THE HYDROGEOLOGY OF MOAB-SPANISH VALLEY, GRAND AND SAN JUAN COUNTIES, UTAH, WITH EMPHASIS ON MAPS FOR WATER-RESOURCE MANAGEMENT AND LAND-USE PLANNING

by

Mike Lowe, Janae Wallace, Stefan M. Kirby, and Charles E. Bishop

SPECIAL STUDY 120
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Cover Photo: *View looking to the southwest of Moab-Spanish Valley. Photo by Janae Wallace.*

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ABSTRACT

Moab and Spanish Valleys are two contiguous valleys in southeastern Utah, herein referred to as Moab-Spanish Valley. Moab-Spanish Valley is a semirural area in Grand and San Juan Counties that is experiencing an increase in residential development. While most of the development in the Grand County portion of Moab-Spanish Valley is on a community sewer system, development in the San Juan County portion uses septic tank soil-absorption systems for wastewater disposal. Many of these septic-tank systems are on valley-fill deposits that are a drinking-water aquifer for the area. The purpose of our study is to provide tools for water-resource management and land-use planning; to accomplish this purpose we (1) characterize the relationship of geology to ground-water conditions in the Glen Canyon and the unconsolidated valley-fill aquifers, (2) classify the ground-water quality of the Glen Canyon (east of the valley only) and valley-fill aquifers to formally identify and document the beneficial use of ground-water resources, and (3) 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 valley-fill aquifer and thereby recommend appropriate septic-system density requirements to limit water-quality degradation.

Moab-Spanish Valley is part of a regionally extensive, collapsed salt anticline; high-angle normal faults that developed as a result of this collapse are present along both margins of Moab-Spanish Valley, and the Moab fault lies buried along the axis of the valley. Geologic units in the Moab-Spanish Valley area include Pennsylvanian, Permian, Triassic, Jurassic, and Cretaceous sedimentary rocks; Tertiary igneous intrusive rocks; and Quaternary unconsolidated sediments. Most ground water in the Moab-Spanish Valley area comes from one of two aquifer systems—the Glen Canyon aquifer, which consists of the Wingate, Kayenta, and Navajo Formations, or the unconsolidated valley-fill aquifer.

Most public water supply is from the Glen Canyon aquifer, which is separated into two structural compartments by the Moab fault beneath Moab-Spanish Valley. The Glen Canyon Group ranges in thickness from about 330 feet (100 m) south and southeast of Moab to about 1300 feet (400 m) beneath southeastern Moab-Spanish Valley. The Glen Canyon Group is absent in the subsurface near Moab in the northwestern end of Moab-Spanish Valley. Most ground-water flow in the Glen Canyon aquifer is through rock fractures (joints and faults).

Based on our analysis of bedrock outcrop data, joint orientation at most sites is bimodal, although eight of 25 outcrop sites have a unimodal joint orientation. Most joints are steeply dipping (greater than 65°) with a northwest-striking primary joint set and a northeast-striking secondary joint set. Based on our analysis of lineaments from aerial photography, which correspond to laterally continuous joint zones, we define six lineament domains based on lineament orientation, length, geometry, and interrelation between lineaments. Most lineaments trend northwest, and lineament trends are strongly unimodal and less variable than joint trends measured at outcrops. Joint and lineament orientations and densities indicate increased permeability parallel to the valley axis due to joints and joint zones. Valley-margin normal faults, where present, may reduce permeability perpendicular to the valley axis.

Once the most important source of culinary water in Moab-Spanish Valley, the valley-fill aquifer is now primarily used for domestic and agricultural purposes. The valley fill of Moab-Spanish Valley consists mainly of stream, alluvial-fan, mass-movement, and wind-blown deposits that are more than 400 feet (120 m) thick near the Colorado River northwest of Moab. The valley fill thins to about 100 feet (30 m) over a concealed bedrock high southeast of Moab and then thickens to more than 300 feet (90 m) beneath southeastern Moab-Spanish Valley. The valley fill generally lacks extensive fine-grained layers and the valley floor and surrounding bedrock are classified as primary recharge areas.

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 3000 mg/L; Class III (Limited Use), 3000 to less than 10,000 mg/L; and Class IV (Saline), 10,000 mg/L and greater. The Glen Canyon aquifer, northeast of Moab-Spanish Valley, generally yields ground water of Pristine quality as TDS concentrations are predominantly below 500 mg/L. Ground-water quality data com-

piled from 24 water wells completed in the Glen Canyon aquifer in the Moab-Spanish Valley area indicate 83 percent of the Glen Canyon aquifer samples had TDS concentrations of less than 250 mg/L. Ground-water quality in the Glen Canyon aquifer along the northeastern margin of Moab-Spanish Valley has been designated a Sole Source Aquifer by the U.S. Environmental Protection Agency, and is therefore classified as Class IB, Irreplaceable ground water; this is one of two classes in the Utah Water Quality Board ground-water quality classification system that is not based on TDS concentrations.

Ground water in the valley-fill aquifer is classified as Class IA (Pristine; 13 percent) and Class II (Drinking Water Quality; 87 percent), based on data from ground water from 72 wells and one Pack Creek sample analyzed between 1968 and 2004 by the U.S. Geological Survey, Utah Division of Environmental Quality, the Utah Department of Agriculture and Food, public-water suppliers, and the Utah Geological Survey. Class II ground water predominates throughout most of the valley. Class IA ground water is generally confined to the northeastern margin of Moab-Spanish Valley where recharge from the sandstone aquifer to the valley-fill aquifer occurs. Total-dissolved-solids concentrations in Moab-Spanish Valley's valley-fill aquifer range from 140 to 1818 mg/L, and average 690 mg/L. Nitrate-as-nitrogen concentrations in Moab-Spanish Valley's valley-fill aquifer, based on analyses of ground-water samples from 72 wells, range from 0.06 to 7.37 mg/L, with an average (background) nitrate concentration of 2.1 mg/L.

Nitrogen in the form of nitrate is one of the principal indicators of pollution from septic-tank-soil absorption systems. To provide recommended septic-system densities, we used a mass-balance approach in which 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 using a regional, three-dimensional, steady-state, ground-water flow model. Our ground-water flow analysis using a mass-balance approach indicates that two categories of recommended maximum septic-system densities are appropriate for development using septic-tank soil-absorption systems for wastewater disposal: 10 and 20 acres per system (4 hm^2/system and 8 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 three ground-water flow domains on the basis of flow-volume similarities.

INTRODUCTION

Moab and Spanish Valleys (figure 1) are two contiguous valleys in southeastern Utah, referred to as Moab-Spanish Valley. Moab-Spanish Valley is a semirural area in Grand and San Juan Counties that is experiencing an increase in residential development. Water-resource managers need a better understanding of the relationship of geology to ground-water conditions to better appropriate and manage water rights within the area. Additionally, while most of the development in the Grand County portion of Moab-Spanish Valley is on a community sewer system, development in the San Juan County portion uses septic-tank soil-absorption systems for wastewater disposal. These septic-tank systems are on valley-fill deposits that are a major drinking-water aquifer for the area. 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 Moab-Spanish Valley. Local government officials in Moab-Spanish 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. Local government officials would like to formally identify current ground-water quality to provide a basis for defendable land-use regulations to protect ground-water quality; they would also like a scientific basis for determining recommended densities for septic-tank systems as a land-use planning tool.

Purpose and Scope

The purpose of this study is to provide tools for water-resource management and land-use planning; to accomplish this purpose we (1) characterize the relationship of geology to ground-water conditions in the Glen Canyon and the unconsolidated valley-fill aquifers, (2) classify the ground-water quality of the Glen Canyon (east of the valley only) and valley-fill aquifers to formally identify and document the beneficial use of ground-water resources, and (3) 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 valley-fill aquifer, and thereby recommend appropriate septic-system density requirements to limit water-quality degradation. The latter two study components will provide land-use planners with tools to use in approving new development in a manner that will be protective of ground-water quality.

Geologic Framework Characterization

The relationship of geology to ground-water conditions was characterized by:

(1) conducting a literature search and reviewing geologic maps and reports for the study area;
(2) compiling a geologic map of the study area from existing maps by Doelling (2001, 2004);
(3) examining outcrops of the Glen Canyon Group in the field;
(4) evaluating drillers' logs of water wells completed in the Glen Canyon Group, unconsolidated valley fill, and other geologic units;
(5) constructing cross sections showing geologic relationships across the study area using the compiled geologic map, dips of bedding planes measured in the field, pre-existing studies of the Moab fault, water- and petroleum-well data, and gravity data;
(6) using scan-line techniques, measuring deformation band, fault, and joint characteristics (orientation, aperture width, fracture filling, spacing) at Glen Canyon Group outcrops;
(7) mapping lineaments (which correspond to joint zones and major fractures) using aerial photos and satellite imagery;

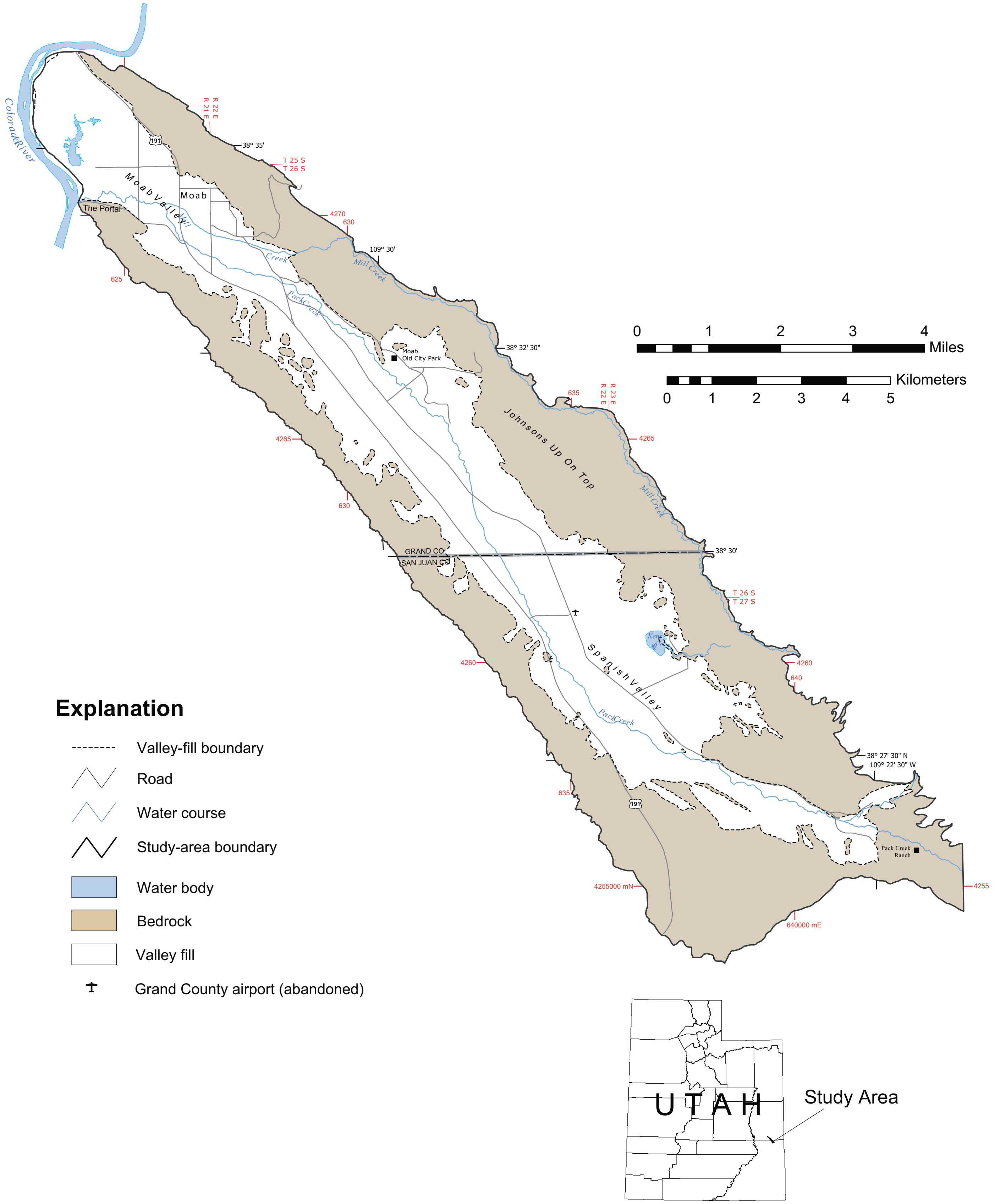

Figure 1. *Moab-Spanish Valley study area, Grand and San Juan Counties, Utah.*

(8) calculating fracture density and orientation statistics for both outcrop-scale and remote data sets; and

(9) constructing fracture-domain, structure-contour, and isopach maps for the Glen Canyon Group, and isopach and hydrogeologic setting (ground-water recharge-/discharge area) maps for the valley-fill deposits. Fieldwork was conducted during the fall of 2004.

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, milligrams per liter [mg/L] equals parts per million). If any contaminant exceeds Utah's ground-water quality (health) standards (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. Note that Class IB (Irreplaceable ground water) and Class IC (Ecologically Important ground water) are not based on TDS concentrations.

To classify the quality of ground water in the Moab-Spanish Valley valley-fill aquifer, we used ground-water quality data from the U.S. Geological Survey, Utah Division of Water Quality, Utah Department of Agriculture and Food, Utah Geological Survey, and Utah Division of Drinking Water. The U.S. Geological Survey and Utah Division of Water Quality data are from a study conducted by Steiger and Susong (1997) that was specifically designed to provide the information (water-quality and recharge-area mapping) necessary for ground-water quality classification. The well numbering system used in Utah is presented in appendix A. Water-quality data are presented in appendix B.

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 (appendix C) based on Utah's Drinking Water Source Protection Rules.

Septic-Tank Density/Water-Quality Degradation Analysis

To provide recommended septic-tank densities for Moab-Spanish Valley using the mass-balance approach to evaluate potential water-quality degradation, we used the digital ground-water flow simulation of Downs and Kovacs (2000), modified using data from an aquifer test we conducted in 2002, to estimate ground-water flow in the valley fill available for mixing (dilution). We then (1) grouped areas into three ground-water flow domains (geographic areas with 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, using the appropriate amount of wastewater and accompanying nitrogen load introduced per septic-tank system, projected nitrogen loadings in each domain based on increasing numbers of septic-tank soil-absorption systems. By limiting allowable degradation of ground-water nitrate concentration to 1 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.

Location and Geography

Moab-Spanish Valley is a northwest-trending valley in the Colorado Plateau physiographic province (Stokes, 1977), and is about 14 miles (23 km) long and averages 1.25 miles (2 km) wide with an area of about 18 square miles (47 km2) (figure 1). The rectilinear valley is an elongate, crag-walled trough bounded on the northeast and southwest by sandstone mesas and cuestas. Moab-Spanish Valley ranges in elevation from about 3950 feet (1200 m) at the Colorado River near

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/IB[1]/IC[2]	less than 500 mg/L[3]	Pristine/Irreplaceable/ Ecologically Important
Class II	500 to less than 3000 mg/L	Drinking Water[4]
Class III	3000 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.

[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 7000 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.

The Portal in the northwest to about 6100 feet (1860 m) in the upper reaches of Pack Creek within valley-fill material (figure 1); the drainage basin reaches 12,646 feet (3855 m) in elevation at Mount Mellenthin to the east of the study area.

Moab-Spanish Valley is in the 144 square-mile (373 km^2) drainage basin for Mill and Pack Creeks on the west side of the La Sal Mountains to the east of the study area (Sumsion, 1971). Mill and Pack Creeks and their tributaries flow west and northwestward from the La Sal Mountains into Moab-Spanish Valley and, ultimately, the Colorado River, which cuts the northwest end of Moab-Spanish Valley at The Portal (figure 1). Mill and Pack Creeks are perennial streams, but parts of the Pack Creek channel are dry except during periods of heavy runoff because flow is diverted for irrigation (Sumsion, 1971). Pack Creek enters Moab-Spanish Valley at its southeast end and flows generally northwest. The diversion for Pack Creek is located just below the crossing of the road to Pack Creek Ranch south of the Loop Road; the diversion ditch crosses under the Loop Road, travels west on its north side, then flows north into Kens Lake (Lance Christie, Grand County resident, written communication, May 28, 2003). Mill Creek enters the valley near Moab and flows across the valley-fill deposits for about 2.5 miles (4 km) before it is joined by Pack Creek on the west side of Moab. Mill Creek is a gaining stream throughout its length; Pack Creek is a gaining stream just north of Kerby Lane after a long, dry stretch; the old diversion fed a now-abandoned ditch west of the now-abandoned airport in San Juan County and along its lower reaches below Moab Old City Park (figure 1) (Lance Christie, written communication, May 28, 2003).

Population and Land Use

Moab-Spanish Valley is an increasingly popular site for vacation and retirement homes, and a growing tourist industry provides employment for many valley residents. The result is population growth and a decrease in agricultural land use. Moab-Spanish Valley includes Moab, the County Seat of Grand County, and a portion of unincorporated San Juan County. In 2000, the population of Moab was 4779, and the population of all unincorporated areas of San Juan County was 9293 (Demographic and Economic Analysis Section, 2001); by 2030, these populations are expected to increase to 5719 and 10,923, respectively (Demographic and Economic Analysis Section, 2000).

Climate

Average annual precipitation in the Moab-Spanish Valley drainage basin increases with altitude and ranges from about 8 inches (20 cm) at the Colorado River to more than 30 inches (76 cm) in the La Sal Mountains (Blanchard, 1990). The Moab weather station, at an elevation of 4021 feet (1,226 m), provides the following information (Ashcroft and others, 1992). Normal annual precipitation from 1961 to 1990 was 9.00 inches (22.9 cm). Summer precipitation is typically in the form of brief, localized, intense thunderstorms, whereas winter precipitation is of longer duration, less localized and intense, and falls primarily as snow at higher elevations (Blanchard, 1990). Temperature ranges from a record high of 114°F (45.6°C) to a record low of -29°F (-33.9°C) for the 1893 to 1992 period of the weather station's existence. Normal mean annual temperature from 1961 to 1990 was 56.8°F (13.8°C). Average annual evapotranspiration was 6.3 times greater than precipitation for the period of record. 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).

PREVIOUS INVESTIGATIONS

Geologic mapping in the Moab-Spanish Valley area includes Weir and others (1961), Doelling (1985, 2001, 2004), and Doelling and others (1995, 2002). Hydrogeologic studies relevant to Moab-Spanish Valley were conducted by Sumsion (1971), Weir and others (1983), Blanchard (1990), Freethey and Cordy (1991), Steiger and Susong (1997), Eisinger and Lowe (1999), and Downs and Kovacs (2000). Steiger and Susong's (1997) study was specifically conducted to provide data needed for ground-water quality classification.

GEOLOGIC SETTING

Introduction

Structurally, Moab-Spanish Valley is part of a regionally extensive, collapsed salt anticline (figure 2) (Doelling and others, 2002). 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 Moab-Spanish 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 (Doelling and others, 2002). Subsequently, the overlying rock strata collapsed and eroded, forming the inverted topography of Moab-Spanish Valley in the core of the anticline. High-angle normal fault systems that developed as a result of the collapse of the salt diapir are present along both margins of Moab-Spanish Valley (Doelling and others, 2002).

Geologic units surrounding Moab-Spanish Valley include Pennsylvanian, Permian, Triassic, Jurassic, and Cretaceous sedimentary rocks (plate 1; appendix D) (Doelling, 2001, 2004; Doelling and others, 2002). Small outcrops of Pennsylvanian Paradox Formation caprock (gypsum, gypsiferous mudstone, and black shale) exist along the northwest and northeast margins of Moab-Spanish Valley near Moab. A limited exposure of sandstone and conglomerate of the Permian Cutler Formation crops out along the northwest margin of Moab-Spanish Valley. Triassic Chinle and Moenkopi Formations, undivided, are exposed at the base of the cliffs in the northwest end of Moab-Spanish Valley northwest of Moab; the Moenkopi Formation includes sandstone, silty sandstone, and minor siltstone and conglomerate (Doelling, 2001). Sandstone, siltstone, conglomeratic sandstone, and mudstone of the Triassic Chinle Formation are exposed along both margins the northwest end of Moab-Spanish Valley

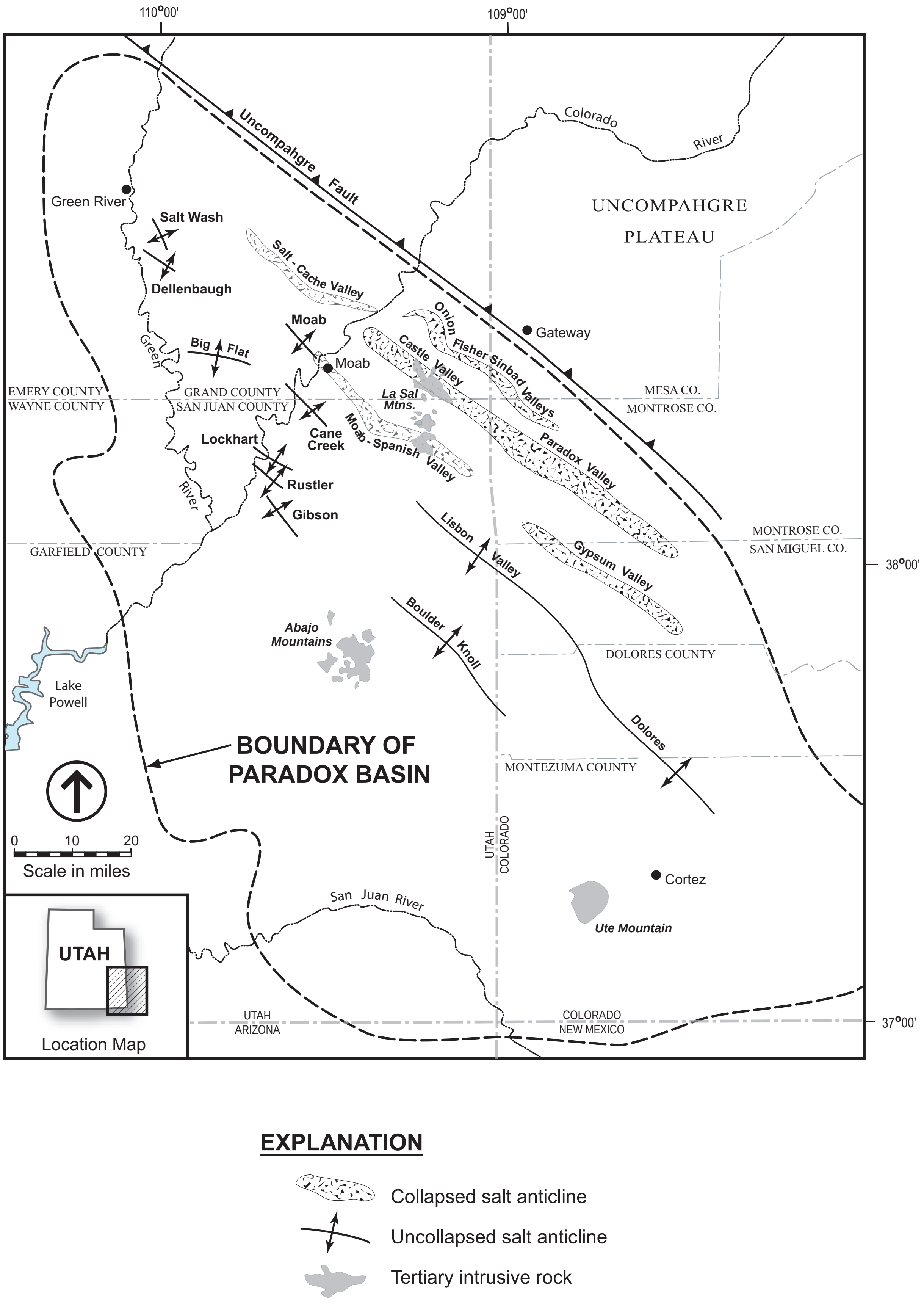

Figure 2. *Regional tectonic setting of the study area, showing major tectonic features including salt anticlines, Paradox basin, Uncompahgre uplift (Uncompahgre Plateau) and fault, and Tertiary intrusions (modified from Doelling, 1988).*

(Doelling, 2001). The Wingate Sandstone is exposed in the cliffs above these Triassic units in the northwest two-thirds of the valley (Doelling, 2001). Sandstones of the Jurassic Kayenta and Navajo Formations are exposed in the cliffs and/or cap the cuestas and mesas in much of the Moab-Spanish Valley area (Doelling, 2001). The Wingate, Kayenta, and Navajo Formations form the Glen Canyon Group where they cannot be differentiated (Doelling, 2001), and also form the Glen Canyon aquifer, an important source of ground water, especially along the northwest margin of Moab-Spanish Valley. Younger rock units are exposed in the southeastern end of Moab-Spanish Valley, including siltstone and sandstone of the Jurassic Carmel Formation; sandstone and mudstone of the Jurassic Entrada Sandstone; mudstone, sandstone, and thin limestone of the Jurassic Morrison Formation; sandstone and conglomerate of the Cretaceous Burro Canyon Formation; sandstone and conglomerate of the Cretaceous Dakota Sandstone; and shale, siltstone, and sandstone of the Cretaceous Mancos Shale (Doelling, 2004).

The valley fill of Moab-Spanish Valley consists mainly of stream, alluvial-fan, mass-movement, and wind-blown deposits (Doelling, 2001). Modern alluvium at the northwest end of Moab-Spanish Valley consists of channel-fill and low terrace deposits of sand, silt, and clay, with local lenses of gravel, deposited by the Colorado River (Doelling and others, 1995, 2002). Alluvium along Mill Creek and Pack Creek consists mainly of silty sand with abundant pebble and cobble gravel in active channels; the gravel clasts include both locally derived sedimentary rocks and intrusive igneous rocks from the La Sal Mountains (Doelling and others, 1995, 2002). Late Pleistocene to early Holocene stream deposits form the floor of Moab-Spanish Valley and are generally poorly to well-sorted sand, silt, and clay, with some gravel lenses; these deposits are up to 30 feet (9 m) thick and contain larger percentages of fine-grained material than the underlying older alluvium (Doelling and others, 1995, 2002). Older alluvium consists of river and stream gravels, alluvial-fan deposits, and possibly some eolian interbeds, and is at least 406 feet (124 m) and possibly up to 450 feet (137 m) thick (Doelling and others, 1995, 2002). Alluvial-fan deposits form apron-like slopes along the northwest and southeast sides of Moab-Spanish Valley and consist mainly of poorly sorted, generally unstratified, muddy to sandy cobble gravel with boulders common in the upper reaches of the fans (Doelling and others, 1995, 2002). Talus and colluvium, consisting of rock-fall blocks, angular boulders, gravel, sand, silt, and clay exist along steep slopes below most cliffs in the study area (Doelling and others, 1995, 2002), and landslide deposits are mapped in the far southeast end of the valley (Weir and others, 1961; Doelling, 2004); landslide composition depends on the nature of the geologic unit from which slide material is derived. Well-sorted, unstratified to cross-bedded windblown sand deposits cover surfaces and fill hollows at many locations along the margins of Moab-Spanish Valley (Weir and others, 1961; Doelling, 2001, 2004).

Structural Framework

Introduction

The rocks of the Glen Canyon Group are structurally compartmentalized across the study area. Previous work on the Moab fault northwest of the study area reported the fault and its attendant structural features to be a barrier to transverse fluid flow (Foxford and others, 1996; Davatzes and Aydin, 2003, 2005). In Moab-Spanish Valley, the Moab fault lies buried beneath valley-fill deposits and juxtaposes the Glen Canyon Group against varying bedrock lithologies along its trace (plates 1, 2, and 3) (Olig and others, 1996; Foxford and others, 1996; Doelling and others, 2002; Doelling, 2004). Maximum offset across the Moab fault beneath Moab-Spanish Valley is estimated at 1000 feet (300 m); average offset may be less than this, or approximately 650 feet (200 m) (Foxford and others, 1996; Olig and others, 1996). The Moab fault trace defines two primary structural compartments of Moab-Spanish Valley (plate 2). A third bedrock compartment consisting of rocks dipping southwest into the Kings Bottom syncline is evident but will not be discussed in detail because its lies entirely outside of Moab-Spanish Valley. Plate 2 summarizes the structural compartments of Moab-Spanish Valley and displays fracture-site data discussed in the “Outcrop Joint Data and Analysis” section.

Bedrock is likely hydrologically compartmentalized across the trace of the Moab fault, beneath Moab-Spanish Valley. However, valley fill is contiguous across the trace of the Moab fault overlying both hanging-wall and footwall rocks. Flow paths, which may be impeded between rocks of the Glen Canyon Group across the Moab Fault, may therefore exist via the overlying valley fill.

Structural Compartment A

Hanging-wall bedrock northeast of the Moab fault forms the principal structural compartment (structural compartment a) of the study area. Northeast of the Moab fault, a zone of structurally contiguous Glen Canyon Group bedrock extends along the length of Moab-Spanish Valley from Pack Creek Canyon nearly to Moab (plate 2). Fluid flow may be inhibited across several northwest-striking valley margin normal faults near Moab including the Kayenta Heights fault (plate 2). Other small, northwest-striking normal faults may locally affect flow across hanging-wall rocks along the southeast margin of Moab-Spanish Valley. Smaller normal faults and their effect on rock mass permeability are discussed in the “Fracture Control on Ground Water” section.

Structural Compartment B

Along the southwest valley margin, a continuous zone of small-offset, down-to-the-northeast normal faults and small valley-parallel folds separates rocks in the immediate footwall of the Moab fault from contiguous exposures of the Glen Canyon Group which dip into the Kings Bottom syncline (plate 2) (Doelling and others, 2002). These faults and the Moab fault to the northeast define a bedrock structural compartment (structural compartment b) along the western half of Spanish Valley.

Cross Sections and Glen Canyon Group Geometry

Cross sections drawn at right angles to the axis of Moab-Spanish Valley show synclinal bedrock geometry trending along the valley axis southeast of Moab in Triassic and younger rocks (plate 3). Slip on the Moab fault, differential salt movement, and salt dissolution, has produced much of this geometry. Underlying salts of the Paradox Formation form a salt anticline or wall. Constraints on all units below the Wingate Sandstone are few beneath Spanish Valley. All thicknesses are assumed based on correlation with existing mapping, sparse well data, and other regional studies (Doelling, 1981, 2002; Foxford and others, 1996; Ge and others, 1996). Offset for the buried section of the Moab fault is assumed to be approximately 650 to 820 feet (200-250 m) based on cross sections and seismic data (Olig and others, 1996). The fault is also assumed to sole into salts of the Paradox Formation within 1.2 to 1.6 miles (2-2.5 km) of the land surface (Olig and others, 1996). Explanation of data and constraints used to create the cross sections are presented in appendix E.

Cross section J to J′ shows the geometry of the Moab fault hanging-wall rocks along the extent of Moab-Spanish Valley (plate 3). This speculative cross section shows the inferred geometry of the Glen Canyon Group just northeast of the Moab fault trace. Depth to top of the Glen Canyon Group northeast of the Moab fault trace decreases northwest of the Pack Creek syncline, and then remains relatively constant beneath much of Spanish Valley before decreasing again near Moab over the Moab anticline. Folding and uplift over the salt-cored Moab anticline and its subsequent erosion have removed the Glen Canyon Group from the subsurface near Moab where Quaternary valley fill rests directly on the insoluble cap rock of the Pennsylvanian Paradox Formation (Doelling and others, 2002).

Changes in depth of the Glen Canyon Group are apparent along the axis of Moab-Spanish Valley (plates 3 and 4). Depth of the Glen Canyon Group is greatest along the Pack Creek syncline. To the northwest the Glen Canyon Group directly underlies unconsolidated valley fill beneath much of Spanish Valley. The Glen Canyon Group is absent in the subsurface near Moab and beneath the northwest end of Moab-Spanish Valley where valley fill rests directly on the Triassic-age rocks and the Paradox Formation caprock at the core of the Moab anticline (Doelling and others, 2002). In the footwall rocks southwest of the trace of the Moab fault, the top of the Glen Canyon Group deepens towards the Moab fault beneath the valley fill.

Thickness of the Glen Canyon Group

Thickness of the Glen Canyon Group varies across existing salt structures near the study area (Doelling and others, 1988). Previous mapping and limited well data near and beneath Moab-Spanish Valley show relatively uniform thickness of the Glen Canyon Group at least along the southeast portion of Spanish Valley. Structural geometry and subsequent erosion control thickness of Glen Canyon Group rocks beneath Moab-Spanish Valley (plate 5). The Glen Canyon Group is probably thickest beneath southeastern Spanish Valley in the hanging wall of the Moab fault where unit thickness is assumed to be more than 1300 feet (400 m) (plate 5). In-place thickness of the Glen Canyon Group is inferred to be between 330 and 660 feet (100 and 200 m) along the footwall of the Moab fault, beneath southwestern Spanish Valley. In-place Glen Canyon Group thickness decreases to the northwest toward Moab, where the Glen Canyon Group is absent across the crest of the Moab salt-cored anticline (Doelling and others, 2002).

Fracture Control on Ground Water

Introduction

Analyses of outcrops and information from well logs in Moab-Spanish Valley indicate the Glen Canyon Group is at least partially fractured. Fracturing provides primary control on aquifer characteristics of the Glen Canyon Group, altering hydraulic conductivity and effective porosity by several orders of magnitude (Hood and Patterson, 1984; Freethey and Cordy, 1991). High values of hydraulic conductivity encountered in culinary supply wells along the eastern margin of Moab-Spanish Valley are attributed to fracturing of the bedrock aquifer (Eisinger and Lowe, 1999). Fracture characterization is therefore important in understanding the hydrogeology of the Glen Canyon Group in Moab-Spanish Valley. This section describes fracture type, distribution, and character as it relates to ground-water conditions in the study area.

Three fracture types—joints and joint zones, faults, and deformation bands—exist and were examined in the study area. Joints are the most prevalent fracture type in the study area. The density and orientation of joints and joint zones in the Glen Canyon Group are quantified, both at outcrop scale and remotely, using three ortho-rectified imagery sets and ArcGIS. Joints at outcrop scale were examined using the scan line methods of Lapointe and Hudson (1985). Regional scale joint zones were examined using image lineament analysis techniques after Gustafsson (1994) and Mabee and others (1994). Appendix F provides a detailed description of the methods used to examine joints and joint zones. Results of both outcrop joint and regional-scale joint-zone data can be used to assess the relative importance of these fracture types on ground-water conditions within the study area. Joint data and analysis are presented below along with a qualitative discussion of deformation bands and faults in the study area and their effect on ground-water conditions.

Joints and Joint Zones

Joints are planar discontinuities or rock fractures that have separation perpendicular to their plane but no offset subparallel or parallel across their plane (Pollard and Aydin, 1988). Scale and lengths of joints may range from micrometers to several kilometers. Joints may be open or infilled with various minerals and, if open, generally create a preferred pathway for fluid flow through otherwise intact rock (Antonellini and Aydin, 1994; Laubach, 2003). Individual joints may coalesce into joint zones consisting of discrete groups of subparallel, closely spaced joints, commonly having lengths greater than 330 feet (100 m) and internal fracture densities an order of magnitude greater than adjoining rock (Antonellini and Aydin, 1994). Joints may control outcrop or wellhead scale permeability and hydraulic conductivity, whereas joint zones may control regional or larger scale permeability across the study area (Antonellini and Aydin, 1994, 1995; Jourde and others, 2002). Joint and joint-zone characteristics, including orientation and areal density, correlate directly with the hydraulic conductivity and permeability of a rock mass (Antonellini and Aydin, 1994, 1995; Zhang and Sanderson, 1995; Zhang and others, 1996). To assess joint and joint-zone characteristics of the Glen Canyon Group aquifer near Moab-Spanish Valley, we collected and analyzed outcrop-scale and remote lineament data.

Outcrop Joint Data and Analysis

Data collected at the outcrop included joint orientation, trace length, fill type, planarity, joint interrelations, and termination habit. Joint density and normalized orientations were calculated from measured data using the methods of LaPointe and Hudson (1985). We examined a total of 25 sites, primarily in the Navajo Sandstone along the northeast valley margin from just south of Kens Lake to near Moab. Site locations were chosen based on measurable outcrops, and proximity to hanging-wall rocks of the Glen Canyon Group penetrated by nearby wells in Moab-Spanish Valley. Detailed description of outcrop data acquisition and analysis is presented in appendix F.

Most joints in the Glen Canyon Group dip steeply (greater than 65°). Shallowly dipping (less than 30°) bedding plane joints, while much less numerous, also exist in the Navajo Sandstone. Bedding plane joints such as these are likely closed at depth due to their orientation, and therefore are not directly relevant to fracture permeability. Joint dip can influence the geometric and permeability character of a joint set, but its effect is not quantified due to a lack of data; all subsequent data assume vertically dipping joint planes.

Character of jointing including trace length, curvature, interconnection, and termination vary across all fracture sites (plate 2, table 2, table F.1). Some generalizations can, however, be made for these parameters. Joint traces are commonly straight or just slightly arcuate; shorter joints may curve into longer joints near their terminations. Measured joint trace lengths at outcrop range from 7 cm (2.76 inches) to over 15 m (49 ft); long joints generally extend beyond the measurable extent of the outcrop. The smallest joints measure less than 0.25 m (0.82 ft) in length, and commonly do not intercept other joints. Joints with trace lengths greater than 3 m (9.84 ft) commonly intercept at least two other joints and therefore are likely more important to permeability than shorter joints. Mean aperture for all outcrop fracture site is 1.13 mm (0.04 inches). Joint aperture decreases markedly with depth and loading and is likely much lower than the

Table 2. *Outcrop joint site summary.*

Joint site	N[1]	Fracture orientation [2]	Average aperture[3] (mm)	Anisotropy Factor[4]	Fracture density[5] (m/m^2)	Fracture density (ft/ft^2)
1	86	94 (10), 4 (12)	0.5	1.93	2.84	0.87
2	40	150 (21), 42 (8)	0.9	1.7	0.96	0.29
3	34	170 (32)	0.9	NA	1.9	0.58
4	70	128 (14), 176 (8)	0.9	2.4	1.35	0.41
5	36	22 (28), 113 (12)	0.2	NA	10.36	3.16
6	55	57 (18), 149 (20)	1.1	1.24	0.66	0.20
7	38	144 (16), 53 (10)	0.9	1.46	3.93	1.20
8	94	80 (20)	0.5	2.06	11.62	3.54
9	45	138 (20), 25 (12)	0.2	1.58	2.74	0.84
10	61	154 (20)	0.7	1.6	8.65	2.64
11	47	135 (18), 85 (18), 178 (20)	0.8	1.01	2.64	0.81
12	40	127 (18)	0.3	NA	2.07	0.63
13	67	135 (30), 34 (32)	0.4	1.03	1.38	0.42
14	56	120 (32), 41 (18)	1.3	1.76	1.15	0.35
15	34	106 (28), 3 (22)	1.5	1.39	3.38	1.03
16	35	154 (20), 30 (31)	1.9	1.33	1.86	0.57
17	59	179 (26), 100 (20)	1.6	1.17	8.97	2.74
18	51	13 (26), 114 (28)	0.7	1.86	13.27	4.04
19	55	157 (16)	1.7	5.32	3.53	1.08
20	45	80 (18), 2 (28)	0.9	1.68	2.94	0.90
21	61	134 (32), 72 (32)	1.5	1.04	7.94	2.42
22	42	135 (50)	1.4	2.5	3.31	1.01
23	63	106 (24)	3.3	1.72	3.64	1.11
24	58	72 (28)	3.1	2.76	4.38	1.34
25	41	141 (38), 42 (16)	1.1	1.75	1.66	0.51
all sites	1313	142 (28)	1.1	1.69	2.94	0.90

[1] Number of joints measured.

[2] Orientation in azimuth degrees of principal joint sets, uncertainty is in parantheses, primary joint set listed first, secondary joint set listed second.

[3] Average aperture in mm of joints measured at each site.

[4] Joint anisotropy factor calculated using technique of Zhang and Sanderson (1995), see appendix F for details. NA indicates sites which have only one scan line and cannot have anisotropy factor calculated.

[5] 2-D joint density calculated using technique of LaPoint and Hudson (1985), see appendix F for details.

measured value at depths encountered by wells completed in the Glen Canyon Group. Most joints in the study area have some degree of mineral infilling, most commonly calcite partially lining joint planes; this type of secondary mineral growth in joints is not likely to significantly alter the permeability characteristics of joint sets (Laubach, 2003). Mineralization within fractures increases towards the Moab fault to the northwest of the study area, and may reduce fracture permeability there (Foxford and others, 1996; Davatzes and Aydin, 2005). Beneath Moab-Spanish Valley, fracture mineralization may increase towards the trace of the Moab fault, but this is currently undocumented.

Joint orientations for each site plotted on rose diagrams are summarized in table 2 and plate 2. Joint orientation at many sites is bimodal, displaying an obvious primary joint set and a less prevalent secondary joint (table 2). Eight of the 25 sites had unimodal fracture orientation distributions (table 2). Secondary joint sets commonly have a shorter trace length and terminate against joints of the primary set. Mean outcrop joint strike is northwestly, striking 322°, and 95% of the data is ±14° of this trend across all sites. Secondary fracture orientation is commonly northeast-southwest but varies across the sites examined. Mean orientation across all sites best represents background fracture orientation at this scale in the Glen Canyon Group aquifer. Site specific orientation varies and can be inferred from joint data nearest the location of interest. The orientation of maximum fracture-based permeability roughly parallels the dominant joint trend in many systems, and therefore these data can represent the preferred orientation of permeability in the Glen Canyon Group near each data site.

Because of the potential for sampling bias, an additional measure of the geometric character of a fracture set is warranted (Zhang and Sanderson, 1995). A 2-D geometric anisotropy factor for each site, with data from at least two scan lines, was calculated using the method of Zhang and Sanderson (1995) (see appendix F for explanation). This factor provides an additional measure of the geometric properties of a fracture set. Geometric fracture anisotropy ranges from 1.01 to a maximum of 5.32 (table 2, plate 2). Mean anisotropy across all sites is 1.69; the long axis of mean anisotropy ellipse is assumed to parallel mean fracture strike of 322° (table 2). The anisotropy value may represent the unit ratio of maximum and minimum joint-based permeability, with maximum permeability oriented parallel to the mean or principal joint set.

Calculated outcrop joint density spans two orders of magnitude and shows little correlation with site along the northeastern margin of Spanish Valley (figure 3). This disparity may be the result of sampling bias and relatively small number of sites used for comparison, or may reflect a disconnect between outcrop-scale fracturing and regional structures. Greater fracture densities are more localized and may be driven by local interaction with regional joint zones and/or faults. Mean joint density is 2.94 m/m^2 (0.90 ft/ft^2) and may best represent background levels of jointing in the Glen Canyon Group. Local joint density near a given well is likely to be above or below this value and is best taken from the nearest fracture site and/or additional site-specific fracture measurements.

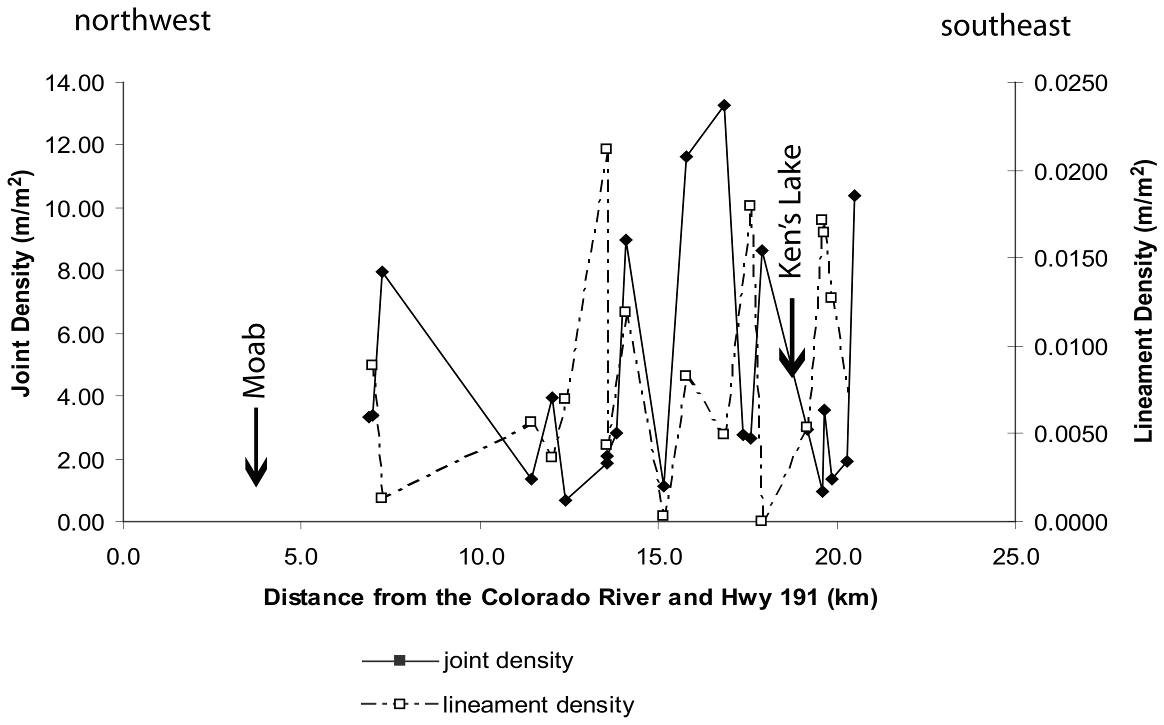

Figure 3. Joint and lineament density versus location. Transect is along the northeast margin of Moab-Spanish Valley, values are for fracture sites measured in the Glen Canyon Group. Position is measured relative to the intersection of highway 191 and the Colorado River. No statistical correlation exists between joint density at outcrop scale and lineament density across the data sets. Individual sites may show a qualitative correlation between the two data sets. Lineament density is calculated from the color-ortho image (figure 6). Arrows show approximate location of Moab and Kens Lake.

Remote Lineament Data and Analysis

Lineaments were analyzed using a technique modified from Mabee and others (1994), discussed in detail in appendix F. Lineaments from the color orthophoto imagery set were divided into six domains based on orientation, fracture trace length, lineament interrelations, and geometries (figure 4, table 3). Stereonets of lineament trends are strongly unimodal for each domain. Corresponding joint zones are therefore likely to contribute a strong orientation bias to regional fracture permeability. Wells encountering joint zones may have permeability several orders of magnitude greater parallel to joint zone strike than wells that do not intercept joint zones. Lineament trends along Moab-Spanish Valley are dominantly northwesterly, one domain trends northeast (figure 4). Wells completed in the Glen Canyon Group along the eastern margin of Moab-Spanish Valley intersecting joint zones are likely to have greatly increased hydraulic conductivity with a spatial maximum oriented to the northwest.

Lineament density distribution near Moab-Spanish Valley is best shown by the lineaments on the color orthophoto image (figure 5). Lineament density from the color orthophoto imagery ranges from 0 to 0.036 m/m^2 (0.011 ft/ft^2) and shows several peaks along Glen Canyon Group exposures adjoining Moab-Spanish Valley (figures 4, 5).

Comparison of outcrop-scale and photo lineament data shows little direct correlation of fracture density trends (figure 3). High outcrop joint density does not numerically correlate with zones of high lineament density. Fracture densities relevant to specific well sites are therefore best taken from nearby outcrop fracture analysis. Lineament densities may alternatively show regional scale zones of relatively high and low permeability within the Glen Canyon Group and be relevant to larger scale analysis. Outcrop site-specific joint orientation is much more variable than lineament orientation (plate 2). However, mean outcrop joint orientation follows mean lineament orientation. Lineament analysis may provide relevant fracture orientation data where outcrop-scale data are lacking but should not be used to estimate well-scale fracture density.

Deformation Bands

Deformation bands are rock discontinuities that accommodate small amounts of shear offset, which commonly form in high-porosity clastic rocks (Aydin, 1978). Deformation bands consist of en echelon to anastamozing tabular bands of cataclasis and grain size reduction, accommodating several millimeters to several centimeters of offset (Antonellini and Aydin, 1994). Based on previous work north of the study area, deformation bands have reduced permeability relative to the host rock mass up to three orders of magnitude, and in general decrease overall permeability of a rock mass transverse to their plane (Antonelleni and Aydin, 1994).

Deformation bands are uncommon relative to joints across the exposures of the Glen Canyon Group examined along the northeast margin of Moab-Spanish Valley. We examined them in greater detail at several locations near Kens Lake in the southeast portion of Spanish Valley. Several of the deformation bands cut and offset preexisting joints at high angles, suggesting shearing deformation postdates jointing at least at these locations. Total joint offset along deformation bands is 1 to 2 centimeters (0.4-0.8 inches). Deformation bands are between 1 millimeter and several centimeters wide consisting of cataclastically reduced grain matrix with small intact pieces of the host rock. Secondary mineralization of deformation bands commonly consists of nearly complete calcite cementation of grains within the slip zone. Some deformation bands are locally cemented with secondary hematite, which may cause a greater reduction of transverse permeability (figure 6). Deformation bands, although only locally present in the Glen Canyon Group, will reduce permeability transverse to their strike. Based on our study, areas near Kens Lake may warrant further investigation to quantify the effects of deformation bands on permeability in the Glen Canyon Group aquifer.

Faults

Normal faults exist along the northeast and southwest margins of Moab-Spanish Valley. These faults cut all map units, excluding surficial deposits, and may control the local hydrologic parameters of the Glen Canyon Group. Fluid flow across these faults will be strongly influenced by fault zone structure and extent (Caine and others, 1996; Shipton and Cowie, 2001). To qualitatively assess fault zone structure, we examined several normal faults cutting interbedded sandstones and mudstones of the Kayenta Formation along the northeast valley margin near Moab. Based on cross-fault stratigraphic correlations, offset across each of the two faults examined is several meters. Both faults have a defined fault core and damage zone. Fault cores consist of zones less than 0.5 meters (1.6 ft) wide of intense cataclasis and grain size reduction and lesser clay gouge, particularly near defined slip surfaces (figure 6). Damage zones consisting of fractured and broken rock with little observable offset flank the fault core in both hanging-wall and footwall rocks. Damage zones of heavily jointed host rock extend 1-2 meters (3.3-6.6 ft) outward from the defined fault cores. Normal faults cutting the relatively homogenous sandstone of the Navajo Sandstone and upper Glen Canyon Group may have different fault zone structures, but are also likely to reduce permeability transverse to their plane (Shipton and Cowie, 2001).

GROUND-WATER CONDITIONS

Introduction

Ground water in Moab-Spanish Valley occurs in two types of aquifers: (1) fractured bedrock, and (2) valley-fill deposits (figure 7). The geologic and hydrologic characteristics of the rock units in the Moab-Spanish Valley drainage basin are summarized in table 4. Much of this section is from Eisinger and Lowe (1999).

Fractured-Rock Aquifers

The Glen Canyon aquifer, the principal fractured-rock aquifer in the Moab-Spanish Valley area, consists of the Wingate, Kayenta, and Navajo Formations (Sumsion, 1971). The Glen Canyon aquifer is the principal source of drinking water for the Moab-Spanish Valley area (Steiger and Susong, 1997). Structural and fracture characteristics of each member of the Glen Canyon Group are examined and the results are presented below.

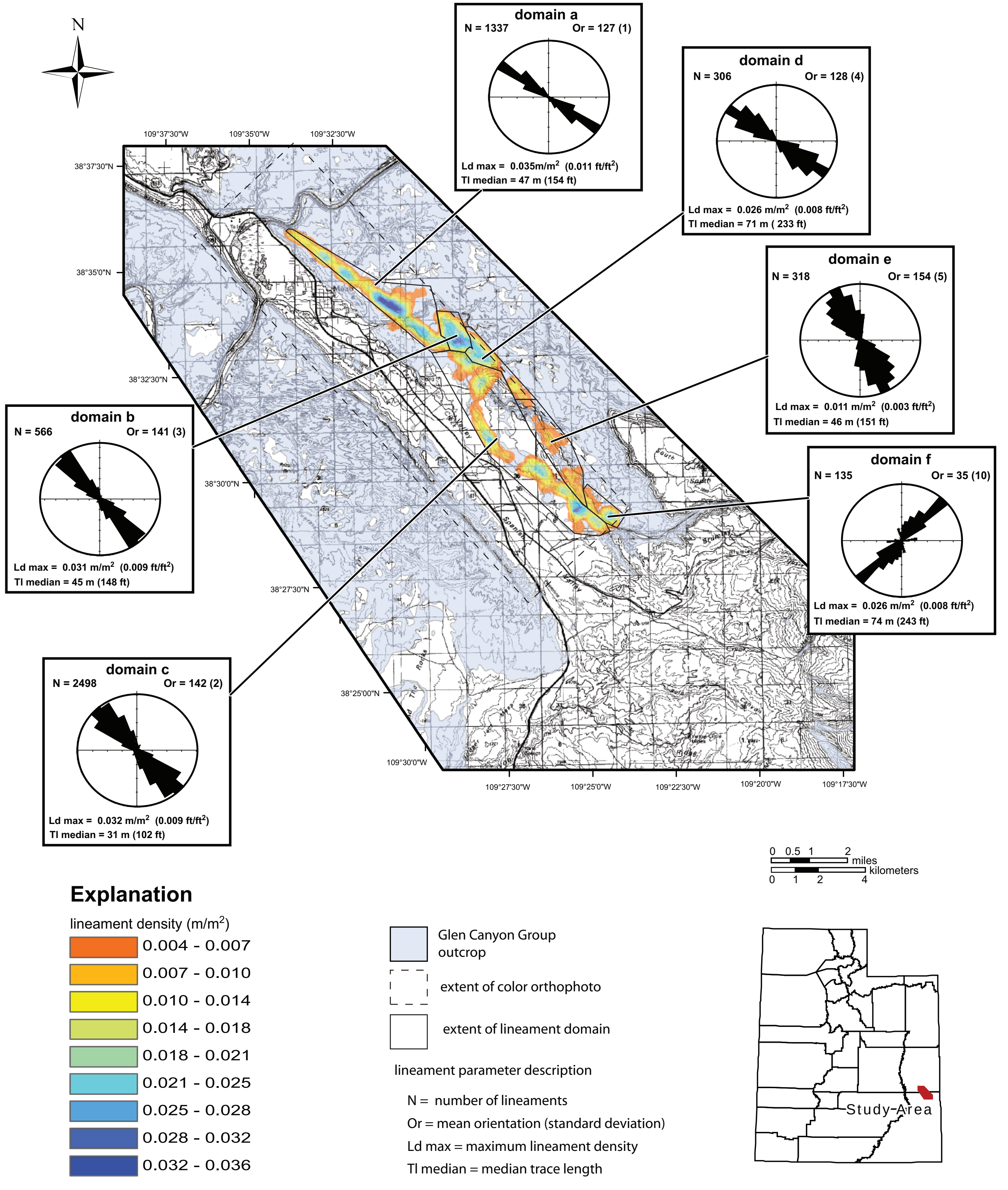

Figure 4. *Lineament data summary. Color shade is lineament density, for color orthophoto set, calculated using ArcGIS spatial analyst. Lineament orientation is unimodal for each domain and trends northwest for the entire data set.*

Table 3. *Lineament domain summary*

Domain	Area (km^2)	N[1]	Orientation of linements[2]	Tl max[3] (m)	Tl min[4] (m)	Tl mean[5] (m)	Lineament density[6] (m/m^2)	Lineament density (ft/ft)^2
A	8.62	1337	127 (1)	1118	4	47	0.035	0.011
B	1.79	566	141 (3)	428	5	45	0.031	0.009
C	2.4	2498	142 (2)	256	4	31	0.032	0.009
D	17.45	306	128 (4)	430	15	72	0.026	0.008
E	4.77	318	154 (5)	278	11	46	0.011	0.003
F	1.53	135	35 (10)	577	15	74	0.026	0.008

[1] Number of lineaments
[2] Orientation in azimuth degrees of principal lineament sets, uncertainty is in parantheses
[3] Maximum lineament trace length
[4] Minimum lineament trace length
[5] Mean lineament trace length
[6] Maximum lineament density calculated using ArcGIS Spatial Analyst

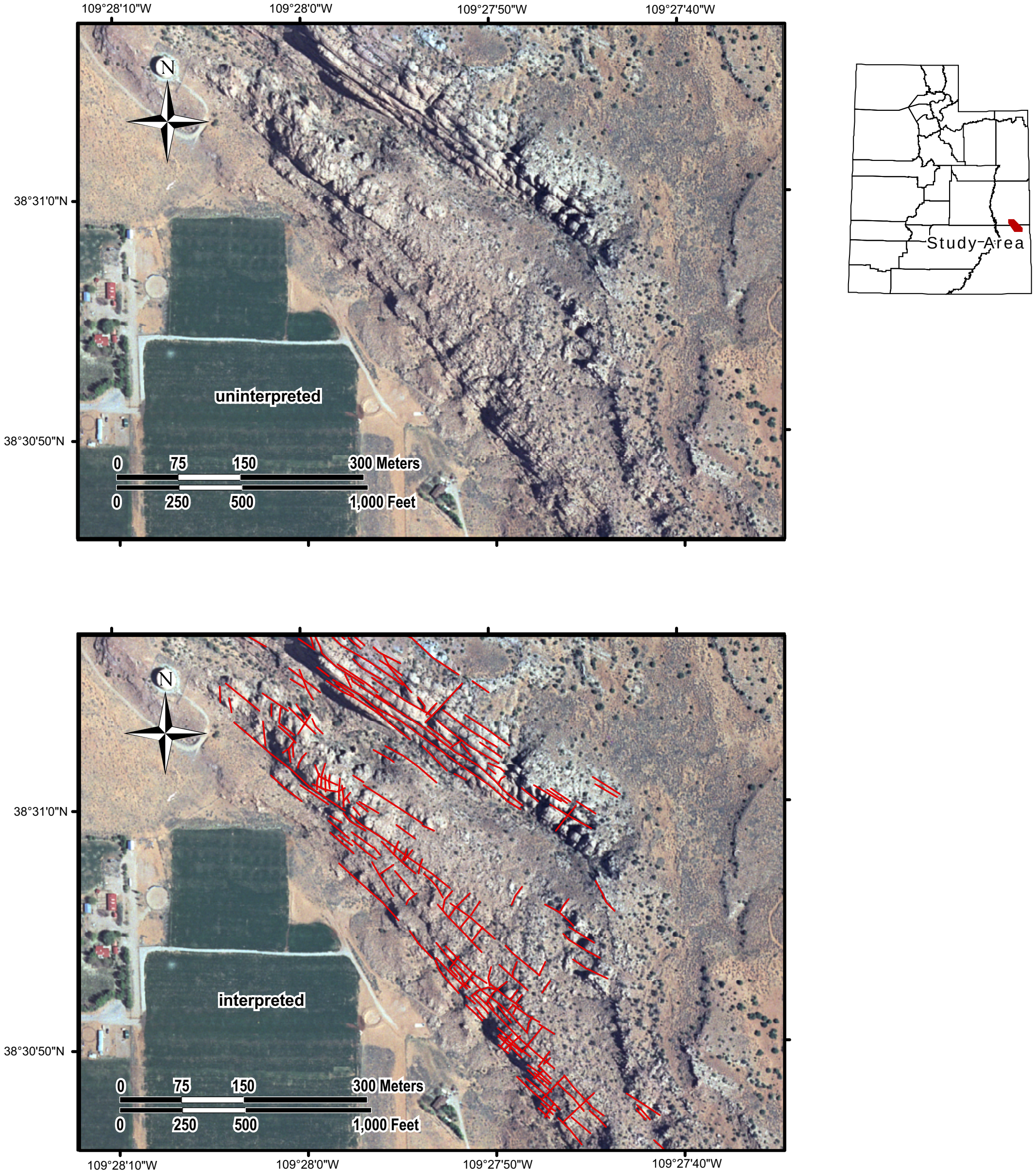

Figure 5. *Photo lineaments along the northeast margin of Spanish Valley. Interpreted lineaments are shown in red. Resolution of color orthophoto set is < 1 m. Lineaments commonly correspond to regional joint zones.*

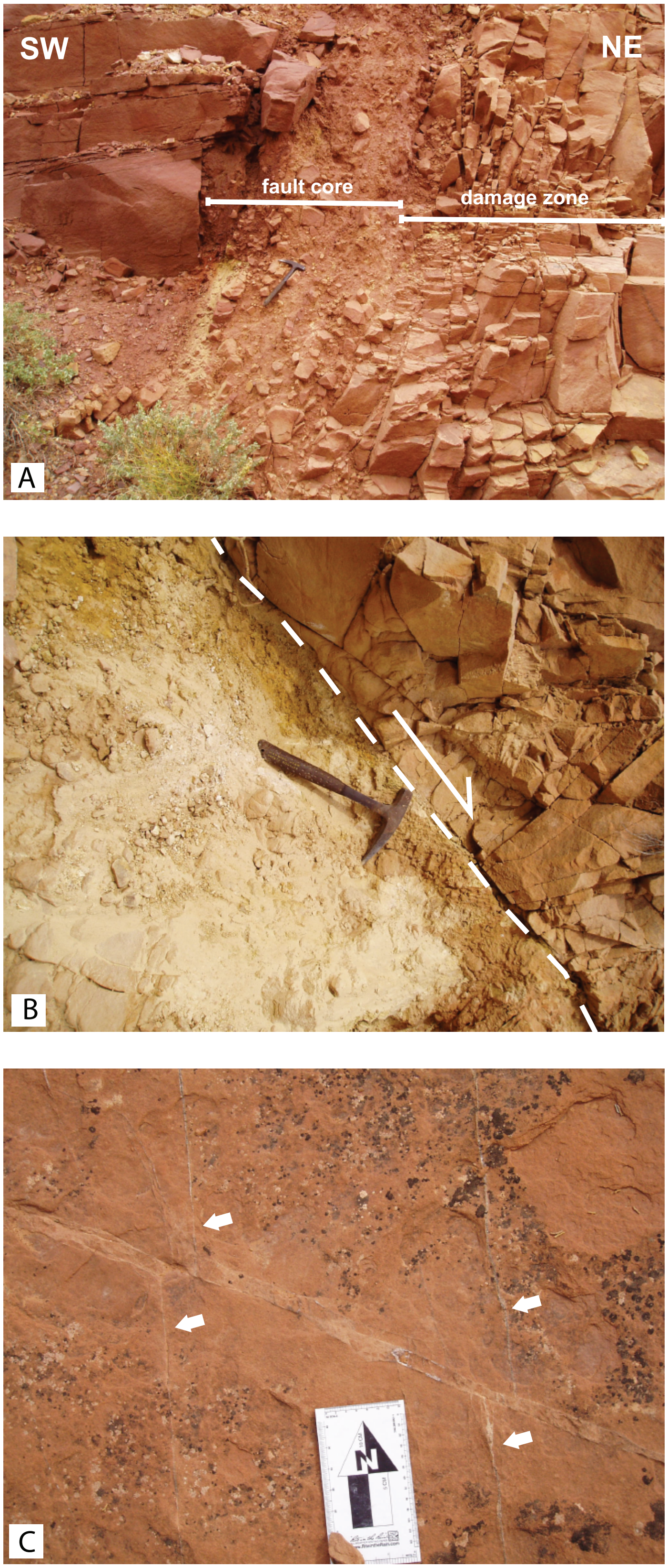

Figure 6. *Fault zones and deformation bands. A. View to the northwest of down-to-the-southwest normal fault in the Kayenta Formation showing a well-defined fault core with significant grain-size reduction and minor clay gouge. Damage zone is best developed in the footwall rocks with fracturing decreasing steadily away from the fault core. B. Close-up of fault core and damage zone in Glen Canyon Group. Total displacement is several meters based on offset markers. Clay gouge is well developed along defined slip surface shown by dashed line. C. Calcite-filled joints offset by late-stage deformation band. Whereas joints such as these may be an effective fluid purveyor, the deformation band likely inhibits transverse fluid flow. White arrows indicate joints.*

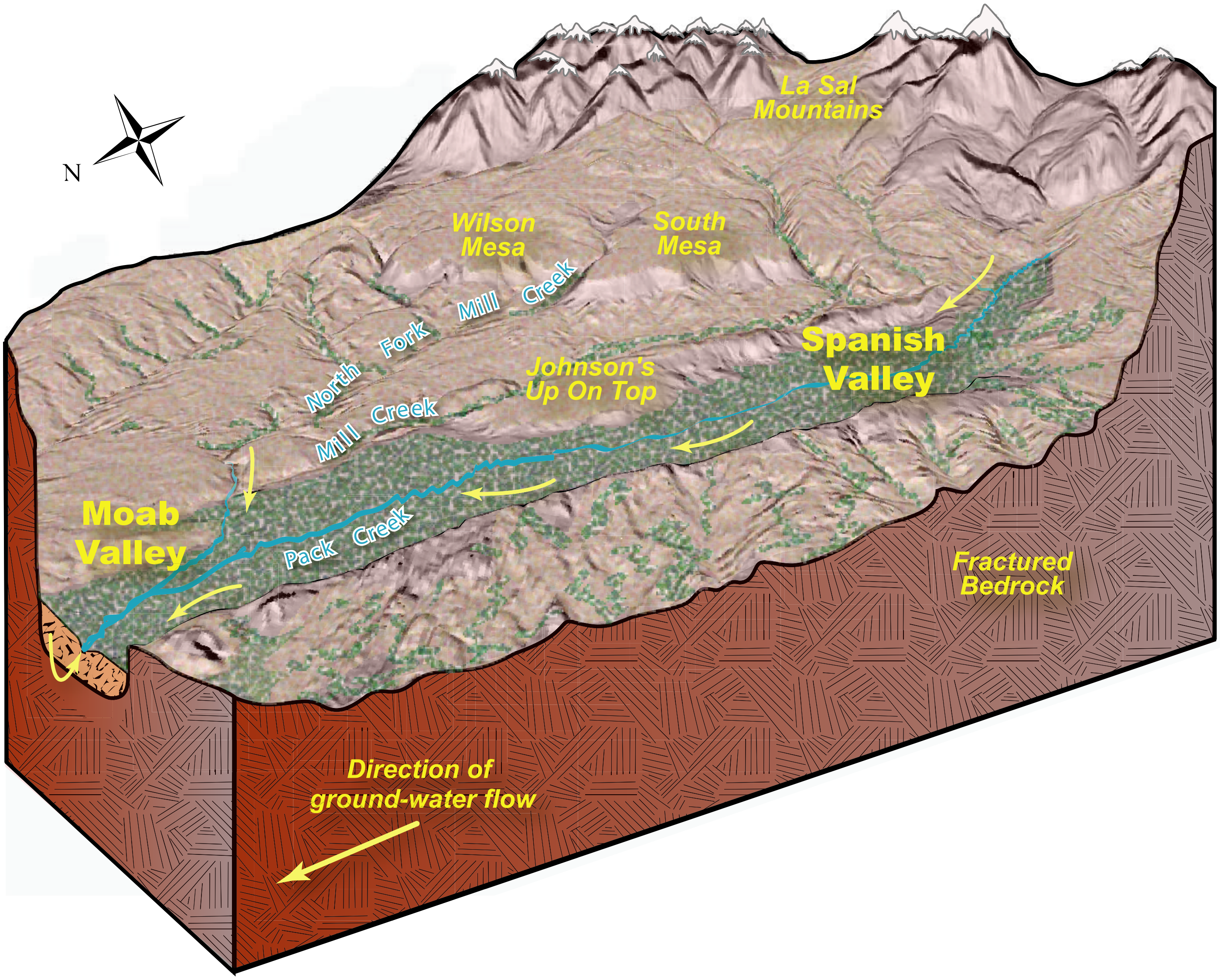

Figure 7. Schematic block diagram showing ground-water flow in Moab-Spanish Valley.

Table 4. *Characteristics of the major geologic units and their hydrologic characteristics and significance, Grand and San Juan Counties (adapted from Weir and others, 1961; Eisinger and Lowe, 1999; and Doelling, 2001, 2004; - stratigraphic thicknesses after Hintze, 1988, and Doelling, 2001).*

Erathem	System	Geologic Unit	Thickness (ft)	Description	Hydrologic characteristics and significance	Aquifer System
Cenozoic	Quaternary	Valley Fill Deposits	0 - 300	Unconsolidated units consisting of alluvial sand and gravel, colluvial deposits, landslide deposits, pediment deposits, glacial till, eolian sands, and terrace deposits.	Principal aquifer, low to high permeability; yields small to large quantities of water to wells and springs. Highest discharge near the Moab well-field area of Spanish Valley.	Unconsolidated Aquifers
	Tertiary	Intrusive igneous rocks of the La Sal Mountains		Consists of diorite, monzonite, and syenite porphyry that intruded older sedimentary formations as dikes, sills, stocks, and laccoliths.	Very low permeability. Known to yield water only where jointed, fractured, or faulted. Recharges adjacent permeable sedimentary rocks. Yields fresh water.	
Mesozoic	Cretaceous	Mancos Shale	300 - 1,100	Marine shale that contains a few thin beds of sandstone or limestone, and is gradational with and laterally interfingers with the overlying Mesaverde Group. The Mancos Shale has three members: The Blue Gate Member at the top, a shale that contains thin beds of bentonite or shaly sandstone and limestone; the Ferron Sandstone Member in the middle, a fine-grained, thin-bedded sandstone and sandy shale; and the Tununk Member at the base, a mudstone and shale that contains some thin bentonite beds.	Very low permeability; a barrier to the movement of water unless fractured. Water in the Mancos Shale, or in alluvium or colluvium derived from it, is saline. The Ferron Sandstone Member yields some water to springs.	Confining Unit
		Dakota Sandstone	0 - 120	Sandstone and conglomerate, interbedded with mudstone, carbonaceous shale, coal, and claystone.	Low to moderate permeability except where faulted or fractured. Yields water to a few small springs.	Dakota Aquifer
		Burro Canyon Formation	0-200	Sandstone, gritstone, and conglomerate, interbedded with minor mudstone. Unit is mapped southeast of the Colorado River.	Low to moderate permeability except where faulted or fractured. Yields water to a few small springs. Commonly combined with Dakota Formation as the Dakota Aquifer.	Dakota Aquifer (Burro Canyon Formation)

Table 4. *(continued)*

Erathem	System	Geologic Unit	Thickness (ft)	Description	Hydrologic characteristics and significance	Aquifer System
Mesozoic	Jurassic	Brushy Basin Member of the Morrison Formation	295 - 400	Laminated, bentonitic mudstone, claystone and siltstone that contains laterally discontinuous lenses of chert-pebble conglomerate and sandstone; typically variegated red, green, and purple color.	Low permeability and is typically a barrier to the movement of water. Sandstone interbeds may yield water to wells.	Confining Unit
		Salt Wash Member of the Morrison Formation	130 - 300	Fine- to medium-grained sandstone, and less common conglomeratic sandstone interbedded with mudstone; contains thin beds of calcareous and gypsiferous shale and thin beds of limestone near the base of the member.	Low permeability; yields small quantities of water to seeps and springs northwest of Moab. Yields saline water to one spring on South Mesa.	Morrison Aquifer (Salt Wash Member)
		Tidwell Member of the Morrison Formation and the Summerville Formation	20 - 65	Siltstone, interbedded sandstone and minor chert. Formations divisible in the field but commonly lumped together for mapping.	Low permeability, may act as a barrier to vertical ground-water movement.	Confining Unit
		Moab Member of the Curtis Formation	0 - 140	Medium- to fine-grained, well-sorted, cross-bedded eolian sandstone.	Moderate permeability. Yields fresh water to springs and wells. Commonly combined with the Slick Rock Member as the Entrada aquifer.	Entrada Aquifer (Moab Member)
		Slick Rock Member of the Entrada Formation	140 - 500	Very fine- to medium-grained, well-sorted, cross-bedded sandstone of eolian and possibly shallow-marine origin.	Moderate permeability. Yields water to seeps and springs, generally less than 5 gpm. Well yields may be higher where unit is fractured. Commonly combined with the Moab Member as the Entrada aquifer.	Entrada Aquifer (Slick Rock Member)
		Dewey Bridge Member of the Carmel Formation	25 - 235	Poorly bedded, sandy siltstone, and silty sandstone deposited in a shallow-marine environment.	Low permeability, may act as a barrier to vertical ground-water movement.	Confining Unit

Table 4. *(continued)*

Erathem	System	Geologic Unit	Thickness (ft)	Description	Hydrologic characteristics and significance	Aquifer System
Mesozoic	Jurassic	Navajo Sandstone	0 - 550	Well-rounded, well-sorted, massive, fine- to medium-grained eolian sandstone. Locally contains beds of cherty, dolomitic, freshwater limestone that were likely deposited in playa lakes. Limestone horizons near top of formation.	Moderate permeability, where fractured yields small to large quantities of water. Yields freshwater to seeps, springs, and wells throughout the area. Spring discharge ranges from less than 5 to more than 300 gpm. Well discharge is as much as 2,000 gpm.	Navajo Aquifer
		Kayenta Formation	140 - 300	Very fine- to coarse-grained, locally conglomeratic, fluvial sandstone, siltstone, and shale, with beds of mudstone.	Low permeability; may act as a barrier to the movement of water except where faulted or fractured. In areas where Navajo and Kayenta are flat lying, springs issue from base of Navajo at contact with the Kayenta. Unit is more permeable in the Mill Creek-Spanish Valley area and, along with the Navajo and Wingate Sandstones, forms the Glen Canyon aquifer.	
		Wingate Sandstone	150 - 450	Well-sorted, very fine- to medium-grained, calcareous, massively bedded, well-cemented, eolian sandstone. Forms vertical cliffs in most exposures.	Moderate permeability except where faulted or fractured. Water from the Wingate is fresh to moderately saline, but locally may be very saline to briny. Yields freshwater to seeps and springs in the Moab Valley-Colorado River area. Recharge dependent upon the permeability and competency of overlying Kayenta.	Wingate Aquifer
	Triassic	Chinle Formation	150 - 650	Siltstone and conglomeratic sandstone near the top; flood-plain, lacustrine, bentonitic mudstone and marly mudstone in the middle, and fluvial, conglomeratic sandstone and mudstone in the lower part.	Very low to low permeability; a barrier to the movement of water except where jointed, faulted, or fractured. Yields little water in Grand County.	Confining Unit

Table 4. *(continued)*

Erathem	System	Geologic Unit	Thickness (ft)	Description	Hydrologic characteristics and significance	Aquifer System
Mesozoic	Triassic	Moenkopi Formation	590 - 750	Upper unit: Red siltstone, thin sandstone, and thick massive sandstone and thin marine limestone. Lower unit: interbedded thin, commonly contorted, beds of fine- to medium-grained, micaceous, silty sandstone and shaly siltstone that locally contain gypsum beds. Represents a marginal marine deposit that grades from tidal-flat, deltaic, and fluvial beds in the eastern part of the county to a shallow-water, marine limestone facies in the western part of the county.	Very low permeability; a barrier to the movement of water except where jointed, faulted, or fractured.	Confining Unit
Paleozoic	Permian	Cutler Formation	400 - 6,000 +	Fluvial arkose and arkosic fanglomerates; conglomerates; and finer-grained continental and nearshore marine clastics. Underlies all of the study area except where removed by erosion on the crests of the salt anticlines and in the deeper canyons.	Very low to low permeability except where faulted or fractured. Shaly beds are barriers to the movement of water except where faulted or fractured. Sandstones are permeable, but the formation generally has a low intrinsic hydraulic conductivity.	Cutler Aquifer
	Pennsylvanian	Paradox Formation caprock	650 - 1,150	Light-gray, contorted gypsum with interlayered black and gray shale with thin limestone and sandstone beds; caprock is the residue after salt is dissolved from the Paradox Formation.	Very low to high permeability. Evaporites are a barrier to the movement of water. Carbonate rocks, except reefs and bioherms, usually are barriers to the movement of water except where faulted or fractured or where solution channels have developed. Reef and bioherm deposits may be highly permeable and can have porosities of as much as 30 percent. Dissolved-solids concentrations can exceed 400,000 mg/L.	Confining Unit
		Paradox Formation	0 - 4,500	The Paradox Formation contains a thick sequence of evaporite deposits interbedded with shale, carbonate, and fine-grained sandstone and siltstone in what was the deepest part of the Paradox Basin, and limestone and dolomite interbedded with shale and fine-grained sandstone to the west and south of the evaporite sequence. The depositional environments range from marine shoal and shelf to hypersaline evaporite basin. (Shown on cross sections only).		Confining Unit

Occurrence

The Wingate Sandstone and Kayenta Formation: The Wingate Sandstone is fine grained and well sorted, with large-scale, high-angle cross-stratification indicative of deposition in an eolian (wind-formed) environment (Sumsion, 1971). It is typically between 150 and 450 feet (50 and 140 m) thick in the Moab-Arches-La Sal area (Hintze, 1988), and generally capped by the erosion-resistant Kayenta Formation.

The amount of water that infiltrates into the Wingate Sandstone is directly related to the permeability and amount of fracturing in the overlying Kayenta Formation (Blanchard, 1990). Although the Kayenta Formation is a confining layer that in most areas of Grand County that separates the Wingate aquifer from the overlying Navajo aquifer, in the Moab-Spanish Valley area the Kayenta consists mostly of sandstone; therefore the three units form the single Glen Canyon aquifer (Blanchard, 1990; Steiger and Susong, 1997).

The Wingate Sandstone's intrinsic permeability is low because of its fine-grained nature, but it is a competent formation that can yield moderate quantities of water where intensely fractured (Sumsion, 1971). Spring discharge for the Wingate ranges from 10 to 240 gallons per minute (0.6-15 L/s) (Blanchard, 1990). Estimated hydraulic conductivity ranges from 0.1 feet per day to 0.4 feet per day (0.03-0.1 m/d), while the Wingate aquifer's transmissivity ranges between 40 and 150 square feet per day (4-14 m^2/d) (Jobin, 1962, in Blanchard, 1990).

The Navajo Sandstone: The Navajo Sandstone is fine grained, displays thick, eolian cross-beds, is weakly cemented by silica or calcium carbonate, and is exposed extensively in southern Grand County as massive cliffs and domes alternating with small depressions (Sumsion, 1971). The Navajo also contains thin, lenticular beds of gray, sandy limestone (Sumsion, 1971). The unit is between 0 and 550 feet (0-170 m) thick in the Moab-Arches-La Sal area (Hintze, 1988).

The Navajo aquifer yields water to seeps and springs throughout its outcrop area. The Navajo Sandstone is the shallowest and most permeable formation in the Glen Canyon Group (Feltis, 1966), and is therefore the target for most bedrock wells drilled in southern Grand County. Spring discharge from the Navajo ranges from less than 5 gallons per minute to more than 300 gallons per minute (0.3-20 L/s), and well discharge is as high as 2000 gallons per minute (125 L/s) (Blanchard, 1990).

The Navajo aquifer has the greatest transmissivity values of the major sandstone units in the Colorado Plateau area because it is thick, well sorted, and has a relatively high permeability (Freethey and Cordy, 1991). There is a slight increase in average grain size and a slight decrease in cementation toward the upper parts of the Navajo (Uygur, 1980), resulting in a corresponding slight upward increase in porosity and hydraulic conductivity (Freethey and Cordy, 1991). However, secondary permeability due to fractures is still the most important factor controlling the ability of the formation to yield water. The hydraulic conductivity derived from unfractured core samples of the Navajo in Emery County ranged from 0.0037 to 5.1 feet per day (0.001-1.5 m/d) (Hood and Patterson, 1984). Based on oil well data, Hood and Patterson (1984) calculated that the hydraulic conductivity of an open 0.001-inch- (0.003 cm) wide fracture would be 132 feet per day (40 m/d). However, such a calculation overestimates the ability of a fractured-rock aquifer to yield water. The highest hydraulic conductivity calculated by Freethey and Cordy (1991) from aquifer tests was 88 feet per day (27 m/d) for a 44-foot (13 m) interval of fractured Navajo Sandstone, and values calculated from aquifer tests in Utah, Arizona, and Colorado were most commonly between 0.1 and 1.0 feet per day (0.03-0.3 m/d). For the Navajo aquifer in Grand County, estimated values for transmissivity range from nearly 0, where the Navajo pinches out in the east, to almost 700 square feet per day (65 m^2/d) in the southwest; hydraulic conductivity ranges from as low as 0.4 feet per day (0.1 m/d) in the northeast to 1 foot per day (0.3 m/d) in the southwest (Jobin, 1962; Blanchard, 1990).

Recharge, Flow Direction, and Discharge

Ground water in the Glen Canyon aquifer is recharged primarily from infiltration of precipitation and stream flow, and flows primarily through fractures; the La Sal Mountains are ultimately the source of most of this recharge (Blanchard, 1990). The direction of ground-water flow in the Glen Canyon aquifer is generally to the west, west-northwest (Blanchard, 1990), or southwest (Steiger and Susong, 1997). Most of the discharge from the Glen Canyon aquifer in the Moab-Spanish Valley area is to wells and springs, mostly on the northeast side of the valley in the vicinity of Moab, to gaining reaches of Mill and Pack Creeks, and as subsurface recharge to the valley-fill aquifer (Sumsion, 1971; Blanchard, 1990).

Ground-Water Quality

Wingate Sandstone: Rush and others (1982) reported that TDS concentrations for nine samples from the Wingate Sandstone ranged from 164 to 680 mg/L, with an average of 260 mg/L. One sample from Salt Springs, which discharges from the base of the Wingate Sandstone, had an unusually high specific conductance of 3760 micromhos per centimeter at 25°C (a TDS of about 2670 mg/L), probably due to a long flow path in a regional flow system (Rush and others, 1982). Blanchard (1990) reported that three samples from springs issuing from the Wingate Sandstone had TDS concentrations ranging from 161 to 174 mg/L, and that a sample from a 765-feet-deep well in Arches National Park had a TDS concentration of 280 mg/L. The Wingate Sandstone typically produces calcium-magnesium-bicarbonate-type water; however, the sample from Jackson Reservoir Springs that produced the 680 mg/L value, was characterized as calcium-sulfate-type water (Weir and others, 1983).

Navajo Sandstone: The Navajo Sandstone generally produces water with low TDS concentrations due to a low soluble-mineral content and because it has an extensive outcrop area in southern Grand County that receives recharge from direct infiltration of precipitation (Rush and others, 1982). Weir and others (1983) reported that TDS concentrations for six samples collected from the Navajo Sandstone ranged from 163 to 505 mg/L, and averaged 275 mg/L. Blanchard (1990) reported that water samples from five springs issuing from the Navajo Sandstone in Grand County had TDS concentrations ranging from 102 to 385 mg/L, and that two wells completed in the Navajo Sandstone had TDS concentrations of 210 and 360 mg/L. The Navajo Sandstone typically contains calcium-bicarbonate- or calcium-magnesium-bicarbonate-type water (Weir and others, 1983; Blanchard, 1990).

Glen Canyon Group, undivided: The Utah Division of Water Quality, as part of Steiger and Susong's (1997) study, sampled wells from the Glen Canyon Group in the Moab-Spanish Valley area where the Glen Canyon aquifer generally contained water with TDS concentrations of less than 500 mg/L, and where 83 percent of the Glen Canyon aquifer samples had TDS concentrations of less than 250 mg/L. Nitrate-plus-nitrate concentrations in ground water from wells completed in the Glen Canyon aquifer, based on Steiger and Susong's (1997) data ranged from 0.02 to 7.37 mg/L.

Valley-Fill Aquifer

Occurrence

Once the principal source of all ground water used in Moab-Spanish Valley (Sumsion, 1971), the valley-fill deposits now provide water used mostly for irrigation and for some domestic water supply (Steiger and Susong, 1997). The valley fill, predominately stream alluvium and alluvial-fan deposits, is 400 to 450 feet (120-140 m) thick in northwestern Moab-Spanish Valley near the Colorado River (Doelling and others, 1995, 2002). These deposits were estimated by Sumsion (1971), based on selected drillers' logs of water wells, to have a textural composition of about 7 percent clay, 4 percent silt, 50 percent sand, and 39 percent gravel. The average thickness of saturated sediments in Moab-Spanish Valley is about 70 feet (20 m) (Sumsion, 1971). Moab-Spanish Valley had over 200 wells completed in unconsolidated deposits by the late 1960s (Sumsion, 1971); these wells range in depth from 30 to 300 feet (9-90 m) (Gloyn and others, 1995; Lowe, 1996) and have water yields ranging from 8 to 1000 gallons per minute (0.5-60 L/sec) (Sumsion, 1971). The average transmissivity for the Moab-Spanish Valley valley-fill aquifer is estimated at approximately 10,000 square feet per day (900 m^2/d) (Sumsion, 1971). Sumsion (1971) estimated approximately 200,000 acre-feet (250 hm^3) of recoverable water in storage in the Moab-Spanish Valley valley-fill aquifer.

Valley-Fill Geometry and Thickness

Moab-Spanish Valley is floored by Quaternary age unconsolidated deposits of the valley-fill aquifer. An isopach map of valley-fill deposits based on water and petroleum wells shows variable thickness of unconsolidated valley fill (plate 6). Near the Colorado River northwest of Moab, unconsolidated deposits rest directly on caprock of the Paradox Formation and are greater than 400 feet (122 m) thick. Southeast of Moab, valley fill thins to approximately 150 feet (46 m) and lies on Triassic rocks (Doelling and others, 2002; plates 3 and 6). Throughout the remainder of Spanish Valley, unconsolidated deposits rest primarily on Middle and Lower Jurassic rocks including the Glen Canyon Group (plate 3). In the central and southeast portions of Spanish Valley, valley fill is thicker along the valley axis with several pockets over 200 feet (61 m) thick along strike (plate 6). Southeast of Kens Lake, valley-fill depth is unconstrained but is inferred to shallow southeastward along the valley axis and toward the valley margins.

Hydrogeologic Setting

Introduction: Hydrogeologic setting is delineated on ground-water recharge-area maps which typically show (1) primary recharge areas, (2) secondary recharge areas, and (3) discharge areas (Anderson and others, 1994). For our geographic information system (GIS) analyses, we assigned hydrogeologic setting to one of these three categories, illustrated schematically in figure 8. Primary recharge areas, commonly the uplands and coarse-grained unconsolidated deposits along basin margins, do not contain thick, continuous, fine grained layers (confining layers) and have a downward ground water gradient. Secondary recharge areas, commonly mountain-front benches, have fine-grained layers thicker than 20 feet (6 m) and a downward ground-water gradient. Ground-water discharge areas are generally in basin lowlands. Discharge areas for unconfined aquifers occur where the water table intersects the ground surface to form springs, seeps, lakes, wetlands, or gaining streams (Lowe and Snyder, 1996). Discharge areas for confined aquifers occur where the ground-water gradient is upward and water discharges to a shallow unconfined aquifer above the upper confining bed, or to a spring. Water from wells that penetrate confined aquifers may flow to the surface naturally. The extent of both recharge and discharge areas may vary seasonally and from dry years to wet years.

We used drillers' logs of 165 water wells in Moab-Spanish Valley (appendix G) to delineate recharge areas and discharge areas, based on the presence of confining layers and relative water levels in the principal and shallow unconfined aquifers. Although this technique is useful for acquiring a general idea of where recharge and discharge areas are likely located, it is subject to a number of limitations. The use of drillers' logs requires interpretation because of the variable quality of the logs. Correlation of geology from well logs is difficult because lithologic descriptions prepared by various drillers are generalized and commonly inconsistent. Use of water level data from well logs is also problematic because levels in the shallow unconfined aquifer are often not recorded and because water levels were measured during different seasons and years.

Confining layers are any fine-grained (clay and/or silt) layer thicker than 20 feet (6 m) (Anderson and others, 1994; Anderson and Susong, 1995). Some drillers' logs show both clay and sand in the same interval, with no information describing relative percentages; these are not classified as confining layers (Anderson and others, 1994). If both silt and clay are checked on the log and the word "sandy" is written in the remarks column, then the layer is assumed to be a predominantly clay confining layer (Anderson and others, 1994). Some drillers' logs show clay together with gravel, cobbles, or boulders; these also are not classified as confining layers, although in some areas of Utah layers of clay containing gravel, cobbles, or boulders do act as confining layers.

Primary recharge areas for valley-fill aquifer systems generally consist of the uplands along the margins of the valley, as well as valley fill not containing confining layers (figure 8). Ground-water flow in primary recharge areas has a downward component. Secondary recharge areas, if present, are locations where confining layers exist, but ground-water flow maintains a downward component. Secondary recharge

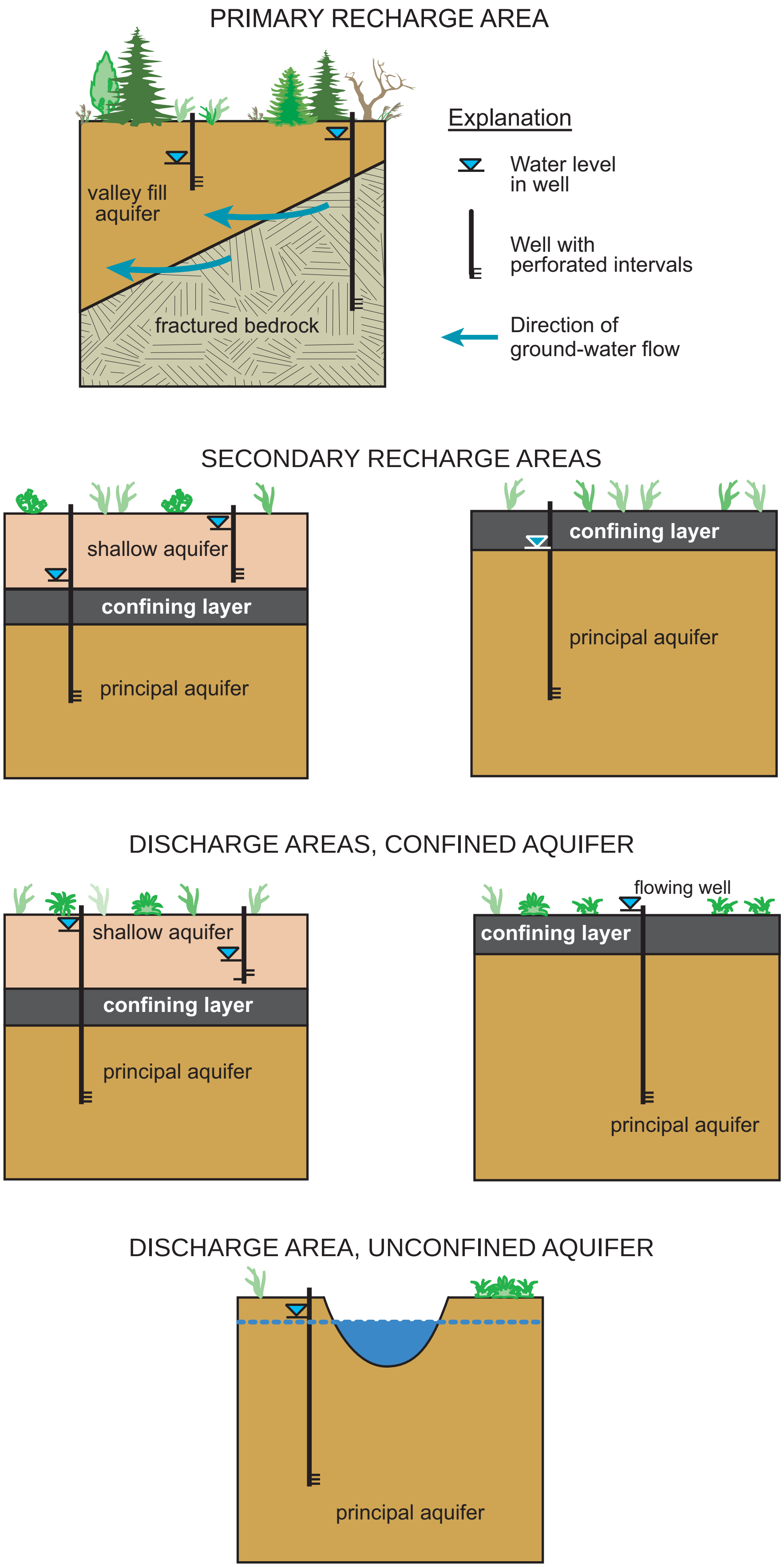

Figure 8. *Relative water levels in wells in recharge and discharge areas (modified from Snyder and Lowe, 1998).*

areas generally extend toward the center of the valley to the point where ground-water flow is upward (figure 8). The ground-water flow gradient, also called the hydraulic gradient, is upward when the potentiometric surface of the principal aquifer system is higher than the water table in the shallow unconfined aquifer (Anderson and others, 1994). Water-level data for the shallow unconfined aquifer are not abundant, but exist on some well logs. When the confining layer extends to the ground surface, secondary recharge areas exist where the potentiometric surface in the principal aquifer system is below the ground surface.

Ground-water discharge areas, if present, generally are at lower elevations than recharge areas. In discharge areas, the water in confined aquifers discharges to the land surface or to a shallow unconfined aquifer (figure 8). For this to happen, the hydraulic head in the principal aquifer system must be higher than the water table in the shallow unconfined aquifer. Otherwise, downward pressure from the shallow aquifer exceeds the upward pressure from the confined aquifer, creating a net downward gradient indicative of secondary recharge areas. Flowing (artesian) wells, indicative of discharge areas, are marked on drillers' logs; some flowing wells are shown on U.S. Geological Survey 7.5-minute quadrangle maps. Wells with potentiometric surfaces above the top of the confining layer can be identified from well logs. Surface water, springs, or phreatophytic plants characteristic of wetlands can be another indicator of ground-water discharge. In some instances, however, this discharge may be from a shallow unconfined aquifer. An understanding of the topography, surficial geology, and ground-water hydrology is necessary before using these wetlands to indicate discharge from the principal aquifer system.

Recharge and discharge areas: Most of the unconsolidated valley-fill in Moab-Spanish Valley and surrounding uplands are mapped as primary recharge areas (plate 7). Important primary bedrock recharge zones occur along both the north and south forks of Mill Creek, extending north and east towards the peaks of the La Sal Mountains. Primary bedrock recharge may also occur where unconsolidated deposits without confining layers directly overlie fractured bedrock aquifers beneath Moab-Spanish Valley. Confining layers and secondary recharge areas are mapped only locally near the center of Moab-Spanish Valley and in eastern Moab (plate 7). Discharge wells are rare, and discharge areas based on well logs are not sufficiently areally extensive to map as a discrete unit. The valley-fill aquifer begins discharging to Pack Creek at the northwestern end of Spanish Valley (Steiger and Susong, 1997), but this discharge area is primarily confined to the stream channel and the extent of the discharge area changes with water levels in the valley-fill aquifer. Southeast of the Colorado River, the water table is at the ground surface (figure 8) and the principal valley-fill aquifer discharges into wetlands and riparian vegetation (Sumsion, 1971) of the Moab Slough; this area is mapped as a discharge area (plate 7).

Potential for water-quality degradation: The potential for ground-water contamination based solely on recharge-type mapping is high across much of Moab-Spanish Valley and the surrounding mesas and bedrock uplands. Much of the water in the principal valley-fill aquifer comes from direct recharge from Mill and Pack Creeks and Kens Lake (Blanchard, 1990). These recharge sources may have relatively few pollutants, but any pollutants in these sources could rapidly degrade ground water in the principal valley-fill aquifer. A large part of Moab-Spanish Valley is mapped as primary recharge and has no significant hydrogeologic barriers to contamination of the principal valley-fill aquifer by pesticides or other water-borne contaminants. The potential for contamination of fractured bedrock aquifers may be high, particularly where bedrock aquifers directly underlie areas of thin valley fill without confining layers along the northeast margin of Moab-Spanish Valley. Care must be taken in siting potential contaminant sources, including septic tanks, in primary recharge areas where fractured bedrock aquifers directly underlie unconsolidated valley fill.

Ground-Water Depth, Volume, and Flow Direction

Depth to ground water ranges from near land surface at the northwest end of Moab-Spanish Valley to over 180 feet (50 m) at the abandoned Grand County Airport (Sumsion, 1971, plate 2). Based on an average saturated thickness of valley fill of 70 feet (20 m) and an estimated specific yield of 0.25, Sumsion (1971) estimated the average volume of ground water stored in the valley-fill aquifer to be about 200,000 acre-feet (250 hm^3). Ground-water flow in the valley-fill aquifer is generally to the northwest (Steiger and Susong, 1997). Sumsion (1971) estimated the hydraulic gradient to be 0.013 to the northwest at the northwest end of Moab-Spanish Valley; the hydraulic gradient flattens to about 0.08 at the abandoned Grand County Airport (Sumsion, 1971, plate 2).

Recharge and Discharge

Recharge in the La Sal Mountains is ultimately the source of recharge to the valley-fill aquifer in Moab-Spanish Valley. Most of the recharge to the valley-fill aquifer is from springs and subsurface flow from the Glen Canyon aquifer, principally along the northeast side of the valley (Sumsion, 1971), and from direct precipitation and infiltration of water from Pack Creek and Kens Lake (Steiger and Susong, 1997). Sources of discharge in Moab-Spanish Valley include outflow to the Colorado River; evapotranspiration by phreatophytes and hydrophytes; and consumptive use of ground water for irrigation, public supply, domestic purposes, and sewage treatment (Sumsion, 1971).

Ground-Water Quality

Ground-water quality in Moab-Spanish Valley is generally good and is suitable for most uses. The Moab-Spanish Valley unconsolidated aquifer generally yields calcium-bicarbonate-type or calcium-sulfate-bicarbonate-type ground water (Sumsion, 1971). Water salinity is classified based on concentration of dissolved solids in mg/L as follows: fresh, 0 to 1000 mg/L; slightly saline, 1000 to 3,000 mg/L; moderately saline, 3000 to 10,000 mg/L; very saline, 10,000 to 35,000 mg/L; and briny, more than 35,000 mg/L (U.S. Geological Survey, 2006).

Sumsion (1971) reported samples collected from nine wells had TDS concentrations ranging from 169 to 1020 mg/L. Steiger and Susong (1997) reported that samples from more than 20 wells completed in the unconsolidated aquifer in Moab-Spanish Valley had TDS concentrations ranging from 260 to 1818 mg/L, and that 86 percent of the samples had TDS concentrations of less than 1000 mg/L. The water in the Moab-Spanish Valley unconsolidated aquifer is generally of poorer quality than water in the Glen Canyon aquifer (Steiger and Susong, 1997), and mixing of water from this fractured-rock aquifer tends to decrease TDS concentrations in the unconsolidated aquifer as ground water in the valley fill flows from southeast to northwest (Sumsion, 1971).

Sumsion (1971) reported nitrate concentrations in the Moab-Spanish Valley unconsolidated aquifer of up to 26 mg/L, more than twice the ground-water quality (health) standard of 10 mg/L (U.S. Environmental Protection Agency, 2002a). Steiger and Susong (1997) reported that dissolved nitrate-plus-nitrite concentrations for ground water in Moab-Spanish Valley ranged from 0.04 to 5.87 mg/L, and suggested nitrate-plus-nitrite concentrations of greater than 3 mg/L in an area in the central portion of the valley resulted from human activities. This is an area where domestic wastewater is or, until recently, was disposed of using septic-tank soil-absorption systems.

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. Background information on ground-water quality classification is presented in appendix H.

Results

Data Sources for the Glen Canyon Aquifer

The Utah Geological Survey used ground-water quality data compiled by Steiger and Susong (1997) from 24 water wells completed in the undivided Glen Canyon aquifer in the Moab-Spanish Valley area. Total-dissolved-solids concentrations were typically less than 500 mg/L, and 83 percent of the Glen Canyon aquifer samples had TDS concentrations of less than 250 mg/L (appendix B). Nitrate-plus-nitrate concentrations in ground water from wells completed in the Glen Canyon aquifer, based on Steiger and Susong's (1997) data, ranged from 0.02 to 7.37 mg/L (appendix B). For this ground-water quality classification, we also obtained maps from a petition designating the Glen Canyon aquifer a Sole Source Aquifer in the area east of Moab-Spanish Valley (U.S. Environmental Protection Agency, 2002b).

Data Sources for the Valley-Fill Aquifer

As part of this ground-water quality classification, the Utah Geological Survey used data from 72 wells and one surface water site sampled between 1968 and 2004 by the U.S. Geological Survey and Utah Division of Water Quality (30 wells and one surface-water sample), Utah Department of Agriculture and Food (13 wells), public-water suppliers (nine wells), and the Utah Geological Survey (20 wells). The U.S. Geological Survey and Utah Division of Water Quality data are from Steiger and Susong's (1997) study that was specifically designed to provide the information (water-quality and recharge area mapping) necessary for ground-water quality classification. Ground water from all 51 of the Utah Geological Survey/U.S. Geological Survey/Utah Division of Water Quality wells and one stream sample from Pack Creek were analyzed for general chemistry and nutrients by the Utah Department of Epidemiology and Laboratory Services or the U.S. Geological Survey (appendix B). Of these 51 wells, ground water from 10 wells was analyzed for organics and pesticides, and ground water from seven wells was analyzed for radionuclides (appendix B). These data were augmented by another 13 wells sampled in September 2000, and analyzed for specific conductance (except for two wells), pesticides, and nutrients (appendix B) by the Utah Department of Agriculture and Food (Quilter, 2001), and specific-conductance, TDS concentration, and selected data from other ground-water constituents from nine wells (four without TDS data) collected from public-supply wells and analyzed by Utah Department of Epidemiology and Laboratory Services (appendix B). The Utah Geological Survey data were collected as part of this study to extend the sampling area to the south into San Juan County.

Total-dissolved-solids concentrations: The Utah Water Quality Board's drinking-water quality (health) standard for total dissolved solids is 2000 mg/L for public-supply wells (table B.2). The secondary ground-water quality standard is 500 mg/L (U.S. Environmental Protections Agency, 2002a) (table B.2), and is imposed primarily to minimize imparting an unpleasant taste to the water (Bjorklund and McGreevy, 1971). Plate 8 shows the distribution of TDS in Moab-Spanish Valley's valley-fill aquifer; the TDS concentration lines largely mirror Steiger and Susong (1997) because 15 of the 16 additional wells with TDS data used in this classification fell within their mapped contours. Based on data from ground-water samples from the 63 wells and one surface-water site, TDS in the valley-fill aquifer of Moab-Spanish Valley range from 140 to 1818 mg/L, with only four wells exceeding 1000 mg/L TDS and an overall average TDS concentration of 690 mg/L (appendix B, plate 8).

The higher TDS concentrations exist in the central part of Moab-Spanish Valley on the west side of Pack Creek (plate 8); the higher TDS concentrations may be due to (1) upward leakage of higher TDS ground water along the Moab fault, (2) contact with pre-Jurassic rocks (plate 3, J-J′; plate 5) that contain more soluble materials than the Glen Canyon Group which underlies the valley fill in most other areas of Moab-Spanish Valley, or (3) a combination of 1 and 2. The lower TDS concentrations found on the east side of Moab-Spanish Valley (plate 8) are likely the result of higher quality water discharging from the Glen Canyon aquifer and mixing locally with water in the valley-fill aquifer (Steiger and Susong, 1997).

Nitrate concentrations: The ground-water quality (health) standard for nitrate as nitrogen is 10 mg/L (table B.2) (U.S. Environmental Protection Agency, 2002a). More than 10 mg/L of nitrate as nitrogen in drinking water can result in a condition known as methoglobinemia, or "blue baby syndrome" (Comley, 1945) in infants under six months. This condition is characterized by a reduced ability for blood to carry oxygen and can be life threatening without immediate medical attention (U.S. Environmental Protection Agency, 2002a). Based on data from ground-water samples from 72 wells, nitrate-as-nitrogen concentrations range from 0.06 to 7.37 mg/L, with 16 wells yielding ground water above 3 mg/L, and an overall average nitrate concentration of 2.1 mg/L (plate 9, appendix B). Nitrate concentrations above 3 mg/L are mostly in ground water from wells in the central part of Moab-Spanish Valley, and are likely the result of human activity (Steiger and Susong, 1997), possibly domestic wastewater disposal via septic-tank systems.

Other constituents: Based on the data presented in appendix B, three wells exceeded primary water-quality standards for the metals lead, silver, and selenium; four wells exceeded water-quality standards for radionuclides alpha (three wells), beta (two wells), radium (one well), and uranium (one well); no pesticides from any of the wells sampled for pesticides were detected (Quilter, 2001). Sixteen wells exceeded secondary ground-water quality standards for iron (one well) and sulfate (15 wells) (appendix B).

The secondary ground-water quality standard for iron is 300 µg/L (table B.2) (U.S. Environmental Protection Agency, 2002a), primarily to avoid objectionable staining to plumbing fixtures, other household surfaces, and laundry (Fetter, 1980; Hem, 1985). 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).

The secondary ground-water quality standard for sulfate is 250 mg/L (table B.2) (U.S. Environmental Protection Agency, 2002a), primarily because of odor/taste problems and because high-sulfate water can have a laxative effect (Fetter, 1980). Dissolved concentrations of sulfate exceeding standards in Moab-Spanish Valley's principal aquifer range from 251.5 to 1061 mg/L. 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, 1985), as is gypsum which occurs in the Paradox Formation.

Resulting Ground-Water Quality Classification

Our ground-water quality classification, approved by the Utah Water Quality Board on November 18, 2005, for the valley-fill aquifer in Moab-Spanish Valley is shown on plate 10. The classification is based on data from ground water from 72 wells and one surface-water site (appendix B). Total-dissolved-solids concentrations for eleven wells sampled by the Utah Department of Agriculture and Food was calculated based on the relationship between specific conductance and TDS derived from data from 21 of the wells in Moab-Spanish Valley for which both values are known (figure 9, appendix B). Where insufficient data exists, extrapolation of ground-water quality conditions is required. We based the extrapolation on local geologic characteristics. The classes (plate 10) are described below.

Class IA—Pristine ground water: For this class, TDS concentrations in Moab-Spanish Valley range from 140 to 454 mg/L (appendix B). Class IA areas are mapped primarily along the central eastern and northeastern margins of the valley where recharge from the Glen Canyon aquifer is sufficient to keep the valley-fill aquifer ground water diluted below 500 mg/L TDS (plate 10). Areas having Pristine water quality cover about 13% of the total valley-fill material.

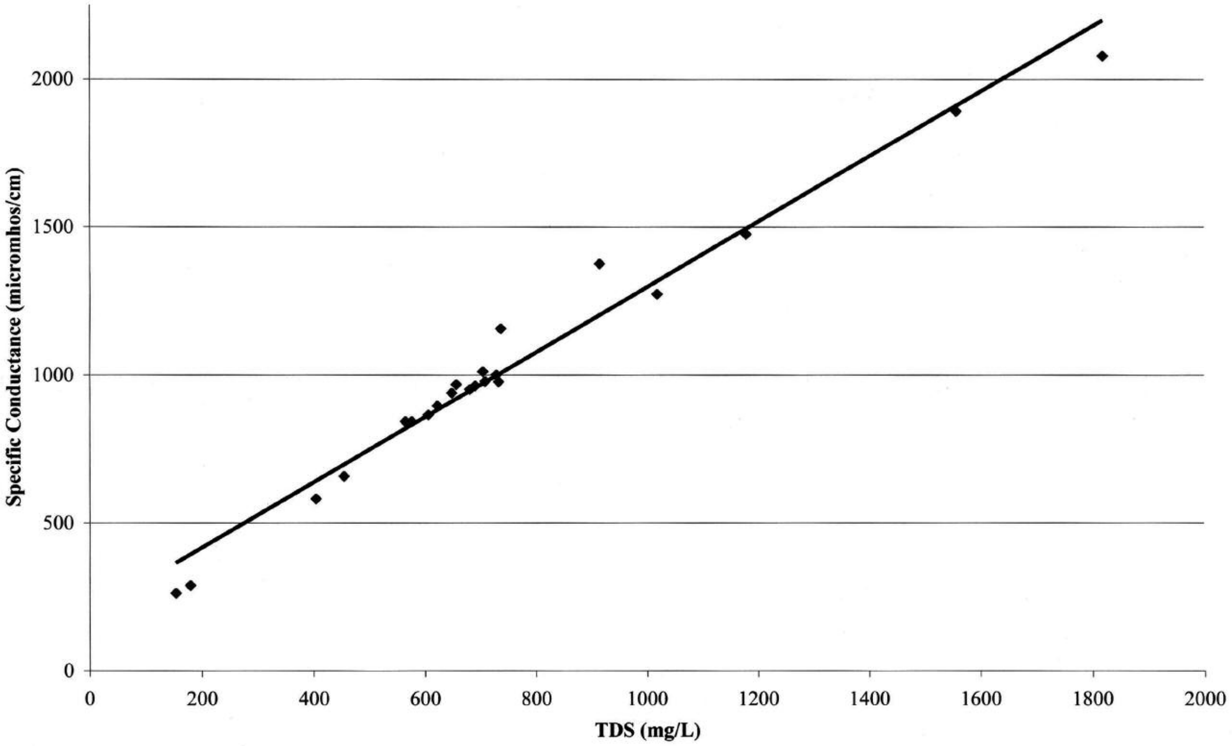

Figure 9. *Specific conductance versus total-dissolved-solids concentration data for 21 wells in Moab-Spanish Valley, Grand and San Juan Counties, Utah. R-squared is 0.97. Based on Hem's (1985) equation for estimating TDS from specific conductance: KA=S, where K=specific conductance, S=TDS, A ranges from 0.59 to 0.87 and with an average A=0.71 used as the conversion factor to compute TDS in the valley.*

Class II—Drinking Water Quality ground water: For this class, TDS concentrations in the Moab-Spanish Valley valley-fill aquifer range from 516 to 1818 mg/L (appendix B). Total valley-fill area coverage of Class II water quality is 87% (plate 10). We project Class II ground-water quality in the southeastern part of the valley (plate 10) based on extrapolated geologic conditions (plate 1); based on the presence of the Cretaceous Mancos Shale in the upper part of the valley, we believe any proposed water wells in valley-fill adjacent to this unit may potentially yield water quality having TDS concentrations between 500 and 3,000 mg/L (Drinking Water Quality) or greater.

Class IB—Irreplaceable ground water: Also approved by the Utah Water Quality Board on November 18, 2005, was the classification of a portion of the Glen Canyon aquifer (plate 10) as Class IB, Irreplaceable Ground Water. This classification is based primarily on the U.S. Environmental Protection Agency's (2002b) Soul Source Aquifer designation for the Glen Canyon aquifer that included this area. Ground-water data for wells completed in the Glen Canyon Aquifer along the margin of Moab-Spanish Valley indicate TDS concentrations are typically less than 500 mg/L (appendix B).

Land-Use Planning Considerations

Current beneficial uses of ground water: Ground water, much of which is from the valley-fill aquifer, is the most important source of water in the Moab-Spanish Valley area, supplying about 79% of municipal, culinary, and industrial water (Utah Division of Water Resources, 2000). More than 1500 perfected water well rights exist in Moab-Spanish Valley (Utah Division of Water Rights, 2005), 23 of which are public-supply wells (plate 10).

Potential for ground-water quality degradation: We mapped potential ground-water contaminant sources including some facilities related to mining, agricultural practices, and junkyard/salvage areas (appendix C, plate 11). A primary objective was to identify potential contaminant sources to establish a relationship between water quality and land-use practices. We mapped approximately 400 potential contaminant sources in the following categories in Moab-Spanish Valley:

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

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

(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; and

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

In addition to the above-described potential contaminants, plates 11 and 12 show the distribution of septic-tank soil-absorption systems in Moab-Spanish Valley. Historically, approximately 1600 septic-tank systems exist in Moab-Spanish Valley (Jim Adamson, Southeastern Utah District Health Department, written communication, October, 2002; Lance Christie, Grand County resident, written communication, May 28, 2003; Dave Vaughn, Grand County, verbal communication, March, 2003); the current number is estimated to be approximately 210 (Lance Christie, Grand County resident, personal communication, July, 2003; Jim Adamson, personal communication, July, 2003). In 1979-81, sanitary sewer services were extended through the Spanish Valley Water and Sewer Improvement District (SVW&SID) to an area which had 1314 septic tanks, and extended again in 1995-97 to an area which had 162 septic tanks. All building owners within 600 feet of a sewer line are assessed a hook-up fee and charged the monthly fee for wastewater treatment once sanitary sewer services are available (Lance Christie, Grand County resident, written communication, May 28, 2003). Septic-tank systems (plate 11) may contribute contaminants such as nitrate and solvents. All approved water wells, shown on plate 10, are also considered potential contaminant sources.

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., 1984; Wallace and Lowe, 1998a, 1999), to require the sizes of lots using septic-tank systems for wastewater disposal to be at least 5 and 3 acres (2 and 1 hm^2), respectively.

Using ground-water quality classification in conjunction with the septic-tank density/water-quality degradation analysis presented below to set maximum densities for development using septic-tank systems for wastewater disposal in Moab-Spanish Valley is one possible application for the ground-water quality classification presented above. 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 EPA Sole Source Aquifer designation of the Glen Canyon sandstone aquifer to enhance restrictions to the siting of new potential pollution sources in the valley-fill portion of the Moab-Spanish Valley drainage basin.

SEPTIC-TANK DENSITY/WATER-QUALITY DEGRADATION ANALYSIS

Introduction

Land-use planners have long used septic tank suitability maps to determine where wastewater from these systems will likely percolate within an acceptable range. However, they are only now becoming aware that percolation alone does not remediate many constituents found in wastewater, including nitrate. See appendix I for a discussion of ground-water contamination from septic-tank systems. 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 as nitrogen 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, 1999d; 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.

A typical single-family septic-tank system in Moab-Spanish Valley discharges about 242 gallons (916 L) of effluent per day containing nitrogen (or nitrate as nitrogen) concentrations of around 54.4 mg/L. The U.S. Environmental Protection Agency maximum contaminant level for drinking water for nitrate as nitrogen 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 Moab-Spanish 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 (Hansen, Allen, and Luce, Inc., 1994; Wallace and Lowe, 1998a, 1998b, 1998c, 1999; Zhan and McKay, 1998; Lowe and Wallace, 1999c, 1999d; Lowe and others, 2000) for land-use planning purposes, 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 242 gallons (916 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, 2001b, p. 28) multiplied by San Juan County's average 3.46 person household (U.S. Census Bureau, 2002); most new septic-tank systems likely to be constructed in Moab-Spanish Valley will likely be in San Juan County. 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 3.46, (2) an average nitrogen loading of 17 g N per capita per day (Kaplan, 1988, p. 149), (3) 265 liters per capita per day water use, and (4) an assumed retainment of 15 percent of the nitrogen in the septic tank (to be later removed 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 (or nitrate as 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 Kovacs (2000).

Limitations

There are many limitations to any mass-balance approach (see, for example, Zhan and McKay,1998; Lowe and Wallace, 1999c, 1999d; Lowe and others, 2000). 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 ground-water gradient data.

(2) Background nitrate concentration is attributed to natural sources, agricultural practices, and use of septic-tank systems, but projected nitrate concentrations 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 ground-water 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 apply to this mass-balance approach, we think it is beneficial 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

Due to increasing population growth and concomitant water use in Moab-Spanish Valley, the Grand County Water and Sewer Service Agency (GCWSSA) investigated the effects of increased water use. As part of the GCWSSA investigation, a three-dimensional finite-difference ground-water flow model of the area was developed by Downs and Kovacs (2000). We used the GMS ground-water modeling system (Boss International, Inc. and Brigham Young University, 1999), applied to the regional, three-dimensional, steady-state MODFLOW (McDonald and Harbaugh, 1988) model of Downs and Kovacs (2000), to estimate the volume of ground water available in the saturated, unconsolidated valley-fill deposits in Moab-Spanish Valley. We modified the three-dimensional, finite-difference, numerical model of ground-water flow in Moab-Spanish Valley by incorporating additional data we collected to provide a better estimate of simulated ground-water flow in the unconsolidated valley-fill, and the amount of water in that aquifer. We realize that a ground-water flow model is a tool to simulate a simplified version of a ground-water system, and we acknowledge this tool may be improved upon by future investigators.

The ground-water flow system in the area extends from the Colorado River to the surface-water divide in the La Sal Mountains; however, the model only includes the area immediately surrounding Moab-Spanish Valley. Downs and Kovacs (2000) used data from previously published hydrogeologic studies in the Moab-Spanish Valley area (Sumsion, 1971; Blanchard 1990) in the construction and calibration of the model. Additional data were obtained from Eychaner (1977).

Downs and Kovacs (2000) identified inflow from the La Sal Mountains, primarily from runoff and snowmelt, as the main source of recharge to the Moab-Spanish Valley and estimated subsurface inflow to be about 13,300 acre-feet per year (16 hm^3/yr). The deposits under Kens Lake are generally in hydraulic continuity with the lake, and recharge to the valley-fill aquifer from the infiltration of water through the bed of the lake was estimated to be about 3300 acre-feet per year (4 hm^3/yr) (Downs and Kovacs (2000).

Ground-water discharge in Moab-Spanish Valley is primarily from seepage to the Colorado River and evapotranspiration in the marshes and wetlands along the Colorado River. The net gain of flow in the Colorado River from seepage over the modeled area of Moab-Spanish Valley is 9530 acre-feet per year (12 hm^3/yr) (Downs and Kovacs, 2000). Discharge from wells used primarily for public-water-supply purposes is from the rock aquifer, and no wells in the valley-fill aquifer were modeled. Downs and Kovacs (2000) estimated discharge from wells and springs to be 6400 acre-feet per year (8 hm^3/yr). Mill Creek and Pack Creek enter the valley and flow toward the Colorado River; both are considered gaining streams where the water table of the valley-fill aquifer intersects coarse-grained sections of their stream channels (Sumsion, 1971). Total discharge of Moab-Spanish Valley is estimated to be about 17,330 acre-feet per year (20 hm^3/yr) (Downs and Kovacs, 2000).

We obtained estimates of hydraulic conductivity for the ground-water flow system from the published reports listed above, and from engineering evaluations in Moab-Spanish Valley. In the model, the values were then grouped into zones based upon the nature of the valley-fill materials and estimates of fracturing in the rock. In general, we assigned higher values of hydraulic conductivity for the valley-fill aquifer to the southeastern part of the valley, which mostly consists of coarser grained material, and lower values of hydraulic conductivity to the northern part of the valley, which consists mostly of finer grained material. We assumed the fractured rock is structurally complex and highly variable, with some regions more fractured than others. We assigned higher values of hydraulic conductivity to the eastern side of the valley where the Glen Canyon aquifer readily yields water to wells. We obtained hydraulic conductivity values for the fractured rock from aquifer tests performed in Moab-Spanish Valley and nearby areas as reported by Blanchard (1990). Downs and Kovak (2000) estimated aquifer thicknesses based on limited water-well data across the valley.

This conceptual model of Moab-Spanish Valley was simplified into the numerical model of ground-water flow for the valley. These simplifying assumptions for the aquifer, from the surface downward, are:

- An upper unconsolidated valley-fill aquifer of variable thickness. The alluvial sediments consist of as much as 400 feet (120 m) of poorly sorted coarse gravel, sand, and silt. Average thickness of saturated valley fill is about 70 feet (20 m). The thickness of the valley-fill aquifer decreases toward the mountains.

- A lower permeable bed that allows ground water to move vertically through it. The hydrologic nature of the contact between the valley-fill sediments and underlying rock aquifer is unknown, but assumed to leak substantial amounts of water.

- An extensive lower fractured-sandstone rock aquifer having an unknown thickness, arbitrarily designated as 400 feet (120 m). This aquifer acts as a single water-bearing unit.

- A solid, impermeable rock base below the fractured rock aquifer.

The steady-state model incorporated averaged hydraulic characteristics and pumping in Moab-Spanish Valley over several time periods. We describe the ground-water flow model below including our modification. For additional model information, see Downs and Kovacs (2000).

Computer Modeling

We used Downs and Kovacs' (2000) three-dimensional, finite-difference, numerical model of ground-water flow for the aquifer system in Moab-Spanish Valley to provide cell-by-cell flow data under steady-state conditions for the valley-fill aquifer. Downs and Kovacs' (2000) model provides the best representation currently available for the Moab-Spanish Valley valley-fill aquifer. The model is constructed to represent a ground-water flow system having no change in storage or long-term water levels—recharge and discharge from the system are equal and the system is in a steady-state.

Description of Downs and Kovacs' (2000) Model

Downs and Kovacs (2000) used the U.S. Geological Survey modular three-dimensional, finite-difference, ground-water flow simulator (MODFLOW) (McDonald and Harbaugh, 1988) to test and refine their conceptual understanding of the flow system in Moab-Spanish Valley. Because aquifer characteristics of the Moab-Spanish Valley aquifer system are not uniform, the aquifer was discretized into rectangular blocks in which the characteristics of the aquifer system were assumed to be uniform at a node in the center of each block. Downs and Kovacs' (2000) model discretizes the valley into a non-uniform, quasi-three-dimensional, node-centered, rectangular grid with variable spacing consisting of 216 rows and 82 columns, with two vertical layers of cells, a valley-fill layer and a rock layer (figure 10). The ground-water flow simulator solves for flow at each node by using a three-dimensional, finite-difference approximation to the partial differential equation of ground-water flow.

The rectilinear model grid consists of 17,712 cells per layer, with 2658 active cells in layer one, and 10,056 active cells in layer two. The model grid has a non-uniform grid-cell spacing ranging between 140 feet by 160 feet (43-49 m) to 500 feet (152 m) on each side, resulting in cell areas ranging from 22,400 to 250,000 square feet (2,081-23,225 m^2).

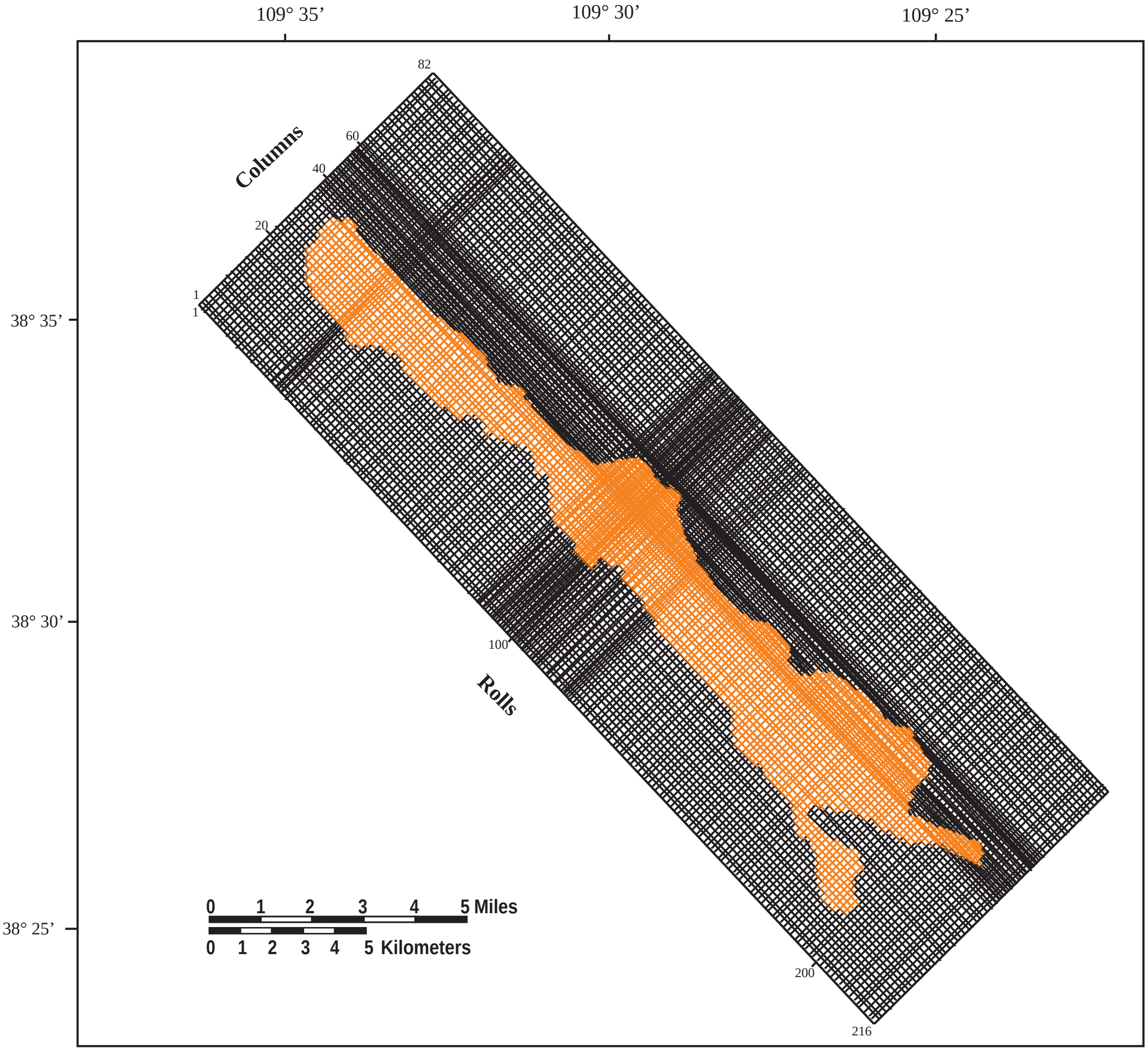

Figure 10. Finite-difference grid used to simulate ground-water flow in the valley-fill aquifer, Moab-Spanish Valley, Grand and San Juan Counties, Utah. Also shown are the active cells in layer one (orange color). North is toward the top of the page.

The model grid extends beyond the boundary of the valley fill because the effects of stress on the valley-fill aquifer extend into valley-margin bedrock aquifers. This variable grid spacing was designed for increased detail in areas having more data, particularly near Moab and along the northeast side of the valley. In general, the largest active cells are in areas where data are sparse and the smallest cells are in areas having more data. The active grid for the valley-fill aquifer represents an area slightly smaller than the actual area of unconsolidated valley fill, because some deposits are not saturated. The model assumes two-dimensional horizontal flow in the aquifer and one-dimensional vertical flow, ignoring storage, between layers using a vertical leakance term. The y-axis of the model is oriented northwest-southeast, parallel to the valley axis and ground-water flow direction.

Ground-surface elevations are from Eychaner (1977). Elevation values were assigned by selecting cells in the model along the contours and assigning constant elevation values to them. The active cells in layer one cover the major parts of Moab-Spanish Valley where valley-fill material is more than 10 feet (3 m) thick. Layer one, the valley-fill aquifer layer, has a variable thickness. In the model, the top elevations for layer two are the same as the bottom elevations of layer one. Layer two represents saturated rock from the base of the valley-fill deposits to an arbitrary, but constant thickness of 400 feet (120 m). The lower boundary of the model is a no-flow boundary.

The Moab-Spanish Valley model uses assigned general boundary conditions that simplify the complex hydrologic system. Downs and Kovacs (2000) specified the lateral boundaries surrounding the active cells of the model as constant head, no-flow, or specified flux. The finite-difference grid and boundaries used to simulate the valley-fill aquifer are shown in figure 11. The northwestern boundary of the model is a constant-head boundary that simulates the elevation of the Colorado River (which varies from 3952 feet to 3950 feet [1205-1204 m] based on the long-term average

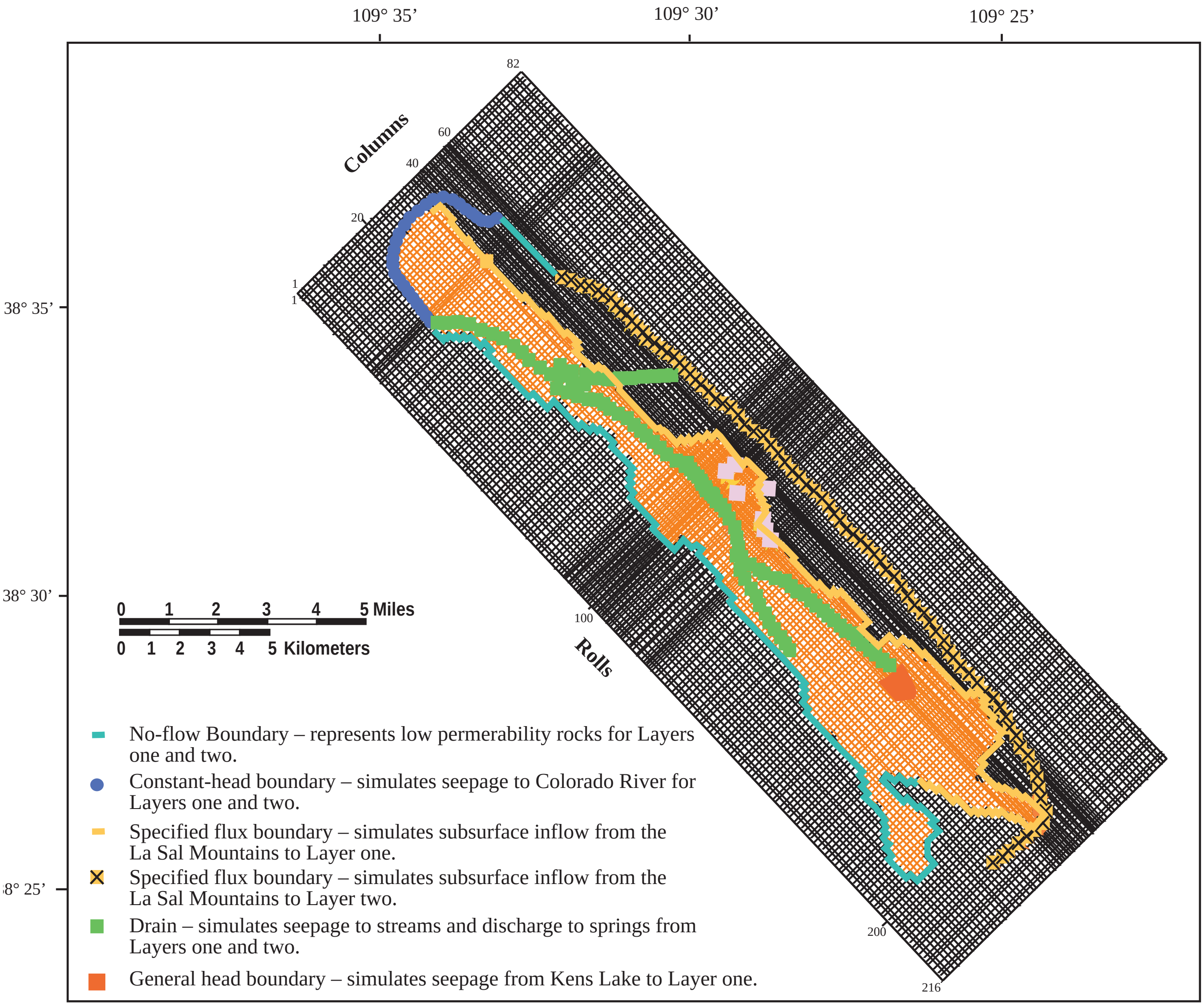

Figure 11. *Distribution of boundary conditions used to simulate ground-water flow in the valley-fill aquifer, Moab-Spanish Valley, Grand and San Juan Counties, Utah. North is toward the top of the page.*

stage of the river). The northeastern and southern boundaries are modeled as a specified flux boundary receiving ground water from the La Sal Mountains. Downs and Kovacs (2000) specified the southwestern lateral boundary of the model, along valley wall, as a no-flow boundary coincident with low-permeability rock. Public-water-supply wells in the valley are mostly screened in the fractured rock aquifer, and wells are only modeled in the rock aquifer. Eight pumping wells are simulated within the model domain. Pumping cells are treated as constant flux nodes, where average daily pumpage rates are assigned.

Downs and Kovaks (2000) used a specified-flux boundary for the upper boundary of the model by applying the recharge and drain packages of MODFLOW to simulate the infiltration of precipitation and discharge of ground water for layer one. Recharge of precipitation has a nonuniform distribution that was based on analysis of surface material, adjusted for evapotranspiration. In the model, recharge of the Moab-Spanish Valley valley-fill aquifer ranges from 0.06 inches per year (0.2 cm/yr) in the northwest to 0.5 inches per year (1.3 cm/yr) in the southeast. The area-weighted average recharge over the model is 0.25 inches (0.6 cm). Pack and Mill Creeks are modeled as drains in the model. Drains in the model receive ground water if the water table is above drain elevation; water exits permanently from the aquifer to the drain. If the water table is below the drain elevation, the drain has no effect. Values of conductance per unit length for Pack and Mill Creek drain cells are estimated by multiplying the hydraulic conductivity in the area by an average four-foot width of the channel. The conductance value is computed for each cell by multiplying the computed length of creek in each cell by the assigned conductance per unit length. Drains also represent springs. Kens Lake is considered a major source of recharge to the valley-fill aquifer. Kens Lake is modeled as a general head boundary and adjusted so that the lake loses about 3300 acre feet per year (4 hm3/yr).

Initially, Downs and Kovacs (2000) used a distribution of hydraulic conductivity with lower values in the northeast and higher hydraulic conductivities to the southwest; this pattern was maintained through the calibration. The vertical hydraulic conductivity values were assigned a value of one-fourth of the horizontal hydraulic conductivity values, due to layering effects. Initial hydraulic conductivity values of layer two were estimated based on aquifer-test data for the fractured-rock aquifer. Horizontal or vertical hydraulic conductivity within the fractured-rock aquifer are considered to be equal, since fracturing, not layering, largely controls water flow. The vertical leakance term connecting layers one and two was based on the hydraulic conductivities assigned to layer one. The vertical leakage used to represent confining units in the model was calculated based on the vertical hydraulic conductivity determined by comparing simulated vertical-head differences between layers.

Model Calibration

Calibration of a ground-water flow model involves changing the values of aquifer properties, or the quantity and distribution of recharge and discharge, or both, until model-calculated water levels match measured water levels and fluxes of water through the system. This iterative process requires adjusting uncertain input data against dependable hydrogeologic characteristics. Ground-water flow was simulated as steady state, which assumed that the volume of ground-water flow into the valley-fill aquifer equals the volume of ground-water flow out of the valley-fill aquifer. The sequence of calibration used in the steady-state simulation was to adjust the value of vertical and horizontal hydraulic conductivity. Thickness of the valley fill, specified fluxes along the edge of the model, and recharge of precipitation were assumed correct and not adjusted. Ground-water levels in the model were calibrated to the average annual water levels in 14 wells and several flux rates from the water budget. The horizontal hydraulic conductivity values used in this model for layer one ranged from 40 feet per day (12 m/day) in the downstream section to 250 feet per day (76 m/day) in the upstream section. The values of hydraulic conductivity used for layer two ranged from 1.0 to 30 feet per day (0.3-9 m/day), along the valley floor and in highly fractured zones, respectively.

Downs and Kovaks (2000) considered the model to be calibrated based on the near matching of the water levels. The best root-mean-squared (RMS) error achieved in the calibration was 60 feet (18 m), which was predictable because: (1) important hydraulic properties of the fractured-rock aquifer are unknown, and locations of fracture regions and degree of fracturing determined from aquifer tests are unavailable; (2) water levels used in the calibration were from measurements taken over a time range, and thus fluctuate; (3) the hydraulic properties used were limited to a small area within the model boundary, any missing hydrogeologic values outside this area were inferred from the general physical description of Moab-Spanish Valley; and (4) the RMS error is sensitive to any significant point-error values. Any or all of these errors may exist because of limited site-specific data.

Our Modification of the Model

The hydraulic characteristics of the valley-fill aquifer control the amount of water moving through the aquifer, water in storage, and water levels in the valley. We modified the modeled hydraulic conductivity and specific conductance in the valley-fill aquifer layer to incorporate additional data we collected (appendix J). New information on hydraulic conductivity of the valley fill was obtained from a single-well test (appendix J) and specific-capacity data reported on drillers' logs from the valley. Hydraulic conductivities were determined by dividing the estimated transmissivities, from the single-well and specific-capacity tests, by the length of the screened interval of the wells. Initial estimates of hydraulic conductivities from these sources ranged from 4.9 to 116 feet per day (1-35 m/day). In Downs and Kovacs' (2000) model, the water table in the valley fill drops below layer one northwest of Kens Lake. Kens Lake is near the head of Moab-Spanish Valley and is a source of seepage to the valley-fill aquifer. We modified the hydraulic conductivities and specific conductance near Kens Lake to prevent layer one from dewatering there. We did not modify the model grid, boundary conditions, or recharge. The initial value of transmissivity used for layer two and the vertical leakance used to represent the connection of layers one and two were maintained because no new information was obtained from any of the tests we conducted or evaluated.

Calibration of the model resulted in a reasonable representation of the ground-water system in Moab-Spanish Valley. A simulated potentiometric surface for the rock aquifer is similar to the rock aquifer potentiometric surface produced by Downs and Kovacs (2000), and the water levels produced by the simulation are reasonable based on existing water levels in the valley-fill aquifer (figure 12).

All water budget components are within 5 percent of the water budget used in the Downs and Kovacs' (2000) model (table 5). The adjusted model is assumed to represent present conditions as accurately as available data permit. Initial estimates were made for each hydrologic characteristic from the field data, and the model was adjusted to improve estimates in areas of uncertainty. Water levels computed by the model after the adjustment do not agree exactly with observed water levels. Although the predictive capability of the model cannot be quantified, the model results should indicate the correct order of magnitude of flow. The final distribution of hydraulic conductivity values for layer two ranged from 50 to 200 feet per day (15-61 m/day) (table 6).

Results

The objectives of the modeling were to simulate the ground-water flow in the valley and use this to estimate the quantity of water flowing through the valley-fill sediments. The simulation improved our understanding of the aquifer system and provided the volumetric flow budget needed for the septic-tank mass-balance calculations. We used model-calculated cell-by-cell flows in this study to identify areas with similar flows of water in layer one; we assume mixing/dilution of septic-tank effluent will occur within ground water modeled by this layer. Based on the spatial distribution of the cell-by-cell flow terms calculated by MODFLOW, we delineated three regions in Moab-Spanish Valley

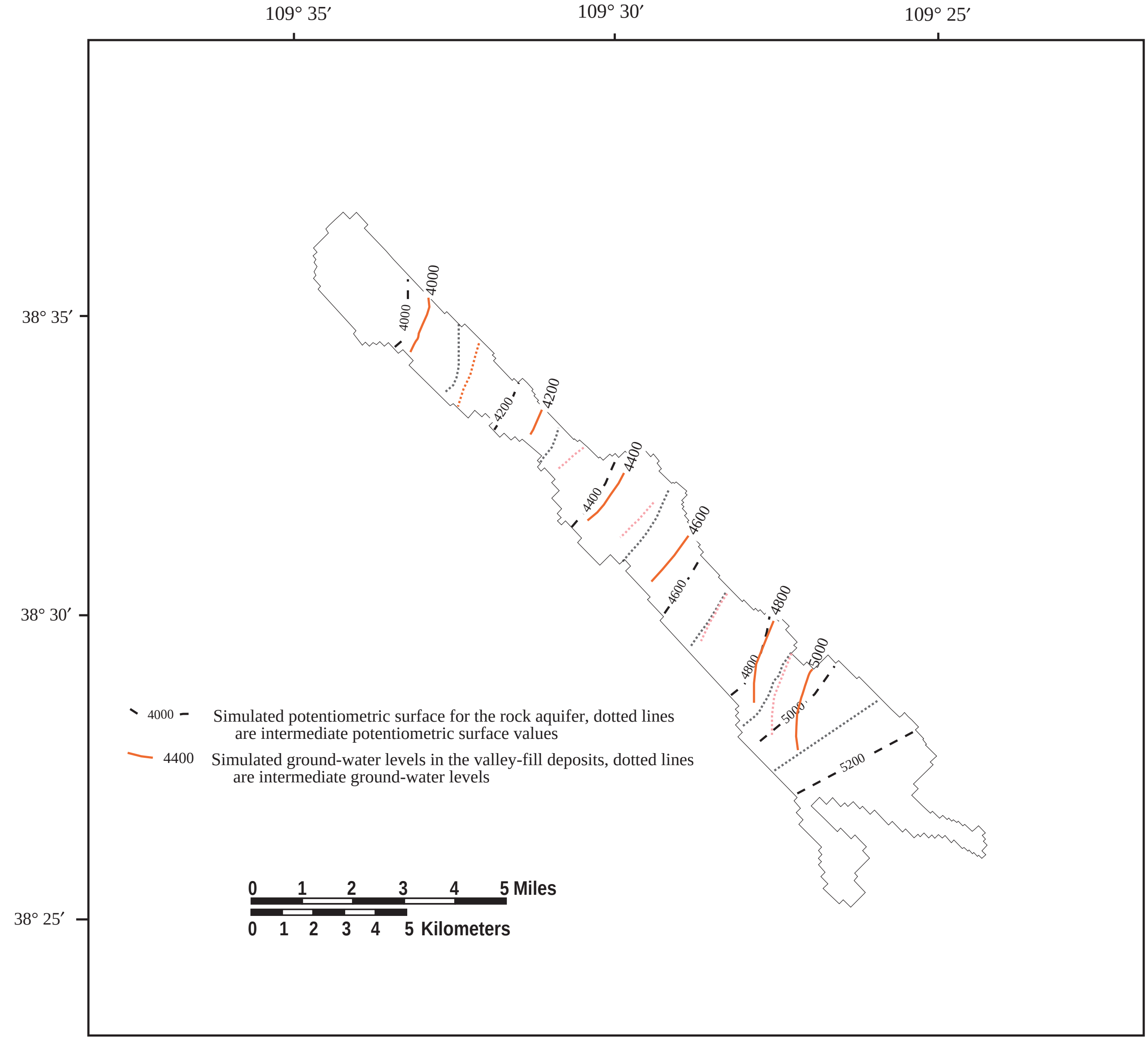

Figure 12. *Water-table contours shown on the valley-fill aquifer layer, Moab-Spanish Valley, Grand and San Juan Counties, Utah. North is toward the top of the page. Contour interval is 200 feet.*

Table 5. *Simulated steady-state ground-water budget for the aquifer system in Moab-Spanish Valley, Grand and San Juan Counties, Utah.*

Component	**Estimated water budget (acre-feet per year)**	**Steady-state calibration water budget (acre-feet per year)**
Recharge		
Subsurface inflow from the La Sal Mountains	13,300	12,765
Infiltration of precipitation for layer one	730	728
Seepage from Kens Lake	3300	3157
Total recharge	17,330	16,650
Discharge		
Seepage to streams (Mill and Pack Creeks)	1140	1099
Withdrawal from wells and springs	6400	6398
Seepage to Colorado River	9530	9153
Total discharge	17,330	16,650

Table 6. *Final hydraulic parameter values used in the Moab-Spanish Valley ground-water flow model, Grand and San Juan Counties, Utah.*

Locations	**Hydraulic conductivity (feet per day)**	**Transmissivity (square feet per day)**	**Vertical leakance (feet per day per feet)**
Model layer one			
Active cells in the lower valley	50 - 70	—	—
Central area of active cells in the valley	90 - 150	—	—
Higher interior active cells in the main valley	200	—	—
Between layers one and two			
All active cells	—	—	0.00028 - 0.0236
Model layer two			
All active cells	1 - 20	400 - 8000	—

on the basis of distinctive flows in layer one (plate 12). We then used the MODFLOW flow budget for each region to determine the available volumetric flows in the saturated valley-fill deposits for each region. These regions, which we designated as domains, vary in area from 1396 to 6749 acres (2.18-10.5 mi^2; 5.6-27.3 km^2) and have volumetric flows from 1.08 to 2.82 cubic feet per second (0.03-0.08 m^3/s). We use the volumetric flows in the mass-balance calculations as the ground-water flow available for mixing.

Modeling Limitations

Simplifying assumptions are required to construct a numerical model of a natural hydrogeologic system. Some of these assumptions limit the scope of application of the model and the hydrologic questions that can reasonably be addressed, and may influence the model results. The numerical model is a simplified and idealized approximation of the actual ground-water flow system. 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 were applied, such as adding a large well, to the system. The model, however, can simulate steady-state conditions and be used to evaluate various ground-water conditions.

Septic-Tank System/Water-Quality Degradation Analyses

Introduction

We calculated projected domain-specific nitrate concentrations in three ground-water flow domains (table 7) by 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 242 gallons per day (916 L/day) contributed by each septic-tank system, with an estimated nitrogen loading of 54.4 mg per liter of septic-tank effluent. The mass-balance approach predicts the impact of nitrate from use of septic-tank systems over a defined area.

We calculated one graph for each area based on a range of parameters that affect the amount of ground water available for dilution. We obtained the number of septic-tank systems permitted (post-1980 records) in each area from the Southeast Utah Health Department (Jim Adamson, written communication, 2002; Lance Christie, verbal communication, 2003). We supplemented these data by identifying potential sites of septic systems from buildings and house dwellings plotted from aerial photographs (Utah State Trust Lands, written communication, 2003); the sites we identified were verified by local county GIS specialist, Dave Vaughn (2003), based on his knowledge of the study area. Tables 7 and 8 list the number of septic-tank systems estimated for each domain. The exact number of septic-tank systems in use and not in use is unknown; we estimate that about 1600 septic-tank systems have been permitted in Moab-Spanish Valley, of these, fewer exist and/or are being utilized in Grand County than in San Juan County; 1314 septic tanks were in the area to which sanitary sewer services were extended through the Spanish Valley Water and Sewer Improvement District (SVW&SID) in 1979–81, and 162 were in the area to which sanitary sewer services were extended by SVW&SID in 1995–97 (Lance Christie, Grand County resident, written communication, June, 2003).

For this analysis, we used 210 septic tanks for all the domains, and ranges from a low of 59 (domain 2) to a high of 77 (domain 3) (tables 7 and 8). Background nitrate concentrations for each domain range from 0.78 mg/L (domain 3) to 3.5 mg/L (domain 2). For domains 1 and 2, we allow 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 [Hansen, Allen and Luce, Inc., 1994; Lowe and Wallace, 1997]). For domain 3, based on consultation with local government officials, we used a total degradation value of 3 mg/L, which is 2.2 mg/L more than the current background level of 0.78 mg/L (the domain having the greatest area acreage), to calculate recommended septic-system density/lot size.

Results

Domain 1: Figure 13a shows a plot of projected nitrate concentration versus septic-tank density and number of septic-tank systems in domain 1 in the southeastern part of central Moab-Spanish Valley (plate 12). Background nitrate concentration for domain 1 is 2.68 mg/L. There are 74 septic systems estimated to be in domain 1 (Lance Christie, Grand County resident, personal communication, 2003). Domain 1 has an area of approximately 1396 acres (565 hm^2), so the existing average septic-system density is 19 acres per system (7.7 hm^2/system). Based on our analyses (table 7), estimated ground-water flow available for mixing in domain 1 is 1.08 cubic feet per second (0.03 m^3/s). For domain 1 to maintain an overall nitrate concentration of 3.68 mg/L (which allows 1 mg/L of degradation), the total number of homes using septic-tank soil-absorption systems should not exceed 132 based on the estimated nitrogen load of 54.4 mg/L per septic-tank system (figure 13a, table 8). This corresponds to a total increase of approximately 55 added septic systems and an average septic-system density of about 10 acres per system (4 hm^2/system) in domain 1 (table 8).

Table 7. *Parameters used to perform a mass-balance analysis for different ground-water flow domains in Moab-Spanish Valley, Grand and San Juan Counties, Utah.*

Domain	Area (acres)	Flow* (cubic feet per second)	Average nitrate concentration (background) (mg/L)	Number of wells sampled	Current number of septic tanks permitted+
1	1396	1.08	2.68	16	74
2	3397	2.06	3.50	12	59
3	6749	2.82	0.78	18	77

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

+septic systems were estimated by the Southeast Utah Health Department (Jim Adamson, 2002, written communication; Lance Christie 2003, verbal communication).

Table 8. *Results of the mass-balance analysis using the best-estimate nitrogen loading of 54 mg N/L* for different ground-water flow domains in Moab-Spanish Valley, Grand and San Juan Counties, Utah.*

Domain	Area (acres)	Flow amount (cfs)	Current density (acres/system)	Number of septic tanks permitted	Projected number of total septic tanks	Calculated lot-size recommendation @1 mg/L (acres)	Lot-size recommendation (acres)
1	1396	1.08	19	74	132	10.5	10
2	3397	2.06	58	59	171	20/15**	20
3	6749	2.82	88	77	222	30/16**	20

*Best-estimate calculation is based on a nitrogen load of 17 g N per capita per day (from Kaplan, 1988) for a 3.46-person household and 242 gallons per capita as the amount of water generated per household based on the 2001 Utah State Water Plan (Utah Division of Water Resources, 2001a).

**Second number after/ corresponds to the calculated lot-size recommendation based on an allowable degradation of overall nitrate concentration to be 5 and 3 mg/L, respectively, for domains 2 and 3.

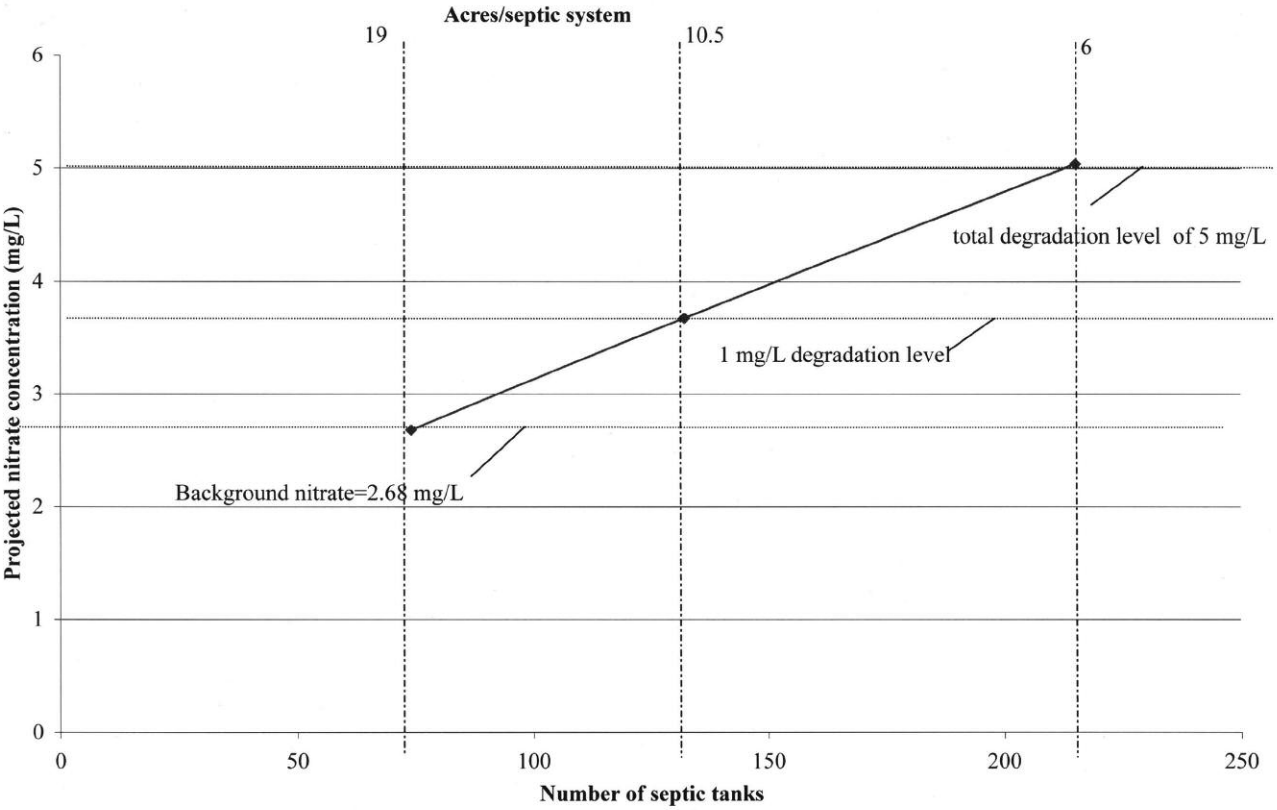

Figure 13a. *Projected septic-tank density versus nitrate concentration for domain 1 in Moab-Spanish Valley, Grand and San Juan Counties, Utah, based on 74 existing septic tanks (see table 10).*

Domain 2: Figure 13b shows a plot of projected nitrate concentration versus septic-tank density and number of septic-tank systems in domain 2 in the central part of most of Moab-Spanish Valley (plate 12). Background nitrate concentration for domain 2 is 3.5 mg/L. There are 59 septic systems estimated to be located in domain 2 (Lance Christie, Grand County resident, verbal communication, 2003). Domain 2 has an area of approximately 3397 acres (1,375 hm^2), so the average septic-system density is 58 acres per system (22 hm^2/system). Based on our analyses (table 7), estimated ground-water flow available for mixing in domain 2 is 2.06 cubic feet per second (0.06 m^3/s). For domain 2 to maintain an overall nitrate concentration of 4.5 mg/L (which allows 1 mg/L of degradation), the total number of homes using septic-tank soil-absorption systems should not exceed 171 based on the estimated nitrogen load of 54.4 mg/L per septic-tank system (figure 13b, table 8). This corresponds to a total increase of approximately 112 added septic systems and an average septic-system density of about 20 acres per system (8 hm^2/system) in domain 2 (table 8).

Domain 3: Figure 13c shows a plot of projected nitrate concentration versus septic-tank density and number of septic-tank systems in domain 3 in the southeastern Moab-Spanish Valley, and along the valley margins surrounding domains 1 and 2 (plate 12). Background nitrate concentration for domain 3, the lowest, is 0.78 mg/L. There are 77 septic systems estimated to be located in domain 3 (Lance Christie, Grand County resident, verbal communication, 2003; Jim Adamson, Southeast Utah Health Department, verbal communication, 2003). Domain 3 has an area of approximately 6749 acres (2,731 hm^2), so the average septic-tank system density is 88 acres per system (36 hm^2/system). Based on our analyses (table 7), estimated ground-water flow available for mixing in domain 3 is 2.82 cubic feet per second (0.08 m^3/s). For domain 3 to maintain an overall nitrate concentration of 1.78 mg/L (which allows 1 mg/L of degradation), the total number of homes using septic-tank soil-absorption systems should not exceed 222 based on the estimated nitrogen load of 54.4 mg/L per septic-tank system (figure 13c, table 8). This corresponds to a total increase of approximately 145 septic systems and an average septic-system density of about 30 acres per system (12 hm^2/system) in domain 3 (table 8). If the allowable degradation level for nitrate concentration is 3 mg/L (a nitrate as nitrogen value similar to the 1 mg/L degradation level for the other two domains, but a lower overall increase), the total number of homes using septic-tank systems can be 410 with a corresponding increase in new septic systems of 333, corresponding to a septic-tank density of about 16 acres per system (6.4 hm^2/system) (table 8).

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. The graphs of projected nitrate concentration versus number of septic-tank systems in each area show recommended septic-tank density for each domain based on the parameters described above. For land-use planning purposes, we believe two categories of recommended

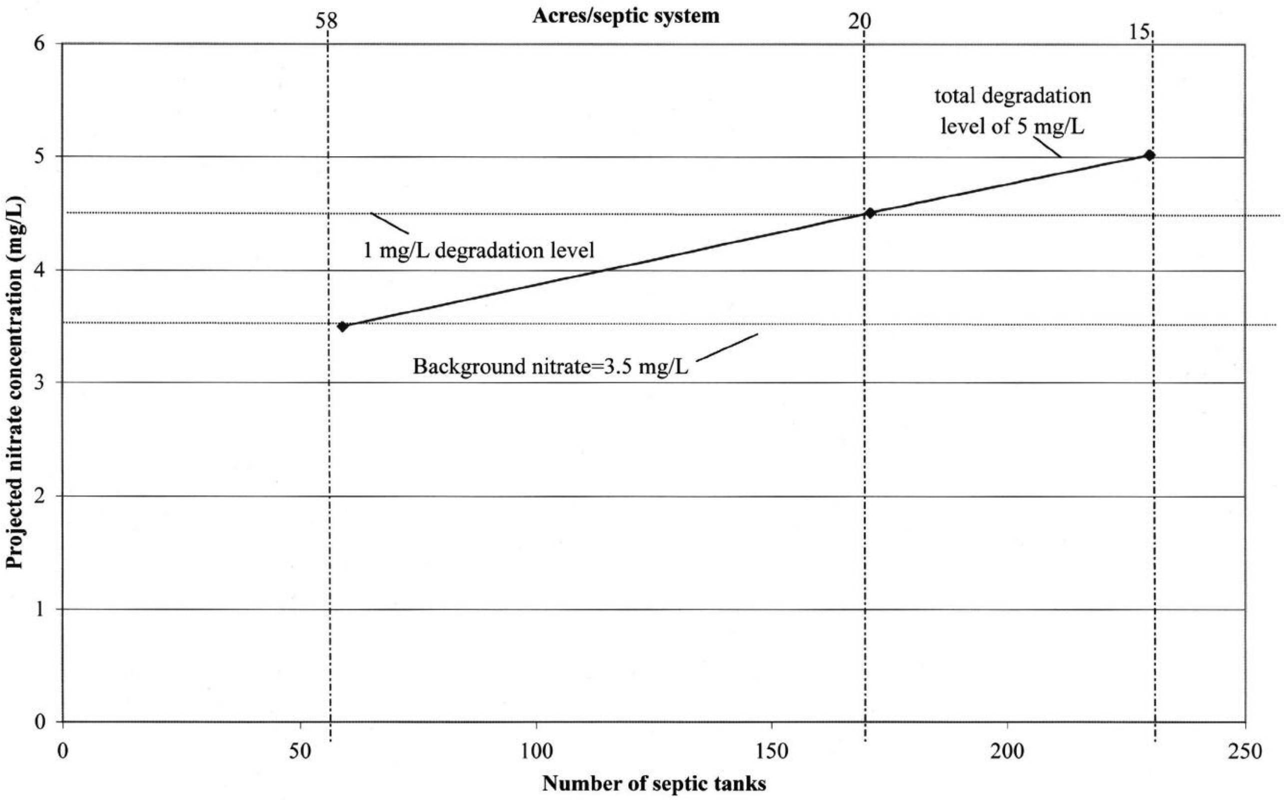

Figure 13b. *Projected septic-tank density versus nitrate concentration for domain 2 in Moab-Spanish Valley, Grand and San Juan Counties, Utah, based on 59 existing septic tanks (see table 10).*

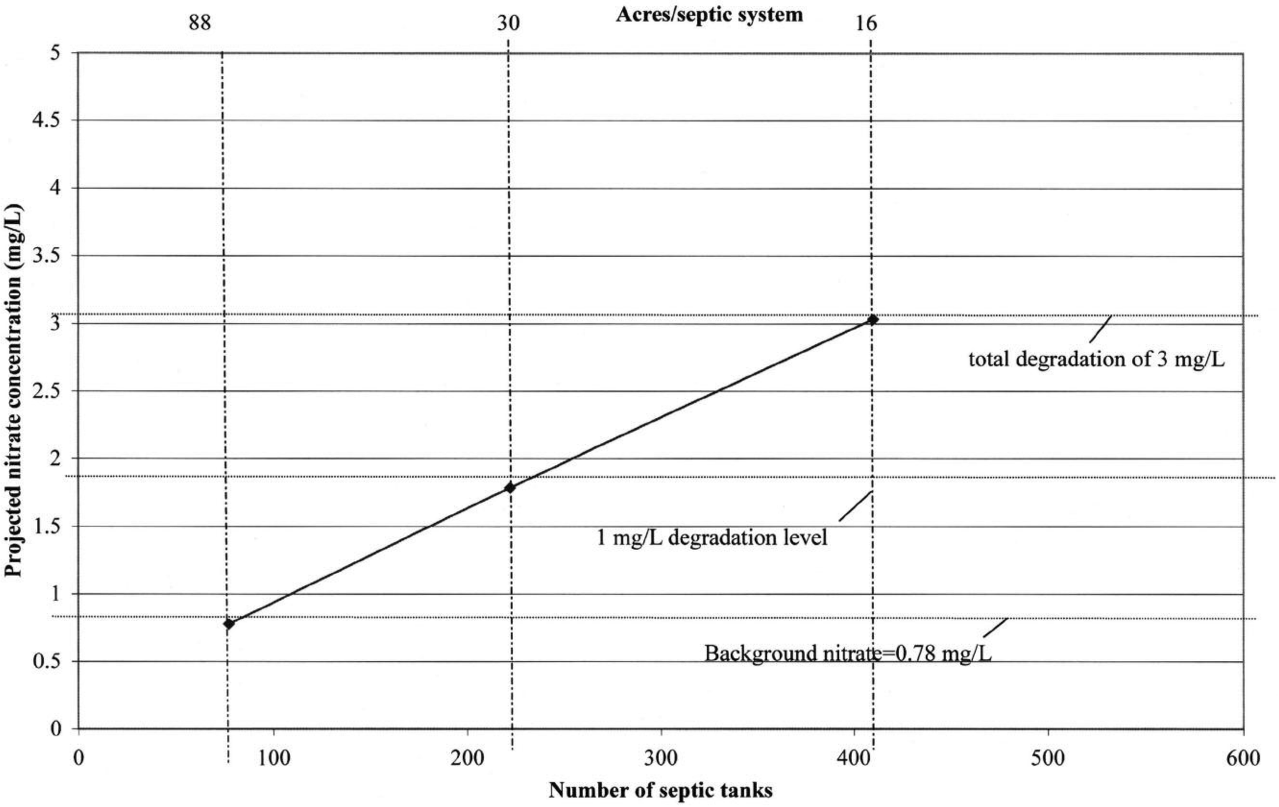

Figure 13c. *Projected septic-tank density versus nitrate concentration for domain 3 in Moab-Spanish Valley, Grand and San Juan Counties, Utah, based on 77 existing septic tanks (see table 10).*

maximum septic-tank system densities are appropriate for development using septic-tank soil-absorption systems for wastewater disposal: 10 and 20 acres per system (4 and 8 hm^2/system) (table 8; plate 12). Based only on our septic-tank density/water-quality degradation analysis, due to the greater amount of ground-water available for mixing per acre in the central areas of Moab-Spanish Valley, a greater number of septic systems can exist compared to the outer margins of the valley and southeastern Moab-Spanish Valley; this is due to Mill and Pack Creeks being a source of recharge to the valley-fill aquifer, and the greater average thickness of the valley-fill deposits in northwestern Moab-Spanish Valley (and in the central parts of the valley compared to valley-margin areas). 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 impact on ground-water quality than septic-tank systems.

SUMMARY AND CONCLUSIONS

Ground water is the principal source of drinking water in Moab-Spanish Valley. Most public water supply is from the Glen Canyon aquifer, which is broken into two structural compartments by the Moab fault beneath Moab-Spanish Valley. The Glen Canyon Group ranges in thickness from about 330 feet (100 m) south and southeast of Moab to about 1300 feet (400 m) beneath southeastern Moab-Spanish Valley. The Glen Canyon Group is absent in the subsurface near Moab in northwestern Moab-Spanish Valley. Most ground-water flow in the Glen Canyon aquifer is through joints. Based on our analysis of outcrop data, most joints are steeply dipping (greater than 65°) with a primary joint set striking to the northwest and a secondary joint set striking to the northeast. Based on our aerial-photograph analysis of lineaments, which correspond to laterally continuous joint zones, we define six lineament domains based on orientation, length, geometry, and interrelation between lineaments. Most lineaments trend to the northwest, and lineament trends are strongly unimodal and less variable than joints measured at outcrops. Joint and lineament orientations and densities indicate increased regional- and well-scale permeability parallel to the valley axis due to joints and joint zones. Valley-margin normal faults, where present, may reduce permeability perpendicular to the valley axis.

Once the most important source of culinary water in Moab-Spanish Valley, the valley-fill aquifer is primarily used for domestic and agricultural purposes. The valley fill of Moab-Spanish Valley consists mainly of stream, alluvial-fan, mass-movement, and eolian deposits that are up to 400+ feet (120 m) thick near the Colorado River northwest of Moab. The valley fill thins to about 100 feet (30 m) over a concealed bedrock high southeast of Moab and then thickens to more than 300 feet (90 m) beneath southeastern Spanish Valley. The valley fill generally lacks extensive fine-grained layers and the valley floor and surrounding bedrock are classified as primary recharge areas.

Ground-water quality classification is a relatively new tool that can be used in Utah to manage potential ground-water contamination sources and protect the quality of ground-water resources. The results of the proposed ground-water quality classification for Moab-Spanish Valley indicate that the valley-fill aquifer contains mostly high-quality ground-water resources that warrant protection. Thirteen percent of ground-water wells representing the aquifer in the area is classified as Class IA, and 87 percent is classified as Class II, based on chemical analyses of water from 72 wells and one surface-water source sampled between 1968 and 2004 (TDS range of 140 to 1818 mg/L). Additionally, ground-water quality in the Glen Canyon aquifer along the eastern margin of Moab-Spanish Valley has TDS concentrations typically below 500 mg/L and has been designated a Sole Source Aquifer by the U.S. Environmental Protection Agency; this area is classified as Class IB.

Septic-tank soil-absorption systems are used to dispose of domestic wastewater, primarily in the San Juan County portion of Moab-Spanish Valley. 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 in ground water, dilution is the principal mechanism for lowering concentrations of these constituents. We used nitrate in septic-tank effluent as an indicator for evaluating the dilution of constituents in wastewater that reach ground-water 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 Moab-Spanish Valley, a source of drinking water, indicates that two categories of recommended maximum septic-tank system densities are appropriate for development using septic-tank soil-absorption systems for wastewater disposal: 10 and 20 acres per system (4 and 8 hm^2/system). These recommended minimum lot sizes are based on hydrogeologic parameters incorporated in the ground-water flow model and geographically divided into three ground-water flow domains on the basis of flow-volume similarities.

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APPENDICES

APPENDIX A

NUMBERING SYSTEM FOR WELLS IN UTAH

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 A.1). 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-26-22)22cdb-1 would be the first well in the northwestern quarter of the southeastern quarter of the southwestern quarter of section 22, Township 26 South, Range 22 East (NW¼SE¼SE¼ section 22, T. 26 S., R. 22 E.).

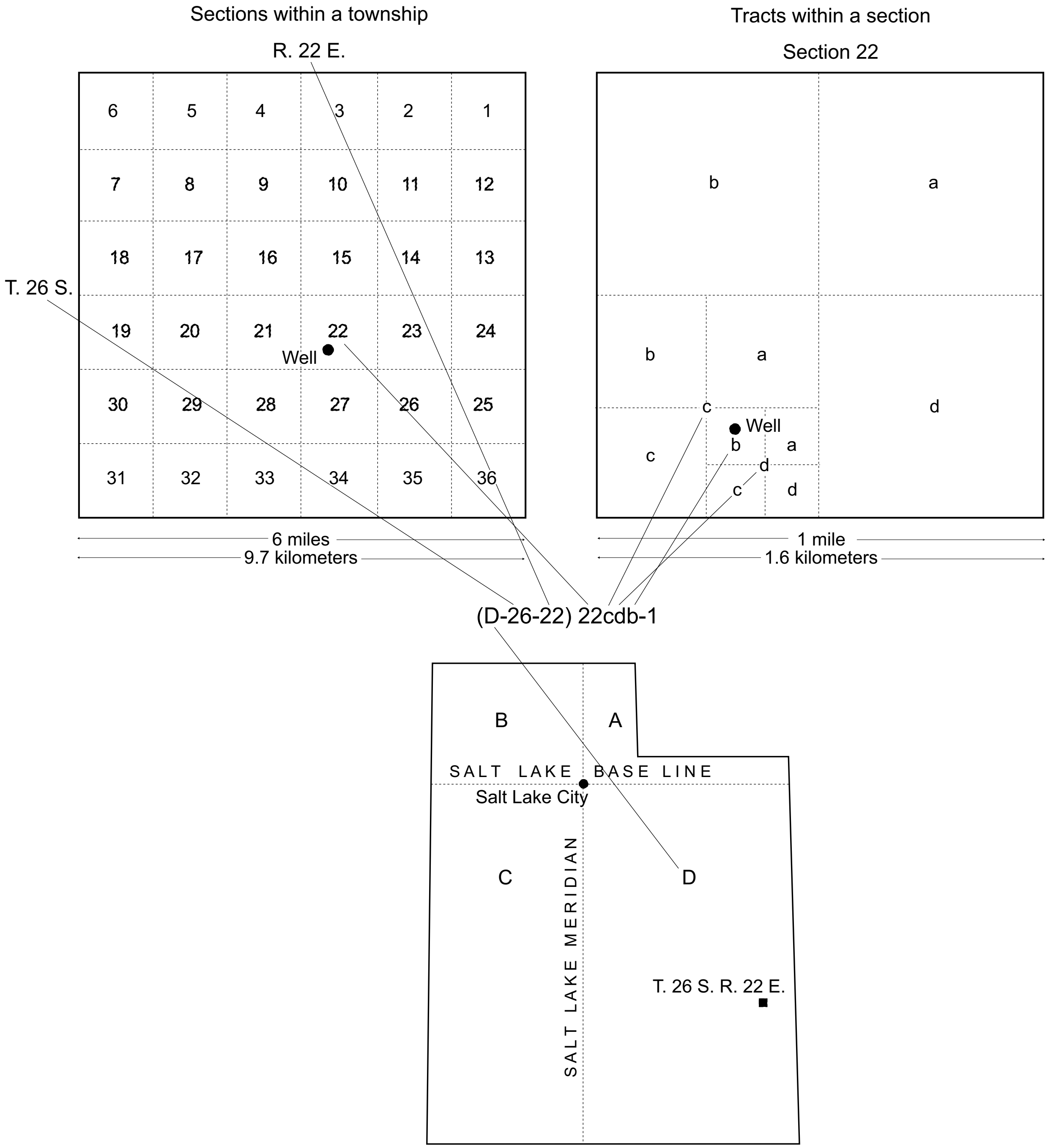


Figure A-1. *Numbering system for wells in Utah (see text for additional explanation).*

APPENDIX B

WATER-QUALITY DATA

Table B.1. Ground-water quality data for Spanish-Moab Valley. See table B.2 for U.S. Environmental Protection Agency analytical methods and ground-water quality (health) standards.

Station ID	Station Name	Sample date	2,2-Dichloro-propionic acid	2,4-Dichloro-phenoxy-acetic acid (2,4-D)	3-Hydroxy-carbo-furan	4,6-Dinitro-2-sec-butyl-phenol (DNBP)	Alachlor	Aldicarb
			ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
1	NATURE CONSERVANCY (D-25-21) 35CCD-1	12/5/1995	-	-	-	-	-	-
2	BULLOCK BRENT (D-26-21) 1BAC-2	12/05/1995	-	-	-	-	-	-
3	VAUGHAN DARREN (D-26-21) 1DAD-1	12/4/1995	U	U	U	U	U	U
4	KNUTSON OLIVER (D-26-22) 7DDB-3	12/6/1995	-	-	-	-	-	-
7	MERRETT SHANE (D-26-22) 16CCA-1	12/6/1995	-	-	-	-	-	-
8	MUSCLOW RUDY (D-26-22) 16DDD-1	12/5/1995	U	U	U	U	U	U
9	WAREHAM GERALS (D-26-22) 17ACB-2	12/6/1995	-	-	-	-	-	-
10	SMITH CYNTHIA (D-26-22) 17ADD-1	12/5/1995	-	-	-	-	-	-
11	JOHNSON JOHN (D-26-22) 17BAD-1	12/6/1995	-	-	-	-	-	-
14	COOPER THOMAS (D-26-22) 22ACB-2	12/4/1995	U	U	U	U	U	U
15	TANGREEN LORRAINE (D-26-22) 22CBA-1	12/6/1995	-	-	-	-	-	-
17	BEEMAN HORACE (D-26-22) 22DCC-1	12/6/1995	-	-	-	-	-	-
18	GEORGE WHITE #3 (D-26-22) 22DDC-1	12/5/1995	U	U	U	U	U	U
20	CASTELLANOS ANDREA (D-26-22) 26BDA-1	12/6/1995	-	-	-	-	-	-
21	SHERMAN VALARIE (D-26-22) 26CAD-1	12/6/1995	-	-	-	-	-	-
23	ESPOSITO MARK (D-26-22) 27AAD-1	12/6/1995	-	-	-	-	-	-
24	BATWINAS BAN (D-26-22) 27ADC-1	12/4/1995	U	U	U	U	U	U
25	DULZELESKI CORY (D-26-22) 35BAC-1	12/4/1995	U	U	U	U	-	U
26	BATHEMASS STEVE (D-26-22) 35BDD-4	12/6/1995	-	-	-	-	-	-
27	SNOW WILLIE (D-26-22) 35DAA-1	12/6/1995	-	-	-	-	-	-
28	(D-25-21) 26dcc-1	3/10/1987	-	-	-	-	-	-
29	(D-26-22) 35ada-1	7/8/1969	-	-	-	-	-	-
30	(D-26-22) 35bdda-2	9/5/1968	-	-	-	-	-	-
5	(D-25-21) 35DDC-1	9/1/1989	-	-	-	-	-	-
32	(D-26-22) 7bad-1	9/5/1968	-	-	-	-	-	-
33	(D-26-22) 17dbc-1	7/9/1968	-	-	-	-	-	-
34	(D-26-22) 21baa-2	7/8/1969	-	-	-	-	-	-
35	(D-26-22) 22dcd-1	7/9/1968	-	-	-	-	-	-
36	(D-26-22) 23ccb-1	11/15/1993	-	-	-	-	-	-
37	(D-26-22) 35ada-1	7/8/1969	-	-	-	-	-	-
38	(D-26-22) 35bdd-2	9/5/1968	-	-	-	-	-	-

Table B.1. *(continued)*

Station ID	Aldicarb sulfone	Aldicarb sulfoxide	Aldrin	Alkalinity, Carbonate as $CaCO_3$ (total alk)	alpha-BHC	Aluminum	Arsenic	Atrazine	Barium	beta-BHC	beta-Endosulfan	Bicarbonate	Boron
	ug/L	ug/L	ug/L	mg/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	mg/L	ug/L
1	-	-	-	321	15	U	U	-	39	-	-	392	-
2	-	-	-	295	-	U	U	-	36	-	-	360	-
3	U	U	U	272	U	U	U	U	21	U	U	332	-
4	-	-	-	134	28.8	U	U	-	17	14	-	164	-
7	-	-	-	133	-	U	U	-	21	-	-	162	-
8	U	U	U	216	9.4	U	U	U	15	U	U	264	-
9	-	-	-	138	-	U	U	-	19	-	-	169	-
10	-	-	-	152	-	U	U	-	18	-	-	185	-
11	-	-	-	128	-	U	U	-	16	-	-	156	-
14	U	U	U	150	U	U	U	U	49	U	U	182	-
15	-	-	-	169	-	U	U	-	18	-	-	206	-
17	-	-	-	154	-	U	U	-	15	-	-	188	-
18	U	U	U	195	U	U	U	U	19	U	U	238	-
20	-	-	-	145	-	U	U	-	22	-	-	177	-
21	-	-	-	231	-	U	U	-	16	-	-	282	-
23	-	-	-	179	-	U	U	-	19	-	-	218	-
24	U	U	U	145	13.3	U	U	U	18	U	U	176	-
25	U	U	-	236	10	U	U	-	25	-	-	288	-
26	-	-	-	272	6.1	U	U	-	17	-	-	332	-
27	-	-	-	261	-	U	U	-	18	-	-	318	-
28	-	-	-	231	-	-	-	-	-	-	-	-	40
29	-	-	-	199	-	-	-	-	-	-	-	240	110
30	-	-	-	217	-	-	10	-	-	-	-	260	60
5	-	-	-	214	-	-	-	-	-	-	-	-	50
32	-	-	-	256	-	-	0	-	-	-	-	310	70
33	-	-	-	138	-	-	-	-	-	-	-	170	0
34	-	-	-	162	-	-	-	-	-	-	-	200	30
35	-	-	-	179	-	-	-	-	-	-	-	220	0
36	-	-	-	-	-	-	<5T	-	40	-	-	-	-
37	-	-	-	199	-	-	-	-	-	-	-	240	110
38	-	-	-	217	-	-	10	-	-	-	-	260	60

Table B.1. *(continued)*

Station ID	Bromacil	Butachlor	Cadmium	Calcium	Carbo-furan	Carbon dioxide	Carbonate ion	Carbonate solids	Chlordane, alpha use cis-Chlordane	Chloride	Chloro-pyrifos	Chromium
	ug/L	ug/L	ug/L	mg/L	ug/L	mg/L	mg/L	mg/L	ug/L	mg/L	ug/L	ug/L
1	-	-	U	110	-	13	0	-	-	12.5	-	U
2	-	-	U	130	-	10	0	-	-	52	-	U
3	U	U	U	110	U	11	0	-	U	15	U	U
4	-	-	U	130	-	4	0	-	-	20	-	U
7	-	-	U	94	-	4	0	-	-	51	-	U
8	U	U	U	250	U	12	0	-	U	55	U	U
9	-	-	U	100	-	4	0	-	-	177.5	-	U
10	-	-	U	200	-	6	0	-	-	70	-	U
11	-	-	U	180	-	5	0	-	-	19	-	U
14	U	U	U	68	U	4	0	-	U	13	U	U
15	-	-	U	180	-	9	0	-	-	52	-	U
17	-	-	U	110	-	4	0	-	-	15.5	-	U
18	U	U	U	120	U	7	0	-	U	17.5	U	U
20	-	-	U	86	-	4	0	-	-	30	-	U
21	-	-	U	140	-	14	0	-	-	10.5	-	U
23	-	-	U	98	-	5	0	-	-	28	-	U
24	U	U	1	120	U	4	0	-	U	16.5	U	U
25	-	-	1	110	U	10	0	-	-	15	-	U
26	-	-	U	120	-	12	0	-	-	6.5	-	U
27	-	-	U	140	-	10	0	-	-	8	-	U
28	-	-	-	82	-	-	-	-	-	16	-	-
29	-	-	-	180	-	-	0	-	-	30	-	-
30	-	-	-	140	-	-	0	-	-	11	-	-
5	-	-	-	93	-	-	-	-	-	12	-	-
32	-	-	-	110	-	-	0	-	-	20	-	-
33	-	-	-	98	-	-	0	-	-	17	-	-
34	-	-	-	120	-	-	0	-	-	30	-	-
35	-	-	-	110	-	-	0	-	-	16	-	-
36	-	-	<1T	-	-	-	-	-	-	-	-	<5T
37	-	-	-	180	-	-	0	-	-	30	-	-
38	-	-	-	140	-	-	0	-	-	11	-	-

Table B.1. *(continued)*

Station ID	Copper	Cyanazine	Dacthal	DDD	DDE	DDT	delta-BHC	Diazinon	Dicamba	Dichlor-prop	Dieldrin	Dipropyl-thiocarba-mic acid S-ethyl ester (EPTC)	Solids, residue @180°C, dissolved
	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	mg/L
1	U	-	-	-	-	-	-	-	-	-	-	-	606
2	U	-	-	-	-	-	-	-	-	-	-	-	778
3	U	U	U	U	U	U	U	U	U	U	U	U	712
4	U	-	-	-	-	-	-	-	-	-	-	-	952
7	U	-	-	-	-	-	-	-	-	-	-	-	704
8	12	U	U	U	U	U	U	U	U	U	U	U	1818
9	U	-	-	-	-	-	-	-	-	-	-	-	914
10	15	-	-	-	-	-	-	-	-	-	-	-	1556
11	U	-	-	-	-	-	-	-	-	-	-	-	1018
14	U	U	U	U	U	U	U	U	U	U	U	U	404
15	U	-	-	-	-	-	-	-	-	-	-	-	1178
17	U	-	-	-	-	-	-	-	-	-	-	-	680
18	U	U	U	U	U	U	U	U	U	U	U	U	708
20	U	-	-	-	-	-	-	-	-	-	-	-	564
21	U	-	-	-	-	-	-	-	-	-	-	-	728
23	U	-	-	-	-	-	-	-	-	-	-	-	656
24	U	U	U	U	U	U	U	U	U	U	U	U	732
25	U	-	-	-	-	-	-	-	U	U	-	-	576
26	12	-	-	-	-	-	-	-	-	-	-	-	622
27	U	-	-	-	-	-	-	-	-	-	-	-	690
28	-	-	-	-	-	-	-	-	-	-	-	-	382
29	-	-	-	-	-	-	-	-	-	-	-	-	962
30	-	-	-	-	-	-	-	-	-	-	-	-	739
5	-	-	-	-	-	-	-	-	-	-	-	-	382
32	-	-	-	-	-	-	-	-	-	-	-	-	749
33	-	-	-	-	-	-	-	-	-	-	-	-	701
34	-	-	-	-	-	-	-	-	-	-	-	-	772
35	-	-	-	-	-	-	-	-	-	-	-	-	664
36	<20T	-	-	-	-	-	-	-	-	-	-	-	268
37	-	-	-	-	-	-	-	-	-	-	-	-	962
38	-	-	-	-	-	-	-	-	-	-	-	-	739

Table B.1. *(continued)*

Station ID	Disulfoton	Dyfonate	Endo-sulfan	Endo-sulfan Sulfate	Endrin	Endrin Aldehyde	Endrin ketone	Fluoride, dissolved	gamma-BHC (Lindane)	gamma-Chlordane	Hardness, Ca,Mg (total)	Heptachlor
	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	mg/L	ug/L	ug/L	mg/L	ug/L
1		-	-	-	-	-	-	-	-	-	430.8	-
2	-	-	-	-	-	-	-	-	-	-	591.8	-
3	U	U	U	U	U	U	U	-	U	U	476.1	U
4	-	-	-	-	-	-	-	-	-	-	554.8	-
7	-	-	-	-	-	-	-	-	-	-	374.4	-
8	U	U	U	U	U	U	U	-	U	U	969.4	U
9	-	-	-	-	-	-	-	-	-	-	422.3	-
10	-	-	-	-	-	-	-	-	-	-	791.1	-
11	-	-	-	-	-	-	-	-	-	-	626	-
14	U	U	U	U	U	U	U	-	U	U	284.9	U
15	-	-	-	-	-	-	-	-	-	-	675.4	-
17	-	-	-	-	-	-	-	-	-	-	397.9	-
18	U	U	U	U	U	U	U	-	U	U	431.1	U
20	-	-	-	-	-	-	-	-	-	-	333.9	-
21	-	-	-	-	-	-	-	-	-	-	460.4	-
23	-	-	-	-	-	-	-	-	-	-	384.4	-
24	U	U	U	U	U	U	U	-	U	U	422.8	U
25	-	-	-	-	-	-	-	-	-	-	373.2	-
26	-	-	-	-	-	-	-	-	-	-	402.3	-
27	-	-	-	-	-	-	-	-	-	-	464.5	-
28	-	-	-	-	-	-	-	0.20	-	-	290	-
29	-	-	-	-	-	-	-	0.50	-	-	610	-
30	-	-	-	-	-	-	-	0.90	-	-	470	-
5	-	-	-	-	-	-	-	0.5	-	-	370	-
32	-	-	-	-	-	-	-	0.8	-	-	110	-
33	-	-	-	-	-	-	-	0.6	-	-	450	-
34	-	-	-	-	-	-	-	0.5	-	-	490	-
35	-	-	-	-	-	-	-	0.5	-	-	420	-
36	-	-	-	-	-	-	-	-	-	-	-	-
37	-	-	-	-	-	-	-	0.5	-	-	610	-
38	-	-	-	-	-	-	-	-	-	-	470	-

Table B.1. *(continued)*

Station ID	Heptachlor epoxide	Hexa-chloro-benzene	Hexa-chloro cyclo-pentadiene	Hexazinone	Hydroxyl ion	Iron	Lead	Magnesium	Malathion	Manganese
	ug/L	ug/L	ug/L	ug/L	mg/L	ug/L	ug/L	mg/L	ug/L	ug/L
1	-	-	-	-	0	820	U	38	-	210
2	-	-	-	-	0	190	U	65	-	680
3	U	U	U	U	0	88	15	49	U	12
4	-	-	-	-	0	31	U	56	-	6.6
7	-	-	-	-	0	40	U	34	-	U
8	U	U	U	U	0	21	U	84	U	5.5
9	-	-	-	-	0	-	-	42	-	77
10	-	-	-	-	0	100	U	71	-	13
11	-	-	-	-	0	250	U	43	-	110
14	U	U	U	U	0	21	U	28	U	U
15	-	-	-	-	0	32	U	55	-	U
17	-	-	-	-	0	53	U	30	-	7.7
18	U	U	U	U	0	33	U	32	U	U
20	-	-	-	-	0	37	U	29	-	U
21	-	-	-	-	0	31	U	27	-	6.5
23	-	-	-	-	0	37	U	34	-	U
24	U	U	U	U	0	140	U	30	U	14
25	-	-	-	-	0	50	3	24	-	U
26	-	-	-	-	0	25	U	25	-	U
27	-	-	-	-	0	120	U	28	-	U
28	-	-	-	-	-	11	-	21	-	7.0
29	-	-	-	-	-	100	-	38	-	-
30	-	-	-	-	-	-	-	28	-	-
5	-	-	-	-	-	790	-	33	-	560
32	-	-	-	-	-	0	-	57	-	-
33	-	-	-	-	-	1300	-	51	-	-
34	-	-	-	-	-	150	-	45	-	-
35	-	-	-	-	-	20	-	38	-	-
36	-	-	-	-	-	-	<3T	16	-	-
37	-	-	-	-	-	100	-	38	-	-
38	-	-	-	-	-	-	-	28	-	-

Table B.1. *(continued)*

Station ID	Mercapto-dimethur	Mercury	Methomyl	Methoxy-chlor	Methyl-parathion	Metolachlor	Metribuzin	Molybdenum	Nitrate	Nitrogen, ammonia (NH3)	Nitrogen, Kjeldahl
	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L			mg/L	mg/L
1	-	U	-	-	-	-	-	-	-	U	0.21
2	-	U	-	-	-	-	-	-	-	U	0.441
3	U	U	U	U	U	U	U	-	-	0.052	0.35
4	-	U	-	-	-	-	-	-	-	U	0.173
7	-	U	-	-	-	-	-	-	-	U	0.202
8	U	U	U	U	U	U	U	-	-	U	0.2
9	-	U	-	-	-	-	-	-	-	U	U
10	-	U	-	-	-	-	-	-	-	U	0.26
11	-	U	-	-	-	-	-	-	-	U	0.15
14	U	U	U	U	U	U	U	-	-	U	0.33
15	-	U	-	-	-	-	-	-	-	U	0.24
17	-	U	-	-	-	-	-	-	-	U	U
18	U	U	U	U	U	U	U	-	-	U	0.27
20	-	U	0.05	0.24	4.79	7.86	U	-	-	U	2.5
21	-	U	-	-	-	-	-	-	-	U	0.24
23	-	U	-	-	-	-	-	-	-	U	U
24	U	U	U	U	U	U	U	-	-	U	0.234
25	U	U	U	-	-	-	-	-	-	U	0.384
26	-	U	-	-	-	-	-	-	-	U	0.193
27	-	U	-	-	-	-	-	-	-	U	0.29
28	-	-	-	-	-	-	-	-	-	-	-
29	-	-	-	-	-	-	-	-	-	-	-
30	-	-	-	-	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-	-	-	-
32	-	-	-	-	-	-	-	-	-	-	-
33	-	-	-	-	-	-	-	-	-	-	-
34	-	-	-	-	-	-	-	-	-	-	-
35	-	-	-	-	-	-	-	-	-	-	-
36	-	<0.2	-	-	-	-	-	-	-	-	-
37	-	-	-	-	-	-	-	-	-	-	-
38	-	-	-	-	-	-	-	-	-	-	-

Table B.1. *(continued)*

Station ID	Nitrogen, Nitrate (NO3) + Nitrite (NO2)	Oxamyl	Paraoxon	Penta-chloro-phenol (PCP)	pH	Phosphorus as P	Phosphorus as P	Picloram	Potassium	Prometone	Propachlor
	mg/L	ug/L	ug/L	ug/L		mg/L	mg/L	ug/L	mg/L	ug/L	ug/L
1	0.06	-	-	-	7.67	U	U	-	1.8	-	-
2	1.78	-	-	-	7.75	U	U	-	4.8	-	-
3	1.3	U	U	U	7.7	U	U	U	3	U	U
4	0.3	-	-	-	7.84	U	U	-	3.6	-	-
7	2.12	-	-	-	7.78	U	U	-	2.8	-	-
8	5.63	U	U	U	7.53	U	U	U	7.9	U	U
9	1.25	-	-	-	7.85	U	U	-	4.3	-	-
10	4.94	-	-	-	7.67	U	U	-	3.9	-	-
11	1.21	-	-	-	7.74	U	U	-	3.3	-	-
14	0.95	U	U	U	7.9	U	U	U	2.4	U	U
15	5.06	-	-	-	7.58	U	0.03	-	3.1	-	-
17	1.98	-	-	-	7.88	U	U	-	2.6	-	-
18	5.13	U	U	U	7.73	U	U	U	2.5	U	U
20	3	-	-	-	U	38	842	-	230.4	-	-
21	1.97	-	-	-	7.52	U	U	-	2.2	-	-
23	5.67	-	-	-	7.83	U	U	-	2.6	-	-
24	2.11	U	U	U	7.81	U	U	U	2.4	U	U
25	3.84	U	-	U	7.66	U	U	U	2.2	-	-
26	1.44	-	-	-	7.64	U	0.01	-	1.9	-	-
27	1.13	-	-	-	7.71	U	U	-	2	-	-
28	0.93	-	-	-	7.6	-	.04D	-	3.6	-	-
29	5.87	-	-	-	7.6	-	-	-	2.1	-	-
30	2.48	-	-	-	7.7	-	-	-	2.1	-	-
5	<0.10	-	-	-	7.6	-	-	-	1.6	-	-
32	2.03	-	-	-	7.8	-	-	-	2.4	-	-
33	0.63	-	-	-	7.5	-	-	-	2.1	-	-
34	2.94	-	-	-	7.9	-	-	-	2.2	-	-
35	2.71	-	-	-	7.6	-	-	-	2.2	-	-
36	0.67	-	-	-		-	-	-	-	-	-
37	5.87	-	-	-	7.6	-	-	-	2.1	-	-
38	2.48	-	-	-	7.7	-	-	-	2.1	-	-

Table B.1. *(continued)*

Station ID	Propoxur	Radio-activity, alpha	Radio-activity, beta	Radium-226	Radium-228	Selenium	Sevin	Silica, dissolved	Silver	Silvex	Simazine	Sodium
	ug/L	pCi/L	pCi/L	pCi/L	pCi/L	ug/L	ug/L	mg/L	ug/L	ug/L	ug/L	mg/L
1	-	15	U	U	U	U	-	-	U	-	-	17
2	-	-	-	-	-	3	-	-	U	-	-	32
3	U	2.6	-	-	-	4	U	-	U	U	U	36
4	-	28.8	14	U	U	3	-	-	U	-	-	41
7	-	7.5	11	U	U	3	-	-	U	-	-	56
8	U	9.4	U	U	U	4	U	-	U	U	U	100
9	-	-	-	-	-	3	-	-	U	-	-	120
10	-	-	-	-	-	7	-	-	U	-	-	100
11	-	-	-	-	-	1	-	-	U	-	-	40
14	U	-	-	-	-	2	U	-	U	U	U	21
15	-	-	-	-	-	7	-	-	U	-	-	57
17	-	-	-	-	-	3	-	-	U	-	-	37
18	U	-	-	-	-	3	U	-	U	U	U	41
20	-	-	-	-	-	347	-	-	156	-	-	0
21	-	-	-	-	-	3	-	-	U	-	-	32
23	-	-	-	-	-	4	-	-	U	-	-	44
24	U	13.3	-	-	-	3	U	-	U	U	U	37
25	U	10	U	U	U	2	U	-	U	U	-	31
26	-	6.108	U	0.5	3.34	2	-	-	U	-	-	28
27	-	-	-	-	-	1	-	-	U	-	-	30
28	-	-	-	-	-	-	-	15	-	-	-	20
29	-	-	-	-	-	-	-	17	-	-	-	54
30	-	-	-	-	-	0	-	14	-	-	-	43
5	-	-	-	-	-	-	-	19	-	-	-	18
32	-	-	-	-	-	-	-	19	-	-	-	41
33	-	-	-	-	-	-	-	10	-	-	-	44
34	-	-	-	-	-	-	-	14	-	-	-	46
35	-	-	-	-	-	-	-	14	-	-	-	48
36	-	-	-	-	-	1T	-	-	-	-	-	-
37	-	-	-	-	-	-	-	17	-	-	-	54
38	-	-	-	-	-	0	-	14	-	-	-	43

Table B.1. *(continued)*

Station ID	Specific conductance	Sulfate	Sulfur	Sum of Anions	Sum of Cations	Terbufos	Total Suspended Solids (TSS)	trans-Nonachlor	Treflan	Trichloro-phenoxy-acetic acid (2,4,5-T)	Turbidity
	umhos/cm	mg/L	mg/L	mg/L	mg/L	ug/L	mg/L	ug/L	ug/L	ug/L	NTU
1	865	166.5	-	372	167	-	19	-	-	-	8.9
2	1237	308.2	-	537	232	-	0	-	-	-	1.7
3	1012	278.3	-	456	198	U	0	U	U	U	2.4
4	1196	622.9	-	723	231	-	0	-	-	-	0.55
7	1012	291.5	-	423	187	-	0	-	-	-	1.8
8	2081	1061.8	-	1247	442	U	0	U	U	U	0.67
9	1376	269.5	-	530	266	-	0	-	-	-	0.95
10	1893	967.4	-	1128	375	-	4	-	-	-	7.2
11	1275	433.7	-	530	266	-	9	-	-	-	18
14	617	186.2	-	289	119	U	0	U	U	U	0.175
15	1476	700.3	-	853	295	-	0	-	-	-	0.85
17	951	296.7	-	404	180	-	0	-	-	-	1.7
18	979	313.4	-	448	196	U	0	U	U	U	0.18
20	0.5	43	-	-	-	-	-	-	-	-	-
21	1001	272.4	-	422	201	-	0	-	-	-	1.1
23	968	251.5	-	387	179	-	0	-	-	-	1.5
24	978	427.5	-	531	189	U	0	U	U	U	3.5
25	842	241.8	-	399	167	-	0	-	-	U	0.52
26	895	236.7	-	406	175	-	0	-	-	-	0.65
27	963	75.4	-	239	200	-	0	-	-	-	1.3
28	650	82	-	-	-	-	-	-	-	-	-
29	1230	450	-	-	-	-	-	-	-	-	-
30	980	310	-	-	-	-	-	-	-	-	-
5	670	53	-	-	-	-	-	-	-	-	-
32	1020	300	-	-	-	-	-	-	-	-	-
33	960	370	-	-	-	-	-	-	-	-	-
34	1040	350	-	-	-	-	-	-	-	-	-
35	930	300	-	-	-	-	-	-	-	-	-
36		91	-	-	-	-	-	-	-	-	-
37	1230	450	-	-	-	-	-	-	-	-	-
38	980	310	-	-	-	-	-	-	-	-	-

Table B.1. *(continued)*

Station ID	Uranium	Vanadium	Zinc	Coliform	E coli	Water Temperature	Data Source
	pCi/L	ug/L	ug/L			°C	
1	1.8	-	U	-	-	-	UDOH*[1]
2	-	-	U	-	-	-	UDOH*[1]
3	-	-	42	-	-	-	UDOH*[1]
4	2.8	-	U	-	-	-	UDOH*[1]
7	2.8	-	88	-	-	-	UDOH*[1]
8	7.9	-	75	-	-	-	UDOH*[1]
9	-	-	130	-	-	-	UDOH*[1]
10	-	-	48	-	-	-	UDOH*[1]
11	-	-	U	-	-	-	UDOH*[1]
14	-	-	80	-	-	-	UDOH*[1]
15	-	-	37	-	-	-	UDOH*[1]
17	-	-	170	-	-	-	UDOH*[1]
18	-	-	U	-	-	-	UDOH*[1]
20	-	-	-	-	-	-	UDOH*[1]
21	-	-	190	-	-	-	UDOH*[1]
23	-	-	U	-	-	-	UDOH*[1]
24	-	-	78	-	-	-	UDOH*[1]
25	2	-	240	-	-	-	UDOH*[1]
26	2	-	31	-	-	-	UDOH*[1]
27	-	-	36	-	-	-	UDOH*[1]
28	-	-	-	-	-	14.5	USGS*[2]
29	-	-	-	-	-	14	USGS*[2]
30	-	-	-	-	-	10	USGS*[2]
5	-	-	-	-	-	15.5	USGS*[2]
32	-	-	-	-	-	16	USGS*[2]
33	-	-	-	-	-	16	USGS*[2]
34	-	-	-	-	-	10	USGS*[2]
35	-	-	-	-	-	16	USGS*[2]
36	-	-	-	-	-	-	USGS*[2]
37	-	-	-	-	-	14	USGS*[2]
38	-	-	-	-	-	10	USGS*[2]

Table B.1. *(continued)*

Station ID	Station Name	Sample date	2,2-Dichloro-propionic acid	2,4-Dichloro-phenoxy-acetic acid (2,4-D)	3-Hydroxy-carbo-furan	4,6-Dinitro-2-sec-butyl-phenol (DNBP)	Alachlor	Aldicarb
			ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
516	17ready mix (D-27-22) 1bbd	7/19/2004	-	-	-	-	-	-
512	13dalton (D-26-22) 36cca	7/19/2004	-	-	-	-	-	-
508	9coates (D-26-22) 35acd	7/19/2004	-	-	-	-	-	-
509	10holyoak (D-26-22) 35dcd	7/20/2004	-	-	-	-	-	-
510	11junge north2 (D-26-22) 36cbc	7/20/2004	-	-	-	-	-	-
511	12tony (D-26-22) 36cbc	7/20/2004	-	-	-	-	-	-
504	5whitmer (D-26-22) 35ada	7/20/2004	-	-	-	-	-	-
517	18zimmerman (D-26-22) 35bdb	7/20/2004	-	-	-	-	-	-
502	3williams (D-26-22) 35bdd	7/20/2004	-	-	-	-	-	-
505	6ruhter (D-26-22) 35bdd	7/20/2004	-	-	-	-	-	-
500	1teeples (D-26-22) 26ddb	7/20/2004	-	-	-	-	-	-
501	2randall (D-26-22) 35bdc	7/20/2004	-	-	-	-	-	-
514	15conclan davis (D-26-22) 35adb	7/20/2004	-	-	-	-	-	-
518	19holyoak allen (D-26-22) 36ccd	7/20/2004	-	-	-	-	-	-
515	16cassamass (D-26-22) 35adb	7/20/2004	-	-	-	-	-	-
513	14bliss (D-26-22) 35add	7/20/2004	-	-	-	-	-	-
503	4gurr (D-26-22) 35aca	7/20/2004	-	-	-	-	-	-
519	20tangren (D-26-22) 26cab	7/20/2004	-	-	-	-	-	-
506	7somerville (D-26-22) 35ad	7/21/2004	-	-	-	-	-	-
507	8somerville stew (D-26-22) 35add	7/21/2004	-	-	-	-	-	-
331	n/a	2000	-	-	-	-	-	-
332	n/a	2000	-	-	-	-	-	-
333	n/a	2000	-	-	-	-	-	-
334	n/a	2000	-	-	-	-	-	-
335	n/a	2000	-	-	-	-	-	-
336	n/a	2000	-	-	-	-	-	-
337	n/a	2000	-	-	-	-	-	-
340	n/a	2000	-	-	-	-	-	-
342	n/a	2000	-	-	-	-	-	-
343	n/a	2000	-	-	-	-	-	-
344	n/a	2000	-	-	-	-	-	-
346	n/a	2000	-	-	-	-	-	-

Table B.1. *(continued)*

Station ID	Aldicarb sulfone	Aldicarb sulfoxide	Aldrin	Alkalinity, Carbonate as $CaCO_3$ (total alk)	alpha-BHC	Aluminum	Arsenic	Atrazine	Barium	beta-BHC	beta-Endo-sulfan	Bicarbo-nate	Boron
	ug/L	ug/L	ug/L	mg/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	mg/L	ug/L
516	-	-	-	(134)	-	<30	<1	-	<100	-	-	163	-
512	-	-	-	147	-	<30	<1	-	<100	-	-	179	-
508	-	-	-	(257)	-	<30	<1	-	<100	-	-	314	-
509	-	-	-	(164)	-	<30	<1	-	<100	-	-	200	-
510	-	-	-	(175)	-	-	-	-	-	-	-	214	-
511	-	-	-	(175)	-	<30	<1	-	<100	-	-	214	-
504	-	-	-	(221)	-	-	-	-	-	-	-	270	-
517	-	-	-	(230)	-	-	-	-		-	-	280	-
502	-	-	-	(169)	-	-	-	-	-	-	-	206	-
505	-	-	-	(251)	-	-	-	-	-	-	-	306	-
500	-	-	-	(159)	-	-	-	-	-	-	-	194	-
501	-	-	-	(202)	-	-	-	-	-	-	-	246	-
514	-	-	-	(243)	-	-	-	-	-	-	-	296	-
518	-	-	-	(136)	-	<30	<1	-	<100	-	-	166	-
515	-	-	-	(235)	-	<30	<1	-	<100	-	-	286	-
513	-	-	-	(244)	-	<30	<1	-	<100	-	-	298	-
503	-	-	-	(238)	-	-	-	-	-	-	-	290	-
519	-	-	-	(171)	-	<30	<1	-	<100	-	-	208	-
506	-	-	-	(269)	-	<30	<1	-	<100	-	-	328	-
507	-	-	-	(202)	-	<30	<1	-	<100	-	-	246	-
331	-	-	-	-	-	-0.1	-0.1	-	-0.1	-	-	2.755	-0.1
332	-	-	-	-	-	-0.1	-0.1	-	-0.1	-	-	4.578	-0.1
333	-	-	-	-	-	-0.1	-0.1	-	-0.1	-	-	3.356	-0.1
334	-	-	-	-	-	-0.1	-0.1	-	0.032	-	-	3.608	-0.1
335	-	-	-	-	-	-0.1	-0.1	-	0.02	-	-	3.996	-0.1
336	-	-	-	-	-	-0.1	-0.1	-	0.02	-	-	4.249	-0.1
337	-	-	-	-	-	0.046	-0.1	-	-0.1	-	-	3.279	0.679
340	-	-	-	-	-	-0.1	-0.1	-	0.057	-	-	2.231	0.057
342	-	-	-	-	-	-0.1	-0.1	-	0.086	-	-	4.326	0.075
343	-	-	-	-	-	-0.1	-0.1	-	0.024	-	-	1.998	-0.1
344	-	-	-	-	-	-0.1	-0.1	-	0.086	-	-	6.518	-0.1
346	-	-	-	-	-	-0.1	-0.1	-	0.024	-	-	4.598	-0.1

Table B.1. *(continued)*

Station ID	Bromacil	Butachlor	Cadmium	Calcium	Carbo-furan	Carbon dioxide	Carbonate ion	Carbonate solids	Chlordane, alpha use cis-Chlordane	Chloride	Chloro-pyrifos	Chromium
	ug/L	ug/L	ug/L	mg/L	ug/L	mg/L	mg/L	mg/L	ug/L	mg/L	ug/L	ug/L
516	-	-	<1	133	-	5	0	80	-	15.7	-	<5
512	-	-	<1	145	-	4	0	88	-	12.7	-	<5
508	-	-	<1	155	-	10	0	154	-	<10	-	<5
509	-	-	<1	154	-	3	0	98	-	10.7	-	<5
510	-	-	-	-	-	4	0	105	-	14.9	-	-
511	-	-	<1	144	-	5	0	105	-	14.3	-	<5
504	-	-	-	-	-	5	0	133	-	10.9	-	-
517	-	-	-	-	-	14	0	138	-	<10	-	-
502	-	-	-	-	-	11	0	101	-	<10	-	-
505	-	-	-	-	-	14	0	151	-	<10	-	-
500	-	-	-	-	-	6	0	96	-	80.7	-	-
501	-	-	-	-	-	10	0	121	-	<10	-	-
514	-	-	-	-	-	11	0	146	-	<10	-	-
518	-	-	<1	148	-	5	0	82	-	15.7	-	<5
515	-	-	<1	150	-	6	0	141	-	<10	-	<5
513	-	-	<1	160	-	10	0	147	-	<10	-	<5
503	-	-	-	-	-	9	0	143	-	<10	-	-
519	-	-	<1	126	-	4	0	102	-	13.5	-	<5
506	-	-	<1	166	-	10	0	161	-	<10	-	<5
507	-	-	<1	160	-	9	0	121	-	11.1	-	6.56
331	-	-	-	132	-	-	-	-	-	9.5	-	-
332	-	-	-	141	-	-	-	-	-	7.8	-	-
333	-	-	-	122	-	-	-	-	-	16.0	-	-
334	-	-	-	123	-	-	-	-	-	20.5	-	-
335	-	-	-	135	-	-	-	-	-	16.8	-	-
336	-	-	-	136	-	-	-	-	-	20.1	-	-
337	-	-	-	9	-	-	-	-	-	47.4	-	-
340	-	-	-	45	-	-	-	-	-	7.3	-	-
342	-	-	-	379	-	-	-	-	-	41.9	-	-
343	-	-	-	32	-	-	-	-	-	15.6	-	-
344	-	-	-	130	-	-	-	-	-	27.5	-	-
346	-	-	-	151	-	-	-	-	-	33.0	-	-

Table B.1. *(continued)*

Station ID	Copper	Cyanazine	Dacthal	DDD	DDE	DDT	delta-BHC	Diazinon	Dicamba	Dichlor-prop	Dieldrin	Dipropyl-thiocarba-mic acid S-ethyl ester (EPTC)	Solids, residue @180°C, dissolved
	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	mg/L
516	38.9	-	-	-	-	-	-	-	-	-	-	-	752
512	<12	-	-	-	-	-	-	-	-	-	-	-	774
508	<12	-	-	-	-	-	-	-	-	-	-	-	704
509	<12	-	-	-	-	-	-	-	-	-	-	-	748
510	-	-	-	-	-	-	-	-	-	-	-	-	758
511	<12	-	-	-	-	-	-	-	-	-	-	-	740
504	-	-	-	-	-	-	-	-	-	-	-	-	710
517	-	-	-	-	-	-	-	-	-	-	-	-	650
502	-	-	-	-	-	-	-	-	-	-	-	-	516
505	-	-	-	-	-	-	-	-	-	-	-	-	616
500	-	-	-	-	-	-	-	-	-	-	-	-	550
501	-	-	-	-	-	-	-	-	-	-	-	-	656
514	-	-	-	-	-	-	-	-	-	-	-	-	706
518	<12	-	-	-	-	-	-	-	-	-	-	-	752
515	30.5	-	-	-	-	-	-	-	-	-	-	-	708
513	53.2	-	-	-	-	-	-	-	-	-	-	-	716
503	-	-	-	-	-	-	-	-	-	-	-	-	684
519	<12	-	-	-	-	-	-	-	-	-	-	-	660
506	<12	-	-	-	-	-	-	-	-	-	-	-	746
507	<12	-	-	-	-	-	-	-	-	-	-	-	860
331	-0.1	-	-	-	-	-	-	-	-	-	-	-	697*
332	0.041	-	-	-	-	-	-	-	-	-	-	-	687*
333	-0.1	-	-	-	-	-	-	-	-	-	-	-	701*
334	-0.1	-	-	-	-	-	-	-	-	-	-	-	689*
335	-0.1	-	-	-	-	-	-	-	-	-	-	-	709*
336	-0.1	-	-	-	-	-	-	-	-	-	-	-	733*
337	0.04	-	-	-	-	-	-	-	-	-	-	-	618*
340	-0.1	-	-	-	-	-	-	-	-	-	-	-	284*
342	-0.1	-	-	-	-	-	-	-	-	-	-	-	-
343	-0.1	-	-	-	-	-	-	-	-	-	-	-	-
344	-0.1	-	-	-	-	-	-	-	-	-	-	-	655*
346	-0.1	-	-	-	-	-	-	-	-	-	-	-	822*

Table B.1. *(continued)*

Station ID	Disulfoton	Dyfonate	Endo-sulfan	Endo-sulfan Sulfate	Endrin	Endrin Aldehyde	Endrin ketone	Fluoride, dissolved	gamma-BHC (Lindane)	gamma-Chlordane	Hardness, Ca,Mg (total)	Heptachlor
	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	mg/L	ug/L	ug/L	mg/L	ug/L
516	-	-	-	-	-	-	-	-	-	-	-	-
512	-	-	-	-	-	-	-	-	-	-	(486.9)	-
508	-	-	-	-	-	-	-	-	-	-	(521.3)	-
509	-	-	-	-	-	-	-	-	-	-	(501.5)	-
510	-	-	-	-	-	-	-	-	-	-	-	-
511	-	-	-	-	-	-	-	-	-	-	(483.5)	-
504	-	-	-	-	-	-	-	-	-	-	-	-
517	-	-	-	-	-	-	-	-	-	-	-	-
502	-	-	-	-	-	-	-	-	-	-	-	-
505	-	-	-	-	-	-	-	-	-	-	-	-
500	-	-	-	-	-	-	-	-	-	-	-	-
501	-	-	-	-	-	-	-	-	-	-	-	-
514	-	-	-	-	-	-	-	-	-	-	-	-
518	-	-	-	-	-	-	-	-	-	-	(496.4)	-
515	-	-	-	-	-	-	-	-	-	-	(505.5)	-
513	-	-	-	-	-	-	-	-	-	-	(532.9)	-
503	-	-	-	-	-	-	-	-	-	-	-	-
519	-	-	-	-	-	-	-	-	-	-	(457.1)	-
506	-	-	-	-	-	-	-	-	-	-	(553.7)	-
507	-	-	-	-	-	-	-	-	-	-	(614.8)	-
331	-	-	-	-	-	-	-	-	-	-	9.5	-
332	-	-	-	-	-	-	-	-	-	-	9.9	-
333	-	-	-	-	-	-	-	-	-	-	9.2	-
334	-	-	-	-	-	-	-	-	-	-	9.1	-
335	-	-	-	-	-	-	-	-	-	-	10.2	-
336	-	-	-	-	-	-	-	-	-	-	10	-
337	-	-	-	-	-	-	-	-	-	-	1	-
340	-	-	-	-	-	-	-	-	-	-	3.8	-
342	-	-	-	-	-	-	-	-	-	-	28.4	-
343	-	-	-	-	-	-	-	-	-	-	2.7	-
344	-	-	-	-	-	-	-	-	-	-	10	-
346	-	-	-	-	-	-	-	-	-	-	12.4	-

Table B.1. *(continued)*

Station ID	Heptachlor epoxide	Hexa-chloro-benzene	Hexa-chloro cyclo-pentadiene	Hexazinone	Hydroxyl ion	Iron	Lead	Magnesium	Malathion	Manganese
	ug/L	ug/L	ug/L	ug/L	mg/L	ug/L	ug/L	mg/L	ug/L	ug/L
516	-	-	-	-	0	<20	<3	36.9	-	<5
512	-	-	-	-	0	<20	<3	30.4	-	<5
508	-	-	-	-	0	36.9	<3	32.7	-	<5
509	-	-	-	-	0	67.6	<3	28.5	-	7.61
510	-	-	-	-	0	-	-	-	-	-
511	-	-	-	-	0	<20	<3	30.2	-	<5
504	-	-	-	-	0	-	-	-	-	-
517	-	-	-	-	0	-	-	-	-	-
502	-	-	-	-	0	-	-	-	-	-
505	-	-	-	-	0	-	-	-	-	-
500	-	-	-	-	0	-	-	-	-	-
501	-	-	-	-	0	-	-	-	-	-
514	-	-	-	-	0	-	-	-	-	-
518	-	-	-	-	0	<20	<3	30.9	-	<5
515	-	-	-	-	0	<20	<3	31.9	-	<5
513	-	-	-	-	0	<20	<3	32.5	-	<5
503	-	-	-	-	0	-	-	-	-	-
519	-	-	-	-	0	<20	<3	34.7	-	<5
506	-	-	-	-	0	<20	<3	33.9	-	14.6
507	-	-	-	-	0	<20	<3	52.4	-	5.52
331	-	-	-	-	-	0.091	-0.1	30.256	-	-0.1
332	-	-	-	-	-	0.099	-0.1	28.2	-	-0.1
333	-	-	-	-	-	0.119	-0.1	34.347	-	-0.1
334	-	-	-	-	-	0.183	-0.1	32.885	-	-0.1
335	-	-	-	-	-	-0.1	-0.1	38.155	-	-0.1
336	-	-	-	-	-	0.021	-0.1	36.099	-	-0.1
337	-	-	-	-	-	0.048	-0.1	7.297	-	-0.1
340	-	-	-	-	-	-0.1	-0.1	18.768	-	-0.1
342	-	-	-	-	-	0.038	-0.1	106.529	-	75
343	-	-	-	-	-	-0.1	-0.1	13.529	-	-0.1
344	-	-	-	-	-	0.024	-0.1	40.831	-	-0.1
346	-	-	-	-	-	0.916	-0.1	61.647	-	-0.1

Table B.1. *(continued)*

Station ID	Mercapto-dimethur	Mercury	Methomyl	Methoxy-chlor	Methyl-parathion	Metolachlor	Metribuzin	Molybdenum	Nitrate	Nitrogen, ammonia (NH3)	Nitrogen, Kjeldahl
	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L			mg/L	mg/L
516	-	<0.2	-	-	-	-	-	-	-	0.06	-
512	-	<0.2	-	-	-	-	-	-	-	0.06	-
508	-	<0.2	-	-	-	-	-	-	-	<0.05	-
509	-	<0.2	-	-	-	-	-	-	-	0.06	-
510	-	-	-	-	-	-	-	-	-	<0.05	-
511	-	<0.2	-	-	-	-	-	-	-	<0.05	-
504	-	-	-	-	-	-	-	-	-	<0.05	-
517	-	-	-	-	-	-	-	-	-	<0.05	-
502	-	-	-	-	-	-	-	-	-	0.09	-
505	-	-	-	-	-	-	-	-	-	0.05	-
500	-	-	-	-	-	-	-	-	-	<0.05	-
501	-	-	-	-	-	-	-	-	-	<0.05	-
514	-	-	-	-	-	-	-	-	-	<0.05	-
518	-	<0.2	-	-	-	-	-	-	-	<0.05	-
515	-	<0.2	-	-	-	-	-	-	-	<0.05	-
513	-	<0.2	-	-	-	-	-	-	-	<0.05	-
503	-	-	-	-	-	-	-	-	-	<0.05	-
519	-	<0.2	-	-	-	-	-	-	-	<0.05	-
506	-	<0.2	-	-	-	-	-	-	-	<0.05	-
507	-	<0.2	-	-	-	-	-	-	-	<0.05	-
331	-	-	-	-	-	-	-	-0.1	1.7	-	-
332	-	-	-	-	-	-	-	-0.1	1.6	-	-
333	-	-	-	-	-	-	-	-0.1	2	-	-
334	-	-	-	-	-	-	-	-0.1	1.9	-	-
335	-	-	-	-	-	-	-	-0.1	3.3	-	-
336	-	-	-	-	-	-	-	-0.1	2.5	-	-
337	-	-	-	-	-	-	-	0.048	1.7	-	-
340	-	-	-	-	-	-	-	-0.1	1.2	-	-
342	-	-	-	-	-	-	-	0.012	1	-	-
343	-	-	-	-	-	-	-	-0.1	0.8	-	-
344	-	-	-	-	-	-	-	-0.1	0.7	-	-
346	-	-	-	-	-	-	-	-0.1	0.6	-	-

Table B.1. *(continued)*

Station ID	Nitrogen, Nitrate (NO3) + Nitrite (NO2)	Oxamyl	Paraoxon	Penta-chloro-phenol (PCP)	pH	Phosphorus as P	Phosphorus as P	Picloram	Potassium	Prometone	Propachlor
	mg/L	ug/L	ug/L	ug/L		mg/L	mg/L	ug/L	mg/L	ug/L	ug/L
516	0.55	-	-	-	7.3	<0.2	-	-	2.42	-	-
512	2.69	-	-	-	7.91	<0.02	-	-	2.43	-	-
508	0.49	-	-	-	7.4	<0.02	-	-	1.6	-	-
509	2.83	-	-	-	7.3	<0.02	-	-	1.76	-	-
510	3.2	-	-	-	7.2	<0.02	-	-	-	-	-
511	3.1	-	-	-	7.4	<0.02	-	-	2	-	-
504	2.37	-	-	-	7.3	<0.02	-	-	-	-	-
517	1.19	-	-	-	7.4	<0.02	-	-	-	-	-
502	<0.1	-	-	-	7.3	<0.02	-	-	-	-	-
505	1.28	-	-	-	7.3	<0.02	-	-	-	-	-
500	4.19	-	-	-	7.4	<0.02	-	-	-	-	-
501	2.24	-	-	-	7.3	<0.02	-	-	-	-	-
514	0.78	-	-	-	7.2	<0.02	-	-	-	-	-
518	3.19	-	-	-	7.4	<0.02	-	-	2.48	-	-
515	0.39	-	-	-	7.5	<0.02	-	-	1.87	-	-
513	0.79	-	-	-	7.3	<0.02	-	-	1.7	-	-
503	0.57	-	-	-	7.72	<0.02	-	-	-	-	-
519	2.24	-	-	-	7.4	<0.02	-	-	2.34	-	-
506	0.5	-	-	-	7.5	<0.02	-	-	1.71	-	-
507	1.62	-	-	-	7.4	<0.02	-	-	1.67	-	-
331	-	-	-	-	7.78	-0.1	-	-	2.776	-	-
332	-	-	-	-	7.47	-0.1	-	-	2.589	-	-
333	-	-	-	-	7.64	-0.1	-	-	3.206	-	-
334	-	-	-	-	7.64	-0.1	-	-	3.409	-	-
335	-	-	-	-	7.83	-0.1	-	-	3.277	-	-
336	-	-	-	-	7.62	-0.1	-	-	3.066	-	-
337	-	-	-	-	8.75	-0.1	-	-	13.123	-	-
340	-	-	-	-	8.10	-0.1	-	-	1.85	-	-
342	-	-	-	-	7.37	-0.1	-	-	8.741	-	-
343	-	-	-	-	8.47	-0.1	-	-	2.097	-	-
344	-	-	-	-	7.51	-0.1	-	-	2.506	-	-
346	-	-	-	-	7.86	-0.1	-	-	3.745	-	-

Table B.1. (continued)

Station ID	Propoxur	Radio-activity, alpha	Radio-activity, beta	Radium-226	Radium-228	Selenium	Sevin	Silica, dissolved	Silver	Silvex	Simazine	Sodium
	ug/L	pCi/L	pCi/L	pCi/L	pCi/L	ug/L	ug/L	mg/L	ug/L	ug/L	ug/L	mg/L
516	-	-	-	-	-	2.54	-	-	<2	-	-	42.3
512	-	-	-	-	-	4.69	-	-	<2	-	-	50.1
508	-	-	-	-	-	1.15	-	-	<2	-	-	32.1
509	-	-	-	-	-	13.4	-	-	<2	-	-	43.2
510	-	-	-	-	-	-	-	-	-	-	-	-
511	-	-	-	-	-	4.89	-	-	<2	-	-	56.3
504	-	-	-	-	-	-	-	-	-	-	-	-
517	-	-	-	-	-	-	-	-	-	-	-	-
502	-	-	-	-	-	-	-	-	-	-	-	-
505	-	-	-	-	-	-	-	-	-	-	-	-
500	-	-	-	-	-	-	-	-	-	-	-	-
501	-	-	-	-	-	-	-	-	-	-	-	-
514	-	-	-	-	-	-	-	-	-	-	-	-
518	-	-	-	-	-	5.33	-	-	<2	-	-	46.7
515	-	-	-	-	-	2.11	-	-	<2	-	-	36.7
513	-	-	-	-	-	1.42	-	-	<2	-	-	31.9
503	-	-	-	-	-	-	-	-	-	-	-	-
519	-	-	-	-	-	3.11	-	-	<2	-	-	43.6
506	-	-	-	-	-	<1	-	-	<2	-	-	32.8
507	-	-	-	-	-	1.48	-	-	<2	-	-	44.2
331	-	-	-	-	-	-0.1	-	-	-	-	-	43
332	-	-	-	-	-	-0.1	-	-	-	-	-	37
333	-	-	-	-	-	-0.1	-	-	-	-	-	43
334	-	-	-	-	-	-0.1	-	-	-	-	-	47
335	-	-	-	-	-	-0.1	-	-	-	-	-	41
336	-	-	-	-	-	-0.1	-	-	-	-	-	51
337	-	-	-	-	-	0.035	-	-	-	-	-	170
340	-	-	-	-	-	-0.1	-	-	-	-	-	12
342	-	-	-	-	-	-0.1	-	-	-	-	-	26
343	-	-	-	-	-	-0.1	-	-	-	-	-	16
344	-	-	-	-	-	-0.1	-	-	-	-	-	30
346	-	-	-	-	-	-0.1	-	-	-	-	-	54

Table B.1. *(continued)*

Station ID	Specific conductance	Sulfate	Sulfur	Sum of Anions	Sum of Cations	Terbufos	Total Suspended Solids (TSS)	trans-Nonachlor	Treflan	Trichloro-phenoxy-acetic acid (2,4,5-T)	Turbidity
	umhos/cm	mg/L	mg/L	mg/L	mg/L	ug/L	mg/L	ug/L	ug/L	ug/L	NTU
516	1013	382	-	480	215	-	<4	-	-	-	2.3
512	1053	383	-	496	228	-	<4	-	-	-	0.501
508	997	316	-	482	221	-	<4	-	-	-	1.53
509	1046	442	-	563	228	-	<4	-	-	-	1.58
510	1082	-	-	-	-	-	<4	-	-	-	0.34
511	1080	439	-	572	233	-	<4	-	-	-	0.163
504	1023	359	-	-	-	-	<4	-	-	-	0.179
517	966	279	-	-	-	-	7.6	-	-	-	3.1
502	790	213	-	-	-	-	<4	-	-	-	16.1
505	920	223	-	-	-	-	<4	-	-	-	1.16
500	854	198	-	-	-	-	<4	-	-	-	0.224
501	953	356	-	-	-	-	<4	-	-	-	1.42
514	1012	387	-	-	-	-	<4	-	-	-	0.186
518	1055	379	-	491	228	-	<4	-	-	-	0.666
515	1012	401	-	554	221	-	<4	-	-	-	1.6
513	1026	296	-	456	226	-	<4	-	-	-	3.12
503	998	376	-	-	-	-	<4	-	-	-	0.972
519	974	310	-	435	207	-	<4	-	-	-	0.222
506	1054	381	-	554	234	-	<4	-	-	-	4.8
507	1196	418	-	557	258	-	10.8	-	-	-	7.85
331	982	-	126.394	-	-	-	-	-	-	-	-
332	968	-	98.126	-	-	-	-	-	-	-	-
333	988	-	113.519	-	-	-	-	-	-	-	-
334	971	-	102.116	-	-	-	-	-	-	-	-
335	998	-	110.674	-	-	-	-	-	-	-	-
336	1033	-	109.405	-	-	-	-	-	-	-	-
337	871	-	62.187	-	-	-	-	-	-	-	-
340	400	-	28.35	-	-	-	-	-	-	-	-
342	-	-	375.009	-	-	-	-	-	-	-	-
343	-	-	14.003	-	-	-	-	-	-	-	-
344	923	-	50.053	-	-	-	-	-	-	-	-
346	1158	-	136.06	-	-	-	-	-	-	-	-

Table B.1. *(continued)*

Station ID	Uranium	Vanadium	Zinc	Coliform	E coli	Water Temperature	Data Source
	pCi/L	ug/L	ug/L			°C	
516	-	-	170		-	24.2	UGS[3]
512	-	-	<30	-	-	20.7	UGS[3]
508	-	-	<30	-	-	15	UGS[3]
509	-	-	99.3	-	-	21.4	UGS[3]
510	-	-	-	-	-	16.6	UGS[3]
511	-	-	<30	-	-	16.8	UGS[3]
504	-	-	-	-	-	16.2	UGS[3]
517	-	-	-	-	-	24.7	UGS[3]
502	-	-	-	-	-	26.6	UGS[3]
505	-	-	-	-	-	25.7	UGS[3]
500	-	-	-	-	-	17.5	UGS[3]
501	-	-	-	-	-	26.3	UGS[3]
514	-	-	-	-	-	18.6	UGS[3]
518	-	-	34.4	-	-	26	UGS[3]
515	-	-	39	-	-	21.1	UGS[3]
513	-	-	36.1	-	-	16.7	UGS[3]
503	-	-	-	-	-	20.2	UGS[3]
519	-	-	<30	-	-	17	UGS[3]
506	-	-	<30	-	-	16.8	UGS[3]
507	-	-	67.9	-	-	17	UGS[3]
331	-	-0.1	-0.1	0	0	16.4	UDAF[4]
332	-	-0.1	0.076	0	0	14.8	UDAF[4]
333	-	-0.1	-0.1	0	0	17.3	UDAF[4]
334	-	-0.1	0.119	0	0	16.3	UDAF[4]
335	-	-0.1	-0.1	1	0	17.7	UDAF[4]
336	-	-0.1	-0.1	0	0	18.6	UDAF[4]
337	-	0.05	0.059	1	0	18.1	UDAF[4]
340	-	-0.1	0.087	1	1	17.2	UDAF[4]
342	-	-0.1	-0.1	1	1	14	UDAF[4]
343	-	-0.1	-0.1	1	0	18	UDAF[4]
344	-	-0.1	0.06	1	0	17.5	UDAF[4]
346	-	-0.1	-0.1	0	0	16.4	UDAF[4]

Table B.1. *(continued)*

Station ID	Station Name	Sample date	2,2-Dichloro-propionic acid	2,4-Dichloro-phenoxy-acetic acid (2,4-D)	3-Hydroxy-carbo-furan	4,6-Dinitro-2 sec-butyl-phenol (DNBP)	Alachlor	Aldicarb
			ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
353	n/a	2000	-	-	-	-	-	-
100	Moab	1978	-	-	-	-	-	-
101	Moab	1992	-	-	-	-	-	-
102	Moab KOA Campground	2002	-	-	-	-	-	-
103	Slickrock Campground	2001	-	-	-	-	-	-
104	Bucks Grill House	2002	-	-	-	-	-	-
105	Grand Water & Sewer Agency	1988	-	-	-	-	-	-
106	Grand Water & Sewer Agency	1999	-	-	-	-	-	-
107	Grand Water & Sewer Agency	1988	-	-	-	-	-	-
108	Pack Creek Ranch	1988	-	-	-	-	-	-
110	Pack Creek Stream (D27-23)22bbb	04/01/1998	-	-	-	-	-	-
	bedrock wells below							
13	CITY WELL #5 (D-26-22) 22AAC-1	12/5/1995	U	U	U	U	U	U
*16	ERICKSON CARL (D-26-22) 22DAD-2	12/5/1995	U	U	U	U	U	U
*19	CHAPMAN WELL (D-26-22) 26ACD-1	12/5/1995	U	U	U	U	U	U
22	CORBIN WELL (D-26-22) 26DBD-1	12/5/1995	U	U	U	U	U	U
39	(D-26-22) 9cdc-1	7/11/1986	-	-	-	-	-	-
40	(D-26-22) 8bad-1	08/17/1988	-	-	-	-	-	-
41	(D-26-22) 14cba-1	06/22/1986	-	-	-	-	-	-
42	(D-26-22) 15acb-1	08/05/1986	-	-	-	-	-	-
43	(D-26-22) 15cca-1	08/09/1986	-	-	-	-	-	-
44	(D-26-22) 15daa-1	08/15/1985	-	-	-	-	-	-
45	(D-26-22) 15daa-2	12/05/1995	-	-	-	-	-	-
46	(D-26-22) 15dca-1	12/05/1995	-	-	-	-	-	-
47	(D-26-22) 15ddc-1	08/25/1987	-	-	-	-	-	-
48	(D-26-22) 20adc-1	12/06/1995	-	-	-	-	-	-
49	(D-26-22) 22aab-1	11/19/1968	-	-	-	-	-	-
50	(D-26-22) 22aac-1	12/05/1995	-	-	-	-	-	-
51	(D-26-22) 22abc-1	08/05/1986	-	-	-	-	-	-
52	(D-26-22) 22dad-1	07/12/1986	-	-	-	-	-	-
53	(D-26-22) 22dad-2	12/05/1995	-	-	-	-	-	-
54	(D-26-22) 23bba-1	09/11/1978	-	-	-	-	-	-

Table B.1. *(continued)*

Station ID	Aldicarb sulfone	Aldicarb sulfoxide	Aldrin	Alkalinity, Carbonate as $CaCO_3$ (total alk)	alpha-BHC	Aluminum	Arsenic	Atrazine	Barium	beta-BHC	beta-Endo-sulfan	Bicarbo-nate	Boron
	ug/L	ug/L	ug/L	mg/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	mg/L	ug/L
353	-	-	-	-	-	-0.1	-0.1	-	0.024	-	-	3.686	-0.1
100	-	-	-	-	-	-	-	-	-	-	-	-	-
101	-	-	-	-	-	-	-	-	-	-	-	-	-
102	-	-	-	-	-	-	-	-	-	-	-	-	-
103	-	-	-	-	-	-	-	-	-	-	-	-	-
104	-	-	-	-	-	-	-	-	-	-	-	-	-
105	-	-	-	-	-	-	-	-	-	-	-	-	-
106	-	-	-	-	-	-	-	-	-	-	-	-	-
107	-	-	-	-	-	-	-	-	-	-	-	-	-
108	-	-	-	-	-	-	-	-	-	-	-	-	-
110	-	-	-	-	-	-	-	-	-	-	-	-	-
13	U	U	U	97	U	U	U	U	49	U	U	118	-
*16	U	U	U	113	-	U	U	U	25	-	-	138	-
*19	U	U	U	126	19.5	U	U	U	34	-	-	154	-
22	U	U	U	161	U	U	U	U	21	U	U	197	-
39	-	-	-	104	-	-	<1	-	82	-	-	-	-
40	-	-	-	-	-	-	<1	-	80	-	-	150	-
41	-	-	-	-	-	-	<1	-	82	-	-		-
42	-	-	-	-	-	-	<1	-	40	-	-		-
43	-	-	-	-	-	-	<1	-	40	-	-		-
44	-	-	-	-	-	-	<1	-	100	-	-		-
45	-	-	-	-	-	-	<5	-	<70	-	-	120	-
46	-	-	-	-	-	-	<5	-	45	-	-	140	-
47	-	-	-	-	-	-	<1T	-	50 T	-	-	140	-
48	-	-	-	-	-	-	<5	-	22	-	-	190	-
49	-	-	-	-	-	-	10	-		-	-	120	40
50	-	-	-	-	-	-	<5	-	49	-	-	120	-
51	-	-	-	-	-	-	<1	-	30	-	-	-	-
52	-	-	-	-	-	-	<1	-	44	-	-	-	-
53	-	-	-	-	-	-	<5	-	25	-	-	-	-
54	-	-	-	-	-	-	<1T	-	70T	-	-	120	-

Table B.1. *(continued)*

Station ID	Bromacil	Butachlor	Cadmium	Calcium	Carbo-furan	Carbon dioxide	Carbonate ion	Carbonate solids	Chlordane, alpha use cis-Chlordane	Chloride	Chloro-pyrifos	Chromium
	ug/L	ug/L	ug/L	mg/L	ug/L	mg/L	mg/L	mg/L	ug/L	mg/L	ug/L	ug/L
353	-	-	-	118	-	-	-	-	-	25.1	-	-
								-				
100	-	-	-	-	-	-	-	-	-	-	-	-
101	-	-	-	-	-	-	-	-	-	-	-	-
102	-	-	-	-	-	-	-	-	-	-	-	-
103	-	-	-	-	-	-	-	-	-	-	-	-
104	-	-	-	-	-	-	-	-	-	-	-	-
105	-	-	-	-	-	-	-	-	-	-	-	-
106	-	-	-	-	-	-	-	-	-	-	-	-
107	-	-	-	-	-	-	-	-	-	-	-	-
108	-	-	-	-	-	-	-	-	-	-	-	-
110	-	-	-	-	-	-	-	-	-	-	-	-
13	U	U	U	33	U	1	0	-	U	5	U	U
*16	-	U	U	71	U	3	0	-	U	22	-	U
*19	-	U	U	62	U	3	0	-	U	12	-	U
22	U	U	U	100	U	5	0	-	U	35	U	U
39	-	-	-	31	-	-	-	-	-	1.8	-	-
40	-	-	<1	35	-	-	0	-	-	29	-	-
41	-	-	-	30	-	-	-	-	-	1.9	-	-
42	-	-	-	30	-	-	-	-	-	2	-	-
43	-	-	-	36	-	-	-	-	-	4	-	-
44	-	-	-	33	-	-	-	-	-	44	-	-
45	-	-	<1	33	-	-	0	-	-	3	-	<5
46	-	-	<1	41	-	-	0	-	-	7.5	-	<5
47	-	-	<1T	41	-	-	1	-	-	4	-	<5T
48	-	-	<1	35	-	-	0	-	-	110	-	<5
49	-	-	-	30	-	-	0	-	-	2.7	-	
50	-	-	<1	33	-	-	0	-	-	5	-	<5
51	-	-	-	72	-	-	-	-	-	8	-	-
52	-	-	-	42	-	-	-	-	-	7	-	-
53	-	-	<1	71	-	-	0	-	-	22	-	-
54	-	-	<1T	34	-	-	0	-	-	1	-	<15T

Table B.1. *(continued)*

Station ID	Copper	Cyanazine	Dacthal	DDD	DDE	DDT	delta-BHC	Diazinon	Dicamba	Dichlor-prop	Dieldrin	Dipropyl-thiocarba-mic acid S-ethyl ester (EPTC)	Solids, residue @180°C, dissolved
	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	mg/L
353	-0.1	-	-	-	-	-	-	-	-	-	-	-	652*
100	-	-	-	-	-	-	-	-	-	-	-	-	140
101	-	-	-	-	-	-	-	-	-	-	-	-	588
102	-	-	-	-	-	-	-	-	-	-	-	-	-
103	-	-	-	-	-	-	-	-	-	-	-	-	-
104	-	-	-	-	-	-	-	-	-	-	-	-	-
105	-	-	-	-	-	-	-	-	-	-	-	-	728
106	-	-	-	-	-	-	-	-	-	-	-	-	248
107	-	-	-	-	-	-	-	-	-	-	-	-	228
108	-	-	-	-	-	-	-	-	-	-	-	-	-
110	-	-	-	-	-	-	-	-	-	-	-	-	732
13	12	U	U	U	U	U	U	U	U	U	U	U	180
*16	12	-	-	-	-	-	-	-	U	U	U	-	454
*19	12	-	-	-	-	-	-	-	U	U	U	U	404
22	12	U	U	U	U	U	U	U	U	U	U	U	648
39	-	-	-	-	-	-	-	-	-	-	-	-	151
40	-	-	-	-	-	-	-	-	-	-	-	-	228
41	-	-	-	-	-	-	-	-	-	-	-	-	150
42	-	-	-	-	-	-	-	-	-	-	-	-	150
43	-	-	-	-	-	-	-	-	-	-	-	-	194
44	-	-	-	-	-	-	-	-	-	-	-	-	154
45	12	-	-	-	-	-	-	-	-	-	-	-	154
46	<12	-	-	-	-	-	-	-	-	-	-	-	226
47	<20T	-	-	-	-	-	-	-	-	-	-	-	204
48	<12	-	-	-	-	-	-	-	-	-	-	-	736
49	100	-	-	-	-	-	-	-	-	-	-	-	218
50	12	-	-	-	-	-	-	-	-	-	-	-	180
51	-	-	-	-	-	-	-	-	-	-	-	-	388
52	-	-	-	-	-	-	-	-	-	-	-	-	238
53	12	-	-	-	-	-	-	-	-	-	-	-	454
54	<5T	-	-	-	-	-	-	-	-	-	-	-	148

Table B.1. *(continued)*

Station ID	Disulfoton	Dyfonate	Endo-sulfan	Endo-sulfan Sulfate	Endrin	Endrin Aldehyde	Endrin ketone	Fluoride, dissolved	gamma-BHC (Lindane)	gamma-Chlordane	Hardness, Ca,Mg (total)	Heptachlor
	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	mg/L	ug/L	ug/L	mg/L	ug/L
353	-	-	-	-	-	-	-	-	-	-	9	-
100	-	-	-	-	-	-	-	-	-	-	-	-
101	-	-	-	-	-	-	-	-	-	-	-	-
102	-	-	-	-	-	-	-	-	-	-	-	-
103	-	-	-	-	-	-	-	-	-	-	-	-
104	-	-	-	-	-	-	-	-	-	-	-	-
105	-	-	-	-	-	-	-	-	-	-	-	-
106	-	-	-	-	-	-	-	-	-	-	-	-
107	-	-	-	-	-	-	-	-	-	-	-	-
108	-	-	-	-	-	-	-	-	-	-	-	-
110	-	-	-	-	-	-	-	-	-	-	-	-
13	U	U	U	U	U	U	U	-	U	U	131.7	U
*16	-	-	-	-	U	-	-	-	U	-	296.5	U
*19	-	-	-	-	U	-	-	-	U	-	249.3	U
22	U	U	U	U	U	U	U	-	U	U	372.9	U
39	-	-	-	-	-	-	-	0.2	-	-	130	-
40	-	-	-	-	-	-	-	-	-	-	140	-
41	-	-	-	-	-	-	-	0.2	-	-	120	-
42	-	-	-	-	-	-	-	0.2	-	-	120	-
43	-	-	-	-	-	-	-	0.1	-	-	150	-
44	-	-	-	-	-	-	-	0.1	-	-	130	-
45	-	-	-	-	-	-	-	-	-	-	130	-
46	-	-	-	-	-	-	-	-	-	-	160	-
47	-	-	-	-	-	-	-	-	-	-	170	-
48	-	-	-	-	-	-	-	-	-	-	230	-
49	-	-	-	-	-	-	-	0.3	-	-	130	-
50	-	-	-	-	-	-	-	-	-	-	130	-
51	-	-	-	-	-	-	-	0.3	-	-	300	-
52	-	-	-	-	-	-	-	0.1	-	-	180	-
53	-	-	-	-	-	-	-	-	-	-	300	-
54	-	-	-	-	-	-	-	-	-	-	120	-

Table B.1. *(continued)*

Station ID	Heptachlor epoxide	Hexa-chloro-benzene	Hexa-chloro cyclo-pentadiene	Hexazinone	Hydroxyl ion	Iron	Lead	Magnesium	Malathion	Manganese
	ug/L	ug/L	ug/L	ug/L	mg/L	ug/L	ug/L	mg/L	ug/L	ug/L
353	-	-	-	-	-	0.037	-0.1	35.579	-	-0.1
100	-	-	-	-	-	-	-	-	-	-
101	-	-	-	-	-	-	-	-	-	-
102	-	-	-	-	-	-	-	-	-	-
103	-	-	-	-	-	-	-	-	-	-
104	-	-	-	-	-	-	-	-	-	-
105	-	-	-	-	-	-	-	-	-	-
106	-	-	-	-	-	-	-	-	-	-
107	-	-	-	-	-	-	-	-	-	-
108	-	-	-	-	-	-	-	-	-	-
110	-	-	-	-	-	-	-	-	-	-
13	U	U	U	U	0	20	U	12	U	5
*16	U	-	U	-	0	20	U	29	-	6.7
*19	U	-	U	-	0	33	U	23	-	5
22	U	U	U	U	0	48	U	30	U	10
39	-	-	-	-	-	27		12	-	-
40	-	-	-	-	-	-	<5	24	-	-
41	-	-	-	-	-	7	-	11	-	-
42	-	-	-	-	-	<10	-	11	-	-
43	-	-	-	-	-	10	-	15	-	-
44	-	-	-	-	-	-	14	11	-	-
45	-	-	-	-	-	20	<3	11	-	5
46	-	-	-	-	-	25	<3	14	-	<5
47	-	-	-	-	-	-	<5T	-	-	-
48	-	-	-	-	-	<20	<3	35	-	<5
49	-	-	-	-	-	90	-	13	-	-
50	-	-	-	-	-	20	<3	12	-	5
51	-	-	-	-	-	40	-	28	-	-
52	-	-	-	-	-	12	-	17	-	-
53	-	-	-	-	-	20	<3	29	-	6.7
54	-	-	-	-	-	-	<20T	-	-	-

Table B.1. (continued)

Station ID	Mercapto-dimethur	Mercury	Methomyl	Methoxy-chlor	Methyl-parathion	Metolachlor	Metribuzin	Molybdenum	Nitrate	Nitrogen, ammonia (NH3)	Nitrogen, Kjeldahl
	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L			mg/L	mg/L
353	-	-	-	-	-	-	-	-0.1	3.7	-	-
100	-	-	-	-	-	-	-	-	0.17	-	-
101	-	-	-	-	-	-	-	-	7.37	-	-
102	-	-	-	-	-	-	-	-	4.57	-	-
103	-	-	-	-	-	-	-	-	0.1	-	-
104	-	-	-	-	-	-	-	-	0.77	-	-
105	-	-	-	-	-	-	-	-	0.25	-	-
106	-	-	-	-	-	-	-	-	0.5	-	-
107	-	-	-	-	-	-	-	-	0.95	-	-
108	-	-	-	-	-	-	-	-	0.23	-	-
110	-	-	-	-	-	-	-	-	-	-	-
13	U	U	U	U	U	U	U	-	-	U	0.91
*16	U	U	U	U	U	-	U	-	-	U	0.3
*19	U	U	U	U	-	U	U	-	-	U	0.23
22	U	U	U	U	U	U	U	-	-	U	0.21
39	-	-	-	-	-	-	-	-	-	-	-
40	-	-	-	-	-	-	-	-	-	-	-
41	-	-	-	-	-	-	-	-	-	-	-
42	-	-	-	-	-	-	-	-	-	-	-
43	-	-	-	-	-	-	-	-	-	-	-
44	-		-	-	-	-	-	-	-	-	-
45	-	<0.2	-	-	-	-	-	-	-	-	-
46	-	<0.2	-	-	-	-	-	-	-	-	-
47	-	<0.2T	-	-	-	-	-	-	-	-	-
48	-	<0.2	-	-	-	-	-	-	-	-	-
49	-	-	-	-	-	-	-	-	-	-	-
50	-	<0.2	-	-	-	-	-	-	-	-	-
51	-	-	-	-	-	-	-	-	-	-	-
52	-	-	-	-	-	-	-	-	-	-	-
53	-	<0.2	-	-	-	-	-	-	-	-	-
54	-	<0.1T	-	-	-	-	-	-	-	-	-

Table B.1. *(continued)*

Station ID	Nitrogen, Nitrate (NO3) + Nitrite (NO2)	Oxamyl	Paraoxon	Penta-chloro-phenol (PCP)	pH	Phosphorus as P	Phosphorus as P	Picloram	Potassium	Prometone	Propachlor
	mg/L	ug/L	ug/L	ug/L		mg/L	mg/L	ug/L	mg/L	ug/L	ug/L
353	-	-	-	-	7.64	-0.1	-	-	3.003	-	-
100	-	-	-	-	-	-	-	-	-	-	-
101	-	-	-	-	-	-	-	-	-	-	-
102	-	-	-	-	-	-	-	-	-	-	-
103	-	-	-	-	-	-	-	-	-	-	-
104	-	-	-	-	-	-	-	-	-	-	-
105	-	-	-	-	-	-	-	-	-	-	-
106	-	-	-	-	-	-	-	-	-	-	-
107	-	-	-	-	-	-	-	-	-	-	-
108	-	-	-	-	-	-	-	-	-	-	-
110	-	-	-	-	-	-	-	-	-	-	-
13	0.21	U	U	U	8.18	U	U	U	1.2	U	U
*16	1.64	U	-	*U	7.94	U	U	U	2.2	-	U
*19	0.77	U	-	U	7.87	0.01	U	U	2.9	-	U
22	6.42	U	U	U	7.76	U	U	U	2.5	U	U
39	-	-	-	-	7.8	-	-	-	1.2	-	-
40	0.95	-	-	-	8.2L	0.02	-	-	2	-	-
41	-	-	-	-	8.2	-	-	-	1.1	-	-
42	-	-	-	-	7.7	-	-	-	1.1	-	-
43	-	-	-	-	7.7	-	-	-	1.3	-	-
44	-	-	-	-	7.8	-	-	-	1.1	-	-
45	0.22	-	-	-	7.9	<0.01	-	-	1	-	-
46	0.4	-	-	-	7.8	<0.01	-	-	1.3	-	-
47	0.3	-	-	-	8.4L	<0.01	-	-	1	-	-
48	15.2	-	-	-	7.8	<0.01	-	-	18	-	-
49	0.29	-	-	-	7.6	-	-	-	1	-	-
50	0.21	-	-	-	8L	<0.01	-	-	1.2	-	-
51	-	-	-	-	7.4	-	-	-	1.7	-	-
52	-	-	-	-	7.7	-	-	-	1.6	-	-
53	1.64	-	-	-	7.7	<0.01	-	-	2.2	-	-
54	0.3	-	-	-	7.8L	<0.02	-	-	1	-	-

Table B.1. *(continued)*

Station ID	Propoxur	Radio-activity, alpha	Radio-activity, beta	Radium-226	Radium-228	Selenium	Sevin	Silica, dissolved	Silver	Silvex	Simazine	Sodium
	ug/L	pCi/L	pCi/L	pCi/L	pCi/L	ug/L	ug/L	mg/L	ug/L	ug/L	ug/L	mg/L
353	-	-	-	-	-	-0.1	-	-	-	-	-	49
100	-	-	-	-	-	-	-	-	-	-	-	-
101	-	-	-	-	-	-	-	-	-	-	-	-
102	-	-	-	-	-	-	-	-	-	-	-	-
103	-	-	-	-	-	-	-	-	-	-	-	-
104	-	-	-	-	-	-	-	-	-	-	-	-
105	-	-	-	-	-	-	-	-	-	-	-	-
106	-	-	-	-	-	-	-	-	-	-	-	-
107	-	-	-	-	-	-	-	-	-	-	-	-
108	-	-	-	-	-	-	-	-	-	-	-	-
110	-	-	-	-	-	-	-	-	-	-	-	-
13	U	-	-	-	-	U	U	-	U	U	U	7.9
*16	U	U	-	-	-	3	U	-	U	U	U	25
*19	U	19.5	U	U	U	2	U	-	U	U	U	24
22	U	-	-	-	-	4	U	-	U	U	U	44
39	-	-	-	-	-	-	-	9.5	<1	-	-	-
40	-	-	-	-	-	<0.2	-	-	3	-	-	24
41	-	-	-	-	-	-	-	9.2	-	-	-	-
42	-	-	-	-	-	-	-	9.1	-	-	-	-
43	-	-	-	-	-	1	-	9.6	-	-	-	-
44	-	-	-	-	-	<1	-	9.2	-	-	-	5.7
45	-	-	-	-	-	<1	-	-	<2	-	-	6
46	-	-	-	-	-	1	-	-	<2	-	-	15
47	-	-	-	-	-	<1T	-	-	<2T	-	-	9
48	-	-	-	U	U	21	-	-	<2	-	-	140
49	-	-	-	-	-	0	-	9.5	-	-	-	6.5
50	-	-	-	-	-	-	-	-	-	-	-	7.9
51	-	-	-	-	-	4	-	12	-	-	-	12
52	-	-	-	-	-	1	-	11	-	-	-	13
53	-	U	U	U	U	3	-	-	<2	-	-	25
54	-	-	-	-	-	<1T	-	-	<5T	-	-	6

Table B.1. *(continued)*

Station ID	Specific conductance	Sulfate	Sulfur	Sum of Anions	Sum of Cations	Terbufos	Total Suspended Solids (TSS)	trans-Nonachlor	Treflan	Trichloro-phenoxy-acetic acid (2,4,5-T)	Turbidity
	umhos/cm	mg/L	mg/L	mg/L	mg/L	ug/L	mg/L	ug/L	ug/L	ug/L	NTU
353	919	-	90.499	-	-	-	-	-	-	-	-
100	-	-	-	-	-	-	-	-	-	-	-
101	-	-	-	-	-	-	-	-	-	-	-
102	-	-	-	-	-	-	-	-	-	-	-
103	-	-	-	-	-	-	-	-	-	-	-
104	-	-	-	-	-	-	-	-	-	-	-
105	-	-	-	-	-	-	-	-	-	-	-
106	-	-	-	-	-	-	-	-	-	-	-
107	-	-	-	-	-	-	-	-	-	-	-
108	-	-	-	-	-	-	-	-	-	-	-
110	-	-	-	-	-	-	-	-	-	-	-
13	290	56	-	119	54	U	68	U	U	U	2.05
*16	658	222.1	-	312	127	-	0	-	-	U	1.95
*19	582	173.1	-	261	112	-	0	-	-	U	0.58
22	940	276	-	408	177	U	0	U	U	U	1.5
39	-	-	-	-	-	-	-	-	-	-	-
40	395	35	-	-	-	-	-	-	-	-	-
41	255	33	-	-	-	-	-	-	-	-	-
42	270	28	-	-	-	-	-	-	-	-	-
43	330	64	-	-	-	-	-	-	-	-	-
44	255	46	-	-	-	-	-	-	-	-	-
45	280	35	-	-	-	-	-	-	-	-	-
46	380	74	-	-	-	-	-	-	-	-	-
47	345	64	-	-	-	-	-	-	-	-	-
48	1170	220	-	-	-	-	-	-	-	-	-
49	275	38	-	-	-	-	-	-	-	-	-
50	305	38	-	-	-	-	-	-	-	-	-
51	620	150	-	-	-	-	-	-	-	-	-
52	380	70	-	-	-	-	-	-	-	-	-
53	660	220	-	-	-	-	-	-	-	-	-
54	450	34	-	-	-	-	-	-	-	-	-

Table B.1. *(continued)*

Station ID	Uranium	Vanadium	Zinc	Coliform	E coli	Water Temperature	Data Source
	pCi/L	ug/L	ug/L			°C	
353	-	-0.1	0.351	0	0	18.8	UDAF^4
100	-	-	-	-	-	-	DEQ/WQ*^{5}
101	-	-	-	-	-	-	DEQ/WQ*^{5}
102	-	-	-	-	-	-	DEQ/WQ*^{5}
103	-	-	-	-	-	-	DEQ/WQ*^{5}
104	-	-	-	-	-	-	DEQ/WQ*^{5}
105	-	-	-	-	-	-	DEQ/WQ*^{5}
106	-	-	-	-	-	-	DEQ/WQ*^{5}
107	-	-	-	-	-	-	DEQ/WQ*^{5}
108	-	-	-	-	-	-	DEQ/WQ*^{5}
110	-	-	-	-	-	-	DEQ/WQ*^{5}
13	-	-	30	-	-	-	UDOH*^{1}
*16	-	-	30	-	-	-	UDOH*^{1}
*19	1.5	-	120	-	-	-	UDOH*^{1}
22	-	-	30	-	-	-	UDOH*^{1}
39	-	-	-	-	-	-	USGS*^{2}
40	-	-	<2	-	-	-	UDOH*^{1}
41	-	-	-	-	-	16	USGS*^{2}
42	-	-	-	-	-	15	USGS*^{2}
43	-	-	-	-	-	16	UDH*^{1}
44	-	-	-	-	-	15.5	USGS*^{2}
45	-	-	30	-	-	14.5	UDOH*^{1}
46	-	-	<30	-	-	-	UDOH*^{1}
47	-	-	10T	-	-	-	UDOH*^{1}
48	-	-	99	-	-	15.5	UDOH*^{1}
49	-	-	-	-	-	13.5	USGS*^{2}
50	-	-	30	-	-	5.5	UDOH*^{1}
51	-	-	-	-	-	15	USGS*^{2}
52	-	-	-	-	-	16.5	USGS*^{2}
53	-	-	30	-	-	15.5	UDOH*^{1}
54	-	-	<5T	-	-	-	UDOH*^{1}

Table B.1. *(continued)*

Station ID	Station Name	Sample date	2,2-Dichloro-propionic acid	2,4-Dichloro-phenoxy-acetic acid (2,4-D)	3-Hydroxy-carbo-furan	4,6-Dinitro-2-sec-butyl-phenol (DNBP)	Alachlor	Aldicarb
			ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
55	(D-26-22) 23ccd-1	11/15/1993	-	-	-	-	-	-
56	(D-26-22) 26acd-1	12/05/1995	-	-	-	-	-	-
57	(D-26-22) 26dbd-1	12/5/1995	-	-	-	-	-	-
58	(D-26-22) 26dda-1	7/12/1986	-	-	-	-	-	-
701	(D-27-22)1cbb	11/17/2004	-	-	-	-	-	-
749	(D-26-22)36cac	11/17/2004	-	-	-	-	-	-
713	(D-26-22)36cad	11/17/2004	-	-	-	-	-	-
717	(D-26-22)36dba	11/17/2004	-	-	-	-	-	-
721	(D-26-22)36ddb	11/17/2004	-	-	-	-	-	-

U = non-detect
a "**-**" indicates *no data*
UGS = Utah Geological Survey
UDAF = Utah Department of Agriculture and Foods
UDH = Utah Department of Health Laboratory
USGS = United States Geological Survey
DEQ/WQ = Department of Environmental Quality / Water Quality
-0.100 indicates no detection (U) above reporting level as reported by the UDAF
Note- Analysis was performed, in UDAF water samples, for the following constituents, however concentrations were less than detection limits and are not reported: Berylium, Cadmium, Cobalt, Carbonate, Chromium, Lithium, and Nickel.

*This well was also tested for Pcb-aroclor 1016, 1221, 1232, 1242, 1248, 1254, and 1260; Benzo(a)pyrene, bis(2-ethylhexyl)adipate, di-sec-octyl phthalate (DEHP), and Toxaphene - ALL with No-detect.

Table B.1. *(continued)*

Station ID	Aldicarb sulfone	Aldicarb sulfoxide	Aldrin	Alkalinity, Carbonate as $CaCO_3$ (total alk)	alpha-BHC	Aluminum	Arsenic	Atrazine	Barium	beta-BHC	beta-Endo-sulfan	Bicarbo-nate	Boron
	ug/L	ug/L	ug/L	mg/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	mg/L	ug/L
55	-	-	-	-	-	-	<5T	-	40T	-	-	-	-
56	-	-	-	-	-	-	<5	-	34	-	-	150	-
57	-	-	-	-	-	-	<5	-	21	-	-	200	-
58	-	-	-	-	-	-	<1	-	56	-	-	-	-
701	-	-	-	-	-	-	-	-	-	-	-	-	-
749	-	-	-	-	-	-	-	-	-	-	-	-	-
713	-	-	-	-	-	-	-	-	-	-	-	-	-
717	-	-	-	-	-	-	-	-	-	-	-	-	-
721	-	-	-	-	-	-	-	-	-	-	-	-	-

Table B.1. *(continued)*

Station ID	Bromacil	Butachlor	Cadmium	Calcium	Carbo-furan	Carbon dioxide	Carbonate ion	Carbonate solids	Chlordane, alpha use cis-Chlordane	Chloride	Chloro-pyrifos	Chromium
	ug/L	ug/L	ug/L	mg/L	ug/L	mg/L	mg/L	mg/L	ug/L	mg/L	ug/L	ug/L
55	-	-	-	-	-	-	-	-	-	-	-	<5T
56	-	-	<1	62	-	-	0	-	-	12	-	<5
57	-	-	<1	100	-	-	0	-	-	35	-	<5
58	-	-	-	81	-	-	-	-	-	16	-	-
701	-	-	-	-	-	-	-	-	-	-	-	-
749	-	-	-	-	-	-	-	-	-	-	-	-
713	-	-	-	-	-	-	-	-	-	-	-	-
717	-	-	-	-	-	-	-	-	-	-	-	-
721	-	-	-	-	-	-	-	-	-	-	-	-

Table B.1. *(continued)*

Station ID	Copper	Cyanazine	Dacthal	DDD	DDE	DDT	delta-BHC	Diazinon	Dicamba	Dichlor-prop	Dieldrin	Dipropyl-thiocarba-mic acid S-ethyl ester (EPTC)	Solids, residue @180°C, dissolved
	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	mg/L
55	<20T	-	-	-	-	-	-	-	-	-	-	-	266
56	12	-	-	-	-	-	-	-	-	-	-	-	404
57	12	-	-	-	-	-	-	-	-	-	-	-	648
58	-	-	-	-	-	-	-	-	-	-	-	-	503
701	-	-	-	-	-	-	-	-	-	-	-	-	494
749	-	-	-	-	-	-	-	-	-	-	-	-	640
713	-	-	-	-	-	-	-	-	-	-	-	-	370
717	-	-	-	-	-	-	-	-	-	-	-	-	202
721	-	-	-	-	-	-	-	-	-	-	-	-	220

Table B.1. *(continued)*

Station ID	Disulfoton	Dyfonate	Endo-sulfan	Endo-sulfan Sulfate	Endrin	Endrin Aldehyde	Endrin ketone	Fluoride, dissolved	gamma-BHC (Lindane)	gamma-Chlordane	Hardness, Ca,Mg (total)	Heptachlor
	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	mg/L	ug/L	ug/L	mg/L	ug/L
55	-	-	-	-	-	-	-	-	-	-	-	-
56	-	-	-	-	-	-	-	-	-	-	250	-
57	-	-	-	-	-	-	-	-	-	-	370	-
58	-	-	-	-	-	-	-	0.3	-	-	320	-
701	-	-	-	-	-	-	-	-	-	-	-	-
749	-	-	-	-	-	-	-	-	-	-	-	-
713	-	-	-	-	-	-	-	-	-	-	-	-
717	-	-	-	-	-	-	-	-	-	-	-	-
721	-	-	-	-	-	-	-	-	-	-	-	-

Table B.1. *(continued)*

Station ID	Heptachlor epoxide	Hexa-chloro-benzene	Hexa-chloro-cyclo-pentadiene	Hexazinone	Hydroxyl ion	Iron	Lead	Magnesium	Malathion	Manganese
	ug/L	ug/L	ug/L	ug/L	mg/L	ug/L	ug/L	mg/L	ug/L	ug/L
55	-	-	-	-	-	-	<3T	-	-	-
56	-	-	-	-	-	33	<3	23	-	5
57	-	-	-	-	-	48	<3	30	-	10
58	-	-	-	-	-	14	-	29	-	-
701	-	-	-	-	-	-	-	-	-	-
749	-	-	-	-	-	-	-	-	-	-
713	-	-	-	-	-	-	-	-	-	-
717	-	-	-	-	-	-	-	-	-	-
721	-	-	-	-	-	-	-	-	-	-

Table B.1. *(continued)*

Station ID	Mercapto-dimethur	Mercury	Methomyl	Methoxy-chlor	Methyl-parathion	Metolachlor	Metribuzin	Molybdenum	Nitrate	Nitrogen, ammonia (NH3)	Nitrogen, Kjeldahl
	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L			mg/L	mg/L
55	-	<0.2T	-	-	-	-	-	-	-	-	-
56	-	<0.2	-	-	-	-	-	-	-	-	-
57	-	<0.2	-	-	-	-	-	-	-	-	-
58	-	-	-	-	-	-	-	-	-	-	-
701	-	-	-	-	-	-	-	-	-	-	-
749	-	-	-	-	-	-	-	-	-	-	-
713	-	-	-	-	-	-	-	-	-	-	-
717	-	-	-	-	-	-	-	-	-	-	-
721	-	-	-	-	-	-	-	-	-	-	-

Table B.1. *(continued)*

Station ID	Nitrogen, Nitrate (NO3) + Nitrite (NO2)	Oxamyl	Paraoxon	Penta-chloro-phenol (PCP)	pH	Phosphorus as P	Phosphorus as P	Picloram	Potassium	Prometone	Propachlor
	mg/L	ug/L	ug/L	ug/L		mg/L	mg/L	ug/L	mg/L	ug/L	ug/L
55	4.31	-	-	-	-	-	-	-	-	-	-
56	0.77	-	-	-	7.6	0.01	-	-	2.9	-	-
57	6.42	-	-	-	7.3	<0.01	-	-	2.5	-	-
58	-	-	-	-	7.6	-	-	-	2.4	-	-
701	-	-	-	-	7.3	-	-	-	-	-	-
749	-	-	-	-	7.3	-	-	-	-	-	-
713	-	-	-	-	7.6	-	-	-	-	-	-
717	-	-	-	-	7.6	-	-	-	-	-	-
721	-	-	-	-	7.5	-	-	-	-	-	-

Table B.1. (continued)

Station ID	Propoxur	Radio-activity, alpha	Radio-activity, beta	Radium-226	Radium-228	Selenium	Sevin	Silica, dissolved	Silver	Silvex	Simazine	Sodium
	ug/L	pCi/L	pCi/L	pCi/L	pCi/L	ug/L	ug/L	mg/L	ug/L	ug/L	ug/L	mg/L
55	-	-	-	-	-	1T	-	-	-	-	-	16
56	-	-	-	-	-	2	-	-	<2	-	-	24
57	-	-	-	-	-	4	-	-	<2	-	-	44
58	-	-	-	-	-	4	-	12	-	-	-	33
701	-	-	-	-	-	-	-	-	-	-	-	-
749	-	-	-	-	-	-	-	-	-	-	-	-
713	-	-	-	-	-	-	-	-	-	-	-	-
717	-	-	-	-	-	-	-	-	-	-	-	-
721	-	-	-	-	-	-	-	-	-	-	-	-

Table B.1. *(continued)*

Station ID	Specific conductance	Sulfate	Sulfur	Sum of Anions	Sum of Cations	Terbufos	Total Suspended Solids (TSS)	trans-Nonachlor	Treflan	Trichloro-phenoxy-acetic acid (2,4,5-T)	Turbidity
	umhos/cm	mg/L	mg/L	mg/L	mg/L	ug/L	mg/L	ug/L	ug/L	ug/L	NTU
55	-	89	-	-	-	-	-	-	-	-	-
56	590	170	-	-	-	-	-	-	-	-	-
57	920	280	-	-	-	-	-	-	-	-	-
58	700	220	-	-	-	-	-	-	-	-	-
701	604	-	-	-	-	-	-	-	-	-	-
749	770	-	-	-	-	-	-	-	-	-	-
713	537	-	-	-	-	-	-	-	-	-	-
717	285	-	-	-	-	-	-	-	-	-	-
721	295	-	-	-	-	-	-	-	-	-	-

Table B.1. *(continued)*

Station ID	Uranium	Vanadium	Zinc	Coliform	E coli	Water Temperature	Data Source
	pCi/L	ug/L	ug/L			°C	
55	-	-	-	-	-	-	UDOH*[1]
56	-	-	120	-	-	7	UDOH*[1]
57	-	-	30	-	-	15	UDOH*[1]
58	-	-	-	-	-	18	USGS*[2]
701	-	-	-	-	-	13.6	UGS[3]
749	-	-	-	-	-	16.3	UGS[3]
713	-	-	-	-	-	15.9	UGS[3]
717	-	-	-	-	-	15.9	UGS[3]
721	-	-	-	-	-	12	UGS[3]

Table B.2. *Utah and EPA primary water-quality standards and analytical method for some chemical constituents sampled in Spanish-Moab Valley, Grand and San Juan County, Utah. U.S. EPA analytical methods are described at http://www.epa.gov/OGWDW/methods/epachem.html.*

CHEMICAL CONSTITUENT	EPA ANALYTICAL METHOD	WATER-QUALITY STANDARD (mg/L)
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
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	0.01
barium	200.7	2.0
cadmium	200.9	0.005
chromium	200.9	0.1
copper	200.7	1.3
lead	200.9	0.015
mercury	245.1	0.002
selenium	200.9	0.05
silver	200.9	0.1
zinc	200.7	5.0
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
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
Alpha, gross	600/4-80-032	15 pCi/L(picocuries per liter)
Beta, gross	600/4-80-032	4 millirems per year
U238MS Fil (Uranium)	600/4-80-032	0.030 mg/L
226Radium	600/4-80-032	5 pCi/L
228Radium	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

Table C.1. *Potential contaminant inventory of Moab-Spanish Valley.*

SITE #	POTENTIAL CONTAMINANT CATEGORY	POTENTIAL CONTAMINANT	LOCATION/SOURCE DESCRIPTION	POLLUTANT
1	AGRICULTURE-ANIMAL	CORRAL	barn, horses, manure stacks	nitrate
2	AGRICULTURE-ANIMAL	GRAZE LAND	pasture with horses	nitrate
3	AGRICULTURE-ANIMAL	GRAZE LAND	pasture with horses, manure stacks	nitrate
4	AGRICULTURE-ANIMAL	CORRAL	corral	nitrate
5	INDUSTRY	INDUSTRY	mini transformer substation	PCB's
6	AGRICULTURE-ANIMAL	ABANDONED CORRAL	abandoned corral	nitrate
7	AGRICULTURE-ANIMAL	GRAZE LANDS	grazing cattle, open broad land	nitrate
8	AGRICULTURE-ANIMAL	GRAZE LANDS	grazing cattle, open broad land	nitrate
9	AGRICULTURE-ANIMAL	GRAZE LANDS	grazing	nitrate
10	MINING	MINING	active gravel pit, mining, bull-dozing equipment	metals, solvents, petroleum
11	AGRICULTURE-ANIMAL	GRAZE LAND	grazing cattle	nitrate
12	MINING	MINING	active gravel mining	metals, solvents, petroleum
13	MINING	MINING	active gravel pit	metals, solvents, petroleum
14	BUSINESS	BUSINESS	rodeo ground, active?, old abandoned tires, bleachers	metals, solvents, nitrate
15	JUNK YARD /SALVAGE	JUNK YARD /SALVAGE	tire dumping ground	metals, solvents
16	INDUSTRY	INDUSTRY	landing strip for airplanes	metals, solvents
17	MINING	MINING	large active gravel pits with the processing plant operations with trucks, equipment, gas tanks, cement grinders, warehouses, storage areas and garages, storage for cars and trucks	metals, solvents, petroleum
18	MINING	MINING	large active gravel pits with the processing plant operations with trucks, equipment, gas tanks, cement grinders, warehouses, storage areas and garages, storage for several cars and trucks	metals, solvents, petroleum
19	BUSINESS	BUSINESS	tire disposal	metals, solvents
20	AGRICULTURE-ANIMAL	CORRAL	large corral, cows and sheep, fenced	nitrate
21	AGRICULTURE-ANIMAL	CORRAL	corral - cows	nitrate
22	AGRICULTURE-ANIMAL	CORRAL	corral - horses	nitrate
23	AGRICULTURE-ANIMAL	ABANDONED CORRAL	abandoned corral	nitrate
24	AGRICULTURE-ANIMAL	CORRAL	corral probably horses and cows, farm equipment - trailers, tractors, hay	nitrate
25	JUNK YARD /SALVAGE	JUNK YARD /SALVAGE	personal junk yard, trailers, vans, boats, campers, canisters, abandoned cars, skimobiles, wooden crates, tractors	metals, solvents, petroleum
26	INDUSTRY	ABANDONED	airport - landing strip with tractors, storage, tires	metals, solvents, petroleum
27	JUNK YARD /SALVAGE	JUNK YARD /SALVAGE	scrap place, warehouse, old gas tanks, old metal cylindrical shaped object, trucks, semi-truck, dump truck, metal scraps	metals, solvents, petroleum
28	AGRICULTURE-ANIMAL	CORRAL	corral	nitrate
29	JUNK YARD /SALVAGE	JUNK YARD /SALVAGE	personal junk yard, cars, trucks, trailers, campers, tires, cars, tractors	metals, solvents, petroleum
30	AGRICULTURE-ANIMAL	CORRAL	corral, vineyard	pesticides

Table C.1. *(continued)*

SITE #	POTENTIAL CONTAMINANT CATEGORY	POTENTIAL CONTAMINANT	LOCATION/SOURCE DESCRIPTION	POLLUTANT
31	AGRICULTURE-PLANT	AGRICULTURE	orchard or a vineyard	pesticides
32	STORAGE TANK	STORAGE TANK	2 gravity driven gas tanks	petroleum
33	STORAGE TANK	STORAGE TANK	2 gravity driven gas tanks	petroleum
34	AGRICULTURE-ANIMAL	CORRAL	corral and fenced area with horses (business)	nitrate
35	JUNK YARD /SALVAGE	JUNK YARD /SALVAGE	personal junk yard with wood, metal scraps, tractor, truck	metals, solvents, petroleum
36	AGRICULTURE-ANIMAL	CORRAL	corral with horses, shed or barn, hay	nitrate
37	STORAGE TANK	STORAGE TANK	5 gravity driven gas tanks	petroleum
38	WASTE DISPOSAL	WASTE DISPOSAL	>100 portable outhouses, within gravel pit grounds	nitrate
39	MINING	MINING	part of gravel pit industries, processing plant	metals, solvents
40	MINING	MINING	gravel and industry, lumber	metals, solvents, petroleum
41	JUNK YARD /SALVAGE	JUNK YARD /SALVAGE	recycle area with junk, junk yard, gravity driven gas tanks, cars	metals, solvents, petroleum
42	INDUSTRY	INDUSTRY	mini- transform station	PCB's
43	AGRICULTURE-ANIMAL	CORRAL	corral, horses, hay (business)	nitrate
44	JUNK YARD /SALVAGE	JUNK YARD /SALVAGE	personal junk yard with cars, trailers, vans	metals, solvents, petroleum
45	STORAGE TANK	STORAGE TANK	warehouse, gravity driven gas tanks	metals, solvents, petroleum
46	MINING	MINING	gravel pit - active, semi-trucks, trailers, tractors, lumber, and trucks	metals, solvents, petroleum
47	MINING	MINING	gravel pit	metals, solvents, petroleum
48	MINING	MINING	mining operation	metals, solvents, petroleum
51	AGRICULTURE-ANIMAL	CORRAL	corral with hay, fenced	nitrate
52	AGRICULTURE-ANIMAL	CORRAL	corral	nitrate
53	AGRICULTURE-ANIMAL	CORRAL	corral with horses	nitrate
54	AGRICULTURE-ANIMAL	CORRAL	corral with a barn, horse trailer, fenced	nitrate
55	MINING	MINING	mining	metals, solvents, petroleum
56	BUSINESS	BUSINESS	storage garage, metal ribbed storage unit, barn?	metals, solvents, petroleum
57	AGRICULTURE-ANIMAL	CORRAL	corral with horses	nitrate
58	AGRICULTURE-ANIMAL	CORRAL	widespread fenced area with horses and cows, grazing	nitrate
59	MEDICAL	MEDICAL	medical center, residential primary care center, or senior citizens	metals, solvents
60	AGRICULTURE-ANIMAL	CORRAL	corral with horses, personal business, small shed, hay stacks	metals, solvents, nitrate
61	AGRICULTURE-ANIMAL	CORRAL	large grazing area for cows, fenced	nitrate
62	AGRICULTURE-ANIMAL	ABANDONED CORRAL	abandoned corral	nitrate
63	AGRICULTURE-ANIMAL	CORRAL	fenced corral	nitrate
64	JUNK YARD /SALVAGE	JUNK YARD /SALVAGE	personal junk yard, cars and trucks, trailer, metal scraps, boat, tires, abandoned	metals, solvents, petroleum
65	AGRICULTURE-ANIMAL	ABANDONED CORRAL	abandoned?animal shelter (sheep or cows?), corral, barn, hay	nitrate
66	AGRICULTURE-ANIMAL	CORRAL	active horse corral with hay	nitrate
67	AGRICULTURE-ANIMAL	CORRAL	corral with horses	nitrate
68	AGRICULTURE-ANIMAL	CORRAL	corral with horses	nitrate

Table C.1. *(continued)*

SITE #	POTENTIAL CONTAMINANT CATEGORY	POTENTIAL CONTAMINANT	LOCATION/SOURCE DESCRIPTION	POLLUTANT
69	LARGE LAWN	NURSERY	greenhouse	nitrate
70	AGRICULTURE-ANIMAL	CORRAL	corral	pesticides
71	AGRICULTURE-ANIMAL	CORRAL	corral, horses	nitrate
72	AGRICULTURE-ANIMAL	CORRAL	barnyard corral	nitrate
73	AGRICULTURE-ANIMAL	CORRAL	corral	nitrate
74	AGRICULTURE-ANIMAL	CORRAL	corral with horses	nitrate
75	MEDICAL	MEDICAL	veterinary clinic	metals, solvents
76	AGRICULTURE-ANIMAL	GRAZE LAND	grazing area with cows	nitrate
77	AGRICULTURE-ANIMAL	CORRAL	sheep corral, grazing	nitrate
78	AGRICULTURE-ANIMAL	CORRAL	corral with horses, barnyard shed, hay	nitrate
79	AGRICULTURE-ANIMAL	CORRAL	corral with horses	nitrate
80	AGRICULTURE-ANIMAL	CORRAL	corral with horses and hay, shed	nitrate
81	AGRICULTURE-ANIMAL	CORRAL	corral with horses, hay, horse trailers	nitrate
82	AGRICULTURE-ANIMAL	AFO	type of fowl (?large cooped black hens)	nitrate
83	AGRICULTURE-ANIMAL	CORRAL	corral with horses, hay, and barns	nitrate
84	AGRICULTURE-ANIMAL	CORRAL	corral with horses, hay, and barns	nitrate
85	AGRICULTURE-ANIMAL	CORRAL	barnyard corral	nitrate
86	AGRICULTURE-ANIMAL	CORRAL	small corral with horses	nitrate
87	AGRICULTURE-ANIMAL	CORRAL	corral, haystacks, fenced	nitrate
88	AGRICULTURE-ANIMAL	CORRAL	farm with llamas and ostriches	nitrate
89	AGRICULTURE-ANIMAL	CORRAL	active corral, horses, sheds, barns, hay, fenced	nitrate
90	AGRICULTURE-ANIMAL	AFO	chickens, hens, coop or housed in barn area	nitrate
91	AGRICULTURE-ANIMAL	CORRAL	corral	nitrate
92	LARGE LAWN	NURSERY	nursery, small business	pesticides
93	AGRICULTURE-ANIMAL	CORRAL	corral, horses	nitrate
94	AGRICULTURE-ANIMAL	CORRAL	active corral with horses, farm equipment, horse trailer	metals, solvents, nitrate
95	AGRICULTURE-ANIMAL	CORRAL	active corral with horses, fenced, hay	metals, solvents, nitrate
96	AGRICULTURE-ANIMAL	CORRAL	small corral with horses	nitrate
97	AGRICULTURE-ANIMAL	CORRAL	corral, barn, horses	nitrate
98	AGRICULTURE-ANIMAL	AFO	ranch with horses and mostly cows	nitrate
99	AGRICULTURE-ANIMAL	CORRAL	area of grazing, cows, fenced	nitrate
100	INDUSTRY	INDUSTRY	industrial complex equipment storage, garage, trailers, drilling supplies	metals, solvents, petroleum
101	STORAGE TANK	STORAGE TANK	gravity driven gas tanks	petroleum
102	BUSINESS	BUSINESS	rodeo grounds, active large facility with long term stalls, overnight boarding stalls, main office, garage, field/track	metals, solvents, petroleum
103	AGRICULTURE-ANIMAL	AFO	chicken coop	nitrate
104	AGRICULTURE-ANIMAL	CORRAL	horses and corral and goats	nitrate

Table C.1. *(continued)*

SITE #	POTENTIAL CONTAMINANT CATEGORY	POTENTIAL CONTAMINANT	LOCATION/SOURCE DESCRIPTION	POLLUTANT
105	BUSINESS	BUSINESS	RV Park	metals, solvents
106	AGRICULTURE-ANIMAL	CORRAL	barns, sheds, associated with rodeo, stalls, corral area	metals, solvents, nitrate
107	AGRICULTURE-ANIMAL	CORRAL	small corral with horses	nitrate
108	AGRICULTURE-ANIMAL	CORRAL	corral with horses, fenced, sheds	nitrate
109	AGRICULTURE-ANIMAL	CORRAL	corral with horses, active	nitrate
110	STORAGE TANK	STORAGE TANK	gravity driven gas tank	petroleum
111	AGRICULTURE-ANIMAL	CORRAL	big barnyard corral	nitrate
112	AGRICULTURE-ANIMAL	CORRAL	corral with horses, haystacks, abandoned trucks, trailers, cars, sprinkler irrigation unit	metals, solvents, petroleum
113	AGRICULTURE-ANIMAL	CORRAL	corral	nitrate
114	AGRICULTURE-PLANT	AGRICULTURE	winery, active	pesticides
115	AGRICULTURE-ANIMAL	CORRAL	small corral with horses	nitrate
116	AGRICULTURE-ANIMAL	CORRAL	corral with horses	nitrate
117	JUNK YARD /SALVAGE	JUNK YARD /SALVAGE	personal junk yard, cars, trailers, school bus, metal scraps, sheds	metals, solvents, petroleum
118	BUSINESS	BUSINESS	small business, with metal scraps, boats, cars	metals, solvents, petroleum
119	AGRICULTURE-ANIMAL	CORRAL	corral with horses, shed	nitrate
120	AGRICULTURE-ANIMAL	ABANDONED CORRAL	abandoned corral	nitrate
121	JUNK YARD /SALVAGE	JUNK YARD /SALVAGE	personal junkyard with cars, wood scraps, trucks, cabs, boats	metals, solvents, petroleum
122	JUNK YARD /SALVAGE	JUNK YARD /SALVAGE	personal junkyard with cars, trucks, boat, trailers, confined	metals, solvents, petroleum
123	AGRICULTURE-ANIMAL	CORRAL	corral with horses, horse trailers, fenced	nitrate
124	LARGE LAWN	LARGE LAWN	grass cemetery	pesticides
125	AGRICULTURE-ANIMAL	CORRAL	corral with horses, hay, fenced	nitrate
126	AGRICULTURE-ANIMAL	AFO	chicken coop	nitrate
127	AGRICULTURE-ANIMAL	CORRAL	corral with horse trailers, horses, sheds	metals, solvents, nitrate
128	AGRICULTURE-ANIMAL	CORRAL	small corral with horses	nitrate
129	AGRICULTURE-ANIMAL	CORRAL	small corral with horses	nitrate
130	AGRICULTURE-ANIMAL	ABANDONED CORRAL	abandoned corral and old cement shed, horse trailers, wood piles	metals, solvents, nitrate
131	JUNK YARD /SALVAGE	JUNK YARD /SALVAGE	abandoned cars, trucks, bikes, cones, equipment, metal scraps, gravity driven gas tanks, tractors	metals, solvents, petroleum
132	AGRICULTURE-ANIMAL	CORRAL	horses and corral	nitrate
133	AGRICULTURE-ANIMAL	CORRAL	corral (chicken coop)	nitrate
135	JUNK YARD /SALVAGE	JUNK YARD /SALVAGE	personal junk yard, jeeps, trash canister, cars, trucks, shells, campers, old station wagon, trailers	metals, solvents, nitrate
136	JUNK YARD /SALVAGE	JUNK YARD /SALVAGE	personal junk yard with campers, boats, cars, campers, trailers, truck cabs, metal canisters, metal casing for drill rigs?, cars, metal scraps	metals, solvents, nitrate
137	BUSINESS	BUSINESS	garage	metals, solvents
138	INDUSTRY	INDUSTRY	substation	PCB's

Table C.1. *(continued)*

SITE #	POTENTIAL CONTAMINANT CATEGORY	POTENTIAL CONTAMINANT	LOCATION/SOURCE DESCRIPTION	POLLUTANT
139	JUNK YARD /SALVAGE	JUNK YARD /SALVAGE	junk yard, cars, station wagons, metal scraps, mini dumping ground, auto junk yard, warehouses, wind mill	metals, solvents, petroleum
140	AGRICULTURE-ANIMAL	CORRAL	corral	nitrate
141	JUNK YARD /SALVAGE	JUNK YARD /SALVAGE	continuation of junk yard in ID139 (separated by power station)	metals, solvents, petroleum
142	BUSINESS	BUSINESS	business, home center	metals, solvents
143	BUSINESS	BUSINESS	business site- office, service, sales, metal scraps, junk, active?	metals, solvents
144	AGRICULTURE-ANIMAL	CORRAL	corral	nitrate
145	JUNK YARD /SALVAGE	JUNK YARD /SALVAGE	junk yard behind garage/shed (may be associated with business), cars, oxygen carrying trucks, trailers	metals, solvents
146	BUSINESS	BUSINESS	drilling company	metals, solvents
147	BUSINESS	BUSINESS	storage, equipment, pipes, water well drilling equipment, petroleum, abandoned cars, trailers	metals, solvents, petroleum
148	AGRICULTURE-ANIMAL	CORRAL	corral with horses	nitrate
149	BUSINESS	BUSINESS	Laundromat and dumping station for sewage disposal	metals, solvents
150	GOVERNMENT	GOVERNMENT	government facility with gravel piles, tractors, asphalt tiles, trailers, road equipment, dumpster, dump truck like equipment	metals, solvents, petroleum
151	AGRICULTURE-ANIMAL	CORRAL	corral with horses	nitrate
152	GOVERNMENT	GOVERNMENT	government facility continuation of site 151 (buildings and garage), some facilities and equipment	metals, solvents, petroleum
153	AGRICULTURE-ANIMAL	CORRAL	corral, horses	nitrate
154	GOVERNMENT	GOVERNMENT	warehouse, cement pipes, PVC pipes, tractors, installation equipment?, metal pipes, scraps	metals, solvents, petroleum
155	AGRICULTURE-ANIMAL	CORRAL	corral with barn, horses, horse trailer	nitrate
156	GOVERNMENT	GOVERNMENT	government, garage	metals, solvents, petroleum
157	LARGE LAWN	LARGE LAWN	golf course - large lawn	pesticides
158	STORAGE TANK	STORAGE TANK	gravity driven gas tank on the golf course	petroleum
159	BUSINESS	BUSINESS	storage/warehouse/garage for golf carts and golf carts	metals, solvents, petroleum
160	AGRICULTURE-ANIMAL	CORRAL	fenced corral	nitrate
161	AGRICULTURE-ANIMAL	CORRAL	corral with horses	nitrate
162	AGRICULTURE-ANIMAL	CORRAL	corral	nitrate
163	AGRICULTURE-ANIMAL	ABANDONED CORRAL	abandoned corral	nitrate
164	AGRICULTURE-ANIMAL	CORRAL	corral with horses (or goats)	nitrate
165	AGRICULTURE-ANIMAL	CORRAL	active corral with horses and hay and horse trucks, trailers, sheds, fenced	nitrate
166	AGRICULTURE-ANIMAL	CORRAL	corral, abandoned?	nitrate
167	LARGE LAWN	LARGE LAWN	park with large lawn	pesticides
168	AGRICULTURE-ANIMAL	CORRAL	corral	nitrate
169	AGRICULTURE-ANIMAL	CORRAL	corral with horses	nitrate

Table C.1. *(continued)*

SITE #	POTENTIAL CONTAMINANT CATEGORY	POTENTIAL CONTAMINANT	LOCATION/SOURCE DESCRIPTION	POLLUTANT
170	AGRICULTURE-ANIMAL	CORRAL	corral with horses and goats	nitrate
171	AGRICULTURE-ANIMAL	CORRAL	corral with horses	nitrate
172	AGRICULTURE-ANIMAL	CORRAL	corral with horses	nitrate
173	AGRICULTURE-ANIMAL	CORRAL	corral with hay and horses, fenced with barns and shed	nitrate
174	AGRICULTURE-ANIMAL	CORRAL	corral with horses and horse trailers	nitrate
175	AGRICULTURE-ANIMAL	CORRAL	corral, horse trailers - no horses	nitrate
176	AGRICULTURE-ANIMAL	CORRAL	abandoned corral with old fences and crates, shed	nitrate
177	AGRICULTURE-ANIMAL	CORRAL	corral with horses and ponies	nitrate
178	BUSINESS	BUSINESS	personal business, storage units	metals, solvents
179	SERVICE STATION	SERVICE STATION	gas station	metals, solvents, petroleum
180	BUSINESS	BUSINESS	RV Park, sewage dumping, Laundromat?	metals, solvents
181	AGRICULTURE	AGRICULTURE	vineyards - small scale	pesticides
182	AGRICULTURE-ANIMAL	CORRAL	corral with horses, fenced	nitrate
183	AGRICULTURE-ANIMAL	CORRAL	active corral with horses, fenced , hay	nitrate
184	AGRICULTURE-ANIMAL	CORRAL	abandoned corral, fenced	nitrate
185	AGRICULTURE-ANIMAL	CORRAL	abandoned corral	nitrate
186	AGRICULTURE-ANIMAL	CORRAL	junk yard, huge	nitrate
187	AGRICULTURE-ANIMAL	CORRAL	active corrals with horses	nitrate
188	AGRICULTURE-ANIMAL	CORRAL	active corrals with horses	nitrate
189	AGRICULTURE-ANIMAL	CORRAL	corral with horses	nitrate
190	JUNK YARD /SALVAGE	JUNK YARD /SALVAGE	personal junk yard with trucks, cabs, trailers, campers, wood and metal scraps, asphalt piles, ripped out campers, tow truck, dump trucks	metals, solvents, petroleum
191	BUSINESS	BUSINESS	pet grooming	metals, solvents
192	JUNK YARD /SALVAGE	JUNK YARD /SALVAGE	personal junk yard with campers, trailers, cars, boats, metal scraps, vans, trucks	metals, solvents, petroleum
193	JUNK YARD /SALVAGE	JUNK YARD /SALVAGE	junk yard /auto supply business- smashed cars, trucks, scraps, metal heap, fenced and occupies more than a block and includes abandoned cars and auto parts	metals, solvents, petroleum
194	BUSINESS	BUSINESS	RV Park	metals, solvents
195	AGRICULTURE-ANIMAL	CORRAL	corral with horses and hay, shed	nitrate
196	AGRICULTURE-ANIMAL	CORRAL	corral with horses and shed, fenced, active	nitrate
197	AGRICULTURE-ANIMAL	CORRAL	corral with horses	nitrate
198	AGRICULTURE	AGRICULTURE	vineyard	pesticides
199	AGRICULTURE	AGRICULTURE	fenced vineyard, next to corral (ID 200), not commercial?	pesticides
200	AGRICULTURE-ANIMAL	CORRAL	goat corral	nitrate

Table C.1. *(continued)*

SITE #	POTENTIAL CONTAMINANT CATEGORY	POTENTIAL CONTAMINANT	LOCATION/SOURCE DESCRIPTION	POLLUTANT
201	JUNK YARD /SALVAGE	JUNK YARD /SALVAGE	person junk yard with wood scraps, pipe, PVC pipe, vans, tractors, cars, trucks, refrigerators	metals, solvents, petroleum
202	JUNK YARD /SALVAGE	JUNK YARD /SALVAGE	personal junk yard, big long trailer/mobile home (trashed), semi-truck cab, machines for ?drilling, trucks, cars, campers, oil canisters, trucks, PVC scraps, rusted cars	metals, solvents, petroleum
203	AGRICULTURE-ANIMAL	CORRAL	corral with horses	nitrate
204	AGRICULTURE-ANIMAL	CORRAL	corral with horses	nitrate
205	MEDICAL	MEDICAL	dental clinic	metals, solvents
206	ABANDONED BUSINESS	ABANDONED BUSINESS	old abandoned personal business, lumber, scraps, feed supply, hay	metals, solvents, nitrate
207	JUNK YARD /SALVAGE	JUNK YARD /SALVAGE	junk on property, gas pump, service station, feed supply and trading post	metals, solvents, petroleum
208	BUSINESS	BUSINESS	personal business, parachute equipment manufacturing, storage units	metals, solvents, petroleum
209	AGRICULTURE-ANIMAL	AFO	chicken coop	nitrate
210	BUSINESS	BUSINESS	furniture supplier, lamination, floor carpet, manufacturer, cabinet shop	metals, solvents, petroleum
211	BUSINESS	BUSINESS	personal business, stored equipment, wooden and metal spools; adjacent to equipment and supplies	metal, solvents
212	JUNK YARD /SALVAGE	JUNK YARD /SALVAGE	posted "Danger Explosives", adjacent to trailer on vacant lot, canisters - plastic and metal, trailer, semi-truck trailer	metals, solvents, petroleum
213	JUNK YARD /SALVAGE	JUNK YARD /SALVAGE	personal junk yard, trailers, plastic cylindrical heaters, trucks, pipes, vans, cars, metal scraps, tires, trailers, old machinery, metal grates, horizontal cylindrical tubes, equipment	metals, solvents, petroleum
214	STORAGE TANK	STORAGE TANK	gravity driven gas tanks	petroleum
215	AGRICULTURE-ANIMAL	CORRAL	corral with horses, barn/shed	nitrate
216	AGRICULTURE-ANIMAL	CORRAL	corral with horses	nitrate
217	AGRICULTURE-ANIMAL	CORRAL	corral with horses	nitrate
218	BUSINESS	BUSINESS	corral, rodeo/supper club, gates and horse-related equipment	metals, solvents, nitrates
219	JUNK YARD /SALVAGE	JUNK YARD /SALVAGE	personal junk yard with cars, trucks, canisters, metal scraps, sheds, equipment, trailers	metals, solvents, petroleum
220	JUNK YARD /SALVAGE	JUNK YARD /SALVAGE	personal junk yard, cars, metal canisters, scraps, trailers, tires, cylinders, campers	metals, solvents, petroleum
221	AGRICULTURE-ANIMAL	CORRAL	corral with horses, hay and sheds	nitrate
222	BUSINESS	BUSINESS	warehouse, garage, storage area	metals, solvents, petroleum
223	BUSINESS	BUSINESS	personal business	metals, solvents
224	BUSINESS	BUSINESS	warehouse/garage and storage facility for boat and rafting company, buses	metals, solvents, petroleum
225	JUNK YARD /SALVAGE	JUNK YARD /SALVAGE	personal junkyard with cars, trailers, metal and wooden scraps	metals, solvents, petroleum
226	AGRICULTURE-ANIMAL	CORRAL	corral with horses	nitrate

Table C.1. *(continued)*

SITE #	POTENTIAL CONTAMINANT CATEGORY	POTENTIAL CONTAMINANT	LOCATION/SOURCE DESCRIPTION	POLLUTANT
227	AGRICULTURE-ANIMAL	ABANDONED CORRAL	abandoned corral and fenced area	metals, solvents, nitrates
228	AGRICULTURE-ANIMAL	CORRAL	corral with horses	nitrate
229	BUSINESS	BUSINESS	personal business with warehouse and trucks	metals, solvents, petroleum
230	JUNK YARD /SALVAGE	JUNK YARD /SALVAGE	junk yard with tractors, trailers, cars, metal cylinders??, metal scraps, cars, campers, tires, metal boxes on trailers, metal scrap yard, tires	metals, solvents, petroleum
231	AGRICULTURE-ANIMAL	CORRAL	corral with horses	nitrate
232	JUNK YARD /SALVAGE	JUNK YARD /SALVAGE	personal junk yard with trailers, trucks, boats, campers, metal and wood scraps, tractor parts	metals, solvents, petroleum
233	JUNK YARD /SALVAGE	BUSINESS JUNK YARD /SALVAGE	business junk yard with cars, trucks, trailers, metal scraps, campers, cabs, dumpsters, cylinders, sheds, warehouses, tires, buses	metals, solvents, petroleum
234	MEDICAL	MEDICAL	medical center	metals, solvents
235	BUSINESS	BUSINESS	foreign car museum with buses and cars sprawling property. 100's of VW's (mostly defunct)	metals, solvents, petroleum
236	SERVICE STATION	SERVICE STATION	buses, warehouse, garage, sprawled cars	metals, solvents, petroleum
237	BUSINESS	BUSINESS	personal business, cabinet making	metals, solvents, petroleum
238	MINING	MINING	gravel pits	metals, solvents, petroleum
239	BUSINESS	BUSINESS	tent manufacturer, teepees	metals, solvents, petroleum
240	AGRICULTURE-ANIMAL	CORRAL	corral	nitrate
241	BUSINESS	BUSINESS	business, storage/ warehouses with junk, tractor, lifts, equipment, metal pipes	metals, solvents, petroleum
242	JUNK YARD /SALVAGE	JUNK YARD /SALVAGE	junk yard area with jeeps, trucks, piles of dirt, storage warehouses, tractors, trailers, campers, ATV's, scraps of metal, truck parts, fenced	metals, solvents, petroleum
243	AGRICULTURE-ANIMAL	CORRAL	corral with horses	nitrate
244	AGRICULTURE-ANIMAL	CORRAL	abandoned? corral with shed, gates, manure, horse trailers	metals, solvents, nitrates
245	BUSINESS	ABANDONED BUSINESS	abandoned business (blockaded), junk, vans and cars, tires, motorcycles, old ovens, metal scraps	metals, solvents, petroleum
246	BUSINESS	BUSINESS	TV VCR Repair	metals, solvents, petroleum
247	JUNK YARD /SALVAGE	JUNK YARD /SALVAGE	ditch filled with junk, campers, trailers, truck beds, trucks, blazer, vans, metal scraps, tires, cars below water tower tank	metals, solvents, petroleum
248	BUSINESS	BUSINESS	personal business, storage units	metals, solvents
249	JUNK YARD /SALVAGE	BUSINESS JUNK YARD /SALVAGE	business- junk yard, abandoned smashed down cars, vans, jeeps, trucks; warehouse	metals, solvents, petroleum
250	STORAGE TANK	STORAGE TANK	two or three gas pumps, abandoned antiques, engine parts	metals, petroleum
251	AGRICULTURE-ANIMAL	CORRAL	corral with horses	nitrate
252	JUNK YARD /SALVAGE	JUNK YARD /SALVAGE	personal junk yard, metal scraps, cars, trucks, trailers, wood scraps, tires	metals, solvents, petroleum
253	AGRICULTURE-ANIMAL	CORRAL	corral with horses	nitrate

Table C.1. *(continued)*

SITE #	POTENTIAL CONTAMINANT CATEGORY	POTENTIAL CONTAMINANT	LOCATION/SOURCE DESCRIPTION	POLLUTANT
254	AGRICULTURE-ANIMAL	CORRAL	corral with horses	nitrate
255	AGRICULTURE-ANIMAL	CORRAL	corral with horses	nitrate
256	JUNK YARD /SALVAGE	JUNK YARD /SALVAGE	personal junk yard, trailers, wooden shack, metal shack, tires, trucks, campers, cars, old equipment - cement mixer, canister, pipe, metal	metals, solvents, petroleum
257	STORAGE TANK	STORAGE TANK	gravity driven gas tanks	petroleum
258	AGRICULTURE-ANIMAL	CORRAL	corral with horses	nitrate
259	JUNK YARD /SALVAGE	JUNK YARD /SALVAGE	junk yard with small shed, former junk dealer?, cars, parts	metals, solvents, petroleum
260	BUSINESS	BUSINESS	storage/garage for vans, trailers, buses, cars, rafting/kayak, hiking exploring adventures	metals, solvents, petroleum
261	BUSINESS	BUSINESS	rental hauling trucks	metals, solvents, petroleum
262	JUNK YARD /SALVAGE	JUNK YARD /SALVAGE	cars, cylinders, scraps, dump trucks	metals, solvents, petroleum
263	BUSINESS	BUSINESS	business - truck rentals with trucks, cranes, dump trucks	metals, solvents, petroleum
264	BUSINESS	BUSINESS	business - trucks and equipment	metals, solvents, petroleum
265	JUNK YARD /SALVAGE	JUNK YARD /SALVAGE	landfill transfer station -business with scraps of cars- compressed, refrigerators, fenced	metals, solvents, petroleum
266	BUSINESS	BUSINESS	lab	metals, solvents
267	BUSINESS	BUSINESS	business- shop	metals, solvents
268	AGRICULTURE-ANIMAL	CORRAL	Corral - horses, hay, sheds	nitrate
269	BUSINESS	BUSINESS	personal business - truck and trailer parking/storage - barn/ garage	metals, solvents, petroleum
270	AGRICULTURE-ANIMAL	ABANDONED CORRAL	abandoned corral	nitrate
271	INDUSTRY	INDUSTRY	industry - concrete equipment and trucks	metals, solvents, petroleum
272	JUNK YARD /SALVAGE	JUNK YARD /SALVAGE	personal flea market? fenced with corrugated metal, trucks, abandoned trailers, piles of rocks and debris, equipment, metal scraps, mattresses, truck cabs, rubbish, trailer	metals, solvents, petroleum
273	BUSINESS	BUSINESS	personal printing business (T-shirts?)	metals, solvents, petroleum
274	JUNK YARD /SALVAGE	BUSINESS JUNK YARD /SALVAGE	private junk yard, gulley filled with junk - semi-trucks, truck trailers, camper trailer, trucks, metal , buses	metals, solvents, petroleum
275	BUSINESS	BUSINESS	block long junk with cranes, dumpster, ?government related, storage, tractors, trailers, buses, vans, bulldozer?	metals, solvents, petroleum
276	AGRICULTURE-PLANT	AGRICULTURE	vineyards	pesticides
277	BUSINESS	BUSINESS	campground	petroleum, solvents
278	STORAGE TANK	STORAGE TANK	abandoned gas/service station with pumps, petroleum (propane) storage tanks	metals, solvents, petroleum
279	BUSINESS	BUSINESS	tire company - truck tires	metals, solvents, petroleum
280	JUNK YARD /SALVAGE	JUNK YARD /SALVAGE	junk scattered, tires, cars	metals, solvents, petroleum

Table C.1. *(continued)*

SITE #	POTENTIAL CONTAMINANT CATEGORY	POTENTIAL CONTAMINANT	LOCATION/SOURCE DESCRIPTION	POLLUTANT
281	BUSINESS	BUSINESS	business - rental, plumbing, paint, supplies, electrical tools, lawn and garden, pipes, warehouse	metals, solvents, petroleum
282	AGRICULTURE-ANIMAL	CORRAL	corral with horses	nitrate
283	JUNK YARD /SALVAGE	JUNK YARD /SALVAGE	personal junk yard, trailer for semi-trucks, stove, crates, pallets, cement mixer, tractor, ashes from burning residue, pipes, swing set, metal cylinders	metals, solvents, petroleum
284	MINING	MINING	gravel pits	metals, solvents, petroleum
285	LARGE LAWN	LARGE LAWN	cemetery with grass	pesticides
286	INDUSTRY	INDUSTRY	power substation	metals, solvents, petroleum
287	AGRICULTURE-PLANT	AGRICULTURE	orchard or a vineyard	pesticides
288	AGRICULTURE-ANIMAL	CORRAL	corral with horses	nitrate
289	AGRICULTURE-ANIMAL	CORRAL	corral with horses	nitrate
290	AGRICULTURE-ANIMAL	CORRAL	corral with horses	nitrate
291	BUSINESS	BUSINESS	vacant business, upholstery, upholstery supplies, storage trailer	metals, solvents, petroleum
292			excavation business- large trucks, equipment, trailers, gravel pit	metals, solvents, petroleum
293	LARGE LAWN	LARGE LAWN	large lawn	pesticides
294	BUSINESS	BUSINESS	kennel	metals, solvents, petroleum
295	AGRICULTURE-PLANT	AGRICULTURE	orchard or a vineyard	pesticides
296	LARGE LAWN	LARGE LAWN	large lawn with school and ball park area	pesticides
297	JUNK YARD /SALVAGE	JUNK YARD /SALVAGE	recycle center- wood, glass, clear plastic, aluminum cans, office paper, newspaper, colored paper	metals, solvents, petroleum
298	JUNK YARD /SALVAGE	JUNK YARD /SALVAGE	land fill, dump	metals, solvents, petroleum
299	JUNK YARD /SALVAGE	JUNK YARD /SALVAGE	major industry recycling plant	metals, solvents, petroleum
300	GOVERNMENT	GOVERNMENT	mosquito abatement property	metals, solvents, petroleum
301	BUSINESS	BUSINESS	personal business - teepee/tent manufacturing?, tent/lumber poles, canvas, garage with trucks and equipment	metals, solvents, petroleum
302	AGRICULTURE-ANIMAL	CORRAL	corral with horses and hay, shed, goats, and sheep	nitrate
303	AGRICULTURE-ANIMAL	CORRAL	corral with horses	nitrate
304	AGRICULTURE-ANIMAL	CORRAL	pasture land with cows - fenced - grazing	nitrate
305	AGRICULTURE-ANIMAL	CORRAL	corral with horses	nitrate
306	GOVERNMENT	GOVERNMENT	garage storage facility for school buses, drivers ed cars, equipment	metals, solvents, petroleum
307	AGRICULTURE-ANIMAL	CORRAL	corral with horses, fenced, hay	nitrate
308	AGRICULTURE-ANIMAL	CORRAL	corral with horses	nitrate
309	BUSINESS	BUSINESS	tire service center	metals, solvents, petroleum
310	BUSINESS	BUSINESS	home furnishings	metals, solvents, petroleum
311	BUSINESS	BUSINESS	appliance center	metals, solvents, petroleum
312	BUSINESS	BUSINESS	dumping ground with warehouse, massive cylinders carried on semi-trucks, crates, metal scraps, pipes, trailers, trucks, wooden spools	metals, solvents, petroleum

Table C.1. *(continued)*

SITE #	POTENTIAL CONTAMINANT CATEGORY	POTENTIAL CONTAMINANT	LOCATION/SOURCE DESCRIPTION	POLLUTANT
313	SERVICE STATION	SERVICE STATION	former gas/service station	metals, solvents, petroleum
314	AGRICULTURE-ANIMAL	CORRAL	corral with horses, fenced	nitrate
315	BUSINESS	BUSINESS	business or industrial service, warehouse with canisters, several petroleum storage tanks	metals, solvents, petroleum
316	BUSINESS	BUSINESS	sprawled over two properties - warehouse with pipes, equipment, dump trucks, garages	metals, solvents, petroleum
317	BUSINESS	BUSINESS	bike tour company	metals, solvents, petroleum
318	BUSINESS	BUSINESS	storage sheds	metals, solvents, petroleum
319	BUSINESS	BUSINESS	automotive	metals, solvents, petroleum
320	BUSINESS	BUSINESS	feed place (store)	metals, solvents, petroleum
321	BUSINESS	BUSINESS	meat shop	metals, solvents, petroleum
322	BUSINESS	BUSINESS	garage	metals, solvents, petroleum
323	BUSINESS	BUSINESS	garage with buses and trailers	metals, solvents, petroleum
324	BUSINESS	BUSINESS	dealer of livestock handling equipment	metals, solvents, petroleum
325	BUSINESS	BUSINESS	warehouses, garages, wood shop	metals, solvents, petroleum
326	BUSINESS	BUSINESS	heating and air conditioning business	metals, solvents, petroleum
327	BUSINESS	BUSINESS	continuation of ID 325 warehouse but fewer contaminants (radio ?)	metals, solvents, petroleum
328	JUNK YARD /SALVAGE	JUNK YARD /SALVAGE	junk yard - personal, cars, sheds, motors for boats, boats, campers, tires, trucks, vans, semi-truck, towing, metal scraps, chickens	metals, solvents, petroleum
329	BUSINESS	BUSINESS	mail strip business, including a nail salon	metals, solvents, petroleum
330	BUSINESS	BUSINESS	business	metals, solvents, petroleum
331	BUSINESS	BUSINESS	storage sheds	metals, solvents, petroleum
332	BUSINESS	BUSINESS	Laundromat	metals, solvents, petroleum
333	BUSINESS	BUSINESS	car wash	metals, solvents, petroleum
334	BUSINESS	BUSINESS	ATV's, vans, trucks, fenced	metals, solvents, petroleum
335	GOVERNMENT	GOVERNMENT	government with garages, 2 gas tanks, equipment, snow plows	metals, solvents, petroleum
336	GOVERNMENT	GOVERNMENT	government with dump-trucks, garages, recycling pickup, metal canisters, gravel piles - for sewer or water system, pipes, trucks	metals, solvents, petroleum
337	AGRICULTURE-ANIMAL	CORRAL	corral with hay, barn	nitrate
338	BUSINESS	BUSINESS	gas mini-station with sheds (contaminants?), cylinders with petroleum?	metals, solvents, petroleum
339	BUSINESS	BUSINESS	government facilities?, fork lifts, trucks, hay, dumping ground, wooden palettes, metal cylinders, spools, irrigation pipes, transfer station?	metals, solvents, petroleum
344	BUSINESS	BUSINESS	warehouse with palettes, studio	metals, solvents, petroleum
345	AGRICULTURE	AGRICULTURE	orchard	pesticides
346	BUSINESS	BUSINESS	ranch, stables and barns	metals, solvents, petroleum

Table C.1. *(continued)*

SITE #	POTENTIAL CONTAMINANT CATEGORY	POTENTIAL CONTAMINANT	LOCATION/SOURCE DESCRIPTION	POLLUTANT
347	SERVICE STATION	SERVICE STATION	gas/service station, mini-market, diesel gas	metals, solvents, petroleum
348	MEDICAL	MEDICAL	dental clinic	metals, solvents
349	MEDICAL	MEDICAL	medical hospital	metals, solvents
350	MEDICAL	MEDICAL	physical therapy and medical center	metals, solvents
351	AGRICULTURE-ANIMAL	CORRAL	corral with horses	nitrate
352	AGRICULTURE-ANIMAL	CORRAL	corral with horses	nitrate
353	BUSINESS	BUSINESS	personal business, warehouse, chains, equipment, tires, palettes, sheet metal, canisters, oxygen tanks, cylinders, chemical supplies?	metals, solvents, petroleum
354	BUSINESS	BUSINESS	continuation of ID 353 warehouse but fewer contaminants	metals, solvents, petroleum
355	AGRICULTURE-ANIMAL	CORRAL	corral with horses	nitrate
356	WASTE DISPOSAL	WASTE DISPOSAL	sewage disposal treatment	nitrate
357	AGRICULTURE-ANIMAL	CORRAL	corral with horses	nitrate
358	BUSINESS	BUSINESS	large metal canisters, buses and trailers for rafts and boats, semi-trucks, truck parts, fueling station?	metals, solvents, petroleum
359	BUSINESS	BUSINESS	continuation of 358	metals, solvents, petroleum
360	AGRICULTURE-PLANT	AGRICULTURE	orchard	pesticides
361	BUSINESS	BUSINESS	equipment for rafting expeditions, garages, boats, fuel tanks?	metals, solvents, petroleum
362	AGRICULTURE-ANIMAL	CORRAL	corral with horses	nitrate
363	GOVERNMENT	GOVERNMENT	canisters, equipment, trucks, government? (road paving? project)	metals, solvents, petroleum
364	BUSINESS	BUSINESS	mortuary	metals, solvents, petroleum
365	MEDICAL	MEDICAL	dog and cat clinic -veterinarian	metals, solvents
366	SERVICE STATION	SERVICE STATION	gas station	metals, solvents, petroleum
367	BUSINESS	BUSINESS	printing company	metals, solvents, petroleum
368	BUSINESS	BUSINESS	auto parts	metals, solvents, petroleum
369	MEDICAL	MEDICAL	medical center	metals, solvents
370	BUSINESS	BUSINESS	hardware store	metals, solvents, petroleum
371	BUSINESS	BUSINESS	car wash	metals, solvents, petroleum
372	BUSINESS	BUSINESS	camp ground with disposal station	metals, solvents, petroleum
373	SERVICE STATION	SERVICE STATION	gas station	metals, solvents, petroleum
374	BUSINESS	BUSINESS	car wash	metals, solvents, petroleum
375	BUSINESS	BUSINESS	Laundromat	metals, solvents, petroleum
376	GOVERNMENT	GOVERNMENT	government fire center	metals, solvents, petroleum
377	BUSINESS	BUSINESS	storage units	metals, solvents
378	MEDICAL	MEDICAL	chiropractic and rehab	metals, solvents
379	AGRICULTURE-ANIMAL	CORRAL	corral with horses	nitrate
380	BUSINESS	BUSINESS	car dealership	metals, solvents, petroleum

Table C.1. *(continued)*

SITE #	POTENTIAL CONTAMINANT CATEGORY	POTENTIAL CONTAMINANT	LOCATION/SOURCE DESCRIPTION	POLLUTANT
381	BUSINESS	BUSINESS	car dealership	metals, solvents, petroleum
382	SERVICE STATION	SERVICE STATION	gas station	metals, solvents, petroleum
383	MINING	MINING	uranium mining operation - tailings piles	metals, solvents, petroleum
384	MINING	MINING	uranium mining operation - tailings piles	metals, solvents, petroleum
385	MINING	MINING	uranium operation -water pond that serves tailings pile	metals, solvents, petroleum
386	MINING	MINING	uranium mining operation - tailings piles	metals, solvents, petroleum
387	MINING	MINING	industrial complex	metals, solvents, petroleum
388	INDUSTRY	INDUSTRY	sub station	PCB's
389	LARGE LAWN	LARGE LAWN	large lawn	pesticides
390	STORAGE TANK	STORAGE TANK	2 gravity driven gas tanks	petroleum
391	BUSINESS	BUSINESS	auto shop, motor tune-up, brakes, carburetor, muffler, repair shop	metals, solvents, petroleum
392	LARGE LAWN	LARGE LAWN	large lawn	pesticides
393	MEDICAL	MEDICAL	medical clinic	metals, solvents
394	LARGE LAWN	LARGE LAWN	large lawn	pesticides
395	BUSINESS	BUSINESS	on the map as a large blocked out area of small businesses along most of Main Street (HWY 191), including print shops, gifts shops, service stations, barber shops, etc	solvents, metals
396	LARGE LAWN	LARGE LAWN	large lawn	pesticides
397	LARGE LAWN	LARGE LAWN	large lawn	pesticides
398	MEDICAL	MEDICAL	dentistry	metals, solvents
399	AGRICULTURE-ANIMAL	GRAZE LAND	pasture land, active, cows grazing, not confined	nitrate
400	BUSINESS	BUSINESS	RV Park, tents, trailers, sewage dumping, Laundromat	metals, solvents
401	BUSINESS	BUSINESS	RV Park, tents and trailers, sewage, Laundromat, swimming pool	metals, solvents
402	BUSINESS	BUSINESS	RV Park, trucks and trailer	metals, solvents
403	WASTE DISPOSAL	WASTE DISPOSAL	park, not large lawn, outhouses	nitrate
404	STORAGE TANK	STORAGE TANK	gravity driven gas tanks	petroleum
405	BUSINESS	BUSINESS	industrial operation with cars	metals, solvents, petroleum
406	BUSINESS	BUSINESS	gas station	metals, solvents, petroleum
407	BUSINESS	BUSINESS	used car lot	metals, solvents, petroleum
408	STORAGE TANK	STORAGE TANK	storage tank	petroleum
409	BUSINESS	BUSINESS	brewery? outlet with pallets, tires, tractor, storage, supplier?	metals, solvents, petroleum
410	JUNK YARD /SALVAGE	JUNK YARD /SALVAGE	personal junk yard, abandoned cars and trucks, vans	metals, solvents, petroleum
411	AGRICULTURE-ANIMAL	CORRAL	corral	nitrate
412	AGRICULTURE-ANIMAL	CORRAL	corral	nitrate

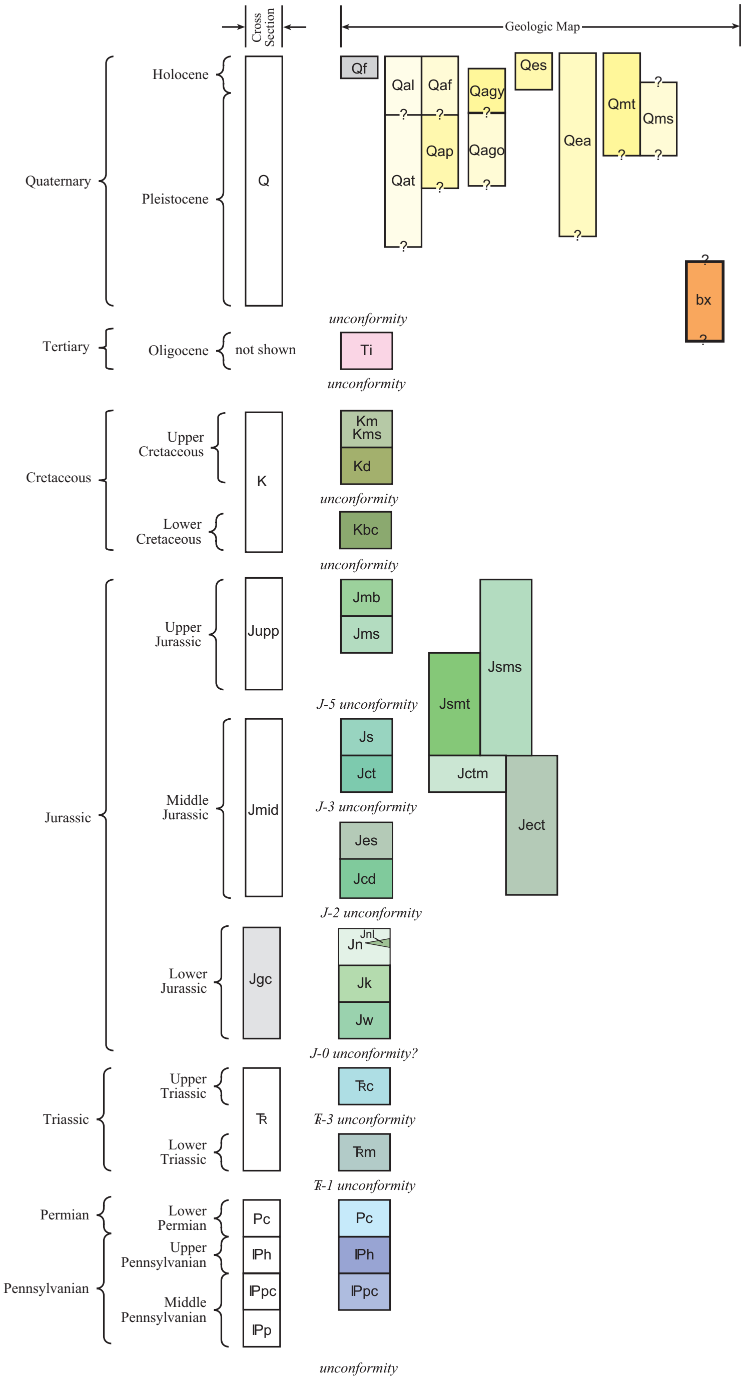
APPENDIX D

DESCRIPTION AND CORRELATION OF MAP UNITS

Geologic Unit Description and Correlation

Geologic unit descriptions and correlation are compiled and summarized from Doelling and others (2002) and Doelling (2001, 2004). For detailed unit descriptions see original sources.

CORRELATION OF GEOLOGIC UNITS



Description of Geologic Units

Qf	Artificial fill: Clay to boulder to size material; locally up to 21 meters (70 ft) thick; latest Holocene.
Qal	Stream alluvium: Sand, silt, clay, and gravel; thickness varies but commonly less than 12 meters (40 ft); Holocene.
Qes	Eolian sand: Fine to coarse unconsolidated sand in dunes and thin sheets; typically less than 15 meters (50 ft) thick; Holocene.
Qea	Mixed eolian and alluvial deposits: Eolian sand deposits with interspersed alluvial gravels, sands, and silts; variable thickness typically less than 12 meters (40 ft); Holocene to middle Pleistocene.
Qaf	Alluvial to fan deposits: Poorly sorted sand, gravel, and cobbles; thickness generally less than 15 meters (40 ft); Holocene to upper Pleistocene.
Qagy	Younger alluvial gravel deposits: Alluvial gravel; includes middle to level terrace deposits up to 7.5 meters (25 ft) thick; Holocene to upper Pleistocene.
Qago	Older alluvial gravel deposits: Alluvial gravel; includes upper to level terrace deposits up to 7.5 meters (25 ft) thick; upper Pleistocene.
Qap	Pediment deposits: Alluvial gravel, cobbles, and boulders; deposited as alluvial fans on flanks of the La Sal Mountains; up to 9 meters (30 ft) thick; upper Pleistocene.
Qat	Terrace deposits: Cobbles, gravel, sand, silt, and clay; caps high benches and mesas including Johnsons up-on-top; typically less than 5 meters (16 ft) thick; middle to upper Pleistocene.
Qmt	Talus deposits: Angular debris including blocks, boulders, gravel, and sand; typically less than 5 meters (16 ft) thick: Holocene to upper Pleistocene.
Qms	Slumps and landslides: Hummocky deposits and slumped material; most common on slopes of the Jurassic Morrison Formation; variable thickness; Holocene to upper Pleistocene.
bx	Collapse breccia pipes: Broken and brecciated rock masses bounded by near vertical circular faults; breccia has been displaced downward up to several hundred feet; breccia contains clasts from overlying and adjacent rocks and is commonly reduced; age unknown, probably Tertiary to Quaternary.
Q	Undivided unconsolidated deposits: includes all unconsolidated deposits; shown only on cross sections; Quaternary.
Ti	La Sal Mountain intrusives: Trachyte and ryholite; intruded as laccoliths, dikes, and sills; dated at 25 to 28 Ma.
Km, Kms	Mancos Shale: Marine shale, lesser siltstone and sandstone; (Kms) is a locally mappable calcareous sandstone 60 to 120 meters thick (200-400 ft); Mancos shale is incompletely exposed, up to 7509 meters (2500 ft) thick; Upper Cretaceous.
Kd	Dakota Sandstone: Sandstone, conglomerate, and interbedded mudstone and shale; thickness varies from 30 to 60 meters (100-200 ft); Cretaceous.
Kbc	Burro Canyon Formation: Sandstone, conglomerate, and mudstone; thickness averages 38 meters (125 ft); Lower Cretaceous.
K	Undivided Cretaceous: includes all Cretaceous units; shown only on cross sections; Cretaceous.
Jmb	Brushy Basin Member of Morrison Formation: Siltstone, mudstone, lessor sandstone conglomerate, minor limestone; 76 to 150 meters (250-500 ft) thick; Upper Jurassic.
Jms	Salt Wash Member of Morrison Formation: Sandstone, siltstone, and mudstone, minor limestone and conglomerate; 58 to 120 meters (190-400 ft) thick; Upper Jurassic.
Jsmt	Tidwell Member of Morrison Formation and Summerville Formation, undivided: Silty sandstone, siltstone, and minor interbedded limestone; 3 to 15 meters (10-50 ft) thick; Jurassic.
Jsms	Summerville and Morrison Formations, undivided: Mapped in areas of poor exposure; sandstone, siltstone, and mudstone; Jurassic.
Jupp	Undivided Upper Jurassic: includes all members of Morrison Formation and Summerville Formation; shown only on cross sections; Upper Jurassic.
Jctm	Moab Member of Curtis Formation: Fine- to medium-grained cliff forming sandstone; 24 to 34 meters (80-110 ft); Jurassic.
Jes	Slick Rock Member of Entrada Sandstone: Fine- to medium-grained cliff forming sandstone; 18 to 95 meters (60-310 ft) thick; Middle Jurassic.
Ject	Slick Rock Member of Entrada Sandstone and Moab Member of Curtis Formation, undivided: Mapped in areas of structural complexity and poor exposure; Middle Jurassic.
Jcd	Dewey Bridge Member of Carmel Formation: Fine-grained sandstones and siltstones; 6 to 24 meters (20-80 ft) thick; Middle Jurassic.

Jmid	Undivided Middle Jurassic: includes Moab Member of Curtis Formation, Slick Rock Member of Entrada Sandstone, and Dewey Bridge Member of Carmel Formation; shown only on cross sections; Middle Jurassic.
Jn Jnl	Navajo Sandstone: Fine to to medium to grained sandstone; cross to bedded; (Jnl) is locally present thin limestone interbeds; Navajo Sandstone thickness 80 to 215 meters (275-700 ft); Lower Jurassic.
Jk	Kayenta Formation: Medium-grained sandstone, thin interbeds of fine-grained sandstone, siltstone, and claystone; 18 to 110 meters (60-360 ft); Lower Jurassic.
Jw	Wingate Sandstone: Fine-grained sandstone; cross-bedded; 67 to 130 meters (220-420 ft); Lower Jurassic.
Jgc	Glen Canyon Group: includes Navajo Sandstone, Kayenta Formation, and Wingate Sandstone; Lower Jurassic.
TRc	Chinle Formation: Sandstone, siltstone, conglomeratic sandstone, and mudstone; 120 to 140 meters (400-450ft) thick; Upper Triassic.
TRm	Moenkopi Formation: Fine-grained sandstone and siltstone, thin beds of claystone; 27 to 37 meters thick (90-120 ft) thick; Triassic.
TR	Undivided Triassic: includes Chinle Formation and Moenkopi Formation; shown only on cross sections; Triassic.
Pc	Cutler Formation: Arkosic sandstone, siltstone, and conglomerate; 120 to 1500 m (400-5,000 ft) thick; Lower Permian.
IPh	Honaker Trail Formation: Limestone, dolomite, sandstone, and mudstone; 0 to 700 meters (0-2,400 ft) thick; Upper Pennsylvanian.
IPpc	Paradox Formation caprock: Gypsum, black shale, dolomite, sandstone; insoluble remnants of Paradox Formation exposed at the surface; thickness highly variable as much as 213 meters (700 ft); Middle Pennsylvanian.
IPp	Paradox Formation: Gypsum, black shale, dolomite, sandstone; interbedded marine evaporites and shales; shown only on cross sections; thickness highly variable due salt flowage during Late Pennsylvanian to Lower Jurassic; 90 to 3,000+ meters (300-10,000+ ft) thick; Middle Pennsylvanian.

APPENDIX E

CROSS SECTION, STRUCTURE CONTOUR, AND ISOPACH MAP METHODS AND DATA

Based on existing well and geophysical data, few constraints exist for the structural geometry of the Glen Canyon Group where it lies buried beneath Moab-Spanish Valley. Therefore, the cross sections presented display a hypothetical geometry of the Glen Canyon Group beneath Moab-Spanish Valley. We used surficial geology from Doelling and others (2002) and Doelling (2001, 2004), and structural studies by Ge and others (1996), Olig and others (1996), and Foxford and others (1996) of the Moab fault to construct six cross sections transverse to the valley axis along Moab-Spanish Valley (plate 3). We drew a cross section parallel to the valley axis, through the immediate hanging wall of the Moab fault based on these six cross sections and three additional cross sections near Moab compiled from Doelling and others (2002) and Doelling (2001) (plate 3). Interpretations of all units beneath the Glen Canyon Group are speculative but gravity data and fault kinematics of the Moab fault (Ge and others, 1996; Olig and others, 1996) suggest a salt anticline at depth. Thickness of units overlying the salt anticline is unconstrained by existing well data, but it is assumed that units of Triassic, Permian, and Pennsylvanian age thin over the salt anticline crest and thicken along its margins. Similar unit thinning has been documented for these units nearby (Doelling, 1988; Doelling and others, 1988).

We drew structure contours for the top of the Glen Canyon Group (plate 4) from geologic map contacts and compiled structure contours from Doelling (2001, 2004). Structure contours beneath Moab-Spanish Valley are based on limited well data shown in tables E.1 and E.2 and cross sections (plate 3).

The valley-fill isopach map, presented on plate 6, is based on water well logs and several petroleum wells. Water wells and petroleum wells used for the isopach are shown in tables E.1 and E.2 and plates 1 and 6.

Thickness of the Glen Canyon Group beneath Spanish Valley was calculated from the structure contour and valley-fill isopach data using ArcGIS Spatial Analyst. Actual thickness may vary, but plate 5 provides a baseline for likely bedrock aquifer thickness beneath Moab-Spanish Valley. Further geophysical investigation of Moab-Spanish Valley is warranted to better constrain Glen Canyon Group thickness and geometry.

Table E.1. *Selected water wells used for this study.*

PLS Location[1]	Easting[2]	Northing[2]	Valley Fill Depth (ft)[3]
N900 E1710 SW 27 25S 21E SL	622660	4272712	82+
N890 E1720 SW 27 25S 21E SL	622663	4272708	64+
N900 E1720 SW 27 25S 21E SL	622663	4272712	83+
N1640 E2040 SW 27 25S 21E SL	622761	4272937	63+
N1630 E2050 SW 27 25S 21E SL	622764	4272934	64+
N1640 E2050 SW 27 25S 21E SL	622764	4272937	63+
S2130 E2205 NW 27 25S 21E SL	622784	4273409	63+
S2120 E2215 NW 27 25S 21E SL	622787	4273412	64+
S2650 E2640 NW 27 25S 21E SL	622916	4273250	64+
N1850 E1180 SW 07 26S 22E SL	627401	4268276	61+
N1800 E1200 SW 07 26S 22E SL	627407	4268261	61+
N1840 E1220 SW 07 26S 22E SL	627413	4268273	66+
S3850 E580 NW 27 25S 21E SL	622288	4272885	304+
S3010 E980 NW 27 25S 21E SL	622410	4273141	120+
S2020 E2190 NW 27 25S 21E SL	622779	4273442	205+
S1100 E2600 NW 27 25S 21E SL	622904	4273723	120+
S680 E2600 NW 27 25S 21E SL	622904	4273851	85+
S1080 E2700 NW 27 25S 21E SL	622935	4273729	153
N3100 W2400 SE 27 25S 21E SL	623023	4273408	53+
N360 W2855 SE 26 25S 21E SL	624502	4272600	84+
N345 W2853 SE 26 25S 21E SL	624502	4272595	35+
N240 W1960 SE 26 25S 21E SL	624774	4272563	53+
N650 E1870 SW 27 25S 21E SL	622709	4272635	62+
N660 E1870 SW 27 25S 21E SL	622709	4272638	61+
N2400 W1500 SE 34 25S 21E SL	623313	4271586	150+
N250 E500 SW 26 25S 21E SL	623907	4272539	64
N709 W985 E4 01 26S 21E SL	626710	4270321	300+
N233 W794 E4 35 25S 21E SL	625137	4271750	60+
N680 E1804 SW 27 25S 21E SL	622689	4272644	45+
N688 E1836 SW 27 25S 21E SL	622698	4272647	50+

PLS Location[1]	**Easting**[2]	**Northing**[2]	**Valley Fill Depth (ft)**[3]
N683 E1884 SW 27 25S 21E SL	622713	4272645	45+
N1022 E1937 SW 27 25S 21E SL	622729	4272749	45+
N1050 E1940 SW 27 25S 21E SL	622730	4272757	35+
N1628 E2148 SW 27 25S 21E SL	622793	4272933	60+
N350 W1200 SE 16 26S 22E SL	630700	4266096	100+
S600 E2200 W4 15 26S 22E SL	631723	4266605	8
S100 E2000 W4 15 26S 22E SL	631662	4266757	120
N2170 E1785 SW 15 26S 22E SL	631610	4266651	10
N2000 W130 S4 15 26S 22E SL	631830	4266598	1
N1835 W100 S4 15 26S 22E SL	631839	4266547	1
0 W3000 E4 01 26S 21E SL	626096	4270105	104+
N815 W360 SE 07 26S 22E SL	628521	4267998	93+
N945 E570 SW 36 25S 21E SL	625561	4271156	78+
S950 E545 NW 01 26S 21E SL	625553	4270579	117+
S945 E115 NW 01 26S 21E SL	625422	4270580	115+
N310 E80 S4 07 26S 22E SL	627861	4267825	8
N35 W1390 E4 15 26S 22E SL	632240	4266801	7
S150 W1100 N4 17 26S 22E SL	629101	4267726	160
N1150 W880 E4 01 26S 21E SL	626742	4270455	100
N560 E430 W4 15 26S 22E SL	631183	4266959	10
N280 E105 SW 16 26S 22E SL	630302	4266050	200+
N1510 W220 SE 07 26S 22E SL	628564	4268210	75+
N1325 E25 SW 07 26S 22E SL	627049	4268116	100
S362 E861 W4 06 26S 22E SL	627273	4269994	128+
S1471 E706 N4 01 26S 21E SL	626410	4270436	60+
S1320 E1340 W4 08 26S 22E SL	629038	4268050	42
S100 E565 W4 36 25S 21E SL	625552	4271649	98+
N550 E720 SW 16 26S 22E SL	630490	4266132	150+
N1720 W360 SE 07 26S 22E SL	628521	4268274	39+
S1168 E983 W4 06 26S 22E SL	627310	4269749	59+
N613 W1122 E4 07 26S 22E SL	628287	4268728	123
S1286 W518 NE 17 26S 22E SL	630084	4267402	2
S1750 E1280 N4 01 26S 21E SL	626585	4270351	8+
S133 E380 W4 06 26S 22E SL	627126	4270064	30+
S740 E788 NW 07 26S 22E SL	627259	4269083	59+
N1261 W1379 SE 15 26S 22E SL	632253	4266371	25
N624 W1225 SE 15 26S 22E SL	632300	4266177	18
N200 E1921 W4 15 26S 22E SL	631638	4266849	30
S625 W2168 NE 35 25S 21E SL	624711	4272300	48+
S700 E940 N4 02 26S 21E SL	624865	4270648	162+
N1279 E1498 SW 16 26S 22E SL	630727	4266354	50
S812 E143 NW 07 26S 22E SL	627063	4269061	125+
S211 E543 NW 22 26S 22E SL	631232	4265925	68
N3350 W2505 SE 17 26S 22E SL	629504	4267185	154
N2111 W1094 S4 07 26S 22E SL	627503	4268374	105+
S3306 E451 N4 17 26S 22E SL	629574	4266764	201
N438 E1481 SW 08 26S 22E SL	629082	4267883	168+
S1014 E608 N4 01 26S 21E SL	626380	4270576	70+
S125 W2340 E4 17 26S 22E SL	629541	4266941	211+
S300 W220 NE 02 26S 21E SL	625320	4270777	90+
N1520 E145 SW 22 26S 22E SL	631134	4264823	87+
N1645 E420 SW 22 26S 22E SL	631218	4264861	127
N750 W770 SE 07 26S 22E SL	628396	4267978	115
S1470 E95 N4 20 26S 22E SL	629497	4265707	55
N1420 W210 SE 07 26S 22E SL	628567	4268182	56
0 E500 W4 22 26S 22E SL	631231	4265175	185+
N460 E80 SW 08 26S 22E SL	628655	4267890	117+
N12 W999 E4 35 25S 21E SL	625075	4271683	81+
N904 W1205 S4 36 25S 21E SL	625827	4271160	103+

PLS Location[1]	Easting[2]	Northing[2]	Valley Fill Depth (ft)[3]
S725 W1050 E4 36 26S 22E SL	635647	4261793	50
S240 W950 E4 36 26S 22E SL	635678	4261940	120
N50 E293 W4 36 26S 22E SL	634449	4261998	210+
N35 W1628 E4 35 26S 22E SL	633864	4261993	210+
N935 E870 SW 21 26S 22E SL	630562	4264620	14
N675 E525 SW 21 26S 22E SL	630457	4264541	96
S720 W1720 E4 26 26S 22E SL	633808	4263379	105
S550 E2290 W4 26 26S 22E SL	633419	4263403	230+
N360 E1270 W4 26 26S 22E SL	633108	4263681	147
N1350 W940 SE 20 26S 22E SL	630011	4264747	60
S1500 W1600 NE 22 26S 22E SL	632186	4265530	98
N1150 E825 W4 21 26S 22E SL	630536	4265495	211
N50 E830 SW 23 26S 22E SL	632958	4264400	79
S2350 W50 NE 20 26S 22E SL	630252	4265448	205
N950 W1160 SE 26 26S 22E SL	633990	4263084	109
N1100 E950 SW 21 26S 22E SL	630587	4264671	14
N1000 E160 W4 26 26S 22E SL	632770	4263876	105
S1328 W1040 NE 21 26S 22E SL	630753	4265569	176+
N850 E230 W4 26 26S 22E SL	632791	4263830	193+
N400 W510 E4 35 26S 22E SL	634204	4262104	192
N500 W1500 SE 35 26S 22E SL	633919	4261323	295
N1039 E2203 W4 35 26S 22E SL	633424	4262272	210
S1510 E2380 W4 26 26S 22E SL	633447	4263111	140+
N1050 E200 S4 26 26S 22E SL	633601	4263100	174
N1000 W1005 E4 35 26S 22E SL	634053	4262287	200
S1260 E1102 NW 01 27S 22E SL	634712	4260787	130
S484 E836 NW 21 26S 22E SL	630526	4265807	67+
N1090 E530 SW 21 26S 22E SL	630459	4264667	230
S582 W304 NE 27 26S 22E SL	632612	4264207	82
S225 W1400 E4 36 26S 22E SL	635541	4261945	105
S175 W325 E4 36 26S 22E SL	635868	4261960	75
S240 W950 E4 36 26S 22E SL	635678	4261940	115
S225 W1100 E4 36 26S 22E SL	635632	4261945	105
S807 W2901 E4 36 26S 22E SL	635083	4261768	60
N982 W2392 SE 36 26S 22E SL	635249	4261505	233
S38 W866 NE 22 26S 22E SL	632409	4265975	16
N91 E231 S4 22 26S 22E SL	631968	4264400	84+
S550 W900 N4 35 26S 22E SL	633266	4262612	211+
S370 W650 N4 35 26S 22E SL	633342	4262667	211+
S1285 E665 N4 20 26S 22E SL	629671	4265763	85
N910 W1822 E4 26 26S 22E SL	633777	4263875	12
N75 W1705 E4 20 26S 22E SL	629763	4265272	135
N765 W565 E4 27 26S 22E SL	632548	4263809	136
N2040 W480 SE 20 26S 22E SL	630151	4264957	220+
N1575 E380 SW 21 26S 22E SL	630413	4264815	305+
N1670 E440 S4 26 26S 22E SL	633674	4263289	226
N1895 W795 SE 20 26S 22E SL	630055	4264913	320+
S625 E555 NW 21 26S 22E SL	630440	4265764	220
S1309 W1603 NE 35 26S 22E SL	633855	4262395	205+
S695 W1020 E4 36 26S 22E SL	635656	4261802	50
S260 W225 E4 36 26S 22E SL	635899	4261934	75
S895 W200 E4 36 26S 22E SL	635906	4261741	200
N70 W820 SE 22 26S 22E SL	632455	4264406	130+
N110 W680 E4 21 26S 22E SL	630873	4265201	120+
N1030 W900 S4 26 26S 22E	633265	4263093	192+
N1090 E530 SW 21 26S 22E	630458	4267889	90
N110 W40 E4 27 26S 22E	632708	4263608	90+
N1150 W340 S4 15 26S 22E	631766	4266338	98
N130 E330 SW 16 26S 22E	630371	4266003	238

PLS Location[1]	Easting[2]	Northing[2]	Valley Fill Depth (ft)[3]
N1303 E133 W4 01 27S 22E	634434	4260749	105
N1318 E234 SW 8 26S 22E	628702	4268151	145+
N1320 E660 SW 26 26S 22E	632937	4263168	209+
N1325 E25 SW 07 26S 22E	627049	4268116	100
N1350 E1430 SW 26 26S 22E	633172	4263177	185+
N1364 E370 S4 36 26S 22E	635289	4261604	105
N1800 E1200 SW 07 26S 22E	627407	4268261	61+
N1840 E1220 SW 07 26S 22E	627413	4268273	66+
N1850 E1180 SW 07 26S 22E	627401	4268276	61+
N1895 E500 SW 01 27S 22E	634564	4260111	0+
N2240 E1136 SW 01 27S 22E	634757	4260216	175
N240 W1960 SE 26 25S 21E	624774	4272563	53+
N2570 W1400 SE 2 26S 21E	624975	4270061	169+
N285 W380 E4 2 26S 21E	625278	4270160	93+
N300 E335 W4 26 26S 22E	632823	4263662	268+
N333 E840 S4 36 26S 22E	635432	4261290	230
N345 W2853 SE 26 25S 21E	624502	4272595	35+
N360 W2855 SE 26 25S 21E	624501	4272599	84+
N438 E1481 SW 8 26S 22E	629082	4267883	168+
N460 E80 SW 08 26S 22E	628655	4267889	117+
N500 E1000 SW 36 26S 22E	634680	4261323	305+
N500 E325 SW 06 26S 22E	627118	4269460	57+
N527 W1526 E4 26 26S 22E	633867	4263758	8
N613 W1122 E4 07 26S 22E	628287	4268728	123+

[1] = *PLS location from water rights database*
[2] = *easting, northing coordinates are in NAD 27 UTM zone 12 N*
[3] = *Depth to bedrock interpreted from well logs*

Table E.2. *Selected petroleum wells used for this study.*

API	#ID	Well name	Northing[1]	Easting[1]	Notes
430371019	A	MULESHOE UNIT 1	4250925	642852	Bottom of Glen Canyon Group at ~1437 meters
430193011	B	CSO-FED WEAVER 1	4263844	630669	Bottom of Glen Canyon Group at ~1025 meters
430192040	C	GREAT LAKES CARBON CORP 1	4270962	625279	Valley-fill to 320 feet no Glen Canyon Group
430191158	D	WESTERN ALLIED OIL CO 1	4269092	626427	Valley-fill to 200 feet no Glen Canyon Group

[1] = *easting, northing coordinates are in NAD 27 UTM zone 12 N*

APPENDIX F

METHODS OF OUTCROP FRACTURE DATA ACQUISITION AND ANALYSIS

We collected fracture data for the Glen Canyon Group at outcrop sites along the eastern margin of Moab-Spanish Valley using the scan line technique of Lapointe and Hudson (1985). Jointing is the dominant mode of fracturing found at outcrop in the Glen Canyon Group and all further references to fracture data will describe joint parameters. At most sites, we examined two scan lines and measured joint orientation, trace length, aperture, mineral infilling, joint termination, and geometry along the length of each scan line (table 2, F.1.).

Table F.1. *Fracture data used for this study.*

Fracture site	UTM	location[1]	Number of fractures measured	Minimum trace length (m)	Maximum trace length (m)	Average aperture (mm)
1	635289	4265206	86	0.80	15.6	0.51
2	638912	4260625	40	0.60	11.6	0.9
3	639474	4260249	34	0.53	10.7	0.97
4	638810	4260159	70	0.30	11.6	0.92
5	638922	4259425	36	0.76	3.8	0.2
6	633363	4265282	55	0.68	15.8	1.12
7	633172	4265595	38	0.70	14.0	0.90
8	635344	4262499	94	0.34	21.6	0.45
9	636391	4261264	45	0.42	8.5	0.17
10	637027	4261145	61	0.48	9.7	0.7
11	637089	4261640	47	0.85	8.4	0.75
12	635329	4265605	40	0.49	9.8	0.29
13	633042	4266327	67	0.64	17.3	0.39
14	634824	4262870	56	0.39	6.7	1.26
15	629722	4269265	34	0.17	6.8	1.47
16	633784	4264061	35	0.35	7.3	1.94
17	634207	4263709	59	0.32	7.9	1.64
18	636170	4261798	51	0.17	4.1	0.73
19	638545	4260224	55	0.10	9.4	1.70
20	637901	4260216	45	0.10	2.3	0.88
21	629450	4268615	61	0.07	3.4	1.49
22	629009	4268704	42	0.14	4.4	1.44
23	623051	4274147	63	0.70	5.5	3.3
24	622794	4274044	58	0.23	6.0	3.1
25	622367	4273802	41	0.07	3.5	1.1

[1] *= easting, northing coordinates are in NAD 27 UTM zone 12 N*

We created stereonet plots of joint orientation for each fracture site and used to display the orientation and deviation of principal, secondary, and ternary joint sets shown in table 2. The orientation of principal joint sets may directly correlate to the direction of maximum joint based permeability, but is often biased based on the scan line technique (Priest and Hudson, 1981). Because of the potential for sampling bias an additional measure of the geometric character of a fracture set is warranted (Zhang and Sanderson, 1995).

A 2-D geometric anisotropy factor (A_f), for each site with data from at least 2 scan lines, was calculated using the method of Zhang and Sanderson (1995) and the following equation:

$$A_f = limit_{(L_x \to \infty,\ L_y \to \infty)} \frac{\frac{1}{L_x}\sum_{i=1}^{n_x} \sin \gamma i}{\frac{1}{L_y}\sum_{j=1}^{n_y} \sin \gamma j}$$

where:
Lx is scan line length in the x direction
Ly is scan line length in the y direction
nx is the number of fractures intersected along x direction
ny is the number of fractures intersected along y direction
γ is the angle between a fracture trace intersecting a scan line and the scan line

Calculation of the anisotropy factor yields a mathematical solution for the geometric properties of joint orientation and trace length relative to scan line orientation (Zhang and Sanderson, 1995). Scan lines are generally oriented perpendicular to principal joint sets, therefore geometric anisotropy factor describes anisotropy of a given fracture set relative to the principal joint orientations. Calculated anisotropy represents the relative ratio of maximum and minimum orientational bias of a fracture set (Zhang and Sanderson, 1995). These unit minima and maxima anisotropy values can be used to plot a geometric anisotropy ellipse which is then oriented long-axis parallel to the principal joint set. Below (figure F.1) is an example of ellipses drawn for different values of A_f, principal joint set is parallel to the y axis for both examples.

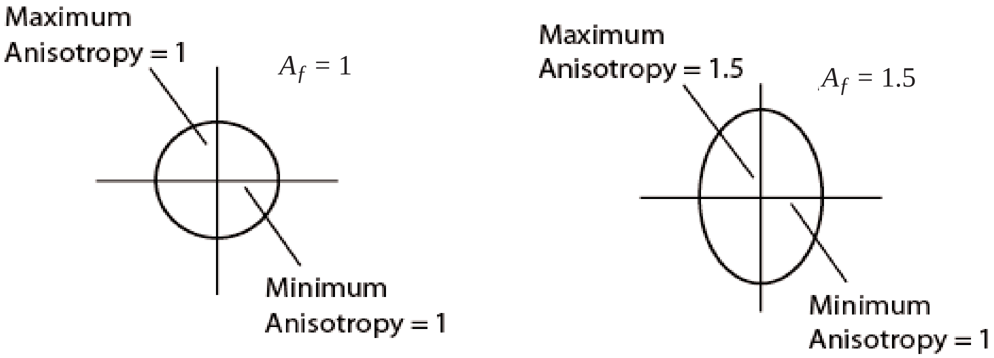


Figure F.1. *Anisotropy ellipse example.*

The anisotropy ellipse is a graphical estimation of the orientation and relative magnitude of the permeability tensor based on jointing measured at each site. Ellipses are shown for each site on plate 2. Anisotropy ellipses, joint stereo plots, and joint densities provide several unique parameters, which can be used to assess the relative impact of joint sets on permeability and hydraulic conductivity.

Orientation and magnitude of the geometric anisotropy factor is related to the measured permeability anisotropy of a fractured rock mass via a power law equation dependent on local site conditions (Zhang and Sanderson, 1995). Outcrop scale fracture parameters including anisotropy, density, and aperture, can directly correlate with aquifer characteristics such as hydraulic conductivity at nearby wells (Hurlow, 1998).

2-D joint density for each outcrop data set was calculated using the technique of Lapointe and Hudson (1985). For detailed description of the equations used see Lapointe and Hudson (1985). Joint density calculated by this technique is dependent primarily on orientation and trace length of joint sets. Density calculated with this technique is essentially limited to the plane of fracture measurement. Joint density can vary depending on the plane of outcrop examined (Lapointe and Hudson, 1985).

Lack of adequate pump test data from the fractured rock aquifer near the measurement sites precluded a numeric correlation of joint data with wellhead conditions in Moab-Spanish Valley. Without a numeric solution mean values from the fracture data set likely are the best proxy for fracture condition at the wellhead (table 3). Future pump test data from the fractured Glen Canyon Group aquifer can be correlated with the joint data presented in the report to provide a numeric solution between measured joint characteristics and well head conditions.

Methods of Remote Lineament Analysis

Three orthorectified image sets of Moab-Spanish Valley and surrounding areas (Digital Ortho Photo Quads [DOPQ]), rectified TM Landsat, and full-color orthophoto (table F.2) were examined for lineaments in Glen Canyon Group exposures (table F.2). Lineaments were digitized directly on each imagery set and then analyzed using ArcGIS Spatial Analyst for orientation and density.

Photo set pixel resolution ranged from 30 m (98 ft) for the Landsat image to less than 1 m (3.28 ft) for the color orthophoto imagery of Moab-Spanish Valley (table F.2). Both the DOPQ and Landsat images cover the entire study area and are appropriate for regional joint zone correlation and analysis. Color orthophoto image (figure 5) covers the valley floor and adjoining bedrock exposures northeast of Moab-Spanish Valley. This imagery set is most relevant to the fracture characteristics of existing and future wells completed in Moab-Spanish Valley and is described in the text. The DOPQ and Landsat image sets provide regional coverage of Glen Canyon Group exposures surrounding the study area and correlation with the color orthophoto image.

Table F.2. *Lineament summary used for this study.*

Image set	DOPQ[1]	TM Landsat[2]	ColorOrtho[3]
pixel resolution (m)	1-4	30	< 1
maximum lineament length (km)	1.2	2.0	1.1
minimum lineament length (m)	2.4	124	3.9
area examined (km^2)	432	432	210
Maximum lineament density (m/m^2)	0.021	0.007	0.036
number of lineaments	3690	571	5178

Image sources

[1] *Digital ortho quads available at http://agrc.its.state.ut.us*
[2] *Thematic Mapper Landsat images available at http://earth.gis.usu.edu/*
[3] *Color ortho-photo image from Utah Division of Water Rights*

Lineaments are linear trends of like-colored pixels on the photo sets (figure 5). Lines defining each lineament were digitized over each image set. Cruikshank and Aydin (1995) noted a direct correlation between lineaments and joint zones in exposures of the Slick Rock Member of the Entrada Formation in Arches National Park. Field investigations of lineaments digitized by this study also found a correlation between lineaments and joint zones. Other lineaments correspond to alignments of vegetation including bushes and trees. It is assumed that increased permeability and water availability produced by underlying joints zones creates these alignments (Gustafsson, 1994; Mabee and others, 1994).

Maps of lineament density were created for each set of imagery using ArcGIS spatial analyst. Density values are dependent on the resolution of the imagery set analyzed; calculated density increases with decreased pixel size, and is therefore different in magnitude for each imagery set (table F.2).

Comparison of lineament trends and densities across Landsat and DOPQ image sets shows a good spatial correlation between the two data sets. Comparison of individual lineaments across image sets shows good correlation between the colorortho image and the DOPQ image. Not all lineaments correlated across image sets. It is assumed that lineaments that do not correlate may be produced by specific characteristics of a photo set.

APPENDIX G

RECORDS OF WATER WELLS USED TO DELINEATE RECHARGE AND DISCHARGE AREAS

Table G.1. *Records of water wells used to delineate recharge and discharge areas in Moab-Spanish Valley. Data are from Utah Division of Water Rights (2005).*

Site #	Local well number or spring name	Northing	Easting	Year well drilled	Elevation (ft)	Total depth	Water level (ft)	Recharge type	Top of confining layer (ft)	Bottom of confining layer (ft)	Bedrock completion
1	(D-25-21) 27cdb	622660	4272712	2000	3970	82	11	P	—	—	3
2	(D-25-21) 27cdb	622663	4272708	2000	3970	64	11	P	—	—	3
3	(D-25-21) 27cdb	622663	4272712	2000	3970	83	11	P	—	—	3
4	(D-25-21) 27cad	622761	4272937	2000	3965	63	11	P	—	—	3
5	(D-25-21) 27cad	622764	4272934	2000	3965	64	11	P	—	—	3
6	(D-25-21) 27cad	622764	4272937	2000	3965	63	11	P	—	—	3
7	(D-25-21) 27bdd	622784	4273409	2000	3971	63	11	P	—	—	3
8	(D-25-21) 27caa	622916	4273250	2000	3961	64	11	P	—	—	3
9	(D-26-22) 7cbd	627401	4268276	2000	4155	61	51	P	—	—	3
10	(D-26-22) 7cbd	627407	4268261	2000	4156	61	51	P	—	—	3
11	(D-26-22) 7cbd	627413	4268273	2000	4155	66	51	P	—	—	3
12	(D-25-21) 27cbc	622288	4272885	2002	3939	304	100	P	—	—	3
13	(D-25-21) 27cba	622410	4273141	2002	3939	120	97	P	—	—	3
14	(D-25-21) 27bdd	622779	4273442	2002	3972	205	9	P	—	—	3
15	(D-25-21) 27bad	622904	4273723	2002	3985	120	12	P	—	—	3
16	(D-25-21) 27bad	622904	4273851	2002	3996	85	34	S	31	56	3
17	(D-25-21) 27abc	622935	4273729	2002	3984	181	24	P	—	—	3
18	(D-25-21) 26cdd	624502	4272600	2002	3974	84	13	P	—	—	3
19	(D-25-21) 26cdd	624502	4272595	2002	3974	35	13	P	—	—	3
20	(D-25-21) 26dcd	624774	4272563	2002	3997	53	30	P	—	—	3
21	(D-25-21) 27cdb	622709	4272635	2003	3965	60	12	P	—	—	3
22	(D-25-21) 27cdb	622709	4272638	2003	3965	61	12	P	—	—	3
23	(D-25-21) 34dba	623313	4271586	2003	3955	150	—	P	—	—	3
24	(D-25-21) 26ccc	623907	4272539	2003	3953	64	—	P	—	—	3
25	(D-26-21) 1adb	626710	4270321	2002	4047	300	—	S	90	140	3
26	(D-25-21) 35adc	625137	4271750	2003	3984	60	13	P	—	—	3
27	(D-25-21) 27cdb	622689	4272644	2004	3967	45	25	P	—	—	3
28	(D-25-21) 27cdb	622698	4272647	2004	3966	50	25	P	—	—	3
29	(D-25-21) 27cdb	622713	4272645	2004	3965	45	25	P	—	—	3
30	(D-25-21) 27cdb	622729	4272749	2004	3963	45	25	P	—	—	3
31	(D-25-21) 27cdb	622730	4272757	2004	3963	35	25	P	—	—	3
32	(D-25-21) 27cad	622793	4272933	2004	3961	60	25	P	—	—	3
33	(D-26-22) 16ddc	630700	4266096	1975	4463	100	41	S	41	63	3
34	(D-26-22) 15caa	631723	4266605	1978	4561	140	80	P	—	—	1
35	(D-26-22) 15caa	631662	4266757	1980	4559	305	65	P	—	—	1
36	(D-26-22) 15cab	631610	4266651	1976	4538	147	—	P	—	—	1
37	(D-26-22) 15caa	631830	4266598	1976	4569	103	65	P	—	—	1
38	(D-26-22) 15cad	631839	4266547	1976	4565	108	60	P	—	—	1
39	(D-26-21) 1bdd	626096	4270105	1976	4006	104	—	P	—	—	3
40	(D-26-22) 7dda	628521	4267998	1969	4210	93	25	P	—	—	3
41	(D-25-21) 36ccb	625561	4271156	1979	3992	78	20	P	—	—	3
42	(D-26-21) 1bbc	625553	4270579	1977	3993	117	22	P	—	—	3
43	(D-26-21) 1bbc	625422	4270580	1976	3989	115	22	P	—	—	3
44	(D-26-22) 7dcc	627861	4267825	1979	4298	105	47	P	—	—	2

Site #	Local well number or spring name	Northing	Easting	Year well drilled	Elevation (ft)	Total depth	Water level (ft)	Recharge type	Top of confining layer (ft)	Bottom of confining layer (ft)	Bedrock completion
45	(D-26-22) 15acd	632240	4266801	1977	4637	205	—	P	—	—	1
46	(D-26-22) 17bab	629101	4267726	1979	4264	160	—	S	10	35	3
47	(D-26-21) 1adb	626742	4270455	1978	4055	100	20	S	70	90	3
48	(D-26-22) 15bcc	631183	4266959	1978	4523	140	—	P	—	—	1
49	(D-26-22) 16ccc	630302	4266050	1974	4470	200	50	S	170	200	3
50	(D-26-22) 7dad	628564	4268210	1979	4185	75	17	P	—	—	3
51	(D-26-22) 7cbc	627049	4268116	1978	4190	130	95	P	80	100	3
52	(D-26-22) 6cba	627273	4269994	1955	4092	128	—	P	—	—	3
53	(D-26-21) 1aca	626410	4270436	1955	4027	60	65	P	—	—	3
54	(D-26-22) 8cdb	629038	4268050	1979	4203	105	—	P	—	—	2
55	(D-25-21) 36cbb	625552	4271649	1979	4001	98	25	P	—	—	3
56	(D-26-22) 16ccd	630490	4266132	1980	4459	150	40	S	120	150	3
57	(D-26-22) 7dad	628521	4268274	1982	4178	39	19	P	—	—	3
58	(D-26-22) 6cbd	627310	4269749	1955	4090	59	—	P	—	—	3
59	(D-26-22) 7adb	628287	4268728	1961	4159	123	11	P	—	—	3
60	(D-26-22) 17aad	630084	4267402	1975	4314	80	36	P	—	—	1
61	(D-26-21) 1aca	626585	4270351	1982	4038	68	18	P	—	—	2
62	(D-26-22) 6cbb	627126	4270064	1956	4077	30	—	P	—	—	3
63	(D-26-22) 7bbd	627259	4269083	1956	4088	59	23	P	—	—	3
64	(D-26-22) 15dca	632253	4266371	1969	4599	181	54	P	—	—	1
65	(D-26-22) 15ddc	632300	4266177	1975	4585	450	32	P	—	—	2
66	(D-26-22) 15bdc	631638	4266849	1992	4563	132	—	P	—	—	1
67	(D-25-21) 35abb	624711	4272300	1991	3971	48	—	P	—	—	3
68	(D-26-21) 2abd	624865	4270648	1994	3973	162	8	P	—	—	3
69	(D-26-22) 16ddb	630727	4266354	1977	4416	240	6	P	76	115	3
70	(D-26-22) 22bbb	631232	4265925	2003	4453	68	18	P	—	—	3
71	(D-26-22) 17acb	629504	4267185	1961	4362	154	126	P	16	79	3
72	(D-26-22) 7cab	627503	4268374	1968	4146	105	—	P	—	—	3
73	(D-26-22) 17dbb	629574	4266764	1961	4426	206	80	S	6	69	1
74	(D-26-22) 8cdc	629082	4267883	1963	4232	168	—	P	—	—	3
75	(D-26-21) 1abc	626380	4270576	1979	4027	70	28	P	—	—	3
76	(D-26-22) 17dbb	629541	4266941	1963	4407	211	—	P	—	—	3
77	(D-26-21) 2aaa	625320	4270777	1997	3985	90	5	P	—	—	3
78	(D-26-22) 22cbc	631218	4264861	1977	4568	160	—	P	—	—	1
79	(D-26-22) 7ddb	628396	4267978	1978	4215	115	—	P	—	—	3
80	(D-26-22) 20abc	629497	4265707	1972	4564	220	150	P	—	—	1
81	(D-26-22) 7dad	628567	4268182	1977	4188	70	26	P	—	—	3
82	(D-26-22) 22bcc	631231	4265175	1971	4538	185	62	P	—	—	3
83	(D-26-22) 8ccc	628655	4267890	1971	4220	117	48	S	12	36	3
84	(D-25-21) 36cdb	625827	4271160	1978	4006	103	22	P	—	—	3
85	(D-26-22) 36dac	635647	4261793	2001	4852	285	210	P	—	—	1
86	(D-26-22) 36dab	635678	4261940	2001	4882	325	212	P	—	—	1
87	(D-26-22) 36bcc	634449	4261998	2004	4764	210	150	P	—	—	3
88	(D-26-22) 35acd	633864	4261993	1961	4738	210	140	P	—	—	3
89	(D-26-22) 21cca	630562	4264620	1979	4638	213	170	P	—	—	1
90	(D-26-22) 21ccb	630457	4264541	1980	4647	260	161	S	70	96	1
91	(D-26-22) 26dbd	633808	4263379	1985	4707	171	—	P	—	—	1
92	(D-26-22) 26caa	633419	4263403	1978	4669	230	103	P	—	—	3
93	(D-26-22) 26bcd	633108	4263681	1979	4641	205	—	P	—	—	1

Site #	Local well number or spring name	Northing	Easting	Year well drilled	Elevation (ft)	Total depth	Water level (ft)	Recharge type	Top of confining layer (ft)	Bottom of confining layer (ft)	Bedrock completion
94	(D-26-22) 20ddb	630011	4264747	1978	4706	400	250	P	—	—	1
95	(D-26-22) 22aca	632186	4265530	1978	4536	115	33	P	—	—	2
96	(D-26-22) 23ccd	632958	4264400	1979	4617	100	58	P	—	—	1
97	(D-26-22) 20add	630252	4265448	1980	4532	260	—	P	—	—	1
98	(D-26-22) 26ddb	633990	4263084	1979	4707	200	130	P	—	—	1
99	(D-26-22) 21cca	630587	4264671	1980	4638	210	165	P	—	—	1
100	(D-26-22) 26bcb	632770	4263876	1981	4617	105	60	P	—	—	3
101	(D-26-22) 21aac	630753	4265569	2000	4515	176	34	P	—	—	3
102	(D-26-22) 26bcb	632791	4263830	1985	4620	193	49	P	—	—	3
103	(D-26-22) 35add	634204	4262104	1980	4753	192	155	P	—	—	3
104	(D-26-22) 35dcd	633919	4261323	1977	4767	295	239	P	—	—	3
105	(D-26-22) 35bda	633424	4262272	1961	4718	210	140	P	—	—	3
106	(D-26-22) 26cda	633447	4263111	1978	4680	140	110	P	—	—	3
107	(D-26-22) 26dcb	633601	4263100	1991	4684	174	—	S	90	120	3
108	(D-26-22) 35adb	634053	4262287	1992	4742	208	—	P	—	—	1
109	(D-27-22) 1bbd	634712	4260787	1994	4842	510	306	P	—	—	1
110	(D-26-22) 21bba	630526	4265807	1973	4490	67	42	P	—	—	3
111	(D-26-22) 21ccb	630459	4264667	1998	4629	90	—	P	—	—	3
112	(D-26-22) 27aaa	632612	4264207	1995	4602	82	27	P	—	—	3
113	(D-26-22) 36dba	635541	4261945	2000	4852	280	230	P	—	—	1
114	(D-26-22) 36daa	635868	4261960	2001	4889	345	247	P	—	—	1
115	(D-26-22) 36dab	635678	4261940	2001	4882	325	212	P	—	—	1
116	(D-26-22) 36dab	635632	4261945	2000	4872	280	230	P	—	—	1
117	(D-26-22) 36cad	635083	4261768	2002	4808	300	182	P	—	—	1
118	(D-26-22) 36dcb	635249	4261505	1995	4830	360	204	P	—	—	1
119	(D-26-22) 22aab	632409	4265975	1961	4580	100	16	P	—	—	1
120	(D-26-22) 22dcc	631968	4264400	1962	4587	84	—	P	—	—	3
121	(D-26-22) 35bab	633266	4262612	1973	4696	211	—	P	—	—	3
122	(D-26-22) 35bab	633342	4262667	1973	4696	211	—	P	—	—	3
123	(D-26-22) 20abd	629671	4265763	1973	4556	260	—	P	—	—	2
124	(D-26-22) 26aca	633777	4263875	2001	4718	305	117	P	—	—	1
125	(D-26-22) 20acd	629763	4265272	1978	4612	280	132	P	—	—	2
126	(D-26-22) 27ada	632548	4263809	1976	4620	136	—	P	—	—	3
127	(D-26-22) 20dad	630151	4264957	1977	4641	220	—	P	—	—	1
128	(D-26-22) 21cbc	630413	4264815	1979	4613	305	183	P	—	—	3
129	(D-26-22) 26dbc	633674	4263289	1979	4691	235	104	P	—	—	1
130	(D-26-22) 20dac	630055	4264913	1980	4649	320	206	P	85	150	3
131	(D-26-22) 21bbb	630440	4265764	1976	4495	250	62	P	—	—	1
132	(D-26-22) 35abd	633855	4262395	1961	4725	205	135	P	—	—	3
133	(D-26-22) 36dac	635656	4261802	2003	4853	285	235	P	—	—	1
134	(D-26-22) 36daa	635899	4261934	2001	4883	345	221	P	—	—	1
135	(D-26-22) 36dad	635906	4261741	2002	4894	425	236	P	—	—	1
136	(D-26-22) 22ddc	632455	4264406	1960	4581	130	21	P	—	—	3
137	(D-26-22) 21add	630873	4265201	1973	4549	120	112	P	—	—	3
138	(D-26-22) 26cdb	633265	4263093	1982	4673	192	—	P	—	—	3
139	(D-26-22) 27add	632708	4263608	2003	4632	90	55	P	—	—	3
140	(D-26-22) 15cda	631766	4266338	1978	4547	183	53	P	—	—	1
141	(D-26-22) 16ccc	630371	4266003	1976	4476	238	—	P	—	—	3
142	(D-27-22) 1bcb	634434	4260749	1998	4832	325	189	P	—	—	1

Site #	Local well number or spring name	Northing	Easting	Year well drilled	Elevation (ft)	Total depth	Water level (ft)	Recharge type	Top of confining layer (ft)	Bottom of confining layer (ft)	Bedrock completion
143	(D-26-22) 8cbc	628702	4268151	1963	4194	145	86	S	61	85	2
144	(D-26-22) 26cca	632937	4263168	1970	4655	209	80	P	—	—	3
145	(D-26-22) 7cbc	627049	4268116	1978	4190	130	95	P	80	100	3
146	(D-26-22) 26cdb	633172	4263177	1982	4663	185	110	P	—	—	3
147	(D-26-22) 36dbc	635289	4261604	2000	4827	360	230	P	—	—	1
148	(D-26-22) 7cbd	627407	4268261	2000	4156	61	51	P	—	—	3
149	(D-26-22) 7cbd	627413	4268273	2000	4155	66	51	P	—	—	3
150	(D-26-22) 7cbd	627401	4268276	2000	4155	61	51	P	—	—	3
151	(D-27-22) 1cbc	634564	4260111	1999	4882	320	240	P	—	—	1
152	(D-27-22) 1cba	634757	4260216	1994	4876	265	158	S	0	25	1
153	(D-25-21) 26dcd	624774	4272563	2002	3997	53	30	P	—	—	3
154	(D-26-21) 2daa	624975	4270061	1978	3995	169	—	P	—	—	3
155	(D-26-21) 2add	625278	4270160	1977	3985	93	—	P	—	—	3
156	(D-26-22) 26bcc	632823	4263662	1985	4628	270	49	P	—	—	1
157	(D-26-22) 36dcd	635432	4261290	1995	4852	400	230	P	—	—	1
158	(D-25-21) 26cdd	624502	4272595	2002	3974	35	13	P	—	—	3
159	(D-25-21) 26cdd	624501	4272599	2002	3974	84	13	P	—	—	3
160	(D-26-22) 8cdc	629082	4267883	1963	4232	168	—	P	—	—	3
161	(D-26-22) 8ccc	628655	4267889	1971	4220	117	48	S	12	36	3
162	(D-26-22) 36ccd	634680	4261323	1977	4815	280	239	P	—	—	1
163	(D-26-22) 6ccc	627118	4269460	1983	4081	57	—	P	—	—	3
164	(D-26-22) 26acd	633867	4263758	2001	4745	252	128	P	—	—	1
165	(D-26-22) 7adb	628287	4268728	1961	4159	123	11	P	—	—	3

Explanation for Table G.1

Site number: See plate 7 for well location. Wells not used to define recharge and discharge areas are not plotted.

Local well number: See text for explanation of well numbering system.

Elevation: In feet above sea level.

Well depth: In feet below land surface.

Water level: In feet below land surface.

Recharge type: P, primary recharge area; S, secondary recharge; D, discharge area.

Top of confining layer: Depth to first confining layer, in feet below land surface.

Bottom of confining layer: Depth to bottom of first confining layer, in feet below land surface.

Bedrock completion:
1, completed in the Glen Canyon Group;
2, completed in other bedrock;
3, completed in unconsolidated valley fill.

— no data available

APPENDIX H

BACKGROUND INFORMATION FOR GROUND-WATER QUALITY CLASSIFICATION

GROUND-WATER QUALITY CLASSIFICATION

The following information, much of which is from the Utah Division of Water Quality's (1998) *Aquifer Classification Guidance Document* and Lowe and Wallace (1999a, b), outlines the purposes and requirements of ground-water quality classification.

Background Information About Ground-Water Quality Classification

On October 4, 1984, Utah Governor Bangerter issued an Executive Order stating, "The quality of ground water will be protected to a degree commensurate with current and probable future uses. Preventive measures will be taken to minimize contamination of the resource so that current and future public and private beneficial uses will not be impaired." Based on public comments, the former Division of Environmental Health (now Department of Environmental Quality) implemented an anti-degradation approach using *differential protection* based on the quality or value of the ground-water resource. The policy of differential protection recognizes possible impacts on ground-water from human activities, but limits any adverse impacts to pre-established acceptable levels tied directly to the existing ground water quality. Ground-water quality classification is one of the principal means for implementing the differential protection policy because it establishes the quality of the ground-water resource.

The Utah Ground Water Quality Protection Regulations, initially adopted in 1989, allow the Utah Water Quality Board to classify the ground-water quality of all or parts of aquifers as a method for maintaining ground-water quality in areas where sufficient information is available. This includes a comprehensive understanding of the aquifer system supported by factual data for existing water quality, potential contaminant sources, and current uses of ground water. Ground-water quality classification (or reclassification) may be initiated by either the Utah Water Quality Board or by a petition submitted by a person, company, or governmental entity. At least one public hearing is required before the Utah Water Quality Board rules on the proposed classification. Once the ground-water quality of an aquifer is classified, commensurate protection levels are applied to classified areas based on the differential protection policy.

Ground-Water Quality Classification: A Planning Tool

Ground-water quality classification is a planning tool for local governments to use in making land-use management decisions. It allows local governments to use ground-water quality as a reason for permitting or not permitting a proposed activity or land use based on the differential protection policy. Many facilities and/or activities exist which can and do have an impact on ground-water quality, but are not regulated by state or federal laws. Examples of such facilities/activities include septic tanks, animal feed lots, land application of animal wastes, and some industrial/manufacturing activities. Many of these facilities/activities are permitted through local land-use management programs. From this perspective, ground-water quality classification can be a useful tool for local governments, if they so desire, to manage their ground-water resources based on the beneficial use established by ground-water quality classification.

There are many potential applications of ground-water quality classification as a land-use management tool. One example is using ground-water quality classification to establish zoning that will locate industrial facilities in areas where ground-water quality is already poor, such as in some areas around Great Salt Lake. Additionally, ground-water quality classification can be used as a basis for determining the density of development in areas that use septic tanks for wastewater disposal. Ground-water quality classification also can be used as a basis for encouraging developers to invest in the infrastructure needed to connect a proposed subdivision onto an existing sewer line, rather than dispose of domestic wastewater using septic-tank systems. However, ground-water quality classification does not result in any mandatory requirement for local governments to take specific actions, such as land-use zoning restrictions, technical assessments, or monitoring.

APPENDIX I

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. 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 I.1) 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, allowing the maximum potential for dilution of those chemicals that do reach ground water (Lowe and Wallace, 1999e).

Table I.1. *Typical characteristics of wastewater in 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	1010 - 1012
Fecal Coliforms	**MPN/100#mL	108 - 1010
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*

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 due to the use of septic-tank systems (Lowe and Wallace, 1999e). Phosphates are removed from septic-tank system effluent by absorption 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, mostly from the human urinary system, are commonly present in wastewater within septic tanks (table I.1). 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 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 exist (Fetter, 1980).

APPENDIX J

AQUIFER HYDRAULIC PROPERTIES

Ground water in Moab-Spanish Valley is found in shallow valley-fill and deeper rock aquifers. Because septic tanks are only located in the valley-fill aquifer, we obtained additional data and information about the hydraulic characteristic of the valley-fill aquifer. The valley-fill aquifer of Moab-Spanish Valley constitutes a reservoir from which a considerable quantity of water is recovered. However, because the valley fill varies in texture and composition, its hydraulic properties are not constant from place to place. Hydraulic properties of the valley-fill deposits in Moab-Spanish Valley were estimated using (1) description of materials from the drillers' logs of water wells, (2) a single-well aquifer test, and (3) well tests (specific-capacity) obtained from drillers' logs of water wells in the valley.

Aquifer Characteristics

The valley-fill aquifer in Moab-Spanish Valley consists of unconsolidated sediments of diverse origin. A combination of deposition, erosion, reworking, and redeposition of alluvial materials by streams and wind has produced a complex sequence of layered, interbedded, and interfingered clay, silt, sand, gravelly sand, gravel, and boulders. Hydraulic properties partially depend on the environment of deposition as well as the types of materials that compose the valley fill. The saturated valley fill probably provides water through its entire length, with zones that are more productive than others. The water-transmitting properties of the valley fill are determined by estimating the aggregate hydraulic conductivity of the discontinuous sequences of mostly gravel and sand. Drillers' water-well logs indicate the valley-fill consists of boulder, cobbles, gravel, sand, clay, and silt. Any layering, if present, cannot be readily correlated between water-well logs. The gradational nature of the valley-fill deposits creates a broad range in both vertical and horizontal hydraulic conductivities.

From the character and genesis of the valley-fill material, it follows that sediments at the southeastern end of Moab-Spanish Valley are relatively thin, but coarse; in the center of the valley the sediments are coarse materials that are relatively thick and thoroughly interconnected; deposits are coarser, more extensive, and more permeable towards the eastern side of the valley and become progressively finer and less permeable away from the east side. Towards the distal (northwestern) end of the valley, the valley-fill aquifer becomes progressively finer grained and thicker. Some of the finer grained materials found in the northwest end of the Moab-Spanish Valley are associated with the wetlands along the Colorado River (Sumsion, 1971).

Sand and gravel deposits are the principal water-bearing materials in Moab-Spanish Valley. Estimates of the average hydraulic conductivities of the materials in the valley-fill aquifer in Moab-Spanish Valley are given in table J.1. As stated above, higher hydraulic conductivities are expected to occur in the southeastern, center, and east side of the valley and lower values on the west side and northwestern end of the valley.

Table J.1. *Estimated ranges of hydraulic conductivity of materials described in drillers' logs of wells.*

Driller's description	Range of hydraulic conductivities (ft/day)
Gravel	70 to 500
Silty sand and gravel	0.5 to 400
Boulders in a matrix of sand, silt, and clay	.001 to 250
Sand	5 to 200
Sand and silt	0.1 to 100
Clay to silt	.005 to 1

Ranges from Freeze and Cherry, 1979

Single-Well Aquifer Test

Location

The Utah Geological Survey conducted a single-well aquifer test in southern Spanish Valley, San Juan County, Utah from June 24 to June 28, 2002. The aquifer test was conducted on a well in section 35, T. 26 S., R. 22 E., Salt Lake Base Line and Meridian. The well is near the Grand-San Juan County line, on the San Juan side. We attempted to locate other wells suitable for an aquifer test, but no other test wells, for either a single- or multi-well aquifer test, could be located. The aquifer-test well is representative of other wells in the area in terms of construction, yield, and hydrologic position. The test was run during part of the month of June, before the start of heavy summer use. The well is completed in the saturated valley-fill aquifer.

Aquifer Material

The aquifer at the aquifer-test site consists of unconsolidated sediments that the domestic well partially penetrates. The water-well driller's log indicates water was encountered in the well at 145 to 155 feet (44-47 m), and at 160 to 210 feet (49-64 m). The driller indicated a clay layer, 5 feet (1.5 m) thick, between 155 feet and 160 feet (47-49 m) depth. The driller's log indicates cobbles and boulders from the surface to 145 feet depth (0-44 m); these are probably in a matrix of clay and sand. At a depth of 145 to 155 feet (44-47 m), the log indicates gravel and then the 5 feet (1.5 m) thick clay layer below this. The clay layer is probably not continuous, and the aquifer is acting as one continuous aquifer. The response of the aquifer to pumping in this part of the valley suggests that the valley-fill aquifer is essentially unconfined. Below the clay layer, from 160 to 210 feet (49-64 m) depth, is gravel that includes the water-yielding interval.

Evaluation of Specific Capacity of the Well

We estimated the transmissivity of the aquifer penetrated by the well from a well test performed after its completion in December of 1961, using the method of Theis (1963). Theis' (1963) analytical solution, used to predict transmissivity specific capacity, was developed for an alluvial aquifer. The well test involved pumping the well at 700 gallons per minute (2.7 m^3/min) for 9 hours (0.37 day), during which 50 feet (15 m) of drawdown was measured. The specific capacity of the well, which is its yield per unit of drawdown, was 14 gallons per minute per foot (0.17 m^3/min/m), and we determined a transmissivity of about 5,717 square feet per day (531 m^2/day) using the method of Theis (1963).

Description of Aquifer Test

To obtain additional transmissivities, hydraulic conductivities, and other information about the aquifer near the well, we conducted a constant-discharge-rate aquifer test from June 24 to June 26, 2002, and measured recovery of the well from June 26 to June 28, 2002. The aquifer test consisted of pumping and observing the water level in one well. The test used the existing pump in the well running at its maximum capacity. The well had not been pumped for 24 hours prior to the test. Water was discharged into a nearby pond about 300 feet (90 m) east of the well, through a 3-inch (8 cm) diameter pipe. We measured discharge rates during the aquifer test with a Controlotron clamp-on portable flow meter. Discharge varied between 63 and 66.7 gallons per minute (0.24-0.25 m^3/min) and averaged about 65 gallons per minute (0.25 m^3/min). The pumping rate probably did not stress the aquifer substantially, and the aquifer test results were evaluated taking this into account.

The static water level in the well at the beginning of the aquifer test, measured using an electric tape, was 135.95 feet (41.44 m). This water level was assumed to be horizontal for the analysis of the aquifer-test data. When the well was drilled in 1961, the static ground-water level was reported at 140 feet (43 m), and in 1967 the water level was about 120 feet (37 m) as indicated in Sumsion (1971).

We monitored water levels in the well during the test using an electric tape. After 24 hours and 20 minutes, we turned the pump off and ended the drawdown phase of the test. We monitored recovery and recorded water levels for 25 hours, until water levels returned to the static water level. Figure J.1 illustrates the water-level response during the aquifer test; this response includes well losses and well-bore storage. The water level in the well was drawn down 2.48 feet (0.75 m) in 24 hours, and returned to its pre-test levels in about 24 hours.

Drawdown Phase: We used the computer program AQTESOLVE for Windows (Hydrosolve, 1996) to evaluate the drawdown phases of the aquifer test and determine "best fit" matches. At the start of the drawdown phase of the aquifer test, a check valve released water down the well column and well-bore storage effects, from the rapid removal of water from the well column, influenced the first 10 minutes of measurements. We used water-level measurements taken during the rest of the drawdown phase of the aquifer test to determine the transmissivity of the aquifer near the pumping well. We analyzed the drawdown phase of the aquifer-test data using the Theis (1935) (figure J.2), and Neuman (1974) (figure J.3) analytical techniques, and the Cooper-Jacob (1946) semilogarithmic approximation method (figure J.4) as implemented in AQTESOLVE for Windows. The well-bore storage effects caused the initial drawdown curve to be steeper than both the Theis and Neuman type curves. We accounted for this error in water-level measurements in matching type curves to the drawdown data. Computations from the drawdown data indicate a transmissivity of 6.182 square feet per minute (0.57 m^2/min) using a Theis type curve, a transmissivity of 5.035 square feet per minute (0.46 m^2/min) using a Neuman type curve, and a transmissivity of 4.078 square feet per minute (0.38 m^2/min) using a Cooper-Jacob approximation.

Recovery Phase: After turning off the pump and ending the drawdown phase of the aquifer test, water in the well's casing fell back into the well, providing erratic data, so we could not get reliable water-level measures for the first 5 minutes of the recovery test. The water level in the well recovered to its pre-test level in about 24 hours after we turned off the pump. We evaluated the post-five-minute recovery phase data for the well using the Theis recovery analytical techniques (figure J.5). Using the recovery data, we determined a transmissivity of 6.82 square feet per minute (0.63 m^2/min) using a Theis recovery method.

Summary

Transmissivities calculated from our aquifer-test data range from 4.078 to 6.82 square feet per minute (0.38-0.63 m^2/min). The drawdown-phase data show a reasonably good match to Theis and Neuman type curves. A reasonably straight line could be fitted to part of the recovery data on a semilogarithmic plot. The drawdown data results from the Neuman and Theis meth-

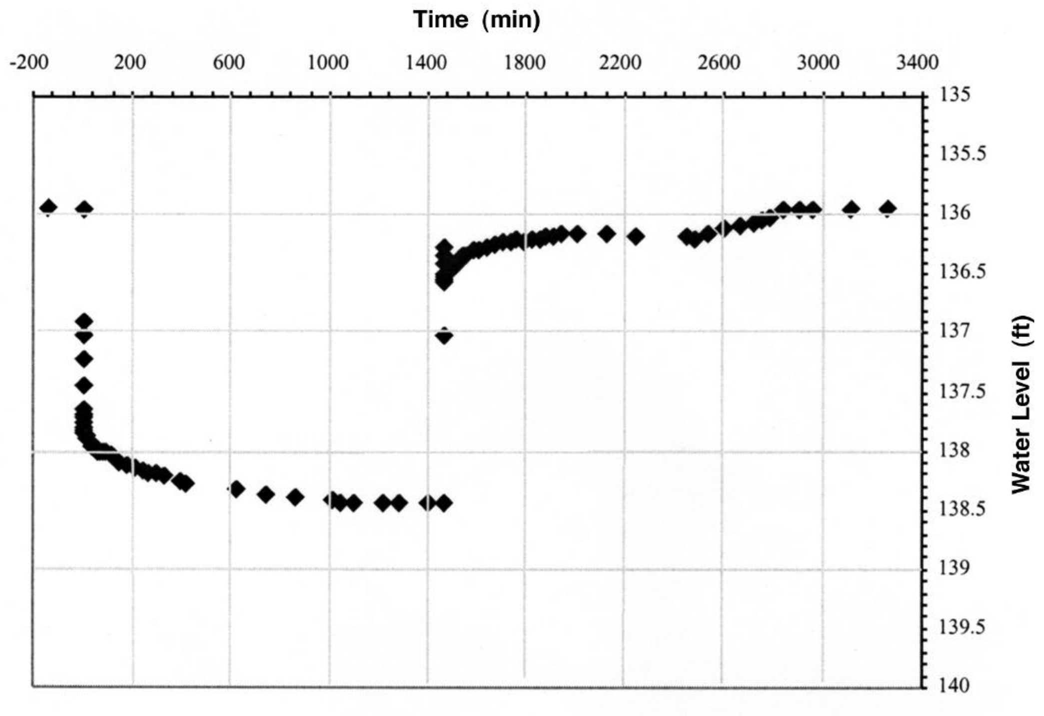


Figure J.1. *Water-level curves for the aquifer test conducted in the well from June 24 to June 28, 2002. Time is relative to the aquifer test.*

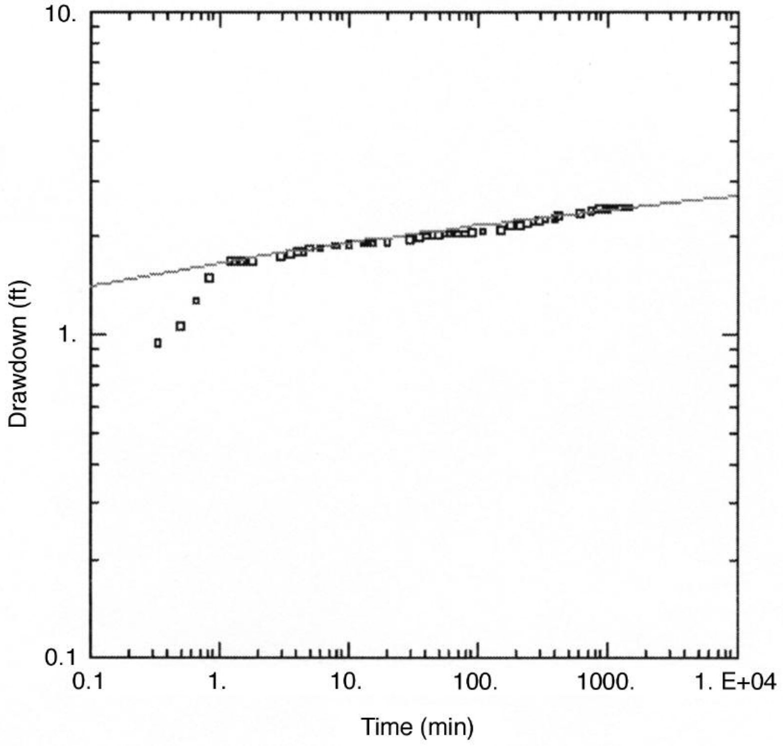


Figure J.2. *Logarithmic graph of drawdown versus time in the well for the 24-hour aquifer test. Logarithmic presentation used in matching test data with a Theis type curve.*

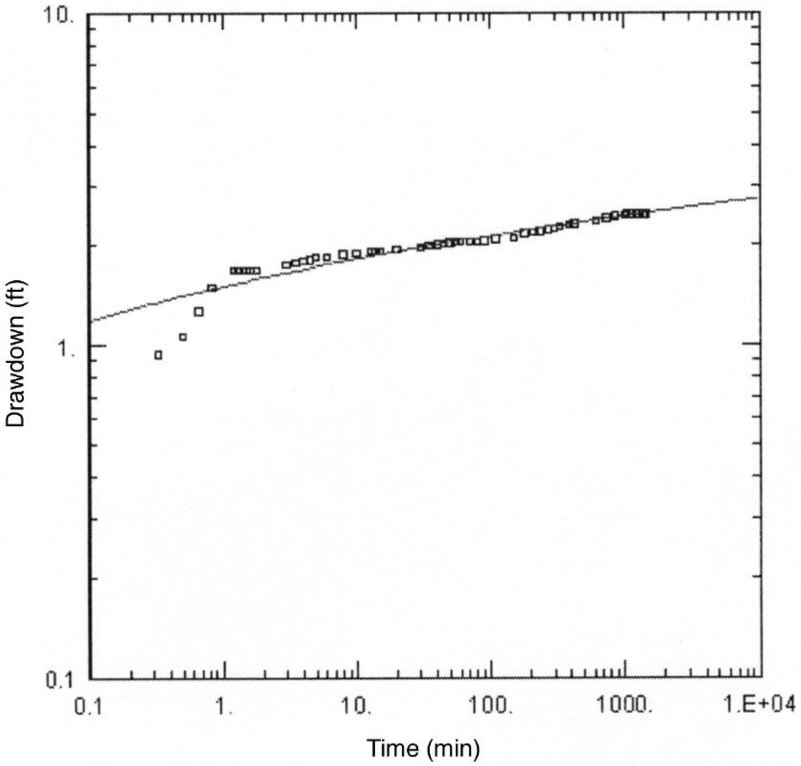


Figure J.3. *Logarithmic graph of drawdown versus time in the well for the 24-hour aquifer test. Logarithmic presentation used in matching test data with a Neuman type curve.*

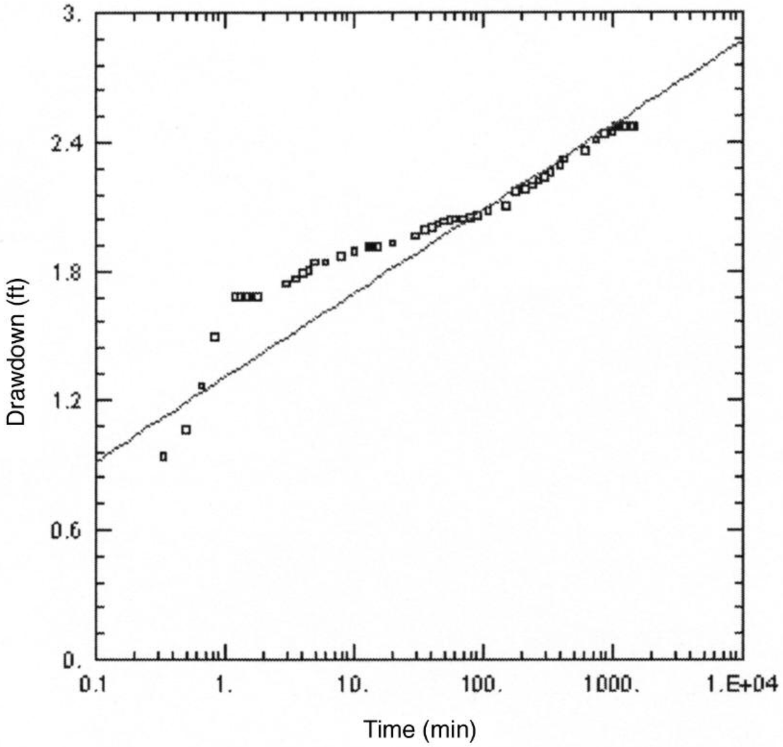


Figure J.4. *Semilogarithmic graph of drawdown versus time in the well for the 24-hour aquifer test. Semilogarithmic presentation used in solving with a straight line.*

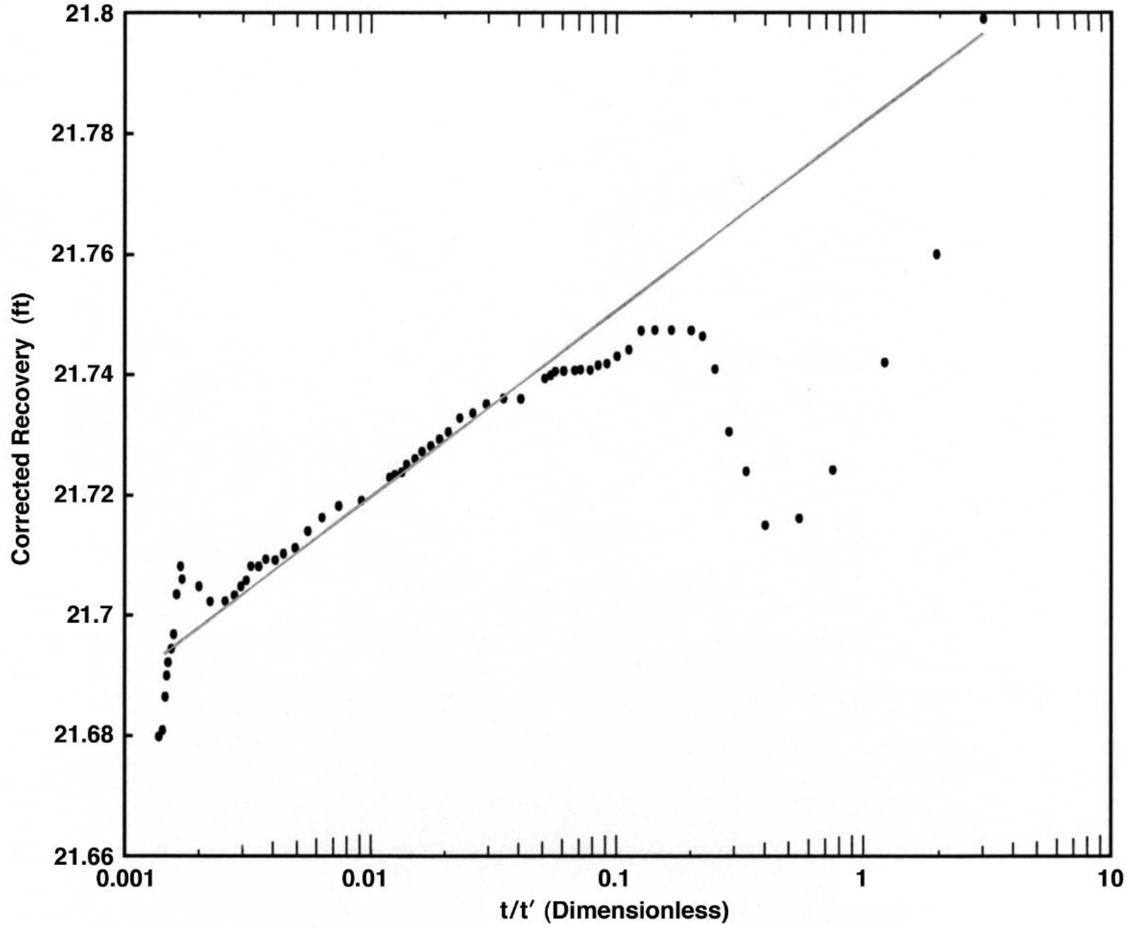


Figure J.5. *Semilogarithmic graph of recovery of water level versus time in the well during the recovery test. Semilogarithmic presentation used in Theis recovery method.*

ods yield hydraulic conductivities characteristic of silt, silty sand, and clean sand, respectively (Freeze and Cherry, 1979). Based on the sediments described on the driller's log, the hydraulic conductivities from the aquifer test analysis are characteristic of the aquifer.

Additional Hydraulic Properties

We estimated additional hydraulic properties of the valley-fill deposits in Spanish Valley from the results of well-test data from drillers' reports throughout the valley. Some of these values were reported in Sumsion (1971), and some are from other wells located in the valley. Wells completed in the valley-fill aquifer are concentrated along the center and in the northwest part of the valley, but there has been enough development in the southern part of the valley to provide some additional information. Estimates of hydraulic conductivity were determined for 32 wells in Spanish Valley by dividing the estimated transmissivity determined from specific-capacity data by the thickness of the aquifer. Values of specific capacity, transmissivity, and hydraulic conductivity for specific locations are listed in table J.2. Specific-capacity values of wells completed in the valley-fill deposits range from 0.66 to 60 gallons per minute per foot (0.008-0.74 m^3/min per m) of drawdown. Specific capacity depends on well construction and hydraulic properties of the valley fill at the well. Transmissivity of the valley-fill deposits ranges from 197 to 72,750 feet squared per day (18-6,758 m^2/day). Generally, the largest transmissivity values are found in the center of the valley, where the valley fill is the thickest.

Table J.2. *Estimated hydraulic properties of the valley-fill deposits.*

Well location	Specific capacity gpm/ft of drawdown	Transmissivity ft^2/day	Saturated thickness ft	Hydraulic conductivity ft/day
T.25 S. R.21 E. Sec36 cda	41	8,000	225	36
T.26 S. R.22 E. Sec 6 cbb	36	7,000	140	49
T.26 S. R.22 E. Sec 6 cbb	20	3,700	125	29
T.26 S. R.22 E. Sec 7 bac	25	4,300	125	35
T.26 S. R.22 E. Sec 8 cba	20	3,700	40	94
T.26 S. R.22 E. Sec 8 dcb	30	5,700	50	115
T.26 S. R.22 E. Sec 16 cdd	36	7,000	65	107
T.26 S. R.22 E. Sec 15 bdb	2.0	314	20	15.69
T.26 S. R.22 E. Sec 17 aac	48	8,700	50	174
T.26 S. R.22 E. Sec 17 aad	18	3,100	70	44
T.26 S. R.22 E. Sec 17 ada	10	1,600	50	32
T.26 S. R.22 E. Sec 17 cab	20	3,700	50	75
T.26 S. R.22 E. Sec 20 acd	20	3,700	30	124
T.26 S. R.22 E. Sec 21 bdd	20	3,600	50	72
T.26 S. R.22 E. Sec 22 cbd	5.45	816	12	68
T.26 S. R.22 E. Sec 22 cbb	32	5,700	75	76
T.26 S. R.22 E. Sec 22 cbd	60	11,600	100	116
T.26 S. R.22 E. Sec 22 dcb	90	13,900	105	132
T.26 S. R.22 E. Sec 22 abd	30	4,700	120	39
T.26 S. R.22 E. Sec 22 bdd	30	5,700	160	36
T.26 S. R.22 E. Sec 22 cbd	60	72,750	150	485
T.26 S. R.22 E. Sec 22 cbb	6.7	8,318	85	97.8
T.26 S. R.22 E. Sec 22 adb	2.4	2,930	110	26.6
T.26 S. R.22 E. Sec 22 acb	0.67	788	120	6.6
T.26 S. R.22 E. Sec 35 bbd	9	11,271	122	92.4
T.26 S. R.22 E. Sec 35 bdb	0.68	806	100	80.6
T.26 S. R.22 E. Sec 35 bda	4	4,959	95	52.2
T.26 S. R.22 E. Sec 35 daa	2.5	3,081	70	44.0
T.26 S. R.22 E. Sec 35 dda	3	3,974	90	44.2
T.26 S. R.22 E. Sec 36 cbd	5	6,216	80	77.7
T.27 S. R.22 E. Sec 1 cbc	0.75	197	40	4.9
T.27 S. R.22 E. Sec 1 dab	0.66	781	40	19.5