA Region III non-carcinogenic criteria.

The minimum, maximum and/or mean observed concentration is higher than one or more of the screening criteria for several metals, including aluminum (total and dissolved), arsenic (total and dissolved), barium, cadmium, chromium, iron (total and dissolved), lead, manganese (total and dissolved), mercury, phosphorous, strontium and zinc. Total aluminum and total and dissolved iron are above the SMCL and the EPA Region III non-carcinogenic criteria. Dissolved aluminum is above the SMCL. Total and dissolved arsenic is above the MCL, the Pennsylvania Act 2 criteria, and the EPA Region III carcinogenic and non-carcinogenic criteria. Barium, cadmium, and mercury are above the MCL, the Pennsylvania Act 2 criteria, and the EPA non-carcinogenic criteria. Chromium and lead are above the MCL and the Pennsylvania Act 2 criteria. Total and dissolved manganese and zinc are above the SMCL, the Pennsylvania Act 2 criteria, and the EPA Region III non-carcinogenic criteria. Phosphorous and strontium are above the EPA Region III non-carcinogenic criteria.

Figure 3-8 shows the locations where concentrations of one or more chemicals were historically above screening criteria in the complete groundwater quality dataset.

Table 3-3. Summary of Water Quality Parameters (Complete Dataset, including Environmental Impact Data) Monitored in Groundwater in Bradford and Susquehanna Counties

											Including NDs			Excluding NDs															
Class	Parameter	Field Results	Frac.	Units	EPA Class	No. Samples	No. Locations	No. ND	Min	Max	Median	Mean	SD	Median	Mean	SD	Begin Sample Date	End Sample Date	MCL	N Above MCL (no NDs)	SMCL	SMCL High	N Above SMCL (no NDs)	Act 2	N Above Act 2 (no NDs)	EPA Carc.	N Above EPA Carc. (no NDs)	EPA Non-Carc.	N Above EPA NonCarc. (no NDs)
Dissolved Gas	Carbon dioxide	No	Tot.	mg/l	-	86	86	0	0.3	1970	10	38.1	211	10	38.1	211	May-55	Jul-82											
Gen WQ	Alkalinity as CaCO3	No	Tot.	mg/l	M	165	153	0	0.01	350	128	130	61.2	128	130	61.2	Sep-80	Oct-06											
Gen WQ	Alkalinity as CaCO3	Yes	Tot.	mg/l	M	556	172	0	1	966	124	152	109	124	152	109	Jul-30	Jan-90											
Gen WQ	Hardness as CaCO3	No	Tot.	mg/l	-	205	195	0	6	888	110	130	110	110	130	110	Jul-30	Oct-06											
Gen WQ	Hardness, non-carbonate as CaCO3	Yes	Tot.	mg/l	-	49	49	0	1	1080	24	65.9	159	24	65.9	159	Jul-30	Apr-86											
Gen WQ	Organic carbon	No	Tot.	mg/l	M	237	83	60	0.5	110	3.48	8.82	13	5.86	10.7	13.9	Jul-80	Jun-03											
Gen WQ	pH	No	Tot.	std units	M	897	285	0	3.1	11	7.5	7.41	0.576	7.5	7.41	0.576	Feb-79	Aug-02			6.5	8.5	91						
Gen WQ	pH	Yes	Tot.	std units	M	435	400	0	5.2	9.1	7.4	7.34	0.573	7.4	7.34	0.573	May-55	Oct-06			6.5	8.5	39						
Gen WQ	Specific conductance	No	Tot.	umho/cm	M	16	10	0	120	824	471	465	217	471	465	217	May-92	Jun-03											
Gen WQ	Specific conductance	Yes	Tot.	umho/cm	M	812	514	0	2	99999	260	535	4420	260	535	4420	Jan-69	Oct-06											
Gen WQ	Temperature, water	No	Tot.	deg C	M	190	64	0	7	28.3	11	11.2	1.9	11	11.2	1.9	Jul-30	Jun-06											
Gen WQ	Total dissolved solids	No	Dis.	mg/l	-	654	272	1	1.44	9200	197	324	542	198	325	543	Jul-30	Oct-06				500	218						
Gen WQ	Total solids	No	Tot.	mg/l	-	359	70	0	16	1041000	532	3840	21100	532	3840	21100	Feb-79	Feb-88											
Gen WQ	Total suspended solids	No	Susp.	mg/l	-	327	64	10	0.5	15060	154	943	2440	154	947	2440	Jul-79	Jan-90											
Gen WQ	Turbidity	No	Tot.	NTU	M	149	52	4	0.07	6750	29.9	99.4	245	33.1	101	247	Apr-82	Oct-06											
Major Anions	Bromide	No	Dis.	mg/l	M	154	154	21	0.0027	2.9	0.023	0.137	0.397	0.0292	0.158	0.424	Jul-77	Oct-77											
Major Anions	Chloride	No	Dis.	mg/l	CA	1157	610	46	0.05	5050	8	34	189	8.1	34.2	189	Jul-30	Oct-06				250	41						
Major Anions	Fluoride	No	Dis.	mg/l	M	552	507	109	0.008	60	0.1	0.175	1.33	0.1	0.202	1.46	May-55	Oct-06	4	1		2	1	4	1			0.62	6
Major Anions	Sulfate	No	Dis.	mg/l	CA	768	326	17	0.5	2000	15	31.2	80.1	15.5	31.7	80.6	Jul-30	Oct-06				250	104						
Major Cations	Calcium	No	Dis.	mg/l	CA	278	164	0	2.9	134000	32.5	78.5	483	32.5	78.5	483	Jul-30	Oct-88											
Major Cations	Calcium	No	Tot.	mg/l	CA	304	120	0	0.5	350	41.6	52.3	51.3	41.6	52.3	51.3	Sep-80	Oct-06											
Major Cations	Magnesium	No	Dis.	mg/l	CA	203	202	0	0.44	88	6.75	9.35	10	6.75	9.35	10	Jul-30	May-88											
Major Cations	Magnesium	No	Tot.	mg/l	CA	309	120	0	0.1	121.6	8.5	10.9	8.74	8.5	10.9	8.74	Sep-80	Oct-06											
Major Cations	Potassium	No	Dis.	mg/l	CA	135	134	0	0.2	25	1.05	1.92	2.31	1.05	1.92	2.31	Jul-30	Jul-82											
Major Cations	Potassium	No	Tot.	mg/l	CA	97	92	4	0.4	19.8	1.1	1.6	2.22	1.1	1.63	2.25	Jul-81	Oct-06											
Major Cations	Sodium	No	Dis.	mg/l	CA	421	420	0	1.18	2000	9.82	27.1	104	9.82	27.1	104	Jul-30	May-88	20	108									
Major Cations	Sodium	No	Tot.	mg/l	CA	438	158	1	0.05	2510	13.8	53.8	209	13.8	53.8	209	Sep-80	Oct-06	20	131									
Metals	Aluminum	No	Dis.	ug/l	M	521	413	55	2	13900	40	148	482	40	159	544	Oct-73	Oct-88				200	93					16000	0
Metals	Aluminum	No	Tot.	ug/l	M	229	124	99	0.025	752000	100	12500	72400	510	21500	94300	Jul-79	Oct-06				200	59					16000	9
Metals	Antimony	No	Tot.	ug/l	M	17	14	17	ND	ND	ND	ND	ND	ND	ND	ND	May-94	Oct-06	6	0				6	0			6	0
Metals	Arsenic	No	Dis.	ug/l	CA	11	11	0	3	178	12	31	50.1	12	31	50.1	Oct-73	Jun-06	10	7				10	7	0.045	11	4.7	10
Metals	Arsenic	No	Tot.	ug/l	CA	343	156	294	0.5	500	2.5	29.8	105	11.3	18.6	22.7	Jan-80	Oct-06	10	24				10	24	0.045	49	4.7	40
Metals	Barium	No	Tot.	ug/l	CA	201	118	39	5	98000	95	1350	9180	106	1690	10300	Oct-81	Oct-06	2000	5				2000	5			2900	5
Metals	Beryllium	No	Tot.	ug/l	M	17	14	17	ND	ND	ND	ND	ND	ND	ND	ND	May-94	Oct-06	4	0				4	0			16	0
Metals	Cadmium	No	Tot.	ug/l	M	254	111	166	0.1	28.1	0.285	4.48	8.57	0.8	1.78	1.85	Jul-81	Oct-06	5	6				5	6			6.9	4
Metals	Chromium	No	Dis.	ug/l	M	55	54	0	10	50	10	14.8	9.47	10	14.8	9.47	Jan-75	Jul-82	100	0				100	0				
Metals	Chromium	No	Tot.	ug/l	M	338	145	210	0.5	1070	10	20.3	34.6	17	37.1	65.7	Jan-80	Oct-06	100	16				100	16				
Metals	Copper	No	Tot.	ug/l	M	28	25	22	2	40	8	15.8	14.4	13.5	16.2	7.7	Oct-80	Oct-06	1300	0		1000	0	1000	0			620	0
Metals	Dysprosium	No	Dis.	ug/l	-	285	285	270	0.0005	2.375	0.01	0.032	0.19	0.15	0.483	0.707	Jul-77	Oct-77											
Metals	Iron	No	Dis.	ug/l	M	250	146	5	10	47500	130	1030	4300	130	1030	4300	Jul-30	Oct-88				300	127					11000	4
Metals	Iron	No	Tot.	ug/l	M	530	173	37	0.016	36600000	380	56000	499000	458	60200	517000	Feb-79	Oct-06				300	277					11000	83
Metals	Lead	No	Tot.	ug/l	M	134	102	89	0.5	500	2.5	16.5	52.5	14.5	49.8	94.1	Jul-81	Oct-06	15	18				5	33				
Metals	Manganese	No	Dis.	ug/l	M	458	354	73	5	4600	99.4	171	339	99.4	189	411	May-55	Oct-88				50	298	300	67			320	65
Metals	Manganese	No	Tot.	ug/l	M	338	163	39	0.05	38300	120	816	2590	180	1000	2850	Jul-79	Oct-06				50	215	300	134			320	129
Metals	Mercury	No	Tot.	ug/l	M	114	42	97	0.1	4900	1	25.3	151	14.1	189	509	Oct-73	Oct-06	2	9				2	9			0.63	14
Metals	Nickel	No	Tot.	ug/l	M	76	74	74	5	50	25	30.6	19.1	15	15	7.07	Aug-81	Oct-06						100	0			300	0
Metals	Phosphorus	No	Tot.	ug/l	M	13	13	2	5	18690	150	2100	5120	220	2480	5510	Nov-83	Aug-84										0.31	11
Metals	Selenium	No	Tot.	ug/l	CA	122	47	111	0.15	28	5	4.98	2.01	12	13.7	4.70	Oct-81	Oct-06	50	0				50	0			78	0

Table 3-3. Summary of Water Quality Parameters (Complete Dataset, Including Environmental Impact Monitoring Data) Monitored in Groundwater in Bradford and Susquehanna Counties (Continued)

											Including NDs			Excluding NDs															
Class	Parameter	Field Results	Frac.	Units	EPA Class	No. Samples	No. Locations	No. ND	Min	Max	Median	Mean	SD	Median	Mean	SD	Begin Sample Date	End Sample Date	MCL	N Above MCL (no NDs)	SMCL	SMCL High	N Above SMCL (no NDs)	Act 2	N Above Act 2 (no NDs)	EPA Carc.	N Above EPA Carc. (no NDs)	EPA Non-Carc.	N Above EPA NonCarc. (no NDs)
Metals	Silver	No	Tot.	ug/l	M	20	16	19	0.15	250	3.75	34.5	55.5	8	8	-	Oct-81	Oct-06				100	0	100	0			71	0
Metals	Strontium	No	Tot.	ug/l	CA	66	66	4	5	80000	150	1690	9940	160	1800	10200	Aug-83	Apr-86										9300	2
Metals	Thallium	No	Tot.	ug/l	M	17	14	17	ND	ND	ND	ND	ND	ND	ND	ND	May-94	Oct-06	2	0				2	0			0.16	0
Metals	Uranium	No	Dis.	ug/l	M	285	285	24	0.001	4.837	0.14	0.471	0.772	0.196	0.514	0.793	Jul-77	Oct-77	30	0									
Metals	Vanadium	No	Dis.	ug/l	M	285	285	253	0.05	2	0.1	0.197	0.258	0.35	0.472	0.39	Jul-77	Oct-77						260	0			78	0
Metals	Zinc	No	Dis.	ug/l	M	127	126	0	10	5700	30	193	719	30	193	719	Oct-73	Jul-82				5000	1	2000	3			4700	2
Metals	Zinc	No	Tot.	ug/l	M	131	115	25	1.5	670	30	51	91.8	30	60.7	98.1	Oct-80	Oct-06				5000	0	2000	0			4700	0
Minor Anion	Cyanide	No	Tot.	mg/l	-	108	32	49	0.0005	0.0862	0.015	0.0113	0.00573	0.0078	0.00809	0.00619	Jun-82	Nov-99											
Nutrients	Ammonia	No	Tot.	mg/l as N	-	162	37	0	2.10E-05	0.068376	0.00162	0.00391	0.00642	0.00162	0.00391	0.00642	Jul-79	Jan-90											
Nutrients	Ammonia-nitrogen as N	No	Dis.	mg/l	M	735	211	114	0.005	19.8	0.07	0.18	0.421	0.0888	0.204	0.452	Mar-70	Oct-06											
Nutrients	Kjeldahl nitrogen	No	Tot.	mg/l as N	-	90	28	7	0.05	16.8	1.29	2.22	2.05	1.64	2.31	2.03	Oct-80	Oct-86											
Nutrients	Nitrate as N	No	Dis.	mg/l	CA	987	325	93	0.002	43.2	0.389	1.16	2.13	0.46	1.29	2.22	Jul-30	Oct-06	10	54				10	54			25	7
Nutrients	Nitrite as N	No	Dis.	mg/l	CA	729	278	295	0.000125	5.07	0.005	0.0307	0.233	0.001	0.057	0.323	Jul-79	Oct-06	1	10				1	10			1.6	5
Nutrients	Phosphate as P	No	Tot.	mg/l	-	118	76	38	0.0005	6.7	0.025	0.253	0.679	0.031	0.425	1.13	Jul-79	Apr-86											
Organic	Surfactants -- CWA 304B	No	Tot.	mg/l	-	192	29	135	0.005	9.7025	0.04	0.0959	0.156	0.19	0.201	0.191	Jul-79	May-89											
Organics, other	Phenols and phenolic compounds	No	Tot.	ug/l	-	200	29	76	0.0005	475	5.9	14.1	19	11.3	24.3	27.2	Oct-81	May-89											

M – measured, as defined in EPA QAPP for the Bradford/Susquehanna Retrospective Case Study (EPA, 2012b).
CA = Critical Analyte, as defined in EPA QAPP for the Bradford/Susquehanna Retrospective Case Study (EPA, 2012b).
A red highlight indicates the value is above a screening criteria.
MCL: EPA Maximum Contaminant Levels (National Primary Drinking Water Regulation)
SMCL: EPA Secondary MCL (Non-enforaceable guidance for drinking water)
Act 2: State of Pennsylvania Land Recycling Program (Voluntary Remediation Program) Screening Limits: Limits are for used, residential groundwater aquifer with TDS ≤ 2500 mg/L
EPA Carc./EPA Non-Carc.: The carcinogenic and non-carcinogenic screening limits established by the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)
Note: Sodium does not have an MCL; the value listed in the MCL column represents the EPA Health Advisory Level.
ND = non-detect
SD = standard deviation

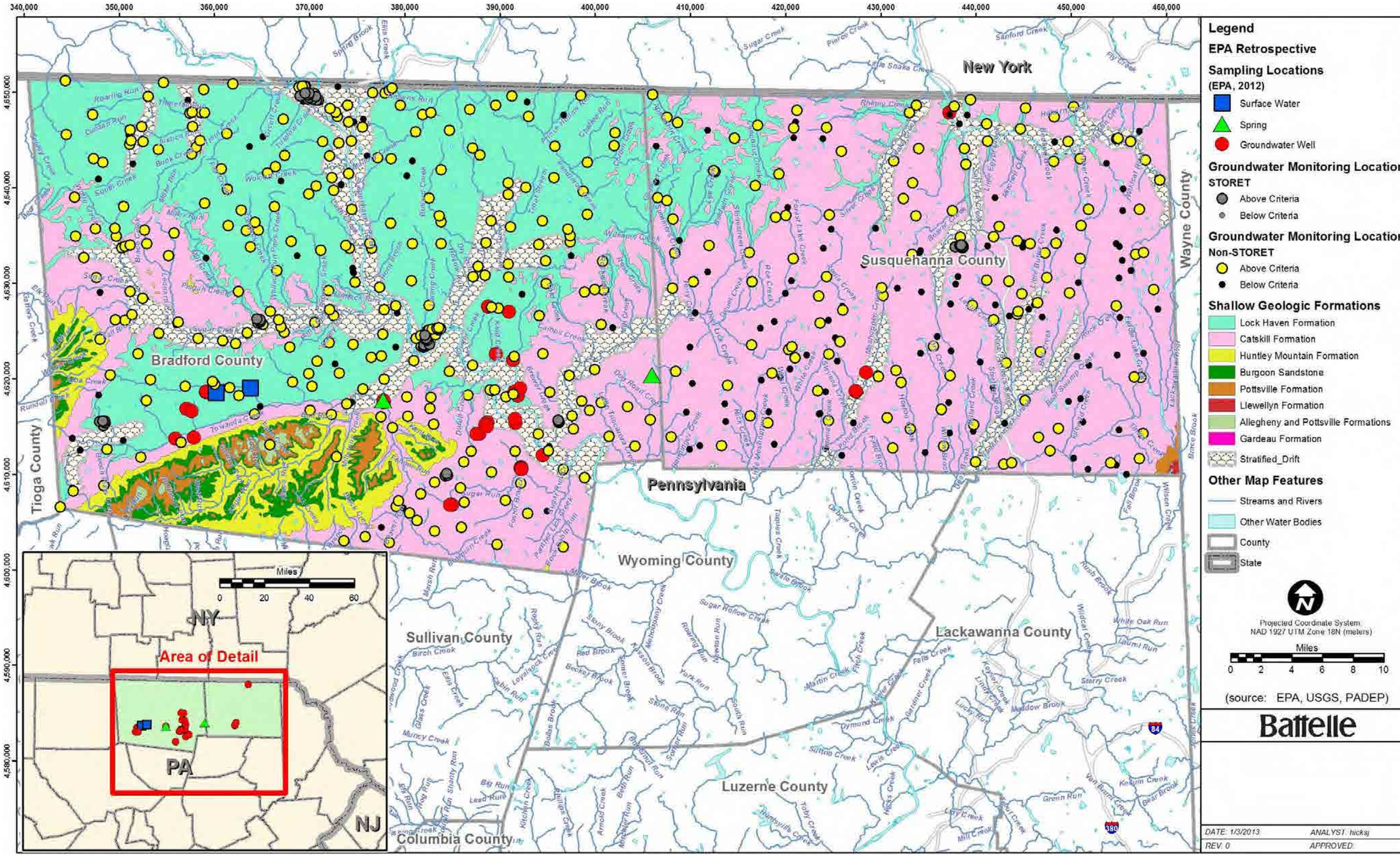

Figure 3-8. Spatial Distribution of Detections above Screening Criteria in Groundwater in Bradford and Susquehanna Counties

Organic Summary. There are limited data for organic compounds in the groundwater quality data set. There are no EPA CA or M parameters with sufficient water quality characterization data to warrant evaluation. Data were reported for several EPA CA and M parameters with two sample results available, but none had more than two measurements nor were any reported concentrations above the analytical detection limit.

Methane is a commonly detected in the environment, but data on methane was not available in the data sources used by Battelle to develop the baseline understanding of water quality. Recently, GSI (2011) evaluated more than 1,700 groundwater samples from Susquehanna County sampled and tested prior to gas well drilling. Groundwater samples were collected from within 1,000 feet of a gas drilling site in 2008 and 2009 and within 2,500 feet since 2010. Stable isotope data from PADEP in 2009 and 2010 were also included in the evaluation (GSI, 2011). Results showed detectable methane in 78% of the pre drill water samples and that elevated methane in groundwater is natural and is a function of geologic features rather than shale gas development. Potential sources of methane were noted to include thermogenic from gas-charged sandstones in the Catskill Formation and biogenic from organics in thick valley alluvium. GSI (2011) also noted the isotopic signature of thermogenic methane from deposits overlying the Marcellus can be distinguished from the isotopic signature of Marcellus shale gas.

Comparison Against Reduced Data Table. Table 3-4 provides summary of pre-2007 groundwater data in similar format to Table 3-3, with the exception of 116 locations that were removed due to potential data quality issues associated with environmental impact monitoring or inaccurate data location (see Table 2-3 and Figure 3-8). This summary data table was created for comparison against the complete background groundwater quality summary data table (Table 3-3) to determine whether the removed data have a significant effect of background water quality values.

The parameters that are above screening criteria in the reduced summary data table (Table 3-4) are similar to those in the comprehensive data summary table include pH, TDS, chloride, sodium, aluminum, arsenic, barium, chromium, iron, lead, manganese, strontium, zinc, and nitrate as N. For fluoride, the reduced data set indicated concentrations are above only the EPA Region III non-carcinogenic critera. There are no concentrations of sulfate, cadmium, mercury, phosphorous, or nitrate as N above screening criteria in the reduced summary data tables. For pH, chloride, fluoride, dissolved chromium, lead, dissolved zinc, nitrate as N, and nitrite as N, there is virtually no difference between the parameter-specific mean concentations in the two data sets. For TDS, sulfate, dissolved sodium, aluminum, dissolved arsenic, iron, and manganese, the parameter-specfic mean concentrations in the reduced data set is lower. For total sodium, total arsenic, barium, total chromium, and total zinc, the parameter-specfic mean concentrations in the reduced data set is higher. These results suggest that that inclusion of data potentially indicative of environmental impact monitoring or those with data location issues may bias the characteriztion of background water quality conditions.

3.2.3 Coverage of EPA QAPP Analytes. Parameters identified by EPA for the Bradford and Susquehanna Counties retrospective case study were identified in the QAPP for the study (EPA, 2012b). Of the parameters identified in the QAPP, 192 are designated as either CA (83) or M parameters (109). Table 3-3 summarizes the available groundwater quality data for parameters that are part of the EPA study (12 CA and 26 M). Table 3-5 summarizes 128 EPA parameters for which no historical groundwater quality data are available (64 CA and 64 M) and 26 parameters (seven CA and 19 M) for which the number of result locations was less than eight or all results were non-detect.

Table 3-4. Summary of Water Quality Parameters Monitored in Groundwater (Reduced Dataset, Excluding Environmental Impact Data) in Bradford and Susquehanna Counties

Class	Parameter	Field Results	Frac.	Units	EPA Class	No. Samples	No. Locations	No. ND	Min	Max	Including NDs Median	Including NDs Mean	Including NDs SD	Excluding NDs Median	Excluding NDs Mean	Excluding NDs SD	Begin Sample Date	End Sample Date	MCL	N Above MCL (no NDs)	SMCL	SMCL High	N Above SMCL (no NDs)	Act 2	N Above Act 2 (no NDs)	EPA Carc.	N Above EPA Carc. (no NDs)	EPA Non-Carc.	N Above EPA NonCarc. (no NDs)
Dissolved Gas	Carbon dioxide	No	Tot.	mg/l	-	86	86	0	0.3	1970	10	38.1	211	10	38.1	211	May-55	Jul-82											
Gen WQ	Alkalinity as CaCO3	No	Tot.	mg/l	M	127	126	0	6	350	120	129	61.7	120	129	61.7	May-82	Jul-82											
Gen WQ	Alkalinity as CaCO3	Yes	Tot.	mg/l	M	106	102	0	20	308	138	145	63.9	138	145	63.9	Jul-30	Apr-86											
Gen WQ	Hardness as CaCO3	No	Tot.	mg/l	-	163	162	0	6	542	100	115	74.5	100	115	74.5	Jul-30	Jul-82											
Gen WQ	Hardness, non-carbonate as CaCO3	Yes	Tot.	mg/l	-	49	49	0	1	1080	24	65.9	159	24	65.9	159	Jul-30	Apr-86											
Gen WQ	Organic carbon	No	Tot.	mg/l	M	19	19	1	0.5	18	1.3	4.06	5.55	1.3	4.26	5.64	Jul-81	Jul-82											
Gen WQ	pH	No	Tot.	std units	M	202	197	0	6.2	9.2	7.6	7.47	0.553	7.6	7.47	0.553	Jul-81	Apr-86			6.5	8.5	10						
Gen WQ	pH	Yes	Tot.	std units	M	367	367	0	5.2	9.1	7.4	7.35	0.579	7.4	7.35	0.579	May-55	Jun-06			6.5	8.5	36						
Gen WQ	Specific conductance	Yes	Tot.	umho/cm	M	424	424	0	2.9	99999	260	565	4860	260	565	4860	Jan-69	Jun-06											
Gen WQ	Temperature, water	No	Tot.	deg C	M	26	26	0	9.3	15	11	11.2	1.31	11	11.2	1.31	Jul-30	Jun-06											
Gen WQ	Total dissolved solids	No	Dis.	mg/l	-	223	217	1	54	9200	196	300	562	197	301	563	Jul-30	Apr-86				500	22						
Major Anions	Bromide	No	Dis.	mg/l	M	151	151	21	0.0027	2.9	0.0232	0.139	0.401	0.0303	0.161	0.428	Jul-77	Oct-77											
Major Anions	Chloride	No	Dis.	mg/l	CA	502	496	2	0.1	5050	8	34.4	206	8	34.6	207	Jul-30	Apr-86				250	14						
Major Anions	Fluoride	No	Dis.	mg/l	M	444	438	64	0.008	1	0.0965	0.114	0.112	0.1	0.127	0.117	May-55	Apr-86	4	0		2	0	4	0			0.62	4
Major Anions	Sulfate	No	Dis.	mg/l	CA	231	226	6	1	250	15	20.8	27.7	15	21.1	27.8	Jul-30	Apr-86				250	0						
Major Cations	Calcium	No	Dis.	mg/l	CA	159	158	0	2.9	235	31	36.7	26.9	31	36.7	26.9	Jul-30	Jul-82											
Major Cations	Calcium	No	Tot.	mg/l	CA	70	70	0	0.5	349	39.7	49.1	47.1	39.7	49.1	47.1	Aug-81	Apr-86											
Major Cations	Magnesium	No	Dis.	mg/l	CA	197	196	0	0.44	88	6.69	8.9	9.64	6.69	8.9	9.64	Jul-30	Jul-82											
Major Cations	Magnesium	No	Tot.	mg/l	CA	69	69	0	0.1	45.8	8.1	9.98	8.07	8.1	9.98	8.07	Jul-82	Apr-86											
Major Cations	Potassium	No	Dis.	mg/l	CA	135	134	0	0.2	25	1.05	1.92	2.31	1.05	1.92	2.31	Jul-30	Jul-82											
Major Cations	Potassium	No	Tot.	mg/l	CA	82	78	0	0.4	19.8	1.1	1.66	2.39	1.1	1.66	2.39	Jul-81	Apr-86											
Major Cations	Sodium	No	Dis.	mg/l	CA	410	409	0	1.18	2000	9.86	25.8	104	9.86	25.8	104	Jul-30	Jul-82	20	104									
Major Cations	Sodium	No	Tot.	mg/l	CA	82	78	0	2.1	2510	16.6	77.4	291	16.6	77.4	291	Jul-81	Apr-86	20	38									
Metals	Aluminum	No	Dis.	ug/l	M	400	400	2	2	6230	40	134	447	40	135	448	Oct-73	Jul-82				200	44					16000	0
Metals	Aluminum	No	Tot.	ug/l	M	54	54	35	5	24000	50	563	3260	100	1510	5460	Aug-83	Apr-86				200	4					16000	1
Metals	Arsenic	No	Dis.	ug/l	CA	10	10	0	3	40.1	11.5	16.3	11.9	11.5	16.3	11.9	Oct-73	Jun-06	10	6				10	6	0.045	10	4.7	9
Metals	Arsenic	No	Tot.	ug/l	CA	109	103	93	2	500	2.25	41.3	127	10	21	22	Jul-81	Jun-06	10	7				10	7	0.045	16	4.7	13
Metals	Barium	No	Tot.	ug/l	CA	52	52	20	5	98000	200	2570	13700	300	4170	17400	Aug-83	Apr-86	2000	3				2000	3			2900	3
Metals	Cadmium	No	Tot.	ug/l	M	50	46	50	ND	ND	ND	ND	ND	ND	ND	ND	Jul-81	Apr-86	5	0				5	0			6.9	0
Metals	Chromium	No	Dis.	ug/l	M	55	54	0	10	50	10	14.8	9.47	10	14.8	9.47	Jan-75	Jul-82	100	0				100	0				
Metals	Chromium	No	Tot.	ug/l	M	82	78	62	5	120	15	21.9	21.9	10	26.5	36.3	Jul-81	Apr-86	100	2				100	2				
Metals	Dysprosium	No	Dis.	ug/l	-	278	278	263	0.0005	2.375	0.01	0.0326	0.192	0.15	0.483	0.707	Jul-77	Oct-77											
Metals	Iron	No	Dis.	ug/l	M	141	140	0	10	47500	110	1000	4380	110	1000	4380	Jul-30	Jul-82				300	48					11000	3
Metals	Iron	No	Tot.	ug/l	M	82	78	6	10	56400	293	1550	6470	340	1670	6730	Jul-81	Apr-86				300	39					11000	2
Metals	Lead	No	Tot.	ug/l	M	54	52	52	2	500	2.5	17.5	69.9	300	300	283	Jul-81	Apr-86	15	2				5	2				
Metals	Manganese	No	Dis.	ug/l	M	344	343	1	5	4600	99.2	162	332	99.3	162	333	May-55	Jul-82				50	256	300	36			320	34
Metals	Manganese	No	Tot.	ug/l	M	81	77	22	5	7370	80	258	850	140	354	992	Jul-81	Apr-86				50	46	300	13			320	12
Metals	Nickel	No	Tot.	ug/l	M	54	54	54	ND	ND	ND	ND	ND	ND	ND	ND	Aug-81	Apr-86						100	0			300	0
Metals	Strontium	No	Tot.	ug/l	CA	66	66	4	5	80000	150	1690	9940	160	1800	10200	Aug-83	Apr-86										9300	2
Metals	Uranium	No	Dis.	ug/l	M	278	278	22	0.001	4.837	0.136	0.471	0.775	0.195	0.511	0.795	Jul-77	Oct-77	30	0									
Metals	Vanadium	No	Dis.	ug/l	M	278	278	246	0.05	2	0.1	0.2	0.261	0.35	0.472	0.39	Jul-77	Oct-77						260	0			78	0
Metals	Zinc	No	Dis.	ug/l	M	127	126	0	10	5700	30	193	719	30	193	719	Oct-73	Jul-82				5000	1	2000	3			4700	2
Metals	Zinc	No	Tot.	ug/l	M	82	78	7	5	670	30	58.2	106	30	62.6	110	Jul-81	Apr-86				5000	0	2000	0			4700	0
Nutrients	Ammonia-nitrogen as N	No	Dis.	mg/l	M	135	134	1	0.005	3.2	0.02	0.122	0.331	0.02	0.123	0.332	Mar-70	Jul-82											
Nutrients	Nitrate as N	No	Dis.	mg/l	CA	226	221	14	0.009	13.9	0.119	0.748	1.64	0.16	0.794	1.68	Jul-30	Aug-98	10	2				10	2			25	0
Nutrients	Nitrite as N	No	Dis.	mg/l	CA	194	188	102	0.001	0.04	0.005	0.00383	0.00375	0.001	0.00248	0.00518	Jul-81	Aug-98	1	0				1	0			1.6	0
Nutrients	Phosphate as P	No	Tot.	mg/l	-	52	52	5	0.0005	0.212	0.0168	0.0316	0.0413	0.018	0.0342	0.0426	Aug-83	Apr-86											

Table 3-4. Summary of Water Quality Parameters Monitored in Groundwater (Reduced Dataset, Excluding Environmental Impact Data) in Bradford and Susquehanna Counties (Continued)

M – measured, as defined in EPA QAPP for the Bradford/Susquehanna Retrospective Case Study (EPA, 2012b).
CA = Critical Analyte, as defined in EPA QAPP for the Bradford/Susquehanna Retrospective Case Study (EPA, 2012b). A red highlight indicates the value is above a screening criteria.
MCL: EPA Maximum Contaminant Levels (National Primary Drinking Water Regulation)
SMCL: EPA Secondary MCL (Non-enforaceable guidance for drinking water)
Act 2: State of Pennsylvania Land Recycling Program (Voluntary Remediation Program) Screening Limits: Limits are for used, residential groundwater aquifer with TDS ≤ 2500 mg/L
EPA Carc./EPA Non-Carc.: The carcinogenic and non-carcinogenic screening limits established by the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)
Note: Sodium does not have an MCL; the value listed in the MCL column represents the EPA Health Advisory Level.
ND = non-detect
SD = standard deviation

Table 3-5. Parameters in EPA QAPP Groundwater Analyte List for Which No Historical Data Are Available in the Complete Dataset

Parameter - Measured		Parameter - Critical Analyte	
NOT FOUND			
Inorganic carbon	2.3.5.6-Tetrachlorophenol	Butane	Dibutyl phthalate
Iron, ion (Fe2+)	adamantane	Ethane	Diethyl phthalate
Redox Potential	Aniline	Methane	Dimethyl phthalate
Sulfide	Azobenzene	Propane	Fluoranthene
Diethylene glycol monobutyl ether acetate	Benzoic acid	2,4,5-Trichlorophenol	Fluorene
tetraethylene glycol	bis(2-ethylhexyl) adipate	2,4,6-Trichlorophenol	Hexachlorobutadiene
triethylene glycol	Cyclohexene, 1-methyl-4-(1-methylethenyl)-, (4R)-	2,4-Dichlorophenol	Hexachloroethane
Carbon-13/Carbon-12 ratio	Diphenylamine	2,4-Dimethylphenol	Indeno[1,2,3-cd]pyrene
d2H	Hexachlorobenzene	2,4-Dinitrotoluene	Isophorone
d87/86Sr	m-Dinitrobenzene	2,6-Dinitrotoluene	m-Cresol
Oxygen-18/Oxygen-16 ratio	N-Nitrosodimethylamine	2-Chloronaphthalene	m-Dichlorobenzene
acetate	p-Nitrophenol	2-Methylnaphthalene	m-Nitroaniline
Butyric acid	Phenol	3,3'-Dichlorobenzidine	N-Nitrosodi-n-propylamine
formate	Pyridine	4,6-Dinitro-o-cresol	Naphthalene
isobutyrate	squalene	4-methylphenol	Nitrobenzene
Lactic acid	terpineol	Acenaphthene	o-Chlorophenol
Propionic acid	tri(2-butoxethyl)phosphate	Acenaphthylene	o-Cresol
Cerium	1,1-Dichloroethane	Anthracene	o-Nitroaniline
Molybdenum	1,2,3-Trimethylbenzene	Benz[a]anthracene	o-Nitrophenol
Silicon	1,2,4-Trimethylbenzene	Benzo(b)fluoranthene	p-Bromophenyl phenyl ether
Sulfur	1,3,5-Trimethylbenzene	Benzo[ghi]perylene	p-Chloro-m-cresol
Titanium	Acetone	Benzo[k]fluoranthene	p-Chloroaniline
Gross alpha	Carbon disulfide	Benzyl alcohol	p-Chlorophenyl phenyl ether
Gross beta	Chloroform	Bis(2-chloroethoxy) methane	p-Nitroaniline
Ra 226/228	Cumene	Bis(2-chloroethyl) ether	Phenanthrene
1,2-dinitrobenzene	Ethyl tert-butyl ether	Bis(2-chloroisopropyl) ether	Pyrene
1,3-dimethyl adamantane	Isopropyl ether	Butyl benzyl phthalate	Acrylonitrile
1,4-dinitrobenzene	m-Xylene	Carbazole	Diesel range organics
1-Methylnaphthalene	Methyl tert-butyl ether	Chrysene	Ethanol
2,3,4,6-Tetrachlorophenol	o-Xylene	Di-n-octyl phthalate	Gasoline range organics
2,4-Dinitrophenol	p-Xylene	Dibenz[a,h]anthracene	isopropyl alcohol
2-butoxyethanol	tert-Amyl methyl ether	Dibenzofuran	tert-Butanol
Parameter - Measured		**Parameter - Critical Analyte**	
SAMPLE SIZE ≤ 8			
Oxygen	cis-1,2-Dichloroethylene	Boron	o-Dichlorobenzene
Cobalt	Ethylbenzene	1,2,4-Trichlorobenzene	p-Dichlorobenzene
Hexachlorocyclopentadiene	Methylene chloride	Benzo[a]pyrene	Pentachlorophenol
1,1,1-Trichloroethane	Tetrachloroethylene	Di(2-ethylhexyl) phthalate	
1,1,2-Trichloroethane	Toluene		
1,1-Dichloroethylene	trans-1,2-Dichloroethylene		
1,2-Dichloroethane	Trichloroethylene		
Benzene	Vinyl chloride		
Carbon tetrachloride	Xylene		
Chlorobenzene			

3.3 Surface Water and Spring Quality

This section summarizes the characteristics of surface water resources and springs in Bradford and Susquehanna Counties. An analysis is also provided of available surface water and spring quality data in comparison to water quality screening criteria.

3.3.1 Watershed Characteristics. Both counties are located within the Susquehanna River Basin, which has a total drainage of 27,200 square miles. Table 3-6 summarizes the HUC 8 subbasins crossing Bradford and Susquehanna Counties. This list includes six subbasins, which drain to the Upper Susquehanna (HUC 020501) and one subbasin that drains to the West Branch of the Susquehanna (HUC 020502). The Upper Susquehanna-Tunkhannock subbasin (HUC 02050106) covers the majority of the land area across the two counties, so the discussion of known water quality impairments is focused primarily within this drainage area. Figure 3-9 shows the locations of named streams and rivers within Bradford and Susquehanna Counties. The major rivers and creeks in Bradford County include the Susquehanna River, Chemung River, Sugar Creek, Towanda Creek, and Wysox -Wyalusing Creek. The major rivers and creeks in Susquehanna County include the Susquehanna River, Tunkhannock Creek, and Wysox-Wyalusing Creek. Figure 3-10 shows the HUC 8 boundaries for the watersheds in Bradford and Susquehanna Counties.

Table 3-6. Definitions of HUCs for Bradford and Susquehanna Counties[11]

HUC Code	Definition	Size, square miles	Location
0205	Sub-region	27,200	Susquehanna River Basin in MD, NY, and PA
020501	Accounting Unit	11,200	Upper Susquehanna: Susquehanna River Basin above the confluence with the West Branch Susquehanna River Basin in NY and PA
02050101	Subbasin	2,260	Upper Susquehanna in NY and PA
02050103	Subbasin	1,040	Owego-Wappasening in NY and PA
02050104	Subbasin	1,370	Tioga in NY and PA
02050105	Subbasin	1,200	Chemung in NY and PA
02050106	Subbasin	1,980	Upper Susquehanna-Tunkhannock in PA
02050107	Subbasin	1,760	Upper Susquehanna-Lackawanna in PA
020502	Accounting Unit	6,920	West Branch Susquehanna: West Branch Susquehanna River Basin, PA
02050206	Subbasin	1,810	Lower West Branch Susquehanna, PA

As part of its authority under the CWA, PADEP has reviewed water quality conditions to characterize the nature and extent of water pollution or degradation across the state. The information gathered is reported in the *2012 Pennsylvania Integrated Water Quality Monitoring and Assessment Report* (PADEP, 2012a).

[11] Note: Only those HUC 8 subbasins crossing Bradford and Susquehanna County are listed here. The full list of HUCs within the Susquehanna River Basin can be found at http://water.usgs.gov/GIS/huc_name.txt.

Under the CWA, PADEP identifies streams that are impaired for their intended beneficial use and describes the nature of the impairments (e.g., the constituents of concern) and the potential causes of the impairment (e.g., the activities that led to the contaminant loading to the surface water). Figure 3-10 shows the location of streams and rivers within Bradford and Susquehanna Counties for which TMDLs have been established due to known surface water quality impairments. There are over 144 miles of impaired streams and rivers in Bradford County, representing approximately 6.7% of the total stream length. Table 3-7 shows the constituents of concern that have caused these surface water impairments in Bradford County, comprising pH, metals, polychlorinated biphenyls (PCBs), and siltation. There are over 87 miles of impaired streams and rivers in Susquehanna County, representing approximately 5.5% of the total stream length. Table 3-7 shows the constituents of concern that have caused surface water impairments in Susquehanna County, comprising pH, metals, PCBs, nutrients, siltation, and suspended solids (PADEP, 2012a).

Table 3-7. Sources of Surface Water Impairments within Bradford and Susquehanna Counties

Parameter Causing Impairment	Bradford County Miles of Impaired Streams and Rivers	Susquehanna County Miles of Impaired Streams and Rivers
Metals; pH	34	60
PCBs	63	9
Siltation; Nutrients; Suspended Solids	58	23

Note: Some streams have overlapping impairments on the same reach so the values here should not be summed to a total value.

Table 3-8 shows the date that each TMDL was approved for the surface water bodies in Bradford and Susquehanna Counties. Five of seven TMDLs listed were approved prior to 2007. Two of the TMDL designations were made post-2007 in Bradford County. One TMDL designation was approved in 2011 for siltation impacts to surface water caused by agricultural activities and road runoff, while a second TMDL designation is pending for pH impairments to surface water caused by AMD.

Table 3-9 shows the causes of impairments as determined by PADEP in 2006, which are listed for the Upper Susquehanna-Tunkhannock Subbasin crossing both Bradford and Susquehanna Counties (EPA, 2012c). This information was not available at the county level, so it is summarized in Table 3-9 at the watershed (subbasin) level that extends beyond the borders of Bradford and Susquehanna Counties. This subbasin covers over 70% of the land area of the two counties combined. The top two known causes of impairments are road runoff (93 miles) and agriculture (78 miles). The entire length of the Susquehanna River is impaired primarily for PCBs with advisories limiting fish consumption in both Bradford and Susquehanna Counties. Agricultural impacts from siltation are primarily located in the Wysox Creek watershed in Bradford County (SRBC, 2004). There are known AMD impairments caused by low pH and high metals concentrations as a result of historic coal mining activities located in the south central section of Bradford County in the Towanda Creek watershed (PADEP, 2004). Agricultural impacts with elevated nutrients and siltation are known in the Wyalusing Creek watershed in Susquehanna County (PADEP, 2001). As shown in Figure 3-10, there are AMD impairments in the far southeastern corner of Susquehanna County in the Lackawanna River watershed; these impairments are located primarily in the Upper Susquehanna-Lackawanna Subbasin and therefore not included in Table 3-9.

Table 3-8. Dates of Surface Water Impairments in Bradford and Susquehanna Counties (PA DEP, 2012)[12]

Surface Water Body	County	Date TMDL Approved	Category	Cause	Notes
Susquehanna River	Bradford and Susquehanna	3/12/1999	Fish Consumption	PCBs	Prior to 2007
Stephen Foster Lake	Bradford	4/9/2001	Non-point source	Nutrients	Prior to 2007
South Branch Wyalusing Creek	Susquehanna	4/9/2001	Non-point source	Nutrients, siltation, suspended solids	Prior to 2007
Long Valley Watershed	Bradford	4/1/2005	AMD	Metals, pH	Prior to 2007
Lackawanna River Watershed	Susquehanna	4/7/2005	AMD	Metals, pH	Prior to 2007
Johnson Creek Watershed	Bradford	6/22/2011	Non-point source	Siltation	Impaired by sediment from agricultural land use practices and road runoff
Lycoming Creek	Bradford	Pending	Non-point source	pH	AMD

Table 3-9. Causes of Impairments in the Upper Susquehanna-Tunkhannock Subbasin Crossing Both Bradford and Susquehanna Counties as Reported by PADEP in 2006 (EPA, 2012c)

Cause of Impairment	Miles
Source Unknown	124.1
Road Runoff/Logging Roads	92.7
Agriculture	77.5
Abandoned Mine Drainage	12.7
Urban Runoff/Storm Sewers	8.7
Channelization	6.7
Municipal Point Source Discharges	6.5
Silviculture Activities	6.4
Erosion From Barren Land	4.5
Upstream Impoundments	4.5

[12] http://www.ahs.dep.pa.gov/TMDL/

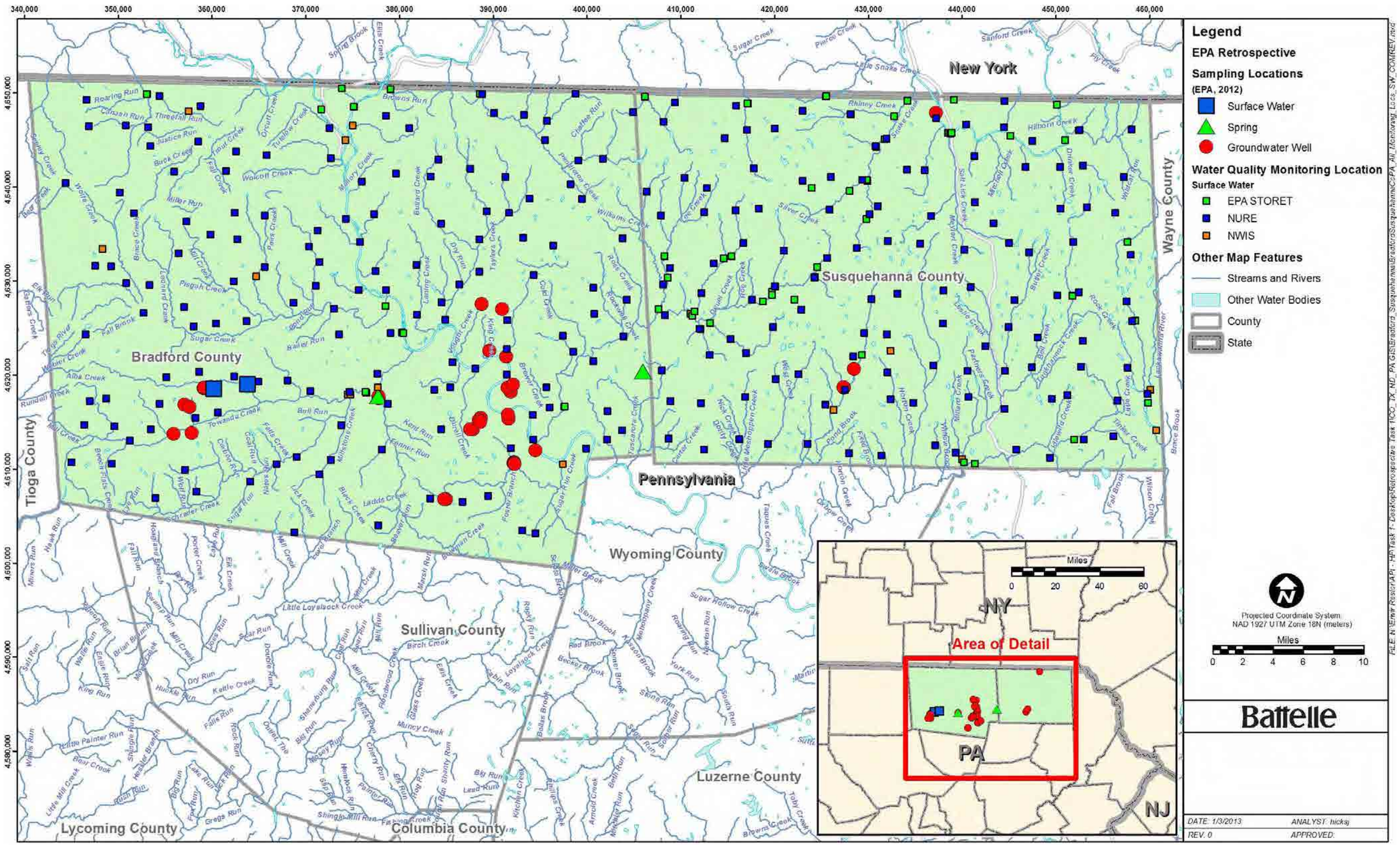

Figure 3-9. Surface Water Resources and Surface Water Quality Monitoring Locations in Bradford and Susquehanna Counties

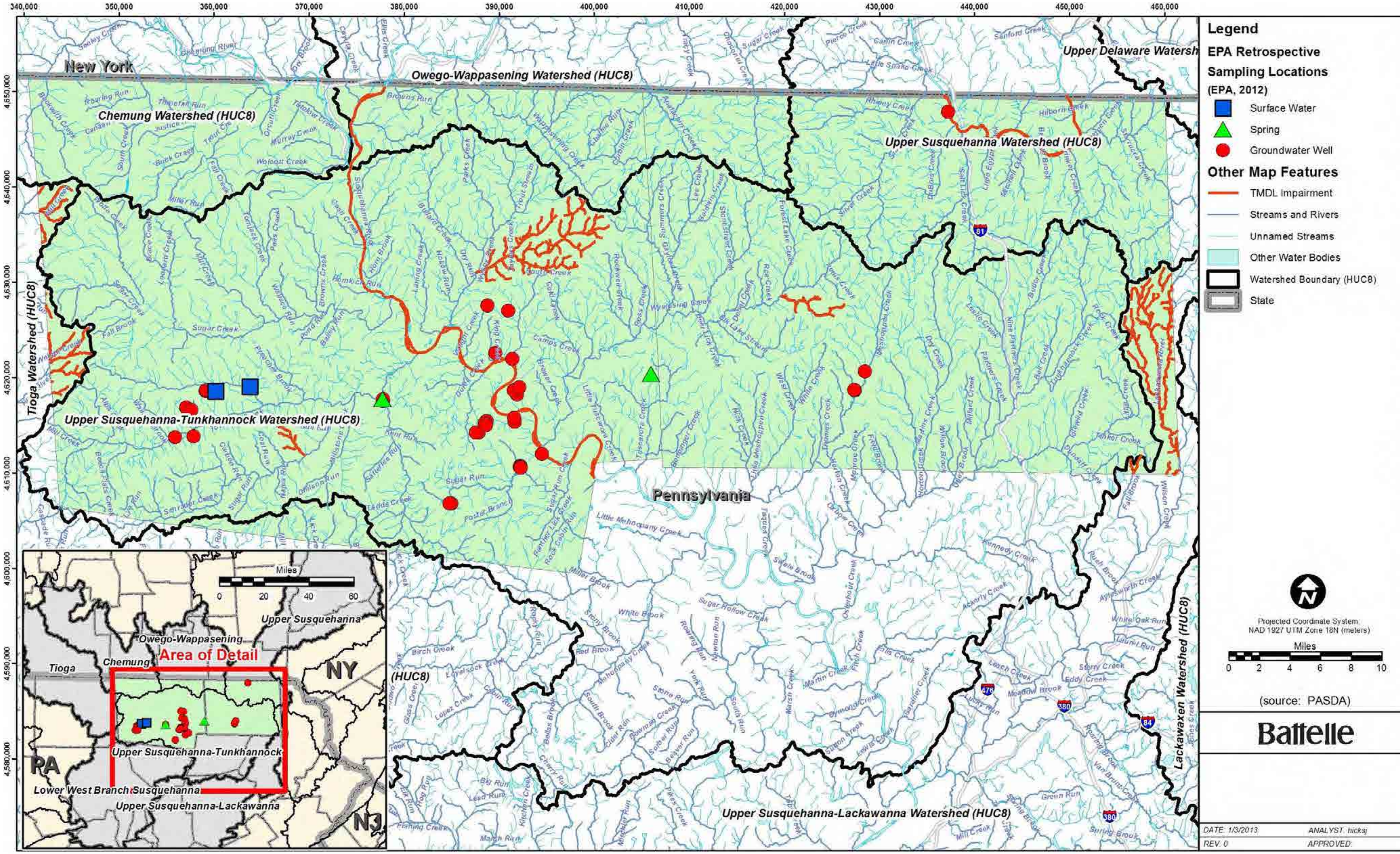

Figure 3-10. HUC 8 Watersheds and Surface Water Impairments in Bradford and Susquehanna Counties

3.3.2 Surface Water Data Summary. Water-quality data (from the sources identified in Section 2.0) were compiled into a database to characterize the condition of surface water resources within Bradford and Susquehanna Counties. Summary tables were compiled as noted in Section 2.0 for the complete dataset (includes data potentially associated with environmental impacts) and for a reduced dataset that removed data potentially associated with environmental impacts. Figure 3-9 shows the location of the 353 surface water quality monitoring stations represented in the database (including locations potentially associated with environmental impacts). The dates of the sampling events at these surface water quality stations range from 1935 to 2011. For the purpose of this evaluation, surface water data were limited to the time frame prior to 2007 so that baseline water quality could be considered prior to when unconventional oil and gas development via hydraulic fracturing began.. The parameters monitored in surface water include general water quality parameters, major and minor ions, metals, radionuclides, and organics including VOCs and semivolatile organic compounds (SVOCs).

Data tables were produced to summarize the available surface water quality data, including the number of samples, the minimum, maximum, median, and mean constituent concentration, the standard deviation of the concentration range, and the date range for sample collection. Relevant surface water quality screening criteria were also included for comparison. Table 3-10 provides a summary of water quality data for surface water generated prior to 2007 (the complete dataset that includes data potentially associated with environmental impacts). Summary data tables presented are limited to parameters having a minimum of eight sample locations. Observed concentrations in the surface water quality dataset were compared to EPA MCLs and SMCLs, Pennsylvania surface water quality standards for public water supply systems, Pennsylvania fish and aquatic life criteria, and CWA freshwater surface water quality criteria (chronic).

Inorganic Summary. Observed constituent concentrations from prior to 2007 are above of one or more of the screening criteria for three general water quality parameters (alkalinity, pH, and TDS) and two major anions (chloride and sulfate). Total sodium also was higher than the EPA Health Advisory level of 20 mg/L in one sample. For metals, observed results were above one or more of the screening criteria for aluminum, copper, iron, lead, manganese, and zinc. Nitrate and nitrite as N results also showed detections above screening criteria. Figure 3-11 shows the surface water sampling locations for the complete dataset where detected concentrations are above one or more of the screening criteria.

Organic Summary. No organic constituents in surface water were detected in eight or more sample locations.

3.3.2.1 Comparison Against Reduced Data Table. Table 3-11 provides a summary of pre-2007 surface water data in a similar format to Table 3-10, with the exception of 67 locations that were removed (63 from STORET and four from NURE) based on the rationale provided in Table 2-3. This summary data table was created for comparison against the complete background surface water quality summary data table (Table 3-10) to determine whether the data identified as indicative of potential environmental impact monitoring or having location issues has a significant effect on background water quality.

The parameters that are outside of the limits of the screening criteria in the reduced or revised summary data table (Table 3-10) are similar to those in the comprehensive data summary table; these include alkalinity, pH, chloride, sulfate, aluminum, copper, iron, manganese, nitrate, and nitrite. Except for total manganes, the maximum detected values for these parameters are identical when comparing the two datasets, as are the respective screening criteria that are not met. There are no results for lead or zinc in surface water in the reduced data summary table. Variations in TDS and sodium between the two data sets are discussed below.

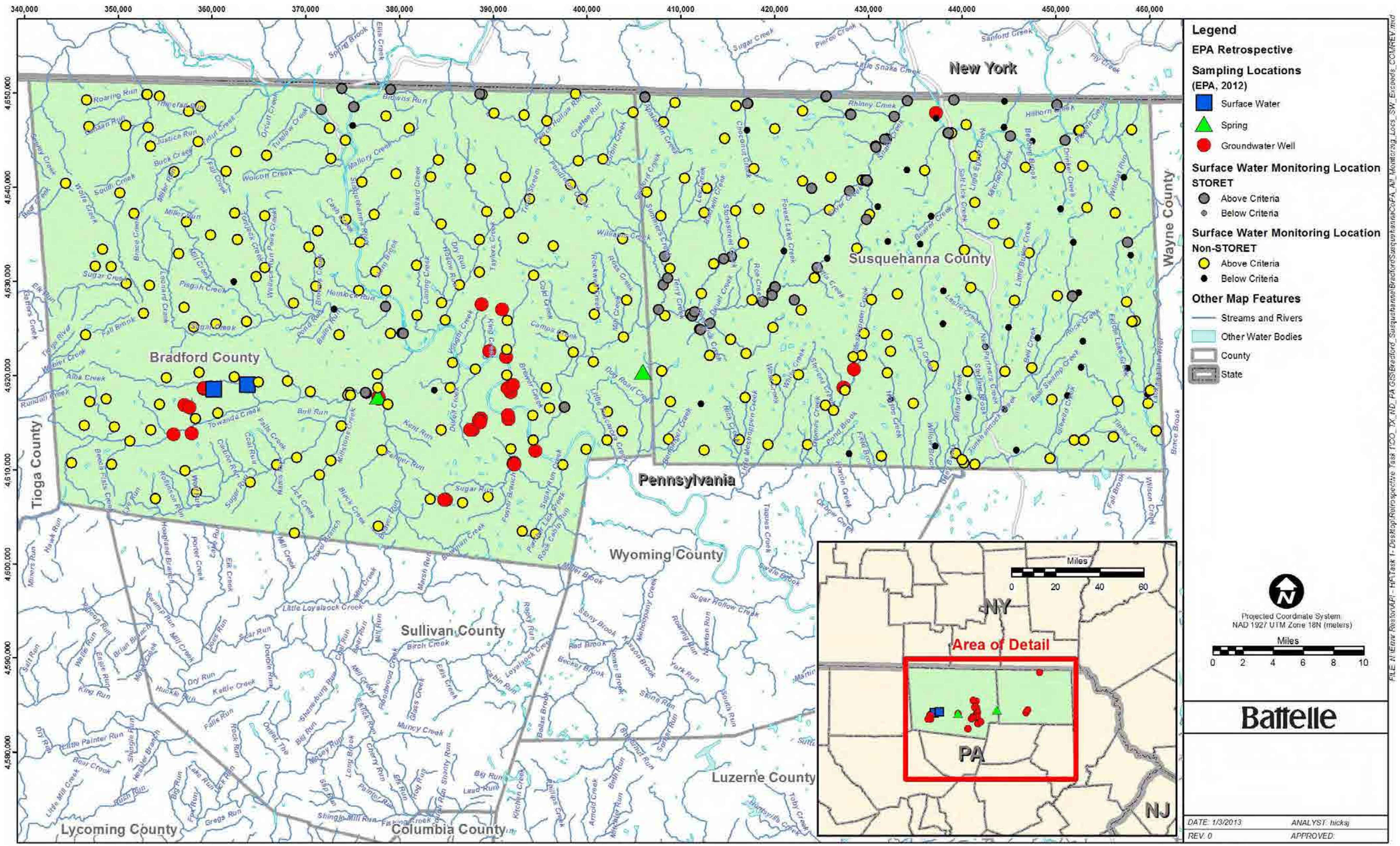

Figure 3-11. Surface Water Monitoring Stations and Spatial Distribution of Detections above Screening Criteria in Surface Water in Bradford and Susquehanna Counties

Table 3-10. Summary of Water Quality Parameters Monitored (Complete Dataset, Including Environmental Impact Data) in Surface Water in Bradford and Susquehanna Counties

											Including NDs			Excluding NDs															
Class	Parameter	Field Result	Frac.	Units	EPA Class	No. Samples	No. Locations	No. ND	Min	Max	Median	Mean	SD	Median	Mean	SD	Begin Sample Date	End Sample Date	MCL	N Above MCL (no NDs)	SMCL	SMCL High	N Above SMCL (no NDs)	CWA Chronic	N Above CWA Chronic (no NDs)	PA SW Qual PWS	N Above SW Qual PWS (no NDs)	PA SW Qual Fish	N Above Qual Fish (no NDs)
Dissolved Gas	Carbon dioxide	No	Tot.	mg/l	-	320	24	0	0.1	84	4.08	5.3	5.53	4.08	5.3	5.53	Mar-45	Nov-06											
Gen WQ	Acidity, hydrogen ion (H+) as CaCO3	Yes	Tot.	mg/l	-	230	11	0	1	50	5.08	4.78	2	5.08	4.78	2	Apr-86	May-03											
Gen WQ	Alkalinity as CaCO3	No	Tot.	mg/l	M	154	11	0	13	99	63.1	52.1	22.4	63.1	52.1	22.4	Aug-82	Nov-06						20	13				
Gen WQ	Alkalinity as CaCO3	Yes	Tot.	mg/l	M	784	75	0	4	790	29.3	37.1	25.9	29.3	37.1	25.9	Sep-35	Nov-06						20	161				
Gen WQ	Hardness as CaCO3	No	Tot.	mg/l	-	483	32	0	10	200	57.5	62.4	26.7	57.5	62.4	26.7	Sep-35	Dec-06											
Gen WQ	Hardness, non-carbonate as CaCO3	Yes	Tot.	mg/l	-	65	15	0	3	55	15	14.8	5.03	15	14.8	5.03	Sep-35	Apr-75											
Gen WQ	Organic carbon	No	Tot.	mg/l	M	634	32	0	1	60	2.74	3.12	1.61	2.74	3.12	1.61	Oct-69	Dec-06											
Gen WQ	Oxygen	No	Dis.	mg/l	M	311	14	0	2.5	15.9	11.1	10.9	0.807	11.1	10.9	0.807	Jul-69	Nov-06											
Gen WQ	Oxygen	Yes	Dis.	mg/l	M	837	62	0	4.28	15.94	8.53	8.15	1.95	8.53	8.15	1.95	Aug-82	Dec-06											
Gen WQ	pH	No	Tot.	std units	M	377	24	0	5.5	8.7	7.41	7.38	0.497	7.41	7.38	0.497	Mar-81	Dec-06			6.5	8.5	12						
Gen WQ	pH	Yes	Tot.	std units	M	1493	352	0	0.7	10.4	7.6	7.52	0.663	7.6	7.52	0.663	Mar-45	Dec-06			6.5	8.5	108						
Gen WQ	Specific conductance	No	Tot.	umho/cm	M	372	23	0	1.47	483	184	170	66.4	184	170	66.4	Mar-81	Dec-06											
Gen WQ	Specific conductance	Yes	Tot.	umho/cm	M	1516	352	0	8.47	1165	110	128	60.9	110	128	60.9	Mar-45	Dec-06											
Gen WQ	Temperature, water	No	Tot.	deg C	M	412	24	0	0.1	27.5	13	12.9	3.03	13	12.9	3.03	Mar-45	Nov-06											
Gen WQ	Temperature, water	Yes	Tot.	deg C	M	854	63	0	-0.04	29	12.4	14.2	4.92	12.4	14.2	4.92	Aug-82	Dec-06											
Gen WQ	Total dissolved solids	No	Dis.	mg/l	-	711	39	1	0.018	3728	99.6	108	43.8	99.6	108	43.8	Sep-35	Dec-06				500	4			750	2		
Gen WQ	Total suspended solids	No	Non-filterable	mg/l	-	178	9	55	1	800	13	20.4	22.5	14	23.7	24	Aug-62	Nov-06											
Gen WQ	Total suspended solids	No	Susp.	mg/l	-	482	25	0	2	822	54.8	59.3	56.2	54.8	59.3	56.2	Aug-73	Dec-06											
Gen WQ	Turbidity	No	Tot.	NTU	M	237	15	0	1	44	3.59	4.03	1.64	3.59	4.03	1.64	Apr-86	Sep-05											
Major Anions	Bromide	No	Dis.	mg/l	M	203	203	103	0.0007	1.34	0.013	0.0453	0.162	0.0213	0.0834	0.224	Aug-77	Oct-77											
Major Anions	Chloride	No	Dis.	mg/l	CA	873	309	4	0.05	2200	8.2	9.61	8.57	8.2	9.65	8.57	Sep-35	Sep-05				250	2	230	2	250	2		
Major Anions	Fluoride	No	Dis.	mg/l	M	309	264	44	0.0015	0.7	0.044	0.0495	0.0334	0.045	0.0512	0.0342	Feb-69	Jan-05	4	0		2	0			2	0		
Major Anions	Sulfate	No	Dis.	mg/l	CA	806	55	1	0.5	880	14.9	17.3	11.8	14.9	17.3	11.8	Sep-35	Dec-06				250	1			250	1		
Major Cations	Calcium	No	Dis.	mg/l	CA	78	17	0	4	49	15.7	17.8	7.76	15.7	17.8	7.76	Feb-48	Mar-02											
Major Cations	Calcium	No	Tot.	mg/l	CA	679	34	0	5.27	61	14.6	17.6	8.8	14.6	17.6	8.8	Jan-70	Dec-06											
Major Cations	Magnesium	No	Dis.	mg/l	CA	93	32	1	0.05	21	3.14	4	3.43	3.14	4	3.42	Feb-48	Mar-02											
Major Cations	Magnesium	No	Tot.	mg/l	CA	716	33	0	0.494	12.3	3.07	3.56	1.34	3.07	3.56	1.34	Nov-72	Dec-06											
Major Cations	Sodium	No	Dis.	mg/l	CA	291	274	1	0.015	17.99	8.2	7.31	3.84	8.37	7.33	3.82	Jul-58	Oct-77	20	0									
Major Cations	Sodium	No	Tot.	mg/l	CA	8	8	0	4.07	41	9.7	13.9	11.5	9.7	13.9	11.5	Jul-01	Sep-05	20	1									
Metals	Aluminum	No	Dis.	ug/l	M	355	278	17	2	2916	70.5	98.7	188	70.5	98.7	188	Sep-64	Jan-05				200	34	87	109			750	4
Metals	Aluminum	No	Tot.	ug/l	M	366	29	88	0.1	12500	356	435	352	400	514	363	Aug-82	Dec-06				200	201	87	245			750	55
Metals	Copper	No	Tot.	ug/l	M	163	14	141	2	1820	9.15	63	165	17	73.2	169	Oct-69	Nov-06	1300	1		1000	1						
Metals	Dysprosium	No	Dis.	ug/l	-	264	264	250	0.0005	2.393	0.013	0.0348	0.2	0.0705	0.418	0.801	Aug-77	Oct-77											
Metals	Iron	No	Dis.	ug/l	M	282	19	31	4.48	700	60	95.1	74.9	60	97.2	72.8	Sep-64	Jan-05				300	18	1000	0	300	18		
Metals	Iron	No	Tot.	ug/l	M	828	42	4	0.26	34300	552	1070	1930	564	1090	1940	Jul-69	Dec-06				300	331	1000	139	300	331		
Metals	Lead	No	Tot.	ug/l	M	168	12	139	0.5	14.6	0.775	1.41	1.22	2.3	2.32	1.13	Apr-02	Nov-06	15	0				2.5	11				
Metals	Manganese	No	Dis.	ug/l	M	450	264	23	0.1	1204	91	93.6	82.9	91.3	95.4	82.7	Jul-58	Jan-05				50	252			1000	1		
Metals	Manganese	No	Tot.	ug/l	M	584	34	17	0.06	631	40.7	52.3	37.8	42	55.3	38.9	Feb-69	Dec-06				50	153			1000	0		
Metals	Phosphorus	No	Tot.	ug/l	M	289	19	28	4	600000	30	3040	12500	33.3	3210	12900	Aug-69	Nov-06											
Metals	Uranium	No	Dis.	ug/l	M	262	262	51	0.001	0.755	0.0255	0.0708	0.131	0.038	0.0873	0.141	Aug-77	Oct-77	30	0									
Metals	Vanadium	No	Dis.	ug/l	M	261	261	185	0.05	1.8	0.1	0.209	0.232	0.4	0.446	0.231	Sep-64	Oct-77										510	0
Metals	Zinc	No	Tot.	ug/l	M	210	14	120	2.5	60000	17.8	1100	4040	30.1	1110	4030	Apr-71	Dec-06				5000	1	120	3				
Nutrients	Ammonia-nitrogen as N	No	Dis.	mg/l	M	598	40	120	0.005	23.5	0.0636	0.125	0.272	0.0688	0.136	0.287	Feb-69	Dec-06											
Nutrients	Nitrate as N	No	Dis.	mg/l	CA	674	39	6	0.02	91	0.354	0.625	1.01	0.354	0.628	1.01	Sep-35	Nov-06	10	2						10	2		
Nutrients	Nitrite as N	No	Dis.	mg/l	CA	420	24	148	0.002	3.3	0.02	0.0313	0.0385	0.0234	0.0449	0.0872	Feb-69	Nov-06	1	1						10	0		
Nutrients	Nitrogen	No	Dis.	mg/l	-	112	11	0	0.17	2.48	0.462	0.639	0.379	0.462	0.639	0.379	Jul-00	Dec-06											
Nutrients	Nitrogen	No	Tot.	mg/l	-	456	30	0	0.07	21	0.586	0.661	0.301	0.586	0.661	0.301	Apr-75	Dec-06											
Nutrients	Orthophosphate as P	No	Dis.	mg/l	-	393	19	0	0.002	1.14	0.0149	0.0209	0.0257	0.0149	0.0209	0.0257	Nov-87	Dec-06											

Table 3-10. Summary of Water Quality Parameters Monitored (Complete Dataset, Including Environmental Impact Data) in Surface Water in Bradford and Susquehanna Counties (Continued)

											Including NDs			Excluding NDs															
Class	Parameter	Field Result	Frac.	Units	EPA Class	No. Samples	No. Locations	No. ND	Min	Max	Median	Mean	SD	Median	Mean	SD	Begin Sample Date	End Sample Date	MCL	N Above MCL (no NDs)	SMCL	SMCL High	N Above SMCL (no NDs)	CWA Chronic	N Above CWA Chronic (no NDs)	PA SW Qual PWS	N Above SW Qual PWS (no NDs)	PA SW Qual Fish	N Above Qual Fish (no NDs)
Nutrients	Phosphate as P	No	Dis.	mg/l	-	295	15	0	0.003	1.44	0.0245	0.0333	0.0322	0.0245	0.0333	0.0322	Jun-73	Dec-06											
Nutrients	Phosphate as P	No	Tot.	mg/l	-	438	25	56	0.004	6	0.03	0.0794	0.202	0.0358	0.0865	0.21	Oct-69	Nov-06											

M – measured, as defined in EPA QAPP for the Bradford/Susquehanna Retrospective Case Study (EPA, 2012b).CA = Critical Analyte, as defined in EPA QAPP for the Bradford/Susquehanna Retrospective Case Study (EPA, 2012b).
A red highlight indicates the value is above a screening criteria.
MCL: EPA Maximum Contaminant Levels (National Primary Drinking Water Regulation)
SMCL: EPA Secondary MCL (Non-enforaceable guidance for drinking water)
Act 2: State of Pennsylvania Land Recycling Program (Voluntary Remediation Program) Screening Limits: Limits are for used, residential groundwater aquifer with TDS ≤ 2500 mg/L
EPA Carc./EPA Non-Carc.: The carcinogenic and non-carcinogenic screening limits established by the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)
Note: Sodium does not have an MCL; the value listed in the MCL column represents the EPA Health Advisory Level.
ND = non-detect
SD = standard deviation

Table 3-11. Surface Water Summary Data (Reduced Dataset, Excluding Environmental Impact Monitoring Data) for Bradford and Susquehanna Counties

											Including NDs			Excluding NDs															
Class	Parameter	Field Results	Frac.	Units	EPA Class	No. Samples	No. Locations	No. ND	Min	Max	Median	Mean	SD	Median	Mean	SD	Begin Sample Date	End Sample Date	MCL	N Above MCL (no NDs)	SMCL	SMCL High	N Above SMCL (no NDs)	CWA Chronic	N Above CWA Chronic (no NDs)	PA SW Qual PWS	N Above SW Qual PWS (no NDs)	PA SW Qual Fish	N Above Qual Fish (no NDs)
Dissolved Gas	Carbon dioxide	No	Tot.	mg/l	-	320	24	0	0.1	84	4.08	5.3	5.53	4.08	5.3	5.53	Mar-45	Nov-06											
Gen WQ	Alkalinity as CaCO3	Yes	Tot.	mg/l	M	196	20	0	4	790	38.3	48.1	36	38.3	48.1	36	Sep-35	Aug-81						20	27				
Gen WQ	Hardness as CaCO3	No	Tot.	mg/l	-	263	21	0	10	200	47.3	55.6	24.2	47.3	55.6	24.2	Sep-35	Nov-06											
Gen WQ	Hardness, non-carbonate as CaCO3	Yes	Tot.	mg/l	-	65	15	0	3	55	15	14.8	5.03	15	14.8	5.03	Sep-35	Apr-75											
Gen WQ	Organic carbon	No	Tot.	mg/l	M	150	8	0	1	60	3.36	4.11	2.78	3.36	4.11	2.78	Oct-69	Mar-05											
Gen WQ	Oxygen	No	Dis.	mg/l	M	311	14	0	2.5	15.9	11.1	10.9	0.807	11.1	10.9	0.807	Jul-69	Nov-06											
Gen WQ	pH	No	Tot.	std units	M	151	8	0	5.6	8.7	7.37	7.34	0.561	7.37	7.34	0.561	Mar-81	Nov-06			6.5	8.5	5						
Gen WQ	pH	Yes	Tot.	std units	M	671	286	0	0.7	10.4	7.65	7.58	0.689	7.65	7.58	0.689	Mar-45	Nov-06			6.5	8.5	56						
Gen WQ	Specific conductance	No	Tot.	umho/cm	M	147	8	0	60	389	145	150	63.8	145	150	63.8	Mar-81	Nov-06											
Gen WQ	Specific conductance	Yes	Tot.	umho/cm	M	665	286	0	22	372	111	127	58.2	111	127	58.2	Mar-45	Nov-06											
Gen WQ	Temperature, water	No	Tot.	deg C	M	412	24	0	0.1	27.5	13	12.9	3.03	13	12.9	3.03	Mar-45	Nov-06											
Gen WQ	Total dissolved solids	No	Dis.	mg/l	-	248	20	1	1	302	86.5	91.9	29.9	86.5	92.1	29.9	Sep-35	Nov-06				500	0			750	0		
Gen WQ	Total suspended solids	No	Non-filterable	mg/l	-	178	9	55	1	800	13	20.4	22.5	14	23.7	24	Aug-62	Nov-06											
Major Anions	Bromide	No	Dis.	mg/l	M	201	201	103	0.0007	1.115	0.0129	0.0389	0.134	0.0212	0.0711	0.187	Aug-77	Oct-77											
Major Anions	Chloride	No	Dis.	mg/l	CA	474	279	4	0.05	2200	8.1	9.17	8.25	8.15	9.2	8.25	Sep-35	Jan-05				250	2	230	2	250	2		
Major Anions	Fluoride	No	Dis.	mg/l	M	305	260	44	0.0015	0.7	0.0445	0.0498	0.0336	0.046	0.0516	0.0343	Feb-69	Jan-05	4	0		2	0			2	0		
Major Anions	Sulfate	No	Dis.	mg/l	CA	337	24	1	0.5	880	15.4	18.1	14.2	15.4	18.1	14.1	Sep-35	Nov-06				250	1			250	1		
Major Cations	Calcium	No	Dis.	mg/l	CA	72	16	0	4	49	15.7	18	7.95	15.7	18	7.95	Feb-48	Aug-76											
Major Cations	Calcium	No	Tot.	mg/l	CA	150	8	0	6.2	41.6	14	16.8	7.01	14	16.8	7.01	Jan-70	Nov-06											
Major Cations	Magnesium	No	Dis.	mg/l	CA	86	30	1	0.05	21	3.14	4.09	3.51	3.14	4.09	3.5	Feb-48	Sep-77											
Major Cations	Sodium	No	Dis.	mg/l	CA	287	270	1	0.015	17.99	8.38	7.32	3.82	8.39	7.35	3.8	Jul-58	Oct-77	20	0									
Metals	Aluminum	No	Dis.	ug/l	M	293	263	17	2	2916	69	93.2	190	69	93.2	190	Sep-64	Jan-05				200	11	87	68			750	2
Metals	Copper	No	Tot.	ug/l	M	150	8	141	2	1820	5.6	97.1	218	20	121	226	Oct-69	Nov-06	1300	1		1000	1						
Metals	Dysprosium	No	Dis.	ug/l	-	260	260	246	0.0005	2.393	0.013	0.0352	0.202	0.0705	0.418	0.801	Aug-77	Oct-77											
Metals	Iron	No	Tot.	ug/l	M	266	16	4	5	34300	1020	1730	2940	1240	1860	3010	Jul-69	Nov-06				300	98	1000	29	300	98		
Metals	Manganese	No	Dis.	ug/l	M	290	249	23	0.1	1204	91.4	95.7	84.1	92.2	97.7	83.8	Jul-58	Jan-05				50	211			1000	1		
Metals	Manganese	No	Tot.	ug/l	M	149	10	17	1	280	36.9	45.8	28	52.7	55.9	34.2	Feb-69	Nov-06				50	24			1000	0		
Metals	Phosphorus	No	Tot.	ug/l	M	265	12	28	5	600000	42.2	4630	15800	51.1	5060	16500	Aug-69	Nov-06											
Metals	Uranium	No	Dis.	ug/l	M	258	258	51	0.001	0.755	0.0255	0.0713	0.132	0.038	0.0883	0.143	Aug-77	Oct-77	30	0									
Metals	Vanadium	No	Dis.	ug/l	M	257	257	181	0.05	1.8	0.1	0.211	0.233	0.4	0.446	0.231	Sep-64	Oct-77										510	0
Nutrients	Ammonia-nitrogen as N	No	Dis.	mg/l	M	266	14	120	0.005	23.5	0.0438	0.175	0.442	0.0643	0.208	0.466	Feb-69	Nov-06											
Nutrients	Nitrate as N	No	Dis.	mg/l	CA	307	21	6	0.02	91	0.372	0.796	1.34	0.372	0.802	1.34	Sep-35	Nov-06	10	2						10	2		
Nutrients	Nitrite as N	No	Dis.	mg/l	CA	219	14	148	0.002	3.3	0.0275	0.0444	0.0453	0.037	0.0766	0.117	Feb-69	Nov-06	1	1						10	0		
Nutrients	Nitrogen	No	Tot.	mg/l	-	176	9	0	0.07	2.3	0.569	0.633	0.264	0.569	0.633	0.264	Apr-75	Nov-06											
Nutrients	Phosphate as P	No	Tot.	mg/l	-	223	10	56	0.005	6	0.03	0.132	0.318	0.0435	0.166	0.351	Oct-69	Nov-06											

M – measured, as defined in EPA QAPP for the Bradford/Susquehanna Retrospective Case Study (EPA, 2012b). CA = Critical Analyte, as defined in EPA QAPP for the Bradford/Susquehanna Retrospective Case Study (EPA, 2012b).
A red highlight indicates the value is above a screening criteria.
MCL: EPA Maximum Contaminant Levels (National Primary Drinking Water Regulation)
SMCL: EPA Secondary MCL (Non-enforaceable guidance for drinking water)
Act 2: State of Pennsylvania Land Recycling Program (Voluntary Remediation Program) Screening Limits: Limits are for used, residential groundwater aquifer with TDS ≤ 2500 mg/L
EPA Carc./EPA Non-Carc.: The carcinogenic and non-carcinogenic screening limits established by the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)
Note: Sodium does not have an MCL; the value listed in the MCL column represents the EPA Health Advisory Level.
ND = non-detect
SD = standard deviation

For metals, the reduced or revised data set appears to contain higher levels of copper and iron on average and only slightly lower levels of manganese and aluminum on average. Considering only detected values, the mean total copper and total iron levels are significantly higher when the incident data are removed (from 65% to 70% higher in the reduced data set, respectively). The maximum value of dissolved manganese is the same in both data sets, but the maximum value of total manganese is lower in the reduced data set. Considering only detections, the mean value of dissolved manganese levels is only 2.4% lower and the mean value of total manganese is only 1.1% lower in the reduced data set. Considering only detections, the dissolved aluminum concentration is 5.6% lower in the reduced data set.

For TDS and dissolved sodium, the mean values vary between the two data sets. Removing data associated with potential environmental impact monitoring and with location issues removes 19 out of 39 locations with TDS measurements and lowers the mean TDS concentration from 108 mg/L to 92 mg/L (or 15% lower). Removing these data removes 4 out of 274 locations with dissolved sodium measurements and raises the mean sodium concentration from 7.33 to 7.35 mg/L (0.27% higher considering only detections).

3.3.2.2 Statistical Comparison. Figure 3-12 shows the average concentration of dissolved chloride in surface water in the complete dataset over each decade spanning the 1960s through 2006. Figure 3-13 shows the percentage of results for total iron, total manganese, and dissolved sulfate above SMCLs over each decade spanning the1960s through 2006. Overall water quality has improved in the region over time, with the exception being increasing chloride levels starting as early as the 1960s through the 1990s. This increase in chloride may correspond to the growing application of salt for deicing roads (USGS, 2009). It has been well documented in the literature that chloride concentrations in glacial till aquifers in the northeastern United States have been increasing over time based on statistical studies of historic NWIS data. In these studies, temporal spikes in concentration were noted especially during winter months from November to April, indicating a likely relationship with winter (application of deicing road salts) activities. The USGS has attributed the increased chloride loading over time to “changes in the application of deicing salt, the expansion of road networks and impervious areas that require deicing, increases in the number of septic systems, increases in the volume of wastewater discharge, and the arrival of saline groundwater plumes from landfills and salt-storage areas over time” (USGS, 2009). It has also been noted by SRBC that due to the leachability of the glacial till geology, stream beds in the area may have relatively elevated chloride, sulfate, TDS, conductance, and turbidity levels (SRBC, 2012).

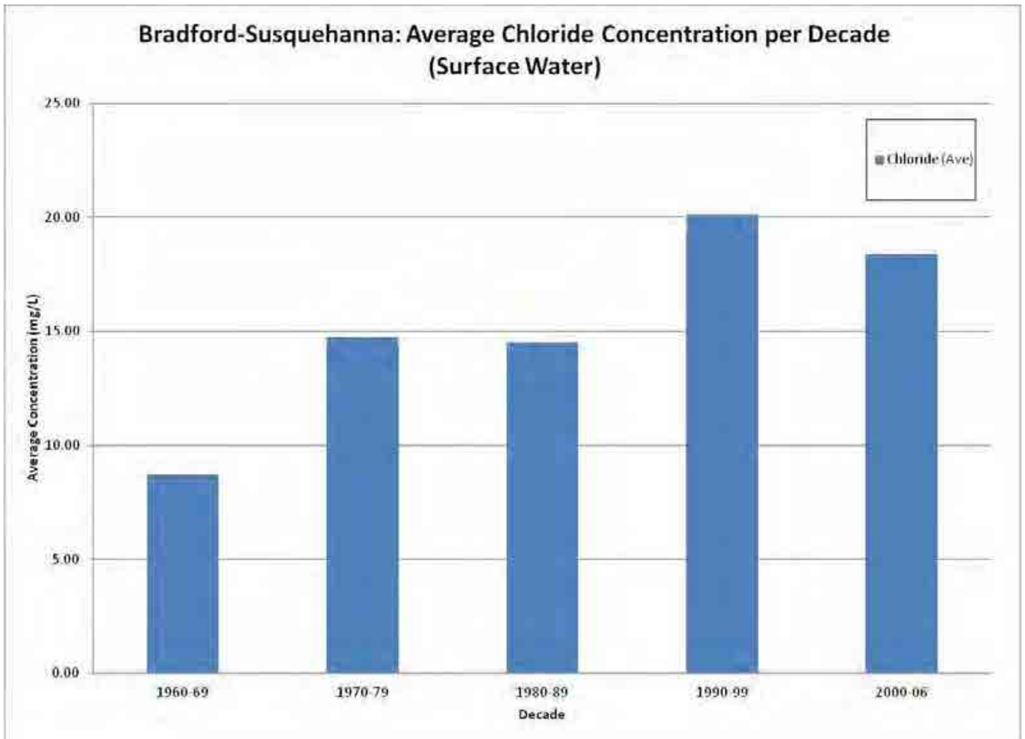

Figure 3-12. Average Chloride Concentration per Decade in Surface Water

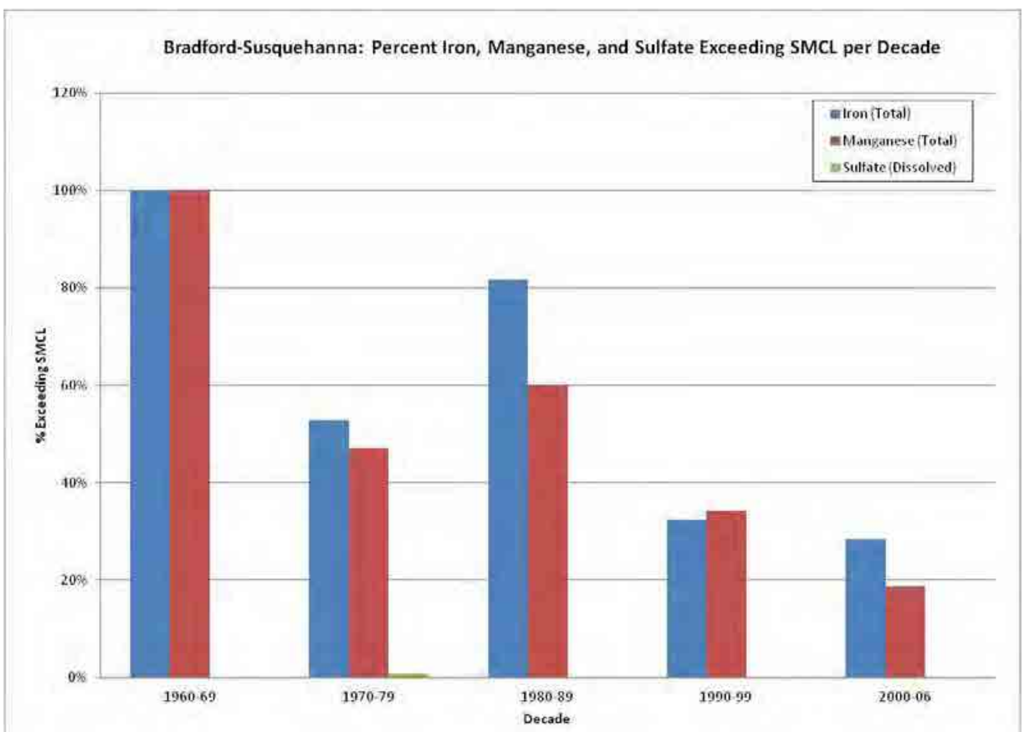

Figure 3-13. Percentage of Iron, Manganese, and Sulfate Above SMCLs per Decade

3.3.3 Spring Water Data Summary. Water quality data (from the sources identified in Section 2.0) were compiled into a database to characterize the condition of springs within Bradford and Susquehanna Counties. Summary tables were compiled as noted in Section 2.0 for the complete dataset (includes data potentially associated with environmental impacts) and for a reduced dataset that removed data potentially associated with environmental impacts. Figure 3-14 shows the location of the 96 spring water quality monitoring locations represented in the database (including locations potentially associated with environmental impacts). The dates of the sampling events (temporal boundary) ranged from 1976 to 1997. The parameters monitored include general water-quality parameters, major ions, and metals. As was done for the groundwater and surface water results, the data summarytables presented are limited to parameters having a minimum of eight sample locations..

Summary data tables are provided with a list of detected parameters, number of samples (total number and number of locations), minimum, maximum, median, mean, standard deviation, date range for sample collection, and comparison against screening criteria. Table 3-12 provides a summary of spring quality parameters prior to 2007 (that includes data from locations associated with potential environmental impact monitoring). Spring water quality parameters were compared to surface water quality screening criteria, including EPA MCLs and SMCLs and Pennsylvania Surface Water Screening Limits for PWS and fish. The data were also compared to CWA freshwater surface water quality criteria (chronic).

Inorganic Summary.
As indicated in Table 3-12, observed results are above one or more of the screening criteria for pH, chloride, sodium, aluminum, and manganese. In several samples, pH values were lower than the SMCL mimimum value of 6.5, although there were no values above the upper limit of 8.5. Chloride detections were higher than the CWA freshwater surface water quality criteria (chronic) in four samples. Sodium was higher than the EPA Health Advisory level of 20 mg/L in one sample. Aluminum detections were higher than the CWA freshwater surface water quality criteria (chronic) in four samples. Manganese detections were higher than the SMCL in a majority of samples. Figure 3-15 shows the locations where detected concentrations in springs are above one or more of the water-quality screening criteria.

Organic Summary.
No organic constituents in surface water were detected in eight or more sample locations.

3.3.3.1 Comparison Against Reduced Data Table. Table 3-13 provides a summary of pre-2007 spring water data in a similar format to Table 3-12, with the exception of four locations that were removed (two from NURE and two from USGS) based on the rationale provided in Table 2-3. This summary data table was created for comparison against the complete background spring water quality summary data table (Table 3-12) to determine whether the data identified as having location issues has a significant effect on background water quality.

The list of parameters (pH, chloride, sodium, aluminum, and manganese) and associated parameter-specific number of detections above screening criteria in the reduced summary data table (Table 3-13) are identical to those in the comprehensive data summary table, with the exception of one fewer pH detection above the SMCL. There is virtually no difference between the parameter-specific mean concentrations in the two data sets.

3.3.3.2 Statistical Comparison. No statistical analysis was performed on the spring water quality data.

3.3.4 Coverage of EPA QAPP Analytes. Tables 3-14 and 3-15 list whether or not the monitored parameters are part of the EPA QAPP for Bradford and Susquehanna Counties for surface water and springs, respectively. Of the parameters identified in the QAPP, 192 are designated as either CA (83) or M parameters (109).

Table 3-10 summarizes the available surface water quality data for parameters that are part of the EPA study (seven CA and 16 M). Table 3-14 summarizes 144 EPA parameters for which no historical surface water quality data are available (71 CA and 80 M) and 18 parameters (five CA and 13 M) for which the number of sample locations was less than eight or all results were non-detect. Table 3-12 summarizes the available spring water quality data for parameters that are part of the EPA study (three CA and eight M). Table 3-15 summarizes 148 EPA parameters for which no historical spring water quality data are available (76 CA and 86 M) and 23 parameters (four CA and 15 M) for which the number of sample locations was less than eight or all results were non-detect.

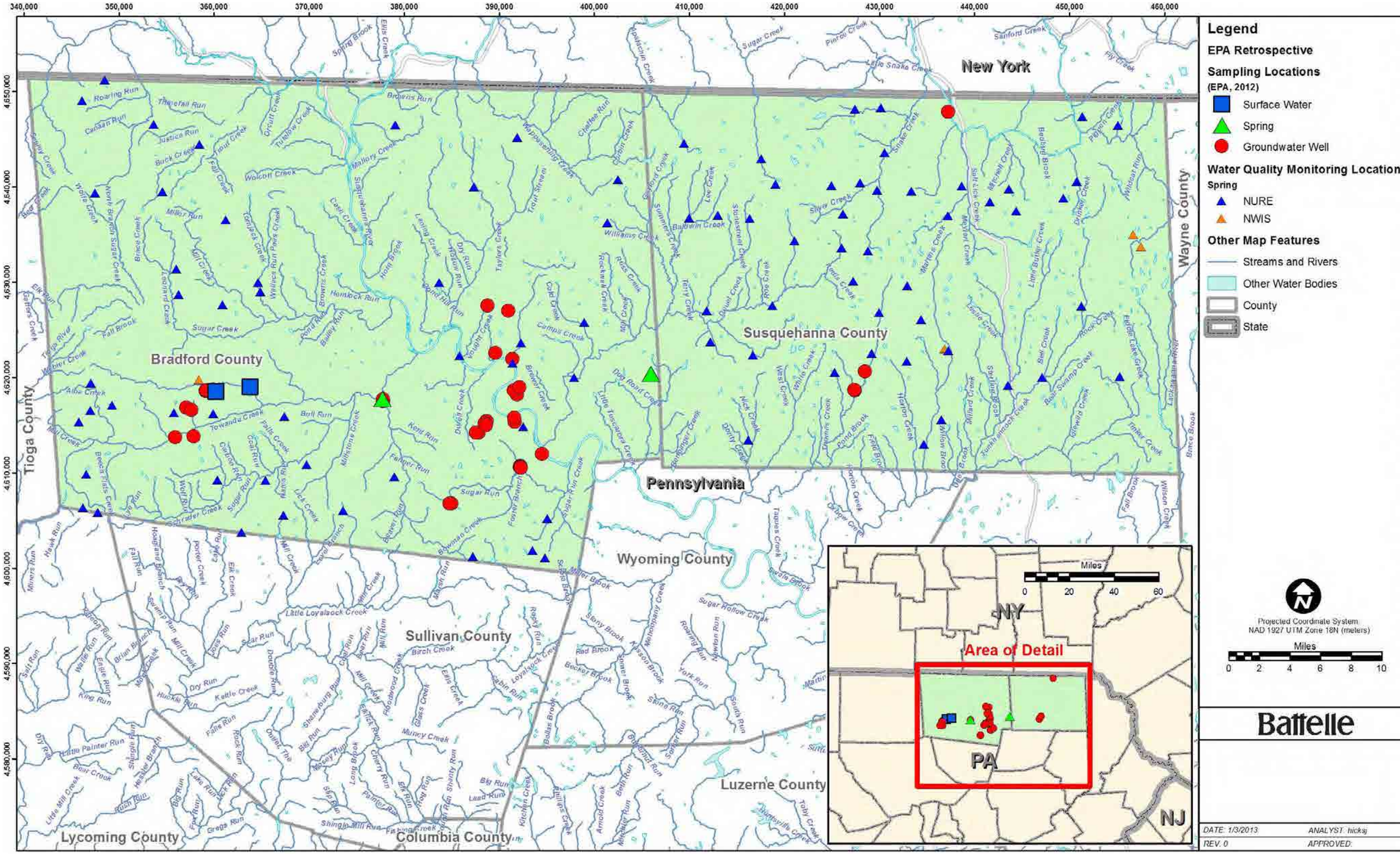

Figure 3-14. Surface Water Resources and Spring Water Quality Monitoring Locations in Bradford and Susquehanna Counties

Table 3-12. Summary of Water Quality Parameters Monitored (Complete Dataset, including Environmental Impact Data) in Spring Water in Bradford and Susquehanna Counties

											Including NDs			Excluding NDs															
Class	Parameter	Field Results	Frac.	Units	EPA Class	No. Samples	No. Locations	No. ND	Min	Max	Median	Mean	SD	Median	Mean	SD	Begin Sample Date	End Sample Date	MCL	N Above MCL (no NDs)	SMCL	SMCL High	N Above SMCL (no NDs)	CWA Chronic	N Above CWA Chronic (no NDs)	PA SW Qual PWS	N Above SW Qual PWS (no NDs)	PA SW Qual Fish	N Above Qual Fish (no NDs)
Gen WQ	pH	Yes	Tot.	std units	M	94	94	0	4.5	7.9	6.95	6.8	0.723	6.95	6.8	0.723	Mar-76	May-97			6.5	8.5	31						
Gen WQ	Specific conductance	Yes	Tot.	umho/cm	M	91	91	0	25	780	110	130	95.8	110	130	95.8	Jul-77	May-97											
Major Anions	Bromide	No	Dis.	mg/l	M	43	43	9	0.0029	0.7916	0.0141	0.0438	0.132	0.0164	0.0544	0.147	Jul-77	Oct-77											
Major Anions	Chloride	No	Dis.	mg/l	CA	95	95	0	2	174.2	5.2	8.75	18	5.2	8.75	18	Jul-30	May-97				250	0	230	0	250	0		
Major Anions	Fluoride	No	Dis.	mg/l	M	88	88	15	0.007	0.125	0.035	0.0428	0.0319	0.037	0.0448	0.0309	Mar-76	May-97	4	0		2	0			2	0		
Major Cations	Magnesium	No	Dis.	mg/l	CA	28	28	0	0.74	12.64	4.15	4.93	3.23	4.15	4.93	3.23	Jul-77	Oct-77											
Major Cations	Sodium	No	Dis.	mg/l	CA	91	91	0	0.68	66.46	4.37	5.51	7.1	4.37	5.51	7.1	Mar-76	Oct-77	20	1									
Metals	Aluminum	No	Dis.	ug/l	M	92	92	0	5	106	37	37.7	24	37	37.7	24	Mar-76	Oct-77				200	0	87	4			750	0
Metals	Dysprosium	No	Dis.	ug/l	-	90	90	88	0.0005	0.16	0.01	0.00864	0.0185	0.12	0.12	0.0566	Jul-77	Oct-77											
Metals	Manganese	No	Dis.	ug/l	M	63	63	1	5	385.8	78.7	78.1	48.5	79.9	79.3	48	Mar-76	Oct-77				50	49			1000	0		
Metals	Uranium	No	Dis.	ug/l	M	90	90	19	0.001	3.575	0.055	0.189	0.425	0.084	0.239	0.467	Jul-77	Oct-77	30	0									
Metals	Vanadium	No	Dis.	ug/l	M	90	90	81	0.05	0.55	0.1	0.128	0.128	0.3	0.289	0.105	Jul-77	Oct-77										510	0

M – measured, as defined in EPA QAPP for the Bradford/Susquehanna Retrospective Case Study (EPA, 2012b).
CA = Critical Analyte, as defined in EPA QAPP for the Bradford/Susquehanna Retrospective Case Study (EPA, 2012b).
A red highlight indicates the value is above a screening criteria.
MCL: EPA Maximum Contaminant Levels (National Primary Drinking Water Regulation)
SMCL: EPA Secondary MCL (Non-enforaceable guidance for drinking water)
Act 2: State of Pennsylvania Land Recycling Program (Voluntary Remediation Program) Screening Limits: Limits are for used, residential groundwater aquifer with TDS ≤ 2500 mg/L
EPA Carc./EPA Non-Carc.: The carcinogenic and non-carcinogenic screening limits established by the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)
Note: Sodium does not have an MCL; the value listed in the MCL column represents the EPA Health Advisory Level.
ND = non-detect
SD = standard deviation

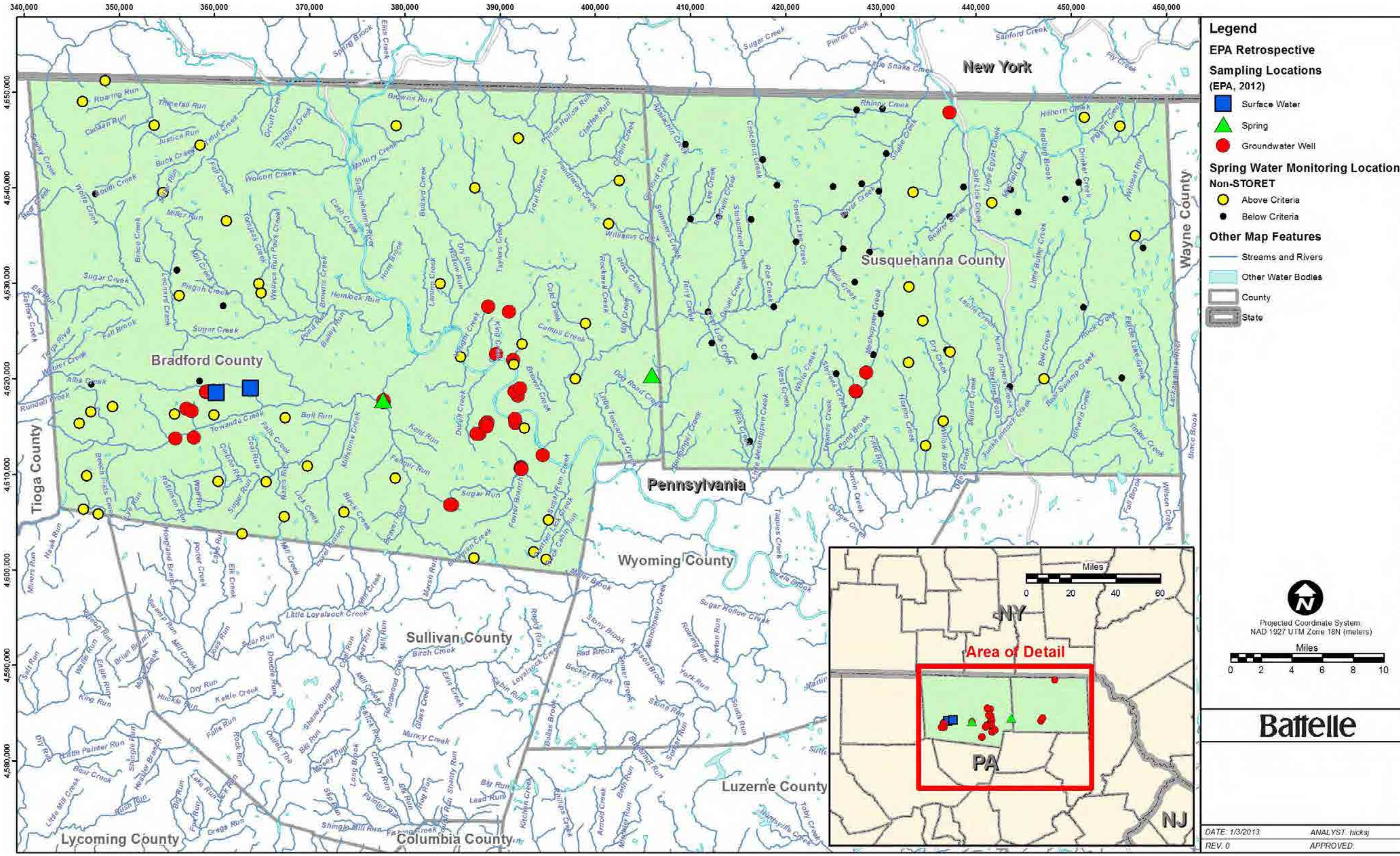

Figure 3-15. Spring Water Monitoring Stations and Spatial Distribution of Detections above Screening Criteria in Spring Water in Bradford and Susquehanna Counties

Table 3-13. Summary of Water Quality Parameters (Reduced Dataset, Excluding Environmental Impact Data) Monitored in Spring Water in Bradford and Susquehanna Counties

											Including NDs			Excluding NDs															
Class	Parameter	Field Results	Frac.	Units	EPA Class	No. Samples	No. Locations	No. ND	Min	Max	Median	Mean	SD	Median	Mean	SD	Begin Sample Date	End Sample Date	MCL	N Above MCL (no NDs)	SMCL	SMCL High	N Above SMCL (no NDs)	CWA Chronic	N Above CWA Chronic (no NDs)	PA SW Qual PWS	N Above SW Qual PWS (no NDs)	PA SW Qual Fish	N Above Qual Fish (no NDs)
Gen WQ	pH	Yes	Tot.	std units	M	90	90	0	4.5	7.9	6.9	6.79	0.73	6.9	6.79	0.73	Mar-76	Oct-77			6.5	8.5	30						
Gen WQ	Specific conductance	Yes	Tot.	umho/cm	M	88	88	0	25	780	100	130	97.4	100	130	97.4	Jul-77	Oct-77											
Major Anions	Bromide	No	Dis.	mg/l	M	43	43	9	0.0029	0.7916	0.0141	0.0438	0.132	0.0164	0.0544	0.147	Jul-77	Oct-77											
Major Anions	Chloride	No	Dis.	mg/l	CA	91	91	0	2	174.2	5.2	8.91	18.3	5.2	8.91	18.3	Jul-30	Oct-77				250	0	230	0	250	0		
Major Anions	Fluoride	No	Dis.	mg/l	M	84	84	13	0.007	0.125	0.032	0.0399	0.0295	0.037	0.0429	0.0292	Mar-76	Oct-77	4	0		2	0			2	0		
Major Cations	Magnesium	No	Dis.	mg/l	CA	26	26	0	0.74	12.64	4.15	4.85	3.29	4.15	4.85	3.29	Jul-77	Oct-77											
Major Cations	Sodium	No	Dis.	mg/l	CA	89	89	0	0.68	66.46	4.34	5.51	7.18	4.34	5.51	7.18	Mar-76	Oct-77	20	1									
Metals	Aluminum	No	Dis.	ug/l	M	90	90	0	5	106	37	37.2	24	37	37.2	24	Mar-76	Oct-77				200	0	87	4			750	0
Metals	Dysprosium	No	Dis.	ug/l	-	88	88	87	0.0005	0.08	0.01	0.00702	0.00914	0.08	0.08		Jul-77	Oct-77											
Metals	Manganese	No	Dis.	ug/l	M	63	63	1	5	385.8	78.7	78.1	48.5	79.9	79.3	48	Mar-76	Oct-77				50	49			1000	0		
Metals	Uranium	No	Dis.	ug/l	M	88	88	19	0.001	3.575	0.0525	0.183	0.427	0.082	0.232	0.471	Jul-77	Oct-77	30	0									
Metals	Vanadium	No	Dis.	ug/l	M	88	88	80	0.05	0.55	0.1	0.127	0.128	0.25	0.288	0.113	Jul-77	Oct-77										510	0

M – measured, as defined in EPA QAPP for the Bradford/Susquehanna Retrospective Case Study (EPA, 2012b).
CA = Critical Analyte, as defined in EPA QAPP for the Bradford/Susquehanna Retrospective Case Study (EPA, 2012b).
A red highlight indicates the value is above a screening criteria.
MCL: EPA Maximum Contaminant Levels (National Primary Drinking Water Regulation)
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Act 2: State of Pennsylvania Land Recycling Program (Voluntary Remediation Program) Screening Limits: Limits are for used, residential groundwater aquifer with TDS ≤ 2500 mg/L
EPA Carc./EPA Non-Carc.: The carcinogenic and non-carcinogenic screening limits established by the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)
Note: Sodium does not have an MCL; the value listed in the MCL column represents the EPA Health Advisory Level.
ND = non-detect
SD = standard deviation

Table 3-14. List of EPA Parameters Not Present in the Complete Bradford and Susquehanna Counties Surface Water Quality Characterization Database

Parameter - Measured		Parameter - Critical Analyte	
NOT FOUND			
Iron, ion (Fe2+)	Hexachlorocyclopentadiene	Butane	Dibutyl phthalate
Redox Potential	m-Dinitrobenzene	Ethane	Diethyl phthalate
Sulfide	N-Nitrosodimethylamine	Methane	Dimethyl phthalate
Diethylene glycol monobutyl ether acetate	p-Nitrophenol	Propane	Fluoranthene
tetraethylene glycol	Phenol	Selenium	Fluorene
triethylene glycol	Pyridine	1,2,4-Trichlorobenzene	Hexachlorobutadiene
Carbon-13/Carbon-12 ratio	squalene	2,4,5-Trichlorophenol	Hexachloroethane
d2H	terpineol	2,4,6-Trichlorophenol	Indeno[1,2,3-cd]pyrene
d87/86Sr	tri(2-butoxethyl)phosphate	2,4-Dichlorophenol	Isophorone
Oxygen-18/Oxygen-16 ratio	1,1,1-Trichloroethane	2,4-Dimethylphenol	m-Cresol
acetate	1,1,2-Trichloroethane	2,4-Dinitrotoluene	m-Dichlorobenzene
Butyric acid	1,1-Dichloroethane	2,6-Dinitrotoluene	m-Nitroaniline
formate	1,1-Dichloroethylene	2-Chloronaphthalene	N-Nitrosodi-n-propylamine
isobutyrate	1,2,3-Trimethylbenzene	2-Methylnaphthalene	Naphthalene
Lactic acid	1,2,4-Trimethylbenzene	3,3'-Dichlorobenzidine	Nitrobenzene
Propionic acid	1,2-Dichloroethane	4,6-Dinitro-o-cresol	o-Chlorophenol
Antimony	1,3,5-Trimethylbenzene	4-methylphenol	o-Cresol
Cerium	Acetone	Acenaphthene	o-Dichlorobenzene
Silicon	Benzene	Acenaphthylene	o-Nitroaniline
Sulfur	Carbon disulfide	Anthracene	o-Nitrophenol
Thallium	Carbon tetrachloride	Benz[a]anthracene	p-Bromophenyl phenyl ether
Gross alpha	Chlorobenzene	Benzo(b)fluoranthene	p-Chloro-m-cresol
Gross beta	Chloroform	Benzo[a]pyrene	p-Chloroaniline
Ra 226/228	cis-1,2-Dichloroethylene	Benzo[ghi]perylene	p-Chlorophenyl phenyl ether
1,2-dinitrobenzene	Cumene	Benzo[k]fluoranthene	p-Dichlorobenzene
1,3-dimethyl adamantane	Ethyl tert-butyl ether	Benzyl alcohol	p-Nitroaniline
1,4-dinitrobenzene	Ethylbenzene	Bis(2-chloroethoxy) methane	Pentachlorophenol
1-Methylnaphthalene	Isopropyl ether	Bis(2-chloroethyl) ether	Phenanthrene
2,3,4,6-Tetrachlorophenol	m-Xylene	Bis(2-chloroisopropyl) ether	Pyrene
2,4-Dinitrophenol	Methyl tert-butyl ether	Butyl benzyl phthalate	Acrylonitrile
2-butoxyethanol	Methylene chloride	Carbazole	Diesel range organics
2.3.5.6-Tetrachlorophenol	o-Xylene	Chrysene	Ethanol
adamantane	p-Xylene	Di(2-ethylhexyl) phthalate	Gasoline range organics
Aniline	tert-Amyl methyl ether	Di-n-octyl phthalate	isopropyl alcohol
Azobenzene	Tetrachloroethylene	Dibenz[a,h]anthracene	tert-Butanol
Benzoic acid	Toluene	Dibenzofuran	
bis(2-ethylhexyl) adipate	trans-1,2-Dichloroethylene		
Cyclohexene, 1-methyl-4-(1-methylethenyl)-, (4R)-	Trichloroethylene		
Diphenylamine	Vinyl chloride		
Hexachlorobenzene	Xylene		
SAMPLE SIZE < 8			
Inorganic carbon	Mercury	Potassium	Boron
Turbidity	Molybdenum	Arsenic	Strontium
Beryllium	Nickel	Barium	
Cadmium	Silver		
Chromium	Titanium		
Cobalt	*Zinc*		
Lead			

Table 3-15. List of EPA Parameters Not Present in the Complete Bradford and Susquehanna Counties Spring Water Quality Characterization Database

Parameter - Measured		Parameter - Critical Analyte	
NOT FOUND			
Inorganic carbon	Cyclohexene, 1-methyl-4-(1-methylethenyl)-, (4R)-	Butane	Di-n-octyl phthalate
Iron, ion (Fe2+)	Diphenylamine	Ethane	Dibenz[a,h]anthracene
Organic carbon	Hexachlorobenzene	Methane	Dibenzofuran
Oxygen	Hexachlorocyclopentadiene	Propane	Dibutyl phthalate
Redox Potential	m-Dinitrobenzene	Potassium	Diethyl phthalate
Sulfide	N-Nitrosodimethylamine	Barium	Dimethyl phthalate
Diethylene glycol monobutyl ether acetate	p-Nitrophenol	Boron	Fluoranthene
tetraethylene glycol	Phenol	Selenium	Fluorene
triethylene glycol	Pyridine	Strontium	Hexachlorobutadiene
Carbon-13/Carbon-12 ratio	squalene	Nitrite as N	Hexachloroethane
d2H	terpineol	1,2,4-Trichlorobenzene	Indeno[1,2,3-cd]pyrene
d87/86Sr	tri(2-butoxethyl)phosphate	2,4,5-Trichlorophenol	Isophorone
Oxygen-18/Oxygen-16 ratio	1,1,1-Trichloroethane	2,4,6-Trichlorophenol	m-Cresol
acetate	1,1,2-Trichloroethane	2,4-Dichlorophenol	m-Dichlorobenzene
Butyric acid	1,1-Dichloroethane	2,4-Dimethylphenol	m-Nitroaniline
formate	1,1-Dichloroethylene	2,4-Dinitrotoluene	N-Nitrosodi-n-propylamine
isobutyrate	1,2,3-Trimethylbenzene	2,6-Dinitrotoluene	Naphthalene
Lactic acid	1,2,4-Trimethylbenzene	2-Chloronaphthalene	Nitrobenzene
Propionic acid	1,2-Dichloroethane	2-Methylnaphthalene	o-Chlorophenol
Cerium	1,3,5-Trimethylbenzene	3,3'-Dichlorobenzidine	o-Cresol
Cobalt	Acetone	4,6-Dinitro-o-cresol	o-Dichlorobenzene
Molybdenum	Benzene	4-methylphenol	o-Nitroaniline
Phosphorus	Carbon disulfide	Acenaphthene	o-Nitrophenol
Silicon	Carbon tetrachloride	Acenaphthylene	p-Bromophenyl phenyl ether
Silver	Chlorobenzene	Anthracene	p-Chloro-m-cresol
Sulfur	Chloroform	Benz[a]anthracene	p-Chloroaniline
Titanium	cis-1,2-Dichloroethylene	Benzo(b)fluoranthene	p-Chlorophenyl phenyl ether
Gross alpha	Cumene	Benzo[a]pyrene	p-Dichlorobenzene
Gross beta	Ethyl tert-butyl ether	Benzo[ghi]perylene	p-Nitroaniline
Ra 226/228	Ethylbenzene	Benzo[k]fluoranthene	Pentachlorophenol
1,2-dinitrobenzene	Isopropyl ether	Benzyl alcohol	Phenanthrene
1,3-dimethyl adamantane	m-Xylene	Bis(2-chloroethoxy)methane	Pyrene
1,4-dinitrobenzene	Methyl tert-butyl ether	Bis(2-chloroethyl) ether	Acrylonitrile
1-Methylnaphthalene	Methylene chloride	Bis(2-chloroisopropyl) ether	Diesel range organics
2,3,4,6-Tetrachlorophenol	o-Xylene	Butyl benzyl phthalate	Ethanol
2,4-Dinitrophenol	p-Xylene	Carbazole	Gasoline range organics
2-butoxyethanol	tert-Amyl methyl ether	Chrysene	isopropyl alcohol
2.3.5.6-Tetrachlorophenol	Tetrachloroethylene	Di(2-ethylhexyl) phthalate	tert-Butanol
adamantane	Toluene		
Aniline	trans-1,2-Dichloroethylene		
Azobenzene	Trichloroethylene		
Benzoic acid	Vinyl chloride		
bis(2-ethylhexyl) adipate	Xylene		
SAMPLE SIZE ≤ 8			
Alkalinity as CaCO3	Iron	Calcium	Arsenic
Temperature, water	Lead	Sulfate	Nitrate as N
Turbidity	Mercury		
Antimony	Nickel		
Beryllium	Thallium		
Cadmium	Zinc		
Chromium	Ammonia-nitrogen as N		
Copper			

4.0: KEY FINDINGS AND CONCLUSIONS

EPA is conducting a retrospective case study in Bradford and Susquehanna Counties, Pennsylvania, as part of its evaluation of whether there is a relationship between hydraulic fracturing and drinking water. EPA selected this area "in response to complaints about appearance, odors, and possible health impacts associated with water from domestic wells" (EPA, 2012b). To investigate these complaints, EPA is collecting groundwater and surface water quality data for water wells, springs, and surface waters in the complaint areas. Although initial drilling efforts occurred in both counties in late 2006, substantial drilling and completions in the Marcellus Shale were completed largely from 2007 to present. To assess potential water quality effects from post-hydraulic fracturing sampling results in the appropriate context at a future date, pre-existing water quality conditions in the county must be understood. To this end, this report provides an initial understanding and characterization of water quality conditions in Bradford and Susquehanna Counties based upon readily available groundwater and surface water analytical data and information from the USGS, EPA, and Commonwealth of Pennsylvania.

The primary objective of this report is to help understand and characterize groundwater, springs, and surface water quality conditions within the study area prior to (pre-2007) unconventional oil and gas development, and identify parameters and impacts that may be present due to historic land use activities, or present as naturally occurring consitituents in these waters. This objective was satisfied by systematically conducting the steps outlined below.

- **Define the spatial boundaries and attributes of the Bradford and Susquehanna County study area.**
  The EPA sampling locations in Bradford County are located within several townships including: Leroy Township; Granville Township; Monroe Township; Albany Township; Terry Township; Wyalusing Township; Standing Stone Township; Wysox; and Tuscarora Township. The EPA sampling locations in Susquehanna County are located in Dimock and Great Bend Townships. However, the EPA study plan notes the areas investigated may expand or change within Bradford and Susquehanna Counties. Accordingly, the spatial boundary is defined as respective county boundaries for this characterization report. Available information summarized in this report on land use, groundwater and surface water quality define the attributes of the study area. The study area of interest is vertically confined by near-surface geologic formations that serve as drinking water resources. The average depth to groundwater in northeastern Pennsylvania is approximately 175 feet, but is commonly located at depths less than 40 to 50 feet based on variable topography. Fresh groundwater occurs to depths of approximately 800 feet in upland areas and 200 feet in valleys. Water below these depths is commonly saline, however saline zones are common at depths shallower than 200 feet, mostly in the major stream valleys, as described in a 1998 USGS report for this area (Williams et al., 1998). The depth to the Marcellus Shale formation ranges from roughly 4,000 to 7,000 ft bgs across the county

- **Identify historical and current land use and water quality data that can be used to provide context for characterizing water resources in the defined study area, along with identifying associated parameters that could impact drinking water resources.**
  Groundwater and surface water in Bradford and Susquehanna Counties have been impaired by historical land uses that occurred before shale gas drilling was introduced in late 2006. These historical activities could provide sources for a number of pollutants that may exist in groundwater and/or surface water in the study area. In addition, numerous recognized environmental sites were noted across the counties and in close proximity to the EPA

sampling locations, which could limit the ability to isolate impacts from one potential source and therefore require significant further investigation.Poor groundwater well location and well construction are key factors resulting in water supply contamination, A statewide survey of 701 private wells conducted by the Pennsylvania Master Well Owner Network in 2009 showed that wells with poor construction had poor water quality and noted that statewide regulations requiring well construction components appeared to be warranted (Swistock et al., 2009).

Areas of poor water quality are known to occur naturally in Pennsylvania. Many of the water quality parameters evaluated within this report have been present historically since testing began and are naturally occurring in groundwater, spring water, and surface waters of the area, such as iron and manganese. As noted by Taylor (1984), water quality is largely determined by the composition of the soil and rock through which the water flows and the length of time the water has been in contact with the soil and rock. As shown in reduced dataset summaries presented in Tables 4-1 through 4-3, many naturally occurring parameters are detected above one or more screening criteria.

The main causes of documented water-quality impairments in Bradford and Susquehanna County are agriculture and road runoff. Other land uses known to impact water quality in the county include habitat modification, septic systems, non-point sources; point sources; and resource extraction from coal and non-coal mineral mining. Each of these activities has been in existence prior to unconventional oil and gas development, and likely impacted water quality. Water quality parameters commonly associated with these land uses are summarized below:

- Agricultural runoff: Includes insecticides, herbicides, fungicides, fertilizers (e.g., nitrogen and phosphorous), metals (e.g., arsenic), and other constituents (e.g., dissolved solids, bromide, selenium) have been applied for agricultural activities. In addition, algal blooms caused by agricultural runoff of nitrogen and phosphorous can be a source of organic carbon that promotes the formation of DBPs upon chlorination of surface water in water treatment plants (EPA, 2005). Agricultural and livestock activities can also be a source of methane (King, 2012).
- Road runoff: Road salt application to paved roads can contain chloride and bromide. It has been well documented that chloride concentrations in surface waters and glacial till aquifers in the northeast have been increasing over time based on statistical studies of historic water quality data (pre-dating hydraulic fracturing activities). In these studies, temporal spikes in concentration were noted especially during winter months from November to April, indicating a likely relationship with winter deicing activities (USGS, 2009). Runoff from impervious roadways can also be a source of heavy metals (e.g., iron, lead, zinc), petroleum hydrocarbons, and VOCs/SVOCs. In addition, runoff from dirt and gravel roads, which are extensive in rural areas of Bradford and Susquehanna County, are known to contribute sediment loading and runoff of other road-related substances to nearby surface waters.
- Septic systems: Studies have shown elevated levels of nitrate, potassium, boron, ammonia, chloride, organics, dissolved organic carbon, and sulfate concentrations in monitoring and domestic wells in proximity to septic tanks (Katz et al., 2011).
- Non-point sources, stormwater runoff, and industrial activities: general water quality, PAHs, PCBs, metals; salts, pH; siltation; suspended solids; and nutrients depending upon the types of activities in the area. Habitat modification can cause stream bank instability and significant soil erosion and sediment pollution in nearby streams.

- Non-coal mineral mining: groundwater quality and quantity can be impacted by dewatering activities in sand, gravel, and crushed stone quarries. Water quality parameters that may be influenced by these type of activities could include TSS, turbidity, temperature changes, pH, and oil and grease from runoff and washing operations in the vicinity of mechanical equipment and vehicles.
- Coal mining and AMD: metals, sulfate, and general water quality (i.e., TDS, pH). A limited amount of coal mining has been conducted in Bradford and Susquehanna Counties, but known impairments to watersheds exist.
- Conventional oil and gas development: petroleum hydrocarbons, BTEX, and methane. Conventional oil and gas activity has been present in Bradford and Susquehanna Counties since the mid-1800s, but in very limited amounts prior to development of the Marcellus Shale play.
- TMDLs have been established due to known surface water quality impairments for over 231 miles of impaired streams and rivers in Bradford and Susquehanna Counties. The chemicals that have caused these surface water impairments in Bradford and Susquehanna Counties include pH, metals, PCBs, nutrients, siltation, and suspended solids.

- Numerous regulations and permitting requirements are in place to protect water resources from different land uses. Pennsylvania's oil and gas regulatory program is focused on the protection of water resources and is one of the most stringent programs of any oil and gas producing state. STRONGER, a multi-stakeholder organization requested by PADEP to review its oil and gas regulatory program, concluded in 2010 that the framework in place in Pennsylvania was well-managed, professional, and meeting its stated objectives (STRONGER, 2010).**Develop a comprehensive list of water quality parameters detected or monitored for in the study area, and compare to EPA QAPP requirements.**
A comprehensive list of water-quality parameters monitored for and detected in Bradford and Susquehanna Counties was established using information collected in the databases discussed in Section 2.2. One limitation of these databases is that the water-quality data were focused on general water quality, and data on organic water-quality parameters is limited. The data sources used are considered secondary or historical data, and by definition were not originally collected for the specific purposes of this report. However, these databases are commonly used to define background or baseline groundwater or surface water quality. For this study, data collected prior to 2007 represent conditions prior to significant development of the Marcellus Shale through directional drilling and hydraulic fracturing in Bradford and Susquehanna Counties, and were considered background conditions.

The majority of the parameters have insufficient data to adequately characterize background water quality. The evaluation identified 154 groundwater quality, 191 spring quality, and 169 surface water quality parameters out of a total of 192 listed (as M or CA) in the EPA QAPP for the retrospective study that have no results or results from fewer than eight locations.. This lack of historical water-quality data in conjunction with their natural occurrence, historical land use, and known impairments makes it difficult to determine whether recent hydraulic fracturing has impacted water quality in some instances without further investigation.

Methane is a commonly detected in the environment, but data on methane was not available in the data sources used by Battelle to develop the baseline understanding of water quality. Results from 1,700 samples collected in Susquehanna County (GSI, 2011) showed detectable methane in 78% of the pre drill water samples and that elevated methane in groundwater is a function of geologic features rather than shale gas development. Potential sources of methane were noted to include thermogenic from shallow gas-charged sandstones in the Catskill Formation and biogenic from organics in thick valley alluvium. GSI (2011) also noted the isotopic signature of thermogenic methane from deposits overlying the Marcellus can be distinguished from the isotopic signature of Marcellus shale gas.

- **Conduct summary statistical analyses and comparing the water quality summary statistics to state and federal screening criteria.**
  - Groundwater quality data summary
    - Groundwater quality data were compiled to characterize Bradford and Susquehanna County groundwater quality prior to unconventional oil and gas development (i.e., pre-2007). The data represent samples collected from 651 locations between 1930 and 2007.
    - Data for organic compounds are extremely limited and are insufficient to characterize historical (pre-2007) groundwater quality.
    - Parameters above one or more screening criteria are presented in Table 4-1.
      - General water quality parameters (pH and TDS) are above one or more screening criteria. pH is identified as an EPA M parameter.
      - Major ions chloride, fluoride, sodium, and sulfate are above one or more screening criteria; chloride, sodium and sulfate are identified as EPA CA, whereas fluoride is an EPA M parameter.
      - Metals including aluminum, arsenic, barium, cadmium, chromium, iron, lead, manganese, mercury, phosphorous, strontium, and zinc are above one or more screening criteria. Arsenic, barium, and strontium are identified as EPA CA, and the remainder are identified as EPA M parameters.
      - Two nutrients, nitrate as N and nitrite as N, are EPA CA and are above two screening criteria.
    - Inclusion of chemical data from 116 locations identified as potentially being associated with environmental impact monitoring or having location issues may bias background groundwater quality conditions, although the bias is not consistent for all parameters affected.
  - Surface water-quality data summary
    - Surface water-quality data were compiled to characterize Bradford and Susquehanna County surface water quality prior to unconventional oil and gas development (i.e., pre-2007). The data represent samples collected from 353 locations between 1930 and 2007.
    - Data for organic compounds are extremely limited and are insufficient to characterize surface water quality.
    - Parameters above one or more screening criteria are presented in Table 4-2
      - General water quality parameters alkalinity, pH and TDS are above one or more screening criteria. Alkalinity and pH are identified as EPA M parameters.
      - Major ions chloride, sulfate, and sodium are above one or more screening criteria; all are identified as EPA CA.
      - Metals including aluminum, copper, iron, lead, manganese, and zinc are above one or more screening criteria; all are identified as EPA M parameters.

        - Two nutrients, nitrate as N and nitrite as N, are EPA CA and are above two screening criteria.
    - Inclusion of chemical data from 67 locations identified as potentially being associated with environmental impact monitoring or having location issues may bias background surface water quality conditions, although the bias is not consistent for all parameters affected.
- Spring water quality data summary
    - Spring water quality data were available at 96 locations; none of the locations had multiple samples.
    - Data for organic compounds are extremely limited and are insufficient to characterize spring water quality.
    - Parameters above one or more screening criteria are presented in Table 4-3
        - pH (EPA M parameter) is above one or more screening criteria.
        - Major ions cloride and sodium are above one or more screening criteria; both all are identified as EPA CA parameters.
        - Metals including aluminum and manganese are above one or more screening criteria; both are identified as EPA M parameters.
    - Inclusion of chemical data from four locations having incident issues does not affect spring water quality.

Determining a relationship between hydraulic fracturing and drinking water will be challenging given the lack of adequate data to characterize background water quality conditions, especially for organics. Water-quality data presented to characterization conditions prior to hydraulic fracturing in this report should only be used in the context of providing an understanding of the observed range in parameter concentrations for the study area (e.g., Bradford and Susquehanna Counties). As noted in several independent water quality investigations (DeSimone, 2009; Ayotte et al., 2011; Low and Chichester, 2006; Low and Galeone, 2007) and observed in the data presented here, natural variability, land use patterns and other factors affect observed water quality. These factors have to be understood at the local level or specific areas of interest before a good understanding of background water quality can be determined for those areas. Without adequate background water quality, impacts observed as part of the EPA study will require a rigorous investigation before relating those impacts to hydraulic fracturing.

Table 4-1. Pre-2007 Groundwater Quality Summary of Parameters Above Screening Criteria

Class	Parameter	Fraction	EPA	Complete Dataset N	Complete Dataset No. Above Screening Criteria	Complete Dataset % Above Screening Criteria	Reduced Dataset N	Reduced Dataset No. Above Screening Criteria	Reduced Dataset % Above Screening Criteria
Gen WQ	pH	Total	M	897	91	10	202	10	4.9
Gen WQ	pH	Total	M	435	39	9.0	367	36	9.8
Gen WQ	TDS	Dissolved	-	654	218	33	223	22	9.9
Major Anions	Chloride	Dissolved	CA	1,157	41	3.5	502	14	2.8
Major Anions	Fluoride	Dissolved	M	552	6	1.1	444	4	0.9
Major Anions	Sulfate	Dissolved	CA	768	104	14	231	0	0
Major Cations	Sodium	Dissolved	CA	421	108	26	410	104	25
Major Cations	Sodium	Total	CA	438	131	30	82	38	46
Metals	Aluminum	Dissolved	M	521	93	18	400	44	11
Metals	Aluminum	Total	M	229	59	26	54	4	7.4
Metals	Arsenic	Dissolved	CA	11	11	100	10	10	100
Metals	Arsenic	Total	CA	343	49	14	109	16	15
Metals	Barium	Total	CA	201	5	2.5	52	3	5.8
Metals	Cadmium	Total	M	254	6	2.4	50	0	0
Metals	Chromium	Total	M	338	16	4.7	82	2	2.4
Metals	Iron	Dissolved	M	250	127	51	141	48	34
Metals	Iron	Total	M	530	277	52	82	39	48
Metals	Lead	Total	M	134	33	25	54	2	3.7
Metals	Manganese	Dissolved	M	458	298	65	344	256	74
Metals	Manganese	Total	M	338	215	64	81	46	57
Metals	Mercury	Total	M	114	14	12	0	-	-
Metals	Phosphorus	Total	M	13	11	85	0	-	-
Metals	Strontium	Total	CA	66	2	3.0	66	2	3.0
Metals	Zinc	Dissolved	M	127	3	2.4	127	3	2.4
Nutrients	Nitrate as N	Dissolved	CA	987	54	5.5	226	2	0.9
Nutrients	Nitrite as N	Dissolved	CA	729	10	1.4	194	0	0

M = measured, as defined in EPA QAPP for the Bradford/Susquehanna Retrospective Case Study (EPA, 2012b).
CA = critical analyte, as defined in EPA QAPP for the Bradford/Susquehanna Retrospective Case Study (EPA, 2012b).
N = number of samples
ND = non-detect

Table 4-2. Pre-2007 Surface Water Quality Summary of Parameters Above Screening Criteria

Class	Parameter	Fraction	EPA Class	Complete Dataset N	Complete Dataset No. Above Screening Criteria	Complete Dataset % Above Screening Criteria	Reduced Dataset N	Reduced Dataset No. Above Screening Criteria	Reduced Dataset % Above Screening Criteria
Gen WQ	Alkalinity as CaCO3	Total	M	154	13	8.4	0	-	-
Gen WQ	Alkalinity as CaCO3	Total	M	784	161	21	196	27	14
Gen WQ	pH	Total	M	377	12	3.2	151	5	3.3
Gen WQ	pH	Total	M	1,493	108	7.2	671	56	8.3
Gen WQ	TDS	Dissolved	-	711	4	0.6	248	0	0
Major Anions	Chloride	Dissolved	CA	873	2	0.2	474	2	0.4
Major Anions	Sulfate	Dissolved	CA	806	1	0.1	337	1	0.3
Major Cations	Sodium	Total	CA	8	1	13	0	-	-
Metals	Aluminum	Dissolved	M	355	109	31	293	68	23
Metals	Aluminum	Total	M	366	245	67	0	-	-
Metals	Copper	Total	M	163	1	0.6	150	1	0.7
Metals	Iron	Dissolved	M	282	18	6.4	0	-	-
Metals	Iron	Total	M	828	331	40	266	98	37
Metals	Lead	Total	M	168	11	6.5	0	-	-
Metals	Manganese	Dissolved	M	450	252	56	290	211	73
Metals	Manganese	Total	M	584	153	26	149	24	16
Metals	Zinc	Total	M	210	3	1.4	0	-	-
Nutrients	Nitrate as N	Dissolved	CA	674	2	0.3	307	2	0.7
Nutrients	Nitrite as N	Dissolved	CA	420	1	0.2	219	1	0.5

M = measured, as defined in EPA QAPP for the Bradford/Susquehanna Retrospective Case Study (EPA, 2012b).
CA = critical analyte, as defined in EPA QAPP for the Bradford/Susquehanna Retrospective Case Study (EPA, 2012b).
N = number of samples
ND = non-detect

Table 4-3. Pre-2007 Spring Water Quality Summary of Parameters Above Screening Criteria

Class	Parameter	Fraction	EPA Class	Complete Dataset N	Complete Dataset No. Above Screening Criteria	Complete Dataset % Above Screening Criteria	Reduced Dataset N	Reduced Dataset No. Above Screening Criteria	Reduced Dataset % Above Screening Criteria
Gen WQ	pH	Total	M	94	31	33	90	30	33
Major Cations	Sodium	Dissolved	CA	91	1	1.1	89	1	1.1
Metals	Aluminum	Dissolved	M	92	4	4.3	90	4	4.4
Metals	Manganese	Dissolved	M	63	49	78	63	49	78

M = measured, as defined in EPA QAPP for the Bradford/Susquehanna Retrospective Case Study (EPA, 2012b).
CA = Critical Analyte, as defined in EPA QAPP for the Bradford/Susquehanna Retrospective Case Study (EPA, 2012b).
N = number of samples
ND = non-detect

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Appendix A

QA/QC Review

BRADFORD AND SUSQUEHANNA COUNTIES, PA DATA QUALITY ASSESSMENT

The site characterization data quality objectives (DQOs) were followed to assess the quality of the Bradford and Susquehanna Counties, PA site characterization data and inform a general assessment of data quality. This assessment was performed on the full site database to assess the overall quality of available data. In general, it was determined that the available metadata and supporting information were not sufficient to make definitive statements about the quality of the data; therefore, no data were eliminated from the site characterization based on this data quality assessment. Table A-1 summarizes the review and the results of the data quality assessment. The assessment process is described below.

Table A-1. Summary of Data Quality Assessment[13]

DQO Assessment Criteria	DATA TYPE Groundwater	Surface Water	Springs
Organizations contributing data	USGS (NWIS, NURE, PA DEP)	USGS (NWIS, NURE), STORET	USGS (NWIS, NURE, PA DEP)
• Data were collected by an agency known to implement a rigorous quality system. • Data were collected under approved Quality Assurance Project Plan (QAPP)/Field Sampling Plan (FSP)	Yes	Yes	Yes
Data were collected by laboratories known to implement a rigorous quality system.	Unknown	Unknown	Unknown
The analysis methods were identified and appropriate	Unknown	Variable	Unknown
For non-detect values, the detection limits were defined and sensitive enough for the parameter.	Yes Except for Arsenic	Yes Except for Selenium	Yes Except for Selenium
If quality control data were available, accuracy was demonstrated to be ≥80% and precision was demonstrated to be ±30%. Otherwise, is there evidence that quality-related qualifiers were applied to the data.	Unknown	Unknown	Unknown

[13] Assessment Criteria: **Yes** (DQO assessment criteria achieved for ≥90% of data in full dataset).
Variable (DQO assessment criteria achieved for 50-90% of data in full dataset). **No** (DQO assessment criteria achieved for <50% of data in full dataset. **Unknown** (information was not provided ≥90% of data in full dataset).

Organization and Quality Documentation

The existence and application of a quality system is a critical aspect of collecting high-quality data because it indicates that an organization has a documented, systematic approach to apply quality principles to data collection. A review of the website of each organization collecting data for the study was reviewed to for evidence that a quality system was in place. Evidence could include a reference or link to a quality management plan, quality assurance (QA) project plan, sampling and analysis plan, SOPs, a discussion of quality control, or other elements of a QA document.

- **Groundwater**. Groundwater data were gathered from three sources; these sources and the approximate percent of data contributed by each are as follows:
  - USGS NURE (15%)
  - USGS NWIS / USGS PA Water Science Center (31%)
  - USGS PA Report (54%)

Data collected by USGS are supported by a documented quality system. Field samples and measurement data are collected under the USGS National Field Manual for the Collection of Water-Quality Data and National Field Quality Assurance Program, respectively. The NURE database does not identify the organizations that contributed data posted on the website. None of the websites identified the laboratories performing analysis. Despite these unknowns, the quality of groundwater data is likely acceptable due to significant involvement of USGS as both the database source and organization reporting the data.

- **Surface Water**. Surface water data were gathered from three sources; these sources and the approximate percent of data contributed by each are as follows:
  - EPA STORET (49%)
    - EPA National Aquatic Resource Survey (0.2%)
    - PA Department of Environmental Protection (PA DEP) (22%)
    - Susquehanna River Basin Commission (SRBC) (27%)
  - USGS NURE (8%)
  - USGS NWIS / USGS PA Water Science Center (43%)

As noted above, data collected by USGS is supported by a quality system. Similarly, the PA DEP, SRBC, and EPA National Aquatic Resource Survey appear to have a quality system for the collection of environmental samples. The websites for all three organizations reference a QA/QC plan, QAPPs or other quality system documents. Although the laboratories performing analysis are not defined for half of the surface water data, the quality of these data is likely acceptable because it is supported by the quality systems of the collection organizations and, for NURE and NWIS, the requirements of the source databases.

- **Springs**. Springs water data were gathered from three sources; these sources and the approximate percent of data contributed by each are as follows:
  - USGS NURE (90%)
  - USGS NWIS / USGS PA Water Science Center (5%)
  - USGS PA Report (5%)

As noted above, data collected by USGS is supported by a quality system. Although the laboratories performing analysis are not defined for any springs water data, the quality of these data is likely acceptable because it is supported by the quality systems of the collection organizations and, for NURE and NWIS, the requirements of the source databases.

Laboratories
The qualifications of analytical laboratories are critical in supporting the quality of data produced. Laboratory accreditation by an independent body such as the National Environmental Laboratory Accreditation Program (NELAP) indicates that the laboratory has a quality system in place.

- **Groundwater**
  The analytical laboratories were not defined for 97% of the 20938 groundwater results and therefore the qualifications of the laboratory cannot be assessed.
- **Surface Water**
  The analytical laboratories were not defined for any of the 38473 surface water results and therefore the qualifications of the laboratory cannot be assessed.
- **Springs**
  The analytical laboratories were not defined for all but one of the 1140 spring results and therefore the qualifications of the laboratory cannot be assessed.

Methods
Many water quality parameters can be collected and measured using more than one method. For example, methods for collection and analysis of water samples for total organic carbon (TOC) analysis are described EPA SW846 method 9060, EPA waste water method 415.2 and Standard Methods 5310. Each method is appropriate for specific applications but may yield different results or have different detection limits. Therefore, it is important to know the sample collection and analytical methods used for analysis so that the appropriateness of the method for the current application can be determined.

- **Groundwater**
  Analytical methods were reported for only 6% of the groundwater data. NWIS was the only organization reporting the methods associated with the analytical results. All of the methods reported were internal standard operating procedures (SOPs). However, the fact that internal SOPs exist for the analysis indicates that the methods are established and standardized. The groundwater data are considered unknown for this assessment element.
- **Surface Water**
  Analytical methods were reported for 52% of the surface water data. EPA STORET was the only organization reporting the methods associated with the analytical results. The methods cited were primarily organizational SOPs for which the analytical laboratory is not identified. As noted above, the fact that internal SOPs exist for the analysis indicates that the methods are established and standardized. The surface water data are considered variable for this assessment element.
- **Springs**
  Analytical methods were reported for only one entry for the spring data. The method cited was an organizational SOP for which the analytical laboratory is identified as the Pennsylvania Department of Environmental Resources. However, since over 99% of the data have no associated analytical method provided, the spring water data are considered unknown for this assessment element.

Detection Limits
Laboratory detection limits must be appropriate for the intended use of the data. While detection limits may be appropriate for the initial data collection purpose, they may not be appropriate for a secondary use, such as this report. Therefore, the detection limits of the data set were reviewed vs. State and Federal

screening criteria applicable to Bradford and Susquehanna Counties. The results are summarized in Tables A-2 through A-4.

- **Groundwater**
  For groundwater, of the 6660 results for EPA chemicals of interest, results for 932 samples were below the laboratory detection limits (Table A-5). Laboratory detection limits were reported for all "U" values in the data set with the exception of three metal results (cadmium, lead, and silver) from one sample reported in the NWIS database. The results of parameters were not included in the data analysis procedures because no result could be inferred. Laboratory detection limits for 307 parameters were above one or more screening criteria. Most notably, of the 362 Arsenic results, 297 results were not detected above detection limits which were higher than the EPA Reg3_Carcinogen threshold. In 10 instances, organic parameter results were above one or more screening criteria. In each case, the only results were below the laboratory detection limits and those detection limits were higher than one or more screening criteria. Data quality based on laboratory detection limits is acceptable except for arsenic.

- **Surface Water**
  For surface water, of the 6897 results for EPA chemicals of interest, 427 were measured below the laboratory detection limits (Table A-6). Laboratory detection limits were reported for all "U" values in the data set with the exception of 6 metal results for six different metals reported in the NWIS database. All reported laboratory detection limits were lower than any applicable screening criteria with the exception of selenium. All 37 selenium results in the database were reported as less than the detection limit of 7µg/l, which is higher than the CWA chronic screening threshold of 5 µg/l. Data quality based on laboratory detection limits is acceptable with the exception of selenium.

- **Springs**
  For spring water, of the 240 results for EPA chemicals of interest, 7 were measured below the laboratory detection limits (Table A-7). Laboratory detection limits were reported for all "U" values in the data set with the exception of 6 metal results for four different metals reported in the NWIS database. All reported laboratory detection limits were lower than any applicable screening criteria with the exception of selenium. Both selenium results in the database were reported as less than the detection limit of 7µg/l, which is higher than the CWA chronic screening threshold of 5 µg/l. Data quality based on laboratory detection limits is acceptable with the exception of selenium.

Quality Control

Quality control samples collected in the field (field blanks and field duplicates) and in the laboratory (method blanks and spiked samples) are used to identify potential field or laboratory contamination and to quantify the bias, accuracy and precision of the entire measurement system.

- **Groundwater**
  For groundwater, no laboratory QC, field equipment blank, or field duplicate data were reported. Overall, there is insufficient QC data available to assess data quality, therefore, on the basis of QC data, data quality is unknown.

- **Surface Water**
  For surface water, no laboratory QC or field equipment blank data were reported. However, results for three pairs of field duplicates were reported by PA DEP or USGS Pennsylvania Water Science Center. The results were excellent. The relative percent difference (RPD) between field parameters measured in routine and duplicate samples was 0% (i.e., 100%

agreement) for all three duplicate samples. The RPD for laboratory measurement duplicates was <20% for all parameters except phosphorus as P. For phosphorus as P, the RPD was >100% for two of the three duplicate pairs. Overall, there are insufficient QC data available to assess data quality, therefore, on the basis of QC data, data quality is unknown.

Spring
For spring water, no laboratory QC or field equipment blank data were reported. Overall, there is insufficient QC data available to assess data quality, therefore, on the basis of QC data, data quality is unknown.

Data Qualifiers
Data qualifiers assigned by either a laboratory or independent validation provide information about the reported results. Of primary interest are qualifiers that indicate problems with sample collection, handling, analysis, or quality control samples that could influence the accuracy or precision of the reported results. For the data sets examined for this report, laboratory comments also provide valuable information about the data when no qualifiers are assigned. An exhaustive review of comment fields was conducted as part of this review. In some cases, the comments provided addition information about sample preservation or processing procedures, such as acidification or filter size; most comments documented data quality issues. These comments were used to assign three qualifiers to the data: U (detected below reporting limits) J (estimated value); and S (suspect).

- U qualifiers were assigned if the comment indicated a value (a) was less than (<) another number, assumed to be the reporting limit; (b) was less than a practical quantitation limit or reporting limit, or (c) was between the reporting limit and method detection limit.
- J qualifiers were applied if the comment indicated problems with quality control sample results, blank contamination, holding time or temperature deviations, or if the values were estimated.
- S qualifier (suspect) was assigned if the data entry comment indicated that it was suspect; if the parameter was marked as a highly variable compound; if the method high range was exceeded; or if processing errors were noted.

If more than one qualifier applied to the same value the qualifiers were assigned according to the hierarchy: U > S > J. The assessment of data qualifiers is summarized below.

For the Bradford and Susquehanna data, the data set did not provide comments that could be used to assess data quality. Without data qualifiers or quality control data it is not possible to determine if the results of quality control samples analyzed with the field samples demonstrated that the analytical quantification system was in control. A summary of the qualifiers applied by the laboratories is presented below.

- **Groundwater**
  Overall, approximately 20% of the data were assigned qualifiers (Table A-5). Of the qualifiers assigned, the vast majority were “U” qualifiers, indicating that a compound was not detected above the detection limit. Five “J” qualifiers were assigned to EPA compounds of interest and one “J” qualifier was assigned to a parameter measured by EPA. Overall, less than 1% of the data were qualified with either data quality-related J or S qualifiers. However, because few comments were provided with the data results and because it appears that laboratory qualifiers were not assigned to the vast majority of data, the actual data quality is considered unknown.

- **Surface Water**
  Overall, less than 10% of the data were assigned qualifiers (Table A-4). For surface water data, only the "U" qualifier was applied, indicating compounds not detected above the reporting limit. No "J" (estimated) qualifiers were assigned to the data set. Comments were provided with many of the data results and because it appears that laboratory qualifiers were assigned appropriately, the actual data quality is considered variable.

- **Spring**
  Overall, approximately 22% of the data were assigned qualifiers (Table A-5). For spring water data, only the "U" qualifier was applied, indicating compounds not detected above the reporting limit. No "J" (estimated qualifiers were assigned to the data set. No comments were provided with the data results and because it appears that laboratory qualifiers were not assigned to the vast majority of data, the actual data quality is considered unknown.

Table A-2. Groundwater Non-Detected Values with Detection Limits Equal to or Above Screening Criteria. (Bolded value indicates detection limits above screening criteria).

Source	EPA Chemical of Interest	Fraction	Lab Detection Limit	Non-Detected Values (U) > Screening Criteria	MCL	SMCL hi	PA Act2	Reg3 Carc	Reg3 NonCarc
USGS NWIS	Arsenic	Total	1	3	10		10	**0.045**	4.7
USGS NWIS	Arsenic	Total	4	51	10		10	**0.045**	4.7
USGS USGS NWIS	Arsenic	Total	5	30	10		10	**0.045**	**4.7**
NWIS	Arsenic	Total	1000	5	**10**		**10**	**0.045**	**4.7**
USGS PA	Arsenic	Total	1	10	10		10	**0.045**	4.7
USGS PA	Arsenic	Total	4	32	10		10	**0.045**	4.7
USGS PA	Arsenic	Total	5	95	10		10	**0.045**	**4.7**
USGS PA	Arsenic	Total	10	58	**10**		**10**	**0.045**	**4.7**
USGS PA	Arsenic	Total	25	1	**10**		**10**	**0.045**	**4.7**
USGS PA	Arsenic	Total	30	9	**10**		**10**	**0.045**	**4.7**
USGS PA	Arsenic	Total	1000	3	**10**		**10**	**0.045**	**4.7**
USGS PA	1,2,4-Trichlorobenzene	Total	500	1	**70**		**70**	**0.99**	**3.9**
USGS PA	Benzo[a]pyrene	Total	0.5	1	**0.2**		**0.2**	**0.0029**	
USGS PA	Benzo[a]pyrene	Total	500	1	**0.2**		**0.2**	**0.0029**	
USGS PA	Di(2-ethylhexyl) phthalate	Total	0.5	1			6	**0.071**	4.6
USGS PA	Di(2-ethylhexyl) phthalate	Total	500	1			**6**	**0.071**	**4.6**
USGS PA	o-Dichlorobenzene	Total	500	1	600		600		**280**
USGS PA	p-Dichlorobenzene	Total	0.5	1	75		75	**0.42**	470
USGS PA	p-Dichlorobenzene	Total	500	1	**75**		**75**	**0.42**	**470**
USGS PA	Pentachlorophenol	Total	0.5	1	1		1	**0.17**	78
USGS PA	Pentachlorophenol	Total	500	1	**1**		**1**	**0.17**	**78**
Total				**307**					

Note: All values reported in µg/L.

Table A-3. Surface Water Non-Detected Values with Detection Limits Equal to or Above Screening Criteria. (Bolded value indicates detection limits above or screening criteria).

Source	EPA Chemical of Interest	Fraction	Lab Detection Limit	Non-Detected Values (U)>Screening Criteria	Units	MCL	SMCL hi	PA PWS	PA Fish	CWA Chronic
USGS NWIS	Selenium	Total	7	37	ug/l	50				**5**
Total				**37**						

Table A-4. Spring Water Non-Detected Values with Detection Limits Equal to or Above Screening Criteria

(Bolded value indicates detection limits above screening criteria).

Source	EPA Chemical of Interest	Fraction	Lab Detection Limit	Non-Detected Values (U)>Screening Criteria	Units	MCL	SMCL hi	PA PWS	PA Fish	CWA Chronic
USGS NWIS	Selenium	Total	7	2	ug/l	50				**5**
Total				**2**						

Table A-5. Groundwater Data Qualifiers Based on Data Source and Chemicals Listed in the EPA QAPP

Data Source	>	C	J	S	U	No Qualifier Assigned	Total
EPA Chemicals of Interest							
USGS NURE					1	608	609
USGS NWIS			5		246	1762	2013
USGS PA RPT					685	3353	4038
Total Qualifiers			5		932	5723	6660
Chemicals Measured by EPA But Not Chemicals of Interest							
USGS NURE					331	1733	2064
USGS NWIS			1		299	1852	2152
USGS PA RPT	5				1069	3958	5032
Total Qualifiers	5		1		1699	7543	9248
Chemicals Not Measured by EPA							
USGS NURE					270	300	570
USGS NWIS				2	580	1676	2258
USGS PA RPT	8	162			441	1591	2202
Total Qualifiers	8	162		2	1291	3567	5030
GW Grand Total	**13**	**162**	**6**	**2**	**3922**	**16833**	**20938**

Table A-6. Surface Water Data Qualifiers Based on Data Source and Chemicals Listed in the EPA QAPP

Data Source	U	No Qualifier Assigned	Grand Total
EPA Chemicals of Interest			
EPA STORET	1	3875	3876
USGS NURE	2	541	543
USGS NWIS	424	2054	2478
Total Qualifiers	427	6470	6897
Chemicals Measured by EPA But Not Chemicals of Interest			
EPA STORET		9478	9478
USGS NURE	353	1671	2024
USGS NWIS	1925	5918	7843
Total Qualifiers	2278	17067	19345
Chemicals Measured by EPA But Not Chemicals of Interest			
EPA STORET		5452	5452
USGS NURE	250	278	528
USGS NWIS	733	5518	6251
Total Qualifiers	983	11248	12231
SW Grand Total	**3688**	**34785**	**38473**

Table A-7. Spring Water Data Qualifiers Based on Data Source and Chemicals Listed in the EPA QAPP

Data Source	U	No Qualifier Assigned	Grand Total
EPA Chemicals of Interest			
USGS NURE		208	208
USGS NWIS	1	11	12
USGS PA RPT	6	14	20
Total Qualifiers	7	233	240
Chemicals Measured by EPA But Not Chemicals of Interest			
USGS NURE	120	518	638
USGS NWIS	11	13	24
USGS PA RPT	20	12	32
Total Qualifiers	151	543	694
Chemicals Not Measured by EPA			
USGS NURE	88	92	180
USGS NWIS	2	24	26
Total Qualifiers	90	116	206
Spring Grand Total	**248**	**892**	**1140**

Conclusion for Groundwater Data:
Based on the data quality assessment, the groundwater data should be used as with care for the following reasons: the analytical laboratories, analytical methods, and laboratory quality control data or quality-related qualifiers are unknown. Quality system elements that support the data include collection organizations with known quality systems and acceptable laboratory detection limits (with the exception of Arsenic).

Conclusion for Surface Water Data:
Based on the data quality assessment, the surface water data should be used as with care for the following reasons: the analytical laboratories and laboratory quality control data or quality-related qualifiers are unknown; the reporting of analytical methods was variable. Quality system elements that support the data include collection organizations with known quality systems and acceptable laboratory detection limits (with the exception of Selenium).

Conclusion for Spring Water Data:
Based on the data quality assessment, the spring data should be used as with care for the following reasons: the analytical laboratories, analytical methods, and laboratory quality control data or quality-related qualifiers are unknown. Quality system elements that support the data include collection organizations with known quality systems and acceptable laboratory detection limits (with the exception of selenium).

Appendix B

Water Quality Data

BRADFORD AND SUSQUEHANNA COUNTY GROUNDWATER, SPRING WATER, AND SURFACE WATER QUALITY DATA

The groundwater, surface water and spring water quality data collected for this report were collected from several different databases. Often the parameter name for a compound was provided in a slightly different form or in different units. Where appropriate, the data were standardized to consistent units and parameter names prior to developing summary statistics for each parameter. Further screening of the parameters was performed prior to inclusion in the Section 3 summary data tables. For example, there had to be sufficient data for a parameter to be included in the summary tables. In this case, sufficient data were defined as having a result from at least 8 distinct locations (note distinct locations were selected to reduce the influence of having multiple results from a single sampling location on the reported baseline data set). Prior to inclusion in Section 3 summary data tables, the collected data were aggregated by media (groundwater, surface water, spring water) initially, then screened for inclusion; data were removed from the summary tables if:

- There were less than 8 distinct locations having at least one result (as noted above, this screen was included to minimize the influence of multiple results for a parameter from a single location).
- All results for a parameter are non-detect. Note for EPA parameters (M or CA), if the number of locations (N) with at least one result is 8 or more, the parameter is identified as having sufficient baseline data for this effort and is included in the Section 3 summary data tables; if N<8 the parameter is identified as having <8 results (insufficient baseline data for this effort).
- Results for a parameter are identified as redundant, meaning there are more than one reported result for the parameter for an individual sample (for example, total dissolved solids is reported both as a calculated and laboratory measured result by sample; the calculated values are identified as redundant and are not included in the summary data tables).

There were also several parameters for which result fractions were reported in a number of different ways depending upon the different data sources queried, even after the initial data standardization. In these cases, the result fraction with the greatest number of results is included in the Section 3 summary tables for EPA parameters (M or CA). Professional judgment was further used to reduce the number of non-EPA parameters included in Section 3 summary tables to exclude data that are of little or no concern to understanding baseline water quality conditions. Table B-1 summarizes data removed based upon the parameter name, result fraction, or reported units by media. This same screen was used for each characterization report; therefore, some of the parameters, result fractions, or units specified in Table B-1 may not be included within the raw data collected for this report.

All removed data are retained in this appendix for potential future use in electronic format. The electronic data are also provided by media. Four Excel files are included:

- Table B-2 Bradford-Susquehanna Removed 20121218.xls
- Table B-3 Bradford-Susquehanna GW Data Dump 20121218.xls
- Table B-4 Bradford-Susquehanna SW Data Dump 20121218.xls
- Table B-5 Bradford-Susquehanna SPR Data Dump 20121218.xls

Table B-2 contains three worksheets for data that were not included (data removed) from the Section 3 summary data tables, one each for the groundwater, surface water, and spring water quality data. Tables B-3, B-4, and B-5 in the MS Excel files contain the collected groundwater, surface water, and spring data for Bradford-Susquehanna Counties. This information represents all of the data used to characterize the water quality in Bradford-Susquehanna Counties, PA.

Table B-1. Data Removed Based on Parameter, Result Fraction, or Result Units by Media

All Media		
Result Fraction	Supernate	
Result Fraction	Suspended - as long as parameter name is not total suspended solids	
Result units	ueq/l, %, meq/l, none, or nu	
Surface and Spring Water		
Parameter Name	**Result Fraction**	**Result Units**
Acidity	Total	mg/l as H
Acidity	Total	mg/L CaCO3
Ammonia and Ammonium	Dissolved	mg/l NH4
Ammonia and Ammonium	Total	mg/l NH4
Bicarbonate		
Hydrogen ion		
Gross alpha radioactivity	Dissolved	pCi/l
Thorium-230 ref std	Dissolved	pCi/l
Cesium-137 ref std	Dissolved	pCi/l
Inorganic nitrogen (nitrate and nitrite)	Total	
Inorganic nitrogen (nitrate and nitrite) as N	Total	
Inorganic nitrogen (nitrate and nitrite) as N	Dissolved	
Nitrate	Dissolved	mg/l
Nitrate-nitrite	Total	
Nitrogen, mixed forms (NH3), (NH4), organic, (NO2) and (NO3)	Total	mg/l NO3
Phosphate	Dissolved	mg/l
Phosphate	Dissolved	mg/l as P
Phosphorous as PO4	Total	mg/l
Sodium adsorption ratio		
Sodium plus potassium		
Sodium, percent total cations		
Strontium	Dissolved	ug/l
Surfactants -- CWA304B		
Total Solids		
Turbidity	Total	FNU
Turbidity	Total	JTU
Groundwater		
Parameter Name	**Result Fraction**	**Result Units**
Acidity	Total	mg/l as H
Acidity	Total	mg/L CaCO3
Carbonate (CO3)		
Hydrogen ion		
Bicarbonate		
Sodium adsorption ratio		
Sodium plus potassium		
Sodium, percent total cations		
Nitrate	Dissolved	mg/l
Nitrate-Nitrite	Dissolved	mg/l
Nitrite	Dissolved	mg/l

Table B-1. Data Removed Based on Parameter, Result Fraction, or Result Units by Media (Continued)

Phosphate	Dissolved	mg/l
Phosphorous as PO4	Total	mg/l
Orthophosphate as PO4	Total	mg/l
Settleable solids	Total	mg/l
ammonia and ammonium	Dissolved	mg/l as NH4
ammonia and ammonium	Total	mg/l as NH4
d13C DIC		