Apogee Scientific, Inc.

Ground Survey Of The Raton Basin For Methane Seeps

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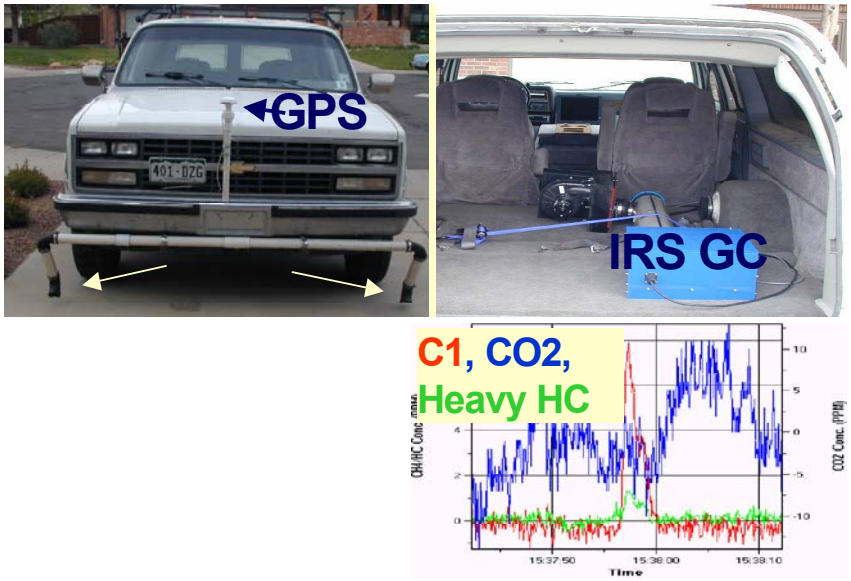
Introduction

The Raton Basin is located in south central Colorado with an area of approximately 1,300 square miles. The basin is underlain by two coal seams, the Raton and the Vermejo. These coals outcrop around the basin and within the basin. Raton and Vermejo coals have been mined for over one hundred years. Currently, the coals within the basin are being drilled to produce methane. A project was undertaken by the Colorado Oil and Gas Conservation Commission (COGCC) to identify the existing historical methane seeps, and to the extent possible, identify and document conditions prior to coalbed methane development. Apogee Scientific, Inc. (ASI) was contracted by COGCC to fulfill a part of phase one of this project, a ground survey to locate methane seeps within the Raton Basin. This report documents the ground survey conducted by ASI.

This survey was conducted using a 4-wheel drive vehicle equipped with an infrared-based gas detector developed by ASI. This gas detector was designed to find leaks in natural gas pipelines, and is referred to as the Apogee Leak Detection System (LDS). The LDS is a three-channel instrument capable of measuring methane (CH_4), total hydrocarbons (HC) and carbon dioxide (CO_2) at sub part per million (PPM) concentrations and a speed of 10 samples per second. The vehicle was also equipped with a Global Positioning System (GPS) based navigation system. The navigation system consisted of a Garmin III+ GPS, and a computer running the Delorme Street Atlas program. In addition to the LDS and navigation system, the vehicle was equipped with a differential GPS, wind speed, wind direction, and temperature sensors. The survey vehicle is shown in Figure 1.

Figure 1. Survey vehicle (from Gorody 2003)



The survey took place between November 9, 2000 and April 11, 2001. A total of 216 hours on 26 different days was spent surveying the basin. During this time, 2749 miles were driven within the basin plus an additional 1499 miles were driven around the edge of the basin in order to obtain access to the basin. A total of 67 seeps were located.

Procedures

Equipment

The LDS consists of a high-speed gas analyzer that can detect methane, total hydrocarbons, and carbon dioxide in gas plumes at sub part per million concentrations. The LDS is coupled to a Global Positioning System (GPS) receiver to determine vehicle location, and has a computer-based data acquisition system for data logging and display. The computer monitor simultaneously displays methane, total hydrocarbon, and carbon dioxide concentrations as they are detected and for the previous sixty seconds. A comparison of the relative concentrations of the three gases helps determine the probable source of the emission being detected. For example, a plume with above background concentrations of methane and carbon dioxide will be likely coming from biological sources, such as cows, rather than from a methane seep. The presence of elevated total hydrocarbons, carbon dioxide and methane is an indication that exhaust from a combustion source, such as an automobile, is being sampled.

The LDS was mounted in the rear of the survey vehicle. Ambient air was collected at the front of the vehicle at a height of approximately 2 feet above the ground, passed through a filter to remove particles and other debris from the air stream, and was carried to the LDS through 3 inch diameter pipe. The delay time between gas entering the entrance of the collection system and being detected by the LDS was on the order of 1 second.

The navigation system consisted of a Garmin III+ GPS receiver equipped with an external antenna. Output from the GPS receiver, in the form of NEMA 183B data sentences, was captured by both the LDS data acquisition computer and a separate navigation computer. The navigation computer was running the Delorme Street Atlas program, and displayed the current location of the survey vehicle, the path the vehicle had previously taken and all previously discovered seeps overlaid on a very detailed street map. A Corvallis Micro-Technology Model MARCH II GPS that had the capability of differentially correcting the position data was also used to mark some of the seep locations.

Wind speed and direction were measured using NRG systems model 40 anemometers and model 200 wind vane respectively. The sensors were mounted at a height of 34 inches above the roof of the survey vehicle, which placed the sensors 108 inches above the ground. The wind vane was positioned such that wind directions were measured relative to the front of the vehicle (e.g. a wind from the front of the vehicle was recorded as 0 degrees and a wind from the rear of the vehicle was recorded as 180 degrees). The true wind direction was obtained by adding the apparent wind direction as measured by the wind vane to the direction the vehicle was facing, which was obtained from the GPS. Wind speed and direction data was recorded manually with the vehicle stationary.

Air temperature was measured using a type K thermocouple probe connected to an Omega Engineering model HH22 thermocouple reader. The temperature data was recorded manually.

Data Collection

The survey vehicle was driven on those roads, lease roads, and jeep trails providing representative coverage of the Raton basin, as shown in figure 2. The areas of lighter coverage were due to mountains, private property which we did not have permission to enter, and snow blocked or otherwise inaccessible roads.

The typical procedure followed while performing this survey was to drive the survey vehicle along the road/lease road/jeep trail being surveyed. The LDS display and audio output would be continually checked for indications of an elevated methane concentration. When a methane plume was detected, the vehicle was driven upwind into the plume, looking for the source of the methane plume. The locations of the seeps were recorded in a logbook and marked on the navigation program. The wind speed, direction and temperature were also recorded along with any comments or observations about the seep site. Plumes that could be identified as coming from gas production equipment were not recorded.

The survey vehicle was stopped at approximately 15 minute intervals to allow collection of wind speed, direction and temperature data. These measurements were made in flat, open areas where possible.

Results

A total of 2749 miles were surveyed within the Raton basin, taking 216 hours and performed over 25 days. During this period a total of 67 separate seeps were found. Each seep was given a unique ID number based on the date the seep was found, and the sequence within that day. A summary of these seeps is presented in Appendix A, and a map showing the locations of the seeps is shown in Figure 2. Also plotted in Figure 2 is the path taken by the survey vehicle within the Raton Basin. A companion compact disk (CD) to this report has been prepared which contains all of the data collected during this project. The content of this CD is documented in Appendix B.

Interpretation of Results

The presence of methane seeps in the Raton basin is not surprising due to the large methane-containing coal beds present only a few hundred feet below the ground. Any activity that penetrates the overburden above the coal beds or removes water from the coal beds, weather natural occurring or due to the activities of man, has the potential to cause the release of methane.

The focus of this study was to discover the location of methane gas seeps. The survey vehicle was constrained to stay on the roads and jeep trails being surveyed, thus the precise location of seeps that apparently came from inaccessible areas off the roads was not determined. With the recorded position where the plume intercepted the road, and the wind direction at that time, it should be relatively easy to find the leak source using hand held leak survey equipment. The peak methane concentration measured at each seep was recorded and is presented in Appendix A. These peak concentrations are dependent on wind speed, measurement location and other factors in addition to the methane emission rate, but can be used to infer relative seep rates.

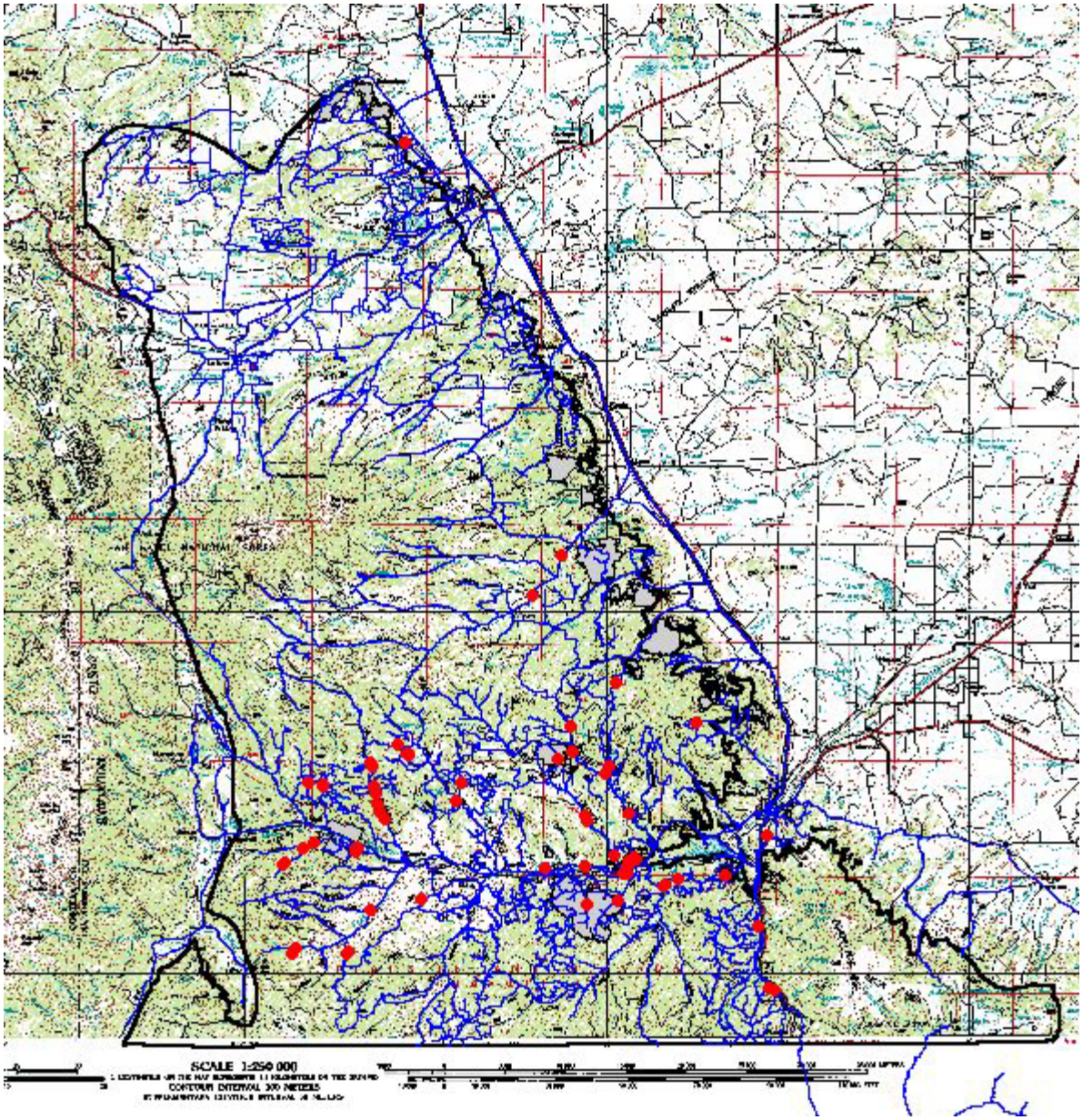


Figure 2. Map showing all seeps (red circles) and vehicle track (blue line) within the Raton basin.

The most obvious pattern to the methane seeps discovered in the Raton basin is that they are clustered in the southern end of the Basin along the Purgatorie River valley through which Route 12 passes (Figure 2). The single seep discovered in the northern end of the basin is very likely due to mining activities (the seep was coming out an 8 inch diameter hole located over a State of Colorado Mine Land Reclamation site). Another feature of the methane seeps is that they are generally found in valleys.

The methane seeps discovered were persistent, at least over the time span of the field measurements. In all cases, when the survey vehicle returned to a seep, it was still emitting methane.

Some of the seeps were clearly associated with mining activities, such as seep 040601-01, which was located over a State of Colorado Mine Land Reclamation site. Other seeps, such as those shown in Figure 3 also appear to be associated with mining activity due to their

proximity to underground mines. The cause of most of the seeps discovered cannot be determined based solely of this data set.

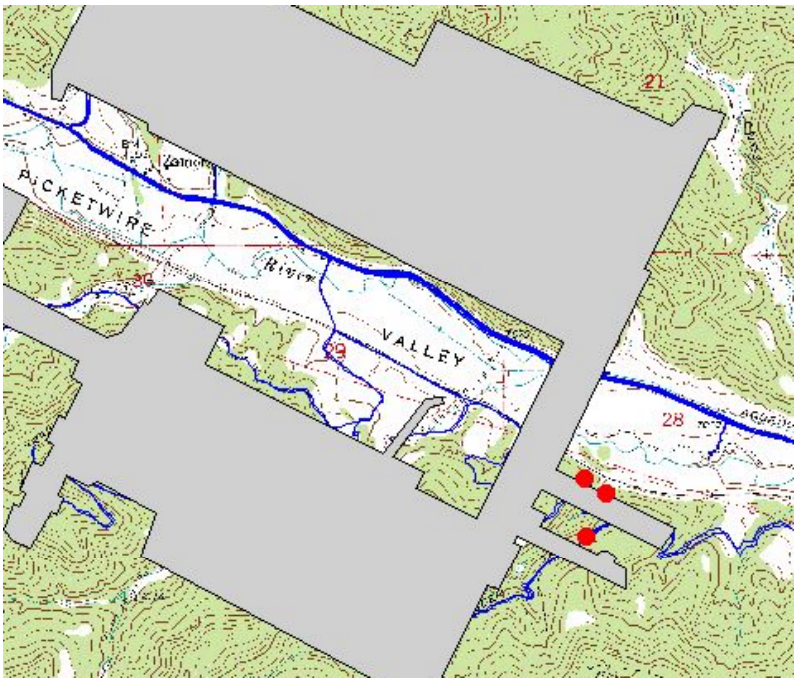


Figure 3. Seeps 110900-05, 110900-06 and110900-07. The gray area is a mine, the red circles are the seeps and the blue line is the survey vehicle track.

Conclusions and Recommendations

There are many methane seeps in the Raton basin, most of which are located in the southern portion of the basin along the Purgatorie River valley. The cause of these seeps can not be determined from this data set alone. However, when geological data, mine locations, gas well locations and other data sets are combined with this data set, a much better understanding of the cause of methane seeps should be possible. This data set will also provide a good baseline to help determine if future gas well drilling activities within the Raton basin causes an increase in the number of methane seeps.

It is recommended that a representative number of seeps be selected for further emission rate monitoring, to determine the relationship, if any, between coal bed methane development and methane seeps. The precise location of each of these seeps, if not already determined, should then be determined. Following that, the surface area of the seeps should be measured and documented and emission rates calculated for each of the selected seeps. Then, at periodic intervals, these seeps should again be studied to determine any changes in their surface extent, emission rates, and other characteristics.

Appendix A

Summary of Methane Seeps

Table A-1. Summary of seeps discovered in Raton Basin.

Seep ID	Date	Time	Peak Methane Concentration (PPM)	Wind Speed (MPH)	Wind Direction (degrees)	Comments
110900-01	11/9/00	8:25	38	10	256	This seep appeared to be coming from a bare patch of ground approximately 100 feet by 30 feet located just to the south side of the road and possibly extending into the road.
110900-02	11/9/00	9:43	195	2	154	
110900-03	11/9/00	9:59	675	14	161	Methane venting from open pipe on top of a coal mine vent shaft.
110900-04	11/9/00	11:28	510	2	162	Methane venting from small valve on top of coal mine vent shaft.
110900-05	11/9/00	11:34	180	2	332	This seep appeared to be located downhill, to the north side of the road. Forested terrain prevented a clear view of the source area.
110900-06	11/9/00	12:13	910	1	302	This seep was coming from a bare patch of ground to the west of the road at the top of a steep hill where the road turns sharply to the southeast.
110900-07	11/9/00	13:38	500	1	302	Methane escaping from a casing head.
110900-08	11/9/00	14:14	32	1	329	This response was detected Highway 12 near Valdez. The precise location of the seep was not determined.
110900-10	11/9/00	18:41	35	0	--	
110900-11	11/9/00	18:49	150	0	--	
111000-01	11/10/00	8:15	7	1	205	This seep appeared to be coming down a draw. There was a definite rise in methane concentration above low background levels.

Table A-1. Summary of seeps discovered in Raton Basin.

Seep ID	Date	Time	Peak Methane Concentration (PPM)	Wind Speed (MPH)	Wind Direction (degrees)	Comments
111000-02	11/10/00	8:32	560	4	279	This seep was measured for approximately 100 yards along the road. The location was about one quarter mile from a gas well but the wind was not coming from that direction. A steep valley was observed in the direction from which the wind was blowing.
111000-03	11/10/00	8:44	6	1	187	There were no man-made structures near this seep. There was a definite rise above low background levels.
111000-04	11/10/00	15:10	15	0	--	There were no man-made structures near this seep.
111600-01	11/16/00	12:33	92	3	113	This seep was coming from an open field in which several plastic vent pipes were located.
111600-02	11/16/00	17:55	25	0	--	This seep was from an old water well casing near a power pole surrounded by an old fence. The seep was detected on a sharp curve in the road near an intersection to the south.
111600-03	11/16/00	18:03	82	0	--	The seep appeared to be coming from the west side of the road, but the precise location of the seep could not be determined. There were no man-made structures in close proximity to the seep.
111700-01	11/17/00	14:08	13	10	150	The seep was coming from an embankment on the east side of the road near a telephone utility box.
111700-02	11/17/00	16:52	15	3	303	This seep was coming from an embankment on the west side of the road at the intersection with Timber Ridge Road. The seep appears to be between the intersection and the Timber Ridge sign.
111700-03	11/17/00	17:02	40	4	290	This seep appeared to be coming from the bank on the east side of the road.

Table A-1. Summary of seeps discovered in Raton Basin.

Seep ID	Date	Time	Peak Methane Concentration (PPM)	Wind Speed (MPH)	Wind Direction (degrees)	Comments
111700-04	11/17/00	17:12	130	4	275	This seep appeared to be coming from the west side (stream side) of the road.
111700-05	11/17/00	17:19	210	6	328	This seep appeared to be coming from the west side (stream side) of the road.
121300-01	12/13/00	10:15	23	4	190	The seep was coming from the direction of a pasture and plowed field on the stream side of the road. No man-made structures that could cause the seep were evident. Surveys on the other side of the stream discovered no seeps above the stream valley.
121300-02	12/13/00	13:02	22	8	254	This seep was coming from the stream side of the road in the direction of a house on the other side of the stream. Vector analysis with seep 121300-03 suggests this seep is the same as 121300-03 and located very close to the house in the picture included on the companion CD.
121300-03	12/13/00	14:32	53	3	305	This seep was coming from the stream side of the road in the direction of a house on the other side of the stream. Vector analysis with seep 121300-02 suggests this seep is the same as 121300-02 and is located very close to the house in the picture included on the companion CD.
121300-04	12/13/00	15:05	48	12	240	This seep was originally detected downwind of a point where a pipeline right-of-way is close to a bend in the county road. The methane response was tracked from there upwind to a point directly over the pipeline where the methane response rapidly disappeared. This is normally indicative of a pipeline leak The pipeline was uncovered the next day and no apparent leak in the pipeline was discovered.

Table A-1. Summary of seeps discovered in Raton Basin.

Seep ID	Date	Time	Peak Methane Concentration (PPM)	Wind Speed (MPH)	Wind Direction (degrees)	Comments
121300-05	12/13/00	16:45	7	0	--	This leak was detected between a stream and a county road just north of where a county road bridge crosses the stream. The leak appeared to be coming from a 50-square-yard area. However, it is also possible that the leak is located up a small ravine to the west.
121400-01	12/14/00	9:28	18	16	265	This seep was detected from a bridge on the county road. Previous surveys of this location have shown slight indications of a seep in this area but nothing consistently apparent. This response clearly indicates a seep to the west of the road in the direction of, or beyond, the stream. No man-made structures to which the seep could be attributable were evident.
121400-02	12/14/00	9:45	47	7	277	The seep was detected with a steady west wind blowing. However, there was a stronger response on the east side of the road than on the west side of the road. Previous surveys past this point in the last six months detected no seeps at this point. With a pipeline right-of-way on the east edge of the road, these factors suggest the possibility of a pipeline seep causing this response.
121400-03	12/14/00	10:25	14	14	120	The seep was coming from an area between the stream and the road, just south of a cattle guard on the road and just north of a lease road going to the west. This seep had been located previously and was where the manure-like substance just below the surface was first noticed to be associated with methane seeps.
121400-04	12/14/00	15:23	400	0	--	The seep is the furthest south of five seeps located in a large meadow area. The owner (Mr. McDonald) said grass and trees had started dying in this area during the summer of 1999.

Table A-1. Summary of seeps discovered in Raton Basin.

Seep ID	Date	Time	Peak Methane Concentration (PPM)	Wind Speed (MPH)	Wind Direction (degrees)	Comments
121400-05	12/14/00	15:29	280	3	66	This seep is the second furthest south of five seeps located in a large meadow area. The owner (Mr. McDonald) informed us that the grass and trees in this area had started dying during the summer of 1999.
121400-06	12/14/00	15:32	320	0	--	This seep is the second furthest north of five seeps located in a large meadow area. The owner (Mr. McDonald) informed us that the grass and trees had started dying in this area during the summer of 1999.
121400-07	12/14/00	15:36	250	10	90	This seep is the furthest north of five seeps located in a large meadow area. The owner (Mr. McDonald) informed us that the grass and trees had started dying in this area during the summer of 1999.
121400-08	12/14/00	15:51	160	2	163	This seep is the furthest east of five seeps located in a large meadow area. The owner (Mr. McDonald) informed us that the grass and trees had started dying in this area one and during the summer of 1999.
121500-01	12/15/00	8:11	34	0	--	This seep was detected on the road paralleling the railroad tracks on the west side of the river. This seep was detected as a significant spike in an area of relatively high background methane levels. It was located just east of an embankment going up to a higher level and just west of an embankment going down to the river. The seep appears to be a smaller seep in the vicinity of a much larger seep.
121500-02	12/15/00	8:17	27	0	--	This seep was detected on the road paralleling the railroad tracks on the west side of the river. This seep was detected as a significant spike in an area of relatively high background methane levels. It was located just east of an embankment going up to a higher level and just west of an embankment going down to the river. The seep appears to be a smaller seep in the vicinity of a much larger seep.

Table A-1. Summary of seeps discovered in Raton Basin.

Seep ID	Date	Time	Peak Methane Concentration (PPM)	Wind Speed (MPH)	Wind Direction (degrees)	Comments
121500-03	12/15/00	9:10	690	0	--	This seep was located within 60 feet of a residence in an area of approximately 10 dead trees. It could be the larger seep, or one of a number of larger seeps, that is creating the relatively high background methane levels in the area of seeps 121500-01 and 121500-02.
121500-04	12/15/00	14:18	8	2	61	The methane response was a variable but distinct rise above background levels. It is forested on both sides of the road so as to prevent observation for any significant distance. The general area consisted of a large-lot subdivision. There were several homes within a mile of the location of the response.
121500-05	12/15/00	16:50	39	2	338	This seep was located just downwind from a water well casing head in the front yard of a residence. See picture for further description. The propane tank in the picture, if seeping, would have caused a much greater response on the total hydrocarbon channel. This did not occur.
121500-06	12/15/00	17:28	700	0	--	This seep appeared to be coming from an area of dead grass just to the east of the road.
010301-01	1/3/01	10:36	400	0	--	This is a methane seep over a pipeline right-of-way at a well site.
010301-02	1/3/01	18:20	160	4	271	This seep was detected at a culvert for the Torres Canyon drainage. The wind was blowing down the drainage. No gas production facilities that could have caused the response were apparent in the area.
010501-01	1/5/01	11:51	500	0	--	This seep was detected at the intersection of Saddle Road and Fisher Drive. Maximum concentration occurs near the utility box junction and telephone pole on the NE corner of the intersection.

Table A-1. Summary of seeps discovered in Raton Basin.

Seep ID	Date	Time	Peak Methane Concentration (PPM)	Wind Speed (MPH)	Wind Direction (degrees)	Comments
010701-01	1/7/01	9:57	50	3	103	This seep was detected at the bend of county road 18.3 where a culvert passes under the road at the bottom of a draw. 2 or 3 possibly dying evergreens were approximately 30 ft. up the draw. There was a light wind from the downhill side of the draw (creek side).
010701-02	1/7/01	10:20	300	0	--	This seep is approximately 150 yards southwest of seep 010701-01, and is indicated by a small patch of dead and dying grass on the west side of the road.
010701-03	1/7/01	11:10	80	3	26	This is the third in a series of three seeps along the same road. This seep is approximately 50 yards southwest from 010701-02.
010701-04	1/7/01	13:20	160	4	79	This seep was detected near a telephone pole on a sharp corner in the road. A black post with telephone wires is on the east side of the road, and on the west side is a brown support pole. No methane was measured 50 feet upwind of where seep was detected.
010701-05	1/7/01	15:17	60	1	350	This seep was detected on the north side of the road just before a slight bend to the west, and southwest of a gated road heading to the east.
010701-06	1/7/01	16:40	75	0	--	This seep is near a road cut on a sharp bend in the road approximately 50 yards south of two plastic pipes extending out of the ground.
010701-07	1/7/01	16:48	50	0	--	This seep is near another road cut south of seep 010701-06. The methane response varied over the distance of the road cut.
011201-01	1/12/01	10:47	100	12	181	This seep was detected at the north side of a triangular intersection near a road cut and appeared to be located within the triangular area outlined by the roads.

Table A-1. Summary of seeps discovered in Raton Basin.

Seep ID	Date	Time	Peak Methane Concentration (PPM)	Wind Speed (MPH)	Wind Direction (degrees)	Comments
011201-02	1/12/01	15:44	12	13	165	This seep gave a small but fairly constant methane response west of a bulldozed area to east of the road, just south of a sharp turn in the road to the east and going downhill. There were no apparent man-made facilities to account for the seep.
011201-03	1/12/01	16:11	170	14	197	This seep was near several concrete structures and heavy earth-moving equipment at a spot where a draw meets the road above the railroad tracks and I-25. The methane response disappeared near the concrete structures and appeared to come from the ground beside the road.
011301-01	1/13/01	12:14	70	0	--	This seep was detected south of a point where the road crosses a creek and north of roads running west marked "No Trespassing---Dangerous Mine Openings." The response was also detected with a wind speed of 3 mph and a wind direction of 11 degrees.
011401-02	1/14/01	16:54	670	0	--	This seep was located near a pile of old bridge planks and road culverts that were disposed of on the property when Highway 12 was relocated, according to property owner Peter Saint. The seep was very near the spot marked because it disappeared rapidly when we moved. Mr. Saint assured us there were no mines or pipelines on the property.
011501-01	1/15/01	13:56	55	4	349	A consistent response between 4 and 20 PPM just south of a trailer home and just east of a creek. There were no dead evergreens apparent. The seep occurs in an area where landowner Gene Lujan (former Las Animas county commissioner) said he has seen bubbles coming from the stream. The stream was frozen today except for one small section.

Table A-1. Summary of seeps discovered in Raton Basin.

Seep ID	Date	Time	Peak Methane Concentration (PPM)	Wind Speed (MPH)	Wind Direction (degrees)	Comments
011501-02	1/15/01	14:34	40	8	269	This seep was in the west end of a shallow depression in a cow pasture approximately 100 yards from a river. The maximum response disappeared very rapidly as we moved away from the source.
011501-03	1/15/01	16:48	70	3	229	This seep is along the dirt road into seep 011501-02 near a coal outcrop 50 feet north of Highway 12.
011501-04	1/15/01	17:49	250	0	--	This seep was along a county road with frequent spikes to 60 PPM. Strongest peaks with slight wind from NE.
011601-01	1/16/01	12:50	60	0	--	There was a slight breeze from 12 degrees. The seep was between a farm access road and creek culvert and county road. There is a pipeline running east of the creek but there was no gas apparent on that side of the creek.
040601-01	4/6/01	12:06	15	6	250	This seep was detected at a road intersection. A 4 to 6 foot deep hole was observed southwest of the intersection just off the road. Methane is apparently coming from the hole. There is a marker near the hole reading "State of Colorado Mine Land Reclamation, ST1/4 S26 T27 R67W"
040801-01	4/8/01	14:36	500	0	--	This response was from a 500 foot well on John Rose's house site. There is water at the bottom of the well. The driller says that he encountered rubble while drilling, which could have been an old mine.
040901-01	4/9/01	11:47	40	7	195	The seep was south of a road and just west of a small culvert. The vehicle was directly over the seep when marked.
040901-02	4/9/01	14:35	20	1	260	This seep was on what appeared to be a pipeline right of way. The highest concentration was on the north (uphill) side of road. Response seems to be from an area of stained/discolored soil.

Table A-1. Summary of seeps discovered in Raton Basin.

Seep ID	Date	Time	Peak Methane Concentration (PPM)	Wind Speed (MPH)	Wind Direction (degrees)	Comments
040901-03	4/9/01	20:23	20	0	--	Exact location of seep not found.
041001-01	4/10/01	20:29	20	0	135	Exact location not found. Highest response obtained when wind was from 135 deg.

Appendix B

Contents of Supplemental Data CD

Directory	Filename	Description
/DATA	LEAKS.XLS	An EXCEL spread sheet containing information about each seep. The information contained in this spread sheet includes: the seep ID, latitude, longitude, date and time discovered, maximum methane reading, wind speed, wind direction, comments, and links to pictures of the leak site.
/DATA	Wind Data.XLS	An EXCEL spreadsheet containing all wind speed and direction data. The information contained in this spread sheet includes: date and time measurement made, latitude and longitude, wind speed, wind direction, rotation direction and temperature. The rotation direction is a calculated field used with ArcView. If an arrow symbol is rotated by this amount in ArcView, the arrow will point in the direction of the wind.
/Data/Pictures	All .JPG files	These are pictures of the leak site in JPEG format. The name of a file is the corresponding leak ID prefixed with the two letters "BP". If multiple pictures were of the same leak site, a letter has been added to the end of the file name.
/Data	GPS.XLS	An EXCEL spreadsheet containing the latitude and longitude as reported by the MARCH II GPS. The information contained in this spreadsheet includes: seep ID, latitude, and longitude.
/Data	MARCH.XLS	An EXCEL spreadsheet containing the March II GPS data. (Note: this data uses the WGS 84 datum)
/Shape Files/Seeps	Seeps.*	The ArcView shape file of the seep data.
/Shape Files/Wind	Wind.*	The ArcView shape file of the wind and temperature data.
/Shape Files/	Track.*	The ArcView shape file of the path taken by the survey vehicle.
/Shape Files/Raton Basin Outline	Raton Basin Outline.*	The ArcView shape file of the Raton basin outline
/Shape Files/Base Map	250K Base Map	Topographical map of the Raton basin in TIFF format for use with ArcView.
/ArcView	Raton Basin.APR	An ArcView project that displays the included shape files.

Notes:

1. All GPS data uses the NAD27 datum unless otherwise noted.
2. There is a UTM directory in each of the /Shape Files sub-directories that contains the shape file projected in the UTM coordinate system.