SECTION 4
Groundwater Monitoring Program

GROUNDWATER POLLUTION PREVENTION, MONITORING AND RESPONSE ACTION PLAN

Pinedale Anticline Project Area
Sublette County, Wyoming

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4.0 GROUNDWATER MONITORING PROGRAM

The goal for the Groundwater Monitoring Program (GMP) (see **Section 2.2**) is to:

> ***Establish a Groundwater Monitoring Program to monitor groundwater for impacts from oil and gas activities that is based on the PAPA groundwater characterization, is appropriate to the level of risk, and will include constituents that are: most indicative of impacts from oil and gas activities; most likely to appear first at monitoring sites; and most hazardous to public health and the environment.***

The GMP was developed to meet this goal and 10 specific objectives (see **Section 2.2**), and conform with requirements of the Wyoming Oil and Gas Conservation Commission's (WOGCC's) groundwater baseline sampling, analysis and monitoring rule (WOGCC 2014a; Section 46 and Appendix K of Chapter 3 – Operational Rules, Drilling Rules). In particular, the GMP will serve as a "master plan" for the Pinedale Anticline Project Area (PAPA) Operators under WOGCC rules.

This section of the Plan provides data quality objectives for the GMP, describes technical approaches for establishing monitoring locations and water quality parameters, and presents groundwater quality thresholds. Also described in this section are the Sampling and Analysis Plan (SAP) and Quality Assurance Project Plan (QAPP) that will dictate data collection activities; each of these plans is appended to this section. At the end of this section, procedures for data management and validation are presented along with the results reporting system, GMP review cycles, and a discussion of decommissioning the monitoring network.

4.1 DATA QUALITY OBJECTIVES

Objective O2.1 indicates that data quality objectives (DQOs) be developed in consideration of applicable and appropriate regulatory requirements in accordance with standard environmental practices and consistent with the groundwater characterization completed under Step 2 of the Record of Decision (ROD) (Bureau of Land Management [BLM] 2008a). U.S. Environmental Protection Agency (EPA) guidance on systematic planning using the DQO process (EPA 2006) was consulted to prepare DQOs to assure that adequate data of sufficient quality will be collected to fulfill objectives presented in **Section 2.2**, and enable fully supported decision-making. The process involves completing seven steps aimed at: 1) defining the problem statement; 2) identifying the goal of the GMP and various decisions to be made; 3) identifying information/decision inputs; 4) defining boundaries for the GMP; 5) developing the analytic approach; 6) specifying performance or acceptance criteria; and, 7) developing a detailed plan for obtaining data (e.g., optimizing sample design). The DQOs for this GMP are summarized in **Table 4-1**.

4.2 MONITORING LOCATIONS – TECHNICAL APPROACH

This section outlines the approach used to design the monitoring well network to fulfill the following three objectives for the GMP.

Objective	Description
O2.3	Develop a tiered approach to groundwater monitoring that includes different water quality parameters and sampling frequencies for monitoring locations based on risk, proximity to active [natural gas] development, and when a threshold is reached.
O2.5	Establish groundwater monitoring locations to provide for early detection of potential impacts from oil and gas activities in areas of greatest environmental sensitivity.
O2.6	Establish groundwater monitoring locations to provide spatial coverage of the PAPA.

To address these groundwater monitoring objectives, an assessment was completed to identify: areas of active oil and gas development; areas with greatest risk to groundwater resources; and, areas of greatest environmental sensitivity in the PAPA.

4.2.1 Active Development Areas

Natural gas well drilling in the PAPA is anticipated to continue through about year 2024 and may involve all five core development areas established in BLM's 2008 ROD (**Figure 4-1**). For 2015, Operators expect development to occur in the central portion of Development Area 1 (DA-1), eastern portion of DA-3, and southeast portion of DA-4. Plans for development beyond 2015 are not yet determined, but could occur throughout the development areas. For this reason, this GMP assumes that active oil and gas development will take place in the five development areas.

4.2.2 Evaluation of Risk and Environmental Sensitivity

NewFields evaluated studies aimed at designating aquifer sensitivity/vulnerability and aquifer prioritization for Wyoming. NewFields considered work completed by Hamerlinck and Ameson (1998) and summarized by AMEC Geomatrix (2009) to evaluate groundwater vulnerability relative to oil and gas activities in the PAPA. Hamerlinck and Ameson (1998) developed the Wyoming Sensitivity/Vulnerability model which defines sensitivity as "the relative ease with which contaminants can move from the surface through various substrates to pollute groundwater." The term vulnerability is defined as incorporating "aquifer sensitivity and the potential for a contaminant to be spilled on the surface." According to AMEC Geomatrix (2009), 'sensitivity' describes an aquifer's susceptibility to contamination based solely on natural physical properties (e.g., depth, soil, geology); whereas 'vulnerability' describes susceptibility to contamination based on both natural physical properties and human activities on the surface (e.g., herbicide use on irrigated cropland).

Using the model Hamerlinck and Ameson (1998) developed for Wyoming, Geomatrix (2002) produced an aquifer sensitivity map for the PAPA. This map was included as Figure 3 in the Interim Plan (Geomatrix 2008) and shows areas of greatest sensitivity being portions of the Mesa, areas along the New Fork and Green rivers, and an area coincident with Sand Draw.

In addition to the aquifer sensitivity map prepared by Geomatrix (2008), NewFields considered work completed by Bedessem et al. (2005), which focused on identifying high priority aquifers for Wyoming's

ambient groundwater monitoring strategy. Their work includes an evaluation of aquifer sensitivity, current water use, and the potential for surface contamination from known land uses. This approach combines physical factors used to determine aquifer sensitivity with information on aquifers that are used for drinking water sources, and with aquifers that are most susceptible to point and non-point source pollution. Bedessem et al. (2005) identifies high priority aquifers as those used for drinking water sources and which are most susceptible to pollution. **Figure 4-2** shows the aquifer prioritization map for the PAPA based on Bedessem et al. (2005). High priority aquifers in the PAPA are primarily associated with those located in the New Fork River valley.

The approaches described above to identify sensitive/vulnerable aquifers and high priority aquifers for the area encompassing the PAPA do not consider the three dimensional groundwater flow system, specific potential sources of groundwater impacts from oil and gas activities, and the potential fate of contaminants if they entered the groundwater system. However, results produced by a groundwater flow and transport model of the PAPA (AMEC 2013a) help further define those areas that possess the greatest risk of being impacted from oil and gas activities.

The PAPA numerical model (AMEC 2013a) is a three-dimensional model of the groundwater flow system and can be used to identify areas located hydraulically downgradient of oil and gas activities. The model can also be used to predict the areas within the PAPA where groundwater could potentially be impacted by oil and gas activities.

NewFields expanded on work reported by AMEC (2013a) by simulating the movement of particles through the PAPA groundwater flow field for a period of 110 years (see **Section 4.2.3** and **Appendix 4-A**), which is approximately twice the anticipated production life of the Pinedale Anticline (BLM 2008a). The particle track simulations included 110 year-long forward particle tracks from potential oil and gas source areas, and 110 year-long reverse particle tracks from those areas identified as sensitive/vulnerable to groundwater contamination (note: these sensitive/vulnerable areas generally coincide with high priority aquifers mapped by Bedessem et al. [2005]). NewFields' particle tracking simulations addressed uncertainty in the model that was discussed by AMEC (2013a). Results of particle track simulations focused on the area considered to be of greatest environmental sensitivity and with the greatest relative risk of being impacted, and only involved those areas with potential receptors (e.g., New Fork River) that had a potential oil and gas source located hydraulically upgradient. **Figure 4-3** shows this area which is hereafter referred to as the "River Corridor Envelope". The area comprises the zone enveloping potential sources located hydraulically upgradient of their potential receptors over a 110-year travel time from potential source to potential receptor.

4.2.3 Monitoring Boundary and Well Network Design

The Conditions of Approval for the 2000 ROD (BLM 2000) stated that all water wells within a one-mile radius of existing and proposed oil and gas development be monitored on an annual basis. BLM's 2008 ROD (BLM 2008a) supersedes in its entirety the 2000 ROD but required an Interim Plan (Geomatrix 2008) for continued groundwater monitoring until this Plan was completed and approved. The annual groundwater monitoring program has been continued through 2015. Maps provided in annual water quality reports issued by the Sublette County Conservation District (SCCD) show areas north of DA-1 boundary and east of the boundaries for DA-1 and DA-2 where existing private water wells have been

monitored per the 2000 ROD (SCCD's annual groundwater data summary reports are available at: http://www.blm.gov/wy/st/en/field_offices/Pinedale/pawg/DataResults.html). Some of these areas with existing private wells also coincide with high priority aquifers mapped by Bedessem et al. (2005; see **Figure 4-2**).

The GMP monitoring boundary (defined below) does not include some of the areas where existing private water wells had been previously monitored under requirements of BLM's 2000 ROD. As stated in **Section 2.2** and in the beginning of **Section 4.0**, the goal developed by the regulatory agencies for the GMP includes monitoring groundwater for impacts from oil and gas activities based on the PAPA groundwater characterization. The areas north of the DA-1 boundary and east of the boundaries of DA-1 and DA-2 are hydraulically upgradient of potential contaminant sources associated with natural gas development based on maps presented in Martin (1996), as determined from groundwater elevations measured during the Hydrogeologic Data Gaps Study (see **Section 1.6.1** and AMEC 2012) and as numerically modeled (see **Section 1.6.2** and AMEC 2013a). As a result, the areas north of the boundary of DA-1 and east of the boundaries of DA-1 and DA-2 are not included in the GMP monitoring boundary.

Information presented in **Sections 4.2.1** and **4.2.2**, above, was used to determine the monitoring boundary for the GMP. In accordance with the stated goal of the GMP (see **Section 2.2**), the GMP is to be based on the groundwater studies completed for Step 2 of the ROD including consideration of groundwater flow direction determined for the PAPA. Areas in the PAPA to be monitored under the GMP are described in three objectives:

- Objective O2.3 – monitor the area proximal to active development and in areas with greatest environmental risk;
- Objective O2.5 – monitor to provide early detection in areas of greatest environmental sensitivity; and
- Objective O2.6 – monitor to provide spatial coverage in the PAPA.

The area of active natural gas development in the PAPA is defined by the borders of DA-1 through DA-5. The area that is considered to be of greatest environmental sensitivity and greatest relative risk of being impacted from natural gas development is the River Corridor Envelope, which was determined by the following:

- Locations of high priority aquifers mapped by Bedessem et al. (2005; **Figure 4-2**).
- Results of numerical particle tracking from potential receptors identified by the agencies (BLM, DEQ and EPA) and the Operators in 2011 (AMEC 2013a). Receptors included private domestic and stock water wells, and the New Fork River.
- Locations of potential oil and gas sources relative to these receptors (i.e., hydraulically upgradient).

Based on these factors, the monitoring boundary for the GMP is described as the area bound by DA-1 through DA-5 and the River Corridor Envelope (**Figure 4-3**).

NewFields divided the PAPA groundwater monitoring boundary into areas both north and south of the River Corridor Envelope. The North Zone includes DA-1 and a portion of DA-2, and the South Zone includes a portion of DA-3, all of DA-4 and DA-5. These three general monitoring zones (River Corridor Envelope, North Zone, and South Zone) of the PAPA are shown on **Figure 4-3**.

Within the monitoring boundary, there are several existing private domestic, private stock, and Operator-owned industrial water supply wells. As noted above, private domestic and stock wells are considered potential receptors of groundwater impacts from oil and gas activities. Based on the GMP objective to provide early detection of potential impacts (Objective O2.5), the GMP monitoring well network was designed to monitor groundwater upgradient of these potential receptors. This strategy aims to identify groundwater degradation issues before they reach and impact potential receptors (e.g., domestic and stock wells, and the New Fork River).

PAPA Operators are being required by this Plan to monitor wells for the GMP and, consequently, certain wells were excluded from consideration into the GMP well network if the Operators would not be reasonably able to:

- Control security and access to the monitoring wells; and
- Operate and maintain monitoring wells in accordance with BMPs listed in **Table 3-2**.

Qualitative and quantitative approaches were used to select well locations for the monitoring network. NewFields applied a combination of analytical tools to design the monitoring network to fulfill the three well-siting objectives listed at the beginning of **Section 4.2**. These tools were used in consideration of the hydrogeologic conceptual model for the PAPA and included: GIS coupled with the project's Environmental Data Management System (EDMS; **Section 1.7.3**); PAPA numerical groundwater model to conduct advective particle track simulations; and a geospatial utility in Visual Sample Plan (VSP, Version 7.0; PNNL 2014). The subsections below describe selection of well locations in the three monitoring zones:

- River Corridor Envelope downgradient of potential sources and upgradient of potential receptors to monitor the Wasatch HSU;
- Core of the River Corridor Envelope to monitor the Alluvial HSU;
- Area encompassing DA-1 and a portion of DA-2 north of the River Corridor Envelope to monitor the Wasatch HSU (i.e., North Zone); and
- Area encompassing a portion of DA-3, and all of DA-4 and DA-5 south of the River Corridor Envelope to monitor the Wasatch HSU (i.e., South Zone).

Consideration of using existing wells (completed at various depths with various screened/perforated intervals) for the GMP well network outside of the River Corridor Envelope was made for the following reasons:

- The WOGCC specifies use of existing wells to fulfill requirements of their baseline monitoring rule;

- Existing wells were required to be sampled by the 2000 ROD, have been sampled through 2014 and will be sampled in 2015 ; and,
- Results from water quality sampling of existing wells have been used for regulatory decisions made by both BLM and DEQ.

As part of the selection process for the GMP well network, water quality data from wells completed at various depths in the Wasatch Formation in the PAPA were evaluated to assess if statistically significant relationships are evident between well depth and select water quality parameters.

A statistical test (t-test) was performed using data produced by SCCD between 2004 and 2013 to evaluate similarity in concentrations of chloride and total dissolved solids (TDS) versus the depth (depth below ground surface) of the midpoint of the well screen interval and the absolute elevation of the midpoint in the well screen interval. These two depth variables were analyzed due to the relief present in the PAPA, as the ground surface elevations of some natural gas well pads on the Mesa in the North Zone are approximately 7,600 feet and the elevation of the New Fork River in the center of the PAPA is about 6,900 feet. A description and results of the t-test are presented in **Appendix 4-A**.

The following data were used in the t-test:

- Water quality sample results stored in the project geodatabase (i.e., EDMS) that included data collected by SCCD from 2004-2013 and data collected during the completion of the Step 2 groundwater studies.
- Water quality data were used from industrial water supply, stock, domestic, and study wells completed in the Wasatch Formation that are located within the GMP monitoring boundary as described above.
- Data from wells enrolled in DEQ's Voluntary Remediation Program were not used in the t-test. In addition, quantile-quantile probability plots were used to visually inspect the datasets and remove outliers.
- After removal of outliers, chloride data were available from 820 samples and TDS data from 811 samples that were collected from 95 wells within the GMP monitoring boundary.
- The depth of the midpoint of well screens in the 95 wells ranges from 54 to 1,210 feet below ground surface whereas the elevation ranges from 6,306 to 7,263 feet above mean sea level. The average elevation of the midpoints of well screens for the 95 wells is 6,700 feet.

Results of the analysis indicate that there is no statistically significant relationship between concentrations of chloride or TDS with mid-screen depth or elevation based on samples from 95 wells located within the GMP monitoring boundary. Consequently, comparing sample results from wells completed in the Wasatch Formation at the depth ranges listed above with new Wasatch Formation wells for the GMP appears appropriate.

4.2.3.1 River Corridor Envelope – Wasatch HSU

NewFields followed a series of steps to identify groundwater monitoring locations in the north half and south half of the River Corridor Envelope between potential sources and potential receptors. These monitoring wells would help satisfy Objective O2.5, which is early detection of potential impacts from oil and gas activities in areas of greatest environmental sensitivity. As groundwater movement in the Wasatch HSU is toward the New Fork River (**Figure 4-4**), the northern and southern portions of the Envelope are both upgradient of the New Fork River.

Potential oil and gas sources and environmentally sensitive receptors/areas were identified based on studies presented in **Section 4.2.2** and the three technical groundwater studies conducted pursuant to BLM's 2008 ROD, including the Hydrogeologic Data Gaps Investigation (AMEC 2012), Numerical Groundwater Model (AMEC 2013a), and Low-Level Petroleum Hydrocarbon Compounds (LLPHC) study (AMEC 2013b). Potential existing sources include well pads and facilities, centralized liquid gathering system (LGS) facilities, LGS pipelines, and injection wells. Potential existing receptors include the New Fork River and associated floodplain and riverine system, stock wells, and domestic wells on private land.

After identifying reasonable potential sources and receptors, NewFields performed the steps outlined below to select optimum locations for monitoring wells; **Appendix 4-A** contains further details of the approach:

1. The first step involved assessing the maximum width of a plume originating at a potential source (e.g., drill pad). This was necessary to evaluate the lateral spacing between monitoring wells. Results from the solute transport model (AMEC 2013a) were used as the basis for well spacing. Based on a numerical simulation of a chloride release from a legacy gas well (see Figure 61 in AMEC 2013a), the maximum width of a 1 milligram per liter (mg/L) chloride plume would be about 2,100 feet (7 model cells). This distance was used for the approximate spacing between proposed monitoring wells for the GMP which were placed a minimum of 1,800 feet apart (6 cells). Locations of upgradient sources (pads) were also evaluated to position the potential monitoring wells in a downgradient direction.
2. Potential receptors in the PAPA were confirmed, which are generally located in or adjacent to the floodplain of the New Fork River. These receptors include isolated domestic wells on the north side of the New Fork River and domestic wells serving residents of the Wild Horse Subdivision along the south side of the New Fork River.
3. After having established the initial spacing between potential monitoring wells (2,100 feet) particles in the groundwater flow model were placed at these locations in the first "fully" saturated sandstone layer, and their movement backward (reverse) was tracked in the groundwater flow field for a period of 110 years. Particles were also placed at deeper layers of the model and confirmed that reverse particle tracks (flow paths) did not vary significantly from particle tracks in the shallow layers of the model. Consequently, target depths for new Wasatch HSU monitoring wells in this area would be the first continuously saturated sandstone unit, estimated to be approximately 100-200 feet below ground surface.

4. The particle tracks were then assessed as to whether the particles intercepted or "captured" locations of existing potential sources. In some cases, new monitoring well locations were adjusted to ensure adequate coverage (capture) for potential sources.

Lastly, individual well locations were evaluated relative to a surface land management hierarchy, with the most beneficial to least beneficial as follows: BLM—State—County—Operator owned—Operator leased—private. Areas that are currently disturbed/developed and have vehicular access would be beneficial compared to undeveloped areas for installing new monitoring wells.

Results of the well location analysis for Wasatch HSU monitoring wells in the River Corridor Envelope are shown on **Figure 4-5**. Based on the approach described above and presented in **Appendix 4-A**, 13 Wasatch HSU wells are needed in the River Corridor Envelope to satisfy monitoring objectives, with seven new wells north of the New Fork River and six new wells south of the river. For this GMP, new wells in the River Corridor Envelope will be designated with the prefix "RCE-" followed by a consecutive number (e.g., RCE-07). **Table 4-2** lists the new Wasatch HSU monitoring wells for the River Corridor Envelope.

Wasatch HSU vertical groundwater gradients are upward in the portion of the New Fork River valley occupied by the River Corridor Envelope (AMEC 2012, 2013a). Given oil and gas development in and upgradient of the River Corridor Envelope, the new River Corridor Envelope wells will target sandstone units in the uppermost portion of continuously saturated Wasatch Formation. Based on land surface elevations, elevation of the New Fork River, water well information for a limited number of existing wells (e.g., X-4-SW; AMEC 2012), and groundwater modeling results (AMEC 2013a), the anticipated total well depths for the Wasatch HSU will be approximately 100 to 200 feet (**Table 4-2**). Each new River Corridor Envelope well will be completed in a saturated sandstone unit in the uppermost portion of the Wasatch Formation with an estimated thickness of 20 to 40 feet.

4.2.3.2 River Corridor Envelope – Alluvial HSU

Natural gas is currently being developed from four pads in the center of the River Corridor Envelope, on the north side of the New Fork River. Liquids produced at these pads are transported via truck or pipeline. The primary corridor for north-south pipelines carrying liquids and natural gas produced in the PAPA also extends beneath the New Fork River in the eastern half of the River Corridor Envelope. These potential sources are in the previously defined environmentally sensitive area and proximal to the Alluvial HSU.

To fulfill GMP Objective O2.5, a total of four monitoring wells are needed in the Alluvial HSU downgradient of these potential sources. **Figure 4-6** shows locations of the four existing alluvial monitoring wells downgradient of oil and gas infrastructure, with study well X-4a-A (AMEC 2012) as one of the four wells. The other three wells were installed by a former PAPA Operator in 2013 and are located on the downgradient edge of three existing natural gas well pad locations. These four alluvial wells range in depth from 13 to 18 feet; **Table 4-2** provides additional information regarding the existing Alluvial HSU monitoring wells for the River Corridor Envelope and **Annex 4C-3** contains well logs.

4.2.3.3 North Zone – Wasatch HSU

NewFields applied VSP, Version 7.0 software (PNNL 2014) to help develop the network of wells for groundwater monitoring in the North and South zones of the PAPA. VSP is based on statistical sampling theory to support decision-making. By using the software, NewFields selected the appropriate number and location of groundwater samples to ensure adequate spatial coverage in the North and South zones of the PAPA (see GMP Objective O2.6). The analysis was spatial and did not include statistical evaluations.

An assumption was made that the entire North Zone development area could be subject to development in the future and that a generally uniform density of wells for monitoring is appropriate. The following steps were taken to select wells for the monitoring program in the North Zone (see **Appendix 4-A** for further details of the approach):

1. Using core development area and disturbed area shapefiles provided by BLM's Pinedale Field Office, locations of existing wells from the project's EDMS, and a year 2013 aerial photograph of the PAPA, a "Sample Area" was created. The Sample Area encompasses DA-1 and the portion of DA-2 outside the River Corridor Envelope (**Figure 4-3**).
2. All wells were then eliminated that were outside the Sample Area.
3. A radius for a "hotspot" was determined based on hydrogeologic properties of the Wasatch HSU and results of numerical modeling. A hotspot is defined as an individual area within the Sample Area that can be represented by a sample. The Sample Area is covered by hotspots of equal size, with each hotspot representing an individual sample. To determine the hotspot radius, groundwater velocity calculations from AMEC (2012) and particle tracking results from AMEC (2013a) were used:
    - Based on Section 7.5.2.2 in AMEC (2012), the maximum advective groundwater velocity was calculated to be 40 feet/year, meaning that groundwater can move approximately 4,400 feet in 110 years (twice the duration of PAPA natural gas production as reported in BLM's 2008 ROD).
    - From Figure 38 in AMEC (2013a), the maximum travel length of particles released from industrial water supply wells and traced for 110 years in the Wasatch HSU is about 6,000 feet (average travel length is much less).
    - Given these two 110-year groundwater travel lengths, the smaller radius of 4,400 feet was used as the target hotspot radius.
4. After selecting the hot spot radius, VSP was used to calculate the largest unsampled area in the North Zone given the current water well network. This method uses spatial calculations rather than statistics.
5. Considering locations of all existing wells in the North Zone Sample Area, the radius of the largest unsampled area was approximately 4,825 feet, which is larger than the target hotspot radius of 4,400 feet.

6. As a result of the spatial analysis, there was one hotspot that was not represented by any existing water well in the North Zone Sample Area; meaning that a new monitoring well would need to be installed to meet the criterion. This well was added in the largest unsampled area, and the analysis was re-run to confirm that the target radius criterion was met.
7. The monitoring well network was then optimized to minimize the number of wells needed to satisfy the spatial coverage objective, and biasing the selection to those wells downgradient of the maximum number of potential sources. For example, in hotspots with multiple existing water wells, candidate wells were eliminated one-by-one and the hotspot test was re-run. If the radius of the largest unsampled area did not increase, the well was removed and the process was repeated. As part of the analysis, the hotspot radius was increased slightly from 4,400 feet to 4,472 feet.

The spatial analysis described above resulted in a total of 13 wells needed to represent groundwater sampling locations for the North Zone. These include 12 existing water wells and one new well. All existing wells and the new monitoring well location are located on disturbed areas (i.e., well pads). The new well for the North Zone will be installed on the existing Mesa 6-27 pad and will be designated as well GMPN-01. Based on an evaluation of water well log information for wells in the vicinity of the Mesa 6-27 pad and groundwater modeling results (AMEC 2013a), total depth of the new well will be approximately 250 to 300 feet, and will be completed in a sandstone unit that has an estimated thickness of 20 to 40 feet. **Figure 4-7** shows locations of the 13 wells identified for sampling in the North Zone, and **Table 4-2** lists pertinent information for these Wasatch HSU wells.

4.2.3.4 South Zone – Wasatch HSU

The network of GMP wells in the South Zone was developed using the methods and assumptions described in **Section 4.2.3.3** above. **Appendix 4-A** contains details of the spatial analysis, and general steps for the South Zone analysis are as follows:

1. The process was initiated by eliminating the T-3 study wells located on the WB 7-15 pad (AMEC 2012) and the WB 7-15 water supply well as candidate monitoring wells because the WB 7-15 pad is being investigated under the direction of the Wyoming Department of Environmental Quality's (DEQ) Voluntary Remediation Program (VRP).
2. The Sample Area for the VSP spatial analysis encompasses the South Zone development area and 4,400 feet was used as the radius for a hotspot.
3. Given the density of existing water supply wells in the South Zone, a total of 11 sampling points were needed in the Wasatch HSU to meet the criterion of at least one sampling point in each hotspot.
4. The well network was optimized to identify the most appropriate locations for monitoring in hot spots containing more than one existing well. During the analysis, the hotspot radius was increased slightly from 4,400 feet to 4,421 feet.

The spatial analysis for the South Zone resulted in a total of 11 wells for groundwater sampling. Of the 11 locations, five are represented by existing wells and six new wells (GMPS-01 through GMPS-06) will

be installed for the GMP. As with the North Zone, existing and new wells in the South Zone are located on natural gas well pads.

Figure 4-8 shows locations of the 11 wells identified for sampling in the South Zone, and **Table 4-2** lists key information for these Wasatch HSU wells. Based on an evaluation of existing water well log information in the vicinity of the locations for the six new wells, the estimated total depth of each new well will range from about 200 to 600 feet (**Table 4-2**). Similar to other Wasatch HSU monitoring wells being installed for the GMP, these new wells will be completed in a sandstone unit that is an estimated 20 to 40 feet thick in the uppermost portion of continuously saturated Wasatch Formation.

4.2.4 Summary of Monitoring Well Network

NewFields partitioned the PAPA into three principal zones to develop the well network for groundwater monitoring: North Zone, River Corridor Envelope, and South Zone. The River Corridor Envelope is the zone designated to have the greatest environmental sensitivity and the greatest relative risk of being impacted. It is the zone enveloping potential sources with associated potential receptors over a 110-year travel time for contaminants in groundwater to move from potential source to potential receptor. The bounds of the North and South Zones are designated by borders of the core development areas and the intersection with the River Corridor Envelope. These three zones are shown on **Figure 4-3**.

A combination of particle tracking analyses using the numerical model, and spatial analysis using VSP software, was used to identify groundwater monitoring locations. To satisfy GMP objectives O2.3, O2.5 and O2.6, a total of 41 wells will be required for water quality monitoring. The chart below summarizes the existing and proposed new wells in the three principal monitoring zones of the PAPA; **Figure 4-9** shows locations for each of the 41 wells and **Table 4-2** lists information for each well.

Area or Zone	HSU	Existing Wells	New Wells	Total
North Zone	Wasatch	12	1	13
River Corridor Envelope	Wasatch	0	13	13
River Corridor Envelope	Alluvial	4	0	4
South Zone	Wasatch	5	6	11
TOTALS		**21**	**20**	**41**

4.3 Water Quality Parameters – Technical Approach

Two GMP objectives address selecting water quality parameters and establishing groundwater quality thresholds, as listed in the chart below.

Objective	Description
O2.2	Establish groundwater quality thresholds (actual values and statistically significant changes in concentrations) that, if exceeded, trigger an action that is designed to prevent undesirable change to usable water (i.e., BLM's definition of usable water at <10,000 milligrams per liter Total Dissolved Solids).
O2.4	Establish a core list and supplemental list of groundwater quality parameters and frequency based on the WOGCC [Wyoming Oil and Gas Conservation Commission] baseline groundwater monitoring rule that include constituents that are: 1) most hazardous to public health and the environment; 2) most indicative of impacts from oil and gas activities; and, 3) most likely to appear first at the monitoring sites.

The following subsections first describe the process used to establish groundwater quality parameter lists (Core and Supplemental), then explain how groundwater quality thresholds (actual values and statistically significant increases in concentration) were or will be determined, and finally describe groundwater sampling frequencies.

4.3.1 Groundwater Quality Parameters

Objective O2.4 stipulates that the GMP water quality parameter, analyte, or constituent list be based on the WOGCC's groundwater baseline sampling, analysis, and monitoring rule (WOGCC Rule) (see Table 1 in Appendix K, Chapter 3, Section 46 of the WOGCC rules; found at: http://wogcc.state.wy.us/downloads/5072014_K_Sampling_and_Analysis_Procedures.pdf). Objective O2.4 requires that constituents be selected based on three criteria listed in the chart above. Also required by Objective O2.4 is establishing both a Core List and Supplemental List of parameters to be analyzed during implementation of the GMP.

Two flow charts have been developed to show the logic used to fulfill requirements of Objective O2.4 (**Figures 4-10** and **4-11**). Results of technical studies completed under Step 2 of BLM's 2008 ROD (AMEC 2012, 2013a, 2013b) were considered while developing the flow charts, along with groundwater quality results generated by pursuant to BLM's 2000 ROD (i.e., SCCD groundwater monitoring data found at: http://www.blm.gov/wy/st/en/field_offices/Pinedale/pawg/DataResults.html). The purpose of each flow chart is described below:

- **Figure 4-10** shows the process to "rank" each water quality constituent listed in WOGCC's Rule relative to the three criteria in Objective O2.4.
- **Figure 4-11** illustrates how parameters were selected for the Core List and Supplemental List under the GMP.

Table 4-3 presents the results of moving each of the 33 constituents included in WOGCC's rule through the two flow charts. The table includes available water quality standards for each constituent including: EPA (2009) Primary Drinking Water Standards (i.e., Maximum Contaminant Levels or MCLs); DEQ (2014) VRP groundwater cleanup levels; DEQ (2005) Water Quality Division (WQD) groundwater classification standards; and WOGCC (2014a) action and notification levels. The table shows which parameters have

been previously analyzed in groundwater pursuant to either BLM's 2000 ROD or 2008 ROD. **Table 4-3** also identifies if a constituent is considered to meet one or more of the following criteria specified in Objective O2.4:

- Most hazardous to public health and the environment – based on whether the constituent has a listed available standard, action level, or notification level;
- Most indicative of impacts from oil and gas activities – based on evaluating chemical signatures of potential source material samples (i.e., drilling mud, produced water, condensate and flowback fluid) determined from the LLPHC study (AMEC 2013b) relative to the constituent; and/or
- Most likely to appear first at monitoring site – based on an assessment of whether the constituent migrates conservatively in groundwater or is attenuated due to various mechanisms including biodegradation, volatilization, and retardation in the aquifer matrix.

Lastly, **Table 4-3** presents constituents for the Core List and Supplemental List, or not proposed for analysis under the GMP. Constituents identified for each of these categories are also shown on **Figure 4-11**.

Section 4.2.4 describes the 20 monitoring wells that would be installed to support the GMP well network. To honor the requirements of WOGCC's Rule, these wells will be subjected to initial sampling and analysis for more parameters than listed on either the Core List or Supplemental List. **Figure 4-12** presents the logic used to decide what parameters (or list of parameters) should be analyzed in samples from an individual well; the right side of the figure explains initial testing for each new well. The three "threshold" conditions shown in the center of **Figure 4-12** are explained in **Section 4.4**.

The 41 wells included in the GMP will be regularly sampled for parameters listed on either the Core List and/or Supplemental List. All wells will be analyzed for Core List parameters, whereas wells located in the area considered to be of greatest environmental sensitivity and with the greatest relative risk of being impacted (i.e., River Corridor Envelope wells RCE-01 through RCE-16 and X-4a-A) will also be analyzed for Supplemental List parameters. The GMP's SAP, described in **Section 4.5.1** and contained in **Appendix 4-C**, provides detailed information regarding sampling procedures and analytical methods.

4.3.2 Monitoring Frequency

Objective O2.4 requires that a groundwater monitoring frequency be established for the GMP. NewFields considered requirements of the WOGCC Rule, requirements of the BLM 2000 ROD, and findings from the LLPHC study (AMEC 2013b) to set the monitoring frequency for the GMP:

- The WOGCC Rule requires three groundwater sampling events: initial sampling within 12 months of spudding a gas or oil well, and two subsequent sampling events. The time between each sampling event is not more frequent than 12 months. The first round of subsequent sampling must occur between 12 and 24 months after setting the well's production casing or liner. The second round of subsequent sampling must occur between 36 and 48 months after

setting the well's production casing or liner, and at least 24 months after the first round of subsequent sampling.

- Since 2004 and extending through 2015, Operators have contracted the SCCD to sample water wells in the PAPA. The BLM's 2000 ROD requires an annual sampling frequency. Note that for 2014 and 2015, WOGCC granted Ultra and QEP a one-year variance from the baseline groundwater monitoring rule (WOGCC 2014b). According to the variance, the interim monitoring program performed by SCCD serves as a Master Groundwater Monitoring Plan for the PAPA.
- The LLPHC study (AMEC 2013b) determined that no widespread impact to groundwater in the PAPA is evident as a result of spills or leaks of materials used in, or by-products of, natural gas development.

Based on these considerations and the hydrogeologic characteristics of the Wasatch Formation (i.e., maximum advective groundwater velocity calculated to be 40 feet/year), the frequency of groundwater monitoring for the GMP wells completed in the Wasatch Formation will be annually.

The four alluvial monitoring wells included in the GMP are each located on the perimeter of natural gas pads, downgradient of most pad facilities including above ground storage tanks. Using hydrogeologic data for the alluvial system reported in AMEC (2013a), the average advective groundwater velocity in alluvium is about 5 feet per day. Assuming a potential release could occur on the upgradient edge of a pad furthest from a monitoring well, the travel time of a non-retarded constituent such as chloride to the well would be on the order of 160 days. Based on this reasoning, the frequency of groundwater monitoring in alluvial wells will be semi-annual.

Summer months are the ideal time for monitoring given weather conditions in the high-altitude setting of the PAPA. Besides summer, alluvial GMP wells will be monitored at the beginning of each calendar year and any necessary confirmation re-sampling (i.e., threshold exceedance; see **Section 4.4**) would occur before the summer monitoring event. If alluvial GMP well sampling is conducted at the beginning of the year and then all GMP wells are monitored in the summer, and considering a typical 3-week turn-around-time for laboratory analytical results, any necessary confirmation re-sampling could be accomplished by early fall. Obtaining groundwater data from all wells in the summer would also permit reporting and accommodate periodic Review Team meetings (see **Section 4.8**) in the same calendar year in which monitoring is conducted.

4.4 Groundwater Quality Thresholds

Groundwater quality data will be generated during regular (annual) monitoring events (see **Section 4.3.2**), and results for each well will be compared to established thresholds. A threshold is an absolute concentration value, statistically significant trend, or increase in dissolved methane concentrations (see below) that, if exceeded, will trigger an action that is designed to prevent an undesirable change to usable water. These three triggering conditions are shown on **Figure 4-12**. For the GMP, thresholds were designed to provide early detection of potential groundwater degradation at monitoring sites, and include: 1) an absolute value; 2) test for a statistically significant increasing trend; and 3) an increase of 5

mg/L in methane concentrations. The Response Action Program (**Section 5.0**) will be implemented if resampling confirms that one of these thresholds is reached at a monitoring site (**Figure 4-12**).

Methane is the principal gas being developed in the PAPA and can be indicative of impacts from oil and gas activities. The WOGCC (2014a) established a notification level for methane (increase of 5 mg/L in successive sampling events) which will be used as one of the three thresholds for the GMP. The absolute value and statistically significant trend thresholds are described in the following subsections.

4.4.1 Absolute Value

Table 4-4 presents absolute value thresholds for each parameter on the Core and Supplemental sampling lists. Absolute value thresholds are single, parameter-specific numerical values applied to all wells in the monitoring network. If a water quality result exceeds an absolute value threshold for a given parameter and is confirmed by resampling (**Figure 4-12**), the Response Action Program (see **Section 5.0**) will be launched.

Figure 4-13 presents a flow chart depicting how absolute value thresholds were determined for parameters specified in WOGCC's Rule and listed in **Table 4-3**. If a parameter is not included in the Core or Supplemental sampling lists (**Figure 4-11** and **Table 4-3**), an absolute value threshold is not required. For parameters that have a National Primary Drinking Water Standard (EPA 2009), DEQ (2005) groundwater classification standard, DEQ (2014) VRP groundwater cleanup level, or WOGCC (2014a) action and notification level, and are not likely to appear first at monitoring points, the absolute value threshold was set as one-half the applicable standard. For the remaining parameters, absolute value thresholds were established through statistical analysis of existing groundwater quality data contained in the EDMS (see **Section 1.7.3**).

An absolute value threshold was not calculated for bromide because a standard does not exist and there is insufficient existing data within the PAPA to calculate a value. This parameter will be evaluated on an intra-well basis using a statistically significant trend threshold (see **Section 4.4.2**). In addition, absolute value thresholds were calculated using Wasatch Formation data and are not applicable to monitoring wells screened in alluvial material. Absolute value thresholds were not calculated for alluvial monitoring wells because insufficient water quality data exists for alluvial groundwater in the monitoring boundary. Data collected from alluvial monitoring wells will be evaluated using one-half the applicable water quality standard or on an intra-well basis using a statistically significant trend threshold.

NewFields applied statistical background techniques to calculate absolute value thresholds for six (6) of the 19 parameters involved in the GMP, including: alkalinity, calcium, chloride, potassium, sodium, and total dissolved solids. AMEC (2013b) concluded that no widespread impact to groundwater in the PAPA is evident as a result of natural gas activities. Despite this conclusion, groundwater quality data collected pursuant to BLM's 2000 and 2008 RODs (BLM 2000, 2008a, 2008b) was subjected to a series of rigorous and thorough outlier analyses. The objective of these analyses was to exclude and remove any measurement which is actually or potentially above background conditions in the PAPA. The investigated dataset included annual groundwater samples collected by the SCCD on behalf of the Operators from 2004 to 2013 and data collected as part of AMEC (2012) and AMEC (2013b) from 2010 through 2012.

For calculating absolute value thresholds, sample results from the Pinedale EDMS were compiled for each parameter listed above into separate datasets. The objective of the analysis is to determine background groundwater quality thresholds for previously defined monitoring areas in the PAPA (see **Section 4.2.3**). Sample results from wells located outside of these monitoring areas were not considered in the analysis. These exclusions were made in order to avoid any undue bias or distortion associated with unrepresentative data collected outside of the monitoring areas.

To remove sample results that may bias or distort threshold values and determine if geographical differences exists for the evaluated parameters in the PAPA, outlier and spatial analyses were performed on each dataset prior to establishing absolute value thresholds. After completion of these analyses, a background threshold analysis was performed using ProUCL (EPA 2013b) to establish the absolute value threshold for the six parameters.

Statistical analyses of the investigated data were initiated by identifying potential outlier values. Outlier data points can distort statistics and yield inflated background threshold values. Outliers can occur for several reasons, including: 1) measurement recording errors; 2) measurement from an impacted well; or 3) rare or unexpected event (Helsel and Hirsch 2002). To avoid inflated or unrepresentative background threshold values, all outliers were removed from the datasets.

Outliers were determined by inventorying wells enrolled in DEQ's VRP, and using quantile-quantile (Q-Q) probability plots to visually identify outliers. Groundwater samples for wells in DEQ's VRP were assumed to be potentially impacted, and thus, their associated data were removed from the datasets. On a Q-Q plot, elevated measurements that are separated from the majority of data were considered outliers and removed from the dataset. Additional information regarding outliers is provided in **Appendix 4-B**.

After outliers were removed, the remaining data were separated based on the defined monitoring areas (see **Section 4.2.3**) into North Zone, South Zone, and River Corridor Envelope. An analysis of variance (ANOVA) test was then performed for each parameter to determine if statistically significant differences exist between measurements in the three areas.

The ANOVA test is a commonly used method of comparing the means of multiple groups of data (Field 2009). The test is performed by producing an F statistic, which is associated with a p-value which is the probability of obtaining that F statistic. The p-value is compared to a pre-defined significance level to determine if a statistically significant difference exists between the group means. In this work, a 5 percent significance level was used for the test, thus if the calculated p-value is less than or equal to 0.05, there is a statistically significant difference between the mean values in the three areas.

Based on results of the ANOVA test, there is a statistically significant difference between the three monitoring areas for a majority of the parameters. Therefore, area-specific absolute value thresholds were calculated for each parameter.

Prior to absolute threshold analysis, parameter datasets in each monitoring area were re-analyzed using Q-Q plots to remove remaining area-specific outliers. Upon completion of thorough analyses of outliers and spatial differences, absolute value thresholds were established. Given the fact that there is no evidence of widespread contamination in the PAPA from natural gas activities (AMEC 2013b), the

datasets, excluding outliers, were considered as representative of background conditions for each of the three monitoring areas.

Two methods were used to calculate absolute value thresholds:

a) Method A - Using all available data for a monitoring area as a single population. This is a common approach where the upper threshold value of the dataset is set as the absolute value threshold.

b) Method B - Using only the highest concentration subpopulation, as determined based on visual identification of a 'break' in the Q-Q plot. Consistent with Singh et al. (2014), a 'break' in a dataset is defined as a visually discernable jump or change in slope of the Q-Q plot.

ProUCL was used to calculate upper tolerance limits (UTL) with 95 percent confidence and 95 percent coverage. ProUCL provides UTL calculated based on normal, gamma, and log-normal distributions, as well as non-parametric UTL. The software also provides statistical tests to identify if the data follow normal, gamma, or log-normal distribution. When data follow normal or gamma distribution, the corresponding distribution-specific UTL was used; otherwise, non-parametric UTL was used. In addition, when there are non-detects in the data, the Kaplan-Meier method was used to calculate more accurate UTL values.

In general, absolute value thresholds calculated using the highest background subpopulations were selected. These choices were driven by the following facts:

- Throughout the background analysis, absolute care was taken to remove any actual and potential outliers from background datasets. These exclusions and removals were performed at multiple stages by first identifying and removing potentially impacted wells, followed by parameter- and area-specific outlier analyses, resulting in the removal of 64 measured values from the background datasets.
- The remaining background datasets clearly consisted of multiple subpopulations. Under such conditions, absolute value thresholds must accommodate all of the background subpopulations present in the datasets. This means that only the thresholds associated with the highest subpopulation would meet such criterion.

Appendix 4-B provides further detail regarding establishment of absolute value thresholds.

4.4.2 Statistically Significant Trend

Based on analysis of data collected pursuant to BLM's 2000 and 2008 RODs (BLM 2000, 2008a), it is anticipated that water quality results for the majority of wells in the monitoring program will be less than half of the absolute value thresholds described above. In order to meet Objective O2.5 (see **Section 2.2**), which specifies that the monitoring program provide early detection of potential degradation, a second threshold is needed.

The Mann-Kendall trend test will be used as the second threshold to determine if parameter concentrations in groundwater samples are increasing over time (Mann 1945; Kendall 1975; Gilbert

1987; EPA 2000). The test is performed on an intra-well basis and is used to identify statistically significant trends for individual parameters at a monitoring site. The Response Action Program (see **Section 5.0**) will be launched if a parameter has a statistically significant increasing trend based on a 95 percent confidence level and the concentration is confirmed by resampling (**Figure 4-12**). The test will be performed once groundwater quality data from each sampling event have been validated (see **Sections 4.5.1** and **4.5.2**). A minimum of six samples are needed to perform the test, so it will not be applicable until the after the sixth sampling event. For future trend analysis, the six most recent data points will be used. Time-series graphical displays will accompany trend analysis results in order to visually determine if increasing trends are a concern and warrant further investigation. Implementation of the trend test is described in **Section 4.7**.

4.5 Planning Documents

Objective O2.1 requires that the GMP be governed by a Sampling and Analysis Plan (SAP) and Quality Assurance Project Plan (QAPP) that are developed in consideration of applicable and appropriate regulatory requirements, in accordance with standard environmental practices, and consistent with the groundwater characterization completed under Step 2 of BLM's 2008 ROD (BLM 2008a). The following two subsections introduce these plans. The complete SAP and QAPP documents are contained in **Appendices 4-C** and **4-D**, respectively.

4.5.1 Sampling and Analysis Plan

The SAP is based on and adapted from the WOGCC sampling and analysis procedure (Appendix K of the WOGCC Rule). The SAP for this Project also follows guidance in DEQ (2013) Fact Sheet #29 (Sampling and Analysis Plans).

The purpose of the SAP is to document field monitoring and sampling procedures, and laboratory methods that will be used to ensure that consistent and representative data are collected, and that a uniform method of data reporting to the agencies and Operators is established. The primary monitoring activities for the GMP in the PAPA will include: installing and developing new monitoring wells; collecting water samples from existing and new monitoring wells; and, measuring water levels in GMP wells.

4.5.2 Quality Assurance Project Plan

The QAPP for this Project also conforms to the WOGCC Rule. Data generated during environmental monitoring and measurement efforts under the GMP must be valid (i.e., supported by documented procedures), such that they can be used with confidence to support determinations regarding the need for and design of subsequent monitoring or the need for corrective measures. The QAPP for this Project presents the policies, organization, objectives, functional activities, and specific quality assurance (QA) and quality control (QC) activities designed to achieve data quality goals of the Plan.

The QAPP was prepared following EPA guidance reported in: "Guidance on Quality Assurance Project Plans" (EPA 2012); "Guidance on Environmental Data Verification and Data Validation" (EPA 2002); "National Functional Guidelines for Superfund Organic Methods Data Review" (EPA 2008); and "National

Functional Guidelines for Inorganic Superfund Data Review" (EPA 2013a). For the purpose of the Plan and GMP, QA and QC are defined as follows:

- **Quality Assurance** - The program or structure used to define procedures for the evaluation and documentation of investigation functions (*e.g.*, sampling and laboratory methodologies) to provide a uniform basis for reporting and managing data, and performing investigation functions.
- **Quality Control** - Tasks and procedures designed to provide measures of performance for analytical procedures, including accuracy and precision of data, and procedures for corrective action.

This QAPP consists of four primary elements that are arranged to reflect the logical flow of the project life-cycle:

- **Project Management (*Plan*)** – This element covers the basic area of project management, including the project history, project objectives, and roles/responsibilities of the participants.
- **Data Acquisition (*Do*)** – This element covers all aspects of measurement and data acquisition systems design and implementation. This step ensures the intended measurements, data collection, or acquisition methods are appropriate for achieving project objectives.
- **Assessments (*Check*)** – This element addresses the activities for assessing the effectiveness of the implementation of the project and associated QA/QC activities. The purpose of assessment is to ensure that the QAPP is implemented as prescribed and that project actions are implemented as expected.
- **Review, Evaluation of Usability, and Reporting Requirements (*Act*)** – This element covers the QA activities that occur after the data collection (or use) phase of the project is completed. Implementation of this element will help to determine that the data conform to the specified criteria, thus achieving the project objectives and ensuring that data usability can be documented in a final project report.

4.6 Data Management and Validation

Data collected as part of the monitoring program will be compiled, reviewed/verified, validated, and analyzed using partially and fully automated systems. Data review and validation procedures are described in the SAP and QAPP (**Appendices 4-C** and **4-D**, respectively). Automating portions of the process will allow the Review Team to efficiently and effectively review sampling results and identify wells that may need to be further assessed. The goal of this system is to reduce the amount of time it takes to compile and validate data, increase consistency, and produce tables that can be used for data analysis and reporting. Tools that will be used to compile, validate, and analyze the data are described in the following sub-sections.

4.6.1 Data Compilation and Validation

Data collected pursuant to this GMP will be stored in EDMS, a customized database system hosted in Microsoft Access™ (see **Section 1.7.3**). Queries and macros within EDMS will allow the Operators' Contractor to quickly upload and validate new data, efficiently analyze sampling results, automatically produce report tables, and export data to different systems including the Risk Based Data Management System (RBDMS) being developed by DEQ. In addition, EDMS is customizable and can be modified based on potential future changes to the GMP as determined by the Review Team during their cyclic Plan reviews (see **Section 4.8**).

Data generated from sampling events will be provided to the Operator's Contractor in electronic data deliverable (EDD) format from the laboratory. The Operator's Contractor will work with the laboratory to develop a consistent EDD format that can be seamlessly imported in to EDMS using an automated uploader. The format will be consistent with the format to be specified by WOGCC (see Section 3.0 in Appendix K of the WOGCC Rule). This uploader will partially validate the data and check results for consistency (e.g., sample names, analyte names, reporting units, etc.). If necessary, the Operator's Contractor will resolve any inconsistencies found in the EDDs using built-in tools in EDMS. After inconsistencies are resolved, the Operator's Contractor will complete data validation in accordance with the guidelines established in the QAPP (see **Section 4.5.2** and **Appendix 4-D**). EDMS will generate tables that reduce the time required to complete the validation process.

After the data are compiled, uploaded, and validated, they will be analyzed using built-in queries in EDMS and external tools developed for this Project (see **Section 4.6.2**). In addition, reports will automatically be generated that provide an overview of the monitoring results, and data will be exported to a web application (see **Section 4.7**).

4.6.2 Data Analysis

Data will be available for analysis and reporting after they have been compiled and validated as described in **Section 4.6.1**. Several partially and fully automated tools will be used to analyze data, including queries in EDMS and macros in Microsoft Excel™. These tools are designed to allow the Operator's Contractor and the Review Team to quickly and efficiently identify potential groundwater degradation or potential adjustments that need to be made to the monitoring program. Initial attention will be directed to determining if any DEQ water quality standard has been exceeded (**Table 4-4**).

Primary data analysis will consist of comparing sample results to DEQ water quality standards, and to established thresholds which include an absolute value, statistically significant increasing trend, and an increase of 5 mg/L of methane in successive sampling events (see **Section 4.4**). Queries in EDMS will allow the user to generate result tables for the 5 mg/L increase in methane and absolute value thresholds. The user simply clicks on the pre-built queries and the analysis and results tables are generated automatically. These queries allow rapid data analysis because query updates are not required; if new data are received, the queries are rerun. Tables generated from these queries will include a comprehensive summary of results showing sample data and threshold values, as well as a condensed table that displays only results that exceed a threshold. The threshold exceedance table will

include the well name, sample date, parameter threshold, and sample result. This will provide the Review Team with a full summary of absolute value threshold results within seconds after completion of data validation.

EDMS queries and a customized macro in Microsoft Excel will be used to analyze data for statistically significant increasing trends. A query in EDMS will export data to a Microsoft Excel template that contains a customized macro constructed using the programing language Visual Basic for Applications (VBA). Once the data are in the template, the macro will be run with a built-in button. The user simply clicks the button and the macro automatically performs the statistical analysis and produces output tables and graphical displays. Output tables will include a comprehensive summary table that presents the calculated trend in each well (e.g., increasing, decreasing, or stable) and a condensed table showing only wells that have a statistically significant increasing trend. Similar to the tables produced in EDMS described above, these tables will allow the Review Team to quickly determine if there is evidence of potential groundwater degradation. Graphical displays will consist of concentration versus time plots for each well in the monitoring network. These graphs will allow the Review Team to visually confirm the trend for each well and determine if potential degradation may be occurring.

4.7 Results Reporting System

The GMP reporting system was designed to efficiently and effectively communicate monitoring results to WOGCC in accordance with its rule (WOGCC 2014a) and to the Review Team. The goal in developing the system is to minimize the amount of time between sample collection and reporting, and the amount of time required to produce reports. In addition, the system provides an interactive way for the Review Team to explore data and produce customized reports.

Interactive Web Application

The reporting system will primarily focus on an interactive web application. This application will be fully integrated with the EDMS database through PostgreSQL (2014) software. PostgreSQL is a powerful open-source database system that allows transfer of data stored in Microsoft Excel, Microsoft Access™, and GIS formats to web-based environments. EDMS has a built-in export tool for PostgreSQL whereby the user simply clicks an upload button and PostgreSQL is automatically updated after data have been validated. PostgreSQL will in-turn automatically populate a web-based application that the Review Team will use to assess monitoring results and generate reports.

The web application will be map-based, similar to commonly used mapping applications (e.g., Google Maps). The application will have a secure login so that only Review Team members can access the data; a public system can be produced if the Review Team determines this to be necessary. Within the application, users will be able to zoom in and out, pan, turn on and off different map layers, download tables generated from data analysis (see **Section 4.6.2**), and produce graphs, tables, and reports (including a standardized annual report) in web-based, PDF, or other formats as required. This system provides the following key advantages:

- Near real-time data analysis and reporting;
- Minimizes time required to produce reports; and

- Allows members of the Review Team to produce dynamic customized reports.

Annual Summary Report

On an annual basis, and within three months of the sampling event, a summary report will be prepared by the Operators' contractor for submittal to WOGCC, BLM, and Review Team members. In consideration of reporting requirements specified by WOGCC (2014a), the report will include:

- A project background section and discussion of the monitoring network and schedule;
- A description of the sampling event, including figures showing sampled wells and the potentiometric surface determined from groundwater elevation data;
- A tabular summary of analytical results referenced to wells and their spatial coordinates, with a comparison to DEQ water quality standards and the three threshold conditions;
- Graphical displays of parameter concentrations versus time for each well;
- A discussion of data quality including results of field and analytical laboratory data reviews, and results of data validation;
- A discussion of any outstanding concerns including notifications made (e.g., required notifications to WOGCC and well owners), new data outliers, water quality exceedences, indications that the existing hydrogeologic model needs to be revised, and/or unforeseen circumstances that were encountered;
- Recommendations for modifications to the GMP, if any; and
- Supporting information appended to the report, including:
    - Lithologic and well completion logs for any well installed, and logs for any well that was abandoned,
    - Copies of field documentation (e.g., field log books, sampling forms, instrument calibration records),
    - Analytical laboratory reports, and
    - Electronic data deliverables (EDD).

Data generated through annual sampling will also be reported electronically to WOGCC for upload into their RBDMS.

4.8 Monitoring Program Review Cycle

According to Objective 02.10, a GMP review cycle is required to "*evaluate the effectiveness and continued relevance and appropriateness of sampling constituents, methods, thresholds, and the existing hydrogeologic conceptual model.*" A similar overall Plan review cycle is specified by Objective O3.5 for the Response Action Program (see **Sections 2.3** and **5.3**). It is envisioned that reviews of the GMP and the overall Plan would occur during the same Review Team meeting, and would initially occur on an annual frequency.

BLM's Project Lead will schedule the annual Plan Review Meeting in conjunction with the regular Annual Planning Meeting held between the BLM and PAPA Operators at BLM's Pinedale Field Office, Wyoming. An agenda for the Plan Review Meeting will be prepared by the BLM's Project Lead and distributed to the Review Team. At a minimum, agenda items for the portion of the meeting dedicated to the GMP would include:

- Changes to Review Team or Project Oversight Team members;
- Changes to Operators or changes in natural gas operations in the PAPA;
- Changes in Operator development plans which could impact the GMP monitoring boundary, including the potential need for additional monitoring wells if development expands outside of DAs 1-5 or reducing the number of monitoring wells if development ceases in all or portions of DAs 1-5;
- Report on condition of monitoring wells;
- Summary of changes in groundwater elevations;
- Summary of groundwater quality results including trends, threshold exceedances, etc.;
- Summary of any changes in dissolved methane concentrations in groundwater samples;
- Discussion regarding any sampling or analytical laboratory issues that would necessitate revisions to the SAP or QAPP;
- Discussion of the effectiveness, continued relevance and appropriateness of:
    - well network (modifications to add/remove wells),
    - Core and Supplemental List parameters,
    - sampling or laboratory analysis methods,
    - thresholds (absolute values or statistically significant concentration increases),
    - sampling frequency,
    - reporting system (including analysis tools and EDMS), and
    - existing hydrogeologic conceptual model.
- Discussion of the reasons for retaining and maintaining any of the study wells and piezometers installed for the Hydrogeologic Data Gaps Investigation (AMEC 2012).

4.9 Monitoring Program Decommissioning

Operators are obligated to maintain all wells involved in the GMP, including existing water supply wells in the North and South zones, and new monitoring wells installed in the River Corridor Envelope and North and South zones (**Table 4-2**). Maintenance includes ensuring that locking well caps are in-place on all wells to minimize the potential for tampering and the entrance of any contaminants into the well, and that surface seals around well casings are intact. Another 42 study wells and piezometers installed for the Hydrogeologic Data Gaps Investigation (AMEC 2012) are also the responsibility for Operators to

maintain (note that well X-4a-A is the only study well included in this GMP). According to the State Engineer's Office (SEO) (see Chapter 4, Section 4 (a), in SEO 2011), "when a well is temporarily removed from service, it shall be kept in a state of good repair. The top of the well casing shall be sealed with a secure watertight cap that will prevent tampering and entrance of contaminants, animals, or debris."

The GMP and Plan review cycles described in **Sections 4.9** and **5.3**, respectively, require that the Review Team discuss the effectiveness, continued relevance and appropriateness of the well network during each review meeting. During the first GMP review cycle after the Plan is approved by BLM's AO, the disposition of the 42 study wells/piezometers will be discussed. With the exception of study well X-4a-A, no other study well or piezometer met the criteria in GMP objectives (**Section 2.2**) for inclusion to the GMP well network. Consequently, plans for plugging and abandonment would be made during the first GMP review cycle meeting. Unless Operators transfer ownership of study wells and piezometers to another party or need the wells for other purposes, Operators would plug and abandon the study wells and piezometers in 2017 to prevent contamination from the surface or any other source, and to remove any further hazard potential that unused wells/piezometers might pose. Plugging and abandonment would be completed under SEO (2011) regulations, and well/piezometer sites would be reclaimed based on conditions that existed in 2009-2010 when wells were installed and in consideration of land owner desires.

In subsequent regular review cycle meetings, the status of each GMP well will continue to be discussed in terms of its relevance and appropriateness to the GMP well network. It is envisioned that natural gas production will be completed in different portions of the PAPA at different times in the future. Besides the natural gas production wells, facilities associated with that production will no longer be necessary (e.g., above ground tanks, LGS pipelines) and the collective disturbance related to the completed gas production activities will be reclaimed in accordance with state and federal requirements (see **Section 3.7**). At that time during a regular review cycle meeting, the Review Team will evaluate the GMP monitoring well(s) downgradient of that area and determine the continued need for groundwater monitoring. Any well determined by the Review Team to be unnecessary will be plugged and abandoned by the Operators in accordance with SEO (2011) regulations. It is not known when E&P activities in the PAPA will cease, but eventually each well in the GMP network will be plugged and abandoned, and well sites will be reclaimed.

4.10 References for Section 4.0

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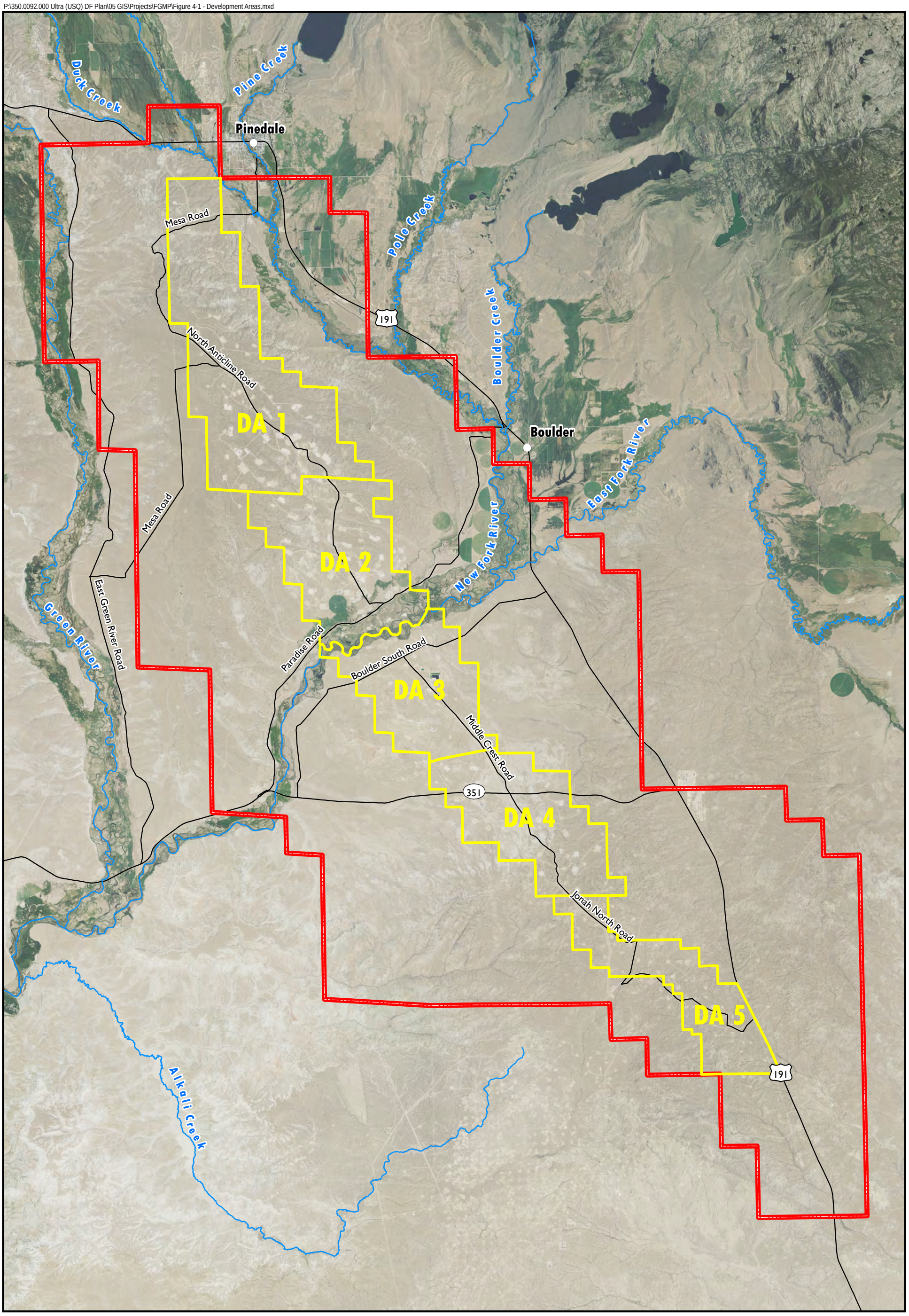
FIGURES

P:\350.0092.000 Ultra (USQ) DF Plan\05 GIS\Projects\FGMP\Figure 4-1 - Development Areas.mxd



Source: 2013 NRIS

N

0 Miles 2.5

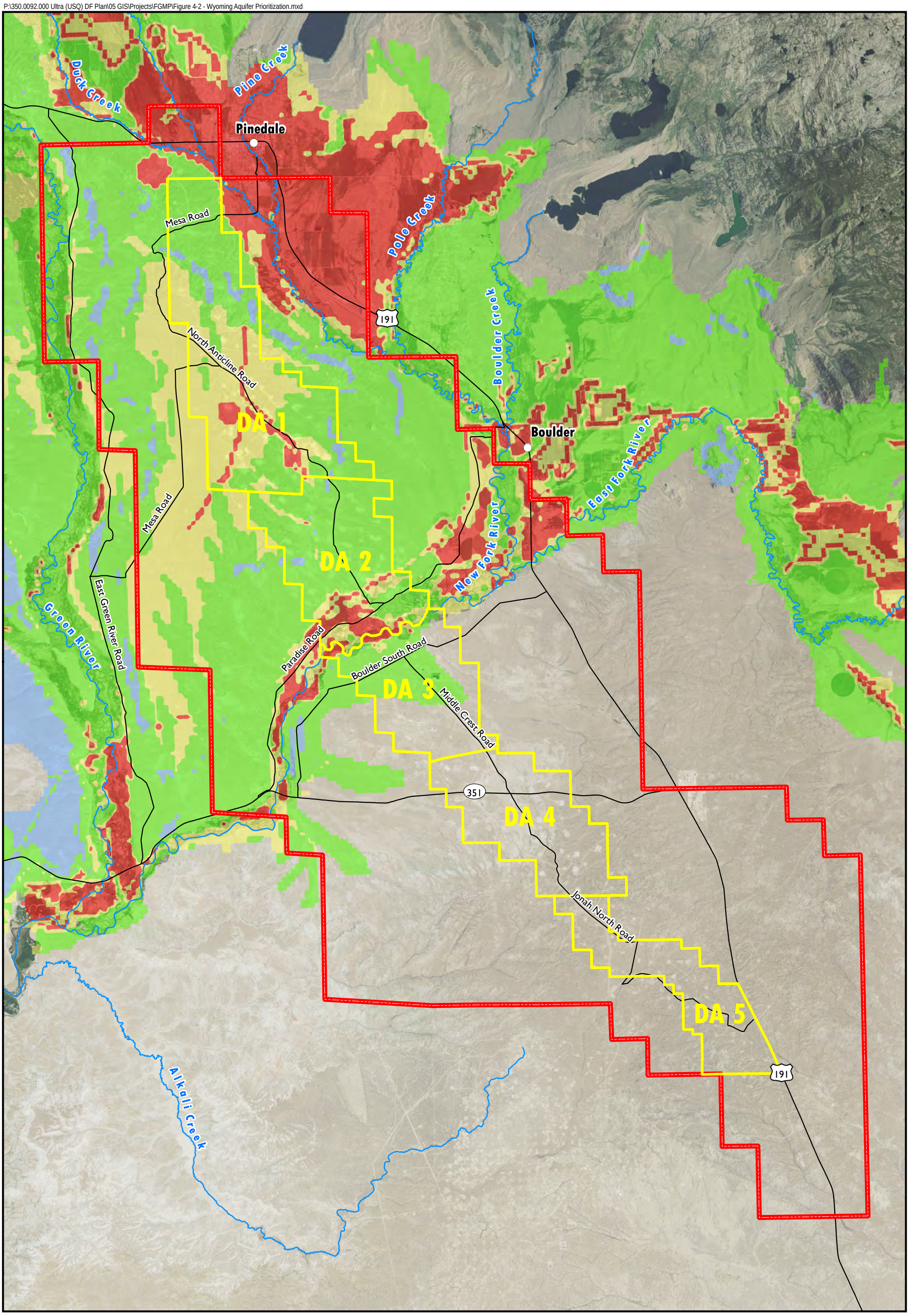
NewFields

Development Area

Pinedale Anticline Project Area

Development Areas
Pinedale Anticline Project Area
Sublette County, Wyoming
FIGURE 4-1

P:\350.0092.000 Ultra (USQ) DF Plan\05 GIS\Projects\FGMP\Figure 4-2 - Wyoming Aquifer Prioritization.mxd



Source: 2013 NRIS

N

0 Miles 2.5

NewFields

Development Area

Pinedale Anticline Project Area

Aquifer Prioritization (Bedessem et. al., 2005)

Low

Low - Moderate

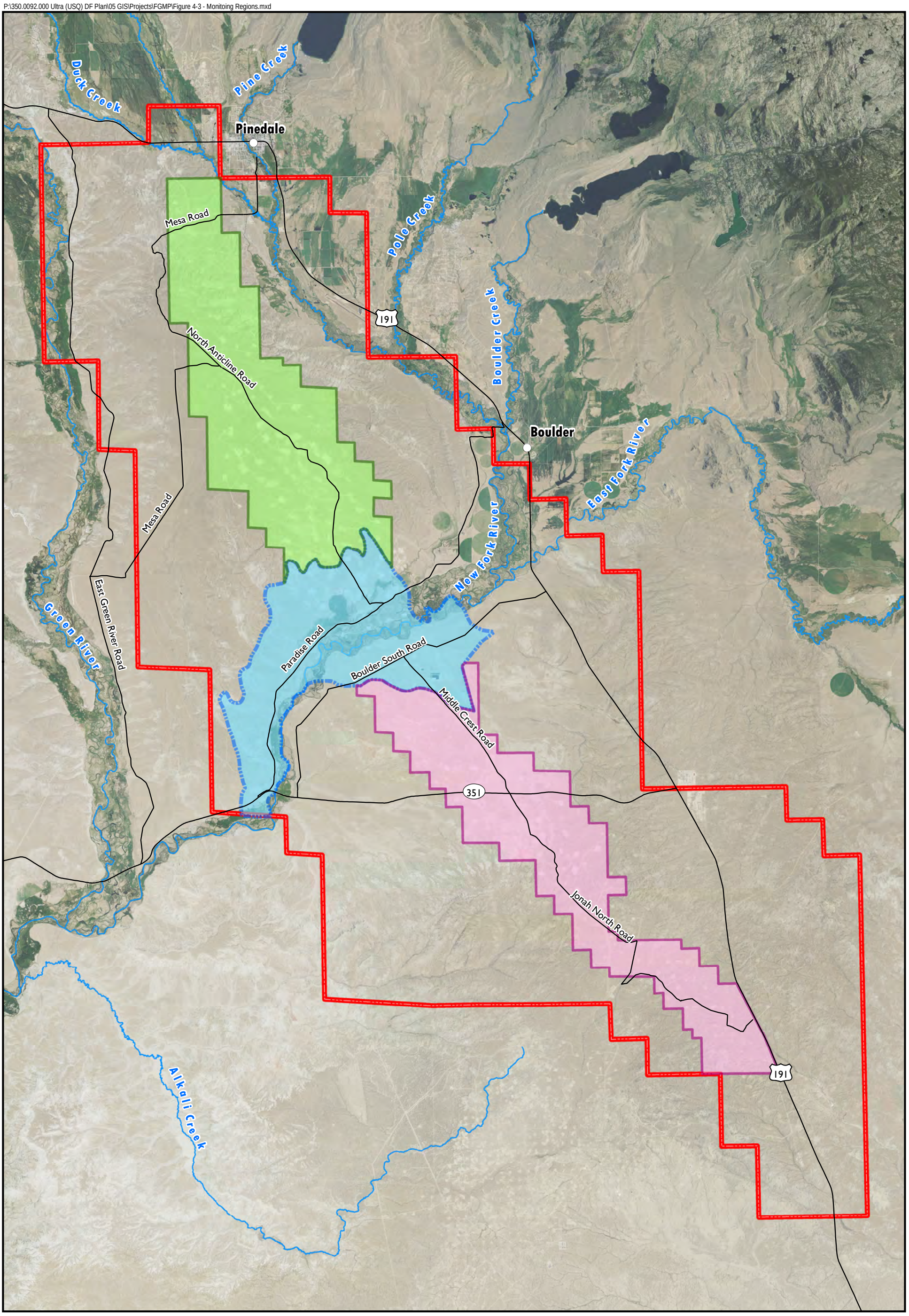
Moderate - High

High

No Data

Wyoming's Aquifer Prioritization for the PAPA
Pinedale Anticline Project Area
Sublette County, Wyoming
FIGURE 4-2

P:\350.0092.000 Ultra (USQ) DF Plan\05 GIS\Projects\FGMP\Figure 4-3 - Monitoing Regions.mxd



Source: 2013 NRIS

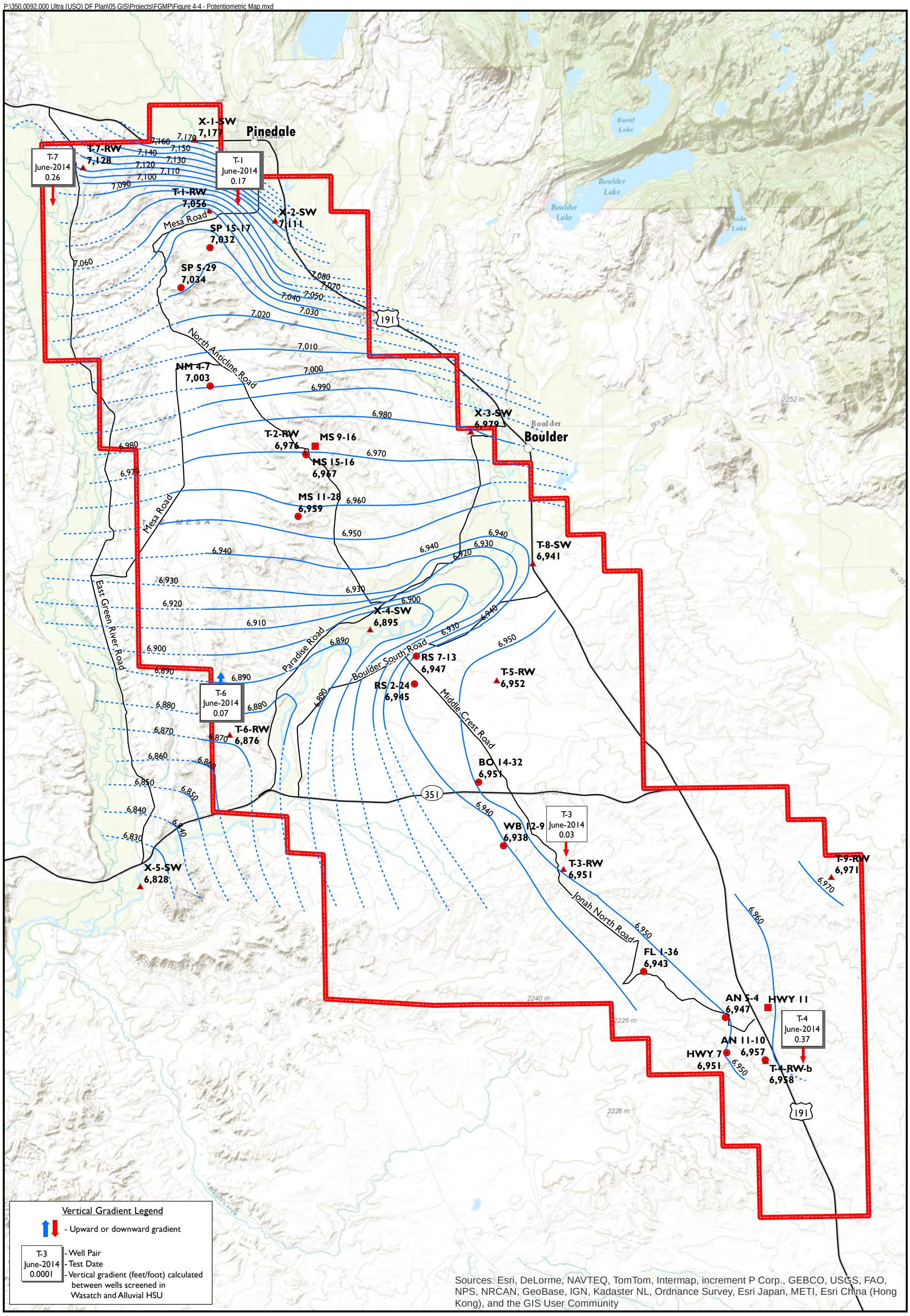
0 Miles 2.5

NewFields

North Zone
South Zone
River Corridor Envelope
Pinedale Anticline Project Area

Monitoring Regions
Pinedale Anticline Project Area
Sublette County, Wyoming
FIGURE 4-3

P:\350.0092.000 Ultra (USQ) DF Plan\05 GIS\Projects\FGMP\Figure 4-4 - Potentiometric Map.mxd



N

0 Miles 2.5

NewFields

6,958 June 2014 Groundwater Elevation

10 ft Contour (feet above mean sea level, Datum: NAVD88)

Inferred 10 foot Contour

Note:
Contours are hand-drawn;
HSU = Hydrostratigraphic Unit.

7,020 Inferred Groundwater Elevation (USGS 7.5' Quads WYGISC)

Study Wells

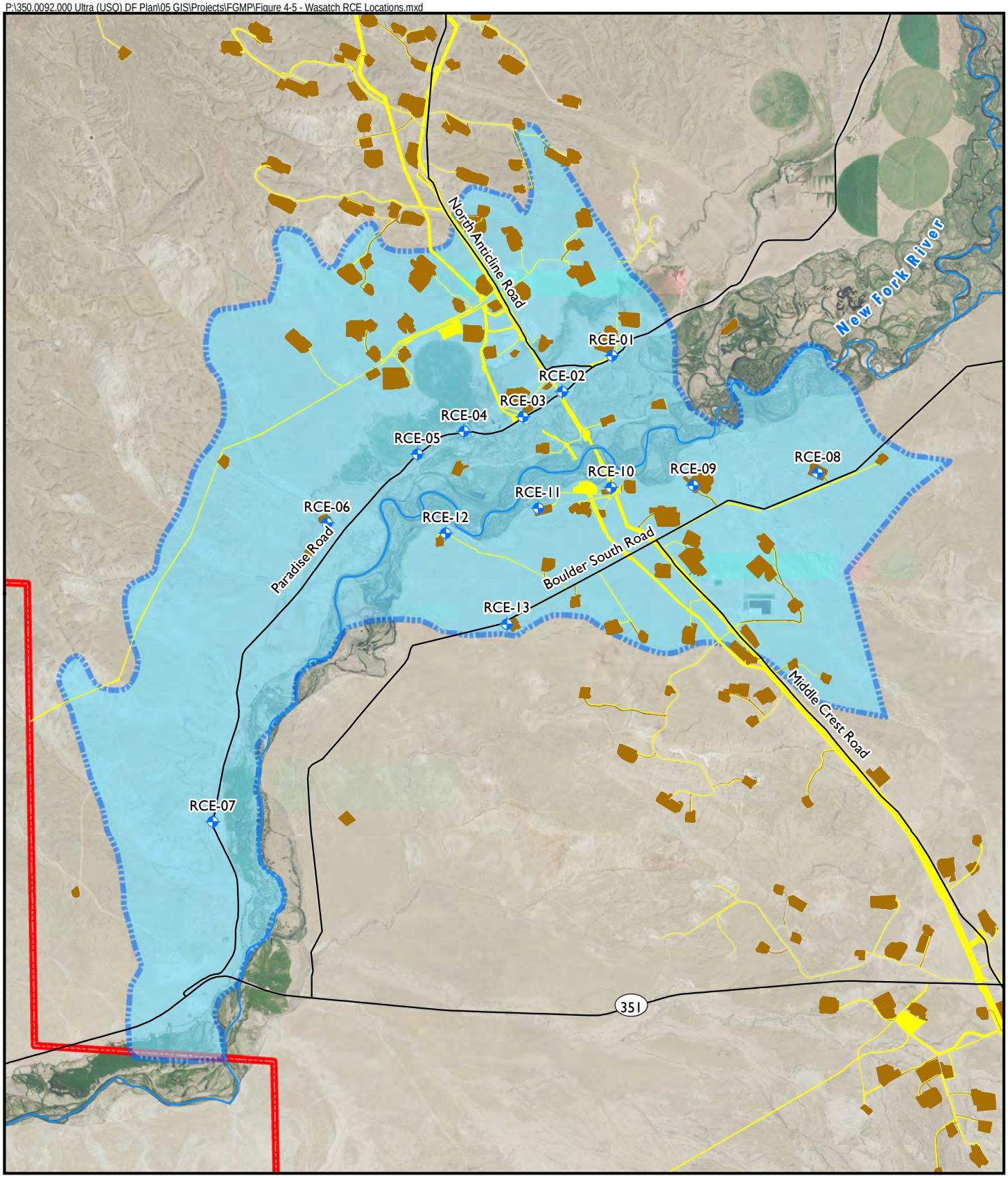
Industrial Supply Wells

Outliers

Pinedale Anticline Project Area (PAPA)

Potentiometric Map of the Wasatch HSU, June 2014
Pinedale Anticline Project Area
Sublette County, Wyoming
FIGURE 4-4

P:\350.0092.000 Ultra (USO) DF Plan\05 GIS\Projects\FGMP\Figure 4-5 - Wasatch RCE Locations.mxd



Source: 2013 NRIS

N

0 Feet 6,000

NewFields

Monitoring Well

River Corridor Envelope

Pinedale Anticline Project Area

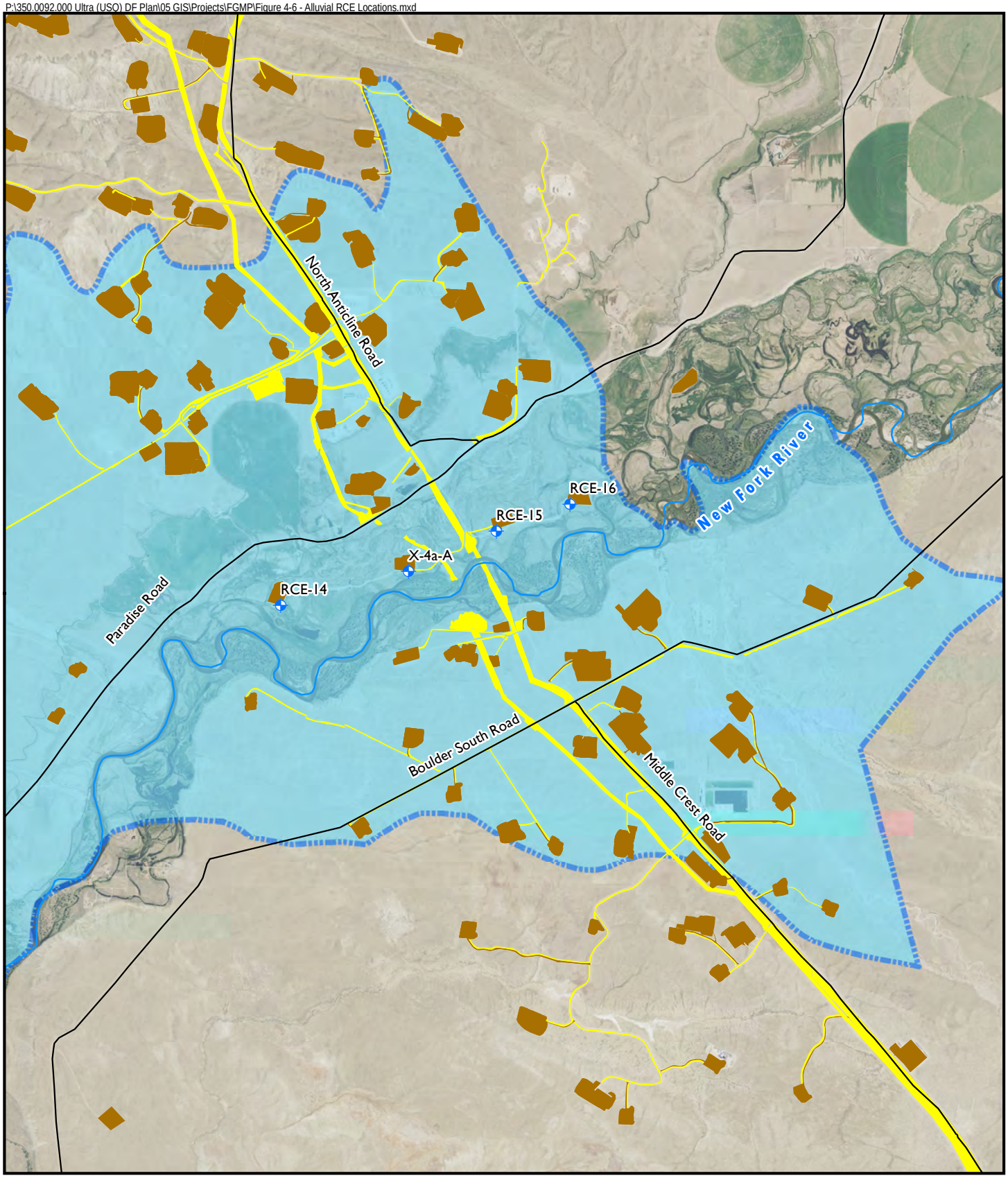
Potential Source

Pipeline

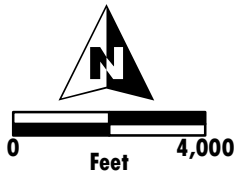
Well Pad

Wasatch HSU Monitoring Locations
in the River Corridor Envelope
Pinedale Anticline Project Area
Sublette County, Wyoming
FIGURE 4-5

P:\350.0092.000 Ultra (USO) DF Plan\05 GIS\Projects\FGMP\Figure 4-6 - Alluvial RCE Locations.mxd



Source: 2013 NRIS



Monitoring Well

River Corridor Envelope

Potential Source

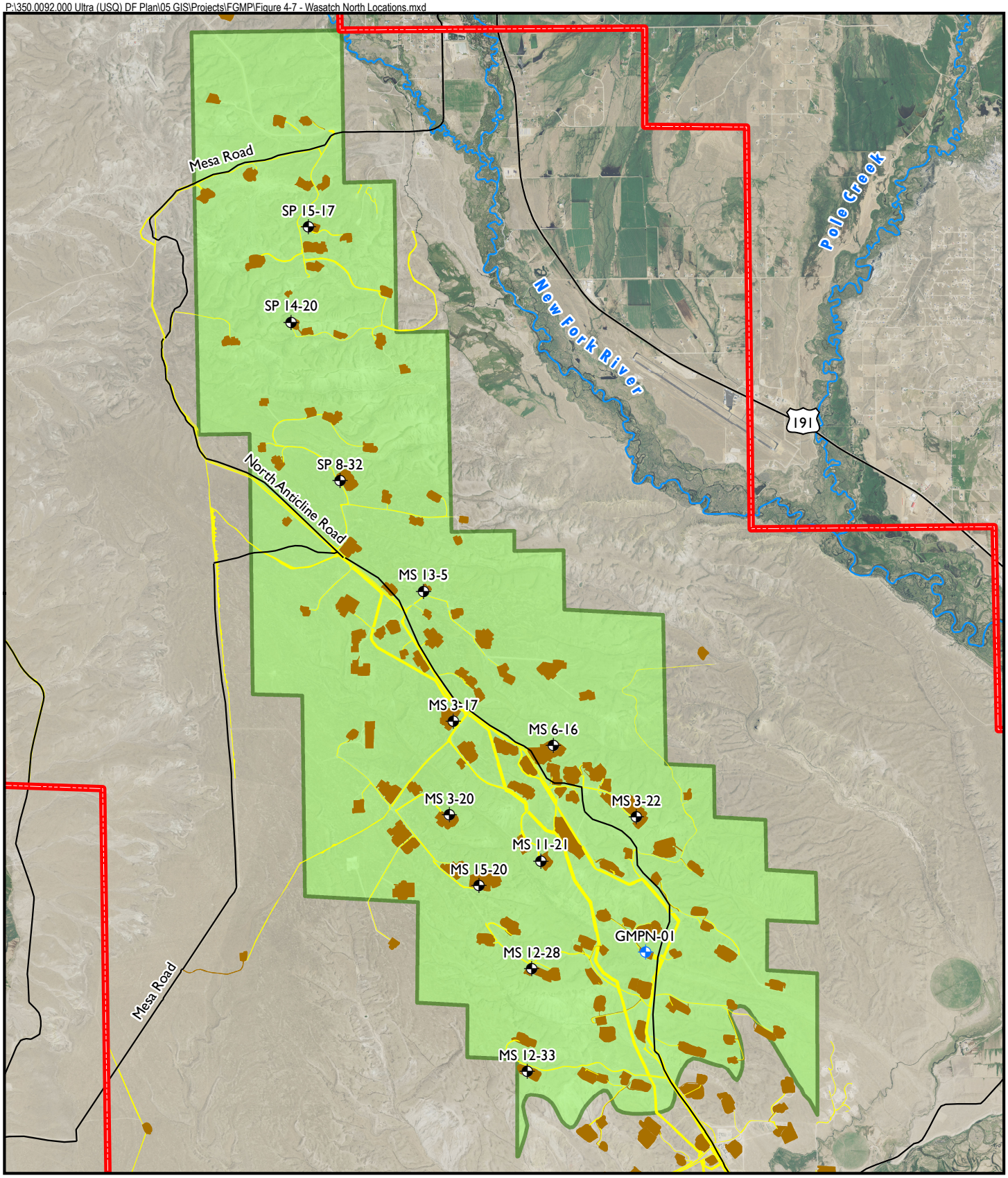
Pipeline

Well Pad

NewFields

Alluvial HSU Monitoring Locations
in the River Corridor Envelope
Pinedale Anticline Project Area
Sublette County, Wyoming
FIGURE 4-6

P:\350.0092.000 Ultra (USQ) DF Plan\05 GIS\Projects\FGMP\Figure 4-7 - Wasatch North Locations.mxd



Source: 2013 NRIS

N

0 Feet 7,000

NewFields

Monitoring Well

Industrial Water Supply Well

Pinedale Anticline Project Area

North Zone

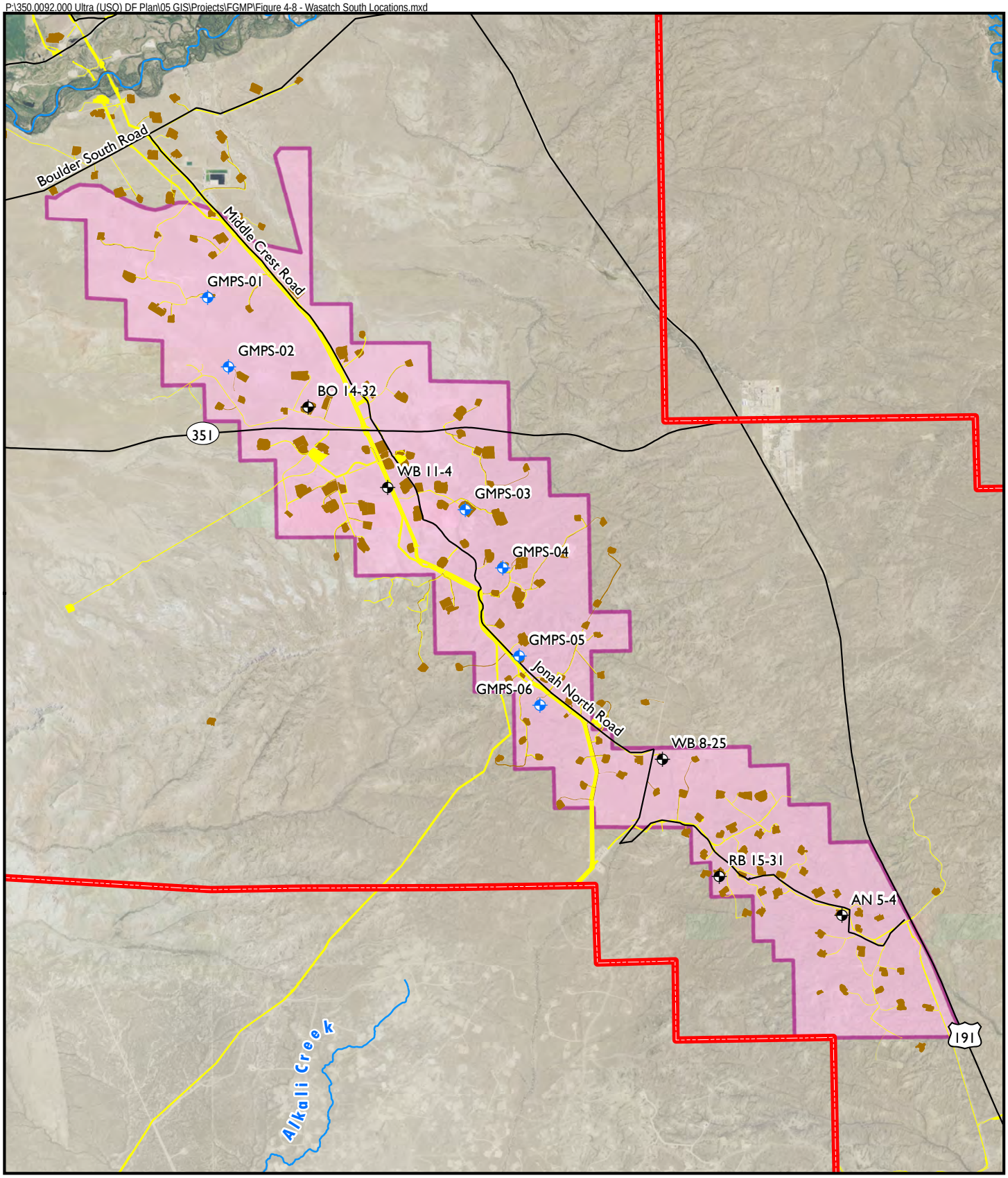
Potential Source

Pipeline

Well Pad

Wasatch HSU Monitoring Locations,
North Zone
Pinedale Anticline Project Area
Sublette County, Wyoming
FIGURE 4-7

P:\350.0092.000 Ultra (USO) DF Plan\05 GIS\Projects\FGMP\Figure 4-8 - Wasatch South Locations.mxd



Source: 2013 NRIS

N

0 Feet 9,000

NewFields

Monitoring Well

Industrial Water Supply Well

Pinedale Anticline Project Area

South Zone

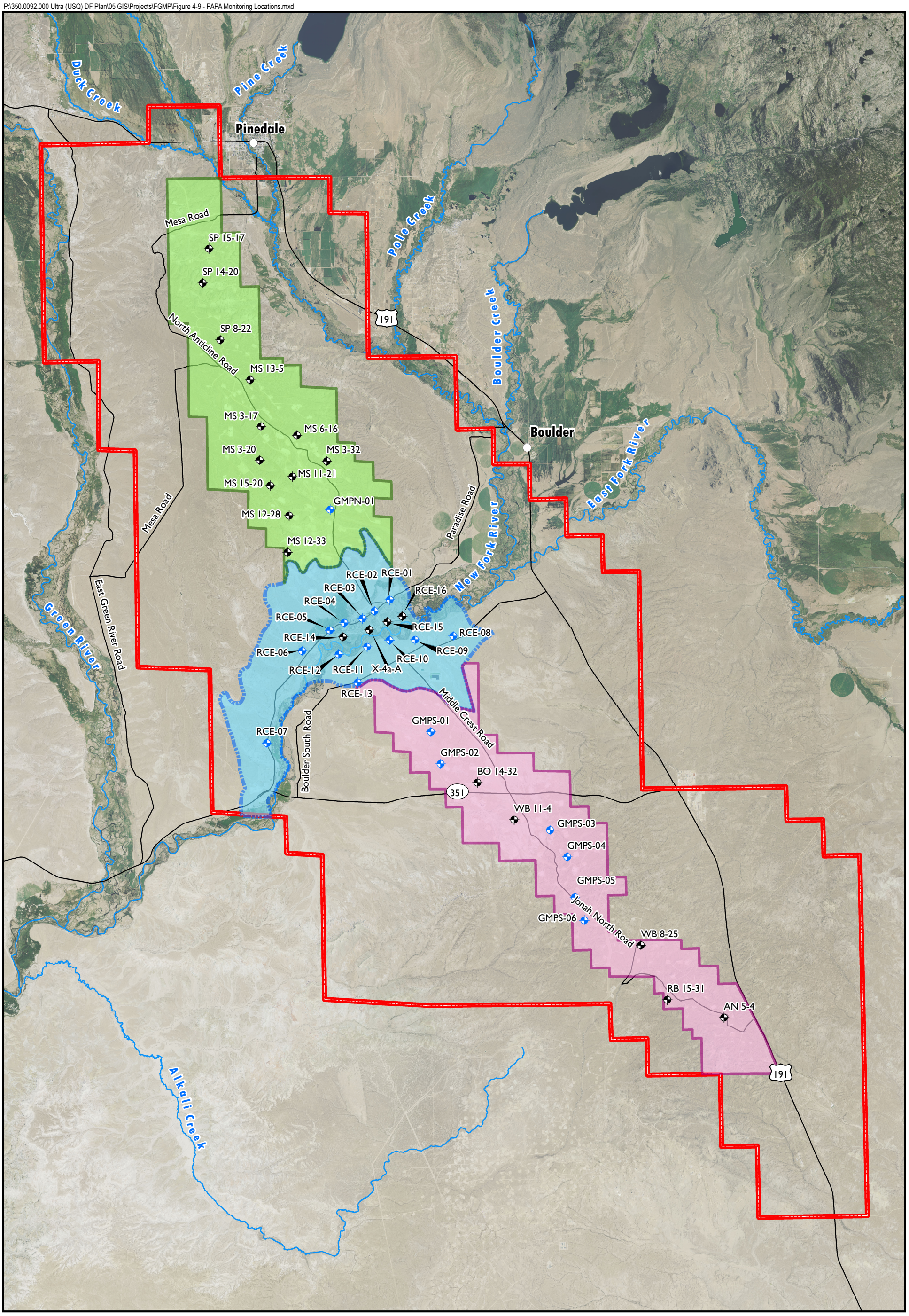
Potential Source

Pipeline

Well Pad

Wasatch HSU Monitoring Locations, South Zone
Pinedale Anticline Project Area
Sublette County, Wyoming
FIGURE 4-8

P:\350.0092.000 Ultra (USQ) DF Plan\05 GIS\Projects\FGMP\Figure 4-9 - PAPA Monitoring Locations.mxd



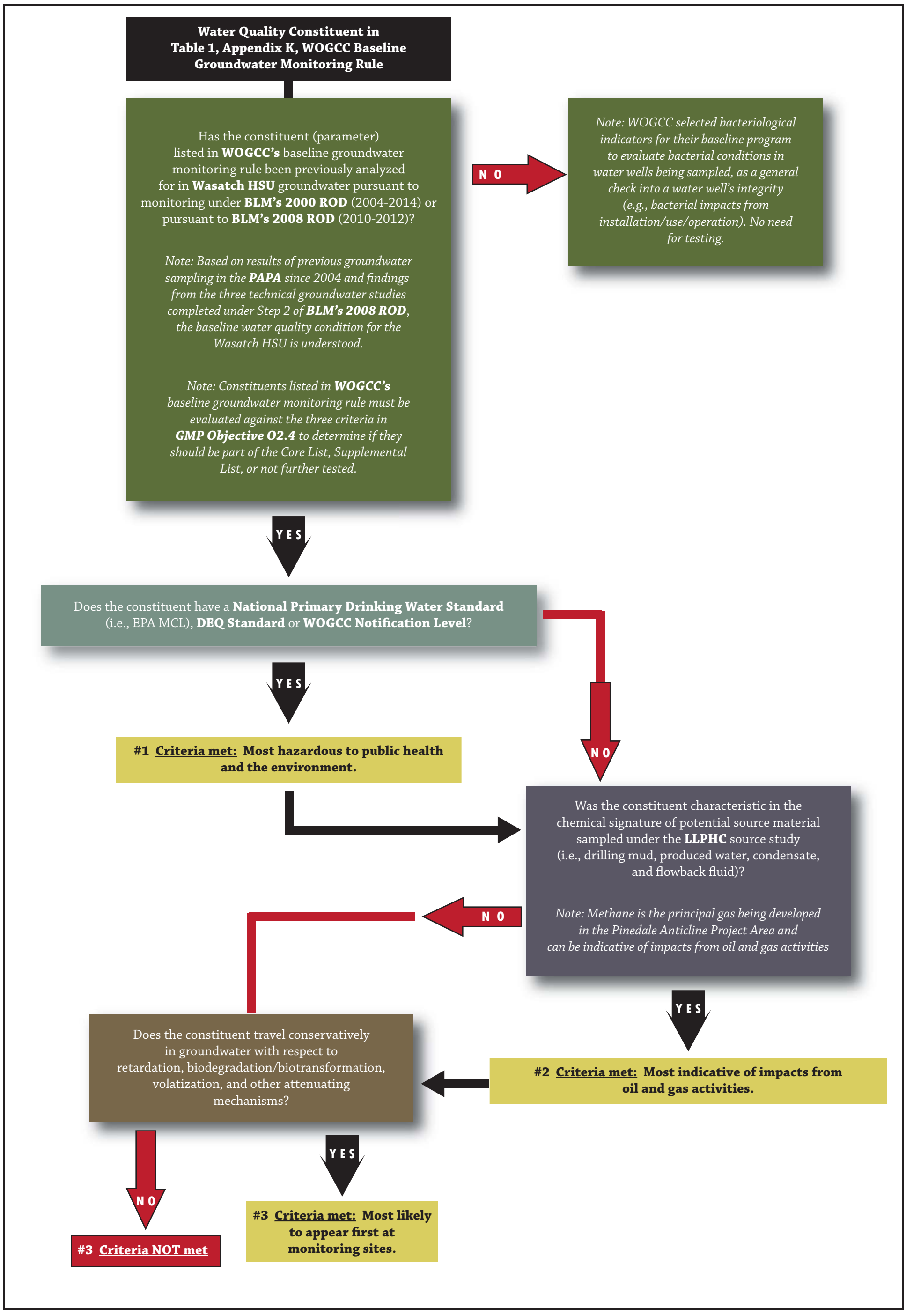
Source: 2013 NRIS

0 Miles 2.5

NewFields

Monitoring Well
Industrial Water Supply Well
South Zone
North Zone
River Cooridor Envelope
Pinedale Anticline Project Area

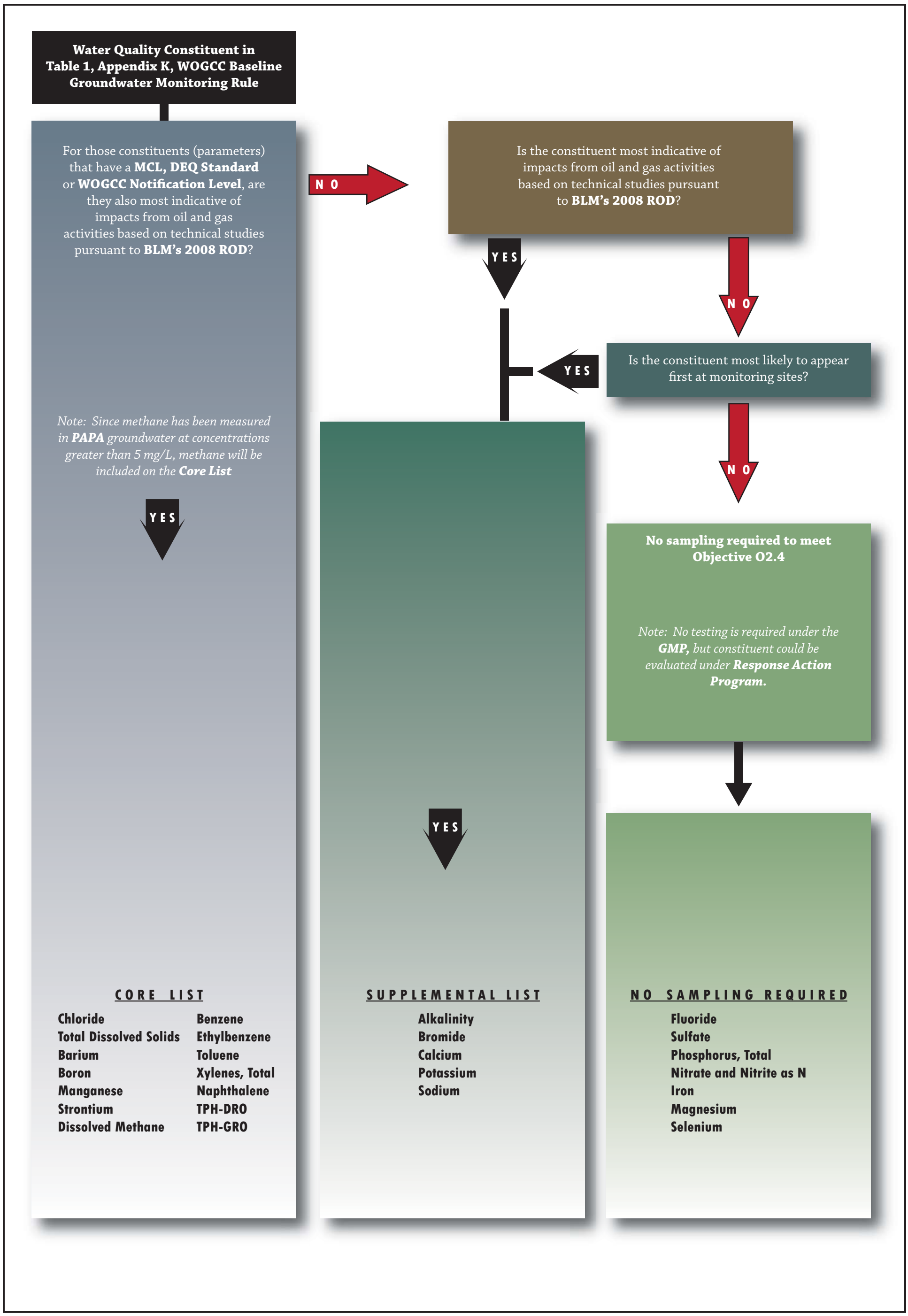
PAPA Groundwater Monitoring Locations
Pinedale Anticline Project Area
Sublette County, Wyoming
FIGURE 4-9



Note: Individual constituents are ranked relative to Criteria in Table 4-3.

Flow Chart to Rank WOGCC Water Quality Constituents
Relative to Criteria in Objective O2.4
Pinedale Anticline Project Area
Sublette County, Wyoming
FIGURE 4-10

NewFields



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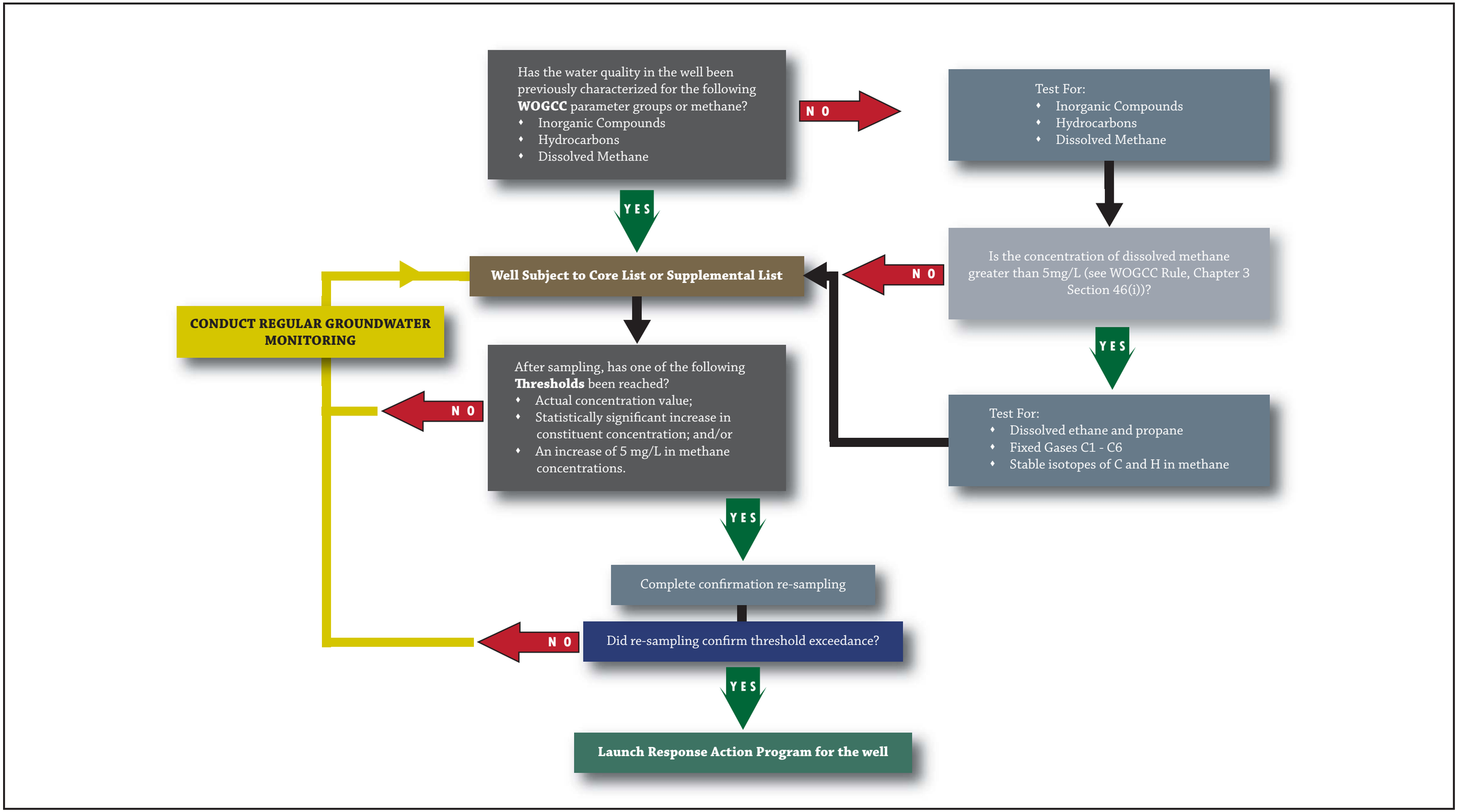
Flow Chart to Select Core List and Supplemental List Parameters
Pinedale Anticline Project Area
Sublette County, Wyoming
FIGURE 4-11



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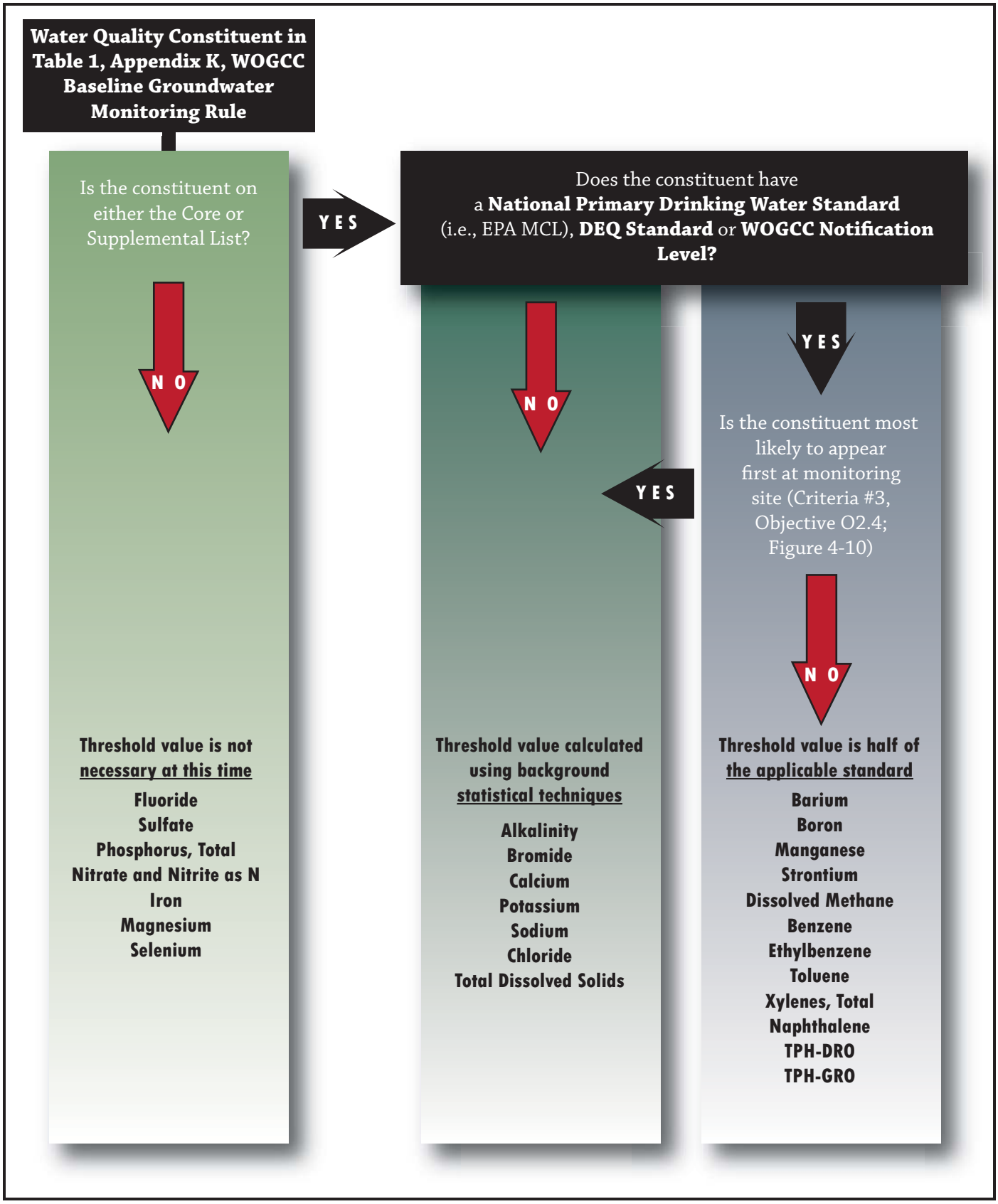
Flow Chart to Decide Water Quality Parameter List for Individual Wells
Pinedale Anticline Project Area
Sublette County, Wyoming
FIGURE 4-12



Flow Chart to Determine Absolute Threshold Value for Each Constituent
Pinedale Anticline Project Area
Sublette County, Wyoming
FIGURE 4-13

NewFields

TABLES

TABLE 4-1
Process Steps to Identify Data Quality Objectives
Groundwater Monitoring Program, Pinedale Anticline Project Area, Sublette County, Wyoming

Step 1: Define Problem	Step 2: Identify the Goal	Step 3: Identify Information Inputs	Step 4: Set Study Boundaries	Step 5: Develop Analytic Approach	Step 6: Specify Performance Criteria	Step 7: Develop Plan for Data Collection
Problem Statement: As part of the Plan, a long-term Groundwater Monitoring Program (GMP) is required for the PAPA to demonstrate that groundwater resources are not being impacted by oil and gas activities. This program is to be designed to meet 10 specific objectives approved by the BLM in June 2014 and also serve as the Master Plan to fulfill baseline groundwater monitoring requirements of the WOGCC. The program will be implemented in 2015. BLM's 2008 Record of Decision (ROD) related to groundwater resources required proponents to complete three (3) steps. Step 1 (data compilation) was completed in March 2008. Step 2 required comprehensive groundwater characterization of the PAPA. Three detailed technical studies were conducted and BLM determined that Step 2 was completed in November 2013. The final step (Step 3) was to develop and implement a long-term plan to protect groundwater resources in the PAPA (Groundwater Pollution Prevention, Monitoring and Response Action Plan; "Plan"). Findings from the Low-Level Petroleum Hydrocarbon Compounds (LLPHC) study (AMEC 2013b) determined that no widespread impact to groundwater in the PAPA is evident as a result of spills or leaks of materials used in, or by-products of, natural gas development. This indicates that best management practices (BMPs) to prevent groundwater pollution have been effective.	The goal is to establish a GMP to monitor groundwater for impacts from oil and gas activities that is based on the PAPA groundwater characterization, is appropriate to the level of risk, and will include constituents that are: most indicative of impacts from oil and gas activities; most likely to appear first at monitoring sites; and most hazardous to public health and the environment. Ten specific objectives for this goal were approved by BLM in June 2014. Key questions for the GMP include: • Are monitoring locations in areas that will provide for early detection of potential impacts from oil and gas activities in areas of greatest environmental sensitivity? • Do monitoring locations provide for adequate spacial coverage of the PAPA? • Are groundwater quality parameters selected for analysis based on the WOGCC baseline monitoring rule and do they include constituents that are: 1) most likely to appear first at monitoring sites; 2) most hazardous to public health and the environment; and 3) most indicative of impacts from oil and gas activities? • Are both a Core List and Supplemental List of parameters established for analysis in groundwater samples collected from wells in areas of higher relative risk and those areas with less risk? • Are groundwater quality thresholds (actual values and statistically significant changes in concentrations) established that are protective of groundwater resources?	Additional hydrogeologic data will be generated through installation of new wells to meet GMP well location objectives. Wells will be installed in accordance with a Sampling and Analysis Plan (SAP) and Quality Assurance Project Plan (QAPP) appended to the Plan. Data will be used to evaluate if the existing hydrogeologic conceptual model needs to be updated. Groundwater samples from the well network need to be collected and analyzed in accordance with WOGCC's Appendix K to its baseline monitoring rule (Chapter 3, Section 46 WOGCC rules). Samples are to be obtained on a regular frequency and compared to thresholds, as follows: • Actual values for thresholds need to be developed by first determining if a constituent has a regulatory standard (i.e., National Primary Drinking Water Standard, DEQ Standards, or WOGCC Notification/Action Level). If so, the threshold value needs to be established at a level less than the regulatory standard (e.g, twice as protective as the regulatory standard). • For constituents without regulatory standards and that have been routinely analyzed in Wasatch HSU groundwater pursuant to BLM's 2000 ROD, background threshold values will need to be calculated using background statistical techniques. • After at least six samples have been collected from GMP wells, data for each well will be statistically evaluated (after each sampling round) to test for increasing concentrations over time (i.e., Mann-Kendal nonparametric test to determine if there is a statistically significant increase in concentration). Note: The threshold for dissolved methane gas in groundwater has been established by WOGCC as a 5 mg/L increase over previous sample results.	The GMP study boundary consists of the five development areas (DA-1 through DA-5) of the PAPA including a corridor enveloping an area around the New Fork River in the center of the PAPA. The River Corridor Envelope was established by predictive modeling described by AMEC (2013a). The study area is divided into three zones: • River Corridor Envelope – The area designated to have the greatest environmental sensitivity and with the greatest relative risk of being impacted; • North Zone – the area encompassing DA-1 and DA-2 north of the River Corridor Envelope; and, • South Zone – the area encompassing DA-3, DA-4 and DA-5 south of the River Corridor Envelope. On a routine basis as described in the GMP, Wasatch HSU groundwater will be sampled and analyzed in each of the three zones. Groundwater in the Alluvial HSU will also be sampled and analyzed on a schedule outlined in the GMP from wells located in the River Corridor Envelope.	Groundwater samples will be collected and analyzed on a routine frequency (see Figure 4-12) from existing and new wells in the PAPA. New wells installed for the GMP will be initially tested for WOGCC parameters including Inorganic Compounds, Hydrocarbons, and Dissolved Methane. Once data for each sampling round are verified and validated, results will be compared to thresholds described under Step 3. The following decision rules will be used: • If a threshold for any parameter is not exceeded in a sample from a GMP well, the well will be included in the next regularly scheduled monitoring event for either the Core List of parameters or Core and Supplemental Lists of parameters. • If a threshold for any parameter is exceeded in a sample from a GMP well, confirmation re-sampling will be conducted. • If a threshold for any parameter is not exceeded in a confirmation re-sample of a GMP well, the well will be included in the next regularly scheduled monitoring event for either the Core List of parameters or Core and Supplemental Lists of parameters. • If a threshold for any parameter is exceeded in a confirmation re-sample of a GMP well, the Response Action Program will be launched for that well. The Response Action Program (the third component of the overall Plan) will: 1) describe how exceedances of thresholds will be managed; 2) identify steps to be taken when a threshold is reached to provide an appropriate incremental response; 3) investigate what caused a threshold exceedance (e.g., failed BMP, absent BMP) and; 4) determine if additional BMPs are necessary and appropriate to prevent further threshold exceedences, and list rationale for requiring any additional BMPs.	All groundwater data collected under the GMP will adhere to sampling procedures and analytical methods stipulated in WOGCC's baseline groundwater monitoring rule (Chapter 3, Section 46); any alternative methods would have to be approved by the WOGCC and BLM. Quality assurance and quality control will be in accordance with the Plan's Quality Assurance Project Plan (QAPP), developed in consideration of applicable and appropriate regulatory requirements in accordance with standard environmental practices, and consistent with the groundwater characterization completed under Step 2 of BLM's 2008 ROD. Groundwater data developed under the GMP will be used to determine if the existing hydrogeologic model (AMEC 2012) requires revision/update, and whether water quality thresholds have been exceeded (see Step 3). A review cycle (e.g., annual) will be established for the Review Team to evaluate the effectiveness and continued relevance and appropriateness of sampling constituents, methods, thresholds, and the existing hydrogeologic conceptual model.	Groundwater monitoring locations were selected using spatial analysis techniques in consideration of the technical studies completed under Step 2 of BLM's 2008 ROD. Visual Sample Plan (VSP) software was used with inputs from AMEC (2012, 2013a, 2013b) to select the number and location of wells in the North and South Zones of the GMP boundary. VSP gives confidence to decisions that will be made from statistical analyses of the resulting data. By coupling solute transport model results (AMEC 2013a) and locations of potential receptors and potential sources in the River Corridor Envelope, particle tracking simulations by the numerical groundwater flow model (AMEC 2013a) were used to locate appropriate monitoring locations in the River Corridor Envelope. Alluvial HSU monitoring wells for GMP sampling are located downgradient of existing oil and gas development in the New Fork River floodplain. The plan for groundwater sampling and analysis will conform with Appendix K of the WOGCC Rules, and will need to be approved by WOGCC as a Master Plan for the PAPA. The GMP will contain a project-specific SAP and QAPP that specify the number and types of samples, data collect procedures, required analytes and analytical methods, and sampling frequency to meet GMP objectives.

TABLE 4-2

Water Wells in the Groundwater Monitoring Network

Groundwater Monitoring Program, Pinedale Anticline Project Area, Sublette County, Wyoming

AREA or ZONE	WELL NAME	SCCD ID	NATURAL GAS PAD NAME	HSU	EXISTING	NEW	TOTAL DEPTH		COORDINATES[2]		OWNERSHIP AND/OR SURFACE MANAGEMENT
							Existing Wells[1] *(feet)*	Anticipated for New Wells *(feet)*	Northing	Easting	
NORTH	MS 11-21	AMI154	MS 11-21	Wasatch	X		910		15,523,864	1,950,885	QEP - BLM
	MS 12-28	AMI160	MS 11-28	Wasatch	X		1020		15,518,183	1,950,403	Ultra - BLM
	MS 12-33	AMI167	MS 12-33	Wasatch	X		1,000		15,512,795	1,950,170	Ultra - BLM
	MS 13-5	AMI029	MS 13-5	Wasatch	X		940		15,538,048	1,944,707	QEP - BLM
	MS 15-20	AMI239	MS 15-20	Wasatch	X		1,120		15,522,558	1,947,624	QEP - BLM
	MS 3-17	AMI112	MS 3-17	Wasatch	X		1,200		15,531,222	1,946,282	QEP - BLM
	MS 3-20	AMI027	MS 3-20	Wasatch	X		940		15,526,279	1,946,080	QEP - BLM
	MS 3-22	AMI014	MS 3-22	Wasatch	X		772		15,526,170	1,955,913	QEP - BLM
	MS 6-16	AMI114	MS 6-16	Wasatch	X		1,000		15,529,939	1,951,551	QEP - State of Wyoming
	SP 14-20	AMI139	SP 14-20	Wasatch	X		1,000		15,552,193	1,937,755	QEP - BLM
	SP 15-17	AMI111	SP 15-17	Wasatch	X		940		15,557,192	1,938,670	QEP - BLM
	SP 8-32	AMI205	SP 8-32	Wasatch	X		1,090		15,543,866	1,940,325	QEP - BLM
	GMPN-01	NA	MS 6-27	Wasatch		X		250 - 300	15,519,064	1,956,395	Ultra - BLM
RIVER CORRIDOR ENVELOPE	RCE-01	NA	NA	Wasatch		X		100 - 200	15,505,864	1,965,144	County Road ROW
	RCE-02	NA	NA	Wasatch		X		100 - 200	15,504,228	1,962,891	County Road ROW
	RCE-03	NA	NA	Wasatch		X		100 - 200	15,503,108	1,961,134	County Road ROW
	RCE-04	NA	NA	Wasatch		X		100 - 200	15,502,442	1,958,472	County Road ROW
	RCE-05	NA	NA	Wasatch		X		100 - 200	15,501,415	1,956,366	County Road ROW
	RCE-06	NA	NA	Wasatch		X		100 - 200	15,498,332	1,952,301	State
	RCE-07	NA	NA	Wasatch		X		100 - 200	15,484,849	1,947,143	County Road ROW
	RCE-08	NA	BR 16-7	Wasatch		X		100 - 200	15,500,575	1,974,417	Ultra - BLM
	RCE-09	NA	RS 15-12	Wasatch		X		100 - 200	15,500,028	1,968,814	Ultra - Private
	RCE-10	NA	JN 16-11	Wasatch		X		100 - 200	15,499,918	1,965,101	Ultra - Private
	RCE-11	NA	JN 3-14	Wasatch		X		100 - 200	15,498,996	1,961,819	Ultra - Private
	RCE-12	NA	NA	Wasatch		X		100 - 200	15,497,859	1,957,639	BLM
	RCE-13	NA	RS 4-23	Wasatch		X		100 - 200	15,493,783	1,960,404	Ultra - Private
	X-4a-A	NA	JN 11-11	Alluvial	X		20 / 18		15,501,438	1,962,124	Ultra - Private Land
	RCE-14	NA	JN 15-10	Alluvial	X		13		15,500,425	1,958,285	Ultra - Private Land
	RCE-15	NA	VB 8-11	Alluvial	X		13		15,502,653	1,964,758	Ultra - Private Land
	RCE-16	NA	VB 3-12	Alluvial	X		13		15,503,471	1,966,973	Ultra - Private Land
SOUTH	AN 5-4	AMI131	AN 5-4	Wasatch	X		550		15,444,730	2,014,015	Linn Energy - BLM
	BO 14-32	AMI280	BO 14-32	Wasatch	X		700		15,479,112	1,977,944	Ultra - BLM
	RB 15-31	AMI189	RB 15-31	Wasatch	X		740		15,447,371	2,005,747	Linn Energy - BLM
	WB 11-4	AMI301	WB 11-4	Wasatch	X		800		15,473,663	1,983,316	Ultra - BLM
	WB 8-25	AMI242	WB 8-25	Wasatch	X		670		15,455,310	2,001,889	Ultra - BLM
	GMPS-01	NA	BR 5-30	Wasatch		X		100 - 200	15,486,528	1,971,152	Ultra - BLM
	GMPS-02	NA	BR 6-31	Wasatch		X		150 - 250	15,481,841	1,972,550	Ultra - BLM
	GMPS-03	NA	WB 3-10	Wasatch		X		300 - 400	15,472,189	1,988,568	Ultra - BLM
	GMPS-04	NA	WB 16-10	Wasatch		X		400 - 500	15,468,253	1,991,107	Ultra - BLM
	GMPS-05	NA	WB 4-23	Wasatch		X		500 - 600	15,462,303	1,992,215	Ultra - BLM
	GMPS-06	NA	WB 11-23	Wasatch		X		500 - 600	15,458,969	1,993,604	Ultra - BLM

Notes:

RCE - River Corridor Envelope

SCCD ID - Sublette County Conservation District Identification Number

HSU - Hydrostratigraphic Unit as defined in AMEC (2012)

ROW - Right of Way

NA - Not applicable

Footnotes:

1 - If two depths are reported, the first is drilled depth and the second value is the depth cased.

2 - Northing and Easting values are in feet relative to UTM Zone 12; coordinates for new wells are approximate.

TABLE 4-3
Water Quality Parameters, Available Standards, Previous Testing, Ranking, and Selection for Sampling and Analysis
Groundwater Monitoring Program, Pinedale Anticline Project Area, Sublette County, Wyoming

WOGCC BASELINE GROUNDWATER QUALITY ANALYTICAL PARAMETER LIST	CAS #	EPA *MCL* (mg/L)	DEQ STANDARDS		WOGCC LEVELS		PREVIOUSLY TESTED		GMP OBJECTIVE O2.4			CONSTITUENTS FOR GMP		
			DEQ VRP Cleanup (mg/L)	*DEQ WQD Classification* (mg/L)	*WOGCC Action Levels* (mg/L)	*WOGCC Notification Levels* (mg/L)	Pursuant to BLM's 2000 ROD (2004-14)	Pursuant to BLM's 2008 ROD (2010-12)	Most Hazardous to Public Health and the Environment (Criteria #1)	Most Indicative of Impacts from O&G Activities[c] (Criteria #2)	Most Likely to Appear First at Monitoring Sites (Criteria #3)	CORE LIST	SUPPL. LIST	NOT PROPOSED FOR GMP[d,e]
INORGANIC COMPOUNDS														
Alkalinity	471-34-1						x	x		X	X		•	
Bromide	24959-67-9							x		X	X		•	
Chloride	16887-00-6		250	250			x	x	X	X	X	•		
Fluoride	16984-48-8	4	4	4			x	x	X					•
Sulfate	14808-79-8		250	250			x	x	X					•
Total Dissolved Solids	--		500	500			x	x	X	X	X	•		
Phosphorus, Total	7723-14-0		*					x						•
Nitrate and Nitrate as N	14797-55-8	10	10	10				x	X					•
Barium	7440-39-3	2	2	2				x	X	X		•		
Boron	7440-42-8		0.75	0.75				x	X	X		•		
Calcium	7440-70-2						x	x		X			•	
Iron	7439-89-6		23.3					x	X					•
Magnesium	7439-95-4						x	x						•
Manganese	7439-96-5		0.05	0.05				x	X	X		•		
Potassium	9/7/7440						x	x		X			•	
Selenium	7782-49-2	0.05	0.05	0.05				x	X					•
Sodium	7440-23-5						x	x		X			•	
Strontium	7440-24-6		20					x	X	X		•		
HYDROCARBONS														
Benzene	71-43-2	0.005	0.005		0.005	0.005	x	x	X	X		•		
Ethylbenzene	100-41-4	0.7	0.7		0.7	0.7	x	x	X	X		•		
Toluene	108-88-3	1	1		1	1	x	x	X	X		•		
Xylenes, Total	--	10	10		10	10	x	x	X	X		•		
Naphthalene	91-20-3		0.667		0.729	0.729		x	X	X		•		
TPH-DRO	--		1.0[a] or 10[b]		1.1[a] or 10[b]	1.1[a] or 10[b]	x	x	X	X		•		
TPH-GRO	--		6.6		7.3	7.3	x	x	X	X		•		
GASES														
Dissolved Methane	74-82-8					10		x		X		•		
Increase in Dissolved Methane	74-82-8					5				X		NA	NA	NA
Dissolved Ethane	4-84-0							x						•
Dissolved Propane	74-98-6							x						•
GAS COMPOSITIONAL ANALYSIS														
Fixed Gases C1-C6	--							x						•
Stable isotropic concentration of the carbon (^{12}C and ^{13}C) and hydrogen (^{1}H and ^{2}H) in the methane	--					thermogenic or mixture of thermogenic and biogenic gas		x						•
BACTERIOLOGICAL														
IRB	--											NA	NA	NA
SRB/SFB	--											NA	NA	NA

Notes:
Parameter listed in Table 1, Appendix K, found at http://wogcc.state.wy.us/downloads/5072014_K_Sampling_and_Analysis_Procedures.pdf
Blank cells -- no data/information
Alkalinity -- total bicarbonate, and carbonate as CaCO3
IRB – Iron Reducing Bacteria
SRB/SFB – Sulfate Reducing Bacteria/Slime Forming Bacteria
TPH-DRO – Total Petroleum Hydrocarbons Diesel Range Organics
TPH-GRO – Total Petroleum Hydrocarbons Gasoline Range Organics
Cleanup - VRP: updated December 2014; accessed on-line at: deq.state.wy.us/volremedi/downloads/.../FS_13.pdf
Classification - WQD: from Chapter 8, DEQ Water Quality Rules and Regulations found at https://deq.state.wy.us/wqd/WQDrules/Chapter_08.pdf
WOGCC Action Levels: from Appendix K found at http://wogcc.state.wy.us/downloads/5072014_K_Sampling_and_Analysis_Procedures.pdf
WOGCC Notification Levels: from Section 46 of Chapter 3, WOGCC rules found at http://soswy.state.wy.us/Rules/RULES/9411.pdf
NA - not applicable

Footnotes:
* DEQ VRP has a cleanup standard for white phosphorus (elemental phosphorus), not total phosphorus.
a. This level is applicable when naphthalene and/or methylnaphthalenes along with the other chemicals of concern are detected in groundwater above the MCL/DWEL (assuming that reporting limits are adequate in comparison to cleanup levels) OR when there is free product present on the groundwater table.
b. This level is applicable when naphthalene and/or 2-methylnaphthalene along with the other chemicals of concern are below MCL/DWEL
c. Considers chemical signature findings from LLPHC study (AMEC 2013b) for condensate, produced water, flowback fluid, and drilling mud.
d. If water quality in well has not been tested previously for these constituents, it will be tested at the onset of the GMP.
e. Constituent may be tested if the Response Action Program is triggered by a threshold exceedence in a monitoirng well.

TABLE 4-4

Water Quality Parameters, Available Standards, Absolute Value Threshold, and Core/Suplemental Sampling List

Groundwater Monitoring Program, Pinedale Anticline Project Area, Sublette County, Wyoming

WOGCC BASELINE GROUNDWATER QUALITY ANALYTICAL PARAMETER LIST	CAS #	EPA *MCL*	DEQ STANDARDS		WOGCC LEVELS		ABSOLUTE VALUE THRESHOLD				CONSTITUENTS FOR GMP	
			DEQ VRP Cleanup	*DEQ WQD Classification*	*WOGCC Action Levels*	*WOGCC Notification Levels*	*North Zone*	*South Zone*	*River Corridor Envelope*	THRESHOLD BASIS	CORE LIST	SUPPLEMENTAL LIST
		(mg/L)	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*			
INORGANIC COMPOUNDS												
Alkalinity	471-34-1						265	336	317	B		•
Bromide[a]	24959-67-9											•
Chloride	16887-00-6		250	250			51	225	93	B	•	
Total Dissolved Solids			500	500			1,219	984	855	B	•	
Barium	7440-39-3	2	2	2			1	1	1	A	•	
Boron	7440-42-8		0.75	0.75			0.375	0.375	0.375	A	•	
Calcium	7440-70-2						146	76	53	B		•
Manganese	7439-96-5		0.05	0.05			0.025	0.025	0.025	A	•	
Potassium	7440-09-7						3.9	2.5	3.0	B		•
Sodium	7440-23-5						369	616	282	B		•
Strontium	7440-24-6		20				10	10	10	A	•	
HYDROCARBONS												
Benzene	71-43-2	0.005	0.005		0.005	0.005	0.0025	0.0025	0.0025	A	•	
Ethylbenzene	100-41-4	0.7	0.7		0.7	0.7	0.35	0.35	0.35	A	•	
Toluene	108-88-3	1	1		1	1	0.5	0.5	0.5	A	•	
Xylenes, Total		10	10		10	10	5	5	5	A	•	
Naphthalene	91-20-3		0.667		0.729	0.729	0.3335	0.3335	0.3335	A	•	
TPH-DRO			1.0[b] or 10[c]		1.1[b] or 10[c]	1.1[b] or 10[c]	0.5[b] or 5[c]	0.5[b] or 5[c]	0.5[b] or 5[c]	A	•	
TPH-GRO			6.6		7.3	7.3	3.3	3.3	3.3	A	•	
GASES												
Dissolved Methane	74-82-8					5 mg/L increase[d]	5 mg/L increase[d]	5 mg/L increase[d]	5 mg/L increase[d]	C	•	

Footnotes:

a. An absolute threshold value was not calculated for bromide because a standard does not exist and there is insufficient data to calculate a value.

b. This level is applicable when naphthalene and/or methylnaphthalenes along with the other chemicals of concern are detected in groundwater above the MCL/DWEL (assuming that reporting limits are adequate in comparison to cleanup levels) OR when there is free product present on the groundwater table.

c. This level is applicable when naphthalene and/or 2-methylnaphthalene along with the other chemicals of concern are below MCL/DWEL.

d. 5 mg/L increase over successive sampling events.

Notes:

Alkalinity - total bicarbonate, and carbonate as CaCO3

TPH-DRO – Total Petroleum Hydrocarbons Diesel Range Organics

TPH-GRO – Total Petroleum Hydrocarbons Gasoline Range Organics

mg/L - milligram per liter

Blank cell = Not Applicable or information not available

Cleanup - VRP: updated December 2014; accessed on-line at: deq.state.wy.us/volremedi/downloads/.../FS_13.pdf

Notes on Threshold Basis:

A = Threshold is one-half the applicable standard.

B = Threshold is the Upper Tolerance Limit (UTL) with 95% confidence and 95% coverage based on statistical evaluation.

C = Threshold is based on WOGCC notification level for methane.