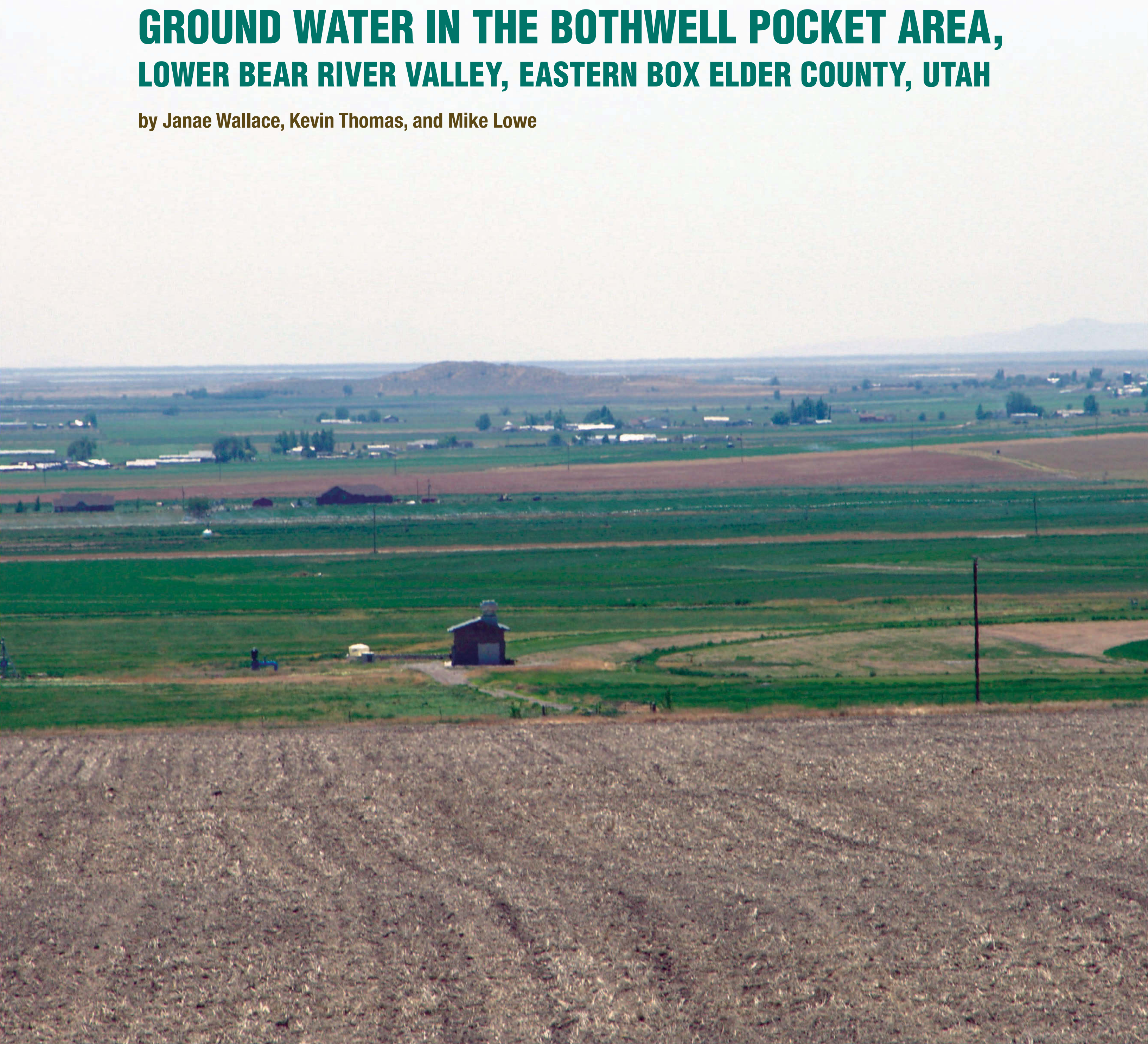
EVALUATION OF SOURCES OF POOR QUALITY GROUND WATER IN THE BOTHWELL POCKET AREA,

LOWER BEAR RIVER VALLEY, EASTERN BOX ELDER COUNTY, UTAH

by Janae Wallace, Kevin Thomas, and Mike Lowe



SPECIAL STUDY 135
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Cover photo: *View south of typical agricultural land use in the Bothwell Pocket.*

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EVALUATION OF SOURCES OF POOR QUALITY GROUND WATER IN THE BOTHWELL POCKET AREA,

LOWER BEAR RIVER VALLEY, EASTERN BOX ELDER COUNTY, UTAH

ABSTRACT

The Bothwell Pocket in northwestern Utah is a rural area dominated by agricultural activity but also experiencing an increase in residential development. The unconsolidated basin-fill aquifer is an important source of drinking water. In cooperation with the Utah Division of Water Rights, the Utah Geological Survey assessed water-level changes and water quality in the basin-fill aquifer to determine (1) whether a decline in water levels during different pumping seasons has occurred, (2) the relationship of ground-water quality to geology and land use in the drainage basin, (3) if water-quality degradation due to encroachment of poor quality ground water is occurring, (4) the relative age of water from selected water wells, and (5) if the potentiometric surface of the basin-fill aquifer is declining. We measured water levels during different pumping seasons in 2006 and 2007 for 24 wells and mapped water quality in the basin-fill aquifer with emphasis on salinity and total-dissolved-solids (TDS) and nitrate concentrations. Water-well samples from domestic, municipal, and irrigation sources were collected and analyzed during autumn 2006 and spring 2007. We selected 36 water-sampling sites, including wells, springs, canals, and sloughs/lakes, without bias to land-use practice, to represent a valley-wide distribution of water-quality data. Most of the sampled wells are less than 200 feet (60 m) deep. Water samples from all wells were analyzed for nitrate, general ion chemistry, and dissolved metals. Samples having relatively high (>5 mg/L) nitrate concentrations (10 wells) were analyzed for nitrogen and oxygen isotopes in nitrate. Nineteen samples were analyzed for the environmental tracers oxygen and deuterium isotopes in water, tritium, chlorofluorocarbons (CFCs), and carbon isotopes. We added data from 12 wells and springs from the Utah Division of Drinking Water and the U.S. Geological Survey to that collected in this study.

Most wells showed variable changes in water level between seasons. During the irrigation season, pumping from wells in the center of the Bothwell Pocket creates a cone of depression extending across the pocket, with a maximum drawdown of 40 feet (12 m). The water table rises to a local high surrounding the Highline Canal and West Canal. Water levels in wells near the canals increase slightly during the irrigation season, with a maximum increase of 6 feet (2 m), while those south of Thatcher have little or no change in water levels. The ground-water mound surrounding the canals is likely caused by seepage from the canals during the irrigation season. The water table north of Bothwell is nearly flat, sloping gently toward the south. Water levels in the north end of the pocket have risen by about 10 feet (3 m) since 1971.

Ground-water chemistry is variable throughout the area, but is predominantly calcium-sodium-chloride type. Total-dissolved-solids concentrations for water wells and springs in the valley range from 220 to 4392 mg/L (average 1350 mg/L and 1050 mg/L median). Total-dissolved-solids concentrations for 51% of the wells and springs are greater than 1000 mg/L. Elevated TDS concentrations are likely due to dissolution of minerals from Paleozoic carbonate rocks, return irrigation water, or encroachment from ground water near wetlands proximal to Great Salt Lake.

Nitrogen and oxygen isotopes in nitrate indicate high nitrate in wells is derived from human and/or animal sources, soil nitrate, nitrate fertilizer, nitrate in precipitation, and mixed sources. Field observation of possible nitrate sources upgradient of high-nitrate wells suggests human waste (from septic systems) and nitrate fertilizer may be the nitrate source. Nitrate concentrations for 31 water samples in the study area range from <0.1 mg/L to 40.8 mg/L, average 6.5 mg/L, and have a median of 2.6 mg/L. Forty-two percent of the wells and springs yielded values >5 mg/L, and 23% showed nitrate values that exceed the Utah and EPA primary drinking-water-quality standard of 10 mg/L.

Oxygen and deuterium isotopes in water indicate most water was recharged at moderate elevations and moderate atmospheric temperatures. Tritium analysis of ground water from wells indicates that contaminated ground water was recharged pre-, post-, and during above-ground nuclear testing when tritium concentrations in the atmosphere were at their low, medium, and peak levels, respectively. Chlorofluorocarbon data show wells have an overall date range from 1943 to 1988 (for CFC-11, CFC-12, and CFC-113). Ground-water dates derived from carbon isotope data range from modern to 13,200 years (^{14}C yr B.P.) old, and show ground water is derived from both old and young ground-water sources. Overall, most ground water in the area likely reflects mixed or combined sources of water.

INTRODUCTION

The Bothwell Pocket is an important agricultural area in eastern Box Elder County (figure 1) that is undergoing increased residential development. An important source of municipal and domestic water for the area is ground water from the basin-fill aquifer. Water-resource managers would like to better understand the nature of this aquifer. Additionally, there have long been concerns over water-quality degradation due to encroachment of poor quality ground water. These concerns have increased due to recent reports of declining ground-water quality in the basin-fill aquifer (Will Atkins, Utah Division of Water Rights, verbal communication, August 2006). Water-resource managers would like to determine if ground-water quality is indeed declining in the basin-fill aquifer and, if so, the cause.

Purpose and Scope

The primary goals of this study are to (1) determine water levels of the principal basin-fill aquifer during two different recent pumping seasons and compare those values to 1971 water levels, and (2) determine if ground-water quality has declined in the Bothwell Pocket since Bjorklund and McGreevy's (1973, 1974) study, and, if so, identify sources of the degradation with an emphasis on salinity, total dissolved solids (TDS), and nitrate. To better define the aquifer system, we (1) compiled existing geologic mapping for the study area, (2) measured water levels in wells before and after the start of irrigation, and (3) constructed potentiometric-surface maps for each of the two water-level measurement periods.

Water levels were measured in wells during the winter, and again during the summer to compare levels between the irrigation and non-irrigation periods. To document if water-quality degradation has occurred, and, if so, the cause(s) of the degradation, we conducted geochemical sampling of wells to characterize the ground-water (wells and springs), recharge sources, and surface water (including irrigation canals). All water samples were analyzed for general chemistry (including bromide) and a smaller subset of wells was analyzed for environmental tracers including nitrogen and oxygen isotopes in nitrate, oxygen and deuterium isotopes in water, tritium, chlorofluorocarbons (CFCs), and carbon isotopes.

Methods

Water-Level Measurements

We selected 24 wells to measure water levels (figure 2, appendix A) in order to compare water levels during times of increased pumping (irrigation season) to levels measured during times of decreased pumping. In December 2006 and March 2007, we measured water levels in wells when irrigation pumping was not occurring and the irrigation canals were dry. We measured water levels again in June 2007, when the irrigation canals were full and irrigation pumping was occurring. Water levels were measured using either an electric tape or a sonic water-level meter.

Water-Well Sampling

We selected 36 wells and 5 surface-water sites (figure 2, appendix B) for sampling during autumn 2006 and spring of 2007. Water from 24 of the wells was analyzed for the nutrients nitrate and nitrite and general chemistry by Brigham Young University (BYU). Samples from three of these wells were analyzed for nitrate by the Utah Division of Epidemiology and Laboratory Services. Water from two sloughs on the southern border of the study area and a sample from Willard Bay were analyzed by the U.S. Geological Survey (USGS) for general chemistry. Water from 10 wells and 2 canal locations was tested for field parameters only (including specific conductance, dissolved oxygen, temperature, and pH). Twelve of the wells were sampled twice, once during each sampling interval; we augmented our data with analyses provided by the Utah Division of Drinking Water for 12 public-supply wells and 5 samples (wells and one spring) from the USGS. We used data from a total of 55 samples. Appendix C provides the constituents sampled for, the EPA analysis method, and ground-water quality standard (if the constituent has been assigned one).

Stable Isotopes/Environmental Tracers

Stable isotopes can be useful tracers of ground-water flow paths (Kendall and Caldwell, 1998) and ground-water recharge ages, and hence are indicators of the source of water bearing similar isotopic signatures. To gain a better understanding of the ground-water hydrology in the Bothwell Pocket area, water samples were collected and analyzed for the following isotopes/environmental tracers: nitrogen-15 and oxygen-18 in nitrate (expressed as $\delta^{15}N_{NO3}^{-}$ and $\delta^{18}O_{NO3}^{-}$), and oxygen-18 (expressed as $\delta^{18}O_{H20}$), tritium (^{3}H), carbon-14 (^{14}C), carbon-13 ($\delta^{13}C$), deuterium ($\delta^{2}H$), and chlorofluorocarbons (CFCs) in water. Ten samples were tested for $\delta^{15}N_{NO3}^{-}$ and $\delta^{18}O_{NO3}^{-}$; 15 for $\delta^{18}O_{H20}$ and $\delta^{2}H$; 19 for ^{3}H, ^{14}C, and $\delta^{13}C$; and 17 for CFCs. Nitrogen and oxygen isotopes in nitrate help determine the source of nitrate. The $\delta^{18}O_{H20}$ and deuterium isotopes are used to identify sources of recharge water. Data from samples tested for tritium, carbon isotopes, and CFCs are used to determine the age of the ground water.

Nitrogen and oxygen: Nitrogen and oxygen isotopes have been used to help determine sources of nitrate, and can be useful tracers of ground-water flow paths (Kendall and Caldwell, 1998). By measuring the ratio of isotopes taken from different sources and environments and comparing them to ratios of the same ground-water isotopes (e.g.,

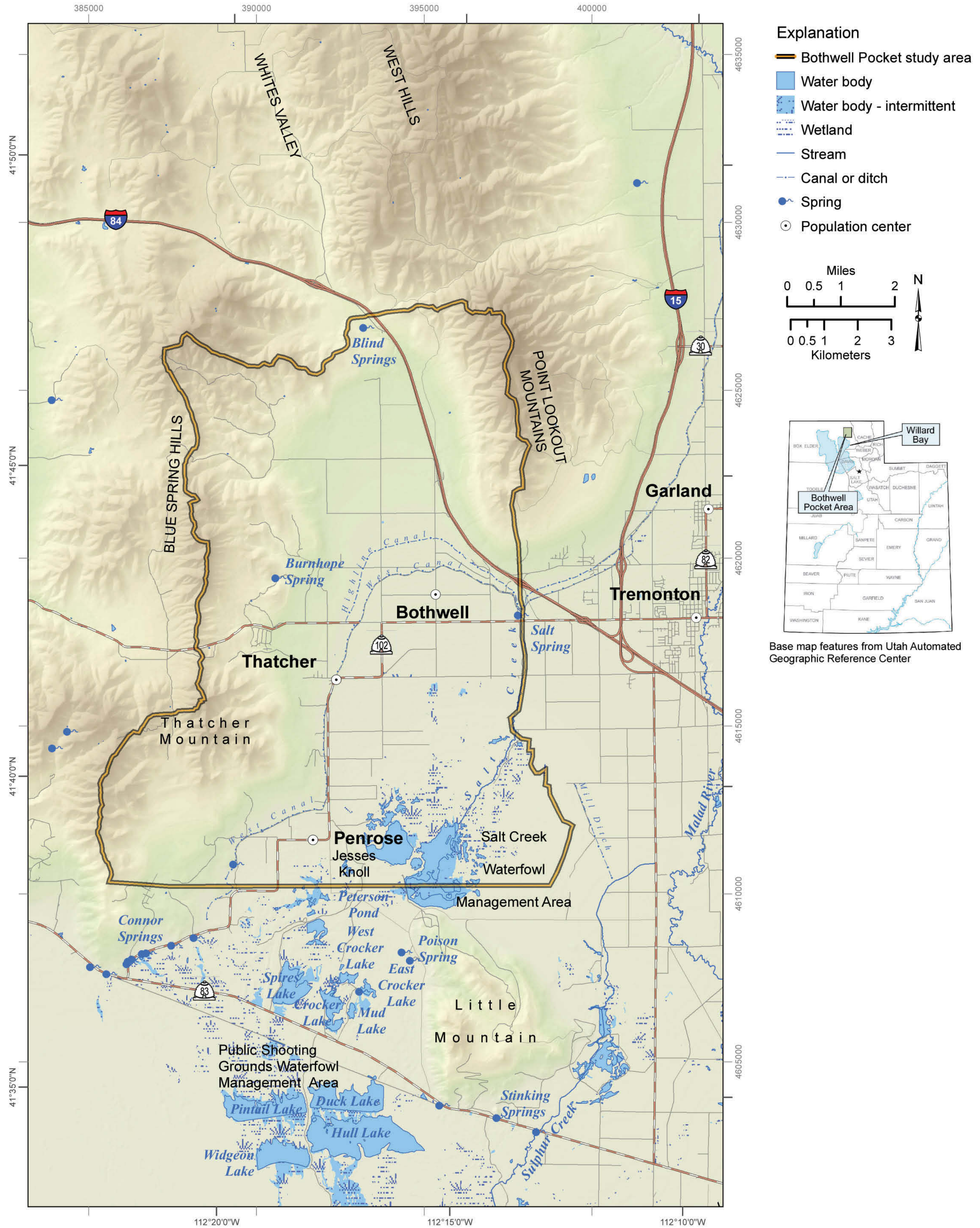


Figure 1. *Bothwell Pocket drainage-basin study area, Box Elder County, Utah.*

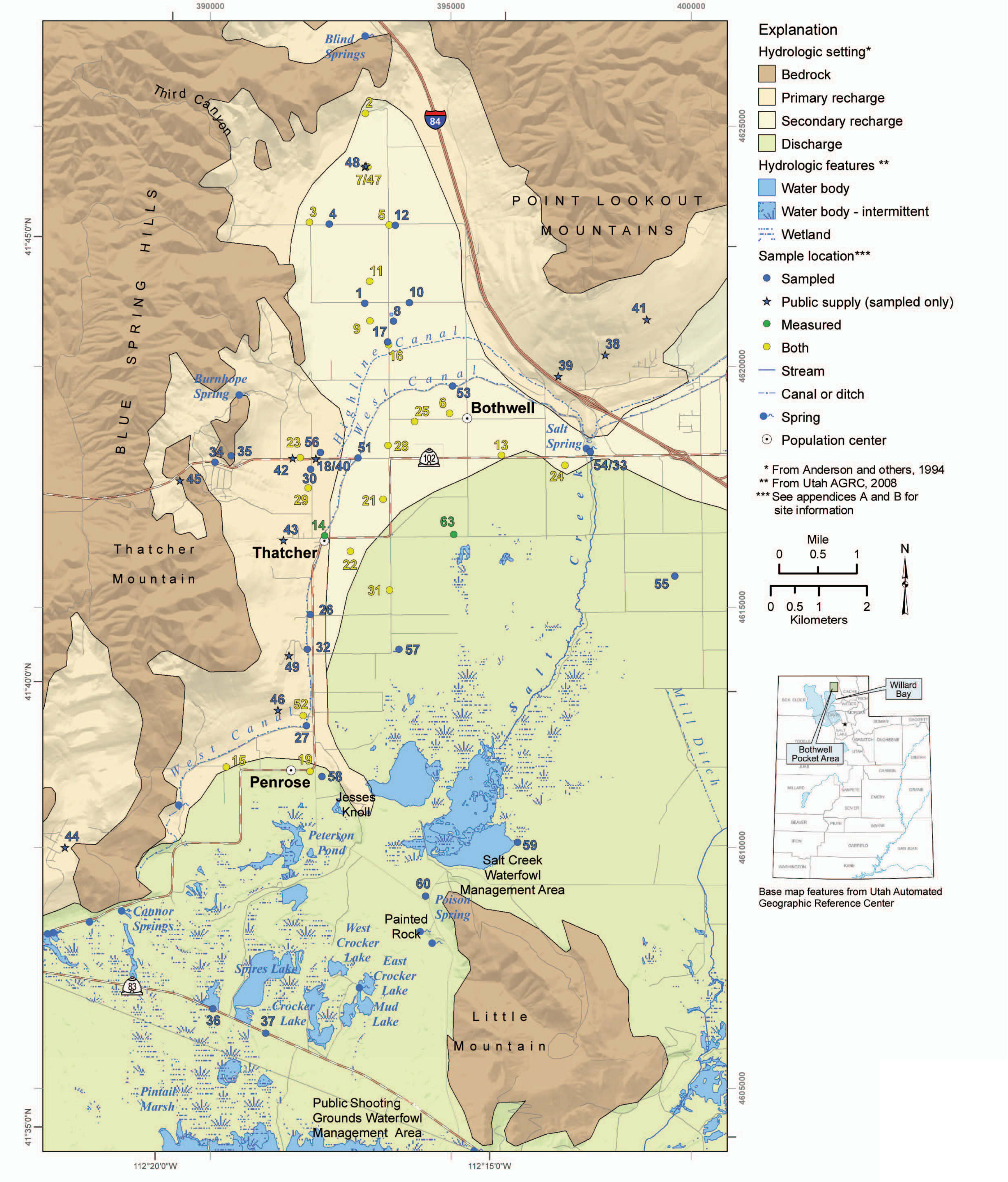


Figure 2. *Hydrologic setting and location of ground and surface water sampled for chemistry and measured for water levels in the Bothwell Pocket area.*

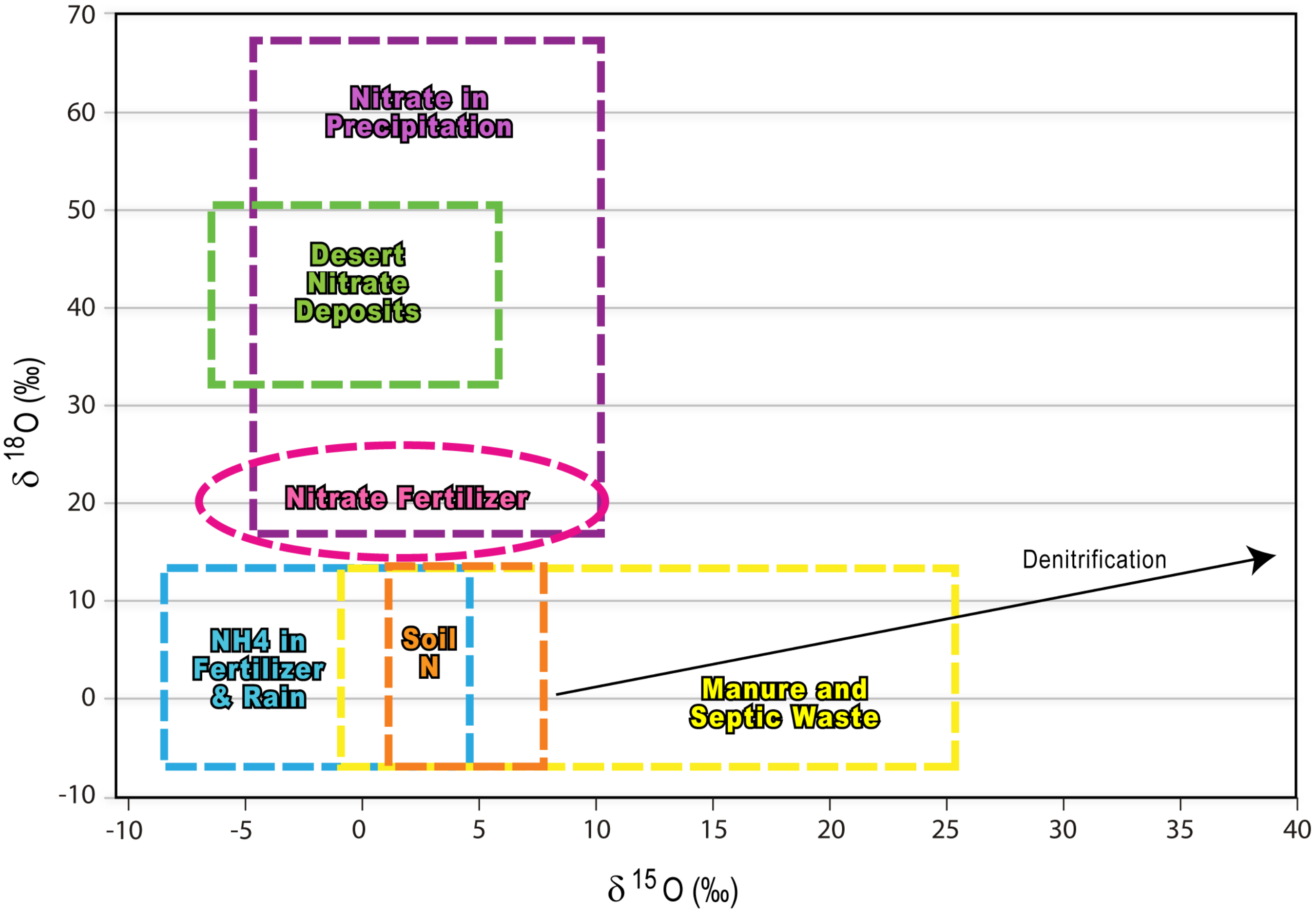


Figure 3. *Plot of nitrogen and oxygen isotopes characterizing sources of nitrate (from Kendall, 1998).*

comparing nitrogen isotope ratios from a documented source [such as fertilizer] to nitrogen isotope ratios of nitrate in ground water) the source of potential contamination to aquifers can be determined (Canter, 1997). In general, stable isotopes are reported as a ratio of the relative abundance of the isotope in the sample to the relative abundance of the isotope in a standard and expressed as:

$$\delta \text{ Isotope (in ‰)}=[(R_{sample}/R_{Standard})-1] \times 1000 \qquad (1)$$

where R is the ratio of the “heavy” isotope to the “light” isotope in the sample or standard. Isotopes are reported as parts per thousand, commonly termed as parts per mil, or symbolically as ‰, and can be expressed as positive or negative numbers depending on the relationship to the given standard. For nitrate, the standard is atmospheric nitrogen (N_2) and nitrogen isotopes are commonly represented as δ^{15}N (where δ^{15}N=0 ‰ for N in air); the standard for oxygen is Vienna Standard Mean Ocean Water (VSMOW) (Gonfiantini, 1978), with the oxygen isotope reported as δ^{18}O. Nitrogen has two common stable isotopes: ^{15}N and ^{14}N. Oxygen has three common stable isotopes: ^{16}O, ^{17}O, and ^{18}O.

Figure 3 shows the relationship between nitrogen/oxygen isotopes of nitrate and selected nitrate source types (Kendall, 1998); figure 4 shows the common ranges for nitrogen isotope composition for septic waste, animal waste, fertilized soil, and natural soil (Kendall, 1998). Fertilizer typically has a δ^{15}N value range from –2 to +2‰, non-cultivated fertilized soils typically have a δ^{15}N value range from +2 to +8‰ (Canter, 1997), and values that range between -5 and 5‰ are typically associated with ammonia-rich fertilizer and rain. Animal and human waste are generally isotopically indistinguishable, δ^{15}N ranging between +10 and +20‰ (Kendall, 1998); Canter (1997) reported decomposed animal waste has a range from +10 to +22‰. Animal waste is common to barnyard and feed lots, whereas human waste is found in effluent from septic-tank systems. Nitrate derived from nitrate in precipitation, desert nitrate deposits, and nitrate fertilizer typically has $\delta^{18}O_{NO3}$ values greater than 15‰ and lower $\delta^{15}N_{NO3}$ values (less than 10‰) (figure 3). Processes such as denitrification and mixing of ground water can affect isotopic signature, and thus mask the actual source(s) of nitrate. Isotopic analysis for $\delta^{15}N_{NO3}$ and $\delta^{18}O_{NO3}$ was performed by the University of Waterloo, Ontario, Canada.

Oxygen-18 and deuterium: Oxygen-18 and deuterium are naturally occurring stable isotopes of oxygen and hydrogen. Values for oxygen-18 and deuterium are expressed as ratios in delta notation (δ) as ‰ relative to a

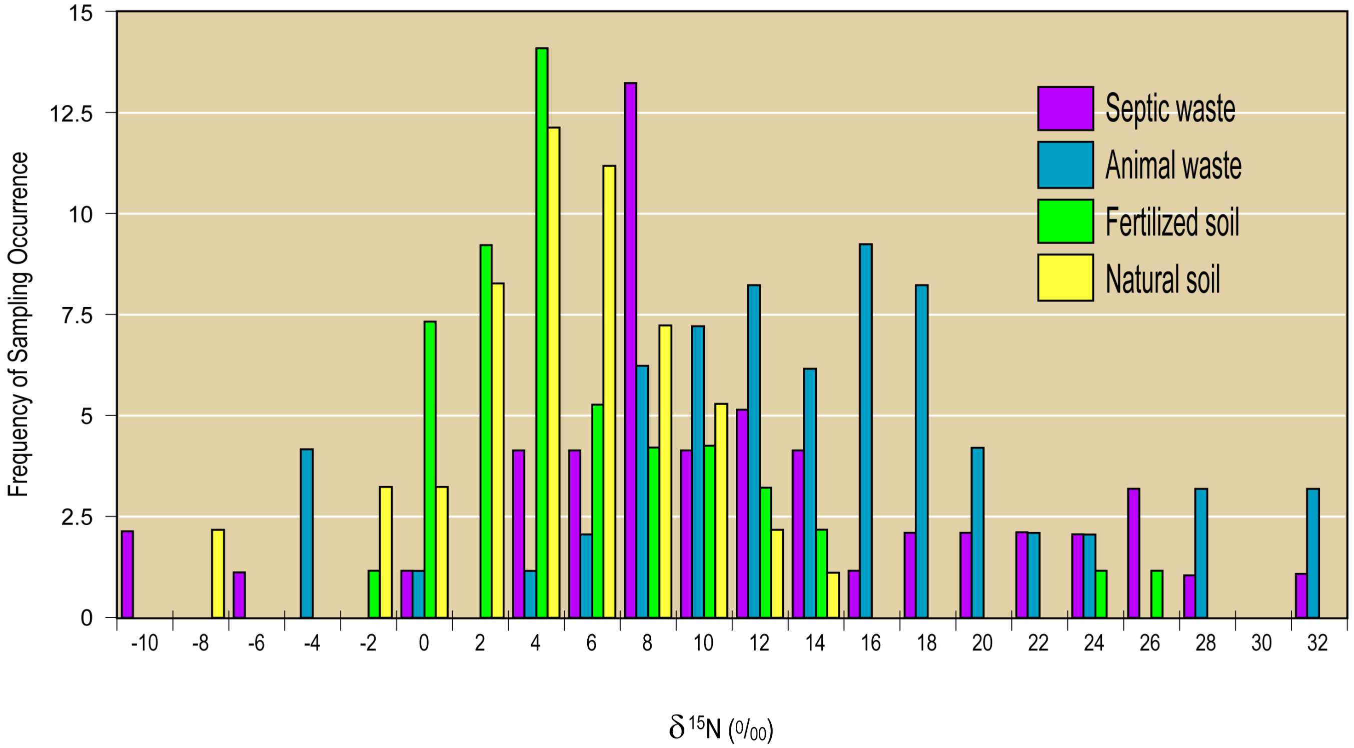


Figure 4. *Summary of range of* $\delta^{15}N$ *values for septic waste, animal waste, fertilized soil, and natural soil compiled from global sources (modified from Kendall, 1998).*

reference standard according to equation 1 above. The reference standard for oxygen-18 and deuterium is VSMOW (Gonfiantini, 1978). The isotopic ratio of the sample is the ratio of the heavy isotope to the light isotope.

The global meteoric water line (GMWL) is modified from Clark and Fritz (1997) (figure 5). The GMWL represents approximate isotopic composition for oxygen and deuterium of rain and snow on the Earth, where:

$$\delta D = 8(\delta^{18}O) + 10 \qquad (2)$$

The GMWL provides a good reference to help identify provenance of ground water, where isotopically depleted waters are linked to colder geographic regions compared to warmer regions, where isotopically enriched waters plot (figure 5) (Clark and Fritz, 1997). Isotopic signatures from seawater fall below the GMWL, precipitation from cooler places plot along the GMWL with coldest places plotting farther to the lower left.

Other processes, such as evaporation, produce similar effects. The hydrologic cycle fractionates light and heavy water during evaporation and condensation; lighter water evaporates more readily and heavy water condenses more readily (Clark and Fritz, 1997). Evaporation of surface water or soil water, prior to recharge, can cause enrichment of heavier isotopes in ground water. If snowmelt is a significant recharge source, heavy isotope enrichment could be from sublimation of the snow and evaporation of surface runoff. However, if ground water is recharged episodically by heavy precipitation events, ground-water data plot along the meteoric water line. Isotopic analysis of $\delta\,^{18}O$ and $\delta\,^{2}H$ was performed by BYU, Provo, Utah.

Tritium: Tritium (^3H) provides a qualitative age of ground water for determining the relative time when water entered the ground-water system (Clark and Fritz, 1997). Tritium is an unstable isotope of hydrogen with a half-life of 12.3 years; tritium concentration in ground water isolated from other water will decrease by one-half after 12.3 years. Tritium occurs naturally in the atmosphere, but above-ground nuclear testing from 1952 to 1969 added tritium to the atmosphere in amounts that far exceed the natural production rates, and, as a result, tritium concentrations in precipitation also increased. The amount of tritium in the atmosphere from weapons testing probably peaked in the early to mid-1960s, and has been declining since atmospheric nuclear testing ceased. Modern concentrations are typically between 5 and 10 tritium units (1 tritium unit [TU] equals 1 tritium atom per 10^{18} H atoms) (Clark and Fritz, 1997). Tritium in the atmosphere incorporates into water molecules and enters the ground-water system as recharge from precipitation. Because tritium is part of the water molecule, it is not affected by chemical reactions other than radioactive decay, and thus can be used as a tracer of ground water on a time scale of less than 10 to about 55 years before present. Water that entered the ground-water system before 1952 and has remained isolated from younger water contains negligible

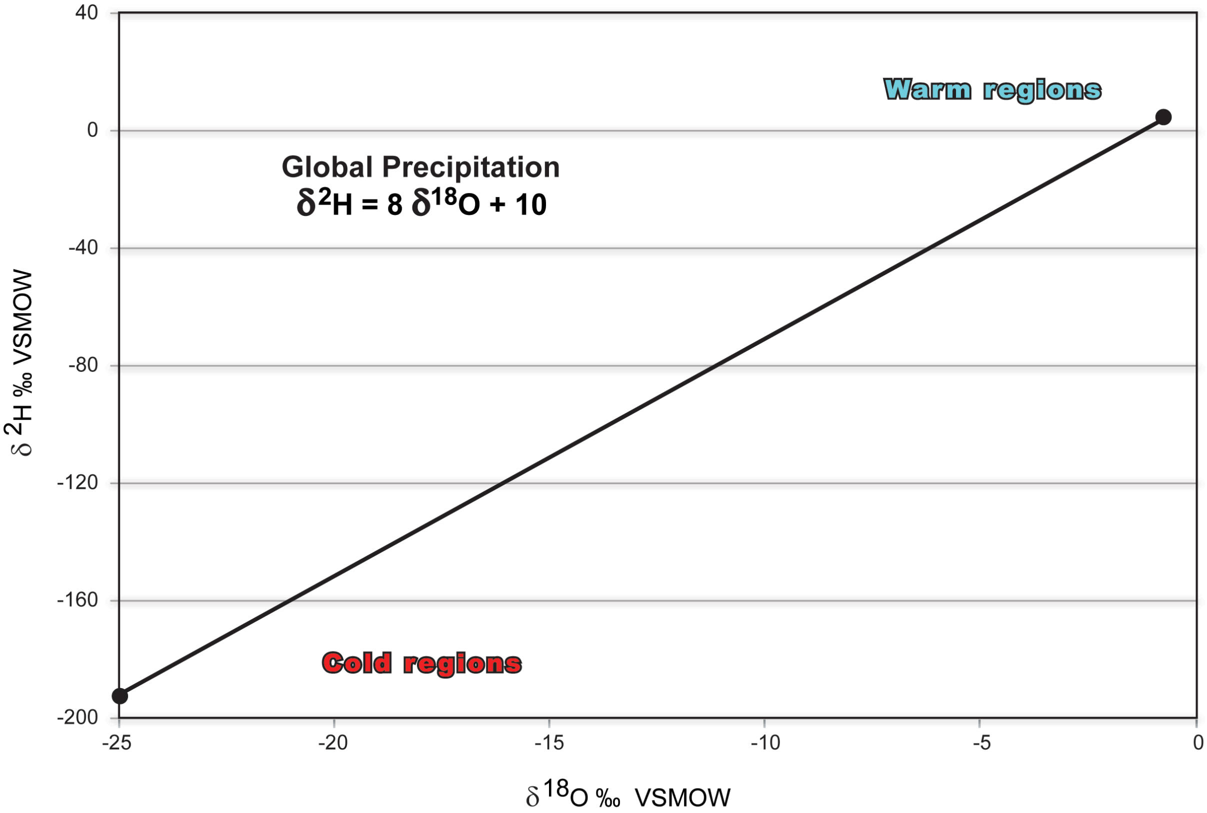


Figure 5. *Plot of the global meteoric water line (GMWL) (modified from Clark and Fritz, 1997).*

tritium (<0.8 TU), and is interpreted to have recharged before 1952. Therefore, tritium can be used to distinguish between water that entered an aquifer before 1952 and water that entered the aquifer after 1952. A mixture of waters having different tritium ages complicates interpretation. Tritium analysis was performed by BYU, Provo, Utah.

Chlorofluorocarbons: Chlorofluorocarbons (CFCs) are stable synthetic compounds used in the production of refrigerants, propellants, and manufactured products in the electronics industry, and were introduced into the environment during the 1930s (Plummer and Busenberg, 1999). CFC-12 and CFC-11 were first produced in the United States during 1931 and 1936, respectively, with CFC-113 more commonly produced subsequently. The compounds CFC-11 and CFC-12 are used as coolants in air-conditioning and refrigeration, blowing agents in foams, insulation, propellants in aerosol cans, and solvents. The CFC-113 compound is used by the electronics industry in semiconductor chips, in vapor degreasing and cold immersion cleaning of microelectronic components, and as solvents (Plummer and Busenberg, 1999). When a ground-water sample is collected and analyzed for CFC concentrations, the concentration in the water is related to the concentration of CFC in the atmosphere at the time the water entered the subsurface (University of Utah Dissolved & Noble Gas Lab [DNGL], 2008). The conditions for CFC analysis described herein were obtained from the lab-analysis sampling sheet by the DNGL (undated, unpublished sample form). For each sample analyzed for CFC content in ground water, current local physical and chemical parameters must be considered, such as the salinity of the water (at the time of recharge), the recharge temperature, and the recharge elevation. Chlorofluorocarbon raw data are calculated as the concentration of CFCs in air that would be in equilibrium with the sample at the temperature and elevation given; the calculation compares the equivalent air concentration with the atmospheric mixing ratios to estimate the recharge year. The atmospheric mixing ratio for CFC-11 began declining in 1994. As of 2001 it had dropped to about the same value it was in 1989. Thus, the CFC-11 dates are not unique for the period 1989 to 2001 (as of 2001) as there are two possible years that correspond to the same concentration. The results are typically reported as the older of the two possible dates. The same circumstance exists for CFC-113 starting in 1991. Chlorofluorocarbon analysis was performed by the DNGL, Salt Lake City, Utah.

Carbon: Carbon-14 (^{14}C) is a naturally occurring radioactive isotope of carbon that has a half-life of about 5730 years (Clark and Fritz, 1997). Carbon-14 data can provide information on ground water of greater ages than the other environmental tracers, which only provide relative ground-water ages for water dating to the 20th century.

Carbon-14 data are expressed as percent modern carbon (PMC) based on the National Bureau of Standards oxalic acid standard. Atmospheric testing of nuclear weapons also produced ^{14}C, so in some instances values greater than 100 PMC can occur in ground water that contains tritium, because the water was recharged when the atmosphere had above natural levels of ^{14}C. Carbon-14 is not part of the water molecule, so ^{14}C activities are affected by chemical reactions between the aquifer material and the dissolved constituents in the water. Chemical reactions can either add or remove carbon; therefore, knowledge of chemical reactions that occur during recharge and transport through the aquifer are necessary for estimating the initial activity of ^{14}C, which is the most difficult aspect in using ^{14}C for dating ground water. The methods for dating carbon in ground water are complex and beyond the scope of this report; only a brief description is provided. Age calculations require estimates of some chemical parameters during recharge and model calculations of reactions during ground-water transport. Calculation of ground-water age (expressed in years before present [^{14}C yr B.P.], where "present" is A.D. 1950) from raw carbon isotope data was performed by Dr. Alan Mayo of Brigham Young University (written communication, May 25, 2008). Percent modern carbon (PMC) values were calculated following the procedure of Stuiver and Polach (1977). Clark and Fritz (1997) provide a more detailed description of carbon isotope dating and the various required parameters to calculate carbon-based ages.

Carbon-13 is a naturally occurring stable isotope of carbon that is used to evaluate chemical reactions involving carbon (Clark and Fritz, 1997). Carbon-13 is expressed using the delta notation as a ratio with carbon-12, similar to $\delta^{18}O_{H20}$ and δD_{H20}, but with the Vienna Pee Dee Belemnite (VPDB) as the reference standard. The $\delta^{13}C$ concentration in ground water depends upon numerous factors, which include the type of vegetation in the recharge area, whether carbonates (and the $\delta^{13}C$ compositions of those minerals) are dissolved or precipitated during recharge, and whether the system is open or closed. Carbon isotope analysis was performed by BYU, Provo, Utah.

LOCATION AND GEOGRAPHY

The Bothwell Pocket is located in northern Utah and is part of the Basin and Range physiographic province (Stokes, 1977) (figure 1). The Bothwell Pocket surface-drainage basin is bounded by drainage divides in the Blue Spring Hills to the west and northwest, the West Hills to the northeast and east, Salt Creek to the southeast, and Great Salt Lake and Little Mountain to the south. For the northern study area boundary, we used the southern margin of Whites Valley. For the southern study area boundary, we used the boundary between T. 10 N. and T.11 N., Salt Lake Base Line and Meridian; the study area covers about 68 square miles (176 km^2).

The principal communities in the study area are Bothwell, Thatcher, and Penrose. Tremonton is located immediately to the east of the study area. Agriculture and residential development are the principal land uses. The Utah Division of Water Resources 1:24,000 scale Land Use/Water Related Use GIS data set, based on a 2001 to 2006 inventory, indicates that grain, alfalfa, and corn are the principal crop types; much land is also used for pasture. Much of the residential development is new, and many of the residents work at the Alliant Tech – Thiokol Propulsion Group facilities located west of the study area.

CLIMATE

The climate in the Bothwell Pocket is semiarid. The average annual precipitation (at Bothwell) is 12.97 inches (32.9 cm), and average annual evapotranspiration (at Tremonton using the Hargreaves equation [based on perennial rye grass or Alt fescue as reference crop]) is 40.83 inches (104 cm) (Ashcroft and others, 1992); the mountainous areas receive a greater amount of precipitation. The drainages in the Bothwell Pocket are all ephemeral streams, with most runoff likely coming from the Whites Valley area. Irrigation canals divert water from the Bear River into the Bothwell Pocket area.

PREVIOUS WORK

Carpenter (1913, p. 37–50) described the ground-water resources of the lower Bear River drainage basin. Bjorklund and McGreevy (1973, 1974) conducted a more comprehensive evaluation of ground-water resources, and speculated that water-quality problems might become an issue in the Bothwell Pocket. Bjorklund and McGreevy (1974) identified two potential sources of water-quality degradation: (1) migration of saline water from Great Salt Lake should large general declines in the potentiometric surface occur, and (2) movement of saline water in deeper basin-fill deposits into drawdown cones of depression at large irrigation wells. Anderson and others (1994) mapped ground-water recharge and discharge areas for the Wasatch Front and adjacent areas, including the Bothwell Pocket. Doelling (1980) mapped an inferred north-south trending fault along the western edge of the Bothwell Pocket, and Jordan and others (1988) mapped the local geology of Thatcher Mountain quadrangle. Lowe and others (2005) and Lowe and Wallace (2006) conducted pesticide sensitivity and vulnerability analyses for eastern Box Elder County, including the Bothwell Pocket area.

GEOLOGIC SETTING

Bedrock bounding the basin-fill material consists of the Pennsylvanian-Permian Oquirrh Formation (limestone, sandstone, quartzite, and siltstone), and the Permian Thatcher Mountain Formation (sandstone) (Bjorklund and McGreevy, 1974; Jordan and others, 1988). The basin-fill material is composed of early Tertiary to Quaternary, unconsolidated to semi-consolidated, fluvial and lacustrine gravel, sand, silt, and clay deposits, which have a maximum thickness of more than 765 feet (233 m) (Bjorklund and McGreevy, 1974).

Major structures in the study area include the north-south trending, eastward overturned Thatcher Mountain syncline within the Blue Spring Hills, and high-angle north-south trending normal faults that bound the western margin of the basin (figure 6) (Jordan and others, 1988). Normal faults cut older folds in the Blue Spring Hills. North-striking faults on the western margin of the basin likely have large offsets and are inferred to exist beneath Quaternary deposits. Along the east side of Thatcher Mountain, the normal faults are truncated by east-striking faults southwest of Penrose (Jordan and others, 1988). A north-south trending thrust fault is mapped in the southern part of the Blue Spring Hills and is concealed beneath Quaternary deposits there.

STRATIGRAPHIC UNITS

Oquirrh Formation

The Pennsylvanian-Permian Oquirrh Formation consists of three informal members in the Bothwell Pocket area: the oldest limestone member, the middle bioturbated limestone member, and the youngest thinly bedded member. The limestone member consists of medium to thickly bedded gray limestone with minor brown sandstone beds. The bioturbated limestone member consists of silty and sandy gray limestone and brown, calcareous, very fine grained sandstone. The thinly bedded member consists of thinly bedded siltstone and silty limestone with common dark-brown chert lenses (Bjorklund and McGreevy, 1974; Jordan and others, 1988). The Oquirrh Formation is exposed in the southern end of the Blue Spring Hills, in the far southwestern corner of the Bothwell Pocket area, and at Jesses Knoll, near the southern boundary of the study area (figure 6).

Thatcher Mountain Formation

The Permian Thatcher Mountain Formation consists of reddish-brown, thinly to thickly bedded, fine- to coarse-grained sandstone, locally cross-bedded, with interbedded limestone or dolomite (Jordan and others, 1988). The Thatcher Mountain Formation comprises the vast majority of the exposed bedrock in the hills surrounding the Bothwell Pocket.

Salt Lake Formation

A small patch of the Tertiary Salt Lake Formation is mapped in the Blue Spring Hills west of the study area. The Salt Lake Formation consists of tuffaceous to calcareous conglomerate and sandstone with local lacustrine limestone beds (Jordan and others, 1988). The Salt Lake Formation is also shown on a geologic cross section in Jordan and others (1988; plate 2) and may underlie the alluvial fill material that comprises the basin-fill aquifer (Bjorklund and McGreevy, 1974).

Quaternary Deposits

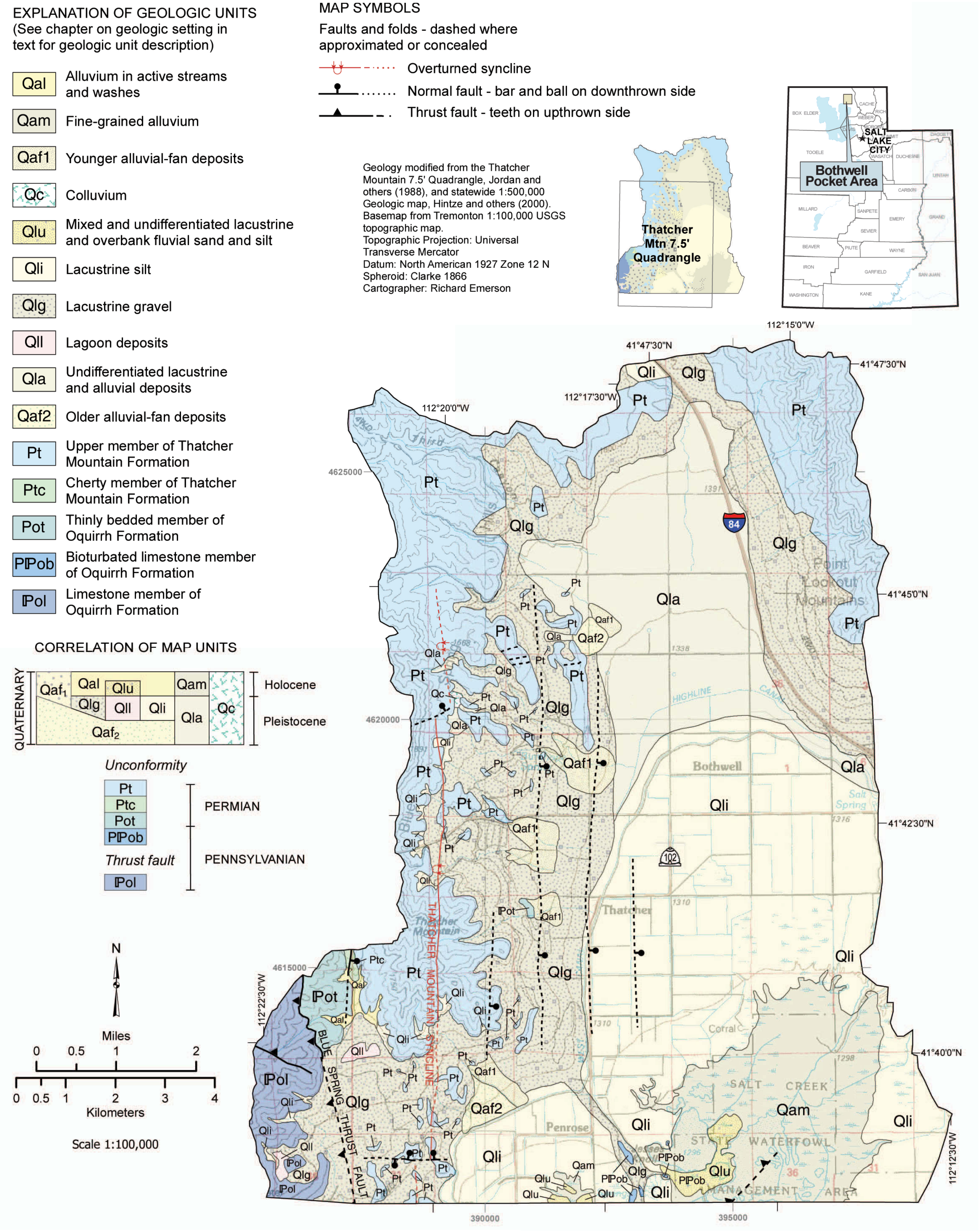
Quaternary deposits in the Bothwell Pocket are located at the base of the hills surrounding the pocket and in the basin. The base of the hills above the pocket is covered by lacustrine gravel deposited along Lake Bonneville shorelines. The basin fill in the northern Bothwell Pocket consists of lacustrine silt deposited by Lake Bonneville. The area surrounding the Salt Creek Waterfowl Management Area, in the southeastern corner of the study area, contains silt and clay deposits in active marshes. Basin-fill deposits have a maximum thickness greater than 765 feet (233 m) (figure 7) based on drillers' well-log information.

GROUND-WATER CONDITIONS

Aquifer Characteristics

The Bothwell Pocket is the northwestern-most extension of a larger hydrologic basin (lower Bear River basin) that comprises the northern part of the Lake Bonneville basin; we emphasize water conditions in the northwestern-most part of the basin in this study. Ground water in the Bothwell Pocket area is obtained principally from unconsolidated deposits of the basin-fill aquifer. Ground water is under unconfined conditions along the basin margins and most of the area north of Bothwell, and under confined conditions in the southern part of the study area (Anderson and others, 1994) (figure 8). The apparent potentiometric surface in the valley-fill aquifer is irregular and depends on the well depth, season, and the year water-level measurements are made. Ground water flows generally from the mountains to the valley, and then south toward marshes and lakes of the wetlands area north of Great Salt Lake (Bjorklund and McGreevy, 1974, figure 5).

Unconsolidated sediments of the Bothwell Pocket area have a maximum thickness of more than 765 feet (233 m)



Geology modified from the Thatcher Mountain 7.5' Quadrangle, Jordan and others (1988), and statewide 1:500,000 Geologic map, Hintze and others (2000).
Basemap from Tremonton 1:100,000 USGS topographic map.
Topographic Projection: Universal Transverse Mercator
Datum: North American 1927 Zone 12 N
Spheroid: Clarke 1866
Cartographer: Richard Emerson

Figure 6. *Compiled geology of the Bothwell Pocket study area.*

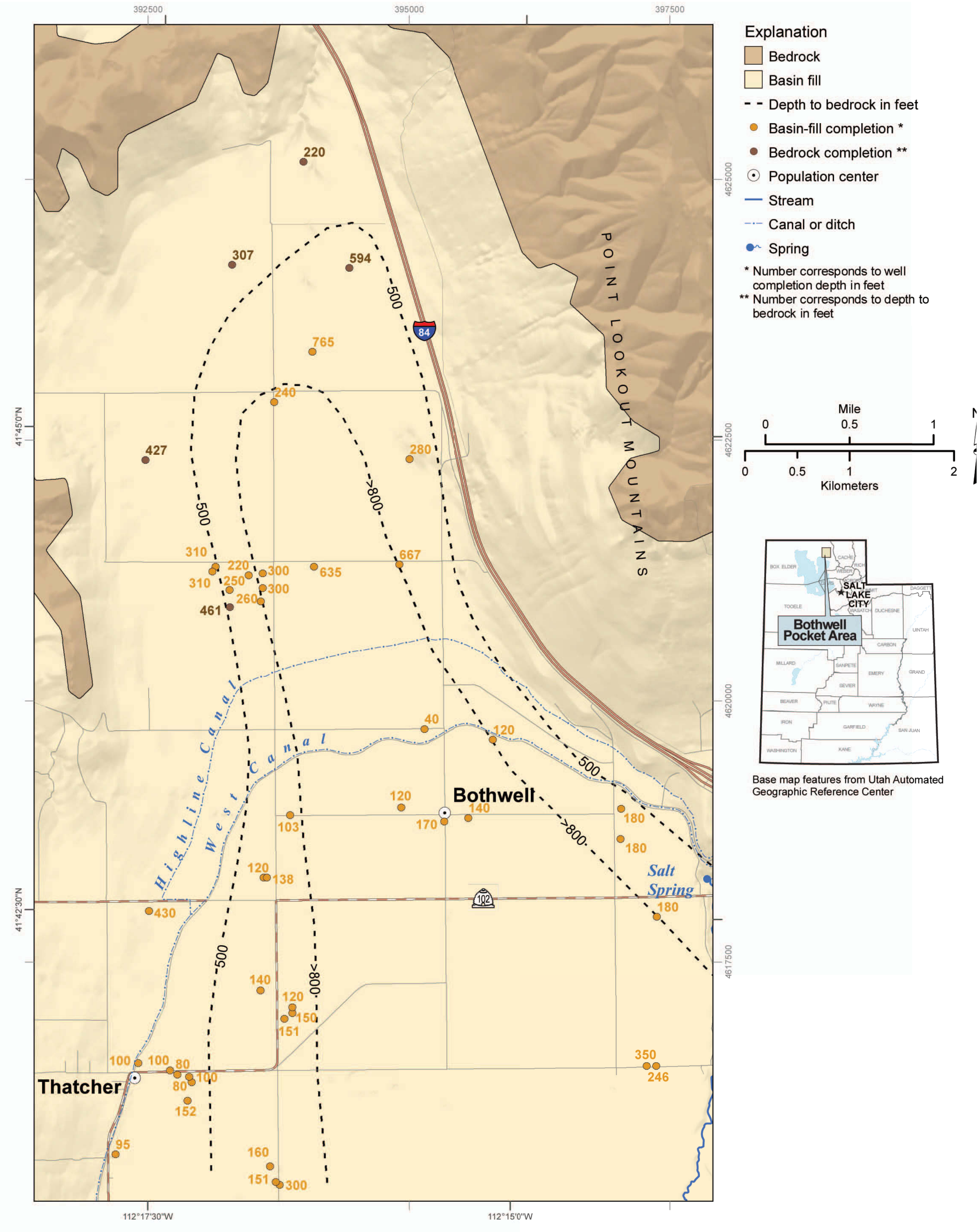


Figure 7. *Schematic isopach of basin-fill deposits in the Bothwell Pocket area. Thickness is estimated based on drillers' log information and statewide gravity map.*

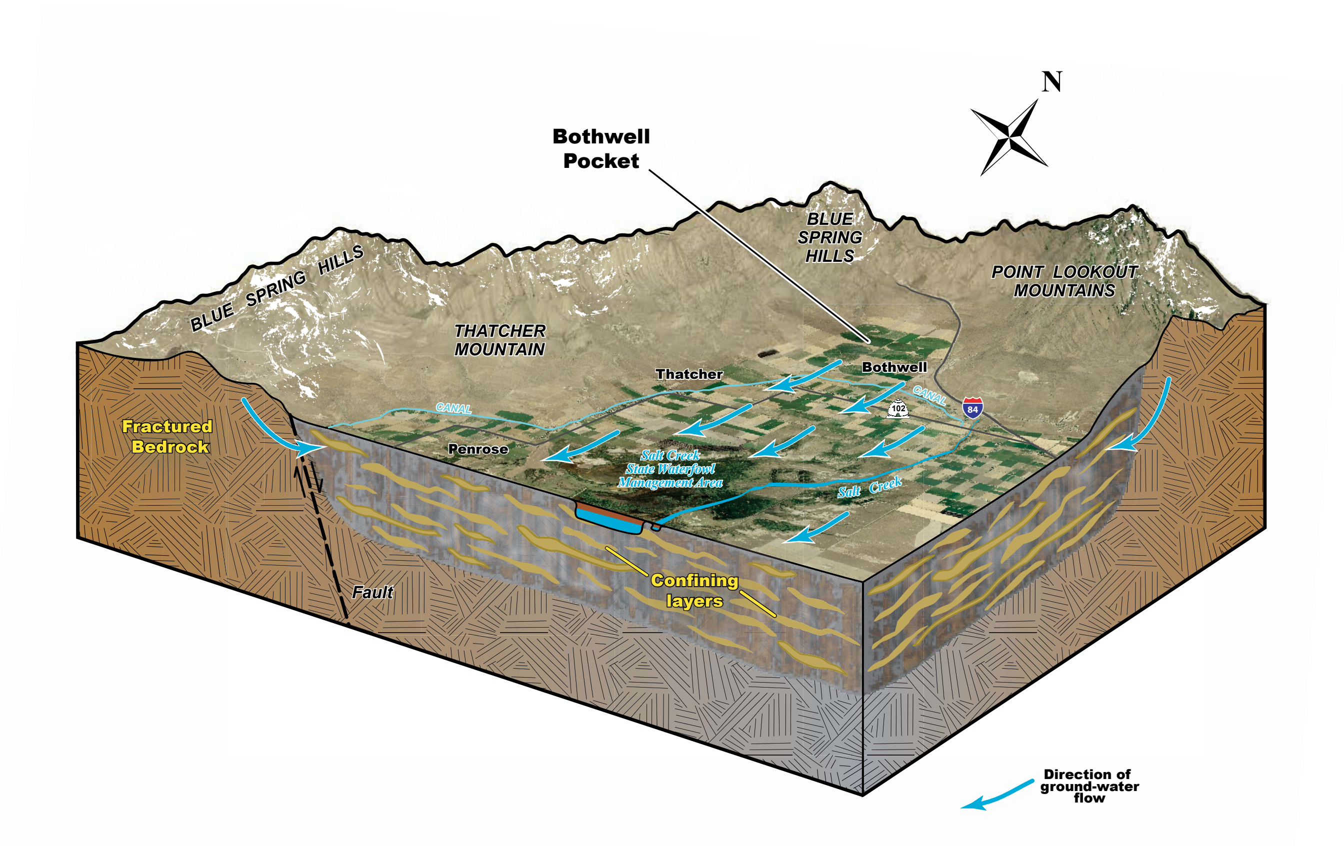


Figure 8. *Schematic block diagram showing aquifer conditions and general direction of ground-water (arrows) flow in the Bothwell Pocket area. Topographic relief is exaggerated.*

(Bjorklund and McGreevy, 1974). Unconsolidated sediments consist of clay, silt, sand, and gravel that formed in alluvial-fan, fluvial, and lacustrine environments. Based on the examination of drillers' logs for the area, the aquifer in the area is composed of heterogeneous units; the basin-fill deposits consist of coarse-grained alluvial-fan marginal deposits that grade into fluvial and/or fluvial-lacustrine finer grained deposits. Confining (or clay) layers are discontinuous; the degree of interconnectedness between coarser grained material is unknown. The use of drillers' logs requires interpretation because of the variable quality of the logs. Correlation of geology from well logs is difficult because lithologic descriptions prepared by various drillers are generalized and commonly inconsistent. Use of water level data from well logs is also problematic because levels in the shallow unconfined aquifer are commonly not recorded and because water levels were measured during different seasons and years.

Ground-Water Recharge/Discharge

Most of the following information on ground-water recharge and discharge is taken from Lowe and others (2005) as reported by Bjorklund and McGreevy (1974) for the basin-fill aquifer in eastern Box Elder County, of which the Bothwell Pocket is the northwestern-most portion. Ground-water recharge in the basin-fill aquifer is from precipitation, surface-water seepage, and subsurface inflow. Bjorklund and McGreevy (1974) suggested that recharge in the Box Elder study area is equal to discharge, as indicated by small changes in water levels in wells, and ground-water storage is minor. Recharge from precipitation occurs mainly in and around the mountains. Significant infiltration occurs where streams flow from canyons onto permeable alluvial deposits along the basin margins. Substantial increases in recharge have occurred from surface-water diversions used for irrigation; annual rises in water levels in wells average 6 feet (2 m), mostly due to seepage from irrigation canals. Subsurface inflow of ground water likely enters the area from the north through the Malad River valley and from the Blue Spring Hills area on the western margin. Discharge from the basin-fill aquifer is from springs, drains, wells, evapotranspiration, and subsurface outflow. The greatest discharge is by evapotranspiration from mudflats and phreatophytes in low-lying areas. Springs and drains discharge both saline and fresh water into the basin center and into the Malad and Bear Rivers, which gain flow downstream. Some ground water is discharged from wells and/or is transported out of the basin as subsurface flow (Bjorklund and McGreevy, 1974).

Potentiometric Surface and Water-Level Measurements

To determine whether water levels are declining in the Bothwell Pocket area and to generate potentiometric-surface maps, we measured 24 water wells during two different seasons and compared them to previously published potentiometric-surface maps. We measured wells in December 2006 and March 2007, when irrigation pumping was not occurring and the irrigation canals were dry, to establish a baseline level for the non-irrigation season. We measured water levels in the same wells again in June 2007, when the irrigation canals were full and irrigation pumping was taking place. Depths to water ranged from 330 feet (99 m) in the north end of the pocket to 2 feet (0.6 m) above ground level south of Thatcher.

The water table north of Bothwell is nearly flat, sloping gently toward the south. The water table rises to a local high surrounding the Highline Canal and West Canal (figures 9 and 10). South of the West Canal, the water table slopes southward, and roughly follows the land surface south of Thatcher.

Most wells showed little change (<5 feet) in water level between seasons (appendix A), except for a few wells near canals. During the irrigation season, pumping from wells in the northern part of the Bothwell Pocket creates a cone of depression extending across the pocket, with a maximum drawdown of 40 feet (12 m). Water levels in wells near the canals increase slightly during the irrigation season, with a maximum increase of 6 feet (2 m), while wells south of Thatcher have little or no change in water levels (figures 9 and 10). The ground-water high surrounding the canals is likely caused by seepage from the canals during the irrigation season. Figure 11 shows a three-dimensional schematic image of the potentiometric surface as measured from the two different seasons; the ground-water high is evident during the irrigation season compared to the non-irrigation season.

A potentiometric surface map published by Bjorklund and McGreevy (1974), based on data collected in 1971, shows ground-water levels that are comparable to our non-irrigation season levels, though water levels in the north end of the pocket have actually risen by about 10 feet (3 m). This rise may be associated with an increase in recharge or from a decline in well-water withdrawal from nearby wells not currently being used. Other non-irrigation season water levels in the Bothwell area have remained relatively consistent. We collected more detailed data in the Bothwell Pocket than Bjorklund and McGreevy (1974) and our data denote a more southerly direction of ground-water flow north of Bothwell, where Bjorklund and McGreevy (1974) show a generally eastward flow direction. Bjorklund and McGreevy (1974) did not produce a potentiometric-surface map for the irrigation season.

Transmissivity

Based on information obtained from Drinking Water Source Protection plans filed with the Utah Division of Drinking Water, we were able to use calculated and estimated transmissivities from public-supply wells located sporadically throughout the basin (figure 2), reported below from locations north to south. We report transmissivity data for bedrock wells and alluvial wells. Bjorklund and McGreevy (1974) reported a range of transmissivity values for Lake Bonneville deposits of 2000 to 20,000 feet squared per day (186–1860 m^2/day). Transmissivity from alluvial wells along the basin margin ranges from 13,000 to 20,000 feet squared per day (1200–1860 m^2/d); a transmissivity of 140,000 feet squared per day (13,000 m^2/d) was also recorded in a well that likely penetrates limestone (noted in Bjorklund and McGreevy [1974] as a well penetrating an unknown geologic unit that is located near wells that penetrate the Oquirrh Formation).

The Newman well and its backup well (wells 48 and 47, respectively, figure 2), drilled in 2001 after Bjorklund and McGreevy's (1974) study, operated by Bear River Water Conservancy District and located in the northernmost part of the study area, have a transmissivity value of 207,000 feet squared per day (19,200 m^2/day), computed by a 24-hour aquifer test. Both wells penetrate alluvial material composed of clay, sand, and gravel to about 300 feet (91 m) below the land surface and are completed in limestone bedrock to depths of 680 and 433 feet (207 and 132 m), respectively. Two other public supply wells serve the community of Bothwell. The northeastern well (well 39, figure 2) is located in the foothills of the southern tip of Point Lookout Mountains (also called the West Hills). This well was drilled in 1949 and according to the driller's well log consists "mostly of rock with a few inches of clay now and then," likely the Oquirrh Formation (mapped nearby). The well has a transmissivity of 2604 feet squared per day (242 m^2/day), computed by a single-well pump test. The second public water-supply well for Bothwell (well 42, figure 2) is located in the eastern foothills of Blue Spring Hills. This well penetrates unconsolidated clays and gravels to a depth of 430 feet (131 m). Transmissivity for the well was estimated from other aquifer data obtained from nearby wells in the same aquifer from Bjorklund and McGreevy (1974). Based on the drinking water source protection plan, the estimated transmissivity for this well is 13,000 feet squared per day (1208 m^2/day). The Marble Hills subdivision public supply well (well 45, figure 2) is located in the Blue Spring Hills, northwest of the community of Thatcher. The well has a transmissivity, estimated from specific capacity data on a driller's well log, of about 2200 feet squared per day (200 m^2/d). The well is completed in bedrock, presumably the Thatcher Mountain Formation. The Thatcher-Penrose well (well 43, figure 2), situated due west of the community of Thatcher and due east of Thatcher Mountain peak, penetrates about 234

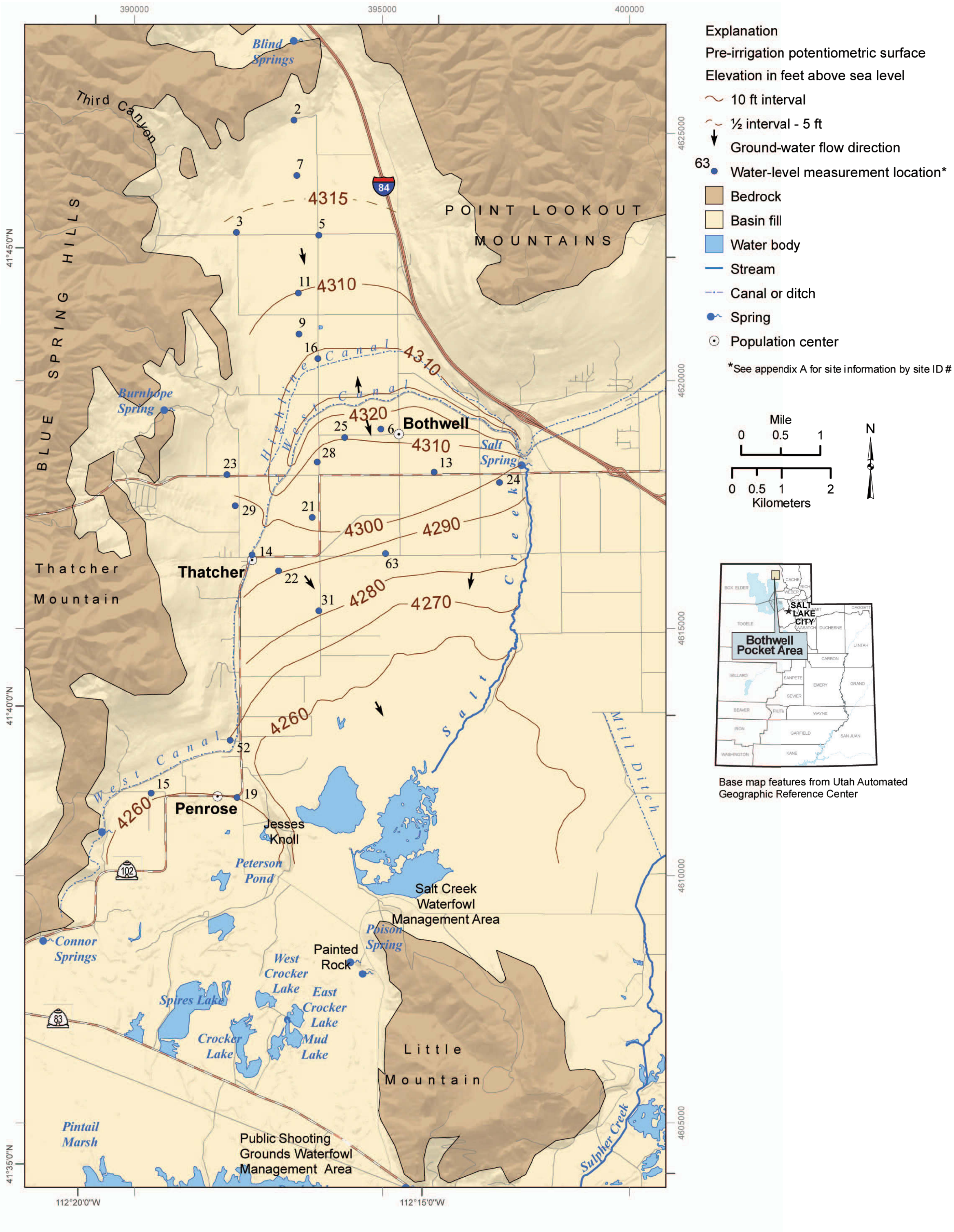


Figure 9. *Pre-irrigation season potentiometric surface, Bothwell Pocket area.*

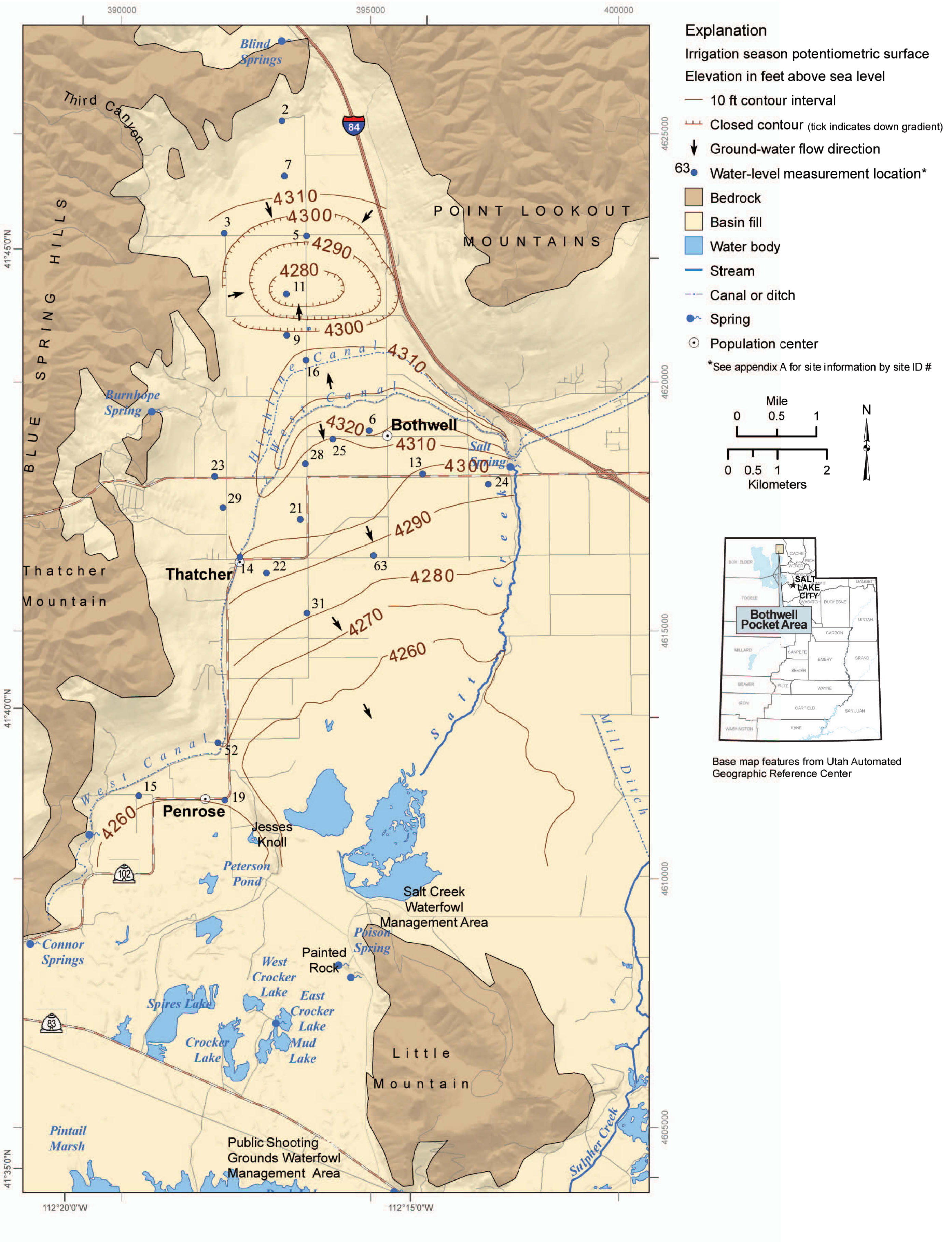
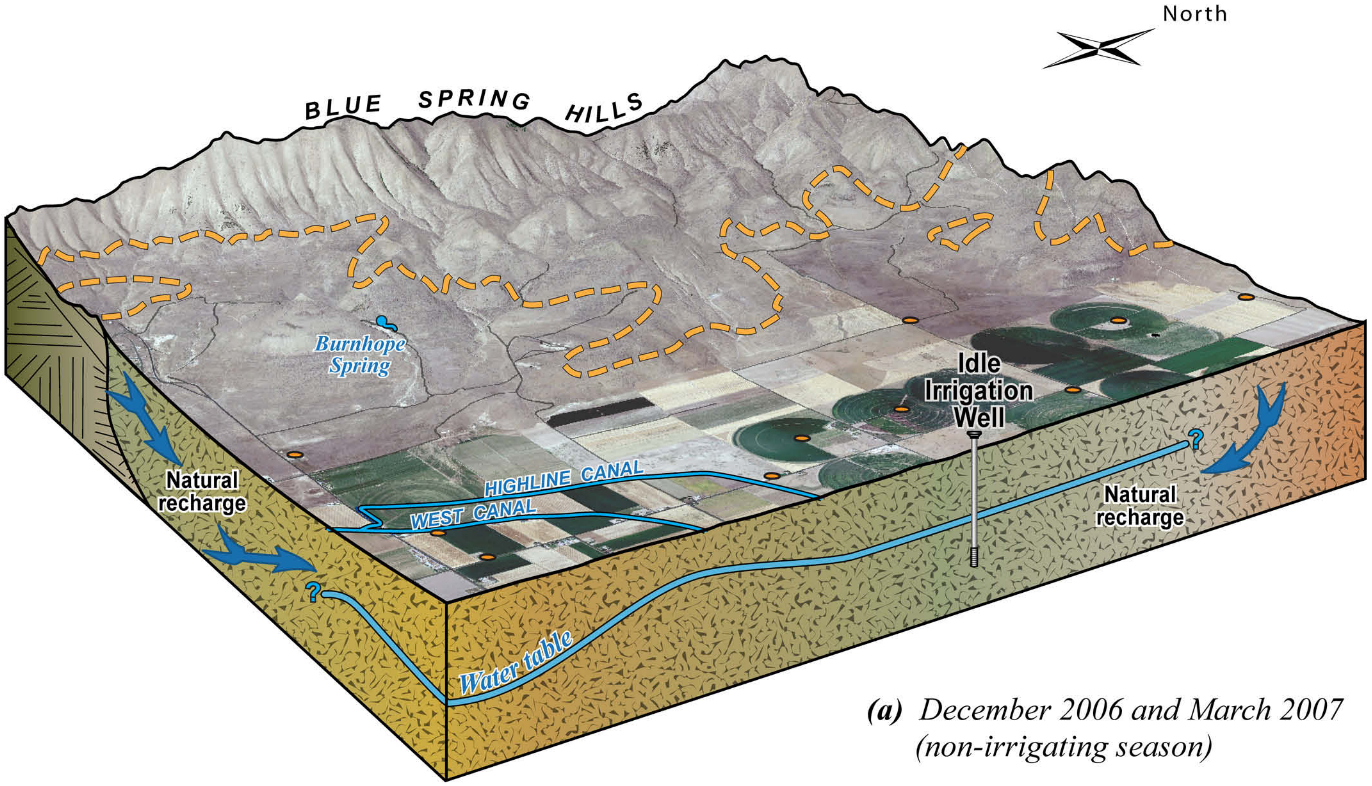
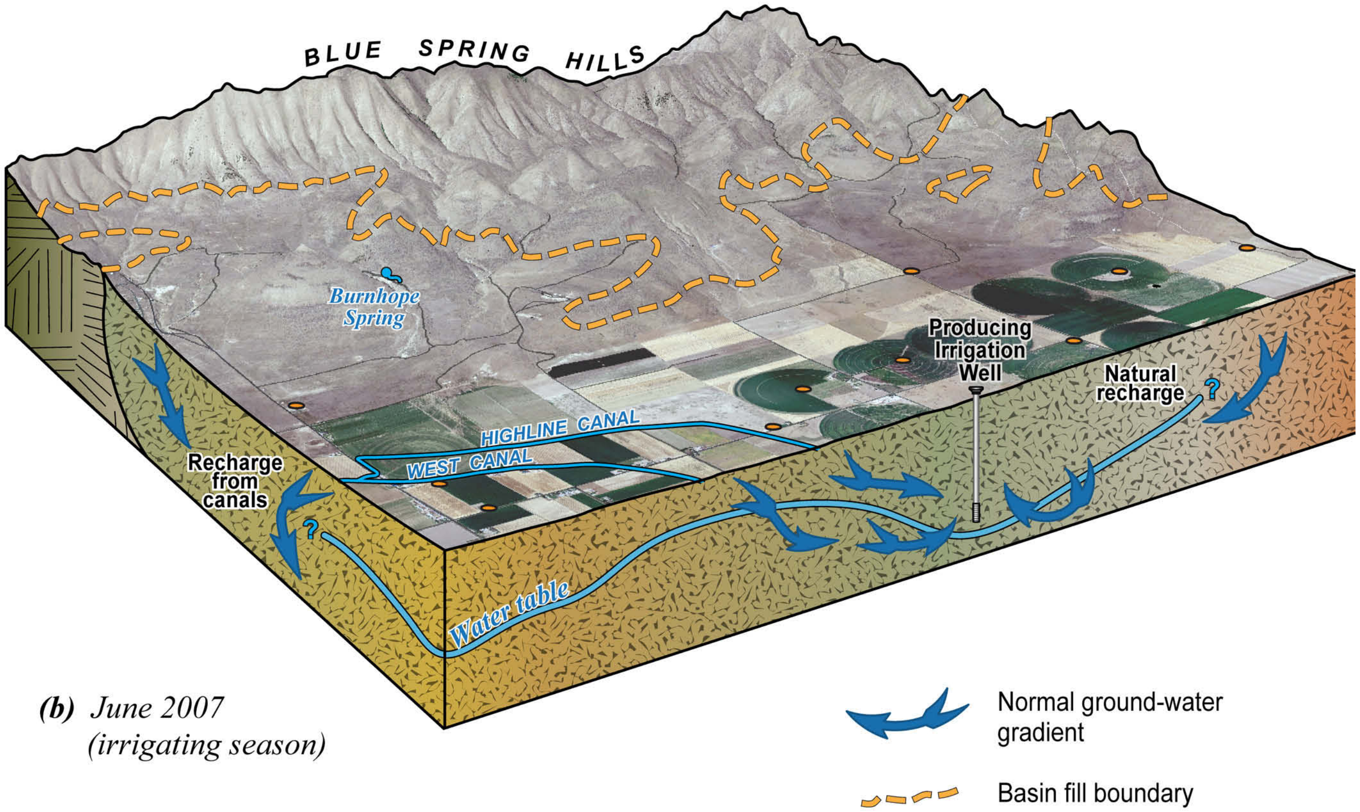


Figure 10. *Irrigation season potentiometric surface, Bothwell Pocket area.*



(a) *December 2006 and March 2007 (non-irrigating season)*



(b) *June 2007 (irrigating season)*

Figure 11. *Three-dimensional schematic illustrations of the water-table elevation during two different seasons in the Bothwell Pocket study area. Water-table elevation is vertically exaggerated and not to scale.*

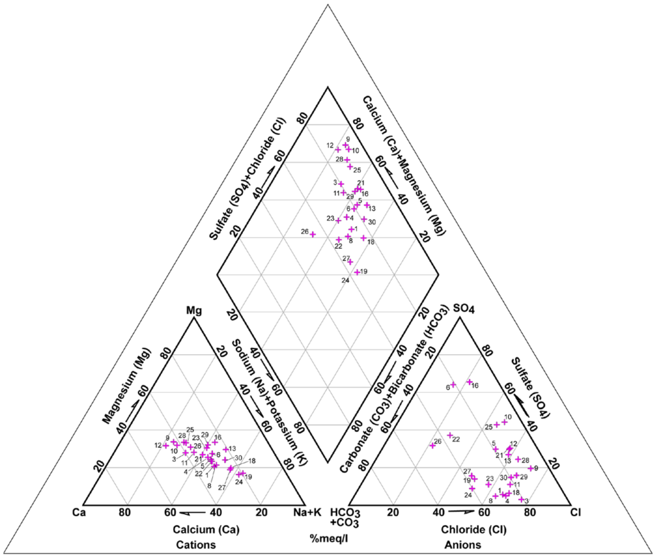


Figure 12. *Piper diagram showing chemistry type for water well samples in the Bothwell Pocket area. Numbers correspond to well site in appendix B.*

feet (70 m) of unconsolidated deposits composed of clay, silt, sand, and gravel and is completed in fractured limestone and quartzite from 234 to 324 feet (70–99 m). We estimated transmissivity based on specific capacity data from the driller's well log to be 15,500 feet squared per day (1440 m^2/day). The Sunset Park well (well 44, figure 2), located in the southwesternmost part of the study area, has a transmissivity estimated from specific capacity data on the driller's well logs of about 3400 feet squared per day (316 m^2/day). The well penetrates alluvial material composed of gravel to about 60 feet (18 m) below the land surface, and is completed in bedrock to a depth of 430 feet (130 m).

WATER-QUALITY RESULTS

Ground-water quality in the Bothwell Pocket area is generally good with TDS concentrations primarily below 1500 mg/L, although elevated TDS and nitrate concentrations exist in the basin-fill aquifer. We plotted both Piper and Stiff diagrams to show how the ion concentrations from water wells vary throughout the study area. A trilinear Piper diagram (figure 12) showing general chemistry for 24 water samples indicates that ground-water chemistry is variable throughout the area, but is dominantly calcium-sodium-chloride type, with a few wells having a sodium-potassium and sulfate component (figure 13). Appendix B summarizes the chemistry.

Total-Dissolved-Solids Concentrations

Most of our total-dissolved-solids concentration data were converted from ion concentrations measured in BYU's laboratory by using RockWorks 2002 Utilities TDS hydrochemistry program. This program reads a listing of ion concentrations from a compiled RockWorks data sheet and computes total dissolved solids for each sample based on measured ion concentration data. TDS was also computed by converted specific conductance field measurements. Public water-supply wells and USGS data are reported as laboratory-measured TDS. We report water quality as TDS as not all wells were measured for specific conductance. Total-dissolved-solids concentrations in the Bothwell Pocket area, excluding Poison Spring, range from 220 to 4392 mg/L (plate 1; appendix B); the average TDS concentration from the basin-fill aquifer is 1350 mg/L, and the median value is 1050 mg/L. Total-dissolved-solids concentrations for ground-water samples from 51% of the samples are above 1000 mg/L. The highest quality water, in terms of low specific conductance and TDS, exists in the northernmost part of the study area (upgradient from any major land-use activity), on part of the west bench area in the north (typically in bedrock wells), and in a few isolated places in the southern and central part of the study area (plate 1).

Ground water having TDS concentrations less than 1000 mg/L in the Bothwell Pocket area ranges from 220 to 983 mg/L. Water having TDS greater than 3000 mg/L exists in two shallow domestic wells (~100 feet [30 m] deep), one off-line 635-foot (194 m) deep irrigation well, Poison Spring, and one slough (plate 1). Except for the three well samples, TDS concentrations are similar to those sampled by Bjorklund and McGreevy (1973, 1974). We attribute the elevated TDS concentrations to return irrigation water and long-residence time in the upper shallow aquifer; the deep well with high TDS (site 10) is an idle irrigation well for a sod farm in the northern part of the study area, and has been inactive due to its elevated TDS concentration. Plate 1 superimposes TDS concentration on a land-use map. Many of the high TDS concentration wells are located near or downgradient from irrigated cropland and grass/turf farms (plate 1).

Nitrate Concentrations

Nitrate values in ground water range from less than 0.02 mg/L to 40.8 mg/L (figure 14, appendix B). Average nitrate concentration in the basin-fill aquifer is about 6.5 mg/L and the median is 2.6 mg/L; 43% of the ground water from wells analyzed for nitrate yielded values equal to or greater than 5 mg/L. Seven samples (23%) of the ground water from water wells analyzed for this study exceeded the EPA maximum contaminant level (MCL) of 10 mg/L. Overall, nitrate concentrations in the basin-fill aquifer vary. The average nitrate concentration of 6.5 mg/L and percentage of wells having relatively high nitrate concentration are higher in average compared to other rural areas in Utah (Lowe and Wallace, 1999, Lowe and others, 2002, 2003). The highest nitrate concentrations (>10 mg/L) exist in

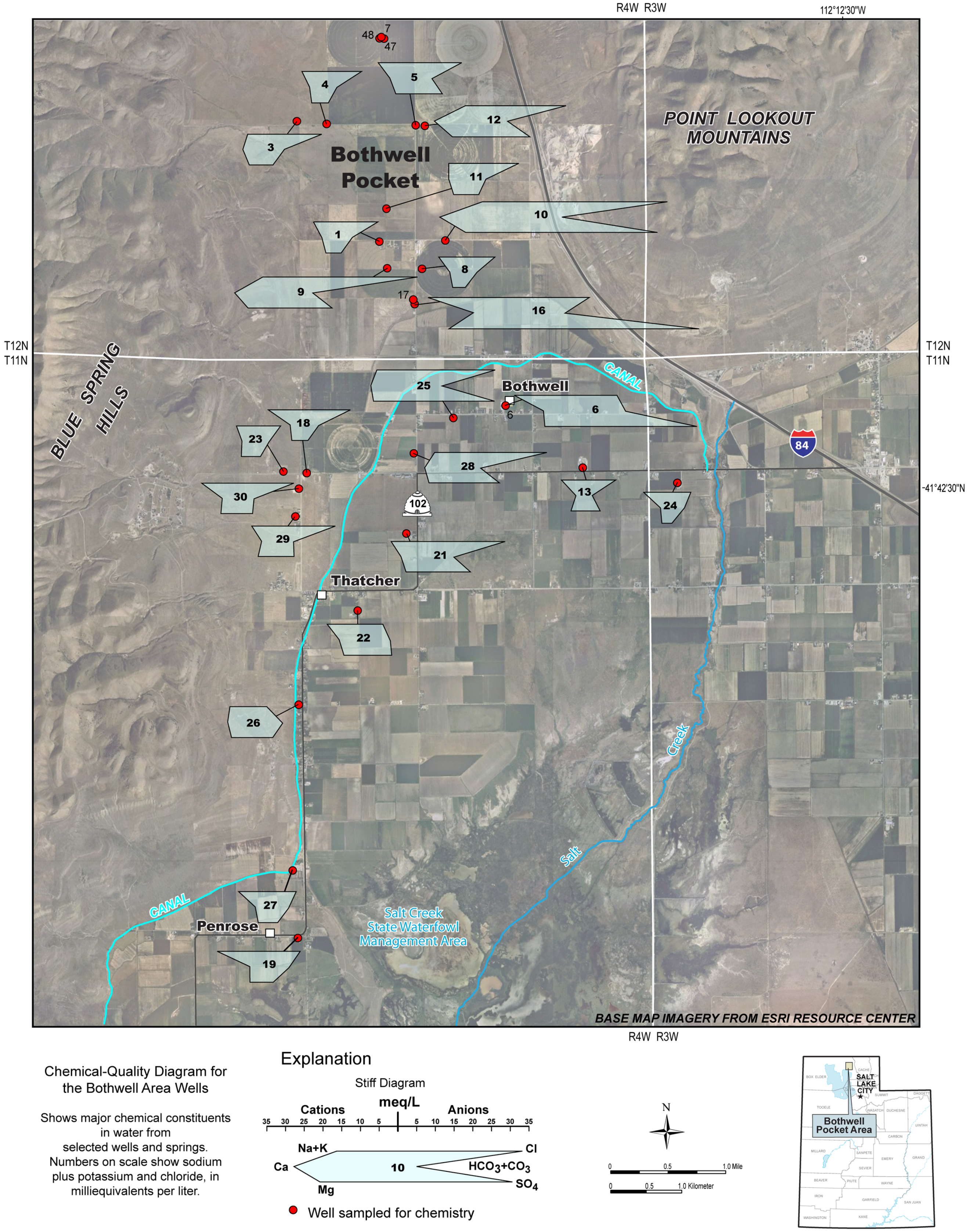


Figure 13. *Map showing Stiff diagrams for ion concentrations in water well samples, Bothwell Pocket area. Label numbers refers to site ID (see appendices A and B).*

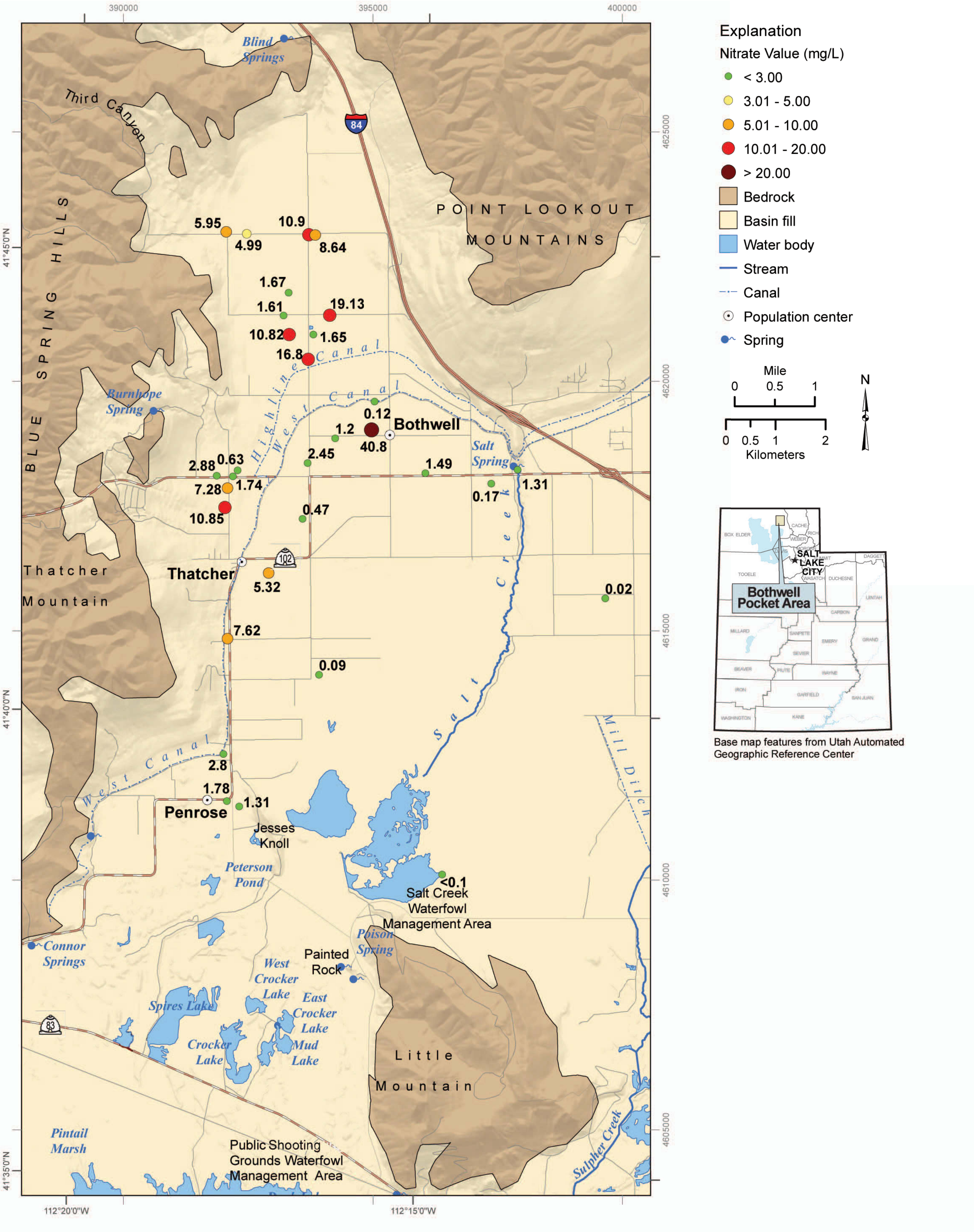


Figure 14. *Nitrate concentrations for sampled wells, springs, and surface water, Bothwell Pocket area.*

shallow wells, and in wells near septic-tank systems, corrals, and sod farms. Bjorklund and McGreevy (1974) took fewer samples in the Bothwell Pocket area, and no wells in their study had water exceeding the EPA MCL for nitrate as nitrogen; only two wells had water showing relatively high nitrate concentrations of 5.8 and 9.5 mg/L. Sources of nitrate are discussed in subsequent sections.

Other Chemical Constituents

Secondary drinking-water standards for sulfate were exceeded in 11 wells, and for chloride in 22; these constituents are not deleterious to human health, but may impart an unpleasant taste, odor, or color to the water (appendices B and C). No water samples from wells were analyzed for constituents classified as having primary EPA drinking-water standards (such as selenium, arsenic, and lead). The irrigation well for a sod farm in the northern part of the study area, noted above for having one of the highest TDS concentration, also has the highest chloride concentration (1144 mg/L) in ground water in the area (figure 15). Another shallow well (100 feet [30 m] deep, site 16) that was sampled in 2006 and 2007 had TDS concentrations of 3278 and 4392 mg/L and corresponding chloride concentrations of 308 and 520 mg/L and sulfate concentrations of 1404 and 2097 mg/L, respectively (appendix B). Chloride was the dominant anion present in the basin-fill aquifer, as reported by Bjorklund and McGreevy (1974, their plate 5), and continues to be the dominant anion in most wells we sampled (figure 13).

NITRATE SOURCES

Background

Nitrogen in the natural environment is abundant and is derived from a multitude of sources. Whole-earth abundance of nitrogen is 0.03%, with 97.76% of the total nitrogen present in rocks, 2.01% in the atmosphere, and the remainder in the hydrosphere and biosphere (Kendall, 1998). Nitrogen oxides are present in the environment and can undergo various chemical reactions that in the presence of H^+ can convert nitrogen (N) to nitrate (NO_3^-) or ammonia (NH_3). Nitrogen that is present as NH_4^+ can transform to ammonia in basic environments and subsequently can be released as NH_3 gas to the atmosphere (Canter, 1997). With increasing oxygen content, nitrification of ammonium occurs (NH_4^+ to NO_3^-). When anoxic conditions prevail, denitrification of nitrate can occur with the production of N_2 gas (Canter, 1997). Identifying single or multiple sources of nitrogen is difficult due to complex chemical, biological, and physical interactions that occur in the environment. Figure 16 shows the complex nature of the nitrogen cycle and the types of chemical, physical, and biological processes involved with nitrification and denitrification of septic-tank effluent. The cycle is similar for other nitrate sources. Under ideal circumstances, the analysis of nitrogen and oxygen isotopes can help determine the source of nitrogen; more commonly, the interaction of nitrogen and oxygen with other chemical and biological species obscures the true origin of the nitrate species.

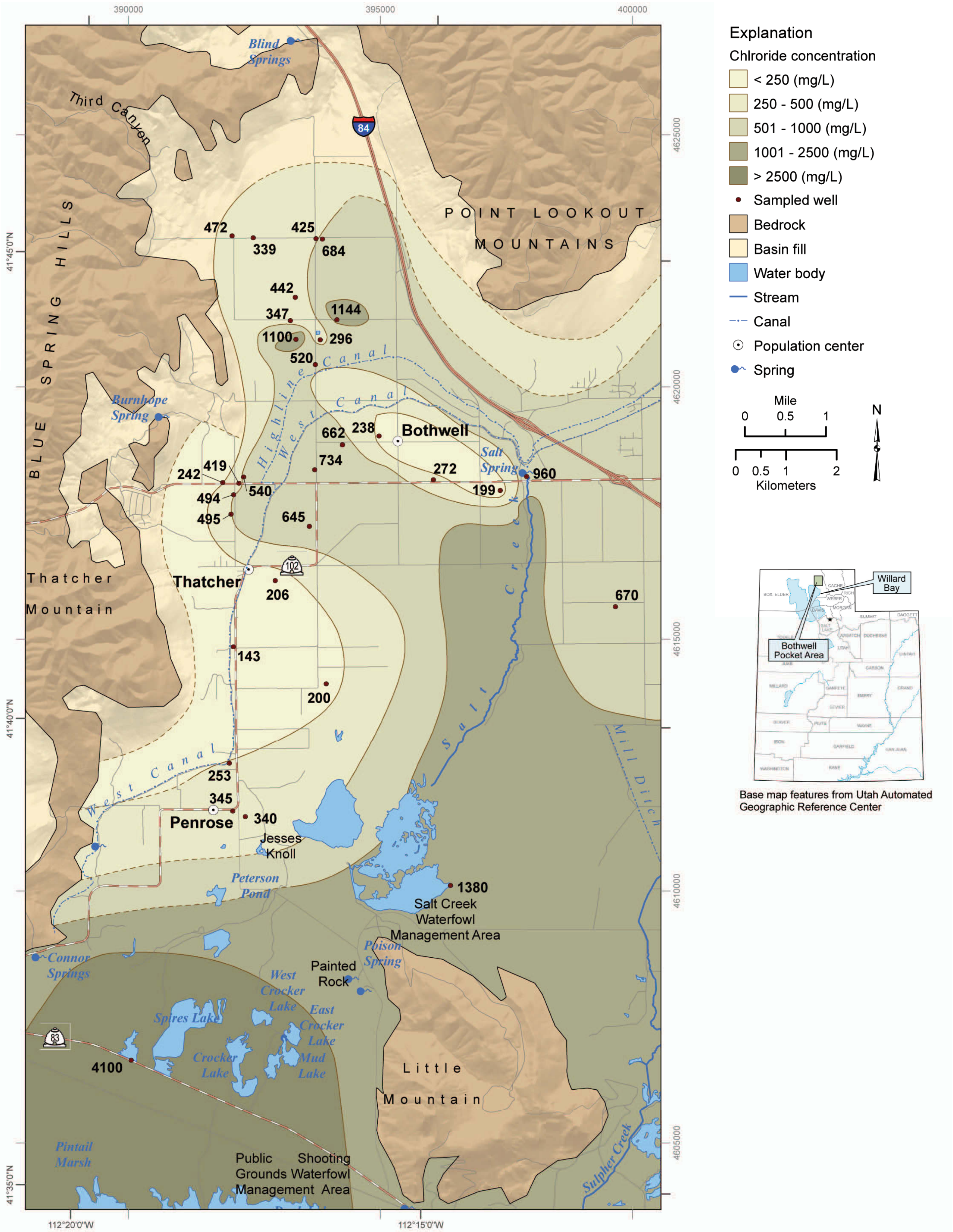
Both natural and anthropogenic sources of nitrate are common. Natural sources of nitrogen (including atmospheric, biologic, and geologic components) can contribute, to some extent, to nitrate concentrations in ground water. Common anthropogenic sources include septic-tank systems, fertilizer, agricultural practice (current and historical), animal-feeding operations, and improperly sealed/constructed wells. Ground water having less than 0.2 mg/L nitrate is assumed to represent natural background concentrations; ground water having nitrate concentrations between 0.21 and 3.0 mg/L is considered transitional, and may or may not represent human influence (Madison and Brunett, 1985). Ground water having concentrations exceeding 3 mg/L is typically associated with human- or animal-derived sources, but higher concentrations have also been identified with natural sources (Green and others, 2008), albeit less commonly.

Nitrate Source Analysis

Based on an evaluation of nitrate and chloride data coupled with environmental tracer data for nitrogen and oxygen isotopes in nitrate presented in the following sections, we attempt to identify the sources of nitrate in ground water in the Bothwell Pocket area, with the caveat that processes such as mixing of different sources of water in aquifers, ammonia volatilization, denitrification, nitrification, ion exchange, and plant uptake complicate determining a source or sources of nitrate contamination for each high-nitrate well. In addition, this report uses data from only one sampling event for N isotopes; numerous sampling events examining temporal and spatial trends in water chemistry are preferable to document and understand long-term sustainability of the ground-water resource. Using $\delta^{15}N$ to determine the source/relative contributions of fertilizer and animal waste to ground water is complicated by reactions described above. These processes can modify the $\delta^{15}N$ values of nitrogen sources prior to mixing, causing estimations of the relative contributions of the sources of nitrate in the resultant mixtures to be inaccurate (Kendall, 1998).

Nitrate and Chloride Concentration

We analyzed nitrate and chloride concentration data to determine whether denitrification is a common process in the Bothwell Pocket. Nitrate and chloride behave similarly in ground water in terms of mobility, but because



Base map features from Utah Automated Geographic Reference Center

Figure 15. *Chloride concentration for sampled wells, springs, and surface water in the Bothwell Pocket area.*

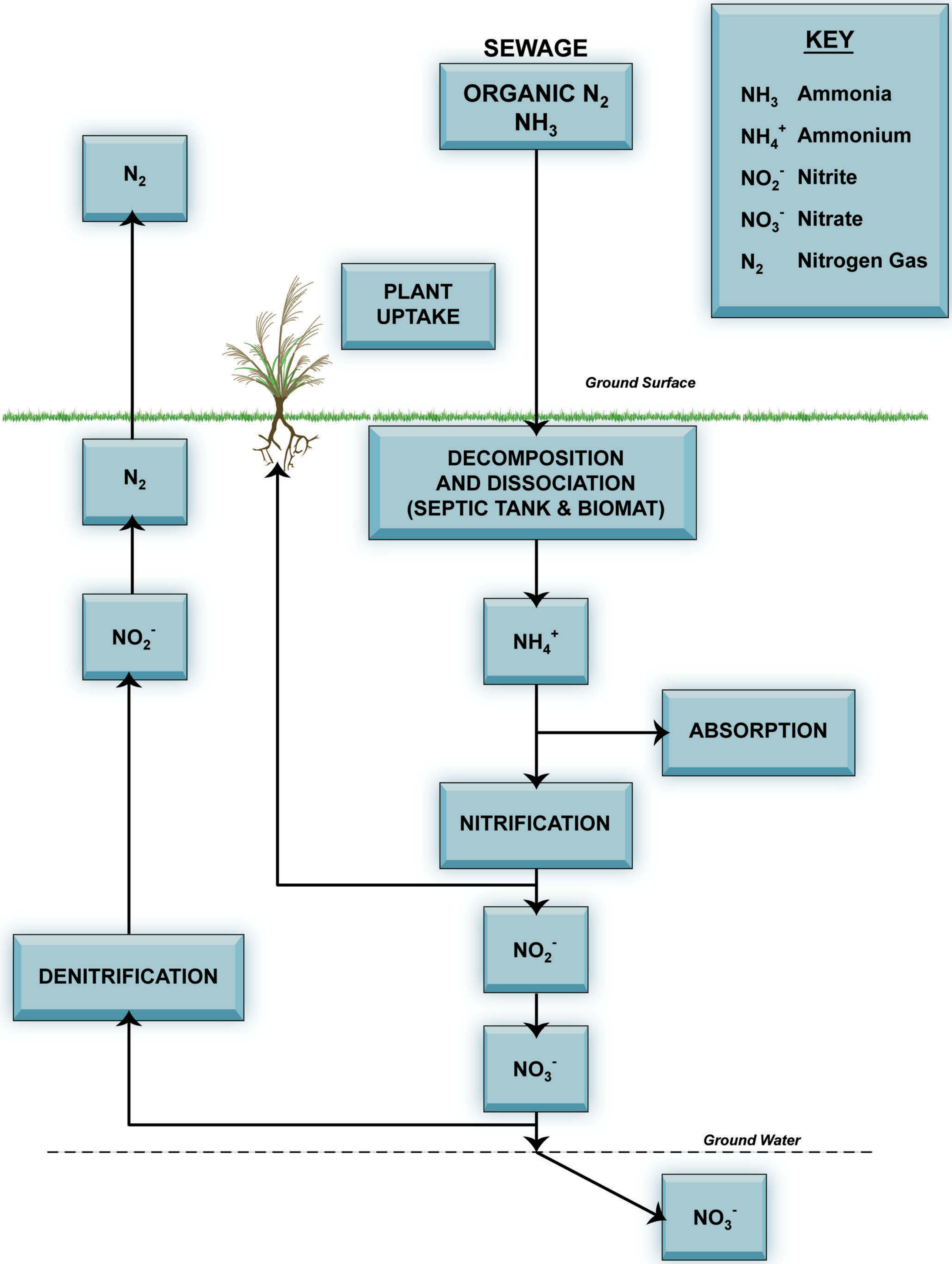


Figure 16. *Diagram of the nitrogen cycle in the environment (modified from Hansen, Allen, and Luce, Inc., 1994).*

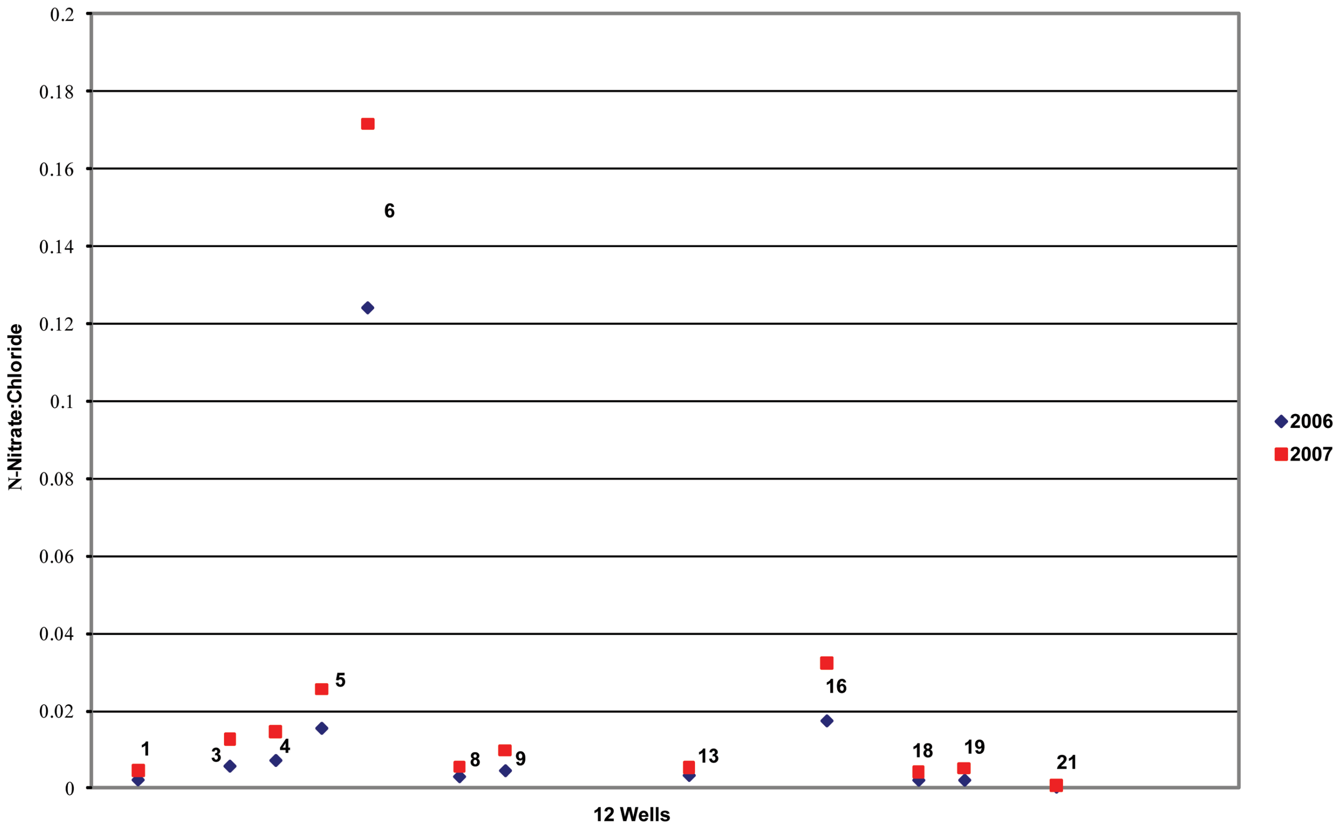


***Figure 17.** Plot of nitrate to chloride ratio over two sampling intervals for 12 wells: 2006 and 2007. A decrease in nitrate-chloride ratio with time indicates denitrification; this graph shows a nearly constant ratio between the two species in the Bothwell Pocket area, hence, denitrification is unlikely. Labels on graph are the site ID number (see appendix B).*

chloride is not affected by biological processes, the ratio of nitrate to chloride can be an indicator of nitrification and denitrification. A relatively constant nitrate-chloride ratio is indicative of nitrate leaching, whereas a decrease in nitrate-chloride ratio is indicative of denitrification (Canter, 1997). We plotted the ratio of nitrate to chloride for 12 wells, each sampled twice, as one method to determine whether denitrification processes occurred (figure 17). Most nitrate-chloride ratio values remained below 0.04, although one well had ratios between 0.12 and 0.17. We believe the absence of a decrease in the ratio of nitrate to chloride indicates negligible denitrification, but also recognize that the effects of mixing may nullify our interpretation.

ENVIRONMENTAL TRACER ANALYSIS

To determine the influences of processes such as mixing of recharge sources on ground-water chemistry, we collected environmental tracer data. Environmental tracers can help document the source and age of recharge water, and the different tracers can be used in tandem to help understand ground-water flow. Table 1 summarizes environmental tracer data.

Nitrogen and Oxygen Isotopes

We sampled 10 wells in the Bothwell Pocket area having relatively high nitrate concentrations (nitrate concentrations from 5 to 41 mg/L) for $\delta^{15}N_{NO3}$ and $\delta^{18}O_{NO3}$ analyses (table 1; figure 18). A plot of $\delta^{18}O_{NO3}$ versus $\delta^{15}N_{NO3}$ (figure 18) shows the value of nitrogen isotopes ranges from -0.14 to +11.1‰, with a median of 7.5‰; $\delta^{18}O_{NO3}$ values range from –0.27 to +32.8‰, with a median of 13.8‰ (table 1). While some data fall in the nitrate-in-precipitation and manure/septic-tank nitrogen fields, many plot in the area of overlap between the soil nitrogen and manure/septic-tank nitrogen fields. The nitrogen in samples having values for $\delta^{15}N$ between 5 and 8.5‰ may have been derived from nitrate in soil cultivated without fertilizer as well as from manure/septic systems. One sample had a value for $\delta^{15}N$ greater than 10‰ and $\delta^{18}O_{NO3}$ of 7.66‰ (table 1), and likely was derived from nitrate from animal manure and/or septic-tank sources, which typically range between 10 and 25‰ $\delta^{15}N$ and greater (Canter, 1997). One sample plots in overlapping fields of the nitrate-fertilizer and nitrate-in-precipitation categories, two plot within the nitrate-in-precipitation category, and two plot outside but very near this field.

Determining whether nitrate in ground water is derived from nitrate in precipitation based on isotopic data is

Table 1. *Isotope and CFC data for selected water wells in the Bothwell Pocket area.*

Site ID[1]	$\delta^{18}O_{H2O}$	±σ	δ D	±σ	^{3}H (TU)	±σ	$\delta^{13}C$ 0/00	^{14}C (PMC)	±σ	^{14}C Age (yr BP) Pearson[2]	^{14}C Age (yr BP) Fontes[2]	CFC-11 Rech. year	CFC-12 Rech. year	CFC-113 Rech. year	^{3}H Age[4]	Interpreted Age	$\delta^{15}N$ 0/00	$\delta^{18}O_{NO3}$ 0/00	Well depth (feet)
1	-15.96	0.25	-127.8	1.0	0.3	0.3	-10.08	25.7	0.2	5750	6250	1961	1961	1943	pre-1952	mixed/old	-	-	310
3	-15.79	0.25	-127.4	1.0	0.2	0.2	-9.41	24.8	0.2	5500	6600	1956	1970	1943	pre-1952	mixed/old	-	-	365
4	-15.77	0.25	-126.4	1.0	-	-	-	-	-	-	-	1971	1973	1971	-	>1973	8.10	3.59	285
5	-15.19	0.25	-124.4	1.0	1.7	0.3	-10.53	16.1	0.2	10000	10500	1971	1962	1943	mixed	mixed/old	6.12	7.51	235
6	-12.94	0.25	-110.2	1.0	8.7	0.4	-12.70	106.9	0.6	modern	modern	1986	contam[3]	1979.5	modern	modern	11.09	7.66	110
8	-15.83	0.25	-127.9	1.0	-	-	-	-	-	-	-	1969	1971	1943	-	>1971	-0.14	20.78	668
9	-15.80	0.25	-127.1	1.0	0.6	0.3	-9.19	20.2	0.2	7000	8000	1968	1969.5	1943	pre-1952	mixed/old	10.12	26.9	470
10	-14.44	0.25	-120.7	1.0	4.7	0.3	-11.09	43.7	0.3	2250	2500	-	-	-	modern?	mixed/old	-	-	635
11	-15.84	0.25	-128.0	1.0	0.1	0.3	-10.85	22.5	0.2	7500	7250	1959.5	1953	1943	pre-1952	mixed/old	-	-	478
12	-14.94	0.25	-122.3	1.0	2.2	0.3	-9.73	26.3	0.2	5250	6500	-	-	-	mixed	mixed/old	6.25	0.1	422
13	-15.45	0.25	-125.4	1.0	0.3	0.3	-10.52	12.8	0.1	12000	11750	1957	1946.5	1943	pre-1952	mixed/old	-	-	100?
16	-13.46	0.25	-112.2	1.0	7.4	0.3	-11.84	90.1	0.5	modern	modern	contam	contam	1984.5	modern	modern	6.02	-0.27	100
18	-15.35	0.25	-125.9	1.0	0.0	0.3	-8.14	19.3	0.2	6500	8250	-	-	-	pre-1952	mixed/old	-	-	262
19	-13.86	0.25	-116.9	1.0	6.0	0.3	-10.93	44.0	0.3	2000	1500	1970	1988	1975	modern	mixed/old	-	-	<60
21	-15.71	0.25	-125.5	1.0	2.5	0.3	-11.72	13.0	0.1	12750	12000	1958.5	1958	1943	mixed	mixed/old	-	-	140
22	-	-	-	-	8.8	0.4	-12.10	83.45	0.4	modern	modern	1963	1967	1943	modern	mixed/mod	6.91	30.16	79
23	-	-	-	-	0.7	0.3	-10.11	43.18	0.3	-	2100	1978	1966	1943	pre-1952	mixed/old	-	-	218
25	-	-	-	-	4.0	0.4	-12.23	39.48	0.3	-	4200	1960	1960	1943	mixed	mixed/old	-	-	119
26	-	-	-	-	7.1	0.4	-11.86	80.09	0.4	modern	modern	1972	1982	1973	modern	mixed/mod	-	-	70
28	-	-	-	-	0.3	0.3	-10.51	12.82	0.1	-	13200	1960	1965	1943	pre-1952	mixed/old	-	-	120
29	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9.99	32.83	172
30	-	-	-	-	1.9	0.4	-9.93	55.2	0.3	modern	modern	-	-	-	mixed	mixed	8.81	19.91	181

[1]Site ID in appendix B; [2]Carbon- age calculations by A. Mayo, BYU, written communication, 2007, using 2 different methods (Pearson and Hanshaw [1970]; Fontes and Garnier [1979]); [3]contaminated; [4]Tritium ages from Clark and Fritz (1997), modern refers to <10 yrs.

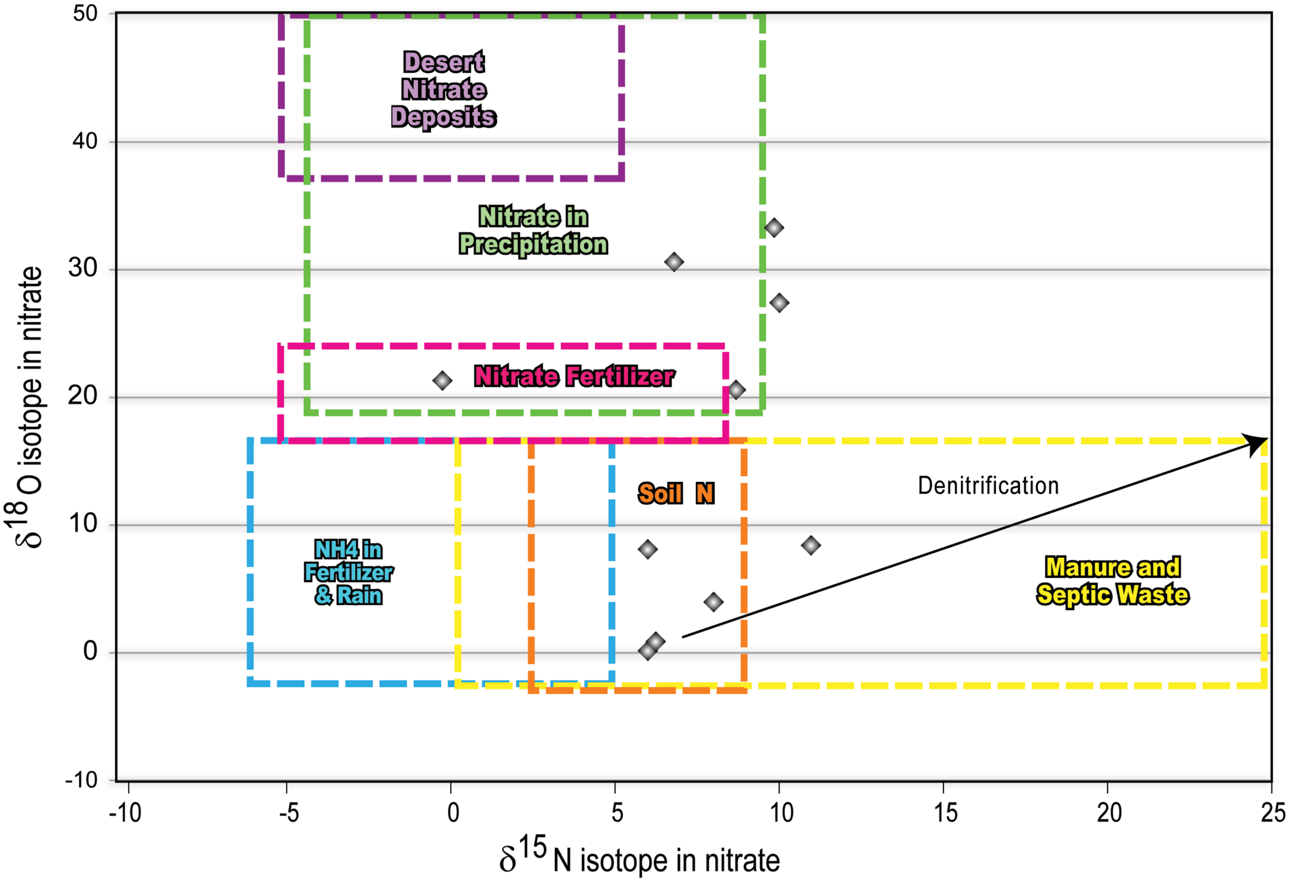


Figure 18. *Plot of nitrogen and oxygen stable isotope data for 10 wells in the Bothwell Pocket area. Labeled fields of nitrogen sources taken from Kendall and others (1998).*

problematic. Nitrate concentration in precipitation is inconsistent and depends on many factors (Kendall, 1998) such as climate, season, proximity to industries emitting air pollutants, impact from agricultural emissions (such as ammonia associated with certain fertilizers or grazing of large animal populations), combustion of fossil fuels, and atmospheric conditions and events (lightning, for example). According to Kendall (1998) comprehensive studies of δ^{15}N of precipitation are difficult because of dilution, and "isotope shifts of several permil can occur between and within storms because of selective washout of N-bearing materials (Heaton, 1986), and the total range observed at any single location can be as large as 20‰."

A wide range for $\delta^{18}O_{NO3}$ in nitrate in precipitation also exists (figure 19). In addition, Kendall (1998) indicates that limited data exist for $\delta^{18}O_{NO3}$ of nitrate from atmospheric sources, "with almost nothing known about possible spatial or temporal variability, or their causes." The five data points in figure 18 plotting in or near the field of nitrate in precipitation may be anomalous. If nitrate in precipitation is a major contributor to nitrate in ground water, we would expect the isotopic signature to be present in all samples, or at least in all shallow wells sampled, but this is not the case. It is beyond the scope of this study to address the complexity of nitrate in precipitation as a possible source of nitrate in ground water. Based on field observation, the nitrate sampled in these five wells is more likely derived from nitrate fertilizer. The overlap of one data point in the fertilizer and nitrate in precipitation fields and those data falling outside any data field category may indicate mixing of ground-water sources having different isotopic signatures, and thus nitrate sources. Field investigation confirmed the validity of animal-manure and agricultural (possibly from fertilizer) nitrate source interpretations. Septic-tank systems likely contribute nitrate to many of the samples, but their locations are unknown and probably near domestic developments. Because most of the data fall in overlapping fields, a sole source cannot be identified.

Septic systems in residential developments may be the source of nitrate contamination in some areas. All residential developments in the Bothwell Pocket use septic systems as a method of wastewater disposal. Because most of the isotopic data for the study area are not the high δ^{15}N and low $\delta^{18}O_{NO3}$ values more typical of septic systems, the expected septic-related isotopic signatures

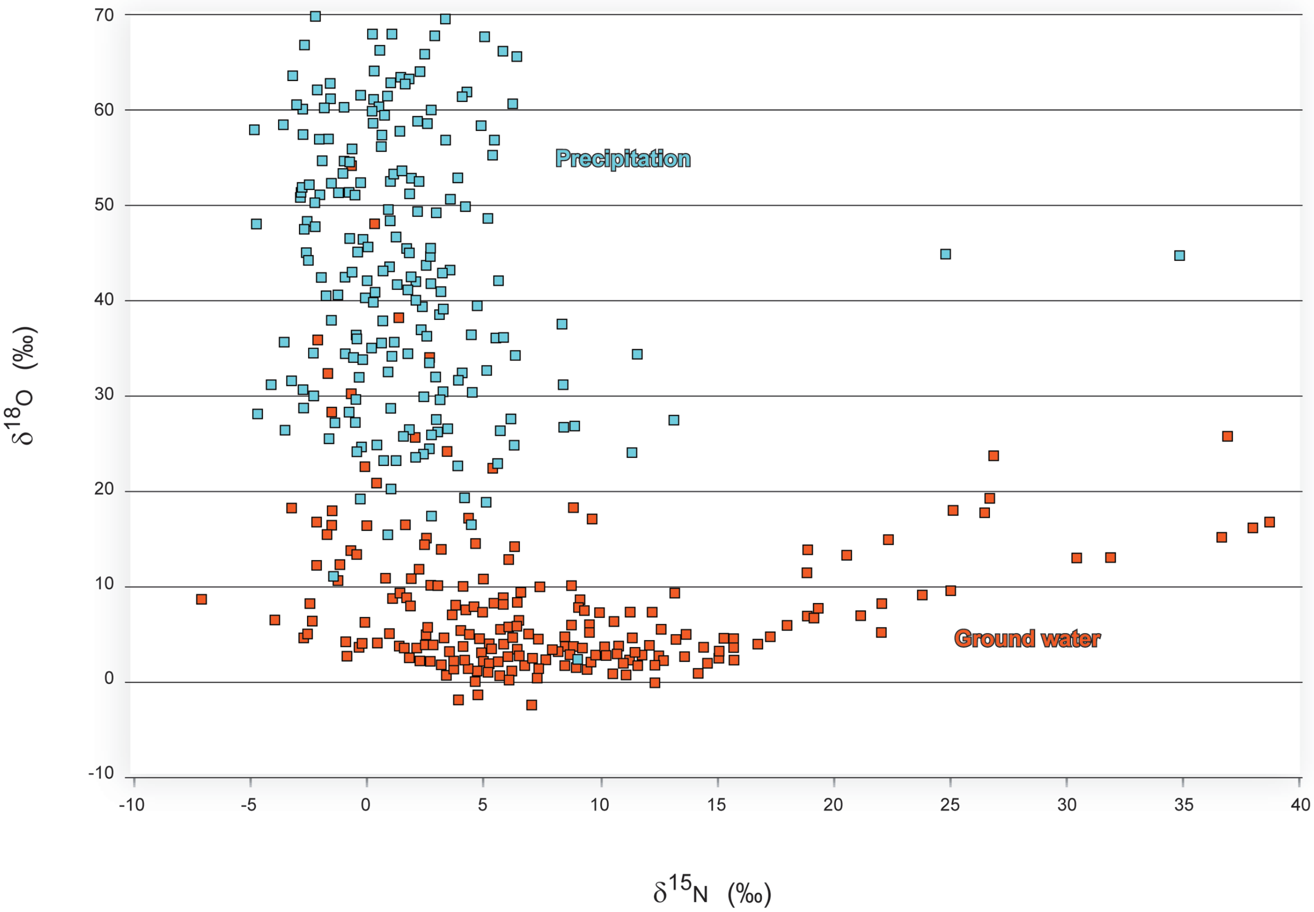


Figure 19. *Compilation of nitrate $\delta^{18}O$ and $\delta^{15}N$ isotope data in precipitation (in blue) and ground-water (in red) samples (modified from Kendall, 1998).*

could be obscured by dilution/mixing with recharge (lighter $\delta^{15}N$ water) associated with precipitation or soil $\delta^{15}N$ and $\delta^{18}O_{NO3}$ values (figure 18). Most development is also located where irrigation is a potential source of recharge water; irrigation water may have water with the lighter isotopes in nitrate and ammonium fertilizer.

Many of the data points for $\delta^{15}N$ and $\delta^{18}O_{NO3}$ isotopes fall within the soil N field, but determining whether nitrate from soil is a source of ground-water nitrate in wells is complicated. Such an interpretation deserves caution due to the complexities of the processes by which the nitrate moves from the root zone/soil profile vertically to the water table. Concentrations of nitrogen in soil vary widely and depend on local conditions, including climate, soil type, vegetation, presence (or absence) of animal burrowing, and land use. Recent investigations in arid/desert environments indicate residual vadose zone nitrate as a source of elevated nitrate concentrations in ground water (Stonestrom and others, 2003; Walvoord and others, 2003; Osenbrück and others, 2006). In areas where native vegetation is sparse and rainfall is low, nitrate can leach into subsoil horizons and accumulate in a subsoil reservoir; subsequent nitrate migration can be caused by a change in recharge through a change in land use (e.g., from natural recharge on native vegetation to irrigation). The process of nitrate accumulation and migration typically spans thousands to tens of thousands of years (Stonestrom and others, 2003; Walvoord and others, 2003; Osenbrück and others, 2006; Scanlon and others, 2007). Other recent studies show that variability in nutrient enrichment (including nitrate) is based on microecological changes in desert environments where nutrient concentrations and types varied between different types of shrubs, burrowed versus non-burrowed areas, amounts of original organic matter, vegetation spacing/density (Titus and others, 2002), as well as by differences in water fluctuations, leaching rates, fertilizer application amounts, and evapotranspiration (Green and others, 2008). Green and others (2008) examined nitrogen fluxes through unsaturated zones in agricultural settings and determined that soil nitrate moves by advective transport below the root zone under conditions conducive to this process: high evapotranspiration and low water-table flux in areas having sandier sediments in unsaturated zones. Under these conditions, Green and others (2008) show soil nitrate can reach deeper parts of the aquifer and contribute to elevated nitrate concentrations in ground water.

The data points for $\delta^{15}N$ and $\delta^{18}O_{NO3}$ isotopes that fall into/near the nitrate fertilizer field may derive from recharge water from return irrigation of fertilized fields. Although we did not investigate the fertilizer application rate or type in this study, variations in nitrate concentrations in wells throughout the basin may be explained by differences in fertilizer application rates and irrigation practices by individual landowners.

Using $\delta^{15}N$ to determine the source/relative contributions of fertilizer and animal waste to ground water is complicated by reactions including ammonia volatilization, nitrification, denitrification, ion exchange, plant uptake, and ground-water mixing (figure 16). These processes can modify the $\delta^{15}N$ values of nitrogen sources prior to mixing and in the resultant mixtures, causing estimations of the relative contributions of the sources of nitrate to be inaccurate (Kendall, 1998). Denitrification is likely negligible in the study area based on the combination of high-nitrate-concentration data and overall low $\delta^{15}N$ values, as well as the relatively constant nitrate-chloride ratios documented in ground-water samples taken during different years and seasons. With future analyses of seasonally collected samples for chemical species (e.g., chloride, manganese, and dissolved oxygen, as well as seasonal $\delta^{15}N$ and $\delta^{18}O_{NO3}$ isotopes), we may be able to better assess the nitrate source(s) and whether other processes, such as denitrification, occur with time. The overlapping nature of the data likely reflects ground-water mixing, which is discussed below based on ground-water age data.

Oxygen and Deuterium Isotopes

Precipitation is the ultimate source of ground-water recharge, hence, factors such as altitude, latitude, location within a continent (and proximity to a mountain range), and the amount of rainfall affect the enrichment factor of isotopes (Kendall and Caldwell, 1998). Heavier isotopes of oxygen and deuterium are associated with lower altitudes (on windward mountain sides), decreasing latitude, coastal versus inland areas, and smaller rainfall amounts (not applicable to snowfall) (Kendall and Caldwell, 1998).

We sampled water from 15 wells for oxygen isotopes and deuterium. The isotopic ratios in water range from -12.94 to -15.96‰ for oxygen and -128 to -110‰ for deuterium (table 1). Data for oxygen isotopes in water in the study area indicate most water was recharged at moderate elevations and moderate climatic temperatures.

A plot of the oxygen and deuterium data is shown in figure 20. The local meteoric water line (LMWL) is taken from Lindon, Utah, based on analysis of 192 samples from 1999 to 2009 (Alan Mayo and David Tingey, BYU, personal communication, November 9, 2009). The ground-water data collected from the Bothwell Pocket area plot below both the LMWL, which indicates that the ground water is slightly enriched in ^{18}O relative to deuterium. Enrichment of heavier isotopes (less negative isotopic signatures) in ground water in the western United States has been attributed to paleoclimate effects (White and Chuma, 1987), such as arid conditions, and to extensive evaporation prior to recharge. The enrichment of heavier isotopes in the ground water shown on figure 20 indicates evaporation of surface or soil water or sublimation of the snow and evaporation of surface runoff (compare to figure 5). If ground water is recharged by more ephemeral heavy precipitation, then data for the ground water may plot on the meteoric water line. A line that diverges from the meteoric water line typically indicates an evaporative signature. Spring runoff is probably a significant component of recharge in the study area, so the enrichment is most likely a result of evaporation of water during runoff but prior to recharge.

Elevated concentrations of sodium and chloride exist in the ground water in most areas in Bothwell Pocket. High specific conductance could result from evapotranspiration of irrigation water applied to agricultural fields, and resulting salt deposition in the soil (Hurlow and Burk, 2008). Figure 21 presents a plot of chloride concentration and $\delta^{2}H$ of the data. If evaporation were concentrating salt in the soil, a positive correlation may exist between chloride and $\delta^{2}H$, where the concentration of chloride increases as deuterium becomes more enriched (Hurlow and Burk, 2008). The plot does not display a positive relationship, but instead shows a weak negative correlation; hence, evaporation is not likely the primary agent that concentrates salt in the soil and ground water. Rather the accumulation of salt is likely caused by transpiration of irrigation water from the vadose zone. Flood irrigation was likely the principle irrigation method in the past. Most farmers currently use sprinkler irrigation methods, as opposed to flood irrigation.

Tritium

We use tritium for a qualitative estimate of ground-water age, or time since ground water was recharged. Quantitative determination of ground water ages with tritium requires multiple samples collected over a certain time period, multiple samples collected from different depths in the same well, or estimation of the initial tritium concentration prior to recharge. Additionally, mixing of recent ground water with old ground water can cause complications using quantitative methods, so using qualitative methods is the most appropriate method for this study.

We collected water samples for tritium analysis from 19 wells in the Bothwell Pocket area (appendix B, figure 22, table 1). Tritium concentrations measured in ground water from these wells range from <0.2 to 8.8 tritium units (TU) with a median of 1.9 TU. Tritium concentrations that have values less than 0.8 TU are categorized as pre-1952

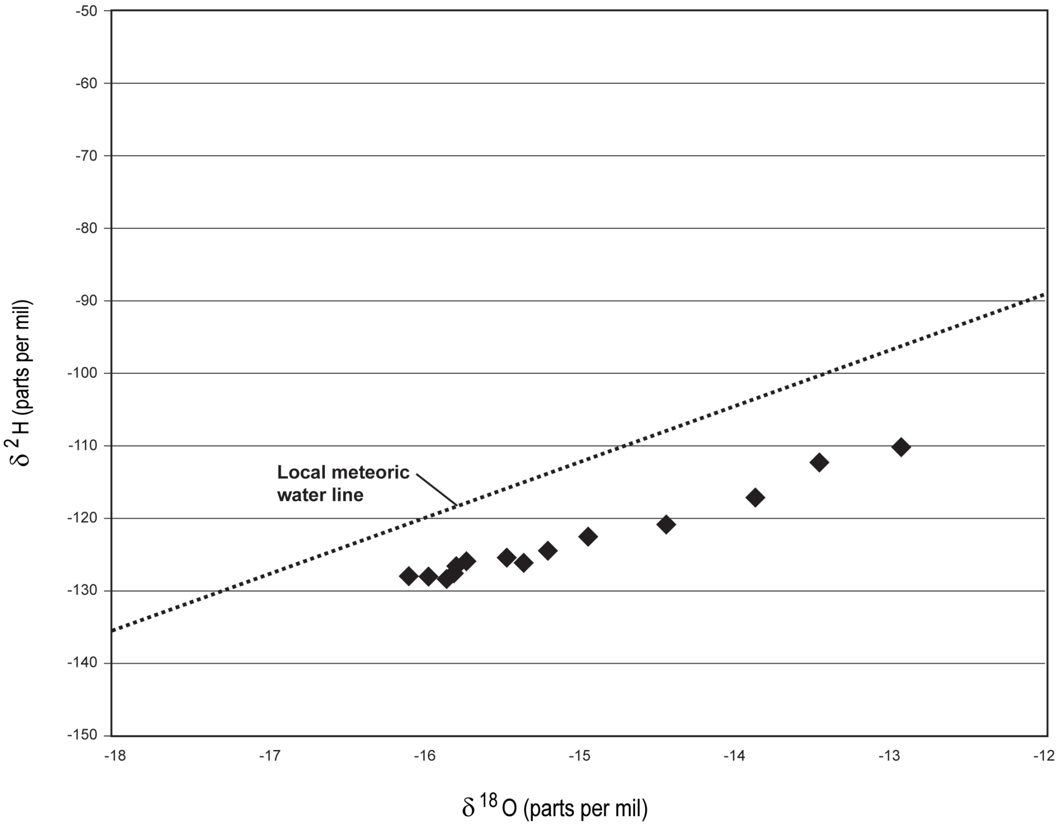


Figure 20. *Plot of deuterium versus oxygen isotopes for 15 wells in the Bothwell Pocket area. The local meteoric water line is taken from Lindon, Utah, based on analysis of 192 samples obtained during 1999–2009 (Alan Mayo and David Tingey, BYU, written communication, Novemeber 9, 2009).*

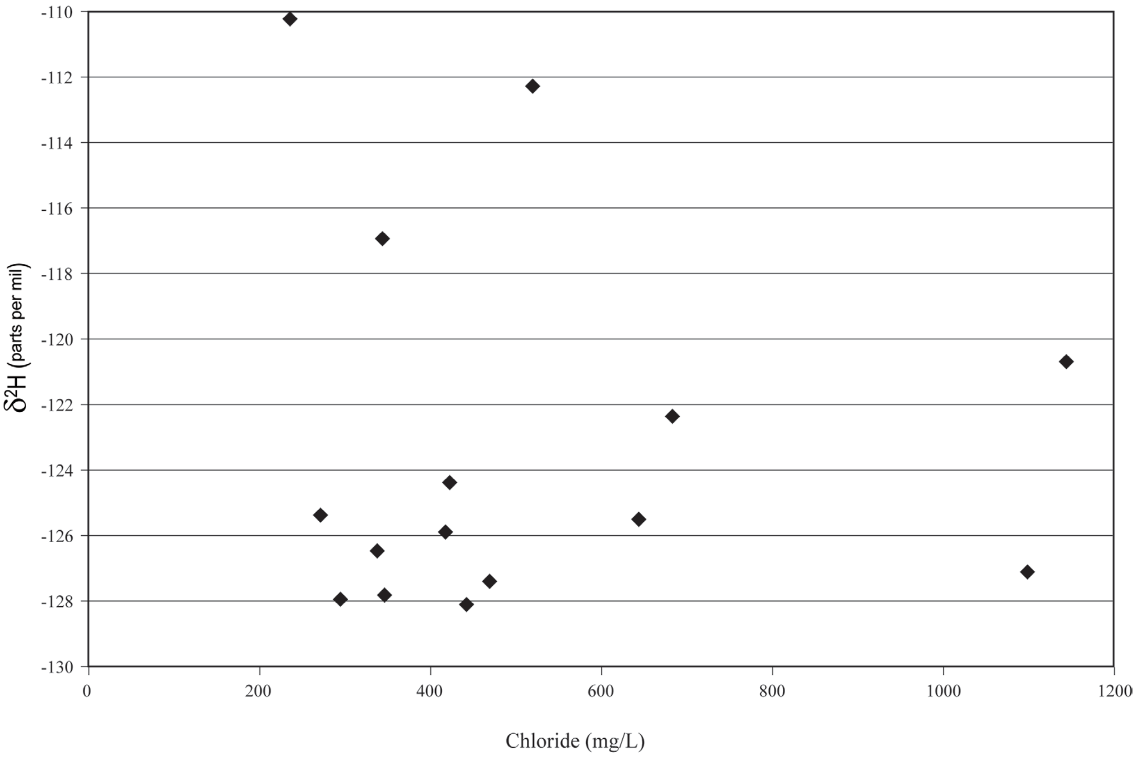


Figure 21. *Plot of deuterium versus chloride for 15 water samples in the Bothwell Pocket area.*

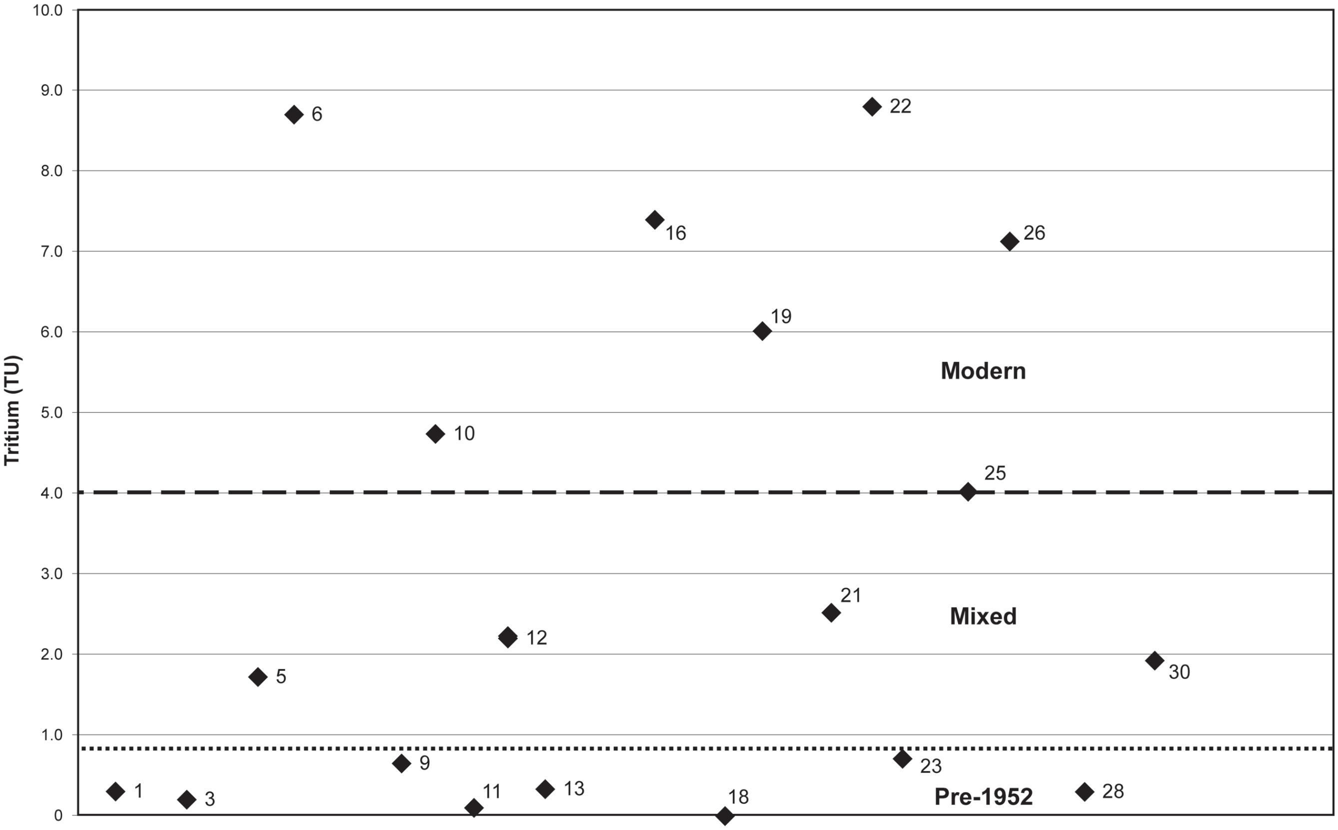


Figure 22. *Plot of tritium data for 19 wells in the Bothwell Pocket area. The categories of pre-1952, mixed, and modern are from Clark and Fritz (1997); labels refer to well ID (see appendix B).*

(pre-bomb [atmospheric nuclear testing] water); values between 0.8 and 4 TU are categorized as mixed water (pre- and post-1952); values from 4 to 10 are categorized as modern water (less than 50 years old; Alan Mayo, BYU, written communication, March 17, 2010); and values exceeding 10 TU are categorized as "bomb-age" water (Clark and Fritz; 1997). The tritium values in this report have eight samples that are classified as pre-bomb water; four as mixed water; and six as modern water (table 1, figure 22). One sample has a standard deviation that overlaps the modern and mixed water classes (table 1). The values indicate that at least some of the water must have been recharged when the atmospheric tritium levels were greater than 1000 TU. Tritium concentrations suggest that some well water was recharged approximately 40 years ago (post-atmospheric testing) when tritium concentrations in the atmosphere were near peak levels. Some ground water in the area may be older than the estimated minimum age but younger than pre-1952 water, due to mixing with younger, lower tritium ground water. These data represent a pre- and post-atmospheric testing age, as well as a mixture of the two, for ground water entering the aquifer system before traveling to the well. A map of the tritium-age data distribution shows the youngest water is located in the northeast and the southwest quadrants of the study area (figure 23).

Chlorofluorocarbons

Water samples for chlorofluorocarbon (CFC) analysis from 17 wells in the Bothwell Pocket area had CFC concentrations that yield dates ranging from 1943 to 1988 (table 1). The values indicate that four of the water wells must have been recharged recently (early to late 1980s) (table1); these wells have shallow depths ranging from 60 to 110 feet (18–34 m). The majority of data for CFC concentrations in the wells suggest that water was recharged more than 30 years ago and at least 50 years ago; three wells have CFC dates interpreted to have water from the mid-1980s and represent a more recent age (table 1). These data coupled with other environmental tracer and isotope data show mixing of young and older ground water in the Bothwell Pocket area, with a strong component of older water.

Carbon Isotopes

Carbon-14 is an unstable isotope with a half-life of 5730 years, allowing determination of an apparent recharge date for older water, in contrast to the other environmental tracers, which provide relative dates. We collected water samples for carbon-14 and δ^{13}C analysis from 19 wells in the Bothwell Pocket area. Carbon-14 concentrations measured in ground water from these wells range from 12.8

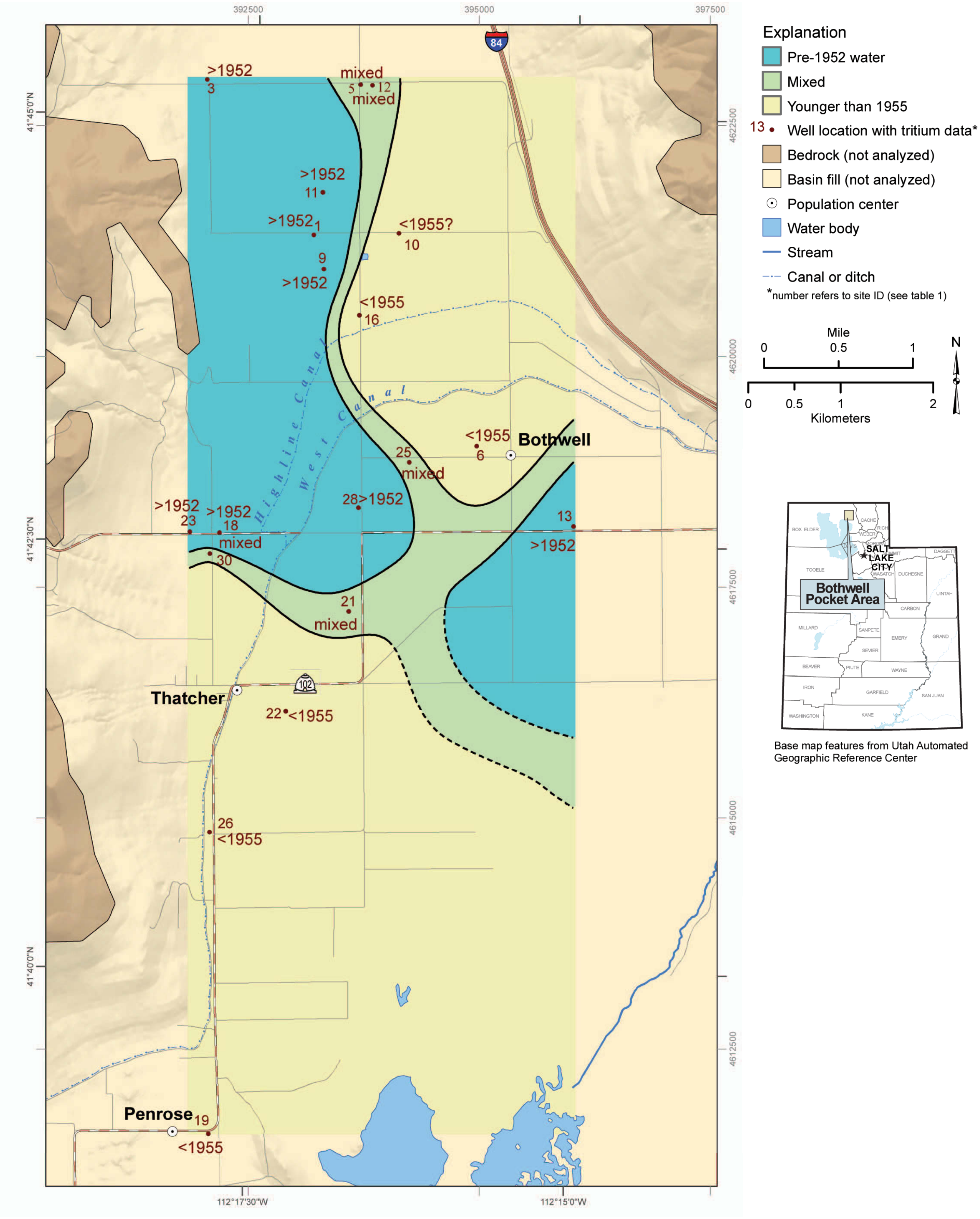


Figure 23. *Ground-water ages determined from tritium data for 19 sampled wells, Bothwell Pocket area. The wells are of different depths and likely do not penetrate the same aquifer; compare with apparent ^{14}C ages in figure 24.*

to 106.9 PMC, and $\delta^{13}C$ range from -12.7 to -8.14‰ (table 1). These values correspond to ground-water ages ranging from 13,200 ^{14}C yr B.P. to modern, based on computation of the raw carbon isotope values according to the methods of Fontes and Garnier (1979) and Pearson and Hanshaw (1970) (Alan Mayo, BYU, written communication, May 25, 2008). Although "modern" water has no standard, it is typically considered as less than 50 years old (Alan Mayo, written communication, March 17, 2010). Of the 19 water samples analyzed for carbon isotopes, five have modern carbon-based ages; the remaining samples have much older ages ranging from 2250 to 13,200 ^{14}C yr B.P. A contour map of the carbon-age data for the 19 wells (figure 24) shows the youngest water is located in the northeast and southwest quadrants of the study area, similar to the tritium age distribution (figure 23).

Figure 25 plots ^{14}C age data versus well depth. Wells having "modern" water as determined by both ^{14}C and tritium methods are dominantly shallow wells less than 110 feet (30 m) deep (except one well at 181 feet [55 m] deep (site ID 30) in the northern part of the study area, and two wells in the southern part of the valley (site IDs 22 and 26; table 1). Most wells greater than 200 feet deep contain water older than 6000 years, which was possibly recharged when ancient Lake Bonneville existed in the area (about 30 ka to 12 ka [Oviatt and others, 1992]). Five wells less than 200 feet (61 m) deep have older 14C ages ranging from 1500 to 13,200 ^{14}C yr B.P. (table 1, figure 25). Modern-age ground water is likely from returned agricultural irrigation water (this may include recharge from irrigation ditches/canals). The older water in wells greater than 200 ft (61 m) deep may derive from connate water in Lake Bonneville deposits. The source of older water in shallow wells is unknown. Wells containing modern-age ground water and wells with water older than 1500 ^{14}C yr BP are located upgradient from irrigation sites. Younger water in these areas may be from local recharge from nearby higher topographic areas or recharge from direct precipitation on the basin floor. Water from the deeper wells may also have been sourced by older water flowing along faults and fractures.

IMPLICATIONS OF SALINE INFLUENCES ON GROUND WATER

Introduction

To determine whether water wells in the Bothwell Pocket area have been affected by subsurface encroachment of saline waters from Great Salt Lake and/or sloughs in wetlands located south of the study area, we analyzed concentrations of chloride, bromide, and TDS in water wells and springs. We compared these data to concentrations of the same species in the saline waters of the sloughs and to samples of Great Salt Lake water obtained near Willard Bay. We plotted these concentrations in wells relative to distance from the wetland/slough area and from Great Salt Lake to determine whether "fresh" water of the Bothwell Pocket area has a hydrologic connection to more saline waters of Great Salt Lake, and whether mixing of waters is occurring. Because West and Highline canals are prominent hydrologic features in the study area (figure 2), we also plotted chloride and TDS concentration data versus distance to the canals.

Chloride and Bromide Concentrations

We sampled 30 wells and one slough for bromide and chloride concentration, and collected two seasonal samples from Great Salt Lake near Willard Bay (appendix B). Bromide and chloride concentrations for the well samples range from 0.09 to 5.61 mg/L and from 143 to 4100 mg/L, respectively. Bromide and chloride concentrations for the slough sample (site 36) were 0.9 and 4100 mg/L, respectively. The Willard Bay (Site 50) samples for bromide and chloride obtained during November 2006 and May 2007 were 0.7 and 1030 mg/L, and 55 and 83,400 mg/L, respectively.

Bromide and chloride are highly soluble in evaporite minerals, conservative ions unlikely to react geochemically, and uncommon constituents in most rock-forming minerals (Kenney and others, 2006). Because of these properties, bromide to chloride ratios will remain similar to that of the original recharge water in the absence of mixing with other sources; conversely, ground-water mixing of fresh water with more saline water should be accompanied by a decrease in the bromide/chloride ratio with increasing chloride concentrations. Figure 26 shows a plot of chloride versus the ratio of bromide to chloride for all samples, except those from Great Salt Lake. If the more saline waters near the slough or Great Salt Lake infiltrated the well water, the data would show the weight ratio of bromide to chloride decreasing with increasing chloride concentration in wells proximal to the more saline waters. The scattered distribution of data shows no prevalent trend, suggesting mixing is not occurring and that encroachment of high-TDS water from Great Salt Lake is unlikely at present.

Total-Dissolved-Solids Concentration Evaluation

We evaluated chloride and TDS concentration of wells versus distance to West and Highline Canals. Converted TDS concentration data from specific conductance data for two canal samples are 554 and 555 mg/L (ID points 51 and 53 on figure 2). These TDS concentrations are two of the lowest values in the study area indicating higher water quality compared to many wells. A linear regression of chloride

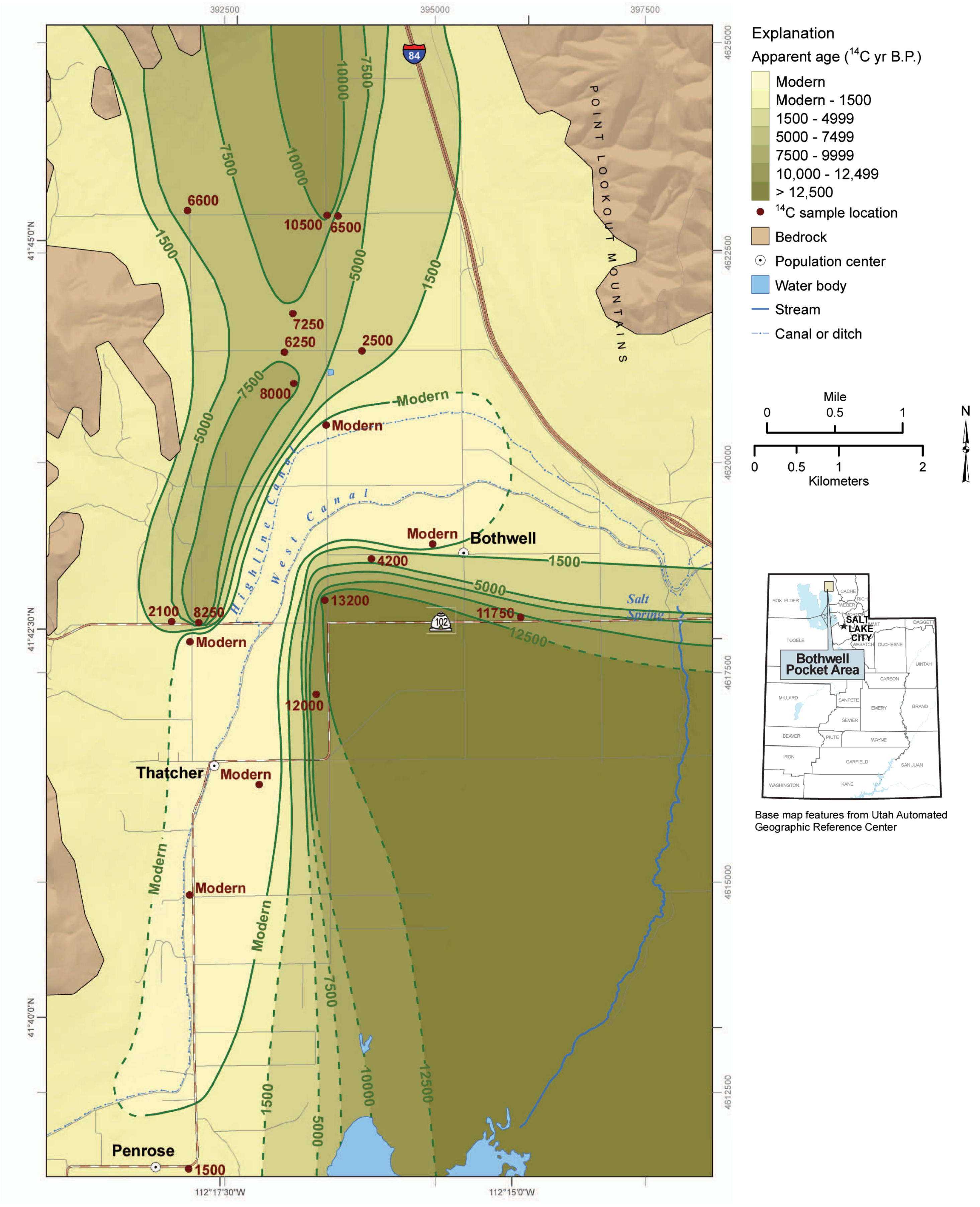


Figure 24. *Apparent ground-water ages determined from ^{14}C isotope data from sampled wells, Bothwell Pocket area. ^{14}C ages calculated from Fontes and Garnier (1979) method. The wells are of different depths and likely do not penetrate the same aquifer; compare with tritium ages in figure 23.*

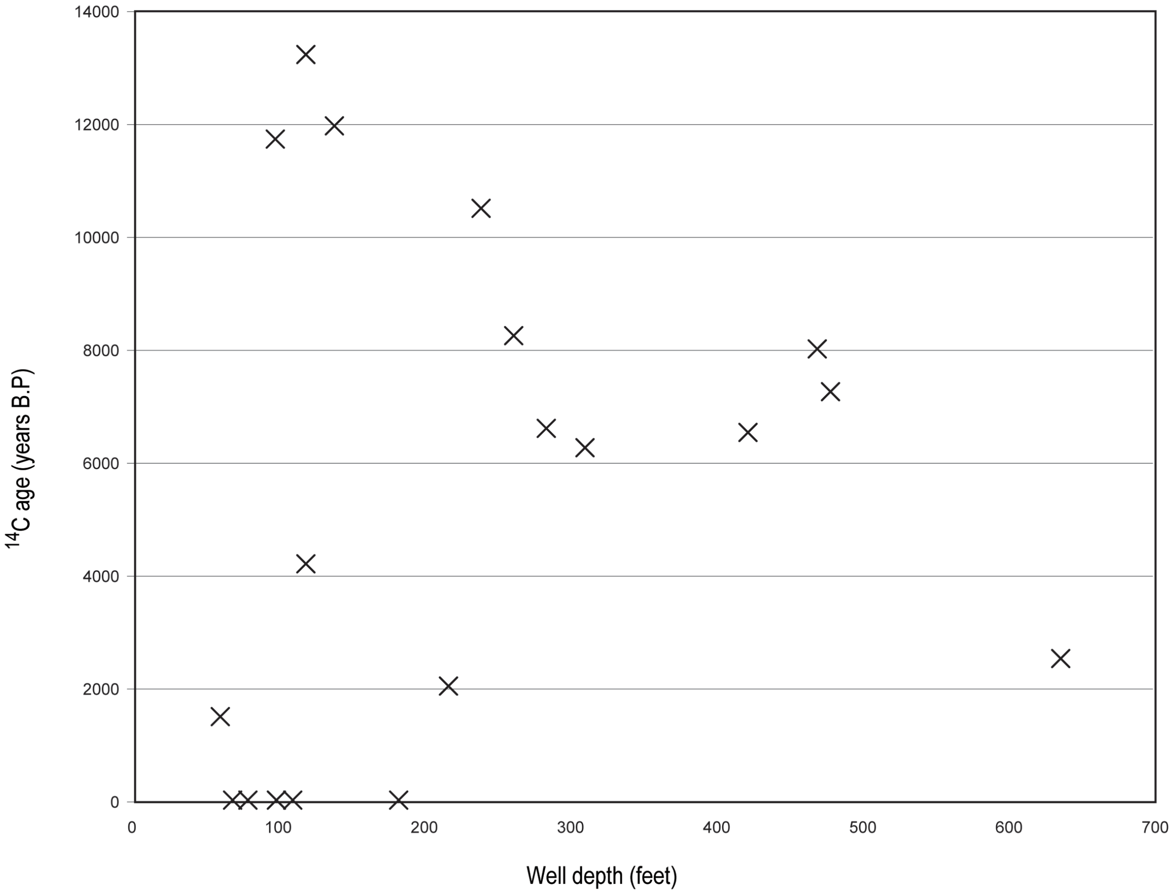
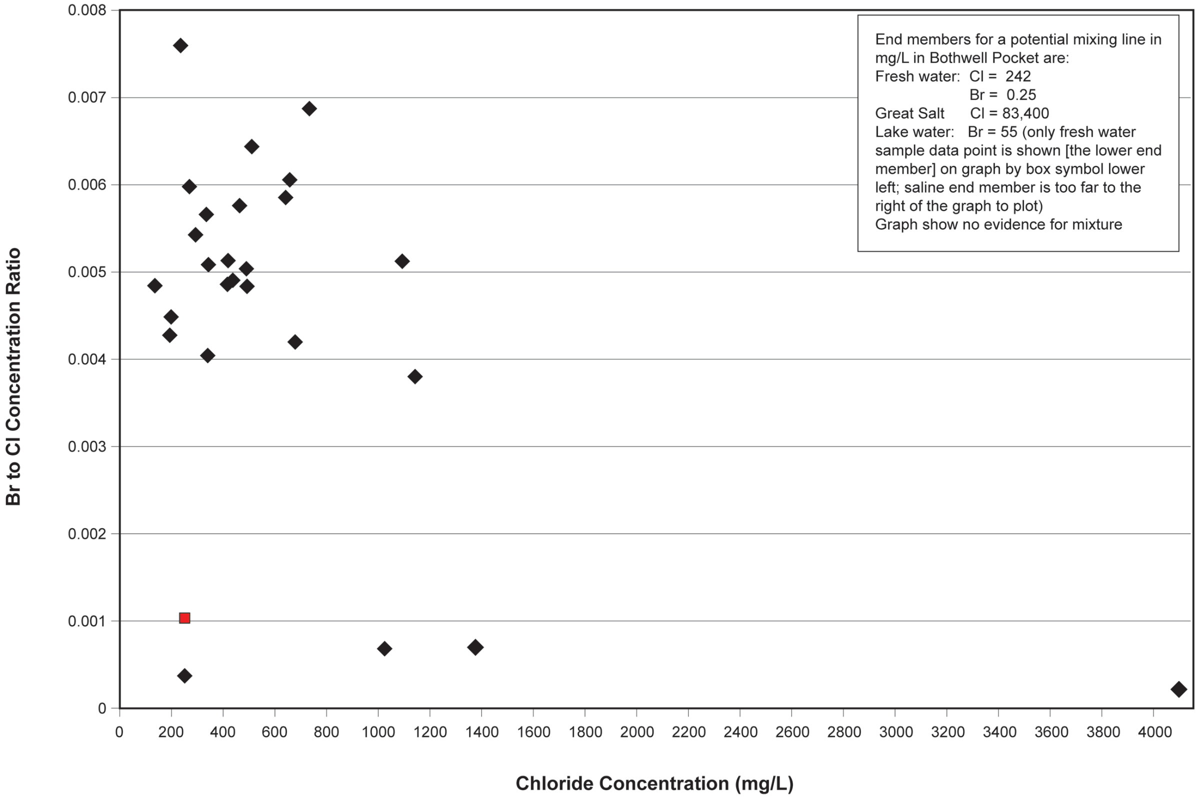


Figure 25. *Plot of apparent ^{14}C age data and well depth for 19 wells in the Bothwell Pocket area. The five ages plotting as "0" are "modern." ^{14}C ages reported using the Fontes and Garnier (1979) method (see table 1).*



End members for a potential mixing line in mg/L in Bothwell Pocket are:
Fresh water: Cl = 242
Br = 0.25
Great Salt Cl = 83,400
Lake water: Br = 55 (only fresh water sample data point is shown [the lower end member] on graph by box symbol lower left; saline end member is too far to the right of the graph to plot)
Graph show no evidence for mixture

Figure 26. *Mass ratio of bromide to chloride versus chloride concentration in water samples from 30 wells, one refuge surface site, and one slough in the Bothwell Pocket area. If mixing of more saline water with fresher ground water existed, Br/Cl would decrease with an increase in chloride; this relationship is not apparent.*

concentration versus distance to canals indicates a poor correlation where R-squared is 0.19. A linear regression of TDS concentration versus distance to canals also indicates a poor correlation where R-squared is 0.0005. If surface water from the canals is contributing to ground water, it is likely mixing with poorer quality connate water or is not reaching well water due to confining layers in the aquifer.

Another trend that might suggest influence of more saline water on fresher ground water would be increasing TDS concentration with proximity to the sloughs or wetland waters from Great Salt Lake. Figure 27 shows an unpredictable relationship in the data where in some cases TDS is better in wells closer to the sloughs/wetlands and Great Salt Lake than in wells farther away. A hydrologic connection between ground water in the Bothwell Pocket area and the saline sloughs south of the study area and Great Salt Lake water is not evident based on the data collected and presented in this report. Poor-quality well water likely results from long residence time of ground water in the basin-fill deposits and/or from return irrigation water. Scanlon and others (2010) report salt "bulges" exist in heavily irrigated agricultural soil zones that build up due to over pumping. A resulting "closed" ground-water basin that originally discharged to springs and wells will then discharge primarily through ground-water pumpage, thus recycling ground water where salts cannot be removed from the soil zone because flow is unsaturated. Scanlon and others (2010) further report that declining ground water levels, due to over pumping by irrigation, can exacerbate salinity problems by reducing assimilative capacity of aquifers.

SUMMARY AND CONCLUSIONS

This study evaluated ground-water quality, and water-level changes in select water wells during the winter and summer months to compare levels between the irrigation and non-irrigation periods in the aquifer of the Bothwell Pocket area in northwestern Utah in Box Elder County. Comparison of water levels between times of increased pumping (irrigation season) and decreased pumping in 24 wells showed little change. During the irrigation season, pumping from wells in the center of the Bothwell Pocket creates a cone of depression extending across the pocket, with a maximum drawdown of 40 feet (12 m). Water levels in wells near the canals increase slightly during the irrigation season by a maximum of 6 feet (2 m); wells south of Thatcher have little or no water-level change. A ground-water high surrounding the canals is likely caused by seepage from the canals during the irrigation season and may represent a barrier to ground-water flow from the north end of the Bothwell Pocket to the southern area. No significant change in water levels has occurred since a similar study measured water levels in 1971, though water levels in the north end of the pocket have actually risen by about 10 feet (3 m). The overall direction of ground-water flow is to the south.

We analyzed water from 36 wells, springs, canals, and slough/lake samples for general ion chemistry (including TDS), nitrate, and dissolved metals. A subset of wells was also analyzed for environmental tracers: nitrogen and oxygen isotopes in nitrate, oxygen and deuterium isotopes in water, tritium, chlorofluorocarbons (CFC), and carbon isotopes. We used various data from 12 wells and springs from the Utah Division of Drinking Water and the U.S. Geological Survey to augment the study, for a total of 55 samples analyzed.

Total-dissolved-solids concentrations for wells tested for general chemistry range from 220 to 4392 mg/L. Current general ion chemistry from Stiff diagrams shows negligible change in anion chemistry from the 1974 Bjorklund and McGreevy report. Chloride was the dominant anion in both the 1974 report and this study. Elevated TDS and chloride concentrations in ground water are attributed to long residence time in the subsurface and to return irrigation water. TDS concentrations in wells plotted against distance to downstream saline waters do not show increasing TDS concentration with proximity to the sloughs, wetlands, or Great Salt Lake waters. Between some wells, water quality improves downgradient.

Nitrate concentrations range from less than 0.02 mg/L to 40.8 mg/L. Average nitrate concentration in the basin-fill aquifer is about 6.5 mg/L and the median is 2.6 mg/L; 43% of the ground water from wells analyzed for nitrate yielded values equal to or greater than 5 mg/L. Seven samples (23%) of the ground water from wells analyzed for this study exceeded the EPA maximum contaminant level of 10 mg/L. Overall, nitrate concentrations in the basin-fill aquifer vary and are derived from multiple sources such as septic systems, livestock and corrals, and sod fertilizer.

Data from nitrogen and oxygen isotopes in nitrate from 10 wells indicate most high-nitrate wells contain nitrate possibly derived from human and/or animal sources, soil nitrate, nitrate in fertilizer, nitrate in precipitation, and mixed sources. Field investigation confirmed fertilizer and animal manure as possible sources of nitrate. Septic-tank systems likely contribute nitrate to many of the wells, but because the data overlap several fields, determination of a sole source is difficult, except in areas lacking development and thus free of septic systems. Determining whether nitrate in ground water is derived from soil, fault zones, or precipitation is more complex. Future work to attempt to determine the spatially variable vadose-zone flow conditions is necessary to better estimate the potential for ground-water nitrate loading from soil. We are unable to determine the transport mechanism by which nitrogen from soil reaches ground water as nitrate because this

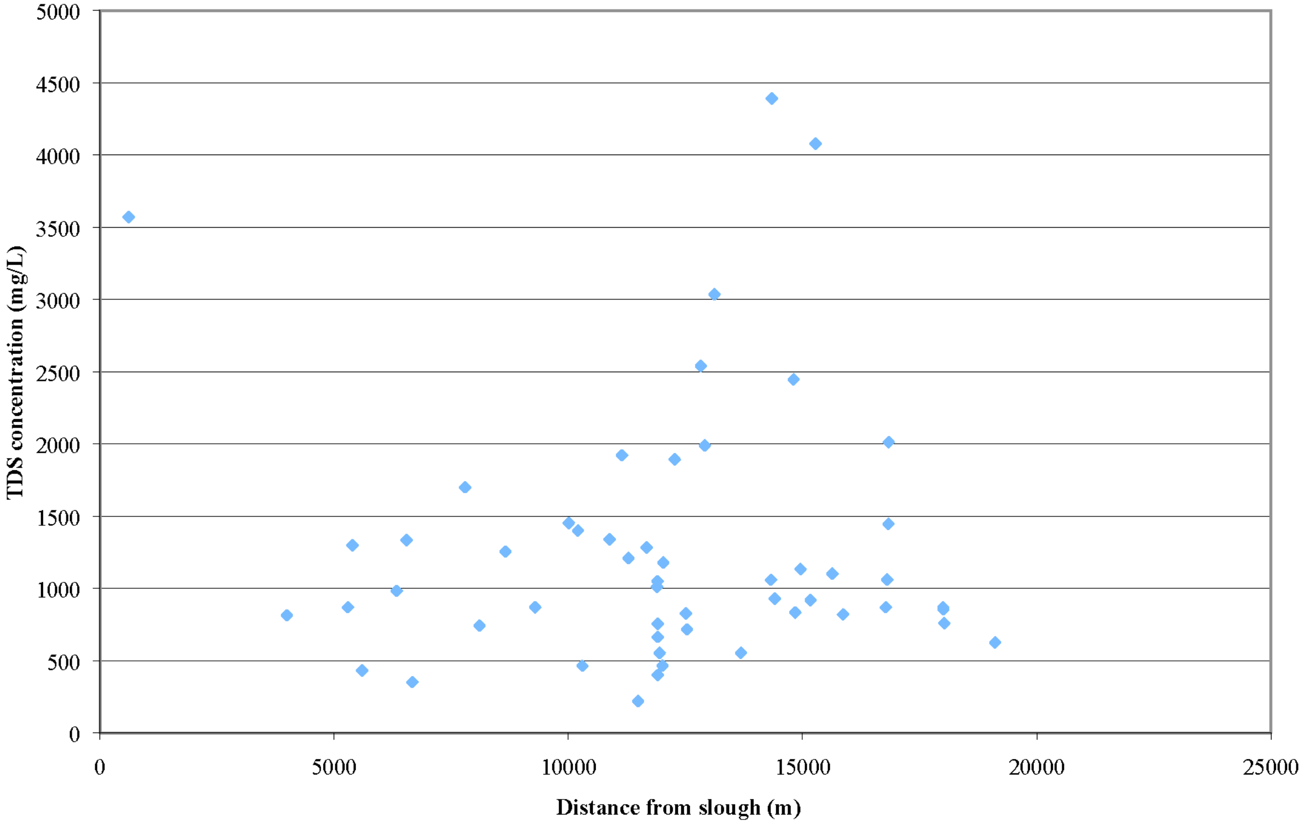


Figure 27. *Plot of TDS from 30 wells in the Bothwell Pocket area versus distance from the sloughs south of the study area. If mixing of more saline water with fresher ground water existed, TDS would decrease with distance. R-squared of 0.00008 indicates a poor correlation exists between TDS and distance to more saline water.*

study did not include a ground-water flow model and does not address subsurface conditions. In addition, because nitrate concentration in precipitation is inconsistent and depends on factors such as climate, season, proximity to industries emitting air pollutants, impact from agricultural emissions, combustion of fossil fuels, and atmospheric conditions and events, we did not address nitrate in precipitation as a viable source. The overlapping nitrogen and oxygen isotope data indicate mixing of groundwater sources having different isotopic signatures, and thus nitrate sources.

We analyzed nitrate and chloride concentration data to determine whether denitrification is a common process in the Bothwell Pocket. We plotted the ratio of nitrate to chloride for 12 wells, each sampled twice, as one method to determine whether denitrification occurred. Most nitrate-chloride ratio values did not change in water sampled during different seasons and years; thus we believe the absence of a decrease in the ratio of nitrate to chloride indicates negligible denitrification. Another method for determining denitrification is analyzing dissolved oxygen, manganese, and iron concentration data relative to nitrate concentration data. In denitrification processes, an increase in manganese and iron is commonly coupled to a decrease in dissolved oxygen (Kendall, 1998). Manganese and iron were not analyzed in this study, but future analyses of additional samples for chemical species (e.g., chloride, manganese, dissolved oxygen, and $\delta^{15}N$ and $\delta^{18}O_{NO3}$ isotopes) may allow us to better assess the nitrate source(s) and whether denitrification occurs with time.

We used environmental tracers and isotopes to help determine a relative age of ground water for a subset of wells. Oxygen and deuterium isotope data in water indicate that most water tested was recharged at moderate elevations and moderate atmospheric temperatures. Tritium analysis of ground water from 19 wells indicates that contaminated ground water was recharged pre-, post- and during the bomb years when tritium concentrations in the atmosphere were at their low, medium, and peak levels, respectively. CFC data show most tested wells have a ground-water component with recharge ages ranging from 1943 to 1988 (for CFC-11, CFC-12, and CFC-113). Carbon-14 and $\delta^{13}C$ data indicate apparent ground-water ages which range from modern to 13,200 ^{14}C yr B.P., and show ground water is derived from both modern and very old recharge waters that likely have mixed with younger recharge water. Based on all environmental tracer data, most ground water reflects mixed or combined sources of water. Fourteen samples have water older than 1500 yrs B.P.; these same samples also contain some water with a younger, 20th century signature. Five wells have modern ^{14}C ages; of these, water in two wells is interpreted as modern based on other environmental tracer analysis. All wells contain some ground water recharged during the 20th century; thus, most wells contain water having a mixture of young and old waters. Because all samples analyzed for environmental tracer data (mostly tritium and CFC) have water with a recharge-age component indicative of historical time, we believe the dominant sources of nitrate in ground water in the area are from human-related activity, such as increased residential development (and septic systems) and irrigation.

To determine whether water wells in the Bothwell Pocket area have been affected by subsurface encroachment of waters associated with Great Salt Lake and/or sloughs/wetlands south of the study area, we analyzed concentrations of chloride, bromide, and TDS in water wells and springs and compared this data to concentrations of the same species in waters from the sloughs and from Great Salt Lake water near Willard Bay. Bromide and chloride concentrations for 30 samples, respectively, range from 0.09 to 5.61 mg/L and from 143 to 4100 mg/L. If the more saline waters near the slough or Great Salt Lake influenced the well water, the data would show a trend of decreasing bromide to chloride ratio with increasing chloride concentration in wells proximal to the more saline waters. The scattered distribution of data indicates no prevalent trend. In the absence of such a trend, we conclude there is a negligible saline influence on ground water in the Bothwell Pocket area from more saline waters of Great Salt Lake and its wetlands. A hydrologic connection between ground water in the Bothwell Pocket area and the saline sloughs and Great Salt Lake water is not evident. Surface water from the West and Highline canals likely has not affected the quality of ground water in the Bothwell Pocket area. Based on ion chemistry data, especially TDS, bromide, and chloride concentrations, coupled with the environmental tracer data, we conclude the relatively poor quality of ground water in the Bothwell Pocket is not caused by encroachment of ground water from wetland areas near Great Salt Lake, but from older connate water and younger water affected by land-use practices, mainly irrigation.

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APPENDICES

APPENDIX A
WATER-LEVEL MEASUREMENTS, BOTHWELL POCKET AREA

Table A1. *Water-level measurements for wells in the Bothwell Pocket area, Box Elder County, Utah*

Site #	Northing	Easting	Year drilled	Elevation of wellhead	Off-season potentiometric surface	Measurement date	Irrigation-season potentiometric surface	Measurement date	Change in potentiometric surface	Recharge type
2	4625241	393226	1936	4644	4319	20-Dec-06	4314	26-Jun-07	-5	S
3	4622994	392054	1915?	4570	4313	20-Dec-06	4309	26-Jun-07	-4	S
5	4622904	393727	1981	4466	4312	20-Dec-06	4291	26-Jun-07	-21	S
6	4619032	394967	1995	4328	4319	6-Mar-07	4324	26-Jun-07	5	S
7	4624186	393306	2001	4535	4317	20-Dec-06	4311	26-Jun-07	-6	S
9	4620932	393300	1989	4385	4308	20-Dec-06	4302	26-Jun-07	-6	S
11	4621792	393298	1968	4423	4310	20-Dec-06	4270	26-Jun-07	-40	S
13	4618152	396070	unknown	4315	4306	21-Dec-06	4297	26-Jun-07	-9	S
14	4616488	392390	1998	4330	4296	21-Dec-06	4300	26-Jun-07	4	P
15	4611668	390322	1958	4280	4263	21-Dec-06	4266	26-Jun-07	3	P
16	4620408	393669	1978	4355	4313	21-Dec-06	4315	26-Jun-07	2	S
19	4611557	392099	1999	4268	4260	22-Dec-06	4262	27-Jun-07	2	D
21	4617251	393586	2003	4311	4301	21-Dec-06	4303	26-Jun-07	2	S
22	4616367	392842	1997	4304	4292	6-Mar-07	4298	26-Jun-07	6	S
23	4618151	391818	2004	4463	4308	6-Mar-07	4303	26-Jun-07	-5	P
24	4617953	397381	1999	4313	4299	6-Mar-07	4297	26-Jun-07	-2	S
25	4618817	394254	2003	4327	4310	6-Mar-07	4309	26-Jun-07	-1	S
28	4618355	393698	2003	4325	4306	6-Mar-07	4306	26-Jun-07	0	S
29	4617486	392026	1998	4425	4297	6-Mar-07	4299	27-Jun-07	2	P
31	4615371	393739	1998	4280	4282	21-Dec-06	4282	26-Jun-07	0	D
52	4612737	391933	2002	4337	4269	6-Mar-07	4270	26-Jun-07	1	P
61	4610956	393211	unknown	4280	4259	22-Dec-06	4259	26-Jun-07	0	P
63	4616508	395063	unknown	4292	4285	21-Dec-06	4285	26-Jun-07	0	D
64	4618310	393233	unknown	4330	4320	6-Mar-07	4321	26-Jun-07	1	S

Site number: See figure 2 for well location.
Northing: UTM Northing coordinate, NAD27.
Easting: UTM Easting coordinate, NAD27.
Elevation of wellhead: In feet above sea level.
Off-season potentionmetric surface: Elevation of the photentiometric surface during non-irrigation season, in feet above sea level.
Irrigation-season potentiometric surface: Elevation of potentiometric surface during irrigation season, in feet above sea level.
Change in potentiometric surface: Net change in potentiometric surface between off-season levels and irrigation season levels, in feet. A negative number denotes a drop in the potentiometric surface.
Recharge Type: P, primary recharge area; S secondary recharge area, D, discharge area. From Anderson and others, 1994.

APPENDIX B
CHEMISTRY FOR WATER SAMPLES IN THE BOTHWELL POCKET AREA.

Table B1. *Chemistry for water samples in the Bothwell Pocket study area, Box Elder County, Utah. Site IDs 50a and 50b are from Great Salt Lake.*

Site ID	Date Collected	pH	Temp °C	Specific Conductance µhmos/cm	Dissolved Oxygen (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	HCO_3 (mg/L)	CO_3 (mg/L)	F (mg/L)	Cl (mg/L)
1	06/05/07	7.58	14.1	1640	4	86.85	37.07	158.70	4.61	242.6	< 0.1	0.08	347.19
1	10/17/06	7.35	14.4	1820	-	93.05	41.09	153.70	2.54	244.10	< 0.1	0.14	391.53
2	10/19/06	-	-	1044	-	-	-	-	-	-	-	-	-
3	06/05/07	7.42	14.9	2020	5.43	144.90	62.68	128.50	9.66	211.7	-	-	471.79
3	10/17/06	7.37	14.49	2120	-	135.40	61.46	107.30	9.03	228.30	< 0.1	0.14	492.05
4	06/05/07	7.53	14.46	1620	5.5	85.29	42.91	134.50	6.00	224.5	< 0.1	0.04	338.60
4	10/17/06	7.42	14.18	1670	-	81.58	42.16	136.90	4.45	215.30	< 0.1	0.12	347.59
5	06/04/07	7.53	14.89	2270	5.48	132.30	66.30	223.00	5.14	258.8	-	-	424.72
5	10/17/06	7.16	13.17	2940	-	185.80	101.00	202.00	9.21	327.50	< 0.1	0.14	461.22
6	06/05/07	7.23	12.95	3980	2.6	251.20	151.70	414.20	83.44	551.2	-	-	237.67
6	10/17/06	7.09	13.66	3170	-	184.70	114.10	288.30	80.41	640.40	< 0.1	0.40	165.44
7	10/18/06	-	-	1446	-	-	-	-	-	-	-	-	-
8	06/05/07	7.56	16.88	1510	3.5	75.25	33.81	142.90	4.86	246.5	< 0.1	0.46	296.14
8	10/18/06	7.48	14.37	1590		79.52	35.49	139.90	2.99	252.60	< 0.1	0.30	319.02
8	09/17/08	9.47*	16.8	1780	4.2	-	-	-	-	-	-	-	-
9	06/05/07	7.46	15.1	4110	4.8	345.40	168.20	217.60	6.79	200.5	-	-	1099.84
9	10/18/06	7.51	15.41	3240	-	254.10	110.60	190.70	5.39	210.80	< 0.1	0.09	803.56
9	09/17/08	9.72*	10.5	2420	2.42	-	-	-	-	-	-	-	-
10	10/18/06	7.1	15.02	5990	-	554.90	261.20	392.70	13.14	295.80	< 0.1	0.31	1143.91
11	10/18/06	7.46	15.57	1990	-	121.40	58.63	136.60	3.36	239.80	< 0.1	0.14	442.05
12	10/18/06	7.18	13.55	3360	-	304.90	126.50	156.30	8.47	252.40	< 0.1	0.06	683.78
13	06/04/07	7.67	16.66	1472	1.6	52.13	45.81	99.74	76.47	110.10	< 0.1	0.47	271.85
13	10/18/06	7.54	15.73	1600	-	101.70	47.00	113.40	7.32	227.30	< 0.1	0.26	246.98
14	10/18/06	-	-	773	-	-	-	-	-	-	-	-	-
15	10/18/06	-	-	721	-	-	-	-	-	-	-	-	-
16	06/04/07	7.22	13.52	5410	4.54	319.50	271.50	615.40	51.28	517.1	-	-	519.99
16	10/18/06	7.07	13.09	4260	-	263.40	179.00	436.00	49.12	639.40	< 0.1	0.27	307.61
17	10/18/06	-	-	1550	-	-	-	-	-	-	-	-	-
18	06/05/07	7.52	18.5	1860	3.12	74.40	39.73	204.50	8.02	248.9		0.11	418.96
18	10/19/06	7.65	17.53	1920	-	73.38	38.45	204.20	7.99	254.00	< 0.1	0.21	409.43
19	06/05/07	7.6	17.36	2040	3.2	72.32	40.41	263.80	13.75	427.8	-	0.10	345.29
19	10/19/06	7.54	15.86	2140	-	70.80	39.95	274.20	20.61	449.90	< 0.1	0.27	344.18
21	06/04/07	7.46	13.78	3080	2.27	187.50	95.81	264.40	9.97	273.3	-	-	645.13
21	10/19/06	7.27	12.56	3020	-	163.60	98.12	252.50	14.85	326.10	< 0.1	0.14	608.48
22	06/04/07	7.34	15.4	2520	2.35	120.00	57.12	189.00	31.83	465.9	-	0.82	205.73
23	06/04/07	7.6	18.3	1370	4.2	67.87	43.19	102.20	11.04	223.9	< 0.1	0.57	242.42
24	06/05/07	7.92	14.03	1162	1.12	42.49	19.96	137.40	5.25	262.2	< 0.1	0.40	199.46
25	06/05/07	7.39	16.7	3650	2.5	283.30	164.40	282.00	14.33	285.8	-	-	662.26
26	06/05/07	7.25	13.71	1680	3.3	120.40	63.65	112.60	23.26	510.5	-	0.57	142.81
27	06/05/07	7.5	21.8	1530	3.85	65.58	32.35	170.90	12.95	333.7	-	0.22	253.11
28	06/05/07	7.53	13.85	3130	2.45	229.50	124.90	195.10	9.57	213.7	-	-	733.93
29	06/05/07	7.4	15.36	2050	5.6	102.90	73.36	158.60	23.86	197.3	-	0.08	495.21
30	06/05/07	7.6	14.8	2200	5.05	92.86	57.96	222.80	16.42	244.3	-	0.13	493.57

UGS is Utah Geological Survey, UDW is Utah Division of Drinking Water, USHL is Utah State Health Lab, USGS is United States Geological Survey, BYU is Brigham Young University, UNK is unknown, likely USHL; "-" indicates no data; *pH meter malfunction

Table B1. *continued*

Site ID	Date Collected	pH	Temp °C	Specific Conductance µhmos/cm	Dissolved Oxygen (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	HCO_3 (mg/L)	CO_3 (mg/L)	F (mg/L)	Cl (mg/L)
31	10/19/06	-	-	1448	-	-	-	-	-	-	-	-	-
32	10/18/06	-	-	3540	-	-	-	-	-	-	-	-	-
33	11/1/06	-	-	3330	-	-	-	-	-	-	-	-	-
34	11/1/06	-	-	666	-	-	-	-	-	-	-	-	-
35	11/1/06	-	-	776	-	-	-	-	-	-	-	-	-
36	11/1/06	-	-	5950	-	143	120	2350	110	-	-	-	4100
37	11/1/06	-	-	4600	-	-	-	-	-	-	-	-	-
38	06/20/85	-	-	1880	-	-	-	-	-	-	-	-	-
39	08/13/02	-	-	-	-	-	-	-	-	-	-	-	-
40	08/13/02	-	-	-	-	-	-	-	-	-	-	-	-
41	08/02/01	-	-	-	-	-	-	-	-	-	-	-	-
42	04/27/06	-	-	-	-	-	-	-	-	-	-	-	-
43	03/27/02	-	-	-	-	-	-	-	-	-	-	-	-
44	12/13/96	-	-	1540	-	-	-	-	-	-	-	-	-
45	10/10/02	-	-	-	-	-	-	-	-	-	-	-	-
46	03/19/03	-	-	-	-	-	-	-	-	-	-	-	-
47	04/13/06	-	-	-	-	-	-	-	-	-	-	-	-
48	04/13/01	-	-	1300	-	-	-	-	-	-	-	-	-
49	02/11/03	-	-	-	-	-	-	-	-	-	-	-	-
50a	11/20/06	-	-	4280	-	244	9360	37000	2400	-	-	-	83400
50b	5/30/07	-	-	3950	-	44	136	470	91	199	9	-	1030
51	8/20/08	8.37	21.36	923	6.00	-	-	-	-	-	-	-	-
52	8/20/08	7.53	53.42	2220	3.99	-	-	-	-	-	-	-	-
53	8/20/08	8.56	21.68	925	6.8	-	-	-	-	-	-	-	-
54	6/25/71		19.5	3670	-	52.0	21.0	660.0	29.0	350	0	0.2	960
55	5/13/71	-	14.0	2310	-	52.0	19.0	400.0	9.7	166	0	0.6	1380
56	9/9/69	-	-	2000	-	87.0	49.0	270.0	c	250	0		540
57	9/25/70	-	-	1230	-	68.0	33.0	130.0	9.4	229	0	0.7	200
58	9/9/69	-	-	1470	-	89.0	39.0	170.0	c	250	0	-	340
59	09/17/08	12.69*	17.03	4870	7	-	-	-	-	-	-	-	1380
60	09/17/08	9.3*	18.1	16000	5.6	-	-	-	-	-	-	-	-

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***Table B1.** continued*

Site ID	NO_2 (mg/L)	NO_3 (mg/L)	Br (mg/L)	HPO_4 (mg/L)	SO_4 (mg/L)	TDS mg/L	$\delta^{13}C$	$\delta^{18}O$	±σ	δD	±σ	^{3}H T.U.	±σ T.U.	^{14}C	±σ	Data Source	Lab	well depth(ft)
1	< 0.01	1.61	1.76	< 0.01	41.83	919	-	-	-	-	-	-	-	-	-	UGS	BYU	310
1	< 0.01	0.93	1.80	< 0.01	40.10	966	-10.08	-15.96	0.25	-127.8	1.0	0.3	0.3	25.7	0.2	UGS	BYU	-
2	-	-	-	-	-	626	-	-	-	-	-	-	-	-	-	UGS	n/a	365
3	-	5.95	2.71	-	31.52	1061	-	-	-	-	-	-	-	-	-	UGS	BYU	285
3	< 0.01	2.91	2.27	< 0.01	30.64	1064	-9.41	-15.79	0.25	-127.4	1.0	0.2	0.2	24.8	0.2	UGS	BYU	-
4	< 0.01	4.99	1.91	< 0.01	37.65	870	-	-	-	-	-	-	-	-	-	UGS	BYU	235
4	< 0.01	2.56	1.64	< 0.01	43.70	872	-	-15.77	0.25	-126.4	1.0	-	-	-	-	UGS	BYU	-
5	-	10.90	2.17	-	336.20	1447	-	-	-	-	-	-	-	-	-	UGS	BYU	240
5	< 0.01	7.23	1.62	< 0.01	443.70	1730	-10.53	-15.19	0.25	-124.4	1.0	1.7	0.3	16.1	0.2	UGS	BYU	-
6		40.80	1.80	-	1346.41	3036	-	-	-	-	-	-	-	-	-	UGS	BYU	110
6	< 0.01	20.55	1.40	< 0.01	995.02	2468	-12.70	-12.94	0.25	-110.2	1.0	8.7	0.4	106.9	0.6	UGS	BYU	-
7	-	3.00	-	-	-	868	-	-	-	-	-	-	-	-	-	UGS	n/a	433
8	< 0.01	1.65	1.60	0.31	33.57	833	-	-	-	-	-	-	-	-	-	UGS	BYU	668
8	< 0.01	1.02	1.50	< 0.01	38.61	868	-	-15.83	0.25	-127.9	1.0	-	-	-	-	UGS	BYU	-
8	-	25.30	-	-	-	996.8	-	-	-	-	-	-	-	-	-		USHL	-
9	-	10.82	5.61	-	407.30	2446	-	-	-	-	-	-	-	-	-	UGS	BYU	470
9	< 0.01	3.80	4.19	< 0.01	213.08	1788	-9.19	-15.80	0.25	-127.1	1.0	0.6	0.3	20.2	0.2	UGS	BYU	-
9	-	3.52	-	-	-	1355	-	-	-	-	-	-	-	-	-		USHL	-
10	< 0.01	19.13	4.33	< 0.01	1416.91	4079	-11.09	-14.44	0.25	-120.7	1.0	4.7	0.3	43.7	0.3	UGS	BYU	635
11	< 0.01	1.67	2.16	< 0.01	100.29	1102	-10.85	-15.84	0.25	-128.0	1.0	0.1	0.3	22.5	0.2	UGS	BYU	478
12	< 0.01	8.64	2.86	< 0.01	480.09	2012	-9.73	-14.94	0.25	-122.3	1.0	2.2	0.3	26.3	0.2	UGS	BYU	422
13	-	1.49	1.62	< 0.01	172.04	828	-	-	-	-	-	-	-	-	-	UGS	BYU	-
13	< 0.01	0.87	1.59	< 0.01	177.15	921	-10.52	-15.45	0.25	-125.4	1.0	0.3	0.3	12.8	0.1	UGS	BYU	-
14	-	-	-	-	-	464	-	-	-	-	-	-	-	-	-	UGS	n/a	100
15	-	-	-	-	-	433	-	-	-	-	-	-	-	-	-	UGS	n/a	51
16	-	16.80	3.34		2097.25	4392	-	-	-	-	-	-	-	-	-	UGS	BYU	100
16	< 0.01	5.41	0.69	< 0.01	1403.72	3278	-11.84	-13.46	0.25	-112.2	1.0	7.4	0.3	90.1	0.5	UGS	BYU	-
17	-	-	-	-	-	930	-	-	-	-	-	-	-	-	-	UGS	n/a	85-150
18	-	1.74	2.03		55.18	1050	-	-	-	-	-	-	-	-	-	UGS	BYU	-
18	< 0.01	0.94	1.95	< 0.01	54.63	1042	-8.14	-15.35	0.25	-125.9	1.0	< 0.2	0.3	19.3	0.2	UGS	BYU	-
19	-	1.78	1.39	0.05	135.15	1299	-	-	-	-	-	-				UGS	BYU	-
19	< 0.01	0.79	0.13	0.12	141.23	1341	-10.93	-13.86	0.25	-116.9	1.0	6.0	0.3	44.0	0.3	UGS	BYU	-
21	-	0.47	3.76	0.02	445.47	1922	-	-	-	-	-	-	-	-	-	UGS	BYU	-
21	< 0.01	0.30	3.23	< 0.01	342.19	1806	-11.72	-15.71	0.25	-125.5	1.0	2.5	0.3	13.0	0.1	UGS	BYU	-
22	-	5.32	0.92	-	383.78	1453	-12.08	-	-	-	-	8.8	0.4	83.45	0.4	UGS	BYU	-
23	< 0.01	2.88	0.25	< 0.01	65.44	756	-10.11	0	-	0	-	0.7	0.3	43.18	0.3	UGS	BYU	-
24	< 0.01	0.17	0.85	< 0.01	48.63	716	-	-70	-	-490	-	-	-	-	-	UGS	n/a	-
25	-	1.20	4.00	-	848.12	2540	-12.23	-20.00	-	-95.0	-	4.0	0.4	39.48	0.3	UGS	BYU	-
26	-	7.62	0.69	-	282.03	1255	-11.86	-	-	-	-	7.1	0.4	80.09	0.4	UGS	BYU	-
27	-	2.80	0.09	-	114.74	983	-	-	-	-	-	-	-	-	-	UGS	BYU	-
28	-	2.45	5.03	-	385.82	1893	-10.51	-	-	-	-	0.3	0.3	12.82	0.1	UGS	n/a	-
29	-	10.85	2.39	-	159.82	1211	-	-	-	-	-	-	-	-	-	UGS	BYU	-
30	-	7.28	2.48	-	154.51	1283	-9.93	-	-	-	-	1.9	0.4	55.2	0.3	UGS	BYU	-

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***Table B1.** continued*

Site ID	**NO_2** (mg/L)	**NO_3** (mg/L)	**Br** (mg/L)	**HPO_4** (mg/L)	**SO_4** (mg/L)	**TDS** mg/L	**$\delta^{13}C$**	**$\delta^{18}O$**	**±σ**	**δD**	**±σ**	**^3H** T.U.	**±σ** T.U.	**^{14}C**	**±σ**	**Data Source**	**Lab**	**well depth(ft)**
31	-	-	-	-	-	869	-	-	-	-	-	-	-	-	-	UGS	n/a	-
32	-	-	-	-	-	2124	-	-	-	-	-	-	-	-	-	UGS	n/a	-
33	-	-	-	-	-	1998	-	-	-	-	-	-	-	-	-	UGS	n/a	-
34	-	-	-	-	-	400	-	-	-	-	-	-	-	-	-	UGS	n/a	-
35	-	-	-	-	-	466	-	-	-	-	-	-	-	-	-	UGS	BYU	-
36	-	225	0.9	-	1.9	3570	-	-	-	-	-	-	-	-	-	UGS	USGS	-
37	-	-	-	-	-	2760	-	-	-	-	-	-	-	-	-	UGS	n/a	-
38	-	-	-	-	-	1134	-	-	-	-	-	-	-	-	-	UDW	UNK	-
39	-	-	-	-	-	1060	-	-	-	-	-	-	-	-	-	UDW	UNK	-
40	-	-	-	-	-	1010	-	-	-	-	-	-	-	-	-	UDW	UNK	-
41	-	-	-	-	-	820	-	-	-	-	-	-	-	-	-	UDW	UNK	-
42	-	-	-	-	-	664	-	-	-	-	-	-	-	-	-	UDW	UNK	-
43	-	-	-	-	-	1401	-	-	-	-	-	-	-	-	-	UDW	UNK	-
44	-	-	-	-	-	814	-	-	-	-	-	-	-	-	-	UDW	UNK	-
45	-	-	-	-	-	220	-	-	-	-	-	-	-	-	-	UDW	UNK	-
46	-	-	-	-	-	352	-	-	-	-	-	-	-	-	-	UDW	UNK	-
47	-	-	-	-	-	856	-	-	-	-	-	-	-	-	-	UDW	UNK	-
48	-	-	-	-	-	760	-	-	-	-	-	-	-	-	-	UDW	UNK	-
49	-	-	-	-	-	1700	-	-	-	-	-	-	-	-	-	UDW	UNK	-
50a	-	<1	55	-	1100	2568	-	-	-	-	-	-	-	-	-	UGS	USGS	-
50b	-	2.5	0.7	-	211	2130	-	-	-	-	-	-	-	-	-	UGS	USGS/USHL	-
51	-	0.13	-	-	-	554	-	-	-	-	-	-	-	-	-	UGS	USHL	-
52	-	4.68	-	-	-	1332	-	-	-	-	-	-	-	-	-	UGS	USHL	-
53	-	0.12	-	-	-	555	-	-	-	-	-	-	-	-	-	UGS	USHL	-
54	-	1.30964	-	-	67	1990	-	-	-	-	-	-	-	-	-	USGS	USGS	-
55	-	<0.1	0.956	-	48	1340	-	-	-	-	-	-	-	-	-	USGS	USGS	-
56	-	0.63224	-	-	42	1180	-	-	-	-	-	-	-	-	-	USGS	USGS	-
57	-	0.09032	-	-	110	743	-	-	-	-	-	-	-	-	-	USGS	USGS	-
58	-	1.30964	-	-	51	870	-	-	-	-	-	-	-	-	-	USGS	USGS	-
59	-	<0.1	0.956	-	-	2922	-	-	-	-	-	-	-	-	-	UGS	USHL	-
60	-	-	-	-	-	9600	-	-	-	-	-	-	-	-	-	UGS	n/a	-

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APPENDIX C

UTAH AND EPA PRIMARY AND SECONDARY DRINKING WATER-QUALITY STANDARDS AND ANALYTICAL METHODS FOR SOME CHEMICAL CONSTITUENTS

Table C1. *Utah and EPA primary and secondary drinking water-quality standards and analytical methods for some chemical constituents sampled in the Bothwell Pocket, Box Elder County, Utah.*

CHEMICAL CONSTITUENT	EPA ANALYTICAL METHOD[1]	WATER-QUALITY STANDARD (mg/L)
Nutrients:		
total nitrate/nitrite	353.2	10.0
ammonia as nitrogen	350.3	-
total phosphorous and dissolved total phosphate	365.1	-
Dissolved metals (as listed in State of Utah Public Health Laboratory online manual):		
arsenic	200.9	0.01
barium	200.7	2.0
cadmium	200.9	0.005
chromium	200.9	0.1
copper	200.7	1.3
lead	200.9	0.015
mercury	245.1	0.002
selenium	200.9	0.05
silver*	200.9	0.1
zinc*	200.7	5.0
General Chemistry :(as listed in State of Utah Public Health Laboratory online manual)		
total dissolved solids (TDS)	160.1	2000+** or (500*++)
pH*	150.1	between 6.5 and 8.5

CHEMICAL CONSTITUENT	EPA ANALYTICAL METHOD[1]	GROUND-WATER QUALITY STANDARD (mg/L)
aluminum*	200.7	0.05 to 0.2
calcium	200.7	-
sodium	200.7	-
boron	200.7	-
bicarbonate	406C	-
carbon dioxide	406C	-
carbonate	406C	-
chloride*	407A	250
total alkalinity	310.1	-
total hardness	314A	-
specific conductance	120.1	-
iron*	200.7	.03
potassium	200.7	-
hydroxide	406C	-
sulfate *++	375.2	250
magnesium	200.7	-
manganese	200.7	0.5

\- no drinking-water quality standard exists for the chemical constituent

*for secondary standards (exceeding these concentrations does not pose a health threat)

\+ maximum contaminant level is reported from the Utah Administrative Code R309-200 (Utah Division of Drinking Water)

**For public water-supply wells, if TDS is greater than 1000 mg/L, the supplier shall satisfactorily demonstrate to the Utah Water Quality Board that no better water is available. The Board shall not allow the use of an inferior source of water if a better source of water is available.

++TDS and sulfate levels are given in the Primary Drinking Water Standards, R309-200. They are listed as secondary standards, excess of recommended levels cause consumer complaint.

[1] http://www.epa.gov/safewater/methods/analyticalmethods_ogwdw.html#one

UTAH GEOLOGICAL SURVEY
a division of
Utah Department of Natural Resources

Plate 1
Utah Geological Survey Special Study 135
Evaluation of Sources of Poor Quality Ground Water in the Bothwell Pocket Area, Lower Bear River Valley, Eastern Box Elder County, Utah

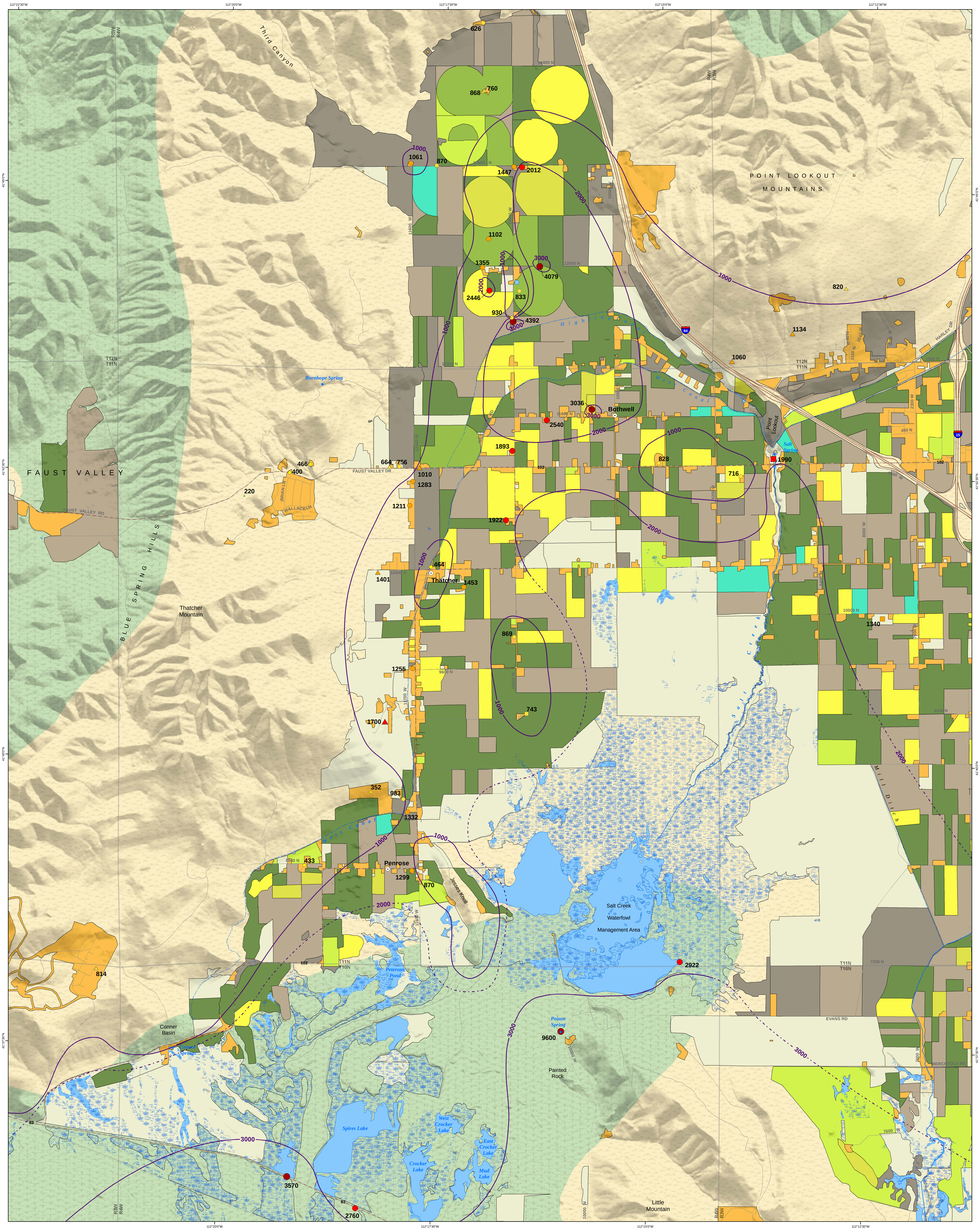


PLATE 1. TOTAL-DISSOLVED-SOLIDS CONCENTRATIONS AND WATER-RELATED LAND USE

By Janae Wallace, Kevin Thomas, and Mike Lowe

2010

Total-dissolved-solids sample location by source

	Utah Geological Survey	Utah Division of Water Quality	U.S. Geological Survey
< 250 mg/L		▲	
250 - 500 mg/L	●	▲	
501 - 1000 mg/L	●	▲	■
1001 - 1500 mg/L	●	▲	■
1501 - 3000 mg/L	●	▲	■
> 3000 mg/L	●		

Land use*

- Alfalfa
- Turf farms
- Grass hay
- Safflower & sorghum
- Grain & seeds
- Idle or fallow
- Corn
- Onion & other vegetable
- Pasture & range
- Residential & urban
- Ponds, lakes & reservoirs

*From Utah Division of Water Resources, 2009

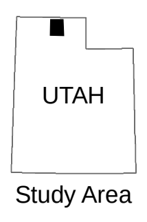
Land cover - not in use+

- Herbs & shrubs
- Grasses & sedges
- Water body - intermittent
- Wetland & riparian

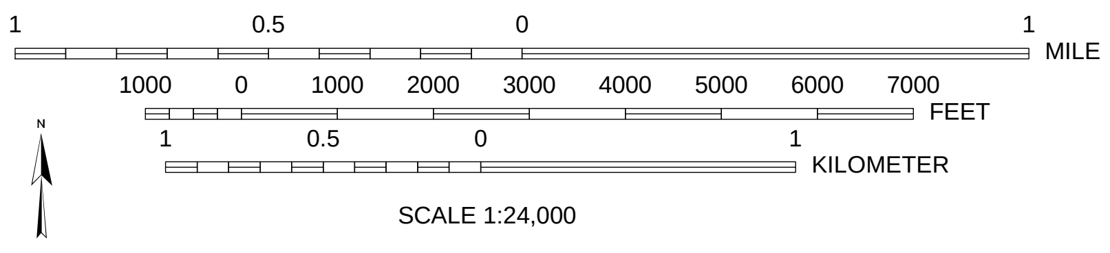
+ From Utah Division of Wildlife Resources, 2009

Other symbols

- 3000 Total-dissolved-solids (mg/L) line of equal concentration, dashed where approximated
- Stream
- Canal or ditch
- Spring



Study Area



SCALE 1:24,000

Projection: Universal Transverse Mercator
Datum: North American 1983 Zone 12 N
Spheroid: Clarke 1866
Basemap features from Utah Automated Geographic Reference Center
Cartographer: Richard Emerson