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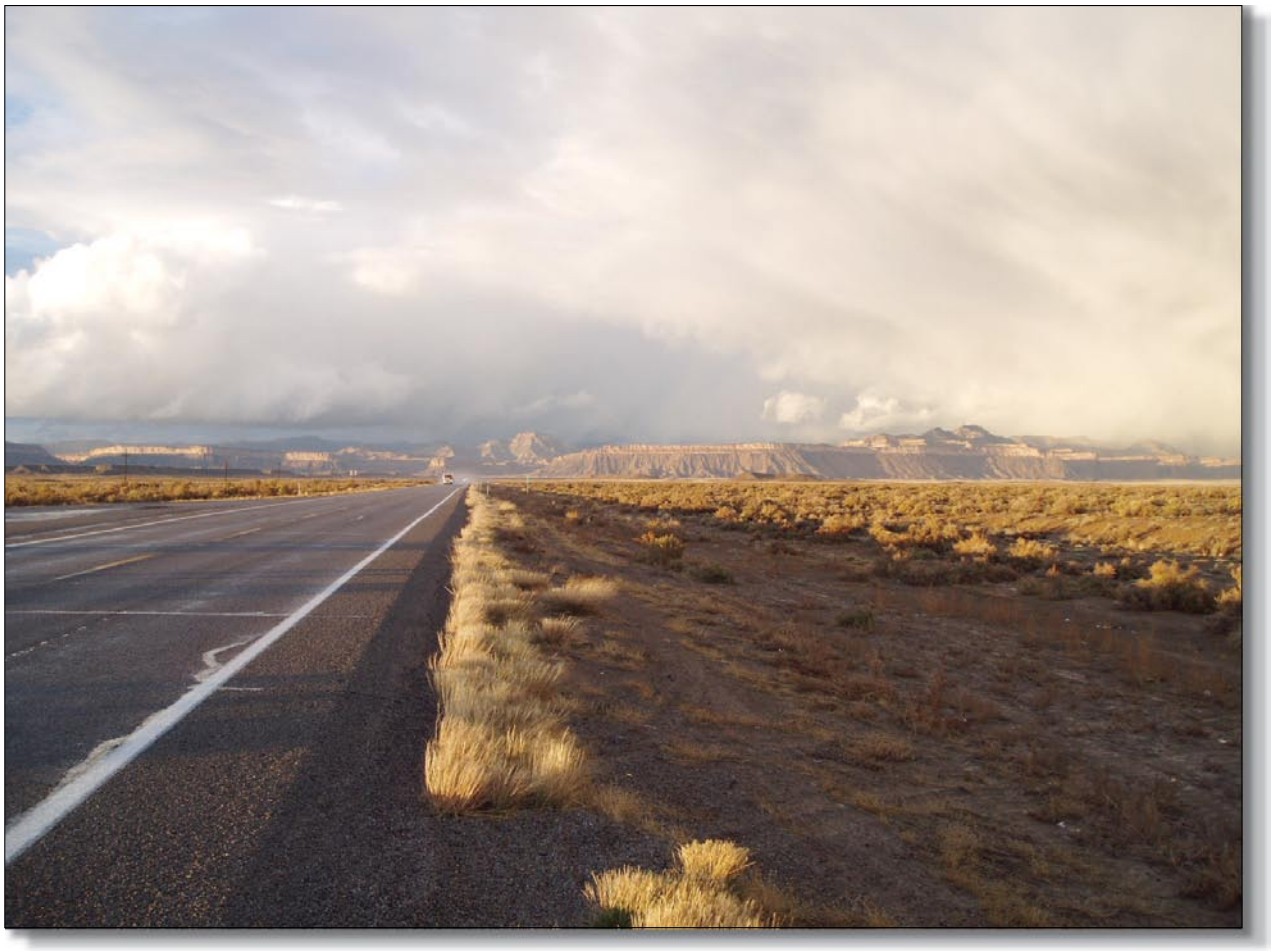
Methane Gas Concentration in Soils and Ground Water, Carbon and Emery Counties, Utah, 1995-2003



Scientific Investigations Report 2006-5227

U.S. Department of the Interior
U.S. Geological Survey

Cover: Photograph of Book Cliffs in east-central Utah. Taken by B.J. Stolp.

Methane Gas Concentration in Soils and Ground Water, Carbon and Emery Counties, Utah, 1995-2003

By B.J. Stolp, A.L. Burr, and K.K. Johnson

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DIRK KEMPTHORNE, Secretary

U.S. Geological Survey
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CONVERSION FACTORS, HORIZONTAL DATUM, AND ABBREVIATED WATER-QUALITY UNITS

Multiply	By	To obtain
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)

Horizontal coordinate information is referenced to the North American datum of 1983 (NAD 83).

Methane gas concentration is reported in parts per million by volume (ppmv). As an example, an air sample with a methane concentration of 1,000 ppmv would contain 1,000 molecules of methane for every 1,000,000 molecules of air.

Methane Gas Concentration in Soils and Ground Water, Carbon and Emery Counties, Utah, 1995-2003

By B.J. Stolp, A.L. Burr, and K.K. Johnson

Abstract

The release of methane gas from coal beds creates the potential for it to move into near-surface environments through natural and human-made pathways. To help ensure the safety of communities and determine the potential effects of development of coal-bed resources, methane gas concentrations in soils and ground water in Carbon and Emery Counties, Utah, were monitored from 1995 to 2003. A total of 420 samples were collected, which contained an average methane concentration of 2,740 parts per million by volume (ppmv) and a median concentration of less than 10 ppmv. On the basis of spatial and temporal methane concentration data collected during the monitoring period, there does not appear to be an obvious, widespread, or consistent migration of methane gas to the near-surface environment.

Introduction

The release of methane gas from coal beds creates the potential for it to move into near-surface environments through natural and human-made pathways. Natural pathways include fractures through the rock layers and voids between the grains of rock. Human-made pathways can be created when different types of wells are drilled. Methane is a combustable gas and can catch on fire if airborne concentrations exceed 5 percent (Eltschlager and others, 2001, p. 34-37). To help ensure the safety of communities and determine the potential effects of development of coal-bed resources, the U.S. Geological Survey and the Utah Department of Natural Resources, Division of Oil, Gas, and Mining, cooperated in a program to monitor methane gas concentration in soils and ground water in areas of coal-bed methane production. Initial findings from the monitoring program are discussed in a fact sheet by Naftz and others (1998).

Monitoring of methane gas in soils and ground water at selected locations in Carbon and Emery counties in Utah began in 1995 in response to commercial development of coal-bed methane resources from geologic formations that extend along the western edge of the San Rafael Swell in an area commonly referred to as the Ferron coal trend. The coal trend extends underneath the towns of Price, Huntington, Castle Dale, Ferron, and Emery (*fig. 1*). Methane is generated as a byproduct during formation of coal and is released as gas when ground water is pumped from geologic formations that contain coal beds. Boreholes are used to remove ground water and recover liberated methane. Substantial amounts of methane have been recovered from the Ferron trend coal beds since the early 1990s.

Purpose and Scope

This report tabulates, summarizes, and interprets the results of methane monitoring of soils and ground water in Carbon and Emery Counties, Utah, from 1995 to 2003. A description of collection and analytical procedures used for soil gas and ground water samples is presented in the appendix.

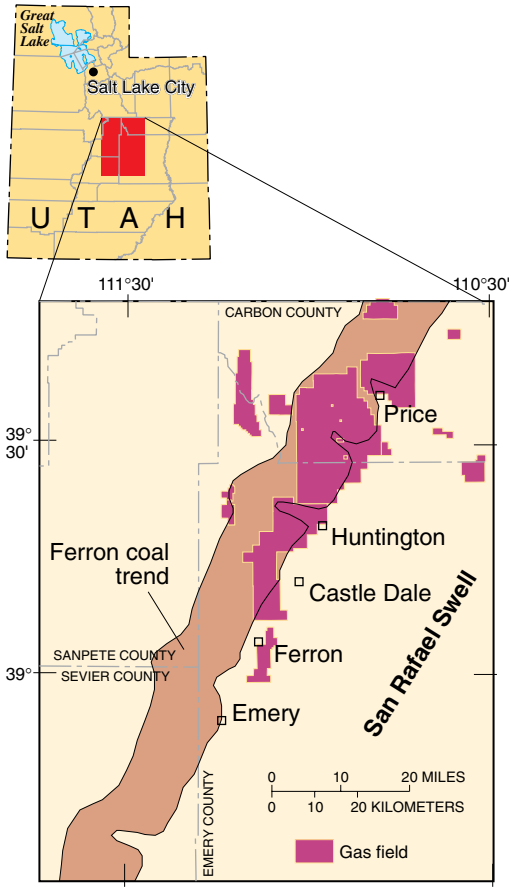

Figure 1. Generalized area of coal-bed methane development, Carbon and Emery Counties, Utah, 1985-2003.

Physical Setting

Coal originates as plant matter deposited in swamp-like environments that then decays as it is buried and compressed over geologic time. Methane from the Ferron coal trend is produced from coal beds and sandstone in the Ferron Sandstone Member of the Mancos Shale and in the Blackhawk Formation of the Upper Cretaceous Mesaverde Group. Depth to these formations from land surface ranges from 1,000 to 4,500 ft (Tabet and others, 1995; Stevens, 1993). Methane is recovered through boreholes that are drilled into the formations with a variety of different drilling, completion, and extraction technologies (Stevens, 1993). Gas is released when hydrostatic pressure created by overlying water is reduced. Hydrostatic pressure is reduced by pumping water out of the formations. Almost all of this water is currently (2006) disposed of by injecting it into geologic formations located thousands of feet below the Measverde Group.

Well-Field History and Development

Pilot development of coal-bed methane resources began near Price, Utah, in 1985. By 1991, methane production had spread south toward Orangeville and Ferron and as of November 2003, there were 772 coal-bed methane wells. Regulatory agencies continue (2006) to receive applications to drill additional coal-bed methane wells in the area, although at a much slower pace than in the past. The eventual number of wells will be determined primarily by the physical and economic limitations of the gas resource.

Peak production occurred in 2002 and was about 102 billion cubic feet of methane for the year. Gas production from 1985 through 2003 is shown in decatherms in *figure 2*. Decatherm is the unit used in most natural gas billing and is a measure of the heat produced when methane is ignited. The conversion from volume of methane gas to decatherm is made with the assumption that the heat value of methane from the Ferron coal trend is 1,000 British Thermal Units (BTU) per cubic foot of methane.

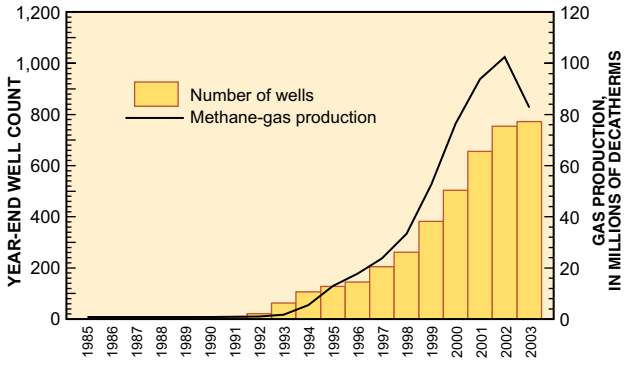

Figure 2. Number of coal-bed methane gas-production wells and annual methane-gas production from the Ferron coal trend, Carbon and Emery Counties, Utah, 1985-2003.

Monitoring Program

The monitoring described in this report began in 1995 and lasted through 2003. The program focused on established production-well sites and methane-gas production fields near residential areas. A priority was to identify and quantify trends and establish baseline methane concentrations in the soil and (or) ground water for future comparison. A core of twenty perimeter sites was established around Price, Huntington, Orangeville, and Ferron (*fig. 3*). These sites were monitored annually to determine whether or not methane concentrations were increasing near populated areas. Additional sites were established to monitor expanding areas of production and newly drilled production wells. A total of 420 shallow (2- to 4-ft depth) soil-gas and ground-water samples were collected from 174 soil and 15 ground-water sites (*figs. 3 and 4*). Summary statistics of methane concentrations for five areas of coal-bed production (*fig. 3*) are listed in table 1. Multiple samples were collected at 75 sites. Data describing site locations, sampling specifics, and methane concentrations are reported in *tables 2-4*, located at the back of this report. Sample collection and analysis procedures are described in the appendix, which is also located at the back of this report.

Methane Gas Concentrations

The average measured methane concentration for the monitoring period (1995-2003) was 2,740 parts per million by volume (ppmv); the median concentration was less than 10 ppmv. For calculation of summary statistics, sample values below the minimum detection limit or greater than the maximum detection limit were assigned the value of the detection limit. Two hundred and ten samples (52 percent of the sample set) had concentrations that were less than the detection limit. Twenty samples (5 percent of the sample set) had concentrations greater than 10,000 ppmv. On the basis of spatial and temporal methane concentration data collected during the monitoring period, there does not appear to be an obvious, widespread, or consistent migration of methane gas to the near-surface environment.

Inside buildings, methane-gas levels greater than 10,000 ppmv are potentially dangerous; in open air, methane levels above 50,000 ppmv can result in combustion of the air (Eltschlager and others, 2001, p. 34-37). At a concentration of less than 5,000 ppmv, methane poses no immediate threat (Eltschlager and others, 2001, p. 34-37).

Summary statistics of methane concentrations for five areas of coal-bed production (*fig. 3*) are listed in *table 1*. None of the production areas had average concentrations that are considered to be dangerous (greater than 5,000 ppmv). The median concentration for all areas is less than the average value, indicating that most values in the sample set are less than that average value. Twenty samples from 11 sites had methane concentrations that exceeded 10,000 ppmv. Those

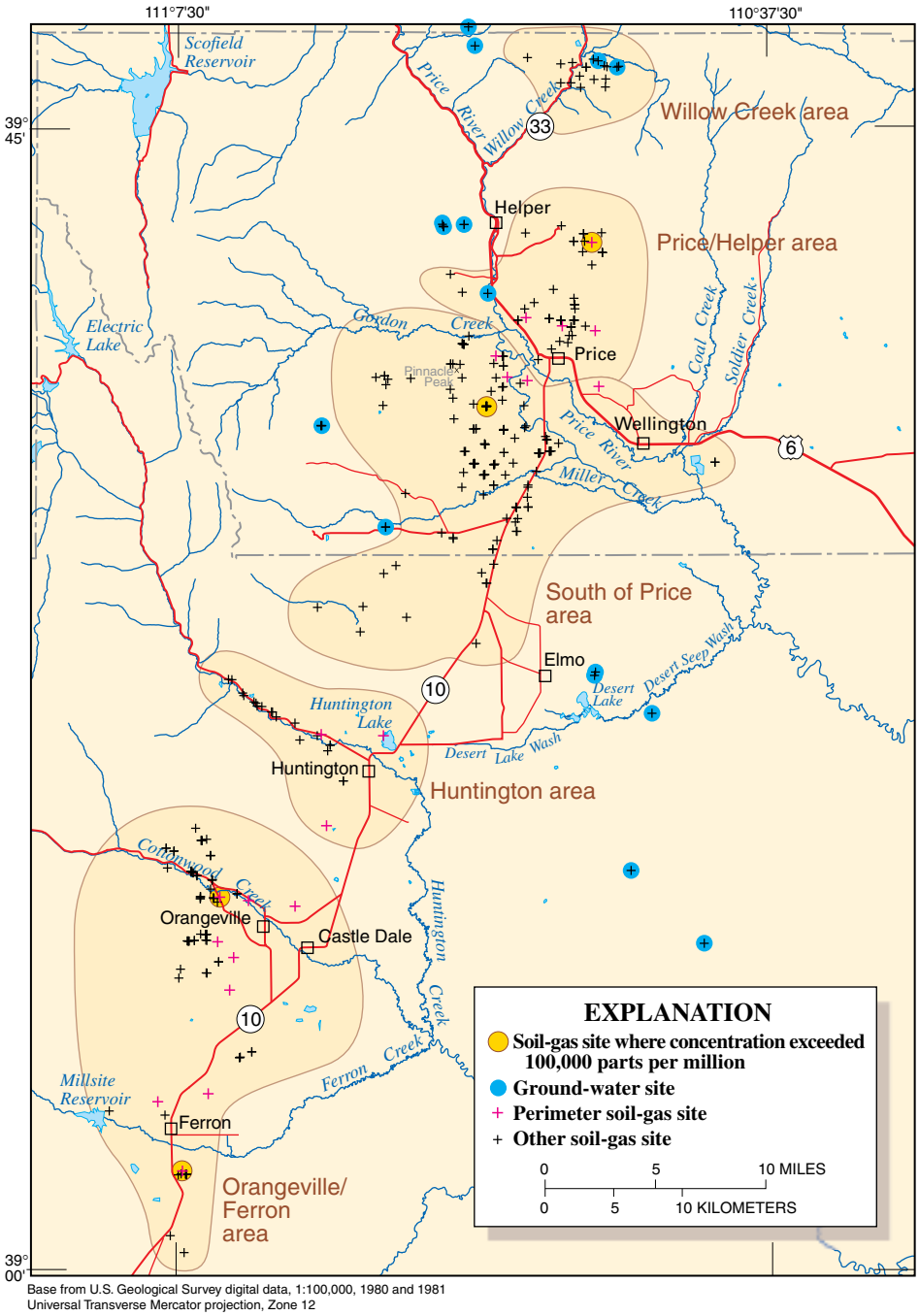

Figure 3. Location of sites where samples were collected and analyzed for methane concentration in Carbon and Emery Counties, Utah, 1995–2003.

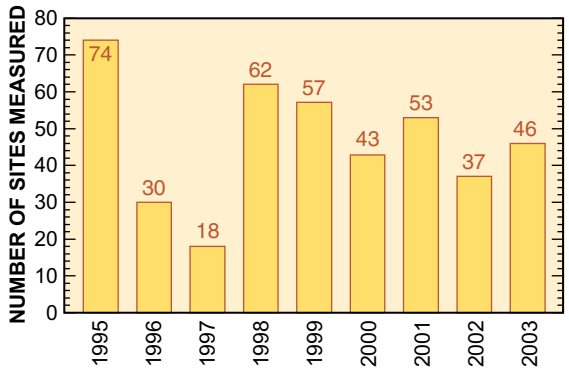

Figure 4. Number of methane-gas monitoring sites measured annually, Carbon and Emery Counties, Utah, 1995-2003.

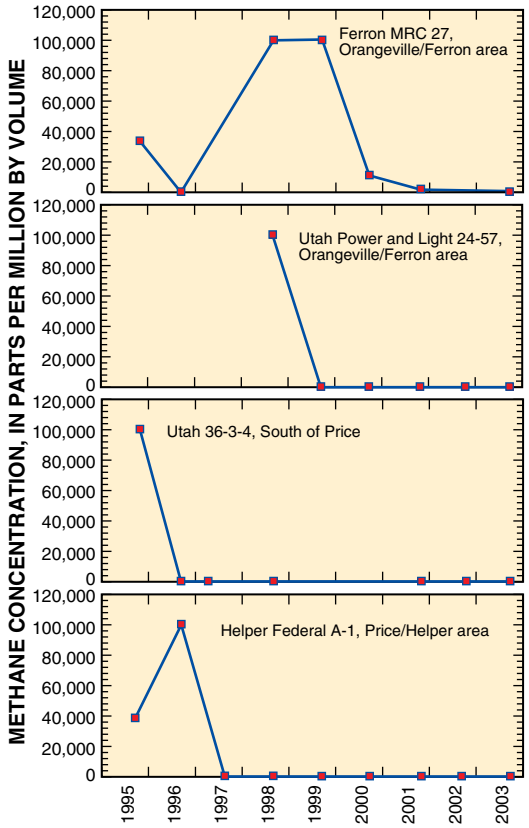

Figure 5. Long-term trend at monitoring sites at which the highest concentrations of soil-gas methane were measured, Carbon and Emery Counties, Utah, 1995-2003.

sites are scattered across the entire area and do not indicate specific locations of high concentrations.

At 75 sites, soil-gas samples were collected multiple times during the monitoring period. These data show a general trend of decreasing methane concentration over time. At sites where a concentration of 10,000 ppmv or greater was measured at some time during the monitoring period, the most recent repeat measurements averaged 23 ppmv methane. Methane concentrations over time at sites with the highest concentrations (greater than 100,000 ppmv) are shown in *figure 5*. These high concentrations might be associated with disturbances to the geohydrologic conditions that occur during drilling of coal-bed gas wells or problems with well maintenance. High methane concentrations are commonly observed shortly after drilling. If wells are properly constructed and maintained, concentrations that result from drilling geneally decrease and remain low over time.

At 15 of the 75 sites where temporal data were collected, soil-gas methane concentrations were inconsistent. Variations on the order of 10 to 1,000 ppmv were measured from year to year and showed no consistent increasing or decreasing trends. Eight of these sites are located in the Orangeville/Ferron area. Changes of this type and magnitude, associated with this monitoring program, are likely a result of (1) intermittent pumping at the methane-gas well prior to sampling; (2) variations in climatic conditions including temperature, barometric pressure, and soil moisture (Rose and others, 1979); and (3) inherent uncertainties associated with field collection and analysis of soil-gas samples (*table 3*).

Monitoring of methane concentration in ground water was limited. An initial inventory of coal-bed methane production areas in 1995 resulted in sample collection from 14 sites that included springs, drains, and ponds. The average methane concentration was 20 ppmv. Multiple samples were collected at a single spring from 2000 through 2002. Methane concen-

Table 1. Summary statistics of methane concentration for five areas of coal-bed production, Carbon and Emery Counties, Utah, 1995-2003

[ppmv, parts per million by volume; <, concentration is less than the minimum detection limit of the analytical equipment; >, concentration is greater than the minimum detection limit of the analytical equipment]

Area	Average concentration (ppmv)	Median concentration (ppmv)	Minimum concentration (ppmv)	Maximum concentration (ppmv)	Number of samples
Willow Creek	800	<10	<10	6,390	15
Price/Helper	2,260	10	<1	>100,000	75
South of Price	1,750	<10	<1	>100,000	152
Huntington	15	4	<1	160	24
Orangeville/Ferron	4,920	<10	<1	>100,000	137

tration at that site decreased from 26,200 ppmv in 2000 to 160 ppmv in 2002.

Summary

To help ensure the safety of communities and determine the potential effects of development of coal-bed resources, the U.S. Geological Survey and the Utah Department of Natural Resources, Division of Oil, Gas, and Mining, cooperated in a program to monitor methane concentrations in soils and ground water in areas of coal-bed methane production. The monitoring program began in 1995 and lasted through 2003. Commercial development of coal-bed methane resources began in the early 1990s from geologic formations within the Ferron coal trend. The monitoring program focused on established production-well sites and methane-gas production fields near residential areas. A core of twenty perimeter sites was established around Price, Huntington, Orangeville, and Ferron and monitored annually. Additional sites were established to monitor expanding areas of production and newly drilled production wells. A total of 420 shallow (2- to 4-ft depth) soil-gas and ground-water samples were collected from 174 soil and 15 ground-water sites. Multiple samples were collected at 75 sites. The average measured methane concentration for the monitoring period was 2,740 parts per million by volume (ppmv); the median concentration was less than 10 ppmv. On the basis of spatial and temporal methane concentration data collected during the monitoring period, there does not appear to be an obvious, widespread, or consistent migration of methane gas to the near-surface environment.

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Table 2. Soil-gas methane concentration in samples collected adjacent to selected well sites, Carbon and Emery Counties, Utah, 1995-2003

[**Site name:** Utah Division of Oil, Gas, and Mining well designations or field notes. **Location:** d, degree; m, minute; s, second. **Methane concentration:** ppmv, parts per million by volume. Samples collected from 1995 through 2000 were analyzed by the OVA 128 Century Organic Vapor Analyzer, which was considered for this monitoring program to have a minimum detection limit of 10 ppmv. Samples collected from 2001 through 2003 were analyzed by the HNU Systems Inc. Model 311 Portable Gas Chromatograph, which was considered for this monitoring program to have a minimum detection limit of 1 ppmv. When no methane was detected at a sample site, a value of either less than 10 ppmv (<10) or less than 1 ppmv (<1) is reported. A dash (—) indicates no sample was collected. **Area:** Refers to areas delineated in figure 3]

Site name	Location		Sample date	Methane concentration (ppmv)		Area
	Latitude (ddmmss)	Longitude (dddmmss)		Sample collected within 10 feet of well	Sample collected more than 10 feet from well	
Helper Federal A-3	394040	1104652	09/06/1995	<10	—	Price/Helper
Washington Park	393625	1104834	09/07/1995	<10	—	Price/Helper
City Park, Price	393640	1104744	09/07/1995	<10	—	Price/Helper
River Gas Well 30-5-15	393455	1105105	09/08/1995	<10	—	South of Price
River Gas Well 24-16-18	393517	1105124	09/08/1995	<10	—	South of Price
River Gas Well 23-4-20	393549	1105314	09/08/1995	<10	—	South of Price
River Gas Well 24-2-15	393551	1105131	09/08/1995	<10	—	South of Price
River Gas Well 35-1-9	393415	1105233	09/12/1995	<10	—	South of Price
River Gas Well 27-9-30	393429	1105336	09/12/1995	<10	—	South of Price
River Gas Well 27-8-29	393450	1105344	09/12/1995	<10	—	South of Price
River Gas Well 23-14-21	393517	1105308	09/12/1995	<10	—	South of Price
River Gas Well 24-80	393040	1105203	09/13/1995	<10	—	South of Price
River Gas Well 14-64	393058	1105309	09/13/1995	<10	—	South of Price
River Gas Well 6-40	393254	1105027	09/13/1995	<10	—	South of Price
River Gas Well 18-69	393127	1105056	09/14/1995	<10	—	South of Price
River Gas Well 7-59	393155	1105032	09/14/1995	<10	—	South of Price
River Gas Well 30-14-14	393424	1105105	09/14/1995	<10	—	South of Price
Federal 16-15	394644	1104703	09/18/1995	<10	—	Willow Creek
Shimmin Trust 3	394703	1104622	09/18/1995	<10	—	Willow Creek
Jensen 7-15	394711	1104706	09/18/1995	120	—	Willow Creek
Shimmin Trust 11-11	394751	1104624	09/18/1995	<10	—	Willow Creek
Jensen 11-15 near Highway 191 (between mile 163 and164)	394655	1104733	09/19/1995	<10	—	Willow Creek
Utah 9-16	394655	1104804	09/19/1995	<10	—	Willow Creek
Shimmin Trust 14-12	394734	1104506	09/19/1995	<10	—	Willow Creek
Shimmin Trust 1	394736	1104540	09/19/1995	2,840	—	Willow Creek
Jensen 16-9	394740	1104804	09/19/1995	<10	—	Willow Creek
Jensen 11-10	394743	1104728	09/19/1995	2,420	—	Willow Creek
Federal 6-8	394755	1104946	09/19/1995	<10	—	Willow Creek
Utah 25-7-6	393445	1105139	09/20/1995	<10	—	South of Price
Federal 16-14	394645	1104547	09/20/1995	<10	—	Willow Creek
Shimmin Trust 2	394704	1104546	09/20/1995	6,390	—	Willow Creek
Jenson 16-10	394732	1104646	09/20/1995	<10	—	Willow Creek
Abandoned Gas Well 1	392910	1105411	09/21/1995	<10	—	South of Price
Abandoned Gas Well 2	390659	1110557	10/24/1995	160	—	Orangeville/Ferron
Abandoned well marker	392711	1105153	10/24/1995	<10	—	South of Price
MRC 21	390046	1110715	10/25/1995	<10	—	Orangeville/Ferron
Active gas well - Ferron	390350	1110733	10/25/1995	<10	—	Orangeville/Ferron
Backyard 650 N 300 E	393643	1104809	09/09/1996	<10	—	Price/Helper
Helper Federal B-1	393846	1104828	09/09/1996	<10	—	Price/Helper
Ferron MRC 17	390126	1110757	09/10/1996	<10	—	Orangeville/Ferron

Table 2. Soil-gas methane concentration in samples collected adjacent to selected well sites, Carbon and Emery Counties, Utah, 1995-2003—Continued

Site name	Location		Sample date	Methane concentration (ppmv)		Area
	Latitude (ddmmss)	Longitude (dddmmss)		Sample collected within 10 feet of well	Sample collected more than 10 feet from well	
Chandler Buzzard Bench Federal 3-24	391136	1110732	09/10/1996	<10	—	Orangeville/Ferron
Buzzard Bench Chandler Federal 6-3	391157	1110727	09/10/1996	<10	—	Orangeville/Ferron
Utah Federal A 26-2	391320	1110626	09/10/1996	<10	—	Orangeville/Ferron
SWD-1 Injection Well	391436	1110535	09/10/1996	<10	—	Orangeville/Ferron
Utah Federal K 5-34	392219	1110320	09/12/1996	<10	—	Huntington
River Gas 14-62	393133	1105304	09/12/1996	<10	—	South of Price
Arcadia Telonis (D-2) Injection Well	393514	1105655	09/12/1996	<10	—	South of Price
E.G. Telonis Etal #1	393529	1105549	09/12/1996	<10	—	South of Price
Possibly Old CVA-12 site	393258	1104853	09/13/1996	<10	—	South of Price
Utah 19-222	391448	110528	09/03/1998	50	<10	Orangeville/Ferron
Helper Federal B-5	394105	1104553	04/08/1997	<10	—	Price/Helper
Utah Federal H 6-21	390621	1111103	04/09/1997	<10	—	Orangeville/Ferron
Utah Federal M 6-25	392230	1110344	04/09/1997	<10	—	Huntington
River Gas 30-78 NE4/NE4	393504	1105010	04/09/1997	<10	—	South of Price
Helper State SWD-1	393800	1104722	08/31/1998	<10	—	Price/Helper
Helper State A-5	393810	1104723	08/31/1998	<10	<10	Price/Helper
Helper State A-1	393825	1104725	08/31/1998	<10	—	Price/Helper
Birch A-1	393800	1104956	09/01/1998	<10	—	Price/Helper
Federal 35-5	391306	1110610	09/02/1998	<10	—	Orangeville/Ferron
Utah 19-222	391448	1110528	09/03/1998	50	<10	Orangeville/Ferron
Utah 36-135	392852	1105122	09/14/1999	<10	—	South of Price
Robertson 32-127	393411	1104959	09/15/1999	<10	—	South of Price
Kakatsides 31-197	393412	1105710	09/15/1999	<10	—	South of Price
Telonis 30-156	393501	1105701	09/15/1999	<10	—	South of Price
Prettyman 11-114	393656	1105247	09/15/1999	<10	—	South of Price
Woolstenhulme 5-266	393815	1104927	09/15/1999	<10	—	Price/Helper
USA 30-289	392944	1105019	09/16/1999	<10	—	South of Price
USA 20-287	393033	1104952	09/16/1999	<10	—	South of Price
Helper State A-13	393719	1104650	09/17/1999	<10	—	Price/Helper
USA 2	392936	1105028	09/18/2000	<10	—	South of Price
Powell 30-173	392944	1105055	09/18/2000	<10	—	South of Price
Ferron 1-22	390352	1110727	09/19/2000	<10	—	Orangeville/Ferron
Nelson 1	390611	1110816	09/19/2000	<10	—	Orangeville/Ferron
Scorpion 1-23	392448	1105229	09/19/2000	<10	—	South of Price
USA 01-312	392756	1105135	09/19/2000	<10	—	South of Price
Utah 17-101	393135	1104924	09/19/2000	<10	—	South of Price
Utah Power and Light 24-51	391444	1110548	09/21/2000	<10	—	Orangeville/Ferron
Utah Power and Light 24-53	391507	1110559	09/21/2000	<10	—	Orangeville/Ferron
Utah U 2-49	391705	1110611	09/21/2000	<10	—	Orangeville/Ferron
Utah U 2-11	391731	1110644	09/21/2000	<10	—	Orangeville/Ferron
Gardner Trust 16-121	392100	1110124	10/26/2001	<1	—	Huntington
Utah BB 08-122	392206	1110251	10/26/2001	8	—	Huntington
Huber-Shimmin Trust 2-11	394735	1104550	10/26/2001	99	—	Willow Creek
Utah 17-370	392550	1105558	10/30/2001	4	—	South of Price
Utah 5-343	392753	1105631	10/30/2001	2	—	South of Price

Table 2. Soil-gas methane concentration in samples collected adjacent to selected well sites, Carbon and Emery Counties, Utah, 1995-2003—Continued

Site name	Location		Sample date	Methane concentration (ppmv)		Area
	Latitude (ddmmss)	Longitude (dddmmss)		Sample collected within 10 feet of well	Sample collected more than 10 feet from well	
William I 09-118	392140	1110142	09/11/2002	<1	—	Huntington
Conover 14-171	392034	1110002	09/23/2003	—	2	Huntington
Utah Power and Light 06-104	392227	1110340	09/23/2003	—	16	Huntington
Utah Power and Light 06-102	392250	1110421	09/23/2003	—	9	Huntington
Utah T 36-100	392322	1110454	09/23/2003	—	160	Huntington
Utah 1	393441	1105129	09/23/2003	—	<1	South of Price
Ferron Federal 4-36-18-7	391309	1110540	09/24/2003	—	21	Orangeville/Ferron
Utah 24-560	392516	1105822	09/24/2003	—	4	South of Price
PPCO 15-555	392614	1110033	10/01/2003	—	18	South of Price
Clawson Spring State H-2	392616	1105814	10/01/2003	—	45	South of Price
Utah 20-333	393043	1105604	10/01/2003	—	43	South of Price
Utah 2-404	393840	1105309	10/01/2003	—	40	Price/Helper
Utah 34-510	393922	1105346	10/01/2003	—	133	Price/Helper
Helper Federal E-6	394060	1104956	10/01/2003	—	100	Price/Helper
Blackhawk A-4	394116	1104806	10/01/2003	—	33	Price/Helper

Table 3. Soil-gas methane concentration in multiple samples collected adjacent to selected well sites, Carbon and Emery Counties, Utah, 1995-2003

[**Site name:** Utah Division of Oil, Gas, and Mining well designations or field notes. **Location**: d, degree; m, minute; s, second. **Methane concentration:** ppmv, parts per million by volume. Samples collected from 1995 through 2000 were analyzed by the OVA 128 Century Organic Vapor Analyzer, which was considered for this monitoring program to have a minimum detection limit of 10 ppmv. Samples collected from 2001 through 2003 were analyzed by the HNU Systems Inc. Model 311 Portable Gas Chromatograph, which was considered for this monitoring program to have a minimum detection limit of 1 ppmv. When no methane was detected at a sample site, a value of either less than 10 ppmv (<10) or less than 1 ppmv (<1) is reported. Both analytical instruments were considered for this monitoring program to have a maximum detection limit of 100,000 ppmv. When analysis of a gas sample resulted in a value ıh, that exceeded 100,000 ppmv, the value is reported as greater than 100,000 (>100,000). A dash (—) indicates no sample was collected. **Area:** Refers to areas delineated in figure 3]

Site name	Location		Sample date	Methane concentration (ppmv)		Area
	Latitude (ddmmss)	Longitude (dddmmss)		Sample collected within 10 feet of well	Sample collected more than 10 feet from well	
Ferron MRC 22	390352	1110710	10/24/1995	32,900	—	Orangeville/Ferron
			09/02/1998	<10	—	
			09/19/2000	—	2,730	
			10/24/2001	8	—	
			09/16/2003	12	—	
Ferron MRC 27	390406	1110723	10/25/1995	33,600	—	Orangeville/Ferron
			09/10/1996	<10	—	
			09/02/1998	>100,000	>100,000	
			09/14/1999	>100,000	77,500	
			09/19/2000	11,000	—	
			10/24/2001	92	1,830	
			09/16/2003	43	—	
Fossil 1-4	390650	1110841	09/19/2000	<10	—	Orangeville/Ferron
			10/24/2001	2	—	
			09/10/2002	15	—	
			09/16/2003	1	—	
Sorenson 1-2	390709	1110605	09/02/1998	5,470	2,740	Orangeville/Ferron
			09/14/1999	20	<10	
			09/19/2000	100	—	
			10/24/2001	23	2	
			09/10/2002	221	—	
			09/16/2003	5	—	
FL Energy Ralph's 1-30A	390828	1110427	10/24/1995	<10	—	Orangeville/Ferron
			09/02/1998	23,900	<10	
			09/14/1999	<10	—	
FL Energy Ralph's 2-30	390841	1110350	10/24/1995	<10	—	Orangeville/Ferron
			09/02/1998	<10	—	
Ferron Federal 7-12-19-7	391114	1110500	09/21/2000	<10	—	Orangeville/Ferron
			10/24/2001	5	—	
			09/10/2002	4	—	
			09/16/2003	1	—	
Orangeville State 10-2-19-7	391148	1110609	09/21/2000	<10	—	Orangeville/Ferron
			10/24/2001	6	—	
Chandler 4-1	391214	1110531	09/10/1996	20	—	Orangeville/Ferron
			04/09/1997	<10	—	
Chandler Orangeville State 1- 36-18	391232	1110448	09/10/1996	40	—	Orangeville/Ferron
			04/09/1997	60	—	
			09/02/1998	<10	—	

Table 3. Soil-gas methane concentration in multiple samples collected adjacent to selected well sites, Carbon and Emery Counties, Utah, 1995-2003—Continued

Site name	Location		Sample date	Methane concentration (ppmv)		Area
	Latitude (ddmmss)	Longitude (dddmmss)		Sample collected within 10 feet of well	Sample collected more than 10 feet from well	
Chandler Orangeville State 1- 36-18—Continued			09/14/1999	<10	—	
			09/21/2000	180	—	
			10/24/2001	2	—	
			09/10/2002	2	—	
			09/17/2003	<1	—	
Ferron State 4-36-18-7	391302	1110540	09/22/2000	<10	—	Orangeville/Ferron
			10/24/2001	2	—	
			09/10/2002	3	—	
Federal A 34-7	391304	1110707	09/02/1998	1,470	—	Orangeville/Ferron
			09/22/2000	10	—	
			10/25/2001	13	24	
			09/10/2002	10	—	
Federal A 35-5	391305	1110645	09/02/1998	2,630	<10	
			09/14/1999	<10	—	
Federal A 26-4	391326	1110613	09/22/2000	40	—	Orangeville/Ferron
			10/25/2001	385	24	
			09/10/2002	614	—	
			09/24/2003	226	—	
Orangeville Unit Federal 10-21	391433	1110141	09/12/1996	<10	—	Orangeville/Ferron
			09/21/2000	10	—	
			10/26/2001	2	—	
			10/14/2002	32	—	
			09/24/2003	<1	—	
Farm Fence Near Orangeville	391446	1110404	09/21/2000	<10	—	Orangeville/Ferron
			10/25/2001	2	—	
			09/10/2002	4	—	
			09/24/2003	4	—	
Utah Power and Light 23-51	391443	1110547	09/03/1998	<10	—	Orangeville/Ferron
			09/14/1999	40	<10	
Federal C 23-8	391455	1110631	09/03/1998	20	<10	Orangeville/Ferron
			10/25/2001	18	—	
			10/15/2002	<1	—	
			09/24/2003	—	19	
Utah Power and Light 24-57	391456	1110533	09/02/1998	>100,000	<10	Orangeville/Ferron
			09/14/1999	<10	—	
			09/21/2000	<10	—	
			10/25/2001	3	—	
			10/14/2002	4	—	
			09/24/2003	1	—	
D and D Curtis Well 14-54	391535	1110554	09/14/1999	<10	—	Orangeville/Ferron
			10/25/2001	103	—	
			10/14/2002	9	—	
			09/24/2003	—	2	

Table 3. Soil-gas methane concentration in multiple samples collected adjacent to selected well sites, Carbon and Emery Counties, Utah, 1995-2003—Continued

Site name	Location		Sample date	Methane concentration (ppmv)		Area
	Latitude (ddmmss)	Longitude (dddmmss)		Sample collected within 10 feet of well	Sample collected more than 10 feet from well	
Utah Power and Light 14-55	391538	1110638	09/03/1998	<10	—	Orangeville/Ferron
			10/25/2001	1	—	
L and M Curtis 15-67	391555	1110658	09/03/1998	60	<10	Orangeville/Ferron
			09/21/2000	4,460	—	
			10/25/2001	11	11	
			09/10/2002	14	—	
			09/24/2003	—	<1	
USA 11-71	391632	1110559	10/25/2001	206	—	Orangeville/Ferron
			10/14/2002	21	—	
			09/24/2003	7	—	
Grimes Wash Federal A-1 Sec10	391637	1110747	09/10/1996	17,600	—	Orangeville/Ferron
			4/09/1997	<10	—	
Utah Federal Q 4-44	391643	1110814	10/25/2001	2,000	—	Orangeville/Ferron
			09/10/2002	<1	—	
Utah 2-50	391711	1110625	09/03/1998	34,400	<10	Orangeville/Ferron
			09/14/1999	16,800	<10	
			09/21/2000	<10	—	
			10/25/2001	2	—	
			10/14/2002	1	—	
			09/24/2003	—	6	
Southwest of Huntington	391737	1110005	10/26/2001	2	—	Huntington
			10/14/2002	2	—	
SWD 5	391930	1105918	09/11/2002	72	—	Huntington
			09/23/2003	—	5	
Malone 14-131	392053	1105957	09/11/2002	15	—	Huntington
			09/23/2003	4	—	
North of Huntington State Park	392117	1105712	09/19/2000	<10	—	Huntington
			10/26/2001	1	—	
			10/14/2002	<1	—	
			09/23/2003	—	<1	
L and M Lemmon 10-1	392119	1110022	09/03/1998	<10	—	Huntington
			09/19/2000	<10	—	
			10/26/2001	2	—	
			09/11/2002	4	—	
			09/23/2003	—	<1	
USA 1-265	392735	1105209	09/14/1999	<10	—	South of Price
			10/30/2001	4	—	
Utah 36-137	392832	1105135	09/16/1999	<10	—	South of Price
			10/30/2001	9	—	
Utah M-2	392856	1105336	09/21/1995	<10	—	South of Price
			10/30/2001	3	—	
USA 30-290	392914	1105023	09/16/1999	<10	—	South of Price
			10/30/2001	7	—	

Table 3. Soil-gas methane concentration in multiple samples collected adjacent to selected well sites, Carbon and Emery Counties, Utah, 1995-2003—Continued

Site name	Location		Sample date	Methane concentration (ppmv)		Area
	Latitude (ddmmss)	Longitude (dddmmss)		Sample collected within 10 feet of well	Sample collected more than 10 feet from well	
USA 20-288	393011	1104949	09/16/1999	20	<10	South of Price
			09/18/2000	<10	—	
USA 19-222	393011	1105024	09/16/1999	<10	—	South of Price
			10/30/2001	10	—	
Utah 13-67	393103	1105132	09/14/1995	20	—	South of Price
			04/10/1997	<10	—	
Utah 17-103	393058	1104947	09/11/1996	<10	—	South of Price
			09/16/1999	<10	—	
Utah 13-66	393135	1105205	09/13/1995	4,850	—	South of Price
			10/26/1995	<10	—	
			09/11/1996	<10	—	
			04/10/1997	<10	—	
			10/16/2002	3	—	
			09/22/2003	5	—	
Utah 12-15-37	393151	1105131	09/14/1995	260	—	South of Price
			09/11/1996	<10	—	
			04/10/1997	<10	—	
			10/30/2001	4	—	
Utah 11-52	393154	1105234	09/14/1995	220	—	South of Price
			09/11/1996	<10	—	
			04/10/1997	<10	—	
			09/04/1998	<10	—	
			09/16/1999	50	<10	
Utah 8-100	393156	1104015	09/04/1998	<10	—	South of Price
			09/16/1999	<10	—	
Utah 8-97	393218	1104913	09/14/1995	<10	—	South of Price
			09/11/1996	<10	—	
			04/10/1997	<10	—	
			09/04/1998	<10	—	
			09/16/1999	<10	—	
Utah 7-57	393220	1105100	09/14/1995	90	—	South of Price
			09/4/1998	<10	—	
Utah 9-413	393230	1104842	09/18/2000	5,880	—	South of Price
			10/30/2001	388	—	
			10/15/2002	174	—	
			09/22/2003	4	—	
Utah 11-51	393223	1105302	09/13/1995	<10	—	South of Price
			10/29/2001	1	—	
Utah 1-44	393240	1105202	09/13/1995	80	—	South of Price
			04/10/1997	<10	—	
			09/03/1998	<10	—	
			09/16/1999	<10	—	
Utah 4-129	393250	1104849	09/13/1996	<10	—	South of Price
			04/08/1997	<10	—	
			09/03/1998	<10	—	

Table 3. Soil-gas methane concentration in multiple samples collected adjacent to selected well sites, Carbon and Emery Counties, Utah, 1995-2003—Continued

Site name	Location		Sample date	Methane concentration (ppmv)		Area
	Latitude (ddmmss)	Longitude (dddmmss)		Sample collected within 10 feet of well	Sample collected more than 10 feet from well	
Utah 4-129			09/15/1999	<10	—	
Utah 6-39	393322	1105104	09/13/1995	4,850	—	South of Price
			10/26/1995	<10	—	
			09/11/1996	<10	—	
			09/03/1998	<10	—	
			10/16/2002	3	—	
			09/22/2003	1	—	
Utah 2-46	393317	1105225	09/14/1995	100	—	South of Price
			09/11/1996	<10	—	
			09/03/1998	<10	—	
			09/16/1999	<10	—	
Utah 5-94	393319	1104957	09/03/1998	<10	—	South of Price
			09/15/1999	<10	—	
Utah 36-3-4	393410	1105154	10/25/1995	>100,000	62,400	South of Price
			09/11/1996	<10	—	
			04/10/1997	<10	—	
			09/03/1998	<10	—	
			10/29/2001	19	—	
			10/16/2002	11	—	
			09/22/2003	4	—	
Bawden #1			09/20/2000	<10	—	South of Price
			10/29/2001	3	—	
			09/09/2002	2	—	
			09/25/2003	1	—	
Utah 1	393510	1104951	09/20/2000	<10	—	South of Price
			10/29/2001	1	—	
			09/09/2002	2	—	
Utah 19-14-12	393526	1105052	09/08/1995	<10	—	South of Price
			09/01/1998	<10	—	
			09/15/1999	<10	—	
			09/20/2000	<10	—	
			10/29/2001	1	—	
			09/09/2002	4	—	
			09/23/2003	—	3	
Utah 19-171	393522	1105705	04/08/1997	<10	—	South of Price
			09/15/1999	<10	—	
Utah 19-77	393545	1105104	09/11/1996	<10	—	South of Price
			09/20/2000	<10	—	
Utah 22-76	393550	1105343	09/12/1995	660	—	South of Price
			09/11/1996	<10	—	
			09/03/1998	<10	—	
Utah 18-93	393614	1105106	09/20/2000	12,400	—	South of Price
			10/29/2001	6	—	
			09/09/2002	465	—	
			09/23/2003	2	—	

Table 3. Soil-gas methane concentration in multiple samples collected adjacent to selected well sites, Carbon and Emery Counties, Utah, 1995-2003—Continued

Site name	Location		Sample date	Methane concentration (ppmv)		Area
	Latitude (ddmmss)	Longitude (dddmmss)		Sample collected within 10 feet of well	Sample collected more than 10 feet from well	
Utah 13-92	393616	1105127	09/15/1999	66,500	2,370	South of Price
			09/20/2000	150	—	
			10/29/2001	653	—	
			09/09/2002	9	—	
			09/23/2003	2	—	
USA 14-122	393636	1105304	09/01/1998	980	360	South of Price
			09/20/2000	1,160	—	
			10/29/2001	12	—	
City Ball Field	393657	1104740	09/07/1995	<10	—	Price/Helper
			09/13/1996	<10	—	
Helper State A-14	393715	1104623	09/17/1999	<10	—	
			09/20/2000	<10	—	
			10/29/2001	<1	—	
			09/09/2002	<1	—	
			09/22/2003	—	<1	
Helper State A-12	393716	1104735	09/01/1998	100	10	Price/Helper
			09/13/1999	<10	—	
Helper State B-2	393726	1104806	09/01/1998	<10	—	Price/Helper
			09/17/1999	<10	—	
			09/20/2000	160	—	
			10/29/2001	1	—	
			09/09/2002	1	—	
			09/22/2003	—	1	
Helper State A-9	393742	1104731	08/31/1998	990	—	Price/Helper
			09/01/1998	100	—	
			09/13/1999	<10	—	
			10/16/2002	11	—	
			09/22/2003	4	—	
Helper State B-1	393733	1104809	09/01/1998	<10	—	Price/Helper
			09/17/1999	30	<10	
Harmond A-1	393733	1105019	09/17/1999	<10	—	Price/Helper
			09/20/2000	<10	—	
Helper Federal F-4	393736	1104843	09/01/1998	60	<10	Price/Helper
Helper Federal F-4	393736	1104843	09/13/1999	<10	—	Price/Helper
Birch A-2	393746	1104957	09/01/1998	17,000	10	Price/Helper
			09/14/1999	3,670	<10	
			09/17/1999	<10	—	
			09/20/2000	<10	—	
			10/29/2001	411	—	
			10/16/2002	998	—	
			09/25/2003	6	—	
Helper Federal D-1	394016	1104601	09/09/1996	<10	—	Price/Helper
			04/08/1997	<10	—	
			08/31/1998	6,590	<10	
			09/13/1999	<10	—	

Table 3. Soil-gas methane concentration in multiple samples collected adjacent to selected well sites, Carbon and Emery Counties, Utah, 1995-2003—Continued

Site name	Location		Sample date	Methane concentration (ppmv)		Area
	Latitude (ddmmss)	Longitude (dddmmss)		Sample collected within 10 feet of well	Sample collected more than 10 feet from well	
Helper Federal A-1	394044	1104632	09/20/1995	38,400	—	Price/Helper
			09/13/1996	>100,000	—	
			04/08/1997	<10	—	
			08/31/1998	100	<10	
			09/13/1999	<10	—	
			09/20/2000	<10	—	
			10/29/2001	6	—	
			09/09/2002	7	—	
			09/25/2003	—	9	
Helper Federal A-2	394038	1104724	08/31/1998	<10	<10	Price/Helper
			09/13/1999	<10	—	
Helper Federal C-1	394058	1104655	08/31/1998	110	—	Price/Helper
			09/13/1999	<10	<10	

Table 4. Soil-gas methane concentration in samples collected at selected ground-water sites, Carbon and Emery Counties, Utah, 1995-2002

[**Site name:** Utah Division of Oil, Gas, and Mining designations or field notes. **Location**: d, degree; m, minute; s, second. **Methane concentration:** ppmv, parts per million by volume. Samples collected from 1995 through 2000 were analyzed by the OVA 128 Century Organic Vapor Analyzer, which was considered for this monitoring program to have a minimum detection limit of 10 ppmv. Samples collected from 2001 and 2002 were analyzed by the HNU Systems Inc. Model 311 Portable Gas Chromatograph, which was considered for this monitoring program to have a minimum detection limit of 1 ppmv. When no methane was detected at a sample site, a value of less than 10 ppmv (<10) is reported]

Site name	Location		Sample date	Methane concentration (ppmv)
	Latitude (ddmmss)	Longitude (dddmmss)		
Canyon above Standardville (by sheep pen) spring discharge from cliff face	394120	1105301	09/07/1995	<10
Canyon above Standardville Finkbinder Spring	394116	1105405	09/07/1995	<10
Covered Old Mine entrance just North of Kenilworth	394115	1105404	09/07/1995	<10
Golf Course Spring in the Pond	393837	1105149	09/12/1995	<10
Anadarko Office “CPF”	394747	1104609	09/18/1995	<10
Spring near Box Spring (NW) in Section 1- Matts Summit Quad	394823	1105227	09/19/1995	<10
Shimmin Trust 14-12 (Water sample from lot)	394732	1104511	09/19/1995	<10
Clawson Spring - Poison Spring Quad	392924	1105702	09/21/1995	30
Spring on east side of Kyune Quad Block 35	394908	1105247	09/21/1995	<10
Spring-fed pond by Desert Lake (Elmo Area)	392202	1104330	10/23/1995	130
Irrigation drain	392332	1104625	10/23/1995	<10
Irrigation drain (shallow ground water)	392340	1104622	10/23/1995	<10
Spigot at spring/seep source	391257	1104053	10/23/1995	<10
Staker Spring	391550	1104435	10/26/1995	<10
Unnamed spring	393324	1110022	09/18/2000	26,200
			10/30/2001	560
			10/14/2002	160

Appendix

This section describes the collection and analysis procedures used for soil-gas and ground-water samples collected during the 1995-2003 monitoring period. Samples were analyzed for methane using two analytical instruments: the (1) OVA 128 Century Organic Vapor Analyzer and (2) HNU 311 Portable Gas Chromatograph. Sample-collection techniques were the same for both analytical instruments. The desciptions are detailed enough so that any future monitoring can be designed to be comparable to the monitoring program described in this report.

Sample Collection

Gas samples were extracted from the soil by hand-pounding a perforated steel tube into the ground. The tube has a 3/8-in. outside diameter (OD) and is 4 ft long; perforations are miscellaneous 3/16-in. holes drilled in the bottom 1 ft of the tube. The tip of the steel tube is driven to a depth of 2 to 4 ft below land surface. Once the tube is in the ground, the void (annular) space between the tubing and the soil at land surface is sealed by wiggling the tube until fine-grained material fills in the void space. About 0.75 liter (L) of water is poured around the probe to create the seal. At some locations, the ground is hard and the task of sealing the interface is difficult. If a good seal is not obtained, a notation is recorded on the field form. A bad seal could result in an incorrect measurement of soil gas as a result of contamination of ambient air from above ground getting pulled into the subsurface along the annular space.

In ground water, methane concentration was measured by analyzing the headspace gas in a vial (bottle) of sample water. Two or three vials are gently rinsed, filled with sample water, and sealed with septum caps. The samples are visually inspected to ensure that there are no air bubbles in the bottle. Fifty milliliters (ml) of ambient air are injected through the septum into each bottle with a glass syringe. A second needle (without an attached syringe) also is inserted through the septum to allow displaced water to flow out of the bottle. Once the headspace is created, the needle and syringe are removed, and the vials are set aside for 20 minutes to allow the headspace to equilibrate with the dissolved methane in the water. After that time, a known volume of air is removed from the headspace through the septum with a glass syringe. The withdrawn air is then injected into the analysis equipment.

Analysis Procedures for the OVA 128 Century Organic Vapor Analyzer

The OVA 128 Century Organic Vapor Analyzer is equipped with a gas chromatograph column to separate methane from other hydrocarbon gases. The OVA 128 uses a hydrogen flame ionization detector (FID). This type of detector is a carbon-molecule counter. Gas samples are injected directly into the OVA 128 with a syringe. The OVA 128 startup procedure is described in the instruction manual. The OVA 128 is a delicate instrument and is transported in the cab of the field vehicle and disconnected from all external gas-supply lines between site visits. The OVA 128 is calibrated once a week during field-data collection and checked daily. Calibration is done by using a 95 parts per million by volume (ppmv) methane-to-air standard. Instrument responses to known methane amounts are compiled in a calibration plot that relates a unitless peak height to the mass of methane in a sample volume of soil gas. The calibration process is discussed in detail by Chafin and others (1993) and summarized in Naftz and others (1998).

Soil gas is collected by means of a small vacuum pump hooked to a short flexible hose that is attached to the top of a perforated steel tube that has been driven into the ground (see "Sample collection" section of the appendix). The pump is run for 2 minutes to purge the tube and hose. A known gas-sample volume is withdrawn from an inline-septum-sample port with a glass syringe and injected into the OVA 128. A unitless peak-height response is recorded. Peak height is converted to concentration with the calibration curve, as explained in Chafin and others (1993) and Naftz and others (1998). For ground water, the dissolved gas is separated from the water sample by using a gas bottle sealed with a septum cap (see "Sample collection" section of appendix). A known gas-sample volume is withdrawn from the sample-bottle headspace through the septum with a glass syringe and injected into the OVA 128. As with soil gas, a unitless peak height is recorded and converted to a methane concentration.

Analysis Procedures for the HNU 311 Portable Gas Chromatograph

The HNU 311 Portable Gas Chromatograph (GC) used for the monitoring program was equipped with a packed column, an FID, and a 1-cubic-centimeter (cm^3) sample loop. Control of the HNU 311 is automated and the parameters are set on a computer with Peakworks software. Communication to the HNU 311 is made by using an RS 232 cable connected to PORT 1. Setup communications on the PC are as follows:

MY COMPUTER → CONTROL PANEL → SYSTEM DEVICE MANAGER → PORTS → COM1→ PORT SETTINGS → bits per second = 9,600

Once the communications port has been set up, the gas chromatograph parameters must be adjusted. From the menu bar, select **Method**. From the **Method** drop-down menu, select the **Edit** dialog box and set the following parameters:

Parameter	Setting
INJ/DET Temp	110
Oven Temp	50
Analysis Time	1:30

[1]Sample Time	2:00
Inject Time	0:15

For the remaining parameters, use the default setting. After exiting the dialog box, save the job file using the **File** drop down menu. Every time a dialog box is exited, save the job file.

From the menu bar, select **Method**. From the **Method** drop-down menu, select the **Detector A** dialog box, turn on the detector, and set the following parameters:

Parameter	Setting
Length	0:30
Segment Width	10
Units	PPM
Range	100

For the remaining parameters, use the default setting.

Continuing from the **Method** drop-down menu, select the **Detector B** dialog box and turn off the detector.

From the menu bar, select **Method**. From the **Method** drop-down menu, select the **Components** table, select the **Edit** dialog box, toggle on, and set the following parameters:

Parameter	Setting
Name	Methane
Peak RT	0:39
Window	0:05

For the remaining parameters, use the default setting.

Continuing from the **Method** drop-down menu, select the **Standards** table and highlight the Methane record. Select the **Edit** dialog box and set the following parameter:

Parameter	Setting
Stand. 0	[2]9.78

Now, from the **Options** drop-down menu, select the **Preferences** dialog box and set the following parameter:

Parameter	Setting
Port	COM 1:

Remember to save the job file using the **File** drop down menu.

If the HNU 311 starts to beep and the beeping cannot be stopped, the power must be manually cycled. This is a known HNU 311 bug. Follow the steps below:

Remove the HNU 311 from case.

Disconnect ground cable.

On left side top, slide out first circuit board and push it back in. This power cycles the board and should stop the beeping.

[1]This is the time that the HNU 311 pumps in a sample, maximum flow rate is 250-300 cubic centimeters per minute (cm^3/min) (p. 3-9 in the HNU 311 instruction manual). Sample time needs to be long enough to ensure that three sample volumes have been pumped through the sample rod and connecting plumbing.

[2]This value needs to match the methane concentration of the gas mixture used for calibration of the gas chromatograph.

In the field, the HNU 311 is calibrated each day prior to any sample collection and intermittently throughout the day depending on drift, response, and circumstances. If the standard is different from that used during initial setup, the concentration is adjusted with Peakworks. The HNU 311 is a delicate instrument and is transported in the cab of the field vehicle and disconnected from all external gas-supply lines between site visits. The oven is turned off between sites, but a small amount of nitrogen (from the internal tank) is kept flowing through the column to cool it down and prevent ambient air from diffusing into the column. The HNU 311 is powered by a gas generator with a rating of at least 2,000 watts. Ultra-pure-grade nitrogen is the carrier gas, and hydrogen gas is used for the FID. Standard-size cylinders containing each of these gases are transported to the field to refill the smaller internal HNU 311 gas bottles (as described in the instruction manual for HNU 311).

Calibration gas enters the instrument at the inlet port labeled “CAL GAS IN” through a short tube hooked directly to the calibration gas pressure tank. Soil-gas samples are inlet to the HNU 311 at the port labeled “SAMPLE PUMP IN” by using a 30-ft length of 1/8-in. OD gas-impermeable nylon tubing attached to the top of a perforated steel tube that has been driven into the ground (see “Sample collection” section of the appendix). The HNU 311 has an internal pump that pulls a sample in through the tubing. A small air filter (or piece of foam) is inserted in the line between the steel tube and the 1/8-in. nylon tubing to prevent dust and other detritus from being sucked into the HNU 311. Flow rate of the internal pump is 250-300 cm^3/minute at the inlet (p. 3-9 of the instruction manual) and the tube is pumped for 2 minutes to ensure that air in the tube is from the surrounding soil and that there is no residual methane in the steel tube and line from previous samples or ambient air. The gas volumes in the steel and connecting tubing are:

Volume is calculated as Pi*radius^2*length. Based on outside diameter, the steel tubing volume is:

$(0.375 \text{ in} * 2.54 \text{ cm/in} * 0.5)^2 * 3.142 = 0.713 \text{ cm}^2 * 4 \text{ ft} * 30.48 \text{ cm/ft} = 87 \text{ cm}^3$.

Based on outside diameter, the connecting tubing volume is:

$(0.125 \text{ in} * 2.54 \text{ cm/in} * 0.5)^2 * 3.142 = 0.079 \text{ cm}^2 * 30 \text{ ft} * 30.48 \text{ cm/ft} = 72 \text{ cm}^3$.

Consecutive readings are made at a site until there is a discrepancy of less than 10 percent between readings. Normally, this requires three to six measurements. The last measurement is reported as the methane soil-gas concentration for the site. Local ambient-air methane measurements were obtained after the analysis of soil gas.

For ground water, the dissolved gas is separated from the water sample by using a gas bottle capped with septum (see “Sample collection” section of the appendix). A known gas-sample volume is withdrawn from the sample-bottle headspace

through the septum with a glass syringe and injected into the HNU 311 at the injection port (fig. 3.1 of the instruction manual). When samples are manually injected rather than pumped (as is the situation for soil-gas samples), operation of the HNU 311 must be modified with the Peakworks software. From the menu bar, select **Method**. From the **Method** drop-down menu, select the **Edit** dialog box and toggle on Syringe Inj.