The following section briefly reviews the mechanism of natural gas release from Gas Storage Well No. 26, evaluates subsurface migration processes and presents a conceptual model for gas migration consistent with the available data.

5.1 RELEASE MECHANISM

Immediately after the accidental release of natural gas was detected on October 22, 2006, CIG monitored gas well pressures and determined that the leak was in Gas Storage Well No. 26. After the gas storage reservoir was isolated from the leak by placing a cast-iron bridge plug at 5,460 feet bgs above the well's perforated interval, cased-hole well logs and downhole video cameras verified that the source of the leak was a casing collar at 846 feet bgs in the well. The exact cause of the casing split is not known because detailed photographs taken inside the casing did not reveal any flaws or corrosion. However, the failure is likely due to a combination of metal fatigue and corrosion outside the casing.

Currently, Gas Storage Well No. 26 remains sealed to prevent further leakage. At the time the leak was discovered, downhole reservoir pressures measured by CIG in Gas Storage Well No. 26 were approximately 2,100 pounds per square inch (psi), and the bradenhead pressure was 548 psi.

The rock formation surrounding Gas Storage Well No. 26 at the depth of the casing leak is the Pierre Shale. As the name implies, the Pierre Shale is predominantly shale or mudstone, which typically has very low permeability. In the area of the Gas Plant, the Pierre Shale extends from the base of the alluvium, about 100 feet bgs, to a depth of approximately 5,000 feet bgs. The Niobrara Formation immediately underlies the Pierre Shale. As discussed in the previous section, the upper Pierre Shale also contains sandstone and carbonate rocks locally.

Borehole geophysical logs run when Gas Storage Well No. 26 was drilled show that the Pierre Shale extends for more than 100 feet above and below the depth of the casing split. However, the high pressure of gas escaping from the casing split was sufficient to cause hydro-fracturing of the shale and allow rapid gas flow through open fractures. At a depth of 846 feet, the lithostatic stress regime would favor propagation of horizontal rather than vertical fractures. Thus, fractures would be more likely to form sub-parallel to bedding. With increasing distance away from the well, the gas pressure gradient would diminish and cause less fracturing. After the release, CIG estimated that approximately 580 MMcf of gas was lost.

5.2 GAS MIGRATION

Gas pressure differences, and the resultant fluid potential gradients within the porous media, are the major driving forces for gas migration. However, the actual gas migration pathways are controlled by the physical characteristics of the pore spaces that govern fluid transmission. In simple terms, gas will migrate from areas of higher fluid potential (pressure) to lower fluid potential, along the path of least resistance. Paths of less resistance for gas migration may be caused by geologic discontinuities from structural deformation, variability in rock type, and strength. Thus, the lithologic characteristics and depositional environment of the sedimentary deposits, and post-depositional geologic structures are major factors that influence gas migration pathways.

In the upper Pierre Shale at this site, fractures along bedding plane partings and fractures associated with faults appear to be the key factors that caused gas to migrate from the point of release to the observed areas of land surface disruption. Figure 4-19 illustrates the conceptual model for gas migration. At the point of release from 846 feet at Gas Storage Well No. 26, gas initially migrated along fractures oriented parallel with bedding. Natural bedding plane partings in shale provide higher permeability in the direction parallel to bedding compared to much lower permeabilities perpendicular to bedding. Several previous hydrogeologic studies at other sites have reported that horizontal permeability is greater than the vertical permeability of flat lying sedimentary aquifers, typically by a factor of 10 to 100 times.

Hydro-fracturing caused by the high-pressure gas release would have expanded the natural fractures along bedding planes, and extended those fractures laterally. This would result in a significant increase in permeability in directions parallel to the shale bedding. Because lithostatic pressure diminishes with depth, the gas-induced fractures would migrate upward, sub-parallel to the natural bedding orientations. Thus, gas would have migrated updip away from Gas Storage Well No. 26, until reaching other pathways of less resistance.

Steeply dipping fractures associated with fault zones likely provided additional preferred pathways for gas migration. As illustrated on Figure 4-19, faults that displace the deeper reflectors (e.g., Shallow4) probably cause fractures to form in the overlying strata, through the depth interval of UP2 and UP3. The UP1 sandstone is more resistant to vertical fracturing from faults in Shallow4 because it is more dense, stronger and higher in the stratigraphic section than UP2 and UP3. Thus, the UP1 sandstone is likely to have restricted the vertical upward gas migration. Rather than breaking through the UP1 sandstone and migrating vertically up to the ground surface at that point, the gas migrated along preferred pathways lying sub-parallel to the bedding of the sandstone. Thus, in the area north of the Gas Plant, the gas likely migrated laterally and upward along the bedding until encountering near-vertical fracture zones, which are associated with the relatively shallow slump faults. These slump faults are located immediately northeast, east, and southeast of the plant and lie adjacent to the apparent UP1 surface low underlying that area.

As discussed in the previous section, the general configuration of the UP1 surface low and slump faults are seen on the 3-D seismic reflection data collected in 1996. Details of the slump faulting and likely causes are even more clearly seen on the high-resolution seismic survey lines conducted in 2007. Sub-vertical fractures associated with the slump faults, which are likely attributable to dissolution and collapse of a limestone mound in the upper Pierre, provided preferred pathways for upward gas migration into the overlying alluvium. The hypothesized dissolution zone is illustrated by an orange circular zone on Figure 4-19, with overlying slump faults.

After reaching the overlying alluvium, gas continued to migrate upward along pathways of least resistance. More permeable zones of sand and gravel lying near the base of the alluvium provided preferred pathways in directions generally parallel to the alluvial deposits. The alluvial deposits consist of paleochannels and fine-grained overbank deposits (e.g., clay lenses), which have complex, tortuous geometry (like stream channels) in the subsurface. Preferred pathways for gas migration would have generally been southward because stream channel deposits dip northward, as does the base of the alluvium and top of the Pierre Shale bedrock.

As the volume and pressure of gas in the alluvium increased, the gas migrated laterally along the more permeable stream channel deposits while tighter beds of silt and clay restricted upward migration. Areas where clay beds are absent allowed more rapid upward migration to the areas where surface eruptions were observed. Figure 4-20 is a north-south cross section of alluvium located on the east side of the Gas Plant that is based on CPT borings, and illustrates preferred pathways in the alluvium that allowed gas migration to an area of surface disruption south of the plant. An east-west cross-section that lies just north of the plant, Figure 4-21, shows a westward-dipping lens of clay and silt that likely limited upward migration of gas and caused further eastward migration to the surface.

Figure 4-22 illustrates the conceptual model of preferred gas migration pathways in map view. The color-shaded base map on this figure is the UP1 structure contour map, which is presented previously as Figure 4-16. This structure contour map shows the bedding orientations of the upper Pierre Shale. Preferred pathways are depicted on Figure 4-22 as dark blue lines. The figure shows migration upward along bedding in two directions from Gas Storage Well No. 26, one toward the east and another toward the southwest. Dashed dark blue lines on this figure represent possible pathways, which are based largely on the 1996 3-D seismic survey data, but these are less likely than the solid dark blue pathways.

The dashed red lines on Figure 4-22 represent the upward projections of faults in the Shallow4 reflector horizon observed in the 3-D seismic data. Preferred pathways for upward migration are also indicated along these projected faults. Circular areas of yellow shown on Figure 4-22 depict the areas where land surface disruptions occurred. Figure 4-23 provides a 3-D perspective of the UP1 structural contours and shows preferred gas migration pathways with red arrows. The pink arrows indicate possible, but less likely, pathways based on the 1996 3-D seismic data and available well log information.

In addition to the land surface disruptions caused by the escaping gas in areas east and southeast of the Gas Plant, another area of surface disruption caused by escaping gas occurs further to the southwest of the plant. That area is beyond the eastern margin of the high-resolution 2-D seismic surveys. The nature of the surface disruption, soil sampling and groundwater sampling there were previously described in the *Interim Phase II Report* (URS 2007). Even though there are relatively few subsurface data to define the preferred pathways in that area, the gas migration mechanisms and pathways are expected to be the same as those described above.

5.3 MONITORING OF GAS MIGRATION PATHWAYS

By understanding the reasons that gas migrated from Gas Storage Well No. 26 to the surface disruption areas and extent of dissolved methane in the alluvial aquifer, potential future migration directions can be more clearly identified and monitored to protect health and safety.

The key reason for conducting the groundwater monitoring described in the Phase I and Interim Phase II reports is to detect natural gas concentrations in shallow groundwater and thus provide an early warning of potential further migration toward residential areas. Groundwater monitoring has been conducted around the perimeter of the alluvial aquifer plume, and should continue with less frequency in the future. High-priority monitoring points include the CPT piezometers located between occupied residences and the edge of the dissolved methane.

Results of the seismic surveys and the conceptual model also provide useful information to plan the future groundwater monitoring program. An additional degree of conservatism for health and safety can be afforded by including shallow groundwater monitoring points to detect potential upward movement along preferred pathways. Thus, to detect upward gas migration near occupied residences, it is prudent to perform sampling and analyses of natural gas concentrations in groundwater from CPT piezometers located along the identified preferred gas migration pathways in the upper Pierre Shale. These factors were taken into account in selecting monitoring wells for the the long-term monitoring program, which is described in Section 6.

The conclusions inferred from the seismic study and the groundwater monitoring are:

- Geophysical data show that preferred pathways in upper Pierre Shale controlled gas migration from Gas Storage Well No. 26 toward surface discharge areas.
- Clay lenses and paleochannels in alluvium controlled gas migration locally in disrupted areas.
- The dissolved methane plume in groundwater is stable and diminishing in some areas.

Based on these conclusions, future monitoring is recommended, but it can be focused and less intensive. This section describes the groundwater monitoring and reporting activities that will be conducted at the Fort Morgan site for the remainder of 2008.

During the March 17, 2008 meeting with the COGCC, the long-term monitoring plan for the site was discussed and it was agreed that continued monitoring (i.e., monitored natural attenuation) is the appropriate response action at this time and quarterly monitoring was considered to be the appropriate frequency for monitoring. Quarterly groundwater monitoring is consistent with Task 6, Long-Term Monitoring, which was defined in the *Draft Environmental and Engineering Assessment Work Plan for the Fort Morgan Natural Gas Storage Facility* (CIG 2006), and this activity will complete the activities outlined in the work plan.

In addition, to the quarterly groundwater monitoring program discussed in the remainder of this section, the COGCC requested (email dated April 4, 2008) that one monitoring well be installed as close as possible to CPT-57R. CIG does not own the property where CPT-57R is located, so it was agreed that the new monitoring well could be placed on CIG's property at the southwest corner of the intersection of CR N and CR 18.

The monitoring well installation was completed in June 2008. The monitoring well was installed as close as possible to CPT-57R, given the location of underground utilities, CIG's pipeline, overhead power lines, and any other restricting condition (e.g., trees in the front yard, etc.). The well was drilled to a depth of 55 feet and completed with 10 feet of PVC screen. The COGCC email indicated that the purpose of the monitoring well installation is to:

- Add a groundwater monitor well to the monitoring network that conforms to State of Colorado well construction requirements.
- Provide an additional monitoring point in an area with relatively high levels of dissolved methane.
- Comply with COGCC directives for the ongoing monitoring program at the facility.

The new monitoring well has been included in the monitoring network for 2008, as discussed below. The follow sections describe the sampling schedule, the sampling locations, the sample analyses, and the reporting activities.

6.1 FIELD ACTIVITIES

Sampling events are planned for June, September, and November of 2008. The June event was conducted on June 24 through June 26, 2008. The sampling network (shown on Figure 6-1) included the remaining 28 piezometers that have been permitted, three domestic wells (H66, H98, and H100), and the new monitoring well (MW-01) installed near CPT-57R. The results for the March 2008 monitoring are discussed in this report. Results for the June 2008 event will be summarized in the Second Quarter 2008 Long Term Monitoring Report (URS, *in preparation*), which will be transmitted to CIG and COGCC under separate cover.

During future monitoring events, headspace monitoring using a combustible gas indicator will be done immediately upon removing the piezometer cap. The static water level and total depth of each piezometer will be measured. The piezometers will be developed and field parameters will be recorded throughout well development and prior to sample collection.

Field quality control samples include field duplicates, matrix spike/matrix spike duplicates (MS/MSDs), and trip blanks. Field duplicates will be collected at a frequency of 1 per 20 field samples, or one per day if fewer than 20 field samples are collected. Triple sample volume for MS/MSD will be collected at a frequency of 1 per 20 field samples. A trip blank sample will be included in each cooler shipped to the laboratory containing samples for analysis of volatile constituents. The duration of each sampling event is estimated to be one week.

6.2 SAMPLE ANALYSIS

Table 6-1 summarizes the long-term monitoring program. As shown in Table 6-1, the samples will be analyzed for dissolved gases and BTEX. The dissolved gases samples will be submitted to Microseeps in Pittsburgh, Pennsylvania for analysis by method AM-20Gax. The dissolved gases analyte list includes methane and other significant natural gas constituents. The samples for BTEX analysis will be submitted to SPL in Houston, Texas. Results will be reported to URS in hardcopy and electronic formats. BTEX may be removed from the monitoring program at some future date pending the results obtained for the previous monitoring events.

6.3 DATA VALIDATION AND DATABASE MANAGEMENT

Data validation and database management activities previously established for the Phase I and Phase II investigations will continue for the 2008 monitoring. Headspace gas measurements, water levels, field parameters, chemical data, and data validation qualifiers will be entered into the existing project database.

6.4 REPORTING ACTIVITIES

Results for testing of domestic wells will be reported to residents by URS on CIG's behalf within 45 days of sample collection if there are no exceedances of standards or action limits. Should any result exceed a Colorado Basic Groundwater Standard or the COGCC action limit for methane (2 mg/L), the residents will be notified immediately.

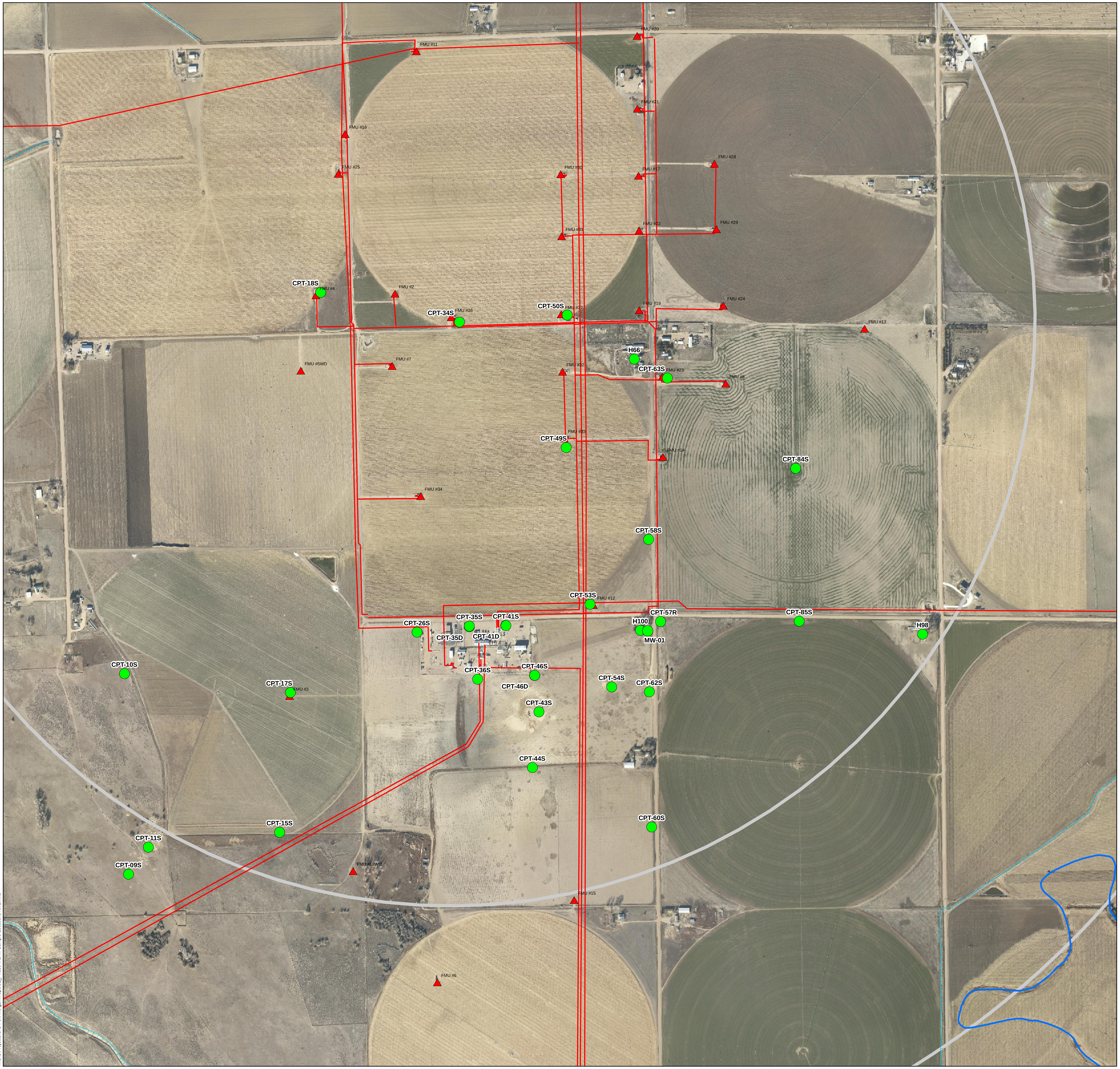
The March 2008 results are included in this report. Results for future monitoring will be reported to CIG and the COGCC in a quarterly letter report. The report will include a summary of field activities, data tables summarizing results, a groundwater potentiometric surface map, and a dissolved methane plume map. The narrative will compare results obtained to previous sampling events and will include an assessment of the dissolved methane plume stability. The data validation review narratives will be included as an attachment to each quarterly letter report. Additionally, an electronic database deliverable will be submitted to the COGCC by URS with each quarterly report.

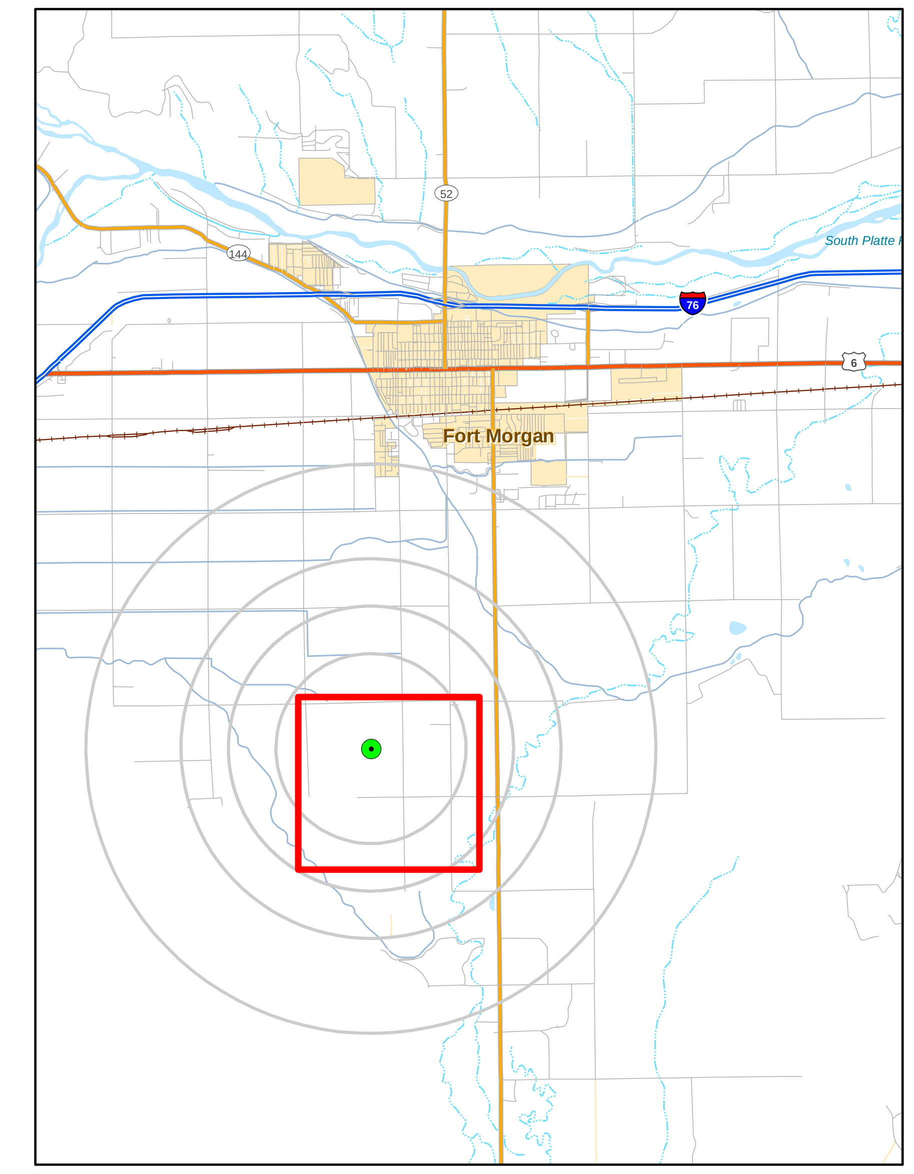
Monitoring activities beyond 2008 will be determined at the end of 2008 based on results obtained from 2008 monitoring, with COGCC concurrence.

Table 6-1
Summary of Long-Term Monitoring Program

Location	Type of Monitoring Point	Q1 March 2008 [1]	Q2 June 2008	Q3 September 2008	Q4 December 2008
CPT- 09S	Piezometer	DG & BTEX	DG & BTEX	DG & BTEX	DG; BTEX TBD
CPT- 10S	Piezometer	DG & BTEX	DG & BTEX	DG & BTEX	DG; BTEX TBD
CPT- 11S	Piezometer	DG & BTEX	DG & BTEX	DG & BTEX	DG; BTEX TBD
CPT- 15S	Piezometer	DG & BTEX	DG & BTEX	DG & BTEX	DG; BTEX TBD
CPT- 17S	Piezometer	DG & BTEX	DG & BTEX	DG & BTEX	DG; BTEX TBD
CPT- 18S	Piezometer	DG & BTEX	DG & BTEX	DG & BTEX	DG; BTEX TBD
CPT- 26S	Piezometer	DG & BTEX	DG & BTEX	DG & BTEX	DG; BTEX TBD
CPT- 34S	Piezometer	DG & BTEX	DG & BTEX	DG & BTEX	DG; BTEX TBD
CPT- 35D	Piezometer	DG & BTEX	DG & BTEX	DG & BTEX	DG; BTEX TBD
CPT- 35S	Piezometer	DG & BTEX	DG & BTEX	DG & BTEX	DG; BTEX TBD
CPT- 36S	Piezometer	DG & BTEX	DG & BTEX	DG & BTEX	DG; BTEX TBD
CPT- 41D	Piezometer	DG & BTEX	DG & BTEX	DG & BTEX	DG; BTEX TBD
CPT- 41S	Piezometer	DG & BTEX	DG & BTEX	DG & BTEX	DG; BTEX TBD
CPT- 43S	Piezometer	DG & BTEX	DG & BTEX	DG & BTEX	DG; BTEX TBD
CPT- 44S	Piezometer	DG & BTEX	DG & BTEX	DG & BTEX	DG; BTEX TBD
CPT- 46D	Piezometer	DG & BTEX	DG & BTEX	DG & BTEX	DG; BTEX TBD
CPT- 46S	Piezometer	DG & BTEX	DG & BTEX	DG & BTEX	DG; BTEX TBD
CPT- 49S	Piezometer	DG & BTEX	DG & BTEX	DG & BTEX	DG; BTEX TBD
CPT- 50S	Piezometer	DG & BTEX	DG & BTEX	DG & BTEX	DG; BTEX TBD
CPT- 53S	Piezometer	DG & BTEX	DG & BTEX	DG & BTEX	DG; BTEX TBD
CPT- 54S	Piezometer	DG & BTEX	DG & BTEX	DG & BTEX	DG; BTEX TBD
CPT- 57R	Piezometer	DG & BTEX	DG & BTEX	DG & BTEX	DG; BTEX TBD
CPT- 58S	Piezometer	DG & BTEX	DG & BTEX	DG & BTEX	DG; BTEX TBD
CPT- 60S	Piezometer	DG & BTEX	DG & BTEX	DG & BTEX	DG; BTEX TBD
CPT- 62S	Piezometer	DG & BTEX	DG & BTEX	DG & BTEX	DG; BTEX TBD
CPT- 63S	Piezometer	DG & BTEX	DG & BTEX	DG & BTEX	DG; BTEX TBD
CPT- 84S	Piezometer	DG & BTEX	DG & BTEX	DG & BTEX	DG; BTEX TBD
CPT- 85S	Piezometer	DG & BTEX	DG & BTEX	DG & BTEX	DG; BTEX TBD
H- 100	Domestic Well [2]	DG & BTEX	DG & BTEX	DG & BTEX	DG; BTEX TBD
H- 66	Domestic Well	DG & BTEX	DG & BTEX	DG & BTEX	DG; BTEX TBD
H- 98	Domestic Well	DG & BTEX	DG & BTEX	DG & BTEX	DG; BTEX TBD
EP-MW- 01-Well	Monitor Well	DG & BTEX	DG & BTEX	DG & BTEX	DG; BTEX TBD

[1] Results presented and discussed in this report.
[2] Property is owned by CIG and residence is unoccupied; well is inactive except for sampling.
DG = dissolved gases
BTEX = benzene, toluene, ethylbenzene, and xylenes
TBD = To be determined





Legend

- Groundwater Sampling Location
- CIG Gas Storage Wells
- Natural Gas Pipeline (El Paso)

Hydrologic Features (National Hydrography Dataset)
- Canal or Ditch
- Connector
- Stream or River

Buffers 1, 1.5, and 2 miles from Gas Storage Well #26

N

0 300 600 900 1,200 1,500 Feet

Figure 6-1
Long-Term Monitoring Sample Locations

CIG Fort Morgan Gas Storage Field

URS

Revision 1
June 23, 2008

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