GROUND-WATER QUALITY CLASSIFICATION AND RECOMMENDED SEPTIC TANK SOIL-ABSORPTION- SYSTEM DENSITY MAPS, CASTLE VALLEY, GRAND COUNTY, UTAH

by

Mike Lowe, Janae Wallace, Charles E. Bishop, and Hugh A. Hurlow

View to the northeast of Castle Valley, Grand County, Utah. The foreground shows part of the River Ranchos Community, where most of the population in the valley resides. The lone spire of Castle Rock is on the end horizon of Parriott Mesa.

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ABSTRACT

Castle Valley in southeastern Utah is experiencing an increase in residential development, all of which uses septic tank soil-absorption systems for wastewater disposal. Most of this development is on unconsolidated deposits of the unconfined valley-fill aquifer, the primary source of drinking water. The purposes of our study are to (1) classify the ground-water quality of the principal aquifer to formally identify and document the beneficial use of the valley's ground-water resource, and (2) apply a ground-water flow model using a mass-balance approach to determine the potential impact of projected increased numbers of septic-tank systems on water quality in the Castle Valley valley-fill aquifer and thereby recommend appropriate septic-system density requirements to limit water-quality degradation.

Utah's ground-water quality classes are based mostly on total-dissolved-solids (TDS) concentrations as follows: Class IA (Pristine), less than 500 mg/L; Class II (Drinking Water Quality), 500 to less than 3,000 mg/L; Class III (Limited Use), 3,000 to less than 10,000 mg/L; and Class IV (Saline), 10,000 mg/L and greater. Aquifer classification is based on data from water wells representing the valley-fill material.

In the mass-balance approach, the nitrogen mass from projected additional septic tanks is added to the current nitrogen mass and then diluted with ground-water flow available for mixing plus the water added by the septic-tank systems themselves. Ground water available for mixing was calculated based on estimated parameters representing existing conditions using a Brigham Young University simulation of the ground-water flow system in Castle Valley.

The quality of water in the Castle Valley valley-fill aquifer is generally good. In the northwestern part (40 percent) of the valley, we classify ground water in 48 percent of the aquifer as Class IA and 52 percent as Class II, based on data from 54 wells sampled during either October 2001 or February 2003, and on TDS values converted from specific-conductance data for 14 wells and 4 surface-water sites reported by the Utah Department of Agriculture and Food, the Utah Division of Water Rights, the Utah Geological Survey, and the Utah Department of Water Quality. Total-dissolved-solids concentrations in the valley-fill aquifer range from 204 to 2,442 mg/L, and average 785 mg/L. Data are insufficient to classify the southeastern part (60 percent) of the valley-fill aquifer. Nitrate-as-nitrogen concentrations in the valley-fill aquifer range from less than 0.1 to 4.27 mg/L, the average (background) nitrate concentration being 0.52 mg/L.

The results of our ground-water flow simulation using the mass-balance approach indicate that two categories of recommended maximum septic-system densities are appropriate for development in Castle Valley: 5 and 15 acres per system (2 hm^2/system and 6 hm^2/system). These recommended maximum septic-system densities are based on hydrogeologic parameters incorporated in the ground-water flow simulation and geographically divided into four ground-water flow domains (background nitrate concentrations ranging from 0.18 to 0.48 mg/L) on the basis of flow-volume similarities.

INTRODUCTION

Castle Valley, Grand County, is a rural area in southeastern Utah (figure 1) experiencing an increase in residential development, all of which uses septic tank soil-absorption systems for wastewater disposal. Most of this development is situated on unconsolidated deposits of the valley-fill aquifer. Ground water, mostly from the valley-fill aquifer, provides all of the drinking-water supply in Castle Valley. Preservation of ground-water quality and the potential for ground-water quality degradation are critical issues that should be considered in determining the extent and nature of future development in Castle Valley. Local government officials in Castle Valley have expressed concern about the potential impact that development may have on ground-water quality, particularly development that uses septic tank soil-absorption systems for wastewater disposal.

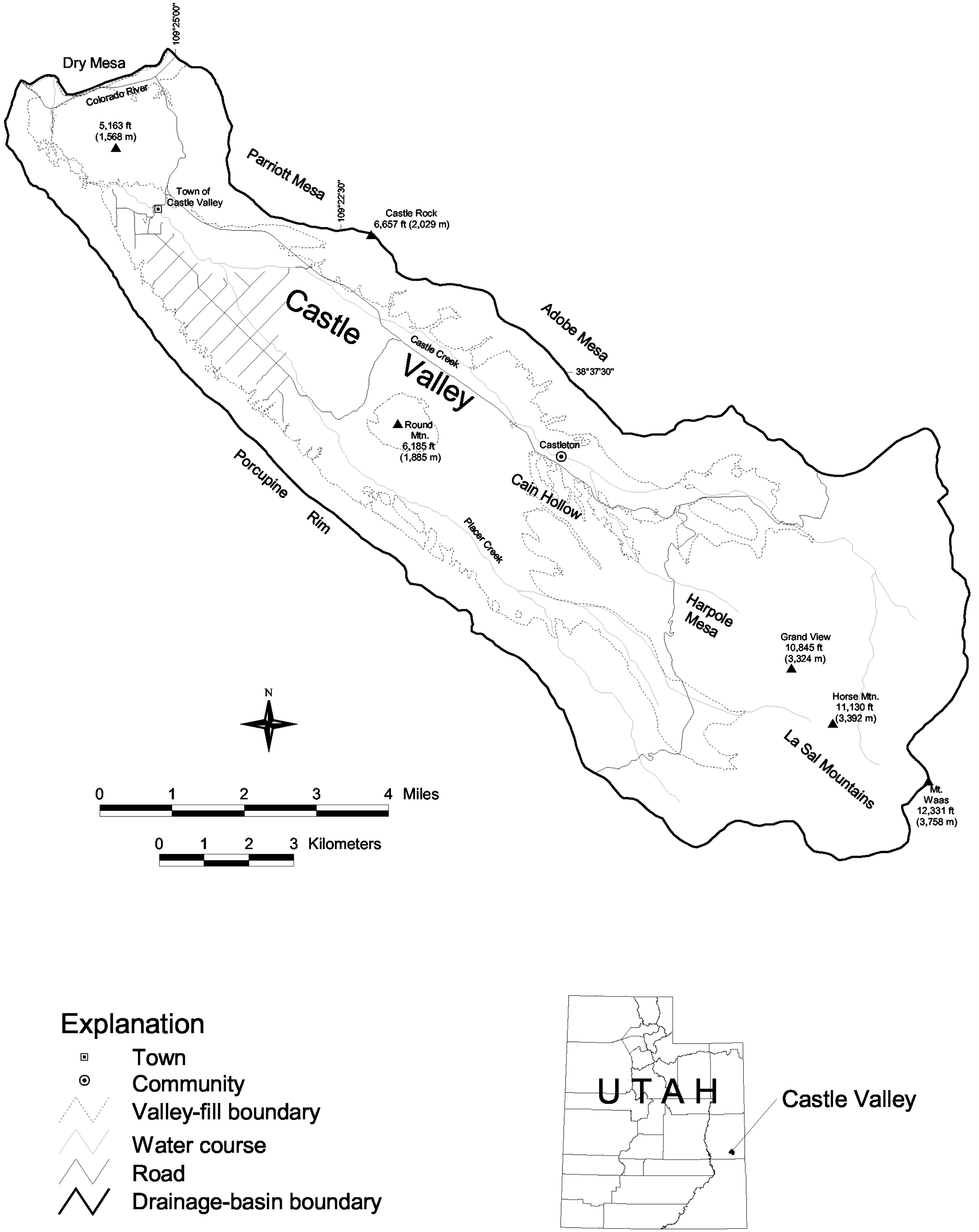

***Figure 1**. Drainage-basin study area, Castle Valley, Grand County, Utah.*

Purpose and Scope

The purposes of our study are to (1) classify the ground-water quality of the valley-fill aquifer to formally identify and document the beneficial use of Castle Valley's ground-water resource, and (2) apply a ground-water flow simulation and use a mass-balance approach to determine the potential impact of projected increased numbers of septic-tank systems on water quality in the valley-fill aquifer and thereby recommend appropriate septic-system-density requirements. These two study components will, in concert, provide land-use planners with a tool to use in approving new development in a manner that will be protective of ground-water quality.

Ground-Water Quality Classification

Ground-water quality classes under the Utah Water Quality Board classification scheme are based largely on total-dissolved-solids (TDS) concentrations (table 1) (for the ranges of chemical-constituent concentrations used in this report, including those for TDS, mg/L equals parts per million). If any contaminant exceeds Utah's ground-water quality (health) standards (appendix B) (and, if human caused, cannot be cleaned up within a reasonable time period), the ground water is classified as Class III, Limited Use ground water.

To classify the quality of ground water in the Castle Valley valley-fill aquifer, we sampled ground water from 40 wells in October 2001, and had the samples analyzed for general chemistry and nutrients by the Utah Department of Epidemiology and Laboratory Services; of these 40 wells, ground water from 10 wells was analyzed for organics and pesticides and ground water from 5 wells was analyzed for radionuclides (appendix A). These data were augmented by (1) another 43 wells sampled in September 2000 that were analyzed for bacteria, specific conductance, pesticides, and nutrients (appendix A) by the Utah Department of Agriculture and Food (Quilter, 2001), (2) specific-conductance and TDS-concentration data from ground water from 6 wells measured by the Utah Division of Water Rights between 1991 and 1996 (appendix A) (Ford and Grandy, 1997), and (3) specific-conductance data we collected in February 2003 from another 5 wells (appendix A). Specific-conductance data that we collected from four surface-water sites in February 2003 were also used as part of this classification (appendix A); because of an apparent hydraulic connection between ground and surface water in the valley-fill aquifer, surface-water quality is likely representative of ground-water quality. Appendix B summarizes the constituents analyzed for and, where appropriate, ground-water quality (health) standards for the constituents; our water-quality data are presented in appendix A.

In July 2003, some local citizens of Castle Valley sampled water from 17 wells and surface-water sites, and had the samples analyzed for TDS concentration by the Utah Department of Epidemiology and Laboratory Services (appendix A); of these samples, eight were from wells, eight from springs, and one from Castle Creek. Total-dissolved-solids-concentration values range from 188 to 1,944 mg/L. However, these data were not used to supplement the TDS concentration data from Lowe and Wallace (2003) because they did not meet sampling protocol requirements associated with our Quality Assurance Project Plan approved by the U.S. Environmental Protection Agency.

Table 1. *Ground-water quality classes under the Utah Water Quality Board's total-dissolved-solids (TDS) based classification system (modified from Utah Division of Water Quality, 1998).*

Ground-Water Quality Class	TDS Concentration	Beneficial Use
Class IA[1]/IB[1]/IC[2]	less than 500 mg/L[3]	Pristine/Irreplaceable/ Ecologically Important
Class II	500 to less than 3,000 mg/L	Drinking Water[4]
Class III	3,000 to less than 10,000 mg/L	Limited Use[5]
Class IV	10,000 mg/L and greater	Saline[6]

[1] *Irreplaceable ground water (Class IB) is a source of water for a community public drinking-water system for which no other reliable supply of comparable quality and quantity is available due to economic or institutional constraints; it is a ground-water quality class that is not based on TDS. In addition to TDS, Class IA must also meet standards listed in appendix B.*

[2] *Ecologically Important ground water (Class IC) is a source of ground-water discharge important to the continued existence of wildlife habitat; it is a ground-water quality class that is not based on TDS.*

[3] *For concentrations less than 7,000 mg/L, mg/L is about equal to parts per million (ppm).*

[4] *Water having TDS concentrations in the upper range of this class must generally undergo some treatment before being used as drinking water.*

[5] *Generally used for industrial purposes.*

[6] *May have economic value as brine.*

Another component of the classification process is to document existing and potential pollution sources that may threaten the public's drinking-water supply. We mapped potential pollution sources based on Utah's Drinking Water Source Protection Rules (appendix C).

Septic-Tank Density/Water-Quality Degradation Analysis

To provide recommended septic-tank densities for Castle Valley using the mass-balance approach to evaluate potential water-quality degradation, we used the digital ground-water flow simulation of Downs and Lasswell (undated), after modifying the simulation using data from an aquifer test we conducted in 2000 and slug tests, to estimate ground-water flow available for mixing (dilution). We then (1) grouped areas into four ground-water flow domains (geographic areas having similar characteristics of flow volume per unit area); (2) determined area acreage, ground-water flow volumes, number of existing septic-tank systems, and ambient (background) nitrate concentrations for each domain; and (3) calculated projected nitrogen loadings in each domain, based on increasing numbers of septic tank soil-absorption systems and using the appropriate amount of wastewater and accompanying nitrogen load introduced per septic-tank system. By limiting allowable degradation of ground-water nitrate concentration to 3 mg/L, the amount of water-quality degradation determined to be acceptable by local government officials, we were then able to derive septic-tank density recommendations for each domain.

Well-Numbering System

The numbering system for wells in this study is based on the federal government cadastral land-survey system that divides Utah into four quadrants (A-D) separated by the Salt Lake Base Line and Meridian (figure 2). The study area is in the southeastern quadrant (D). The wells are numbered with this quadrant letter (D), followed by township and range, all enclosed in parentheses. The next set of characters indicates the section, quarter section, quarter-quarter section, and quarter-quarter-quarter section designated by letters a through d, indicating the northeastern, northwestern, southwestern, and southeastern quadrants, respectively. A number after the hyphen corresponds to an individual well within a quarter-quarter-quarter section. For example, the well (D-25-23) 17adb-1 would be the first well in the northwestern quarter of the southeastern quarter of the northeastern quarter of section 17, Township 25 South, Range 23 East (NW$^1/_4$SE$^1/_4$ NE$^1/_4$ section 17, T. 25 S., R. 23 E.).

Location and Geography

Castle Valley is a northwest-trending valley in the Colorado Plateau physiographic province (Stokes, 1977), and is about 10 miles (19 km) long and 2 miles (3 km) wide with an area of about 21.5 square miles (56 km^2) (figure 1). Castle Valley is bordered by Parriott and Adobe Mesas to the northeast, the La Sal Mountains to the southeast, Porcupine Rim to the west, and the Colorado River to the northwest (figure 1). Castle Valley ranges in elevation from about 4,120 feet (1,250 m) at the Colorado River to the northwest to about 6,800 feet (2,100 m) in the upper reaches of Castle Creek within valley-fill material in the foothills of the La Sal Mountains to the southeast; the drainage basin reaches 12,331 feet (3,758 m) in elevation at Mount Waas (figure 1).

The headwaters of Castle Creek and Placer Creek, the principal drainages in Castle Valley, are in the La Sal Mountains (figure 1). Castle Creek is a perennial stream whereas Placer Creek is ephemeral (Ford and Grandy, 1997). These streams flow into the valley on either side of Cain Hollow and Round Mountain, join near the town of Castle Valley, and then flow through a short, narrow canyon and enter the Colorado River.

Population and Land Use

Most people in Castle Valley live within the limits of the recently incorporated (November 27, 1985) Town of Castle Valley, but some live outside the town limits. The 2000 U.S. Census population of the Town of Castle Valley is 349, a 65.4 percent increase from the 1990 Census population of 211 (Demographic and Economic Analysis Section, 2001). The Utah School and Institutional Trust Lands Administration (SITLA) is anticipating the sale of its land for the development of new lots, which may lead to continued growth in Castle Valley.

Much of the land use in Castle Valley is residential, but some of the valley is irrigated cropland. Cattle grazing also takes place in the valley, primarily in the winter (Snyder, 1996a, b).

Climate

Average annual precipitation in the Castle Valley drainage basin increases with altitude and ranges from about 9 inches (23 cm) at the Colorado River to more than 30 inches (76 cm) in the La Sal Mountains (Blanchard, 1990). Average annual precipitation from 1978 to 1992 was 11.5 inches (29.2 cm) at the Castle Valley Institute in the Town of Castle Valley (elevation 4,720 feet [1,439 m]). Average annual precipitation from 1963 to 1978 in the community of Castleton, farther southeast in Castle Valley at an elevation of 5,840 feet (1,780 m), was 13.63 inches (34.6 cm) (Ashcroft and others, 1992). Summer precipitation is usually in the form of brief, localized, intense thunderstorms, whereas winter precipitation is of longer duration, less localized, less intense and, at higher elevations, primarily in the form of snow (Blanchard, 1990). Temperatures range from a record high of 107°F (41.2°C) at the Castle Valley Institute for the 1978 to 1992 time period to a record low of -15°F (-26.1°C) at Castleton for the 1963 to 1978 time period. Average mean temperatures were 53.9 and 50.2°F (12.2 and 10.1°C) at the Castle Valley Institute and Castleton, respectively, for the periods of record (Ashcroft and others, 1992). Average annual evapotranspiration was 4.4 and 3.4 times precipitation at the Castle Valley Institute and Castleton, respectively, for the same time periods (Ashcroft and others, 1992). Because of the brevity of precipitation events and higher evapotranspiration rates in the summer, most recharge to ground-water aquifers takes place during spring snowmelt (Blanchard, 1990).

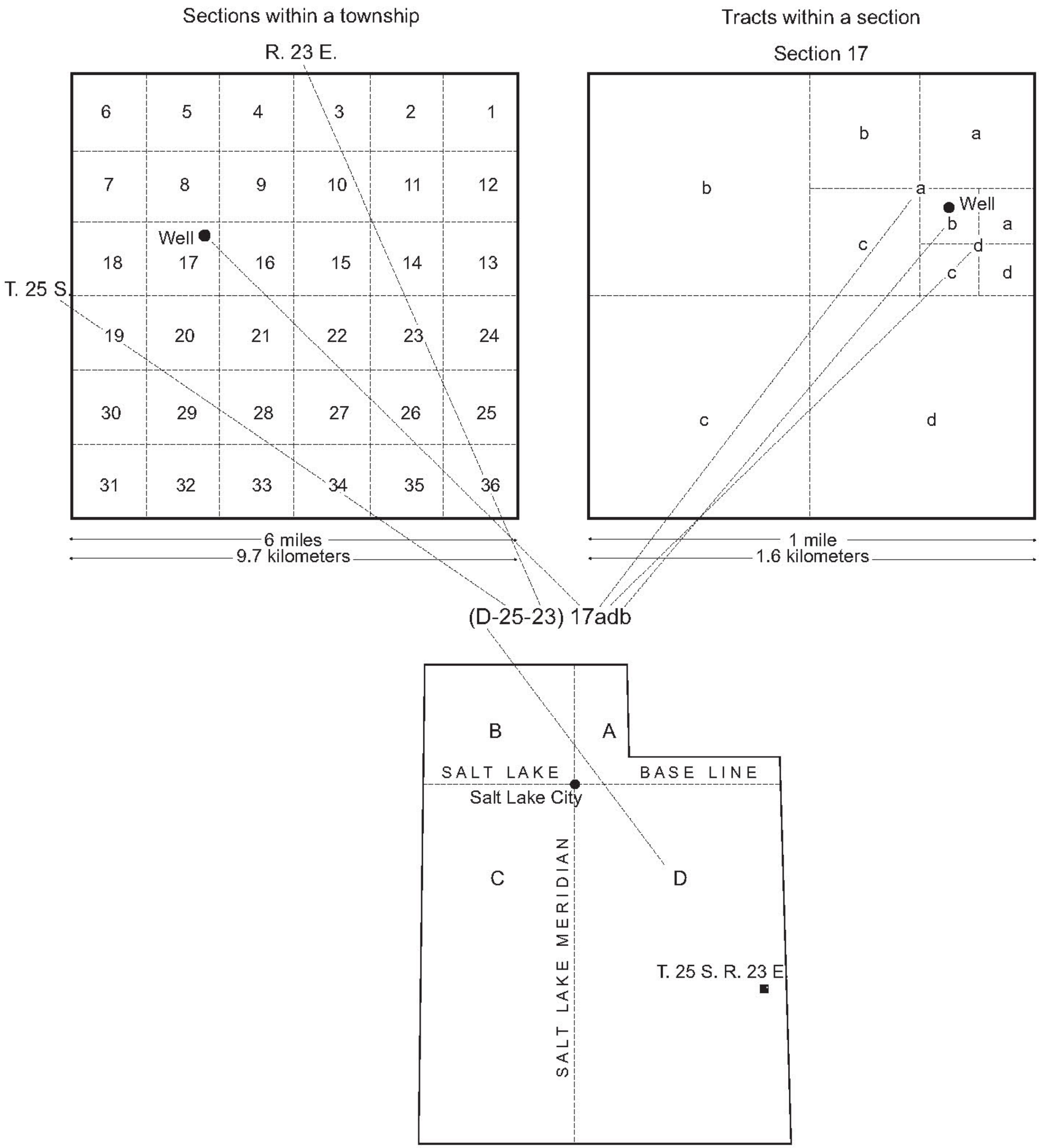

Figure 2. *Numbering system for wells in Utah (see text for additional explanation).*

PREVIOUS INVESTIGATIONS

Geologic mapping in Castle Valley includes that of Shoemaker (1952), Harper (1960), Doelling and Ross (1998), and Doelling (2001, 2002). We used unpublished geologic mapping of the Mount Waas and Warner Lake quadrangles by M.L. Ross, formerly with the Utah Geological Survey, as part of this study. Mulvey (1992) mapped geologic hazards in Castle Valley and provided information on the potential for ground-water contamination. Hydrogeologic studies relevant to Castle Valley were conducted by Sumsion (1971), Weir and others (1983), Blanchard (1990), Freethey and Cordy (1991), Snyder (1996a, b), Ford and Grandy (1997), Eisinger and Lowe (1999), and Town of Castle Valley (2000).

GEOLOGIC SETTING

Structurally, Castle Valley is part of a regionally extensive, collapsed salt anticline that includes Paradox Valley to the southeast (figure 3) (Doelling and Ross, 1998). The Pennsylvanian Paradox Formation, which underlies the Paradox basin region, contains thick salt layers deposited under marine conditions (Hintze, 1988). As these salt layers were buried by younger sediments, they became mobile and formed a diapir under present-day Castle Valley. Due to differences in the specific gravity of salt and bedrock, the diapir rose, folding overlying rocks into an anticline. The subsequent uplift of the Colorado Plateau in the late Tertiary resulted in high rates of erosion and allowed ground and surface water to contact and dissolve the salt layers from the core of the anticline (Mulvey, 1992; Doelling and Ross, 1998). Subsequently, the overlying rock strata collapsed and eroded, forming Castle Valley in the core of the anticline. Mulvey (1992) mapped a suspected Quaternary fault parallel to Porcupine Rim on the southwest side of the valley and attributed a sinkhole along this fault to localized dissolution or piping. High-angle normal fault systems that developed as a result of the collapse of the salt diapir are present along both margins of Castle Valley (plate 1, appendix D) (Doelling and Ross, 1998). Geologic cross sections display the relationship between the "cap rock" of the Paradox Formation and the overlying valley-fill material (plate 2) (see also, Town of Castle Valley, 2000, plate 1).

Geologic units surrounding Castle Valley include Pennsylvanian to Tertiary sedimentary and igneous rocks (plate 1; table 2; appendix D) (Doelling, 2001). Gypsum, mudstone, and shale of the Pennsylvanian Paradox Formation cap rock are exposed along the southwest margin of Castle Valley and around Round Mountain; interbedded evaporite, clastic, and carbonate rocks of the Paradox Formation underlie Quaternary valley-fill deposits (Doelling, 2001). Sandstone, conglomerate, and mudstone of the Permian Cutler Formation overlie the Paradox in cliffs at the northwest end and central northeast margin of the valley (Doelling and Ross, 1998; Doelling, 2001). Sandstone, siltstone, and mudstone of the Triassic Moenkopi and Chinle Formations, sandstone of the Jurassic Wingate Formation, and sandstone, siltstone, and mudstone of the Jurassic Kayenta Formation overlie the Cutler and form the cliffs along much of the northeast and southwest sides of the valley (Doelling, 2001). Round Mountain and the La Sal Mountains are composed largely of Oligocene intrusive rocks, mainly porphyritic trachyte (Doelling, 2001).

The valley fill of Castle Valley consists mainly of alluvial-fan, mass-movement, and stream deposits (Doelling, 2001). Holocene stream deposits along Castle and Placer Creeks are generally poorly sorted sand, silt, and clay, with some gravel lenses; the amount of gravel in these deposits generally increases updrainage (Doelling and Ross, 1998). Coarse-grained older alluvium (including the Geyser Creek Fanglomerate; appendix D), composed of mainly poorly sorted, sandy, cobble gravel with some small, localized accumulations of boulders, is exposed in the higher parts of Castle Valley and underlies the younger stream alluvium in lower Castle Valley (Snyder, 1996a, b; Doelling and Ross, 1998). Alluvial-fan deposits form apron-like gentle slopes at the base of Porcupine Rim and Adobe Mesa (Doelling and Ross, 1998; Doelling, 2001). The fans consist mainly of poorly sorted boulders, cobbles, and gravels in a crudely bedded fine-grained matrix (Doelling and Ross, 1998). Talus and colluvium, consisting of rock-fall blocks, boulders, angular gravel, sand, and silt, are present along the southern part of Porcupine Rim, and mass-movement deposits are mapped along the upper reach of Placer Creek (Doelling, 2001).

GROUND-WATER CONDITIONS

Introduction

Ground water in Castle Valley occurs in two types of aquifers: (1) fractured bedrock, and (2) unconsolidated valley-fill deposits (figure 4). The geologic and hydrologic characteristics of the rock units in the Castle Valley drainage basin are summarized in table 2. Ground water in fractured-rock aquifers is recharged primarily from infiltration of precipitation and stream flow, and flows primarily through fractures. Blanchard (1990) reported that approximately 30 wells receive water from the Cutler Formation aquifer along the base of Porcupine Rim on the west side of the valley. The Cutler Formation is the main fractured-rock aquifer currently used in Castle Valley, but the number of wells completed in bedrock has increased only slightly over the past 12 years. Bedrock well depths are typically 150 to 300 feet (45-90 m) below the land surface (Snyder, 1996a, b). Recharge to the Cutler Formation aquifer is from the La Sal Mountains (Doelling and Ross, 1998).

Valley-Fill Aquifer

Occurrence

The valley-fill aquifer is the most important source of drinking water in Castle Valley. The valley fill consists predominantly of gravelly stream alluvium and alluvial-fan deposits that are generally coarser grained near source areas at the base of Porcupine Rim and the La Sal Mountains, and finer grained along the lower reaches of Castle Creek (Snyder, 1996a, b; Doelling and Ross, 1998). Although drillers' logs of water wells indicate that a few wells in Castle Valley intersect clay lenses, none of these clay layers is extensive enough to act as a confining layer, so the valley-fill aquifer is

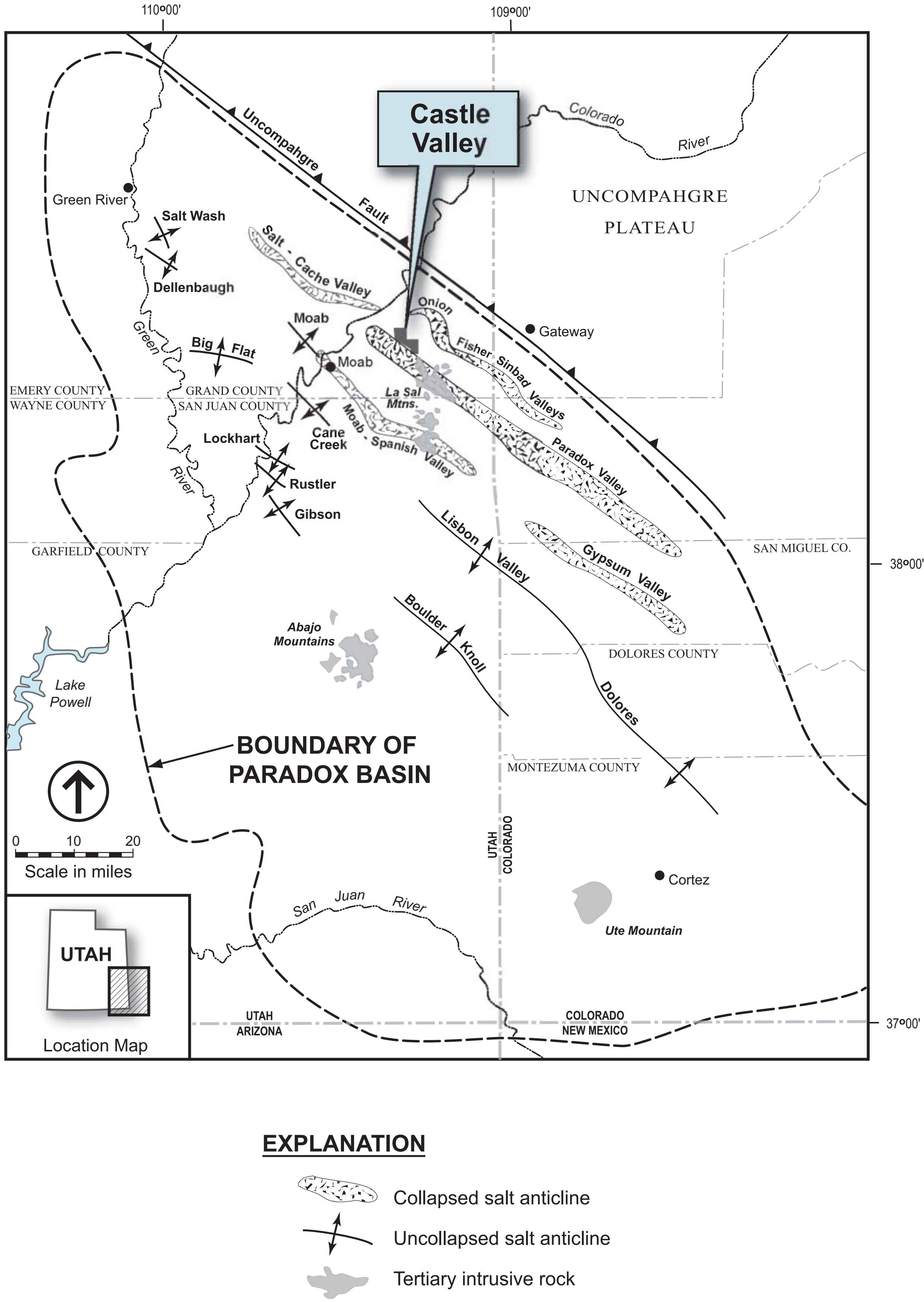

Figure 3. *Regional tectonic setting of the study area showing major tectonic features including salt anticlines, Paradox basin, Uncompahgre uplift and fault, and Tertiary intrusions (modified from Doelling, 1988).*

Table 2. *Geologic and hydrologic characteristics of aquifers in southern Grand County, including Castle Valley. Compiled from Blanchard (1990) and Doelling and Morgan (2000).*

Geologic Unit (aquifer)	Thickness[1] in feet (m)	Lithology	General Hydrologic Characteristics	Yield (gallons per minute)	Water Quality[2]	
					Total Dissolved Solids (mg/L)	**Chemistry Type**
Cedar Mountain Formation	120-200 (37-61)	Interbedded sandstone, conglomerate, and mudstone	Sandstone and conglomerate yield small amounts of water to wells and springs	Springs: < 1 Wells: <1	Spring: 1,020 Well: 1,470	Calcium magnesium sodium sulfate bicarbonate
Brushy Basin Member of Morrison Formation	295-450 (90-135)	Mudstone to fine-grained sandstone	Yields small amounts of water to wells and springs	Springs: < 1 Wells: < 1	Spring: 1,020	Calcium magnesium sodium sulfate bicarbonate
Salt Wash Member of Morrison Formation	130-300 (40-90)	Interbedded sandstone, conglomerate, and mudstone	Sandstone and conglomerate yield small amounts of water to wells and springs	Springs: < 1 Wells: < 1	Spring: 1,160	Calcium magnesium sodium sulfate bicarbonate
Moab Member of Curtis Formation[3]	70-110 (21-34)	Cross-bedded, well-sorted, fine- to medium-grained sandstone, moderately indurated with calcite cement	Yields abundant water to springs and wells	Springs: 0.1-11.1	Springs: 143-157	Calcium carbonate; hard to very hard
Slick Rock Member of Entrada Sandstone	180-400 (55-122)	Cross-bedded, well-sorted, fine- to medium-grained sandstone, weakly to moderately indurated with calcite cement	Yields moderately abundant water to springs and wells	—	Well: 300	Calcium carbonate; hard to very hard
Navajo Sandstone	165-800 (50-244)	Cross-bedded, well-sorted, fine-grained sandstone, weakly to moderately indurated with calcite cement	Yields abundant water to springs and wells	Springs: <1-5	Springs: 102-350 Well: 210-360	Calcium bicarbonate to calcium magnesium bicarbonate
Wingate Sandstone	250-400 (76-122)	Cross-bedded, well-sorted, fine-grained sandstone, indurated with calcite cement	Yields moderately abundant water to springs and wells	Springs: 10-240	Springs: 161-174 Well[4]: 280-45,000	Calcium magnesium bicarbonate; moderately hard to hard
Arkosic member of Cutler Formation	0-4,000 (0-1,220)	Cross-bedded, medium- to coarse-grained sandstone and minor conglomerate	Yields small amounts of water to wells	Wells: 1-40	Wells: 1,420-3,450	Calcium magnesium sulfate; very hard

Notes:

1. *Unit thicknesses are from Doelling and Morgan (2000) and represent ranges from a wider area than shown on the cross sections on plate 2.*
2. *Data from oil-test wells not included. Total-dissolved-solids concentrations of water from oil wells range from about 2,000 to over 100,000 mg/L (Blanchard, 1990, p. 28).*
3. *Blanchard (1990) does not differentiate the Moab Member of the Curtis Formation (considered a member of the Entrada Sandstone at the time of his report) from the underlying Slick Rock Member of the Entrada Sandstone. Assignment of Blanchard's (1990) data to the Moab or Slick Rock Member is based on work done as part of this study.*
4. *Blanchard (1990) reports a measured value of 45,000 mg/L for one shallow well in the Wingate aquifer. He suggests that this anomalous value is caused by an upward gradient moving ground water from the salt-rich Paradox Formation and/or underlying formations into the Wingate aquifer here.*

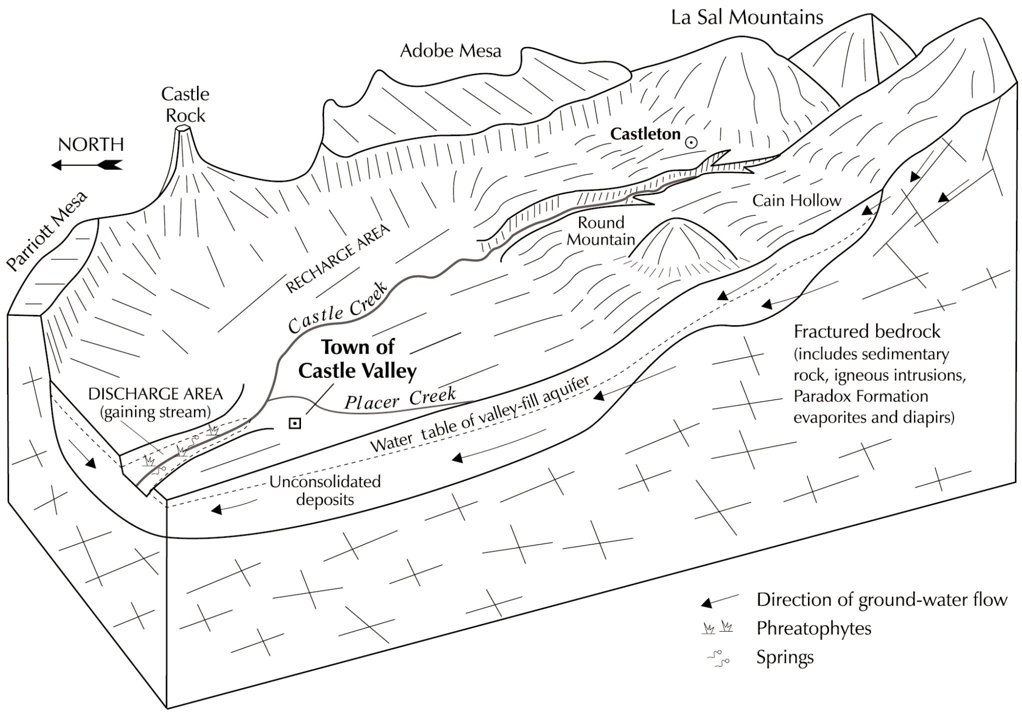

Figure 4. *Schematic block diagram showing ground-water flow in Castle Valley (from Snyder, 1996a).*

unconfined (Snyder, 1996a, b). Wells depths in valley fill range from 58 to 248 feet (18-79 m) and are typically less than 150 feet (45 m) below the land surface (appendix A).

Thickness

Plate 3 illustrates the thickness of unconsolidated valley-fill deposits in Castle Valley. The 25-, 50-, and 100-foot contours (8-, 15-, and 31-m contours, respectively) define a "Y" shape, with the lower arm pointing northwest along Castle Creek and the upper arms diverging from northwest of Round Mountain and following Pinhook Creek and upper Castle Creek. The thickest deposits form a narrow trough over 350 feet (107 m) thick below Castle Creek in sections 8, 9, and 15, T. 25 S., R. 23 E., Salt Lake Base Line and Meridian (SLBM), and deposits southeast of this trough below the central part of the valley are up to 250 feet (76 m) thick. Elsewhere in the valley, unconsolidated deposits are generally less than 150 feet (46 m) thick with numerous buried bedrock ridges and small, deep troughs. The most prominent buried ridge is in sections 7 and 17, T. 25 S., R. 23 E., SLBM, where it strikes northwest and is bounded to the northeast and southwest by narrow troughs 150 to 250 feet (46-76-m) thick. The shapes of these second-order features are not well constrained, and some may be artifacts of the driller's interpretation of relatively soft sedimentary rocks as unconsolidated deposits or large slide blocks as bedrock. The thickness of alluvial-fan deposits along the valley margins is highly variable, and in many places between the 0- and 25-foot (0 and 8 m) contours, it may locally exceed 25 feet (8 m) or thin to zero.

The isopach map was constructed from water-well driller's logs and detailed logs of water-well cuttings by Wallace (2002). The majority of wells are in the northwestern third of the valley, so the contours are best constrained there. The comparatively simple structure southeast of this area is likely a result of sparse well coverage. For this reason, the maximum valley-fill thickness between Round Mountain and the area of greatest residential development is poorly constrained.

The Geyser Creek Fanglomerate consists of poorly to moderately consolidated conglomerate and sandstone, and is not included with the valley-fill deposits on plate 3 because its hydraulic conductivity is likely significantly lower than that of the unconsolidated Quaternary deposits. The Geyser Creek Fanglomerate may, however, underlie unconsolidated deposits below northwestern Castle Valley, and could have been interpreted as gravel, conglomerate, or bedrock in the drillers' logs, depending on its degree of cementation. The isopach contours may, therefore, locally include some Geyser Creek Fanglomerate. Some well logs show "conglomerate" below unconsolidated deposits; this "conglomerate" may represent the Geyser Creek Fanglomerate or younger, partially cemented stream deposits, or both. These wells are aligned in a narrow belt below the valley center northwest of Round Mountain (plate 3), suggesting the course of a former stream draining the valley.

Ground-Water Depth, Volume, and Flow Direction

The water table ranges from 30 feet (9 m) to over 100 feet (30 m) below the land surface (Ford and Grandy, 1997). Based on Snyder's (1996a, b) potentiometric surface map (figure 5), the thickness of valley fill shown on plate 3, and an assumed specific yield of 0.25, we estimate the average volume of ground water stored in the valley-fill aquifer is about 150,000 acre-feet (187 hm^3). Ground water flows from valley margins toward Castle and Placer Creeks and

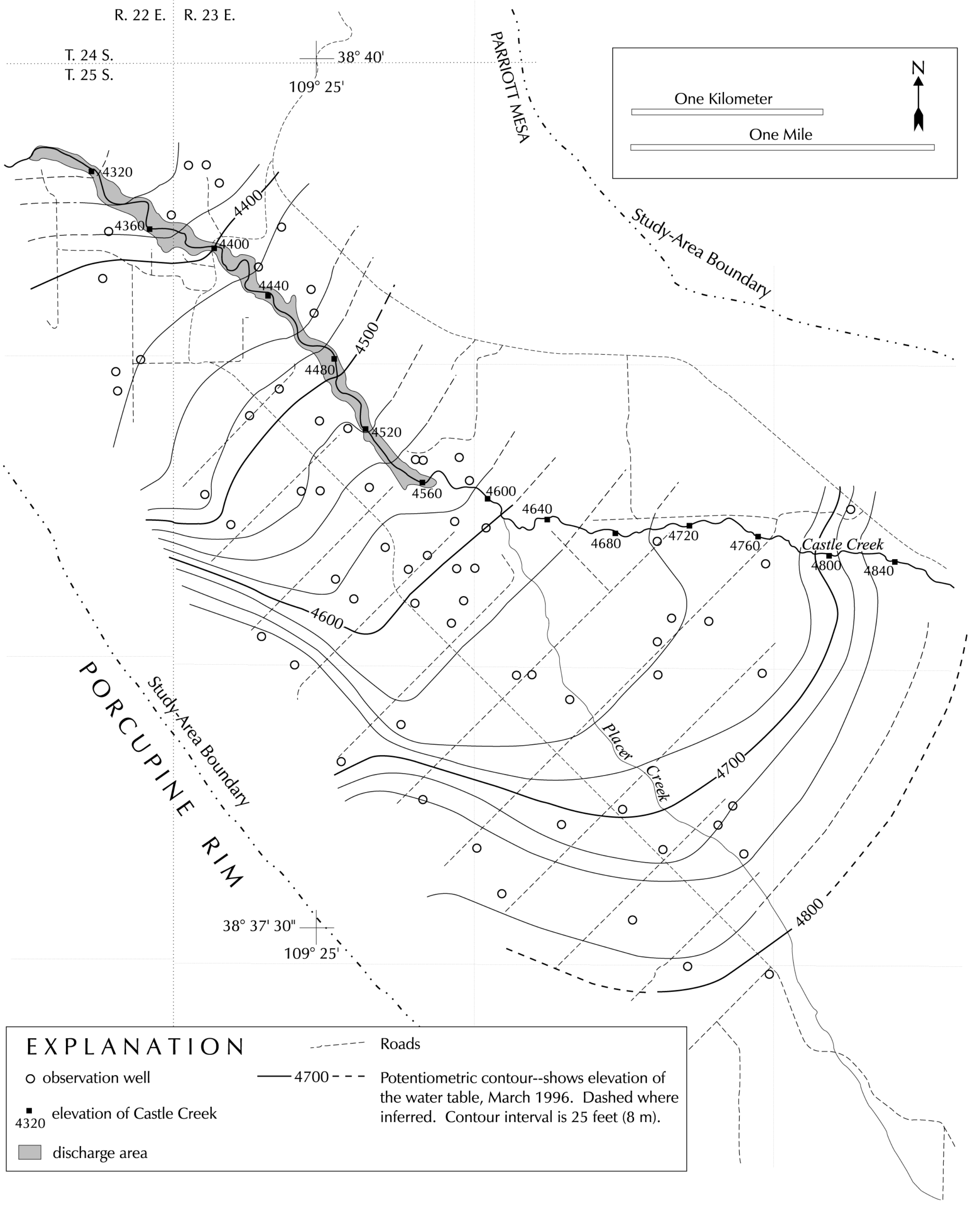

Figure 5. *Potentiometric-surface map of northern Castle Valley showing discharge area and elevations of Castle Creek (from Snyder, 1996a).*

then generally to the northwest parallel to Castle and Placer Creeks toward the Colorado River (figure 5). The hydraulic gradient is estimated to be 0.027 (Town of Castle Valley, 2000) to the northwest parallel to the flows of Castle Creek and Placer Creek (figure 5).

Recharge and Discharge

Castle and Placer Creeks, which originate high in the La Sal Mountains, are sources of recharge to the valley-fill aquifer (Snyder, 1996a, b). As Castle Creek flows across the coarse-grained valley fill along most of its course, much of the flow percolates into the aquifer (Ford and Grandy, 1997); it acts as the primary source of recharge in the valley. Castle Creek is a losing stream and most of the valley is a primary recharge area, except near the town of Castle Valley where the stream channel is incised up to 40 feet (12 m) into the valley fill and has intersected the water table, forming a small discharge area (Snyder, 1996a, b) (figures 4 and 5). Other sources of recharge include (1) direct infiltration of precipitation, especially in the higher parts of the valley, (2) seepage of irrigation water, and (3) subsurface inflow from adjacent fractured bedrock aquifers (Snyder, 1996a, b). Discharge is from (1) wells, (2) evapotranspiration, especially along lower Castle Creek, and (3) underflow to the Colorado River (Snyder, 1996a, b). An annual water budget has not been developed for the Castle Valley valley-fill aquifer system.

Relationship of Geology to Ground-Water Quality

Ground-water quality in Castle Valley is generally good and is suitable for most uses. Most wells in Castle Valley are completed in either the Cutler aquifer or the unconsolidated valley-fill aquifer. Ground-water quality in both aquifers is influenced by proximity to various bedrock units, with the Paradox Formation having the strongest influence.

The Cutler aquifer in Castle Valley typically contains calcium-magnesium-sulfate- or calcium-magnesium-sodium-sulfate-type water (Blanchard, 1990). Ground water from wells completed in the Cutler Formation is generally higher in TDS concentration than ground water from wells completed in adjacent valley fill (Snyder, 1996a, b). The lowest TDS values come from the shallower wells in eastern Castle Valley that may be receiving some recharge from the valley-fill aquifer; the highest values come from wells at the base of Porcupine Rim where gypsum along drainages may indicate proximity to Paradox Formation evaporites (Snyder, 1996a, b). Blanchard (1990) reported that ground-water samples from three wells in the Cutler Formation near the town of Castle Valley had TDS concentrations ranging from 1,420 mg/L to 3,450 mg/L, and that two of these wells exceeded the ground-water quality (health) standard of 10 micrograms per liter for selenium (the wells yielded 21 and 30μg/L selenium; the standard is presently 50 micrograms per liter). Ford and Grandy (1997) reported that ground-water samples from wells completed in the Cutler aquifer in Castle Valley had specific-conductance values ranging from 835 to 4,650 micromhos per centimeter at 25°C. However, Ford and Grandy (1995) did not find high selenium concentrations in any of the wells they sampled. Snyder (1996a, b) noted that most of the ground water yielded to wells from the Cutler aquifer fell within Class II, but that some wells yielded Class III ground water in the northern part of the valley. Snyder (1996a, b) attributed the poor-quality ground water in the Cutler aquifer to be the result of some combination of three possible factors: (1) long residence time and flow path, (2) dissolved fine-grained constituents, such as evaporites, of the Cutler Formation, and (3) hydraulic connection to the Paradox Formation evaporites beneath the Cutler Formation.

Ford and Grandy (1995) reported that specific-conductance values for samples from eight valley-fill aquifer wells in Castle Valley ranged from 357 to 1,960 micromhos per centimeter at 25°C. Ground water from wells and springs in the valley-fill aquifer exhibits a general down-valley increase in dissolved solids (Weir and others, 1983; Ford, 1994; Snyder, 1996a, b). Higher quality ground water (less than 1,000 micromhos/cm) along Castle and Placer Creeks confirms that Castle Creek is a principal source, and Placer Creek a subordinate source of recharge to the valley-fill aquifer (Snyder, 1996a, b; Doelling and Ross, 1998). Lower-quality ground water (greater than 2,000 micromhos/cm) from valley-fill wells and springs, and from Castle Creek in the far northwestern part of Castle Valley, is probably due to a local hydraulic connection to water in the Paradox Formation (Snyder, 1996a, b; Doelling and Ross, 1998). Snyder (1996a, b) attributed the down-valley increase in TDS concentrations in the valley-fill aquifer to recharge from the Cutler and Paradox Formations which contain poorer-quality water.

Ford and Grandy (1995) reported nitrate concentrations of less than 1 mg/L for ground-water samples from wells completed in the Castle Valley valley-fill aquifer. Additionally, Ford and Grandy (1995) found no fecal coliform in the eight valley-fill wells sampled in Castle Valley.

GROUND-WATER QUALITY CLASSIFICATION

Introduction

Ground-water quality classification, based primarily on TDS (table 1), is a tool for local governments in Utah to use for managing potential ground-water contamination sources and for protecting the quality of their ground-water resources. Information regarding ground-water quality classification, including what is required to classify ground-water quality and why ground-water quality classification should be considered as a tool to protect ground-water quality, is presented in the Utah Division of Water Quality's (1998) *Aquifer Classification Guidance Document* and Lowe and Wallace (1999a, b).

Results

2000-2003 Data for Valley-Fill Aquifer

Data sources: As part of this ground-water quality classification, we sampled ground water from 40 wells in October 2001, and had the samples analyzed for general chemistry and nutrients by the Utah Department of Epidemiology and Laboratory Services; of these 40 wells, ground water from 10 wells was analyzed for organics and pesticides and ground water from 5 wells was analyzed for radionuclides (appendix

A). We also measured specific conductance of water from another five wells and four surface-water sites in February 2003; because of an apparent hydraulic connection between ground and surface water in the Castle Valley valley-fill aquifer, surface-water quality is likely representative of ground-water quality. These data were augmented by another 43 wells sampled in September 2000 and analyzed for specific conductance, pesticides, and nutrients (appendix A) by the Utah Department of Agriculture and Food (Quilter, 2001), and specific-conductance and TDS concentration data from ground water from 6 wells measured by the Utah Division of Water Rights between 1991 and 1996 (appendix A) (Ford and Grandy, 1997). Data reported by the Utah Division of Water Rights were also analyzed by the Utah Department of Epidemiology and Laboratory Services.

Total-dissolved-solids concentrations: The Utah Water Quality Board's drinking-water quality (health) standard for TDS is 2,000 mg/L for public-supply wells (appendix B). The secondary ground-water quality standard is 500 mg/L (U.S. Environmental Protection Agency, 2002) (appendix B), and is primarily due to imparting a potential unpleasant taste to the water (Bjorklund and McGreevy, 1971). Plate 4 shows the distribution of TDS in Castle Valley's valley-fill aquifer. Based on data from ground-water samples from 54 wells and the 4 surface-water sites, TDS concentrations in the valley-fill aquifer range from 204 to 2,442 mg/L. Only 17 wells exceed 1,000 mg/L TDS and the overall average TDS concentration of the 54 wells is 785 mg/L (appendix A, plate 4).

The higher TDS concentrations exist along the northwest margins of Castle Valley (plate 4) where the Cutler Formation is encountered at relatively shallow depths and where negligible mixing of ground and surface water occurs. Relatively high TDS concentrations are also present around Castleton and at the northwest end of the valley (figure 1, plate 4) where the Paradox Formation is exposed (plate 1).

Nitrate concentrations: The ground-water quality (health) standard for nitrate is 10 mg/L (appendix B) (U.S. Environmental Protection Agency, 2002). More than 10 mg/L of nitrate in drinking water can result in a condition known as methoglobinemia, or "blue baby syndrome" (Comley, 1945) in infants under six months and can be life threatening without immediate medical attention (U.S. Environmental Protection Agency, 2002). This condition is characterized by a reduced ability for blood to carry oxygen. Based on data from ground-water samples from 52 wells, nitrate-as-nitrogen concentrations range from less than 0.1 to 4.27 mg/L. Six wells yield ground water above 1 mg/L and the overall average nitrate concentration for the 52 wells is 0.52 mg/L (appendix A). No apparent trend in the distribution of nitrate concentrations exists (plate 5); the highest concentrations (1.54 and 4.27 mg/L) are likely attributed to proximity to stables/corrals.

Other constituents: Based on the data presented in appendix A, no wells exceeded primary water-quality standards for any chemical constituent, and no pesticides were detected (Quilter, 2001). However, one well exceeded the secondary ground-water quality standards for iron and chloride, and 25 wells exceeded the secondary ground-water quality standard for sulfate (figure 6, appendix A).

The secondary ground-water quality standard for iron is 300μg/L (appendix B) (U.S. Environmental Protection Agency, 2002), primarily to avoid objectionable staining to plumbing fixtures, other household surfaces, and laundry (Fetter, 1980; Hem, 1989). Water high in dissolved iron can also lead to the growth of iron bacteria which may lead to the clogging of water mains, recirculating systems, and sometimes wells (Driscoll, 1986). At concentrations over 1.8 mg/L, iron imparts a metallic taste to drinking water (Fetter, 1980). Concentrations of dissolved iron in Castle Valley's principal aquifer from ground-water samples from 52 wells range from less than 20 to 330 μg/L, with an average (background) dissolved-iron concentration of 53.6 μg/L. A total of 30 wells yielded ground water that was below the detection limit for dissolved iron of 20 μg/L (appendix A) for the analysis method listed in table 2. The location of the one well that yielded water exceeding the secondary ground-water quality standard for iron is shown on figure 6.

The secondary ground-water quality standard for sulfate is 250 mg/L (appendix B) (U.S. Environmental Protection Agency, 2002), primarily because of odor/taste problems and because high-sulfate water can have a laxative effect (Fetter, 1980). Concentrations of dissolved sulfate in Castle Valley's principal aquifer range from 39.6 to 1,350 mg/L, with an average (background) sulfate concentration of 340 mg/L. No wells yielded ground water below the detection limit for sulfate of 10 mg/L (appendix A) for the analysis method listed in appendix B. Twenty-five wells yielded water samples that exceed the secondary ground-water quality standard for sulfate (figure 6). Geologic provenance (source rock for valley-fill sediment) likely is an important factor determining the distribution of sulfate in the valley-fill aquifer; metallic sulfides in both igneous and sedimentary rocks are common sources of sulfur in its reduced form (Hem, 1989), as is gypsum which is found in the Paradox Formation.

The secondary ground-water quality standard for chloride is 250 mg/L (appendix B) (U.S. Environmental Protection Agency, 2002), primarily because of the potential for imparting a salty taste to drinking water (Hem, 1989). Chloride at concentrations over 500 mg/L can cause corrosion to wells and plumbing (Driscoll, 1986). Concentrations of dissolved chloride in Castle Valley's principal aquifer (figure 6) range from 13.7 to 282 mg/L, with an average (background) chloride concentration of 68.2 mg/L. No wells yielded ground water below the detection limit for chloride of 3 mg/L (appendix A) for the analysis method listed in appendix B. One well yielded a water sample that exceeds the secondary ground-water quality standard for chloride (figure 6). Geologic provenance likely is an important factor determining the distribution of chloride in the valley-fill aquifer; although chloride is present at low concentrations in many rock types, it is more common in sedimentary rocks, especially evaporites (Hem, 1989). The Paradox Formation is a known source of chloride (Sumsion, 1971).

Resulting Ground-Water Quality Classification

Shown on plate 6 is our ground-water quality classification for the northwestern part (40 percent) of the valley-fill aquifer in Castle Valley, approved by the Utah Water Quality Board on December 5, 2003. The classification is based on data from 54 wells presented in appendix A and discussed above, and on TDS values converted from specific-conductance data for 14 wells and 4 surface-water sites reported by

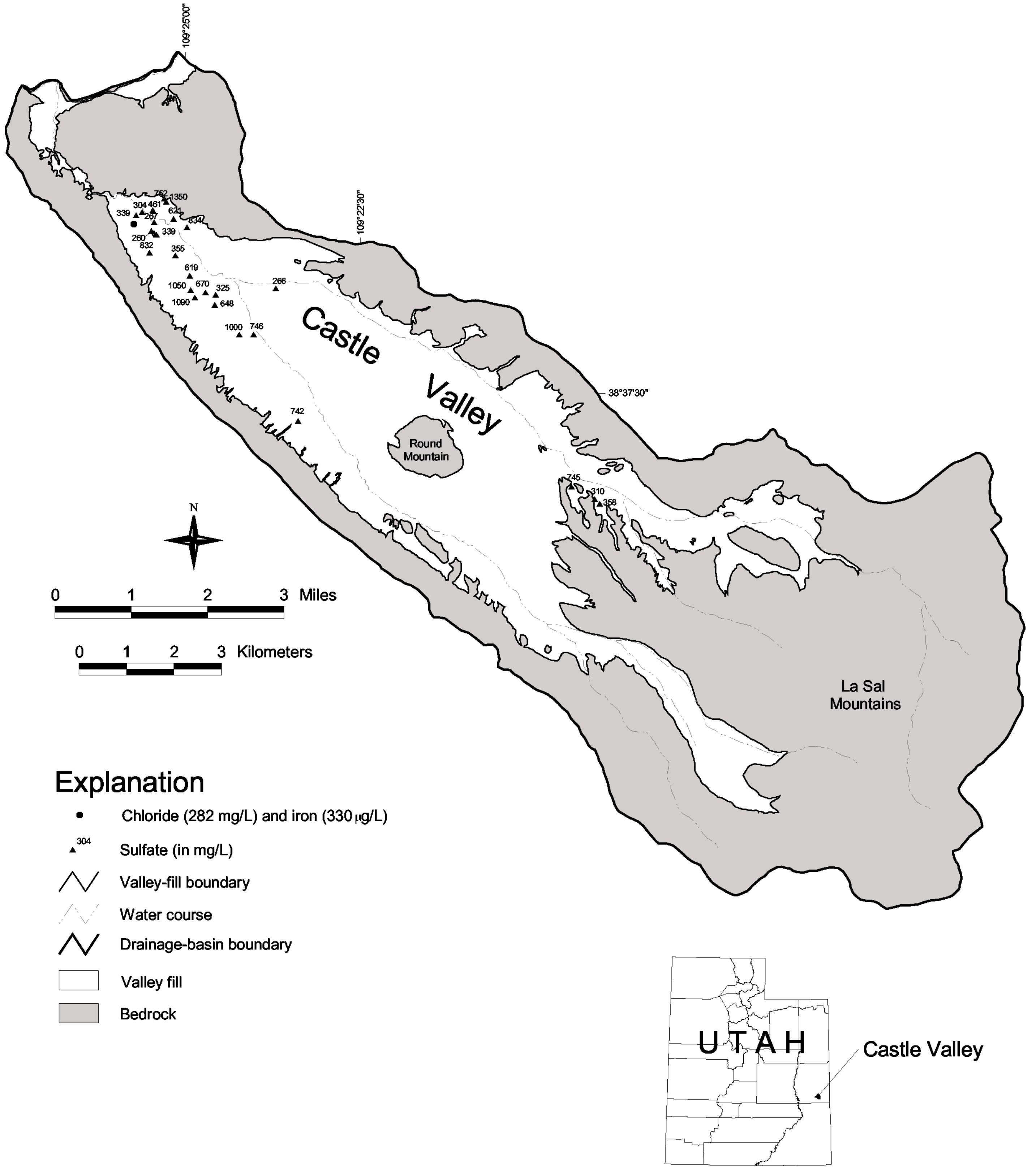

Figure 6. *Water wells having chemical constituents that exceed secondary drinking-water standards in Castle Valley, Grand County, Utah. One well has elevated chloride and iron concentrations and 25 wells have elevated sulfate concentrations.*

the Utah Geological Survey (UGS), Utah Department of Agriculture and Food, Utah Division of Water Rights (UDWRi), and Utah Division of Water Quality (UDWQ). Total-dissolved-solids concentrations for the 14 wells and 4 surface-water sites were calculated based on the relationship between specific conductance and TDS derived from data from 44 wells in Castle Valley for which both values are known (figure 7, appendix A). Some TDS data collected in the southern part of the valley by the UGS, UDWQ, and UDWRi were resampled by citizens of Castle Valley during different seasons; the resulting data show variations in water quality (seasonally fluctuating between Class IA and Class II), and were not useful in classifying ground water in the southeastern part (60 percent) of Castle Valley because of insufficient water-quality data. Where limited and variable water-quality data exist (temporally and spatially), extrapolation of ground-water quality conditions is required. We based the extrapolation on local geologic characteristics (see geologic cross sections, plate 1, Town of Castle Valley, 2000). The classes (plate 6) are described below.

Class IA- Pristine ground water: For this class, TDS concentrations in Castle Valley range from 204 to 480 mg/L (appendix A). Class IA areas are mapped primarily in the central part of northwestern Castle Valley near the confluence of Castle and Placer Creeks where recharge from surface water is sufficient to keep ground water diluted below 500 mg/L total dissolved solids (plate 6), or are pristine due to the presence of less-soluble minerals in the alluvium there. Areas having Pristine water quality cover about 48 percent of the classified part of the valley-fill material in northwestern Castle Valley.

Class II- Drinking Water Quality ground water: For this class, TDS concentrations in the Castle Valley valley-fill aquifer range from 602 to 2,442 mg/L (appendix A). Class II areas defined by TDS data, and some specific-conductance data converted to TDS, collected as part of this and previous studies represent about 52 percent of the classified part of the valley-fill material in northwestern Castle Valley, and are found along the western margin and northern end of the valley (plate 6).

Unclassified part of valley-fill aquifer in Castle Valley: Areas having limited data within the drainage basin cover about 60 percent of the total valley-fill material. We believe this area will yield both Class IA and Class II quality ground water based on extrapolated geologic conditions (see plate 1 cross sections, Town of Castle Valley, 2000; plate 2) and water-quality information collected from all four agencies described earlier. The water-quality data indicate both temporal and spatial fluctuations in water quality. Based on the nature of the Cutler Formation beneath valley-fill material in some areas, and along faults, we believe proposed water wells adjacent to or tapping into this unit may potentially yield water having TDS between 500 and 3,000 mg/L (Drinking Water Quality ground water) or greater, similar to water quality reported from bedrock wells (Ford and Grandy, 1997). We also recognize areas near the less-soluble igneous

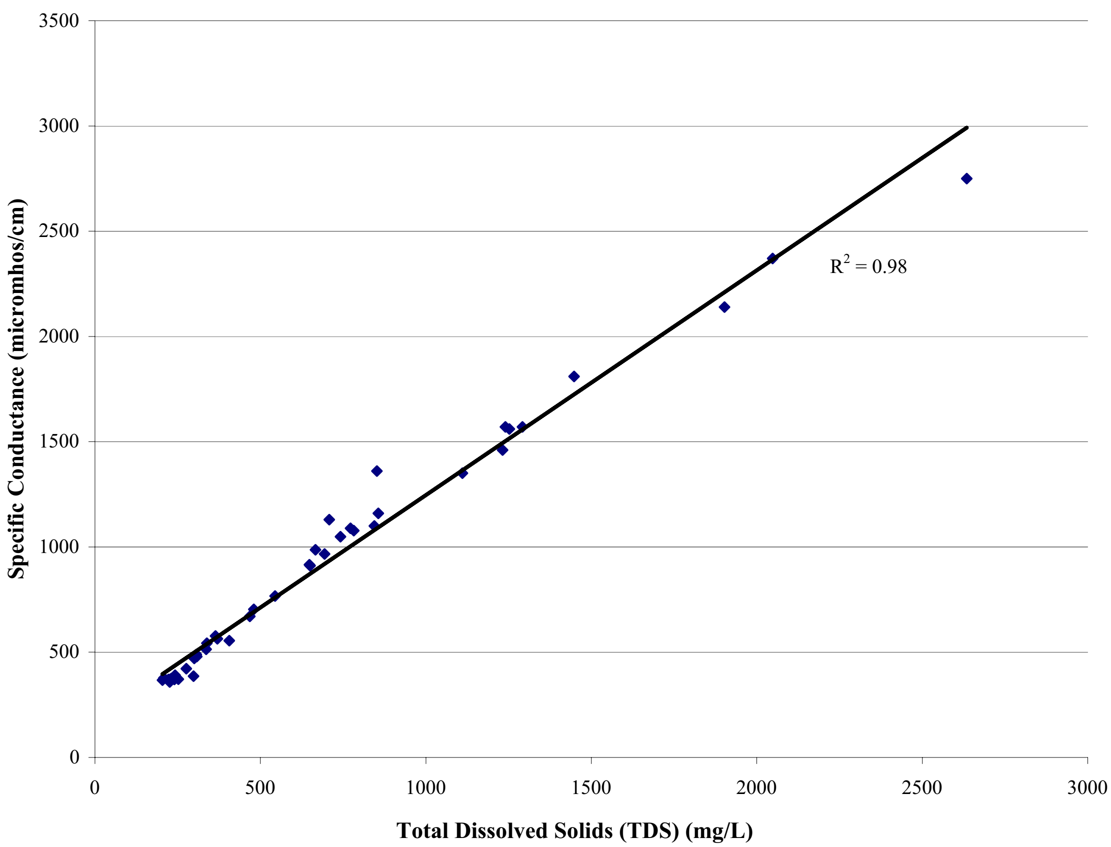

***Figure 7**. Specific conductance versus total-dissolved-solids concentration data for 44 wells in Castle Valley, Grand County, Utah. R-squared is 0.98. Based on Hem's (1985) equation for estimating TDS from specific conductance: KA=S, where K is specific conductance, S is TDS, and A is a coefficient slope that ranges from 0.55 to 0.96. We used an average A=0.69 to compute TDS in Castle Valley.*

rocks of the La Sal Mountains, especially in the extreme southeast part of the valley, as well as areas near Castle Creek, may yield water having TDS less than 500 mg/L (Pristine ground water) (plate 5). However, insufficient data are available to bring a proposed ground-water quality classification before the Utah Water Quality Board.

Land-Use Planning Considerations

Current beneficial uses of ground water: Ground water, most of which is from the valley-fill aquifer, is the most important source of water in Castle Valley. All of the domestic (culinary) water and, on average, 50 percent of the irrigation water used in Castle Valley is from ground-water sources (Casey Ford, Utah Division of Water Rights, verbal communication, July 29, 2002). Castle Valley has 270 approved water wells, one of which is a public-supply well that serves a private school community (Mark Jensen, Division of Drinking Water, verbal communication, August 2002) accommodating up to 25 attendees during the school year. The locations of all water-supply wells are shown on plate 6. The results of the ground-water quality classification for Castle Valley indicate the valley-fill aquifer contains mostly high-quality ground-water resources that warrant protection.

Potential for ground-water quality degradation: We mapped potential ground-water contaminant sources including facilities related to mining, agricultural practices, and junkyard/salvage areas (appendix C, plate 7). A primary objective was to identify potential contaminant sources to establish a relationship between water quality and land-use practices. We mapped 85 potential contaminant sources in the following categories:

(1) mining, which includes abandoned and active gravel mining operations,

(2) agricultural sites, which consist of irrigated and non-irrigated farms, active and abandoned animal feed lots, corrals, stables/barnyards, and animal wastes, including wastes dominantly produced from feeding facilities, waste transported by runoff, and excrement on grazing or pasture land,

(3) junkyard/salvage areas that potentially contribute metals, solvents, and petroleum products,

(4) government facility/equipment storage associated with a variety of sources such as salt storage facilities, transportation/equipment storage, and mosquito abatement equipment that may contribute metals, solvents, and petroleum,

(5) cemeteries, nurseries, greenhouses, and a golf course that may contribute chemical preservatives, fertilizer, and pesticides,

(6) storage tanks that may contribute pollutants such as fuel and oil, and

(7) oil and gas wells that may also contribute pollutants such as petroleum and oil.

In addition to the above-described potential contaminants, plate 7 shows the distribution of septic tank soil-absorption systems in Castle Valley. Castle Valley currently has approximately 235 septic-tank systems (Jim Adamson, Southeastern Utah District Health Department, written communication, June 2002). Septic-tank systems may contribute contaminants such as nitrate and solvents. All approved water wells, shown on plate 6, are also considered potential contaminant sources because of the potential for substances to be placed in or poured down them.

Possible land-use planning applications of this ground-water quality classification: Ground-water quality classification is a tool that can be used in Utah to manage potential ground-water contamination sources and protect the quality of ground-water resources. As such, the wide range of land-use planning applications of this tool have not been fully explored. Ground-water quality classification has been used in Heber Valley in Wasatch County and Ogden Valley in Weber County, in concert with septic-tank density/water-quality degradation studies (Hansen, Allen, and Luce, Inc., 1994; Wallace and Lowe, 1998a, 1999; Lowe and Wallace, 2001), to determine appropriate sizes of lots using septic-tank systems for wastewater disposal.

One possible application of the ground-water quality classification presented above is using the classification in conjunction with the septic-tank density/water-quality degradation analysis presented below to set areal maximum densities for development using septic-tank systems for wastewater disposal in Castle Valley. Additional potential uses include using ground-water quality classification as a basis for prohibiting the dumping of poor-quality water and other liquid or solid wastes into creek beds or canals and ditches. Ground-water quality classification can also be used in conjunction with the existing Sole Source Aquifer designation to enhance restrictions to the siting of new potential pollution sources in the valley-fill portion of the Castle Valley drainage basin.

SEPTIC-TANK DENSITY/WATER-QUALITY DEGRADATION ANALYSIS

Introduction

Land-use planners have long used septic-tank suitability maps to determine where these systems will likely percolate within an acceptable range. However, they are now becoming aware that percolation alone does not remediate many constituents found in wastewater, including nitrate. Ammonium from septic-tank effluent under aerobic conditions can convert to nitrate, contaminating ground water and posing potential health risks to humans (primarily very young infants). The U.S. Environmental Protection Agency's maximum contaminant level for drinking water (Utah ground-water quality standard) for nitrate is 10 mg/L. With continued population growth and installation of septic tank soil-absorption systems in new developments, the potential for nitrate contamination will increase. One way to evaluate the potential impact of septic-tank systems on ground-water quality is to perform a mass-balance calculation (Hansen, Allen, and Luce, Inc., 1994; Zhan and McKay, 1998; Lowe and Wallace, 1999c, d; Wallace and Lowe, 1999; Lowe and others, 2000). This type of analysis may be used as a gross model for evaluating the possible impact of proposed developments using septic-tank systems for wastewater disposal on ground-water quality, allowing planners to more effectively determine appropriate average septic-system densities.

Ground-Water Contamination from Septic-Tank Systems

Pathogens

As the effluent from a septic tank soil-absorption system leaves the drain field and percolates into the underlying soil, it can have high concentrations of pathogens, such as viruses and bacteria. Organisms such as bacteria can be mechanically filtered by fine-grained soils and are typically removed after traveling a relatively short distance in the unsaturated zone. However, in coarse-grained soils, or soils containing preferential flow paths like cracks, worm burrows, or root holes, these pathogens can reach the water table. Living pathogens can travel up to 40 feet (12 m) in the unsaturated zone in some soils (Franks, 1972). Some viruses can survive up to 250 days (U.S. Environmental Protection Agency, 1987), which is the minimum ground-water time of travel for public water-supply wells or springs to be separated from potential biological contamination sources.

Household and Industrial Chemicals

Many household and industrial chemicals (table 3) are commonly disposed of through septic systems and, unless they volatilize easily, are not remediated by percolation through soils in the unsaturated zone. Contamination from these chemicals can be minimized by reducing their disposal via septic-tank systems, maximizing the potential for dilution of those chemicals that do reach ground water (Lowe and Wallace, 1999e).

Phosphate

Phosphate, typically derived from organic material or some detergents, is discharged from septic-tank systems (Fetter, 1980). While phosphate (and phosphorus) is a major factor in causing eutrophication of surface waters (Fetter, 1980), it is generally not associated with water-quality degradation from septic-tank systems (Lowe and Wallace, 1999e). Phosphates are removed from septic-tank system effluent by adsorption onto fine-grained soil particles and by precipitation with calcium and iron (Fetter, 1980). In most soils, complete removal of phosphate is common (Franks, 1972).

Nitrate

Ammonia and organic nitrogen are commonly present in effluent from septic-tank systems (table 3), mostly from the human urinary system. Typically, almost all ammonia is converted into nitrate before leaving the septic tank soil-absorption system drain field. Once nitrate passes below the zone of aerobic bacteria and the roots of plants, there is negligible attenuation as it travels farther through the soil (Franks, 1972). Once in ground water, nitrate becomes mobile and

Table 3. *Typical characteristics of wastewater from septic-tank systems (from Hansen, Allen, and Luce, Inc., 1994).*

Parameter	Units	Quantity
Total Solids	mg/L	680 - 1000
Volatile Solids	mg/L	380 - 500
Suspended Solids	mg/L	200 - 290
Volatile Suspended Solids	mg/L	150 - 240
BOD	mg/L	200 - 290
Chemical Oxygen Demand	mg/L	680 - 730
Total Nitrogen	mg/L	35 - 170
Ammonia	mg/L	6 - 160
Nitrites and Nitrates	mg/L	<1
Total Phosphorus	mg/L	18 - 29
Phosphate	mg/L	6 - 24
Total Coliforms	**MPN/100 mL	10^{10} - 10^{12}
Fecal Coliforms	**MPN/100 mL	10^{8} - 10^{10}
pH	-	7.2 - 8.5
Chlorides	mg/L	86 - 128
Sulfates	mg/L	23 - 48
Iron	mg/L	0.26 - 3.0
Sodium	mg/L	96 - 110
Alkalinity	mg/L	580 - 775
P-Dichlorobenzene*	mg/L	0.0039
Toluene*	mg/L	0.0200
1,1,1-Trichloroethane*	mg/L	0.0019
Xylene*	mg/L	0.0028
Ethylbenzene*	mg/L	0.004
Benzene*	mg/L	0.005

** Volatile Organics are the maximum concentrations*
*** Most probable number*

can persist in the environment for long periods of time. Areas having high densities of septic-tank systems risk elevated nitrate concentrations reaching unacceptable levels. In the early phases of ground-water quality degradation associated with septic-tank systems, nitrate is likely to be the only pollutant detected (Deese, 1986). Regional nitrate contamination from septic-tank discharge has been documented on Long Island, New York, where many densely populated areas without sewer systems existed (Fetter, 1980).

A typical single-family septic-tank system in Castle Valley discharges about 171 gallons (747 L) of effluent per day containing nitrate concentrations of around 54.4 mg/L; see discussion below. The U.S. Environmental Protection Agency maximum contaminant level for drinking water (ground-water quality [health] standard) for nitrate is 10 mg/L. Therefore, distances between septic-tank system drain fields and sources of culinary water must be sufficient to allow dilution of nitrate in the effluent to levels below the ground-water quality standard.

We consider nitrate to be the key indicator for use in determining the number or density of septic-tank systems that should be allowed in Castle Valley. Projected nitrate concentrations in all or parts of aquifers can be estimated for increasing septic-tank system densities using a mass-balance approach.

The Mass-Balance Approach

General Methods

We use a mass-balance approach for water-quality degradation assessments because it has been used elsewhere in the western United States for land-use planning purposes (Hansen, Allen, and Luce, Inc., 1994; Wallace and Lowe, 1998a, b, c, 1999; Zhan and McKay, 1998; Lowe and Wallace, 1999c, d; Lowe and others, 2000), is easily applied, and requires few data. In the mass-balance approach to compute projected nitrate concentrations, the average nitrogen mass expected from projected new septic tanks is added to the existing, ambient (background) mass of nitrogen in ground water and then diluted with the known (or estimated) ground-water flow available for mixing, plus water that is added to the system by septic tanks. We used a discharge of 171 gallons (747 L) of effluent per day for a domestic home based on a per capita indoor usage of 70 gallons (265 L) per day (Utah Division of Water Resources, 2001a; 2001b, p. 28) by Grand County's average 2.44 person household (U.S. Census Bureau, 2002). We used an estimated nitrogen loading of 54.4 mg/L of effluent per domestic septic tank for nitrogen loadings based on (1) an average number of people per household of 2.44, (2) an average nitrogen loading of 17 g N per capita per day (Kaplan, 1988, p. 149), and (3) an assumed retainment of 15 percent of the nitrogen in the septic tank (to be removed later during pumping) (Andreoli and others, 1979, *in* Kaplan, 1988, p. 148); this number is close to Bauman and Schafer's (1985, *in* Kaplan, 1988, p. 147) nitrogen concentration in septic-tank effluent of 62 ± 21 mg/L based on the averaged means from 20 previous studies. Ground-water flow available for mixing, the major control on nitrate concentration in aquifers when using the mass-balance approach (Lowe and Wallace, 1997), was determined using the ground-water flow model of Downs and Lasswell (undated).

Limitations

All mass-balance approaches have limitations (see, for example, Zhan and McKay [1998]). We identify the following limitations to our application of the mass-balance approach:

1. Calculations are typically based on a short-term hydrologic budget, a limited number of aquifer tests, and limited water-gradient data.
2. Background nitrate concentration is attributed to natural sources, agricultural practices, and use of septic-tank systems, but projected nitrate concentrations used in this approach are based on septic-tank systems only and do not include nitrate from other potential sources (such as lawn and garden fertilizer).
3. Calculations do not account for localized, high-concentration nitrate plumes associated with individual or clustered septic-tank systems, and also assume that the septic-tank effluent from existing homes is in a steady-state condition with the aquifer.
4. The approach assumes negligible denitrification.
5. The approach assumes uniform, instantaneous ground-water mixing for the entire aquifer or entire mixing zone below the site.
6. Calculations do not account for changes in ground-water conditions due to ground-water withdrawal from wells (see Recharge and Discharge section above).
7. Calculations are based on aquifer parameters that must be extrapolated to larger areas where they may not be entirely representative.
8. Calculations may be based on existing data that do not represent the entire valley.

Although many caveats to applying this mass-balance approach exist, we think it is useful in land-use planning because it provides a general basis for making recommendations for septic-tank-system densities. In addition, the approach is cost-effective and easily applied with limited information.

Ground-Water Flow Calculations

Introduction

We used the GMS ground-water modeling system, applied to a modified three-dimensional, steady-state MODFLOW model of Downs and Lasswell (undated), to determine the available ground-water flow in the saturated, unconsolidated valley-fill deposits in Castle Valley. We modified the model by incorporating hydraulic conductivities determined from an aquifer test in the valley. The model simulated unconfined conditions, withdrawal from wells, evapotranspiration, seepage to and from streams, areal recharge, seepage to drains, and seepage from consolidated rock.

Computer Modeling

We used Downs and Lasswell's (undated) numerical model of ground-water flow in Castle Valley to simulate ground-water flow in the unconsolidated valley-fill aquifer, because it provides the best representation currently available of the Castle Valley valley-fill aquifer. The ground-water flow model extends from the surface-water divide in the La Sal Mountains to the Colorado River, and covers an area of about 110 square miles (280 km^2). Because of its rectangular construction, the model area is larger than the 56-square-mile (145 km^2) Castle Valley drainage basin, but this does not affect the results of the mass-balance analysis. The model simulates ground-water flow by approximating the differential equation for steady-state flow of water in an aquifer, in this case, both fractured rock and unconsolidated valley fill in the drainage basin. Application of the model to the valley-fill aquifer requires estimates of recharge, discharge, and the hydraulic characteristics of the aquifer throughout the area. Hydraulic characteristics include saturated thickness, hydraulic conductivities, storage coefficients, and water levels. We made initial estimates for each of these characteristics from field data, and then adjusted the model to improve the estimates of hydraulic characteristics based on aquifer- and slug-test data (appendix E). The steady-state ground-water flow model provided the cells that we used to determine the amount of ground water available in the valley-fill aquifer.

Description of Model of Downs and Lasswell (Undated)

Downs and Lasswell (undated) used the USGS modular three-dimensional, finite-difference, ground-water flow simulator (MODFLOW) by McDonal and Harbaugh (1988) to test and refine their conceptual understanding of the ground-water flow system in Castle Valley. The model assumes three-dimensional flow in the aquifer and one-dimensional vertical flow between layers using a vertical leakance term, and ignores storage.

Downs and Lasswell (undated) developed a generalized conceptual model using limited geologic and hydrologic information. Their conceptual model includes (1) ground-water boundaries, (2) rates of recharge and discharge, (3) estimated values of hydraulic properties, and (4) water levels in the valley-fill aquifer.

The conceptual model does not account for subsurface inflow from adjoining areas outside the surface-drainage basin. The location of the ground-water divides, and general directions of ground-water flow were determined from Snyder's (1996a, b) potentiometric-surface map. Where no water-level data were available, the water table was estimated by extrapolating of the potentiometric-surface gradient from areas having data.

Downs and Lasswell (undated) identified infiltration of precipitation and an areal distribution of representative recharge from the streams as main sources of recharge to the valley-fill aquifer. The estimates of recharge from precipitation are based on the distribution of annual precipitation and evapotranspiration rates. Net recharge rates are relatively high in the mountains and upper valley due to the higher precipitation and stream recharge there. In the lower parts of the valley, evapotranspiration exceeds precipitation and recharge from precipitation is negligible (Downs and Lasswell, undated).

In the Downs and Lasswell (undated) model, the valley-fill aquifer is mostly recharged from the underlying bedrock. However, throughout most of Castle Valley, Castle and Placer Creeks are losing streams and are the primary sources of recharge to the valley-fill aquifer (Snyder, 1996a, b). As modeled by Downs and Lasswell (undated), ground-water discharge from the valley-fill aquifer is primarily from (1) evapotranspiration, (2) seepage to Castle Creek and Placer Creek where streams contact the valley-fill aquifer, (3) withdrawals from water wells, and (4) seepage to the Colorado River.

Downs and Lasswell (undated) simplified this conceptual model of the Castle Valley ground-water system to facilitate creation of their numerical model of ground-water flow. Their simplified assumptions for the aquifer are, from the surface downward:

- An upper unconsolidated valley-fill aquifer of variable thickness. The alluvial sediments consist of as much as 350 feet (107 m) of poorly sorted, coarse gravel, sand, and silt, 0 to 300 feet (0-90 m) of which can be saturated with ground water. The thickness of the valley-fill aquifer decreases toward the mountains. There is no lateral subsurface inflow from adjoining areas.
- A semiconfining boundary condition between the valley-fill aquifer and the underlying fractured-rock aquifers that allows some vertical ground-water movement.
- An extensive, lower fractured-rock aquifer that consists of sandstone having an unknown thickness that Downs and Lasswell (undated) arbitrarily designate as 500 feet (150 m). This aquifer acts as a single water-bearing unit. There is no lateral subsurface inflow to it from adjoining areas.
- An impermeable base of bedrock (no-flow boundary condition) at depths greater than 500 feet (150 m).

The steady-state model incorporates averaged hydraulic characteristics and pumping in Castle Valley over several time periods.

Boundary conditions imposed on the Castle Valley model involved considerable simplification of the hydrologic system. Downs and Lasswell (undated) specified most of the lateral boundaries surrounding the valley as "no-flow" boundaries (figure 8) on the assumption that they coincide with low-permeability bedrock. In layer one, the no-flow boundaries of the active model area were selected to coincide with the natural valley-fill/bedrock boundaries on the northeastern and southwestern sides of the aquifer. In the southeastern part of the drainage, the model boundary coincides with ground-water divides underlying the highest points of land. The northwestern boundary corresponds to the Colorado River, where the aquifer is narrow and flow lines are perpendicular to the river. Exceptions to the no-flow boundaries are the 30 constant-head cells at the north end of the model that simulate the elevation of the Colorado River. The upper boundary of the model is a specified-flux boundary formed by using the recharge, well, evapotranspiration, and drain packages of MODFLOW to simulate the infiltration of precipitation and discharge of ground water for layer one. The lower boundary of the model is a no-flow boundary below layer two. We did not modify the boundary conditions of the model.

Because aquifer characteristics are not uniform, the aquifer was divided into rectangular cells in which the characteristics were assumed to be uniform at a node in the center of each cell, but can vary from node to node. The ground-water flow simulator solves for the flow at each node using a three-dimensional, finite-difference approximation to the partial differential equation of ground-water flow. Downs and Lasswell (undated) discretized the valley-fill aquifer into a three-dimensional grid of 93 rows by 53 columns, and divided the model into a valley-fill layer and a bedrock layer. The rectilinear grid consists of 4,836 cells per layer and covers an area of 110.25 square miles (284 km^2). The model has non-uniform grid-cell dimensions ranging from 50 feet by 50 feet (15 by 15 m) to 300 feet by 300 feet (90 by 90 m) (cell

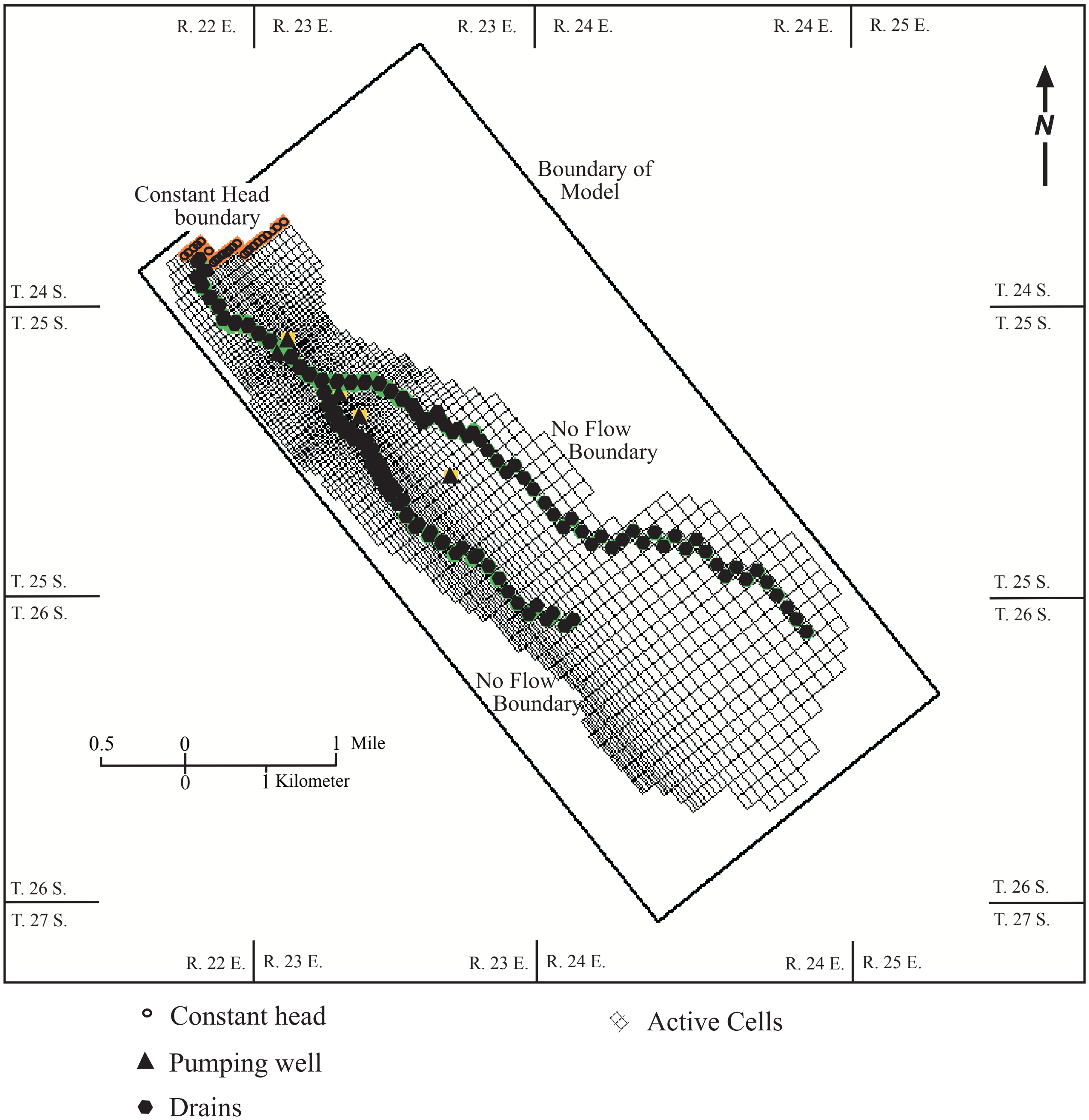

Figure 8. *Finite-difference grid and some boundary conditions used in the mathematical model for the valley-fill aquifer in Castle Valley, Grand County, Utah.*

areas ranging from 2,500 square feet to 90,000 square feet [230-8,300 m^2]). The variable grid dimensions emphasize areas of special interest and/or where more data exist, particularly in the vicinity of the town of Castle Valley. Layer one, the valley-fill aquifer layer, has a variable thickness, and layer two, the bedrock aquifer layer, has a constant thickness of 500 feet (150 m). Each layer has 2,893 active grid cells that cover an area of about 46 square miles (120 km^2). The active cells in layer one cover the major parts of Castle Valley where the Quaternary-age valley-fill material is more than 10 feet (3 m) thick. Layer two represents saturated bedrock from the bottom of the valley-fill deposits to a thickness of 500 feet (150 m). The y-axis of the model is oriented northwest-southeast in alignment with the primary surface-water drainages and predominant direction of ground-water flow. We did not modify the model grid.

The hydraulic characteristics of the valley-fill aquifer affect the amount of water moving through the aquifer, the amount of water in storage, and water levels in the valley. Downs and Lasswell (undated) initially estimated hydraulic parameters and aquifer thickness based on geologic descriptions of valley-fill deposits. The hydraulic parameters for the bedrock aquifer were based on an aquifer test in Spanish Valley.

We modified the hydraulic conductivity in layer one in the model to incorporate new data that we collected as part of this study. To derive an improved estimate of the hydraulic conductivity of the valley-fill aquifer, we (1) conducted a single-well aquifer test of a water well completed in the valley-fill aquifer and analyzed the data, (2) analyzed data from 30 slug tests conducted by the Utah Division of Water Rights on water wells completed in the valley-fill aquifer (appendix F), and (3) calculated hydraulic conductivity from well-test data reported on drillers' logs. All additional data were obtained from wells within the town of Castle Valley. We did not change the value of transmissivity used for layer two and the vertical leakance used to represent the connection of layers one and two from the values used by Downs and Lasswell (undated), because no new information on these parameters was gained from any of the tests we analyzed.

Downs and Lasswell (undated) originally matched averaged water levels in two wells in the valley-fill aquifer to calibrate their model; during the calibration procedure, they modified their original hydraulic-conductivity estimates to obtain acceptable agreement between measured and model-calculated water levels. During our steady-state calibration of the model, we assigned hydraulic conductivities based on the values derived from our aquifer and slug tests (appendix F), and then systematically varied these values until we matched the water levels in the two wells that Downs and Lasswell (undated) used. Horizontal hydraulic-conductivity values of the first layer ranged from 1 to 225 feet per day (0.3-69 m/d) (table 4). The low values of hydraulic conductivity at the edge of the valley reflect the low transmissivity of finer-grained material and no-flow boundary effects.

The model supports Snyder's (1986a, b) determination that ground-water flow in the valley-fill aquifer is from southeast to northwest. The volume of water in the valley-fill aquifer increases with increasing valley-fill thickness and higher transmissivity, resulting in higher storativity. Table 5 summarizes the water budget for the valley-fill aquifer used in the ground-water flow model.

Results

The ground-water flow model used for this study is the best available tool to estimate the amount of water available for mixing with septic-tank effluent. Use of the simulation improved our understanding of the aquifer system and provided the volumetric flow budget needed for the budget for the aquifer in relation to aquifer characteristics, volume of water in storage, and volumes and rates of inflow and outflow. We assume mixing/dilution of septic-tank effluent will occur within ground-water model layer one.

Based on the spatial distribution of the cell-by-cell flow terms calculated by MODFLOW, we identified four domains in Castle Valley with similar flows in layer one. We then used the MODFLOW budget to determine the available ground-water flow in saturated, unconsolidated valley-fill deposits of the unconfined aquifer for each domain. Domains vary in area from 176 to 1,632 acres (71-660 hm^2) and have volumetric flows from 0.28 to 1.1 cubic feet per second (7.9-31.1 L/s) and flow in cubic feet per second per acre of 0.0002 to 0.002 (0.006-0.06 L/s/acre) (table 6; figure 9). We use the volumetric flows in the mass-balance calculations.

Model Limitations

Constructing a numerical model of a natural hydrogeologic system requires simplifying assumptions. Some assumptions limit the scope of the application of the model and the hydrologic questions that can reasonably be addressed,

Table 4. *Final hydraulic parameter values used in the Castle Valley ground-water flow model, Castle Valley, Grand County, Utah.*

Locations	Hydraulic conductivity (feet per day)	Transmissivity (square feet per day)	Vertical leakance (feet per day per feet)
Model Layer one			
Active cells around the lower perimeter of valley	1	—	—
Lower interior active cells in the main valley	5-210	—	—
Higher interior active cells in the main valley	210-225	—	—
Between Layers one and two			
All active cells	—	—	0.0002-0.0018
Model Layer two			
All active cells	—	5,000	—

Table 5. *Simulated steady-state ground-water budget for the valley-fill aquifer in Castle Valley, Grand County, Utah, determined from ground-water flow simulation.*

Component	Steady-state calibration (acre-feet per year)
Recharge	
Infiltration of precipitation for layer one	1,100
Areal distribution at recharge representing recharge from streams	22,500
Total recharge	23,600
Discharge	
Evapotranspiration	2,000
Seepage to streams (Castle Creek)	1,000
Withdrawals from wells	1,600
Seepage to Colorado River	19,000
Total discharge	23,600

Table 6. *Parameters used to perform a mass-balance analysis for ground-water flow domains in Castle Valley, Grand County, Utah.*

Domain	Area (acres)	Flow* (cfs)	Flow per acre (cfs per acre)	Average nitrate concentration (background) (mg/L)	Number of wells sampled	Current number of septic tanks+
1	564	1.1	0.002	0.40	7	15
2	176	0.40	0.0023	0.18	2	14
3	1590	0.70	0.0004	0.48	21	62
4	1632	0.28	0.0002	0.25	17	61

* *Data derived using ground-water flow computer model (see text for explanation).*

+ *Number of septic tanks estimated by the Southeast Utah Health Department (Jim Adamson, written communication, August 2002).*

and may influence the model results. We used a steady-state simulation with time-averaged and measured conditions; thus, the model cannot predict the transient response of the system, because it is not calibrated to transient conditions. This means we cannot use the model to predict flows in the system if new stresses, such as adding a large well, are applied. The simplified boundary conditions and insufficient data to accurately calibrate the model also limit its accuracy. The simulation reasonably reproduces our conceptual model of the ground-water flow system in the valley. No measured ground-water budget exists to compare to the budget we determined through ground-water flow simulation using the model. We believe our revision of Downs and Lasswell's (undated) model is the best tool currently available to simulate steady-state conditions and estimate ground-water flow volumes (figure 9) for use in modeling septic-tank system density/water-quality degradation.

Septic-Tank System/Water-Quality Degradation Analyses

Introduction

We calculated projected domain-specific nitrate concentrations in four ground-water flow domains (table 6) by

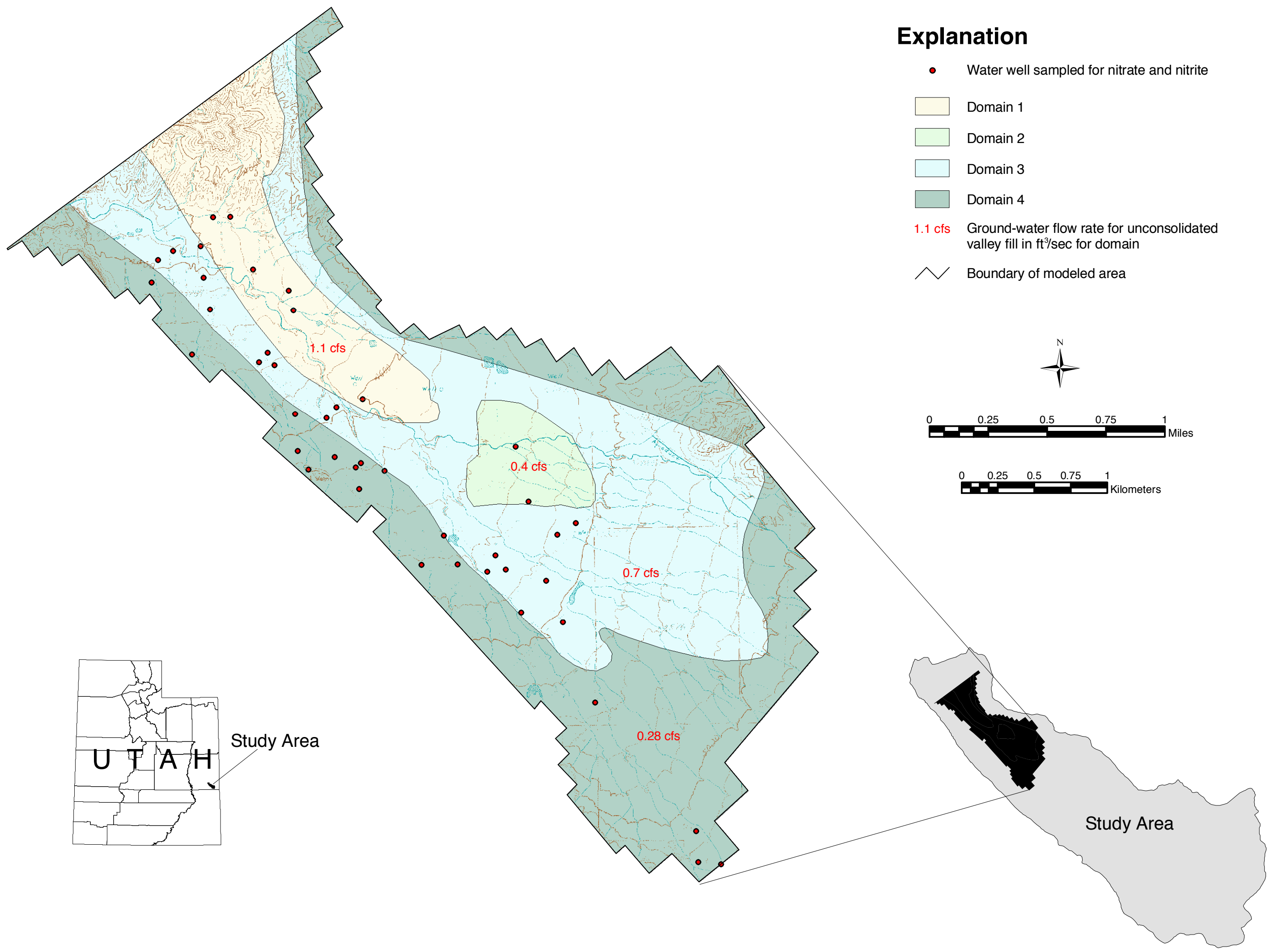

Figure 9. Ground-water flow domains in Castle Valley, Grand County, Utah.

*Table 7. Results of the mass-balance analysis using the best-estimate nitrogen loading of 54.4 mg N/L** for different ground-water flow domains in Castle Valley, Grand County, Utah.*

Domain	Current density (acres/ system)	Current number of septic tanks	Projected number of septic tanks (additional)	Total # projected septic systems (for 1* mg/L)	Calculated lot-size recommendation (acres)		Lot-size recommendation (acres)
					1* mg/L	3* mg/L	
1	38	15	79	94	6	2.5	5
2	12.6	14	28	42	4.2	1.8	5
3	27	62	51	113	15	8.7	15
4	27	61	21	82	20	13.5	15

***Best-estimate calculation is based on a nitrogen load of 17 g N per capita per day (from Kaplan, 1988) for a 2.44-person household and 171 gallons per day as the amount of water generated per household based on the 2001 Utah State Water Plan (Utah Division of Water Resources, 2001a).*

**1 mg/L increase above background nitrate concentration as acceptable level of degradation and a total of 3 mg/L as acceptable level of degradation.*

applying a mass-balance approach using domain-specific parameters, such as the existing nitrogen load (background nitrate concentration) and amount of ground water available for mixing (table 7), and our estimated 171 gallons per day (747 L/d) contributed by each septic-tank system with an estimated nitrogen loading of 54.4 mg/L of septic-tank effluent. The mass-balance approach predicts the impact of nitrate from use of septic-tank systems over a defined area.

We used the mass-balance approach to calculate septic-tank density/water-quality degradation for each area based on a range of parameters that affect nitrogen loading and the amount of ground water available for dilution. We obtained the number of septic-tank systems in each area from the Southeast Utah Health Department (Jim Adamson, written communication, 2002). Tables 6 and 7 list the number of septic-tank systems estimated for each domain. The total number of septic-tank systems in the valley currently is estimated at 152 for all the domains, and ranges from a low of 14 (domain 2) to a high of 62 (domain 3) (tables 6 and 7). Background nitrate concentrations for each domain range from 0.18 mg/L (domain 2) to 0.48 mg/L (domain 3). We consider two scenarios: (1) allowing a 1 mg/L degradation above current background levels of nitrate (a value adopted by Wasatch and Weber Counties as an acceptable level of degradation), and (2) allowing nitrate levels in each domain to increase to 3 mg/L.

Results

We describe our septic-tank-system density calculations only for domain 1 (figure 10a). We calculated septic-tank-system densities for domains 2, 3, and 4 in the same manner as for domain 1, using the information in tables 6 and 7 and figures 10b, 10c, and 10d.

Figure 10a shows a plot of projected nitrate concentration versus septic-tank density and number of septic-tank systems in domain 1 in the central part of northwestern Castle Valley (plate 8). Background nitrate concentration for domain 1 is 0.4 mg/L. Fifteen septic systems are in domain 1 (Jim Adamson, Southeast Utah Health Department, written communication, 2002). Domain 1 has an area of approximately 564 acres (228 hm^2), so the existing average septic-system density is 38 acres per system (15 hm^2/system). Based on our analyses (table 6), estimated ground-water flow available for mixing in domain 1 (figure 10a) is 1.1 cubic feet per second (0.03 m^3/s) (table 6). For the domain 1 area to maintain an overall nitrate concentration of 1.4 mg/L (which allows 1 mg/L of degradation), the total number of homes using septic tank soil-absorption systems should not exceed 94 based on the estimated nitrogen load of 54.4 mg/L per septic-tank system (figure 10a, table 7). This corresponds to an increase of 79 septic systems and an average septic-system density of about 6 acres per system (2.4 hm^2/system) in domain 1 (table 7). If the overall nitrate concentration in domain 1 is allowed to reach 3 mg/L, the total number of homes using septic-tank soil absorption systems should not exceed 227 based on the estimated nitrogen load of 54.4 mg/L per septic-tank system (figure 10a). This corresponds to an increase of 212 septic systems and an average septic-system density of about 2.5 acres per system (1.0 hm^2/system) in domain 1 (table 7).

Recommendations for Land-Use Planning

These approximations of nitrate concentrations/water-quality degradation provide a conservative (worst case) first approximation of long-term ground-water pollution from septic-tank systems. For land-use planning purposes, we be-

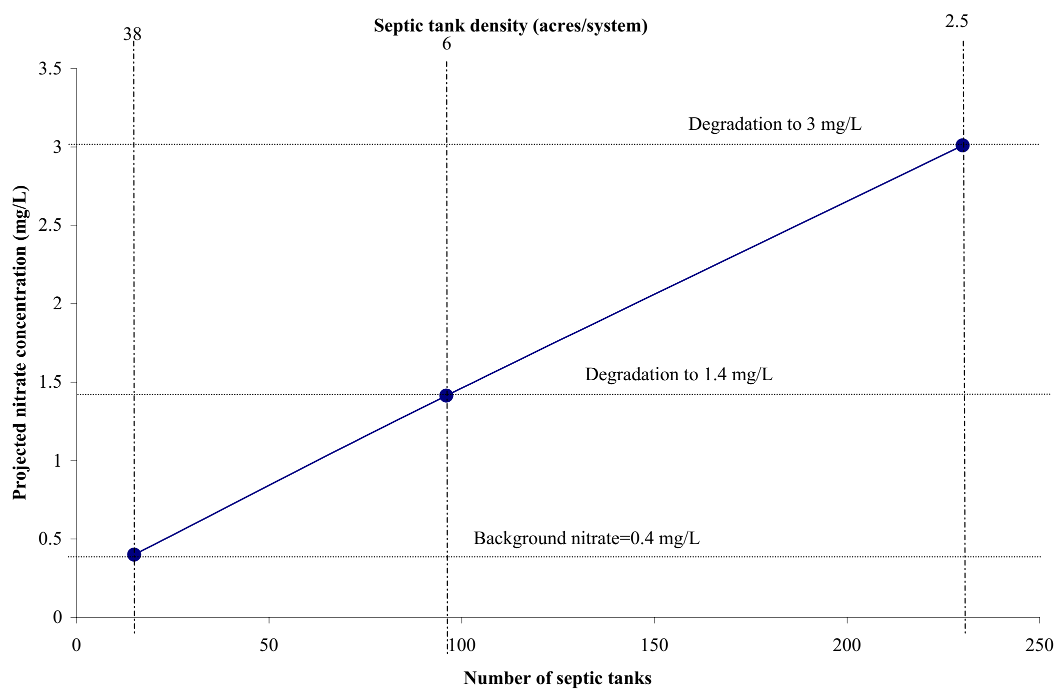

Figure 10a. *Projected septic-tank density versus nitrate concentration for Domain 1 in Castle Valley, Grand County, Utah, based on 15 existing septic tanks (see table 6).*

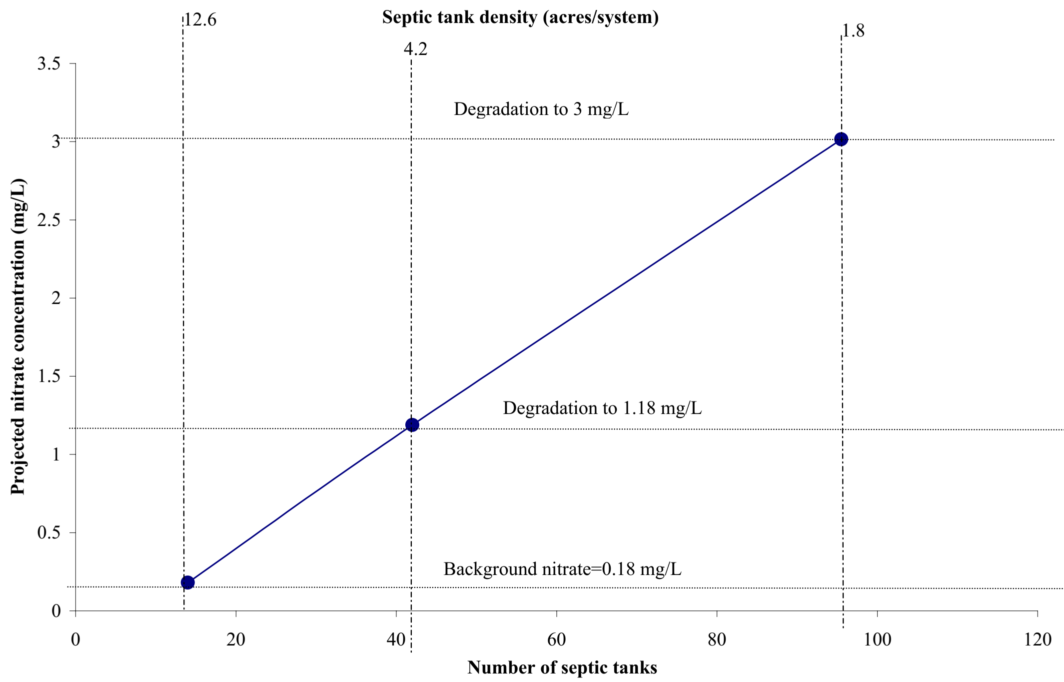

Figure 10b. *Projected septic-tank density versus nitrate concentration for Domain 2 in Castle Valley, Grand County, Utah, based on 14 existing septic tanks (see table 6).*

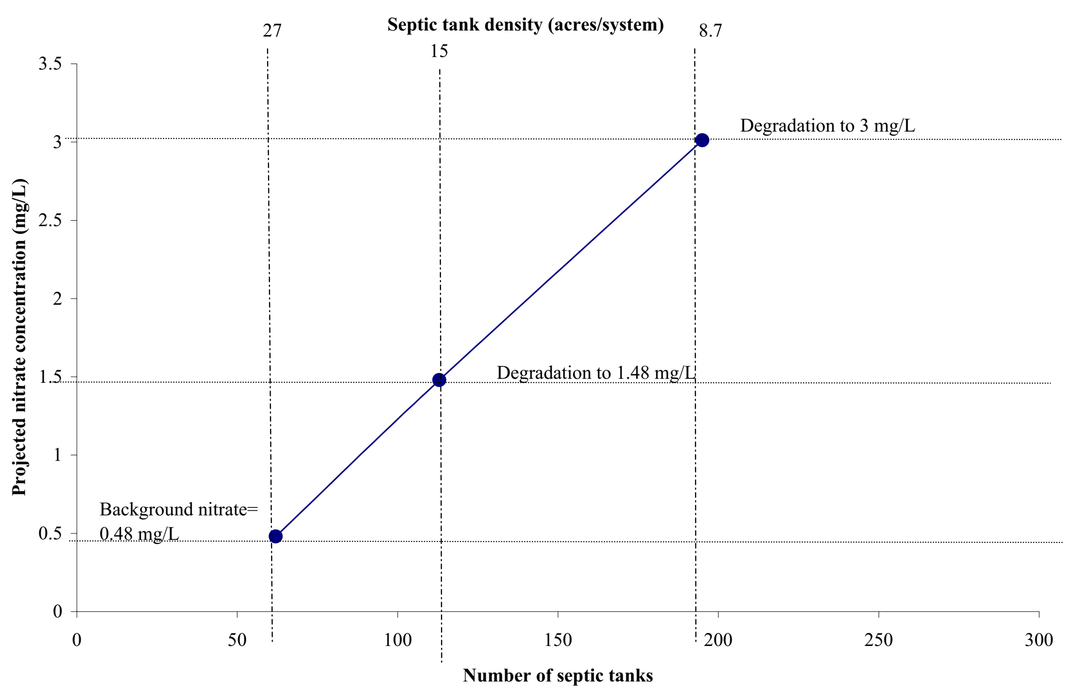

Figure 10c. *Projected septic-tank density versus nitrate concentration for Domain 3 in Castle Valley, Grand County, Utah, based on 62 existing septic tanks (see table 6).*

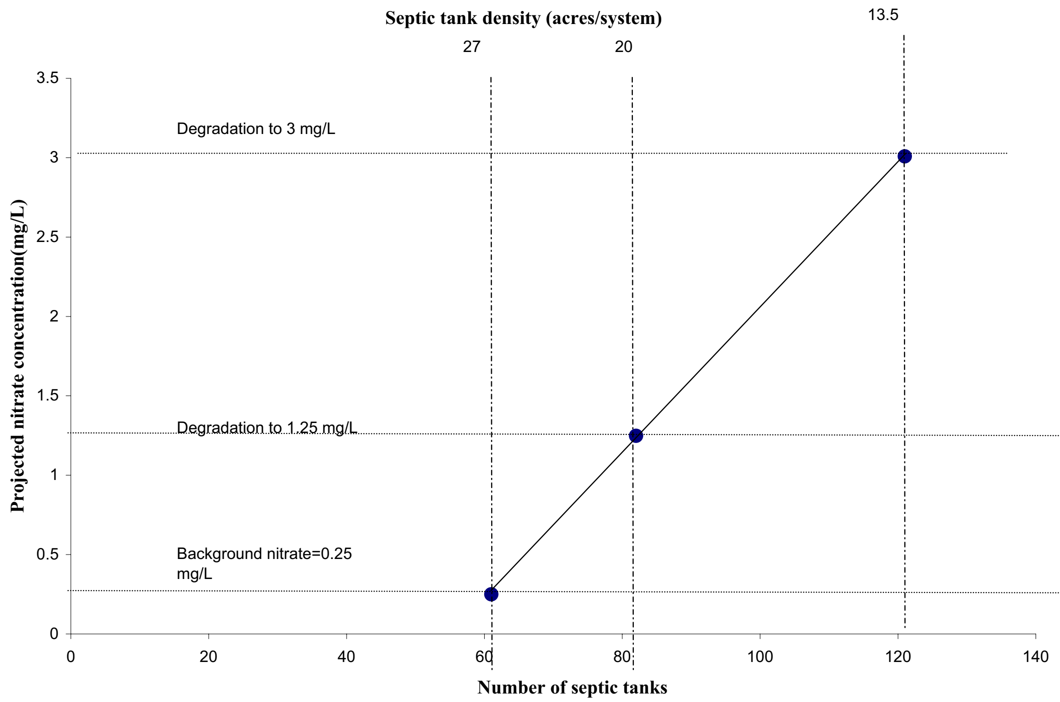

Figure 10d. *Projected septic-tank density versus nitrate concentration for Domain 4 in Castle Valley, Grand County, Utah, based on 61 existing septic tanks (see table 6).*

lieve two categories of recommended maximum septic-tank system densities are appropriate for development in Castle Valley: 5 and 15 acres per system (2 and 6 hm^2/system) (table 7; figure 11; plate 8). Because ground-water flow per acre is similar for domains 1 and 2 (0.002 cfs/acre; table 6) and domains 3 and 4 (~0.0003 cfs/acre; table 6), we grouped the similar flow domains together to create our recommended lot-size map (figure 11). Based only on our septic-tank density/water-quality degradation analysis, a greater number of septic systems can exist in the central areas of Castle Valley along Castle Creek compared to the outer margins of the valley where the amount of ground-water available for mixing is an order of magnitude smaller (table 6); this is due to Castle Creek being a primary source of recharge to the valley-fill aquifer, and the greater average thickness of the valley-fill deposits in northwestern Castle Valley. Our lot-size recommendations apply to development using septic systems for wastewater disposal, and are not relevant to development using well-engineered, well-constructed sewer lagoon systems. However, poorly engineered, poorly constructed sewer lagoon systems could have even greater negative impacts on ground-water quality than septic-tank systems.

SUMMARY AND CONCLUSIONS

Ground water is the principal source of drinking water in Castle Valley. Ground-water quality classification is a tool that can be used in Utah to manage potential ground-water contamination sources and protect the quality of ground-water resources. Our proposed ground-water quality classification for the northwestern part (40 percent) of Castle Valley indicates that the valley-fill aquifer contains mostly high-quality ground-water resources that warrant protection. Forty-eight percent of the land-surface area in the classified part of the valley-fill aquifer is classified as Class IA, and 52 percent is classified as Class II, based on chemical analyses of water from 54 wells and five surface-water sites sampled between 1991 and 2003 (TDS range of 204 to 2,442 mg/L). Insufficient data are available to classify the southeastern part (60 percent) of the valley-fill aquifer in Castle Valley.

The valley-fill material is thickest (about 350 feet [107 m]) along a narrow trough in the northern part of the valley. This area is a reasonable place to site a potential water-supply well (potential well site A; plate 1) for the town of Castle Valley due to its proximity to existing wells and the greatest population density. If the town of Castle Valley opts to drill a public-supply well, the entire valley-fill aquifer can be reclassified by the town of Castle Valley as Class IB, Irreplaceable ground water; this action could strengthen the town's ability to enact policies and regulations to help preserve the quality of Castle Valley's ground-water resource.

All developed areas of Castle Valley use septic tank soil-absorption systems to dispose of domestic wastewater. Many constituents in septic-tank effluent are known to undergo little remediation in the soil environment as they travel through the unsaturated zone to ground water; once they enter ground water, dilution is the principal mechanism for lowering concentrations of these constituents. We used nitrate in septic-tank effluent as an indicator species for evaluating the dilution of constituents in wastewater that reach aquifers; this evaluation uses a mass-balance approach that is based principally on ground-water flow available for mixing with effluent constituents in the aquifer of concern. The mass-balance approach for the valley-fill aquifer in Castle Valley indicates that two categories of recommended maximum septic-tank system densities are appropriate for development: 5 and 15 acres per system (2 and 6 hm^2/system). These recommended minimum lot sizes are based on hydrogeologic parameters incorporated in the ground-water flow model and geographically divided into four ground-water flow domains on the basis of flow-volume similarities.

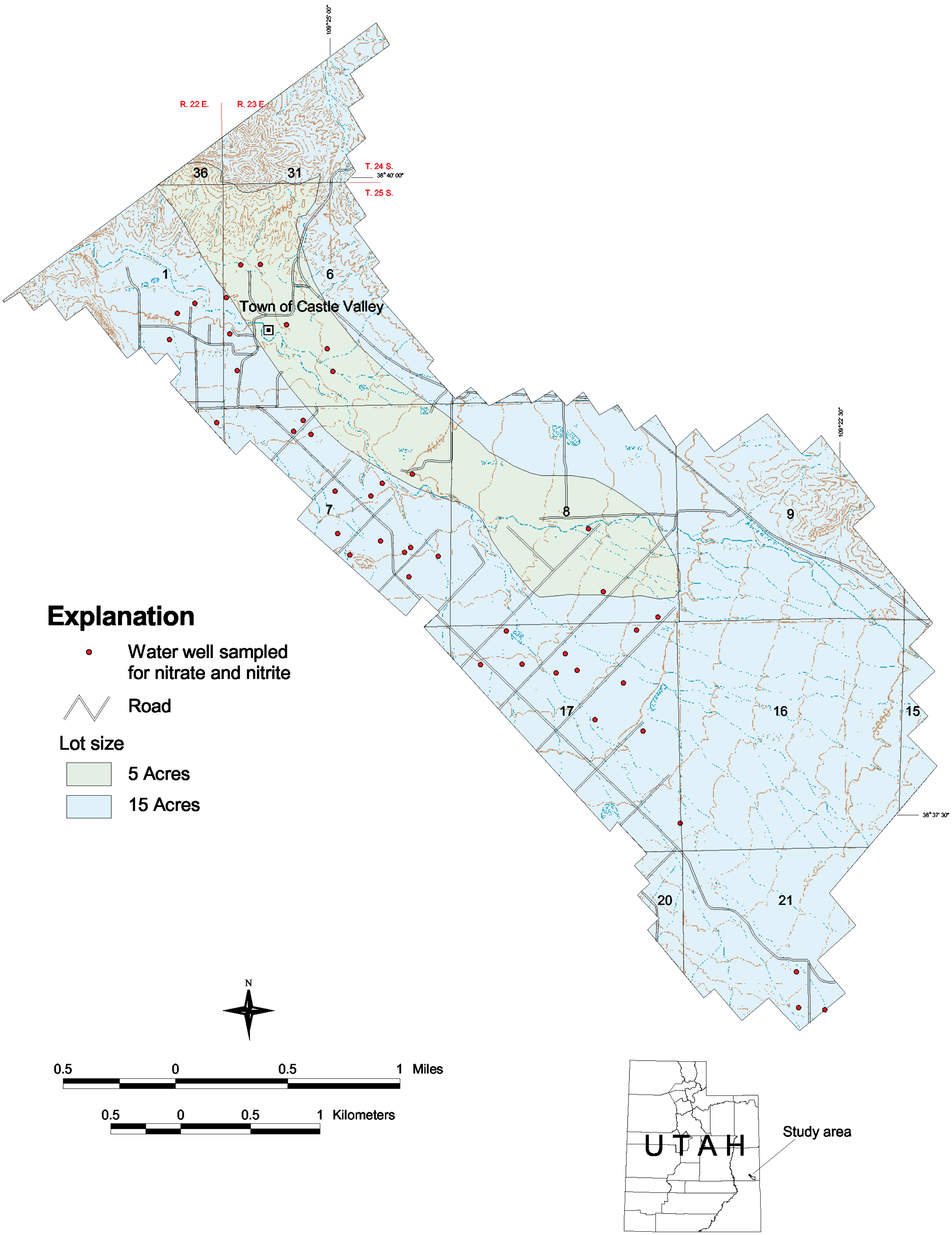

Figure 11. Recommended lot size based on septic-tank system density for northwestern Castle Valley, Grand County, Utah.

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APPENDICES

APPENDIX A

WATER QUALITY DATA

(Site ID numbers shown on plate 6)

Site ID	Data source[2]	Well Depth (feet)	Sample Date	Nitrogen NO2 + NO3 dissolved (mg/L)	Nitrate as N (mg/L)	Solids, sum of constituents, dissolved (mg/L)[1]	Field Temperature, (°C)	Field, Specific Conductance (µmhos)	Lab, Specific Conductance (µmhos)	pH, Field	pH, Lab	Field, Dissolved Oxygen	Alpha, gross (pCi/L)	Aluminum, dissolved (µg/L)	Ammonia (mg/L)	Arsenic, dissolved (µg/L)	Barium, dissolved (µg/L)	Bicarbonate (mg/L)
9	UGS	102	10/22/2001	0.38	-	772	14.8	899	1059	7.5	8.03	5.8	<2	-	-	<5.0	12.2	152
9	UDAF	"	Sept.2000	-	0	-	16.6	929	-	7.74	-	-	-	-0.1	-	-0.1	-0.1	2.4638
10	UGS	180	10/24/2001	0.37	-	468	14.7	580	670	7.8	8.19	6.2	-	<30.0	-	<5.0	15.8	157
10	UDAF	"	Sept.2000	-	2.3	-	16.3	696	-	7.68	-	-	-	-0.1	-	-0.1	21	2.6578
11	UGS	71	10/24/2001	0.33	-	308	13.7	410	479	7.8	8.24	6.5	-	<30.0	-	<5.0	26.7	157
11	UDAF	"	Sept.2000	-	0.9	-	16	508	-	7.73	-	-	-	-0.1	-	-0.1	31	2.8906
12	UGS	120	10/24/2001	0.36	-	480	14.2	597	703	7.8	8.03	6	-	<30.0	-	<5.0	14.6	156
12	UDAF	"	Sept.2000	-	0.7	-	19.3	737	-	7.67	-	-	-	-0.1	-	-0.1	-0.1	2.3668
35	UGS	140	10/23/2001	0.39	-	1232	14.6	1290	1460	7.4	7.85	5	-	<30.0	-	<5.0	8.7	150
35	UDAF	"	Sept.2000	-	0.6	-	18.7	1549	-	7.72	-	-	-	-0.1	-	-0.1	-0.1	2.4444
48	UGS	185	10/23/2001	<0.1	-	2020	15.9	1930	2250	7.3	7.89	4.1	-	<30.0	-	<5.0	7.1	153
48	UDAF	"	Sept.2000	-	1.1	-	16.4	2300	-	7.44	-	-	-	-0.1	-	-0.1	-0.1	2.4638
51	UGS	339?	10/24/2001	0.73	-	336	16.1	432	514	7.8	8.11	5.2	-	<30.0	-	<5.0	23.3	156
51	UDAF	"	Sept.2000	-	1.3	-	19.6	539	-	8	-	-	-	-0.1	-	-0.1	29	2.5414
53	UGS	168	10/24/2001	0.31	-	276	13.3	364	422	7.7	8.31	8	-	<30.0	-	<5.0	33.0	150
53	UDAF	"	Sept.2000	-	1.3	-	16.4	450	-	8.08	-	-	-	-0.1	-	-0.1	37	2.425
56	UGS	136	10/23/2001	<0.1	-	1290	15.2	1320	1570	7.5	7.86	6.2	-	<30.0	-	<5.0	8.9	148
56	UDAF	"	Sept.2000	-	0.9	-	15.8	1637	-	7.75	-	-	-	-0.1	-	-0.1	-0.1	2.3668
59	UGS	168	10/24/2001	0.31	-	2138	16.8	2040	2320	7.3	7.83	5.4	-	<30.0	-	<5.0	7.6	153
59	UDAF	"	Sept.2000	-	0.9	-	7.5	2370	-	7.5	-	-	-	-0.1	-	-0.1	-0.1	2.425
77	UGS	122	10/24/2001	<0.1	-	370	13.5	482	564	7.6	8.2	4.9	-	<30.0	-	<5.0	20.6	155
77	UDAF	"	Sept.2000	-	1.2	-	16.2	652	-	7.58	-	-	-	-0.1	-	-0.1	26	2.5414
78	UGS	139	10/24/2001	0.29	-	650	13.5	802	911	7.6	8.03	5.8	-	<30.0	-	<5.0	12.4	155
78	UDAF	"	Sept.2000	-	0.9	-	18.3	942	-	7.45	-	-	-	-0.1	-	-0.1	-0.1	2.2892
83	UGS	105	10/22/2001	0.32	-	272	15	213	389	7.8	8.14	4.7	<2	-	-	<5.0	32.0	153
83	UDAF	"	Sept.2000	-	1	-	14.2	455	-	8.04	-	-	-	-0.1	-	-0.1	40	2.425
86	UGS	158	10/23/2001	0.31	-	1252	16.4	1326	1560	7.4	7.88	5.8	-	<30.0	-	<5.0	10.5	152
86	UDAF	"	Sept.2000	-	0.9	-	16.2	1654	-	7.86	-	-	-	-0.1	-	-0.1	-0.1	2.425
141	UDWR	130	12/20/1995	-	0.31	280*	-	-	400	-	-	-	-	<0.15	-	<1.0	-	176.90
147	UGS	169	10/24/2001	0.27	-	666	18.2	855	987	7.6	8.0	5.2	-	<30.0	-	<5.0	14.0	166
147	UDAF	"	Sept.2000	-	1.4	-	20.7	1038	-	7.7	-	-	-	-0.1	-	-0.1	25	3.007
158	UGS	121	10/24/2001	<0.1	-	406	14.6	468	555	7.7	8.17	5.9	-	<30.0	-	<5.0	22.4	156
158	UDAF	"	Sept.2000	-	0.9	-	17.1	559	-	8.02	-	-	-	-0.1	-	-0.1	28	2.5414
161	UGS	115	10/22/2001	0.14	-	2068	17.2	2000	2210	7.3	7.83	4.8	<2	-	-	<5.0	7.7	153
161	UDAF	"	Sept.2000	-	1.1	-	22.1	2300	-	7.42	-	-	-	-0.1	-	-0.1	-0.1	2.5996
180	UGS	132	10/24/2001	0.27	-	1802	17.4	1830	2140	7.1	7.76	2.4	-	<30.0	-	<5.0	8.1	153
180	UDAF	"	Sept.2000	-	0.8	-	21.6	1997	-	7.45	-	-	-	-0.1	-	-0.1	-0.1	2.5414
188	UGS	125	10/24/2001	<0.1	-	338	15.4	434	543	7.8	8.12	6.1	-	<30.0	-	<5.0	28.1	165
188	UDAF	125	Sept.2000	-	0.9	-	19.7	541	-	8.04	-	-	-	-0.1	-	-0.1	32	2.3668
193	UGS	267	2/28/2003	-	-	466*	-	675	-	-	-	-	-	-	-	-	-	-
201	UGS	156	10/24/2001	0.11	-	242	14.6	321	379	7.9	8.18	5.5	-	<30.0	-	<5.0	37.7	137
201	UDAF	"	9/27/2000	-	0.8	-	20.5	540	-	8	-	-	-	-0.1	-	-0.1	34	2.3862
204	UGS	125	10/24/2001	0.34	-	228	15.9	336	372	7.8	8.2	6.6	-	<30.0	-	<5.0	42.0	149
204	UDAF	"	9/27/2000	-	1.1	-	14.7	394	-	8.02	-	-	-	-0.1	-	-0.1	47	2.3668
206	UDAF	300	9/27/2000	-	.3	434*	16.1	620	-	7.92	-	-	-	-0.1	-	-0.1	32	2.4832
230	UGS	125	10/24/2001	0.77	-	230	14.7	316	374	8	8.24	3.2	-	<30.0	-	<5.0	42.7	150
230	UDAF	"	Sept.2000	-	1.1	-	17.8	389	-	7.97	-	-	-	-0.1	-	-0.1	47	2.4444
235	UGS	132	10/22/2001	0.26	-	238	16.4	342	386	7.9	8.24	5.4	<2	-	-	<5.0	34.3	141
235	UDAF	"	Sept.2000	-	0.9	-	15	400	-	8.17	-	-	-	-0.1	-	-0.1	41	2.2506
237	UGS	202	2/28/2003	-	-	345*	-	500	-	-	-	-	-	-	-	-	-	-
238	UGS	185	2/28/2003	-	-	500*	-	725	-	-	-	-	-	-	-	-	-	-
244	UGS	142	10/23/2001	0.68	-	208	13.8	315	377	7.9	8.16	6.1	-	<30.0	-	<5.0	41.0	142
244	UDAF	"	Sept.2000	-	1	-	15.8	385	-	8.06	-	-	-	-0.1	-	-0.1	98	2.1728
244	UGS	"	2/29/03	-	-	-	15	300	-	-								
248	UDAF	140	9/27/2000	-	.3	279*	17.4	399	-	7.95	-	-	-	-0.1	-	-0.1	51	2.5026
275	UGS	135	2/28/2003	-	-	207*	-	300	-	-	-	-	-	-	-	-	-	-
279	UGS	126	10/22/2001	0.52	-	226	15.2	315	358	7.7	8.35	5.8	<2	-	-	<5.0	44.2	143
279	UDAF	"	Sept.2000	-	0.9	-	18.5	387	-	8.16	-	-	-	-0.1	-	-0.1	49	2.2892
297	UDAF	unknown	9/28/2000	-	0.9	676*	15.1	-	965	-	7.76	-	-	-0.1	-	-0.1	0.037	3.647
298	UDAF	unknown	9/28/2000	-	0.8	1234*	14.9	-	1762	-	7.41	-	-	-0.1	-	-0.1	-0.1	4.035
300	UDAF	150?	9/28/2000	-	3.5	721*	18.9	-	1031	-	7.82	-	-	-0.1	-	-0.1	0.051	3.24
305	UDWR	135	12/10/1991	0.437	-	232	11.6	-	376	-	8.0	-	-	-	<0.05	<0.005	0.045	152.00
328	UGS	248	10/23/2001	0.26	-	240	14.3	331	371	7.8	8.02	7	-	<30.0	-	<5.0	41.2	154
328	UDAF	"	Sept.2000	-	1	-	21.2	418	-	8.01	-	-	-	-0.1	-	-0.1	42	2.5414
338	UDWR	230	12/20/1995	-	0.16	1400*	-	-	2000	-	-	-	-	<0.15	-	<1.0	-	176.90
352	UGS	135	10/23/2001	0.25	-	204	13.6	307	367	7.7	8.28	6.7	-	<30.0	-	<5.0	45.9	151
352	UDAF	"	Sept.2000	-	0.7	-	14.6	377	-	8.09	-	-	-	-0.1	-	-0.1	174	2.425
358	UGS	110	10/23/2001	0.26	-	222	12.5	315	371	7.7	8.19	6.5	-	<30.0	-	<5.0	48.3	156
358	UDAF	"	Sept.2000	-	1	-	14	388	-	8.02	-	-	-	-0.1	-	-0.1	51	2.7548
359	UGS	105	10/23/2001	<0.1	-	252	12.8	345	372	7.7	8.14	6.6	-	<30.0	-	<5.0	39.7	166
359	UDAF	"	Sept.2000	-	1.3	-	14.8	447	-	7.95	-	-	-	-0.1	-	-0.1	47	2.91
387	UGS	129	10/22/2001	0.32	-	852	14.9	1318	1360	7	7.76	4.5	-	<30.0	-	<5.0	<5.0	170
387	UDAF	"	Sept.2000	-	1.1	-	17.1	1105	-	7.39	-	-	-	-0.1	-	-0.1	-0.1	4.9664
390	UGS	100	10/24/2001	0.4	-	844	13.6	992	1100	7.2	7.88	4.4	-	<30.0	-	<5.0	16.1	270
390	UDAF	"	Sept.2000	-	1	-	16.6	1176	-	7.47	-	-	-	-0.1	-	-0.1	20	4.5978
391	UGS	68	10/24/2001	0.58	-	742	14.2	884	1009	7.6	7.95	4.3	-	<30.0	-	<5.0	12.9	184
391	UDAF	68	9/27/2000	-	0.7	-	15.9	1011	-	7.92	-	-	-	-0.1	-	-0.1	20	3.1234
394	UGS	103	10/24/2001	<0.1	-	694	15.2	836	967	7.7	7.9	6	-	<30.0	-	<5.0	16.8	202
394	UDAF	"	Sept.2000	-	0.9	-	16.5	993	-	7.62	-	-	-	-0.1	-	-0.1	23	3.2592
413	UGS	85	10/24/2001	0.59	-	2440	16.4	2340	2980	7.3	7.88	5.4	-	<30.0	-	<5.0	7.2	136
413	UDAF	"	9/27/2000	-	0.8	-	21	2800	-	7.83	-	-	-	-0.1	-	-0.1	-0.1	2.1728
417	UGS	100	10/25/2001	1.54	-	708	11.2	969	1130	7.4	8.01	6.1	-	<30.0	-	<5.0	<5.0	174
420	UDWR	40	12/10/1991	0.661	-	648	13.8	-	915	-	6.1	-	-	-	<0.05	<0.005	0.020	183.00
432	UDAF	121	9/27/2000	0.1	-	629*	20.4	888	-	9.33	-	-	-	-0.1	-	-0.1	-0.1	2.5608
435	UGS	95	10/24/2001	0.41	-	2048	15.2	2070	2370	7.3	7.81	6.3	-	<30.0	-	<5.0	7.5	183
435	UDAF	"	Sept.2000	-	0.9	-	17.9	2400	-	7.43	-	-	-	-0.1	-	-0.1	-0.1	3.0846
436	UDWR	130	12/20/1995	-	0.21	1861*	-	-	2630	-	-	-	-	<0.15	-	<1.0	0.015	262.30
442	UGS	145	10/24/2001	0.34	-	2442	14.5	2380	2680	7.1	7.58	4	-	<30.0	-	<5.0	8.0	272
442	UDAF	"	Sept.2000	-	0.8	-	16.3	2740	-	7.78	-	-	-	-0.1	-	-0.1	-0.1	4.4426
446	UGS	305	10/23/2001	0.51	-	1448	16	1630	1810	7.2	8.01	2.5	-	<30.0	-	<5.0	8.3	232
446	UDAF	"	Sept.2000	-	0.6	-	17.5	1956	-	7.72	-	-	-	-0.1	-	-0.1	-0.1	3.7636
448	UGS	58	10/24/2001	0.6	-	1850	14.2	1840	2120	7.1	7.65	5.4	-	<30.0	-	<5.0	16.0	278
448	UDAF	"	Sept.2000	-	0.6	-	16.6	1906	-	7.39	-	-	-	-0.1	-	-0.1	20	4.4232
998	UGS	120	10/25/2001	4.27	-	856	13.4	1001	1160	7.3	8.09	7	-	<30.0	-	<5.0	45.7	232
999	UGS	70	10/25/2001	0.93	-	364	15.2	485	577	7.6	8.14	5.7	-	<30.0	-	<5.0	35.1	160
999	UDAF	"	Sept.2000	-	0.6	-	27.9	531	-	7.81	-	-	-	-0.1	-	-0.1	39	2.5608
1000	UDWR	83	12/20/1995	-	-	671*	-	-	-	-	-	-	-	-	-	-	-	-
1001	DWQ	CREEK	3/13/1978	-	0.7	602	-	-	-	-	-	-	-	-	-	-	-	-
1002	UGS	SPRING	2/28/2003	-	-	690*	-	1000	-	-	-	-	-	-	-	-	-	-
1003	UGS	CREEK	2/28/2003	-	-	483*	-	700	-	-	-	-	-	-	-	-	-	-
1004	UGS	93	2/28/2003	-	-	1415*	-	2050	-	-	-	-	-	-	-	-	-	-
1005	UGS	CREEK	2/28/2003	-	-	466*	-	675	-	-	-	-	-	-	-	-	-	-
1006	UGS	CREEK	2/28/2003	-	-	449*	-	650	-	-	-	-	-	-	-	-	-	-
2001	CCV	116	Jul-03	-	-	484	-	-	-	-	-	-	-	-	-	-	-	-
2002	CCV	unknown	Jul-03	-	-	674	-	-	-	-	-	-	-	-	-	-	-	-
2003	CCV	SPRING	Jul-03	-	-	826	-	-	-	-	-	-	-	-	-	-	-	-
2004	CCV	SPRING	Jul-03	-	-	188	-	-	-	-	-	-	-	-	-	-	-	-
2005	CCV	300	Jul-03	-	-	298	-	-	-	-	-	-	-	-	-	-	-	-
2006	CCV	unknown	Jul-03	-	-	1844	-	-	-	-	-	-	-	-	-	-	-	-
2007	CCV	SPRING	Jul-03	-	-	1364	-	-	-	-	-	-	-	-	-	-	-	-
2008	CCV	SPRING	Jul-03	-	-	188	-	-	-	-	-	-	-	-	-	-	-	-
2009	CCV	150	Jul-03	-	-	660	-	-	-	-	-	-	-	-	-	-	-	-
2010	CCV	150	Jul-03	-	-	438	-	-	-	-	-	-	-	-	-	-	-	-
2011	CCV	CREEK	Jul-03	-	-	576	-	-	-	-	-	-	-	-	-	-	-	-
2012	CCV	SPRING	Jul-03	-	-	284	-	-	-	-	-	-	-	-	-	-	-	-
2013	CCV	SPRING	Jul-03	-	-	392	-	-	-	-	-	-	-	-	-	-	-	-
2014	CCV	125	Jul-03	-	-	398	-	-	-	-	-	-	-	-	-	-	-	-
2015	CCV	236	Jul-03	-	-	392	-	-	-	-	-	-	-	-	-	-	-	-
2016	CCV	SPRING	Jul-03	-	-	308	-	-	-	-	-	-	-	-	-	-	-	-
2017	CCV	SPRING	Jul-03	-	-	284	-	-	-	-	-	-	-	-	-	-	-	-

[1]Indicates TDS value converted from specific conductance

[2]UGS=Utah Geological Survey
UDAF=Utah Department of Agriculture and Food
UDWR=Utah Division of Water Rights
DWQ=Utah Division of Water Quality
CCV=Citizens of Castle Valley

-0.1

A "-" indicates no data
All wells except UDAF wells were analyzed by Utah State Health Lab

APPENDIX B

EPA PRIMARY GROUND-WATER QUALITY STANDARDS AND ANALYTICAL METHOD FOR SOME CHEMICAL CONSTITUENTS SAMPLED IN CASTLE VALLEY, GRAND COUNTY, UTAH.

CHEMICAL CONSTITUENT	EPA ANALYTICAL METHOD	GROUND-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:		
arsenic	200.9	0.05
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:		
total dissolved solids	160.1	2000+** or (500*++)
pH	150.1	between 6.5 and 8.5
aluminum*	200.7	0.05 to 0.2
calcium*	200.7	-
sodium*	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	0.3
potassium*	200.7	-
hydroxide	406C	-
sulfate *++	375.2	250
magnesium*	200.7	-
manganese*	200.7	0.5
Organics and pesticides:		
aldicarb	531.1	0.003
aldicarb sulfoxide	531.1	0.004
atrazine	525.2	0.003
carbofuran	531.1	0.04
2, 4-D	515.1	0.07
methoxychlor	525.2	0.4

CHEMICAL CONSTITUENT METHOD	EPA ANALYTICAL	GROUND-WATER QUALITY STANDARD (mg/L)
methiocarb	531.1	-
dinoseb	515.1	0.007
dalapon	515.1	0.2
baygon	515.1	-
picloram	515.1	0.5
dicamba	515.1	-
oxamyl	531.1	0.2
methomyl	531.1	-
carbaryl	531.1	-
3-Hydroxycarbofuran	531.1	-
pentachlorophenol	515.1	0.001
2, 4, 5-TP	515.1	0.05
Radionuclides:		
Alpha, gross	600/4-80-032	15 pCi/L(picocuries per liter)
Beta, gross	600/4-80-032	4 millirems per year
U^{238}MS Fil (Uranium)	600/4-80-032	0.030 mg/L
^{226}Radium	600/4-80-032	5 pCi/L
^{228}Radium	600/4-80-032	5 pCi/L

- no ground-water quality standard exists for the chemical constituent
* for secondary standards only (exceeding these concentrations does not pose a health threat)
+ maximum contaminant level is reported from the Utah Administrative Code R309-103 (Utah Division of Water Quality)
** 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 (i.e., lower in TDS) is available
++TDS and sulfate levels are given in the Primary Drinking Water Standards, R309-103- 2.1. They are listed as secondary standards because levels in excess of these recommended levels will likely cause consumer complaint

APPENDIX C

POTENTIAL CONTAMINANT SOURCES

(Site numbers are shown on plate 7)

SITE #	POTENTIAL CONTAMINANT	LOCATION/SOURCE DESCRIPTION	POLLUTANT
1	ABANDONED CORRAL	Abandoned corral, hay, (fenced in, temporary horses housing?)	fertilizer, manure
2	JUNK/SALVAGE	Abandoned cars & trucks, lots of car parts	metals, solvents, petroleum
3	STORAGE TANK	Gravity-driven gas tank	petroleum
4	STORAGE TANK	Abandoned petroleum storage tank?, rusty red color, has door to it and an outlet on outside, all corroded; petroleum tank?	metals, solvents, petroleum
5	JUNK/SALVAGE	Personal junk yard, abandoned cars, trailers, metal garbage-like cans with petroleum?	metals, solvents, petroleum
6	CORRAL	Corral with horse, adjacent to property with cars, trailer, tires stacked, skimobiles-abandoned cars, farm equipment, personal junk yard & a corral	fertilizer, manure
7	CORRAL	Corral and a small barn/shed & horse trailers	fertilizer, manure
8	JUNK/SALVAGE	Personal junk yard, canisters-metal cylinder shaped (like trash cans) contained some type petroleum product?, pallets, abandoned cars, trucks, van, trailers, tires.	metals, solvents, petroleum
9	ABANDONED CORRAL	Abandoned corral, big fenced in and gated area where they ran horses, next to a water well	fertilizer, manure
10	ABANDONED CORRAL	Abandoned corral	fertilizer, manure
11	JUNK/SALVAGE	Wood pallets, canisters w/ probable petroleum product, personal junk yard, rusted out old car windows, old car & bus frames	metals, solvents, petroleum
12	CORRAL	Active corral, lots of hay, several horses, barn	fertilizer, manure
13	CORRAL	Corral, inactive?	fertilizer, manure
14	STORAGE TANK	Gravity-driven gas tank	petroleum
15	STORAGE TANK	Gravity-driven gas tank	petroleum
16	ABANDONED CORRAL	Abandoned corral	fertilizer, manure
17	JUNK/SALVAGE	Abandoned cars, trucks, trailers, vans on personal property	metals, solvents, petroleum
18	CEMETERY	Cemetery, NOT large lawn, some green, interred	preservative chemicals
19	STORAGE TANK	Gravity-driven gas tank (small)	petroleum
20	STORAGE TANK	Gravity-driven gas tank	petroleum
21	CORRAL	Active corral, lots of manure, active	fertilizer, manure
22	ABANDONED CORRAL	Abandoned corral and barnyard/shed, sheep? little stables	fertilizer, manure
23	JUNK/SALVAGE	Personal junkyard, several abandoned cars, trucks, trailers, equipment, cement mixers, a drilling rig-water well drill (not abandoned), lumber, ammunition looking items, scraps, metal	metals, solvents, petroleum

SITE #	POTENTIAL CONTAMINANT	LOCATION/SOURCE DESCRIPTION	POLLUTANT
24	CORRAL	Horses in little corral and horse trailers	fertilizer, manure
25	CORRAL	Active corral, lots of horses, hay & manure	fertilizer, manure
26	CORRAL	Active corral - horses	fertilizer, manure
27	ABANDONED CORRAL	Abandoned corral, small, little barn/shed next to it (small animals)	fertilizer, manure
28	STORAGE TANK	Gravity driven gas tank	petroleum
29	JUNK/SALVAGE	Personal junk yard, vans, car, tires, metal scraps, few metal canisters, lumber, truck, old stove equipment	metals, solvents, petroleum
30	CORRAL	Active corral, couple of horses	fertilizer, manure
31	ABANDONED CORRAL	Abandoned corral, with hay and dilapidated fence	fertilizer, manure
32	FORMER ANIMAL FEEDING OPERATION	Abandoned shed for animals, chickens?, seed next to shed & cooped in area"	fertilizer, manure
33	CORRAL	Corral, llama, bales of hay, barn/stable, feed trough for animals, animal feeding operation?	fertilizer, manure
34	CORRAL	Active corral, horses, horse trailer, barn	fertilizer, manure
35	ABANDONED CORRAL	Abandoned corral with a little shed	fertilizer, manure
36	JUNK/SALVAGE	Personal junkyard, abandoned jeep, milk delivery truck, lots of lumber and metal scraps, old bathtubs and jewel tanks, old chicken coop, trash	metals, solvents, petroleum
37	JUNK/SALVAGE	Personal junk yard, school bus, metal scraps, storage garage, trailer, boat, (owner may run his personal business out of warehouse/garage)	metals, solvents, petroleum
38	CORRAL	Pasture, fenced area with horse	fertilizer, manure
39	CORRAL	Corral, horses, manure, active	fertilizer, manure
40	ABANDONED CORRAL	Abandoned corral and chicken coops	fertilizer, manure
41	JUNK/SALVAGE	Personal junk yard, vans, campers, trailers, wood and metal scraps, tires, fiberglass cylinders	metals, solvents, petroleum
42	CORRAL	Corral with mules	fertilizer, manure
43	ABANDONED CORRAL	Abandoned corral	fertilizer, manure
44	ABANDONED CORRAL	Abandoned corral with a fence all the way around it, stock water well (irrigated water) piles of dirt or possibly manure, old barn/shed	fertilizer, manure
45	STORAGE TANK	Gravity driven gas tank	petroleum
46	CORRAL	Active corral with horses	petroleum
47	GOLF COURSE	Small personal golf course in large back yard with large lawn	pesticides, fertilizer
48	NURSERY/GREENHOUSE	Nursery business, Greenhouse-indoor/outdoor	pesticides, fertilizer
49	CORRAL	Corral, active?, horse trailers	fertilizer, manure

SITE #	POTENTIAL CONTAMINANT	LOCATION/SOURCE DESCRIPTION	POLLUTANT
50	JUNK/SALVAGE	Personal junkyard, truck, vans, lumber, vans, metal scraps, wooden shed storage	metals, solvents, petroleum
51	CORRAL	Ranch, corrals, horses, stables, Big operation	fertilizer, manure
52	STORAGE TANK	Gravity-driven gas tank	petroleum
53	NURSERY/GREENHOUSE	Farm, 3 greenhouses, nursery operation?, lots of farm equipment, tractors, trailers, cement mixers	pesticides, fertilizer, metals, solvents
54	STORAGE TANK	Cylinder/canister of potassium chloride (sylvite) salt	metals, solvents
55	STORAGE TANK	Gravity-driven gas tank	petroleum
56	STORAGE TANK	Gravity-driven gas tank	petroleum
57	CORRAL	Corral - active	fertilizer, manure
58	JUNK/SALVAGE	Personal junkyard, big one, metal piping, wood & metal scraps, tractor, trailer, vans, bus, cars, lumber	metals, solvents
59	STORAGE TANK	Gravity-driven gas tank	petroleum
60	GOVERNMENT	Government- fire department, fire dept. truck, Natural Resource fire dept., green Gov't trucks - (look like army trucks), facility; cement & brick (fenced in), equipment, mosquito control truck.	metals, solvents, petroleum
61	ABANDONED CORRAL	Abandoned? corral	fertilizer, manure
62	CEMETERY	Graveyard	preservative chemicals
63	MINING	Gravel pit	metals, solvents, petroleum
64	CORRAL	Big corral (presently no horses or cows, but occupied by cows October 2001 grazing in area)	fertilizer, manure
65	MINING	Mining adit (inactive?)	metals, solvents, petroleum
66	CEMETERY	Cemetery, not a greenery, desert, no lawn fertilizer	preservative chemicals
67	ABANDONED CORRAL	Abandoned corral?	fertilizer, manure
68	MINING	Abandoned mine structure, old metal dilapidated structure, inactive	metals, solvents, petroleum
69	ELECTRICAL POWER SUPPLY	Mini transformer station, high voltage, local power supplier?	PCBs, metals, solvents
70	ANIMAL FEEDING OPERATION	Small peacock coop?, (maybe turkeys) BIRD Coop	fertilizer, manure
71	ABANDONED CORRAL	Corral, abandoned?, horse trailers	fertilizer, manure
72	JUNK/SALVAGE	Personal scrap yard, lots of lumber, cars, trucks, metal scraps, large semi-type trailer	metals, solvents, petroleum
73	JUNK/SALVAGE	Dump site, lumber, metal, sink, toilet, oil paint cans, waste disposal site, community junk yard?, old washing machine	metals, solvents, petroleum

SITE #	POTENTIAL CONTAMINANT	LOCATION/SOURCE DESCRIPTION	POLLUTANT
74	ABANDONED CORRAL	Abandoned corral	fertilizer, manure
75	MINING	Gravel pit, mining, mining river sediment, active, bull dozers	metals, solvents, petroleum
76	ABANDONED CORRAL	Corral, abandoned?	fertilizer, manure
77	ABANDONED CORRAL	Abandoned corral	fertilizer, manure
78	MINING	Gravel pit, mining	metals, solvents, petroleum
79	BUSINESS	Plastics, small business manufacturers?	metals, solvents
80	CORRAL	Pasture, with horses	fertilizer, manure
81	OIL/GAS WELL	Oil and gas well	petroleum
82	OIL/GAS WELL	Oil and gas well	petroleum
83	OIL/GAS WELL	Oil and gas well	petroleum
84	OIL/GAS WELL	Oil and gas well	petroleum
85	OIL/GAS WELL	Oil and gas well	petroleum
86-240	Septic tanks	Septic tank soil absorption systems from S.E. Utah Health Department (not numbered on the map)	metals, solvents, nitrate

APPENDIX D

EXPLANATION FOR PLATE 1

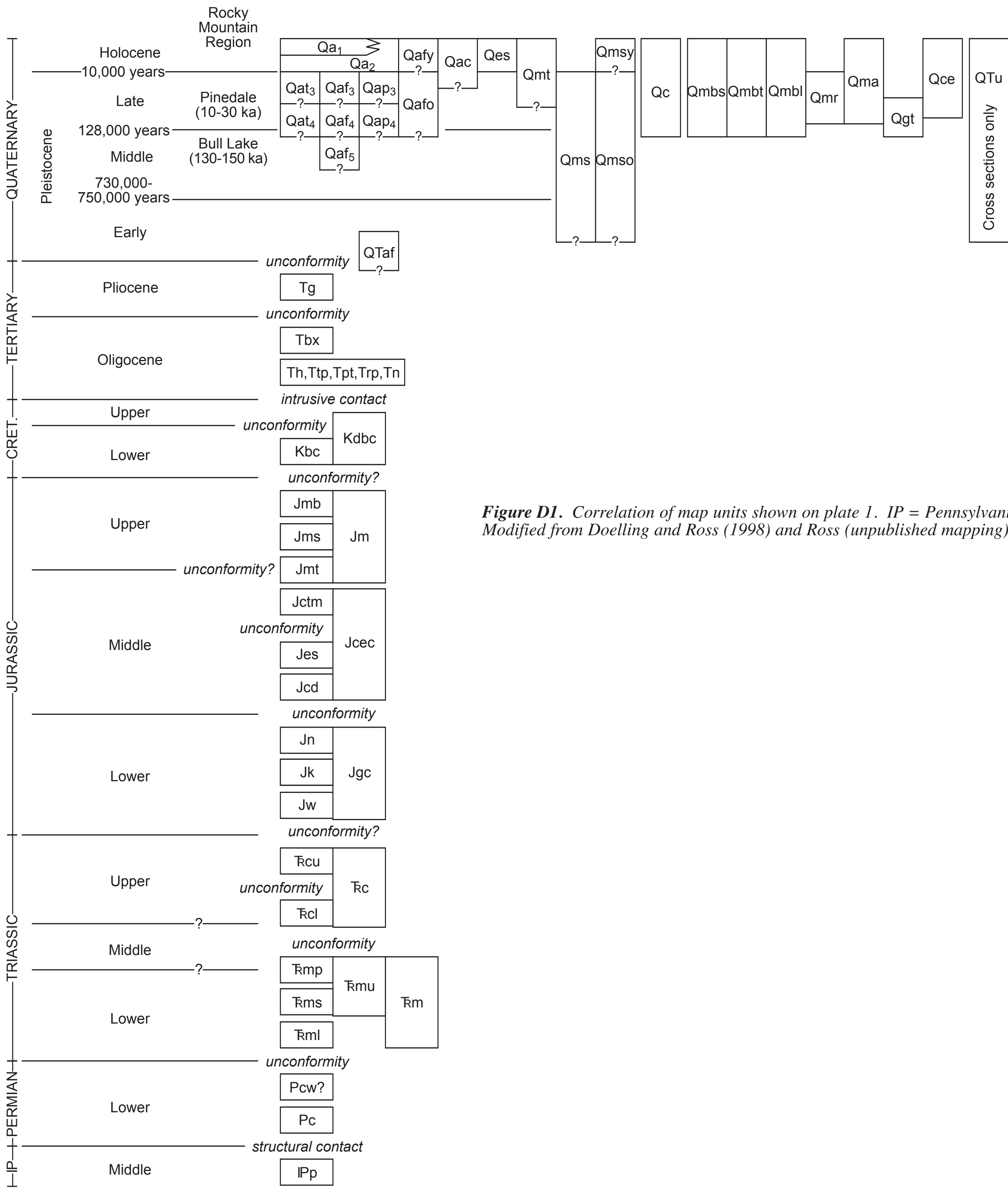


Figure D1. *Correlation of map units shown on plate 1. IP = Pennsylvanian. Modified from Doelling and Ross (1998) and Ross (unpublished mapping).*

DESCRIPTION OF GEOLOGIC UNITS

Modified from Doelling (2001) and Doelling and Ross (1988)

Quaternary

Qa$_1$, Qa$_2$ — Alluvium-- Unconsolidated deposits of poorly to moderately sorted silt, sand, and gravel; Qa$_1$ is located in active larger channels and floodplains; Qa$_2$ deposits form the first surface 6-40 feet (2-12m) above the active channels. Thickness up to 25 feet (8 m).

Qaf$_3$, Qaf$_4$, Qaf$_5$, Qafy, Qafo — Alluvial-fan deposits-- Unconsolidated deposits of poorly sorted, generally unstratified, muddy to sandy cobble gravel; boulders present in proximal areas; Qaf$_3$ and Qaf$_4$ form dissected surfaces and in Castle Valley; younger (Qafy) and older (Qafo) deposits form coalesced fans along the margins of Castle Valley. Up to 350 feet (107 m) thick as basin-fill deposits.

Qap$_3$, Qap$_4$ — Alluvial-pediment-mantle deposits-- Poorly sorted, sandy, matrix-supported gravel; gravel ranges from pebbles to boulders; deposited as a relatively thin veneer on uneven pediment surfaces; coarsens upslope. Deposits are subdivided based on height above current drainage and grading to alluvial terraces along the river. Maximum thickness 25 feet (8 m).

Qgt — Glacial till-- Very poorly sorted, angular to subangular clasts of all sizes; larger clasts are commonly striated; as much as 300 feet (90 m) thick; early Holocene to late Pleistocene.

Mass movement deposits

Qmt — Talus deposits and colluvium-- Generally angular rock-fall blocks, boulders, and small fragments deposited as veneers on slopes below ledges and cliffs; colluvium contains additional slopewash debris in a sandy to muddy matrix. Thickness 0 to 30 feet (0-9 m).

Qms, Qmsy, Qmso — Landslide deposits-- Large coherent blocks to fragmented masses of bedrock and surficial debris transported downslope by mass movement. Thicknesses vary.

Qmbl, Qmbs, Qmbt, Qmbl/Qmso — Block-slope deposits-- Poorly sorted, angular, locally derived debris ranging from block to sand size, deposited as thin accumulations. Qmbl- lateral-spread deposits; Qmbs- slide deposits; Qmbt- talus; Qmbl/Qmso- veneer of lateral-spread deposits overlying older slide deposits. Variable thickness.

Qma — Rock-avalanche deposits-- Poorly sorted, angular, locally derived debris ranging from block to sand size, characterized by flow morphology and lobate form. Deposited by rapid downslope flowage which formed thin, narrow, laterally extensive deposits. Variable thickness.

Qmr — Rock-glacier deposits-- Poorly sorted, angular, boulder- to sand-size debris forming lobate to tongue-shaped deposits in high valleys and cirques of the La Sal Mountains. Contains interstitial ice at least 3 feet (1 m) below the surface. Deposited by downslope flowage of ice from cirque walls or other steep slopes, carrying and incorporating rock-fall debris. Variable thickness.

Qc, Qce, Qc/Qmso — Colluvial deposits-- Poorly to moderately sorted, locally derived gravel, sand, and soil; locally includes talus and alluvial deposits. Deposited by slope wash, soil creep, and minor debris flows. Qce is mixed colluvial and eolian deposits. Qc/Qmso is thin veneer of colluvium over older landslide deposits. Less than about 25 feet (8 m) thick.

Qes — Eolian sand deposits-- Generally fine- to medium-grained quartzose sand forming thin, discontinuous accumulations of sheets and small dunes. Thickness up to 10 feet (3 m).

Qac — Mixed alluvial and colluvial deposits-- Poorly sorted, unconsolidated mixtures of clay- through cobble-size detritus with random boulders; clasts vary from subrounded to angular. Thickness up to 15 feet (5 m).

Quaternary-Tertiary

QTaf — Older alluvial-fan deposits-- Sand, silt, pebbles, cobbles, and sparse boulders deposited at the foot of the La Sal Mountains; thickness 200 to 300 feet (60-90 m); early Pleistocene to Pliocene(?).

Tertiary

Tg — Geyser Creek Fanglomerate-- Yellow-brown to light-gray conglomerate, sandstone, and siltstone derived from the La Sal Mountains; generally poorly sorted and weakly cemented with calcium carbonate; thickness as much as 1,000 feet (305 m), but exposures are generally less than 300 feet (92 m) thick; Pliocene(?).

Tbx — Breccia-- Highly fractured, silicified, and thermally altered rock derived from the Glen Canyon Group and Chinle Formation. Crops out as resistant narrow ridges and cliffs.

Th, Ttp, Tpt, Trp, Tn — La Sal Mountains intrusive rocks-- Alkaline silicic rocks intruded at shallow depths as laccoliths, plugs, sills, and dikes 25 to 28 million years ago (Oligocene).

Cretaceous

Kdbc — Dakota Sandstone and Burro Canyon Formation, undivided-- Mapped in areas where they are too thin to separate accurately. Dakota Sandstone is yellow-gray to brown sandstone, conglomeratic sandstone, and conglomerate interbedded with gray mudstone, carbonaceous shale, coal, and claystone; 0 to 120 feet (0-37 m) thick.

Kbc — Burro Canyon Formation-- Brown to gray sandstone, conglomerate, and limestone and olive-green to gray mudstone; 0 to 200 feet (0-60 m) thick.

Jurassic

Jm — Morrison Formation, undivided

Jmb — Brushy Basin Member-- Bright-green, slope-forming mudstone with thin ledges of conglomeratic sandstone, conglomerate, nodular-weathering limestone, and gritstone. Thickness 300-400 feet (91-104 m).

Jms — Salt Wash Member-- Light-yellow-gray, cross-bedded sandstone interbedded with red and gray, slope-forming mudstone and siltstone. Thickness about 250 feet (76 m).

Jmt — Tidwell Member-- Red silty shale, with interbeds of fine-grained yellow sandstone and gray limestone; Thickness 40-60 feet (12-18 m).

Jcec — Moab Member of Curtis Formation, Slick Rock Member of Entrada Sandstone, and Dewey Bridge Member of Carmel Formation, undivided.

Jctm — Moab Member of Curtis Formation-- Pale-orange or gray-orange, fine- to medium-grained, cliff-forming sandstone. Thickness 90-110 feet (27-34 m). Formerly mapped as a member of the Entrada Sandstone.

Jes — Slick Rock Member of Entrada Sandstone-- Red-brown to brown, fine-grained eolian sandstone; weathers to form smooth cliffs and bare rock slopes. Thickness 250-350 feet (76-107 m).

Jcd — Dewey Bridge Member of Carmel Formation-- Dark-red, fine-grained, silty sandstone; mostly iron-oxide cemented. Thickness 40-60 feet (12-18 m). Formerly mapped as a member of the Entrada Sandstone.

Jgc — Glen Canyon Group-- Includes Navajo Sandstone, Kayenta Formation, and Wingate Sandstone.

Jn — Navajo Sandstone-- Orange to light-gray, eolian sandstone, mostly fine grained, cemented with silica or calcite; well displayed, high-angle cross-beds. Thickness 250-400 feet (76-122 m).

Jk Kayenta Formation-- Orange-pink, red-brown, and lavender sandstone interbedded with dark-red-brown to gray-red silty mudstone, lavender-gray conglomerate, and limestone; light-orange to light-gray eolian sandstone beds more prominent in upper third; mostly cemented with calcite. Thickness 240-300 feet (73-91 m).

Jw Wingate Sandstone-- Light-orange-brown, orange-pink, or red-orange, fine-grained, well-sorted, cross-bedded sandstone; calcareous or siliceous cement. Thickness 250-350 feet (76-107 m).

Triassic

Chinle Formation

TRc Chinle Formation, undivided.

TRcu Upper Member-- Red-brown or gray-red, fine- to coarse-grained sandstone and siltstone with subordinate gritstone and gray limestone; slope forming with prominent ledges. Thickness 200-460 feet (61-140 m).

TRcl Lower member-- Mottled gray, purple, and red-brown interbedded sandstone, conglomerate, and siltstone. Thickness 0-380+ feet (0-116+ m).

Moenkopi Formation

TRm Moenkopi Formation, undivided.

TRmu Pariott and Sewemup Members, undivided-- Undivided where poorly exposed.

TRmp Pariott Member-- Red-brown sandstone interbedded with "chocolate"-brown, orange-brown, or red siltstone, mudstone, and shale; sandstone is fine to medium grained and commonly pebbly, micaceous, poorly to well sorted, and forms a series of ledges; siltstones and mudstones form steep slopes. Thickness 0-450 feet (0-137 m).

TRms Sewemup Member-- Pale-red-orange to gray-red, slope-forming siltstone with subordinate red-brown, fine-grained sandstone; gypsum is common as irregular veinlets and thin beds. Thickness 0-470 feet (0-143 m).

TRml Lower Member-- Red-brown and lavender, silty sandstone and conglomeratic sandstone interbedded with red-brown to red-orange sandstone, siltstone and silty mudstone. Thickness 0-450 feet (0-137 m).

Permian

Cutler Formation

Pcw? White Rim Sandstone Member(?)-- Gray-white, cross-bedded sandstone interbedded with minor siltstone and arkose. Thickness 0-250 feet (0-76 m), exposures limited to southwest flank of Castle Valley.

Pc Arkosic sandstone member-- Red-brown and red-purple sandstone, conglomeratic sandstone, and conglomerate interbedded with silty and sandy mudstone and shale. Thickness 0-6,235+ feet (0-1,900+ m).

Pennsylvanian

IPp Paradox Formation-- Paradox Formation cap rock consists of light-gray to yellow-gray gypsum, gypsiferous claystone, silty shale, fine-grained sandstone, and thin-bedded carbonates; disrupted and contorted bedding in two small exposures. Estimated thickness may be as much as 1,000 feet (309 m). Subsurface consists of interbedded coarse crystalline halite and other salts, massive anhydrite, sparse gray dolomite, gray to black shale, and gray siltstone. Estimated thickness 300-9,500+ feet (90-2,900+ m).

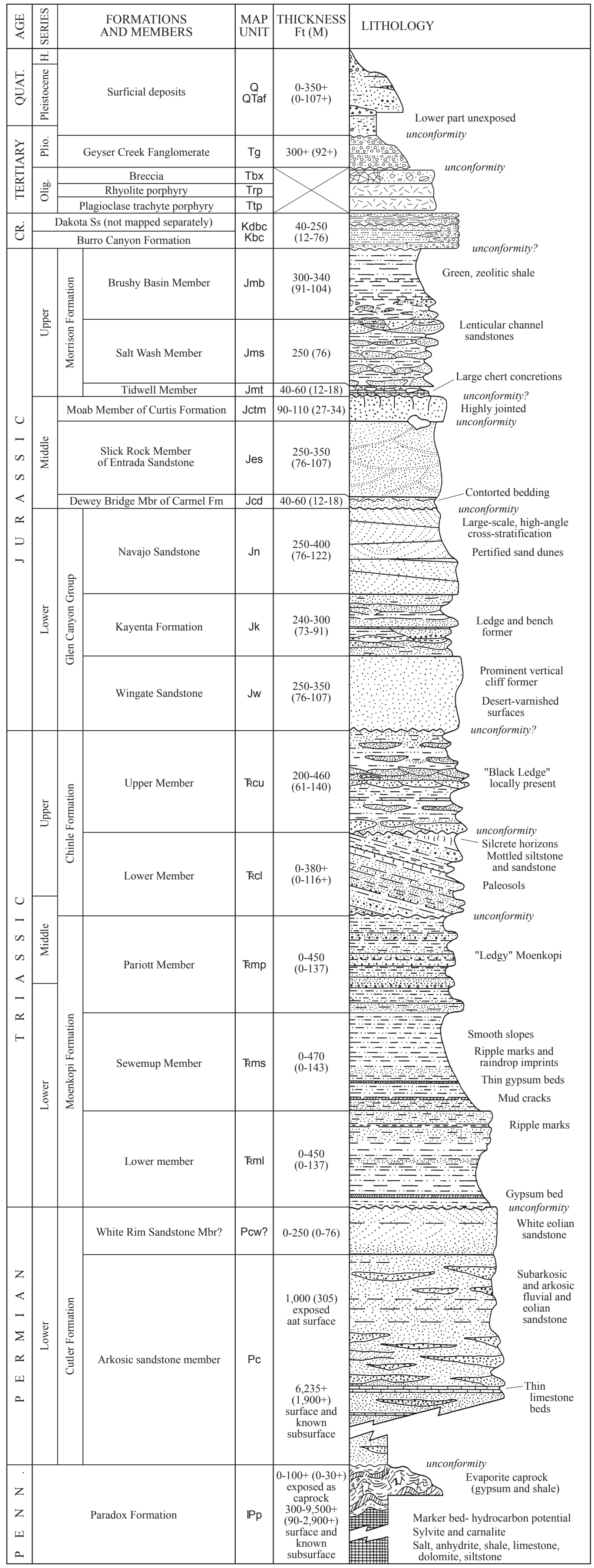


Figure D.2. *Stratigraphic column for units shown on plate 1. From Doelling (2001).*

APPENDIX E

WATER-WELL DATA FOR VALLEY-FILL ISOPACH MAP (PLATE 3)

Table E.1. *Wells used to constrain isopach contours for valley-fill sediment in Castle Valley.*

ID[1]	Location[2]	Depth to Bedrock[3] (feet)
1	N 190 W 1660 SE 25 S22 E1	21
2	N 460 W 1990 E 425 S22 E1	160
3	N 550 W 1660 SE 25 S22 E1	40
4	N 720 W 2045 SE 25 S22 E1	10
5	N 900 W 1660 SE 25 S22 E1	29
6	N 980 W 40 SE 25 S22 E1	5
7	N 1070 W 1000 SE 25 S22 E1	4
8	N 1130 W 110 SE 25 S22 E1	5
9	N 1570 W 1570 SE 25 S22 E1	10
10	N 1720 W 200 SE 25 S22 E1	31?
11	N 1750 W 2090 SE 25 S22 E1	<60
12	N 2160 W 1125 SE 25 S22 E1	>70
13	N 2180 W 630 SE 25 S22 E1	>68
14	N 3470 W 2270 SE 25 S22 E1	>102
15	S 85 W 30 E 425 S22 E1	>58
16	S 1400 W 1700 E 425 S22 E1	15
17	S 50 W 530 NE 25 S22 E12	<125
18	S 280 W 980 NE 25 S22 E12	98
19	S 610 W 980 NE 25 S22 E12	33
20	S 620 W 310 NE 25 S22 E12	>85
21	S 625 W 325 NE 25 S22 E12	30
22	S 1120 W 960 NE 25 S22 E12	56
23	S 1305 W 310 NE 25 S22 E12	40
24	S 1670 W 1040 NE 25 S22 E12	17
25	S 2390 W 430 NE 25 S22 E12	8?
26	N 300 E 1250 SW 25 S23 E5	45?
27	N 50 W 240 SE 25 S23 E6	25?
28	N 700 E 930 SW 25 S23 E6	>100
29	N 780 E 280 SW 25 S23 E6	0
30	N 965 E 780 SW 25 S23 E6	0
31	N 1100 W 1300 SE 25 S23 E6	0
32	N 1700 E 140 SW 25 S23 E6	>103
33	N 1740 E 1725 SW 25 S23 E6	>120?
34	N 1850 W 550 S 425 S23 E6	0
35	N 2340 E 2330 SW 25 S23 E6	2
36	N 2440 E 1930 SW 25 S23 E6	0
37	N 2480 E 55 SW 25 S23 E6	>58
38	N 3160 E 970 SW 25 S23 E6	110
39	N 3510 E 1070 SW 25 S23 E6	8
40	N 3530 E 220 SW 25 S23 E6	102
41	N 3770 E 850 SW 25 S23 E6	4
42	N 40 W 1190 SE 25 S23 E7	290?
43	N 160 E 515 SE 25 S23 E7	0
44	N 180 W 75 SE 25 S23 E7	15
45	N 400 E 550 W 425 S23 E7	8
46	N 580 W 85 E 425 S23 E7	>197
47	N 595 E 120 S 425 S 23 E7	2
48	N 770 W 1230 SE 25 S23 E7	>200
49	N 950 W 300 SE 25 S 23 E7	>83

ID[1]	Location[2]	Depth to Bedrock[3] (feet)
50	N 1070 W 995 SE 25 S23 E7	100
51	N 1100 W 100 SE 25 S23 E7	>110
52	N 1300 W 190 SE 25 S23 E7	>109
53	N 1300 W 200 SE 25 S23 E7	67
54	N 1470 E 200 SE 25 S23 E7	140
55	N 1660 W 1130 SE 25 S23 E7	6
56	S 109 W 332 E 425 S23 E7	>102
57	S 150 E 1000 W 425 S23 E7	45
58	S 220 W 525 NE 25 S23 E7	>106
59	S 267 W 741 E 425 S23 E7	130
60	S 300 E 700 W 425 S23 E7	30
61	S 650 E 2640 W 425 S23 E7	95
62	S 390 W 790 NE 25 S23 E7	>102
63	S 450 E 150 NW 25 S23 E7	20
64	S 475 E 1700 NW 25 S23 E7	>180
65	S 500 E 450 NW 25 S23 E7	30
66	S 605 W 1575 E 425 S23 E7	4
67	S 650 W 1170 NE 25 S23 E7	0
68	S 660 E 2080 NW 25 S23 E7	>105
69	S 970 W 100 N 425 S23 E7	>85
70	S 1070 E 410 N 425 S23 E7	>55
71	S 1210 E 930 NW 25 S23 E7	90
72	S 1310 E 1160 NW 25 S23 E7	10
73	S 1370 W 1945 NE 25 S23 E7	120
74	S 2146 E 2567 NW 25 S23 E7	125
75	N 40 W 1940 SE 25 S23 E8	>155
76	N 92 W 500 SE 25 S23 E8	196
77	N 100 E 250 S 425 S23 E8	>119
78	N 325 W 2120 SE 25 S23 E8	>113
79	N 450 E 1000 SW 25 S23 E8	100
80	N 490 E 700 S 425 S23 E8	>129
81	N 650 E 1280 SW 25 S23 E8	>130
82	N 730 E 270 SW 25 S23 E8	107
83	N 735 W 1150 SE 25 S23 E8	157?
84	N 779 W 1454 SE 25 S23 E8	>202
85	N 800 E 640 SW 25 S23 E8	>136
86	N 810 E 830 S 425 S23 E8	>125
87	N 900 W 1000 SE 25 S23 E8	>150
88	N 1055 W 55 S 425 S23 E8	90
89	N 1115 E 1900 SW 25 S23 E8	>140
90	N 1150 E 850 SW 25 S23 E8	>190
91	N 1510 W 880 SE 25 S23 E8	>137
92	N 1645 E 70 SW 25 S23 E8	>102
93	N 1650 E 1600 SW 25 S23 E8	120
94	N 1720 W 240 SE 25 S23 E8	110
95	N 3710 W 665 SE 25 S23 E8	116
96	S 275 E 210 W 425 S23 E8	>105
97	S 280 W 2030 E 425 S23 E8	110
98	S 600 W 618 E 425 S23 E8	>367
99	S 735 E 405 W 425 S23 E8	>100
100	S 1000 W 2225 NE 25 S23 E15	97
101	N 15 W 1560 SE 25 S23 E17	25
102	N 140 W 820 E 425 S23 E17	85
103	N 200 W 620 S4 25 S23 E17	24
104	N 210 W 280 E 425 S23 E17	>142

ID[1]	Location[2]	Depth to Bedrock[3] (feet)
105	N 250 W 1500 SE 25 S23 E17	>102
106	N 280 W 440 S 425 S23 E17	10
107	N 310 W 640 S 425 S23 E17	0
108	N 460 E 1460 SW 25 S23 E17	0
109	N 580 E 1150 W 425 S23 E17	>146
110	N 640 E 920 S 425 S23 E17	45
111	N 750 W 1610 E 425 S23 E17	>119
112	N 900 W 455 S 425 S23 E17	35
113	N 970 E 1980 W 425 S23 E17	20
114	N 1080 W 600 SE 25 S23 E17	>130
115	N 1213 E 2015 SW 25 S23 E17	85
116	N 1660 E 2020 SW 25 S23 E17	90
117	N 2830 W 372 SE 25 S23 E17	>165
118	N 2100 W 400 SE 25 S23 E17	>248
119	S 200 E 640 N 425 S23 E17	>195
120	S 200 E 1100 NW 25 S23 E17	>121
121	S 240 W 910 NE 25 S23 E17	120
122	S 360 E 1280 W 425 S23 E17	80
123	S 400 W 220 E 425 S23 E17	>130
124	S 430 W 295 E 425 S23 E17	>95
125	S 500 E 1050 NW 25 S23 E17	>132
126	S 565 W 500 N 425 S23 E17	77
127	S 600 E 700 NW 25 S23 E17	40
128	S 660 E 1000 W 425 S23 E17	20
129	S 700 W 550 E 425 S23 E17	>135
130	S 750 W 700 NE 25 S23 E17	>194
131	S 800 E 100 W 425 S23 E17	60
132	S 800 W 1400 E 425 S23 E17	>133
133	S 900 W 2620 E 425 S 23 E17	20
134	S 910 E 600 NW 25 S23 E17	110
135	S 1050 W 275 N 425 S23 E17	>112
136	S 1095 E 215 N 425 S23 E17	>125
137	S 1142 E 2455 NW 25 S23 E17	201
138	S 1405 E 1700 W 425 S23 E17	<93
139	S 1450 W 4250 NE 25 S23 E17	10
140	S 1500 W 2300 NE 25 S23 E17	>145?
141	S 1800 E 850 NW 25 S23 E17	>170
142	S 1810 W 545 NE 25 S23 E17	>135
143	S 2450 E 1050 NW 25 S23 E17	18
144	S 2487 E 2157 W 425 S23 E17	35
145	S 2600 E 50 N 425 S23 E17	>148
146	S 4455 E 2806 NW 25 S23 E17	85
147	N 500 W 600 E 425 S23 E18	35
148	N 600 W 1300 E 425 S23 E18	30
149	N 840 W 2360 E 425 S23 E18	6
150	N 1900 W 880 SE 25 S23 E18	0
151	S 50 W 200 N 425 S23 E18	60
152	S 140 W 3156 NE 25 S23 E18	35
153	S 450 W 280 N 425 S23 E18	20
154	S 450 W 800 NE 25 S23 E18	60
155	S 515 W 1170 NE 25 S23 E18	0
156	S 635 W 420 E 425 S23 E18	30
157	S 800 E 1250 NW 25 S23 E18	0
158	S 1050 W 2200 NE 25 S23 E18	40
159	S 1520 W760 NE 25 S23 E18	25
160	S 1695 W 200 NE 25 S23 E18	30

ID[1]	Location[2]	Depth to Bedrock[3] (feet)
161	S 2000 W 370 NE 25 S23 E18	0
162	S 2420 W 830 NE 25 S23 E18	20
163	N 500 W 950 E 425 S23 E20	40
164	S 100 W 1635 NE 25 S23 E20	25
165	S 100 E 1650 NW 25 S23 E20	0
166	S 600 W 450 N 425 S23 E20	50
167	N 1630 E 330 S 425 S23 E21	>110
168	S 3700 E 2650 NW 25 S23 E21	90
169	S 1920 W 50 NE 25 S23 E25	40
170	N 264 E 1056 SW 25 S23 E26	2
171	N 1183 E 214 S 425 S23 E26	55
172	N 2100 E 0 S 425 S23 E	69
173	S 1050 E 2220 NW 25 S23 E34	0
174	S 100 E 754 W 425 S23 E35	0
175	S 3370 E 1326 NW 25 S23 E35	0

[1] *Corresponds to number on plate 3.*

[2] *Location is given in "Point of Diversion" (POD) notation.*
Example: well 1 is located 190 feet north and 1660 feet west of the southeast corner of section 1 in Township 25 South, Range 22 East, relative to the Salt Lake 1855 Base Line and Meridian.

[3] *Values given are authors' interpretations of drillers' logs from Utah Division of Water Rights files.*
Examples: 35 - well encountered bedrock at 35 feet depth; >110 - well is 110 feet deep, all in unconsolidated deposits, so bedrock is deeper than 100 feet; 157? - best interpretation is that bedrock was encountered at 157 feet, but log is somewhat ambiguous; <60 - log of well repair, beginning at 60 feet depth in bedrock; 0 indicates all bedrock well. Drillers' logs and water rights data are available on the Utah Division of Water Rights Web site: <http://nrwrt1.nr.state.ut.us> and from paper files.

Table E.2. *Records of petroleum-test wells in Castle Valley study area 1.*

ID[2]	Operator	Well Name	API Number	Township	Range	Section	Spot[3]	Completion Date	Elevation (ft)	Total Depth (ft)
OW1	GOLD BAR RESOURCES INC	1 CASTLE VALLEY UNIT	4301910397	25 S	23 E	16	660 FNL 660 FEL	05/18/1965	5019	6502
OW2	INTER-MOUNTAIN OIL & GAS	1 GOVT	4301910599	25 S	23 E	35	660 FNL 660 FEL	07/10/1961	6250	50
OW3	GRAND RIVER OIL & GAS	1 STATE	4301911560	24 S	23 E	36	990 FNL 2310 FEL	01/05/1950	4042	3711
OW4	GRAND RIVER OIL & GAS	1 PACE	4301911564	25 S	23 E	16	1980 FSL 660 FEL	11/11/1950	6250	1725
OW5	CONOCO INC	1 CONOCO FEDERAL 31	4301931180	24 S	23 E	31	1972 FSL 1973 FEL	07/10/1985	4395	11300

Notes

[1] *Data from Utah Division of Oil, Gas and Mining records.*
[2] *Corresponds to letters on figures 3 and 6 and plates 1a and 1b. corresponds to letters on plates 1 and 3.*
[3] *Distances in feet from north (FNL), south (FSL), east (FEL), and west (FWL) section lines.*

APPENDIX F

AQUIFER TESTS

Introduction

The hydraulic properties of an aquifer can be determined by conducting one or more aquifer tests; aquifer tests involve either pumping water from a well at a constant rate or instantaneously changing the water level of a well, and observing the changes in water levels with respect to time. To obtain information about the valley-fill aquifer in Castle Valley, we analyzed specific-capacity data from, and conducted a single-well constant-flow-rate aquifer test using the existing pump on, one well, and evaluated data from 30 slug tests conducted by the Utah Division of Water Rights, all within the Town of Castle Valley.

Evaluation of Specific Capacity

We estimated the hydraulic conductivity of the valley-fill aquifer from a well test performed after the 1979 completion of a private well on lot 425 (figure F.1). The well test involved pumping the well at 30 gallons per minute (100 L/min) for 2 hours and measuring 5 feet (1.5 m) of drawdown. The specific capacity of the well can be determined from these values. Specific capacity is expressed as gallons per minute per foot of drawdown (gpm/ft) derived from the following equation:

$$\text{Specific Capacity } (C_s) = \frac{\text{Yield (Q)}}{\text{Drawdown (s)}}$$

The specific capacity of the well based on the 1979 well test is 6 gpm/ft (7 L/min/m).

We used the calculated specific capacity, Theis' (1963) aquifer-test solutions, and an assumption of a 100 percent efficient well to estimate the hydraulic conductivity of the aquifer penetrated by the well to be 0.67 feet per minute (0.20 m/min). Hydraulic conductivities calculated from specific-capacity data are generally lower than hydraulic conductivities calculated from aquifer tests, due to well (water) losses related to well construction.

Evaluation of Single-Well Constant-Flow-Rate Aquifer-Discharge Test

We also used the well on lot 425 to conduct an aquifer test (figure F.1). This well is used to water the surrounding field, and had not been pumped for some time prior to the test. The driller's report for the well indicates that the aquifer at the well site consists of clay and silt from the surface to a depth of 30 feet (9 m), gravel from 30 feet (9 m) to 98 feet (30 m), and sand and silt from 98 feet (30 m) to the bottom of the well at 102 feet (31 m). The 6-inch (15-cm) diameter well draws water from the bottom of the casing in the gravel, at 96 feet (29 m). With the pump in the well running at its maximum capacity, we measured the drawdown of water levels in the well from February 22 to February 23, 2000; after turning the pump off, we measured recovery of water levels in the well from February 23 to February 24, 2000. Water was discharged into Castle Creek, about 500 feet (152 m) east of the well house, through a 3-inch (8-cm) diameter pipe extending from the well to the creek.

To obtain a current static (initial) water-/piezometric-surface level, we measured the water level in the well several times using an electric tape before performing the aquifer test. The static water level in the well at the time of the aquifer test was 43.22 feet (13.17 m). We assumed this piezometric-surface level to be horizontal for analysis of the aquifer-test data. We measured discharge rates during the aquifer test using a Controlotron clamp-on portable flow meter. Discharge varied between 36 to 38.1 gallons per minute (136-144 L/min) (figure F.2). This low pumping rate probably did not stress the aquifer significantly, and limited the aquifer's area for us to characterize.

After 25 hours of pumping, we turned the pump off and ended the drawdown phase of the test. We monitored recovery and recorded water levels for 6 hours, until water levels returned to the pre-test static water level. Figure F.3 illustrates the water-level response during the aquifer test, showing that the observed water-level change in the well was 9.25 feet (2.82 m), and that the well recovered to the pre-test static water level. The well responded to pumping with an initial rapid drawdown, as indicated by the steep early-time segment portion of the water-level response curve (figure F.3); 95 percent of the drawdown occurred within the first minute of the drawdown phase of the test. After the initial steep drawdown, there was a gradual decline in water levels for the next 24 hours and 59 minutes of the test (figure F.3). After the pump was shut off, 95 percent of the recovery occurred within the first minute of the recovery phase of the test, with a gradual recovery for the rest of the test (figure F.3). In a single-well aquifer test, the drawdown and recovery data can be affected by well losses and well-bore storage effects. We assume that the early drawdown and recovery data are the result of well-bore storage effects; therefore, we do not use this early data in our aquifer test analysis. After the first minute, the flatter water-level response curve reflects dewatering that accompanies the falling water table. The short water-level recovery time of the well in response to the pump stopping suggests high horizontal ground-water flow velocities at the well site.

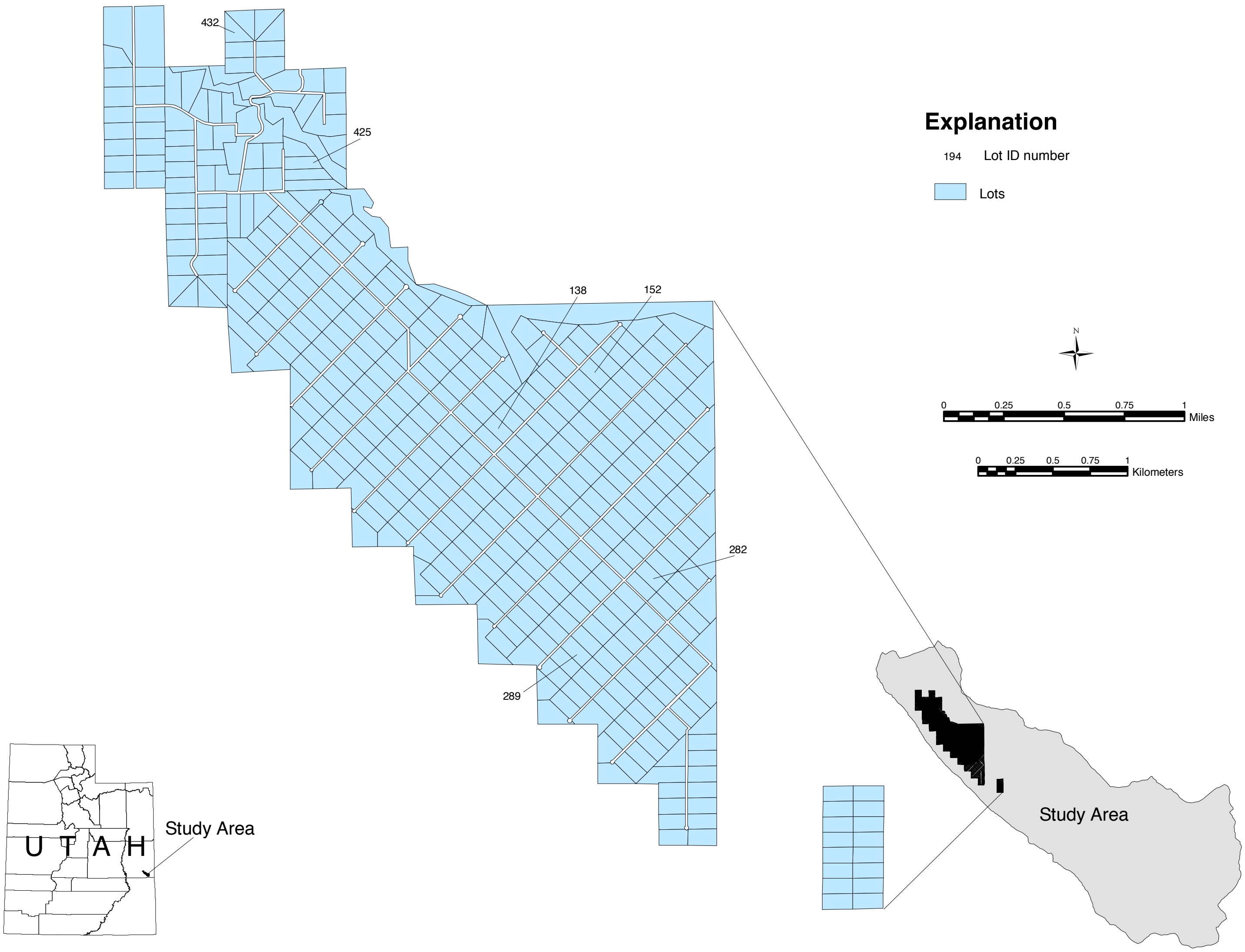


Figure F.1. Locations of wells used for aquifer and slug tests in Castle Valley, Grand County, Utah.

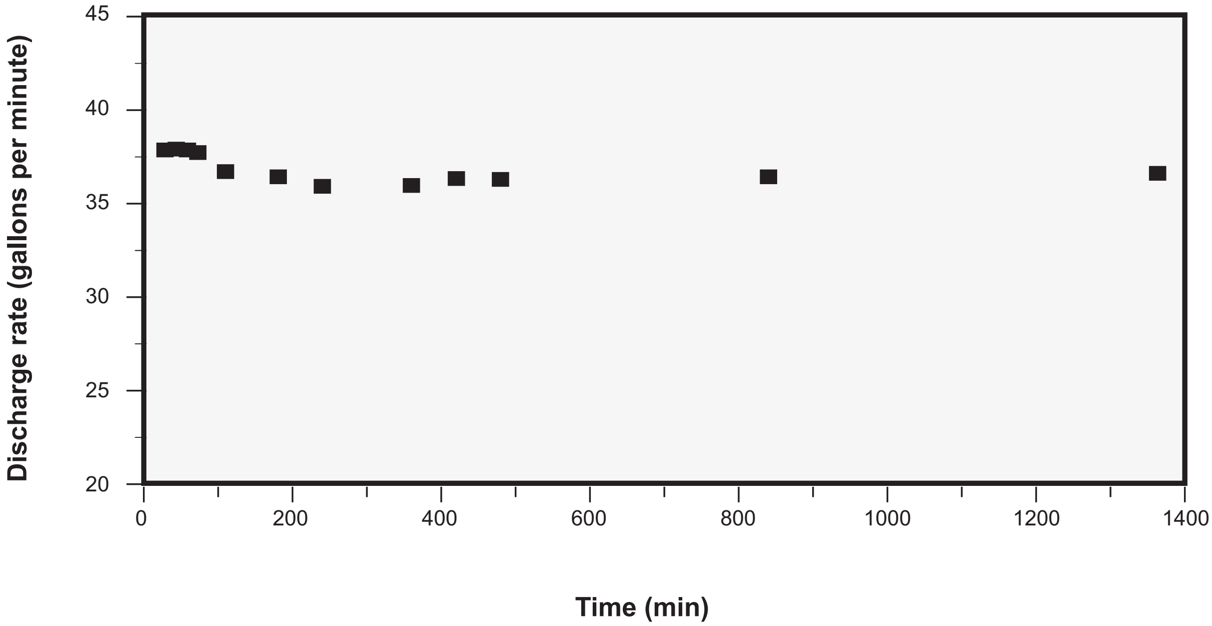


Figure F.2. *Discharge rates for the aquifer test conducted using Lot 425 well from February 22 to February 23, 2000. Time is relative to the aquifer test.*

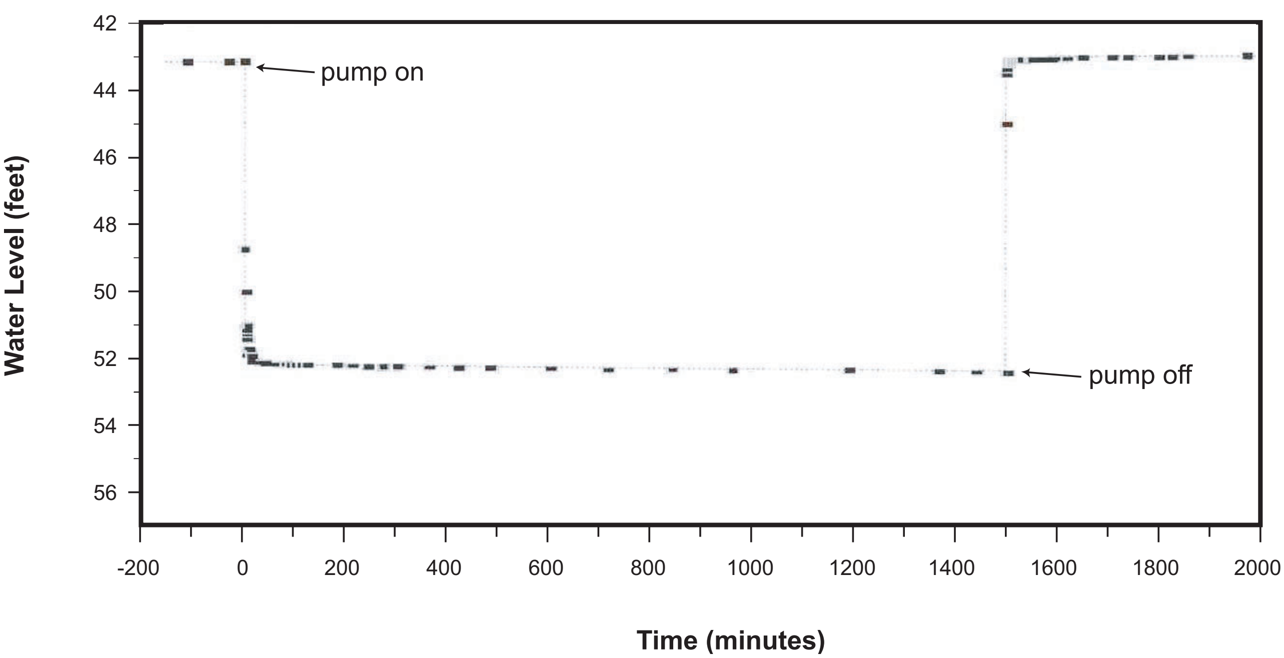


Figure F.3. *Water-level response for the aquifer test conducted using well on Lot 425 from February 22 to February 23, 2000, in Castle Valley, Grand County, Utah. Time is relative to the aquifer test.*

We analyzed the drawdown phase of the aquifer-test data using the Theis (1935) method for an unconfined aquifer with a partially penetrating well as implemented in the computer program AQTESOLVE for Windows (Hydrosolve, 1996), and determined the "best fit" match (figure F.4). The analysis involved traditional type-curve matching procedures using Theis' (1963) model and the hand-measured data to obtain the aquifer parameters. We matched the post-1 minute data to the Theis curve, because of the well-bore storage affects in the first minute of drawdown. This method may slightly overestimate the hydraulic parameters from the drawdown data. A recovery test is invaluable in a single-well test, because well losses have less effect on the calculated hydraulic parameters. We used the Theis (1935) recovery method to evaluate the recovery data; this method consists of calculating hydraulic parameters from the slope of a semi-log straight line (figure F.5). Because recovery occurred in about one-quarter of the time required for drawdown, the recovery data represents aquifer properties even more proximal to the well than the aquifer properties represented by the drawdown data.

Using the drawdown data, we determined a hydraulic conductivity of 0.004 feet per minute (0.001 m/min) using a Theis type curve for an unconfined aquifer. Using the recovery data, we determined a hydraulic conductivity of 6.38 feet per minute (1.9 m/min) using a Theis recovery method. The drawdown and recovery analysis results from the Theis type curve matching and recovery methods yield hydraulic conductivities characteristic of gravel, sand, and sand and gravel (Freeze and Cherry, 1979); in this case we feel the hydraulic conductivity determined using the drawdown data is more accurate because it reflects a larger area of the aquifer.

Evaluation of Slug Tests

Slug tests are used to evaluate aquifer hydraulic properties near individual wells. We interpreted data from 30 slug tests conducted by the Utah Division of Water Rights. These tests consisted of three sets of falling and rising slug tests (six data sets) per site, and were completed in wells on five sites (lots 282, 138, 432, 289, and 152) (figure F.1). The slug tests were conducted by measuring the fall and rise of the water level in wells caused by the introduction of a solid slug, which displaces the water. The slug apparatus was a 3-foot-long (0.9 m), 3-inch-diameter (8 cm) PVC pipe filled with cement and capped on both ends. The slug was quickly submerged in the well to displace a finite volume of water. The subsequent water-level response was measured with a pressure transducer. The duration of all the slug tests was relatively short, and the estimated hydraulic properties determined from the tests are considered to be only representative of aquifer material near the well.

We analyzed data from the slug tests using the method developed by Bouwer and Rice (1976) for an unconfined, incompressible aquifer with a partial penetrating well. Hydraulic conductivities estimated from the slug tests are summarized in tables F.1 through F.5. Figure F.6 shows a typical graph of water-level changes during one slug test for the well on lot 138. Hydraulic conductivities at two of the wells ranged between 0.2372 and 3.022 feet per minute (0.08-0.92 m/min) (lots 432 and 152); the hydraulic conductivities for the other wells ranged from 0.00033 to 0.04779 feet per minute (0.0001-0.007 m/min) (lots 282, 138, and 289).

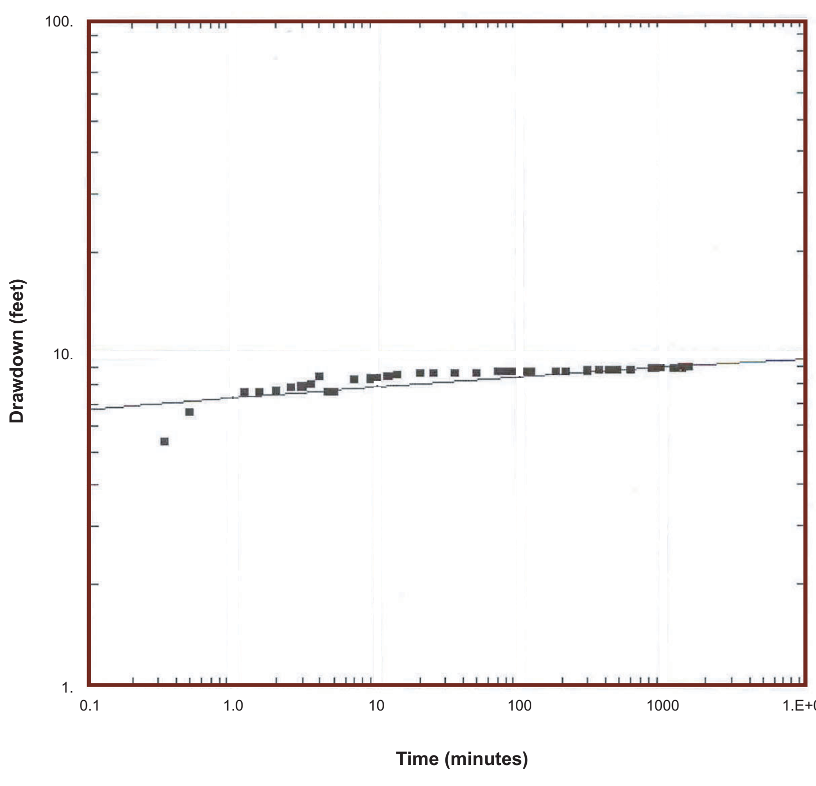


Figure F.4. *Drawdown versus time for the 25-hour aquifer test using well on Lot 425 in Castle Valley, Grand County, Utah. Logarithmic presentation used in matching test data to Theis type curve.*

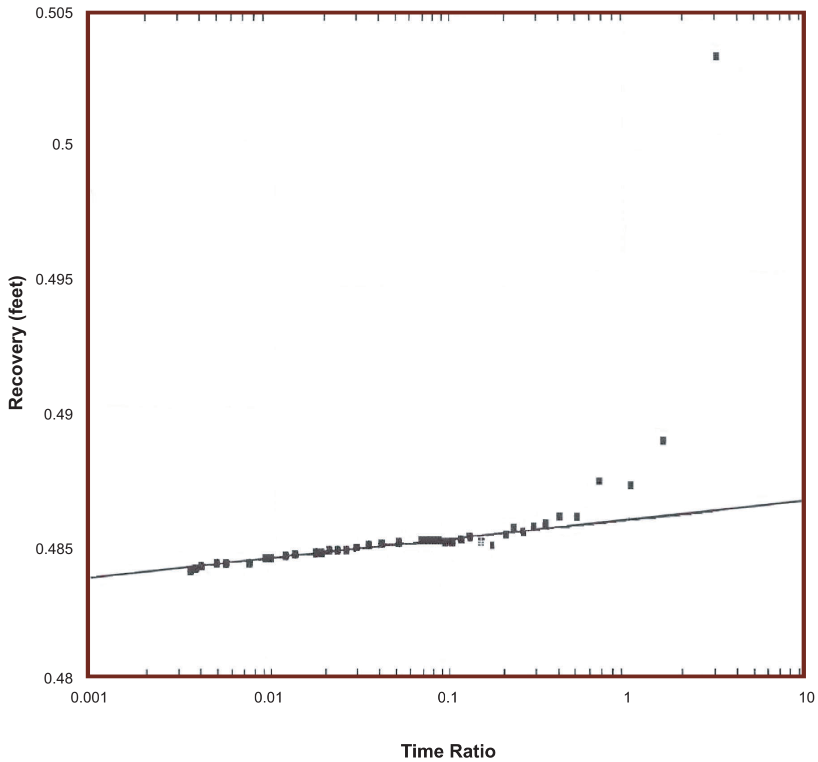


Figure F.5. *Recovery data versus time for the 6-hour recovery test using well on Lot 425 in Castle Valley, Grand County, Utah. Semilogarthmic presentation used in fitting a straight line to test data.*

Table F.1. *Values of hydraulic conductivity determined from slug tests on the well on lot 282, Town of Castle Valley, Grand County, Utah.*

Test	Hydraulic Conductivity ft/min
282-1 falling head	0.03
282-1 rising head	0.02
282-2 falling head	0.02
282-2 rising head	0.02
282-3 falling head	0.02
282-3 rising head	0.02

Table F.2. *Values of hydraulic conductivity determined from slug tests on the well on lot 138, Town of Castle Valley, Grand County, Utah.*

Test	Hydraulic Conductivity ft/min
138-1 falling head	0.002
138-1 rising head	0.001
138-2 falling head	0.001
138-2 rising head	0.002
138-3 falling head	0.002
138-3 rising head	0.003

Table F.3. *Values of hydraulic conductivity determined from slug tests on the well on lot 432, Town of Castle Valley, Grand County, Utah.*

Test	Hydraulic Conductivity ft/min
432-1 falling head	0.30
432-1 rising head	1.62
432-2 falling head	1.99
432-2 rising head	2.41
432-3 falling head	2.0
432-3 rising head	3.02

Table F.4. *Values of hydraulic conductivity determined from slug tests on the well on lot 289, Town of Castle Valley, Grand County, Utah.*

Test	Hydraulic Conductivity ft/min
289-1 falling head	0.03
289-1 rising head	0.04
289-2 falling head	0.14
289-2 rising head	>0.01
289-3 falling head	0.01
289-3 rising head	Could not interpret data

Table F.5. *Values of hydraulic conductivity determined from slug tests on the well on lot 152, Town of Castle Valley, Grand County, Utah.*

Test	Hydraulic Conductivity ft/min
152-1 falling head	0.33
152-1 rising head	0.37
152-2 falling head	0.36
152-2 rising head	0.26
1523 falling head	0.24
152-3 rising head	0.34

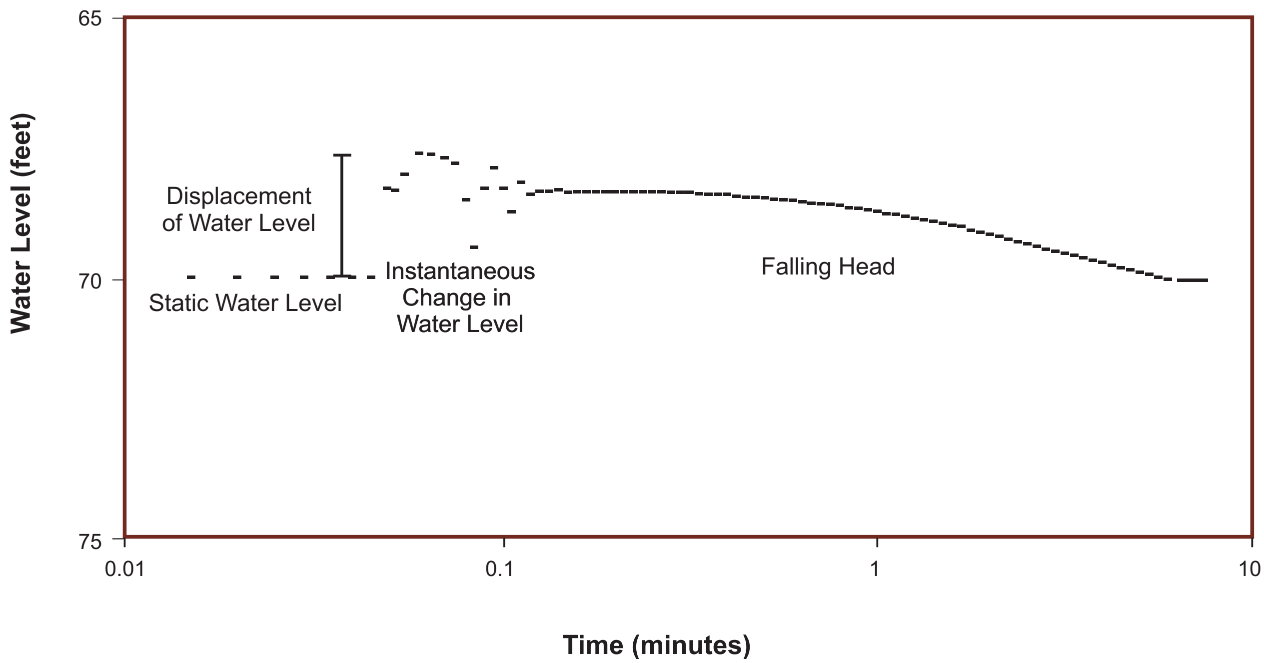


Figure F.6. *Water-level change as a function of time for slug test using well on Lot 138 in Castle Valley, Grand County, Utah. The graph represents a typical falling head slug test used in the Castle Valley study.*

APPENDIX G

POTENTIAL SITES FOR PUBLIC-SUPPLY WELLS

Future population growth in Castle Valley will require additional water-supply sources. Should these additional water-supply sources include a public-supply well, the entire Castle Valley drainage basin may qualify for a Class IB, Irreplaceable ground water, classification based on the U.S. Environmental Protection Agency Sole Source Aquifer designation (Town of Castle Valley, 2000). Here we describe several potential sites for future water wells, as requested by the Town of Castle Valley. We selected the sites primarily for their geologic and hydrologic setting, with some consideration of logistical and water-rights concerns. The latter factors were not thoroughly researched, however, and may eliminate some sites from consideration. Any potential water-well site should receive a site-specific evaluation by a professional hydrogeologist or engineer before development begins. The following paragraphs describe potential well sites in Castle Valley, including their likely advantages and disadvantages. The potential well sites are shown on plates 1, 2, and 3.

Potential site A is northeast of the eastern Castle Valley town boundary, in the northeast quarter of section 16, T. 25 S., R. 23 E., SLBM (plate 1), on land presently owned by the Utah State Institutional and Trust Lands Administration (SITLA). Site A is in a narrow belt of unconsolidated deposits greater than 300 feet (90 m) thick, the thickest unconsolidated deposits known in the valley (plate 3). This belt of thick sediment is defined by only two wells (wells 98 and OW-3, appendix D). We consider the logs of these wells to be reliable, so are confident that unconsolidated deposits in this area are greater than 300 feet (90 m) thick, but the shape and extent of this belt of thick unconsolidated deposits are poorly constrained. A new well should be constructed to draw water exclusively from the alluvial aquifer and not penetrate the underlying Cutler Formation, based on ground-water quality considerations (Town of Castle Valley, 2000).

Advantages of site A include (1) use of a proven aquifer, (2) proximity of the well to Castle Creek, the main recharge source for the unconsolidated aquifer (Snyder, 1996a, b; Town of Castle Valley, 2000), and (3) proximity to present water-distribution systems. Disadvantages of site A include (1) potential decreased flow of Castle Creek and the resulting environmental and water-rights consequences, and (2) vulnerability of the unconfined, unconsolidated aquifer to contamination (Snyder, 1996a, b; Town of Castle Valley, 2000).

Sites B1 and B2 are in the upper part of the north arm of Castle Valley, in sections 29 and 28, respectively, of T. 25 S., R. 24 E., SLBM (plate 1). Site B1 is on U.S. Bureau of Land Management property and site B2 is on U.S. Forest Service property; both sites have similar geologic and hydrologic settings, and are presented as alternatives because the logistics of negotiating drilling permits and water rights may be different for the two agencies.

Sites B1 and B2 penetrate the hinge zone of a syncline below the northern valley margin (cross sections C-C' and D-D', plate 2), and would draw water from the Navajo Sandstone, Kayenta Formation, and Wingate Sandstone aquifers. Recharge to these units likely comes from both Adobe Mesa and Grand View Mountain, and perhaps from Castle Creek. Any site between B1 and B2 would encounter similar geologic and hydrologic conditions and would be equally suitable.

Advantages of sites B1 and B2 include (1) use of aquifers that are proven producers throughout the Colorado Plateau (Freethey and Cordy, 1991) but that are not currently used in Castle Valley, (2) the likelihood that the target aquifers receive recharge from several source areas, and (3) at the potential well sites, the relatively low-permeability Dewey Bridge and Slick Rock Members of the Entrada Sandstone overlie the target aquifers, providing hydrologic isolation from Castle Creek and the unconsolidated aquifer and some protection from contamination. Disadvantages of sites B1 and B2 include (1) possible effects on wells and springs downgradient in Castleton, (2) vulnerability to contamination from activity in the recharge areas, especially the flanks of Grand View Mountain, (3) costliness of deep drilling (~1,000 feet [300 m] for B2), and (4) their distance from present water-distribution systems.

Potential sites C1 and C2 are on the northwestern flank of Grand View Mountain, in section 5, T. 25 S., R. 24 E., SLBM (plate 1), on SITLA property. Fractured trachyte porphyry of the La Sal Mountains intrusion is the target aquifer for both sites. Recharge to the aquifer at the potential well sites comes from precipitation on Grand View Mountain. Site C1 is in a topographic depression, enhancing its recharge potential, but is near the northwestern margin of the intrusion. Because the subsurface geometry of the La Sal Mountains intrusion is poorly known, closer proximity to the intrusion margin results in greater uncertainty about the thickness of the target aquifer there and increases the possibility of encountering salt- and gypsum-rich cap rock of the Paradox Formation (see cross sections C-C′ and D-D′, plate 2). Site C2 is near Spring Branch, a perennial stream, and is closer to the center of the La Sal Mountains intrusion.

Advantages of sites C1 and C2 include (1) their proximity to a large potential recharge area, and (2) the target aquifer presently has little water development. Disadvantages of these sites include (1) the uncertainty in the thickness of trachyte porphyry below the sites, (2) the potential for interference with existing wells in the nearby Castleview subdivision (especially for site C1, which is downgradient from the subdivision), (3) the potential for decreased flow of Spring Branch (especially for site C2), and (4) the great distance from present water-distribution systems.

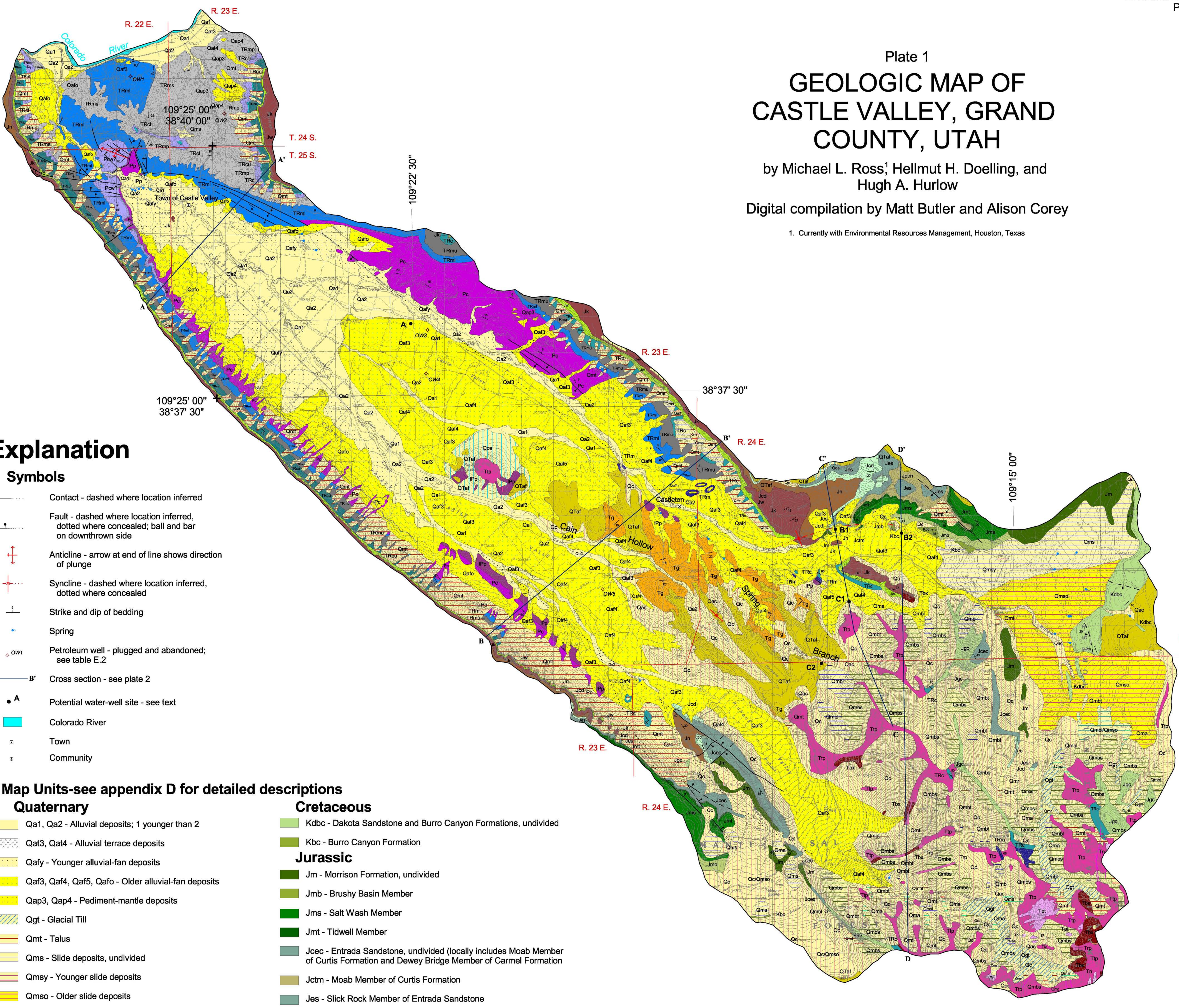
SPECIAL STUDY
Plate 1
2004

Plate 1
GEOLOGIC MAP OF CASTLE VALLEY, GRAND COUNTY, UTAH

by Michael L. Ross,[1] Hellmut H. Doelling, and Hugh A. Hurlow

Digital compilation by Matt Butler and Alison Corey

1. Currently with Environmental Resources Management, Houston, Texas



Explanation

Symbols

- Contact - dashed where location inferred
- Fault - dashed where location inferred, dotted where concealed; ball and bar on downthrown side
- Anticline - arrow at end of line shows direction of plunge
- Syncline - dashed where location inferred, dotted where concealed
- Strike and dip of bedding
- Spring
- OW1 Petroleum well - plugged and abandoned; see table E.2
- B —— B' Cross section - see plate 2
- A Potential water-well site - see text
- Colorado River
- Town
- Community

Map Units-see appendix D for detailed descriptions

Quaternary

- Qa1, Qa2 - Alluvial deposits; 1 younger than 2
- Qat3, Qat4 - Alluvial terrace deposits
- Qafy - Younger alluvial-fan deposits
- Qaf3, Qaf4, Qaf5, Qafo - Older alluvial-fan deposits
- Qap3, Qap4 - Pediment-mantle deposits
- Qgt - Glacial Till
- Qmt - Talus
- Qms - Slide deposits, undivided
- Qmsy - Younger slide deposits
- Qmso - Older slide deposits
- Qmbl - Block-slope lateral-spread deposits
- Qmbl/Qmso - Block-slope lateral-spread deposits on older slide deposits
- Qmbs - Block-slope slide deposits
- Qmbt - Block-slope talus deposits
- Qma - Rock-avalanche deposits
- Qmr - Rock-glacier deposits
- Qc - Colluvial deposits Qc/Qmso - colluvial deposits over older slide deposits
- Qce - Colluvial and eolian deposits
- Qes - Eolian sand
- Qac - Alluvial and colluvial deposits

Quaternary-Tertiary

- QTaf - Alluvial-fan deposits

Tertiary

- Tg - Geyser Creek Fanglomerate
- Tbx - Breccia
- Trp - Peralkaline rhyolite dikes
- Tpt - Peralkaline trachyte
- Tn - Nosean trachyte dikes
- Th - Hornblende-plagioclase trachyte
- Ttp - Quartz-plagioclase trachyte

Cretaceous

- Kdbc - Dakota Sandstone and Burro Canyon Formations, undivided
- Kbc - Burro Canyon Formation

Jurassic

- Jm - Morrison Formation, undivided
- Jmb - Brushy Basin Member
- Jms - Salt Wash Member
- Jmt - Tidwell Member
- Jcec - Entrada Sandstone, undivided (locally includes Moab Member of Curtis Formation and Dewey Bridge Member of Carmel Formation
- Jctm - Moab Member of Curtis Formation
- Jes - Slick Rock Member of Entrada Sandstone
- Jcd - Dewey Bridge Member of Carmel Formation
- Jgc - Glen Canyon Group, undivided (includes Navajo, Kayenta, and Wingate Formations)
- Jn - Navajo Sandstone
- Jk - Kayenta Formation
- Jw - Wingate Sandstone

Triassic

- TRc - Chinle Formation, undivided
- TRcu - Upper member
- TRcl - Lower member
- TRm - Moenkopi Formation, undivided
- TRmu - Parriott and Sewemup Members, undivided
- TRmp - Parriott Member
- TRms - Sewemup member
- TRml - Lower member

Permian

Cutler Formation

- Pcw? - White Rim Sandstone Member?
- Pc - Arkosic sandstone member

Pennsylvanian

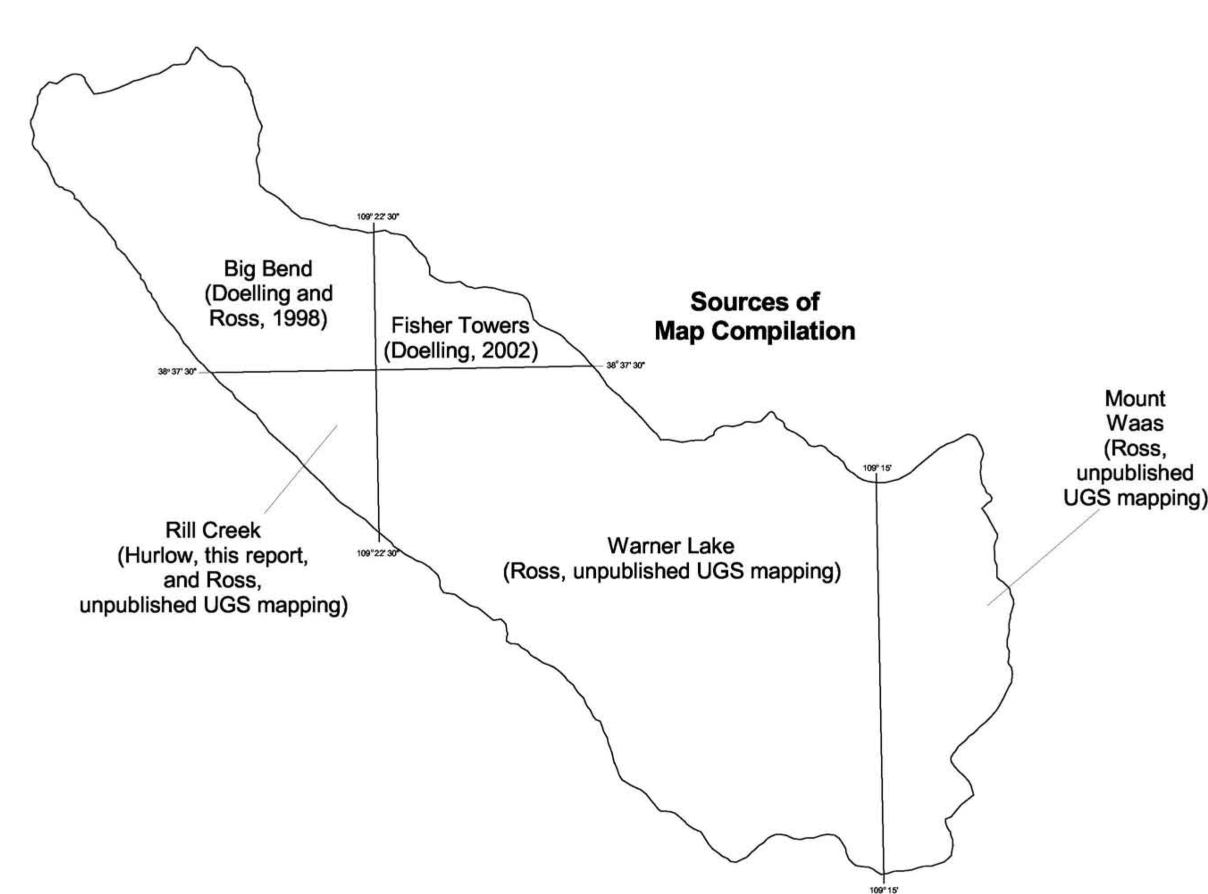
- IPp - Paradox Formation

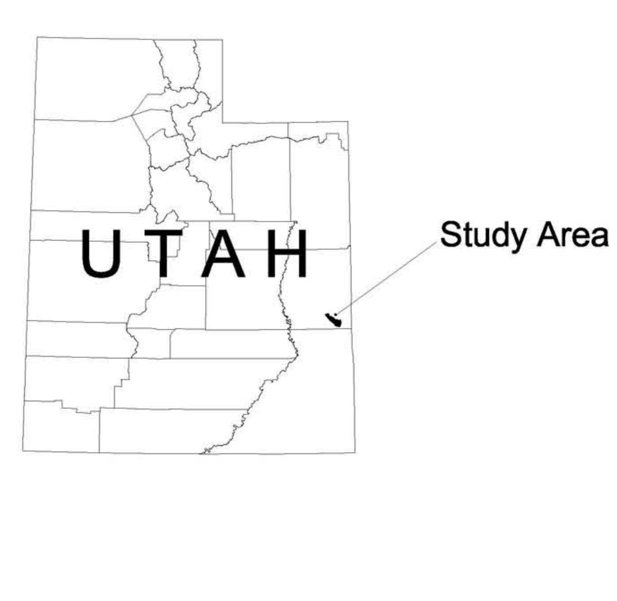
Map Scale: 1:30,000

Contour Interval 40 Feet

0 1 1.5 2 Miles

0 1 1.5 2 Kilometers





Base map from U.S. Geological Survey Big Bend, Fisher Towers, Mount Waas, Rill Creek, and Warner Lake 7-1/2 minute quadrangles.

Projection: UTM Zone 12
Units: Meters
Datum: 1927 North American
Spheroid: Clarke 1866

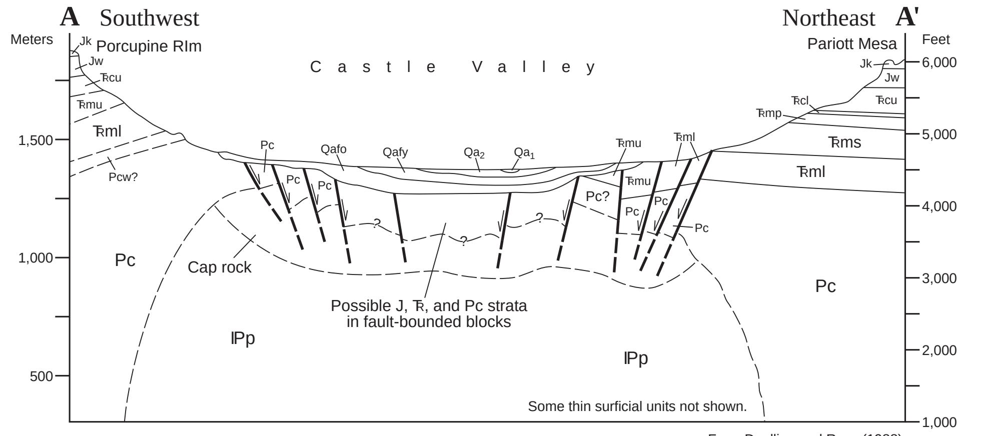
UTAH GEOLOGICAL SURVEY

UTAH GEOLOGICAL SURVEY
a division of
Department of Natural Resources

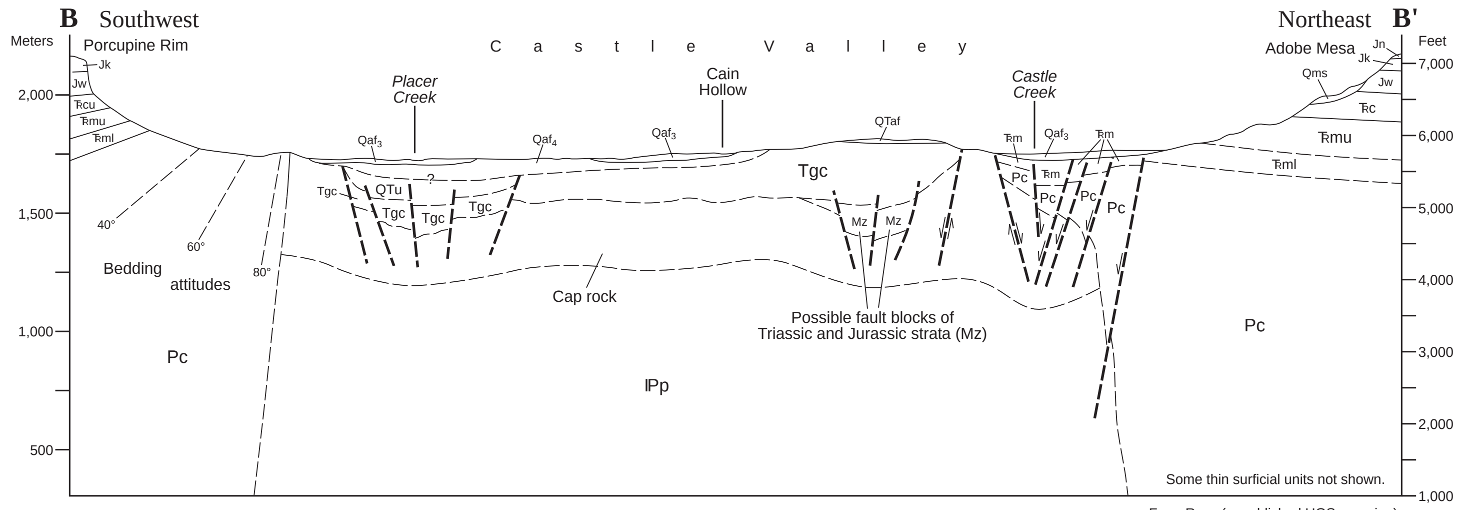
Cross Sections

by
Michael L. Ross, Hellmut H. Doelling, and Hugh A. Hurlow

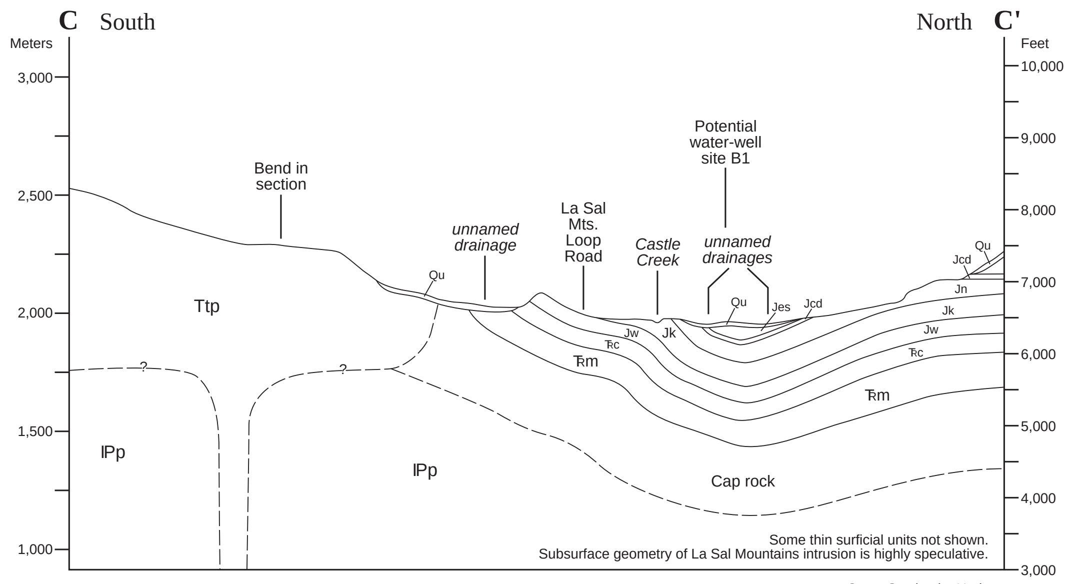
See plates 1 and 3 for locations, and appendix D for descriptions of units



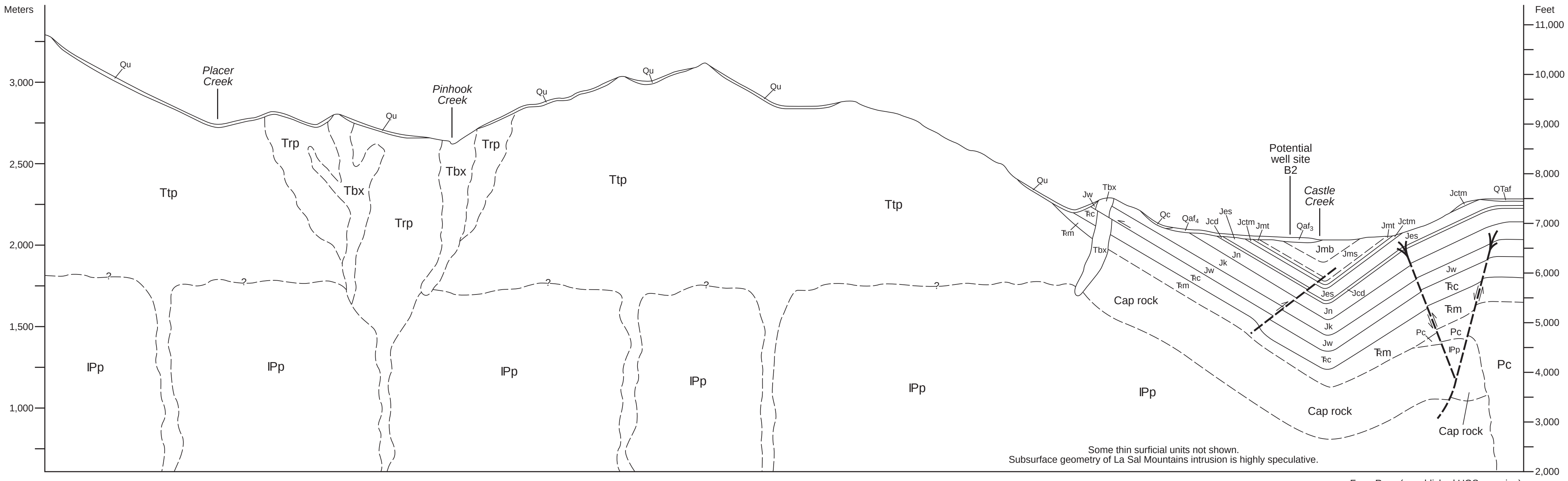
From Doelling and Ross (1988).



From Ross (unpublished UGS mapping).



Cross Section by Hurlow.



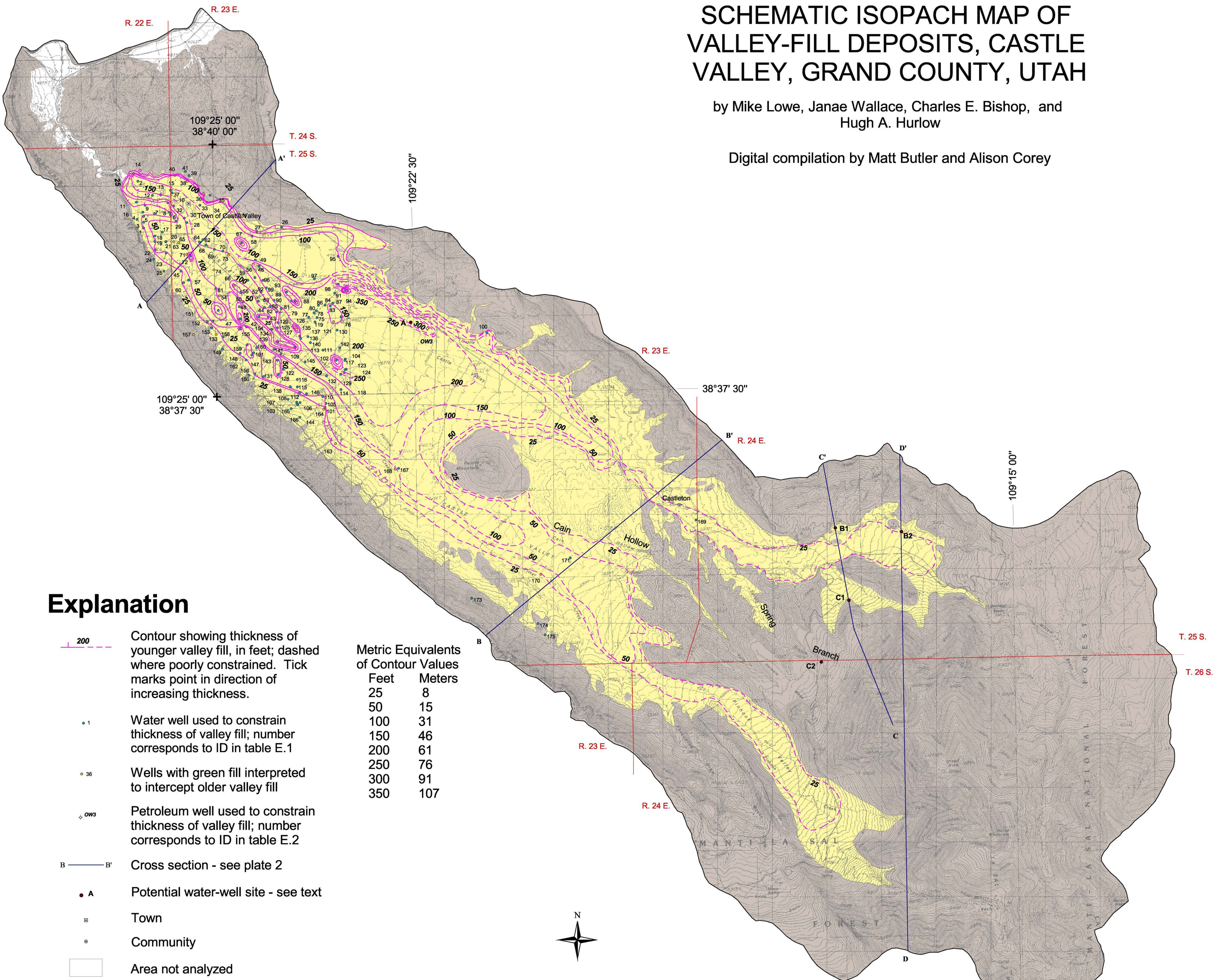
From Ross (unpublished UGS mapping).

Plate 3

SCHEMATIC ISOPACH MAP OF VALLEY-FILL DEPOSITS, CASTLE VALLEY, GRAND COUNTY, UTAH

by Mike Lowe, Janae Wallace, Charles E. Bishop, and Hugh A. Hurlow

Digital compilation by Matt Butler and Alison Corey



Explanation

- Contour showing thickness of younger valley fill, in feet; dashed where poorly constrained. Tick marks point in direction of increasing thickness.
- Water well used to constrain thickness of valley fill; number corresponds to ID in table E.1
- Wells with green fill interpreted to intercept older valley fill
- Petroleum well used to constrain thickness of valley fill; number corresponds to ID in table E.2
- Cross section - see plate 2
- Potential water-well site - see text
- Town
- Community
- Area not analyzed
- Valley-fill deposits
- Bedrock and thin surficial deposits (not analyzed)

Metric Equivalents of Contour Values

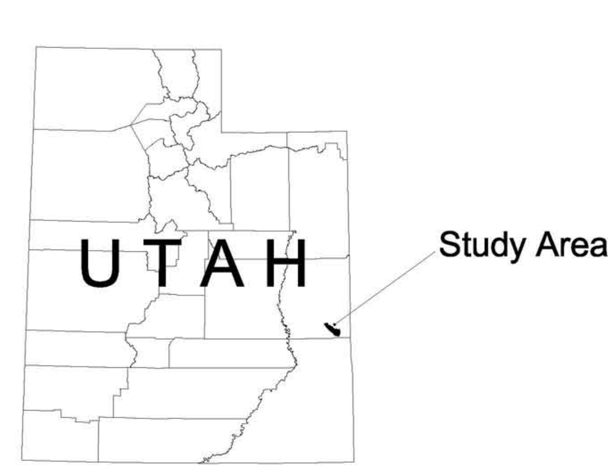
Feet	Meters
25	8
50	15
100	31
150	46
200	61
250	76
300	91
350	107

Map Scale: 1:30,000

Contour Interval 40 Feet

0 1 1.5 2 Miles

0 1 1.5 2 Kilometers



Base map from U.S. Geological Survey Big Bend, Fisher Towers, Mount Waas, Rill Creek, and Warner Lake 7-1/2 minute quadrangles.

Projection: UTM Zone 12
Units: Meters
Datum: 1927 North American
Spheroid: Clarke 1866

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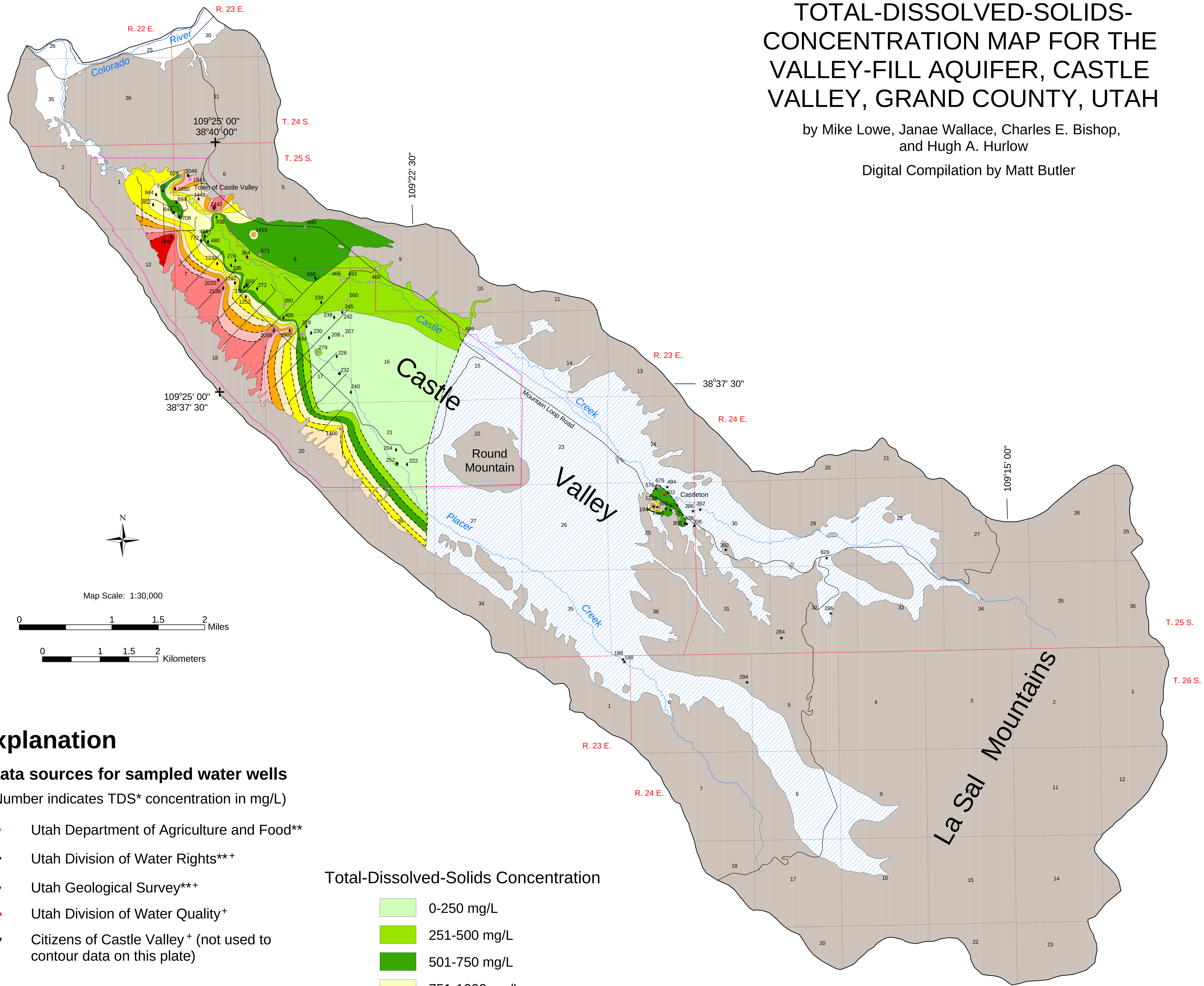
SPECIAL STUDY 113
Plate 4
2004

Plate 4

TOTAL-DISSOLVED-SOLIDS-CONCENTRATION MAP FOR THE VALLEY-FILL AQUIFER, CASTLE VALLEY, GRAND COUNTY, UTAH

by Mike Lowe, Janae Wallace, Charles E. Bishop, and Hugh A. Hurlow

Digital Compilation by Matt Butler



Explanation

Data sources for sampled water wells

(Number indicates TDS* concentration in mg/L)

- Utah Department of Agriculture and Food**
- Utah Division of Water Rights**+
- Utah Geological Survey**+
- Utah Division of Water Quality+
- Citizens of Castle Valley+ (not used to contour data on this plate)

* Total dissolved solids

** Data shown in purple are converted specific conductance data

\+ Analysis by the Utah Department of Epidemiology and Laboratory Services

- Line of equal concentration of dissolved solids - dashed where uncertain
- Study-area boundary
- Municipal boundary
- Road
- Water course
- Town
- Community

Total-Dissolved-Solids Concentration

- 0-250 mg/L
- 251-500 mg/L
- 501-750 mg/L
- 751-1000 mg/L
- 1001-1250 mg/L
- 1251-1500 mg/L
- 1501-1750 mg/L
- 1751-2000 mg/L
- 2001-2250 mg/L
- 2251-2500 mg/L
- No data
- Bedrock (not analyzed)
- Area not analyzed

Projection: UTM Zone 12
Units: Meters
Datum: NAD27
Spheroid: Clarke 1866

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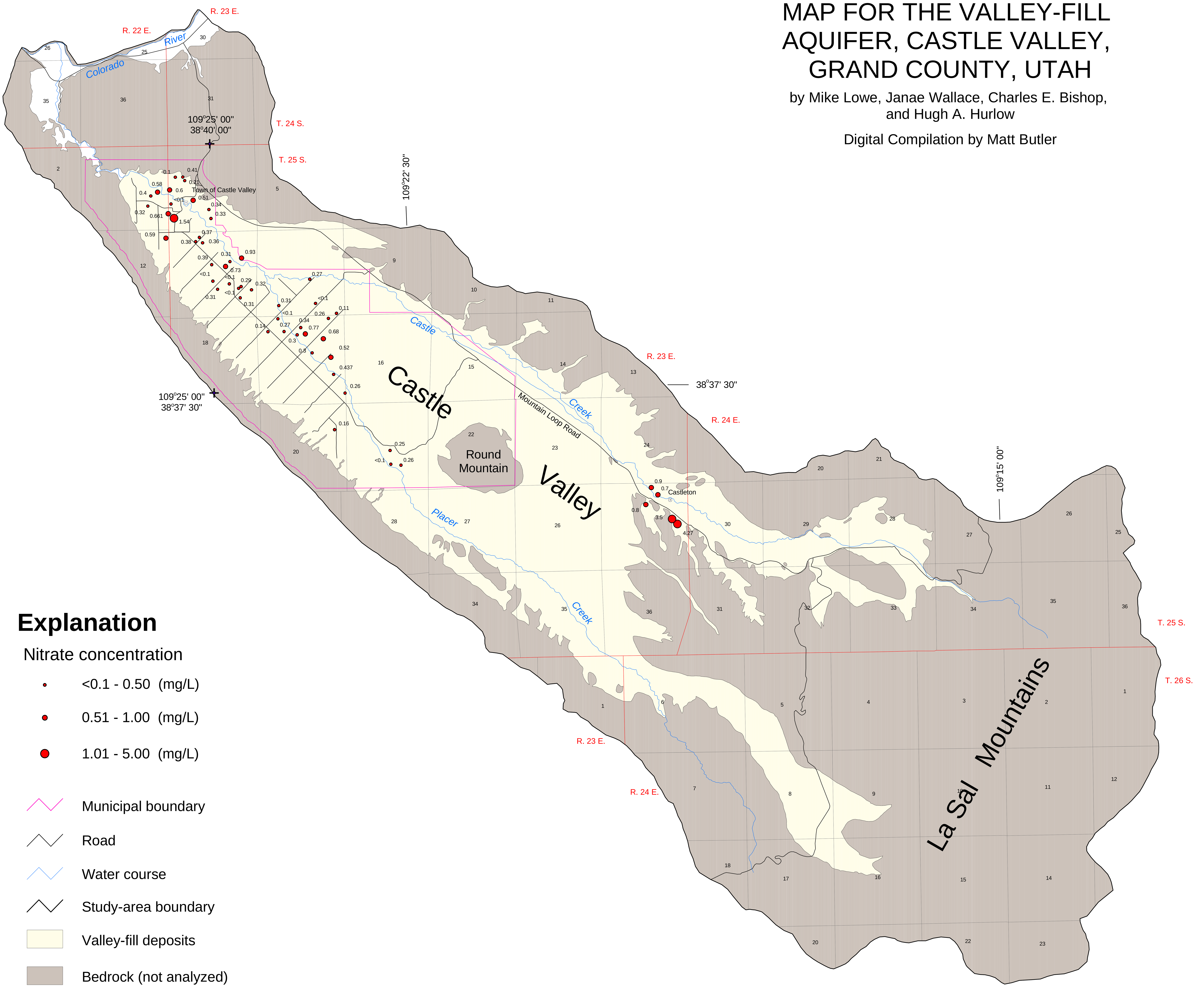
SPECIAL STUDY 113
Plate 5
2004

Plate 5

NITRATE CONCENTRATION MAP FOR THE VALLEY-FILL AQUIFER, CASTLE VALLEY, GRAND COUNTY, UTAH

by Mike Lowe, Janae Wallace, Charles E. Bishop, and Hugh A. Hurlow

Digital Compilation by Matt Butler



Explanation

Nitrate concentration

- <0.1 - 0.50 (mg/L)
- 0.51 - 1.00 (mg/L)
- 1.01 - 5.00 (mg/L)
- Municipal boundary
- Road
- Water course
- Study-area boundary
- Valley-fill deposits
- Bedrock (not analyzed)
- Area not analyzed
- Town
- Community

N

Map Scale: 1:30,000

0 1 1.5 2 Miles

0 1 1.5 2 Kilometers

Projection: UTM Zone 12
Units: Meters
Datum: NAD27
Spheroid: Clarke 1866

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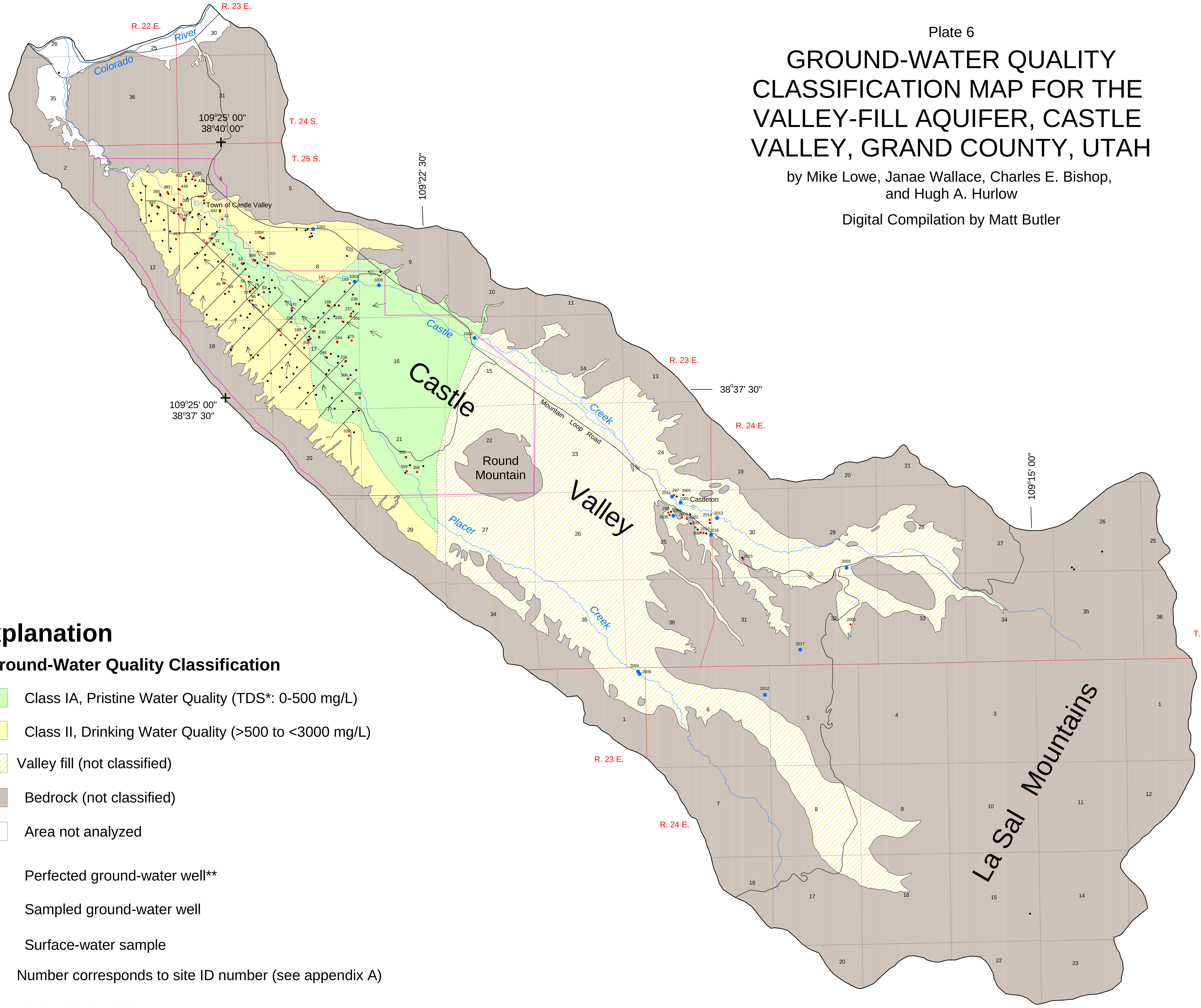
SPECIAL STUDY 113
Plate 6
2004

Plate 6

GROUND-WATER QUALITY CLASSIFICATION MAP FOR THE VALLEY-FILL AQUIFER, CASTLE VALLEY, GRAND COUNTY, UTAH

by Mike Lowe, Janae Wallace, Charles E. Bishop, and Hugh A. Hurlow

Digital Compilation by Matt Butler



Explanation

Ground-Water Quality Classification

- Class IA, Pristine Water Quality (TDS*: 0-500 mg/L)
- Class II, Drinking Water Quality (>500 to <3000 mg/L)
- Valley fill (not classified)
- Bedrock (not classified)
- Area not analyzed

- Perfected ground-water well**
- Sampled ground-water well
- Surface-water sample
- 328 Number corresponds to site ID number (see appendix A)

* Total dissolved solids

** All wells are listed in Utah Division of Water Rights database

- Ground-water quality class boundary
- Valley-fill deposits boundary
- Study-area boundary
- Municipal boundary
- Road
- Water course
- Ground-water flow direction (from Snyder, 1996)
- Town
- Community

N

Map Scale: 1:30,000

0 1 1.5 2 Miles

0 1 1.5 2 Kilometers

Projection: UTM Zone 12
Units: Meters
Datum: NAD27
Spheroid: Clarke 1866

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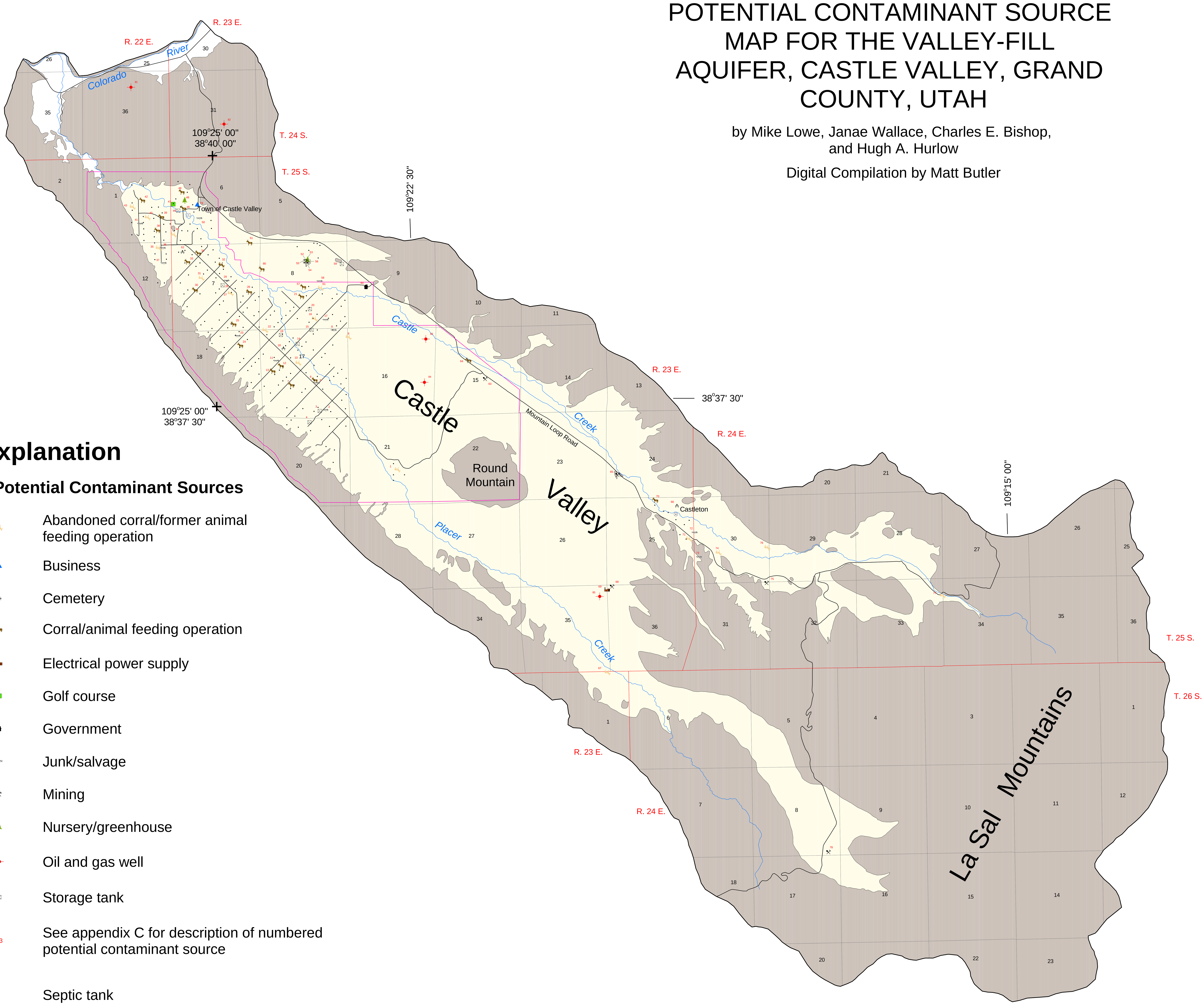
SPECIAL STUDY 113
Plate 7
2004

Plate 7

POTENTIAL CONTAMINANT SOURCE MAP FOR THE VALLEY-FILL AQUIFER, CASTLE VALLEY, GRAND COUNTY, UTAH

by Mike Lowe, Janae Wallace, Charles E. Bishop, and Hugh A. Hurlow

Digital Compilation by Matt Butler



Explanation

Potential Contaminant Sources

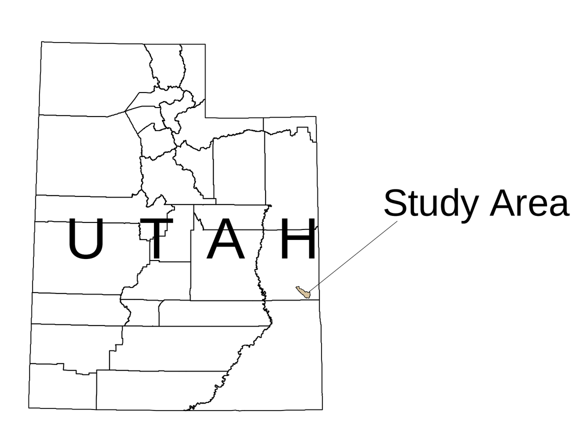
- Abandoned corral/former animal feeding operation
- Business
- Cemetery
- Corral/animal feeding operation
- Electrical power supply
- Golf course
- Government
- Junk/salvage
- Mining
- Nursery/greenhouse
- Oil and gas well
- Storage tank
- 53 See appendix C for description of numbered potential contaminant source
- Septic tank
- Municipal boundary
- Road
- Water course
- Study-area boundary
- Valley-fill deposits
- Bedrock (not surveyed)
- Area not surveyed
- Town (Castle Valley)
- Community

N

Map Scale: 1:30,000

0 1 1.5 2 Miles

0 1 1.5 2 Kilometers



Projection: UTM Zone 12
Units: Meters
Datum: NAD27
Spheroid: Clarke 1866

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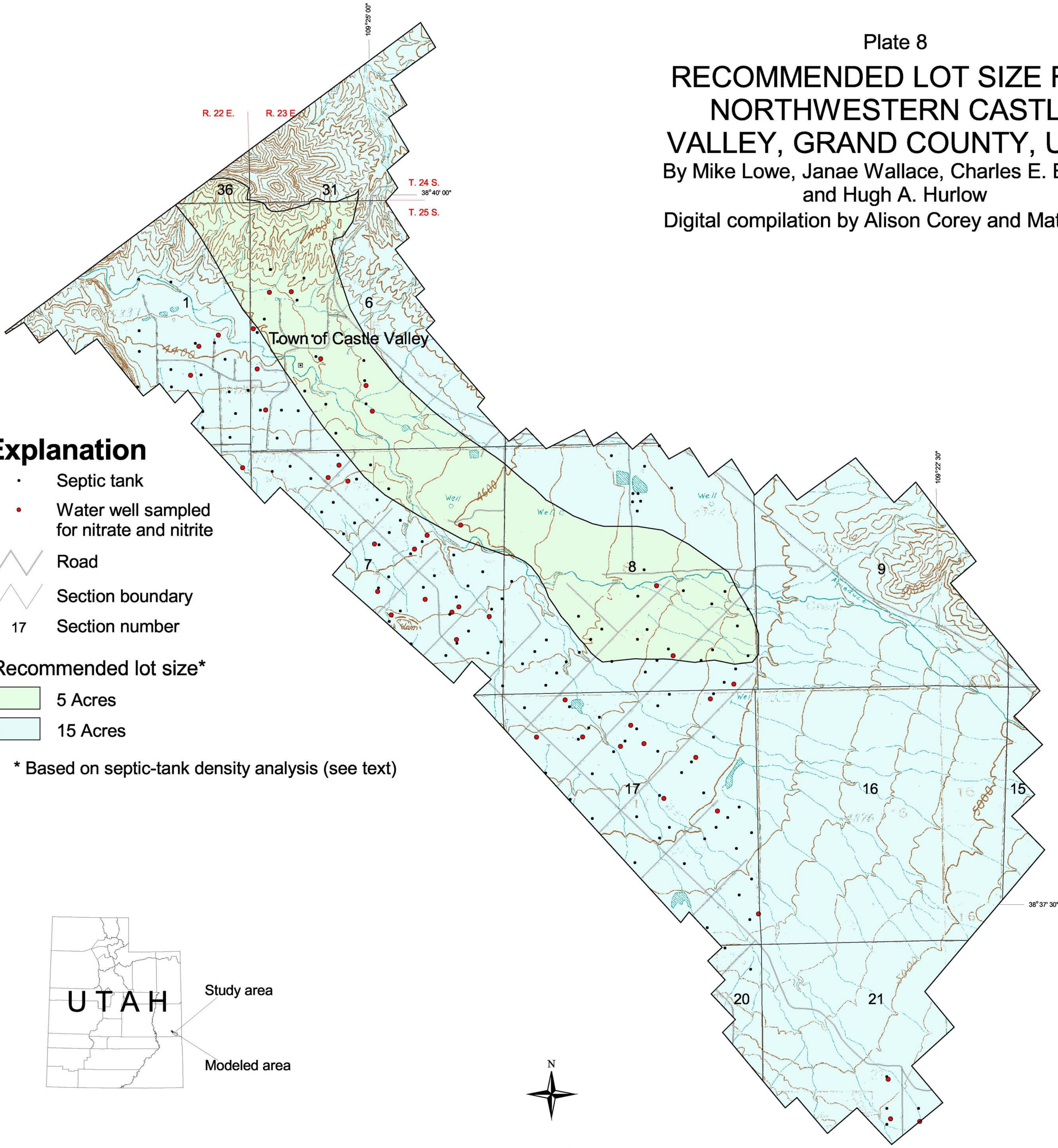
SPECIAL STUDY
PLATE 8
2004

Plate 8

RECOMMENDED LOT SIZE FOR NORTHWESTERN CASTLE VALLEY, GRAND COUNTY, UTAH

By Mike Lowe, Janae Wallace, Charles E. Bishop, and Hugh A. Hurlow
Digital compilation by Alison Corey and Matt Butler



Explanation

- Septic tank
- Water well sampled for nitrate and nitrite
- Road
- Section boundary
- 17 Section number

Recommended lot size*

- 5 Acres
- 15 Acres

* Based on septic-tank density analysis (see text)

1:15,000

0 0.5 1 Miles

0 0.5 1 Kilometers

Base map from U.S. Geological Survey Big Bend, Fisher Towers, Rill Creek, and Warner Lake 7-1/2 minute quadrangles.

Projection: UTM Zone 12
Units: Meters
Datum: NAD27
Spheroid: Clarke 1866

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