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Summary of Characterization Reports for Retrospective Case Study Areas

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SUMMARY OF CHARACTERIZATION REPORTS
FOR RETROSPECTIVE CASE STUDY AREAS

The U.S. Environmental Protection Agency (EPA) has initiated five retrospective case studies as part of the Agency’s evaluation of the potential relationship between hydraulic fracturing of unconventional oil and gas formations and drinking water (EPA, 2011a). EPA’s stated scope of investigation encompasses the hydraulic fracturing lifecycle, including water acquisition, chemical mixing, injection, produced water management, and treatment/disposal stages.

Hydraulic fracturing is the process of injecting fluids into the subsurface under high pressure to fracture oil and gas bearing formations to enhance the recovery of hydrocarbons. Hydraulic fracturing has been in use since 1948, typically through a vertical well with a single “stage” in the oil or gas producing zone. Recent advances in drilling techniques have allowed for deeper exploration and directional drilling, making unconventional recovery of oil and gas from tight formations possible through horizontal wells and multiple sequential stage completion activities within a single well. Although concern has been expressed over the potential for the process of hydraulic fracturing to contaminate drinking water, an array of robust government programs are in place to regulate oil and gas extraction industrial activities and protect the environment. No instances of adverse impact to water resources caused by injecting hydraulic fracturing fluids into the subsurface have been documented in two recent studies in Pennsylvania and Texas (GWPC, 2011; MSAC, 2011).

The EPA retrospective case studies focus on locations with public reports on drinking water contamination within proximity to past hydraulic fracturing operations. EPA is investigating the potential presence and extent of drinking water resource contamination and whether hydraulic fracturing caused or contributed to the contamination. In addition, the Agency intends these case studies to provide information to determine the extent to which conclusions on the impact of hydraulic fracturing can be generalized on local, regional and national scales. EPA selected the retrospective case study sites to be representative of the types of concerns that have been reported during stakeholder meetings. The five areas EPA selected are:

- Marcellus Shale, Washington County, Pennsylvania
- Barnett Shale, Wise and Denton Counties, Texas
- Bakken Shale, Dunn County, North Dakota
- Marcellus Shale, Bradford-Susquehanna Counties, Pennsylvania
- Raton Basin, Colorado

As part of these retrospective studies, EPA is collecting and analyzing water samples for a range of water quality parameters in accordance with a Quality Assurance Project Plan (QAPP) that EPA has prepared for each case.

The American Petroleum Institute (API) and America’s Natural Gas Alliance (ANGA) requested Battelle Memorial Institute (Battelle), an independent non-profit, science and technology research and development organization, to conduct background data collection and research to help answer the questions that EPA’s study plan suggests will be addressed by the retrospective case studies. This background research involved evaluation of regional water resource quality characteristics using readily available data for comparison with the results to be generated by EPA for each retrospective case study. The primary objectives of the work performed by Battelle for each study area were to characterize background water quality of springs, water wells and surface water sources, and to highlight the potential for adverse impacts to have resulted from previous land use activities prior to the onset of unconventional
oil and gas development. This will assist EPA and others in evaluating the site specific data collected by EPA’s retrospective case study program, specifically to permit determination of whether the collected data fall within the observed background range for a particular parameter as well as conditions (natural or anthropogenic) in the area which may influence the composition of EPA’s collected data. Battelle accomplished these objectives by:

- Defining the spatial and temporal boundaries and attributes of each study area.
- Identifying land use and water quality data that could be used to provide historical context for characterizing water resources, along with identifying associated analytical parameters that could be used to evaluate potential impact on drinking water resources.
- Developing a list of available analytes and water quality parameters monitored 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 results to relevant state and federal water quality screening criteria. A value 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 desktop study.

Battelle utilized EPA’s data quality objective (DQO) process to help ensure that an appropriate type and quantity of pre-existing data needed to meet the primary objective was collected (EPA, 2006).

Detailed reports describing regional baseline water quality conditions have been prepared by Battelle for all but the Raton Basin. A report on Raton was not prepared because a large body of data and information exists that was not readily accessible within the timeframe of the Battelle study. Each detailed report characterizes conditions based upon readily available information on land use, known surface water impairments and water quality data from the U.S. Geological Survey (USGS), EPA, state and local sources. The regional characterization can be used to compare EPA or industry-obtained water quality data at each retrospective case study location. Because water quality data from the EPA STOrage and RETrieval Data Warehouse (STORET) database is associated with environmental impact monitoring that could potentially skew background water quality results, separate evaluations were performed using the complete water quality dataset and a dataset excluding the STORET data.

The parameters included in the Battelle regional water quality databases are limited primarily to inorganic general water quality parameters, major ions, metals and nutrients. For many parameters on the EPA analytical list there are insufficient available data to adequately characterize background water quality and permit statistical comparisons against site specific data as indicated in Table 1. Methane is commonly detected in the environment (COGCC, 2003; GSI, 2011; Molofsky et al., 2011) but data on methane were not available from the data sources used by Battelle to develop the baseline water quality characteristics.

The water quality data presented herein provide an observed range in background parameter concentrations prior to the onset of unconventional oil and gas development in each study area. At many sampling locations the data available indicate that background water quality does not meet federal and state water quality standards, criteria or guidance values for several inorganic parameters including pH, total dissolved solids (TDS), chloride, fluoride, sulfate, aluminum, arsenic, barium, beryllium, boron, cobalt, copper, nickel, chromium, manganese, mercury, iron, lead, nitrate, phosphorus, sodium, strontium, turbidity, uranium, vanadium and zinc among others. Insufficient data are available on water quality with respect to organic chemical constituents.
Table 1. Number of parameters included in EPA study and number of parameters in groundwater, spring and surface water with results from at least eight locations for each retrospective study area

<table>
<thead>
<tr>
<th>Location</th>
<th>No. of EPA Parameters</th>
<th>Baseline Groundwater Parameters</th>
<th>Baseline Spring Parameters</th>
<th>Baseline Surface Water Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Washington County, PA</td>
<td>196</td>
<td>29</td>
<td>11</td>
<td>21</td>
</tr>
<tr>
<td>Bradford/Susquehanna Counties, PA</td>
<td>192</td>
<td>29</td>
<td>11</td>
<td>23</td>
</tr>
<tr>
<td>Wise and Denton Counties, TX</td>
<td>188</td>
<td>71</td>
<td>0</td>
<td>24</td>
</tr>
<tr>
<td>Dunn County, ND</td>
<td>237</td>
<td>27</td>
<td>16</td>
<td>28</td>
</tr>
</tbody>
</table>

As reflected in the data, natural variability, land use patterns and other anthropogenic factors can affect water quality. Activities such as agriculture, mining, steel production, manufacturing, conventional oil and gas extraction, urban runoff and sewer overflows are known to have impaired streams, rivers and groundwater in many cases.

Petroleum hydrocarbons and other constituents including metals, salts, organic compounds and naturally-occurring radioactive materials (NORM) have often been associated with oil and gas drilling and production activities. Elevated naturally-occurring methane in groundwater has been shown to be a function of geologic features rather than shale gas development (GSI, 2011). Migration pathways may exist also from historic producing horizons to groundwater aquifers. The oil and gas industry and regulatory agencies are taking steps to proactively manage orphan wells by evaluating the potential pathways and risks posed by each identified well, and mitigating the highest risk wells as a priority measure (IOGCC, 2005; McKee, 2012).

Conclusively determining whether a relationship exists between hydraulic fracturing and drinking water resources will be challenging given the lack of adequate data to fully characterize background water quality conditions. Observations of impaired water quality would require rigorous scientific analysis to differentiate impacts from all potential sources of contamination, including activities associated with hydraulic fracturing operations, from pre-existing conditions and impacts due to other factors. A synopsis of land use and background water resource quality characteristics in each of the five retrospective case study regions follows.
WASHINGTON COUNTY, PENNSYLVANIA

Washington County in southwest Pennsylvania was selected by EPA as a retrospective case study in response to complaints about appearance, odors and taste associated with water in domestic wells (EPA, 2012b). As part of the case study, EPA is collecting samples from domestic water supply wells, springs and surface water bodies and analyzing them for a range of water quality parameters; no rationale was provided in the EPA QAPP for the sampling locations selected (Figure 1).

Land Use
Approximately 857 square miles in area, the population of Washington County is over 200,000, yielding a population density of 242 persons per square mile (U.S. Census Bureau, 2010). In 2005 the total county-wide land use for agricultural, residential, industrial, commercial and services, urban, transportation and communication, and surface extraction was 46.1%; this represents a decline from 1986 when the total for these types of land use was 62.8% (Washington County, 2005). The balance of the land use is transitional, mixed forest, rangeland and water bodies.

Regulatory Administration
Pennsylvania has one of the most rigorous regulatory programs for oil and gas development of any state. Casing and cementing standards for oil and gas wells have been robust since passage of Pennsylvania’s Oil and Gas Act in 1984, and were enhanced by changes to Chapter 78 of Pennsylvania’s environmental regulations in 2011 and recent changes to the Oil and Gas Act in Act 13 of 2012. Because of these standards, risk of groundwater contamination from poor construction of new oil and gas wells is currently lower than at any time in Pennsylvania’s history.

In 2010, the Pennsylvania Department of Environmental Protection (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 operations. Overall, the report concluded that the framework in place in Pennsylvania was well-managed, professional and met its stated objectives (STRONGER, 2010).

Water Resources
The county is situated within the Ohio River Basin. In the northern portion of the county, the streams and tributaries drain directly to the Ohio River; in the southern portion, surface water drains into the Monongahela River, which then flows into the Ohio River near Pittsburgh (Washington County, 2005). Drinking water for most residents of Washington County is from public supplies derived from the Monongahela River in Allegheny County. Rural residents obtain their water from private water supply wells. Near-surface geologic aquifer formations within 300 feet of the ground surface serve as drinking water resources; below this depth water resources are commonly present as brine which is non-potable due to elevated salt content.

Impacts to Water Resources
Agriculture, mining, steel production, manufacturing, and conventional oil and gas extraction have been important industries in Washington County since the 1800s (Washington County, 2005). There are many locations in Washington County with recognized environmental impacts, including 348 storage tank incident sites, 86 land recycling cleanup locations and 13 brownfield sites. In 2010, 58,200 tons of chemicals regulated under the Toxic Releases Inventory (TRI) program were released into the environment in Washington County from 33 facilities (primarily steel, polymer and fabrication companies) through on- and off-site discharge or other forms of release (EPA, 2012b).
The National Research Council (NRC) found the major causes of water quality impairment in southwestern Pennsylvania to be acid mine drainage (AMD), agriculture, urban and stormwater runoff and human waste handling (NRC, 2005). The Pittsburgh coal seam has been deep mined under approximately 53% of Washington County. As of 2006, AMD and surface/subsurface mining was responsible for over 946 miles of impaired streams in the watersheds extending into Washington County (EPA, 2012b). Over 423 miles of streams are documented to be impaired by agricultural runoff, 331 miles impaired from urban stormwater runoff, 216 miles from road runoff, and 176 miles from residential runoff. Some organizations have noted the impact of inadequate sewage treatment on southwestern Pennsylvania’s streams, rivers and groundwater, including sewer overflow discharge without treatment during storm events (WSIP, 2002). Private water wells in Pennsylvania are not required to be permitted or meet specific construction or sanitary standards. Poorly sited groundwater supply wells and inadequate well construction are key factors resulting in water supply contamination; a statewide survey of 701 private wells showed that wells with poor construction had poor water quality (Swistock et al., 2009).

More than 11,600 conventional oil and gas wells have been drilled over time in Washington County. Prior to recent unconventional development (pre-2005) in the deeper Marcellus shale (post-2005), the most prolific oil and gas production was from depths of approximately 2,000 to 2,500 feet. Permitting and registration were not required by the state of Pennsylvania until the 1960s and there were no official regulations for plugging oil and gas wells until the passage of Act 223 in 1984. Little is known about the construction, production and abandonment procedures for these former wells, although it is known that the casing from many of these wells was removed during World War II to support the country’s steel requirements. The oil and gas industry and regulatory agencies are taking steps to proactively manage orphan wells by evaluating the potential pathways and risks posed by each identified well, and mitigating the highest risk wells as a priority measure (IOGCC, 2005; McKee, 2012).

Vertical oil and gas wells have been hydraulically fractured in Washington County since the 1960s. From 1970 to April 2012, over 900 oil and gas wells were drilled in Washington County in formations from 2,000 to 5,000 feet deep with the majority of these vertical wells having been hydraulically fractured. No readily available public information was found by Battelle to indicate that the drilling of wells in the Marcellus shale, roughly 5,000 to 7,500 feet below ground surface (bgs), has impacted drinking water resources. The occurrences of saline water do not correlate with the location of shale gas wells and are consistent with data reported before rapid shale gas development in the region.

Several environmental incidents have been identified in the vicinity of some of the EPA case study sampling locations in Washington County, including violation notices issued by the PADEP and citizen complaints including calls to the U.S. Coast Guard National Response Center. These incidents include alleged stream discharge violations, failure to properly dispose of wastes, improper release of brine, condensate, diesel spills, gas in drinking water, impacts to water wells, odors and sheen, release of fluids into nearby streams, holding pond overflows, reports of oil leaks from a separator tank, and a impuondment fire.

Although concern has been expressed over the potential for the hydraulic fracturing operations to contaminate drinking water, a recent report (MSAC, 2011) suggests no instances have been documented where the process of injecting hydraulic fracturing fluids into the subsurface has negatively impacted water resources despite tens of thousands of wells being fractured in Pennsylvania over the past several decades.

**Water Quality**

Water quality data were evaluated by Battelle for the pre-2005 timeframe prior to unconventional oil and gas development in the Marcellus shale via directional drilling and hydraulic fracturing. Sampling locations where groundwater and surface water quality parameters in the database were found to be
higher than applicable federal and state water quality standards, criteria and guidance values are shown in Figure 1. Table 2 shows the results above screening criteria for the data set with STORET data removed to include alkalinity, pH, sulfide, TDS, chloride, fluoride, sodium, sulfate, aluminum, arsenic, chromium, iron, lead, manganese, nickel and nitrate. Insufficient data are available on water quality with respect to organic chemical constituents.

Groundwater quality data were compiled from 202 water wells; constituents detected above one or more screening criteria include:

- General water quality parameters – pH, TDS and sulfide are above one or more screening criteria, with TDS being higher in 33 out of 97 results (34%).
- Major ions – sodium was above its health advisory level in 43% of the results; chloride and sulfate were greater than their respective secondary maximum contaminant levels (SMCLs) in 4% of the results; fluoride was above the maximum contaminant level (MCL) in two of 156 cases (<1%) and its non-carcinogenic criteria in 11% of the results.
- Metals – aluminum, arsenic, chromium, iron, lead, manganese and nickel were above one or more screening criteria; dissolved manganese in 54 out of 105 occasions (51%), and dissolved iron in 16 out of 66 results (24%) most often were above their SMCLs; arsenic was above its EPA carcinogenic criteria in 8 of 10 results (80%).
- Nutrients – nitrate as N was found above the MCL in one of 11 results in the groundwater data set.

Surface water quality data were compiled from 153 sampling locations; constituents detected above one or more screening criteria include:

- General water quality parameters – alkalinity, pH and TDS were above one or more screening criteria, with TDS results (29%) most often occurring above the SMCL (86 of 298 results).
- Major ions – chloride, fluoride, sulfate and sodium were above one or more screening criteria; sodium (97 of 275 results, 35%) and sulfate (82 of 337, results 24%) most often were above their health advisory level and SMCL respectively.
- Metals – aluminum, iron and manganese were above one or more screening criteria; dissolved manganese (218 of 360 results, 61%) and dissolved aluminum (69 of 123 results, 56%) most often were above their SMCLs; total iron and total manganese were above their respective SMCL 71% and 66% of the time, respectively.

Spring water quality data were available at 53 locations; constituents detected above one or more screening criteria include:

- Major ion - sodium was above one or more screening criteria, with sodium (four of 42 samples, 10%) most frequently detected above its health advisory level.
- Metals including aluminum and manganese were above one or more screening criteria with manganese (7 of 21 samples, 33%) most frequently detected above its SMCL.
Figure 1. Locations where at least one parameter was detected in groundwater (water wells), spring water, or surface water above one or more screening criteria in Washington County.
Table 2. Parameters above one or more screening criteria in reduced (STORET data removed) dataset in Washington County

<table>
<thead>
<tr>
<th>Medium</th>
<th>Total No. Sample Locations</th>
<th>General Water Quality</th>
<th>Major Ions</th>
<th>Dissolved Metals</th>
<th>Nutrient</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Alkalinity</td>
<td>pH (Field)</td>
<td>Total Dissolved Solids</td>
<td>Chloride</td>
</tr>
</tbody>
</table>
| Groundwater  |                            | 3/185                 | 4% of 185 samples; – = No data above screening criteria; † = total metals value
| Surface Water| 153                        | 8/438                 |            | 8/298            | 3/35     | 3/279    | 24/275 | 56/123  | –        | –        | –       | –     | –      | –      | –      | –      |
| Springs      | 53                         | –                     |            | 10/42            | –        | –        | –      | –       | –        | –        | –       | –     | –      | –      | –      | –      |
WISE AND DENTON COUNTIES, TEXAS

EPA initiated a retrospective case study in Wise and Denton Counties in northeast Texas in response to complaints concerning the appearance, odors and taste of water from domestic drinking water wells and concerns over leaks and spills that may have impacted surface waters (EPA, 2012c). As part of the case study, EPA is collecting samples from 10 domestic wells and two surface water bodies in three discrete areas within Wise County and analyzing them for a range of water quality parameters (Figure 2).

Land Use
In 2010, the total population of Wise County was 59,127 within 904 square miles, yielding a population density of 65 persons per square mile; the total population of Denton County was 662,614 within 878 square miles, yielding a population density of 754 persons per square mile. Since 2000, the population of each county increased by 21% and 53%, respectively (U.S. Census Bureau, 2010).

Agriculture was a major form of land use in Wise and Denton Counties in 1986 at 40% and 70%, respectively; however, by 2006 these ratios had decreased dramatically to 14.7% and 25.5%, respectively, with most of the reduction corresponding to a reversion to mixed rangeland. In Denton County, which includes the northern part of the Dallas-Fort Worth metroplex, there have been marked increases in water impoundments, residential, transitional, industrial, commercial and service forms of land use over the intervening 20-year period.

The most common industrial and manufacturing activities in the study area include construction, manufacturing, transportation equipment, carbon and graphite, mining, quarrying and support activities for oil and gas extraction. Mining of sand and gravel deposits for construction materials is an important industry in Wise County, and there are several clay and shale mining operations in Denton County for brick manufacturing.

Wise and Denton Counties have more than 18,000 conventional oil and gas wells and over 3,000 unconventional shale gas wells. The Newark East Field, or Barnett shale, 7,500 to 8,000 feet bgs, was initially developed in southeast Wise County in 1981. The first horizontal well in Wise County was installed in 1992 although it was not until 1998 that another well of this type was completed here. Wise and Denton Counties produced 240,690,271 million cubic feet and 253,389,690 million cubic feet of gas, respectively, in 2011 (Texas Railroad Commission [RRC], 2012).

Regulatory Administration
Two organizations in the state of Texas are responsible for establishing standards and enforcing regulations for oil and gas exploration and production: the RRC and the Texas Commission on Environmental Quality (TCEQ). RRC’s responsibility lies in overseeing aspects of oil and gas activities such as well spacing, well design, groundwater protection during oil and gas activities, and operational and public safety. TCEQ’s primary role is the control of air emissions, required depth of each well’s steel casing and cement, and ensuring that off-site impacts are consistent with standards developed to protect public health and safety.

Water Resources
Wise and Denton Counties are located within the Trinity River Basin which has a total drainage area of 17,969 square miles. The consolidated Cretaceous Trinity aquifer is the largest and most productive water-bearing formation in north-central Texas and outcrops or underlies most of Wise and Denton Counties. Ranging from 400 feet up to almost 2,000 feet in thickness, the aquifer is capable of yielding small to large quantities of potable fresh to slightly saline water. Above the Trinity aquifer is the 700-foot thick Woodbine Group, an aquifer of sufficient quality for use as irrigation and industrial water supply purposes. Groundwater withdrawal estimates for 2006 are 12,059 acre-feet in Denton County and 6,445
Acre-feet for Wise County (Freese and Nichols et al., 2011). Aquifer recharge is primarily from infiltration by precipitation and surface water bodies in outcrop areas. A large cone of depression is present to the south of Denton County under the city of Dallas. This cone of depression has increased in depth over the last 20 years because more groundwater is being withdrawn than recharged to aquifers. These withdrawals have resulted in aquifer water level reductions of up to 400 feet in parts of the north-central Texas area and over 100 feet in southern Wise County.

Impacts to Water Resources
As a result of various historical land use activities, there are many facilities or locations with recognized or potential environmental impacts. The types of facilities identified include construction (crushed stone, limestone quarry plants, asphalt, brick and concrete manufacturing, glass blowing), sewage treatment plants, gas compressor stations, wastewater treatment plants and dry cleaners. Both Wise and Denton Counties have several recognized environmental sites related to oil and gas operations. Environmental restoration sites include a total of 358 storage tank incident sites (73 sites in Wise County and 285 sites in Denton County). In 2010, 8,913 tons of chemicals regulated under the TRI program were released in Wise County and 82,918 tons in Denton County from industries such as fabricated metals, chemical wholesale, food and beverages, transportation equipment manufacturing (transportation equipment, brick, chemical and jewelry) and material recovery.

Runoff from impervious surfaces and other nonpoint source discharges can affect the quantity and quality of surface water and groundwater recharge. For the period 1998-2010 there have been over 96 miles of impaired streams and rivers in Wise County, representing approximately 7% of the total stream length in the county; in Denton County there have been over 22 miles of impaired streams and rivers, representing approximately 2% of its total stream length (EPA, 2012d). Parameters causing these impairments include TDS, dissolved oxygen, chloride and bacteria. As of 2010, there were 167 (Wise) and 406 (Denton) on-site sewage facilities in the study area (TCEQ, 2010). Water quality problems have been associated with population growth and aging infrastructure of wastewater treatment plants in some areas such as the southeast corner of Wise County, specifically Eagle Mountain Lake (Roth, 2010).

Between 1993 and 2008, over 16,000 horizontal shale gas wells with multi-stage hydraulic fracturing stimulations were completed in Texas of which 895 and 1,379 were in Wise and Denton Counties respectively. During this same time, RRC has documented 211 groundwater contamination issues caused by oilfield activities in Texas (Groundwater Protection Council [GWPC], 2011). More than 35% of the incidents resulted from waste management and disposal activities, including 57 legacy incidents caused by produced water disposal pits that were banned in 1969 and closed before 1984. However, RRC has not identified a single groundwater contamination incident resulting from site preparation, drilling, well construction, completion and hydraulic stimulation or production operations at any of the shale gas wells conducted during this period (GWPC, 2011).

Water Quality
A database of water quality parameters prior to 1998 was assembled by Battelle and represents conditions prior to significant development of the Barnett Shale through unconventional oil and gas techniques. Figure 2 shows both surface water and groundwater (water wells) sampling sites where one or more parameters were detected above one or more screening criteria. Table 3 provides a summary of parameters detected above one or more screening criteria for the data set with STORET data removed. Results above screening criteria include pH, TDS, chloride, fluoride, sodium, sulfate, arsenic, boron, cobalt, copper, iron, manganese, phosphorous, uranium, vanadium and zinc. Benzene was also detected above criteria; however, in general, insufficient data are available on water quality with respect to organic chemical constituents.
Groundwater samples were available from 489 locations in the study area; constituents that were detected above one or more screening criteria include:

- General water quality parameters – pH and TDS were above one or more screening criteria with TDS at 69% (443 of 646 results) most often above its SMCL.
- Major ions – chloride, fluoride, sulfate and sodium, were above one or more screening criteria with dissolved sodium (129 of 138 results above health advisory level, 93%) and chloride (76 of 648 results above SMCL, 12%) most often detected above their screening criteria.
- Metals – arsenic, beryllium, boron, cobalt, iron, manganese, phosphorus, uranium and vanadium were above one or more screening criteria with dissolved arsenic (34 of 139 results, 24%) most frequently above its EPA carcinogenic screening criteria.
- Two organic compounds, p-p′-DDE and benzene were detected in groundwater with 11 sample results each; benzene was above the screening criteria in one of 11 samples.

Surface water quality data were compiled from 33 sampling locations; constituents detected above one or more screening criteria include:

- General water quality parameters – pH and TDS were above one or more screening criteria with TDS (77 of 1,125 results, 7%) most often above SMCL.
- Major ions – chloride, fluoride, sulfate and sodium were above one or more screening criteria; sodium (566 of 1,102 results, 51%) was most often above its health advisory level.
- Metals – arsenic, copper, iron, manganese and zinc were above one or more screening criteria; dissolved manganese (310 of 1,267 results, 25%) was most often detected above its SMCL.

There was no spring water quality data available in the data sources used to assess water quality in Wise-Denton Counties. Therefore, no evaluation of spring water quality data is provided in this report.
Figure 2. Locations where at least one parameter was detected above one or more screening criteria from groundwater (water wells) or surface water in Wise and Denton Counties.
Table 3. Parameters above one or more screening criteria in reduced (STORET data removed) dataset in Wise and Denton Counties

<table>
<thead>
<tr>
<th></th>
<th>General Water Quality</th>
<th>Major Ions</th>
<th>Dissolved Metals</th>
<th>Organics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total No. Sample Locations</td>
<td>pH (Field)</td>
<td>Total Dissolved Solids</td>
<td>Chloride</td>
</tr>
<tr>
<td>Surface Water</td>
<td>33</td>
<td>3/4031</td>
<td>7/1125</td>
<td>&lt;1/1176</td>
</tr>
<tr>
<td>Springs</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

* Excludes STORET data; \(\frac{4}{185} = 4\% \) of 185 samples; – No data above screening criteria; \(\dagger\) = total metals value
DUNN COUNTY, NORTH DAKOTA

Dunn County in western North Dakota was selected by EPA as a retrospective case study in response to a blowout that occurred at Well Franchuk 44-20SWH during the hydraulic fracturing stage of well development, resulting in the release of approximately 84,000 gallons of hydraulic fracturing fluids (EPA, 2011b). Fluids released at the surface were captured on the well pad which was double-lined and diked to contain spills at the surface. As part of the case study, EPA is collecting samples from domestic water wells in the vicinity of the blowout, the City of Killdeer public water supply wells, and eight monitoring wells around the well pad installed after the incident occurred (Figure 3). Once the gas well was repaired, one additional monitoring well was installed immediately adjacent to the gas well. Samples collected from the wells during nine monitoring events spanning March 2011 through November 2012 have shown no impacts to groundwater in the Killdeer aquifer. No impacts were detected in the nearest surface water body, Spring Creek.

Land Use
Approximately 2,008 square miles in area, the population of Dunn County is 3,536, corresponding to a population density of about 1.8 people per square mile (U.S. Census Bureau, 2010). Agriculture is the predominant land use, comprising over 90% of the total (U.S. Geological Survey [USGS], 1986). Rangeland represents about 48% of the land use while cropland and pastures represent about 44%. Deciduous forest land, water bodies and wetland comprise the other 8%.

Conventional oil and gas extraction began in 1960 and produced a relatively small quantity of oil during the 1960s and early 1970s of a few hundred to a few thousand barrels per month. Oil production increased by an order of magnitude during the late 1970s. Horizontal drilling and hydraulic fracturing were introduced in 1987 and have contributed to a boom in the oil and gas exploration and production industry since 2005. Currently, more than 2 million barrels are produced in Dunn County each month (North Dakota Industrial Commission [NDIC], 2012).

Regulatory Administration
The NDIC Department of Mineral Resources, Division of Oil and Gas regulates the oil and gas development in the state. Rules and regulations for oil and gas are set forth in the North Dakota Century Code (NDCC) Chapter Title 38. Authority to administer the oil and gas rules and regulations is given to the NDIC in Title 43 of the North Dakota Administrative Code (NDAC).

Water Resources
The county is situated within the Little Missouri and Oahe River Basins. Spring Creek drains the central part of the county while the southern part is drained by the Little Knife, Knife and Green Rivers (North Dakota Geological Survey [NDGS], 2001). Most of the water used in Dunn County is obtained from wells tapping sandstone and lignite aquifers in the upper portion of the Sentinel Butte Formation which is present at ground surface throughout the majority of the county. The rural population of Dunn County relies upon groundwater for domestic and livestock use. Groundwater wells extend up to 2,000 feet in depth, but most wells are less than 200 feet deep. The city of Halliday obtains a portion of its municipal water supply from a 1,555 feet deep well drilled into the consolidated Fox Hills aquifer, while the city of Killdeer obtains its water supply from a 70-foot deep well in the unconsolidated Killdeer aquifer.

Impacts to Water Resources
Historically, agriculture and conventional oil and gas extraction have been important industries in Dunn County. Facilities or locations in Dunn County with recognized environmental impacts include five storage tank incident sites and 16 oil and gas related sites based on the names of companies listed. The oil and gas related entries include seven pipeline sites, three exploration sites, two gas plants and two compressor stations, and one site each owned by an oil company and an oil field service company. There
are no brownfield sites reported for Dunn County nor were there any reported releases of chemicals regulated under the TRI program through on- and off-site treatment, recycling, disposal, discharge or other forms of release (EPA, 2012a).

There are approximately 168 miles of impaired streams and rivers located within Dunn County, representing a relatively small portion of the total length of streams and rivers in the county. Of the 168 miles of impaired waterways, approximately 125 miles are impaired by mercury from atmospheric deposition; the remaining 43 miles are impaired by E. coli and/or fecal coliform, most likely resulting from agricultural practices (EPA, 2012b). Of the 168 miles of impaired waterways, only 63 miles (38%) have an established total maximum daily load (TMDL); the remaining 105 miles were still in need of one as of 2010.

Oil was not discovered in North Dakota until 1951 when the Clarence Iverson #1 on the Nesson anticline was completed (Heck et al., 2012). The first reported discovery of natural gas was in 1892 from a Dakota Sandstone water supply well near Edgeley (Heck et al., 2012). Approximately 1,100 conventional oil and gas wells have been drilled over time in Dunn County. Oil has been recovered from 35 formations, the most prominent being the Madison and the Bakken formations which have produced about 46% and 16% of the oil recovered, respectively.

**Water Quality**

Water quality data were evaluated by Battelle for the pre-2005 timeframe, prior to unconventional oil and gas development in the Bakken shale via directional drilling and hydraulic fracturing. Sampling locations where groundwater, surface water and spring water quality parameters in the database were found to be higher than applicable federal and state water quality standards, criteria and guidance values are shown in Figure 3. Table 4 provides a summary of parameters detected above one or more screening criteria for the data set with STORET data removed for Dunn County. Results above screening criteria include pH, TDS, chloride, fluoride, sodium, sulfate, aluminum, arsenic, beryllium, boron, iron, manganese, mercury, phosphorous, selenium, strontium, zinc and nitrate. Insufficient data are available on water quality with respect to organic chemical constituents.

Groundwater quality data from 711 locations were reviewed; constituents detected above one or more screening criteria include:

- **General water quality parameters** – pH and TDS were above one or more screening criteria, with TDS at 85% (689 of 807 results) most often above its SMCL.
- **Major ions** – chloride, fluoride, sodium and sulfate were above one or more screening criteria, with sodium (778 of 802 results above EPA health advisory level, 97%) and fluoride (476 of 795 results above EPA non-carcinogenic screening level, 60%) were most frequently above one or more screening criteria.
- **Metals** – including aluminum, arsenic, beryllium, boron, iron, manganese, mercury, phosphorous and strontium were above one or more screening criteria, with arsenic (14 of 20 results, 70%) most frequently above the EPA carcinogenic screening level.
- **One nutrient**, nitrate as N, was detected in 5% of samples (19 of 350 samples) above its MCL.

The levels of calcium, chloride, manganese, sodium and sulfate in groundwater were evaluated based on geologic formation and depth. Results of regression analyses indicate that a relationship exists between concentrations of these parameters and depth beneath the ground surface. Most pronounced were the high chloride concentrations at greater depths.
Surface water quality data were compiled from 49 locations; constituents detected above one or more screening criteria include:

- General water quality parameters – pH, dissolved oxygen, and TDS were above one or more screening criteria, with TDS at 85% (372 of 436 results) most often above the SMCL.
- Major ions – sodium (428 of 435 results above EPA health advisory level, 98%) and sulfate (352 of 435 results above SMCL, 81%) were above one or more screening criteria.
- Metals – beryllium, iron, manganese, mercury, selenium and zinc were above one or more screening criteria, with total mercury (28 of 47 results, 60%) most frequently detected above North Dakota criteria.

Spring water quality data were compiled from 30 locations; constituents detected above one or more screening criteria include:

- General water quality parameters – TDS is above its SMCL in 20 of 30 results (67%).
- Major ions – chloride, sodium and sulfate are above one or more screening criteria, with sodium at 90% (28 of 31 results) most often above its EPA health advisory level.
- Metals – iron (10 of 28 results above SMCL, 36%) and manganese (14 of 24 results above SMCL, 58%) were above one or more screening criteria.
Figure 3. Locations where at least one parameter was detected in groundwater (water wells), surface water, or spring water above one or more screening criteria in Dunn County.
Table 4. Parameters above one or more screening criteria in reduced (STORET data removed) dataset in Dunn County

<table>
<thead>
<tr>
<th>Medium</th>
<th>General Water Quality</th>
<th>Major Ions</th>
<th>Dissolved Metals</th>
<th>Nutrient</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total No. Sample Locations</td>
<td>pH (Field)</td>
<td>Dissolved Oxygen</td>
<td>Total Dissolved Solids</td>
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<tr>
<td>Springs</td>
<td>30</td>
<td>– /30</td>
<td>67 /22</td>
<td>5 /31</td>
</tr>
</tbody>
</table>

* Excludes STORET data; \( \frac{4}{185} = 4\% \) of 185 samples; \( – \) = No data above screening criteria; \( † \) = total metals value
BRADFORD AND SUSQUEHANNA COUNTIES, PENNSYLVANIA

The Bradford and Susquehanna counties retrospective case study in northeast Pennsylvania was selected by EPA in response to complaints of contaminated groundwater and drinking water wells and suspected surface water contamination from a spill of hydraulic fracturing fluid (EPA, 2012b). As part of the case study EPA is collecting and analyzing samples from domestic wells, springs and surface water bodies and analyzing them for a range of water quality parameters (Figure 4). No rationale was provided in the EPA QAPP for selecting the specific sampling locations.

Land Use
Approximately 1,147 square miles in area, Bradford County has a population of over 62,622. Susquehanna County encompasses approximately 823 square miles and has a population of over 43,356 (U.S. Census Bureau, 2010). In both cases, population density is a little over 50 persons per square mile. In 1986, farming (cropland, pasture and orchards) was a major land use at 40% and 51% for Bradford and Susquehanna Counties, respectively. Since then, some agricultural land has reverted to forest, rangeland and transitional use which accounted for 70 to 80% of the combined land cover in 2006. Total land use dedicated to higher intensity development comprising residential, urban, industrial, commercial and services, and transportation areas, was less than 2% in both counties over this time period.

Regulatory Administration
Pennsylvania has one of the most robust regulatory programs for oil and gas development of any state. Casing and cementing standards for oil and gas wells have been in place since passage of Pennsylvania’s Oil and Gas Act in 1984, and were enhanced by changes to Chapter 78 of Pennsylvania’s environmental regulations in 2011 and recent changes to the Oil and Gas Act in Act 13 of 2012. Because of these standards, risk of groundwater contamination from poor construction of new oil and gas wells is currently lower than at any time in Pennsylvania’s history.

In 2010, PADEP requested to have its oil and gas regulatory program reviewed by STRONGER. This was the latest of four STRONGER reviews of the PADEP’s program and the first to focus on hydraulic fracturing operations. Overall, the report concluded that the framework in place in Pennsylvania was well-managed, professional and met its stated objectives (STRONGER, 2010).

Water Resources
Both counties are located within the Susquehanna River Basin which has a total drainage area of 27,200 square miles. All rivers and streams in Bradford and Susquehanna counties are considered drinking water resources or contribute to surface water bodies that may serve as drinking water resources. In Pennsylvania, over 3 million residents obtain their drinking water from private groundwater wells. The average depth to groundwater in northeastern Pennsylvania is approximately 175 feet, but is commonly located at depths less than 40 to 50 feet in areas of low topography.

In Bradford and Susquehanna Counties, potable groundwater resources primarily occur within Pleistocene-age unconsolidated sedimentary deposits and consolidated Pennsylvanian, Mississippian and Devonian age sedimentary rocks. Unconsolidated glacial outwash and till deposits associated with the Wisconsin Stage of the Pleistocene period are typically between a few feet to hundreds of feet thick and yield a relatively small quantity of potable water. Rocks of the Catskill formation are important water-bearing features in northeastern Pennsylvania yielding moderate supplies of good quality water. Below the Catskill formation, the Lock Haven formation yields a small to moderate amount of fair quality water in shallow portions of the aquifer. Taylor (1984) found naturally occurring constituents (most often iron and manganese) above their respective SMCLs in 36% of groundwater samples in the Upper Susquehanna River Basin, which includes Bradford and Susquehanna Counties. Elevated iron, sulfate, TDS and low pH were noted in areas where anthracite coal occurs or was mined. Naturally occurring
saline groundwater has been found to occur in both the Catskill and Lock Haven Formation at depths less than 200 feet (Williams, 1998).

**Impacts to Water Resources**

The primary causes of surface water quality impairment in the region are agriculture, road runoff and other non-point sources, human waste handling, industrial discharges, and resource extraction including coal and other mineral mining activities. The top two known causes of impairments are road runoff and agriculture. There are over 144 miles of impaired streams and rivers in Bradford County, representing approximately 6.7% of total stream length due to pH, metals, polychlorinated biphenyls (PCBs) and siltation TMDL exceedances (PADEP, 2012). Over 87 miles of impaired streams and rivers in Susquehanna County, representing approximately 5.5% of the total stream length, have surface water impairments due to pH, metals, PCBs, nutrients, siltation and suspended solids TMDL exceedances. The entire length of the Susquehanna River is impaired primarily by PCBs with advisories limiting fish consumption in both counties.

In 2010, 1,430 tons of chemicals regulated under the TRI Program were released in Bradford County through on- and off-site treatment, recycling, disposal, discharge or other forms of release. 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 releases large enough to be noted under the TRI Program within Susquehanna County.

There are many facilities or locations in Bradford County and Susquehanna County with recognized environmental impacts. This includes environmental restoration sites such as 88 storage tank incident sites, 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.

Conventional oil and natural gas development has occurred in a limited way for over a century in Bradford and Susquehanna Counties (Young, 2002). Up to 25 historic ventures in Susquehanna County from the 1860s to early 1900s had little to no success in yielding economic quantities of oil or gas. The only economical conventional sources of gas were small, deep gas fields in northern Bradford County; this is in contrast to the large shallow and deep oil and gas fields in Western Pennsylvania (McCoy and Schmitt, 2007). Although economic quantities were not obtained from conventional gas wells in the area, the presence of methane gas in natural seeps and shallow water wells has been documented in this region for many decades (Molofsky et al., 2011). Permitting and registration of oil and gas wells were not required by the state of Pennsylvania until the 1960s, and there were no official regulations for plugging oil and gas wells until the passage of Act 223 in 1984. Little is known about the construction, production and abandonment procedures for these former wells although it is known that the casing from many of these wells was removed during World War II to support the country’s steel requirements. These older conventional wells typically targeted shallower formations than the Marcellus Shale in Bradford and Susquehanna Counties. The oil and gas industry and regulatory agencies are taking steps to proactively manage orphan wells by evaluating the potential pathways and risks posed by each identified well, and mitigating the highest risk wells as a priority measure (IOGCC, 2005; McKee, 2012).

Private water wells in Pennsylvania are not required to be permitted or meet specific construction or sanitary standards. Poorly sited groundwater supply wells and inadequate well construction are key factors resulting in water supply contamination; a statewide survey of 701 private wells showed that wells
with poor construction had poor water quality (Swistock et al., 2009). The study found poor well construction was the most important factor for the elevated levels of coliform bacteria observed in 33% of the wells.

Although concern has been expressed over the potential for hydraulic fracturing operations to contaminate drinking water, no instances have been documented where the process of injecting hydraulic fracturing fluids into the subsurface has negatively impacted water resources despite tens of thousands of wells being fractured in Pennsylvania over the past several decades (MSAC, 2011).

**Water Quality**

Water quality data were assembled and evaluated by Battelle for the pre-2007 timeframe, prior to unconventional oil and gas development in the Marcellus shale via directional drilling and hydraulic fracturing. Several water quality parameters were found to be higher than applicable federal and state water quality standards, criteria or guidance values. Figure 4 shows those locations where the values were higher than the water quality criteria for groundwater (water wells), spring water and surface water. Insufficient data are available on water quality with respect to organic chemical constituents. Table 5 provides a summary of parameters detected above one or more screening criteria for the data set with STORET data removed for Bradford-Susquehanna Counties. Results above screening criteria include alkalinity, pH, TDS, chloride, fluoride, sodium, sulfate, aluminum, arsenic, barium, chromium, iron, lead, manganese, strontium, zinc and nitrate. Insufficient data are available on water quality with respect to organic chemical constituents.

Groundwater quality data were compiled from 535 locations; constituents detected above one or more criteria include:

- General water quality parameters – pH and TDS are above one or more screening criteria with TDS (22 of 223 samples, 10%) most often above the SMCL.
- Major ions – sodium (total [38 of 82 samples, 46%] and dissolved [104 of 410 samples, 25%]) were higher than the EPA health advisory level; chloride, fluoride and were greater than their respective SMCLs with chloride most often above its SMCL in 14 of 502 samples (3%), and fluoride in 4 of 444 samples (1%).
- Metals – aluminum, arsenic, barium, chromium, iron, lead, manganese, strontium and zinc were greater than one or more criteria; arsenic (dissolved) in 10 of 10 samples (100%) and barium in 3 of 52 samples (6%) most often were detected above their MCLs; dissolved iron (48 of 141 samples, 34%) and dissolved manganese (211 of 290 samples, 74%) most frequently were above their SMCLs.
- Nutrients – nitrate as N was found above the MCL in 2 of 226 samples (1%), respectively.

Surface water quality data were compiled from 286 sampling locations; constituents detected above one or more screening criteria include:

- General water quality parameters – alkalinity (27 of 196 samples outside Clean Water Act criteria (14%), pH and TDS were above one or more screening criteria with pH, 56 of 671 results (8%), most often outside the SMCL criteria.
- Major ions – chloride and sulfate were above one or more screening criteria, with chloride in 2 of 474 results (<1%) most often above its SMCL.
- Metals – aluminum, copper, iron and manganese were above one or more screening criteria; dissolved aluminum (68 of 293 samples, 23%), total iron (98 of 266 samples, 37%) and dissolved manganese (211 of 290 samples, 73%) most often were above their SMCLs.
- Nutrients – nitrate as N was found above the MCL in 2 of 307 samples (<1%), and nitrite as N was found above the MCL in 1 of 219 samples (<1%)

Spring water quality data were available at 92 locations; constituents detected above one or more screening criteria include:

- General water quality parameter – pH was above the SMCL in 30 of 90 samples (33%).
- Major ions – sodium was above the health advisory level in one of 89 samples.
- Metals including aluminum and manganese were above one or more screening criteria, with dissolved manganese most frequently detected above the SMCL in 49 of 63 samples (78%).
Figure 4. Locations where at least one parameter was detected in groundwater (water wells), spring water, or surface water above one or more screening criteria in Bradford-Susquehanna Counties.
Table 5. Parameters above one or more screening criteria in reduced (STORET data removed) dataset in Bradford-Susquehanna Counties

<table>
<thead>
<tr>
<th>Medium</th>
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<td>Springs</td>
<td>92</td>
<td>33 /90</td>
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* Excludes STORET data; 4/185 = 4% of 185 samples; – = No data above screening criteria; † = total metals value
The Raton Basin in southwest Colorado was selected by EPA as a retrospective case study in response to complaints about appearance, odors and taste associated with water in domestic wells (EPA, 2012b). EPA (2012b) noted potential sources of groundwater contamination to include activities associated with coalbed methane (CBM) extraction, residential or agricultural practices, gas well completion and enhancement techniques, improperly plugged and abandoned wells, and gas migration. As part of the case study, EPA is collecting samples from six domestic wells in Huerfano County, three monitoring wells, three production wells, two surface water locations and one produced water discharge in Las Animas County and analyzing them for a range of water quality parameters (Figure 5).

**Land Use**
In 2006 the total county-wide land use for agricultural and developed land (residential, industrial, commercial and services, urban, transportation and communication, and surface extraction) was 1.3%; this represents a decline from 1986 when the total for these types of land use was 4.8% (U.S. Department of Agriculture [USDA], 2006, U.S. Geological Survey [USGS], 1986). The balance of the land use is forested upland, shrubland, natural grassland, wetlands and water bodies.

Since the mid-1990s, over 2,800 CBM wells have been drilled in the Colorado portion of the Raton Basin. CBM production involves the dewatering of coalbeds to reduce pore pressures and ultimately liberate methane gas from the coal. The methane gas is then captured by a pipe network of production wells and eventually sent to market. CBM produced water disposal methods include underground injection wells, pits, surface water discharge, re-use/recycling, road watering, centralized waste treatment, commercial disposal, and mitigation for temporary water supply for firefighting. CBM activities terminated on the Huerfano County side of the Spanish Peaks in 2007 due to uneconomical production of the coal seams. In most of the Raton Basin in Colorado the potential for interference of CBM wells with nearby water-supply wells (greater than 100 feet of vertical separation) is limited (Watts, 2006).

**Regulatory Administration**
Colorado’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. The multi-stakeholder organization STRONGER (2011) concluded that the Colorado program is well managed and professional.

**Water Resources**
Potable groundwater resources occur within shallow unconsolidated Quaternary alluvial deposits and consolidated Tertiary age sedimentary rocks in the Raton Basin. Principal bedrock aquifers are the Dakota Sandstone-Purgatoire Formation, Raton Formation-Vermejo Formation-Trinidad Sandstone, Cuchara-Poison Canyon Formation and volcanic rocks (Abbott et al., 1983). Bedrock formations generally yield small (0.5 to 20 gallons per minute) to moderate (20 to 100 gpm) quantities of groundwater to wells and springs, although in the northwestern and southwestern parts of the area, sandstone and conglomerate may yield large quantities of groundwater.

**Impacts to Water Resources**
Commercial development of the area began with mining of the Raton Mesa Vermejo and Raton Formation coals in Colorado in 1870 (Hemborg, 1998), and at least 371 mines have historically operated in the region (Boreck and Murray, 1979). In 1995 the last remaining coal mine in the area closed for economic reasons. In early 2010 the New Elk underground mine in Las Animas County reopened for rehabilitation and subsequent coal production. It is currently the only active mine in the Raton Basin study area.
There are a number of facilities or locations with recognized environmental impacts in the Raton Basin study area including gravel pits, active coal mining, CBM well discharge locations, gas stations, solid waste disposal sites and landfills. There are no reported Brownfield sites within the Raton Basin nor was there any reported release of chemicals (through March 2012) to the environment regulated under the Toxic Release Inventory (TRI) program through on- or off-site disposal or other forms of release (EPA, 2012b).

In 2004 EPA conducted a study of the Raton Basin to assess impacts to drinking water sources from hydraulic fracturing of CBM reservoirs. After reviewing data and incident reports, EPA found no conclusive evidence of water quality degradation that was a direct result of injection of hydraulic fracturing fluids into CBM methane wells and subsequent movement of these fluids. EPA (2004) noted several other factors may contribute to groundwater problems including resource development, naturally occurring conditions, population growth, and historical well-completion or abandonment practices. EPA went on to state that operators noted elevated methane in coal seams that have been intruded by igneous rocks, particularly in the Huerfano County side of the Spanish Peaks divide. Hydraulic pressure differences between deep bedrock aquifers and shallow water bearing units suggest they are not in communication.

**Water Quality**
Deterioration in groundwater quality has occurred locally on the western side of the basin and nearly everywhere on the eastern side due to coal mining (Geldon, 1989). Elevated nitrogen was noted near the surface likely due to human and animal waste and fertilizers. Iron, manganese, zinc and selenium locally are higher than standards for domestic consumption. Water quality in streams is affected by tributary inflows, mine discharge, contact with and seepage from tailings, groundwater seepage, diversion ditches and changes in stage.

Deep coal seams of the Raton and Vermejo Formations contain groundwater that meets the water quality criteria for an underground source of drinking water (USDW). Typical Raton produced waters exhibit average TDS concentrations of 1,905mg/L (EPA, 2010b). Historic studies of CBM target zones in the Raton Basin in Colorado suggest varying groundwater yields and heterogeneity within what might be considered a single aquifer (Abbott et al., 1983).

Coalbeds targeted for development occur within the same formations as aquifers used for water supply. The formations are very heterogeneous limiting both lateral and vertical connectivity. The potential for interference of coalbed-methane wells with nearby water-supply wells likely is limited where 100 feet or more of vertical separation exist between the wells. Methane is naturally present and widespread in groundwater and seeps across the basin.

In 2003 the Colorado Oil and Gas Conservation Commission (COGCC) completed a Raton Basin Baseline Study to document the existing conditions, collect data that can be used to address future complaints, and identify and monitor areas of concern within the basin. The results of the Raton Basin Baseline Study did not identify any issues that required immediate actions. A total of 246 private water sources and CBM wells were analyzed as part of the study. Methane was detected in 114 of the 246 samples (46%) at concentrations ranging from 0.00029 mg/L to 38 mg/L. The COGCC confirmed that methane is widely distributed in the shallow aquifers across the Raton Basin. The water well values detected indicated a biogenic, i.e., less thermally mature source of methane, and the gas well values tended to indicate more thermogenic, i.e., more thermally mature methane source.

EPA (2004) found no conclusive evidence of water quality degradation that is a direct result of injection of hydraulic fracturing fluids into CBM wells and subsequent movement of these fluids. Other impacts to
water quality including resource development, naturally occurring conditions, population growth and historical well-completion or abandonment practices were noted.
Figure 5. Raton Basin study area
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