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º	degrees
>	greater than
<	less than
-	negative
#	number
%	percent
±	plus or minus
+	positive
µg/L	micrograms per liter
3-D	three-dimensional
ACGIH	American Conference of Governmental Industrial Hygienists
bgs	below ground surface
BL	disposable Teflon bailer
BP	bladder pump with dedicated tubing
BTEX	benzene, toluene, ethylbenzene, and xylenes
C	Celsius
CCR	Colorado Code of Regulations
CIG	Colorado Interstate Gas
cm	centimeter
CO	carbon monoxide
COC	chain of custody
COGCC	Colorado Oil and Gas Conservation Commission
CPT	cone penetrometer testing
CR	County Road
CWQCC	Colorado Water Quality Control Commission
D	deep piezometer (e.g., CPT-41D)
DEM	digital elevation model
DHV	Down Hole Video
FID	flame ionization detector
Field	Fort Morgan underground natural gas storage field
f_s	sleeve friction
ft	foot (feet)
ft/d	feet per day

ft/ft	feet per feet
FV	foot valve (i.e., dedicated 0.5” PVC tubing with a stainless steel check valve)
GR/N	gamma-ray/neutron log
H_2S	hydrogen sulfide
I.D.	inside diameter
LEL	lower explosive limit
LiDAR	Light Detecting & Ranging
MCL	maximum contaminant level
MDL	method detection limit
meq/L	milliequivalents per liter
mg/L	milligrams per liter
msl	mean sea level
O_2	oxygen
psi	pounds per square inch
PVC	polyvinyl chloride
q_c	tip resistance
R_f	friction ratio
RL	reporting limit
RMLD	remote methane leak detector
S	shallow piezometer (e.g., CPT-02S)
SBT	soil behavior type
TDS	total dissolved solids
TLV	threshold limit value
u	dynamic pore pressure
URS	URS Corporation
USGS	United States Geological Survey
UTL	upper tolerance limit
V	vapor probe (e.g., CPT-46V)
VOA	volatile organic analysis
Work Plan	Environmental and Engineering Assessment Work Plan for the Fort Morgan Natural Gas Storage Facility (CIG 2007a)

This Interim Phase II Investigation Report documents the field activities conducted through May 2007 and findings at Colorado Interstate Gas' (CIG) Fort Morgan Natural Gas Storage Facility. These activities were performed in accordance with the Environmental and Engineering Assessment Work Plan (the "Work Plan"; CIG 2007a) developed for the Facility to document the response to an accidental leak from Gas Storage Well #26 that occurred on October 22, 2006. The results of the Phase I Investigation were previously reported (CIG 2007b; CIG 2007c).

Task 1-Land Surface Monitoring

A benchmark monitoring program was established to monitor potential changes in the elevation of the land surface following the gas release and thus provide information for evaluating the stability of the Gas Plant and surrounding area.

The results of four rounds of land surface monitoring suggest that the extent of heave or subsidence since the gas release was relatively small and does not appear to have affected the overall stability of the Gas Plant or surrounding areas.

Task 2-Land Surface Stability Assessment

A cone penetrometer testing (CPT) investigation was conducted to assess surface stability in areas affected by the gas release and to evaluate the nature and extent of the gas-impacted areas, the potential impact of the gas release on human health or the environment, and to assess the potential gas migration pathways within the saturated alluvium. Information developed from the CPT investigation is being used to determine whether or not mitigation measures for ground stability and/or groundwater quality are necessary.

Ninety-one (91) CPT borings were pushed to depths ranging between 39 and 140 feet (ft). Natural gas was primarily detected in CPT borings pushed in areas where the gas surfaced during the release. The distribution of natural gas measured in the CPT borings is consistent with the extent of dissolved methane found in groundwater sampled at the CPT piezometers and domestic wells.

Pore pressure dissipation tests were performed to assess whether abnormal formation water pressures were present in the subsurface that might indicate the presence of trapped natural gas. None of the dissipation tests indicated abnormal formation pressures that might have indicated trapped gas in the subsurface.

Shallow piezometers were installed at 85 of the 91 CPT locations. In addition, at 7 of these locations, a deep piezometer was also installed. The piezometers were installed at depths ranging between 25 and 85 ft. Soil vapor monitoring probes were installed in the shallow vadose zone at 28 of the 91 CPT locations at depths between 8 and 15 ft.

Subsurface fissures and openings were noted at only one CPT location, CPT-81, during the Phase II investigation. The subsurface opening was encountered a depths ranging between 5 ft and 23 ft below grade and appears to have been caused by soil liquefaction and subsequent piping.

Task 3-Nature and Extent of Gas-Impacted Areas

A high-resolution aerial survey was conducted to delineate the gas-affected areas at the ground surface (e.g., craters and fissures) by obtaining a comprehensive set of detailed color orthophotographs and Light Detecting & Ranging (LiDAR) data that covered all areas within 2 miles of CIG Gas Storage Well #26. The orthophotos and topographic map document the location of the craters and fissures produced during the gas release and provided an accurate base map for the subsequent CPT investigation and other field activities.

Task 4A-Continued Nature and Extent Evaluation

Task 4A involves an on-going assessment of the nature and extent of natural gas in alluvial groundwater via one round of pre-irrigation and two rounds of irrigation season sampling at CPT piezometers.

Headspace Gas Monitoring

Piezometer and soil vapor monitoring probe headspace gas monitoring was performed in March and May 2007. The combustible gas levels measured in May were generally lower than those measured in March, except for four locations (CPT-46D, CPT-53S, CPT-57R, and CPT-57S), where the combustible gases levels were 100 percent (%) of the lower explosive limit (LEL) in both March and May. Piezometers with combustible gas levels of 100% LEL are coincident with areas of elevated dissolved methane in alluvial groundwater.

Hydrogen sulfide (H_2S) monitoring was conducted in April 2007 at 57 locations. All of the H_2S results were less than 0.010 parts per million (ppm). These H_2S concentrations are three or more orders of magnitude below established American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Value (TLV) (10 ppm) or Short-Term Exposure Limit (STEL) (15 ppm) action levels and, thus, pose no health and safety concern.

Groundwater Flow Conditions

Groundwater within the alluvium occurs under water table conditions. Prior to the startup of irrigation, groundwater was found at depths ranging between approximately 10 and 60 ft below grade. The depth to groundwater beneath the Gas Plant in March 2007 was about 25 ft below grade. The saturated thickness of the alluvium ranges between 18 and 115 ft. Groundwater within the shallow alluvial aquifer generally flows from south-southwest to north-northeast during this period. This flow direction is generally consistent with regional groundwater flow toward the South Platte River. The average groundwater flow rates are estimated to range between 1.2 feet per day (ft/d) and 6.8 ft/d.

Groundwater levels were also measured in May 2007 after irrigation started in the area. Groundwater flow direction within the alluvium are generally consistent with those observed in March 2007, except that the flow direction has changed from northeastward to northwestward in the area of CPT-01S and CPT-19S where local irrigation pumping has created a cone of depression.

Alluvial Aquifer Groundwater Quality

In March 2007, dissolved methane concentrations in groundwater from the alluvial aquifer ranged between 0.000019 J and 26 milligrams per liter (mg/L). Dissolved methane plumes occur beneath the areas where gas erupted at the ground surface during the October 2006 release. The maximum dissolved methane concentrations in both these areas are similar; however, the southwestern plume is much smaller in extent than the plume south and east of the Gas Plant. The lateral plume extents are consistent with the locations of craters and fissures associated with the gas release.

In March 2007, chloride concentrations in the alluvial aquifer ranged between 14 mg/L and 325 mg/L. The areal distribution of the chloride does not suggest that the incident caused brackish water to be introduced into the overlying alluvial aquifer.

In March 2007, sulfate concentrations in the alluvial aquifer ranged between 100 mg/L and 2,030 mg/L. These sulfate results are consistent with the elevated sulfate concentrations historically reported in the Fort Morgan area since the 1940s (Bjorklund and Brown 1957).

In March 2007, TDS concentrations in the alluvial aquifer ranged between 461 mg/L to 4,470 mg/L. The high TDS concentrations are largely a result of the historically high sulfate concentrations found in this area.

The groundwater results for the alluvial aquifer were compared to the background Upper Tolerance Limits (UTLs) developed during the Phase I investigation to evaluate whether or not the alluvial groundwater was affected by the natural gas release. A UTL is a statistical measure of the upper limit of the background concentration for an analyte. In March, 2007, dissolved methane, ethane, ethane, and propane concentrations in some groundwater samples exceeded their respective background UTLs. Locations where these dissolved gases exceeded the background UTL may have been affected by the natural gas release.

The groundwater results from the alluvial aquifer were compared to applicable Colorado groundwater quality standards. Most of the dissolved metals in groundwater are less than their respective Colorado groundwater quality standards. Dissolved boron, iron, manganese, and selenium exceed the Colorado groundwater quality standard at least once. None of the dissolved metal exceedances appear to be related to the natural gas release.

Sulfate is the only inorganic parameter that exceeds its Colorado groundwater quality standard (250 mg/L). These sulfate results are consistent with the previously reported Phase I sulfate results and with the historically elevated sulfate concentrations reported in groundwater in the Fort Morgan area since the 1940s (Bjorklund and Brown 1957).

Comparison of Alluvial and Bedrock Groundwater Quality

Major water quality characteristics of groundwater in the alluvium and bedrock formations were compared using Piper and Stiff diagrams to determine whether the release caused brackish water to be introduced into the overlying alluvial aquifer.

The groundwater chemical compositions indicate that the alluvial and bedrock groundwaters are compositionally distinct, which also indicates that significant quantities of brackish water were **not** introduced into the alluvium during the gas release.

Task 4B-1996 Seismic Data Interpretation

Interpretation of the 1996 3-D seismic data indicates the presence of subsurface faults and structures that could potentially influence the natural gas release migration path if these structures persist at shallower depths. Based on results of the interpretation of the 1996 3-D seismic data interpretation, CIG plans to conduct a new seismic survey (high-resolution reflection) focusing on improving the definition of geologic structures existing at shallower depths (e.g., 200 to 2,000 ft below ground surface [bgs]). It is anticipated that collecting and interpreting the new data will provide further definition of geologic structures that may have influenced the natural gas release migration paths.

Task 5-Cased-Hole Logging

Two rounds of cased-hole logging (Rounds I and II) indicate that all Fort Morgan wells have integrity with the exception of Gas Storage Well #26 where a casing leak was identified. Results of the cased-hole logging program and a review of shut-in surface casing pressures indicate that the gas has migrated mainly to the south and east of Gas Storage Well #26. Further investigation using irrigation season groundwater sampling results and the additional seismic studies should help delineate trends of shallow gas movement in the Fort Morgan Field area.

Continued Phase II Investigation

Of the six Phase II Investigation tasks, Tasks 2, 3, and 5 are complete. For all other tasks, additional field studies are planned for 2007 and results from the continued studies will be reported in a subsequent Phase II Investigation Report.

On October 22, 2006, an accidental leak from Gas Storage Well Number #26 within the Fort Morgan underground natural gas storage field (the "Field"), owned/operated by Colorado Interstate Gas (CIG), was discovered. CIG implemented corrective action during the afternoon of October 22 to notify local authorities and residents and to shut off the well to prevent further leakage of natural gas. After discovering the natural gas leak, CIG also notified the Colorado Oil and Gas Conservation Commission (COGCC) and other pertinent agencies, and retained URS Corporation (URS) to provide environmental sampling and geotechnical engineering support services.

CIG prepared an Environmental and Engineering Assessment Work Plan for the Fort Morgan Natural Gas Storage Facility (the "Work Plan") (CIG 2007a) for the COGCC to document the response to the accidental leak from Gas Storage Well #26 and to identify the Phase I and Phase II Investigation tasks being conducted in response to the incident.

The overall objective of the Phase I investigation activities was to assess the effect, if any, of the gas release on air quality, water quality of domestic wells, and to conduct research on health and safety issues related to natural gas. The results of the Phase I investigation are presented in two reports. The first report is the Phase I Well Water and Air Sampling Report (CIG 2007b) submitted to the COGCC on February 12, 2007. The second report is the Phase I Well Water and Air Sampling Report Addendum (CIG 2007c) submitted to the COGCC on May 2, 2007.

The overall objective of the Phase II investigation is to assess the long-term effect, if any, to groundwater and land stability in areas disturbed by the gas release and to evaluate the need for mitigation activities. The Phase II investigation is ongoing. This report documents the current status of the Phase II investigation and the data collected thus far.

1.1 FACILITY LOCATION AND DESCRIPTION

In 1961, CIG acquired the Fort Morgan Facility and Field, which now consists of 34 wells (26 injection/withdrawal wells, 6 observation wells, and 2 disposal wells). The Fort Morgan Facility is located northeast of Denver, approximately 5 miles south-southwest of the town of Fort Morgan, Colorado as shown on Figure 1-1, Site Location Map. The site address is:

Fort Morgan Compressor Station
17642 Morgan County Road N
Fort Morgan, CO 80701

1.2 PREVIOUS INVESTIGATIONS (PHASE I)

The Phase I Investigation activities involved emergency response air monitoring and groundwater sampling and characterization to assess the effect, if any, of the gas release on the water quality of domestic wells and included research on health and safety issues related to natural gas. The work for the Phase I investigation was subdivided into 6 tasks as follows:

- Task 1 – Indoor Air Monitoring and Water Sampling at Homes
- Task 2 – Development of Ongoing Monitoring Plan for Water Wells within 1 Mile of Gas Storage Well #26
- Task 3 – Laboratory Coordination and Data Validation

- Task 4 – Limited Health Exposure Summary for Exposure to Natural Gas
- Task 5 – Additional Sampling per COGCC Request for Additional Groundwater and Soil Data
- Task 6 – Reporting of Results to Landowners

The Phase I Investigation began in October 2006 and concluded in February 2007. The results were presented in two reports. The first report is the Phase I Well Water and Air Sampling Report (CIG 2007a) which was submitted to the COGCC on February 12, 2007. The second report is the Phase I Well Water and Air Sampling Report Addendum (CIG 2007b) which was submitted to the COGCC on May 2, 2007. The major conclusions of the Phase I reports are summarized below:

- No indoor air monitor alarms in homes were triggered. Additionally, no air monitor alarms were triggered during sampling activities. Air monitoring using the remote methane leak detector (RMLD) instruments has sporadically detected only minimal amounts of gas at a few locations where gas was previously detected at the ground surface.
- Based on the Phase I groundwater results, it does not appear that the gas release had any significant effect on groundwater quality at the sampled locations, nor did it release any constituents that adversely affected groundwater quality at concentrations that exceed Colorado groundwater quality standards or COGCC action levels.
- Based on soil data collected during Phase I, the natural gas release does not appear to have introduced salts or altered soil pH in the visually disturbed soils, and thus has not impaired the ability of the soils to support crop growth.

The information contained in the Phase I report is being used in conjunction with data collected during Phase II studies to fully determine the need for long-term monitoring and/or mitigation activities.

1.3 CONTINUED AIR MONITORING RESULTS (MAY THROUGH AUGUST OF 2007)

At the conclusion of the Phase I investigation, CIG continued to perform monthly monitoring with the RMLD at various ground surface locations. Appendix A.1, Remote Methane Leak Detector Monitoring Data, presents the results of the May through August 2007 monitoring results. The presence of methane gas was detected at two locations in both May and June, however, methane gas was not detected at any of the monitored locations in July and only one location in August.

Methane was detected in the air above the wheat field northwest of the intersection of County Road (CR) 18 and CR N at 100 parts per million (ppm) and 200 ppm, respectively, during May and June. These results indicate a decrease since the March and April measurements, which were greater than (>) 3,000 ppm and 2,000 ppm, respectively.

Likewise, methane was detected at the well head for H100 at concentrations of 250 and 200 ppm, respectively for May and June. These results are comparable to the March and April measurements, which were nondetect and 400 ppm, respectively.

In August, methane was detected at the location of a recently identified sink hole west of CR N at a concentration that ranged between 2,000 and 3,000 ppm.

These results are not unexpected, and indicate that methane gas continues to migrate upward through localized pathways to the land surface in some areas. The overall decrease in methane concentration at the ground surface suggests that the gas in the vadose zone and the gas diffusing from the water table may be dissipating. However, the groundwater data discussed in Section 5, Evaluation of Gas Release Mechanism (Phase II, Task 4), indicate that elevated concentrations of dissolved methane continue to exist locally in the alluvial aquifer.

1.4 RECENT SURFACE OBSERVATIONS

On June 19, 2007, four sinkholes that reportedly formed after the October 2006 incident were observed by CIG. The four sinkholes are located south and east of the gas plant. Their approximate locations are shown on Figure 1-2, Recently Identified Sink Hole Locations. The sinkholes are generally circular in shape, about 15 to 25 feet (ft) in diameter, and about 5 to 8 ft deep. The upper 3 to 4 ft of the sinkhole walls are typically near vertical and consist of medium stiff sandy clays. Open voids or cavities were observed in some of the sinkholes immediately below the clays. Bottoms of the sinkholes were typically filled with sloughed or caved soils. The closest sinkhole was located northwest of the largest crater about 230 ft from the southeast corner of the gas plant. The largest crater area had recently been regraded. Photos of the sinkholes taken during the site visit are presented in Figure 1-3, Site Photographs of Recently Identified Sinkholes, 6/19/97.

1.5 COMMUNITY OUTREACH

Throughout the Phase I and Phase II investigations, CIG has maintained a community outreach program, which is discussed in the Phase I Well Water and Air Monitoring Report. Community outreach actions that have occurred since the Phase I report include the distribution of update newsletters which are discussed below. Additionally, on May 24, 2007, CIG placed a press release in the Fort Morgan Times regarding plans to repair CR 18.

CIG has continued to issue newsletters to keep the community updated on activities related to the Phase I and Phase II investigations. On February 28, the Fort Morgan Update #5 newsletter was distributed to local residents. This edition of the newsletter summarized the findings presented in the Phase I Well Water and Air Sampling Report. On March 30, 2007, the Fort Morgan Update #6 newsletter was distributed to local residents. This edition of the newsletter summarized the irrigation well canvass activities conducted within a 1-mile radius of CIG's Fort Morgan Gas Storage Well #26 and the associated results. Copies of these two newsletters and the press release are included in Appendix A.2, Community Outreach. CIG anticipates to continue issuing the newsletter on an as needed basis.

For irrigation wells within a 1-mile radius of Gas Storage Well #26, the Update #6 newsletter contained a recommendation that headspace gas in irrigation wells be screened immediately prior to start-up to determine that methane is not present at explosive concentrations. Additionally, CIG recommended that methane monitoring also be continued at these wells during the irrigation season, if they are shut down for extended periods of time (i.e., more than 24 hours). To date, no residents have contacted CIG to conduct the recommended screening.

1.6 UPDATE ON LAND AND LAND-OWNER ISSUES

The land issues and land-owner issues addressed since the Phase I Report are summarized below.

Backfilling of Craters

On March 6, 2007, CIG requested permission from the COGCC to backfill all crater areas. On May 7, 2007 the craters southwest of the plant were backfilled. Also, on May 7, 2007, CIG initiated work to backfill the craters south and southeast of the plant. A land-owner requested that CIG stop work before actual back-filling operations commenced. The craters in this area remain open because of this request, but are slated for backfilling this year.

Repair of CR 18

Beginning on May 29, 2007, a 1/8-mile section of CR 18 was repaired south of the intersection with CR N. During the repair process, the top 5 ft of the road were excavated so that the road base could be built with appropriate compaction. The repair effort was coordinated with Morgan County, the Quality Water District, and various utility companies. The repair of CR 18 was completed on June 4, 2007 and the road was re-opened.

During the repair activity, a cavity approximately 10-12 ft deep and 10 ft in diameter was identified. The cavity was located on the west side of the road in the drainage ditch area. It was estimated to be approximately 50 ft north of the cratered area. The global positioning system (GPS) coordinates for the cavity are North 40.18750 and West 103.81101. CIG personnel filled the cavity with 20 cubic yards of flowable fill to prevent future damage to the road and nearby utility lines.

This subsurface cavity and surface sinkholes recently observed in the areas where the natural gas surfaced in October 2006 are residual void features resulting from the liquefaction and piping of subsurface soils during the natural gas release. The soils bridging these subsurface voids collapsed over time resulting in the recently observed sinkholes. Other unknown subsurface voids may exist, but are expected to be limited to areas where the natural gas and liquefied soils escaped at the surface.

Affected Landowners - Vacant Homes

Since the incident in October of 2006, two residences have remained vacant. These are H100 at the intersection of CR N and CR 18 and H101, which is on CR 18 approximately 1,000 ft south of H100. These two residences are those closest to the plant and are near the areas where the gas surfaced. CIG provided alternate living arrangements for the affected families and CIG has recently purchased the affected homes.

Sampling of Krening Irrigation Well (I32) per Land-owner Request

On March 13, 2007, a groundwater sample was collected from the Krening irrigation well (I32). The sample was collected from a 10-inch discharge line. The water was collected in a 5-gallon bucket and the sample containers were filled. The sample was analyzed for dissolved gases, dissolved metals, and inorganics. The results, presented in Table 1-1, Analytical Results for

Krening Irrigation Well (I32), March 12, 2007, indicate that the water was acceptable for use in irrigation. The results were reported to the resident.

Sampling of the Windmill Southwest of the Plant (WMSWP) per Land-owner Request

On April 18, 2007, a groundwater sample was collected from well location Windmill Southwest of the Plant (WMSWP). The sample was analyzed for dissolved gases, dissolved metals, and inorganics. The results, presented in Table 1-2, Analytical Results for Windmill Southwest of the Plant (WMSWP), April 18, 2007, indicate that the water was acceptable for watering livestock. The results were reported to the land-owner.

1.7 REPORT OBJECTIVES

The intent of this Interim Phase II Report is to discuss progress of Phase II investigations to date and interim findings. The Phase II investigation is divided into six tasks, each intended to collect data to evaluate the release mechanism and migration pathways of the gas, the extent of subsurface gas in the alluvium, and to determine whether or not mitigation measures for ground stability and water quality are necessary. The tasks and subtasks are listed below:

- Task 1 - Assess the potential for land-surface subsidence as related to the gas release
- Task 2 - Assess surface stability in areas affected by the gas release
- Task 3 - Evaluate the nature of gas-impacted areas and the extent to which the release poses a risk to human health or the environment, and to correlate the surface information with the subsurface
- Task 4 - Evaluate the gas release mechanism and migration pathways and the extent of affected groundwater
- Task 5 - Down-hole logging of the gas storage wells
- Task 6 - Evaluate the need for long-term groundwater monitoring

To date, activities for Phase II, Tasks 1, 2, 3, 4, and 5 are either underway or completed. Progress to date for Tasks 1 through 5 is discussed in Sections 2 through 6 of this report. Within each section is a summary of each task's objectives. Section 7, Summary of Findings, provides a Phase II investigation summary. Lastly, Section 8 of this report, Continued Phase II Investigation Activities, summarizes the Phase II investigation activities that will occur in the future in order to complete the Phase II scope of work outlined in the Work Plan.

Task 1 of the Phase II investigation involved land surface stability monitoring using ground-based GPS surveying at benchmarks installed at CIG facilities, area homes selected by CIG, and other field-determined locations. Four rounds of surveying were conducted to detect changes in local ground elevation resulting from potential soil subsidence or heaving in response to the gas release and thus provide information for evaluating the stability of the Gas Plant and surrounding area. The surveyed elevations have a 1-centimeter (cm) precision between survey events.

2.1 BENCHMARK MONITORING PROGRAM

Two-foot long survey pins were placed in the ground by Flatirons Surveying, Inc. of Boulder, Colorado to serve as benchmarks. A total of 148 benchmarks were placed over an approximately 5 square mile area surrounding the Gas Plant. The benchmark locations are shown on Figure 2-1, Benchmark Locations.

The benchmarks were surveyed using real-time kinematic GPS survey equipment capable of achieving a tolerance of approximately 1 cm (0.035 foot [ft]). An initial benchmark survey was performed during the week of November 10, 2006. This initial survey was arbitrarily established as the baseline to which future benchmark surveys were compared. Four additional benchmark surveys were performed during the weeks of November 17, 2006, November 28, 2006, December 12, 2006, and March 16, 2007.

2.2 BENCHMARK MONITORING RESULTS

The benchmark survey data were compared to the November 10, 2006 baseline survey by preparing maps showing the cumulative change in benchmark elevation for each of the subsequent surveys. These maps were prepared by subtracting the baseline elevation (November 10) for each benchmark from the subsequent benchmark elevation (November 17, November 28, December 12, and March 16). The resulting differences in elevation were contoured and mapped to show relative changes in areal ground elevation to highlight potential areas of ground heave or subsidence relative to the November 10th baseline. Figure 2-2, Benchmark Elevation Differential Maps, shows these benchmark elevation difference maps for each survey period. The hatched patterns shown on this figure depict areas where the elevation change was >1 cm (0.035 ft or 0.42 inch) tolerance of the survey data.

The benchmark differentials across the four surveys ranged between positive (+) 0.13 ft (+1.6 inches) and negative (-) 0.52 ft (-6.3 inches) relative to the November 10, 2006 baseline. The average benchmark differentials (an average of the November 17th, November 28th, December 12th, 2006 and the March 16th, 2007 differentials) across the four surveys ranged between +0.09 ft (+1.1 inches) at Benchmark 628 and -0.37 ft (-4.4 inches) at Benchmark 429. Benchmark 628 is located on a foundation pier of the gas pipeline gallery on the north side of the CIG Gas Plant. Benchmark 429 is located adjacent to Gas Storage Well #18 southwest of the CIG Gas Plant. Based on the average differentials, it appears that significantly more subsidence had occurred after the gas release event than heaving.

Review of Figure 2-2, Benchmark Elevation Differential Maps, shows that some areas appear to have subsided (blue hatch pattern) and some areas appear to have heaved (red hatch pattern) relative to the November 10th baseline. The apparent subsidence areas appear to provide the most consistent results as they tend to coincide with known or potential areas of gas movement or release at the surface. Since the survey data are compared to a baseline taken after the gas release on October 22, the subsidence areas appear to reflect areas that may have heaved during the release, but have subsequently subsided following the release as the land surface relaxes to its initial condition. The apparent heave areas are enigmatic as they tend to largely occur around the perimeter of the benchmark survey area.

The map depicting the results of the November 17th survey shows a large area west of the Gas Plant that appears to have heaved relative to the November 10th baseline. Isolated areas of apparent heave and subsidence occur throughout the central portion of the map. Of particular note is the apparent ground subsidence in the area around Gas Storage Well #26.

The November 28th results show larger areas of apparent subsidence adjacent to Gas Storage Well #26, along CR 18 at its intersection with CR N, in the southwest crater area, and south of the Gas Plant in the area of Gas Storage Well #18. These apparent subsidence areas are larger in extent and appear to have subsided more compared to the November 17th results.

The December 12th results show a similar pattern to the November 28th results. The principal areas of apparent subsidence persist in the area adjacent to Gas Storage Well #26, along CR 18 at its intersection with CR N, in the southwest crater area, and south of the Gas Plant in the area of Gas Storage Well #18. The apparent subsidence areas near Gas Storage Wells #26 and #18 appear to have increased in size relative to the November 28th results.

The March 16th results show a similar pattern to the December 12th results. The main subsidence areas continue to exist near Gas Storage Well #26, along CR 18 at its intersection with CR N, in the southwest crater area, and south of the Gas Plant in the area of Gas Storage Well #18, however, some of the apparent subsidence areas appear to be less extensive during this period. This may reflect that the land surface is slowing returning to its pre-gas release level.

2.3 ASSESSMENT OF LAND STABILITY

The results of the land surface monitoring suggests that the apparent areal heave or subsidence since the gas release was relatively small and does not appear to have affected the overall stability of the Gas Plant or surrounding areas. The apparent subsidence areas coincide with known areas of gas migration or release. These subsidence areas appear to reflect relaxation of the land surface that may have heaved (domed) during the gas release. The apparent heave areas are enigmatic as they tend to largely occur around the perimeter of the benchmark survey area.

As part of Task 2, CIG evaluated the surface stability of the CIG Fort Morgan natural gas storage facility (CIG facility) and the area surrounding the natural gas release (CIG Gas Storage Well #26) by conducting a site reconnaissance visit and evaluating existing data sources as well as conducting an expedited site assessment. The site reconnaissance visit and evaluation of existing data sources are discussed in Section 3.1, Land Surface Stability Assessment. The expedited site assessment (i.e., cone penetrometer investigation) and results are discussed in Sections 3.2, Purpose and Scope of Cone Penetrometer Testing Investigation, and 3.3, Discussion of Cone Penetrometer Testing Investigation, respectively.

3.1 LAND SURFACE STABILITY ASSESSMENT

CIG evaluated the geologic and geotechnical characteristics of the area by visually observing the CIG facility structures, impacted homes located immediately east of the facility, and the surrounding terrain to identify and document engineering evidence of the gas release (e.g., foundation cracks, craters, and ground fissures). CIG's engineering observations were facilitated by compiling the geologic and geotechnical information from the CIG files (e.g., plant geotechnical reports, water well logs, drillers' logs, water levels, gas storage well logs, and data acquired in Task 5 – Down-hole well logging), and from publicly-available sources (e.g., Colorado Division of Water Resources, Colorado Geological Survey, Soil Conservation Service, United States Geological Survey [USGS]).

The results of the review of these records were used to prepare the site area description found in Section 2 of the Phase I Report (CIG 2007a) and the Bedrock Topography map (Figure 3-3, Bedrock Topography). This site description is augmented by the results of the cone penetrometer (CPT) investigation, which are described in Section 3.3, Discussion of Cone Penetrometer Testing Investigation. Additionally, the results were used to prepare an Interim Stability Report to address foundation stability in Area D of the Plant. As a result of the October 2006 incident, a planned construction project in Area D was suspended pending the results of the movement monitoring and CPT investigation. Following three rounds of benchmark monitoring (Section 2), the CPT investigation, the site reconnaissance visit, and review of CIG and public records, an Interim Stability Report was prepared to address foundation stability in Area D of the Plant. This report was recently updated to include the fourth round of benchmark monitoring results and is included in Appendix B, Interim Stability Report. The report concludes that the geotechnical foundation design criteria used by CIG for the Area D foundations are appropriate based on (1) site observations, (2) the 1993 geotechnical investigation, (3) the 2006/2007 CPT soundings (inferred soil types, tip resistance, relative density, correlated blow counts, and shear wave velocities), and (4) the movement monitoring program.

A 5th round of benchmark monitoring will be done and the results will be use to evaluate whether a continued stability monitoring program is necessary for CIG facilities.

A preliminary liquefaction/settlement assessment of the CIG facilities and two impacted homes immediately east of the CIG facility is not considered necessary because (1) the soil types, densities, and strengths correlated from the CPT soundings are generally consistent with the 1993 geotechnical investigation and (2) the correlated penetration resistance, blow counts (N-values) are generally greater than or equal to the 1993 N-values.

3.2 PURPOSE AND SCOPE OF CONE PENETROMETER TESTING INVESTIGATION

3.2.1 Purpose of the Cone Penetrometer Testing Investigation

The CPT investigation was conducted to assess surface stability in areas affected by the gas release (Phase II Task 2 Land Surface Stability Assessment) and to evaluate the nature and extent of the gas-impacted areas, the potential impact of the gas release on human health or the environment, and to assess the potential gas migration pathways within the saturated alluvium (Phase II Task 4 Gas Release Mechanisms, Migration Pathways, and Extent of Affected Groundwater). Information developed from the investigation is being used to determine whether or not mitigation measures for ground stability and/or groundwater quality are necessary.

To support the land surface stability assessment (Phase II Task 2), the CPT investigation collected subsurface data to define the soil geotechnical properties, soil types, pore pressures, gas occurrences, and water levels. In some selected areas, the CPT was also used to investigate whether subsurface fissures and openings were present. Piezometers and soil vapor monitoring probes were installed during the CPT investigation to evaluate the gas migration pathways and the extent of affected groundwater (Phase II Task 4).

3.2.2 Scope of the Cone Penetrometer Testing Investigation

The CPT investigation was initiated on December 19, 2006 and subsequently postponed because of a blizzard in the Fort Morgan area on December 20, 2006. Persistent inclement weather conditions resulted in the investigation being postponed until January 5, 2007. The CPT investigation resumed on January 5, 2007 and was completed on February 16, 2007. The CPT borings were pushed to determine the subsurface stratigraphy of the alluvium, the depth to the water table, the presence of subsurface natural gas, identify abnormal pore pressures, determine the geotechnical properties of the soils, and to look for subsurface fissures or evidence of subsurface piping.

A 20-ton compression-type piezocone was used for all of the CPT soundings. The CPT system electronically recorded tip resistance (q_c), sleeve friction (f_s), and dynamic pore pressure (u) at 0.164 ft depth intervals. These parameters were used to develop soil classification (e.g., sand, clay, silt) based on soil behavior type (SBT), estimate pore pressures and water levels, and estimate geotechnical parameters. Ninety-one (91) CPT borings were pushed during the investigation using either a truck- or track-mounted CPT rig. The CPT borings ranged in depth from approximately 39 ft at CPT-09S to 140 ft at CPT-56S. The 91 CPT borings are shown on Figure 3-1, CPT Boring Locations. Appendix C, Cone Penetrometer Logs, provides the CPT boring logs.

Pore pressure dissipation tests were completed in most of the CPT borings. These tests were performed to assess whether abnormal formation water pressures were present in the subsurface that might indicate the presence of trapped natural gas. The dissipation tests were typically performed in sand strata beneath silt or clay layers where gas might have been trapped. The test was performed by stopping the piezocone at specific depths and letting the excess dynamic pore pressure dissipate. The change in pore pressure with time was recorded until the pore pressure reached static equilibrium (i.e., no variation in pore pressure with time). The recorded dissipation data were graphically plotted and an equilibrium piezometric pressure estimated.

Appendix D, Dissipation Test Plots, provides the dissipation test plots. The dissipation test locations and equivalent water depths (in ft) are shown on the CPT boring logs (Appendix C, Cone Penetrometer Logs).

Resistivity profiling was performed at 19 CPT locations (CPTs-07, -11, -26, -28, -29, -34, -35, -36, 39, -40, -41, -42, -43, -46, -53, -62, -73, -75, and -76) to measure the electrical resistivity of the subsurface soils. Electrical resistivity is a measure of how strongly a soil opposes the flow of an electric current. Low resistivity (i.e., high conductivity) indicates a soil that readily allows an electric current to flow. Resistivity is inversely proportional to conductivity. The resistivity profiles are shown on the CPT logs in Appendix C, Cone Penetrometer Logs.

Seismic wave velocity profiles were performed at 6 CPT locations (CPTs-33B, -35, -39, -40, -41, and -42) to measure the shear wave velocity of the alluvium and the underlying Pierre Shale. The shear wave velocity profiles and velocity calculations are provided in Appendix E, Shear Wave Velocity Profiles and Calculations.

Piezometers were installed at 85 of the 91 CPT locations to facilitate measurement of groundwater levels, obtain groundwater samples, and measure headspace gas concentrations. The piezometers were installed at depths ranging between 25 ft at CPT-11S and 85 ft at CPT-46D. Depending on their depth, the piezometers were designated with a suffix as either shallow (S) or deep (D). Seven piezometer locations (CPTs-26, -29, -35, -41, -45, -46, and -57), primarily at the Gas Plant, were equipped with shallow and deep piezometers to facilitate measurement of differences in groundwater levels, analyte concentrations, and gas concentrations at varying depths.

The piezometers were installed using ¾-inch inside diameter (I.D.), flush-threaded, Schedule 80 polyvinyl chloride (PVC) blank riser and factory-slotted (0.020 inch) screen. The screen length was 5 ft in all piezometers. Filter packs were not installed along the screened intervals. In-situ native soils (sands and gravels) form the filter pack. A 0.5-inch to 0.75-inch bentonite chip seal was placed along the riser in the upper 3 ft of the boring. The piezometer installation depths are shown on the CPT boring logs (Appendix C, Cone Penetrometer Logs).

Soil vapor monitoring probes were installed in the shallow vadose zone (i.e., above the water table) at 28 of the 91 CPT locations to facilitate measurement of headspace gas concentrations. The soil vapor monitoring probes are designated with a "V" suffix (e.g., CPT-46V). The soil vapor monitoring probes were installed at depths of 8 ft (CPT-05V), 10 ft (CPT-09V and CPT-11V), and 15 ft (the other 25 soil vapor monitoring probes). The soil vapor monitoring probes were completed using the same materials and approach as the piezometers. The soil vapor monitoring probe installation depths are shown on the CPT boring logs (Appendix C, Cone Penetrometer Logs).

3.3 DISCUSSION OF CONE PENETROMETER TESTING INVESTIGATION

3.3.1 Subsurface Fissures and Openings

Subsurface fissures and openings were noted at only one CPT location, CPT-81, during the Phase II investigation. This CPT boring was located on CR 18 approximately 500 ft south of CR N in the area where gas release craters and fissures were found along the road. The subsurface opening was encountered a depths ranging between 5 ft and 23 ft below grade. This feature was recognized by the lack of cone resistance, sleeve friction, and dynamic pore pressure response while pushing the piezocone. The SBT is interpreted as sensitive fines for the disrupted soil interval. The subsurface opening appears to have been caused by soil liquefaction and subsequent piping. No other subsurface fissures or openings were encountered in any of the CPT borings.

3.3.2 Depth to Bedrock and Bedrock Topography

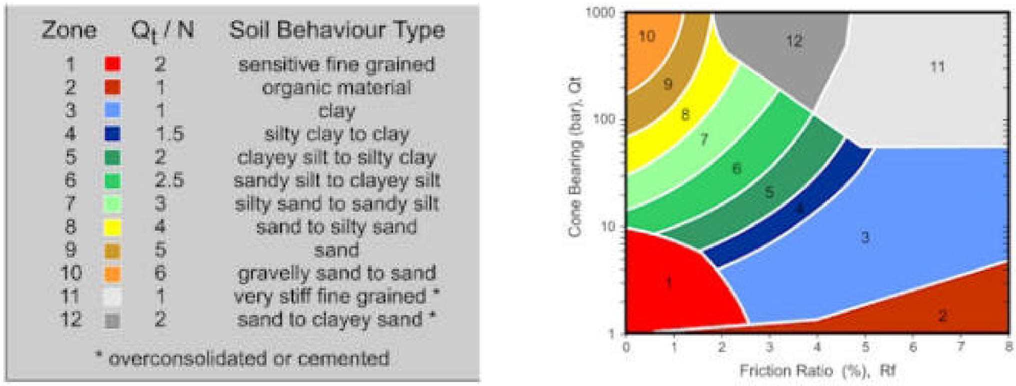
The top of bedrock was encountered in 22 of the CPT borings, mostly southwest of the Gas Plant. These CPT data were used with other bedrock data from residential, livestock, irrigation, or cathodic protection wells drilled in the area to create a map of the bedrock topography underlying the alluvium (Figure 3-3, Bedrock Topography). Thus, in addition to the 22 CPT borings that penetrated the bedrock surface, this map is based on bedrock tops from 94 geologic logs of wells or borings from the State Engineers Office and the USGS (Bjorklund and Brown 1957; Hurr 1972).

Review of Figure 3-3, Bedrock Topography, shows that the top of bedrock is higher in areas southwest of the Gas Plant and gradually decreases in elevation to the east and north of the Gas Plant. Regionally, the bedrock surface decreases in elevation towards the South Platte River valley. The highest bedrock elevation lies southwest of the Gas Plant at approximately 4,360 feet mean sea level (ft msl). The lowest bedrock elevations are found north of the Gas Plant at an approximate elevation of 4,180 ft msl. The bedrock topography depicted on Figure 3-3 reflects an erosional surface formed by a dendritic drainage pattern typical of fluvial (i.e., stream and river) drainages. A prominent north-south trending bedrock valley lies about 0.5-mile east of the Gas Plant along the ancestral Badger Creek valley.

Southwest of the Gas Plant, the depth to bedrock beneath the craters is about 40 ft below grade. The craters appear to be located on top of a local bedrock ridge. The depth to bedrock beneath the Gas Plant is about 100 ft below grade. Although deeper, the Gas Plant also appears to be situated above a bedrock low area adjacent to a local bedrock ridge. This ridge is flanked to the northwest by a small paleo-valley that drained to the north and then east toward the ancestral Badger Creek valley east of the Gas Plant. Gas Storage Well #26 lies within this local paleo-valley, and may have served as a pathway for up-dip gas migration within the alluvium.

3.3.3 Subsurface Alluvium Stratigraphy

The subsurface alluvium stratigraphy was mapped using the SBT data obtained from the q_c and f_s data. The SBT classification is based on the ratio of the q_c to the friction ratio (R_f). The friction ratio is defined as the ratio of (f_s/q_c)*100. The resulting SBT classification is shown in the figure below.



The SBT values for each CPT interval in each CPT boring were modeled in three dimensions using Rockworks 2006 (Rockware 2006). Numerous geologic sections were developed (Figure 3-4, Geologic Section Location Map) using the three-dimensional (3-D) block model and are shown as Figures 3-5 through 3-7 (Geologic Sections A-A' through F-F', Geologic Sections G-G' through J-J', and Geologic Sections K-K' through M-M', respectively). The SBT intervals were simplified for illustration on the geologic sections. The simplified SBT stratigraphy is mapped on the sections as SBT zones 1 and 2 (sensitive and organic soils; blue-green), 3 and 4 (clays; green), 5 and 6 (silts; olive), 7, 8, and 9 (sands; yellow), 10 (gravels; light brown); 11 (overconsolidated clays and silts; brown), and 12 (cemented sands; dark brown).

Figure 3-4, Geologic Section Location Map, shows the locations of the geologic sections depicted in Figures 3-5 through 3-7 (Geologic Sections A-A' through F-F', Geologic Sections G-G' through J-J', and Geologic Sections K-K' through M-M', respectively). Sections A-A' through H-H' (Figures 3-5 and 3-6) are west to east sections. Section A-A' is constructed through the northernmost CPT borings; Section H-H' is constructed through the southernmost CPT borings.

Review of the geologic sections (Figures 3-5 through 3-7 [Geologic Sections A-A' through F-F', Geologic Sections G-G' through J-J', and Geologic Sections K-K' through M-M', respectively]) shows that the alluvium is a heterogeneous sequence of interbedded clays, silts, sands, and gravels typical of fluvial deposition. The sediments shown in these sections were deposited as flood plain and point bar deposits from meandering streams and rivers eroding the adjacent bedrock highlands south and west of the Gas Plant. Thus, these sedimentary deposits tend to be laterally variable in texture and discontinuous because of the complex depositional and erosional relationships present in fluvial systems.

Section C-C' runs through Gas Storage Well #26. CPT-34 is adjacent to Gas Storage Well #26. Review of this section shows that the upper interval of the alluvium is dominated by fine-grained clays and silts. Below an elevation of approximately 4,300 ft msl, coarse-grained sands and gravels predominate.

Section D-D' runs along CR N in front of the Gas Plant. CPTs-26, -73, -35, -41, and -45 are located in and adjacent to the Gas Plant. Review of this section shows that the alluvium beneath the Gas Plant is comprised primarily of coarse-grained sands and gravels. This thick accumulation of sands and gravels may indicate a period of long-term point bar deposition in this area. Similarly thick accumulations of sands and gravels are noted in the central portions of the geologic sections south of the Gas Plant (Sections E-E' through H-H'). The alluvium interval east and west of the Gas Plant has more clays and silts typical of flood plain deposits. Of note is the silts and clays that directly lie beneath the groundwater surface in the area south of the Gas Plant and along CR 18. This silt-clay interval appears to play an important role in the liquefaction and piping of the underlying sands. It is also worth noting that the silt bed near the base of CPT-41 appears to locally limit vertical migration of higher dissolved gas concentrations in groundwater at deep piezometer (CPT-41D) to groundwater in the shallow piezometer (CPT-41S). Dissolved gas traps are discussed further in Section 5.3, Phase II Groundwater Investigation Results.

Section F-F' runs through the crater area southwest of the Gas Plant. The alluvium depicted on this section is typical of the heterogeneous alluvium stratigraphy found beneath the Gas Plant and surrounding area. The alluvium on this section at CPT-11 is much thinner and is comprised predominantly of silts and clays, except near the top of bedrock (black) where thin sands are found. The alluvium in this area was deposited on top of a local bedrock ridge that is situated beneath the southwest crater area.

Sections I-I' through M-M' are north to south sections. Section I-I' is constructed through the westernmost CPT borings; Section M-M' is constructed through the easternmost CPT borings. Review of the alluvium stratigraphy shown on these sections is similar to that shown on Sections A-A' through H-H'. Section I-I' shows increasing silt and clay content in the alluvium towards the south, near the southwest crater area. This section also shows the dune sands that overlie the alluvium in the area of CPT-07. The shallow bedrock ridge beneath the southwest crater area clearly evident between CPT-10 and CPT-06.

Sections J-J' and L-L' run north-south along the west and east sides of the Gas Plant, respectively. Section K-K' runs north-south through the center of the Gas Plant. Section J-J' shows a thicker section of sands and gravels, particularly at CPTs-26 and -29 adjacent to the Gas Plant, that likely represents alluvial point bar deposition. This is consistent with the channel deposits on Sections D-D' through H-H'. Sections K-K' and L-L' show increasing silt and clay contents in the alluvium towards the east. CPTs-45 and -46 along the east end of the Gas Plant have more silt and clay intervals than the corresponding interval along the west end of the plant (CPTs-26 and -29). Section M-M' runs north-south along CR 18.5 parallel to the predominant bedrock valley defining the approximate location of ancestral Badger Creek. This section contains thick sections of sands and gravels suggesting alluvial point bar deposition along ancestral Badger Creek.

3.3.4 Occurrence of Natural Gas

Natural gas concentrations were monitored with a Q-Rae 4-gas meter and flame ionization detector (FID) while drilling the CPT borings. Figure 3-8, Natural Gas Occurrences, shows the CPT borings where natural gas was detected (red) and where it was not detected (green). Natural gas was primarily detected in CPT borings pushed in areas where the gas released through the surface. The gas detected was of insufficient pressure to register on the blowout preventer pressure transducer which was capable of detecting a minimum of 1 pound per square inch (psi) pressure. The distribution of natural gas measured during advancement of the CPT borings is consistent with the extent of dissolved methane found in groundwater sampled from the CPT piezometers and wells (Section 5.3, Phase II Groundwater Investigation Results).

The objectives of this task were to characterize and document the nature and extent of the land surface features caused by the natural gas release. This is an important step in assessing the nature and extent of the environmental impacts. Aerial mapping of the impacted soils (e.g., craters, ground fissures) was conducted to provide an indication of areas where the gas release may have affected groundwater in the alluvium. Correlation of impacted soils with subsurface geologic features, and man-made structures such as utility lines and pipelines, provides information to assess the migration of groundwater contamination, if any, from the gas source areas.

To address these objectives, an aerial survey was conducted to delineate the gas-affected areas at the ground surface by obtaining one comprehensive set of detailed color orthophotographs and Light Detecting & Ranging (LiDAR) data that covered all areas within 2 miles of CIG Well 26. The orthophotographs documented the ground surface features as of November 2006, while the LiDAR data defined the topographic elevations with high precision (approximately 5 cm). These data have been used to prepare a digital elevation model (DEM) and a topographic map (in 1 ft contours), which serves as a base map for the other data collection activities (see Figure 4-1, Aerial Photo and Topography). Even though the primary focus is groundwater assessment, these aerial surveys also provide useful information for the stability monitoring and assessment (Task 1 and Task 2). For example, these aerial survey data were used to guide the selection of favorable locations for land survey benchmarks and CPT borings along the edges of craters and ground fissures created during the gas release.

The Environmental and Engineering Assessment Work Plan for the Fort Morgan Natural Gas Storage Facility (CIG 2007) defined the scope of Task 4 as summarized below.

TASK 4 – EVALUATE GAS RELEASE MECHANISMS, MIGRATION PATHWAYS AND EXTENT OF AFFECTED GROUNDWATER (NATURE AND EXTENT EVALUATION)

The main objectives of this task are to evaluate:

- *how the natural gas migrated from the deep well leakage point upward into the shallower aquifers and to the ground surface;*
- *the nature of impacts and the extent of shallow soil and groundwater effects caused by the gas release;*
- *the potential for future impacts to groundwater users in the site area; and*
- *whether remediation is necessary to mitigate adverse affects of the release that are considered to pose a threat to human health or the environment.*

Thus, the Task 4 activities were designed to identify and document how and where the gas leak occurred and other potential subsurface pathways (e.g., known faults or fractures, bedding plane contacts, etc.) that may have controlled migration of gas to the surface. Task 4 was subdivided into sub-tasks, Task 4A, Task 4B, and Task 4C, as described below.

Task 4A involves an on-going assessment of the nature and extent of natural gas in the sub-surface via one round of pre-irrigation season and two rounds of irrigation season sampling at the piezometers installed during the CPT investigation (Task 2) and selected residences. The current status of activities and data collected under Task 4A is described in Section 5.1, Task 4A – Piezometer Sampling Activities.

Task 4B focused on the evaluation and interpretation of a previous 3-D seismic survey of the site. Additionally, new seismic studies will be conducted to augment the nature and extent evaluation by locating sub-surface features that may impact or control gas migration pathways. The current status of activities and data collected under Task 4B is described in Section 5.4, Task 4B – Interpretation of 1996 3-Dimensional Seismic Data.

Task 4C will focus on the installation of vent and monitoring wells which will be sited based on information collected in Tasks 4A and 4B. The findings from Task 4A and Task 4B, to be reported in a subsequent Phase II Report, will be used to identify necessary locations for the installation of monitoring wells and vent wells. If well installation is necessary, a well installation plan, including proposed locations, will be prepared and submitted to COGCC, prior to any well installation activities.

5.1 TASK 4A – PIEZOMETER SAMPLING ACTIVITIES

Per the Phase II Sampling Plan Addendum, Phase II sampling activities include vapor monitoring and groundwater sampling of piezometers, selected domestic wells, and one livestock well during three sampling events. The first sampling event was a pre-irrigation sampling event that was conducted in March 2007 and is discussed in this report. The two subsequent sampling events are scheduled during the irrigation season (June and August, 2007). Results will be reported in a subsequent Phase II report.

The March 2007 pre-irrigation sampling event encompassed headspace monitoring at 27 vapor probes and 85 piezometers, and the collection of groundwater samples at all 85 piezometers (7 deep and 78 shallow), 11 domestic wells, and one livestock well. Additionally, per a land-owner request, one irrigation well was sampled. Table 5-1a, Pre-Irrigation Season Vapor Probe Analysis Summary, and Table 5-1b, Pre-Irrigation Season Sampling and Analysis Summary, summarize the sampling and analytical program for the Phase II Pre-Irrigation sampling event conducted in March 2007. This table lists all locations sampled and the suite of analyses conducted for samples from each location. Figure 5-1, Sample Locations, shows the location of each of the vapor probes, piezometers, and domestic and livestock wells that were sampled in March 2007. At this time, it is likely that both irrigation season sampling events will follow the same sampling and analysis program unless evaluation of the data suggests that modifications to the sampling and analytical program should be made.

The pre-irrigation sampling outlined in the Phase II Sampling Plan Addendum was conducted over two periods:

1. March 12-13, 2007: selected piezometers located in fields adjacent to the CIG Fort Morgan compressor station were prioritized to minimize interference with farming activities. In addition, the Krening irrigation well (I32) was re-visited to collect a groundwater sample, and additional samples for comparative analyses between two different analytical laboratories (SPL and Paragon) were collected at House H100 and Gas Storage Wells #3 and #6.
2. March 19-23, 2007: the remaining piezometers and selected domestic and livestock wells were sampled.

In addition to the planned pre-irrigation sampling of groundwater, supplemental monitoring and sampling were conducted. Supplemental headspace monitoring included a H_2S gas headspace survey conducted in April at selected vapor probes and piezometers and a methane headspace survey at all vapor probes and piezometers in May. As mentioned in Section 1.6, Update on Land and Land-Owner Issues, the location WMSWP was sampled per a land-owner request. This location was sampled on April 18, 2007. Coincidentally, Gas Storage Well #18 was venting and producing water at this time and a sample was collected from Gas Storage Well #18. Lastly, as mentioned in Section 1, Introduction, a groundwater sample was collected at I32 per a land-owner request. I32 was sampled on March 12, 2007.

The headspace monitoring and piezometer sampling procedures are briefly summarized in Section 5.1.1, Headspace Monitoring Procedures, and Section 5.1.2, Piezometer Sampling Procedures. Section 5.1.3, Domestic Well Sampling Procedures, summarizes the modification to the domestic well sampling program. Section 5.1.4, Decontamination Procedures, and Section 5.1.5, Sample Handling and Shipping Procedures, summarize the decontamination procedures and sample handling and shipping procedures, respectively. All Phase II groundwater sampling activities were performed under the existing Safe Work Plan (URS 2006), Revision 3 for this project. Health and safety briefings were held and documented prior to going in the field each day.

5.1.1 Headspace Monitoring Procedures

On arrival at each piezometer, gas concentrations in the piezometer headspace were measured using a Q-Rae 4 gas meter that measures combustible gas as a percent of the lower explosive limit (%LEL), % oxygen (O_2), carbon monoxide (CO) in ppm, and H_2S in ppm. The sensitivity levels are 1% LEL for combustible gas, 0.1% for O_2, and 1 ppm for CO and H_2S. The headspace monitoring was conducted by carefully and slowly removing the cap of the piezometer and quickly putting a stopper with a small diameter tube connected to the Q-Rae meter in the piezometer. The system was allowed to equilibrate for 60 seconds; the maximum values obtained during the equilibration period were recorded on the sampling form.

The H_2S headspace survey was conducted using a Jerome H_2S Analyzer (Model 631). The instrument has a detection range of 0 to 50 ppm and a sensitivity of 0.003 ppm. The headspace sampling method period described above was also used for the H_2S survey.

5.1.2 Piezometer Sampling Procedures

Piezometer sampling procedures were conducted in accordance with the Phase II Groundwater Sampling Plan Addendum (CIG 2007a). These procedures generally comply with the COGCC sampling procedures, however, procedure modifications were made to facilitate low-flow purging and sampling of the small diameter piezometers and the substantial flow generated at the irrigation and gas storage wells, as described in the following sections.

Groundwater Sample Locations

Selection of Piezometer Groundwater Sampling Methodology

In preparation for the March sampling event, three potential piezometer sampling methodologies were evaluated over February 20-21, 2007.

1) bladder pump with dedicated tubing [BP];

2) disposable Teflon bailer [BL]; and

3) 0.5" PVC tubing with a stainless steel check valve [FV]).

The focus of the evaluation was to compare the analytical results for dissolved gases using these sampling methods so that a least-biased analytical dataset for the dissolved gases is developed.

A comparison of the analytical results for dissolved methane using these sampling methods is presented below. The highest dissolved methane concentration in each piezometer is highlighted in yellow.

COMPARISON OF DISSOLVED METHANE RESULTS FOR THREE SAMPLING TECHNIQUES

Piezometer Number	Dissolved Methane Concentration (µg/L)		
	Bladder Pump	Bailer	Foot Valve
CPT-57S	3.9	**14**	9.6
CPT-61S	**14**	4.6	3.0
CPT-62S	2.9	**3.3**	1.6
CPT-91S	930	**18,000**	12,000

Note:
µg/L micrograms per liter

With the exception of CPT-61S, the bailer sampling method produced the highest dissolved methane results. Based on the proximity of CPT 91 (18,000 micrograms per liter [µg/L]) to house H100 (19,000 µg/L), it can be inferred that the bailer sampling method results are very comparable to the COGCC preferred method. Overall, samples collected by the foot valve technique showed slightly lower dissolved methane results compared to the bailer. Use of the bladder pump was discounted as an effective sampling technique because it appears that the water becomes too aerated during purging using the bladder pump and therefore produces results that have a potential low bias.

It was determined that any of the collection methods would be suitable for collection of samples for dissolved metals and inorganics analysis, and decisions for these parameters could be based on efficiency. Therefore, based on these data, it was concluded that the greatest sample integrity was achieved by collecting dissolved gases using a pre-cleaned, dedicated bailer. Samples for analysis of inorganic water quality parameters and dissolved metals groundwater were collected using a bladder pump.

Piezometer Sampling

On arrival at each piezometer, gas concentrations in the piezometer headspace were measured for at least 60 seconds and the peak results for the four gases (% LEL, CO, O_2, and H_2S) recorded on the sampling form. After the headspace gas measurement has been completed, the depth to water and total depth of the piezometer was measured using an electric water level meter and the information was recorded on the field sampling form.

Prior to collecting a groundwater sample, each piezometer was purged so that the stagnant water standing in the pipe was evacuated and "fresh" water flowed into the casing. During purging, field observations of water color, water clarity or turbidity, odors, effervescence (e.g., exsolving gas), sediment, or bacterial fouling were noted and recorded on the field sampling form. In addition, the last result for each of the field parameters were also recorded on the field sampling form once the purge water has stabilized.

It is standard practice to collect a water sample from a piezometer after the field parameters have stabilized. However, this was not always feasible in some cases. Some of the piezometers only produced water at very low flow rates, which may require exceedingly long purging times before the field parameters stabilize. Other piezometers produce water at higher rates, which allows the field parameters to quickly stabilize. Purging at two piezometers, CPT-57R and CPT-44S, purged the piezometer dry. For both of these piezometers, groundwater samples were collected after the water levels recovered. Due to insufficient water in the CPT-44S piezometer, the requested anion dataset was reduced to TDS, sulfate, and chloride analyses from the planned full suite of anions. Sufficient volume was collected for the dissolved gases and dissolved metals analyses. For all piezometers, at least one casing volume of groundwater was removed prior to sampling whether or not the field parameters stabilized.

On completion of purging, groundwater sample aliquots were collected from the piezometer. Sample aliquots for inorganic water quality parameters were collected by discharging the groundwater directly from the bladder pump discharge line into the laboratory-supplied sample containers. Sample aliquots for dissolved metals were also collected using the bladder pump. The bladder pump was fitted with a pre-cleaned, disposable 0.45 micron filter on the discharge line so that a filtered sample could be obtained for the dissolved metals analysis. The filtered groundwater was discharged directly from the filter discharge line into laboratory-supplied sample containers.

Dissolved gas samples were collected using a pre-cleaned, dedicated bottom-filling bailer equipped with clean, dedicated polypropylene (or similar) rope of appropriate length. The bailer was slowly lowered by hand into the piezometer so that the groundwater was not aerated. The bailer was slowly lowered below the top of the water in the piezometer so that it filled completely. Once filled, the bailer was slowly removed from the piezometer so that the sample was not agitated. Once at the surface, the sample was slowly discharged from the bottom of the bailer using the bottom discharge tube into a laboratory-supplied dissolved gas sample container (e.g., volatile organic analysis [VOA] vials). The sample container was filled so that, when capped, no air bubbles are trapped under the cap. This process was repeated until the necessary number of sample aliquots was obtained.

The laboratory-supplied containers contained preservatives as required for specific analyses. Once the appropriate sample volumes were collected the bottles were labeled, capped, sealed, and stored in a cooler on ice.

5.1.3 Domestic Well Sampling Procedures

Sampling of domestic and livestock wells followed the Phase I sampling program procedures (CIG 2007a; CIG 2007b).

Initially, the sampling plan called for collection groundwater samples from six domestic wells. These locations included H100 and H101, which have shown the highest concentrations of dissolved gases. Selection of the other domestic wells was based on previous rounds of analytical data that showed that these locations had results for one or more analytes that slightly exceeded upper tolerance limits (UTL) (i.e., H34, H67, and H98). Additional sampling was conducted to assist in evaluating whether the UTLs exceedances were random events or are truly representative of the local groundwater quality. The last domestic well location was L59 which is used to water livestock. L59 is downgradient from H100 and H101 and sampling at this location was included to further evaluate the dissolved gas levels downgradient from H100 and H101.

Groundwater samples were also collected from six additional residential locations to monitor the potential migration of dissolved gases at the edges of the plume. These locations included H61, H52/57, H62/63, H64/H65, H66, and H38.

5.1.4 Decontamination Procedures

All non-dedicated sampling equipment (e.g., bladder pumps, electric water level probe) was cleaned prior to use so as to minimize sample integrity issues and to avoid cross-contamination of the piezometers and samples. At a minimum, non-dedicated equipment was rinsed thoroughly with clean, distilled water and wiped with a clean, dry cloth (e.g., paper towel) between uses.

Once purging and sampling was completed, the bladder pump was removed from the piezometer and cleaned prior to use at the next piezometer to avoid cross contamination. Decontamination was accomplished by flushing the bladder pump with clean distilled water for approximately five minutes prior to its use at the next sampling location.

The dedicated tubing, bailer, and rope were removed from the piezometer on completion of sampling. Equipment was wiped with a clean cloth (e.g., paper towel) and placed in a clean plastic bag labeled with the specific piezometer number.

5.1.5 Sample Handling and Shipping Procedures

During sampling activities, samples were stored on ice in a cooler at less than (<) 6 degrees Celsius (ºC). Samples were taken to the field office for final processing, packing, and shipping. A chain of custody (COC) was maintained for all samples collected, and COC copies accompanied sample shipments. Samples were shipped daily to the laboratory by overnight carrier (i.e., FedEx) so that they would be received and analyzed within their appropriate holding times.

5.2 PRE-IRRIGATION SEASON HEADSPACE MONITORING RESULTS

The headspace monitoring results are presented in Table 5-2a, Headspace Monitoring Results, March 2007, Table 5-2b, Headspace Monitoring Results, April, 2007; and Table 5-2c, Headspace Monitoring Results, May 2007; and the H_2S results are presented in Table 5-3, Hydrogen Sulfide Monitoring Results, April 2007. Section 5.2.1, Combustible Gas Monitoring (March and May 2007), discusses the headspace monitoring results and Section 5.2.2, Hydrogen Sulfide Monitoring, discusses the H_2S monitoring results.

5.2.1 Combustible Gas Monitoring (March and May 2007)

Tables 5-2a, 5-2b, and 5-2c present the headspace monitoring results for March, April, and May 2007, respectively. Because only two locations were sampled in April, the following discussion focuses on the March and May sampling events in which the monitoring encompassed the same extended sampling network.

The combustible gas levels values for May are generally lower than those measured in March with the exception of four locations at which the combustible gas levels measured were 100% of the LEL in both March and May. These four locations include: CPT-46D, CPT-53S, CPT-57R, and CPT-57S. Elevated dissolved methane concentrations ranging from 8.0 mg/L to 15.0 mg/L have been detected in groundwater samples collected at these piezometers. As such, these higher combustible gas levels are not unexpected.

O_2 and CO results at all locations vary within expected and normal limits for both the March and May monitoring events.

5.2.2 Hydrogen Sulfide Monitoring

On April 4 and 5, 2007, a H_2S-specific monitoring survey was conducted at 57 locations, including all 28 vapor probe locations and 29 selected piezometers because of the potential presence for "sour-gas." Conflicting H_2S monitoring results between URS and COGCC during the CPT investigation prompted further investigation with a H_2S-specific instrument.

The H_2S results are presented in Table 5-3, Hydrogen Sulfide Monitoring Results, April 2007, and are displayed on Figure 5-2, Hydrogen Sulfide Concentration, Piezometers and Soil Vapor Probes. A Jerome H2S Analyzer (Model 631) instrument, specific to only H_2S, was used for analysis. Any value recorded in the field notes as 0.000 ppm is displayed as <0.003 ppm because the value of 0.003 ppm represents the instrument's sensitivity level. Values recorded as below 0.003 ppm but >0.000 ppm are considered to be estimated values and are denoted in the table by a "J" qualifier since the quantitative uncertainty below the instrument sensitivity threshold is very high.

The H_2S results range from nondetect (i.e., <0.003 ppm) to 0.016 ppm. Forty-two of the 57 April results are either nondetect or detections below or at the reporting limit of 0.003 ppm; these results are shown as green symbols on Figure 5-2, Hydrogen Sulfide Concentration, Piezometers and Soil Vapor Probes. Ten results are >0.003 ppm, but <0.010 ppm; these results are shown as yellow symbols on Figure 5-2. Five results are >0.010 ppm; these results are shown as red symbols on Figure 5-2. These five locations include CPT-44V, CPD-91V, CPT-22S, CPT-22V, and CPT-30V.

The locations with the highest H_2S concentrations do not correlate with locations with the higher methane detections. For example, the H_2S concentration measured at CPT-22S, CPT-22V and CPT-30V were 0.016, 0.012 and 0.013 ppm, respectively. March methane concentrations in the associated piezometers were relatively low at 0.0051 mg/L and 0.018 mg/L. In contrast, H_2S results for CPT-44V and CPT-91V were 0.012 and 0.014 ppm. The March methane results for the associated piezometers were relatively high at 12 and 11 mg/L, respectively. The difference is likely due to the fact that the screened interval is much shallower for the vapor probes compared to the piezometers. Additionally, the difference could be that H_2S present is dissolved in groundwater.

H_2S results for March, measured with the Q-Rae instrument, were predominantly nondetect (i.e., <1 ppm) with only seven positive results ranging from 1 to 2 ppm. The H_2S results for May, also measured with the Q-Rae, were all nondetect (i.e., <1 ppm).

It is difficult to compare the March H_2S results measured with the Q-Rae to the April H_2S results measured with the Jerome meter because the sensitivity levels differ. Additionally, only 3 of the locations with positive March results were monitored in April. At location CPT-44S the March H_2S reading was 1 ppm vs. <0.003 ppm obtained for the April monitoring. At location CPT-31S the March H_2S result was 1 ppm vs. 0.004 ppm obtained for the April monitoring. At location CPT-53S the March H_2S result was 2 ppm vs. 0.007 ppm obtained for the April monitoring.

All H_2S results are one to three orders of magnitude below established action levels. The American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Value (TLV) for H_2S is 10 ppm. This is the amount of H_2S that a worker could be exposed to for an 8-hour work day. The ACGIH Short-Term Exposure Limit (STEL) for H_2S is 15 ppm. This is the amount of H_2S a worker could be exposed to for a duration of up to 15 minutes. The H_2S results obtained thus far indicate that H_2S is not present at sufficient levels to be a health concern.

5.3 PHASE II GROUNDWATER INVESTIGATION RESULTS

This section discusses the Phase II groundwater investigation results. The Phase II results discussed below include the areal groundwater conditions and groundwater quality based on groundwater measurements and groundwater sampling and analysis at the CPT piezometers and some residential wells in March 2007.

The Phase II groundwater quality data are summarized in Table 5-5, Pre-Irrigation Dissolved Gases Results, Table 5-6, Pre-Irrigation Dissolved Metals Results, and Table 5-7, Pre-Irrigation Inorganic Results. Although nondetects are reported at the reporting limit (RL) in the dissolved gases and dissolved metals tables, the threshold used by the analytical laboratory for reporting detections was the method detection limit (MDL). Thus, any detections above the MDL, but below the RL, would have been reported as detects. The MDLs were sufficiently low for comparison to UTLs. A UTL is a statistical measure of the upper limit of the background groundwater concentration for an analyte.

The associated data validation reports are presented in Appendix F, Data Validation Reports. Any data qualifiers assigned during data validation were added to the electronic database. The hardcopy data packages and qualified data sheets are retained in the project files. The groundwater conditions within the alluvial aquifer are discussed in Section 5.3.1, Groundwater Conditions. Section 5.3.2, Alluvial Aquifer Groundwater Quality, discusses the groundwater quality within the alluvial aquifer. Section 5.3.3, Bedrock Formation Groundwater Quality, discusses the groundwater quality in the bedrock formations. Section 5.3.4, Comparison of Alluvial and Bedrock Groundwater Quality, compares and contrasts the water quality in the alluvial aquifer and bedrock formations using Piper and Stiff diagrams.

5.3.1 Groundwater Conditions

5.3.1.1 Groundwater Occurrence, Elevations, and Flow Direction

Groundwater occurs in the alluvium and dune sands under water table conditions at depths ranging between about 10 ft below grade at CPT-05S and 60 ft below grade at CPT-02S. The depth to groundwater beneath the Gas Plant is about 25 ft below grade. Groundwater levels in the alluvial aquifer were measured at 77 shallow piezometers in March 2007 prior to the startup of irrigation. A potentiometric surface map was prepared to illustrate groundwater elevations in the shallow alluvial aquifer, which is shown as Figure 5-3, Groundwater Elevations in Alluvial Aquifer, March 2007. Review of Figure 5-3 shows that groundwater within the shallow alluvial aquifer generally flows from south-southwest to north-northeast during March 2007. This flow direction is generally consistent with regional groundwater flow toward the South Platte River. Groundwater elevations in March 2007 range between about 4,358 ft msl at CPT-07S and 4,306 ft msl at CPT-67S. The groundwater elevation beneath the Gas Plant during this time period is about 4,321 ft msl. The saturated thickness of the alluvial aquifer was estimated using the potentiometric surface and the bedrock topography. Saturated thickness of the alluvial aquifer ranges between 18 ft at CPT-13S and 115 ft at CPT-67S. Figure 5-4, Saturated Thickness (feet) of the Alluvium, March 2007, shows the estimated saturated thickness across the Phase II investigation area in March 2007.

Groundwater levels were also measured in May 2007 after irrigation started in the area. Groundwater levels were measured in the alluvial aquifer at 68 shallow piezometers in May 2007. Fewer piezometers were monitored during May 2007 because some of the piezometers in planted fields were temporarily buried below grade for the growing season to accommodate land-owner requests. A potentiometric map was developed for these data and is shown as Figure 5-5, Groundwater Elevations in Alluvial Aquifer, May 2007. Review of Figure 5-5 shows that groundwater within the shallow alluvial aquifer generally flows from south-southwest to north-

northwest during May 2007. These flow directions are generally consistent with those observed in March 2007, except the flow direction has changed from northeastward to northwestward in the area of CPT-01S and CPT-19S. This local change in flow direction is likely due to irrigation pumping in the area of these piezometers that locally lowered the water table, created a cone of depression, and changed the flow direction in that area. Groundwater elevations in May 2007 range between about 4,360 ft msl at CPT-07S and 4,306 ft msl at CPT-01S. The groundwater elevation beneath the Gas Plant in May 2007 is about 4,321 ft msl. This is consistent with the groundwater elevation observed beneath the Gas Plant in March 2007.

The changes in groundwater levels between March and May 2007 were calculated by subtracting the March groundwater elevations from the corresponding May groundwater elevations. Positive differences indicate that the May groundwater elevation is higher than the March groundwater level. Similarly, negative differences indicate that the May groundwater elevation is lower than the March groundwater level. The difference in groundwater levels for these two periods ranges between -2.76 ft and +2.44 ft, averaging +0.21 ft. The standard deviation about the mean is plus or minus (±) 0.78 ft.

Figure 5-6, Change in Groundwater Level in the Alluvial Aquifer Between March and May 2007, shows the change in groundwater levels between March and May 2007. Figure 5-6 shows several distinct areas where the groundwater levels are lower in May (blue contours). These areas with lower groundwater levels generally correspond to areas where irrigation pumping is occurring. However, most of the areas with higher groundwater levels in May (yellow contours) also have ongoing irrigation. The higher groundwater levels in some areas might be explained by differences in soil hydraulic conductivity and/or excessive irrigation that results in groundwater mounding.

5.3.1.2 Horizontal Hydraulic Gradient and Groundwater Flow Rate

The average horizontal hydraulic gradient within the alluvial aquifer is approximately 0.004 foot/foot (ft/ft). Using the hydraulic conductivity estimates (66 ft/d to 422 ft/d) from pumping tests conducted in the alluvium by the USGS (Bjorklund and Brown 1957), the average hydraulic gradient (0.004 ft/ft), and an assumed porosity of 0.25, average groundwater flow rates (seepage velocities) within the alluvium are estimated at 1.2 ft/d to 6.8 ft/d.

The spacing of the potentiometric contours depicted on Figure 5-3, Groundwater Elevations in Alluvial Aquifer, March 2007, indicates that the horizontal hydraulic gradient in the shallow alluvial aquifer varies substantially throughout the study area. The horizontal hydraulic gradient southwest of the Gas Plant is steeper (approximately 0.009 ft/ft) based on the closely-spaced potentiometric contours. This suggests that the transmissivity of the alluvial aquifer in the southwest area is lower. The horizontal hydraulic gradient south and north of the Gas Plant is relatively flat (approximately 0.002 ft/ft) based on the widely-spaced potentiometric contours. This suggests that the transmissivity of the alluvial aquifer in these areas is much higher. This apparent change in transmissivity is consistent with the thinner saturated thickness southwest of the Gas Plant and the much thicker saturated thickness south and north of the Gas Plant. These varying hydraulic gradients result in varying groundwater flow rates within the alluvium. For the range of hydraulic gradients and hydraulic conductivities in this area, the estimated groundwater flow rates (seepage velocities) would range between 0.4 foot per day (ft/d) and 15.2 ft/d, assuming the effective porosity is 0.25.

5.3.1.3 Vertical Hydraulic Gradient

Seven piezometer clusters (shallow and deep) were installed within the alluvial aquifer in the area of the Gas Plant. Groundwater elevation measurements at these piezometers suggest that a vertical hydraulic gradient exists between the shallow and deep piezometers that causes a portion of the groundwater flow component to move either downward (positive gradient) or upward (negative gradient). Table 5-8, Vertical Hydraulic Gradients in the Alluvial Aquifer, March 2007, provides a summary of the vertical hydraulic gradients calculated for the alluvial aquifer at the site. The vertical hydraulic gradients calculated for the alluvial aquifer range between -0.003 ft/ft at CPT-46S/46D and +0.032 ft/ft at CPT-35S/35D. The occurrence of vertical hydraulic gradients within the alluvial aquifer is consistent with the stratigraphic heterogeneity of the stratum where sand and gravel strata are intercalated with silt and clay layers. Downward gradients over a broad area are also consistent with increased recharge caused by application of irrigation water at ground surface contemporaneously with pumping of large irrigation wells. On the other hand, some areas may show little or no downward gradient where irrigation is not being applied or where shallow soils do not allow significant deep percolation. The occurrence of localized upward (negative) gradients may represent the natural hydraulic condition where irrigation effects are insignificant, or possibly could indicate the localized presence of natural gas.

5.3.2 Alluvial Aquifer Groundwater Quality

5.3.2.1 Dissolved Methane

Methane is the major natural gas constituent and is used as an indicator parameter to delineate the presence of dissolved natural gas in groundwater. In March 2007, dissolved methane concentrations in groundwater from the alluvial aquifer ranged between 0.000019 mg/L (an estimated value) at H64/65 and 26 mg/L at H100. Dissolved methane concentrations at 16 locations exceed the COGCC dissolved methane action level of 2 mg/L. Dissolved methane concentrations at an additional 15 locations exceed the background UTL of 0.0067 mg/L, but are less than the COGCC dissolved methane action level of 2 mg/L.

Figure 5-7, Dissolved Methane in Groundwater, March 2007, shows the areal distribution of dissolved methane in groundwater in March 2007. This figure shows two areas having elevated levels of dissolved methane in groundwater, which underlie and surround the areas where gas erupted at the ground surface during the October 2006 release. Review of Figure 5-7 indicates that the maximum dissolved methane concentrations in both these areas are similar; however, the southwestern area is much smaller in extent than the other area south and east of the Gas Plant. The lateral plume extent of these areas is consistent with the locations of craters and fissures in the ground surface associated with the gas release.

Dissolved methane concentrations in the southwestern area exceed the COGCC methane action level of 2 mg/L at piezometers CPT-05S (5.7 mg/L), CPT-11S (12 mg/L), and CPT-09S (23 mg/L). Two other piezometers (CPT-06S and CPT-07S) and one livestock well (WMSWP) located south of the plume have dissolved methane concentrations that are less than the COGCC dissolved methane action level (2 mg/L) but greater than the background UTL (0.0067 mg/L).

Dissolved methane concentrations near the Gas Plant range between 2.4 mg/L at CPT-41D on the north side of the Gas Plant, and 26 mg/L at H100 east of the Gas Plant. Twelve piezometers and one residential well in the Gas Plant plume exceed the COGCC 2 mg/L dissolved methane action level. These locations include residential well H100 and piezometers CPT-35S, -36S, -41D, -43S, -44S, -46S, -46D, -53S, -54S, -57R, -85S, and -91S. One residential well H101 and five piezometers CPT-29S, -45D, -30S, -61S, and -62S have dissolved methane concentrations that are less than the COGCC dissolved methane action level (2 mg/L) but greater than the background UTL (0.0067 mg/L).

Three piezometers (CPT-32S, -48S, and -65S), two residential wells (H34 and H67) and one irrigation well (I32) have dissolved methane concentrations that are less than the COGCC dissolved methane action level (2 mg/L) but greater than the background UTL (0.0067 mg/L). These locations are situated north of Gas Storage Well #26 but are not located in areas where the gas release surfaced. Dissolved methane at irrigation well I32, residential wells H34 and H67, and CPT-48S may be related. The dissolved methane concentration at I32 is the highest (1.2 mg/L) of the locations sampled outside the known plume areas; however, this well has been reported to have dissolved methane since the 1980s. Past CIG investigations have demonstrated that the methane at I32 does not appear to come from the storage reservoir based on the ratio of various natural gas components. CPT-32S, CPT-48S, and CPT-65S contain dissolved methane at concentrations slightly above the background UTL (0.0067 mg/L). These piezometers are located adjacent to existing Gas Storage Wells #6, #30, and #13, respectively.

Seven piezometer clusters (shallow and deep) were installed within the alluvial aquifer in the area of the Gas Plant. Comparison of dissolved methane concentrations between the piezometer pairs (Table 5-9, Comparison of Analyte Concentrations in the Shallow and Deep Alluvial Aquifer, March 2007) where significant (> 50 µg/L) dissolved methane is present suggests that higher dissolved methane concentrations occur in the deeper piezometers. This difference in dissolved methane concentrations with depth appears to be related to a confining layer in the lower alluvium that is capable of trapping and limiting upward gas migration. This condition is particularly evident at CPT-57S (shallow) and CPT-57R (deep) where the dissolved methane concentration is significantly higher in CPT-57R, the deeper piezometer. Also, the gas pressure noted at this deeper piezometer is substantially higher because the piezometer vented gas and water when left uncapped.

5.3.2.2 Chloride, Sulfate, and Total Dissolved Solids

During the Phase I investigation, chloride, sulfate, and TDS were identified as potential indicator parameters of brackish water associated with the natural gas release. Thus, these constituents were analyzed at all of the piezometers and residential, irrigation, and livestock wells sampled as part of the Phase II investigation in March 2007. The concentration ranges and areal extents of these indicator constituents are discussed below.

Chloride

Figure 5-8, Chloride in Groundwater, March 2007, shows the areal distribution of chloride in alluvial aquifer groundwater in March 2007. The chloride results shown on this map range in concentration from approximately 14 mg/L at CPT-11S to 325 mg/L at CPT-74S. Of the 97 locations sampled and analyzed, only one result (325 mg/L at CPT-74S) exceeds the Colorado

Water Quality Control Commission (CWQCC) domestic water supply drinking water standard (CWQCC 5 Colorado Code of Regulations [CCR] 1002-41, Table 2, Regulation No. 41) for chloride (250 mg/L). None of the results exceed the background UTL (361 mg/L) determined during the Phase I investigation (CIG 2007b). Chloride contents in the alluvium in the Fort Morgan area reported by the USGS are generally <100 mg/L (Bjorklund and Brown 1957). Evapoconcentration of dissolved salts attributable to irrigation practices are likely to have caused increased levels of chloride in alluvial groundwater through time, which may explain some trends on Figure 5-12, Piper Diagram of Alluvium and Bedrock Groundwater, and suggests that the chloride levels in the alluvial aquifer prior to the October 2006 event were higher than those reported by the USGS (Bjorklund and Brown 1957).

The areal distribution of the chloride results (Figure 5-8, Chloride in Groundwater, March 2007) does not suggest that groundwater quality in the alluvial aquifer has been impacted by upward migration of brackish water due to the natural gas release. The highest chloride concentrations shown on Figure 5-8 do not coincide with areas where the gas surfaced. The highest chloride concentrations (>200 mg/L) are found as an "island" within a "sea" of lower chloride concentrations over the gas storage reservoir in the general vicinity of Gas Storage Well #26. The highest chloride concentration occurs at CPT-74S adjacent to Gas Storage Well #19. The origin of these higher chloride concentrations is not clear at this time. They may be related to the gas release, storage field operations, and/or fertilization and irrigation practices. The lowest chloride concentrations (<50 mg/L) are found southwest of the Gas Plant in the area of the southwest methane plume. The low chloride content in this area suggests that these waters may be influenced by infiltration of precipitation in nearby recharge areas further south.

Sulfate

Figure 5-9, Sulfate in Groundwater, March 2007, shows the areal distribution of sulfate in alluvial aquifer groundwater in March 2007. The sulfate results shown on this map range in concentration from approximately 100 mg/L at CPT-11S to 2,030 mg/L at CPT-57R. All of the results exceed the CWQCC domestic water supply drinking water standard (CWQCC 5CCR 1002-41, Table 2, Regulation No. 41) for sulfate (250 mg/L). The background UTL for sulfate also exceeds the Colorado drinking water standard. Furthermore, these sulfate results are consistent with the elevated sulfate concentrations historically reported in the Fort Morgan area since the 1940s (Bjorklund and Brown 1957). Of the 97 locations sampled and analyzed, 24 results exceed the background UTL (1,350 mg/L) determined during the Phase I investigation (CIG 2007b).

The areal distribution of sulfate (Figure 5-9, Sulfate in Groundwater, March 2007) is similar to that of chloride (Figure 5-8, Chloride in Groundwater, March 2007), where the highest sulfate concentrations (those typically exceeding the background UTL) are found in the alluvium overlying the gas storage reservoir and in the area of the craters and fissures south and east of the Gas Plant. This "island" of high sulfate concentrations is surrounded by a "sea" of lower sulfate concentrations. Some of the lowest sulfate concentrations are found in the cratered and fissured area southwest of the Gas Plant. Although coincident with the surface features of the gas release near the Gas Plant, the higher sulfate concentrations do not appear to be related to upward migration of brackish water associated with the gas release because subsurface water vented from Gas Storage Wells #3, #6, and #18 has very low sulfate content (and correspondingly high chloride content). The higher sulfate concentrations in this area are probably related to naturally-elevated sulfate levels in the Pierre Shale and local fertilization and irrigation practices.

Total Dissolved Solids

Figure 5-10, Total Dissolved Solids in Groundwater, March 2007, shows the areal distribution of TDS in alluvial aquifer groundwater in March 2007. The TDS results shown on this map range in concentration from approximately 461 mg/L at CPT-11S to 4,470 mg/L at CPT-48S. However, elevated TDS concentrations have been known in this area since the 1940s (Bjorklund and Brown 1957). The high TDS concentrations are largely a result of the historically high sulfate concentrations found in this area. None of the TDS results exceed the background UTL (4,872 mg/L) determined during the Phase I investigation (CIG 2007b).

The areal distribution of TDS (Figure 5-10, Total Dissolved Solids in Groundwater, March 2007) largely reflects a similar areal distribution shown by sulfate (Figure 5-9, Sulfate in Groundwater, March 2007). The highest TDS concentrations are primarily found in the general area of Gas Storage Well #26 and in the area of the craters and fissures south and east of the Gas Plant. Like sulfate, TDS shows a similar "island" of high TDS concentrations surrounded by a "sea" of lower TDS concentrations.

5.3.2.3 Comparison to Background Upper Tolerance Limits

Table 5-10, Summary of Background Levels (Upper Tolerance Limits) for Alluvial Groundwater, lists the background groundwater UTLs developed during the Phase I investigation. A UTL is a statistical measure of the upper limit of the background groundwater concentration for an analyte. Appendix E of the Phase I Report (CIG 2007b) presents a detailed description of the statistical procedure used to calculate the background UTLs. The groundwater results for wells completed in the alluvial aquifer are compared to the background UTLs to evaluate whether or not the alluvial groundwater may potentially have been affected by the natural gas release. Table 5-5, Pre-Irrigation Dissolved Gases Results, compares the dissolved gases results to the background UTLs. Table 5-6, Pre-Irrigation Dissolved Metals Results, compares the dissolved metals results to the background UTLs. Table 5-7, Pre-Irrigation Inorganic Results, compares the inorganic parameters to the background UTLs. Results exceeding the UTLs in Table 5-10, Summary of Background Levels (Upper Tolerance Limits) for Alluvial Groundwater, are shaded.

Review of Table 5-5, Pre-Irrigation Dissolved Gases Results, indicates that dissolved methane, ethane, ethane, and propane concentrations in some groundwater samples (highlighted in yellow) exceed their respective background UTLs. Locations where these dissolved gases exceed the background UTL may have been affected by the natural gas release.

Review of Table 5-6, Pre-Irrigation Dissolved Metals Results, indicates that boron, cadmium, calcium, iron, magnesium, manganese, silver, thallium, and vanadium concentrations in a few of the groundwater samples (highlighted in yellow) slightly exceed their respective background UTLs for these constituents. These results are consistent with frequency of background UTL exceedances for these constituents found during the Phase I evaluation, which are attributable to expectable false positive error rates, and do not indicate that brackish water has been introduced into the alluvial aquifer during the gas release.

5.3.2.4 Comparison to Groundwater Quality Standards

The dissolved methane results were compared with the COGCC action level (2 mg/L) for dissolved methane in groundwater. The results of this comparison indicate that the dissolved methane concentrations are greater than the 2 mg/L COGCC action level at 16 locations. The locations where the dissolved methane concentration exceed the COGCC action level are shown on Figure 5-7, Dissolved Methane in Groundwater, March 2007.

Most of the dissolved metals in groundwater are less than their respective Colorado groundwater quality standards. Dissolved boron, iron, manganese, and selenium exceed the Colorado groundwater quality standard at least once. Dissolved iron exceeds the groundwater quality standard at the Krening irrigation well (I32). Dissolved selenium exceeds its groundwater quality standard at CPT-91S. However, the selenium result is J qualified (i.e., estimated). Dissolved boron exceeds the Colorado groundwater quality standard at CPT-65S, -84S, -85S, and -91S. Dissolved manganese exceeds its groundwater quality standard (0.05 mg/L) most frequently of the dissolved metals. Of the 61 results, 43 (70%) exceed the manganese groundwater quality standard. It should be noted that the background UTLs for dissolved iron (0.60 mg/L), manganese (0.0932 mg/L), and selenium (0.486 mg/L) are also higher than their respective groundwater quality standards.

Sulfate is the only inorganic parameter that exceeds its Colorado groundwater quality standard (250 mg/L). Sulfate concentrations at 85 locations exceed the sulfate standard. It should be noted that the background sulfate UTL (1,350 mg/L) is also higher than the sulfate groundwater quality standard. These sulfate results are consistent with the previously reported Phase I sulfate results and with the historically elevated sulfate concentrations reported in groundwater in the Fort Morgan area since the 1940s (Bjorklund and Brown 1957). Therefore, the elevated concentrations of sulfate in the alluvial groundwater do not appear to be related to the gas release incident.

5.3.3 Bedrock Formation Groundwater Quality

Subsurface water was obtained from Gas Storage Wells #3, #6, and #18 when the surface casing was vented to remove natural gas. Waters from these wells were analyzed for dissolved gases, benzene, toluene, ethylbenzene, and xylenes (BTEX) (Gas Storage Wells #3 and #6 only), dissolved metals, and inorganic parameters to characterize bedrock formation water quality. The analytical results are summarized in Table 5-5, Pre-Irrigation Dissolved Gases Results, Table 5-6, Pre-Irrigation Dissolved Metals Results, and Table 5-7, Pre-Irrigation Inorganic Results.

5.3.3.1 Dissolved Gases

The dissolved methane concentrations in the subsurface water from Gas Storage Wells #3, #6, and #18 were similar and ranged between 14 (Gas Storage Well #18) and 23 mg/L (Gas Storage Well #3). These dissolved methane concentrations are greater than the COGCC action level of 2 mg/L, but do not represent a safety hazard since water from these wells (and the bedrock formations) is not used for domestic, livestock, or irrigation purposes. The dissolved methane concentrations observed at these wells were expected as the waters were obtained during venting of the gas storage well surface casings and likely represent residual methane remaining in the bedrock formations following the gas release. The surface casings are set about 200 ft below ground surface (bgs) and about 100 ft into the Pierre Shale, thus the subsurface water is most likely from the Pierre Shale and possibly the deeper Niobrara Formation, but not from the gas storage reservoir in the D Sandstone.

5.3.3.2 Chloride, Sulfate, and Total Dissolved Solids

Chloride, sulfate, and TDS were identified as indicator parameters during the Phase I investigation. Water produced during venting of the surface casing at Gas Storage Wells #3, #6, and #18 is from the Pierre Shale and/or the deeper Niobrara Formation and is chemically distinct from the alluvial groundwaters. Groundwater within these bedrock formations is characterized by high sodium, chloride, and bicarbonate and low calcium and sulfate concentrations. The alluvial groundwaters typically have high calcium, bicarbonate, and sulfate and low sodium and chloride concentrations. The waters produced during venting are also characterized by high boron, bromide, and iodide concentrations compared to the alluvial groundwaters. Both the subsurface waters from the gas storage wells and alluvial groundwater are characterized by high TDS concentrations. Chloride concentrations found in the subsurface waters from the gas storage wells exceed the Colorado groundwater standard for chloride (250 mg/L), however, this water is not used for domestic, livestock, or irrigation purposes and therefore comparison to Colorado groundwater standards in not appropriate based on aquifer usage.

5.3.3.3 Comparison to Background Upper Tolerance Limits

Comparison of the groundwater concentrations found in the subsurface water from Gas Storage Wells #3, #6, and #18, to the background groundwater UTLs calculated for the alluvial aquifer is not appropriate because the produced water is from deeper bedrock formations and is not comparable to background UTLs developed for the alluvial aquifer.

5.3.3.4 Comparison to Groundwater Quality Standards

The dissolved methane concentrations for the three gas storage well samples exceed the COGCC action level of 2 mg/L (Table 1). The methane concentrations for samples from Gas Storage Wells #3, #6, and #18 are 23, 21, and 14 mg/L, respectively. Additionally, benzene concentrations from these gas storage wells exceed MCLs and the Colorado Groundwater Standards (Table 2), which are established at 5 µg/L. The benzene results for Gas Storage Wells #3 and #6 are 93 µg/L and 53 µg/L, respectively. These exceedances do not pose a health risk because these water samples are from deep bedrock formations which are not used for drinking water or domestic use. Considering the extensive oil and gas occurrences in the Fort Morgan area, these dissolved methane and benzene concentrations are not unexpected. There were no other BTEX compounds, dissolved metals, or major ions that exceeded applicable standards.

5.3.4 Comparison of Alluvial and Bedrock Groundwater Quality

Major water quality characteristics of groundwater in the alluvium and bedrock formations were compared using Piper and Stiff diagrams to determine whether brackish water entrained in the natural gas may have migrated upward into the alluvial aquifer during the release. Stiff and Piper diagrams provide a graphical means of comparing water quality analyses. Alluvial groundwater quality is represented by data collected at the residential, livestock, and irrigation wells and CPT piezometers during Phases I and II. Bedrock water quality is represented by the subsurface water quality data collected at Gas Storage Wells #3, #6, and #18 during venting of the surface casing. Based on the gas storage well completions, subsurface water from these wells appears to be predominantly from the Pierre Shale and/or Niobrara Formation overlying the gas storage reservoir (D-Sandstone).

Appendix G, Stiff Diagrams, provides individual Stiff diagrams for groundwater and subsurface water results for each of the residential, livestock, irrigation, CPT, and gas storage wells or piezometers sampled during Phases I and II. Stiff diagrams are also included for the groundwater quality data obtained from the Pierre Shale (Bjorklund and Brown 1957) and the D Sandstone (CIG 2006). Stiff diagrams plot the abundance of major ions (as milliequivalents per liter [meq/L]), such as calcium, magnesium, sodium, potassium, chloride, sulfate, and bicarbonate + carbonate, in a groundwater sample and facilitate visual comparison of the results with those from other wells. Stiff diagrams with similar shapes depict groundwater samples having similar composition.

Figure 5-11, Stiff Diagram Map, Phase I and II Groundwater Results, is a map showing Stiff diagrams for each of the residential, livestock, irrigation, CPT piezometers, and gas storage wells sampled during Phases I and II. This map illustrates the spatial variability of major chemical components in groundwater using the Stiff diagrams for each well sample. Review of this figure indicates that less mineralized recharge water in upland and dune sand areas increases in dissolved solids concentration as it moves downgradient towards the South Platte River. The increase in dissolved solids concentration primarily results from an increase in sulfate as the alluvial groundwater migrates downgradient. Increasing TDS contents are visually shown by the increasing size of the Stiff diagrams from the recharge area west-southwest of the gas plant, northeast towards the South Platte River. This trend is consistent with dissolution of gypsum within the alluvial aquifer and underlying Pierre Shale. The Stiff diagrams for subsurface waters from the Gas Storage Wells #3, #6, and #18 (red diagrams) are shown for comparison. Comparison of the shape of the Stiff diagrams for the alluvial groundwater with those from the bedrock formations clearly shows the chemical differences between these groundwaters and indicates that brackish water was not introduced to any significant extent into the alluvial aquifer.

Figure 5-12, Piper Diagram of Alluvium and Bedrock Groundwater, is a Piper diagram showing the Phase I and II groundwater results. The data depicted on this figure include groundwater from residential, livestock, irrigation, or CPT piezometers (alluvium groundwater; black symbol; 119 analyses) and groundwater from three gas storage wells (subsurface water; red symbol; 3 analyses) sampled during the Phase II investigation. Historical groundwater results are also shown for the alluvium (green symbol; 38 analyses), the Pierre Shale (blue symbol; 8 analyses), and the D Sandstone reservoir (orange symbol; 10 analyses) are also shown for comparison. The historical alluvium and Pierre Shale data were obtained from Bjorklund and Brown (1957). The D Sandstone data were obtained from CIG (CIG 2006). A Piper diagram depicts the relative abundance of major ions (in % meq/L) in groundwater samples, identifies chemically similar groundwaters, and shows the evolution of water chemistry along groundwater flow paths.

Figure 5-12, Piper Diagram of Alluvium and Bedrock Groundwater, shows that the alluvial groundwater compositions range from calcium-sodium bicarbonate water which occurs in upland recharge areas to a calcium-sodium sulfate water that is found in the area of and downgradient of the CIG Gas Plant. This change in groundwater composition from upgradient to downgradient areas is depicted by the approximately linear pattern of alluvial groundwater compositions shown the Piper diagram and reflects an increase in dissolved solids concentrations, primarily sulfate, as the water moves through the alluvium towards the South Platte River. Water quality data from the Pierre Shale, Niobrara Formation, and D Sandstone are also shown on Figure 5-12 and have much higher chloride, sodium, and potassium contents than alluvium groundwater. The predominant water found in these formations is a sodium chloride type, which is commonly associated with groundwater that has had a very long residence time in sedimentary aquifers or has been influenced by dissolution of evaporite minerals.

The groundwater compositions depicted on the Piper and Stiff diagrams indicate that the alluvial and bedrock (Pierre Shale, Niobrara Formation, and D Sandstone) groundwaters are compositionally distinct. These results also indicate that brackish water was not introduced into the alluvium during the gas release as the brackish water from the bedrock formations has significantly higher sodium and chloride concentrations compared to alluvial groundwater.

5.4 TASK 4B – INTERPRETATION OF 1996 3-DIMENSIONAL SEISMIC DATA

5.4.1 Purpose and Scope of Activity

CIG conducted a 3-D seismic survey over the Fort Morgan Gas Storage Field in 1996 to help delineate and evaluate the geologic structure and stratigraphy of the D Sandstone for natural gas storage. This sandstone occurs at a depth of approximately 5,600 ft in the field area. The seismic data collection methodology used in the 1996 3-D survey focused on acquiring good quality subsurface data at the target "D" sandstone depth.

Figure 5-13, Geophysical Interpretation Grid, 1996 3-D Seismic Survey, shows the 3-D seismic coverage in the area of interest. This figure also shows the location of CIG's compressor station and Gas Storage Well #26 in relation to seismic survey lines.

As part of CIG's ongoing studies, the 1996 3-D seismic data were reviewed, and interpretations of geologic structure were prepared for four horizons at shallower depths than the reservoir (e.g., 1,500 to 3,000 ft bgs) to evaluate implications for migration pathways for the October 2006 natural gas release from Gas Storage Well #26. The findings are summarized in the next section.

5.4.2 Findings

Results from the recent interpretation of the 1996 3-D seismic data within the depth range of 1,500 to 3,000 ft bgs, are summarized below.

Structure contour maps were prepared for four horizons identified from the 1996 3-D seismic lines. These mapped horizons correspond to approximate depths shown below.

Shallow 1 - 1,535 ft bgs

Shallow 2 - 1,850 ft bgs

Shallow 3 - 2,270 ft bgs

Shallow 4 - 2,850 ft bgs

Figure 5-14, Crossline 188 through FMU #26, a portion of Seismic Line 118, shows the mapped horizons, interpreted faults, and the approximate location of Gas Storage Well #26. This figure also demonstrates that the continuity of the seismic reflectors for Shallow 4, Shallow 3, and most of Shallow 2 is quite good; however, the shallowest seismic reflector for Shallow 1 is discontinuous and requires interpolation between gaps in the seismic data to prepare a coherent structure contour map. Consequently, the Shallow 1 structure map has relatively large uncertainty.

The Shallow 4 structure contour map with interpreted faults is presented in Figure 5-15, Shallow 4 Time Structure with Faults. This map shows an overall structural high (yellow and orange colors) complicated by faulting predominantly in the following areas: E ½ of Section 36; SE ¼ of Section 30; and the W ½ of Section 30 (T3N R57W). This structural high extends upward through the section and is still evident with some variations in Shallow 1, as seen on Figure 5-16, Shallow 1 Time Structure. However, faults that were clearly visible at Shallow 4 are not evident in Shallow 3, Shallow 2, or Shallow 1 (Figure 5-14, Crossline 118 through FMU #26). It could be that those faults do propagate upward into shallower zones but the quality of the 3-D data is not sufficient to map them.

It is apparent from the structure map of Shallow 1 (Figure 5-16, Shallow 1 Time Structure) that the main area where natural gas surfaced (immediately south and east of the compressor station) is generally up-dip (at a higher structural elevation) from the Gas Storage Well #26 release point. However, the natural gas surface expression in the SW ¼ of NW ½ of Section 36, is rather far removed from both Gas Storage Well #26 and the compressor station, and appears to be inconsistent with up-dip gas migration from Gas Storage Well #26. Moreover, because the faulting seen at the Shallow 4 horizon may extend upward to shallower depths, the possibility of fracturing extending above the faults into shallower units also exists. Relatively high permeability zones formed along bedding in the upper Pierre Shale and fault-related fracture zones may be preferred pathways for natural gas migration from the casing leak at Gas Storage Well #26. Barriers to gas migration may also occur where substantial displacement of bedding across the fault planes has created zones of clayey gouge along the faults.

Based on results of the interpretation of the 1996 3-D seismic data discussed above, CIG plans to conduct a new high-resolution seismic reflection survey focusing on improving the definition of geologic structures existing at shallower depths (e.g., 200 to 2,000 ft bgs). It is anticipated that collecting and interpreting the new seismic data will provide further definition of geologic structures that may have served as natural gas migration pathways. The new seismic survey is slated for 4th quarter 2007.

Task 5, Cased-hole Logging of Gas Storage Wells, involved investigation of the lateral extent of gas related to the subsurface leak at the Fort Morgan Gas Storage Well #26. The plan included running several specialized tools into the well bore to confirm the well was no longer leaking gas and to look for shallow accumulations of gas behind the casing that may migrate to the surface. The plan also included well logging of other gas storage wells and gathering surface casing pressure readings on all of the gas storage wells in the Field on a daily basis to assess the extent of elevated gas pressure near the surface and to monitor pressure as gas dissipated to the atmosphere.

The specialized tools utilized included a down-hole temperature-sensing device (temperature log) to identify any temperature anomalies that may indicate gas leakage from the well bore. In addition, CIG used sensitive noise monitoring equipment (noise log) which is capable of detecting leakage from the well bore, and a specialized tool, a gamma-ray/neutron log (GR/N log), that is capable of identifying gas that leaked from the well and has accumulated behind the well casing in porous rock formations. CIG also used a down-hole video camera to look for evidence of failure in the well casing. Additionally, CIG ran casing inspection logs to assess the well casing integrity.

6.1 FIELD ACTIVITIES

Standard oilfield cased-hole logging tools and services were contracted by CIG through Baker Atlas to determine the presence of gas saturation, temperature, noise, cased-hole apparent metal loss and gather video images. The logging responses from these tools were then interpreted for gas accumulation trends in the subsurface. The cased-hole well logging portion of the investigation included various combinations of GR/N, temperature, noise (Sonan), cased-hole video and Micro-Vertilog logging tools depending on the well completion configurations.

Two rounds of logging were completed in the Fort Morgan field. Round I started on October 23, 2006 and finished on November 11, 2006. A second round of logging (Round II) started on November 27, 2006 and finished on December 7, 2006. The total number of wells logged in Rounds I and II were 16 and 20, respectively. Table 6-1, Fort Morgan Field Baseline Casing Inspection Log Summary, presents pre-event baseline results for cased-hole logging surveys whereas Table 6-2, Fort Morgan Daily Progress Report - Round I, and Table 6-3, Fort Morgan Daily Progress Report - Round II, present the results of the two post-event rounds of cased-hole logging.

A key objective of the Round II logging program was to assess the extent to which gas accumulations identified during Round I were dissipating naturally and as a result of the venting activity. During Round II, wells with elevated surface casing pressures were vented/flared to aid in dissipating gas that leaked from Gas Storage Well #26 into the Pierre Shale. Surface casing pressures and associated vented/flared gas volumes are being recorded and reported to the COGCC at the requested frequency and therefore are not discussed in this report.

6.2 LOGGING TECHNICAL DISCUSSION

CIG's Reservoir Services group completed a review of the Round I and Round II logging results for the Fort Morgan Gas Storage Field. Figure 6-1, Map of Round I and Round II Logging, displays the wells logged in the Round I and Round II logging programs. One-page summaries from Round I are included in Appendix H.1, Round I Cased-Hole Logging Summaries, while Round II summaries reside in Appendix H.2, Round II Cased-Hole Logging Summaries. Baker Atlas reviewed the logging results with Reservoir Services personnel on November 7, 2006 for Round I and again on January 9, 2007 for Round II.

Round I logs included the GR/N, temperature, Sonan, Micro-Vertilog and down hole video cameras. The well selection for this round was designed to give a north-south and east-west view and investigate if the leak occurrence in Gas Storage Well #26 was an isolated incident or possibility a common problem across the field. Two different independent video logging companies (Down Hole Video [DHV] and Jet West) were utilized to gather the down hole videos. DHV provided video services for 10 wells which are only casing completions. None of the Fort Morgan wells completed with tubing were inspected with the video services. Jet West provided side-scan video services for the Gas Storage Well #26 well only. This video provided a visual picture of the casing failure near a casing collar in the well at approximately 846 ft below ground level. A review of the videos and Micro-Vertilogs did not suggest the other wells in the Fort Morgan Field have integrity problems.

Micro-Vertilog casing inspection tools were utilized on cased-hole completion wells. Nine Micro-Vertilog logs were collected in Round I. Casing inspection logs (Vertilogs/Micro-Vertilogs) were previously run in all storage wells in Fort Morgan between 1999 and 2001 (Table 6-1, Fort Morgan Field Baseline Casing Inspection Log Summary). Round II logs included the GR/N, temperature and Sonan logging tools and additional wells were added to the logging program based on the results obtained in Round I.

6.3 LOGGING OBSERVATIONS AND ANOMALIES

The following are observations from the Round I and Round II logging programs. Due to the subjective interpretation of the temperature and noise logs, the results from the GR/N tool were relied upon to a greater degree in determining the presence of gas behind the production casing at subsurface depths.

6.3.1 Round I Logging Results

Gamma Ray/Neutron

Gas Storage Well	Depth(s) (feet)	Comment
#3	352-399	Neutron response indicated possible gas saturation
#4	188-326	Neutron response indicated possible gas saturation
	850-860	Neutron response indicated possible gas saturation
	1077-1108	Neutron response indicated possible gas saturation
#11	188-1108	Several neutron responses indicated possible gas saturation
#12	14-214	Several neutron responses indicated possible gas saturation
#15	404-592	Several neutron responses indicated possible gas saturation
#24	214-219	Neutron response indicated possible gas saturation
#26	144-618	Several neutron responses indicated possible gas saturation
	836-844	Neutron response goes off scale (depth of casing leak); indicated gas saturation

Temperature

No indications from the temperature logs of gas leaks or fluids entering any of the wells in the field except for Gas Storage Well #26. For the temperature anomalies, Gas Storage Wells #11, #23, #26 and #27 wells show anomalies in the range of 210-950 ft depths. Temperature anomalies vary from 1/8º to 1º cooling anomalies except for Gas Storage Well #23 where a slight warming trend was observed.

Sonan

No indications from the Sonan logs of gas leaks or fluids entering any of the wells in the field except for Gas Storage Well #26. Several wells show noise and the logging notes describe these in detail. Generally noise responses appeared above or surrounding neutron anomalies which may indicate fluid movement behind pipe.

Micro-Vertilog

No leaks have been detected in any other wells in Round I of the Micro-Vertilog logging. *Nine wells had Micro-Vertilogs run during Round I.* A detailed report from Baker Atlas dated January 5, 2007 on Gas Storage Well #26 is attached as Appendix H.3, Baker Atlas Report. This report compares the 2001 and 2006 Micro-Vertilogs for Gas Storage Well #26. The report provided by Baker Atlas outlines a clear difference between the two Micro-Vertilog data sets on the signature of the collar containing the leak. The report also incorporates the video logging for comparison with the Micro-Vertilog technology. At the identified leak in Gas Storage Well #26, the Micro-Vertilog is not able to quantify the severity of the damage but can identify a large flux leakage response due to the exposed collar threads.

Video

The Gas Storage Well #26 cased-hole video confirmed a casing failure at 846 ft. No other wells indicate collar or casing leaks. The second video captured a side-scan video coverage of the casing failure in Gas Storage Well #26 and video from 1,003.8 ft on up. No other abnormal collars or features were seen with the side-scan video.

6.3.2 Round II Logging Results

Gamma Ray/Neutron

Gas Storage Well	Depth(s) (feet)	Comment
#3	184-399	Neutron response has dissipated to base log levels
	216-238	Neutron response indicated possible gas saturation
#4	573-604	Neutron response not present on 2001 log
	1077-1108	Collar at 1083 ft not present on 2001 log
#6*	144-150	Neutron feature not present on 2001 log
#11	160-162	Neutron response indicated possible gas saturation Not present on 11/6/06 log
	162-165	High gamma ray not present on 2001 log
#12	14-200	Dissipated neutron response to base log
	200-207	Increase in neutron response-possible gas
#15	302-319	Opposite collar and elevated neutron response
	404-592	Dissipated to base log levels
#19*	146-213	Neutron response indicated possible gas saturation
	1012-1020	Neutron response indicated possible gas saturation
	1533-1565	Neutron response indicated possible gas saturation
#24	167-169	Neutron response indicated possible gas saturation
	173-176	Neutron response indicated possible gas-opposite collar
	214-219	Neutron response indicated possible gas saturation
#26	144-618	Several neutron responses indicated gas saturation
	210-230	Apparent accumulation of gas at base of surface casing
	836-844	Dissipated Neutron response -dissipated now
	668-696	High gamma ray may be due to clay content in fluid or salt

Notes:
* Denotes wells logged only in Round II thus far
Dissipated is referenced to the Round I GR/N logging.
“Base log” refers to the initial GR/N logs run in 1999-2001

Temperature

No indications from the temperature logs of gas leaks or fluids entering any of the wells in the field except for Gas Storage Well #26. Temperature anomalies are seen in the following wells: Gas Storage Wells #4, #11, #15, #23, #24, #26, #27, #30 and #33. These wells show anomalies in the range of 100-1,140 ft depths. Temperature anomalies vary from 1/8º to 3º cooling and warming trends. Some anomalies may be due to unstable conditions in the well bore.

Sonan

No indications from the Sonan logs of gas leaks or fluids entering any of the wells in the field except for Gas Storage Well #26. The fluid level in Gas Storage Well #26 was at 668 ft at the time of the Round II of logging (December 1, 2006), which is above the casing failure. Several wells show noise gains and the logging notes describe these in detail. Generally, the noise is seen above or surrounding neutron anomalies which may indicate fluid movement behind pipe.

Micro-Vertilog

No Micro-Vertilog logs were run in the Round II logging program. The type of completion in the additional wells of the Round II logging program could not accommodate the Micro-Vertilog tool.

Video

No videos were run in Round II of the logging program.

6.4 INVESTIGATION CONCLUSIONS

Rounds I and II of the logging investigation program indicate that all Fort Morgan gas storage wells have integrity with the exception of Gas Storage Well #26 where a casing leak was identified. The GR/N tool was used as the main indicator of potential gas saturation in the subsurface behind casing. While CIG's Reservoir Services Department believes the temperature log responses may be subjective, they do indicate potential fluid movement in this depth range. Figure 6-2, Neutron Anomalies – Potential Gas Saturation Locations, highlights the wells with interpreted neutron gas saturations from Rounds I and II. Results of the cased-hole logging program and a review of shut-in surface casing pressures indicate that the gas has migrated mainly to the south and east of Gas Storage Well #26 in a depth range from 140-850 ft with several anomalies around the ± 200 ft depth range. However, Gas Storage Well #11, located to the north of Gas Storage Well #26 provides some indications of gas accumulation to the north. Further investigation using CPT data, in addition to groundwater sampling, should help delineate trends of shallow gas movement in the Fort Morgan Field area.

7.1 LAND SURFACE MONITORING (PHASE II, TASK 1)

The results of the land surface monitoring suggests that the apparent areal heave or subsidence since the gas release was relatively small and does not appear to have affected the overall stability of the Gas Plant or surrounding areas. The apparent subsidence areas coincide with known areas of gas migration or release. These subsidence areas appear to reflect relaxation of the land surface that may have heaved (domed) during the gas release. The apparent heave areas are enigmatic as they tend to largely occur around the perimeter of the benchmark survey area.

7.2 LAND SURFACE STABILITY ASSESSMENT (PHASE II, TASK 2)

Ninety-one (91) CPT borings were pushed to depths ranging between 39 and 140 ft. CPT borings were pushed to determine the subsurface stratigraphy of the alluvium, the depth to the water table, the presence of subsurface natural gas, identify abnormal pore pressures, determine the geotechnical properties of the soils, and to look for subsurface fissures or evidence of subsurface piping.

Natural gas was primarily detected in CPT borings pushed in areas where the gas release surfaced. The distribution of natural gas measured during advancement of the CPT borings is consistent with the extent of dissolved methane found in groundwater sampled from the CPT piezometers and wells.

Pore pressure dissipation tests were performed to assess whether abnormal formation water pressures were present in the subsurface that might indicate the presence of trapped natural gas. None of the dissipation tests indicated abnormal formation pressures that might have indicated trapped gas in the subsurface.

Subsurface fissures and openings were noted at only one CPT location, CPT-81, during the Phase II investigation. The subsurface opening was encountered a depths ranging between 5 ft and 23 ft below grade. The subsurface opening appears to have been caused by soil liquefaction and subsequent piping. No other subsurface fissures or openings were encountered in any of the CPT borings.

The top of bedrock was encountered in 22 of the CPT borings, mostly southwest of the Gas Plant. These CPT data were incorporated with other bedrock data to develop a bedrock topographic map which shows that the top of bedrock is higher in areas southwest of the Gas Plant and gradually decreases in elevation to the east and north of the Gas Plant. The highest bedrock elevation lies southwest of the Gas Plant at approximately 4,360 ft msl. The lowest bedrock elevations are found north of the Gas Plant at an approximate elevation of 4,180 ft msl. A prominent north-south trending bedrock valley lies about 0.5-mile east of the Gas Plant along the ancestral Badger Creek valley.

Southwest of the Gas Plant, the depth to bedrock beneath the craters is about 40 ft below grade. The depth to bedrock beneath the Gas Plant is about 100 ft below grade. Both of these areas appear to be situated on local bedrock ridges. Gas Storage Well #26 lies within a local bedrock valley that may have served as a pathway for up-dip gas migration within the alluvium.

Geologic sections in the area of the Gas Plant show that the alluvium beneath the Gas Plant is comprised primarily of coarse-grained sands and gravels. This thick accumulation of sands and gravels may indicate a period of long-term point bar deposition in this area. Similarly thick accumulations of sands and gravels are noted in the central portions of the geologic sections south of the Gas Plant. These channel sands and gravels may have served as a gas migration pathway. Near surface silts and clays that directly overlie sands appear to play an important role in the liquefaction and piping of the underlying sands. Deeper silts and clays may also locally limit vertical migration of higher dissolved gas concentrations in the lower part of the alluvium.

7.3 NATURE AND EXTENT OF GAS-IMPACTED AREAS (PHASE II, TASK 3)

A high-resolution aerial survey was conducted to delineate the gas-affected areas at the ground surface (e.g., craters and fissures) by obtaining a comprehensive set of detailed color orthophotographs and LiDAR data that covered all areas within 2 miles of CIG Gas Storage Well #26. The orthophotos and topographic map provided an accurate base map for the subsequent data collection activities and CPT investigation.

7.4 CONTINUED NATURE AND EXTENT EVALUATION (PHASE II, TASK 4A)

Task 4A involves an on-going assessment of the nature and extent of natural gas in the sub-surface via one round of pre-irrigation season and two rounds of irrigation season sampling at piezometers installed during the CPT investigation.

7.4.1 Headspace Gas Monitoring

Piezometer and soil vapor monitoring probe headspace gas monitoring was performed in March and May 2007 using a combustible gas meter. The combustible gas levels measured in May were generally lower than those measured in March, except for four locations (CPT-46D, CPT-53S, CPT-57R, and CPT-57S) where the combustible gas measurements were 100% of the LEL in both March and May. Piezometers with combustible gas concentrations of 100% of the LEL are coincident with areas of elevated dissolved methane in alluvial groundwater.

H_2S monitoring was conducted in April 2007 at 57 locations, including all 28 vapor probe locations and 29 selected. All of the H_2S results were <0.010 ppm. These H_2S concentrations are three or more orders of magnitude below established ACGIH TLV (10 ppm) or STEL (15 ppm) action levels and, thus, pose no health and safety concern.

7.4.2 Groundwater Flow Conditions

Groundwater within the alluvium occurs under water table conditions. Prior to the startup of irrigation, groundwater was found at depths ranging between approximately 10 and 60 ft below grade. The depth to groundwater beneath the Gas Plant in March 2007 was about 25 ft below grade. Saturated thickness of the alluvium ranges between 18 and 115 ft. Groundwater within the shallow alluvial aquifer generally flows from south-southwest to north-northeast during this period. This flow direction is generally consistent with regional groundwater flow towards the South Platte River.

Groundwater levels were also measured in May 2007 after irrigation started in the area. The groundwater levels and flow directions within the alluvium are generally consistent with those observed in March 2007, except that the flow direction has changed from northeastward to northwestward in the area of CPT-01S and CPT-19S, where local irrigation pumping has created a cone of depression.

The horizontal hydraulic gradient within the alluvial aquifer ranges between approximately 0.002 ft/ft to 0.009 ft/ft and averages approximately 0.004 ft/ft in March 2007. For the range of hydraulic gradients and hydraulic conductivities in this area, the estimated groundwater flow rates (seepage velocities) range between 0.4 ft/d and 15.2 ft/d, assuming the effective porosity is 0.25. The average groundwater flow rates range between 1.2 ft/d and 6.8 ft/d.

Groundwater elevation measurements at seven piezometer clusters suggest that a vertical hydraulic gradient exists between the shallow and deep piezometers that causes a portion of the groundwater flow component to move either downward (positive gradient) or upward (negative gradient). The vertical hydraulic gradients calculated for the alluvial aquifer range between -0.003 ft/ft and +0.032 ft/ft. The occurrence of vertical hydraulic gradients within the alluvial aquifer is consistent with the stratigraphic heterogeneity of the stratum, where sand and gravel strata are intercalated with silt and clay layers. The downward (positive) gradients may reflect areas of increased recharge or localized pumping effects. The occurrence of localized upward (negative) gradients may represent the natural hydraulic condition where irrigation effects are insignificant, or may indicate the localized presence of natural gas.

7.4.3 Alluvial Aquifer Groundwater Quality

In March 2007, dissolved methane concentrations in groundwater from the alluvial aquifer ranged between 0.000019 J and 26 mg/L. Dissolved methane concentrations at 16 locations exceeded the COGCC dissolved methane action level of 2 mg/L. Dissolved methane concentrations at an additional 15 locations exceeded the background UTL of 0.0067 mg/L, but are less than the COGCC dissolved methane action level of 2 mg/L.

Dissolved methane plumes occur beneath the areas where gas erupted at the ground surface during the October 2006 release. The maximum dissolved methane concentrations in both these areas are similar; however, the southwestern plume is much smaller in extent than the plume south and east of the Gas Plant. The lateral plume extents are consistent with the locations of craters and fissures in the ground surface associated with the gas release.

Dissolved methane concentrations at piezometer clusters (shallow and deep) generally suggest that higher dissolved methane concentrations occur in the deeper piezometers. This difference in dissolved methane concentrations with depth appears to be related to a confining layer in the lower alluvium that is capable of trapping and limiting upward gas migration.

In March 2007, chloride concentrations in the alluvial aquifer ranged between 14 and 325 mg/L. The areal distribution of the chloride does not suggest that groundwater quality in the alluvial aquifer has been impacted by upward migration of brackish water during the natural gas release. The highest chloride concentrations do not coincide with areas where the natural gas surfaced.

In March 2007, sulfate concentrations in the alluvial aquifer ranged between 100 mg/L and 2,030 mg/L. These sulfate results are consistent with the elevated sulfate concentrations historically reported in the Fort Morgan area since the 1940s (Bjorklund and Brown 1957). The areal distribution of sulfate is similar to that of chloride. Although coincident with the surface features of the gas release near the Gas Plant, the higher sulfate concentrations do not appear to be related to upward migration of brackish water associated with the gas release because subsurface water from Gas Storage Wells #3, #6, and #18 has very low sulfate content (and correspondingly high chloride content). The higher sulfate concentrations in this area are probably related to naturally-elevated sulfate concentrations in the Pierre Shale and/or local fertilization and irrigation practices.

In March 2007, TDS concentrations in the alluvial aquifer ranged between 461 mg/L to 4,470 mg/L. Elevated TDS concentrations have been known in this area since the 1940s (Bjorklund and Brown 1957). The high TDS concentrations are largely a result of the historically high sulfate concentrations found in this area.

The groundwater results for the alluvial aquifer were compared to the background UTLs developed during Phase I to evaluate whether or not the alluvial groundwater may potentially have been affected by the natural gas release. In March, 2007, dissolved methane, ethane, ethane, and propane concentrations in some groundwater samples exceeded their respective background UTLs. Locations where these dissolved gases exceeded the background UTL may have been affected by the natural gas release.

Comparison of inorganic analytes to the background UTLs indicates that boron, cadmium, calcium, iron, magnesium, manganese, silver, thallium, and vanadium concentrations in a few of the groundwater samples slightly exceed their respective background UTLs. These results are consistent with frequency of background UTL exceedances for these constituents found during the Phase I evaluation, which are attributable to false positive error rates, and do not indicate that brackish water has been introduced into the alluvial aquifer during the gas release.

The groundwater results from the alluvial aquifer were compared to applicable Colorado groundwater quality standards. Most of the dissolved metals in groundwater are less than their respective Colorado groundwater quality standards. Dissolved boron, iron, manganese, and selenium exceed the Colorado groundwater quality standard at least once. It should be noted that the background UTLs for dissolved iron, manganese, and selenium are higher than their respective groundwater quality standards. None of the dissolved metal exceedances appear to be related to the natural gas release.

Sulfate is the only inorganic parameter that exceeds its Colorado groundwater quality standard (250 mg/L). Sulfate concentrations at 85 locations exceed the sulfate standard. The background sulfate UTL (1,350 mg/L) is also higher than the sulfate groundwater quality standard. These sulfate results are consistent with the previously reported Phase I sulfate results and with the historically elevated sulfate concentrations reported in groundwater in the Fort Morgan area since the 1940s (Bjorklund and Brown 1957).

7.4.4 Bedrock Formation Groundwater Quality

Subsurface water was obtained from three gas storage wells (Gas Storage Wells #3, #6, and #18) when the surface casing was vented to remove natural gas. The dissolved methane concentrations in the subsurface water from these gas storage wells were similar and ranged between 14 and 23 mg/L. The dissolved methane concentrations observed at these wells were expected as the waters were obtained during venting of the observation gas storage well surface casings and likely represent residual methane remaining in the bedrock formations following the gas release.

The groundwater results from the bedrock formations were compared to applicable Colorado groundwater quality standards. Dissolved methane in the three gas storage wells exceeds the COGCC action level of 2 mg/L. Additionally, benzene concentrations from these gas storage wells exceed groundwater maximum contaminant levels (MCL) and the Colorado groundwater quality standards (5 µg/L). These exceedances do not pose a health risk because these water samples are from deep bedrock formations that are not used for drinking water or domestic use. There were no other BTEX compounds, dissolved metals, or major ions that exceeded applicable standards.

Subsurface water produced during venting of the surface casing at Gas Storage Wells #3, #6, and #18 is from the Pierre Shale and/or the deeper Niobrara Formation and it is chemically distinct from the alluvial groundwaters. Groundwater within these bedrock formations is characterized by high sodium, chloride, bicarbonate, and TDS and low calcium and sulfate concentrations. These waters are also characterized by high boron, bromide, and iodide concentrations.

7.4.5 Comparison of Alluvial and Bedrock Groundwater Quality

Major water quality characteristics of groundwater in the alluvium and bedrock formations were compared using Piper and Stiff diagrams to determine whether brackish water entrained in the natural gas may have migrated upward into the alluvial aquifer during the release.

The groundwater chemical compositions indicate that the alluvial and bedrock groundwaters are compositionally distinct. These results also indicate that significant quantities of brackish water were not introduced into the alluvium during the gas release. Brackish water that is naturally present in the bedrock formations has significantly higher sodium and chloride concentrations compared to the chloride concentrations found in alluvial groundwater.

7.5 1996 SEISMIC DATA INTERPRETATION (PHASE II, TASK 4B)

CIG conducted a 3-D seismic survey over the Fort Morgan Gas Storage Field in 1996 to help delineate and evaluate the geologic structure and stratigraphy of the D Sandstone. Interpretation of the seismic data indicates the presence of subsurface faults and structures that could potentially influence the natural gas release migration path if these structures persist at shallower (<850 ft) depths. Relatively high permeability zones formed along bedding in the upper Pierre Shale and fault-related fracture zones may also be preferred pathways for natural gas migration. Barriers to gas migration may also occur where substantial displacement of bedding across the fault planes has created zones of clayey or cemented gouge along the faults.

Based on results of the interpretation of the 1996 3-D seismic data, CIG plans to conduct a high-resolution seismic reflection survey focusing on improving the definition of geologic structures existing at shallower depths (e.g., 200 to 2,000 ft bgs). It is anticipated that collecting and interpreting the new data will provide further definition of geologic structures that may have influenced the natural gas release migration paths.

7.6 CASED-HOLE LOGGING (PHASE II, TASK 5)

Rounds I and II of the logging investigation program indicate that all Fort Morgan wells have integrity with the exception of Gas Storage Well #26 where a casing leak was identified. The GR/N tool was used as the main indicator of potential gas saturation in the subsurface behind casing. Results of the cased-hole logging program and a review of shut-in surface casing pressures indicate that the gas has migrated mainly to the south and east of Gas Storage Well #26. However, Gas Storage Well #11, located to the north of Gas Storage Well #26 provides some indications of gas accumulation to the north. Further investigation using the groundwater sampling results and the additional seismic studies should help delineate trends of shallow gas movement in the Fort Morgan Field area.

Of the six Phase II Investigation tasks listed in Section 1, Introduction, Tasks 2, 3, and 5 are complete. For Task 2, a Land Stability Report was prepared (Appendix B, Interim Stability Report). For Task 3, the results of the LiDAR survey and orthophotographs have been used to create a base map used for all figures where appropriate. For Task 5, down-hole logging, the logging activities are complete and the results are discussed in Section 6, Case-Hole Logging of Gas Storage Wells (Phase II – Task 5). For all other tasks, additional field studies are planned for 2007. These activities are discussed below by Phase II task number.

8.1 CONTINUED LAND SURFACE MONITORING (TASK 1)

Although the results of the benchmark surveying have not indicated any significant movement of the ground surface, one additional round (5^{th} round) of benchmark monitoring was conducted in July 2007. The results will be used to evaluate the need for additional stability monitoring and will be reported in the Final Phase II Investigation Report with recommendations as appropriate.

8.2 IRRIGATION SEASON SAMPLING AND ANALYSIS (TASK 4A)

Per the Phase II Workplan Addendum, two groundwater sampling rounds are planned for irrigation season. The first of these groundwater sampling events was conducted in June 2007 and the second is planned for August. These two events will follow the sampling and analysis program described in the Phase II Work Plan Addendum, with one modification. The analysis of BTEX analytes will be added to all locations where methane was detected at 2 mg/L or above in pre-irrigation season (i.e., March 2007) samples.

Additionally, in July, supplemental sampling for dissolved gases at selected residences will be conducted to monitor the extent of the methane plume. This supplemental sampling event is intended to provide additional data to monitor movement of the dissolved methane in the Gas Plant vicinity and to the north.

The results will be reported in the Final Phase II Investigation Report.

8.3 NEW SEISMIC STUDIES (TASK 4B)

CIG plans to conduct a high-resolution seismic reflection survey in the vicinity of the Fort Morgan natural gas storage facility. The purpose of the survey is to use seismic reflection techniques to characterize the geologic structure from 200 to 2,000 ft deep in the vicinity of the gas storage facility, to further develop the conceptual model of the gas release mechanism and preferred gas migration pathways. Evaluating these seismic data will assist in the identification of possible locations for monitoring wells and/or vent wells. The following activities are planned as part of Task 4B:

- Preparation of detailed specifications for seismic reflection subcontractors and selection of preferred subcontractor.
- Conduct feasibility-level seismic refraction tomography survey to improve the understanding of the top of bedrock and location of paleo-channels.
- Perform high-resolution seismic reflection surveys.
- Processing and interpretation of new geophysical survey data.

- A geophysical report presenting the results of the new geophysical studies (reflection and refraction tomography).

It is anticipated that field activities will take approximately 4 weeks, data processing will take approximate 4 to 6 weeks, and data interpretation will require approximately 4 weeks. The results will be reported in the Final Phase II Investigation Report.

8.4 MONITOR WELL INSTALLATION (TASK 4C)

Task 4C will focus on the feasibility and potential installation of monitoring wells. Information collected in Tasks 4A and 4B will serve to aid CIG in decisions related to the number and locations of monitor wells. A Well Installation Plan will be developed and provided to COGCC prior to any well installation activities.

8.5 LONG-TERM MONITORING (TASK 6)

The Phase II data will be used to develop an appropriate long-term sampling program. The monitoring program will be summarized in a Long-Term Monitoring Plan, which will be submitted to the COGCC for approval prior to implementation.

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CIG. 2007b. Draft Phase I Well Water and Air Sampling Report, Volumes 1 and 2. February 12.

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Appendix A.1

Remote Methane Leak Detector Monitoring Data

Data for: May 4, 2007
June 4, 2007
July 3, 2007
August 2, 2007

Fort Morgan Well # 26 Leak Incident Field Sheet

Well #	Gas Detected	Water Sampled	Gas Monitor Date SN#
70,71	No	No	Not Applicable
73	No	No	Not Applicable
72	No	No	Not Applicable
74	No	No	Not Applicable
75	No	No	Not Applicable
76	No	No	Not Applicable
31	No	No	Not Applicable
34	No	No	Not Applicable
67	No	No	Not Applicable
68	No	No	Not Applicable
66	No	No	Not Applicable
69	No	No	Not Applicable
100	250 ppm	No	Not Applicable
101	No	No	Not Applicable
99	No	No	Not Applicable
102	No	No	Not Applicable
65,64	No	No	Not Applicable
61	No	No	Not Applicable
NA/West of 59	No	No	Not Applicable
59	No	No	Not Applicable
62,63	No	No	Not Applicable
52,53,54,55,56,57	No	No	Not Applicable
58	No	No	Not Applicable
98	No	No	Not Applicable
Section # 1 South of Plant – Outside 1 mile radius			
114	No	No	Not Applicable
118	No	No	Not Applicable
119	No	No	Not Applicable
120	No	No	Not Applicable
121	No	No	Not Applicable
	Date	***Time***	***Reading***
Surface Areas Venting			
County Rd 18 North of Rd N	5-4-07	1:00 PM	Clear
Wheat Field	5-4-07	1:10 PM	100 ppm
County Rd 18 South of Rd N	5-4-07	1:20 PM	Clear
County Rd N West of Rd 18	5-4-07	1:30 PM	Clear
Sink Holes Venting			
Area 1 In field North of Well # 12	5-4-07	1:40 PM	Clear
Area 2 On County Rd 18	5-4-07	1:50 PM	Clear
Area 3 West of Rd 18	5-4-07	2:30 PM	Clear
Area 4 South/Southeast of plant fence	5-4-07	2:40 PM	Clear
Area 5 Southwest of plant in pasture	5-4-07	2:50 PM	Clear

*Mild = 1,000 to 3,000 ppm *Hot = >3,001 ppm Sampling Date: 05-04-07

Fort Morgan Well # 26 Leak Incident Field Sheet

Well #	Gas Detected	Water Sampled	Gas Monitor Date SN #
70,71	No	No	Not Applicable
73	No	No	Not Applicable
72	No	No	Not Applicable
74	No	No	Not Applicable
75	No	No	Not Applicable
76	No	No	Not Applicable
31	No	No	Not Applicable
34	No	No	Not Applicable
67	No	No	Not Applicable
68	No	No	Not Applicable
66	No	No	Not Applicable
69	No	No	Not Applicable
100	250 ppm	No	Not Applicable
101	No	No	Not Applicable
99	No	No	Not Applicable
102	No	No	Not Applicable
65,64	No	No	Not Applicable
61	No	No	Not Applicable
NA/West of 59	No	No	Not Applicable
59	No	No	Not Applicable
62,63	No	No	Not Applicable
52,53,54,55,56,57	No	No	Not Applicable
58	No	No	Not Applicable
98	No	No	Not Applicable
Section # 1 South of Plant – Outside 1 mile radius			
114	No	No	Not Applicable
118	No	No	Not Applicable
119	No	No	Not Applicable
120	No	No	Not Applicable
121	No	No	Not Applicable
	Date	***Time***	***Reading***
Surface Areas Venting			
County Rd 18 North of Rd N	6-4-07	1:00 PM	Clear
Wheat Field	6-4-07	1:10 PM	200 ppm
County Rd 18 South of Rd N	6-4-07	1:20 PM	Clear
County Rd N West of Rd 18	6-4-07	1:30 PM	Clear
Sink Holes Venting			
Area 1 In field North of Well # 12	6-4-07	1:40 PM	Clear
Area 2 On County Rd 18	6-4-07	1:50 PM	Clear
Area 3 West of Rd 18	6-4-07	2:30 PM	Clear
Area 4 South/Southeast of plant fence	6-4-07	2:40 PM	Clear
Area 5 Southwest of plant in pasture	6-4-07	2:50 PM	Clear

*Mild = 1,000 to 3,000 ppm *Hot = >3,001 ppm Sampling Date: 06-04-07

Fort Morgan Well # 26 Leak Incident Field Sheet

Well #	Gas Detected	Water Sampled	Gas Monitor Date SN #
70,71	No	No	Not Applicable
73	No	No	Not Applicable
72	No	No	Not Applicable
74	No	No	Not Applicable
75	No	No	Not Applicable
76	No	No	Not Applicable
31	No	No	Not Applicable
34	No	No	Not Applicable
67	No	No	Not Applicable
68	No	No	Not Applicable
66	No	No	Not Applicable
69	No	No	Not Applicable
100	No	No	Not Applicable
101	No	No	Not Applicable
99	No	No	Not Applicable
102	No	No	Not Applicable
65,64	No	No	Not Applicable
61	No	No	Not Applicable
NA/West of 59	No	No	Not Applicable
59	No	No	Not Applicable
62,63	No	No	Not Applicable
52,53,54,55,56,57	No	No	Not Applicable
58	No	No	Not Applicable
98	No	No	Not Applicable
Section # 1 South of Plant – Outside 1 mile radius			
114	No	No	Not Applicable
118	No	No	Not Applicable
119	No	No	Not Applicable
120	No	No	Not Applicable
121	No	No	Not Applicable
	Date	***Time***	***Reading***
Surface Areas Venting			
County Rd 18 North of Rd N	7-3-07	1:00 PM	Clear
Wheat Field	7-3-07	1:10 PM	Clear
County Rd 18 South of Rd N	7-3-07	1:20 PM	Clear
County Rd N West of Rd 18	7-3-07	1:30 PM	Clear
Sink Holes Venting			
Area 1 In field North of Well # 12	7-3-07	1:40 PM	Clear
Area 2 On County Rd 18	7-3-07	1:50 PM	Clear
Area 3 West of Rd 18	7-3-07	2:30 PM	Clear
Area 4 South/Southeast of plant fence	7-3-07	2:40 PM	Clear
Area 5 Southwest of plant in pasture	7-3-07	2:50 PM	Clear

*Mild = 1,000 to 3,000 ppm *Hot = >3,001 ppm Sampling Date: 07-03-07

Fort Morgan Well # 26 Leak Incident Field Sheet

Well #	Gas Detected	Water Sampled	Gas Monitor Date SN #
70,71	No	No	Not Applicable
73	No	No	Not Applicable
72	No	No	Not Applicable
74	No	No	Not Applicable
75	No	No	Not Applicable
76	No	No	Not Applicable
31	No	No	Not Applicable
34	No	No	Not Applicable
67	No	No	Not Applicable
68	No	No	Not Applicable
66	No	No	Not Applicable
69	No	No	Not Applicable
100	No	No	Not Applicable
101	No	No	Not Applicable
99	No	No	Not Applicable
102	No	No	Not Applicable
65,64	No	No	Not Applicable
61	No	No	Not Applicable
NA/West of 59	No	No	Not Applicable
59	No	No	Not Applicable
62,63	No	No	Not Applicable
52,53,54,55,56,57	No	No	Not Applicable
58	No	No	Not Applicable
98	No	No	Not Applicable
Section # 1 South of Plant – Outside 1 mile radius			
114	No	No	Not Applicable
118	No	No	Not Applicable
119	No	No	Not Applicable
120	No	No	Not Applicable
121	No	No	Not Applicable
	Date	***Time***	***Reading***
Surface Areas Venting			
County Rd 18 North of Rd N	8-2-07	1:00 PM	Clear
Wheat Field	8-2-07	1:10 PM	Clear
County Rd 18 South of Rd N	8-2-07	1:20 PM	Clear
County Rd N West of Rd 18	8-2-07	1:30 PM	Clear
Sink Holes Venting			
Area 1 In field North of Well # 12	8-2-07	1:40 PM	Clear
Area 2 On County Rd 18	8-2-07	1:50 PM	Clear
Area 3 West of Rd 18	8-2-07	2:30 PM	Hot (2,000 to 3,000 ppm)
Area 4 South/Southeast of plant fence	8-2-07	2:40 PM	Clear
Area 5 Southwest of plant in pasture	8-2-07	2:50 PM	Clear

*Mild = 1,000 to 3,000 ppm   *Hot = >3,001 ppm   Sampling Date: 08-02-07

Appendix A.2

Community Outreach

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Appendix D

Dissipation Test Plots

Appendix E

Shear Wave Velocity Profiles and Calculations

Appendix F

Data Validation Reports

Appendix G

Stiff Diagrams

Appendix H.1

Round I Cased-Hole Logging Summaries

Appendix H.2

Round II Cased-Hole Logging Summaries

Appendix H.3

Baker Atlas Report