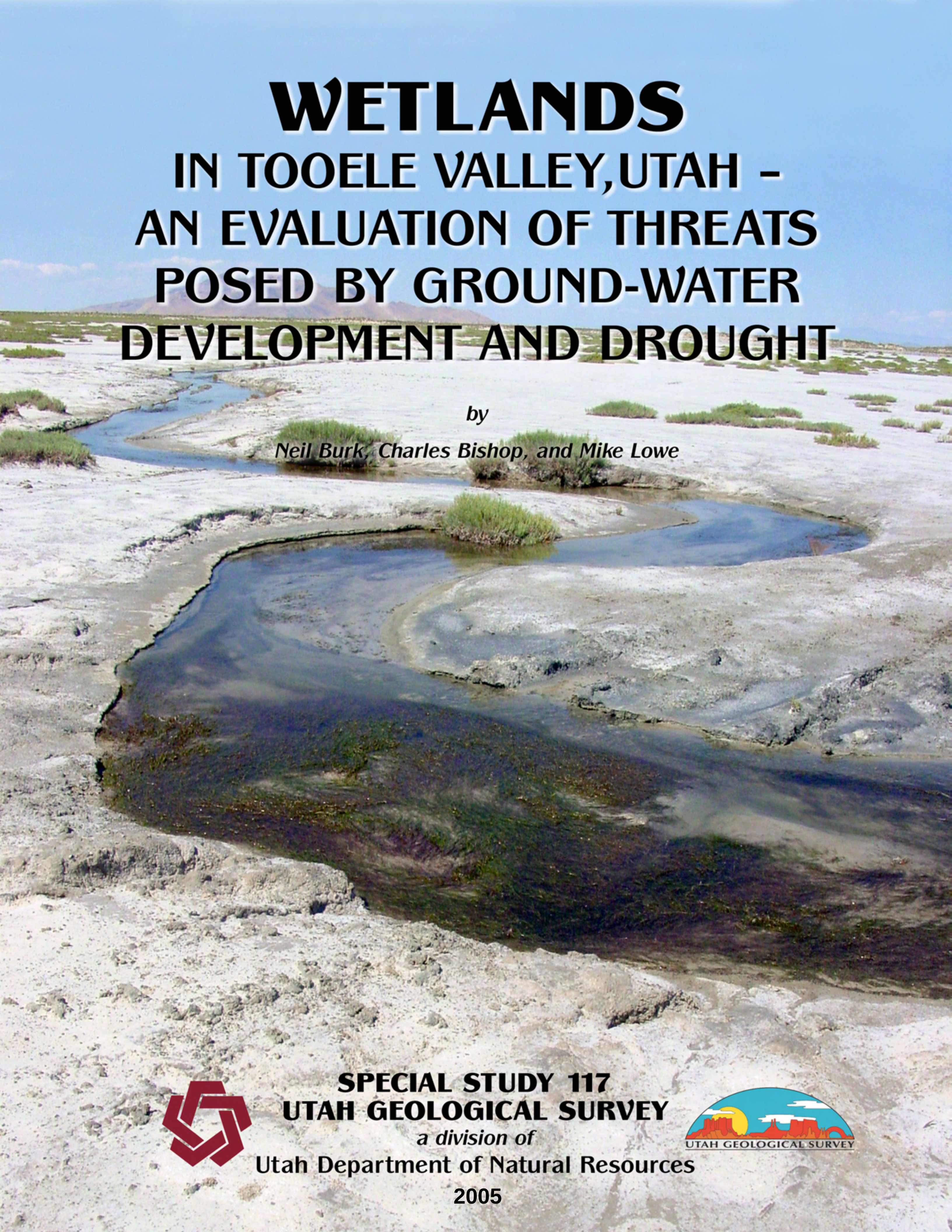

WETLANDS
IN TOOELE VALLEY, UTAH – AN EVALUATION OF THREATS POSED BY GROUND-WATER DEVELOPMENT AND DROUGHT

by

Neil Burk, Charles Bishop, and Mike Lowe

SPECIAL STUDY 117
UTAH GEOLOGICAL SURVEY
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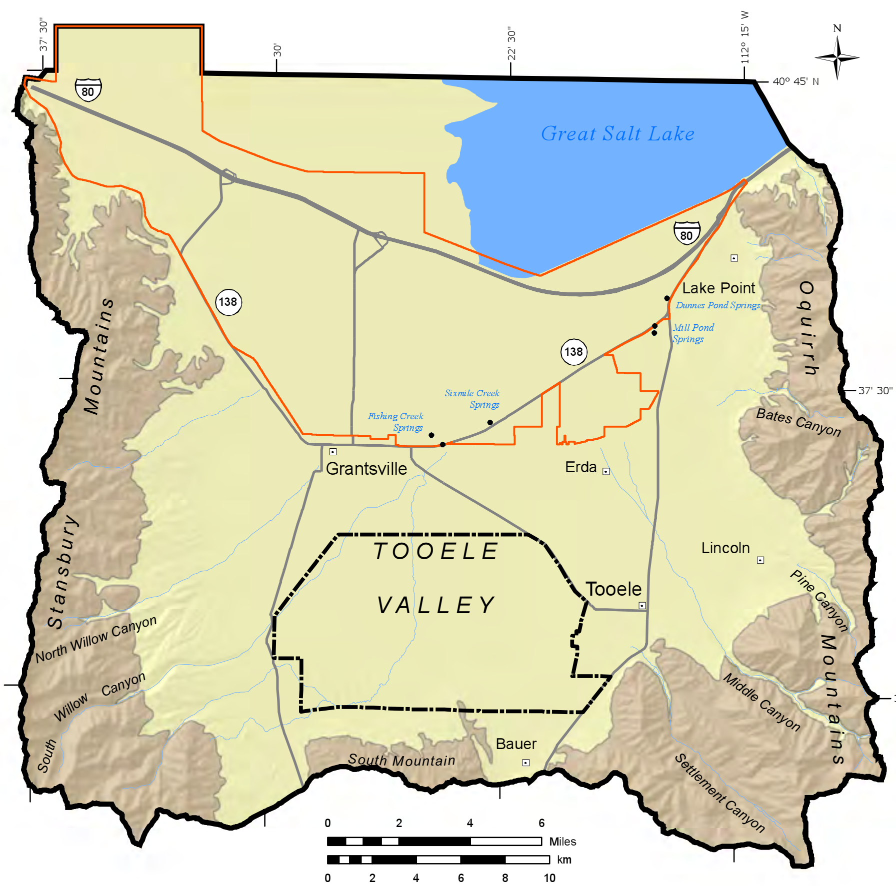

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WETLANDS IN TOOELE VALLEY, UTAH-AN EVALUATION OF THREATS POSED BY GROUND-WATER DEVELOPMENT AND DROUGHT

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ABSTRACT

Tooele Valley, Tooele County, Utah, is a mostly rural area at the south end of Great Salt Lake experiencing a rapid increase in residential development, resulting in less agricultural land use. While most of the development in the incorporated areas of Tooele Valley uses municipal water sources, principally wells, development in the unincorporated areas primarily relies on single-family domestic wells. This change from agriculture to domestic water use could significantly decrease the amount of ground water discharged from the confined aquifer system, where most wells are completed, to the shallow unconfined aquifer system, which provides water to springs and wetlands in ground-water discharge areas. Additionally, drought conditions over the past six years have reduced the amount of recharge to ground-water aquifers across the state, also impacting Tooele County's wetlands. Also, in early 2005, the elevation of Great Salt Lake declined to near its historic lowstand reached in 1963. Tooele County is in the process of creating a Special Area Management Plan (SAMP) for the wetlands in Tooele Valley to balance development with wetland conservation.

To evaluate the potential impacts of drought and increased development on Tooele Valley wetlands, we investigated the current status of the wetlands and used a ground-water flow model of the aquifer system in Tooele Valley to investigate how further drought and development would affect the water budget of the wetlands. Delineation of the wetland boundaries was performed by SWCA Environmental Consultants who created maps of the wetland areas using remote sensing data.

We documented the current status of the wetlands by performing a functional assessment of three wetland areas, and by installing shallow monitoring wells in the three wetland areas. The results suggest that the wetland hydrology has been impacted the most by the numerous roads, canals, and ditches in the area, and that agricultural land use is more beneficial to wetland health and functionality than industrial or urban land use. We found that the magnitude and direction of the hydraulic gradient were similar to those documented previously, where ground water flows from the mountains toward Great Salt Lake. Water samples collected from the shallow monitoring wells indicate no downgradient improvements exist in water quality, as total-dissolved-solids (TDS) concentration typically increases downgradient.

To determine the potential impacts posed by increased ground-water development and further drought, we used and altered the regional, three-dimensional, steady-state and transient MODFLOW models for Tooele Valley to estimate the water budget for the wetland areas. As a conservative goal, the Tooele Valley wetlands should be managed to maintain their current budget of water, which is estimated to be 98,000 acre-feet per year (120,900,000 m^3/yr) as subsurface inflow and 6600 acre-feet per year (8,140,000 m^3/yr) as discharge from springs for the entire wetland region in the transient model. The modeling suggests that subsurface inflow into the wetland areas would be most affected by increased ground-water withdrawals, and discharge from springs that feed the wetlands would be most affected by further drought conditions. Therefore, the worst-case scenario for the wetlands would be a combination of both conditions. These results will be useful in guiding land-use and development decisions in Tooele Valley.

This study indicates that wetlands in Tooele Valley are endangered. The threats posed are from drought and increased development due to population growth,

which could dramatically affect the amount of water the wetlands receive. As development continues, we recommend placing restrictions on the areas of development, such as allowing development only in upland environments or placing a non-development buffer around the wetland areas. The use of single-family domestic wells and septic-tank systems should also be discouraged because of the contamination threat in the shallow unconfined aquifer posed by septic-tank discharge. Use of municipal sewer and water lines should be required; this would help confine urban sprawl and contamination threats would be lower because the wastewater is treated prior to environmental discharge. Wastewater from sewers should, where possible, be reused or discharged to the environment upgradient of the wetlands so that the septic-tank component of ground-water recharge is not lost. Enactment of water conservation practices would also be beneficial for the wetland environments.

INTRODUCTION

Background

Tooele Valley, Tooele County, Utah, is a mostly rural area at the south end of Great Salt Lake experiencing a rapid increase in residential development. While most of the development in the incorporated areas of Tooele Valley uses municipal water sources, principally wells, development in the unincorporated areas primarily relies on single-family domestic wells. Tooele Valley has been closed to new water rights appropriations since 1996, so water rights for development in the incorporated areas are primarily obtained through purchase/exchange of existing water rights, mainly those formerly used for agriculture (John Mann, Utah Division of Water Rights, verbal communication, November 13, 2001). This change from agriculture to domestic water use could have a significant effect on the amount of ground water discharged from the confined aquifer system, where most wells are completed, to the shallow unconfined aquifer system, which provides water to springs and wetlands in ground-water discharge areas. Ground-water discharge areas are predominantly located in the north end of Tooele Valley (Steiger and Lowe, 1997). The amount of ground water discharged from the confined aquifer system to springs feeding the shallow unconfined aquifer system could decrease (Utah Division of Water Resources, 2001) even if no new water rights are issued because, on average, irrigators in this area of Utah generally divert only 57 percent of their allocated water rights (Utah Division of Water Resources, 2001); the percentage of used water rights would likely average much higher for domestic use. Additionally, seepage of unconsumed irrigation water contributes nearly one-seventh of the total recharge to aquifers in Tooele Valley (Lambert and Stolp, 1999); this component of recharge to the aquifer system would likely decrease as a result of changing from agricultural to domestic water usage.

Significant portions of Utah's wetlands are located in areas surrounding Great Salt Lake (Utah Division of Water Resources, 2001), including Tooele Valley. Preliminary estimates from existing GIS wetlands coverage indicate that wetlands in Tooele Valley occupy about 79,000 acres (320 km^2; almost 50 percent of the valley-floor area). Wetlands are important to diverse plant and animal species (about 45 percent of the species listed as threatened or endangered under the Endangered Species Act use wetland habitat), clean and abundant water supplies, and flood and erosion control (National Wildlife Federation, 1989). The Utah State Water Plan recognizes the potential impact of increased ground-water development on these critical natural resources and proclaims: "studies need to be undertaken to ensure that groundwater withdrawals are not adversely affecting spring flows nor impairing water rights associated with existing wetlands" (Utah Division of Water Resources, 2001).

To balance land development and conservation, Tooele County is in the process of developing a Special Area Management Plan (SAMP) for the north part of Tooele Valley where the wetlands are located. A steering committee comprised of local private landowners, Tooele County and Grantsville City representatives, federal and state regulatory/resource agencies, and environmental groups, was formed to develop the plan. The primary goal of the SAMP "is to preserve, restore, and enhance wetlands while allowing for responsible urban development within the plan area" (Tooele County, undated).

Purpose and Scope

The purpose of this study is to use existing state-of-the-art steady-state and transient ground-water-flow models developed by the U.S. Geological Survey (Lambert and Stolp, 1999) to simulate the hydrologic effects on wetlands from various recharge rates and projected ground-water withdrawals at various projected Great Salt Lake levels. These simulations can be used to assess potential threats on wetlands from increased ground-water withdrawals and drought, and provide a basis for (1) implementing restrictions on domestic withdrawals, (2) assessing water needs for wetland preservation, and (3) encouraging the development of water conservation programs. The development and wise use of water resources are best achieved through a comprehensive understanding of the hydrologic system. A second objective is to produce a map showing the locations of known wetlands. This inventory is necessary to get the best estimate of current water usage by wetlands. The final objective is to document the current quality and functionality of three wetland areas that ground-water modeling indicates may be impacted by increased ground-water withdrawals associated with increasing development. The functional assessment of the three wetland areas is based on an evaluation of (1) external ground- and surface-water delivery, (2) internal ground- and surface-water flow, (3) removal of dissolved elements and compounds, (4) particulate retention, (5) flora and fauna habitat support, and (6) wildlife habitat connectivity/patchiness (Keate and others, 2001). The assessment will allow accurate documentation of changes in wetland functionality related to development through periodic reassessment using the same procedure.

We installed nine shallow monitoring wells in three wetland areas for water-quality sampling and water-level measurements. The wells were manually installed using a hand auger to bore a hole into the ground to a depth of about 6 feet (2 m), and then inserting one-inch-diameter slotted PVC and backfilling the void between the borehole and PVC with the hand-auger cuttings. The well locations were determined by using a hand-held GPS device and cross-referencing the location and elevation with the most up-to-date 1:24,000 U.S. Geological Survey topographic map. We used water-level measurements to determine the magnitude and direction of the hydraulic gradient in the shallow unconfined aquifer system supplying water to the wetlands. We used data from water samples to document the current quality of ground water flowing into the wetlands, and to document any downgradient changes in chemistry to determine if water quality improves by flowing through the wetlands.

This report provides the necessary integration of geologic, hydrologic, and wetland studies to more fully understand the hydrologic system of northern Tooele Valley in relation to wetland functionality. The scope of this report includes a thorough literature search; a compilation of published and unpublished geologic, hydrologic, and wetland information; and field sampling and analysis of water data from shallow wells. The detailed USGS models, which are documented in this report, were originally used to identify historical changes in the ground-water flow system in Tooele Valley.

Previous Studies

The first evaluation of ground-water conditions in Tooele Valley was Carpenter's (1913) regional-scale reconnaissance study. Thomas (1946) provided the first comprehensive study of ground-water conditions in Tooele Valley. Gates conducted a number of hydrogeologic studies in Tooele Valley in the 1960s, including an evaluation of possible buried faults affecting ground-water conditions in the Erda area (1962); a study of the hydrogeology of Middle Canyon in the Oquirrh Mountains (1963a); a compilation of selected hydrologic data for the valley (1963b); and a re-evaluation of Thomas' (1946) summary of the valley's ground-water resources (Gates, 1965), including a summary of changes in ground-water conditions from 1941 to 1963. Gates and Keller (1970) produced a concise summary of ground-water conditions in Tooele Valley. Razem and Steiger (1981) produced an updated water budget for the principal aquifer system in Tooele Valley, and projected future ground-water conditions resulting from several water-management alternatives using the two-dimensional ground-water flow model of Razem and Bartholoma (1980). Steiger and Lowe (1997) mapped recharge and discharge areas and studied the quality of ground water in Tooele Valley. Wallace and Lowe (1998) evaluated the potential impact of septic-tank soil absorption systems in Tooele Valley. Lowe and Wallace (1999) and Wallace (1999) classified ground-water quality based primarily on total-dissolved-solids concentrations in Tooele Valley; Wallace (1999) also mapped potential contaminant sources. Lambert and Stolp (1999) produced a three-dimensional, finite-difference, numerical ground-water flow model for Tooele Valley, which is used in this study. Burden and others (2000) reported changes in water levels in the basin-fill aquifer of Tooele Valley from 1970 to 2000.

SETTING

Physiography

Tooele Valley (figure 1) is a north-south-trending valley with an area of about 250 square miles (650 km2). Tooele Valley is in the Uintah Extension section of the Great Basin physiographic province, which is a subdivision of the Basin and Range Province (Stokes, 1977). Tooele Valley is bordered on the east, south, and west by the Oquirrh, South, and Stansbury Mountains, respectively, and by Great Salt Lake to the north (figure 1). Although perennial streams exist in Settlement Canyon in the Oquirrh Mountains and in Davenport, North and South Willow, and Box Elder Canyons in the Stansbury Mountains, they are diverted for irrigation just downstream from canyon mouths (Razem and Steiger, 1981) and surface flow does not reach Great Salt Lake.

Gravity data indicate Tooele Valley is a broad collection of structural troughs and ridges within a larger graben-like structure (Johnson, 1958). This complex structure has up to 8000 feet (2400 m) of sediment in the northern end (Everitt and Kaliser, 1980). The Stansbury Mountains are a north-trending anticline that has been tilted to the east by movement along the Stansbury fault zone in Skull Valley (Rigby, 1958); the

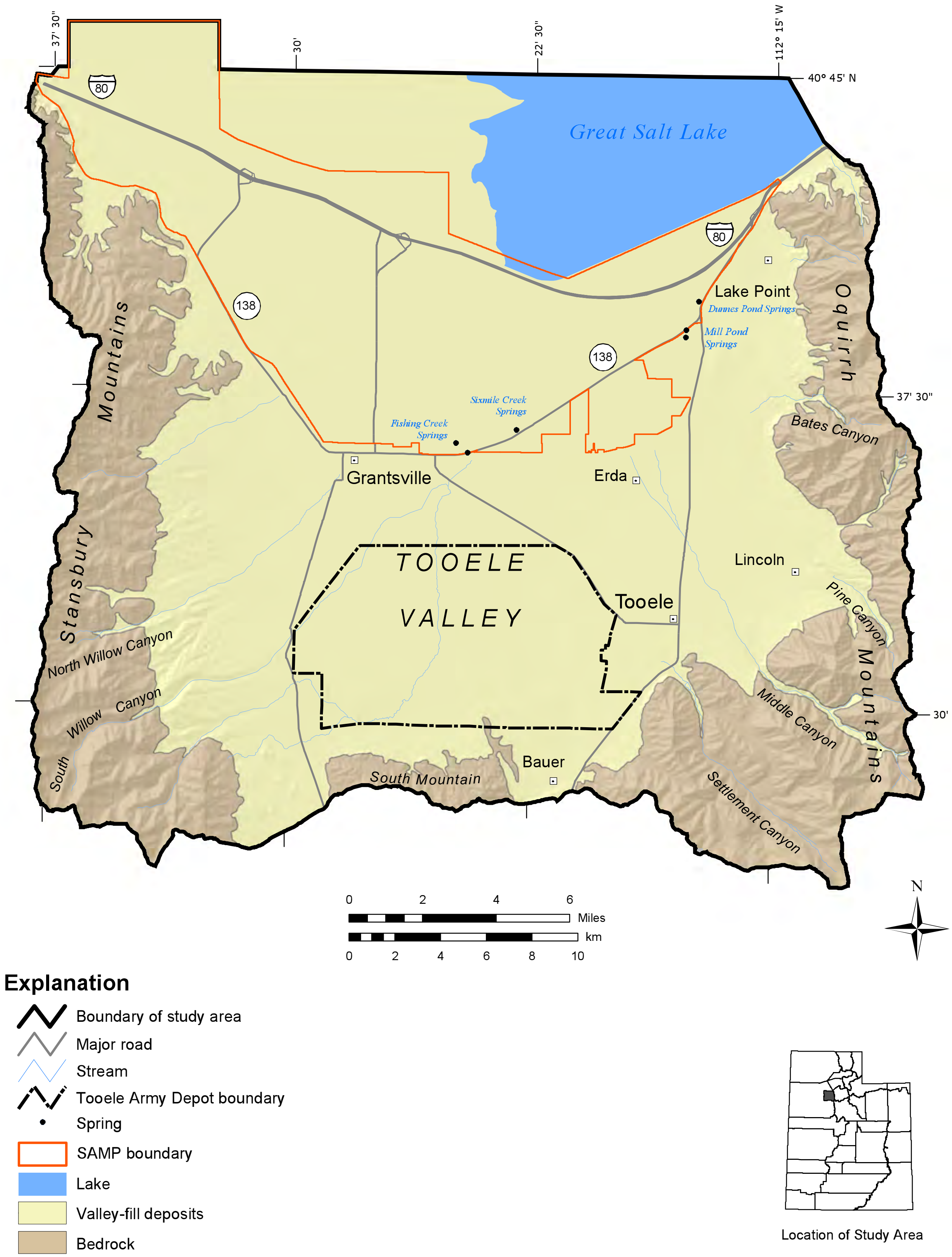

Figure 1. Tooele Valley, Tooele County, Utah, study area, and location of Tooele Valley Wetland Special Area Management Plan (SAMP) area.

less active, west-dipping Broad Canyon fault bounds the east side of the Stansbury Mountains on the west side of Tooele Valley (Rigby, 1958; Helm, 1995, figure 3). The west-dipping Oquirrh fault zone bounds the eastern side of Tooele Valley; rock units in the Oquirrh Mountains have been tilted eastward by movement along this fault zone (Gilluly, 1932; Tooker and Roberts, 1961). The most recent surface faulting along the Oquirrh fault zone occurred between 4300 and 6900 yr B.P. (Olig and others, 1996). Two possible faults, having no surface expression but possibly important to ground-water flow, have been inferred along the east side of Tooele Valley (Thomas, 1946; Gates, 1962; Sheley and Yu, 2000).

The mountains surrounding Tooele Valley consist primarily of Cambrian to Tertiary sedimentary, metamorphic, and igneous rocks. The Oquirrh Mountains and South Mountain consist mostly of limestone and quartzite of the Pennsylvanian-Permian Oquirrh Group (Gates, 1965; Razem and Steiger, 1981). Although many formations of various lithologies crop out in the Stansbury Mountains, the thickest formations are the Oquirrh Group and the Cambrian Tintic Quartzite (Razem and Steiger, 1981).

The valley floor in Tooele Valley ranges in elevation from about 4200 to 5200 feet (1280-1590 m) and is underlain by unconsolidated and semiconsolidated discontinuous layers of silt, sand, and gravel deposited in fluvial, alluvial-fan, and nearshore lacustrine environments separated by layers of silt and clay deposited in offshore lacustrine environments (Steiger and Lowe, 1997). Basin margins are dominantly alluvial-fan deposits that grade into and interfinger with finer grained lacustrine deposits (Solomon, 1993). Pleistocene Lake Bonneville and Holocene Great Salt Lake lacustrine deposits are dominant in the central and northern parts of the valley (Gates and Keller, 1970; Solomon, 1993).

Climate

Three weather stations in the study area operated by the Utah Climate Center provide climatic data: Tooele, Grantsville, and Bauer. Because the normal climatic information represents a more complete data set than annual climate information, the normal values (from Ashcroft and others, 1992) are discussed herein. Temperatures reach a normal annual minimum of 19.5°F (-6.9°C) in January and a normal annual maximum of 88.5°F (31.4°C) in July, both at Tooele. The normal mean annual temperature at Tooele is 50.8°F (10.4°C). Normal annual precipitation ranges from 12.25 inches (31.12 cm) at Grantsville to 18.49 inches (46.96 cm) at Tooele. Normal annual evapotranspiration is 42.50 inches (107.95 cm) at Tooele. The average number of frost-free days is 164 at Tooele.

Population and Land Use

From 1990 to 2001, the population of Tooele County increased 5.3 percent (from 26,581 to 44,431), a tie with Iron County for the second-highest average annual rate of population increase in Utah (Demographic and Economic Analysis Section, 2002). The projected population for Tooele County by 2030 is estimated to be 80,938 (Demographic and Economic Analysis Section, 2000). Most Tooele County residents live in Tooele Valley, and residential development is the major land use in Tooele Valley, but agriculture is expected to remain prominent (Tooele County Engineering Department, 2003). Government agencies, including the Tooele Army Depot, which is located in the south-central part of Tooele Valley, are the largest source of employment in Tooele County. Many of the valley's residents commute to various locations along the Wasatch Front, which is the most populous area in the state and is located just east of Tooele Valley.

GROUND-WATER CONDITIONS

Basin-Fill Aquifers

Due to the complicated stratigraphic relationship between coarse-grained and fine-grained facies, the basin-fill aquifer consists of a complex multiple-aquifer system under both unconfined and confined conditions (Gates, 1965). The confined aquifer exists in the north-central part of the valley (Razem and Steiger, 1981) and is surrounded by a deep unconfined aquifer system between the base of the mountains and the confined aquifer, south and east of Tooele City and south and west of Grantsville (Steiger and Lowe, 1997). The confined aquifer is created by a low-permeability confining layer, deposited in an offshore lacustrine environment, overlying more permeable aquifer sediments. The confined aquifer is typically overlain by a shallow unconfined aquifer made up of more permeable sediments (Razem and Steiger, 1981). Thickness of basin fill material in Tooele Valley varies from a few feet to 250 feet (80 m) near basin margins (Steiger and Lowe, 1997), to as much as 8000 feet (2400 m) in the northern part of the valley near Great Salt Lake (Everitt and Kaliser, 1980).

Depth to ground water in Tooele Valley ranges from about 700 feet (210 m) at the mouth of Pine Canyon in the Oquirrh Mountains to near the ground surface proximal to Great Salt Lake (Bishop, 1997). In the Erda area along the eastern margin of Tooele Valley, water levels in wells declined from 1963 to 1967 and then rose until 1976 (Razem and Steiger, 1981). Razem and Steiger (1981) pointed out that, although long-term water-level trends correlate fairly well with long-term changes in precipitation, part of the water-level rise between 1972 and 1976 may be related to discharge of mine water down Pine Canyon because the rapid water-level rise did not occur in other parts of Tooele Valley. Long-term water levels in wells in the Grantsville area generally declined between 1955 and 1976, because long-term discharge exceeded long-term recharge (Razem and Steiger, 1981).

Ground-water flow in Tooele Valley is generally northwestward from the Oquirrh Mountains, northeastward from the Stansbury Mountains, and northward from South Mountain toward the valley center, and then north toward Great Salt Lake (Gates and Keller, 1970; Stolp, 1994). Bishop (1997) estimated the hydraulic gradient near the Oquirrh Mountain front in the Pine Canyon area is about 100 feet per mile (19 m/km). In the east Erda area the hydraulic gradient is about 5 feet per mile (1 m/km) (Steiger and Lowe, 1997).

Recharge to the basin-fill aquifer is from (1) infiltration of precipitation and surface water, mostly in the mountains and along valley margins, (2) underflow from consolidated rock along the margins of the valley, (3) subsurface inflow from Rush Valley to the south, (4) discharge from mines and tunnels, and (5) seepage from irrigated lands. Discharge from the basin-fill aquifer is from (1) evapotranspiration, (2) well-water withdrawal, (3) springs, and (4) subsurface flow to Great Salt Lake (Gates and Keller, 1970; Razem and Steiger, 1981). According to Stolp (1994), average discharge approximates average recharge at 44,000 acre-feet per year (54,000,000 m^3/yr). Allen and others (1995) reported an average annual ground-water withdrawal of 29,000 acre-feet (36,000,000 m^3) from wells during 1990-94, accompanied by water-level increases for wells in northern, northwestern, and southeastern Tooele Valley, and water-level declines in all other wells.

Ground-Water Quality

Ground-water quality for Tooele Valley is variable and includes calcium-bicarbonate, calcium-magnesium-bicarbonate, and sodium-chloride types (Razem and Steiger, 1981). Additionally, ground water in some areas near Erda is of mixed types and sulfate is one of the major ions (Razem and Steiger, 1981). Total-dissolved-solids (TDS) concentrations in Tooele Valley range from 256 to 37,800 mg/L based on water-quality data collected between 1964 and 1995 (Steiger and Lowe, 1997). Average background TDS concentration is 1310 mg/L (Steiger and Lowe, 1997, tables 2 and 3). In general, recharge areas and basin margins are characterized by very good water quality (TDS concentration less than 500 mg/L). Water quality is more variable throughout the central part of the basin, where TDS concentrations range from less than 500 mg/L to greater than 3000 mg/L, and in some areas near Great Salt Lake TDS concentrations exceed 10,000 mg/L (Steiger and Lowe, 1997).

Nitrate-plus-nitrite concentrations in the basin-fill aquifer range from less than 0.02 to 30.3 mg/L, with an average (background) concentration of 2.5 mg/L (Steiger and Lowe, 1997). Seven wells with water having nitrate concentrations exceeding 10 mg/L, the Utah ground-water quality standard, were identified in the east Erda area (Steiger and Lowe, 1997). The high nitrate concentrations range from 10.01 to 30.3 mg/L (Steiger and Lowe, 1997). These levels are likely associated, at least partially, with contamination from septic-tank systems because fecal coliform bacteria have been found in water from one of the wells (Bishop, 1997). However, mining activities also may be a source of the nitrate contamination, especially if ground water flows along the buried Occidental fault zone (one of the inferred faults having no surface expression) (Bishop, 1997).

Concentrations of dissolved cadmium in water from three wells and one spring equaled or exceeded the ground-water quality standard of 5 µg/L in the 1970s, but concentrations in water from two of these wells were below the standard in 1985 (Steiger and Lowe, 1997). Concentrations of dissolved lead in water from six wells exceeded the ground-water quality standard of 15 µg/L in the 1970s, but concentrations in four of these wells later dropped below the standard (Steiger and Lowe, 1997). Ground water having concentrations above the ground-water quality standards for the volatile organic chemicals trichloroethylene and carbon tetrachloride, 5 µg/L for both, has been identified in the eastern part of Tooele Army Depot (Steiger and Lowe, 1997).

WETLANDS

Introduction

Wetlands are one of the most important ecosystems on Earth. They have numerous functions and are a valuable resource to communities. Wetland functions include wastewater treatment or water filtration, flood-water control and storage, wildlife habitat, biologic productivity, and food-chain support; additionally, they have economic and cultural value (Lock, 1994). In the United States, an estimated 53 percent of wetlands in the lower 48 states have been destroyed since the 1700s due to human activities (Mitsch and Gosselink, 2000). Agricultural fields, commercial developments, and residential developments have typically replaced wetlands. Prior to the mid-1970s, U.S. domestic policies encouraged the drainage of wetlands so that the land could be developed for economic benefits. Now that the value and importance of wetlands have been recognized, conservation efforts have followed. It is the current goal of the U. S. government that no net loss of wetlands occurs, so that when development of wetlands occurs, the amount of wetland area lost must be restored, created, or enhanced through the wetland mitigation process (U.S. FWS, 1994). For additional information about wetlands background, definitions, and functions refer to appendix A.

Tooele Valley Wetlands

The wetlands in Tooele Valley are in the northern portion of the valley near Great Salt Lake. Approximately 80 percent of the wetlands in Utah surround Great Salt Lake, which corresponds to an estimated 400,000 acres (1600 km^2) of wetlands (Lock, 1994). Preliminary estimates from existing GIS wetlands coverage (U.S. FWS, 1990) indicate that wetlands in Tooele Valley occupy about 79,000 acres (320 km^2), or almost 50 percent of the valley-floor area. Lock (1994) estimates that 30 percent of Utah's wetlands has been lost, mostly due to land-development practices.

Most of the Tooele Valley wetlands are located within the Tooele Valley SAMP area (figure 1). The areal extent of Tooele Valley wetlands is controlled by the arid and semiarid conditions, and the elevation of the shallow water table. Most of the SAMP area is classified as a ground-water discharge area by Steiger and Lowe (1997) (figure 2). In the north-central area of Tooele Valley two aquifers exist, one that is confined (called the principal aquifer), and another that is unconfined (called the shallow unconfined aquifer), which overlies the principal aquifer. In the discharge area, ground-water discharges from the principal aquifer upwards into the shallow unconfined aquifer, and as a result the water table is at or near the land surface. These wetlands are typically fed by springs that discharge ground water, and together the low hydraulic conductivity of the soil and the high water table allow ponding of water at or near the discharge area. Dunne's Pond Springs and Mill Pond Springs, in the northeastern part of the valley, and Fishing Creek Springs and Sixmile Creek Springs, east of Grantsville, are large springs in the SAMP area that are presumed to coincide with buried faults that act as conduits for ground water from the principal aquifer (figure 1) (Lambert and Stolp, 1999, p. 13).

Wetland Types

The Emergency Wetland Resources Act of 1986 directs the U.S. Fish and Wildlife Service to map the wetlands of the United States; this mapping effort is referred to as the National Wetlands Inventory (NWI). The wetlands are typically mapped using aerial photographs and are classified using the Cowardin system. The Cowardin system of wetland classification (Cowardin and others, 1979) separates wetlands into five basic categories (1) lacustrine, or lake-like, (2) riverine, or river, (3) palustrine, or pond-like, (4) estuarine, or estuary, and (5) marine, or oceanic. Once the wetlands have been mapped and classified, any changes in their status or trends can be monitored. An NWI map for Tooele Valley (figure 3) shows the majority of the wetlands in the valley are lacustrine and palustrine. The lacustrine wetlands are associated with the shoreline of Great Salt Lake, and the palustrine wetlands are associated with the springs that discharge ground water and form ponds.

As part of the Tooele Valley SAMP, Tooele County contracted SWCA Environmental Consultants to map the type and distribution of the wetlands in the plan area using remote-sensing techniques. SWCA (2004a) used IKONOS satellite imagery, acquired in May 2002, to create the map (plate 1). The map classification is based on the ground cover and/or vegetation that existed when the IKONOS satellite acquired the Tooele imagery, and has an assessed accuracy of 87 percent. This map uses a different classification system than the NWI map, has a greater resolution than the NWI map, and displays the "patchiness" of the Tooele Valley wetlands. The IKONOS map represents the most current and accurate map available for wetlands in Tooele Valley. Appendix B gives additional information on how the map was generated.

Within the plan area are various types of habitats or environments. The western part of the plan area consists of vegetated and non-vegetated mineral and wet mud flats. Wet-meadow and emergent marsh environments are near the southwestern border of the plan area where ponds have formed from flowing springs. The town of Grantsville lies in the west-central part of Tooele Valley, which is mainly upland and agricultural land. Just east of Grantsville and the central upland area are two fairly large areas classified as wet meadow that are separated by an upland and vegetated-mineral-flat area. The water in these wet meadows is from Fishing Creek Springs to the west and Sixmile Creek Springs to the east. The eastern part of the plan area consists of upland, mosaic, wet-meadow, vegetated-mineral-flat and open-water environments, as well as some agricultural land. The open-water environments are associated with Great Salt Lake, sewage treatment ponds, and some other spring-fed ponds; the largest pond was privately constructed and acquires water from a canal (Spencer Martin, SWCA Environmental Consultants, verbal communication, May 19, 2004).

Wetland Evaluation

In an effort to simplify the IKONOS wetland map for evaluation and management purposes, SWCA Environmental Consultants divided the SAMP area into 14 different wetland functional units based on the

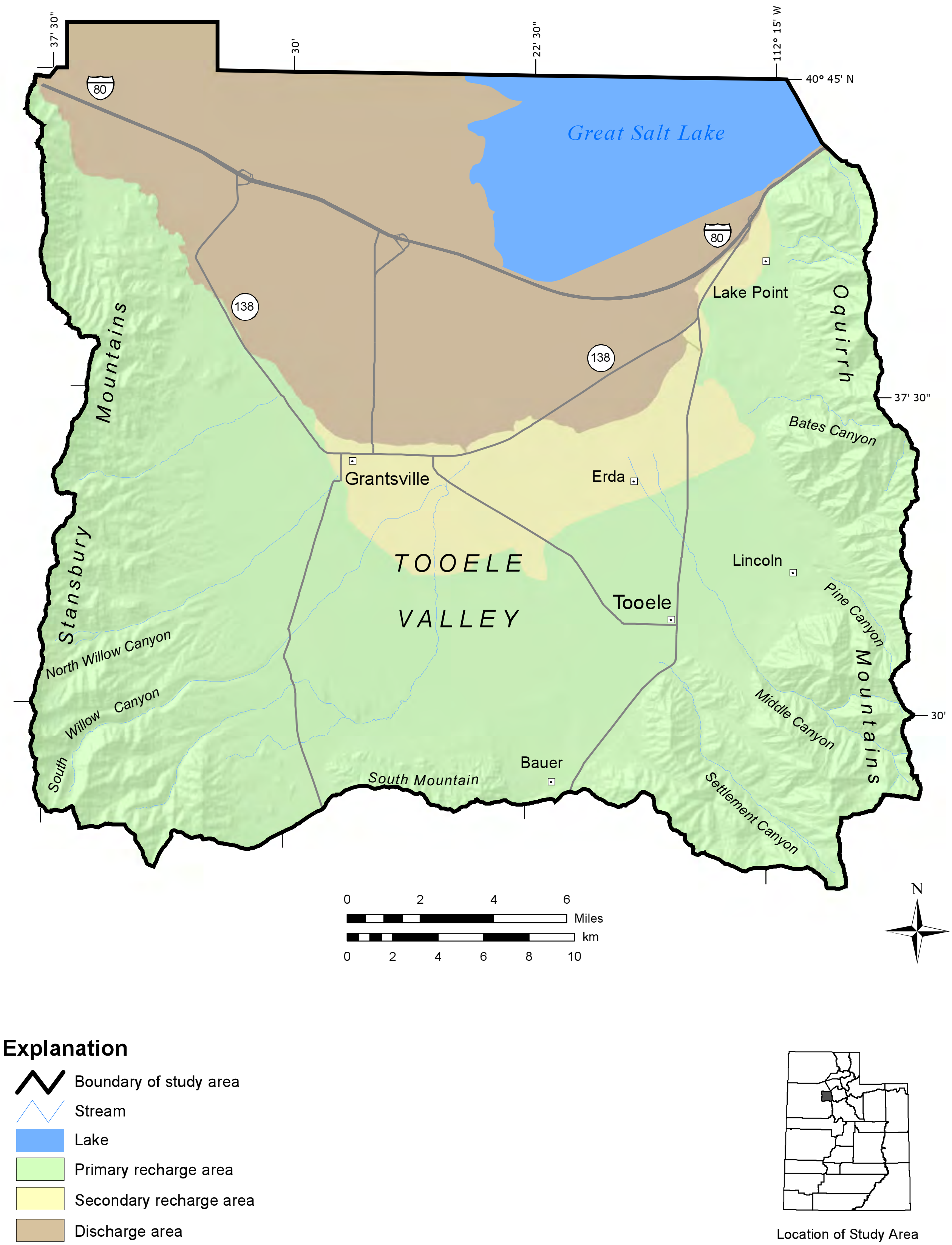

Figure 2. Recharge and discharge areas for the principal aquifer in Tooele Valley, Tooele County, Utah (modified from Steiger and Lowe, 1997).

dominant land and vegetation type in each area (figure 4). We established monitoring wells in three of the wetland functional units (units 2, 8, and 14) for water-quality evaluation, and to determine the magnitude and direction of the hydraulic gradient in the shallow unconfined aquifer. Additionally, SWCA (2004b) performed a functional assessment on the three wetland functional units to evaluate the overall health of the wetlands in those units. Due to land-access issues, the installed monitoring wells were concentrated in a small area of each functional unit evaluated (figure 4). These wetland functional units were investigated because upland plants have been invading the wetland areas. This is presumed to be related to the depth and availability of water, so a greater understanding of the hydrology is desired in these areas.

Description: Based on the wetland classification system developed by Cowardin and others (1979), all of the wetlands evaluated for this study are palustrine or pond-like wetlands. The IKONOS wetland classification map (plate 1) displays the various land types or environments within each wetland functional unit. Unit 2 consists of vegetated and non-vegetated mineral-flat, open-water, upland, wet-meadow, and mosaic environments. The mosaic environment is a complex of upland and wetland vegetation. The vegetation within the area covered by the well distribution consists mainly of grasses, silver sage, greasewood, pickleweed, and some Russian olive trees (figure 5). A clump of tamarisk was also found growing next to a surface water channel. The mineral flats are vegetated with pickleweed and greasewood; the upland environment is vegetated with grasses, silver sage, some greasewood, and Russian olive trees; the wet-meadow environment is vegetated with salt grass; and the mosaic environment is vegetated with plants from the upland and wet-meadow environments.

Unit 8 makes up the largest contiguous wetland area, and is composed of vegetated and non-vegetated mineral-flat and upland environments (figure 6). The wells installed in unit 8 lie in vegetated and non-vegetated areas. The mineral-flat vegetation in unit 8 consists of salt grass and pickleweed, and the upland vegetation consists of silver sage and greasewood.

Unit 14 consists of mosaic, wet-meadow, upland, and open-water environments. The wells installed in unit 14 surround a pond that formed from ground-water discharging from a well or spring (figure 7). The vegetation in unit 14 consists mainly of sedges, bulrushes, and some salt grass in the wet-meadow environment; grasses, Russian olive trees, and silver sage in the upland environment; and a combination of plants in the mosaic environment.

Fine-grained sediments, mainly clay with some silt and probably some fine sand, which are typical of offshore lacustrine deposits, dominate the substrate in which the wells were established. We encountered no gravel or sand lenses during well installation, and the hydraulic conductivity of the upper 10 feet (3 m) of sediment is presumed to be relatively low compared to the underlying principal aquifer.

Hydrology: We determined the magnitude and direction of the hydraulic gradient for the shallow unconfined aquifer by measuring the water levels in the wells in each wetland unit. Table 1 summarizes the water-level information and associated well data, and table 2 gives the magnitude and direction of the hydraulic gradient for the three evaluated wetland units; the directions of the hydraulic gradients are also shown in figure 8. We calculated the direction and magnitude of the hydraulic gradient using EPA's on-line tools for site assessment (U.S. EPA, 2004). The direction of the hydraulic gradient for the evaluated wetland areas is consistent with what was reported by Steiger and Lowe (1997) and Gates and Keller (1970); ground water flows to the north-central end of Tooele Valley, and then toward Great Salt Lake. The direction of the hydraulic gradient changes direction by 3 degrees be-

Table 1. *Location and water-level information for installed wells. Refer to figure 4 for map view.*

Well#	Latitude	Longitude	Wetland Unit #	Ground Elevation (ft)	PVC Height (ft)	Depth to Water (ft)
1	N 40°39.014′	W 112°31.758′	8	4248.0	0.70	2.05
2	N 40°39.326′	W 112°31.571′	8	4222.0	1.59	4.46
3	N 40°39.158′	W 112°31.557′	8	4231.5	1.96	3.46
4	N 40°38.202′	W 112°19.147′	14	4261.0	1.11	4.12
5	N 40°38.335′	W 112°19.151′	14	4251.0	0.90	2.40
6	N 40°38.310′	W 112°19.307′	14	4249.5	0.87	3.16
7	N 40°38.861′	W 112°19.320′	2	4236.0	1.05	3.30
8	N 40°38.666′	W 112°19.067′	2	4247.0	1.55	2.29
9	N 40°38.226′	W 112°19.915′	2	4254.0	1.55	2.50

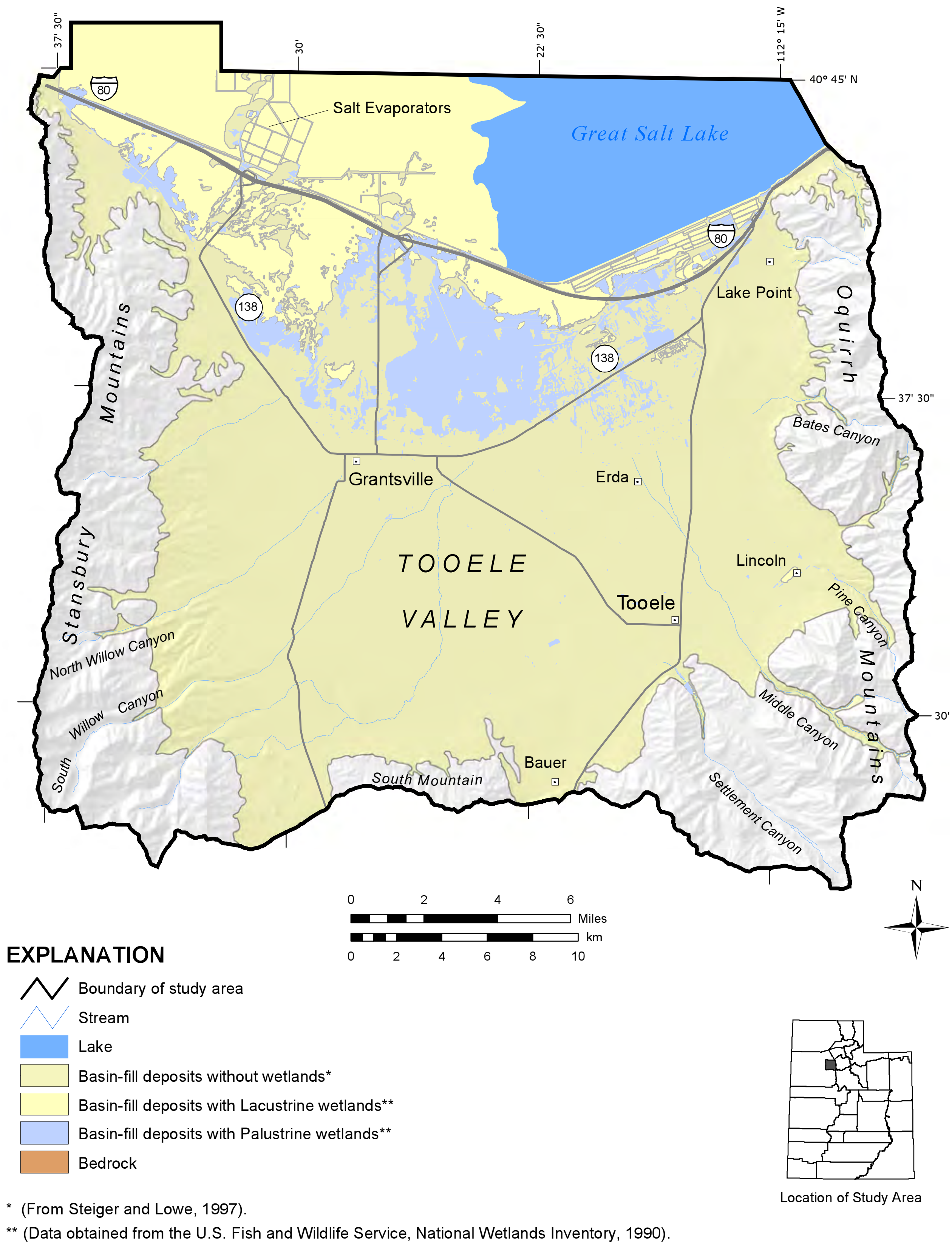

***Figure 3.** National Wetlands Inventory (NWI) map of Tooele Valley wetlands.*

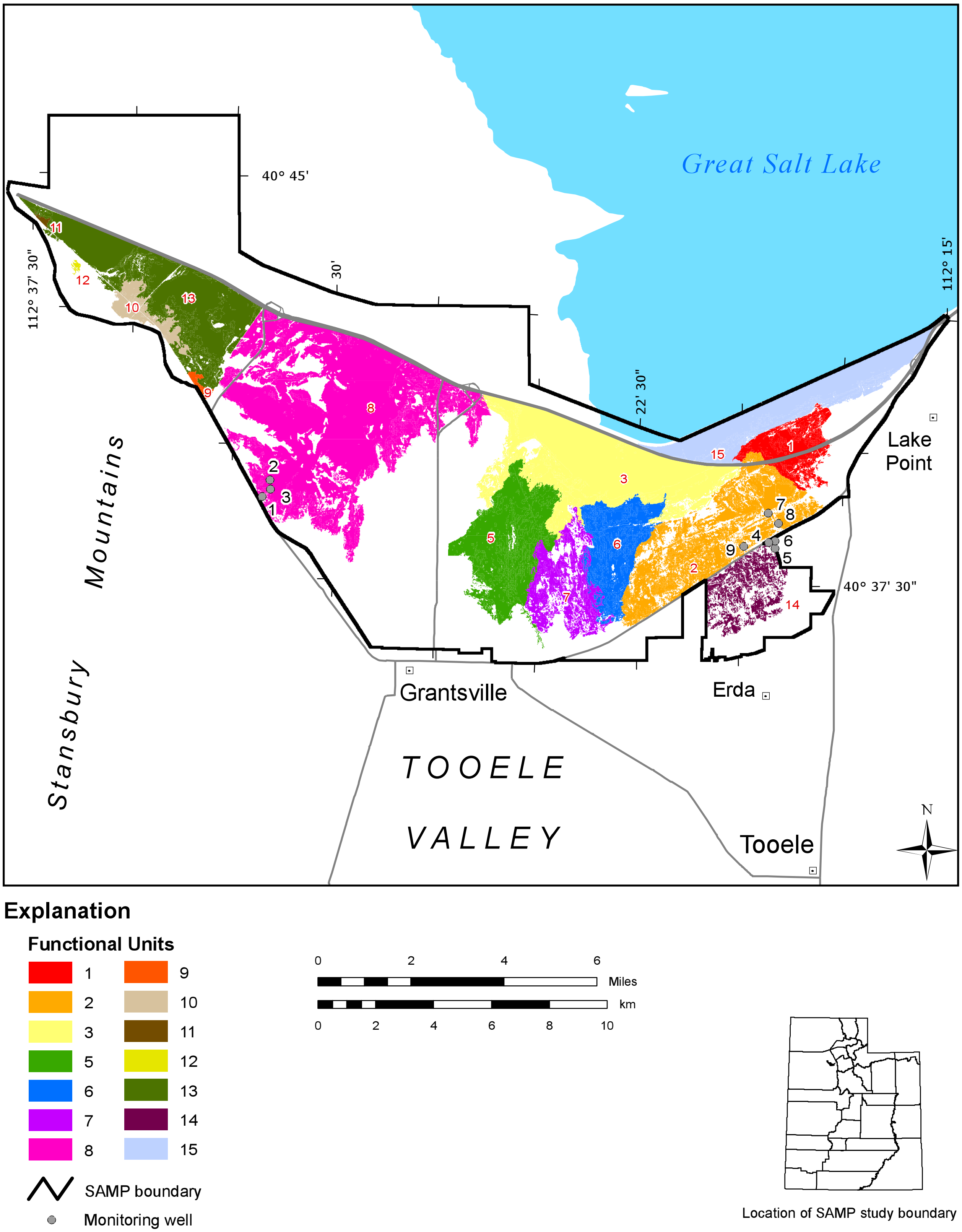

Figure 4. Location and distribution of Tooele wetland functional units and installed monitoring wells, northern Tooele Valley, Tooele County, Utah. Refer to Weland Evaluation section of text for discussion of functional units.

Figure 5. *Wetland unit 2, which includes mosaic environment looking west (top), and wet-meadow environment looking east (bottom).*

Figure 6. *Wetland unit 8, which includes vegetated (top) and non-vegetated (bottom) mineral flats.*

Figure 7. *Wetland unit 14, which includes wet-meadow environment. The photo was taken in August after most of the pond had dried up.*

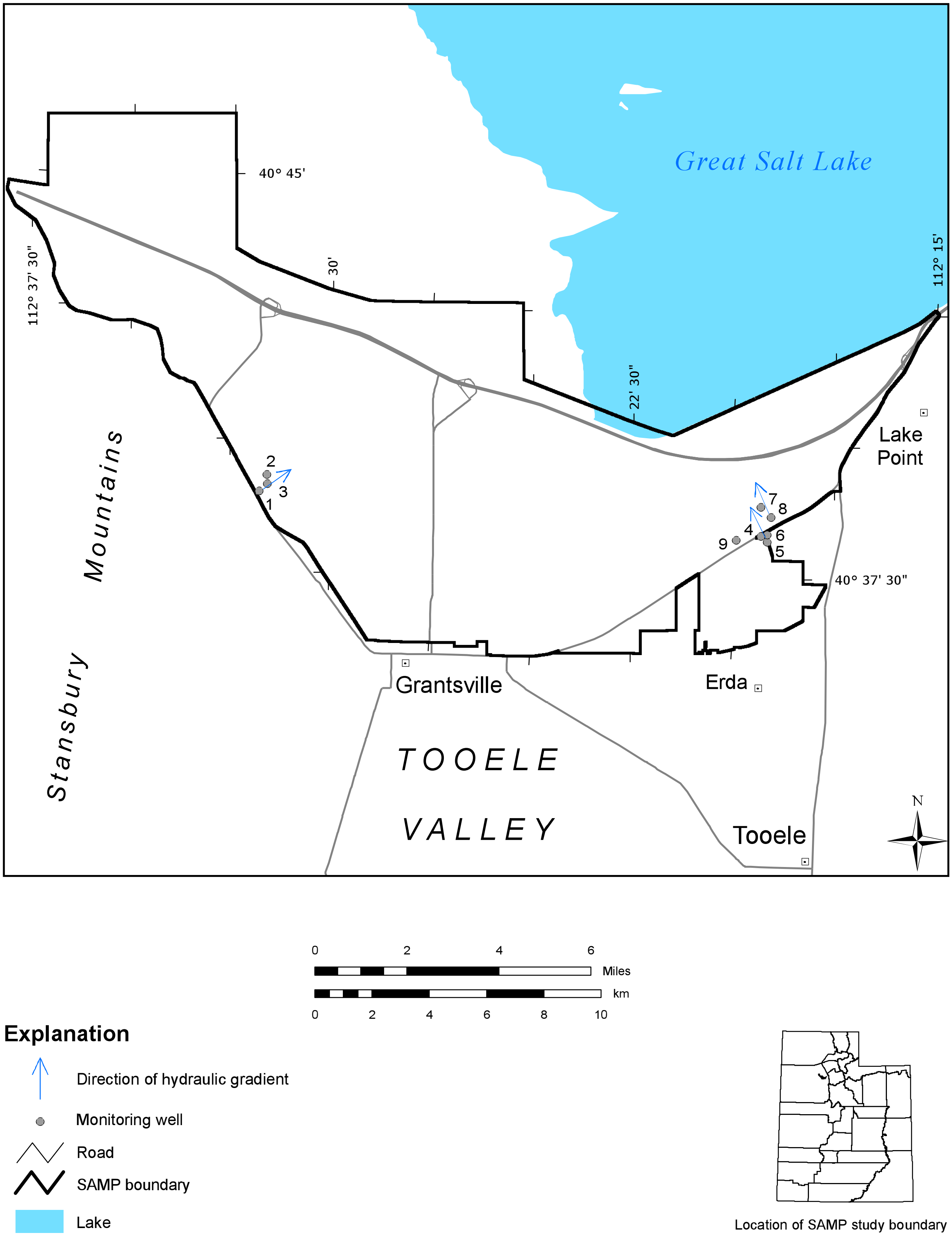

Figure 8. *Direction of hydraulic gradient in each wetland evaluation area, northern Tooele Valley, Tooele County, Utah.*

Table 2. Direction and magnitude of the hydraulic gradient. Refer to figure 8 for map view.

Wetland Unit #	Direction (azimuth)	Magnitude
2	337°	0.0080
8	035°	0.0134
14	334°	0.0117

tween the evaluated wetland areas in units 2 and 14, with the wetland area in unit 2 having a more northerly direction. The magnitude of the hydraulic gradient is also steeper in the evaluated wetland area in unit 14 than it is in unit 2. The reason for these differences in hydraulic gradient is unclear and may not even be significant. Local differences in porosity, permeability, and hydraulic conductivity likely exist between the wetland areas, even though the substrate appeared to be similar, based on cuttings examined during well installation. A gravel bench between the two wetland areas, parallel to Highway 138 to the north, is the Lake Bonneville Gilbert shoreline (Barry Solomon, Utah Geological Survey, verbal communication, December 13, 2004), which could influence differences in hydraulic conductivity. The bench appears to run from the vicinity of Mill Pond Springs (near Lake Point) to Fishing Creek Springs, which have been suggested by Lambert and Stolp (1999, p. 13) to be fault-related springs. Fault zones in this area likely create local differences in the hydraulic conductivity and influence the direction and magnitude of the hydraulic gradient in the shallow unconfined aquifer. However, we cannot conclude that the differences seen in units 2 and 14 are from the fault zones. Another explanation is the presence of Highway 138, which most likely has some influence on the hydrology of the shallow unconfined aquifer. However, the extent to which Highway 138 influences the hydrology in the shallow unconfined aquifer remains largely unknown.

Water quality: The water chemistry for the samples from each well established for this project is presented in appendix C. The shallow ground water collected from wetland unit 8 (wells 1, 2, and 3) is Class IV, based on the Utah Water Quality Board's TDS-based classification system (table 3); the water samples have TDS concentrations greater than 10,000 mg/L. Except for well 5, the TDS concentrations from the unit 8 wells are the highest of the study. Dominant ion chemistry classification for all of the wells in unit 8 is sodium-chloride-type ground water (figure 9). Arsenic is reported in all of the wells in unit 8; well 3 has the highest concentration at 57.1 µg/L, which exceeds the current ground-water quality (health) standard of 50 µg/L (U.S. EPA, 2005a); the U.S. EPA arsenic standard will be lowered to 10 µg/L in 2006 (U.S. EPA, 2005a). Water quality does not improve as water flows downgradient through the evaluated wetland area in unit 8. Downgradient improvement in water quality is one the most valuable wetland functions, but this typically applies to surface water flowing through wetlands and not necessarily ground water. The ground-water quality in unit 8 probably decreases northward, due to the increased salt content in the soil and proximity to Great Salt Lake, where the only outlet for water is evapotranspiration.

Most of the wetlands in Tooele Valley are located in the area that Steiger and Lowe (1997) classified as a ground-water discharge area, where an upward hydraulic gradient exists between the underlying principal aquifer and the overlying shallow unconfined aquifer. Average annual evapotranspiration for the Tooele weather station is 42.5 inches (108 cm; Ashcroft and others, 1992). Evapotranspiration of water from the shallow unconfined aquifer and the upward hydraulic gradient create a system where solutes concentrate in the shallow unconfined aquifer, increasing TDS in the ground water. If solute concentrations reach high enough levels, precipitation reactions may occur. We calculated speciation and saturation index values by using the geochemical modeling program PHREEQC (Parkhurst and Appelo, 2000) to evaluate if any precipitation reactions are occurring in the shallow unconfined aquifer. Modeling indicates that water from well 1 and well 2 is supersaturated with respect to aragonite, calcite, dolomite, hydroxyapatite, and $MnHPO_4$, which suggests that these mineral phases may be precipitating in the shallow unconfined aquifer. Halite and gypsum are both undersaturated. We encountered what appeared to be a carbonate hardpan at a depth of about 6 feet (2 m) during the drilling of well 2, but whether this formed diagenetically or as a tufa deposit from a paleo-shoreline is unknown. Water from well 3 is similar in chemical composition to water from wells 1 and 2, but contains the highest concentration of manganese for samples collected as part of this study. Water from well 3 also contains detectable amounts of iron, which we assume to be in the ferric state and thus insoluble, so in addition to being supersaturated with the same phases as water from wells 1 and 2, water from well 3 is also supersaturated with various iron and manganese oxide and hydroxide phases.

The shallow ground water collected from wetland unit 2 (wells 7, 8, and 9) is Class III and IV (table 3). Steiger and Lowe (1997) classified the underlying principal aquifer for this area as Class II, so the shallow unconfined aquifer water quality is of lower quality than the principal aquifer in this area. The lowest TDS value of 8040 mg/L obtained from unit 2 is from well 7, which is the second-lowest TDS value obtained from all of the established wells in this study. Well 7 is the northernmost well from units 2 and 14; TDS and salinity values typically increase northward towards

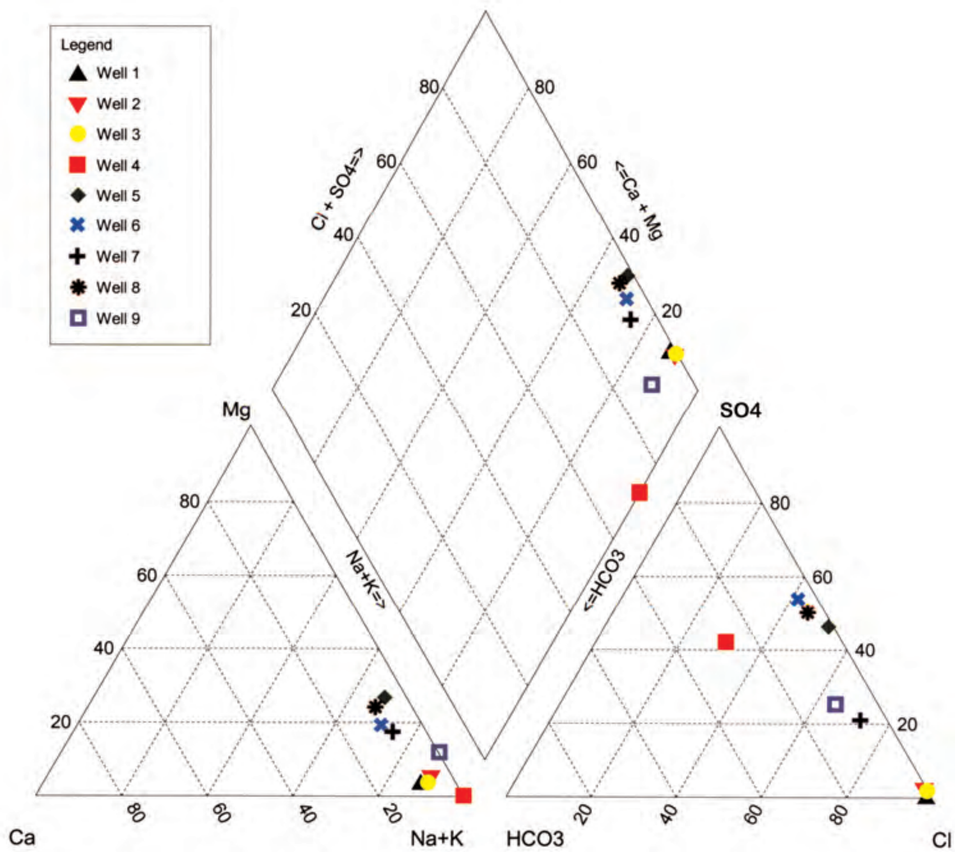

***Figure 9.** Piper diagram of water samples collected from installed wells in three wetland areas, Tooele Valley, Tooele County, Utah.*

Great Salt Lake. Ground water from well 7 appears to be diluted, possibly by the canal that lies just south of the well. The canal diverts fresh water from Sixmile Creek Spring, so some of that water may be seeping into the surrounding ground and diluting the ambient ground water, thus reducing the salinity and TDS concentration. The water in unit 2 ranges from sodium-chloride type for wells 7 and 9 to sodium-sulfate type for well 8 (figure 9). Arsenic concentrations for wells 7, 8, and 9 are 56.8, 50.9, and 304.0 µg/L, respectively, all of which exceed the ground-water quality standard.

Modeling with PHREEQC indicates that water from well 7 is supersaturated with respect to hydroxyapatite and the carbonates aragonite, calcite, dolomite, and magnesite. Water from well 8 is supersaturated with the same mineral phases as water in well 7, in addition to gypsum and $MnHPO_4$. Water from well 9 contains some iron, but lacks detectable amounts of calcium, so the supersaturated mineral assemblage is mostly made up of iron-bearing phases. The only non-iron-bearing phases are magnesite and $MnHPO_4$.

Wells 4, 5, and 6 were established in wetland unit 14. Well 4 contains Class II ground water with 2690 mg/L TDS. The other two wells contain Class IV ground water. The dominant cation in the water samples collected from the wells is sodium. Only well 6 has a dominant anion, and can be classified as sodium-sulfate type on a Piper diagram. Water from well 4 does not have a dominant anion and water from well 5 is a sodium-chloride type that plots near the no-dominant-anion boundary; however, the anion with the highest concentration in both wells is sulfate (figure 9). Sulfate concentrations are greater than chloride concentrations for all three wells in unit 14, and water from well 5 has the greatest sulfate concentration of the study. Of particular interest is the presence of arsenic, selenium, and copper in the water samples collected from the wells in unit 14. Arsenic concentrations are 239.0, 723.0, and 214.0 µg/L for water from wells 4, 5, and 6, respectively, all of which greatly exceed the 50 µg/L ground-water quality standard. Selenium is only detected in the water samples collected from unit 14, with concentrations of 7.9, 27.0, and 22.2 µg/L from wells 4, 5, and 6, respectively; these are below the current ground-water standard of 50 µg/L (U.S. EPA, 2005a). Selenium is found in metal-ore deposits and is associated with the processing of copper ore (U.S. EPA, 2005b). A smelter operated until the 1960s in Pine Canyon (Bishop, 1997), which lies directly upgradient of unit 14 based on the ground-water flow direction presented by Steiger and Lowe (1997). Selenium is also associated with agricultural runoff and is a trace element in many soils (Seiler and others, 2003), so

Table 3. *Ground-water quality classes under the Utah Water Quality Board's total dissolved solids-based (TDS) based classification system (modified from Utah Division of Water Quality, 1998).*

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

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

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

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

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

[5]Generally used for industrial purposes.

[6]May have economic value as brine.

whether the selenium is associated with the smelter or represents natural background concentrations is unknown. Copper is below the detection limit for ground water from all of our wells, except for well 5, which has a concentration of 150.0 µg/L. Iron is detected at concentrations of 113.0 and 127.0 µg/L in water from wells 4 and 6, respectively. The iron concentration in water from well 6 is the highest in this study. The sulfate, arsenic, selenium, copper, and iron data can be used as evidence to suggest that the ground water in unit 14 has been influenced by mining and/or refining activities; further studies would be needed to confirm this speculation. The discharging well that forms the wetland pond in unit 14 was not sampled, so the quality of its water is unknown. The well likely penetrates the principal aquifer, so it probably yields higher quality water than the ground water from the shallow unconfined aquifer.

Modeling with PHREEQC indicates that water from well 4 is supersaturated with iron-bearing phases, mainly iron oxides and hydroxides with a hydrous iron sulfate (jarosite) and a hydrous iron phosphate (strengite) phase. The only non-iron phase is $MnHPO_4$. The lack of other phases is due to the low concentrations of calcium, sodium, and magnesium, even though well 4 has a high alkalinity. Well 4 yields ground water with the lowest TDS of the study, but the reason is unknown. Although well 4 is the most upgradient well of the study, the distance to other wells is not large enough to explain the better water quality. Possible explanations include (1) the solutes could have already precipitated out of solution, (2) some of the solutes could have been attenuated by sorption reactions, or (3) the ground water in the vicinity of well 4 is being diluted by better quality water, either from an upgradient canal or discharge from the principal aquifer. A combination of all of the above scenarios could also contribute to the low TDS value. Ground water from well 5 is supersaturated with anhydrite, aragonite, calcite, dolomite, gypsum, hydroxyapatite, and magnesite. Ground water from well 6 is supersaturated with the same phases in wells 4 and 5.

Downgradient improvements in water quality are difficult to determine for the wetland areas that we evaluated. The wetland area in unit 14 does not display any downgradient improvements in water quality because the best quality water is from the upgradient well. The downgradient well in unit 2 contains better quality water than the upgradient wells; however, this may be attributed to dilution from the nearby canal. Looking collectively at the evaluated wetland areas from units 2 and 14, one could argue that a downgradient improvement in water quality exists, but given the physical characteristics of the ground-water system, this seems unlikely. Except for well 7 in unit 2, the overall trend is a downgradient increase in TDS and salinity as water flows through each wetland area. Water-quality improvements are typically associated with surface water flowing through a wetland where solutes settle out of the water column and are attenuated in the bottom sediments, or are used in biological processes, such as nitrogen fixation, that alter a compound into a more benign form. Most of the wetlands in Tooele Valley that have surface-water ponds are fed by springs or flowing wells that are assumed to derive their water from the principal aquifer, which has better quality water than the shallow unconfined aquifer. However, we sampled no surface water in this study and cannot validate this assumption.

Our conceptual model for the Tooele Valley wetlands is based on data from previous studies and this study. A diagram of the ground-water flow system in relation to the shallow unconfined and principal aquifers in Tooele Valley is presented in figure 10. The wetlands are located in ground-water discharge areas, where the vertical hydraulic gradient is upwards between the principal aquifer and the shallow unconfined aquifer. Ground water from the principal aquifer flows up into the shallow unconfined aquifer and undergoes evapotranspiration, leaving dissolved constituents in the soil. As the solute concentration increases in the water from the shallow unconfined aquifer, certain mineral phases begin to precipitate in the soil, namely carbonates, sulfates, some phosphates, and some iron-bearing oxide and hydroxide phases. Precipitation of solutes caused by evapotranspiration is probably the main mechanism in operation in units 2, and especially, unit 8. In places where surface water ponds exist, like in unit 14, the surface water is probably of better quality than the ground water in the shallow unconfined aquifer. In these pond areas the upwelling ground water mixes with the surface water just below the ground surface, which creates a buffer zone between the surface water and the ground water that is of intermediate quality. Areas having higher quality ground water in the shallow unconfined aquifer are probably localized, and are due to dilution and mixing of water derived from the principal aquifer either by means of leaky artesian conditions, faulting, canals, or discharging wells.

Wetland health: SWCA Environmental Consultants, as part of the SAMP process, determined the overall health of the investigated wetland areas (SWCA, 2004b) by using a functional assessment model created by Keate and others (2001). The model was developed for Great Salt Lake slope wet-meadow wetlands and is "primarily based on land use as a reflection of human impacts on wetland function" (Keate and others, 2001, p. 3). We focus on the results for the functional assessments made on wetland units 2, 8, and 14 (figure 4). The results of the functional assessment model give a number between 0 and 1 for each of the following wetland functions (1) external ground- and surface-water delivery (exhydro), (2) internal ground- and surface-water flow (inhydro), (3) removal of dissolved elements and compounds (dissolved), (4) particulate retention (particulate), (5) flora and fauna habitat support (habitat), and (6) wildlife habitat connectivity/patchiness (connectivity) (Keate and others, 2001).

In the model of Keate and others (2001), the external ground- and surface-water delivery function is related to a wetland's capacity for intercepting ground and surface water entering from areas outside the wetland. This function is based on land uses that affect the rate and amount of ground and surface water entering a wetland; for example, ditches and wells can intercept ground water that would normally flow into a wetland. The internal ground- and surface-water flow function is based on the vegetation in the wetland, which creates surface roughness that can slow the flow of water in the wetland, and land use, which affects the porosity and permeability of the soil in a wetland. The dissolved elements and compounds removal function is associated with a wetland's ability to remove dissolved constituents, which can occur through biotic, physical, and/or chemical processes, and is related to the concentration of nutrients in runoff associated with different land uses inside and outside the wetland. The particulate retention function is related to the deposition and retention of organic and inorganic particulates due to physical processes, and is based on the amount of suspended solids delivered to the wetland. The flora and fauna habitat support function addresses the composition and characteristics of the living plant biomass. The wildlife habitat connectivity/patchiness function is a measure of the extent to which a wetland and its immediate surroundings can provide a corridor for the movement of animals within and between wetlands.

The functional assessment model is essentially a way to measure the operational capacity of the six wetland functions listed above. For example, a result of 1 correlates to the wetland operating at 100 percent capacity for that specific function, and a result of 0.5 correlates to a wetland function operating at 50 percent capacity. Based on the model by Keate and others (2001), the functionality of the wetlands is related to the type and extent (amount, size, area, etc.) of land-use practices in the wetland and surrounding areas. The results of the assessment are presented in table 4.

Unit 2 has the lowest average score, meaning it is the worst functioning wetland area of the three units investigated. The low exhydro and particulate scores are due to alteration of the ground- and surface-water hydrology by the highway and canals in the unit area. The low habitat score is related to land use. The connectivity score is low because that score is related to the exhydro score. Unit 8 has the highest average score, indicating that it is the highest functioning wetland of those evaluated in this study. This is because much of the land has not been modified by development. The only land uses that have lowered the scores are the cement plant located nearby, and the highway.

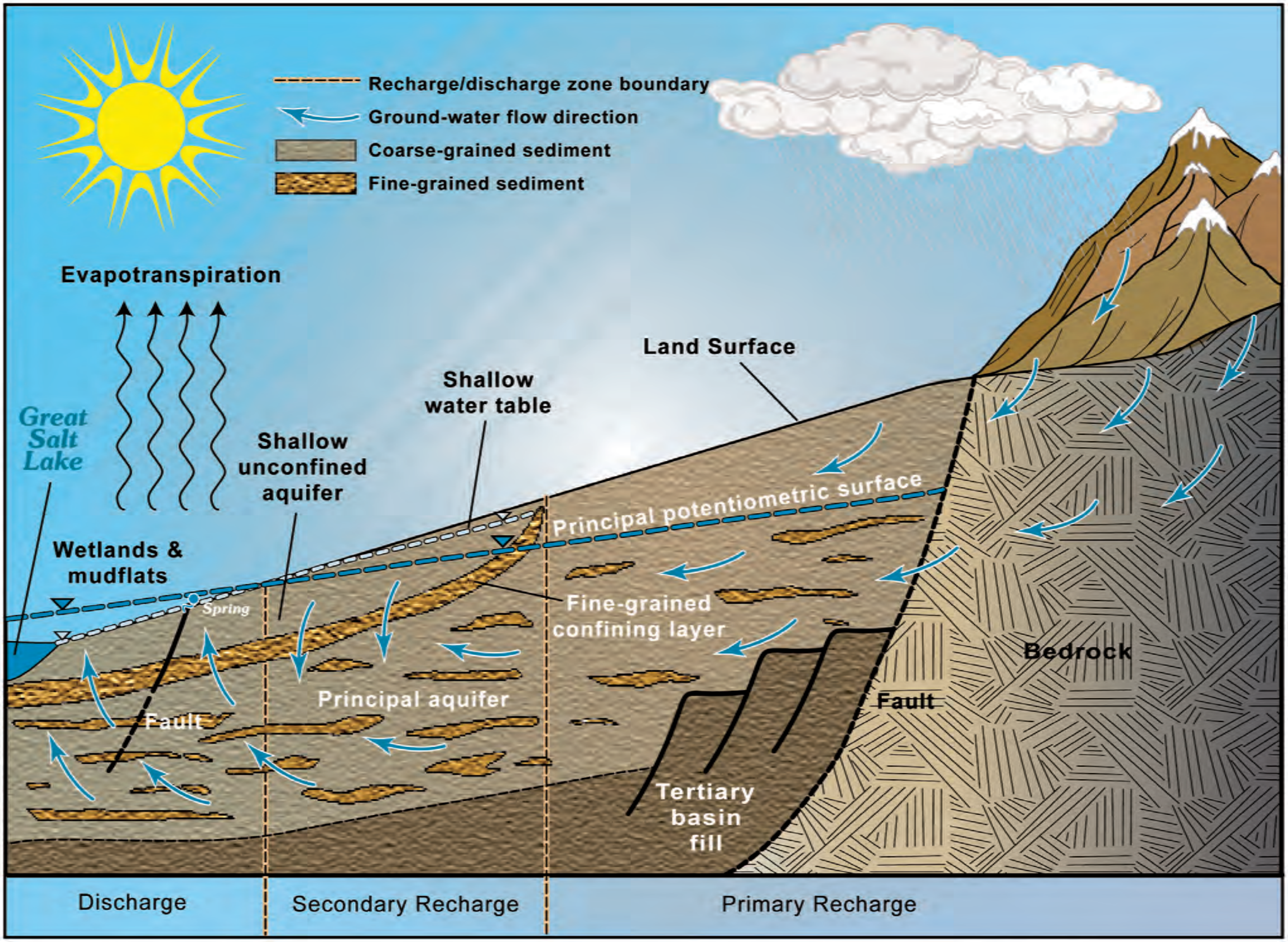

Figure 10. *Schematic diagram of Tooele Valley ground-water flow system.*

Table 4. *Results of the functional assessment based on the model by Keate and others (2001). Refer to the Health subsection of the Wetland Evaluation section for more information.*

Wetland Functions	Unit 2	Unit 8	Unit 14
Exhydro	0.545	0.749	0.706
Inhydro	0.879	0.933	0.911
Dissolved	0.914	0.948	0.908
Particulate	0.567	0.770	0.742
Habitat	0.578	0.819	0.539
Connectivity	0.655	0.530	0.653
Average	0.690	0.792	0.743

The low scores in unit 14 are related to modifications of the hydrology made by the highway and canals in the area, and by some of the land uses in and surrounding the area. The land uses that negatively impact the habitat and connectivity scores the most for unit 14 are residential housing, field crops, and grazing. All of the evaluated wetland areas have high dissolved scores, which suggests that the wetlands are good at removing dissolved elements and compounds, but the quality of the ground water in each wetland area is fairly poor. This seems paradoxical, but the score is calculated based on the land uses inside and surrounding the wetland that could load the wetland with dissolved constituents, such as a highway, a dairy feed lot, or an industrial area. The score does not consider the natural background water quality; it considers only land uses that could degrade the water quality. Because few land uses that degrade the water quality within and surrounding the evaluated wetland areas exist, the score is high.

The overall health or functionality of the evaluated wetland areas can be improved. The function that has been most affected in all of the wetland areas is the hydrology, which typically has been altered by construction of a road, highway, or canal. Improving the hydrology is the single-most effective factor that could increase the health or functionality of all the wetlands that were evaluated. Without changing any of the land uses, the hydrology could be improved by removing flow barriers or by creating more flow pathways through barriers, such as culverts through roads and railways, or back filling unnecessary canals and ditches. Any actions that would promote surface- and ground-water flow in its predevelopment state are likely to improve the hydrologic function of the wetlands.

Land-Use Planning Considerations

The potential for wetland degradation in Tooele Valley is high, considering the pressure to develop the area due to the increasing population and the demand for low-cost housing. Preservation and conservation of the wetlands in Tooele Valley can most effectively be accomplished by leaving the land in the most natural state possible. This is probably not a likely scenario, given the demand to develop the area; however, choices can be made to develop the land in a way that has minimal impacts to the wetlands. Current land uses or types that have the lowest impact on the functionality of the wetlands include non-manipulated range lands, rotational grazing on irrigated pastures, low-density rural developments, and half-acre or greater single-family residential lots with vegetation between them (Keate and others, 2001). Land uses adversely impacting wetland functionality that should be avoided include high-density commercial developments, high-traffic highways, industrial developments, and multi-family residential developments with lots of half an acre or less (Keate and others, 2001).

GROUND-WATER FLOW/WETLANDS DEGRADATION ANALYSIS

Introduction

The wetlands in Tooele Valley are located in the northern portion of the valley, which has been classified as a ground-water discharge area by Steiger and Lowe (1997). In this area ground water discharges to the shallow unconfined aquifer by natural means, mainly by springs, seeps, or mud flats. The source of the discharging ground water is from the confined principal aquifer, where ground water flows from the confined layer to the unconfined layer. Most of the highest functioning wetlands in Tooele Valley form around springs where water collects to form ponds, so these wetlands are dependent upon the springs and seeps as their source of water; any change in discharge from the springs and seeps would alter and possibly adversely degrade the wetlands. Additionally, the population in Tooele Valley is growing rapidly, and land use is becoming more residential and less agricultural. This change in land use would likely decrease the amount of recharge from seepage of unconsumed irrigation water, which contributes nearly one-seventh of the total recharge to aquifers in Tooele Valley (Lambert and Stolp, 1999). Water resources in Tooele Valley rely primarily on ground water, which is derived from the principal aquifer. As figure 11 shows most of the wells in Tooele Valley are upgradient of the wetland areas, so if more wells are drilled or more water is withdrawn from the principal aquifer to support the growing population, less ground water would be discharged out of springs that provide water to the wetlands.

Not only are the wetlands in Tooele Valley threatened by development, but fluctuating climatic conditions are also impacting the wetlands. Utah has been in a drought for approximately the past six years, which has reduced recharge to aquifers throughout the state and lowered the level of Great Salt Lake, the ultimate barometer for water abundance in the northern part of the state. The historical average level of the Great Salt Lake shoreline is 4200 feet (1280 m) above mean sea level. The historical low level of 4191 feet (1277 m) was recorded in 1963. Due to drought, the level of Great Salt Lake declined to 4194 feet (1279 m) late in 2004, only 3 feet (0.9 m) above the historical low. If drought continues, the level of Great Salt Lake may drop even farther. Great Salt Lake is the farthest downgradient component of the hydrologic system in Tooele Valley and the surrounding drainage basins. The wetlands surrounding Great Salt Lake lie just upgradient of the lake, so water-level changes in Great Salt Lake affect the wetlands also.

To evaluate the hydrology of the wetlands in Tooele Valley, we used the steady-state and transient ground-water flow models developed by Lambert and Stolp (1999). We investigated the current and historical water use of the wetlands in Tooele Valley, and altered the models to investigate possible scenarios that could affect the wetlands, including (1) continued drought conditions with accompanying decreased recharge to the aquifer and lower Great Salt Lake level, (2) wet conditions resulting in increased recharge to the aquifer, and (3) increased development and ground-water withdrawals from the principal aquifer. This ground-water model is the best available tool to understand how the wetlands in Tooele Valley could be affected from further development and/or drought.

Ground-Water Flow Calculations

Introduction

We used the regional, three-dimensional, steady-state and transient MODFLOW (McDonald and Harbaugh, 1988) models of Lambert and Stolp (1999) from the U.S. Geological Survey to estimate the water budget for the wetland areas in Tooele Valley. The models simulate the hydrologic system in Tooele Valley, and the relation among ground-water levels, variations in annual ground-water recharge caused by changes in precipitation in and around the valley, and increased pumping in the valley. The hydrologic system in the Tooele Valley model is conceptualized as having five parts (1) an unsaturated zone affected by precipitation and evapotranspiration (not included in the model), (2) a shallow unconfined aquifer system in the northern part of the valley that interacts with the unsaturated zone, (3) a principal aquifer that is both confined and unconfined, (4) a surface-water system that supplies water to bedrock and the basin-fill aquifer, and (5) a surface-water system consisting of Great Salt Lake. Recharge to the basin-fill ground-water flow system in the model is from subsurface inflow from consolidated rock in the surrounding mountains, stream-channel deposits where streams enter the valley, infiltration of precipitation on the valley floor, seepage from irrigated fields, and subsurface inflow from Rush Valley. Discharge from the basin-fill aquifer is primarily through springs and drains, evapotranspiration, water pumped from wells, and subsurface discharge to Great Salt Lake. The models were calibrated and verified by Lambert and Stolp (1999) for 1968 (steady-state), and 1969 to 1994 (transient-state) conditions. Although the simulation is only an approximation of the reality, it is extremely useful for understanding the complex ground-water system in Tooele Valley. For more information about the ground-water flow models refer to appendix D.

Results of Simulation

The ground-water flow models used for this study are the best available tools to qualitatively determine the water budget for various sub-regions of Tooele Valley. Steady-state and transient simulations using historical data were used to indicate how changing runoff and recharge in Tooele Valley affect water flowing to the wetlands. The model simulations provided ground-water flow data in relation to aquifer characteristics, water in storage, and rates of inflow and outflow. The simulations improved our understanding of the aquifer system, and provided the flow budget needed to determine available water supplies in the wetland areas of Tooele Valley.

First, we address the question of how much water the wetlands receive under steady-state conditions using the 1968 calibrated steady-state model of Lambert and Stolp (1999). Lambert and Stolp (1999) assumed hydrologic conditions in 1968 were near steady state, because water level fluctuations from 1964 to 1968 indicate only a small yearly change throughout the valley. Water levels in the valley in 1968 are likely different from those when the valley was first settled

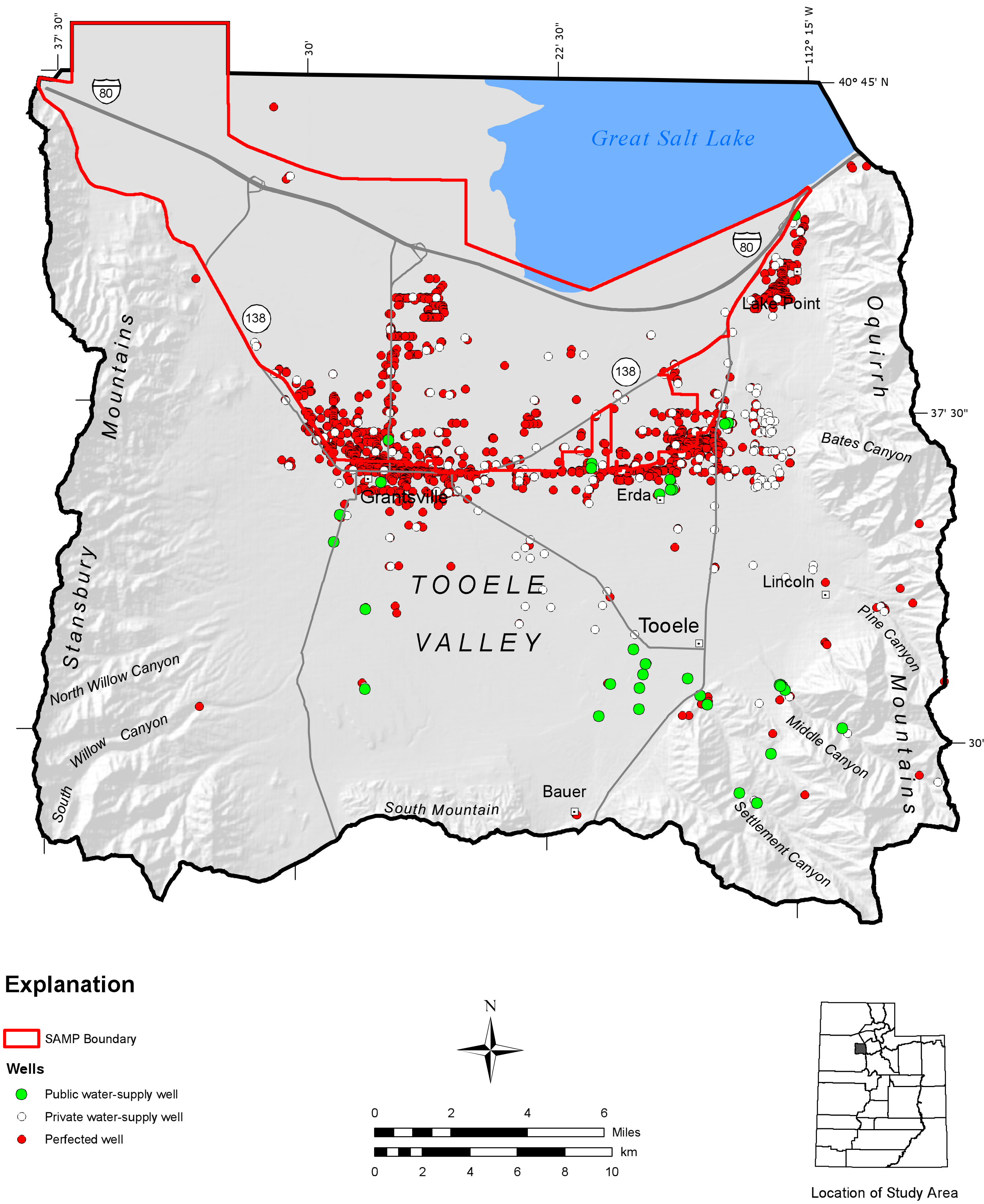

Figure 11. *Wells in Tooele Valley.*

in the 1800s. The practice of diverting streams for irrigation of crops in the late 1800s and early 1900s increased the quantity of recharge to the basin-fill aquifer, and the withdrawal of water from wells increased the discharge from the basin-fill aquifer. The increased recharged probably raised water levels in some areas of the valley, and increased discharge probably decreased water levels in other areas of the valley.

We used the simulated results from the upper model layer (layer 1, which contains the shallow unconfined aquifer and confining layer), because it is the most important in predicting effects on the wetland areas in Tooele Valley. Simulated hydraulic heads from the lower model layer (layers 2 through 5, which contain the principal aquifer) show a similar pattern, but with some vertical offset from heads for the upper layer.

Using the steady-state simulation, about 75,300 acre-feet per year (92,900,000 m^3/yr) recharges the basin-fill aquifer in Tooele Valley. Of this recharge, about 59,600 acre-feet per year (73,500,000 m^3/yr) is simulated as runoff, which is either stream flow entering the model area, or a constant recharge along the edge of the model that correlates to inflow from bedrock. In the model, all stream flow in Tooele Valley recharges the basin-fill aquifer. Recharge from precipitation and unconsumed irrigation water on the valley floor is about 15,400 acre-feet per year (18,900,000 m^3/yr). Discharge of ground water from springs and drains is about 32,000 acre-feet per year (39,500,000 m^3/yr), evapotranspiration from the valley floor is about 30,100 acre-feet per year (37,100,000 m^3/yr), and about 2,000 acre-feet per year (2,500,000 m^3/yr) of water flows out of the model into Great Salt Lake. Pumping accounts for a discharge from the aquifer of 11,200 acre-feet per year (13,800,000 m^3/yr) in 1968. Results of the simulation show that the elevation of water levels in model layer 2 are generally higher than water levels in layer 1 in the northern end of Tooele Valley, where layer 1 is recharged only by precipitation and unconsumed irrigation water. This trend indicates upward flow from layer 2 to layer 1.

The wetlands in the Tooele Valley steady-state model are represented by part of model layer 1. The wetlands, under steady-state conditions, receive about 113,800 acre-feet per year (140,400,000 m^3/yr) of ground water in the subsurface including water in storage, and about 300 acre-feet per year (370,000 m^3/yr) of recharge from precipitation and unconsumed irrigation water. The wetlands discharge about 13,000 acre-feet per year (16,000,000 m^3/yr) by springs and drains, and 22,500 acre-feet per year (27,800,000 m^3/yr) by evapotranspiration.

We also evaluated wetland units 2, 8, and 14 (figure 4) using the steady-state model to determine their water budgets. For unit 8, about 17,500 acre-feet per year (21,600,000 m^3/yr) of ground water flows through the subsurface. Evapotranspiration discharges about 4,900 acre-feet per year (6,040,000 m^3/yr). For unit 2, about 16,700 acre-feet per year (20,600,000 m^3/yr) of ground water flows through the subsurface. Discharge by springs and drains is about 300 acre-feet per year (370,000 m^3/yr), and another 3,100 acre-feet per year (3,800,000 m^3/yr) discharges by evapotranspiration. For unit 14, about 400 acre-feet per year (500,000 m^3/yr) is recharged by precipitation and unconsumed irrigation water, and about 14,100 acre-feet (17,400,000 m^3) of ground water flows through the subsurface. Discharge by springs and drains is about 300 acre-feet per year (370,000 m^3/yr), and 1,100 acre-feet per year (1,400,000 m^3/yr) discharge by evapotranspiration.

An effective evaluation of the Tooele Valley wetlands ground-water budget should involve an appraisal of present, or near present, conditions. To evaluate these conditions, we used the transient model of Lambert and Stolp (1999), which simulates the period 1969 to 1994. The model uses historical ground-water withdrawals and natural variations in recharge for a 26-year period. The results of the transient simulation show changes in the shallow unconfined aquifer were generally less than 5 feet (1.5 m), although the water level declined about 10 feet (3 m) in some areas in the central part of the valley by the end of 1994. The transient simulation covers a period when runoff was variable, but generally low during the past 7 years, and pumpage for irrigation and public water supplies increased.

Table 5 shows the average annual ground-water recharge and discharge for the steady-state and transient simulations. The difference between the two budgets is partly because recharge varied considerably during the 1969-94 simulation, and the distribution of recharge and discharge was different between the two models. Recharge in Tooele Valley from runoff is about 43,400 acre-feet per year (53,500,000 m^3/yr) for the end of 1994 in the transient simulation, about 25 percent less than the 1968 steady-state simulation. Precipitation and unconsumed irrigation water recharge is about 13,200 acre-feet per year (16,300,000 m^3/yr) in the transient simulation, 14 percent less than the steady-state simulation, indicating somewhat drier conditions of the valley during the transient period (1969-1994). Natural discharge from the basin-fill aquifer in Tooele Valley increased slightly at the end of 1994, about a 1 percent increase in discharge to springs and drains, and a 4 percent increase to evapotranspiration. Discharge by pumping wells increased by about 50 percent.

We used the transient ground-water flow model to evaluate selected alternative water conditions for Tooele Valley. Because ground-water flow in Tooele Valley is exceptionally intricate, the alternatives were designed to simulate valley-wide conditions to illustrate how the overall system affects the wetlands. The

Table 5. *Average annual ground-water recharge and discharge for the basin-fill aquifer in Tooele Valley, Tooele County, Utah.*

Water-budget component	Steady-state (1968) simulation Estimated quantity (acre-feet per year)	Transient (1969-1994) simulation Estimated quantity (acre-feet per year)
Recharge		
from Great Salt Lake	300	300
from runoff	59,600	43,400
from infiltration of precipitation & unconsumed irrigation water	15,400	13,200
Discharge		
to Great Salt Lake	2,000	2,000
to springs and drains	32,000	32,400
to pumping and flowing wells	11,200	17,100
to evapotranspiration	30,100	31,200

specific alternatives were chosen after reviewing the Tooele County master plan, and discussing possibilities with technical staff of the U.S. Geological Survey. The primary items of concern were the effects of less runoff and recharge to the aquifer and the accompanying lowering of Great Salt Lake due to drought, more runoff due to wet conditions, and increased public-water supply withdrawals due to increased pumping. These alternatives were simulated using the transient model of Tooele Valley (Lambert and Stolp, 1999), with the last five years of the 26 years of historical data changed to reflect the alternative conditions. As is the case with all ground-water flow models, the Tooele Valley transient model is a simplification of the "real world" ground-water system. Simplifications have a corresponding limitation to model precision, and to how the model can be used. Model parameter estimations in the transient model probably place more limitations on the precision of model responses for local areas or subregions of Tooele Valley than to the overall valley. Since no sensitivity analysis was run on the Tooele Valley transient model, we do not know how model parameters influence the model, or how the changes we imposed on the model affect the precision of the model.

First, we simulated drought conditions using the 1969-94 transient conditions by reducing all basin-fill recharge values by 20 percent and lowering Great Salt Lake 5 feet (1.5 m) in the years 1990-94. The effects on recharge and discharge in layer 1 and the three evaluated wetland functional units are presented in table 6. Analysis of a greater change in average recharge and lake level would require reinterpretation of the model. In this simulation, the Tooele Valley wetlands, represented by part of model layer 1, receive about 30 percent less recharge from precipitation and unconsumed irrigation water than the transient simulation using historical data. However, about 97,800 acre-feet per year ($120,600,000 \ m^3/yr$) of ground water flows through the subsurface, about the same as the transient simulation using historical data. Discharge from springs and drains is about 23 percent less in the wetland areas, and evapotranspiration decreases by about 5 percent.

We evaluated the three wetland functional units (figure 4) using the alternative transient model (drought scenario) to estimate their ground-water budgets. The results are presented in table 6. For unit 8, about 35 percent less ground water flows through the subsurface, and evapotranspiration discharges about 2 percent less. For unit 2, about 1 percent less ground water flows through the subsurface. Discharge from springs and drains is about 5 percent less, and about 2 percent less for evapotranspiration, compared to the transient simulation using historical data. For unit 14, recharge from precipitation and unconsumed irrigation water decreases about 36 percent, and about 10 percent less ground water flows through the subsurface. About 6 percent less water discharges by springs and drains, and about 7 percent less discharges by evapotranspiration.

Next, we simulated what would happen if average recharge is increased slightly (wet scenario). We used the transient simulation with the last 5 years having 20 percent more recharge to the basin-fill model. The results are presented in table 7. In this simulation, the Tooele Valley wetlands receive about 33 percent more recharge from precipitation and unconsumed irrigation water than in the transient simulation using historical data. Flow to the wetlands through the subsurface is about the same as the transient simulation with historical data. Discharge in the wetlands by springs and drains increases by about 20 percent, and discharge by evapotranspiration increases by about 2 percent.

We evaluated wetland functional units 2, 8, and 14 (figure 4) using the increased recharge alternative transient model to evaluate their ground-water budgets.

Table 6. Average annual ground-water recharge and discharge for the drought scenario, in acre-feet per year.

Unit	Recharge		Subsurface flow		Discharge			
	Precipitation and unconsumed irrigation water				Springs and drains		Evapotranspiration	
	Transient simulation	20% reduced simulation	Transient simulation	20% reduced simulation	Transient simulation	20% reduced simulation	Transient simulation	20% reduced simulation
Wetlands	400	280	98,000	97,800	6,600	5,100	22,600	21,500
Unit 8	–	–	14,829	9,700	–	–	2,500	2,450
Unit 2	–	–	14,400	14,268	800	755	3,000	2,949
Unit 14	39	25	12,832	11,592	100	94	1,819	1,703

Table 7. Average annual ground-water recharge and discharge for the wet scenario, in acre-feet per year.

Unit	Recharge		Subsurface flow		Discharge			
	Precipitation and unconsumed irrigation water				Springs and drains		Evapotranspiration	
	Transient simulation	20% increased simulation	Transient simulation	20% increased simulation	Transient simulation	20% increased simulation	Transient simulation	20% increased simulation
Wetlands	400	532	98,000	98,950	6,600	7,893	22,600	22,938
Unit 8	–	–	14,829	17,300	–	–	2,500	3,300
Unit 2	–	–	14,400	14,629	800	843	3,000	3,129
Unit 14	39	47	12,832	14,100	100	107	1,819	1,927

For unit 8, about 17 percent more water flows through the subsurface than in the transient simulation using historical data. Evapotranspiration is about 33 percent greater in the alternative simulation. For unit 2, about 2 percent more ground water flows through the subsurface than in the transient simulation using historical data (1969-1994). Discharge from springs and drains is about 5 percent greater, and evapotranspiration is about 4 percent greater. For unit 14, recharge from precipitation and unconsumed irrigation water increases about 20 percent, and about 10 percent more ground water flows through the subsurface. About 7 percent more water discharges by springs and drains, and evapotranspiration is about 6 percent greater.

Finally, we simulated the effect of the increased pumping of public water supply-wells needed to meet the projected growth estimated in the Tooele County general plan. Future pumpage in Tooele Valley is likely to be somewhat different from past pumpage because old wells occasionally are replaced with new wells, and public water-supply wells will probably replace irrigation wells. Replacement wells typically are near the original well, and are commonly designed to extract water directly from lower hydrogeologic units in the principal aquifer than the original well; this delays the effects of pumpage on the water table. However, given sufficient time these effects will be transmitted to model layer 1. The Tooele County general plan has a projected population growth of about 400 percent for the cities of Grantsville and Tooele, and about 200 percent in the Erda, Lakepoint, and Stansbury areas by the year 2030. The simulated results are presented in table 8.

In the increased pumping simulation, the Tooele Valley wetlands receive the same amount of recharge from precipitation and unconsumed irrigation water as in the transient simulation using historical data (1969-1994). Flow through the wetlands in the subsurface is about 3 percent less than the transient simulation using historical data. Discharge in the wetlands by springs and drains decreases by about 24 percent, and discharge by evapotranspiration decreases by about 1 percent.

Once again we evaluated the three wetland func-

Table 8. *Summary of average annual ground-water recharge and discharge, in acre-feet per year, for the increased pumping scenerio using historical data (1969-1994) in Tooele Valley, Tooele County, Utah.*

Unit	Recharge				Discharge			
	Precipitation and unconsumed irrigation water		Subsurface flow		Springs and drains		Evapotranspiration	
	Transient simulation	20% pumpage simulation	Transient simulation	20% pumpage simulation	Transient simulation	20% pumpage simulation	Transient simulation	20% pumpage simulation
Wetlands	400	400	98,000	94,500	6,600	5,500	22,600	22,300
Unit 8	–	–	14,829	9,610	–	–	2,500	2,300
Unit 2	–	–	14,400	14,050	800	690	3,000	3,000
Unit 14	39	39	12,832	12,660	100	98	1,819	1,750

tional units 2, 8, and 14 (figure 4), using the increased pumping scenario for the transient model to evaluate their ground-water budgets. For unit 8, about 35 percent less water flows through the subsurface than in the transient simulation using historical data. Evapotranspiration is about 8 percent less in the alternative simulation. For unit 2, about 2 percent less ground water flows through the subsurface than in the transient simulation using historical data. Discharge from springs and drains is about 14 percent less, and evapotranspiration is the same as the transient simulation using historical data. For unit 14, recharge from precipitation and unconsumed irrigation water is the same, and about 1 percent less subsurface water enters the area. Springs and drains discharge about 2 percent less, and about 4 percent less is discharged by evapotranspiration.

The U.S. Geological Survey is currently updating and improving the Tooele Valley ground-water flow model by collecting additional hydrologic data. As more and new data are incorporated into the Tooele Valley model and the model is refined, the accuracy of model-predictions may improve. These improvements may allow the new model to more accurately predict the response of the ground-water system to future events.

Wetland Change Scenarios

The wetlands in Tooele Valley are downgradient of most of the water users in the valley, so wetland health and functionality depends on upgradient activity. The greatest factor affecting wetlands vitality is the availability of water, and, for most of the wetlands in the valley, this comes from discharging springs. A significant reduction in spring discharge could have detrimental impacts on the wetlands. In some areas, such as unit 8, springs do not provide water for the wetlands; the water comes from subsurface inflow. Due to the wetland water-delivery mechanisms discussed in the previous section, determining the worst-case scenario in terms of wetland degradation is difficult. This is due in part to the limitations imposed by the ground-water flow model and the complexity of the ground-water flow system in Tooele Valley. As with all models, the ground-water flow model of Tooele Valley is based on a conceptual model of the valley that in turn depends on (1) how well we understand the processes operating in the aquifer, (2) how well we know and represent the geometry of the system, and (3) how accurate our underlying assumptions are in relation to development of the model. It is important to remember that just because the model predicts or suggests something does not necessarily mean that it will occur. The model offers the best qualitative tool that we have for evaluating something as complex as ground-water flow. The model results are meant to generate possible outcomes for the proposed scenarios, which, most importantly, will help guide land-use planning and development decisions.

Our modeling results suggest that discharge from springs and drains over the entire wetland area would be decreased more by continuing drought than by increased pumping. However, subsurface inflow into the entire wetland area would be decreased more by increased pumping than by further drought. The model suggests that a change to wet conditions would increase the discharge to springs and drains more than it would increase subsurface inflow. This represents the most beneficial scenario for the wetlands. The worst-case scenario for the wetlands would be a combination of further drought and increased ground-water development. Considering the pressures for more development and the likelihood of periodic droughts, this combined scenario seems likely. If this combined scenario does occur, the loss of water in the subsurface and the reduction of spring discharge would most likely result in a decrease of the functionality of the wetlands; the wetlands would dry up and upland plants would replace wetland plants, or the land would become so dry and saline that only halophilic plants would be able to survive. Based on the plant communities in the upland and mineral flat environments in unit 2 and the upland and mosaic environments in unit 14, we conclude that upland plants and halophytes are replacing wetland plants in those units, probably as a result of a declining water table. The other possibility under the increased pumping and drought combined scenario would be that the wetlands function for only a short time during the spring when water is abundant enough to produce ponds and marshes; later in the year the water would dry up, leaving little to no water for plants or animals from the wetland community.

CONCLUSIONS AND RECOMMENDATIONS

The extent to which wetlands should be conserved presents issues that need resolution, especially considering the socio-economic importance of the wetlands. The federal government has a "no net loss" policy for wetlands, but it is up to the local community to identify the threats posed to local wetlands, and to develop a plan for preserving and managing the wetlands. To meet this federal policy, the Tooele Valley wetlands should be managed to maintain their current budget of water, estimated to be 98,000 acre-feet per year (120,900,000 m^3/yr) as subsurface inflow and 6600 acre-feet per year (8,140,000 m^3/yr) as discharge from springs for the entire wetland region in the transient model. As development continues, we recommend placing restrictions on the areas of development, such as allowing development only in upland environments or placing a non-development buffer zone around the wetland areas. Another option could be to restrict development to only the more beneficial land uses. Overall, agricultural land use is more beneficial to wetland health and functionality than industrial and urban land use. Allowing only land uses that have minimal impacts to wetlands, such as rotational grazing on irrigated pastures, low-density rural developments, and single-family residential developments with a half an acre of native vegetation between houses, would be the best approach for preserving Tooele Valley's wetlands.

The use of single-family domestic wells should also be discouraged because of the contamination threat in the shallow unconfined aquifer posed by septic-tank discharge. Use of municipal sewer and water lines should be required, this would help confine urban sprawl and contamination threats would be lower because the wastewater is treated prior to environmental discharge. Wastewater from municipal sewers should, where possible, be reused or discharged to the environment upgradient of the wetlands so that the septic-tank component of recharge to the ground water is not lost. The real threat of population growth is population distribution, and not necessarily the actual increase in population. Sprawl is created by the fanning out of the population, which consumes and transforms the land into a less than natural state that may be unfavorable to native and/or wetland species. Enactment of water conservation practices would also be beneficial for wetland environments. This would help ensure that the wetlands receive the water they need to maintain their functionality.

Our studies indicate the wetlands in Tooele Valley are endangered. The threats posed are drought, and increased development due to population growth, which could dramatically affect the amount of water that the wetlands receive. We cannot predict modifications in climate with certainty, but we can plan appropriately for future development.

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APPENDICES

Appendix A

Wetlands Background, Definitions, and Functions

Wetland scientists have had a tremendous amount of difficulty defining a wetland because wetlands can be very different from place to place. Due to this variability, scientists have made numerous attempts at deriving an all-encompassing definition of a wetland. Wetlands are generally defined as transitional lands between terrestrial and aquatic ecosystems. Three criteria are used to define a wetland: hydrology, soil, and vegetation. To be classified as a wetland, an area must have specific characteristics related to one or more of these criteria.

The two interest groups that require a definition for wetlands are wetland scientists and wetland managers and regulators. Wetland scientists are interested in a definition that facilitates classification, inventory, and research of wetlands, whereas wetland managers are interested in the laws and regulations surrounding wetlands. The most widely accepted scientific definition, developed by the U.S. Fish and Wildlife Service (U.S. FWS) as part of the National Wetlands Inventory (NWI), states: "Wetlands are lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water…Wetlands must have one or more of the following three attributes: (1) at least periodically, the land supports predominantly hydrophytes; (2) the substrate is predominantly undrained hydric soil; and (3) the substrate is nonsoil and is saturated with water or covered by shallow water at some time during the growing season of each year" (Cowardin and others, 1979).

The two entities that deal with the laws and regulations on wetlands are the U.S. Environmental Protection Agency (EPA) and the U.S. Army Corps of Engineers, which define wetlands as "those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas" (U.S. Army Corps of Engineers, 1987, p. 9). The U.S. Army Corps of Engineers oversees the regulatory aspect of wetlands, specifically in relation to the Clean Water Act, so they are the agency in charge of enforcing the "no net loss" policy of the federal government.

The presence of water at or near the surface in a wetland is obvious, but water need not be there all the time in a wetland. Many wetlands are "wet" only during certain periods of the year. The presence of water is nonetheless a critical part of a wetland, and influences the soil and vegetation in a wetland. The type of soil in a wetland is termed hydric. "A hydric soil is a soil that is saturated, flooded, or ponded long enough during the growing season to develop anaerobic conditions that favor the growth and regeneration of hydrophytic vegetation" (Mitsch and Gosselink, 2000, p. 756). The term hydrophytic vegetation or hydrophyte refers to "water loving" plants, which are able to survive with little or no oxygen, and can withstand fluctuating water levels. Two types of hydrophytes exist: aquatic and emergent. Aquatic plants, such as the water lily, actually live in the water. Emergent plants have roots that grow in soil that is saturated with water, while the rest of the plant may be exposed to the atmosphere. Emergent plants include cattails, reeds, and sedges. The soil and vegetation in a wetland are very dependent upon water for their development and growth, illustrating that water is the master variable when it comes to wetlands.

One of the most important functions of wetlands is their ability to improve water quality. This occurs by filtration of water as it flows through a wetland. Water that enters a wetland may be laden with pollutants, which can settle out of the water column during transport. Toxic substances can be buried and trapped in bottom sediments. Plants and microorganisms can absorb and consume the toxic substance and return them to the environment in benign forms. Many wastewater treatment plants use constructed or modified wetlands to treat water before returning it to the environment.

Another benefit of wetlands is their ability to control flooding and act as storage reservoirs. When floodwater encounters a wetland, the force and velocity of the water is dissipated, so downstream damage is typically reduced. Additionally, as wetlands capture floodwater, the water is stored in the wetlands and released slowly during the following months. This stored water can recharge ground-water aquifers, which is very important for drought-stricken areas.

Wetlands are also important habitat areas. They have high biodiversity and productivity that is comparable to rain forests and coral reefs (U.S. EPA, 2003). Wetlands are important to many plant and animal species; about 45 percent of the species listed as threatened or endangered under the Endangered Species Act use wetland habitat (National Wildlife Federation, 1989). Wetlands offer habitat for plants, insects, fish, amphibians, reptiles, mammals, and birds, creating a self-sustaining food web. Animals use wetlands as a source for food, as nesting grounds, and as nurseries.

Appendix B

Tooele Valley Wetlands SAMP Satellite Image Processing Steps

The information in this section was provided by SWCA Environmental Consultants (230 South 500 East, Suite 380 Salt Lake City, UT 84102 801-322-4307).

IKONOS 4 band, 4-meter resolution Precision satellite imagery was acquired from Space Imaging for the project area. Image acquisition dates were May 8, 2002 for three scenes and May 16, 2002 for one scene. Using ERDAS Imagine 8.4, the individual band files (R,G,B,NIR) were combined with each other to produce 4-band imagery for four scenes. Then the four scenes were mosaiced together into one scene. The reflectance value differences between the May 16th scene and the other May 8th scenes were negligible and did not warrant further processing. An unsupervised classification of the mosaiced image was then carried out starting with 50 classes. Cluster busting was then done on classes that contained more than one cover type. Cluster-busted data were then dumped back into the original classification using a custom programmed model.

Roads were digitized from the imagery in ArcView 8.2, and an average width was measured from the imagery and attributed to the segments. The roads were then buffered using the width column. The vector buffers were converted to raster using ArcView 8.2 Spatial Analyst and then dumped into the covertype classification. Field ground-truthing and verification was carried out throughout the process to evaluate the accuracy of the classification and cluster busting.

After exhaustive cluster busting, an accuracy assessment was carried out using 300 stratified random points. Ground-truth data and aerial photography interpretation were used to evaluate each accuracy assessment point. Through this process, the classification was determined to be 87% accurate.

After working with the data set for a few months, it was apparent that the IKONOS imagery was acquired too early in the growing season and did not contain enough spectral resolution to accurately map some emergent marsh and some wet meadow areas. To address this problem, SWCA conducted an unsupervised classification of Landsat 7 Satellite Imagery acquired on June 12, 2002. The Landsat 7 classification and ground-truth information were used to delineate areas of interest (AOIs) in order to fix problem areas of the IKONOS classification. AOIs were digitized and used to convert pixels within these problem areas. Areas that were erroneously classified as upland, many of which are actually emergent marsh, were changed to wet meadow and affected emergent marsh polygons were then considered inclusions in the wet meadow covertype. This AOI Fix technique was carried out to fix several problem areas including: Wet Meadow to Upland Fix; Various classes to Open Water Fix (due to sun glare); Vegetated Mineral Flat to Upland Fix; Upland to Algae Bloom Fix. A second accuracy assessment and ground-truth exercise was not carried out due to budget constraints.

After the above refinements were complete, a Recode was carried out to result in the final 14 classes. Next, a Fuzzy Convolution filter using a 3x3 kernel and all defaults was run to reduce "salt and pepper" in the classification. A clump analysis was then run to determine contiguous pixels using an eight neighbor set-up. Next, an eliminate function was run to generalize the 4-meter pixel data to a minimum mapping unit of 1/10th acre. Finally, the 1/10th acre raster data set was converted to vector polygons using ArcView 8.2 Spatial Analyst.

Appendix C

Water-Quality Results

Table C.1. *Water-quality parameter definitions.*

Well #	Well number
Sample Date	Date sample was collected
pH	Field pH
Temp. (degrees C)	Field temperature
Sp. Cond. (mS/cm)	Field specific conductance
D.O. (mg/L)	Field dissolved oxygen
Salin. (PSS)	Field salinity
ORP (mV)	Oxygen reduction potential
NO_2+NO_3 (mg/L)	Nitrite + nitrate
NH_3 (mg/L)	Ammonia
D-Ba (µg/L)	Dissolved barium
D-Ca (mg/L)	Dissolved calcium
D-Cu (µg/L)	Dissolved copper
D-Pb (µg/L)	Dissolved lead
D-Mn (µg/L)	Dissolved manganese
D-Se (µg/L)	Dissolved selenium
D-Na (mg/L)	Dissolved sodium
Bicarbonate (mg/L)	Bicarbonate
Carbonate (mg/L)	Carbonate
Hydroxide (mg/L)	Hydroxide
T. Phos. (mg/L)	Total phosphorous
T. Hardns. (mg/L)	Total hardness
D-Al (µg/L)	Dissolved aluminum
CO_3 Solids (mg/L)	Carbonate solids
T. Sus. Sol. (mg/L)	Total suspended solids
T.O.C. (mg/L)	Total organic carbon
D-As (µg/L)	Dissolved arsenic
D-Cd (µg/L)	Dissolved cadmium
D-Cr (µg/L)	Dissolved chromium
D-Fe (µg/L)	Dissolved iron
D-Mg (mg/L)	Dissolved magnesium
D-K (mg/L)	Dissolved potassium
D-Ag (µg/L)	Dissolved silver
D-Zn (µg/L)	Dissolved zinc
CO_2 (mg/L)	Carbon dioxide
Cl (mg/L)	Chloride
SO_4 (mg/L)	Sulfate
Tot. Alk. (mg/L)	Total alkalinity
Turbidity (NTU)	Turbidity
TDS @ 180C (mg/L)	Total dissolved solids
D-Hg (µg/L)	Dissolved mercury

Table C.2. *Water-quality results.*

Well #	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Sample Date	5/26/04	5/27/04	5/27/04	5/26/04	5/26/04	5/26/04	5/26/04	5/26/04	5/26/04
pH	7.18	7.10	7.07	7.69	7.32	7.51	7.28	7.22	7.50
Temp. (degrees C)	14.31	17.73	19.27	15.98	15.35	19.19	16.52	14.25	18.84
Sp. Cond. (mS/cm)	48.20	51.70	65.30	3.52	44.00	14.90	11.27	15.90	13.00
D.O. (mg/L)	4.23	2.14	3.91	3.03	3.75	4.71	1.40	2.90	3.86
Salin. (PSS)	29.30	33.65	43.80	1.83	28.00	8.60	6.33	9.17	7.42
ORP (mV)	-687	-698	-679	-692	-686	-672	-708	-694	-682
NO_2+NO_3 (mg/L)	<0.1	<0.1	<0.1	<0.1	0.12	<0.1	<0.1	<0.1	<0.1
NH_3 (mg/L)	0.29	<0.5	0.44	0.14	0.16	0.21	0.20	0.14	0.16
D-Ba (μg/L)	239.0	111.0	171.0	<100	<100	<100	<100	<100	<100
D-Ca (mg/L)	728.0	629.0	1090.0	<100	654.0	406.0	210.0	380.0	<100
D-Cu (μg/L)	<130	<130	<130	<60	150.0	<60	<60	<60	<130
D-Pb (μg/L)	<33	<33	<33	<15	<33	<15	<15	<15	<33
D-Mn (μg/L)	199.0	140.0	873.0	37.9	<55	95.3	<25	350.0	480.0
D-Se (μg/L)	<11	<11	<11	7.9	27.0	22.2	<5	<5	<11
D-Na (mg/L)	8820.0	12600.0	16400.0	757.0	8870.0	3170.0	2190.0	3040.0	2950.0
Bicarbonate (mg/L)	332.0	244.0	224.0	708.0	566.0	584.0	482.0	594.0	958.0
Carbonate (mg/L)	0.0	0.0	0.0	10.0	0.0	0.0	0.0	0.0	0.0
Hydroxide (mg/L)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T. Phos. (mg/L)	0.381	0.109	0.271	0.45	0.86	0.516	0.386	1.2	0.739
T. Hardns. (mg/L)	2659.8	4073.0	4405.0	<661	9655.0	2975.6	1663.7	3507.3	1134.1
D-Al (μg/L)	<330	<330	<330	<150	<330	<150	<150	<150	<330
CO_3 Solids (mg/L)	163.0	120.0	110	358.0	278.0	287.0	237.0	292.0	471.0
T. Sus. Sol. (mg/L)	734.0	3496.7	636.0	561.9	2294.0	1006.0	588.4	785.0	1969.1
T.O.C. (mg/L)	13.45	2.35	3.96	7.59	44.63	21.47	8.19	14.34	19.60
D-As (μg/L)	17.3	46.4	57.1	239.0	723.0	214.0	56.8	50.9	304.0
D-Cd (μg/L)	<11	<11	<11	<5	<11	<5	<5	<5	<11
D-Cr (μg/L)	<55	<55	<55	<25	<55	<25	<25	<25	<55
D-Fe (μg/L)	<20	<20	23.5	113.0	<20	127.0	<20	<20	68.4
D-Mg (mg/L)	205.0	396.0	353.0	<100	1950.0	477.0	277.0	622.0	215.0
D-K (mg/L)	267.0	396.0	475.0	<100	838.0	281.0	107.0	399.0	128.0
D-Ag (μg/L)	<22	<22	<22	<10	<22	<10	<10	<10	<22
D-Zn (μg/L)	<330	<330	<330	<150	<330	<150	<150	<150	<330
CO_2 (mg/L)	7.0	10.0	16.0	4.0	14.0	11.0	6.0	7.0	8.0
Cl (mg/L)	14800.0	18100.0	27200.0	459.0	11500.0	2996.0	3143.0	3530.0	3468.0
SO_4 (mg/L)	49.3	576.0	651.0	851.0	13729.0	5263.0	1225.0	5269.0	1836.0
Tot. Alk. (mg/L)	272.0	200.0	184.0	597.0	464.0	479.0	395.0	487.0	786.0
Turbidity (NTU)	1187.0	5250.0	940.0	988.0	4609.0	2722.0	976.0	756.0	3895.0
TDS @ 180C (mg/L)	27590.0	38784.0	52190.0	2690.0	39470.0	12730.0	8040.0	13480.0	9480.0
D-Hg (μg/L)	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2

Appendix D

Review of Ground-Water Flow Model

Lambert and Stolp (1999) developed two valley-wide ground-water flow models of Tooele Valley, steady-state and transient, using their conceptual understanding of the physical properties and the quantity of recharge and discharge to the aquifer system. They used the computer program MODFLOW, developed by McDonald and Harbaugh (1988), which uses standard finite-difference techniques to approximate the partial differential equations describing saturated ground-water flow.

Lambert and Stolp (1999) used a technique referred to as a distributed-parameter approach to simulate observed spatial and temporal variations in the models. Even when using a distributed-parameter approach, not all characteristics of the actual aquifer system can be included in the ground-water flow model. Simplifying assumptions are required to make the modeling effort manageable. Many of the assumptions used by Lambert and Stolp (1999) in developing the Tooele Valley ground-water flow model are characteristic of numerical ground-water flow models. Wang and Anderson (1982), and Anderson and Woessner (1992) give an explanation of these assumptions. McDonald and Harbaugh (1988) described the assumptions underlying the particular computer program used in this study. Additional assumptions made in the application of the computer program to the Tooele Valley aquifer system are discussed in Lambert and Stolp (1999).

Lambert and Stolp (1999) used a finite-difference grid of 118 columns, 110 rows, and 5 layers, and oriented the grid so that the long axis of the valley is parallel to the models, roughly N. 45° W. (figure D.1). Cells representing consolidated rocks were considered to have a lower permeability than the basin fill, and for the purposes of the model were designated inactive. The area of active cells in the models corresponds approximately with basin-fill materials of Quaternary age, and represents the shallow unconfined aquifer, shallow confining layer, and principal aquifer of Tooele Valley.

Boundary conditions of the ground-water flow models of Tooele Valley conform to the physical boundaries of the Tooele Valley basin-fill aquifer system. Lambert and Stolp (1999) specified the lateral boundaries surrounding the active cells of the model as specified-flux boundaries to simulate recharge from bedrock and underflow from Rush Valley into the basin-fill sediments. Head-dependent relations were used to simulate springs, evapotranspiration, and the interaction of the aquifer system. Constant-head cells simulate the interaction between ground water and Great Salt Lake. Specified flux terms are used to approximate discharge from wells and recharge from precipitation, streams, canals, and ditches. The top of the aquifer system was modeled as a specified-flux boundary to represent the water table; the bottom is either rock, the top of a partly consolidated unit, or an arbitrary depth based on the depth of production wells and is modeled as a no-flow boundary.

Division of the aquifer system into hydrogeologic units and model layers was more complex and somewhat more arbitrary than the selection of boundary conditions. The area of active cells in layer 1 represents the areas identified by Steiger and Lowe (1997) as discharge and secondary recharge areas. Layer 1 represents the shallow unconfined aquifer and the underlying shallow confining layer. Layers 2 to 5 represent the principal aquifer and consist of Quaternary-age basin-fill material. In layers 1 and 2, where layer 2 is unconfined, the transmissivity is allowed to vary spatially as a function of saturated thickness of the layer and the equivalent horizontal hydraulic conductivity of the material in the layers. The simulated saturated thickness of layer 1 and parts of layer 2 is variable and related to computed water levels in the layer. In parts of layer 2 and in layers 3 to 5, transmissivity was specified for each cell in the simulations, and the saturated thicknesses of the layers are assumed to remain constant. Transmissivity was varied between groups of model cells, but was assumed to remain constant over time. Flow between the layers was approximated by a relation that uses calculated heads in vertically adjacent cells and an estimate of vertical conductance between cells. Vertical conductance is calculated from vertical hydraulic conductivity, thickness between layers, and horizontal area of the cell. Layers 2 and 3 are 150 feet (46 m) thick each, but where unconfined layer 2 may vary; layer 4 is 300 feet (90 m) thick; and layer 5 is of variable thickness ranging from 50 to 400 feet (15-120 m). For more information about delineation of the model layers refer to Lamber and Stolp (1999).

The hydraulic characteristics of the principal aquifer system in Tooele Valley were estimated from aquifer-test, specific-capacity, and drill-hole data. Comparisons with Salt Lake Valley provided estimates of the hydraulic parameters for the shallow unconfined aquifer, and water levels for layer 2 were used in layer 1 because few water-level data were available for layer 1. Lambert and Stolp (1999) felt that the results of available field tests did not accurately represent the transmissivity of the principal aquifer and used determined values to estimate probable ranges of hydraulic conductivity. Calibration of the ground-water flow models involved a trial-and-error adjustment of model parameters representing aquifer characteristics and certain recharge and discharge components in order to obtain an acceptable match between measured ground-water levels and computed heads.

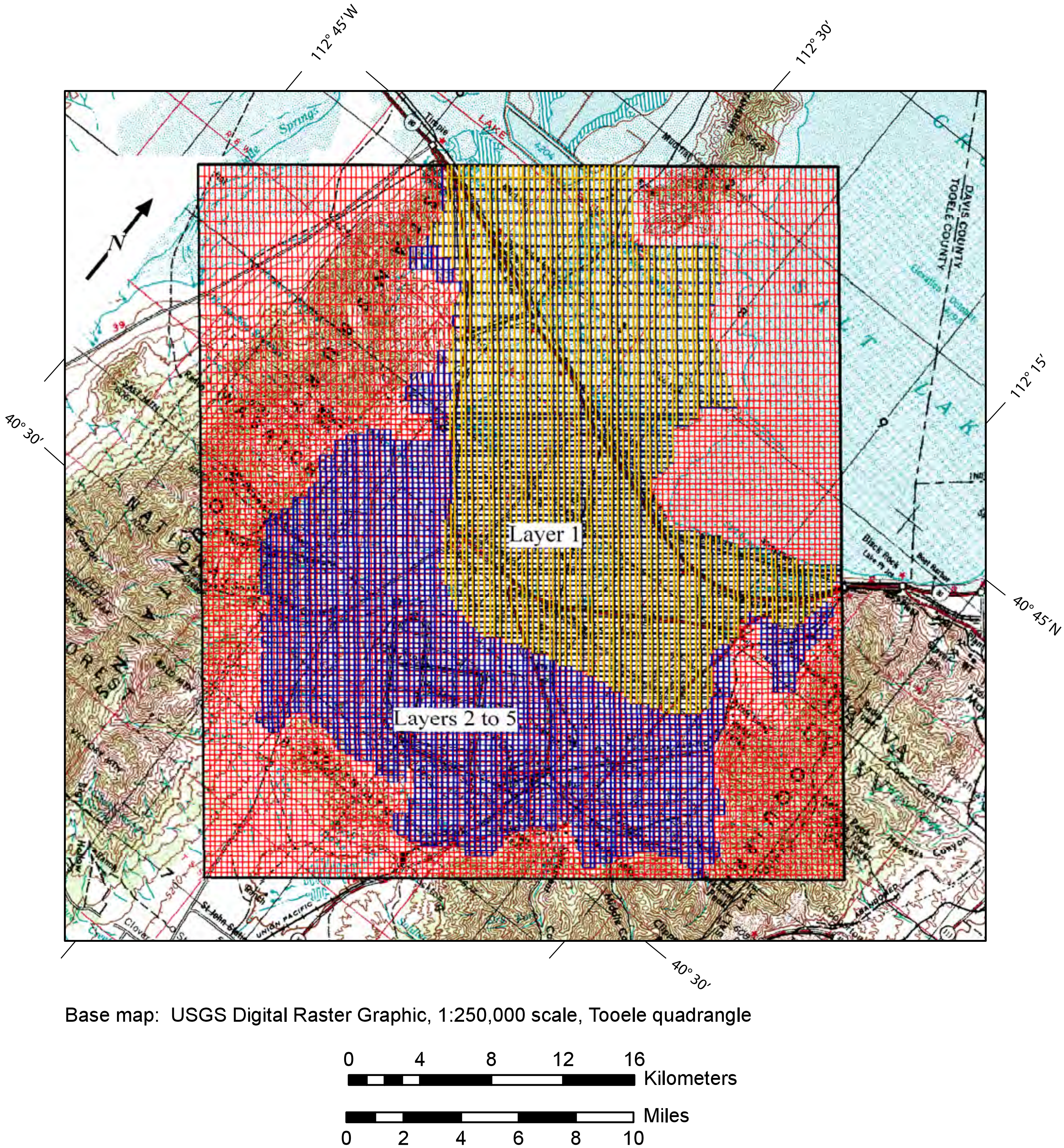

Figure D.1. *Finite-difference grid used to simulate ground-water flow in the basin-fill aquifer, Tooele Valley, Tooele County, Utah, from Lambert and Stolp (1999).*