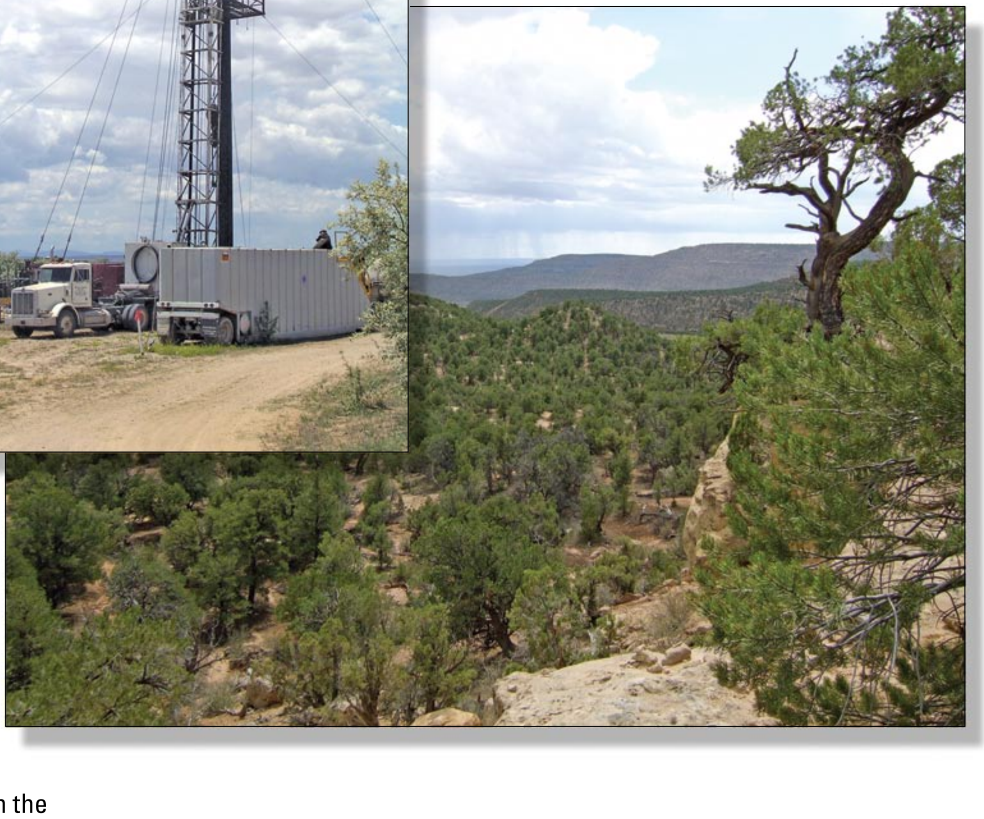
Effects of Saline-Wastewater Injection on Water Quality in the Altamont-Bluebell Oil and Gas Field, Duchesne County, Utah, 1990-2005



Prepared in cooperation with the
UTAH DEPARTMENT OF NATURAL RESOURCES, DIVISION OF OIL, GAS, AND MINING

Scientific Investigations Report 2007-5192

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

Cover photo: Top left: Workover rig plugging an oil well in the Altamont-Bluebell oil and gas field, June 2007. Photo by Helen Sadik-Macdonald, Utah Department of Natural Resources, Division of Oil, Gas, and Mining. Bottom right: Looking west near Talmage, Utah, September 2007. Photo by Joseph Gardner, U.S. Geological Survey.

Effects of Saline-Wastewater Injection on Water Quality in the Altamont-Bluebell Oil and Gas Field, Duchesne County, Utah, 1990-2005

By Judy I. Steiger

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

U.S. Department of the Interior
DIRK KEMPTHORNE, Secretary

U.S. Geological Survey
Mark D. Myers, Director

Reston, Virginia: 2007

For additional information write to:
U.S. Geological Survey
Director, USGS Utah Water Science Center
2329 W. Orton Circle
Salt Lake City, UT 84119-2047
Email: GS-W-UTpublic-info@usgs.gov
URL: http://ut.water.usgs.gov/

For more information about the USGS and its products:
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Contents

Abstract 1
Introduction..1
    Oil and Gas Production in the Altamont-Bluebell Field 3
    Purpose and Scope 3
Water Quality 3
    Relative Concentrations of Major Chemical Constituents 8
    Bromide and Chloride..8
    Trends in Chemical Constituents 15
    Stable Isotopes..15
Summary..18
References Cited..20

Figures

1. Location of the Altamont-Bluebell oil and gas field and surrounding area, Duchesne and Uintah Counties, Utah 2
2. Vertical relation and lithologic character of the source of the drinking-water supply to zones of oil production and disposal of saline wastewater, Altamont-Bluebell area, Duchesne and Uintah Counties, Utah 4
3. Location of saline-wastewater disposal wells and water-quality monitoring wells in the Altamont-Bluebell area, Duchesne and Uintah Counties, Utah.............................5
4. Major-ion composition of saline-wastewater samples and of ground-water-quality samples collected from monitoring wells located in the Bluebell oil field area, Duchesne County, Utah, 1992-93..9
5. Mixing lines constructed between ground water and saline wastewater in relation to the weight ratio of bromide to chloride, for water samples collected from wells in the Altamont-Bluebell area, Duchesne County, Utah...............................16
6. Relation between δ^2H and $\delta^{18}O$ values for ground-water samples collected during 1992-2005 and saline wastewater samples collected during 1993, Altamont-Bluebell area, Duchesne County, Utah...19

Tables

1. Records of water-quality monitoring wells and saline-wastewater disposal wells in the Altamont-Blueball area, Duchesne County, Utah...6
2. Physical properties and results of chemical analyses of water samples collected from selected water-quality monitoring wells and from saline wastewater in the Altamont-Bluebell area, Duchesne County, Utah, with data from 1964-2005...10
3. Physical properties, bromide and chloride concentration, and isotopic ratios of water samples collected from selected water-quality monitoring wells and from saline wastewater in the Altamont-Bluebell area, Duchesne County, Utah, with data from 1964-2005...12

Conversion Factors, Datums, and Abbreviated Water-Quality Units

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	0.4047	hectare (ha)
section (640 acres or 1 square mile)	259	square hectometer (hm^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
cubic foot (ft^3)	0.02832	cubic meter (m^3)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F= (1.8×°C) +32.$$

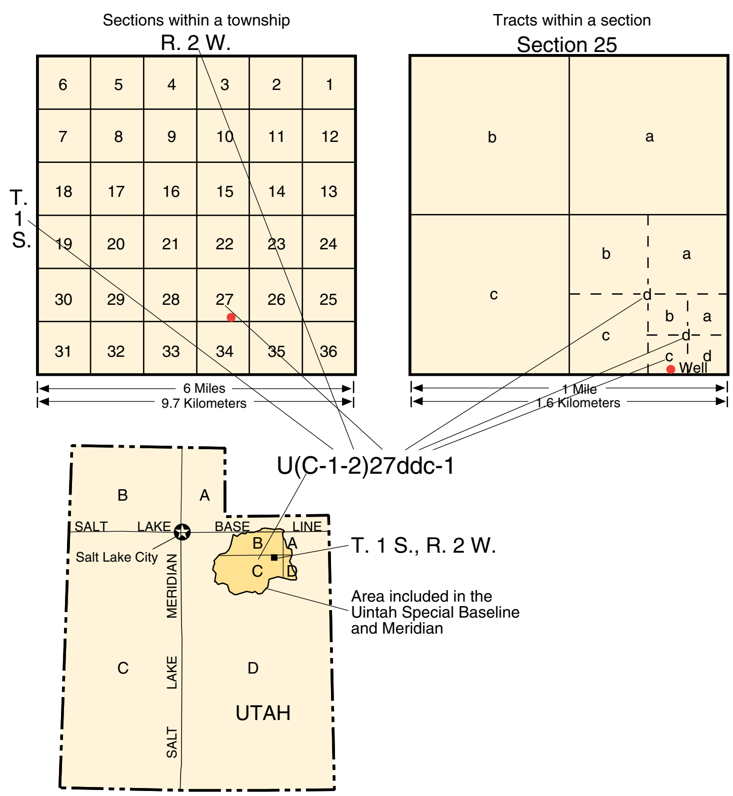
Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83). Vertical coordinate information is referenced to the North American Vertical Datum of 1929 (NGVD 29). Altitude, as used in this report, refers to distance above the vertical datum.

Chemical concentration is reported only in metric units. Chemical concentration is reported in milligrams per liter (mg/L) or micrograms per liter (µg/L). Milligrams per liter is a unit expression of the solute concentration per unit volume (liter) of water. One thousand micrograms per liter is equivalent to 1 milligram per liter. For concentrations less than 7,000 mg/L, the numerical value is about the same as for concentrations in parts per million. Specific conductance is represented in microsiemens per centimeter at 25 degrees Celsius (µS/cm).

Note: Spelling of “Uinta” and “Uintah” throughout this report will vary depending upon usage and context; the different spellings are intentional.

Numbering system for hydrologic-data sites in Utah

The system of numbering wells, springs, and other hydrologic-data sites in Utah is based on the cadastral land-survey system of the U.S. Government. The number, in addition to designating the site, describes its position in the land net. The land-survey system divides the State of Utah into four quadrants by the Salt Lake Base Line and the Salt Lake Meridian—and in the Uinta Basin, by the Uintah Base Line and the Uintah Meridian. These quadrants are designated by the uppercase letters A, B, C, and D, which indicate, respectively, the northeast, northwest, southwest, and southeast quadrants. Numbers that designate the township and range, in that order, follow the quadrant letter, and all three are enclosed in parentheses. The number after the parentheses indicates the section and is followed by three lowercase letters that indicate the quarter section, the quarter-quarter section, and the quarter-quarter-quarter section—generally 10 acres for a regular section[1]. The lowercase letters a, b, c, and d indicate, respectively, the northeast, northwest, southwest, and southeast quarters of each subdivision. The number after the letters is the serial number of the well or spring within the 10-acre tract. Thus, U(C-1-2)27ddc-1 designates the first well visited in the SW ¼ of the SE ¼ of the SE ¼ of Sec. 27, T. 1 S, R. 2 W. The capital letter "U" preceding the information in the parentheses indicates that the site is referenced to the Uintah Base Line and Meridian and that the site is in the Uinta Basin. The capital letter "C" indicates that the township is south of the Uintah Base Line and the range is west of the Uintah Meridian.



[1]Although the basic land unit, the section, is theoretically 1 square mile, many sections are irregular. Such sections are subdivided into 10-acre tracts, generally beginning at the southeast corner, and the surplus or shortage is taken up in the tracts along the north and west sides of the section.

Effects of saline-wastewater injection on water quality in the Altamont-Bluebell oil and gas field, Duchesne County, Utah, 1990-2005

By Judy I. Steiger

ABSTRACT

The Altamont-Bluebell oil and gas field in the Uinta Basin in northeastern Utah has been an important oil and natural gas production area since the 1950s. Saline water is produced along with oil during the oil-well drilling and pumping process. The saline wastewater is disposed of by injection into wells completed in the Duchesne River Formation, Uinta Formation, and other underlying formations. There are concerns that the injected saline wastewater could migrate into the upper part of the Duchesne River and Uinta Formations and surficial deposits that are used for drinking-water supply and degrade the quality of the drinking water. The U.S. Geological Survey, in cooperation with the Utah Department of Natural Resources, Division of Oil, Gas, and Mining, began a program in 1990 to monitor water quality in five wells in the Altamont-Bluebell oil and gas field. By 1996, water-quality samples had been collected from 20 wells. Ten of the 20 wells were sampled yearly during 1996-2005 and analyzed for bromide, chloride, and stable isotopes. Comparison of major chemical constituents, bromide-to-chloride ratios, trend analysis, and isotope ratios were used to assess if saline wastewater is migrating into parts of the formation that are developed for drinking-water supplies. Results of four different analyses all indicate that saline wastewater injected into the lower part of the Duchesne River and Uinta Formations and underlying formations is not migrating upward into the upper parts of the formations that are used for drinking-water supplies.

INTRODUCTION

The Altamont-Bluebell oil and gas field in the Uinta Basin in northeastern Utah (fig. 1) has been an important oil and natural gas production area since the 1950s. The Altamont field is the western portion and Bluebell field is the eastern portion of the area. The Altamont-Bluebell oil and gas field includes a number of smaller fields within its boundary. To the south of the Altamont field is the Duchesne field. In this report, "Altamont-Bluebell area" refers to all the inholdings in the Altamont-Bluebell fields, and "Altamont area" includes the Duchesne field.

Production of oil and natural gas has varied in the Altamont-Bluebell area through the years with the discovery of new reservoirs, maturation of development, and the price of oil. Saline wastewater is produced along with oil during oil-well drilling and oil production. Saline wastewater is collected in surface evaporation ponds or tanks at well heads and then transported to disposal sites where it is injected back into the ground. In 2005, saline wastewater in the Altamont-Bluebell field was injected at depths of from 3,100 to 10,500 ft below land surface into the lower part of the Duchesne River Formation or underlying Uinta and Green River Formations (Utah Division of Oil, Gas, and Mining, written commun., 2006). The State of Utah encourages disposal of wastewater into zones where the ambient concentration of dissolved solids is greater than the concentration of dissolved solids of injection water (Freethey, 1994). Injection of water into the formation can change hydraulic gradients and the direction of ground-water flow (Freethey, 1988). Wells used for drinking-water supplies are completed in the surficial alluvial deposits and the upper part of the Duchesne River and Uinta Formations in the Altamont-Bluebell area. There are concerns that the injected saline wastewater could migrate into portions of the formations and surficial deposits that are used for drinking-water supply and degrade the quality of water. In response to these concerns, the U.S. Geological Survey, in cooperation with the Utah Department of Natural Resources, Division of Oil, Gas, and Mining, developed a water-quality monitoring program with the objective of collecting a long-term data set and assessing water-quality trends in the upper part of the Duchesne River and Uinta Formations and surficial deposits that could be used for drinking water.

The water-quality monitoring program began in phases with the collection of water samples from five wells in the Bluebell field in 1990. In 1991, an additional five wells in the same area were added to the monitoring network. All 10 monitoring wells in the Bluebell field were completed in the Duchesne River Formation. Monitoring expanded again in 1996 to include 10 wells in the Altamont field along with the 10 previously sampled water wells in the Bluebell field. The monitoring wells in the Altamont area included two wells

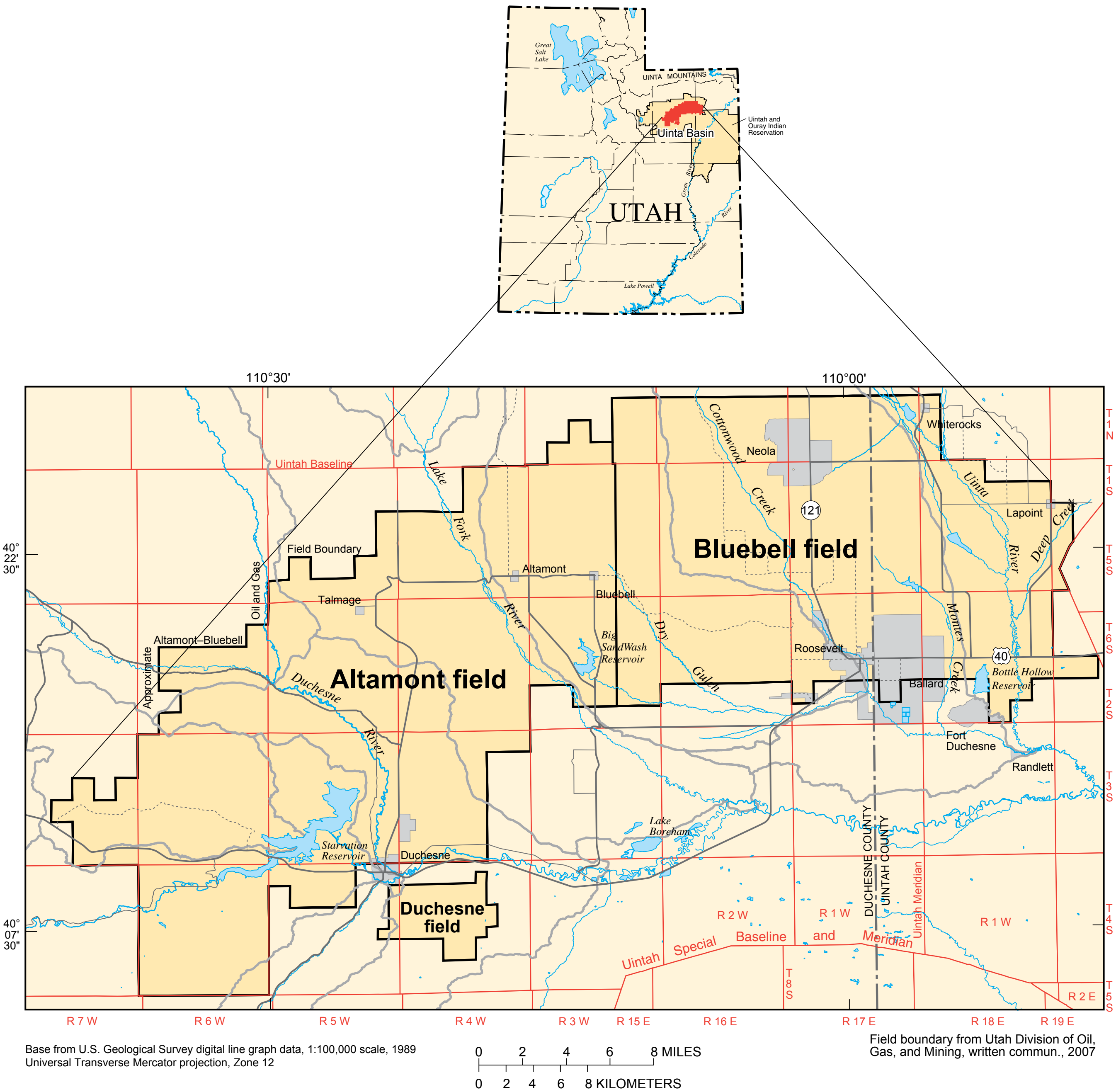


Figure 1. Location of the Altamont-Bluebell oil and gas field and surrounding area, Duchesne and Uintah Counties, Utah.

completed in the Duchesne River Formation, three in surficial deposits, and five in the Uinta Formation. From 1996 through 2004, 10 of the 20 wells were sampled annually on a rotating basis. Since 1993, monitoring of water quality focused on two constituents, bromide and chloride, and two stable isotopes, oxygen-18 (^{18}O) and deuterium (^{2}H).

Oil and Gas Production in the Altamont-Bluebell Field

The Altamont-Bluebell oil and natural gas fields are one of the most productive in Utah. The Green River and Wasatch Formations in the Altamont-Bluebell oil and gas field are the preferred production zone for oil and natural gas wells (fig. 2). About one third of the wells in the fields are completed in other formations: the Uinta Formation, Duchesne River Formation, Flagstaff Limestone, and North Horn Formation (Utah Division of Oil, Gas, and Mining, written commun., 2006).

About 123 million barrels of oil was pumped from the Altamont-Bluebell oil and gas field during 1984-2005, with a peak annual production in 1985 of almost 11 million barrels. Production of oil in the area has declined since the mid-1980s to an average level during 2002-05 of about 2.6 million barrels of oil annually (Utah Division of Oil, Gas, and Mining, written commun., 2006).

Natural gas production in the Altamont-Bluebell field peaked in 1992 at about 17 million ft^3. Production in 2005 was 6 million ft^3 (Utah Division of Oil, Gas, and Mining, written commun., 2006).

Saline water is produced along with the extracted oil. This wastewater is collected at the production sites in tanks or surface evaporation ponds and then transported to disposal wells for injection. In 2006, there were 20 active, 2 inactive, and 12 plugged and abandoned disposal wells in the Altamont-Bluebell area. Depth of the 20 active disposal wells ranges from 3,150 to 15,597 ft (Utah Division of Oil, Gas, and Mining, written commun., 2006). Freethey (1994) identified two zones used for disposal of the saline wastewater (fig. 2). The lower portion of the Duchesne River Formation was referred to as the upper disposal zone and was identified in Freethey (1994) as sandstone layers bounded above and below by shale layers. Depth to the top of the upper disposal zone was defined as the depth to the first shale interval that was greater than 40 ft thick that was overlying the sandstone layers. Freethey (1994) identified the vertical and lateral extent of the upper disposal zone in the Bluebell field by using information from well construction data and geophysical logs. The vertical relation and lithologic character of geologic formations, oil-production zones, and saline-wastewater injection zones for the Altamont-Bluebell area are shown in figure 2.

A lower disposal zone in the Uinta and Green River Formations also was identified by Freethey (1994), but determining the extent of the zone was not within the scope of that report. The lower disposal zone is of concern in the southern part of the Altamont area near Starvation Reservoir and the City of Duchesne. The Duchesne River Formation thins out north of this area and the Uinta Formation is the source of the drinking-water supply (Hood, 1976). Saline wastewater in this area is disposed of in wells completed in the Uinta, Green River, or underlying formations.

Purpose and Scope

The purpose of this report is to present water-quality data collected in the Altamont-Bluebell area of the Uinta Basin in Duchesne County during 1990-2005 and to assess if aquifers used to supply drinking water have been affected by the injection of saline wastewater into deeper zones of the formations. The data include results of water-quality analyses for water sampled from wells completed in the upper parts of the Duchesne River and Uinta Formations and in the surficial deposits. Water-quality data also include results of analyses of saline wastewater prior to disposal by injection into the lower part of the Duchesne River Formation and Uinta and Green River Formations. Bromide-to-chloride ratios, trend analysis, and stable isotopes are used to assess if saline wastewater is migrating into the portion of the formations and surficial deposits that is used to supply drinking water.

WATER QUALITY

Water collected from a network of 20 water wells in the Altamont-Bluebell area has been sampled to monitor changes in water quality. Monitoring of water quality began in 1990 in the Bluebell (eastern) portion of the Altamont-Bluebell field when water from five wells was analyzed for major ions. During 1991-93, water from 10 wells was analyzed for major ions. Beginning in 1992, the stable isotopes of ^{18}O and ^{2}H also were included in the analysis. In 1993, samples of saline wastewater were collected before injection at five disposal well sites (fig. 3) and also were analyzed for major ions and stable isotopes. Ten water wells in the Altamont portion of the area were added to the ground-water sampling network in 1996. During 1996-2005, samples from the water wells were analyzed only for bromide, chloride, ^{18}O, and ^{2}H.

Water from 10 of the 20 water wells was scheduled to be sampled each year. Over time, three of the water-quality monitoring wells have been removed from the network because of well closures and (or) because the owner switched to municipal supply. Saline wastewater was sampled before injection in 1993 at the five designated saline-wastewater disposal wells. Well-construction data and depth of the water-quality monitoring wells and the five saline-wastewater disposal wells have been compiled and summarized in table 1, and the location of each well is shown in figure 3.

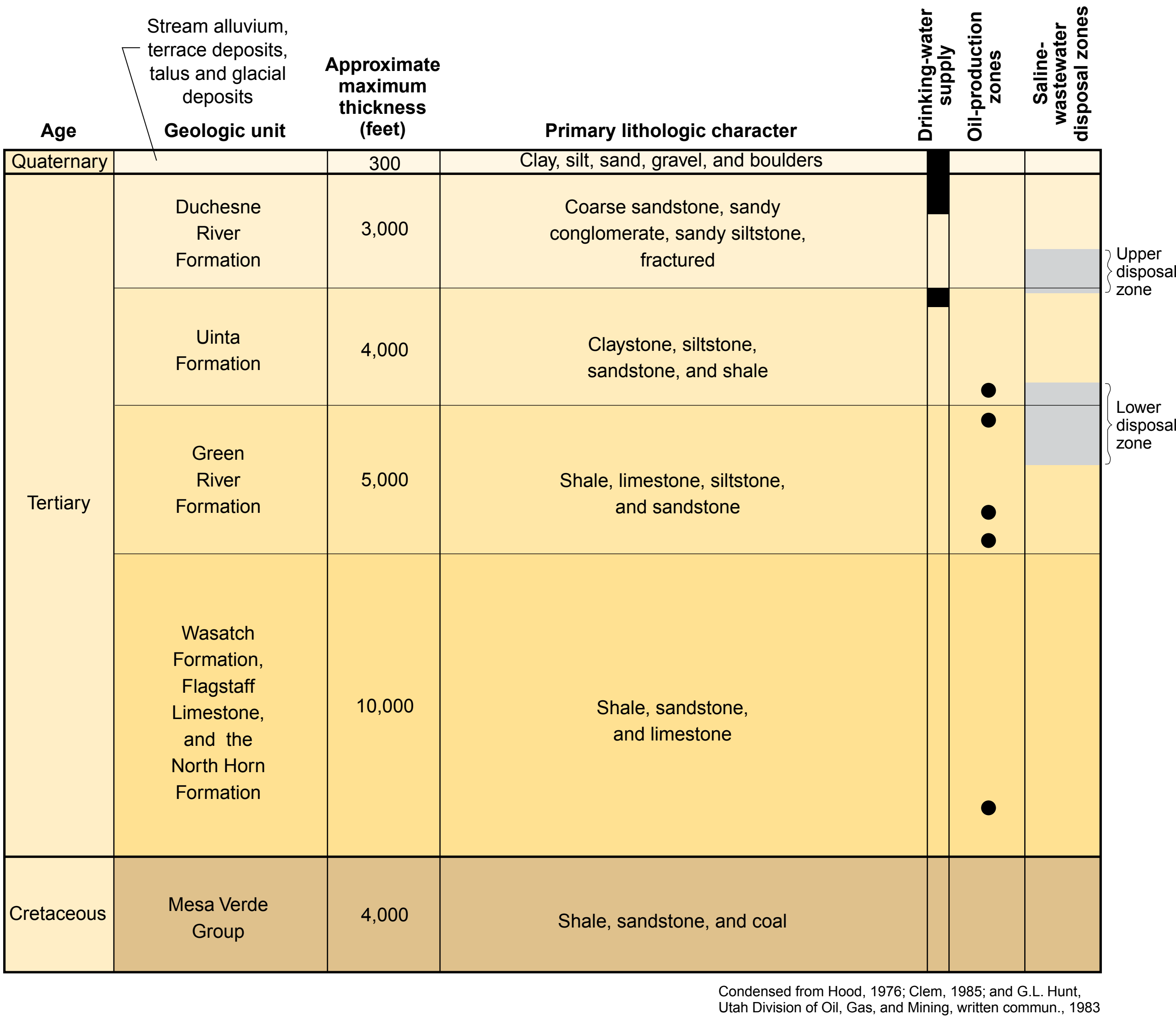


Figure 2. Vertical relation and lithologic character of the source of the drinking-water supply to zones of oil production and disposal of saline wastewater, Altamont-Bluebell area, Duchesne and Uintah Counties, Utah (reprinted from Freethey, 1994).

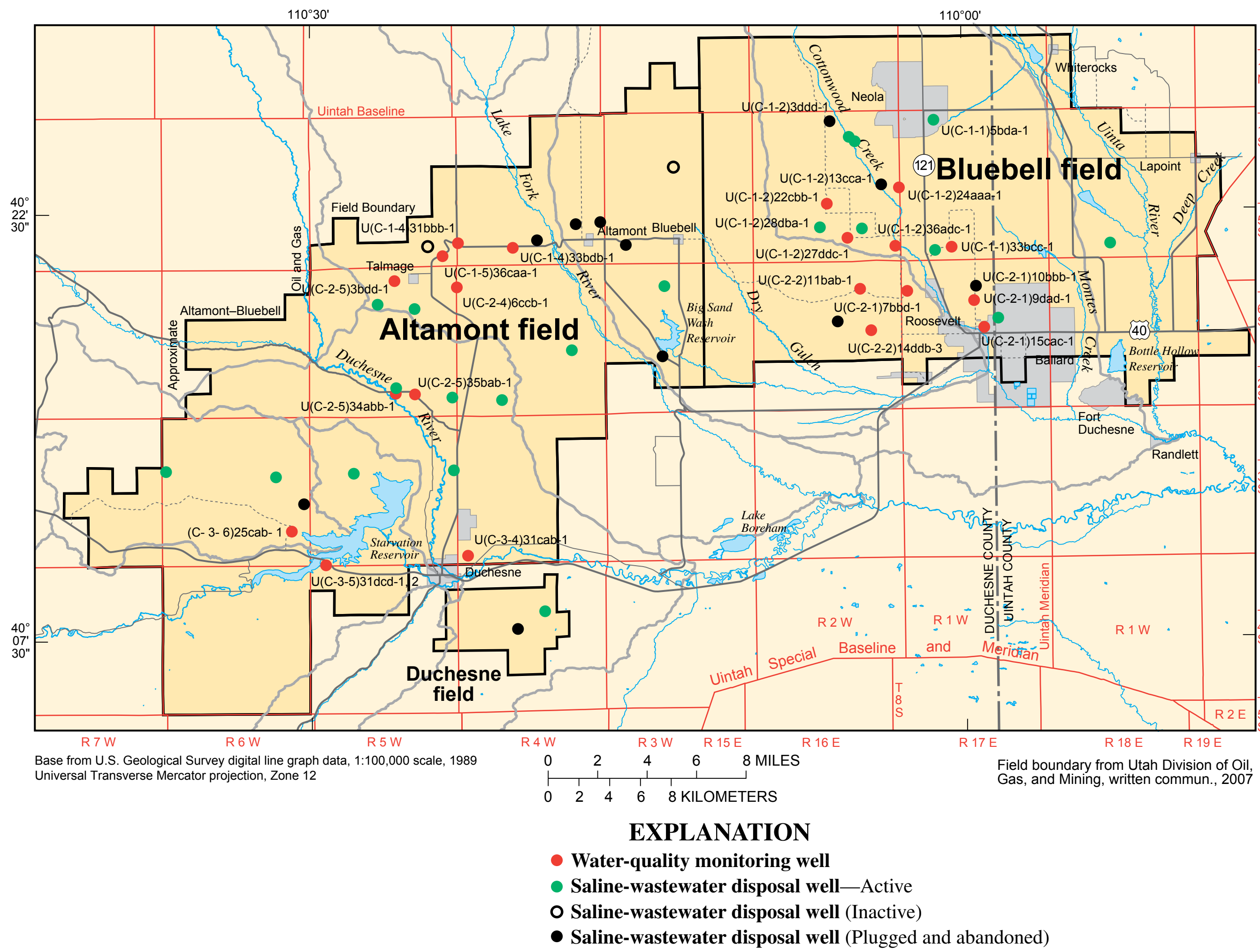


Figure 3. Location of saline-wastewater disposal wells and water-quality monitoring wells in the Altamont-Bluebell area, Duchesne and Uintah Counties, Utah.

Table 1. Records of water-quality monitoring wells and saline-wastewater disposal wells in the Altamont-Blueball area, Duchesne County, Utah.

[Site name: for saline wastewater the name refers to the disposal well where the saline wastewater is injected into the ground; see report text for an explanation of the numbering system for hydologic-data sites; Site number: a unique number identifying a site in the U.S. Geological Survey database, originally based upon latitude and longitude; Primary use of water or site in 2005: H, domestic supply; I, irrigation; S, stock; U, unknown; D, saline-wastewater disposal well; Geohydrologic unit: GRRV, Green River Formation; DCRV, Duchesne River Formation; UINT, Uinta Formation; GRRV-WS, Green River and Wasatch Formations; ALVM, stream deposits, glacial deposits, and terrace deposits; Depth of well casing: R, reported depth; Type of well opening: P, perforated, X, open hole; —, no data]

Site name	Site number	Year constructed	Primary use of water or site	Altitude of land surface (feet)	Depth drilled (feet below land surface)	Depth of well casing (feet)	Diameter of well casing (inches)	Type of well opening
				Bluebell field				
U(C-1-1)33bcc-1	402114110003301	1973	H	5,260	220	220	6,4	P
U(C-1-2)22cbb-1	402246110061501	1961	I	5,705	810	60	8	X
U(C-1-2)24aaa-1	402319110025601	1972	H	5,615	260	220	6,4	P, X
U(C-1-2)27ddc-1	402135110051901	1972	H	5,610	420	320	6,4	X
U(C-1-2)36adc-1	402116110030801	1970	S	5,394	170	40	6	X
U(C-2-1)7bbd-1	401940110023601	1960; 1984	H	5,270	895	895	8,6	P
U(C-2-1)9dad-1	401919109593201	1969	H	5,136	740	207	6	X
U(C-2-1)15cac-1	401823109590401	1940	H	5,081	600	200	8,2	X
U(C-2-2)11bab-1	401946110044601	1975	H	5,420	666	105	6	X
U(C-2-2)14ddb-3	401820110041901	1928-29	H	5,270	—	500 R	6	—
				Altamont field				
U(C-1-4)31bbb-1	402130110231301	1978	H	6,690	100	55	6,5	P, X
U(C-1-4)33bdb-1	402119110204201	1948	S	6,440	30	30	7	—
U(C-1-5)36caa-1	402103110235601	1985	U	6,680	157	157	6	P
U(C-2-4)6ccb-1	401957110231701	—	H	6,650	29	29	6	—
U(C-2-5)3bdd-1	402011110260901	1971	H	6,880	32	32	6	—
U(C-2-5)34abb- 2	401613110260702	1973	H	5,852	200	200	6	P
U(C-2-5)35bab-1	401611110251502	1972	H	5,870	120	120	6,4	P
U(C-3-4)31cab-1	401030110225701	1946	H	5,640	70	70	6	P
U(C-3-5)31dcd-1	401012110292101	1969	H	5,790	200	42	8,6	X
U(C-3-5)31dcd- 2	401012110291901	1975	I	5,785	200	200	10,6	P
U(C-3-6)25cab-1	401124110305501	1978	H	5,260	120	120	6	X
				Saline-wastewater disposal wells				
U(C-1-1)5bda-1	402541110011901	1984	D	5,960	15,645	15,560 9,500	10,7,3	—
U(C-1-2)3ddd-1	402507110051301	1969	D	5,900	3,150	3,108	13.5,10	—
U(C-1-2)13cca-1	402326110034401	1970	D	5,620	12,530	12,520	10.75,7,4.5	—
U(C-1-2)28dba-1	402157110063501	1974	D	5,720	3,500	3,450	13.5,9,3	—
U(C-2-1)10bbb-1	401950109592501	1979	D	5,150	2,513	2,461	5,2.5	—

Table 1. Records of water-quality monitoring wells and saline-wastewater disposal wells in the Altamont-Blueball area, Duchesne County, Utah—Continued.

Site name	Depth of open interval (feet below land surface)	Geohydrologic unit	Remarks
		Bluebell field	
U(C-1-1)33bcc-1	180-220	DCRV	
U(C-1-2)22cbb-1	60-180	DCRV	
U(C-1-2)24aaa-1	216-220; 220-260	DCRV	
U(C-1-2)27ddc-1	320-420	DCRV	
U(C-1-2)36adc-1	40-170	DCRV	
U(C-2-1)7bbd-1	120-140; 160-180; 200-240; 300-780;	DCRV	Originally constructed in 1960; cleaned out and repaired in 1984
U(C-2-1)9dad-1	207-740	DCRV	
U(C-2-1)15cac-1	200-600	DCRV	Well dry in 2002
U(C-2-2)11bab-1	105-666	DCRV	
U(C-2-2)14ddb-3	—	DCRV	
		Altamont field	
U(C-1-4)31bbb-1	40-55; 55-100	DCRV	
U(C-1-4)33bdb-1	—	ALVM	
U(C-1-5)36caa-1	110-157	DCRV	Well reported caved in sometime between 1996-99
U(C-2-4)6ccb-1	—	ALVM	Hand dug well
U(C-2-5)3bdd-1	—	ALVM	Owner said well went dry in August 2003
U(C-2-5)34abb- 2	140-160; 170-190	UINT	
U(C-2-5)35bab-1	90-120	UINT	
U(C-3-4)31cab-1	41-70	UINT	
U(C-3-5)31dcd-1	42-200	UINT	Sampled in 1974, alternate sample site for U(C-3-5)31dcd-2
U(C-3-5)31dcd- 2	140-200	UINT	Well out of service since 1999
U(C-3-6)25cab-1	140-201	UINT	
		Saline-wastewater disposal wells	
U(C-1-1)5bda-1	—	GRRV	Drilled as an oil production well in 1984, converted to disposal well in 1991 and plugged to 9,500 feet depth; later plugged and abondoned
U(C-1-2)3ddd-1	—	UINT	
U(C-1-2)13cca-1	—	GRRV-WS	
U(C-1-2)28dba-1	—	DCRV	
U(C-2-1)10bbb-1	—	DCRV	Well plugged and abandoned in 2001

Relative Concentrations of Major Chemical Constituents

Water quality in the Bluebell portion of the field varies spatially and was evaluated graphically with Stiff diagrams (fig. 4). A Stiff diagram is a simple way to show the relative concentration of major chemical constituents in water: positively charged ions (cations) appear to the left of the center line and negatively charged ions (anions) appear to the right. The distance of a vertex from the center line is proportional to the concentration of the chemical constituent. Stiff diagrams with similar shapes indicate that the respective water samples contain similar proportions of major ions. Concentrations of alkalinity used to determine bicarbonate and carbonate concentrations for the Stiff diagrams were calculated from the residual between the measured anion-cation balances. Water samples collected from the Altamont portion of the field during this study were not analyzed for all of the major ions necessary to construct Stiff diagrams.

Each Stiff diagram represents a single water sample collected in 1993 except for one sample collected in 1992. The five samples of saline wastewater collected in 1993 are associated with the disposal wells into which the water was injected (fig. 4). These Stiff diagrams do not represent the water quality of the water contained within the formations in which these disposal wells are completed, but rather a composite of the waters from multiple formations and oil wells. Analyses of water samples collected from four water wells near Roosevelt (fig. 4, table 2) indicate that the dominant cation is sodium/potassium and the dominant anion is bicarbonate/carbonate. To the north and west of Roosevelt in water sampled from five water wells, the dominant cation is calcium, but the dominant anion is still bicarbonate/carbonate. All of the saline-wastewater samples contain much higher concentrations of dissolved ions than do the water samples collected from the monitoring wells and are of a consistent water type: the dominant cation is sodium/potassium and the dominant anion is chloride.

The Stiff diagrams of the saline wastewater and water collected from the water-quality monitoring wells have distinctive and very different shapes (fig. 4). If mixing of the saline wastewater and water from the monitoring wells were occurring, then the shape of each Stiff diagram would be either similar to that of the saline wastewater or would be a shape that was intermediate between that of the water sampled from the monitoring wells and the saline wastewater, depending on the degree of mixing. As mixing of the types of water occurred, the dominant cation for the mixed water would be expected to be sodium/potassium and the dominant anion would be chloride. Comparison of the relative concentration of major constituents shows a distinct and consistent difference for saline wastewater and water collected from water-quality monitoring wells, indicating a lack of mixing of the waters.

Bromide and Chloride

Beginning in 1994, monitoring for changes in water quality that could be caused by mixing of waters focused on two constituents, bromide and chloride, and two stable isotopes, ^{18}O and ^{2}H. These constituents were selected because differences in concentration or isotope ratios between water samples collected from the ground-water monitoring wells and samples of saline wastewater are large and the constituents are chemically conservative. Physical properties, bromide and chloride concentration, and isotopic ratios measured in samples of ground water and saline wastewater are listed in table 3.

Chloride concentration in water samples collected from the monitoring wells ranged from 0.1 to 205 mg/L (table 3). Saline wastewater had concentrations of chloride ranging from 2,500 to 5,500 mg/L (table 3).

Bromide concentration in water samples collected from the monitoring wells ranged from less than 0.01 to 0.82 mg/L (table 3). Seventy percent of the water samples collected from the monitoring wells had a bromide concentration of 0.03 mg/L or less (table 3). Only five samples, all collected from monitoring wells U(C-1-4)33bdb-1 and U(C-1-5)36caa-1 in the Altamont area, had a bromide concentration greater than 0.10 mg/L. Bromide concentration in saline wastewater ranged from 14 to 22 mg/L (table 3).

Because of the large differences in the concentration of bromide and chloride between water samples collected from the monitoring wells and saline wastewater, any increase in concentration of either of these two constituents in the water collected from the monitoring wells over time might indicate a mixing of the two waters. A plot of the ratio of bromide to chloride with chloride for water from the monitoring wells against a calculated mixing line of the two waters can show if ground water is mixing with saline wastewater. The calculated mixing line is the estimated chemical composition of water derived from mixing water of two different chemical compositions in various proportions. Calculated mixing lines were compared with bromide-to-chloride ratios for 41 water samples from 6 selected monitoring wells. The end member representing water from each monitoring well shown in figure 5 is the mean chloride concentration and median bromide concentration for samples collected from the well during 1990-2005. The end member representing the saline wastewater is the mean chloride concentration (3,780 mg/L) and the mean bromide concentration (18.4 mg/L) of the five samples collected in 1993. If mixing occurred between the two types of water during this time, the concentrations and ratios would change. As a result, the data points on the graphs should plot on or near the corresponding calculated mixing line for each well if the assumptions made about the end members are correct. None of the data from the six monitoring wells plots along the calculated mixing line, which indicates that mixing with saline wastewater is unlikely at these wells.

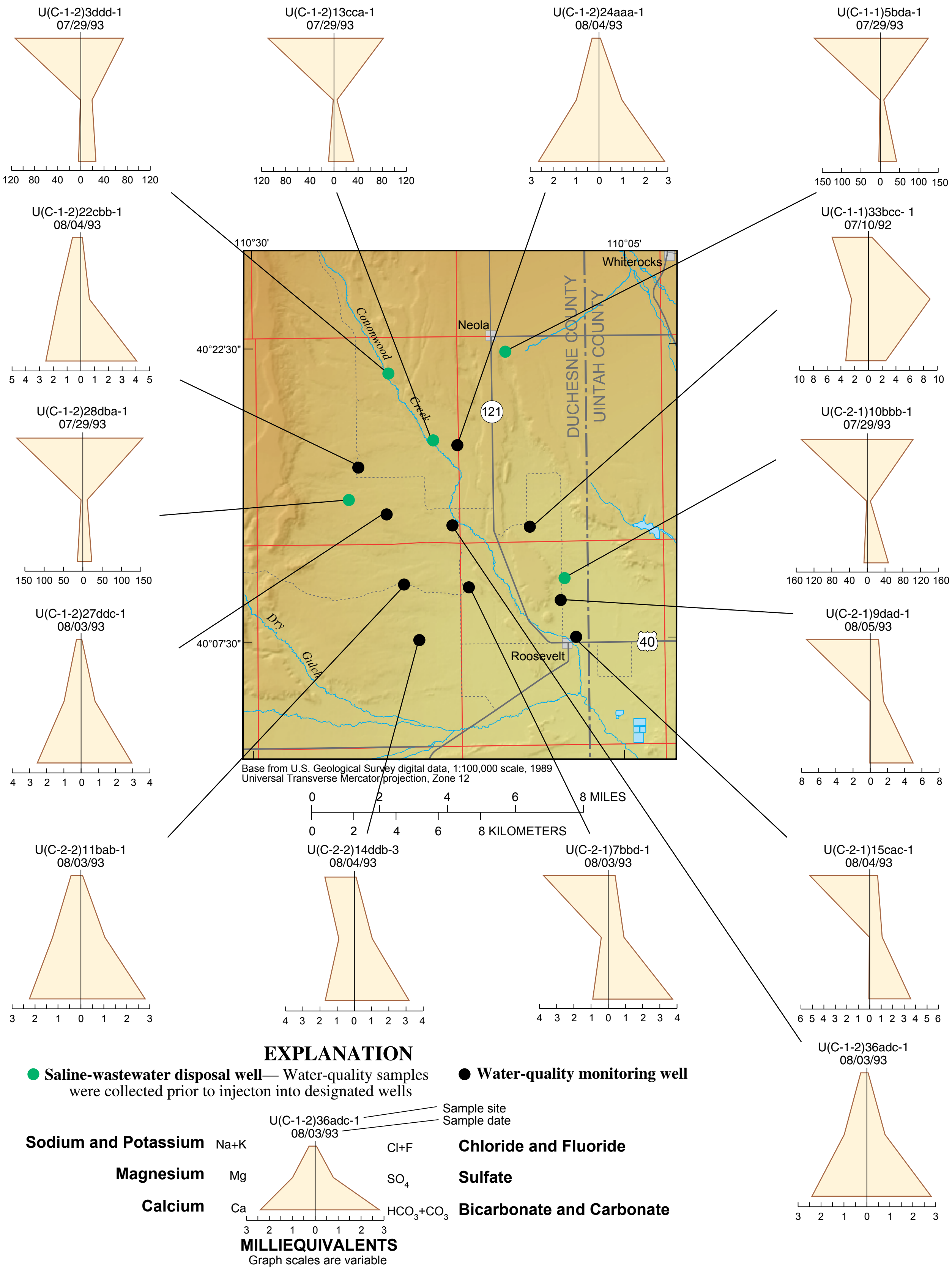


Figure 4. Major-ion composition of saline-wastewater samples and of ground-water-quality samples collected from monitoring wells located in the Bluebell oil field area, Duchesne County, Utah, 1992-93.

Table 2. Physical properties and results of chemical analyses of water samples collected from selected water-quality monitoring wells and from saline wastewater in the Altamont-Bluebell area, Duchesne County, Utah, with data from 1964-2005.

[Site name: for saline wastewater the name refers to the disposal well where the saline wastewater is injected into the ground; see report text for an explanation of the numbering system for hydologic-data sites; µS/cm, microsiemens per centimeter; Alkalinity method: C, calculated from anion-cation balance; UL, unfiltered sample, lab analysis; UF, unfiltered sample, field analysis; FF, filtered sample, field analysis; <, less than; E, estimated value; —, no data]

Site name	Date	pH, unfiltered, field (standard units)	Specific conductance, field (µS/cm at 25 degrees Celsius)	Temperature (degrees Celsius)	Calcium (mg/L)	Magnesium (mg/L)	Potassium (mg/L)	Sodium (mg/L)	Alkalinity, total (mg/L as $CaCO_3$)	Alkalinity method	Bromide (mg/L)
					Bluebell field						
U(C-1-1)33bcc-1	08/16/91	8.4	780	12	40	16	2	110	138	UL	<0.01
	07/10/92	8.3	900	12.5	66	30	2.4	120	—	—	<.01
	08/04/93	8.6	495	12	8.3	3	1.4	100	192	C	.01
	06/25/96	7.8	1,630	12.5	200	46	3.2	100	113	UL	—
	08/31/05	7.6	1,620	14	202	54.4	3.47	117	102	UL	—
U(C-1-2)22cbb-1	10/06/64	7.6	383	12	47	18	—	—	174	UF	—
	08/15/91	7.7	450	13.5	49	20	3.5	11	200	UL	.06
	07/08/92	7.8	410	13.5	48	20	3.2	12	192	FF	.04
	08/04/93	7.6	440	13	51	20	3.3	12	248	C	.05
U(C-1-2)24aaa-1	08/01/90	7.5	365	12	50	11	4.2	4.8	137	UL	.02
	08/18/91	7.7	355	12	51	11	4.1	4.6	139	UL	.02
	07/10/92	8.1	350	12	50	11	3.8	4.6	133	FF	.01
	08/04/93	7.6	365	12.5	53	12	3.8	4.7	175	C	.02
U(C-1-2)27ddc-1	08/16/91	7.7	355	15.5	50	11	3.6	4.4	148	UL	.01
	07/09/92	8	340	12	49	12	3.5	4	142	FF	.01
	08/03/93	7.7	360	13	51	12	3.1	4.3	180	C	.03
U(C-1-2)36adc-1	08/01/90	7.6	330	11.5	46	11	3.9	4.1	137	UL	.02
	08/14/91	7.7	345	11.5	46	13	4	4	137	UL	.01
	07/09/92	8	335	12.5	45	13	3.7	3.9	130	FF	<.01
	08/03/93	7.8	340	12	48	12	3.5	4.1	171	C	.02
U(C-2-1)7bbd-1	08/14/91	8.1	530	14	18	4.9	2.4	98	216	UL	.03
	07/09/92	8.3	415	16.5	17	4.8	2.5	72	172	FF	.01
	08/03/93	8.1	445	14.5	18	4.9	2.3	85	228	C	.04
U(C-2-1)9dad-1	06/03/72	8.8	873	14.5	2.3	.9	1	190	258	UF	—
	08/14/91	9.3	760	13.5	1.1	.43	.7	170	267	UL	.01
	07/10/92	9.2	750	14.5	.98	.31	.7	170	250	FF	.02
	08/05/93	9.2	750	15	.91	.32	.7	170	304	C	.03
U(C-2-1)15cac-1	03/22/73	9.1	549	14.5	1.9	.4	.9	130	192	UF	—
	07/31/90	9	560	14	1.6	.51	.7	130	185	UL	.02
	08/13/91	9.1	570	13	1.5	.56	.7	120	188	UL	.02
	07/10/92	9	550	14	1.9	.42	.7	120	180	FF	<.01
	08/04/93	9.2	570	17	1.5	.41	.7	120	218	C	.02
U(C-2-2)11bab-1	08/03/90	7.8	350	14	43	15	3.7	6.8	135	UL	.02
	08/15/91	7.8	330	13.5	44	13	3.5	5.7	137	UL	.01
	07/09/92	7.9	350	16	43	14	3.4	5.9	130	FF	<.01
	08/03/93	7.9	365	14	45	15	3.2	8	171	C	.02
	08/13/05	7.2	360	14.5	43.5	15.8	3.5	9.2	126	UL	—
U(C-2-2)14ddb-3	08/03/90	7.9	410	13.5	33	11	2.9	38	159	UL	.02
	08/14/91	7.9	400	13	34	11	2.7	34	162	UL	.02
	07/09/92	8	395	13.5	33	11	2.4	36	157	FF	.01
	08/04/93	7.7	420	14	34	11	2.5	38	194	C	.03
					Altamont field						
U(C-3-5)31dcd-1	03/30/72	8.9	1,950	10	4.6	6.4	1.4	450	493	UF	—
					Saline wastewater[1]						
U(C-1-1)5bda-1	07/29/93	8.1	20,100	—	72	10	56	3,900	2,577	C	14
U(C-1-2)3ddd-1	07/29/93	7.8	11,500	—	83	9.4	34	2,600	1,585	C	21
U(C-1-2)13cca-1	07/29/93	7.9	12,300	—	180	15	30	2,500	2,010	C	22
U(C-1-2)28dba-1	07/29/93	7.7	17,900	—	280	57	41	3,900	1,404	C	18
U(C-2-1)10bbb-1	07/29/93	7.9	15,000	—	150	15	31	3,400	2,900	C	17

[1]Water-quality samples were collected prior to injection into designated wells.

Table 2. Physical properties and results of chemical analyses of water samples collected from selected water-quality monitoring wells and saline wastewater in the Altamont-Bluebell area, Duchesne County, Utah, with data from 1964-2005—Continued.

Site name	Chloride (mg/L)	Fluoride (mg/L)	Iodide (mg/L)	Silica (mg/L)	Sulfate (mg/L)	Residue, sum of constituents (mg/L)	Barium (µg/L)	Boron (µg/L)	Iron (µg/L)	Lithium (µg/L)	Manganese (µg/L)	Strontium (µg/L)
Bluebell field												
U(C-1-1)33bcc-1	0.1	1.3	—	—	260	513	—	—	—	—	—	1,100
	16	1.1	.024	7.4	430	751	23	120	550	82	20	2,100
	.7	1.7	.016	7.3	86	—	12	110	220	53	3	210
	.6	1.5	—	7.5	840	1,270	—	116	1,400	—	45	—
	E.7	1.4	—	8.67	784	—	—	—	1,960	—	40.4	—
U(C-1-2)22cbb-1	1.9	—	—	8.6	41	234	—	—	—	—	—	—
	4.4	.4	—	—	30	239	—	—	—	—	—	380
	3	.5	.008	8	37	253	70	60	1,100	36	16	400
	2.9	.5	.008	8.2	30	—	63	60	1,200	38	15	400
U(C-1-2)24aaa-1	1.7	—	—	—	49	203	—	—	—	—	—	380
	.2	.6	—	—	50	205	—	—	—	—	—	360
	.8	.7	.002	7.8	47	207	47	20	570	27	21	370
	.8	.7	.002	8	48	—	40	30	460	29	20	370
U(C-1-2)27ddc-1	3.1	.6	—	—	45	207	—	—	—	—	—	290
	.6	.6	.003	8.4	41	207	55	20	760	23	20	280
	.6	.5	.002	8.7	39	—	48	20	730	26	14	290
U(C-1-2)36adc-1	1.4	—	—	—	39	188	—	—	—	—	—	390
	.2	.8	—	—	44	195	—	—	—	—	—	530
	.9	.8	.002	7.7	42	196	45	30	170	27	26	540
	.6	.7	.002	8	38	—	43	30	200	26	22	390
U(C-2-1)7bbd-1	28	1.5	—	—	47	329	—	—	—	—	—	150
	7.2	1.1	.003	9.2	39	257	55	120	310	27	11	150
	12	1.2	.002	9.5	44	—	47	120	440	29	9	150
U(C-2-1)9dad-1	33	1.2	—	9.8	120	513	—	230	40	—	0	—
	39	1.4	—	—	83	456	—	—	—	—	—	25
	38	1.2	.009	8	71	440	15	50	88	41	5	15
	32	1.2	.009	9	74	—	8	70	53	43	6	17
U(C-2-1)15cac-1	25	.6	—	9.4	70	354	—	50	50	—	<10	—
	26	—	—	—	57	327	—	—	—	—	—	23
	24	.7	—	—	59	319	—	—	—	—	—	21
	28	.7	.003	8.9	57	326	16	50	32	33	4	15
	23	.7	.003	9.1	52	—	18	60	30	33	3	14
U(C-2-2)11bab-1	1.5	—	—	—	49	200	—	—	—	—	—	400
	.3	.5	—	—	51	201	—	—	—	—	—	380
	.7	.6	.002	9.4	52	208	46	40	170	14	22	380
	1.6	.5	.002	9.5	50	—	40	50	95	15	15	410
	1.3	.6	—	10.5	49	210	—	—	222	—	11.9	—
U(C-2-2)14ddb-3	3.1	—	—	—	49	233	—	—	—	—	—	290
	3.9	.6	—	—	52	236	—	—	—	—	—	300
	1.2	.6	.003	9.3	50	238	48	150	150	22	14	280
	2.3	.6	.003	9.4	50	—	42	140	170	22	10	290
Altamont field												
U(C-3-5)31dcd-1	140	1.2	—	18	310	1,230	—	2700	20	—	—	—
Saline wastewater[1]												
U(C-1-1)5bda-1	4,400	—	5.7	18	440	—	300	60,000	310	8,700	170	5,900
U(C-1-2)3ddd-1	2,500	58	14	58	930	—	700	10,000	220	1,700	160	7,600
U(C-1-2)13cca-1	2,900	—	12	78	240	—	—	9,100	60	1,600	260	8,400
U(C-1-2)28dba-1	5,500	—	15	52	540	—	1,200	11,000	180	2,800	310	11,000
U(C-2-1)10bbb-1	3,600	28	9.6	73	330	—	400	23,000	330	6,700	360	8,800

Table 3. Physical properties, bromide and chloride concentration, and isotopic ratios of water samples collected from selected water-quality monitoring wells and from saline wastewater in the Altamont-Bluebell area, Duchesne County, Utah, with data from 1964-2005.

[Site name: for saline wastewater the name refers to the disposal well where the saline wastewater is injected into the ground; see report text for an explanation of the numbering system for hydologic-data sites; µS/cm, microsiemens per centimeter; <, less than; E, estimated value; —, no data]

Site name	Date	pH, unfiltered, field (standard units)	Specific conductance (µS/cm at 25 degrees Celsius)	Temperature (degrees Celsius)	Bromide (mg/L)	Chloride (mg/L)	δ^2H (per mil)	$\delta^{18}O$ (per mil)
				Bluebell field				
U(C-1-1)33bcc-1	08/16/91	8.4	780	12	<0.01	0.1	—	—
	07/10/92	8.3	900	12.5	<.01	16	-127	-17.10
	08/04/93	8.6	495	12	.01	.7	-125	-17.01
	06/21/94	7.8	1,670	13	<.01	.9	—	-16.95
	06/19/95	8.3	770	16	<.01	.7	—	-16.87
	06/25/96	7.8	1,630	12.5	—	.6	—	—
	07/22/98	7.4	1,540	14.5	.03	.77	-125	-16.80
	08/04/00	7.8	1,730	16	—	—	-125	-16.94
	09/06/00	7.5	1,860	15.5	.04	1.07	—	—
	08/29/02	7.3	1,700	13.5	E.02	.82	-126	-16.98
	08/31/05	7.6	1,620	14	—	E.72	—	—
U(C-1-2)22cbb-1	10/06/64	7.6	385	12	—	1.9	—	—
	08/15/91	7.7	450	13.5	.06	4.4	—	—
	07/08/92	7.8	410	13.5	.04	3	-138	-17.90
	08/04/93	7.6	440	13	.05	2.9	-136	-18.04
	06/21/94	7.5	450	13.5	.04	2.5	—	-17.85
	06/19/95	7.5	415	13	.04	2.5	—	-17.81
	08/04/00	7.4	395	24	—	—	-137	-18.00
	09/06/00	7.7	385	20.5	.04	1.68	—	—
	08/29/02	7.6	390	20.5	E.02	1.87	-138	-18.11
	08/31/05	7.5	380	17.5	—	1.19	-139	-18.33
U(C-1-2)24aaa-1	08/01/90	7.5	365	12	.02	1.7	—	—
	08/18/91	7.7	355	12	.02	.2	—	—
	07/10/92	8.1	350	12	.01	.8	-135	-18.10
	08/04/93	7.6	365	12.5	.02	.8	-135	-18.13
	06/21/94	7.5	390	13.5	.01	1	—	-17.96
	06/19/95	7.8	355	15	.02	.9	—	-17.94
	07/22/98	7.4	360	14	.03	1.02	-134	-17.90
	08/04/00	7.7	350	16.5	—	—	-134	-17.92
	09/06/00	7.7	350	15.5	.02	1.09	—	—
	08/29/02	7.7	345	13.5	<.03	1.3	-136	-17.95
U(C-1-2)27ddc-1	08/16/91	7.7	355	15.5	.01	3.1	—	—
	07/09/92	8	340	12	.01	.6	-139	-18.55
	08/03/93	7.7	360	13	.03	.6	-137	-18.59
	06/21/94	7.6	380	13.5	.02	.7	—	-18.40
	06/19/95	7.6	350	13	.02	.6	—	-18.35
	07/22/98	7.6	335	14	.03	.74	-138	-18.36
	08/04/00	7.6	340	22	—	—	-138	-18.38
	09/06/00	7.5	340	17	.05	.79	—	—
	08/29/02	7.6	345	14	<.03	1.21	-138	-18.36
U(C-1-2)36adc-1	08/01/90	7.6	330	11.5	.02	1.4	—	—
	08/14/91	7.7	345	11.5	.01	.2	—	—
	07/09/92	8	335	12.5	<.01	.9	-137	-18.35
	08/03/93	7.8	340	12	.02	.6	-138	-18.61
	06/21/94	7.8	385	13	.01	.8	—	-18.26
	06/19/95	7.8	335	14	.02	1	—	-18.22
	07/23/98	7.5	360	14	.03	1.05	-136	-18.14
	08/03/00	7.8	335	18	—	—	-136	-18.24

Table 3. Physical properties, bromide and chloride concentration, and isotopic ratios of water samples collected from selected water-quality monitoring wells and from saline wastewater in the Altamont-Bluebell area, Duchesne County, Utah, with data from 1964-2005—Continued.

Site name	Date	pH, unfiltered, field (standard units)	Specific conductance (μS/cm at 25 degrees Celsius)	Temperature (degrees Celsius)	Bromide (mg/L)	Chloride (mg/L)	δ^2H (per mil)	$\delta^{18}O$ (per mil)
Bluebell field—Continued								
U(C-1- 2)36adc-1	09/07/00	7.8	340	12	0.04	1.17	—	—
—Continued	08/28/02	7.7	340	14	<.03	1.22	-137	-18.21
	09/03/03	7.3	335	13.5	.02	.95	-138	-18.25
U(C-2-1)7bbd-1	08/14/91	8.1	530	14	.03	28	—	—
	07/09/92	8.3	415	16.5	.01	7.2	-128	-17.30
	08/03/93	8.1	445	14.5	.04	12	-127	-17.33
	06/21/94	8	920	15	.04	95	—	-17.17
	06/19/95	8.1	415	15	.02	4.8	—	-17.14
	07/22/98	7.9	730	16	.05	56.4	-128	-17.13
	08/03/00	8.1	420	15.5	—	—	-130	-17.18
	09/07/00	8.1	430	14.5	.04	5.78	—	—
	08/29/02	8	510	17	<.03	19.8	-127	-17.20
U(C-2-1)9dad-1	06/03/72	8.8	873	14.5	—	33	—	—
	08/14/91	9.3	760	13.5	.01	39	—	—
	07/10/92	9.2	750	14.5	.02	38	-129	-17.45
	08/05/93	9.2	750	15	.03	32	-128	-17.58
	08/05/97	9.1	770	13	.01	33.9	—	-17.27
	07/14/99	9.4	740	15.5	—	—	-127	-17.20
	06/28/01	—	900	17	.03	30.4	-128	-17.15
U(C-2-1)15cac-1	03/22/73	9.1	549	14.5	—	25	—	—
	07/31/90	9	560	14	.02	26	—	—
	08/13/91	9.1	570	13	.02	24	—	—
	07/10/92	9	550	14	<.01	28	-128	-17.40
	08/04/93	9.2	570	17	.02	23	-128	-17.39
	06/21/94	9	550	15	.02	25	—	-17.29
	06/20/95	9.1	540	17	.02	24	—	-17.19
	07/23/98	9	560	14.5	.02	24.6	-127	-17.20
	08/04/00	9	550	15.5	—	—	-129	-17.24
	09/06/00	9	550	17	.03	23.3	—	—
U(C-2-2)11bab-1	08/03/90	7.8	350	14	.02	1.5	—	—
	08/15/91	7.8	330	13.5	.01	.3	—	—
	07/09/92	7.9	350	16	<.01	.7	-137	-18.30
	08/03/93	7.9	365	14	.02	1.6	-136	-18.32
	06/21/94	7.6	430	14.5	.02	1.8	—	-18.18
	06/19/95	7.7	365	16	.02	1.5	—	-18.11
	07/22/98	7.4	375	14	.02	1.63	-136	-18.09
	06/26/01	7.7	360	16.5	.02	2.41	-136	-18.11
	09/03/03	7.6	350	13.5	.02	1.5	-136	-18.13
	08/13/05	7.2	360	14.5	—	1.34	—	—
U(C-2-2)14ddb-3	08/03/90	7.9	410	13.5	.02	3.1	—	—
	08/14/91	7.9	400	13	.02	3.9	—	—
	07/09/92	8	395	13.5	.01	1.2	-137	-18.20
	08/04/93	7.7	420	14	.03	2.3	-128	-18.25
	06/21/94	7.7	425	17	.01	1	—	-18.06
	06/19/95	7.7	330	14	.02	1	—	-18.05
	08/05/97	7.9	415	13	.01	2.68	—	-18.08
	07/14/99	8.1	400	16.5	—	—	-135	-18.04
	08/03/00	7.9	400	16	—	—	-139	-18.02
	09/07/00	7.9	400	15.5	.04	2.86	—	—
	08/28/02	7.7	360	22	<.03	1.33	-138	-18.14

Table 3. Physical properties, bromide and chloride concentration, and isotopic ratios of water samples collected from selected water-quality monitoring wells and from saline wastewater in the Altamont-Bluebell area, Duchesne County, Utah, with data from 1964-2005—Continued.

Site name	Date	pH, unfiltered, field (standard units)	Specific conductance (µS/cm at 25 degrees Celsius)	Temperature (degrees Celsius)	Bromide (mg/L)	Chloride (mg/L)	δ^2H (per mil)	$\delta^{18}O$ (per mil)
				Altamont field				
U(C-1- 4)31bbb-1	08/08/96	7.5	730	13	.06	14	—	-15.86
	07/25/97	7.2	820	13	.09	15.8	—	-15.71
	07/14/99	7.7	840	11.5	—	—	-117	-15.74
	08/03/00	7.2	850	22.5	—	—	-118	-15.62
	09/07/00	7.3	830	12.5	.05	13.4	—	—
	08/28/02	7.1	820	18	.03	11	-116	-15.40
U(C-1-4)33bdb-1	08/08/96	6.9	3,090	12	.51	86	—	-15.01
	07/27/97	6.9	3,100	12	.50	114	—	-14.98
	07/14/99	6.8	3,990	14.5	—	—	-108	-13.72
	06/26/01	6.7	4,310	11.5	.76	200	-108	-13.37
	09/02/03	6.7	3,890	13	.75	205	-103	-12.87
U(C-1-5)36caa-1	08/08/96	7.2	1,760	13	.82	160	—	-14.99
U(C-2- 4)6ccb-1	06/27/96	7.7	830	11.5	.09	19	-115	-15.34
	08/12/98	7.5	890	15	.10	20.3	-114	-14.92
U(C-2-5)3bdd-1	08/08/96	8	270	10	<.01	.70	—	-16.13
	07/25/97	7.8	310	14	<.01	.97	—	-16.62
	07/14/99	7.9	435	16	—	—	-118	-15.81
	06/26/01	7.8	510	10.5	.02	2.78	-115	-15.49
U(C-2-5)34abb-1	06/28/96	8.9	970	12	.03	2	-139	-18.33
	07/23/98	9.5	710	11.5	.04	3.35	-137	-18.16
	09/07/00	9.5	670	12	.04	2.34	—	—
	08/28/02	9.4	680	18.5	E.02	2.11	-138	-18.31
U(C-2-5)35bab-1	06/26/96	8.9	970	12	.04	11	-132	-17.39
	08/05/97	8.9	920	13	.02	10.5	—	—
	07/14/99	9.3	980	13.5	—	—	-131	-17.55
	06/26/01	8.7	1,010	13	.03	19.7	-132	-17.37
	09/02/03	8	1,000	16	.04	19.9	-126	-16.83
U(C-3-4)31cab-1	08/08/96	7.4	680	14.5	.05	7.59	—	-17.08
	07/25/97	7.3	730	19	.03	8.16	—	-17.16
	07/13/99	7.5	730	16.5	—	—	-120	-16.20
	06/26/01	7.3	820	17.5	.04	13.6	-121	-16.21
	09/02/03	7.3	580	17.5	.03	8.46	-120	-15.73
	08/31/05	7.5	820	16	—	11.6	-122	-16.30
U(C-3-5)31dcd-1	03/30/72	8.9	1,950	10	—	140	—	—
U(C-3-5)31dcd-2	06/26/96	9.3	1,860	13.5	.05	150	-137	-17.83
U(C-3-6)25cab-1	06/27/96	9.4	900	11	.04	2.4	—	—
	08/08/96	9.4	910	13	.04	2.7	—	-18.68
	07/25/97	9.4	920	19	.03	2.54	—	-18.66
	07/13/99	9.5	880	15	—	—	-141	-18.72
	06/28/01	—	910	12	.04	2.78	-142	-18.68
				Saline wastewater[1]				
U(C-1-1)5bda-1	07/29/93	8.1	20,100	—	14	4,400	-66.3	-2.39
U(C-1-2)3ddd-1	07/29/93	7.8	11,500	—	21	2,500	-52.3	.40
U(C-1-2)13cca-1	07/29/93	7.9	12,300	—	22	2,900	-49.7	.78
U(C-1-2)28dba-1	07/29/93	7.7	17,900	—	18	5,500	-53.5	.60
U(C-2-1)10bbb-1	07/29/93	7.9	15,000	—	17	3,600	-54.3	.41

[1]Water-quality samples were collected prior to injection into designated wells.

Trends in Chemical Constituents

Another way to assess if injected saline wastewater is migrating into drinking-water production zones is to examine changes over time or trends in chemical constituents. Trends in the concentration of bromide and chloride were analyzed for water samples collected during 1990-2005 from 17 monitoring wells with the Sen slope statistical method. Three sites with two or fewer analyses were not included (U(C-1-5)36caa-1, U(C-2-4)6ccb-1, and U(C-3-5)31dcd-1). The Sen method calculates the slope as a change in measurement per change in time (Sen, 1968). No statistically significant trends at the 90-percent confidence level for the concentration of bromide in water samples collected from the wells were determined from the results of this analysis. For chloride concentration, the analysis of water samples collected from two wells (U(C-1-2)22cbb-1 and U(C-2-1)9dad-1) showed a downward trend and that from one well (U(C-1-4)33bdb-1) showed an upward trend at the 90-percent confidence level. Little change in bromide and chloride concentration has occurred in water samples collected from most of the monitoring wells during the monitoring period, indicating that, in general, injected saline wastewater is not moving into the upper part of the Duchesne River Formation, Uinta Formation, or surficial deposits that are used as drinking-water sources.

The analysis of water samples collected from wells U(C-1-2)22cbb-1 and U(C-2-1)9dad-1 showed decreasing trends in chloride concentration during 1991-2005. Both of the wells are in the eastern portion of the study area near Roosevelt and have completion depths of 810 and 740 ft, respectively. The chloride concentration (table 3) of water from well U(C-1-2)22cbb-1 decreased from 4.4 mg/L in 1991 to 1.19 mg/L in 2005. The chloride concentration for water from well U(C-2-1)9dad-1 decreased from 39 mg/L in 1991 to 30.4 mg/L in 2001. Because the Sen method requires a time series of equally spaced data, the pre-1991 data were not used in the statistics.

The decreasing trend for water from wells U(C-1-2)22cbb-1 and U(C-2-1)9dad-1 is for 1991-2005 only. Water from well U(C-1-2)22cbb-1 had a chloride concentration of 1.9 mg/L in 1964 and water from well U(C-2-1)9dad-1 had a chloride concentration of 33 mg/L in 1972. These earlier data indicate that the trends may not be statistically significant and may be the result of natural long-term fluctuations in precipitation and recharge.

Chloride concentration in water from well U(C-1-4)33bdb-1, about 6 mi west of Altamont, increased steadily from 86 mg/L in 1996 to 205 mg/L in 2003. Bromide concentration for water from this well showed no trend with the Sen method at the 90-percent confidence level; however, bromide concentration did increase from 0.51 mg/L in 1996 to 0.75 mg/L in 2003. These concentrations are more than five times higher than bromide concentrations measured in all but one of the other monitoring wells in the area (water from monitoring well U(C-1-5)36caa-1 had a bromide concentration of 0.82 mg/L in 1996).

Well U(C-1-4)33bdb-1 was drilled into surficial deposits in 1948 and is 30 ft deep. During sample collection from this well in 2003 it was noted that the water had a brown color, was slow to filter, and had a rotten egg smell (Paul Downhour, U.S. Geological Survey, written commun., 2003). Water from this well has a higher specific-conductance and lower pH value than water from the other monitoring wells (table 3). The pH value varied from 6.7 to 6.9 and the specific-conductance value, a measure of the electrical conductivity of water that is related to the concentration of dissolved solids in water, varied from 3,090 to 4,310 µS/cm. The specific-conductance value for water from the nearest observation well, U(C-1-4)31bbb-1 (about 2 ½ mi west) completed at a depth of 55 ft in the Duchesne River Formation, was about 830 µS/cm. This difference in specific conductance may indicate that water quality in well U(C-1-4)33bdb-1 is affected by activities on the land surface rather than from mixing with injected saline wastewater. However, the water from this well is not suitable for domestic use or irrigation because of the high specific-conductance value.

Stable Isotopes

The stable isotopes of oxygen (^{18}O) and hydrogen (^{2}H or deuterium) occur naturally in water and can be used to determine sources of recharge and the extent of mixing in a ground-water system (Thiros, 1995). Water samples collected from 1992 to 2005 from the 20 water-quality monitoring wells were analyzed for isotopes and the results are reported as isotopic ratios ($\delta^{18}O$ and $\delta^{2}H$, table 3). Samples of saline wastewater for injection at five sites were collected in 1993 and analyzed for isotopes. Isotopic ratios of oxygen for water from the monitoring wells ranged from -18.72 to -12.87 per mil and for saline wastewater ranged from -2.39 to 0.78 per mil (table 3). Isotopic ratios of hydrogen for water from the monitoring wells ranged from -142 to -103 per mil and for saline wastewater ranged from -66.3 to -49.7 per mil (table 3). Thus, water from the monitoring wells and saline wastewater have distinctively different isotopic signatures that can be used to assess mixing.

The relation between $\delta^{18}O$ and $\delta^{2}H$ generally is expressed by the equation $\delta^{2}H = 8\ \delta^{18}O + 10$, known as the global meteoric water line (Craig, 1961). Isotopic data from saline wastewater sampled in 1993, water from the monitoring wells grouped by area (Altamont and Bluebell) and by year collected (1992-2005), and the global meteoric water line are shown in figure 6. The isotope data for the saline wastewater deviates from the global meteoric water line, indicating that the water has been enriched in $\delta^{18}O$ relative to $\delta^{2}H$. Because the saline wastewater is first collected in evaporation ponds before being disposed of, the enrichment in $\delta^{18}O$ relative to $\delta^{2}H$ likely is a result of evaporation (Coplen and others, 1999). The isotope data for the Bluebell area are clustered around the global meteoric water line, and the isotope data for the Altamont area are shifted slightly. However, if mixing were

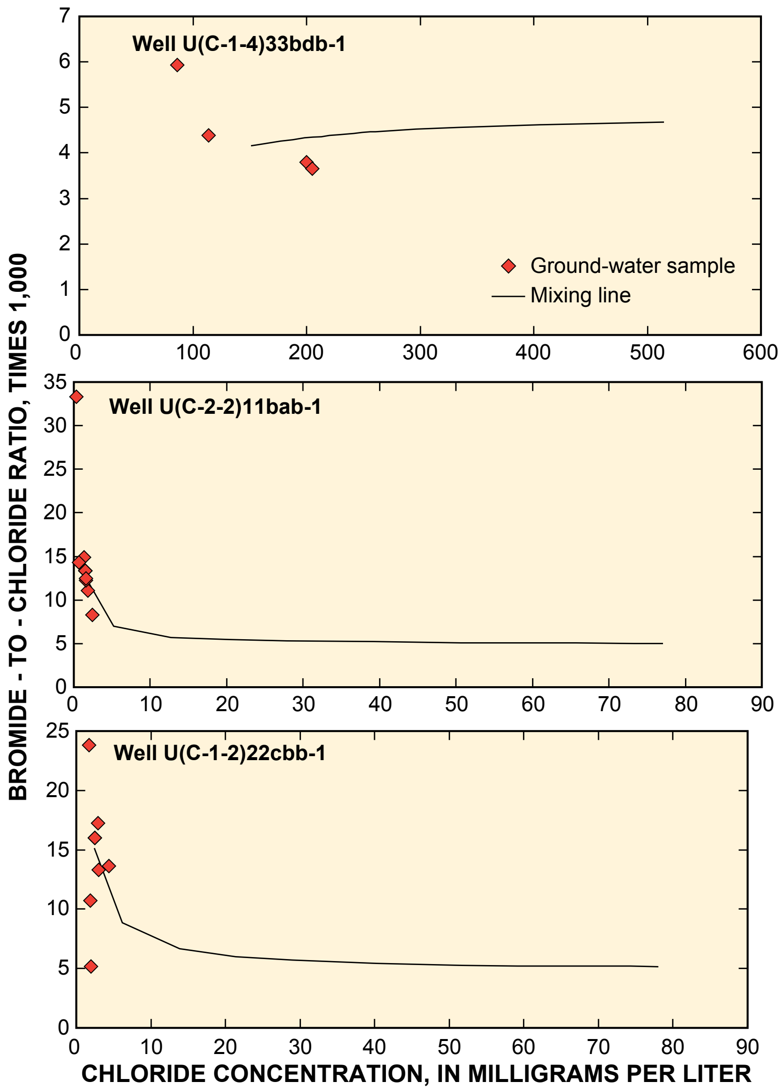


Figure 5. Mixing lines constructed between ground water and saline wastewater in relation to the weight ratio of bromide to chloride, for water samples collected from wells in the Altamont-Bluebell area, Duchesne County, Utah.

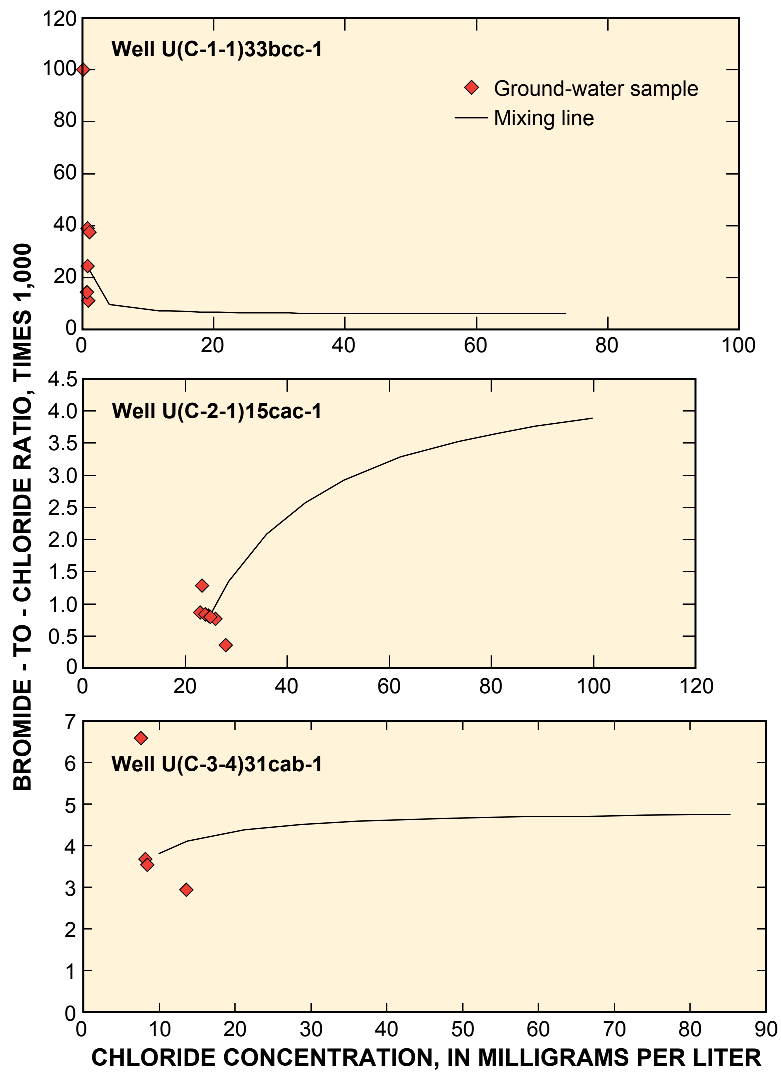


Figure 5. Mixing lines constructed between ground water and saline wastewater in relation to the weight ratio of bromide to chloride, for water samples collected from wells in the Altamont-Bluebell area, Duchesne County, Utah—Continued.

occurring between the saline wastewater and the water from the monitoring wells, the isotope data for the water from the monitoring wells would increasingly deviate from the global meteoric water line over time and trend toward that of the saline wastewater. Isotope data for water from monitoring wells generally do not deviate from the global meteoric water line over time, indicating that the sampled ground water is not mixing with saline wastewater. However, water from one well, U(C-1-4)33bdb-1, did show an increasing trend in $\delta^{18}O$ from -15.01 in 1996 to -12.87 in 2003. Water from this well, which is drilled into the surficial deposits, also showed an increasing trend in bromide and chloride concentration. Because this well is drilled to only 30 ft, it is possible that the changes in water quality may result from sources related to activities on the land surface rather than from mixing with saline wastewater.

SUMMARY

In the process of drilling and pumping oil from the Altamont-Bluebell oil field in the Uinta Basin of northeastern Utah, saline water is produced along with the extraction of oil. This saline wastewater is disposed of in surface evaporation ponds and then injected into disposal wells completed at depths greater than 3,000 ft below land surface in the Duchesne River and underlying formations. The upper part of the Duchesne River Formation also is developed for drinking-water supply. Because of a potential for injected saline wastewater to migrate and mix with water contained within drinking-water aquifers, the U.S. Geological Survey, in cooperation with the Utah Department of Natural Resources, Division of Oil, Gas, and Mining, began to monitor water quality in five wells in the Altamont-Bluebell area in 1990. The number of wells sampled increased to 20 by 1996. The objective of the monitoring program was to collect a long-term data set that could be assessed to determine if saline wastewater was migrating into aquifers used for drinking-water supply. Water samples collected from the monitoring wells and samples of the saline wastewater were analyzed for chloride and bromide concentration and for the ratio of stable isotopes.

Four methods, including comparison of major chemical constituents, bromide-to-chloride ratios, trend analysis, and stable isotope ratios, were used to assess the data set to determine if saline wastewater was affecting drinking-water aquifers. Chemical constituents were plotted on Stiff diagrams, and comparison of the water samples collected from monitoring wells with the samples of saline wastewater indicates a distinct chemical composition for each water source, which indicates a lack of mixing of water. Plots of bromide-to-chloride ratios with chloride concentrations for water samples collected from monitoring wells and for saline wastewater end members did not fall along a calculated mixing line. This indicates that no mixing occurs between the two types of water. Analysis of temporal trends in bromide and chloride concentrations using the Sen slope method determined no statistically significant increasing trends with one exception, which indicates little or no change in concentrations and no indication of mixing between the two types of water. The one exception was anomalous results for water from one well with a total depth of 30 feet that was drilled into and completed in surficial deposits, thus making it possible that the water quality could be affected by activities occurring on the land surface.

Analysis of stable isotope data determined that water samples collected from monitoring wells plotted on the global meteoric water line, and data for saline-wastewater samples were shifted, probably as a result of evaporation occurring while the water was stored in evaporation ponds. If saline wastewater were mixing with water from the monitoring wells, the stable isotope data for these samples should have been shifted away from the global meteoric water line. That this is not the case provides additional evidence that the two types of water are not mixing. The three different analyses all indicate that the saline wastewater injected into the lower part of the Duchesne River, Uinta, Green River, and underlying formations is not migrating upward into the upper part of the Duchesne River and Uinta Formations or surficial deposits that are used for drinking-water supplies. Continued monitoring of ground-water quality in the Altamont-Bluebell area would be useful because oil and gas development in the Uinta Basin has been accelerating in recent years and the injection of saline wastewater will continue.

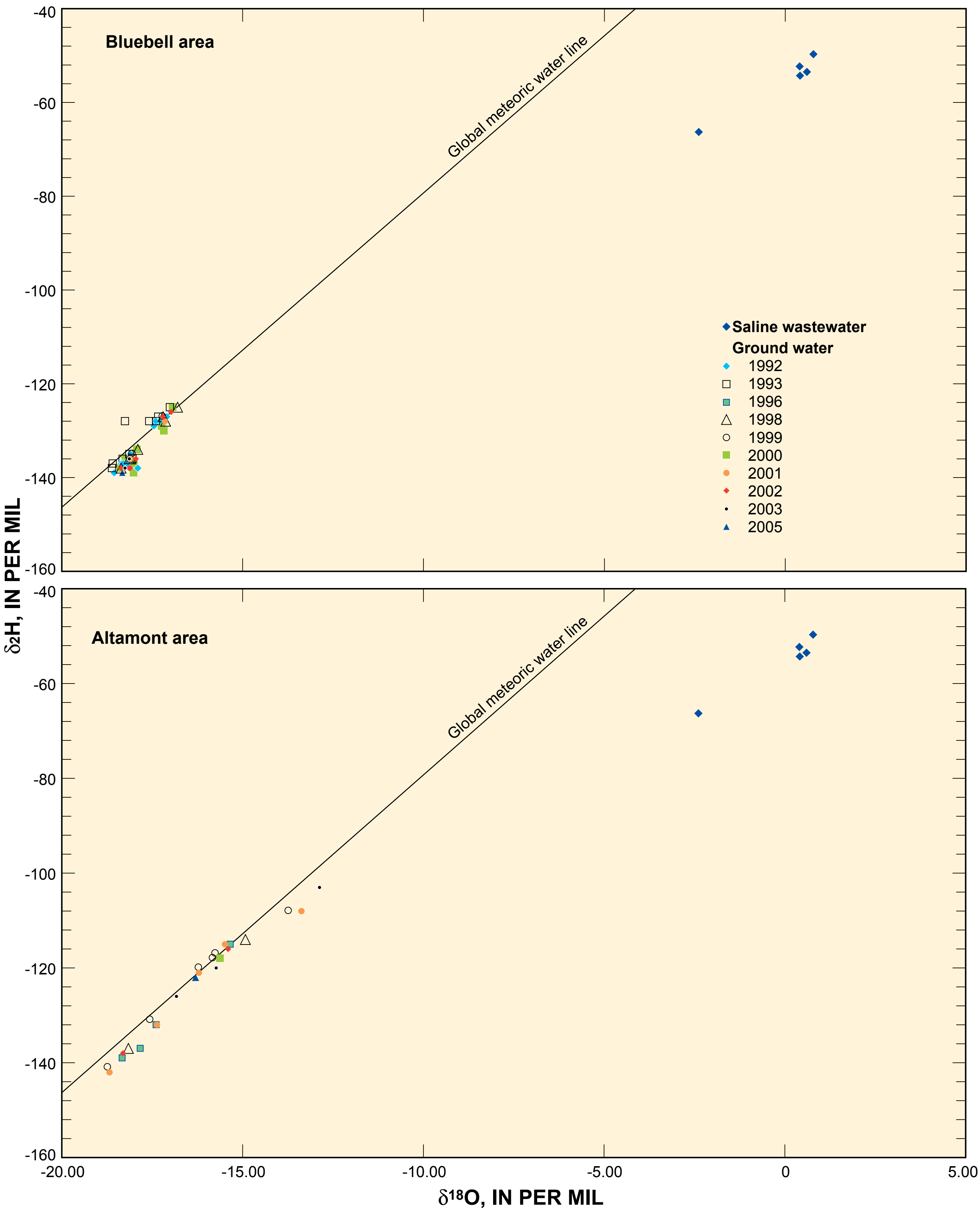


Figure 6. Relation between δ^2H and $\delta^{18}O$ values for ground-water samples collected during 1992-2005 and saline-wastewater samples collected during 1993, Altamont-Bluebell area, Duchesne County, Utah.

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