U.S. FISH & WILDLIFE SERVICE
REGION 6
ENVIRONMENTAL CONTAMINANTS PROGRAM

Saline Seep Impacts on Hailstone and Halfbreed National Wildlife Refuges in South-Central Montana

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DEC ID: 200160001
FFS: 61130- 6N47
June 15, 2007

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LIST OF ACRONYMS AND ABBREVIATIONS

As	Arsenic
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
CRP	Conservation Reserve Program
GPS	Global Positioning System
GWIC	Ground Water Information System
MBMG	Montana Bureau of Mines and Geology
MTFWP	Montana Department of Fish Wildlife and Parks
Mg	Magnesium
Na	Sodium
$Na_2So_4 \cdot 10(H_2O)$	Mirabilite
Na_2SO_4	Thenardite
NRCS	Natural Resource Conservation Service
NWR	National Wildlife Refuge
QA/QC	Quality Assurance/ Quality Control
$S0_4$	Sulfate
SC	Specific Conductance
TDS	Total Dissolved Solids
TERL	Trace Element Research Laboratory
USFWS	United States Fish and Wildlife Service
WMA	Wildlife Management Area

ABSTRACT

Elevated salt and selenium levels in groundwater and in saline seeps within the Lake Basin of northern Stillwater County, Montana have impacted water quality on Hailstone National Wildlife Refuge (NWR), and have the potential to impact water quality at Halfbreed NWR. Additionally, the contribution of salts and selenium from saline seeps creates an unacceptable risk to aquatic birds using Hailstone NWR. This study was conducted to evaluate the background hydrogeologic conditions, selenium source and geochemistry, as well as the distribution of selenium and other constituents of concern, and their impacts to waterfowl and shorebirds using Hailstone and Halfbreed NWRs in south-central Montana. This report emphasizes the Hailstone NWR because all waterbodies at Halfbreed NWR were dry for the duration of this investigation.

Upper Cretaceous marine shale, along with alluvium and colluvium derived from these shales, provide the source of selenium and sulfate salts to Hailstone Reservoir. Prior to crop-fallow farming practices, native prairie grasses consumed most of the precipitation. Crop-fallow farming altered the hydrologic balance and precipitation unused by plants moved below the root zone and accumulated. Groundwater recharge accumulated in the alluvium, colluvium and weathered shale above low permeability shales causing the water table to rise and a groundwater-flow system to develop. Selenium, sulfate salts, and other harmful constituents were dissolved and moved down-gradient with the groundwater through alluvium, colluvium and weathered shale. A groundwater transition zone developed as the water table rose. Subtle rises in the topography of the impermeable shale beds and thinning alluvium forced groundwater towards the land surface. Saline seeps develop along these transition zones. Selenium and sulfate salts are evapoconcentrated in these seeps as the groundwater reaches the surface and evaporates. In Hailstone Basin, runoff from snowmelt and rain storms dissolves these salts as it moves downslope towards Hailstone Reservoir carrying selenium concentrations as high as 3,200 µg/L and sulfate ions as high as 60,000 mg/L. Groundwater below the transition zone has very high sulfate concentrations but relatively low selenium concentrations. Slow moving groundwater containing relatively low selenium concentrations and high sulfate concentrations also discharge into Hailstone Reservoir, although runoff appears to be the primary source of lake water, and is the source of most of the constituents of concern.

Saline seep induced changes to water quality on Hailstone NWR were found to negatively impact waterfowl and shorebirds using the reservoir. Several mortality events related to high salt concentrations were noted during this investigation. In addition, a hazard assessment completed for selenium revealed that Hailstone Reservoir has the potential to cause complete reproductive failure in sensitive waterfowl and shorebirds. The Service is currently unable to manage water levels within Hailstone Reservoir in order to avoid future mortality events.

Keywords: DEC ID: 200160001, FFS: 61130-6N47, Hailstone NWR, Halfbreed NWR, Saline Seep, Selenium, Sodium toxicosis

Congressional District: At Large

INTRODUCTION

Elevated selenium concentrations in groundwater and in saline seeps within the Lake Basin of northern Stillwater County, Montana have impaired the ability of Hailstone and Halfbreed National Wildlife Refuges (NWR) to achieve their management goals. The contribution of salts and trace elements from saline seeps to these refuges has degraded the water quality of surface waters within the refuges and creates an unacceptable risk to waterfowl and shorebirds on Hailstone NWR. This study was conducted to evaluate the background hydrogeologic conditions, selenium source and geochemistry, as well as determine the potential impacts of salinity and selenium on waterfowl and shorebirds using these refuges. This report emphasizes the Hailstone NWR because the lakes at the Halfbreed NWR were dry for the duration of this investigation.

Lake Basin, located in Northern Stillwater County, Montana, is a closed basin isolated from the Musselshell drainage basin to the north and the Yellowstone drainage basin to the south (Figure 1)(Miller and Bergatino 1983). Hailstone and Halfbreed NWRs, managed by the U.S. Fish and Wildlife Service (USFWS), and Big Lake Wildlife Management Area (WMA), managed by Montana Department of Fish, Wildlife and Parks (MTFWP), are located in Lake Basin. Surface water and groundwater (with associated salts) accumulate in the bottom lands of Lake Basin (Kellogg 1984) where these NWRs and WMAs are located. The Lake Basin region is one of the most important waterfowl and migratory bird area in central and southern Montana. Furthermore, during wet years, the density of waterfowl breeding pairs per wet acre is similar to the prairie pothole region (M. Getman, USFWS, Kodiak NWR, 2000 Pers. Comm). In 1996, Halfbreed NWR was designated an important bird area by the American Bird Conservancy; this designation was based on use by threatened, endangered, or vulnerable species as well as the numbers of waterfowl, shorebirds, and wading birds present each year (USFWS 1997). Breeding pair counts conducted on Hailstone and Halfbreed NWRs indicate Halfbreed is a preferred breeding area for waterfowl and shorebirds (USFWS 1997); a preference likely due to better water quality (B. Haglan, USFWS, Washington, DC, 2000 Pers. Comm.). Water quality

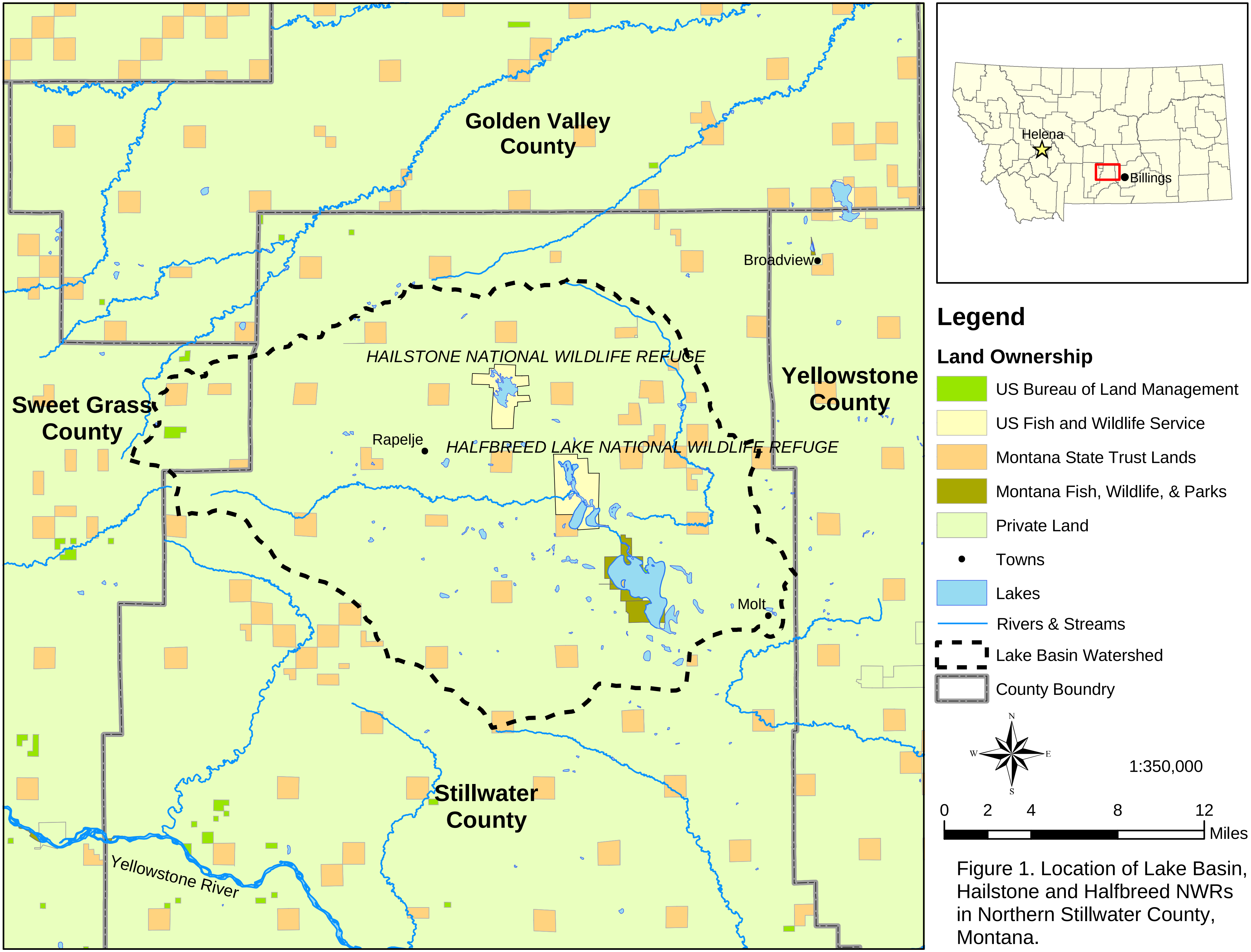


Figure 1. Location of Lake Basin, Hailstone and Halfbreed NWRs in Northern Stillwater County, Montana.

concerns in these areas exist because of high concentrations of nitrates, selenium, salinity in groundwater, and density of saline seeps in the watershed.

Saline Seep Development

Saline seep development in the United States and Canada has taken approximately two million acres out of agricultural production (Miller and Bergatino 1983). In Montana, saline seep development began in 1910 when native grasslands in the northern part of the state were plowed (Bahls and Miller 1973). During the 1940s, numerous “north-slope alkali” or “dryland salinity” seep areas began to appear in Montana and initially the cause of the seeps was unknown (Holzer et al. 1995). Although some saline areas are natural, the term “saline seep” describes only those seeps attributable to agricultural practices (Duaime et al. 1991). When summer-fallow cropping practices began in the 1940s and 1950s, saline seep development increased dramatically. Seep development increased again when larger more powerful tractors were developed in the 1950's and four-wheel drive tractors arrived in the 1970s; these technologies made even more sod-busting possible (Miller, MT- Tech, Butte, 2005, Pers. Comm.). In the late 1960s, investigations were initiated to determine the causes, rate of spread, origin, and methods of mitigation and reduction of seeps (Duaime et al. 1991). During the 1970s, saline seep acreage in Montana increased from 51,000 acres to 200,000 acres, with an estimated loss of $12 million in agricultural revenues (Brown et al. 1983). A number of community water supplies became unpalatable, were more costly to treat, or no longer met water-quality standards due to degradation of the aquifer from saline seeps (Bahls and Miller 1973). Water sources for livestock are unusable in many areas, and in some places, ranchers have ceased livestock operations (Holzer et al. 1995). The USFWS (1991) has documented impacts of these seeps to waterfowl and shorebirds.

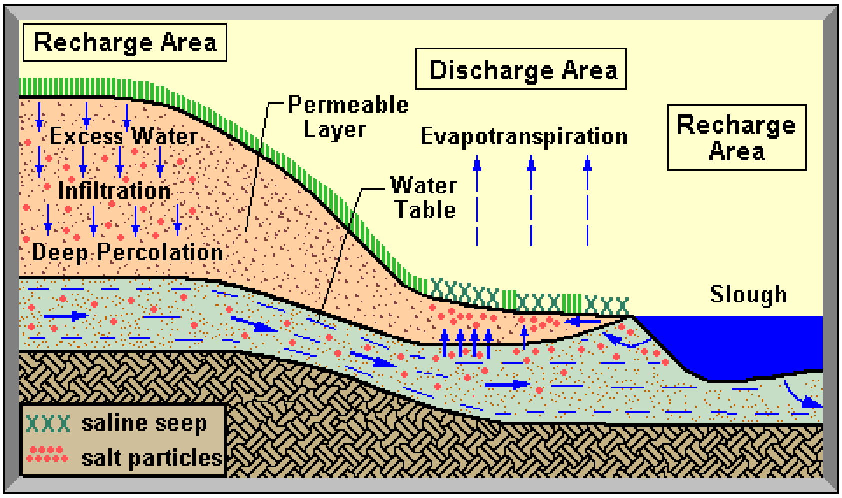


Figure 2. Generalized saline seep formation (Alberta Agriculture, Food, and Rural Development. 1999).

Northern Stillwater County is highly susceptible to saline seep development because its shallow soils are underlain by unweathered, impermeable Cretaceous shales (Miller et al. 1980) and is estimated to have lost the largest area of agricultural land in Montana (Kellogg 1984). Further, the Montana Department of State Lands ranked Stillwater County as having the most saline-affected dryland acres at 23,000 acres in 1974 (Kellogg 1984), and it is estimated that saline seeps increase at a rate of 10 percent annually (Miller et al. 1976). The dominant land-use practice contributing to saline seep formation is the alternate crop-fallow farming practice which allows significant amounts of water to move downward past the root zone and activates groundwater flow (Holzer et al. 1995). Long-term monitoring records and infiltration plot data illustrate increased infiltration under crop-fallow rotation (7-15 percent) in comparison to precipitation percolation under native sod (1-4 percent) (Holzer et al. 1995). Moisture not used by plants migrates downward through the soil profile. Once this moisture moves below a depth of about 4 to 5 feet, it is beyond the root zone of most cereal grains and it continues to migrate downward, dissolving salts from the soil profile. Eventually this moisture reaches an impermeable or less permeable layer, usually a shale or clay, which impedes downward movement of water, thus creating a shallow groundwater zone. Groundwater then moves laterally in this zone down-gradient which is typically determined by topography or the slope of the bedrock. As the water moves laterally, it leaches additional salts along its flow path, increasing the calculated total dissolved solids (TDS) content of the groundwater. Ultimately, this water resurfaces down slope to form a saline seep in the discharge area. It takes years for the water to travel from the recharge area to the discharge area (Figure 2). As the water seeps out, it also brings to the surface all the constituents the water dissolved in the soil profile (Duaime et al. 1991).

Water moving from the recharge area to the discharge area can accumulate approximately 50 mg/L of TDS per foot of movement (Duaime et al. 1991) depending on flow rate, concentration, and the available salt. The predominant soluble constituents picked up by groundwater are sodium, magnesium, sulfate, and nitrate. Trace elements such as selenium also can be mobilized by this groundwater flow (Duaime et al. 1991). Miller et al. (1981) estimated that enough sodium is available in the shallow aquifer system to sustain existing seeps for the next 25 to 100+ years. As soil salinity increases in seep areas, plant growth is affected, and crop growth is reduced and often eliminated in these farm areas (Brown et al. 1983). Conductivity of 4,000 μS/cm in soils, reduces the growth of most plants, and sensitive plants are affected at much lower concentrations (2,000 μS/cm) (Brown et al. 1983).

The purpose of this research was to quantify saline seep impacts to water quality on Hailstone and Halfbreed NWRs. Specifically, this study was designed to 1) characterize the hydrogeology of Lake Basin, 2) investigate specific conductance (SC) and major cation and anions (including nitrate and nitrite) contributing to salinity in Hailstone and Halfbreed reservoirs, 3) determine risk of hypersaline conditions to ducklings as well as adult waterfowl and shorebirds, and 4) conduct a hazard assessment for selenium to determine the potential for selenium food chain bioaccumulation and reproductive impairment to aquatic birds using Hailstone and Halfbreed NWRs.

STUDY AREA

Location, Physiography and Land Use

The study area includes the Hailstone Basin watershed which drains about 30,580 acres (Figure 1.). The Hailstone Basin is located in northern Stillwater County about 5 miles northeast of Rapleje, Montana. It is located in the unglaciated Northern Great Plains Physiographic Province (Fenneman 1931). Hailstone Basin is a topographic valley located in northern Stillwater County, southcentral Montana. Extensive and numerous saline seep problems have developed since the 1950's that are related to the crop-fallow method of dryland farming. Drainage from Hailstone Basin normally flows into the northern part of the Lake Basin, but no water has flowed over the spill-way due to low levels in Hailstone Reservoir during the recent drought. Lake Basin is an internally drained region that formed as the result of faulting along the southeast-northwest trending Lake Basin fault zone. Faulting and subsequent differential erosion resulted in pronounced topographic features consisting of sandstone-rimmed uplands draining towards a central lowland developed on shale. Most of the area is privately owned with the exception of State lands and two NWRs.

Hailstone and Halfbreed NWRs are located in Northern Stillwater County, east of Rapleje, Montana. Hailstone NWR is located in the Hailstone Basin watershed, and Halfbreed is located in the larger Lake Basin watershed. Big Lake WMA is the terminal basin of Lake Basin. Both NWRs are managed by the Charles M. Russell National Wildlife Refuge Office located in Lewistown, Montana.

Hailstone NWR was created in 1942 as an easement refuge of 2,748 acres through an Executive Order of President Franklin D. Roosevelt . The refuge was established primarily as a breeding ground for waterfowl and other wildlife. In 1979, the Service purchased 1,988 acres of the easement to create a Waterfowl Production Area, with 760 acres remaining in easement. Hailstone Creek and its tributaries feed the 660 acre reservoir on the refuge. Hailstone

Reservoir was created by a dam that was constructed in 1938 as a Works Progress Administration project.

Halfbreed NWR was also created in 1942 by an Executive Order of President Franklin D. Roosevelt as an easement refuge of 4,286 acres. Like Hailstone, Halfbreed was established primarily as a breeding ground for waterfowl and other wildlife. In 1986, the Service purchased all but 640 acres of state land and 400 acres of private land which are still covered by the original refuge easement. Three large wetlands are contained within Halfbreed NWR. Halfbreed Lake at the upper end of the refuge is the refuge's most productive with a size of 248 acres. The other two wetlands on the refuge are Grass Lake, a 375 acre shallow wetland located in the middle of the refuge, and Goose Lake, also a shallow wetland of 220 acres located on the lower end of the refuge. All three basins were dry during this investigation.

Geology

A composite map of the geology of Hailstone and Lake Basins is depicted in Figure 3. Hailstone Basin is located near the crest of the Big Coulee–Hailstone structural dome and is a northern outlier of the Lake Basin (Lopez 2000). The northern boundary of Hailstone Basin is formed by a sandstone rimrock made up of the Eagle Sandstone. The southern boundary of Hailstone Basin is the Lake Basin Fault zone; a series of en-echelon faults made up of steeply dipping sheared rocks of the Cretaceous Montana Group. Underlying most of the basin is the Niobrara shale, overlain by Quaternary colluvial, alluvial, and lacustrine sediments. A narrow breach in the fault zone allows surface drainage to flow out of Hailstone Basin into the internally drained Lake Basin (Wilde et al 2000).

The Lake Basin Fault Zone marks the northern boundary of the Lake Basin. This closed basin is underlain by rocks of the Bearpaw Shale, Judith River Formation, and Claggett Shale. Quaternary colluvial, alluvial, and lacustrine sediments overlies the bedrock of the Lake Basin. The west and southern boundaries of the Lake Basin consist of uplands of the Hell Creek

Figure 3. Generalized Geology of the Lake Basin Area.
(Geology adapted from Lopez, 2000a, 2000b, and Wilde and Porter, 2000, 2001).

deformation associated with the Lake Basin Fault Zone appears to have formed the internally drained Lake Basin.

Wetter conditions during the Quaternary period appear to have resulted in an ancestral lake developing in much of the Lake Basin. Remnants of this ancient lake include Big Lake and Dry Lake. Other artifacts of the much larger lake include thick plugs of fine grained materials overlying terrace gravels along an ancestral course of Canyon Creek near Billings, Montana (Olson and Reiten 2002). These sediments appear to have accumulated when Canyon Creek drained out of the Lake Basin. The outlet from the Lake Basin is near Molt. This spillway elevation, of about 3,960 feet above sea level, would have backed up water over much of the Lake Basin (Figure 4). At an elevation of about 4,005 feet, Hailstone Reservoir would have been connected to the ancestral lake covering Lake Basin.

Climate

The Lake Basin has a semiarid climate with warm summers, cold winters and moderate amounts of precipitation. Because of its location, the climate in the Lake Basin is influenced by characteristics of both the Great Plains and the Rocky Mountains.

The average annual precipitation at Rapelje over the entire period of record (1908 to present) is about 13 inches (WRCC 2005). About 30 percent of the annual precipitation falls during the months of May and June. Winters are generally dry with less than 20 percent of the annual precipitation occurring between November and February. Winter is cold, but temperatures are often moderated by extended periods of mild temperatures brought on by strong southwesterly Chinook winds. Spring is usually cloudy and cool with frequent episodes of rain or snow. Summer characteristically has warm days and cool nights with frequent afternoon thunderstorms. Fall months cycle between cool, moist conditions and warm, dry conditions. South-central Montana area has been under drought conditions for the past six years. Long-term precipitation trends are plotted as the cumulative departure from monthly normal from January 1908 through

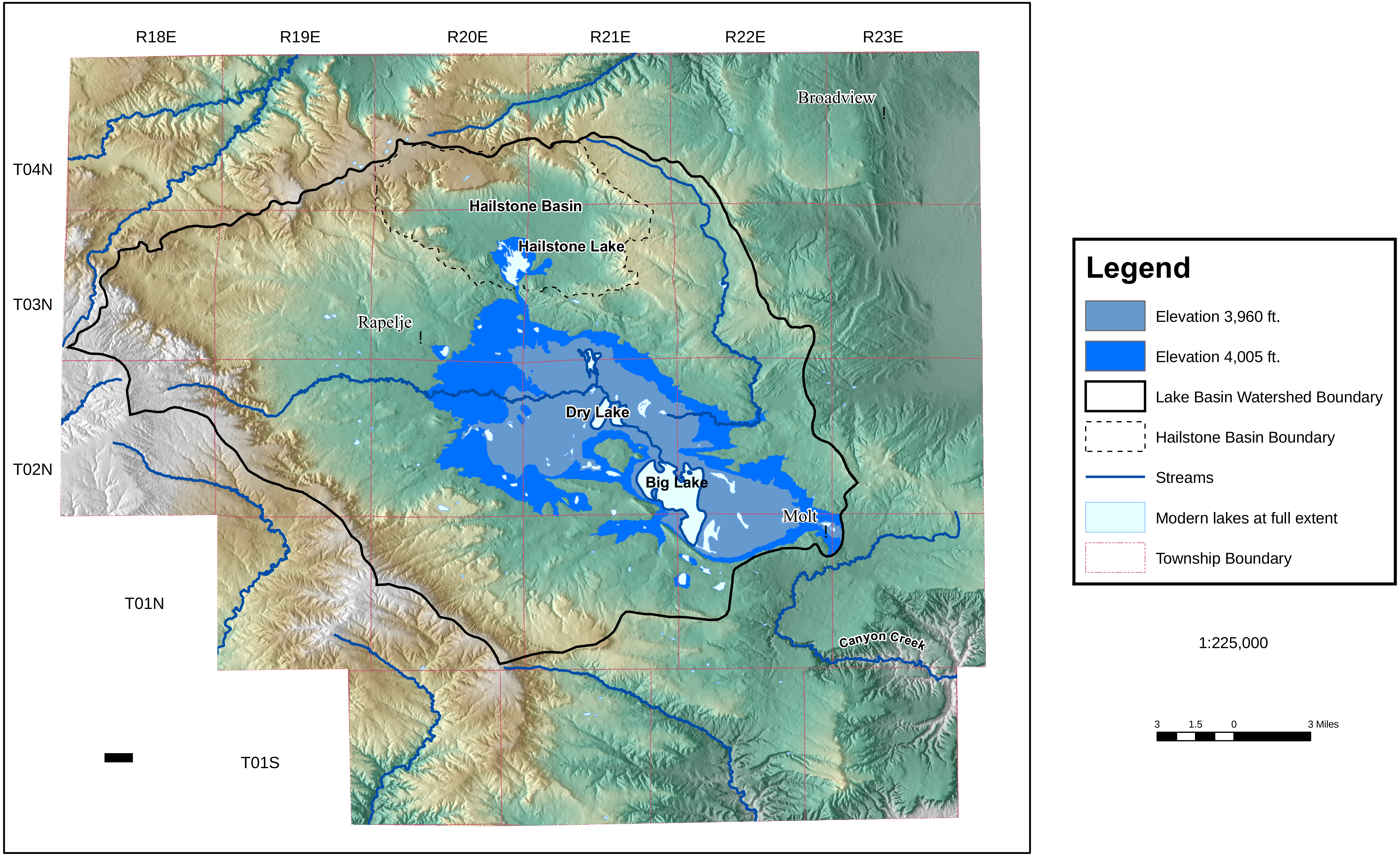


Figure 4. Lake Basin depicted with flood levels of 3,960 ft and 4,005 ft above sea level .

December 2004 are depicted in Figure 5. The drought that began in 1998 stands out significantly and shows the steepest rate of decline recorded at the Rapelje climate station. Hydrographs of water-level fluctuations, represented in later parts of this report, are referenced to this precipitation chart.

MATERIALS AND METHODS

This project commenced in the spring of 2001 and was completed in the fall of 2003 (although additional opportunistic samples were collected from 2004-2006).

Hydrogeologic Assessment

Test drilling in the Lake Basin was conducted in March of 2001 to document and describe hydrogeologic conditions in the Hailstone Refuge. Wet conditions made roads impassable on Halfbreed NWR, delaying drilling in that area. Wells were drilled and constructed from the edge of the refuge down to the Lake to collect the information required to develop profiles of the shallow groundwater flow system, resulting in 27 new wells (Figure 6a). The wells were drilled with a Montana Bureau of Mines and Geology (MBMG) auger rig and were constructed through hollow-stem auger flights. Several additional wells were drilled using an NRCS auger rig in nearby off refuge locations. Six wells were drilled at Halfbreed NWR in the summer of 2002 when road conditions made it possible to access the refuge (Figure 6b). All of the wells were completed using two-inch PVC casing and PVC well screen. The annulus around each well screen was packed with 10/20 slot silica sand and sealed to the surface with bentonite chips, and in some cases bentonitic well cuttings. The wells were flushed with water and developed by pumping and bailing until they produced water representative of ambient groundwater conditions, as determined by field water-quality parameters. Well logs and completion results are available through the MBMG's Ground Water Information System website (www.mbmggwic.edu). To access this data, go to the GWIC homepage where you will be prompted to sign in and establish a password and data use prior to connecting to the database.

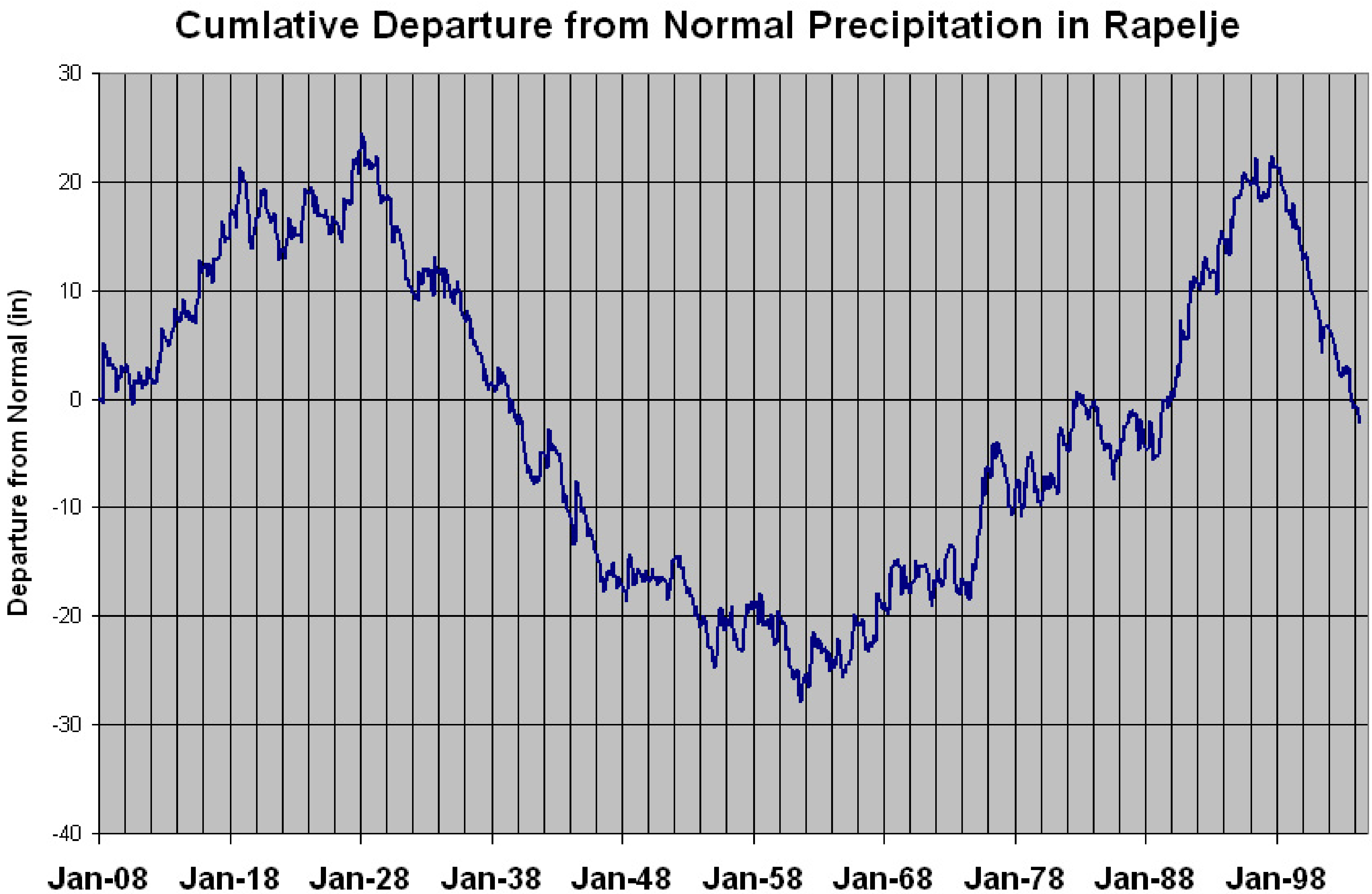


Figure 5. Long term precipitation trends in the Lake Basin area, based on monthly cumulative departure from normal precipitation in Raplje, MT.

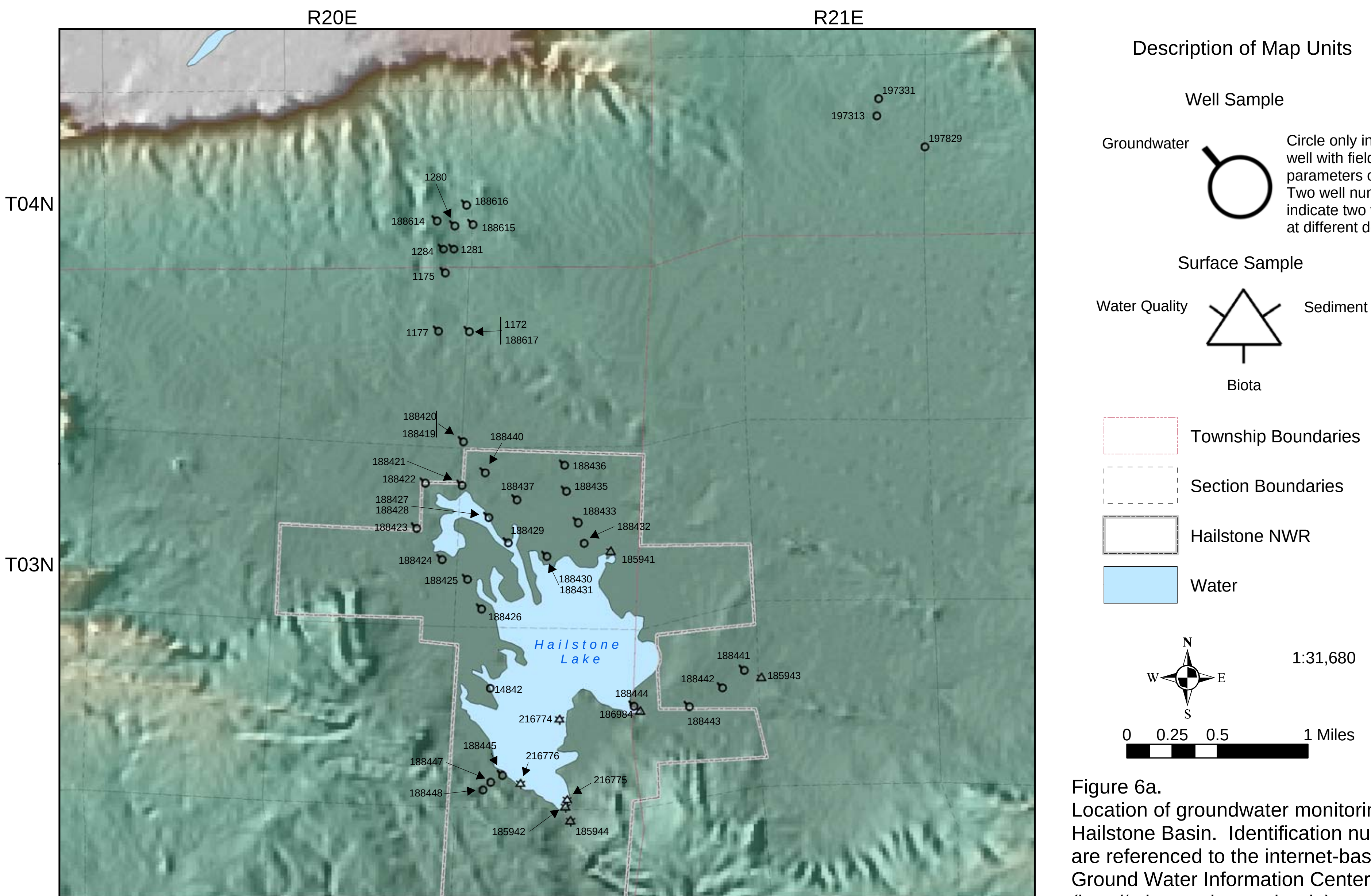


Figure 6a.
Location of groundwater monitoring sites in the Hailstone Basin. Identification numbers are referenced to the internet-based Ground Water Information Center database (http://mbmggwic.mtech.edu).

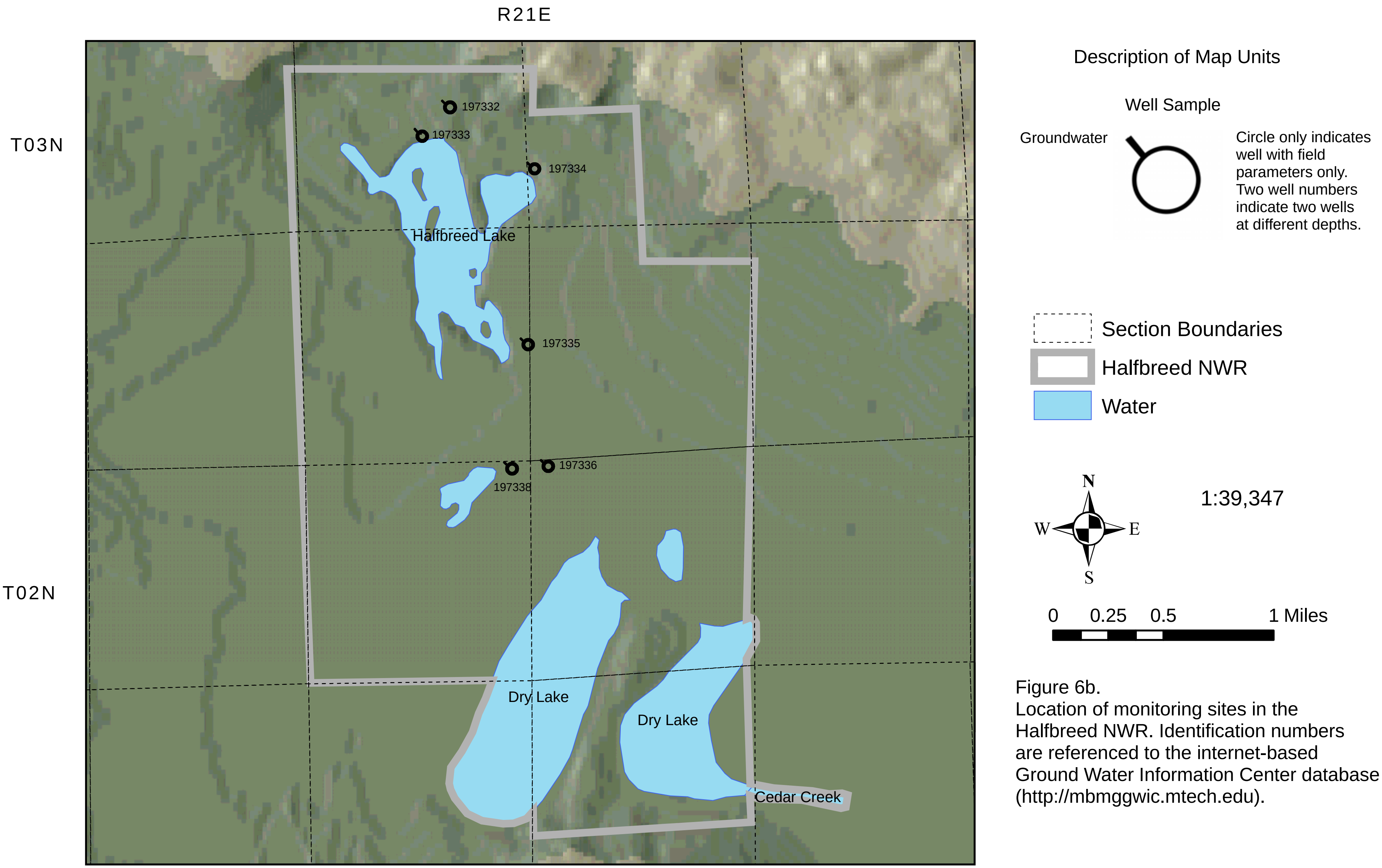


Figure 6b.
Location of monitoring sites in the Halfbreed NWR. Identification numbers are referenced to the internet-based Ground Water Information Center database (http://mbmggwic.mtech.edu).

Data can be accessed by project name, sample number, and location. The best way to view and download data associated with the Hailstone project is to navigate to Ground-Water Projects at the top of the page. Scroll down to General MBMG Program Data to “GW Assessment in Hailstone Basin in Conjunction with USFWS (HAILSTONE)”. For the Hailstone project there are data listed under Site Data, Site Visit Data, Water Quality Data, and Water Level Data. At this point you can select the type of data you want to view. The Site Data table provides direct access to well logs, well completion reports, water quality data, hydrographs, and a plot of the well location.

Initial work consisted of assessing hydrogeologic conditions in the Hailstone Basin and finding and re-establishing monitoring sites from previous investigations located north of Hailstone NWR. Sites re-established were Lewis et al. (1979) wells originally developed in the 1970's and redeveloped as part of the Brickley Site by Duaime et al. (1991). Ten of these wells were flushed out, cleaned up, and added to the Hailstone monitoring network (Figure 6a). The re-established sites were used to compare existing conditions to the previous water chemistry data. This data can provide information on temporal changes, including the effects of land-use changes and climatic fluctuations on water quality and water levels. Well construction data from several of these re-established wells are summarized in Appendix A.

A monitoring network was also established to evaluate water-level fluctuations for a total of 41 wells throughout the Hailstone Basin, these wells were monitored as part of the Stillwater County Lake Basin Project. In addition, a staff gauge was established near the dam at Hailstone Reservoir to allow monitoring of lake levels. Results of water-level monitoring were used to construct hydrographs of groundwater and lake-level fluctuations. These data are stored in the MBMG GWIC data base and are available at the aforementioned web site. Selected hydrographs are displayed in the results section of this report. The tops of well casings were surveyed by Ducks Unlimited and referenced to mean sea level during the spring of 2004. A Garmin III+ Global Positioning System (GPS) (Garmin International, Olathe KS) was used to mark well locations in order to develop a map of sampling sites and the elevations were used to develop cross sections and groundwater flow maps.

Groundwater samples were collected at all wells capable of producing enough water for analysis. Samples were collected by pumping or bailing each well until three well casing volumes were removed, or SC measured with a YSI 85 meter (YSI Inc, Yellow Springs, OH), stabilized. Groundwater was then pumped or bailed into an alcanox washed 10% nitric acid and distilled water rinsed 5-gallon plastic bucket. A Geopump Peristaltic Pump (Geotech Environmental Equipment, Inc, Denver, CO) was used to pump water from the bucket to chemically-clean polyethylene bottles. A Geotech dipos-a-filter (0.45 µm) (Geotech Environmental Equipment, Inc, Denver, CO) was used for samples requiring filtration. Filtered samples collected for trace element analyses were acidified with trace metal grade nitric acid. Samples analyzed for nitrates were preserved with Reagent grade 0.16N sulfuric acid. All samples were stored at 4^0C until shipment or delivery to the MBMG Analytical Laboratory in Butte, MT. Duplicate samples were collected at several locations and analyzed by Trace Element Research Laboratory, Texas A&M University (College Station, TX) (A Service contract Laboratory). Groundwater sample results are listed in Appedix A.

Analytical work on groundwater samples collected was completed by two different laboratories, MBMG analytical Division, and TERL. MBMG completed analytical work for ions and trace elements. These were determined utilizing ICP and ICP-MS for metal including cations, anions were determined using IC. Analytical work for a total metals scan was completed by TERL using atomic fluorescence spectroscopy for selenium, cold-vapor atomic absorption spectroscopy for mercury, graphite furnace atomic absorbtion spectroscopy for arsenic, and ICP for the rest of the trace elements. Quality assurance/ quality control (QA/QC) for both laboratories consisted of procedural blanks, duplicate analysis, and spike recoveries. All reports of QA/QC completed by TERL are also reviewed by the Services Analytical Control Facility for acceptability before results are distributed. QA/QC for ion scans completed by MBMG also included a mass balance.

Geologic mapping was conducted along the Lake Basin Fault Zone forming the southern boundary of Hailstone Basin by a student in the Association of State Geologists mentorship program. Recent mapping through the USGS state mapping program, in addition to interpretations of shallow test hole lithologic data, were used to develop a surficial map of the Hailstone Basin Geology. Mapping will be discussed in the results section of this report.

Several photographs taken by Refuge Operations Specialist/Pilot, Shawn Bayless, document the physical conditions in and around the Hailstone Basin. Figure 7 is an aerial view of the refuge and surrounding area looking to the southwest. Figure 8 shows folded and faulted rocks in the foreground. Figure 9 is an aerial infrared photo, taken by Marvin Miller, MBMG, showing saline seep development (MBMG, Marvin Miller, 1973).

Water Quality Monitoring

Surface water samples were collected approximately monthly (during spring, summer and early fall) throughout the study and submitted for major ion analyses and/or a total metals scan. Water-quality parameters were recorded at locations of surface water samples using a YSI 85 meter to determine dissolved oxygen, SC, and temperature. An Acumet Portable AP61 pH meter (Fisher Scientific, Pittsburgh, PA) was used to measure pH. Grab samples were collected in an alcanox washed 10% nitric acid and distilled water rinsed 5-gallon plastic bucket. A Geopump Peristaltic Pump was used to pump water from the bucket to the certified chemically-cleaned sample bottles. A Geotech dipos-a-filter (0.45 μm) was used for samples requiring filtration. Filtered samples collected for trace element analyses were acidified with trace metal grade nitric acid to a pH <2. All samples were stored at 4^{0}C until shipment to TERL or delivery to MBMG. Surface water sampling locations are shown in Figure 6a.

Water quality was also monitored in Hailstone Reservoir throughout the spring and summer using a Hydrolab DataSonde3 (Hydrolab, Houston, TX). The unit monitored dissolved oxygen, SC, pH, and temperature at hourly intervals during the spring, summer and early fall. Data was downloaded and the unit recalibrated about every six weeks.

Figure 7. Aerial view of the Hailsone Refuge. View is to the SW.

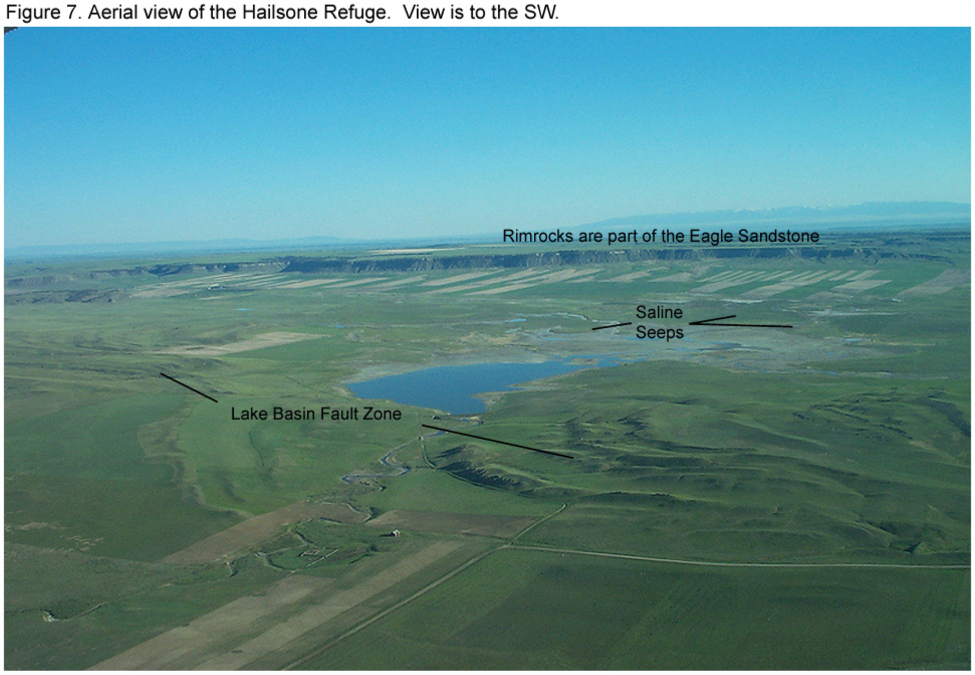


Figure 8. Aerial view of Hailstone Lake showing deformed rocks of the Lake Basin Fault zone
in the foreground and seep development between the Lake and the Rimrocks. View is to the NW.

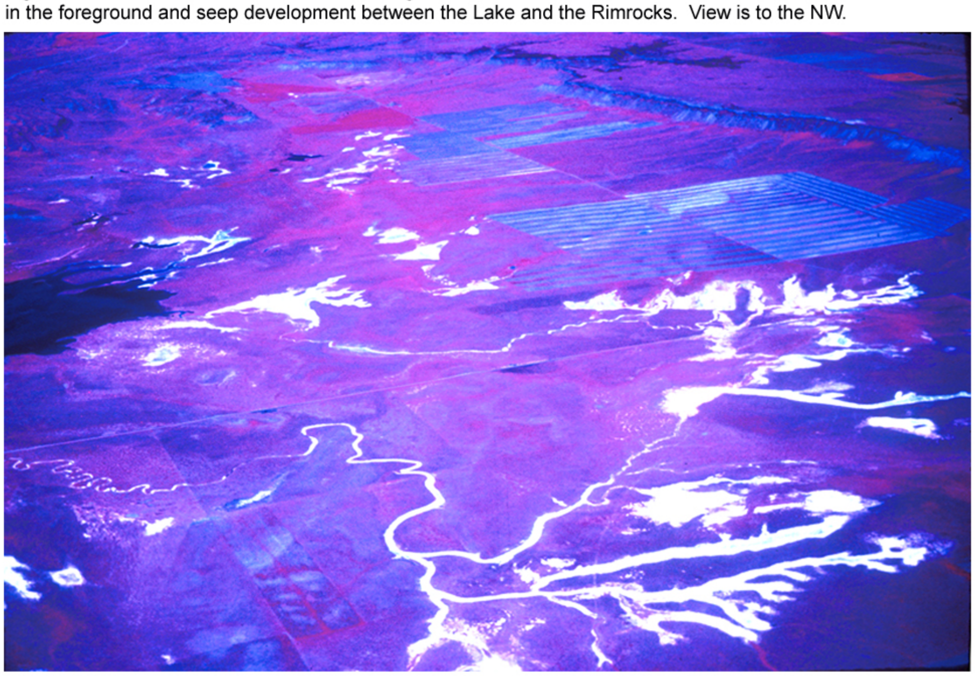


Figure 9. Saline seep development in the Hailstone Basin. Infrared slide taken during the 1970's.
View is to the NW.

Analytical work for surface water was completed by two different laboratories, MBMG analytical Division, and TERL. MBMG completed analytical work for ions and trace elements. These were determined utilizing ICP and ICP-MS for metal including cations, anions were determined using IC. Analytical work for a total metals scan was completed by TERL using atomic fluorescence spectroscopy for selenium, cold-vapor atomic absorption spectroscopy for mercury, graphite furnace atomic absorbtion spectroscopy for arsenic, and ICP for the rest of the trace elements. Quality assurance/ quality control (QA/QC) for both laboratories consisted of procedural blanks, duplicate analysis, and spike recoveries. All reports of QA/QC completed by TERL are also reviewed by the Services Analytical Control Facility for acceptability before results are distributed. QA/QC for ion scans completed by MBMG also included a mass balance.

Aquatic Hazard Assessment for Selenium

Following the methods described in Lemly's (1995) protocol for aquatic hazard assessment of selenium, field activities focused on collection of five ecosystem components (filtered water, sediment, benthic macroinvertebrates, fish eggs or whole body fish, and aquatic bird eggs or bird livers). Sample collection commenced in the spring of 2001 and continued through the summer of 2003. All samples were placed in certified chemically-cleaned glass containers. Water samples were collected as described in the previous water-quality monitoring section. Filtered samples were acidified with trace metal grade nitric acid to a pH<2. Sediment was collected with an alcanox washed 10% nitric acid rinsed plastic spoon from each sample location and placed in a certified chemically-cleaned glass container. Invertebrates in Hailstone Reservoir were limited to brine shrimp which were collected with an alcanox washed 10% nitric acid rinsed fine mesh dip net. Contents of the dip net were then placed in and alcanox washed 10% nitric acid rinsed 250 µm mesh plastic sieve, and using alcanox washed 10% nitric acid rinsed plastic forceps; everything that was not brine shrimp was removed. Contents of the sieve were then placed in certified chemically-cleaned glass containers. Below the dam, invertebrate collections consisted of brine shrimp and ephydridae. Hailstone Reservoir is too saline to support fish so fish were not collected. Waterfowl and shorebird nesting attempts were monitored every spring/summer. When no nests could be located, waterfowl and shorebirds were collected with a shotgun using stainless steel shot. For birds collected with a shotgun, livers were removed and placed in certified chemically cleaned glass containers. When eggs were available, they were collected, dissected, and contents were placed in certified chemically cleaned glass containers. Collected components were frozen (sediment, invertebrates, eggs, and livers) or refrigerated (water) until shipment to TERL. Analytical results for selenium were then compared to hazard profiles established for each ecosystem component; a numeric score was assigned ranging from 1 (no identifiable hazard) to 5 (high hazard). A final hazard characterization was determined by summing the numeric scores. This final number provides an ecosystem-level hazard of selenium (Lemly 1995).

Analytical work for the selenium hazard analysis was completed by TERL using atomic fluorescence spectroscopy. Tissue and sediment samples collected as part of hazard assessment were also submitted for a total metals scan. The total metals scan was completed using, cold-vapor atomic absorption spectroscopy for mercury, graphite furnace atomic absorbtion spectroscopy for arsenic, and ICP for the rest of the trace elements. Quality assurance/ quality control (QA/QC) consisted of procedural blanks, duplicate analysis, and spike recoveries. All reports of QA/QC completed are reviewed by the Services Analytical Control Facility for acceptability before results are distributed.

RESULTS and DISCUSSION

Hydrogeology

The geologic component of saline seep development includes the occurrence of marine shale overlain by colluvial and alluvial sediment derived from the shale. Marine shales provide an abundant source of soluble salts that are readily available in the Hailstone Basin. Oxidation of iron sulfide minerals commonly found in marine deposits has been demonstrated to be a prime source for sulfate anions. Soluble sodium and magnesium in the bentonitic clays are sources for the dominant cations. The development of saline seep conditions in the Hailstone Basin is directly related to these geologic conditions. The geologic map of Hailstone Basin (Figure 10) shows the relationship of the surficial geologic units in the Basin.

The Eagle Sandstone forming the rimrocks on the north side of the Hailstone Basin and resistant sandstones of the faulted Montana Group rocks on the south side of the Hailstone Basin are the source of sandy colluvium deposited as slope wash below these uplands. The colluvial deposits become finer grained towards the center of the basin and are mixed with alluvium deposited by small tributaries and lake sediments. This mixture of colluvium, alluvium, and lake sediments (map unit Qal) overlies the Niobrara Shale. The upper part of the Niobrara Shale is highly weathered and fractured. Below the weathered zone, the Niobrara consists of gray to black, low permeability unweathered shale.

Lithologic data from test holes drilled for this project (and previous work) were used to construct a cross-section from the north edge of the basin to near the outlet of Hailstone Reservoir. Figure 11 shows this cross-section detailing the relationships of alluvial and colluvial sediments overlying the Niobrara Shale within the Basin. The colluvium thins at a slope break where the underlying bedrock forms a slight rise and appears to form a zone of transition that is associated with saline seep development.

Based on these observations in Hailstone Basin, saline seeps in other parts of the Lake Basin appear to form in similar ground-water transition zones. Recharge of high salinity water to underlying aquifers is likely concentrated down-gradient of these transition zones. As this high TDS water slowly moves through the ground-water flow system, it can potentially degrade the water quality of relatively shallow aquifers which supply nearly all stock and domestic wells in the Lake Basin.

Aerial photographs and satellite data from the Hailstone Basin illustrate historic hydrologic

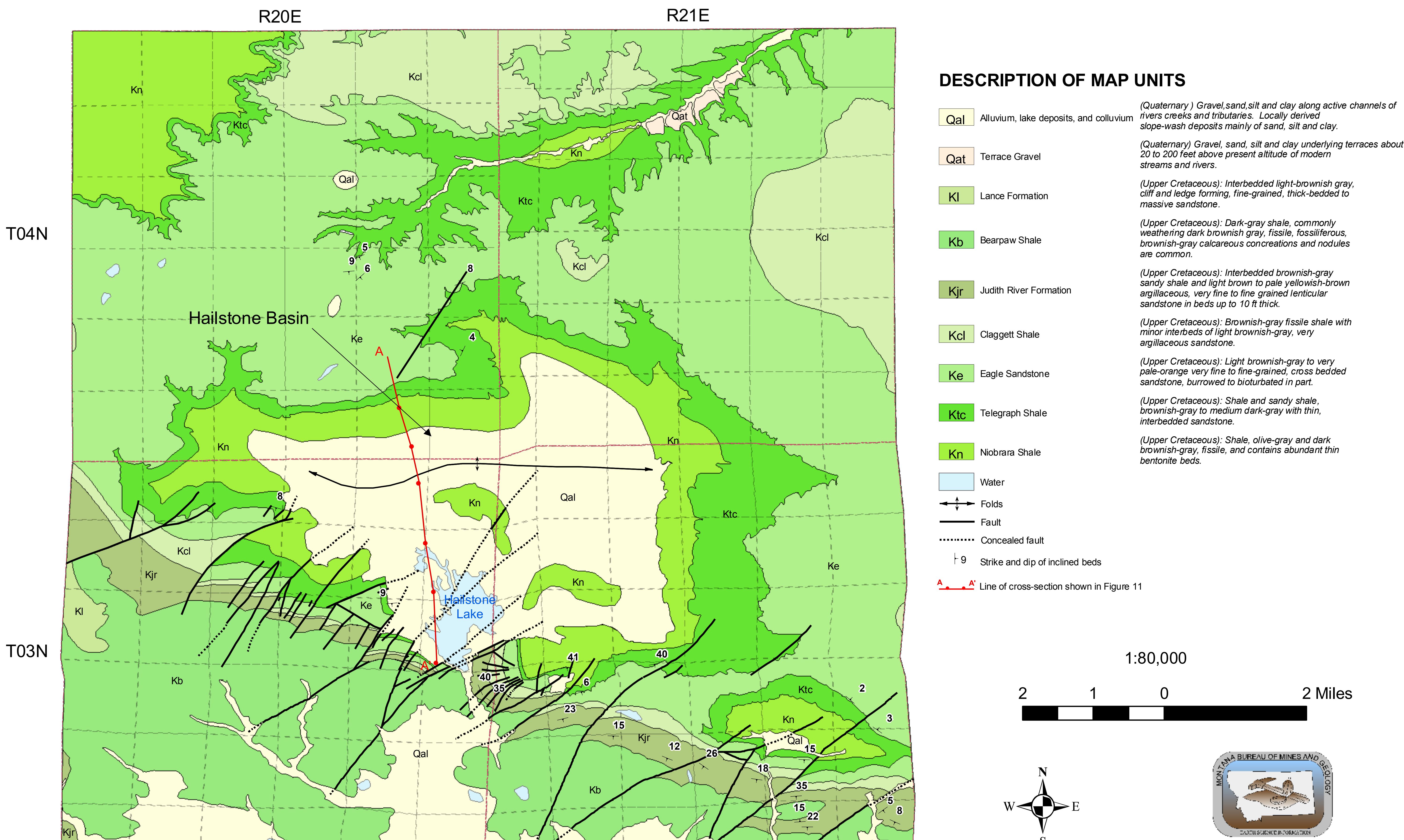


Figure 10. Geology of the Hailstone Basin area.

(Geology adapted from Lopez, 2000 and Wilde and Porter, 2001.)

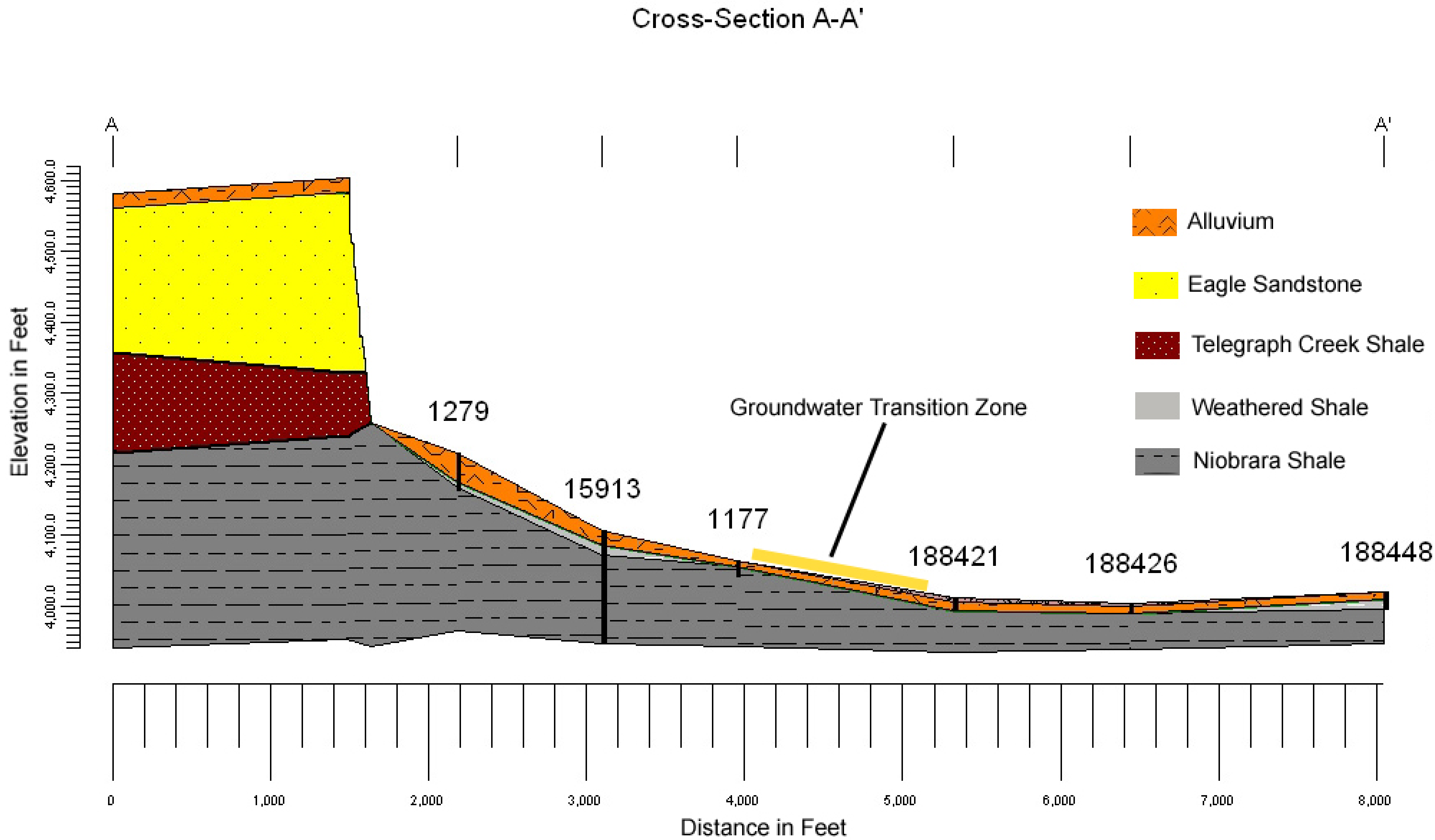


Figure 11. Cross section A - A' (See Figure 10) depicting stratigraphy of major geologic units from the rimrocks on the north side of Hailstone Basin to the outlet of Hailstone Lake.

conditions at Hailstone Reservoir from dam construction to present (Figure 12). Three years after the dam was constructed, Hailstone Reservoir filled a small wetland occupying former channels and oxbows of Hailstone Creek, which is depicted in the 1941 aerial photo. Over time, the nature of the reservoir transformed from a relatively small wetland, covering an area less than 160 acres, to a large, salty playa covering nearly 640 acres in 1979. It appears that salts and sediment are filling low spots within the reservoir causing these hydrologic changes. The 2003 Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) satellite image shows the reservoir as a large salt flat with water only in a few small pools. The obvious white areas shown on aerial photos are efflorescent salts deposited on the land surface. These white areas are saline seeps where sulfate salts precipitate at the ground surface in areas of shallow groundwater, these salts are likely thenardite (Na_2SO_4).

During the spring of 2004, a thick layer of salt formed throughout the Lake. Attempts to core or dig through the salt layer in order to measure the thickness were unsuccessful. Underlying a thin layer of organic rich silt, a very hard, light green, salt layer was penetrated to a depth of about 1.5 feet. The salt layer was never completely penetrated because of difficult digging conditions. This light salt is a sodium sulfate evaporate mineral, probably mirabilite ($Na_2So_4 \cdot 10(H_2O)$). When exposed to the atmosphere mirabilite quickly degrades to a fluffy white-colored efflorescent salt, probably thenardite (Na_2SO_4). It is not known if these salt deposits form permanent salt beds or dissolve when the lake fills during wetter periods.

Groundwater flow

Groundwater flow in the Hailstone Basin, based on relatively low water levels measured in late March of 2004 (Figure 13), is from the edges of the Hailstone Basin towards Hailstone Reservoir. The shallow groundwater flow system is perched on very low permeability shale of the Niobrara Formation. Groundwater is recharged through vertical percolation of rainfall and snowmelt and moves laterally through weathered shale and overlying colluvium towards Hailstone Reservoir. Since the colluvium is more permeable immediately below the rimrocks,

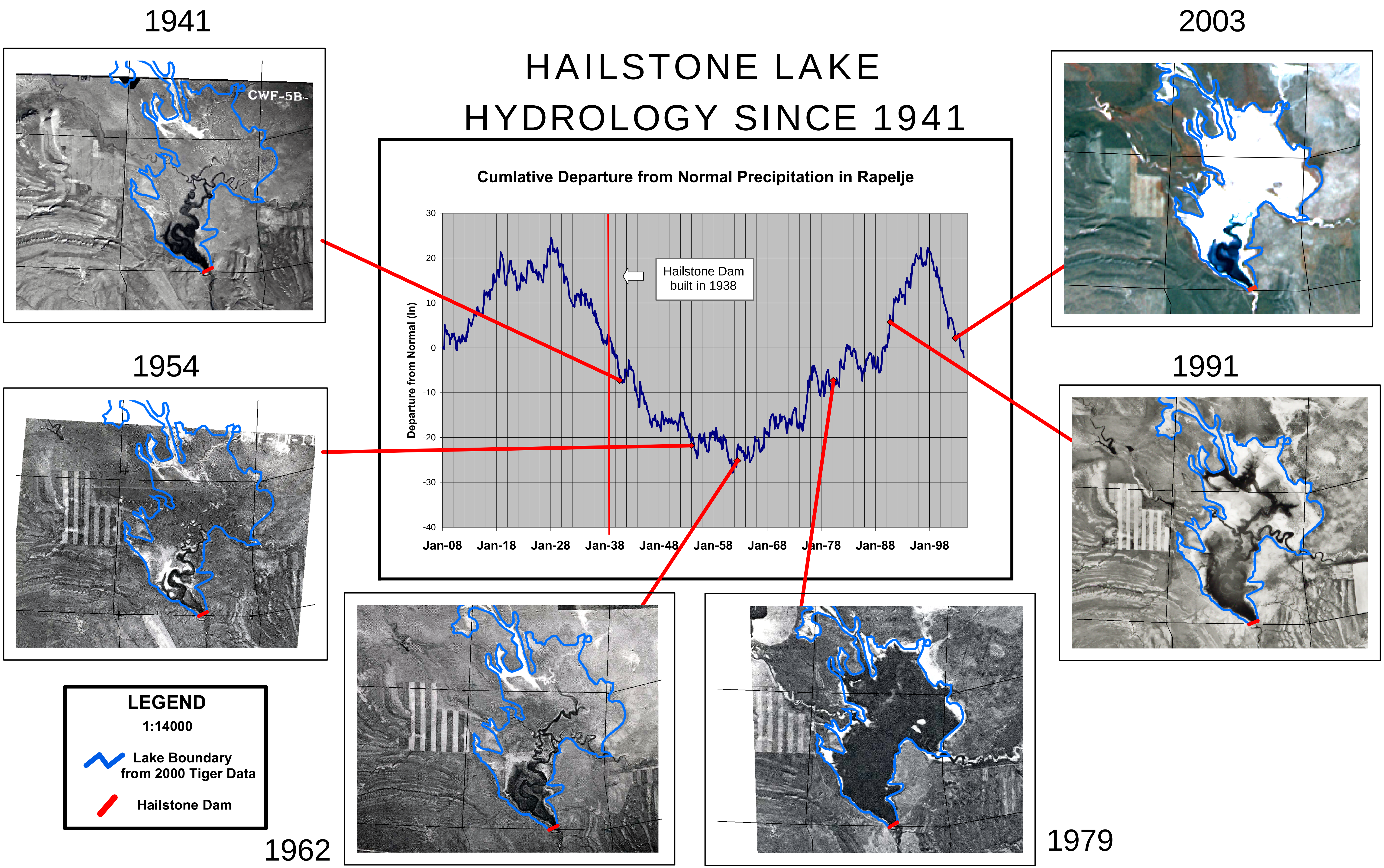
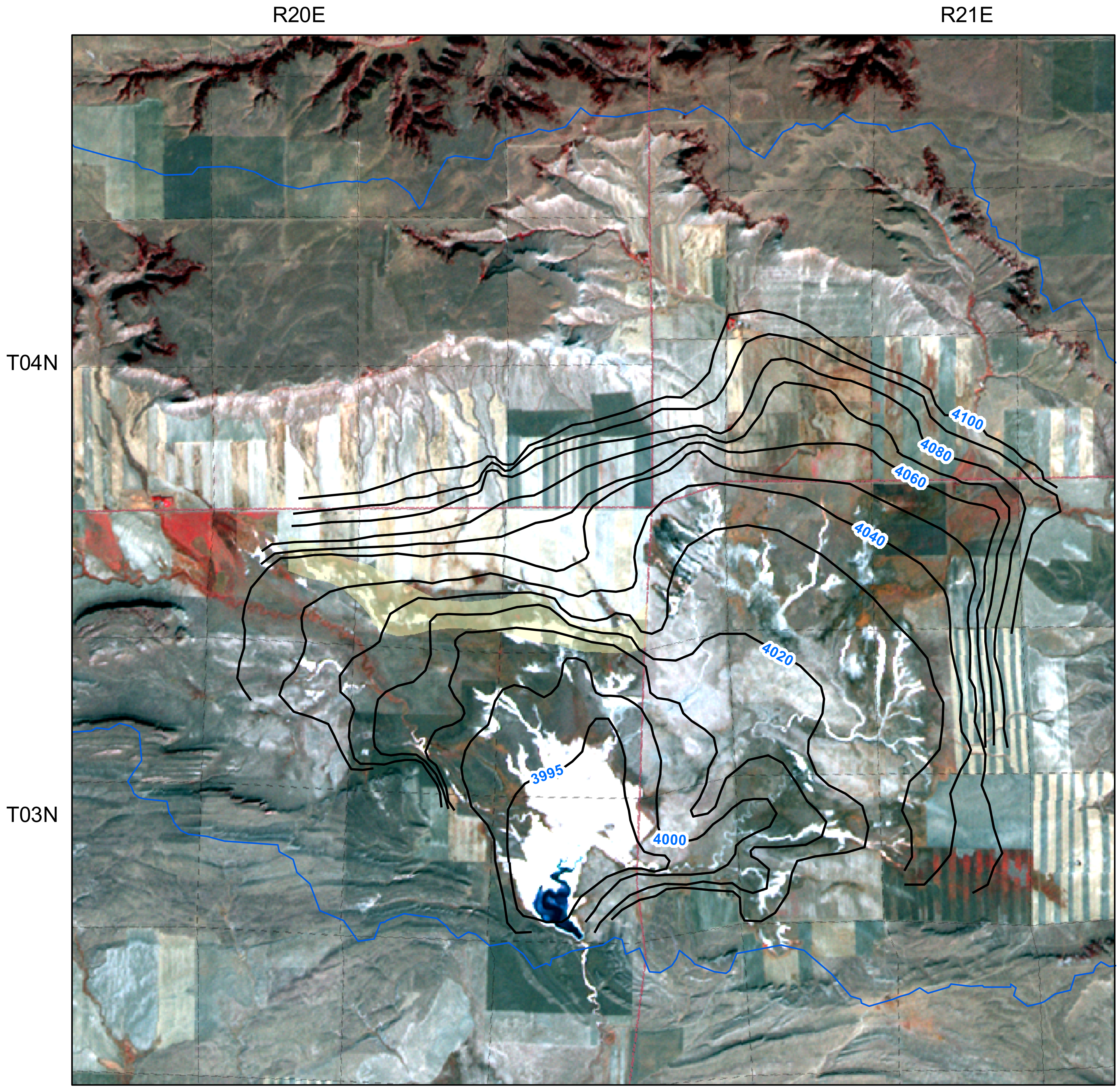


Figure12. Series of air photos showing hydrological history of Hailstone Lake.



DESCRIPTION OF MAP UNITS

Groundwater Contour

10 ft. Contour Interval

Groundwater Transition Zone

Hailstone Basin

Township Boundaries

Section Boundaries

N
W E
S

1:48,004

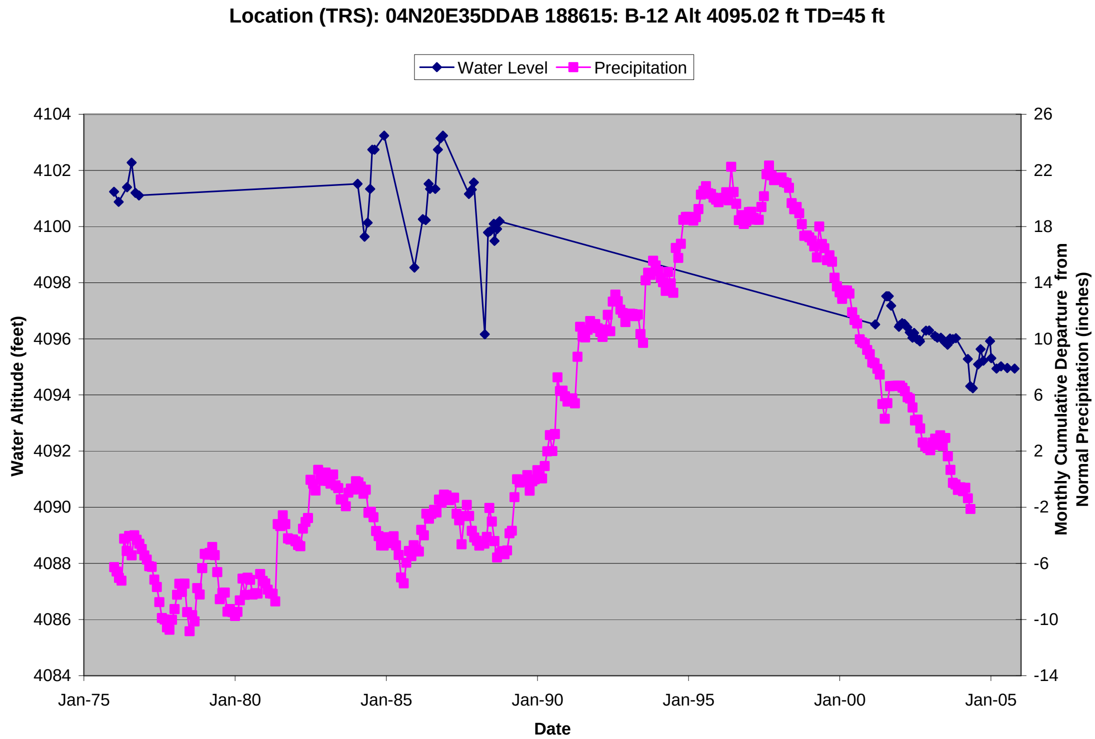
1 0.5 0 1 Miles

Figure 13. Map of groundwater altitiude near the Hailstone Refuge. Water-level altitudes are based on measurements taken on March 29, 2004. Base map is an ASTER satellite image.

the recharge potential is greater near the rims and decreases towards the center of the Hailstone Basin. The groundwater transition zone develops where a slight rise in the bedrock appears to have constricted groundwater flow and forced water towards the land surface. The transition from steep groundwater gradients to relatively flat groundwater gradients appears associated with outbreaks of saline seep at the land surface. This transition zone is well defined north of Hailstone Reservoir by water level elevations measured in monitoring wells and is displayed as a reference on several interpretive maps in this report. The groundwater slope breaks in other areas are estimated based on interpolated water-table contours, topography, surficial hydrology, and saline seep development. This transition zone probably exists throughout the Basin at the transition between steep to shallow groundwater flow gradients. Because of limited data, the transition zone was not mapped over the entire Basin, however, the change in groundwater gradients appears to directly relate to the development of saline seeps.

Hydrographs of several wells are shown in Figure 14. Water-level fluctuations generally reflect the overall drought conditions during this study. Hydrographs combining readings from the 1970’s, 1980’s, and recent data reflect the overall fluctuations of precipitation in this area. Excess infiltration from crop fallow farming also may be a significant factor in the groundwater fluctuations. Relatively low water levels during the 1970's were followed by increases in the 1980's and have generally declined through 2004. These water levels correspond to precipitation trends with increases in the 1980's culminating in the extended drought from the late 1990's to 2004.

Water-level data from several pairs of nested wells documented vertical flow gradients in the colluvial/weathered shale groundwater system (Figure 15). Downward flow gradients are generally found in the area above the transition zone (Figure 15a). Although wet conditions prevented installing wells near saline seeps in the transition zone, upward flow gradients are likely based on seep development. Mixed flow gradients are typical close to the lake; with the typical upward flow gradients reversed during recharge events (Figure 15c).



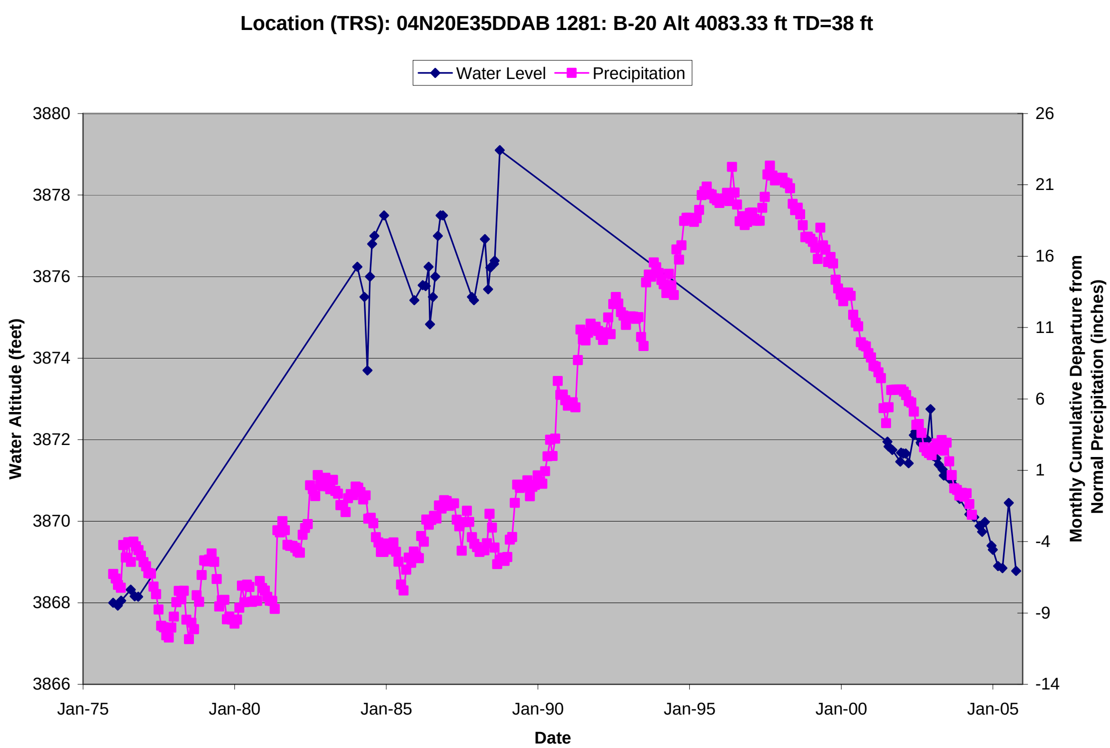
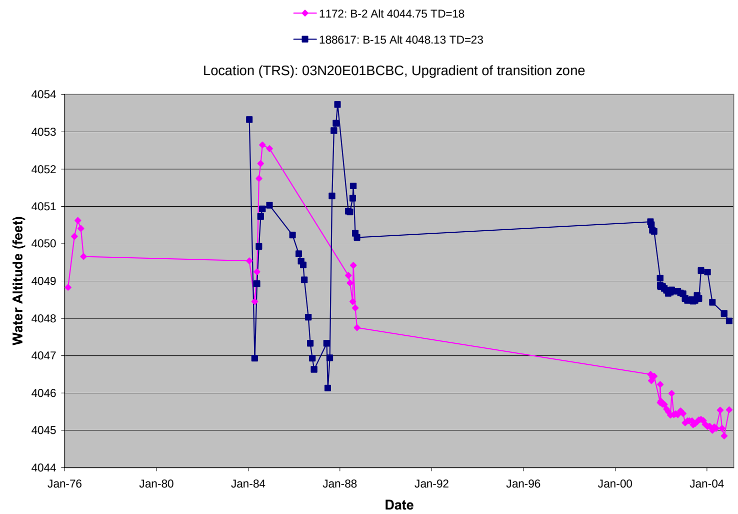
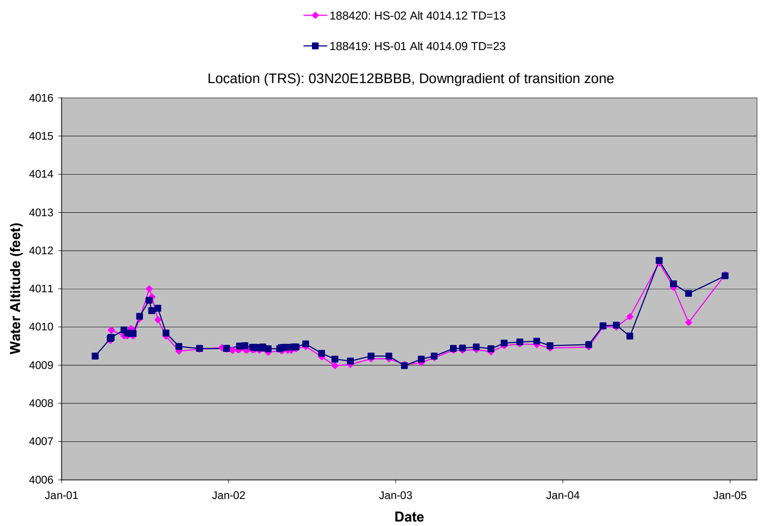


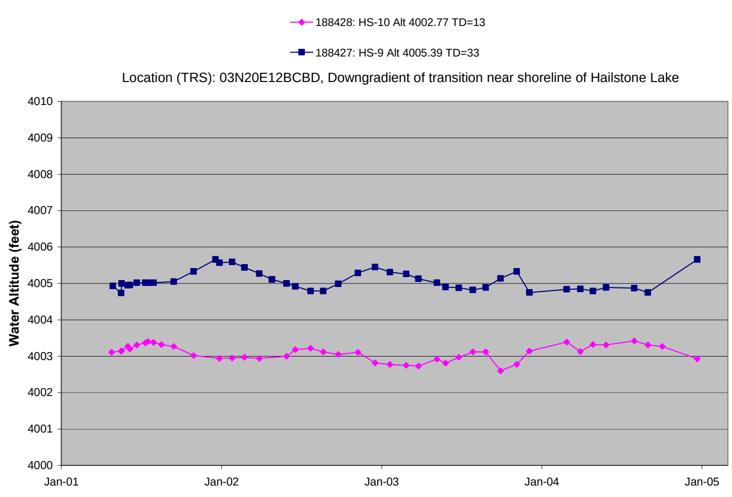
Figure 14. Hydrographs from two wells in Hailstone Basin showing long-term water level fluctuations



a.



b.



c.

Figure 15. Hydrographs from selected wells in Hailstone Basin showing vertical flow gradients at nested wells located a) upgradient (above transition zone), b) downgradient (below transition zone) and c) further downgradient (near Hailstone Lake shoreline).

Groundwater Quality

Groundwater samples were collected from 39 wells; these consisted of 10 reconditioned wells north of Hailstone NWR, 23 wells drilled within or near the boundary of Hailstone NWR, and 6 wells drilled on Halfbreed NWR (www.mbmggwic.edu). Groundwater quality within Hailstone basin fluctuated based on location within the groundwater flow path and groundwater transition zone. This is caused by variations in infiltration of precipitation and the distance of movement through the colluvium and weathered shale of the shallow groundwater system.

The ten reconditioned wells used in this study were originally drilled in 1974-1975 to investigate the spread of saline seeps and effects on groundwater quality (Lewis et al. 1979). These wells were monitored again in the 1980s by Duaime et al. (1991). Both research projects focused on the same two study locations, one north of Hailstone NWR, and the other located near Halfbreed NWR. Only wells north of Hailstone were reconditioned for the current study. When Lewis et al. (1976) initiated the investigation, a portion of the study area was still in native vegetation (the east half of 4N20ESec35 and the east half of 3N20ESec20), seven of the reconditioned wells were located in this native sod. In the spring of 1976, a year after the wells were installed, the ground was broken and planted to small grains. The effects of this conversion were documented in groundwater quantity and quality (Table 1). Duaime et al. (1991) documented similar impacts to groundwater quality and quantity during the five year study site located near Halfbreed NWR, water in test wells rose from 2 to 6 feet, specific conductivity in some wells nearly doubled, and magnesium, nitrate, selenium, sodium, and sulfate all increased.

High nitrate concentrations can result from the initial cultivation of native sod (Custer 1976). Cultivation increases aeration of the soil allowing conversion of organic nitrogen into nitrate by microorganisms; excess moisture then has the potential to deliver nitrates to the subsoil and groundwater (Custer 1976). Groundwater nitrate concentrations below newly cultivated land increase in just one year after cultivation (Custer 1977). Fields under long-term cultivation in Lake Basin contain up to 855 mg/L nitrate in groundwater (Lewis et al. 1979). This trend can be

Table 1. Groundwater quality over time in wells located above the transition zone.

Groundwater Wells located on Ground first Broken in 1976.														
Gwic Id	**1280**	**1280**	**1280**	**1280**	**188616**	**188616**	**1284**	**1284**	**1284**	**1284**	**1284**	**1281**	**1281**	**1281**
Sample Date	9/30/76	7/21/88	12/19/01	8/27/02	9/30/76	8/27/02	3/27/86	5/28/86	7/15/87	8/13/87	7/21/88	9/30/76	7/21/88	8/27/02
Field SC	2260	3779	3700	4093	3970	11680	7160	6500	4100	4505	7174	2260	7159	1281
Ca mg/L		495	488	500		416	454	457			451		437	446
Mg mg/L		162	158	162		930	520	588			604		409	397
Na mg/L		273	323	354		1860	1062	570			677		768	768
HCO3 mg/L		342	339.2	339.2		978.4	630	486			514		473	563.6
SO4 mg/L		2092	2220	2190		7540	4590	3880			4200		3440	3160
Cl mg/L		22	49.3	49		51	126	168			126		169	128
NO3 mg/L	2.2	6.68	16.8 P	15.5 P	71	19.4 P	31	54.6	9.11	72.1	40	2.2	70	107 P
Se µg/L		76	228	199		154	332	587	135	690	572		1040	1700
TDS mg/L		3238	3439	3453		11333	7126	5985			6377		5552	5416

Gwic Id	**1177**	**1177**	**1177**	**1177**	**1177**	**1175**	**1175**	**1175**	**1175**	**1175**	**1175**	**1175**	**1175**
Sample Date	9/30/76	3/27/86	5/30/86	7/21/88	8/27/02	6/14/75	8/13/75	9/30/76	3/27/86	5/28/86	7/21/88	12/19/01	8/27/02
Field SC	4520	18860	15560	16858	17670	8540	7720		6660	7350	8451	8000	7800
Ca mg/L		371	382	397	388	375	320		362	455	415	434	440
Mg mg/L		2034	2155	2265	2500	685	668		645	741	885	792	765
Na mg/L		1764	1897	2230	2299	950	825		590	574	729	729	766
HCO3 mg/L		438	462	513	580.7	762	644		406	366	396	480.7	606.3
SO4 mg/L		11690	12670	13700	13400	4730	4980		3750	4260	5100	4664	4590
Cl mg/L		170	161	175	168	NR	44		166	162	163	257	99
NO3 mg/L	5.3	107	91.2	67	67.9 P	0	0.7	34	100	121	84	<5.0 P	43.8 P
Se µg/L		591	629	998	756				1030	1410	1137	1920	586
TDS mg/L		16387	17618	19127	19149	7502*	7481.7*		5839.1*	6521	7605	7156	7037

Groundwater wells located on historically cultivated lands.								
Gwic Id	**188615**	**188615**	**188615**	**1172**	**1172**	**1172**	**188617**	**188617**
Sample Date	4/8/76	9/30/76	8/27/02	9/30/76	7/21/88	12/19/01	9/30/76	12/19/01
Field SC	5440	3760	14640	14,000	15611	10000	13,300	11000
Ca mg/L	472		226		388	375		376
Mg mg/L	356		578		2280	1130		1380
Na mg/L	460		3290		1640	1170		1130
HCO3 mg/L	318		927.2		625	520.9		507.5
SO4 mg/L	2760		8430		12500	7709		8524
Cl mg/L	302		96		110	88.1		94.6
NO3 mg/L	76	285	<0.5 P	66	66	31.2 P	265	33.1 P
Se µg/L			11.9		385	319		382
TDS mg/L	4760		13100		17325	10796		11828

* TDS calculated using ion concentrations

* P Sample was preserved

NR the value was not reported

seen in Table 1 where concentrations were very low in uncultivated fields, but once those fields were broken, nitrate concentrations increased (M:1175)

One of the most dramatic increases documented in groundwater samples over time was selenium. Selenium concentrations increased in all but one well (M:1172) that monitored for selenium during the Duaime et al. (1991) and the current investigation. Similar concentrations were reported at well M:1172 in 1988 and 2001). Selenium concentrations were highest in wells just below the rimrocks, with the highest concentration found in well M:1175 (1920 μg/L), suggesting that selenium concentrations in the seep discharge area are likely to increase over time (Duaime et al. 1991). Hydrographs showing fluctuations of selenium concentrations and water levels at wells located in these wells are shown in Figure16. Although not re-sampled in this investigation, Duaime et al. (1991) documented selenium increases in groundwater upgradient and to the east of Halfbreed NWR. Concentrations of selenium increased over the 5 years of monitored. The unsaturated zone was sampled by lysimeters installed at depths of 1, 2, and 3 feet. At one foot, selenium increased from 78 μg/L in 1986 to 911 μg/L in 1989; at two feet, the increase was from 187 μg/L in 1986 to 2280 μg/L in 1990; and lastly, at three feet the increase was from 193 μg/L in 1986 to 2390 μg/L in 1990 (Duaime et al. 1991).

Groundwater in the Hailstone Basin contained elevated concentrations of dissolved constituents. The calculated total dissolved solids (TDS) in water samples ranged from 3,452 mg/L below the sandstone rims near the edge of the basin, to 124,480 mg/L in a well from just below the groundwater transition zone. Wells located below the rims, in the saline seep recharge area had the lowest TDS concentrations of all wells with an average of 5,588 mg/L (n=6) in 2001 and 2002. These wells were located in ground broken in 1976. Three wells located downslope (approximately 0.5 miles) from uppermost wells, contained much higher TDS concentrations, 13,924 mg/L TDS (n=3). This increase depicts the increase in the load of dissolved constituents as groundwater moves from the recharge area to the discharge area. Monitoring wells located below the saline seep discharge area contained the highest TDS concentrations, 79,301 mg/L

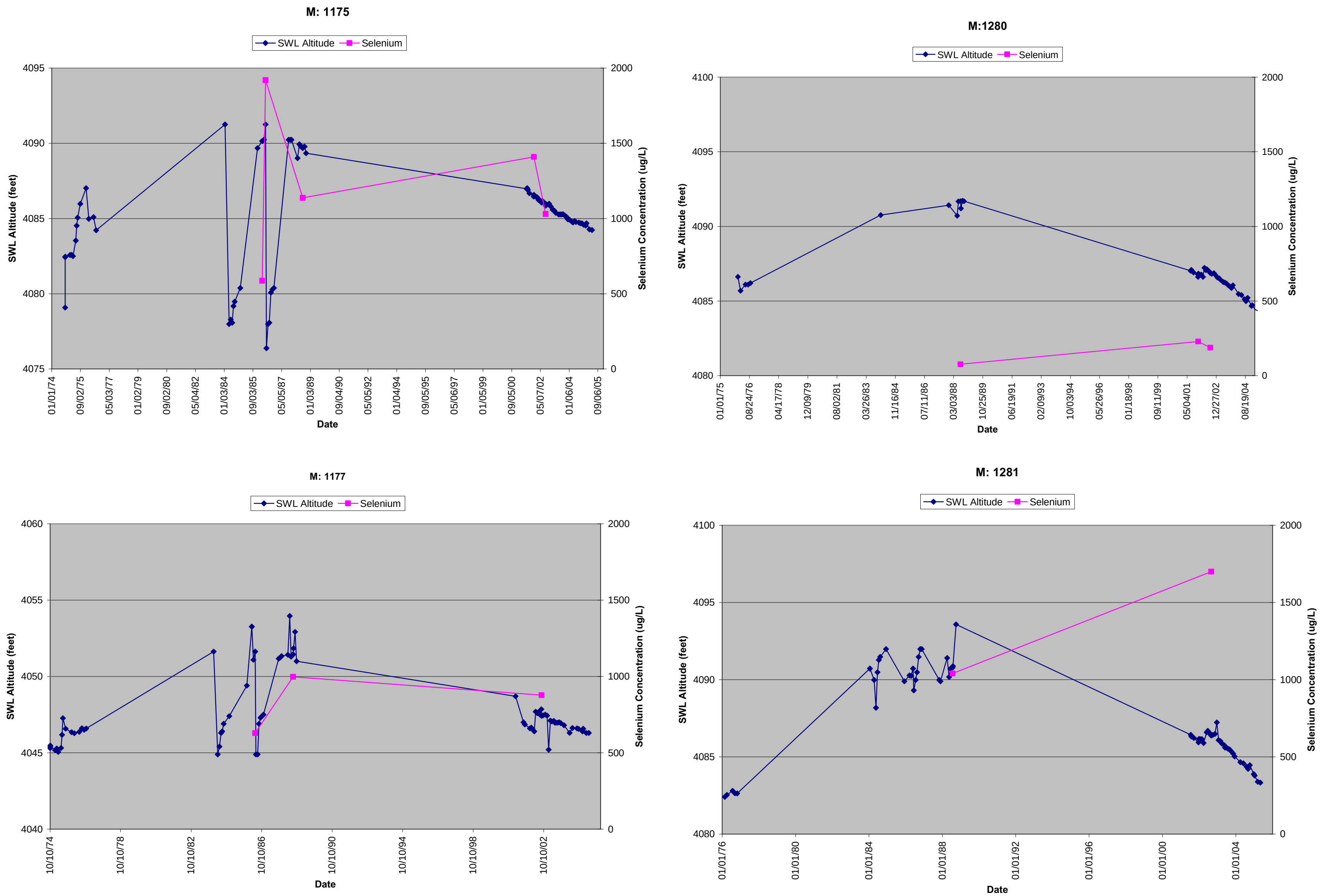


Figure 16. Hydrograph showing fluctuations of Selenium concentrations and water levels through time in water from 4 wells located above the transition zone.

TDS (n=8). Less variability was seen in the groundwater at Halfbreed NWR, where TDS ranged from 33,602 mg/L to 59,089 mg/L. These wells are all located within the refuge boundary and are likely below any groundwater transition zone that might be located in the watershed of Halfbreed NWR. The pH of groundwater in the basin is generally neutral to alkaline ranging from 6.6 to more than 7.73 in all groundwater samples collected. Trace element concentrations vary over a wide range in groundwater samples from the Hailstone and Lake Basins. Trace elements data are included in Appendix A.

Groundwater effects to Surface Water Quality

Both surface water and groundwater are dominated by ions of sodium (Na), magnesium (Mg), and sulfate (SO_4). Piper plots were constructed showing the ionic distribution of well samples (Figure 17), tributary samples (Figure 18), and Hailstone Reservoir samples (Figure 19). Although all samples are strongly dominated by ions of sulfate and sodium; groundwater samples had greater diversity of cation and anion concentrations than lake or tributary. Surface water becomes even more dominated by sodium and sulfate due to the high solubility of these ions. Ions of calcium, magnesium and bicarbonate are more likely to precipitate as carbonate minerals that are less likely to redissolve than are minerals made up of sodium and sulfate ions.

A series of water-quality maps were developed to document the distribution of selected water-quality constituents measured in the waters of Hailstone Basin. The groundwater transition zone appears to be a significant factor in the distribution of SC (Figure 20), TDS (Figure 21), sulfate concentration (Figure 22), and selenium concentration (Figure 23). Specific Conductance (SC) is generally less than about 10,000 µS/cm from wells above the groundwater transition zone. Below the transition zone, SC is generally greater than 30,000 µS/cm. Concentrations in the tributaries range from about 20,000 to 42,000 µS/cm. Lake samples also had very high SC concentrations typically about 40,000 µS/cm or greater.

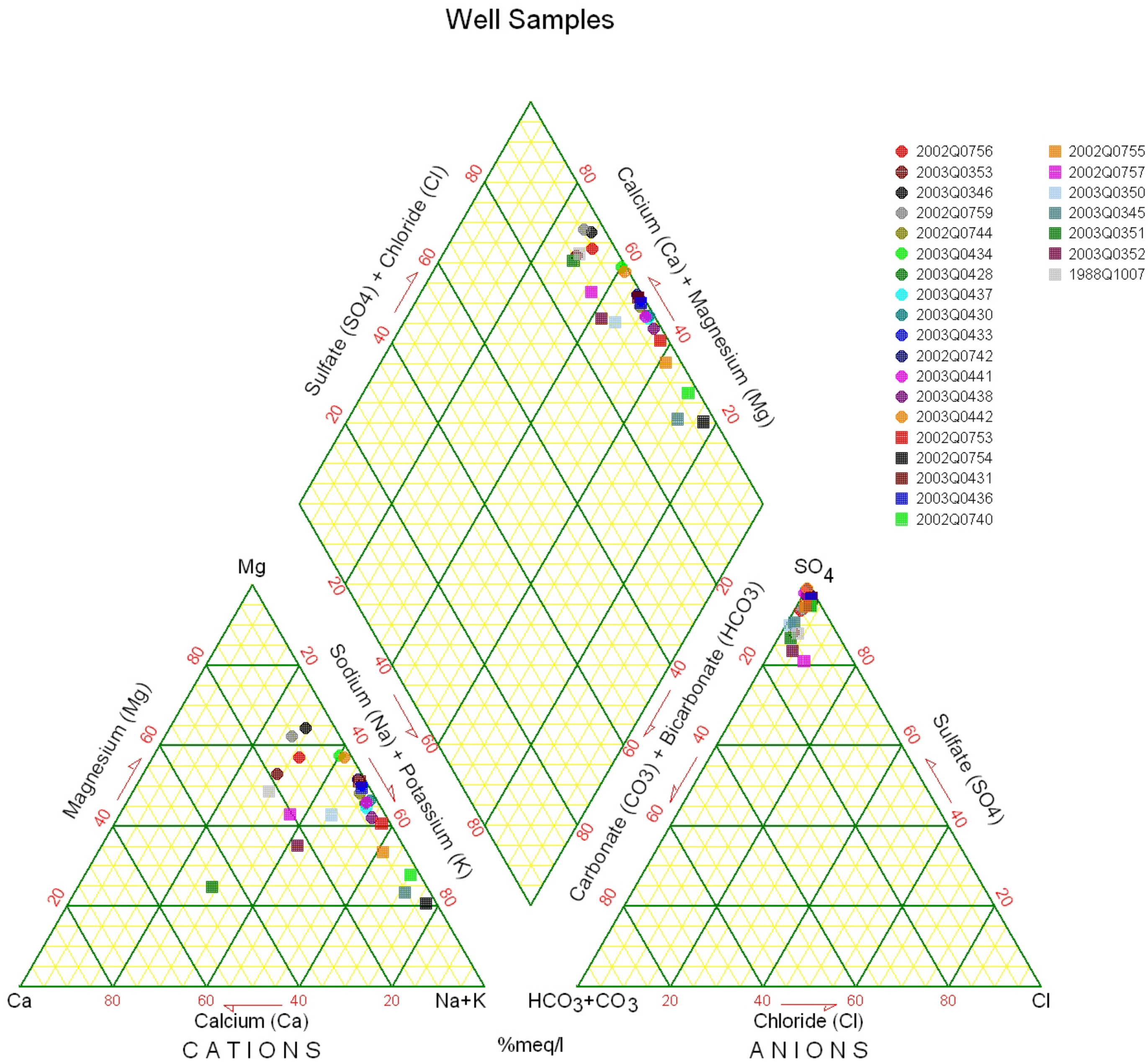


Figure 17. Piper plots of ionic distributions of wells sampled.

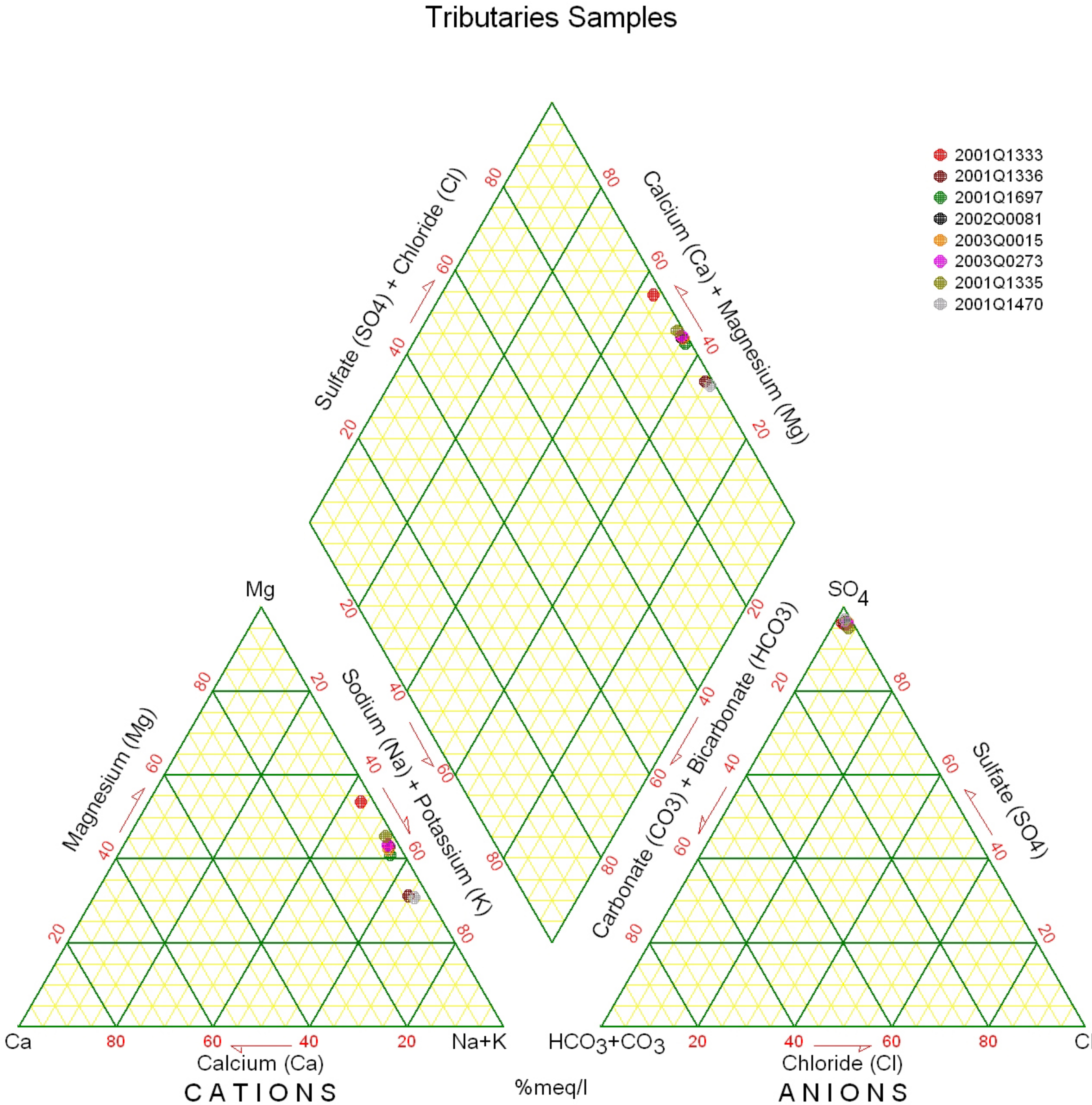


Figure 18. Piper plots of ionic distributions of tributaries sampled.

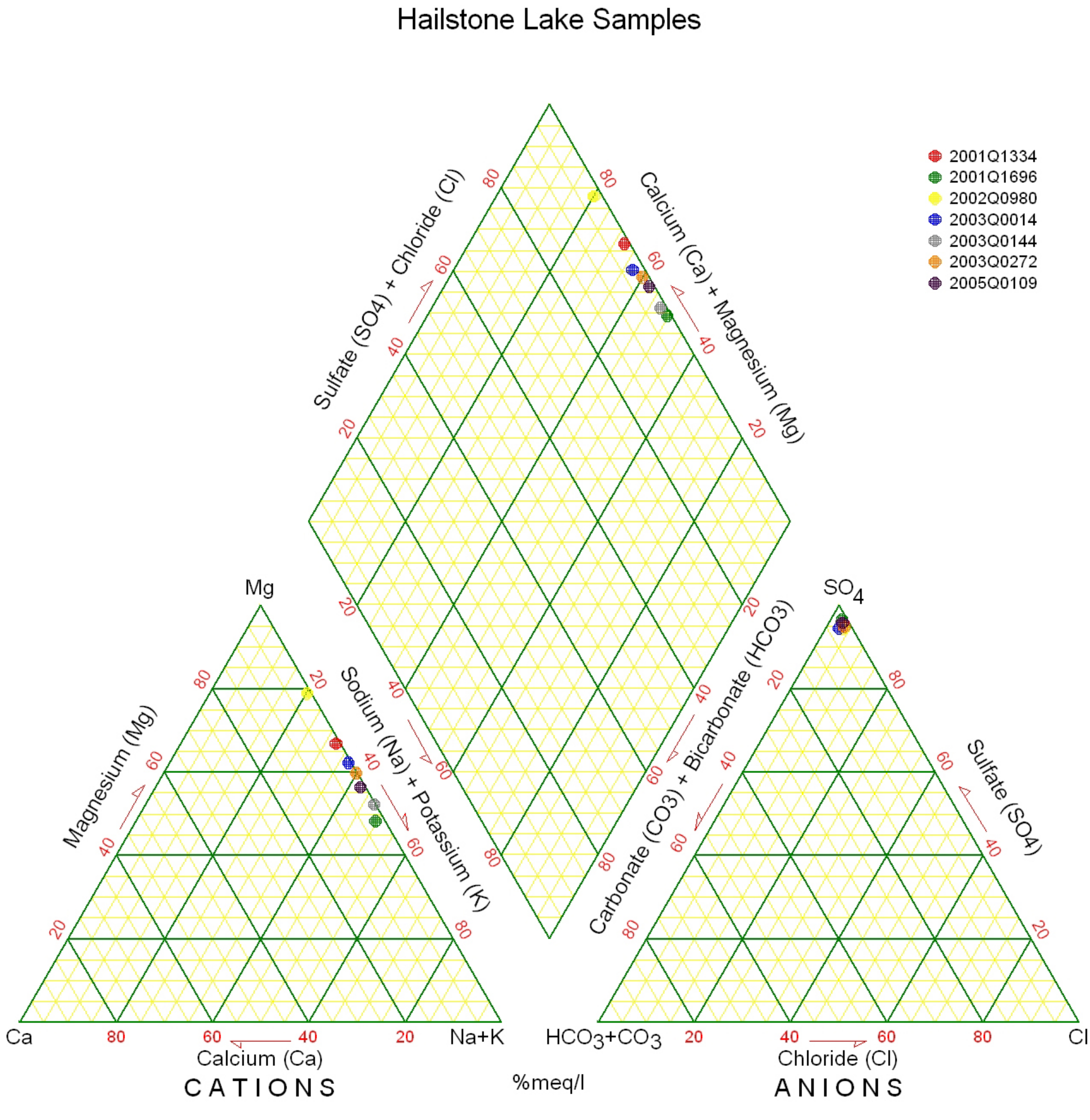
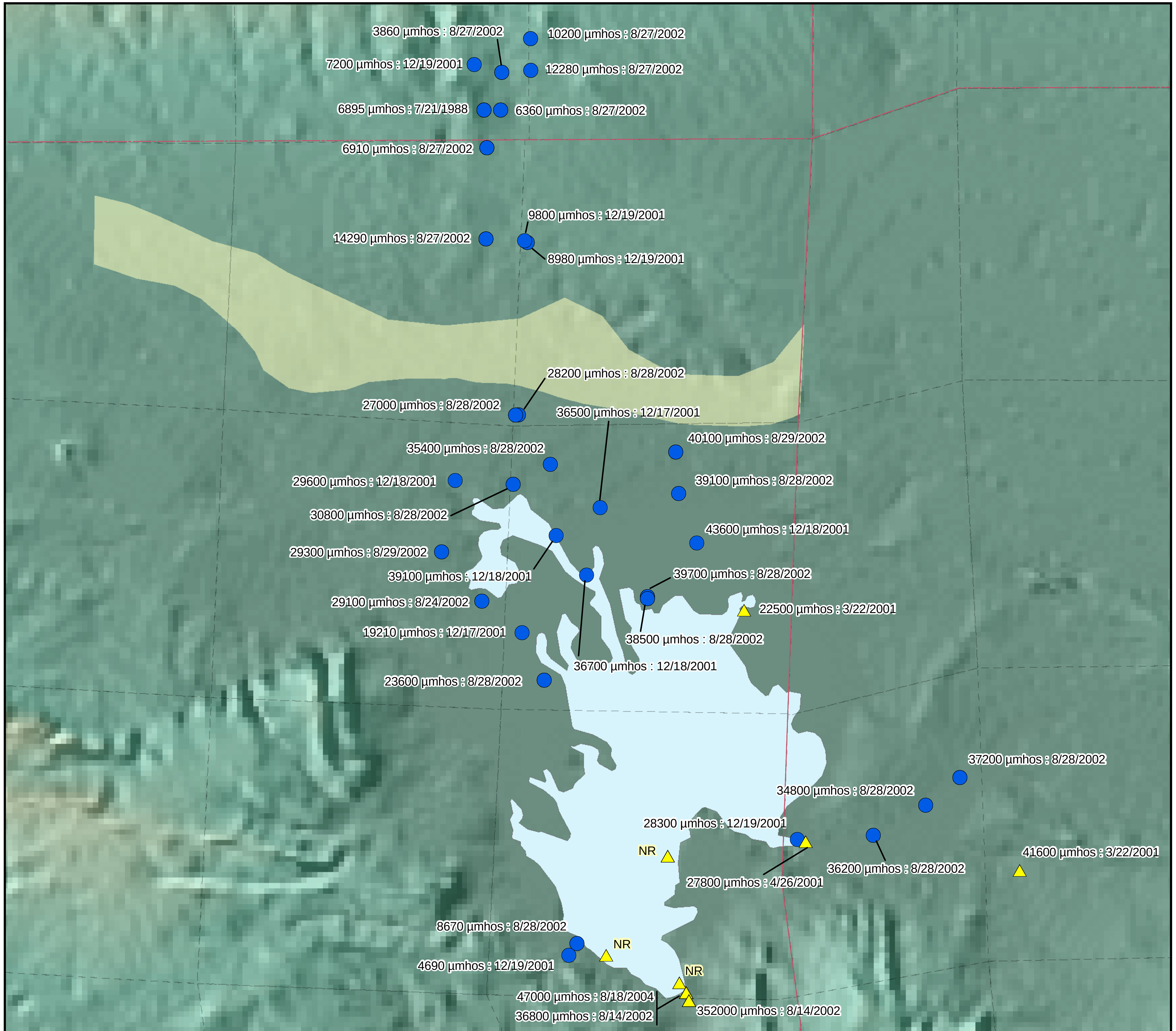


Figure 19. Piper plots of ionic distributions of Hailstone Lake.



DESCRIPTION OF MAP UNITS

Site Type

- Surface - SC : Date
- Groundwater - SC : Date
- Groundwater Transition Zone
- Water
- Township Boundary
- Section Boundary

N W E S

1:24,000

0 0.25 0.5 1 Miles

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Figure 20. Specific conductivity from groundwater and surface water near Hailstone Lake.

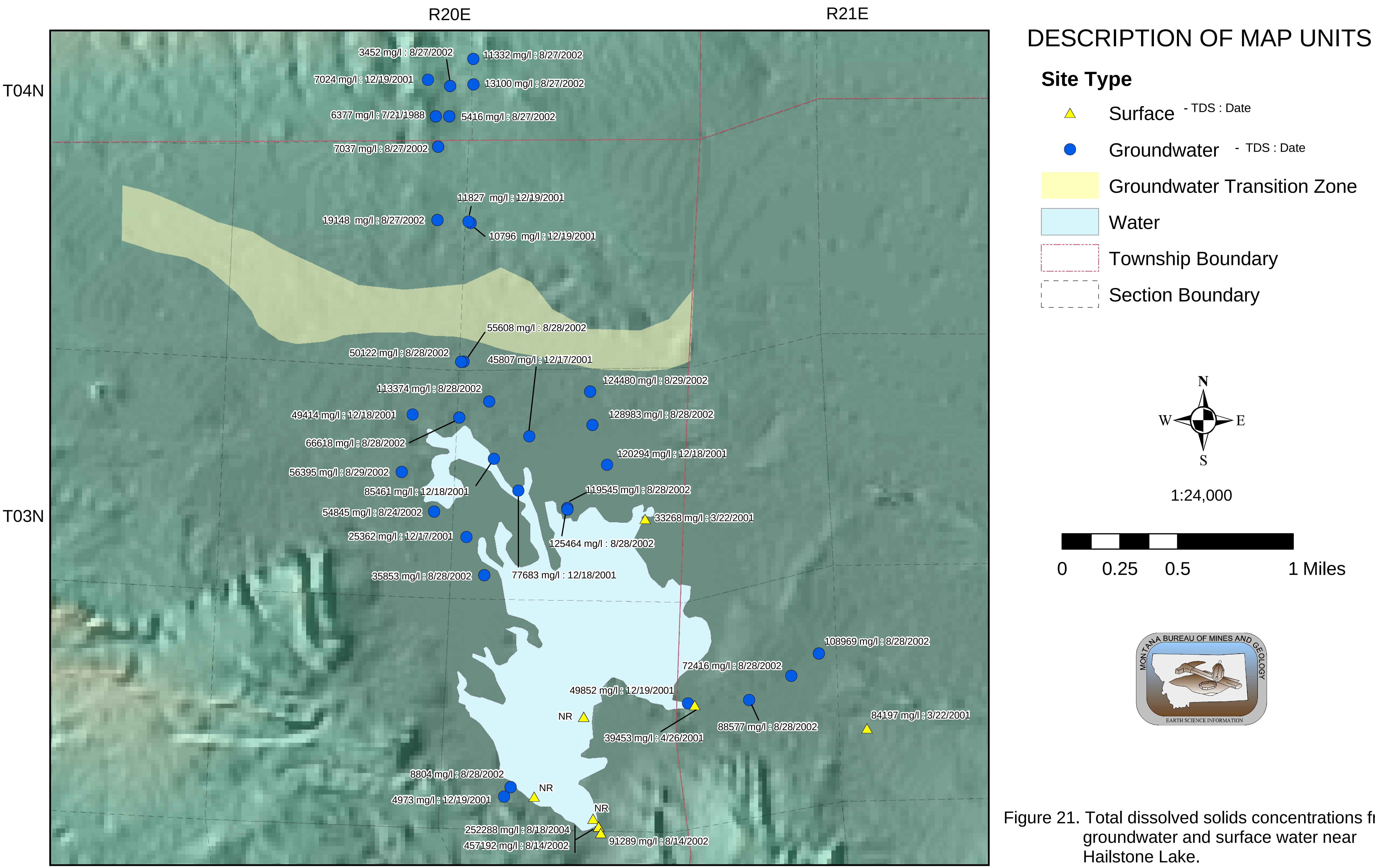


Figure 21. Total dissolved solids concentrations from groundwater and surface water near Hailstone Lake.

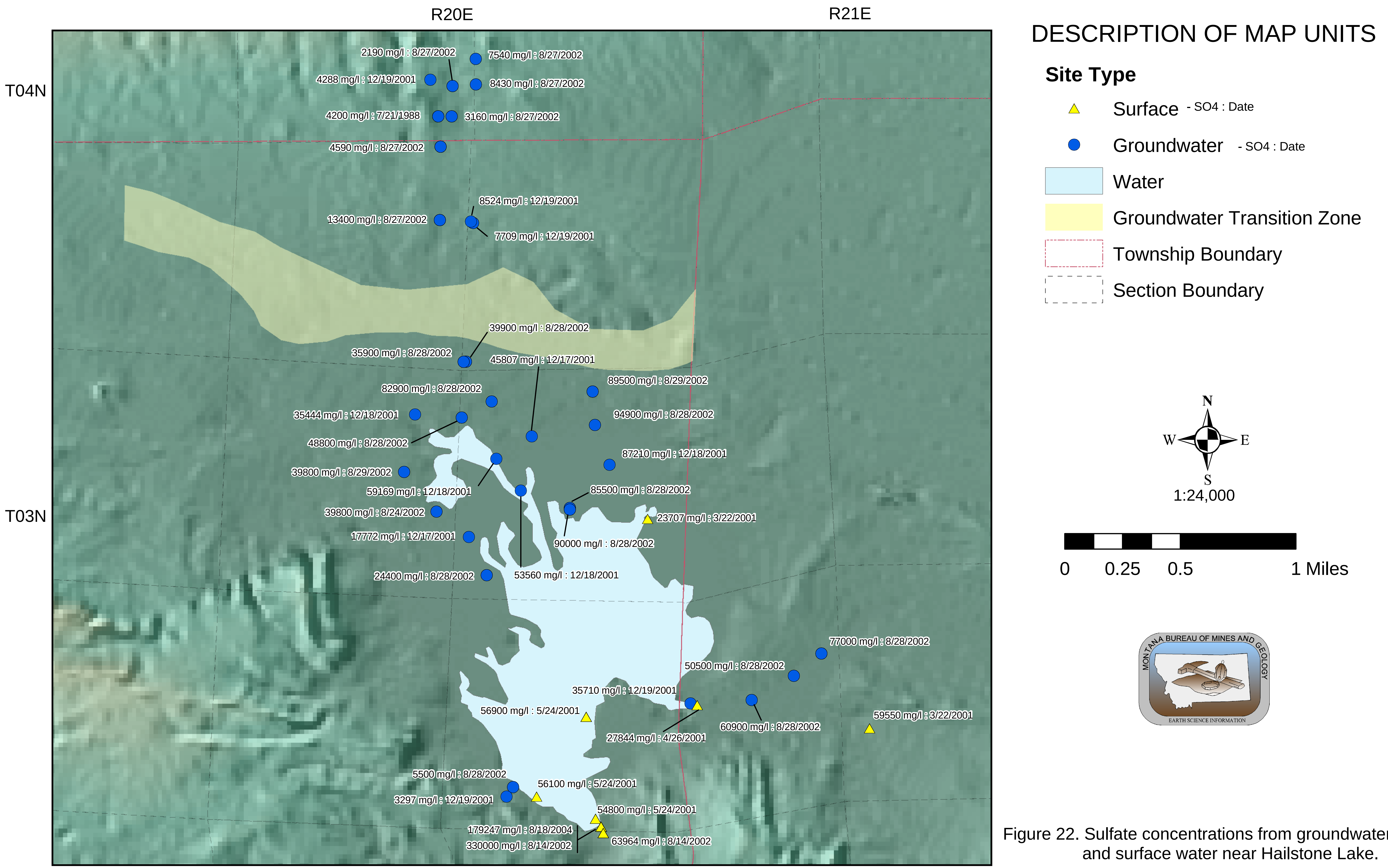
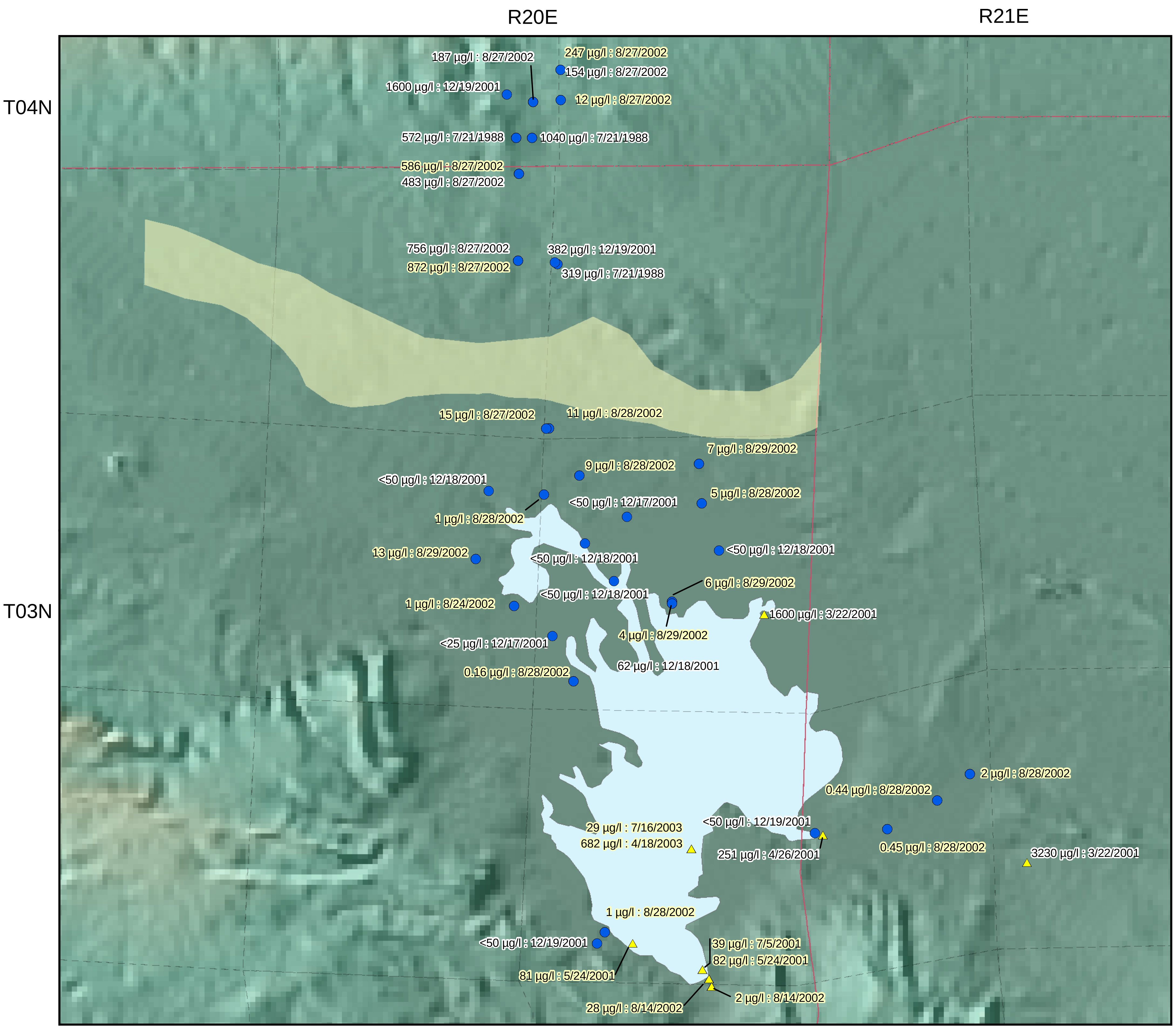


Figure 22. Sulfate concentrations from groundwater and surface water near Hailstone Lake.



DESCRIPTION OF MAP UNITS

Site Type USFWS Sample MBMG Sample

- Surface - Se : Date
- Groundwater - Se : Date
- Groundwater Transition Zone
- Water
- Township Boundary
- Section Boundary

N
W E
S

1:24,000

0 0.25 0.5 1 Miles

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Figure 23. Selenium Concentrations from groundwater and surface water near Hailstone Lake.

As would be expected, the distributions of TDS concentrations were similar to SC. Above the groundwater transition zone, the TDS of groundwater was about 10,000 mg/L (Figure 21). The TDS of groundwater below the transition was generally greater than 50,000 mg/L. Concentrations of TDS in the tributaries ranged from about 30,000 mg/L to more than 84,000 mg/L. Extremely high TDS concentrations were measured from lake samples, exceeding 500,000 mg/L. The typical linear relationship between SC and TDS fell apart in many of the more concentrated samples as accuracy decreases in conductivity meters in highly saline waters.

Sulfate concentrations follow similar trends and are less than about 10,000 mg/L from wells above the groundwater transition zone (Figure 22). Below the transition zone sulfate concentrations are generally greater than 40,000 mg/L. Concentrations in the tributaries range from about 20,000 to 60,000 mg/L. Lake samples also had high sulfate concentrations typically about 55,000 mg/L or greater. In contrast, selenium concentrations are higher from wells above the groundwater transition zone (Figure 23). Above the transition zone, selenium concentrations are generally greater than 300 µg/L. Below the transition zone selenium concentrations are generally less than 15 µg/L. The highest selenium concentrations were identified in the tributaries flowing into Hailstone Reservoir, reaching levels as great as 3,230 µg/L. Lake samples had selenium concentrations ranging from 10 to 246 µg/L. Although lower in comparison, concentrations of the Lake samples were all above the chronic water quality standard for aquatic life, reaching levels nearly 50-times the 5 µg/L chronic standard.

The most mobile inorganic species of selenium is selenate. Dissolved selenate occurs in oxidized environments such as shallow groundwater flow systems and aerated streams. Other inorganic selenium species are less soluble and mobile. Reducing conditions transform selenate to selenite, elemental selenium, or selenide which adsorbs to sediment. Once selenium enters surface waters, biological processes such as algal uptake can potentially remove significant quantities of selenium from water (McNeal and Balistrieri 1989).

Groundwater concentrations of selenium have increased since originally sampled in the late

1980's, and loads transported to Hailstone Reservoir have also likely increased. There may be a geologic formation containing higher concentrations of seleniferous materials based on the distribution of dissolved selenium in the groundwater system. The high selenium concentrations are associated with the material below the rimrocks on the north side of Hailstone Basin. Potential seleniferous sources based on geologic position are the upper part of the Niobrara Shale, The Telegraph Creek Formation and the Eagle Sandstone. Although these appear to be the primary sources, alluvial and colluvial materials that accumulate at the base of slopes below these deposits are the likely location of seleniferous materials that are being transported towards Hailstone Reservoir. Oxidized groundwater flowing through these materials dissolves selenate and concentrations increase until the selenium is depleted from this source (this has not occurred in the 16 years of monitoring).

Selenium concentrations are proportional to nitrate concentrations in Hailstone Basin well samples containing both constituents (Figure 24). This relationship is tightly constrained up to a selenium concentration of about 600 µg/L and a nitrate concentration of about 60 mg/L. Above these concentrations, the proportional relationship is not clear. The fact that selenium and nitrate concentrations vary proportionally indicates that the mobilization of selenium could be directly related to crop-fallow dryland farming. Further, selenate reduction in groundwater is mediated by microbes that prefer nitrate as an electron receptor, so selenate will remain in solution in the groundwater as long as nitrate is present (Nimick et al. 1996). Concentrations of nitrate exceed concentrations of selenium in the groundwater above the transition zone.

Summary of Hydrogeologic Conditions

Saline seep development has adversely impacted the hydrology and water quality of Hailstone Reservoir. The increased recharge in crop-fallow areas have provided water to flow through the near-surface alluvial sediments and weathered shale to form seeps. The groundwater transition zone coincides with development of saline seeps in Hailstone Basin. These seeps form in areas where groundwater flow is constricted and forced to the land surface. At the groundwater

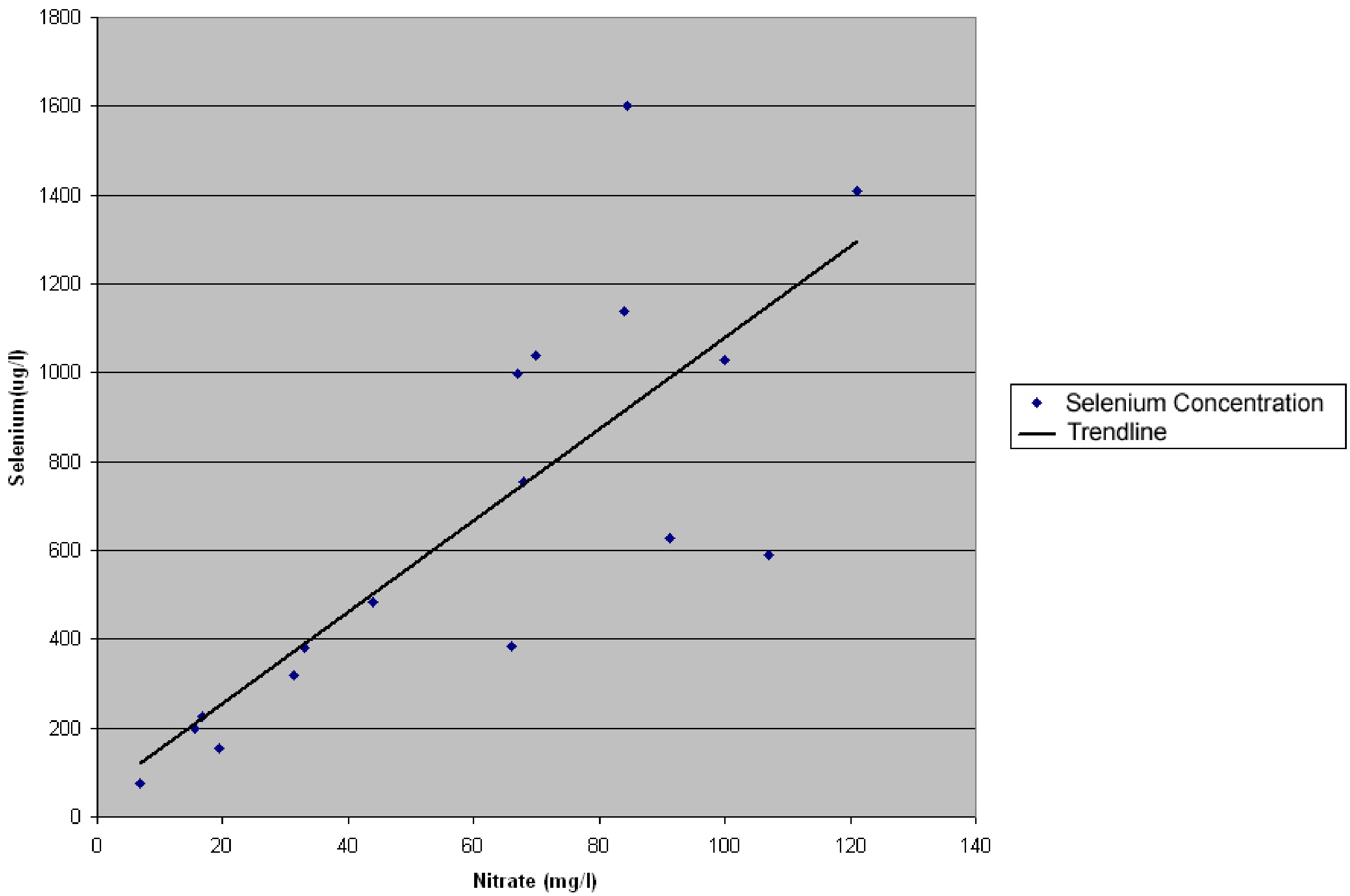


Figure 24. Comparison of nitrate to selenium concentrations in Hailstone Basin well samples.

discharge area, water evaporates and salts precipitate on the land surface. These salts contain high concentrations of sodium, magnesium and sulfate. In addition, it appears that much of the available selenium coprecipitates with these salts. Overland runoff from rainfall or snow melt transports selenium salts from saline seep areas downslope. Similar results were found in as study by Nimick et al. (1996), selenium concentrations in groundwater at the seep location were 1000 μg/L. This selenium precipitates at the ground surface with sodium and magnesium sulfate salts which are easily dissolved in snowmelt or rainfall. In this study area, snowmelt and rainfall redissolves the precipitated salts in saline seeps, and the highly concentrated runoff flows toward Hailstone Reservoir. If flows are high enough, the salt/selenium runoff enters the lake. During lower flows the runoff gathers in small pools and again evapoconcentrates. Salt concentrations fluctuate widely in Hailstone Reservoir, largely as the result of intermittent runoff events followed by periods of evaporation.

A Schoeller plot was constructed to display the evolution of water chemistry in Hailstone Basin (Figure 25). The average major ion concentrations from four different sources were averaged and the concentrations in millequivilents/L were plotted. The resultant shapes can be used to compare and contrast overall water quality and suggest pathways of water-quality evolution. Four sources were identified based on general differences in hydrology and water quality. These sources are 1) groundwater samples from above the mapped groundwater transition zone, 2) groundwater samples from below the mapped groundwater transition zone, 3) surface water samples from tributaries, and 4) surface water samples from Hailstone Reservoir. The snowmelt or precipitation making up the recharge water to the Hailstone Basin groundwater flow system is presumed to be fresh. The average cation concentrations in the area above the groundwater transition zone are relatively uniform and rank from highest to lowest: sodium-magnesium-calcium. The average anion concentrations from this area rank from highest to lowest: sulfate-bicarbonate+carbonate-chloride. Dissolution of minerals as groundwater moves through the highly mineralized alluvium and evapoconcentration appear to be the most significant geochemical processes affecting water-quality evolution. Most ions increase significantly as groundwater moves from the region above the transition zone through the transition zone and

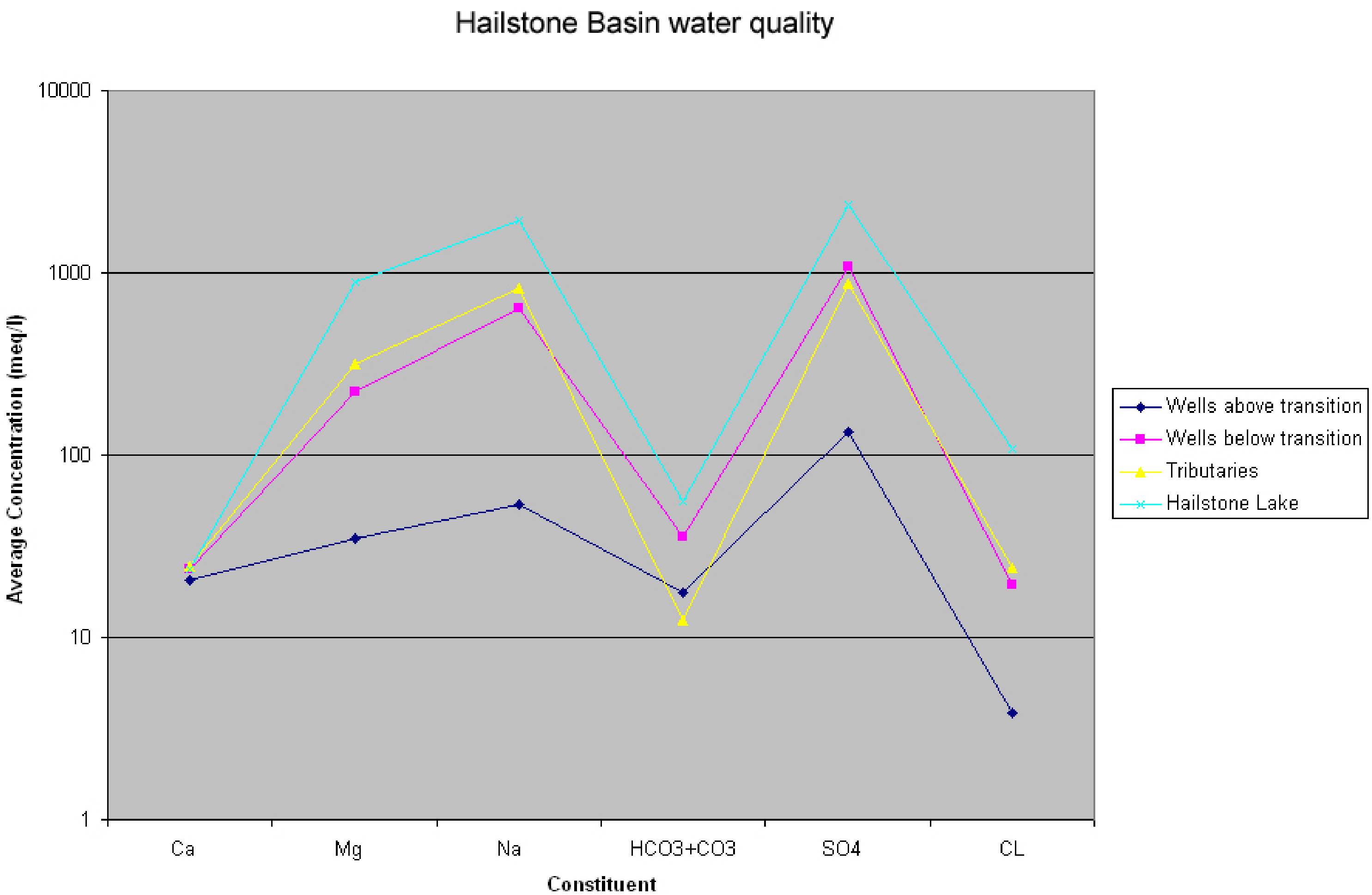


Figure 25. Schoeller diagram of water quality in the Hailstone Basin

into the groundwater system below the transition zone. The tributaries contain water very similar to water from wells below the transition zone with the exception of significantly reduced concentrations of bicarbonate+carbonate ions. Ions of magnesium, sodium, sulfate and chloride from Hailstone Reservoir are elevated more than an order of magnitude above those from above the groundwater transition zone. These increases are attributed to evapoconcentration as the water evolves. The calcium and bicarbonate+carbonate ions are influenced by different geochemical processes than the other major ions. Calcium concentrations did not increase along with the other ions, but remained relatively stable. Carbonates appear to have precipitated; removing ions of calcium and bicarbonate from the evapoconcentrated solution.

Selenium concentrations start out at relatively high levels in the groundwater system above the transition zone. Selenate is dissolved and moves with groundwater to saline seeps forming in the groundwater transition zone. Evapoconcentration of upward flowing groundwater forms efflorescent salts at the ground surface in seep areas. These surface salts dissolve and move in tributary channels down slope towards Hailstone Reservoir. Infiltration of snowmelt and precipitation recharges the groundwater below the transition zone and this water is relatively depleted in selenium. Although no data was directly collected to determine oxidizing and reducing conditions in groundwater, conditions are probably more reducing below the transition zone. This change in redox conditions is probably related to lower selenium concentrations in groundwater below the transition zone. This high TDS low selenium water slowly moves through the groundwater-flow system and eventually reaches Hailstone Reservoir. This groundwater mixes with high TDS, high selenium surface water flowing down the tributaries towards Hailstone Reservoir.

Surface Water Quality

Remote water-quality monitoring with a Hydrolab DataSonde 3 was initiated with unit deployment at the end of May, 2001, and water-quality parameters were recorded until November 15, 2001. Data were downloaded from the DataSonde and probes were recalibrated periodically. The DataSonde can only be deployed when water temperatures are above freezing, as the pH probe can burst under freezing temperatures. Levels of SC during deployment in 2001 are displayed in Figure 26. This graph was based on readings taken at 12:00 PM each day, rather than plotting all 24 readings recorded daily. Specific conductance ranged from 49,900 µS/cm in March (taken with a handheld YSI 85 meter during water sample collection) to the highest recorded level of 92,000 µS/cm in September, 2001. The decrease in SC from 85,200 µS/cm to 72,800 µS/cm occurred in June when 2.34 inches of rain fell over a three day period (Figure 26). A larger decrease in SC was expected with the influx of rain and the decrease in temperature, but the delivery of salts from saline seeps likely entered the reservoir during the rain event adding additional dissolved salts. The only other reduction in SC occurred when the water temperature declined and dissolved salts precipitated as solid crystals on the lake bed. On September 7, 2001, the SC declined from a 90,600 µS/cm at 5:00 to 55,200 µS/cm at 12:00 September 8, 2001. Increased temperature over the next few weeks appeared to have dissolved these precipitated salts. This trend occurred again on October 2, 2001 at 2:00 when 83,600 µS/cm SC began declining and dropped to the lowest level of 12,790 µS/cm on October 16, 2001. Salt precipitates were noted during DataSonde retrieval in November. At this time, the salt crust on the sediments would almost support a 55 kg person, whereas on previous occasions, each step resulted in sinking two to three feet in the sediment.

Figure 27. Salt coated

The Hydrolab DataSonde was again deployed in April 2002, however by July salt precipitation from continuing evapoconcentration resulted in much of the reservoir becoming solid salt. When the DataSonde was retrieved in August, it was incased in a foot of salt and significant effort was required to free the unit (Figure 27). Conversations with technical support at Hydrolab revealed that the electrodes on the DataSonde are likely to be quickly covered in a thin coat of salt and will no longer provide accurate readings. The decrease in SC depicted in Figure 28 is therefore likely the result of this encrustment. Water in the Hailstone Reservoir felt viscous to the touch in July and August. The change in water quality also had an effect on birds, On July 22, 2002, dead birds

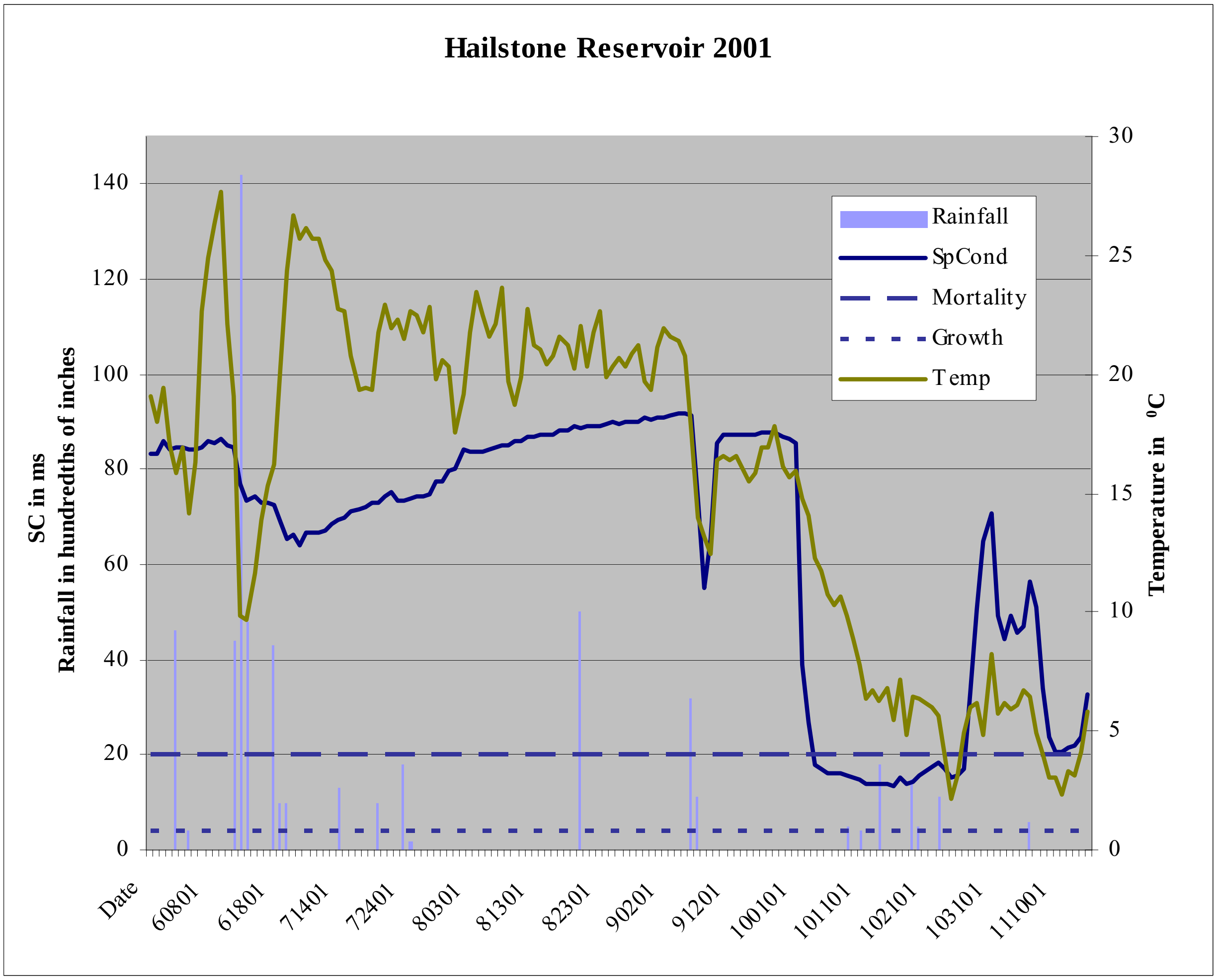


Figure 26. Specific Conductance recorded using a DataSonde3 Hydrolab, deployed May through November, 2001. Note that for the duration of the summer and fall, SC exceeded the level where reduced growth occurs in ducklings, and generally exceeds SC levels resulting in duckling mortality (Mitcham and Wobeser 1988a).

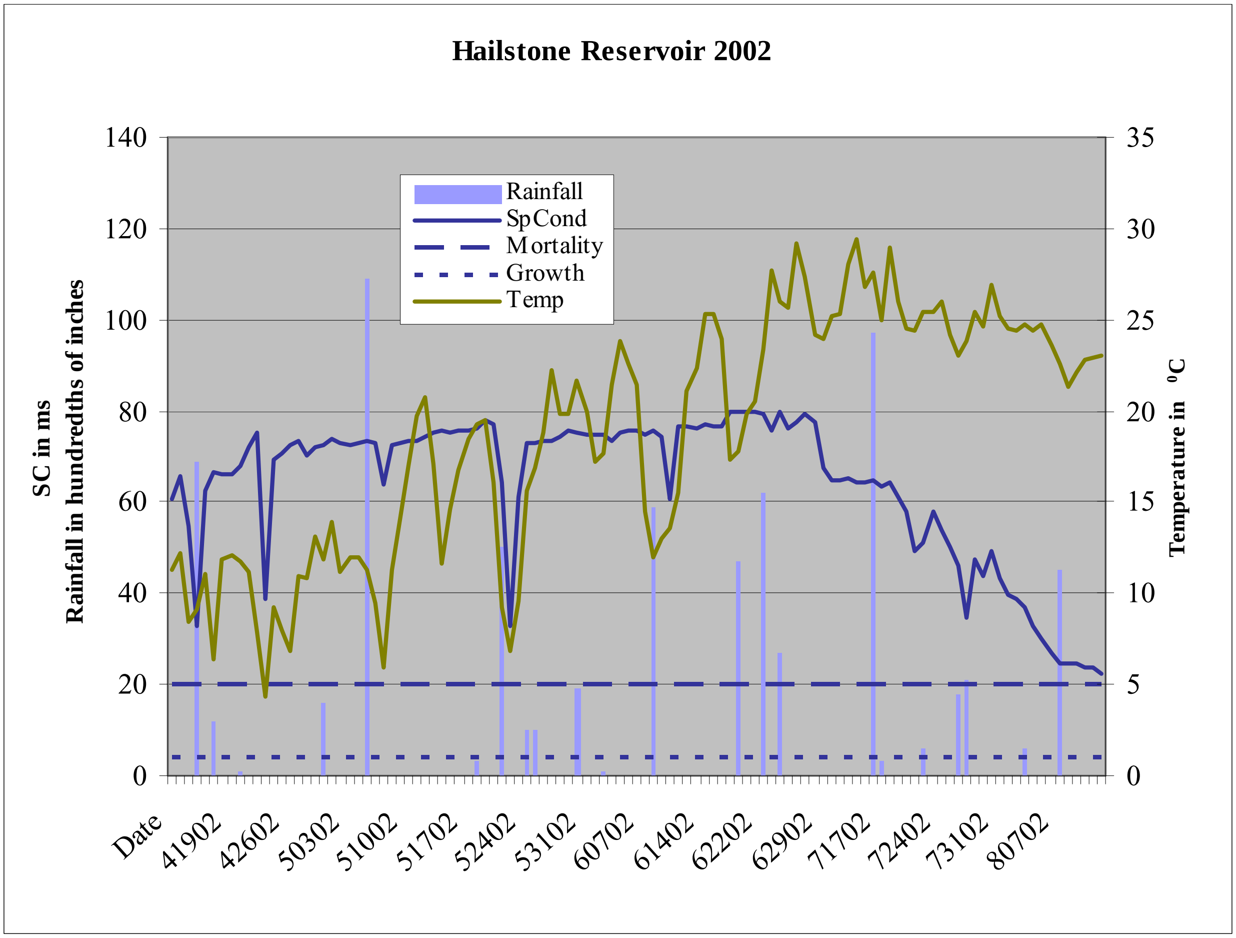


Figure 27. Specific Conductance recorded using a DataSonde3 Hydrolab, deployed April through August, 2002. Note that for the duration of the spring and summer, SC exceeded the level where reduced growth occurs in ducklings, as well as SC levels resulting in duckling mortality (Mitcham and Wobeser 1988a).

were reported on the Hailstone Refuge. Upon investigating the die-off the next day, 10 dead gulls and 8 dead ducks were found. Carcasses were covered in salt which made identification difficult. Three birds (two euthanized and one carcass) were collected on the same day for submission to the National Wildlife Health Center (NWHC) for diagnosis. Monitoring for dead birds continued until August. A total of 44 dead birds were marked. These included one unidentified passerine, 10 gulls, and 33 ducks. The die-off was likely much larger as predation rates were likely high, and partially consumed bird remains were noted on a few occasions. Results of the die-off are reported in the next section. A final site visit in early September, 2002, revealed that approximately 50 blue-winged teal had landed and Hailstone Reservoir and the salts from the highly saline waters encrusted the feathers so they could not fly off. Several birds were captured, rinsed clean of salts and released on the Yellowstone River, the remaining birds likely died from salt poisoning, or were victims of predation raising the known mortality to around 90 birds in 2002.

By the spring of 2003, the salt crust on the bottom of Hailstone Reservoir was so thick, no location on the reservoir was deep enough to deploy the Hydrolab, and the depth of the salt crust likely exceeded 3 feet in some areas of the reservoir. A few SC recordings were taken with the YSI 85 handheld DO/Conductivity meter and an Acumet AP61 pH meter throughout the year (Table 2). A site visit on September 2, 2003 revealed another small die-off, and several salt encrusted blue-winged teal were using the reservoir. Although the teal still appeared to be in good condition, their feathers were encrusted with salt, so they were unable to fly (Figure 29). Several birds were collected, washed and taken to the Yellowstone River for release (Figure 30). Figures 31-33 illustrate the increasing salt precipitation within the Hailstone Reservoir and salt bergs forming in 2002. By 2003, very little standing water was present and most of the Reservoir was solid salt.

Figure 29. Salt encrusted blue-winged teal, 2002

Figure 30. One salt encrusted duck waiting to be cleaned before release, September, 2002.

Summer, 2001

Summer, 2002

Summer, 2003

Figure 31, 32, 33. Hailstone Reservoir in Summer 2001-2003.

Table 2. SC, pH, and temperature in water samples collected from 2003 to 2005 at Hailstone Reservoir at the dam.

Date	4/18/03	6/25/03	7/16/03	9/02/03	9/25/03	8/14/04	8/05/05
SC in µS/cm	57,000	65,700	88,900	59,100	52,100	87,420	45,290
pH	9.21	8.5	8.17	7.98	8.16	8.97	9.48
Temperature in ^{0}C	15.6	17.2	29.3	24.9	17.1	19.0	25.1

Previous data on the salinity of the water at Hailstone is limited to one unpublished report from Montana Department of Environmental Quality (MTDEQ). A single SC reading collected April 26, 1993, was 44,100 µS/cm. Notes from the sampling event mentioned that the water level was five feet below the spillway. Wet years occurred between 1993 and 2001 (Figure 5).

Ions and Trace Elements

Water sampling for ions and trace elements commenced with spring runoff in March 2001 and continued through August 2005. The March 22, 2001 sampling trip, however, was the only time during this study when the East Tributary and the North Tributary were flowing (Tables 3-4). Sodium and magnesium were the dominant cations and sulfate the dominant anion. Selenium

Table 3. Ion composition of water flowing into the Hailstone Reservoir from the North and East tributaries (Fe, Mn, SiO2 were eliminated from the graph, since these were not analyzed on samples collected 3/22/01 and were below detection or at very low concentrations in the sample collected on 4/26/01).

Site Name	**Date and Time**	**Ca (mg/L)**	**Mg (mg/L)**	**Na (mg/L)**	**K (mg/L)**	**HCO_3 (mg/L)**	**CO_3 (mg/L)**	**SO_4 (mg/L)**	**Cl (mg/L)**	**NO_3 (mg/L)**	**Fe (mg/L)**	**OPO_4 (mg/L)**
North Tributary	3/22/2001 17:00	278	3380	5190	42.9	236.7	198	23707	301	20.4 P	35	<.5
East Trib. (culvert)	3/22/2001 14:20	428	6820	15000	71.3	514.8	297.6	59550	1632	45.1 P	100	<10.0
East Trib. (boundary)	4/26/2001 16:00	335	2100	8500	33.6	235.5	86.4	27844	390	<5.0 P	46.1	<10.0

P indicates the sample was preserved

Table 4. Concentrations of trace elements and TDS flowing into Hailstone Reservoir from the North and East Tributaries (only trace elements with concentrations above detection were included in this table, detection limits were high due to dilution required because of the high salinity).

Site Name	Date and Time	Lab pH (S.U.)	SC (µs/cm)	Br (µg/L)	Cu (µg/L)	Li(µg/L)	Se(µg/L)	Sr (µg/L)	TDS (mg/L)
North Tributary	3/22/2001 17:00	9.16	22500	3930	NR	NR	1600	NR	33333
East Trib (culvert)	3/22/2001 14:20	9.2	41600	8830	NR	NR	3230	NR	84313
East Trib (boundary)	4/26/2001 16:00	9.07	27800	<10000	480	1890	251	7010	39535

*NR not reported

concentrations detected in spring runoff exceeded concentrations of concern (1,600 and 3,230 µg/L in the North and East Tributaries), exceeding by orders of magnitude the fresh water aquatic life standards (5 µg/L chronic, 20 µg/L acute) (MDEQ 2006). Nitrates were also elevated in spring runoff samples, however, these were the only samples that contained nitrate, all other nitrate surface water samples were below the limit of detection. It is possible that denitrification in the anaerobic sediments of Hailstone Reservoir occurs quickly. Complete analytical data for all samples are contained in Appendix A

Samples were collected at the same location in Hailstone Reservoir on eight different occasions in 2001-2005, these were only analyzed for major ions and TDS, additional samples were collected at the same location for trace elements. Tables 5 and 6 depict an increase of major ions during the drought conditions of the study as well as the effects of the evaporation rates exceeding the precipitation rates in this basin. This especially evident in the TDS concentrations, where the last two water samples collected in 2002 were approximately 50% salt. The highest TDS (548,545 mg/L) occurred at the time of a bird die-off documented on the refuge in late July, 2002. In addition to salinity concerns in Hailstone Reservoir, several trace elements were also at concentrations of concern. Selenium concentrations have never met the chronic aquatic life standard of 5 µg/L during the five years surface water samples were collected, the acute standard

Table 5. Concentrations of cations in surface water samples collected on Hailstone Reservoir near the dam.

Date and Time	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	Fe (mg/l)	Mn (mg/l)	SiO_2 (mg/l)
3/22/2001 10:00	493	22400	20200	353	NR	NR	NR
6/20/2001 12:45	314	4570	8850	84.4	3.06	<.1	<10
8/1/2001 13:00	613	11900	29400	205	4.99	1.86	<10
3/19/2002 10:00	603	32100	15200	498	<.25	5.7	<5
6/18/2002 15:30	507	29500	32860	605	<.25	5.06	<5
7/24/2002 11:30	380	45000	76700	852	<0.25	6.44	6.6
8/14/2002 11:45	362	50000	62400	1220	<0.25	1.3	8.19

NR not reported

Table 6. Concentrations of anions and TDS in surface water samples collected on Hailstone Reservoir near the dam.

Date and Time	HCO_3 (mg/L)	CO_3 (mg/L)	SO_4 (mg/L)	Cl (mg/L)	NO_3 (mg/L)	F (mg/L)	OPO_4 (mg/L)	TDS (mg/L)
3/22/2001 10:00	1364	249.6	121510	2991	<10.0	187	<10	124751
6/20/2001 12:45	278.2	110.4	39845	727	<5.0	46.8	<5.0	54687
8/1/2001 13:00	1778.8	0	105030	1753	<10.0	133	<100	149917
3/19/2002 10:00	2715.7	633.6	162882	4802	<5.0	146	<50	218208
6/18/2002 15:30	322.8	3229.3	194000	4240	<25.0	217	<100	265323
7/24/2002 11:30	6139	0	325272	6769	<.5	535	<247	548545
8/14/2002 11:45	6511.7	0	330000	9520	<25.0	488	<50.0	457208
8/18/2004 9:30	1675.1	591.6	3977	112.2	<10.0	<10.0	<10.0	252288

of 20 µg/L was met in only one sample. The average selenium concentration was 84.9 µg/L

(n=12). Similarly, water samples exceeded the chronic aquatic life standard for arsenic (As) 150 µg/L on 5 occasions, and exceeded the acute aquatic life standard of 340 µg/L on four occasions, the average As concentration was 347 µg/L (n=9).

Water samples were also collected at the same location below the dam (Table 7-8). A slow seep in the dam or groundwater recharge appears to feed a very small pool adjacent to the spillway. TDS increased over time, but these waters stayed fresher in comparison to the Hailstone Reservoir. In addition, arsenic and selenium concentrations did not exceed aquatic life standards. On several occasions, waterfowl seeking better quality water used this small pool.

Table 7. Concentrations of cations in surface water samples collected below the dam.

Date and Time	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Fe (mg/L)	Mn (mg/L)
3/22/2001 12:45	350	1640	6400	28.3	NR	NR
6/20/2001 12:49	532	4620	11900	73.6	4.15	7.06
8/3/2001 13:50	553	6510	15700	88.6	4.88	16
6/18/2002 16:00	500	4900	12000	66.7	2.52	1.72
8/14/2002 11:12	619	7350	17400	102	0.449	2.95

NR not reported

Table 8. Concentrations of anions and TDS in surface water samples collected below the dam.

Date and Time	HCO_3 (mg/L)	CO_3 (mg/L)	SO_4 (mg/L)	Cl (mg/L)	NO_3 (mg/L)	F (mg/L)	OPO_4 (mg/L)	TDS (mg/L)
3/22/2001 12:45	453.8	0	20443	329	<2.5 P	30.8	<10.0	29644
6/20/2001 12:49	646.6	55.2	46433	851	<25.0	60.5	<25	64855
8/3/2001 13:50	1121.2	0	66065	1184	<2.5 P	80.8	<100	90754
6/18/2002 16:00	450.2	61.2	44921	853	<5.0 P	68.7	<25.0	63596
8/14/2002 11:12	836.9	48	63964	1343	<25.0	101	<25.0	91344

P preserved sample

Surface water quality on Hailstone Reservoir is severely impaired by the density of saline seeps occurring in the watershed. Evapoconcentration of constituents delivered to the reservoir exacerbate water quality degradation. The degraded surface water quality pose a risk to shorebirds and waterfowl using the refuge. As long as current land uses continue in the area, selenium and salinity concentrations will increase and the quality of water in Hailstone Reservoir will continue to deteriorate. Based on the land us in Lake Basin, it is possible that similar impacts could occur at Halfbreed NWR and Big Lake WMA.

Toxicity of Saline Waters

Saline waters can be a hazard to waterfowl, depending on the salt concentration. Conditions at Hailstone NWR have resulted in several die-offs during this investigation. Waterfowl do have mechanisms to deal with salt, but they can be overwhelmed. Waterfowl are able to excrete excess salt through supraorbital salt glands. These paired, crescent-shaped glands each contain several longitudinal lobes each containing a central duct from which radiate thousands of tubules enmeshed in blood capillaries. These tiny capillaries carry blood along the tubules of the gland, which have walls just one cell thick, and form a simple barrier between the salty fluid within the tubules and the bloodstream; it is here that salt excretion occurs. Na, Cl, and possibly K are the only ions removed through this process (Welty 1982). These ions are then passed through ducts into the nasal cavity and are eliminated in liquid form through the nostrils; this is often accompanied by vigorous shaking of the bird's head (Welty 1982). While these salt glands provide the greatest means for salt excretion, renal excretion and intestinal absorptive mechanisms also play a role in maintaining homeostasis (Wobeser 1981).

Development of these glands in ducklings and goslings usually occurs from four to six days after hatching (Mitcham and Wobeser 1988b, Stolley et al. 1999). Adults with no prior exposure to ingesting saline waters often require a period of acclimation before the salt glands are able to function at full capacity (Franson and Friend 1999). The toxicity of saline waters has been documented by several researchers (Mitcham and Wobeser 1988a, Mitcham and Wobeser 1988b, Meteyer et al. 1997, Stolley et al. 1999). Growth and mortality “effects lines” in figures 26 and 27 relate to a Mitcham and Wobeser (1988a) study where one-day-old mallard ducklings were provided drinking water from 10 saline wetlands. Water with SC as low as 4,000 µS/cm given as a drinking source to these ducklings resulted in an approximate 10% reduction in growth (based on weight) in comparison to controls, excessively fluid excreta was also noted. Six of the ten ducklings that were provided water with SC of 20,000 µS/cm died during the 14 day exposure; reduced weight gain was again noted in survivors. Ducklings given water with 67,000 µS/cm SC resulted in mortality within 30 hours (Mitcham and Wobeser 1988a). The SC documented at Hailstone Reservoir, as well as the fresher pool below the spillway, will result in mortality to ducklings when fresh water is unavailable, and no freshwater seep areas were discovered during this study. Although the water below the dam is slightly fresher, the lowest SC recorded was 45,050 µS/cm in June 2002. Although no ducks were ever documented nesting at Hailstone NWR during this investigation, duckling mortality would likely result if nesting was attempted. Based on the study by Mitcham and Wobeser (1988a), duckling mortality on Hailstone Reservoir would occur quickly.

Salinity impacts are not limited to ducklings, Meteyer et. al (1997) documented salinity impacts to adult ducks. Natural playa lakes receiving potash mine wastewater were investigated for impacts on waterfowl. TDS on these playas ranged from 201,000 mg/L to 316,000 mg/L (Meteyer et al. 1997). Salt deposition on feathers occurred after just three hours on one set of farm-raised mallards that were placed in a cage constructed on the playa (with a TDS of 316,000 mg/L). Within 24 hours, heavy salt encrustation occurred on these mallards. Numerous effects on the eye were also observed such as prolapse of the nictating membrane, swelling and/ or inflammation of the eyelids, and eye surface. Necropsies and histopathology completed on birds housed on the playa lakes revealed lens opacities in the eyes. All brains of mallards housed on the playa lakes contained sodium (Na) concentrations within toxic ranges. Hailstone Reservoir, in comparison, exceeded the TDS concentrations described by Meteyer et al. (1997), known to cause impacts to waterfowl, on several occasions (Table 6). Further, waterfowl collected from Hailstone in July, 2002, during a bird die-off, were diagnosed with sodium toxicosis by the NWHC. Two ducks euthanized during the die-off had brain sodium concentrations of 1,910 and 2,200 ppm wet weight (ww) (Table 9). This occurs when ingested salts exceed the bird's ability to excrete the salt. Normal sodium levels in brain tissue for waterfowl housed on land and provided fresh water averaged 1,359 ppm (Meteyer et al. 1997). Because Hailstone NWR is a satellite refuge (i.e, the site is not staffed), little is known about the frequency of salt encrustation on ducks, how quickly this encrustation occurs, or the frequency of sodium toxicosis. On nearly all late summer/early fall visits to Hailstone from 2002-2004, salt encrusted ducks were found. Although the number was likely much higher, due to predation events, just over 100 dead birds, or birds unable to fly were documented during these visits.

Table 9. Necropsy and brain sodium results of birds Collected 7/23/2002 submitted to the NWHC.

Species / Sex	Specimen type	Brain Na (ppm ww)	Necropsy notes
Lesser Scaup (m)	Euthanized	2,220	55g of salt deposition on bird, brain congested, reddish fluid accumulations in the anterior chambers of the eyes
Mallard (m)	Found dead	2,670 (brain tissue desiccated, concentration likely elevated)	autolysis, unsuitable for necropsy
Redhead (f)	Euthanized	1,910	brain congested, reddish fluid accumulations in conjunctiva of the eye

Other impacts from highly saline waters include severe feather erosion. In the Tulare Lake Drainage District, California, conductivity in evaporation ponds ranged from 5,000 µS/cm to 300,000 µS/cm (Euliss et al 1989). At these high concentrations, carbonate deposition occurred on the feathers of ruddy ducks. The rectrices of ruddy ducks using these ponds were so encrusted with carbonate that the rectrices of the feathers lost plasticity and eventually eroded. This erosion likely impedes diving and flying (Euliss et al. 1989). High salinity was also documented as the cause of a die-off on White Lake, North Dakota (Windingstad et al. 1987). Over 150 waterfowl were found dead from salt toxicosis. Necropsies showed heavy salt accumulations on the feathers, dehydration, sloughing of the gizzard lining, and excessive mucus on the mucosal surface of the proventriculus (Windingstad et al. 1987).

Waterfowl can also be impaired by much lower salt concentrations if they have also been exposed to the neurotoxin produced by Clostridium botulinum Type C (Cooch 1964). Under saline conditions, osmoreceptors release acetylcholine stimulating the salt gland, and botulism toxin inhibits the release of acetylcholine (Cooch 1964). Similarly, exposure to carbamate or organophosphate insecticides can impair the ability of the salt gland to excrete salt (Franson and Friend 1999). Birds submitted to the NWHC from Hailstone NWR were tested for botulism and brain cholinesterase depression. Both tests were negative.

The increasingly saline waters at Hailstone NWR have had a negative impact on waterfowl. It appears that birds using the refuge during fall migration are at greatest risk. Several salt precipitation events were evident in the DataSonde data depicted in Figure 26. Further, as temperatures decrease each evening in the fall, SC concentrations drop as well, indicating salt precipitation occurs each evening. If waterfowl use the Reservoir on these occasions, salt precipitation of feathers likely occurs rapidly. On site visits during these events, birds with salt coated plumage were observed continually bathing, possibly as an attempt to rinse off the coated salt.

Aquatic Hazard Assessment for Selenium

Selenium is a required micronutrient, however, it can be toxic at only slightly higher concentrations (NIWQP 2003). In birds, the most sensitive life stage is the embryo, and selenium exposure can result in deformed embryos and embryo mortality (NIWQP 2003). Female birds exposed to selenium prior to nesting can transfer selenium into eggs at harmful levels (Ohlendorf 2003). The hazard assessment for selenium (Lemly 1995) was conducted at Hailstone NWR three different years to determine the selenium exposure risk to birds using Hailstone NWR. However, as noted, Halfbreed NWR was dry during the entire study, so it could not be included in this assessment. This assessment commenced in 2001, when five different locations on Hailstone Reservoir were selected and sampled. The Hailstone Reservoir salinity is inhospitable to fish, therefore only four of the five ecosystem components were sampled. Invertebrate diversity was also limited because of the high salinity and only brine shrimp (*Artemia franciscana*) were found except for a location below the dam where Ephydridae larvae were collected. Waterfowl and shorebirds were monitored for nesting. No evidence of nesting was found throughout the spring and summer of 2001 season, so bird livers were used to complete the protocol. Table 10 depicts the results of the selenium hazard assessment conducted in 2001. All sites on Hailstone Reservoir were rated as a high hazard. This high hazard predicts that the toxic threat of selenium is sufficient to cause complete or nearly complete reproductive failure in sensitive species of aquatic birds (ducks, family Anatidae; stilts, family

Table 10. Hazard Assessment for selenium using four ecosystem components collected in 2001. Several birds were collected during both collection times, and the highest selenium concentration was used (according to the protocol).

Sample Location	Sediment µg/g dw	Hazard	Water µg/L	Hazard	Invertebrate µg/g dw	Hazard	Bird liver µg/g dw *0.33	Hazard	Total for the site	Evaluation
Below Dam	2.3	3	0.6	1	2.46	2	11.3	3	9	Low*
Hailstone Dam	1.77	2	73	5	15.4	5		3	15	High*
East Hailstone	4.44	5	82	5	17.1	5		3	18	High*
East Tributary	6.67	5	78	5	23.2	5		3	18	High*
West Hailstone	4.2	5	80	5	14.7	5		3	18	High*
Below Dam	1.86	2	1	1	1.62	1	6.37	3	7	Low**
Hailstone Dam	3.36	4	21	5	26.1	5		3	17	High**

* Samples collected in May 2001
** Samples collected in late July, early August 2001

Recurvirostridae) (Lemly 2002). The location below the dam is a low hazard, and according to the protocol, the threat could only marginally effect the reproductive success of some sensitive species, but will leave most species unaffected (Lemly 2002).

Samples were again collected to complete the selenium hazard assessment in 2002. Again, no nesting waterfowl or shorebirds were discovered so bird livers were used. Similar results were obtained with a high hazard on the Reservoir, but the site below the dam was elevated to a moderate hazard (Table 11). A moderate hazard predicts that the toxic threat of selenium will likely substantially impair but not eliminate reproductive success of sensitive species (Lemly 2002).

Table 11. Hazard Assessment for selenium using four ecosystem components collected in 2002. Several birds were collected during both collection times, and the highest selenium concentration was used (according to the protocol).

Sample Location	Sediment µg/g dw	Hazard	Water µg/L	Hazard	Invertebrate µg/g dw	Hazard	Bird liver µg/g dw *0.33	Hazard	Total for the site	Evaluation
Below Dam	3.14	4	1.7	2	5.26	5	7.92	3	14	Moderate*
Hailstone Dam	2.74	3	11	5	13.6	5		3	16	High*
East Tributary	3.74	4	14	5	10.2	5		3	17	High*

* Samples collected in late June, early July 2002.

In the final year of our study, several American Avocets (*Recurvirostra Americana*) nests were found near the East Tributary of Hailstone Reservoir. No eggs were found in the nests, but several addled eggs were located on the mud flats. These eggs were collected as well as the other components required to conduct the hazard assessment. Similar results were found in 2003, and a high hazard was predicted for the East Tributary location (Table 12).

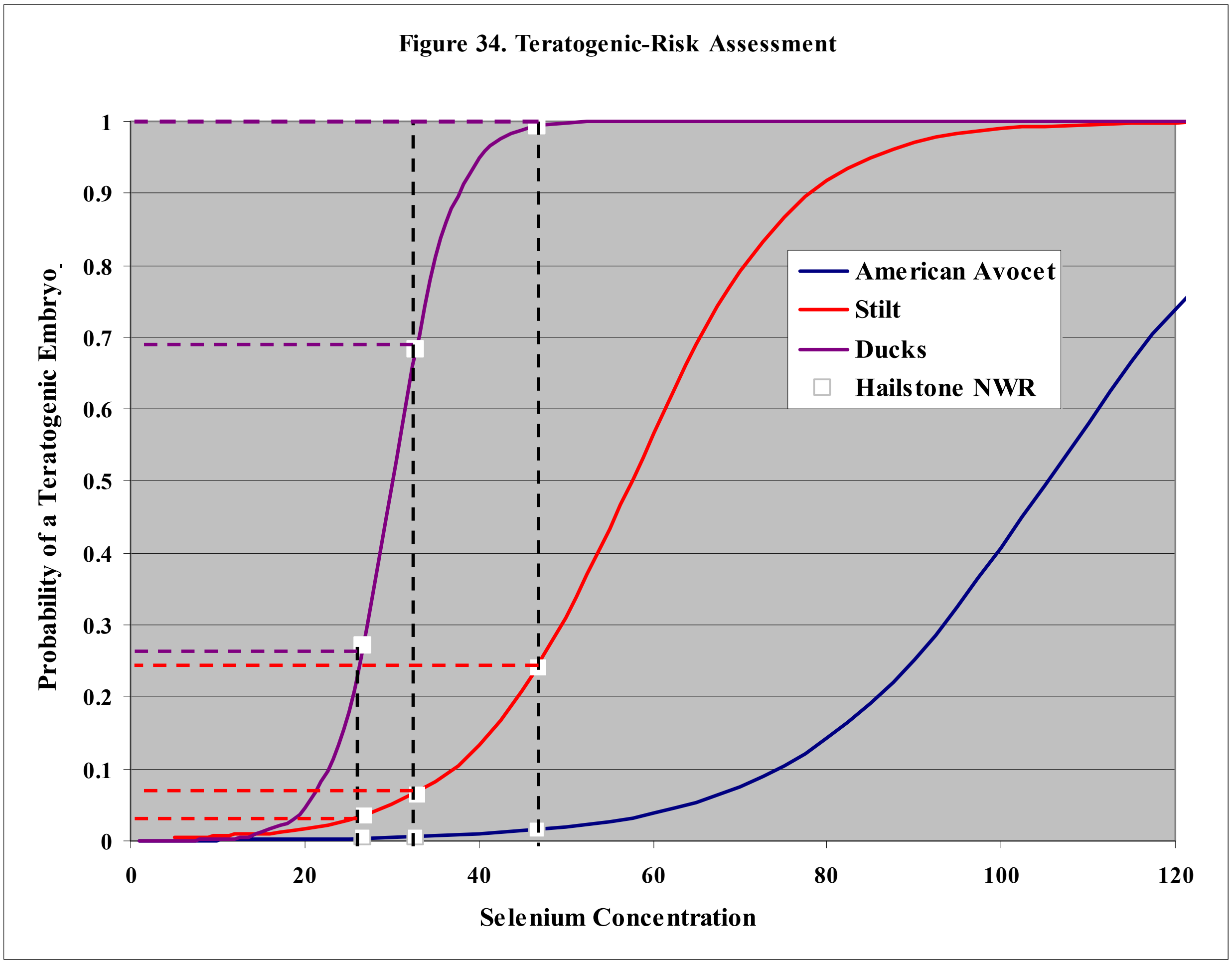
Table 12. Hazard Assessment for selenium using four ecosystem components collected in 2003. Several bird eggs were collected during two site visits, and the highest selenium concentration was used (according to the protocol).

Sample Location	Sediment µg/g dw	Hazard	Water µg/L	Hazard	Invertebrate µg/g dw	Hazard	Bird egg µg/g dw	Hazard	Total for the site	Evaluation
East Tributary	2.27	3	29	5	14.4	5	46.8	3	18	High*

* Samples collected mid July 2003.

An additional tool to assess the risk of selenium to embryos is to use the Teratogenic-Risk Assessment (NIWQP 2003) to determine the probability of a teratogenic embryo based on the selenium concentration detected in an individual egg. Models were developed for ducks, stilts and avocets using logistic-regression response functions. Based on the models developed, the EC_{50} teratogenic response concentrations revealed interspecies sensitivity to selenium (Figure 34). Ducks were the most sensitive to selenium, followed by stilts, and avocets. During this investigation, only three avocet eggs were collected. Selenium concentrations detected in these eggs revealed a very small likelihood of a teratogenic embryo in avocets (0.4 to 1.5%). However, assuming that stilts or ducks nested on the refuge and fed from Hailstone Reservoir, selenium concentrations in the egg would likely be similar (Joe Skorupa, USFWS, Washington D.C., 2007 Pers. Comm.). Using the selenium concentrations detected in avocet eggs, the probability of a teratogenic embryo was determined for ducks and stilts (Figure 34). The probability of a teratogenic embryo in stilts ranged from 4 to 24%, and in ducks the probability ranged from 27 to 99%. Embryo inviability can occur at lower selenium concentrations than those that result in teratogenic response. In fact, selenium induced embryo mortality is underestimated in the teratogenic model by 30 to 40 % (NIWQP 2003).

Selenium concentrations in water and invertebrate food items are at levels of concern for waterfowl and shorebirds using the Hailstone NWR as a breeding area. Documented breeding on the refuge during this investigation has been limited to American avocets and killdeer (*Charadrius vociferous*). Concentrations of selenium in avocet eggs would potentially result in elevated teratogenic, and/or inviable embryos in stilts or ducks if breeding occurred.



Conclusions and Recommendations

Hailstone Reservoir water quality currently creates an unacceptable risk for shorebirds and waterfowl using Hailstone NWR. As long as crop-fallow farming practices continue in the upper watershed of the Hailstone Refuge, the delivery of selenium and salts will continue to increase and the quality of water in Hailstone Reservoir will continue to deteriorate. Infiltration of rainwater and snowmelt in the saline seep recharge areas will continue to dissolve soluble constituents in the soil column for the next 25 to 100+ years (Miller et al. 1981). The refuge is currently unable to manipulate water levels, so surface water arriving in Hailstone Reservoir continues to evapoconcentrate, degrading water quality further.

While the selenium concentrations in Hailstone Reservoir create an unacceptable risk for breeding waterfowl and shorebirds, the more immediate toxic threat to these birds is salt. Because we suspect that salt encrustation of birds using this site can occur within hours, and because flight cannot occur once encrustation occurs, all affected birds will eventually die. Ducks are the most common aquatic bird impacted by this encrustation. On several site visits, encrusted ducks continually exhibit bathing behaviors in an apparent attempt to wash the salt from their feathers in the Hailstone Reservoir, only exacerbating their condition. Preening and drinking of the water at Hailstone Reservoir likely overcomes the salt glands quickly and results in fluid accumulation in the lungs, erosions on the surfaces of the eyes and congestion of the brain (Franson and Friend 1999). Furthermore, the physical encrustation can lead to exertion, muscle degeneration and eventual drowning (Franson and Friend 1999).

The results of this investigation and the documented threat that Hailstone Reservoir poses to waterfowl, warrant action by the USFWS to address water quality concerns at Hailstone NWR. However, improvements in water quality flowing into the refuge will require cooperation of landowners in the watershed of the refuge. Techniques are available to remediate saline seeps. Use of deep-rooted perennial crops such as alfalfa, or alfalfa-grass mixtures will help dry out deep sub-soils quickly in saline seep recharge areas (Miller et al. 1981, Brown et al. 1982). Alfalfa will develop a 6 meter root system in 4 to 5 years and use more than 760 mm of water (Brown et al. 1976). Saline seep reduction can increase economic productivity while potentially providing improved water quality to the refuge. Economic losses incurred by farmers with saline seeps on their land include loss in productivity of crop ground, reduction in farmable area, and increased costs associated with farming around seeps. At the Stillwater Conservation District 10 year demonstration site, 205 acres were planted to alfalfa in 1985 and 1986. Wells were monitored for decreases in groundwater, and in 1987 well measurements indicated that groundwater had declined 9 feet (Duaime 1991). In addition to using alfalfa for reducing groundwater levels, planting recharge areas of seeps to perennial grasses can also be effective. To that end, the Natural Resources Conservation Service (NRCS) in Stillwater County requested and received designation of the Lake and Comanche Basins as a Conservation Priority Area for Conservation Reserve Program (CRP) enrollment (P. Sandoval, NRCS, pers. comm.). Land planted to CRP showed an 11 foot reduction in groundwater levels over a five year period (Holzer 1996). Enrolling seep recharge areas in CRP will improve water quality on the refuge.

Cooperative efforts with NRCS and private landowners to reduce groundwater levels outside the refuge boundary will be essential to dealing with water quality problems at Hailstone NWR. Management actions taken solely within the refuge boundary will not result in a complete solution to this problem. Overland flow of rainfall and snowmelt will continue to deliver salts and selenium from saline seeps to Hailstone Reservoir. Installing a drawdown structure to release water, or breaching the dam completely appears to be the only ways to address current water quality degradation. Holding water behind the dam currently creates an unacceptable risk to waterfowl and shorebirds.

ACKNOWLEDGMENTS

Funding for this research was provided by the U.S. Fish and Wildlife Service's Department of Environmental Quality's On-Refuge Investigations Program. Jay Hansen with MBMG created the maps contained in this report. John Metesh, Edmond Deal, and Marvin Miller from MBMG; and Pete Ramirez, Joe Skorupa, Larry Gamble, and Mark Wilson from the USFWS provided helpful reviews of this report.

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APPENDICIES

Appendix A.

Analytical results of surface and groundwater samples

Sample	Gwic Id	Site Name	Latitude	Longitude	Location (TRS)	Site Type	Depth (ft)	Agency	Sample Date	Water Temp (°C)	Field pH (S.U.)	Field S.C. (µS/cm)	Lab	Lab pH (S.U.)
Lake Samples														
2001Q1334	185942	HAILSTONE LAKE DAM	46.0017	-109.1770	03N20E24ABBB	LAKE	-	MBMG	3/22/2001	8.6	8.90	28000	MBMG	8.60
2001Q5051	185942	HAILSTONE LAKE DAM	46.0017	-109.1770	03N20E24ABBB	LAKE	-	MBMG	5/24/2001		9.11	83200	TERL	
2001Q1696	185942	HAILSTONE LAKE DAM	46.0017	-109.1770	03N20E24ABBB	LAKE	-	MBMG	6/20/2001	20.4	9.42	41360	MBMG	8.95
2002Q5115	185942	HAILSTONE LAKE DAM	46.0017	-109.1770	03N20E24ABBB	LAKE	-	USFWS	7/5/2001				TERL	
2002Q5116	185942	HAILSTONE LAKE DAM	46.0017	-109.1770	03N20E24ABBB	LAKE	-	USFWS	8/1/2001	18.5	8.34	75700	TERL	
2002Q0082	185942	HAILSTONE LAKE DAM	46.0017	-109.1770	03N20E24ABBB	LAKE	-	MBMG	8/1/2001	18.4	8.34	75700	MBMG	8.37
2002Q0980	185942	HAILSTONE LAKE DAM	46.0017	-109.1770	03N20E24ABBB	LAKE	-	MBMG	3/19/2002	27.0	8.44	57000	MBMG	8.46
2003Q0014	185942	HAILSTONE LAKE DAM	46.0017	-109.1770	03N20E24ABBB	LAKE	-	MBMG	6/18/2002	22.1	8.43	74800	MBMG	8.39
2002Q5121	185942	HAILSTONE LAKE DAM	46.0017	-109.1770	03N20E24ABBB	LAKE	-	USFWS	7/24/2002	25.1	8.02	51500	TERL	
2003Q0144	185942	HAILSTONE LAKE DAM	46.0017	-109.1770	03N20E24ABBB	LAKE	-	MBMG	7/24/2002	25.1	8.02	51500	MBMG	8.07
2003Q5064	185942	HAILSTONE LAKE DAM	46.0017	-109.1770	03N20E24ABBB	LAKE	-	USFWS	8/14/2002	22.0	8.52	55400	TERL	
2003Q0272	185942	HAILSTONE LAKE DAM	46.0017	-109.1770	03N20E24ABBB	LAKE	-	MBMG	8/14/2002	22.0	8.52	55400	MBMG	7.95
2003Q5062	185942	HAILSTONE LAKE DAM	46.0017	-109.1770	03N20E24ABBB	LAKE	-	MBMG	4/18/2003	15.6	9.21	57000	TERL	
2004Q5073	185942	HAILSTONE LAKE DAM	46.0017	-109.1770	03N20E24ABBB	LAKE	-	MBMG	7/16/2003	28.2	8.17	84500	TERL	
2005Q0109	185942	HAILSTONE LAKE DAM	46.0017	-109.1770	03N20E24ABBB	LAKE	-	USFWS	8/18/2004	8.9	8.97	87400	MBMG	8.70
2001Q5053	216775	EAST HAILSTONE	46.0022	-109.1775	03N20E13DDDA	LAKE	-	USFWS	5/24/2001		9.00	85000	TERL	
2002Q5118	216775	EAST HAILSTONE	46.0022	-109.1775	03N20E13DDDA	LAKE	-	USFWS	7/5/2001				TERL	
2001Q5055	216776	WEST HAILSTONE	46.0036	-109.1828	03N20E13	LAKE	-	USFWS	5/24/2001		8.90	85500	TERL	
Tributary Samples														
2001Q1333	185941	NORTH TRIBUTARY	46.0210	-109.1727	03N20E12DAB	STREAM	-	MBMG	3/22/2001	13.5	9.64	15800	MBMG	9.16
2001Q1335	185943	EAST CULVERT	46.0078	-109.1528	03N21E18ADCD	STREAM	-	MBMG	3/22/2001	14.0	8.45	23400	MBMG	9.20
2001Q1470	186984	EAST TRIBUTARY	46.0093	-109.1683	03N21E18CBBB	STREAM	-	MBMG	4/26/2001	27.0	9.45	35450	MBMG	9.07
2001Q5054	216774	EAST TRIBUTARY 2	46.0086	-109.1783	03N20E13DBB	STREAM	-	USFWS	5/24/2001		8.75	85200	TERL	
2002Q5119	216774	EAST TRIBUTARY 2	46.0086	-109.1783	03N20E13DBB	STREAM	-	USFWS	6/19/2002	17.1	8.28	76100	TERL	
2003Q5061	216774	EAST TRIBUTARY 2	46.0086	-109.1783	03N20E13DBB	STREAM	-	USFWS	4/18/2003	16.7	9.51	47500	TERL	
2004Q5072	216774	EAST TRIBUTARY 2	46.0086	-109.1783	03N20E13DBB	STREAM	-	USFWS	7/16/2003	27.5	8.39	86800	TERL	
Below Dam Samples														
2001Q1336	185944	HAILSTONE SPILLWAY	46.0013	-109.1768	03N20E24ABBB	STREAM	-	MBMG	3/22/2001				MBMG	8.15
2001Q5052	185944	HAILSTONE SPILLWAY	46.0013	-109.1768	03N20E24ABBB	STREAM	-	USFWS	5/24/2001		8.00	65000		
2001Q1697	185944	HAILSTONE SPILLWAY	46.0013	-109.1768	03N20E24ABBB	STREAM	-	MBMG	6/20/2001	26.4	8.59	47540	MBMG	8.48
2002Q5117	185944	HAILSTONE SPILLWAY	46.0013	-109.1768	03N20E24ABBB	STREAM	-	USFWS	8/1/2001	27.4	8.18	57600	TERL	
2002Q0081	185944	HAILSTONE SPILLWAY	46.0013	-109.1768	03N20E24ABBB	STREAM	-	MBMG	8/3/2001	27.4	8.18	57600	MBMG	8.26
2002Q5120	185944	HAILSTONE SPILLWAY	46.0013	-109.1768	03N20E24ABBB	STREAM	-	USFWS	6/18/2002	23.8	8.49	45050	TERL	
2003Q0015	185944	HAILSTONE SPILLWAY	46.0013	-109.1768	03N20E24ABBB	STREAM	-	USFWS	6/18/2002	23.8	8.49	45050	MBMG	8.53
2003Q5063	185944	HAILSTONE SPILLWAY	46.0013	-109.1768	03N20E24ABBB	STREAM	-	USFWS	8/14/2002	19.0	8.51	57700	TERL	
2003Q0273	185944	HAILSTONE SPILLWAY	46.0013	-109.1768	03N20E24ABBB	STREAM	-	MBMG	8/14/2002	19.0	8.51	57700	MBMG	8.58

Appendix A.

Analytical results of surface and groundwater samples

Sample	Gwic Id	Site Name	Lab S.C. µS/cm	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Fe (mg/L)	Mn (mg/L)	SiO2 (mg/L)	HCO3 (mg/L)	CO3 (mg/L)	SO4 (mg/L)	Cl (mg/L)	NO3 (mg/L)	F (mg/L)	OPO4 (mg/L)
Lake Samples																	
2001Q1334	185942	HAILSTONE LAKE DAM	49900	493	22400	20200	353				1364	249.6	121510	2991	<10.0 P	187	<10
2001Q5051	185942	HAILSTONE LAKE DAM		550	21300	37000	399	0.871	0.125	< 1.00			53400				< 5.00
2001Q1696	185942	HAILSTONE LAKE DAM	31200	314	4570	8850	84.4	3.06	<.1	<10	278.2	110.4	39845	727	<5.0 P	46.8	<5.0
2002Q5115	185942	HAILSTONE LAKE DAM		519	8670	18900	162	0.545	0.778	< 1.00			24600				< 5.00
2002Q5116	185942	HAILSTONE LAKE DAM		593	13000	30200	233	0.689	1.95	< 1.00			38600				< 5.00
2002Q0082	185942	HAILSTONE LAKE DAM	42800	613	11900	29400	205	4.99	1.86	<10	1778.8	0	105030	1753	<10.0 P	133	<100
2002Q0980	185942	HAILSTONE LAKE DAM	42900	603	32100	15200	498	<.25	5.7	<5	2715.7	633.6	162882	4802	<5.0 P	146	<50
2003Q0014	185942	HAILSTONE LAKE DAM	42100	507	29500	32860	605	<.25	5.06	<5	322.8	3229.3	194000	4240	<25.0 P	217	<100
2002Q5121	185942	HAILSTONE LAKE DAM		193	41400	166000		<0.01	5.94								
2003Q0144	185942	HAILSTONE LAKE DAM	38900	380	45000	76700	852	<0.25	6.44	6.6	6139	0	325272	6769	<.5 P	535	<247
2003Q5064	185942	HAILSTONE LAKE DAM		347	52000	121000		<0.1	1.37								
2003Q0272	185942	HAILSTONE LAKE DAM	36800	346	50000	62400	1220	<0.25	1.3	8.19	6511.7	0	330000	9520	<25.0 P	488	<50.0
2003Q5062	185942	HAILSTONE LAKE DAM															
2004Q5073	185942	HAILSTONE LAKE DAM															
2005Q0109	185942	HAILSTONE LAKE DAM	47000	884	27434	38788	535	<5.00	1.95	3.2	1675.1	591.6	179247	3977	<10.0	<10.0	<10.0
2001Q5053	216775	EAST HAILSTONE		544	21900	37900	395	0.863	0.119	< 1.00			54800				< 5.00
2002Q5118	216775	EAST HAILSTONE		502	8490	18300	156	0.528	0.743	< 1.00			23800				< 5.00
2001Q5055	216776	WEST HAILSTONE		579	22200	38400	417	0.916	0.113	< 1.00			56100				< 5.00
Tributary Samples																	
2001Q1333	185941	NORTH TRIBUTARY	22500	278	3380	5190	42.9				236.7	198	23707	301	20.4 P	35	<.5
2001Q1335	185943	EAST CULVERT	41600	428	6820	15000	71.3				514.8	297.6	59550	1632	45.1 P	100	<10.0
2001Q1470	186984	EAST TRIBUTARY	27800	335	2100	8500	33.6	1.94	<.1	<10	235.5	86.4	27844	390	<5.0 P	46.1	<10.0
2001Q5054	216774	EAST TRIBUTARY 2		565	23700	38300	444	0.956	0.141	< 1.00			56900				< 5.00
2002Q5119	216774	EAST TRIBUTARY 2		459	32100	61900		<0.1	4.97								
2003Q5061	216774	EAST TRIBUTARY 2															
2004Q5072	216774	EAST TRIBUTARY 2															
Below Dam Samples																	
2001Q1336	185944	HAILSTONE SPILLWAY	21700	350	1640	6400	28.3				453.8	0	20443	329	<2.5 P	30.8	<10.0
2001Q5052	185944	HAILSTONE SPILLWAY		594	8480	22100	123	0.845	16.7	13.1			25200				< 5.00
2001Q1697	185944	HAILSTONE SPILLWAY	34400	532	4620	11900	73.6	4.15	7.06	<10	646.6	55.2	46433	851	<25.0	60.5	<25
2002Q5117	185944	HAILSTONE SPILLWAY		597	7490	18000	105	0.714	17.4	4.6			21900				< 5.00
2002Q0081	185944	HAILSTONE SPILLWAY	37200	553	6510	15700	88.6	4.88	16	<10	1121.2	0	66065	1184	<2.5 P	80.8	<100
2002Q5120	185944	HAILSTONE SPILLWAY		495	4790	12900		0.09	1.67								
2003Q0015	185944	HAILSTONE SPILLWAY	32200	500	4900	12000	66.7	2.52	1.72	<5	450.2	61.2	44921	853	<5.0 P	68.7	<25.0
2003Q5063	185944	HAILSTONE SPILLWAY		569	7320	20300		0.151	2.89								
2003Q0273	185944	HAILSTONE SPILLWAY	35200	564	7350	17400	102	0.449	2.95	<5.0	836.9	48	63964	1343	<25.0	101	<25.0

Appendix A.

Analytical results of surface and groundwater samples

Sample	Gwic Id	Site Name	Ag (µg/l)	Al (µg/l)	As (µg/L)	B (µg/L)	Ba (µg/l)	Be (µg/l)	Br (µg/l)	Cd (µg/l)	Co (µg/l)	Cr (µ/l)	Cu (µg/l)	Hg (µg/l)	Li (µg/l)	Mo (µg/l)
Lake Samples																
2001Q1334	185942	HAILSTONE LAKE DAM							<10000							
2001Q5051	185942	HAILSTONE LAKE DAM		<500	188	10900	72	<50.		0.3	<50.	<50.	69	<0.15		<100.
2001Q1696	185942	HAILSTONE LAKE DAM	<25	<750	66.2	<3000	<50	<50	4380	<50	<50	<50	99.1		2630	<250
2002Q5115	185942	HAILSTONE LAKE DAM		<500	76.6	4740	57	<50.		<0.1	<50.	<50.	<50.	<0.15		<100.
2002Q5116	185942	HAILSTONE LAKE DAM		<500.	129	6860	67	<50.		0.1	<50.	<50.	56	<0.15		<100.
2002Q0082	185942	HAILSTONE LAKE DAM	<100	<3000	195	5550	<200	<200	<10000	<200	<200	<200	345		6380	<1000
2002Q0980	185942	HAILSTONE LAKE DAM	<50	<1500	690	15000	<100	<100	30900	<100	<100	<100	132		17000	<500
2003Q0014	185942	HAILSTONE LAKE DAM	<100	<3000	621	14100	<200	<200	24300	<100	<100	<200	450		18000	<1000
2002Q5121	185942	HAILSTONE LAKE DAM	<100.	<500.	520	15700	47	<5.		<20.	<50.	<50.	<50.	<0.02		110
2003Q0144	185942	HAILSTONE LAKE DAM		<1500	<500	19800	<100	<100	49400	68	<100	<500	<250		25200	<500
2003Q5064	185942	HAILSTONE LAKE DAM	<100.	<500.	1130	32500	76	<5.		<20.	<50.	<50.	<50.	<0.02		<100.
2003Q0272	185942	HAILSTONE LAKE DAM		1600	<500	28000	<100	<100	62600	65.5	<100	<500	<250		35800	<500
2003Q5062	185942	HAILSTONE LAKE DAM														
2004Q5073	185942	HAILSTONE LAKE DAM														
2005Q0109	185942	HAILSTONE LAKE DAM		1480	1516	13733	123	<40	<10000	<20	<40	<200	<100		16051	<200
2001Q5053	216775	EAST HAILSTONE		<500.	165	11000	71	<50.		0.18	59	<50.	52	<0.15		<100.
2002Q5118	216775	EAST HAILSTONE		<500.	85.5	4540	57	<50.		0.1	<50.	<50.	<50.	<0.15		<100.
2001Q5055	216776	WEST HAILSTONE		<500.	183	11300	71	<50.		0.24	<50.	<50.	57	<0.15		<100.
Tributary Samples																
2001Q1333	185941	NORTH TRIBUTARY							3930							
2001Q1335	185943	EAST CULVERT							8830							
2001Q1470	186984	EAST TRIBUTARY	<100	<3000	<100	<300	<200	<200	<10000	<200	<200	<200	480		1890	<100
2001Q5054	216774	EAST TRIBUTARY 2		<500.	179	12300	78	<50.		0.3	<50.	<50.	65	<0.15		<100.
2002Q5119	216774	EAST TRIBUTARY 2	< 100	591	800	16000	74	< 5		< 20	< 50	< 50	< 50	<0.02		< 100
2003Q5061	216774	EAST TRIBUTARY 2														
2004Q5072	216774	EAST TRIBUTARY 2														
Below Dam Samples																
2001Q1336	185944	HAILSTONE SPILLWAY							<2500							
2001Q5052	185944	HAILSTONE SPILLWAY		<500.	11.3	2220	44	<50.		<0.1	<50.	<50.	<50.	<0.15		<100.
2001Q1697	185944	HAILSTONE SPILLWAY	<25	<750	27.1	<3000	<50	<50	5260	<50	<50	<50	133		1730	<250
2002Q5117	185944	HAILSTONE SPILLWAY		<500.	9.16	2000	37	<50.		<0.1	67	<50.	<50.	<0.15		<100.
2002Q0081	185944	HAILSTONE SPILLWAY	<100	<3000	<100	<3000	<200	<200	4330	<200	<200	<200	<200		2450	<1000
2002Q5120	185944	HAILSTONE SPILLWAY	<10.	345	20	1400	31	<0.5		<2.	8	<5.	<5.	<0.02		30
2003Q0015	185944	HAILSTONE SPILLWAY	<50	<1500	<50	<1500	<100	<100	5220	<100	<100	<100	158		211	<500
2003Q5063	185944	HAILSTONE SPILLWAY	<10.	351	<20.	2030	50	<0.5		<2.	20	<5.	<5.	<0.02		30
2003Q0273	185944	HAILSTONE SPILLWAY		1650	<500	2070	<100	<100	<25000	<50	<100	<500	<250		3060	<500

Appendix A.

Analytical results of surface and groundwater samples

Sample	Gwic Id	Site Name	Ni (µg/l)	Pb (µg/l)	Sb (µg/l)	Se (µg/l)	Sr (µg/l)	Ti (µg/l)	Tl (µg/l)	U (µg/l)	V (µg/l)	Zn (µg/l)	Zr (µg/l)	Total Dissolved Solids(mg/L)
Lake Samples														
2001Q1334	185942	HAILSTONE LAKE DAM				185								169056
2001Q5051	185942	HAILSTONE LAKE DAM	<50.	<50.		73.2	22400	<50.			<100.	<50.		
2001Q1696	185942	HAILSTONE LAKE DAM	<50	<50	<50	83.1	8510	<100	<125		<125	<50	220	54688
2002Q5115	185942	HAILSTONE LAKE DAM	<50.	<50.		41.1	12300	<50.			<100.	<50.		
2002Q5116	185942	HAILSTONE LAKE DAM	<50.	98		21.4	16300	<50.			<100	<50.		
2002Q0082	185942	HAILSTONE LAKE DAM	<200	<200	<200	100	18600	<100	<500	122	<500	<200	282	149917
2002Q0980	185942	HAILSTONE LAKE DAM	<100	<100	<100	246	38500	<50	<250	285	<250	191	<100	218208
2003Q0014	185942	HAILSTONE LAKE DAM	<200	<200	<200	178	35300	<50	<500	235	<500	257	<100	265323
2002Q5121	185942	HAILSTONE LAKE DAM	<50.	<200.		10.8	19100	<50.			<100.	<50.		
2003Q0144	185942	HAILSTONE LAKE DAM	<100	<500	<500		23300	<50	<1000		630	<100	<100	458545
2003Q5064	185942	HAILSTONE LAKE DAM	<50.	<200.		27.9	21700	<50.			<100.	<50.		
2003Q0272	185942	HAILSTONE LAKE DAM	<100	<500	<500		20400	<50	1030		<100	<100	<100	457193
2003Q5062	185942	HAILSTONE LAKE DAM				90.9								
2004Q5073	185942	HAILSTONE LAKE DAM				21.6								
2005Q0109	185942	HAILSTONE LAKE DAM	83.1	<10000	<200	<300	37961	<10	1669		330	<40	<40	252288
2001Q5053	216775	EAST HAILSTONE	<50.	162		82	22100	<50.			<100.	<50.		
2002Q5118	216775	EAST HAILSTONE	<50.	<50.		39.3	11900	<50.			<100.	<50.		
2001Q5055	216776	WEST HAILSTONE	<50.	<50.		80.7	23200	<50.			<100.	<50.		
Tributary Samples														
2001Q1333	185941	NORTH TRIBUTARY				1600								33269
2001Q1335	185943	EAST CULVERT				3230								84198
2001Q1470	186984	EAST TRIBUTARY	<200	<200	<200	251	7010	<100	<500		<500	<200	<200	39454
2001Q5054	216774	EAST TRIBUTARY 2	<50.	<50.		78.1	24200	<50.			<100.	<50.		
2002Q5119	216774	EAST TRIBUTARY 2	< 50	< 200		13.5	33400	< 50	< 100			< 50		
2003Q5061	216774	EAST TRIBUTARY 2				682								
2004Q5072	216774	EAST TRIBUTARY 2				29.2								
Below Dam Samples														
2001Q1336	185944	HAILSTONE SPILLWAY				<50								29445
2001Q5052	185944	HAILSTONE SPILLWAY	<50.	59		0.43	24200	<50.			<100.	<50.		
2001Q1697	185944	HAILSTONE SPILLWAY	<50	<50	<50	32.2	16000	<100	<125		<125	63.7	240	64855
2002Q5117	185944	HAILSTONE SPILLWAY	<50.	<50.		0.58	18500	<50.			<100.	<50.		
2002Q0081	185944	HAILSTONE SPILLWAY	<200	<200	<200	<100	19700	<100	<500	62.6	<500	<200	223	90755
2002Q5120	185944	HAILSTONE SPILLWAY	20	<20.		1.68	13700	7			<10.	<5.		
2003Q0015	185944	HAILSTONE SPILLWAY	<100	<100	<100	<50	14200	<50	<250	77	<250	<100	<100	63597
2003Q5063	185944	HAILSTONE SPILLWAY	40	<20.		1.57	19700	6			<10.	<5.		
2003Q0273	185944	HAILSTONE SPILLWAY	<100	<500	<500	<750	19100	<50	<1000		<500	<100	<100	91289

Appendix A.

Analytical results of surface and groundwater samples

Sample	Gwic Id	Site Name	Latitude	Longitude	Location (TRS)	Site Type	Depth (ft)	Agency	Sample Date	Water Temp (°C)	Field pH (S.U.)	Field S.C. (µS/cm)	Lab	Lab pH (S.U.)
Groundwater above transition														
1988Q1009	1172	BRICKLEY SITE * B-16	46.0396	-109.1883	03N20E01BCBC	WELL	18	MBMG	7/21/1988	9.5	7.04	15611	MBMG	7.21
2002Q0756	1172	BRICKLEY SITE * B-16	46.0396	-109.1883	03N20E01BCBC	WELL	18	MBMG	12/19/2001	10.1	7.12	10000	MBMG	7.22
1986Q0098	1175	BRICKLEY SITE * B-01	46.0444	-109.1912	03N20E02AABB	WELL	23	MBMG	3/27/1986	9.0	7.56	6660	MBMG	7.77
1986Q0409	1175	BRICKLEY SITE * B-01	46.0444	-109.1912	03N20E02AABB	WELL	23	MBMG	5/28/1986	1.0	7.31	7350	MBMG	7.50
1988Q1005	1175	BRICKLEY SITE * B-01	46.0444	-109.1912	03N20E02AABB	WELL	23	MBMG	7/21/1988	9.9	7.05	8451	MBMG	7.21
2002Q0751	1175	BRICKLEY SITE * B-01	46.0444	-109.1912	03N20E02AABB	WELL	23	MBMG	12/19/2001	10.7	7.10	8000	MBMG	7.19
2003Q5073	1175	BRICKLEY SITE * B-01	46.0444	-109.1912	03N20E02AABB	WELL	23	USFWS	8/27/2002	11.4	7.10	7800	TERL	
2003Q0353	1175	BRICKLEY SITE * B-01	46.0444	-109.1912	03N20E02AABB	WELL	23	MBMG	8/27/2002	11.4	7.10	7800	MBMG	7.22
1986Q0099	1177	BRICKLEY SITE * B-02	46.0398	-109.1913	03N20E02ADBA	WELL	23	MBMG	3/27/1986	8.2	7.39	18860	MBMG	7.61
1986Q0410	1177	BRICKLEY SITE * B-02	46.0398	-109.1913	03N20E02ADBA	WELL	23	MBMG	5/30/1986	14.0	7.14	15560	MBMG	7.06
1988Q1006	1177	BRICKLEY SITE * B-02	46.0398	-109.1913	03N20E02ADBA	WELL	23	MBMG	7/21/1988	1.0	7.07	16858	MBMG	7.13
2003Q5072	1177	BRICKLEY SITE * B-02	46.0398	-109.1913	03N20E02ADBA	WELL	23	USFWS	8/27/2002	10.0	6.88	17670	TERL	
2003Q0346	1177	BRICKLEY SITE * B-02	46.0398	-109.1913	03N20E02ADBA	WELL	23	MBMG	8/27/2002	10.0	6.88	17670	MBMG	7.38
1988Q1008	1280	BRICKLEY SITE * B-14	46.0482	-109.1901	04N20E35DADC	WELL	60	MBMG	7/21/1988	1.0	6.90	3779	MBMG	7.38
2002Q0743	1280	BRICKLEY SITE * B-14	46.0482	-109.1901	04N20E35DADC	WELL	60	MBMG	12/19/2001	9.3	7.19	3700	MBMG	7.29
2003Q5076	1280	BRICKLEY SITE * B-14	46.0482	-109.1901	04N20E35DADC	WELL	60	USFWS	8/27/2002	10.8	7.19	4093	TERL	
2003Q0351	1280	BRICKLEY SITE * B-14	46.0482	-109.1901	04N20E35DADC	WELL	60	MBMG	8/27/2002	10.8	7.19	4093	MBMG	7.49
1988Q1010	1281	BRICKLEY SITE * B-20	46.0463	-109.1902	04N20E35DDAB	WELL	38	MBMG	7/21/1988	9.8	7.10	7159	MBMG	7.43
2003Q5077	1281	BRICKLEY SITE * B-20	46.0463	-109.1902	04N20E35DDAB	WELL	38	USFWS	8/27/2002	10.4	7.00	1281	TERL	
2003Q0352	1281	BRICKLEY SITE * B-20	46.0463	-109.1902	04N20E35DDAB	WELL	38	MBMG	8/27/2002	10.4	7.00	1281	MBMG	7.29
1986Q0100	1284	BRICKLEY SITE * B-8	46.0463	-109.1914	04N20E35DDBB	WELL	25	MBMG	3/27/1986	9.9	7.40	7160	MBMG	8.13
1986Q0411	1284	BRICKLEY SITE * B-8	46.0463	-109.1914	04N20E35DDBB	WELL	25	MBMG	5/28/1986	11.0	7.09	6500	MBMG	7.22
1987Q0493	1284	BRICKLEY SITE * B-8	46.0463	-109.1914	04N20E35DDBB	WELL	25	MBMG	7/15/1987	17.1	7.24	4100	MBMG	
1987Q0704	1284	BRICKLEY SITE * B-8	46.0463	-109.1914	04N20E35DDBB	WELL	25	MBMG	8/13/1987	13.8		4505	MBMG	
1988Q1007	1284	BRICKLEY SITE * B-8	46.0463	-109.1914	04N20E35DDBB	WELL	25	MBMG	7/21/1988		6.95	7174	MBMG	7.23
2003Q5085	188445	MBMG RESEARCH SITE * HS25	46.0042	-109.1849	03N20E13CCAD	WELL	18	USFWS	8/28/2002	12.6	7.20	93000	TERL	
2003Q0432	188445	MBMG RESEARCH SITE * HS25	46.0042	-109.1849	03N20E13CCAD	WELL	18	MBMG	8/28/2002	12.6	7.20	93000	MBMG	7.49
2002Q0758	188447	MBMG RESEARCH SITE * HS26	46.0036	-109.1855	03N20E13CCBD	WELL	23	MBMG	12/19/2001	9.6	7.33	5260	MBMG	7.43
2002Q0757	188614	MBMG RESEARCH SITE * B-4	46.0486	-109.1921	04N20E35DACC	WELL	23	MBMG	12/19/2001	9.2	7.07	7500	MBMG	7.29
2003Q5070	188615	MBMG RESEARCH SITE * B-12	46.0483	-109.1880	04N20E35DADD	WELL	45	USFWS	8/27/2002	11.3	7.30	14640	TERL	
2003Q0345	188615	MBMG RESEARCH SITE * B-12	46.0483	-109.1880	04N20E35DADD	WELL	45	MBMG	8/27/2002	11.3	7.30	14640	MBMG	7.81
2003Q5075	188616	MBMG RESEARCH SITE * B-13	46.0499	-109.1880	04N20E35DADA	WELL	26	USFWS	8/27/2002	10.6	6.96	11680	TERL	
2003Q0350	188616	MBMG RESEARCH SITE * B-13	46.0499	-109.1880	04N20E35DADA	WELL	26	MBMG	8/27/2002	10.6	6.96	11680	MBMG	7.33
2002Q0759	188617	MBMG RESEARCH SITE * B-15	46.0397	-109.1885	03N20E02ADAD	WELL	23	MBMG	12/19/2001	10.0	7.15	11000	MBMG	7.30

Appendix A.

Analytical results of surface and groundwater samples

Sample	Gwic Id	Site Name	Lab S.C. µS/cm	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Fe (mg/L)	Mn (mg/L)	SiO2 (mg/L)	HCO3 (mg/L)	CO3 (mg/L)	SO4 (mg/L)	Cl (mg/L)	NO3 (mg/L)	F (mg/L)	OPO4 (mg/L)
Groundwater above transition																	
1988Q1009	1172	BRICKLEY SITE * B-16	15043	388	2280	1640	26	<.002	0.005	7	625	0	12500	110	66	0.2	<.1
2002Q0756	1172	BRICKLEY SITE * B-16	8980	375	1130	1170	21.3	0.485	<.01	7.04	520.9	0	7709	88.1	31.2 P	7.69	<5.0
1986Q0098	1175	BRICKLEY SITE * B-01	6768	362	645	590	14.7	<.002	0.001	9.9	406	0	3750	166	100	1.5	<.1
1986Q0409	1175	BRICKLEY SITE * B-01	7404	455	741	574	16.7	0.016	0.005	10.4	366	0	4260	162	121	0.3	<.1
1988Q1005	1175	BRICKLEY SITE * B-01	7720	415	885	729	21.8	0.12	0.11	11.5	396	0	5100	163	84	0.1	0.1
2002Q0751	1175	BRICKLEY SITE * B-01	7400	434	792	729	25.3	0.408	<.01	10.4	480.7	0	4664	257	<5.0 P	7.02	<5.0
2003Q5073	1175	BRICKLEY SITE * B-01		441	741	727		0.01	0.028								
2003Q0353	1175	BRICKLEY SITE * B-01	6910	440	765	766	24	0.197	0.024	9.49	606.3	0	4590	99	43.8 P	<13.0	<1.0
1986Q0099	1177	BRICKLEY SITE * B-02	15278	371	2034	1764	23	<.002	0.016	9.5	438	0	11690	170	107	1.6	<.1
1986Q0410	1177	BRICKLEY SITE * B-02	15744	382	2155	1897	24.6	<.002	0.015	9.1	462	0	12670	161	91.2	0.6	<.1
1988Q1006	1177	BRICKLEY SITE * B-02	15933	397	2265	2230	26.6	0.81	0.98	10	513	0	13700	175	67	0.2	1
2003Q5072	1177	BRICKLEY SITE * B-02		390	2470	2280		0.124	0.552								
2003Q0346	1177	BRICKLEY SITE * B-02	14290	388	2500	2299	30.3	<0.05	0.519	7.83	580.7	0	13400	168	67.9 P	<25.0	<3.0
1988Q1008	1280	BRICKLEY SITE * B-14	3675	495	162	273	9.1	0.048	0.86	8.8	342	0	2092	22	6.68		0.3
2002Q0743	1280	BRICKLEY SITE * B-14	3920	488	158	323	5.61	0.136	<.01	8.43	339.2	0	2220	49.3	16.8 P	3.08	<.5
2003Q5076	1280	BRICKLEY SITE * B-14		498	147	340		0.151	0.01								
2003Q0351	1280	BRICKLEY SITE * B-14	3860	500	162	354	5.81	0.065	<0.01	8.01	339.2	0	2190	49	15.5 P	<5.0	<0.5
1988Q1010	1281	BRICKLEY SITE * B-20	6460	437	409	768	15.2	0.002	0.081	10.4	473	0	3440	169	70	0.1	<.1
2003Q5077	1281	BRICKLEY SITE * B-20		437	395	849		0.163	0.274								
2003Q0352	1281	BRICKLEY SITE * B-20	6360	446	397	873	15.6	0.298	0.296	10.1	563.6	0	3160	128	107 P	<13.0	<1.0
1986Q0100	1284	BRICKLEY SITE * B-8	7993	454	520	1062	19.7	<.002	0.37	11.8	630	0	4590	126	31	1.1	<.1
1986Q0411	1284	BRICKLEY SITE * B-8	6684	457	588	570	18.4	<.002	0.11	8.9	486	0	3880	168	54.6	0.4	0.1
1987Q0493	1284	BRICKLEY SITE * B-8													9.11		
1987Q0704	1284	BRICKLEY SITE * B-8													72.1		
1988Q1007	1284	BRICKLEY SITE * B-8	6895	451	604	677	19.1	0.006	0.049	6.9	514	0	4200	126	40	0.1	<.1
2003Q5085	188445	MBMG RESEARCH SITE * HS25		442	579	1410		0.01	1.09								
2003Q0432	188445	MBMG RESEARCH SITE * HS25	8670	442	590	1530	10	0.163	0.997	8.89	590.5	0	5500	431	<3.0 P	<3.0	<3.0
2002Q0758	188447	MBMG RESEARCH SITE * HS26	4690	438	344	591	13.8	0.455	0.068	10.2	316	0	3297	119	<5.0 P	4.46	<5.0
2002Q0757	188614	MBMG RESEARCH SITE * B-4	7200	452	578	918	21.5	<.5	<.1	<10	713.7	0	4288	324	84.4 P	6.61	<5.0
2003Q5070	188615	MBMG RESEARCH SITE * B-12		221	564	3190		0.364	1.22								
2003Q0345	188615	MBMG RESEARCH SITE * B-12	12280	226	578	3290	12.8	0.452	1.12	8.52	927.2	0	8430	96	<0.5 P	<25.0	<3.0
2003Q5075	188616	MBMG RESEARCH SITE * B-13		439	998	1970		0.112	0.354								
2003Q0350	188616	MBMG RESEARCH SITE * B-13	10200	416	930	1860	24.9	0.246	0.321	8.01	978.4	0	7540	51	19.4 P	<13.0	<0.5
2002Q0759	188617	MBMG RESEARCH SITE * B-15	9800	376	1380	1130	23.5	0.474	<.01	7.87	507.5	0	8524	94.6	33.1 P	8.08	<5.0

Appendix A.

Analytical results of surface and groundwater samples

Sample	Gwic Id	Site Name	Ag (µg/l)	Al (µg/l)	As (µg/L)	B (µg/L)	Ba (µg/l)	Be (µg/l)	Br (µg/l)	Cd (µg/l)	Co (µg/l)	Cr (µ/l)	Cu (µg/l)	Hg (µg/l)	Li (µg/l)	Mo (µg/l)
Groundwater above transition																
1988Q1009	1172	BRICKLEY SITE * B-16	<2.	<30.		480			<100.	10		<2.	25		1530	<20.
2002Q0756	1172	BRICKLEY SITE * B-16	<10	<300	<10	573	<20	<20	<5000	<20	<20	<20	<20		1020	<200
1986Q0098	1175	BRICKLEY SITE * B-01	<2.	<30.		640			<100.	8		<2.	<2.		685	30
1986Q0409	1175	BRICKLEY SITE * B-01	4	70		510			<100.	4		3	<2.		810	<20.
1988Q1005	1175	BRICKLEY SITE * B-01	<2.	300		510			<100.	3		<2.	17		920	<20.
2002Q0751	1175	BRICKLEY SITE * B-01	<10	<300	31	540	<20	<20	<500	<20	<20	<20	<20		985	<200
2003Q5073	1175	BRICKLEY SITE * B-01	<10.	886	<20.	589	8	<0.5		<2.	<5.	<5.	<5.	<0.02		<10.
2003Q0353	1175	BRICKLEY SITE * B-01		1010	<100	534	<20	<20	<1000	<10	<20	<100	<50		1010	<100
1986Q0099	1177	BRICKLEY SITE * B-02	<2.	1500		870			200	8		<2.	<2.		1.55	60
1986Q0410	1177	BRICKLEY SITE * B-02	10	150		580			<100.	16		<2.	<2.		1520	20
1988Q1006	1177	BRICKLEY SITE * B-02	<2.	560		580			<100.	38		36	21		1750	20
2003Q5072	1177	BRICKLEY SITE * B-02	<10.	299	<20.	599	9	<0.5		<2.	<5.	<5.	6	<0.02		<10.
2003Q0346	1177	BRICKLEY SITE * B-02		887	<100	516	<20	<20	<3000	<10	<20	<100	<50		2250	<100
1988Q1008	1280	BRICKLEY SITE * B-14	<2.	<30.		410			<100.	<2.		<2.	17		210	<20.
2002Q0743	1280	BRICKLEY SITE * B-14	<10	<300	<10	398	<20	<20	<5000	<20	<20	<20	<20		257	<200
2003Q5076	1280	BRICKLEY SITE * B-14	<10.	998	<20.	409	11	<0.5		<2.	<5.	<5.	<5.	<0.02		<10.
2003Q0351	1280	BRICKLEY SITE * B-14		1080	<100	385	<20	<20	<500	<10	<20	<100	<50		262	<100
1988Q1010	1281	BRICKLEY SITE * B-20	<2.	<30.		610			<100.	<2.		<2.	23		580	<20.
2003Q5077	1281	BRICKLEY SITE * B-20	<10.	751	<20.	596	10	<0.5		<2.	<5.	<5.	<5.	<0.02		<10.
2003Q0352	1281	BRICKLEY SITE * B-20		1120	<100	672	<20	<20	<1000	<10	<20	<100	<50		825	<100
1986Q0100	1284	BRICKLEY SITE * B-8	<2.	<30.		1330			200	<2.		<2.	<2.		1350	50
1986Q0411	1284	BRICKLEY SITE * B-8	4	40		770			<100.	<2.		<2.	<2.		880	40
1987Q0493	1284	BRICKLEY SITE * B-8														
1987Q0704	1284	BRICKLEY SITE * B-8														
1988Q1007	1284	BRICKLEY SITE * B-8	<2.	<30.		700			<100.	2		<2.	25		1000	<20.
2003Q5085	188445	MBMG RESEARCH SITE * HS25	<10.	974	<20.	794	11	<0.5		<2.	<5.	<5.	<5.	0.05		<10.
2003Q0432	188445	MBMG RESEARCH SITE * HS25		968	<100	722	<20	<20	<3000	<10	<20	<100	<0		411	<100
2002Q0758	188447	MBMG RESEARCH SITE * HS26	<50	<1500	<50	<1500	<100	<100	595	<100	<100	<100	<100		656	<500
2002Q0757	188614	MBMG RESEARCH SITE * B-4	<100	<3000	<100	<3000	<200	<200	<500	<200	<200	<200	<200		721	<1000
2003Q5070	188615	MBMG RESEARCH SITE * B-12	<10.	207	<20.	851	15	<0.5		<2.	<5.	<5.	<5.	<0.02		<10.
2003Q0345	188615	MBMG RESEARCH SITE * B-12		526	<100	797	<20	<20	<3000	<10	<20	<100	<50		1860	<100
2003Q5075	188616	MBMG RESEARCH SITE * B-13	<10.	833	<20.	783	9	<0.5		<2.	<5.	<5.	<5.	<0.02		<10.
2003Q0350	188616	MBMG RESEARCH SITE * B-13		944	<100	721	<20	<20	<500	<10	<20	<100	<50		1590	<100
2002Q0759	188617	MBMG RESEARCH SITE * B-15	<10	<300	<10	578	<20	<20	<5000	<20	<20	<20	<20		1080	<200

Appendix A.

Analytical results of surface and groundwater samples

Sample	Gwic Id	Site Name	Ni (µg/l)	Pb (µg/l)	Sb (µg/l)	Se (µg/l)	Sr (µg/l)	Ti (µg/l)	Tl (µg/l)	U (µg/l)	V (µg/l)	Zn (µg/l)	Zr (µg/l)	Total Dissolved Solids(mg/L)
Groundwater above transition														
1988Q1009	1172	BRICKLEY SITE * B-16	50			385	5850	4			61	69	<4.	17325
2002Q0756	1172	BRICKLEY SITE * B-16	<20	<20	<20	319	7180	<10	<50	16.7	<50	<20	<20	10796
1986Q0098	1175	BRICKLEY SITE * B-01	30			1030	8710	15			13	<3.	<4.	5839
1986Q0409	1175	BRICKLEY SITE * B-01	20			1410	10500	18			3	72	<4.	6521
1988Q1005	1175	BRICKLEY SITE * B-01	15			1137	10200	9			10	13	<4.	7605
2002Q0751	1175	BRICKLEY SITE * B-01	<20	<20	<20	1920	9870	<50	<50	29.5	<50	<20	<100	7156
2003Q5073	1175	BRICKLEY SITE * B-01	8	<20.		586	9010	6			<10.	8		
2003Q0353	1175	BRICKLEY SITE * B-01	<20	<100	<100	483	9190	<10	<200		<100	<20	<20	7037
1986Q0099	1177	BRICKLEY SITE * B-02	40			591	6850	19			<1.	7	<4.	16387
1986Q0410	1177	BRICKLEY SITE * B-02	70			629	7280	21			<1.	17	<4.	17618
1988Q1006	1177	BRICKLEY SITE * B-02	60			998	7180	8			69	28	<4.	19127
2003Q5072	1177	BRICKLEY SITE * B-02	35	<20.		872	7710	7			<10.	6		
2003Q0346	1177	BRICKLEY SITE * B-02	25.3	<100	<100	756	7520	<10	<200		<100	<20	<20	19149
1988Q1008	1280	BRICKLEY SITE * B-14	<10.			76	6870	6			<1.	3	<4.	3238
2002Q0743	1280	BRICKLEY SITE * B-14	<20	<20	<20	228	9740	<10	<50	27.7	<50	<20	<20	3439
2003Q5076	1280	BRICKLEY SITE * B-14	<5.	<20.		187	8760	8			<10.	<5.		
2003Q0351	1280	BRICKLEY SITE * B-14	<20	<100	<100	199	9060	<10.0	<200		<100	<20	<20	3453
1988Q1010	1281	BRICKLEY SITE * B-20	<10.			1040	7180	6			1	20	<4.	5552
2003Q5077	1281	BRICKLEY SITE * B-20	10	<20.		1700	8060	<5.			<10.	<5.		
2003Q0352	1281	BRICKLEY SITE * B-20	<20	<100	<100	1640	8870	<10	<200		<100	<20	<20	5416
1986Q0100	1284	BRICKLEY SITE * B-8	80			332	863	14			11	19	<4.	7126
1986Q0411	1284	BRICKLEY SITE * B-8	50			587	7450	21			4	56	<4.	5985
1987Q0493	1284	BRICKLEY SITE * B-8				135								
1987Q0704	1284	BRICKLEY SITE * B-8				690								
1988Q1007	1284	BRICKLEY SITE * B-8	12			572	8610	9			5	24	<4.	6377
2003Q5085	188445	MBMG RESEARCH SITE * HS25	7	<20.		0.79	10200	6			<10.	<5.		
2003Q0432	188445	MBMG RESEARCH SITE * HS25	<20	<100	<100	<150	10100	<10	<200		<100	<20	<20	8805
2002Q0758	188447	MBMG RESEARCH SITE * HS26	<100	<100	<100	<50	10500	<50	<250	<25	<250	<100	<100	4974
2002Q0757	188614	MBMG RESEARCH SITE * B-4	<200	<200	<200	1600	11000	<100	<500	<50	<250	<200	<200	7024
2003Q5070	188615	MBMG RESEARCH SITE * B-12	6	<20.		11.9	13700	<5.			<10.	5		
2003Q0345	188615	MBMG RESEARCH SITE * B-12	<20	<100	<100	<150	13700	<10	<200		<100	<20	<20	13100
2003Q5075	188616	MBMG RESEARCH SITE * B-13	24	<20.		247	10200	5			<10.	9		
2003Q0350	188616	MBMG RESEARCH SITE * B-13	<20	<100	<100	154	9970	<10.0	<200		<100	<20	<20	11333
2002Q0759	188617	MBMG RESEARCH SITE * B-15	<20	<20	<20	382	7330	<10	<50	19	<50	<20	<20	11828

Appendix A.

Analytical results of surface and groundwater samples

Sample	Gwic Id	Site Name	Latitude	Longitude	Location (TRS)	Site Type	Depth (ft)	Agency	Sample Date	Water Temp (°C)	Field pH (S.U.)	Field S.C. (µS/cm)	Lab	Lab pH (S.U.)
Groundwater below transition														
2002Q0748	188419	MBMG RESEARCH SITE * HS01	46.0309	-109.1890	03N20E12BBBB	WELL	23	MBMG	12/17/2001	9.3	7.56	40240	MBMG	7.54
2003Q5086	188419	MBMG RESEARCH SITE * HS01	46.0309	-109.1890	03N20E12BBBB	WELL	23	USFWS	8/28/2002	10.6	7.51	38350	TERL	
2003Q0441	188419	MBMG RESEARCH SITE * HS01	46.0309	-109.1890	03N20E12BBBB	WELL	23	MBMG	8/28/2002	10.6	7.51	38350	MBMG	7.63
2002Q0749	188420	MBMG RESEARCH SITE * HS02	46.0309	-109.1892	03N20E12BBBB	WELL	13	MBMG	12/17/2001	9.3	7.70	37740	MBMG	7.63
2003Q5078	188420	MBMG RESEARCH SITE * HS02	46.0309	-109.1892	03N20E12BBBB	WELL	13	USFWS	8/28/2002	13.0	7.71	36300	TERL	
2003Q0438	188420	MBMG RESEARCH SITE * HS02	46.0309	-109.1892	03N20E12BBBB	WELL	13	MBMG	8/28/2002	13.0	7.71	36300	MBMG	7.65
2003Q5079	188421	MBMG RESEARCH SITE * HS03	46.0274	-109.1894	03N20E11AADD	WELL	18	USFWS	8/28/2002	11.0	7.73	41700	TERL	
2003Q0434	188421	MBMG RESEARCH SITE * HS03	46.0274	-109.1894	03N20E11AADD	WELL	18	MBMG	8/28/2002	11.0	7.73	41700	MBMG	7.76
2002Q0744	188422	MBMG RESEARCH SITE * HS04	46.0276	-109.1936	03N20E11AABB	WELL	13	MBMG	12/18/2001	9.6	7.32	37700	MBMG	7.49
2003Q5088	188423	MBMG RESEARCH SITE * HS05	46.0240	-109.1946	03N20E11ADCC	WELL	13	USFWS	8/29/2002	11.8	7.28	63200	TERL	
2003Q0428	188423	MBMG RESEARCH SITE * HS05	46.0240	-109.1946	03N20E11ADCC	WELL	13	MBMG	8/29/2002	11.8	7.28	63200	MBMG	7.84
2003Q5065	188424	MBMG RESEARCH SITE * HS06	46.0215	-109.1917	03N20E11DAAC	WELL	13	USFWS	8/24/2002	19.2	7.62	38250	TERL	
2003Q0437	188424	MBMG RESEARCH SITE * HS06	46.0215	-109.1917	03N20E11DAAC	WELL	13	MBMG	8/29/2002	19.2	7.62	38250	MBMG	7.84
2002Q0755	188425	MBMG RESEARCH SITE * HS07	46.0199	-109.1888	03N20E12CCBC	WELL	18	MBMG	12/17/2001	9.8	7.16	23560	MBMG	7.24
2002Q0752	188426	MBMG RESEARCH SITE * HS08	46.0175	-109.1872	03N20E12CCCD	WELL	13	MBMG	12/18/2001	9.4	7.29	36300	MBMG	7.49
2003Q0429	188426	MBMG RESEARCH SITE * HS08	46.0175	-109.1872	03N20E12CCCD	WELL	13	MBMG	8/28/2002	13.6	7.36	28750	MBMG	7.87
2003Q5087	188426	MBMG RESEARCH SITE * HS08	46.0175	-109.1872	03N20E12CCCD	WELL	13	USFWS	8/29/2002	13.6	7.36	28750	TERL	
2002Q0753	188427	MBMG RESEARCH SITE * HS09	46.0248	-109.1863	03N20E12BCBD	WELL	33	MBMG	12/18/2001	9.8	6.84	62500	MBMG	7.09
2002Q0740	188429	MBMG RESEARCH SITE * HS11	46.0228	-109.1841	03N20E12CACB	WELL	13	MBMG	12/18/2001	10.3		60300	MBMG	7.23
2002Q0746	188430	MBMG RESEARCH SITE * HS12	46.0217	-109.1797	03N20E12CAAD	WELL	13	MBMG	12/18/2001	9.0	7.42	67000	MBMG	7.37
2003Q5091	188430	MBMG RESEARCH SITE * HS12	46.0217	-109.1797	03N20E12CAAD	WELL	13	USFWS	8/29/2002	13.3	7.39	63100	TERL	
2003Q0431	188430	MBMG RESEARCH SITE * HS12	46.0217	-109.1797	03N20E12CAAD	WELL	13	MBMG	8/29/2002	13.3	7.39	63100	MBMG	7.71
2002Q0741	188431	MBMG RESEARCH SITE * HS13	46.0216	-109.1797	03N20E12CAAD	WELL	23	MBMG	12/18/2001	8.2	7.70	67300	MBMG	7.28
2003Q5089	188431	MBMG RESEARCH SITE * HS13	46.0216	-109.1797	03N20E12CAAD	WELL	23	USFWS	8/29/2002	11.8	7.28	63200	TERL	
2003Q0436	188431	MBMG RESEARCH SITE * HS13	46.0216	-109.1797	03N20E12CAAD	WELL	23	MBMG	8/29/2002	11.8	7.28	63200	MBMG	7.57
2002Q0742	188433	MBMG RESEARCH SITE * HS15	46.0244	-109.1761	03N20E12ACAD	WELL	13	MBMG	12/18/2001	9.3		72700	MBMG	7.71
2003Q5084	188435	MBMG RESEARCH SITE * HS16	46.0269	-109.1774	03N20E12ABDD	WELL	13	USFWS	8/28/2002	13.4	7.72	63600	TERL	
2003Q0433	188435	MBMG RESEARCH SITE * HS16	46.0269	-109.1774	03N20E12ABDD	WELL	13	MBMG	8/29/2002	13.4	7.72	63600	MBMG	7.80
2002Q0745	188436	MBMG RESEARCH SITE * HS17	46.0290	-109.1776	03N20E12ABAC	WELL	18	MBMG	12/18/2001	9.7	7.50	68100	MBMG	7.59
2003Q5090	188436	MBMG RESEARCH SITE * HS17	46.0290	-109.1776	03N20E12ABAC	WELL	18	USFWS	8/29/2002	11.6	7.67	63800	TERL	
2003Q0430	188436	MBMG RESEARCH SITE * HS17	46.0290	-109.1776	03N20E12ABAC	WELL	18	MBMG	8/29/2002	11.6	7.67	63800	MBMG	7.86
2002Q0754	188437	MBMG RESEARCH SITE * HS18	46.0262	-109.1831	03N20E12BDBB	WELL	28	MBMG	12/17/2001	9.6	6.95	55100	MBMG	7.15
2003Q5080	188440	MBMG RESEARCH SITE * HS20	46.0284	-109.1867	03N20E12BBCA	WELL	13	USFWS	8/28/2002	13.9	7.73	57000	TERL	
2003Q0442	188440	MBMG RESEARCH SITE * HS20	46.0284	-109.1867	03N20E12BBCA	WELL	13	MBMG	8/28/2002	13.9	7.73	57000	MBMG	7.70
2002Q0747	188441	MBMG RESEARCH SITE * HS21	46.0125	-109.1571	03N20E18ADDB	WELL	18	MBMG	12/19/2001				MBMG	7.78
2003Q5081	188441	MBMG RESEARCH SITE * HS21	46.0125	-109.1571	03N20E18ADDB	WELL	18	USFWS	8/28/2002	11.5	7.24	63500	TERL	
2003Q0439	188441	MBMG RESEARCH SITE * HS21	46.0125	-109.1571	03N20E18ADDB	WELL	18	MBMG	8/28/2002	11.5	7.24	63500	MBMG	7.60
2003Q5083	188442	MBMG RESEARCH SITE * HS22	46.0111	-109.1596	03N20E18ACCC	WELL	18	USFWS	8/28/2002	11.7	6.60	51100	TERL	
2003Q0435	188442	MBMG RESEARCH SITE * HS22	46.0111	-109.1596	03N20E18ACCC	WELL	18	MBMG	8/28/2002	11.7	6.60	51100	MBMG	7.13
2003Q5082	188443	MBMG RESEARCH SITE * HS23	46.0096	-109.1634	03N20E18DBBB	WELL	13	USFWS	8/28/2002	14.0	7.35	58700	TERL	
2003Q0440	188443	MBMG RESEARCH SITE * HS23	46.0096	-109.1634	03N20E18DBBB	WELL	13	MBMG	8/28/2002	14.0	7.35	58700	MBMG	7.88
2002Q0750	188444	MBMG RESEARCH SITE * HS24	46.0094	-109.1689	03N20E18CBAA	WELL	18	MBMG	12/19/2001		7.21	36000	MBMG	7.23

Appendix A.

Analytical results of surface and groundwater samples

Sample	Gwic Id	Site Name	Lab S.C. µS/cm	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Fe (mg/L)	Mn (mg/L)	SiO2 (mg/L)	HCO3 (mg/L)	CO3 (mg/L)	SO4 (mg/L)	Cl (mg/L)	NO3 (mg/L)	F (mg/L)	OPO4 (mg/L)
Groundwater below transition																	
2002Q0748	188419	MBMG RESEARCH SITE * HS01	30000	423	4570	9790	20.9	2.14	0.834	8.39	998	0	37816	298	10.3 P	52.1	<25.0
2003Q5086	188419	MBMG RESEARCH SITE * HS01		437	4620	10700		<0.01	1.39								
2003Q0441	188419	MBMG RESEARCH SITE * HS01	28200	435	4720	10000	22.6	0.767	1.33	8.49	1039.4	0	39900	<500	8. P	<5	<5
2002Q0749	188420	MBMG RESEARCH SITE * HS02	26500	414	3890	9170	18.3	2	<.05	8.43	851.6	0	34329	302	14.5 P	42.3	<100
2003Q5078	188420	MBMG RESEARCH SITE * HS02		466	4230	10300		<0.01	0.01								
2003Q0438	188420	MBMG RESEARCH SITE * HS02	27000	469	3908	9120	19.7	0.809	<0.05	8.67	849.1	0	35900	265	13.0 P	<3.0	<3.0
2003Q5079	188421	MBMG RESEARCH SITE * HS03		452	7560	10100		0.178	3.52								
2003Q0434	188421	MBMG RESEARCH SITE * HS03	30800	469	7572	9395	27.8	0.486	3.5	6.52	697.8	0	48800	<50	<13.0 P	<5.0	<5.0
2002Q0744	188422	MBMG RESEARCH SITE * HS04	29600	412	4250	8170	15.1	2.16	1.27	8.7	895.5	0	35444	629	<5.0 P	42.3	<25.0
2003Q5088	188423	MBMG RESEARCH SITE * HS05		469	5070	11300		0.02	1.52								
2003Q0428	188423	MBMG RESEARCH SITE * HS05	29300	453	4920	10500	26.4	0.776	1.48	7.01	834.5	0	39800	276	<5.0 P	<100	<5.0
2003Q5065	188424	MBMG RESEARCH SITE * HS06		475	4770	11200		0.01	2.53								
2003Q0437	188424	MBMG RESEARCH SITE * HS06	29100	465	4430	9570	26.1	1.1	2.4	7.52	805.2	0	39800	147	<13.0 P	<3.0	<3.0
2002Q0755	188425	MBMG RESEARCH SITE * HS07	19210	370	1460	5060	17.7	0.897	3.67	9.42	807.6	0	17772	249	<.50 P	21.9	<5.0
2002Q0752	188426	MBMG RESEARCH SITE * HS08	25900	410	3090	9390	26.4	1.79	3.51	9.57	884.5	0	31364	408	<5.0	39.7	<25.0
2003Q0429	188426	MBMG RESEARCH SITE * HS08	23600	413	2200	8040	22.9	0.75	5.07	9.27	902.8	0	24400	318	<5.0 P	<50	<5.0
2003Q5087	188426	MBMG RESEARCH SITE * HS08		420	2250	8050		0.03	5.2								
2002Q0753	188427	MBMG RESEARCH SITE * HS09	39100	483	6490	17300	50	11.9	5.63	8.17	1461.6	0	59169	1149	<5.0 P	75.1	<25.0
2002Q0740	188429	MBMG RESEARCH SITE * HS11	36700	476	3740	17800	45.9	2.91	3.65	10	1614.1	0	53560	1202	<5.0 P	47.7	<5.0
2002Q0746	188430	MBMG RESEARCH SITE * HS12	41200	496	11600	18900	39.2	2.21	8.23	11	1271.2	0	86133	1740	<5.0 P	84.2	<25.0
2003Q5091	188430	MBMG RESEARCH SITE * HS12		508	11600	24800		0.05	7.71								
2003Q0431	188430	MBMG RESEARCH SITE * HS12	39700	512	11200	20250	40.3	<0.25	8.14	10.1	1268.8	0	85500	1400	<13. P	<13	<13
2002Q0741	188431	MBMG RESEARCH SITE * HS13	44400	520	11500	19000	46.6	2.51	10.2	9.15	1433.5	0	87573	1723	<5.0 P	70.2	<5.0
2003Q5089	188431	MBMG RESEARCH SITE * HS13		514	12100	24800		0.101	10.6								
2003Q0436	188431	MBMG RESEARCH SITE * HS13	38500	513	12236	20400	48	<0.25	10.9	7.55	1598.2	0	90000	1460	<5.0 P	<13.0	<13.0
2002Q0742	188433	MBMG RESEARCH SITE * HS15	43600	544	11400	19600	49.5	2.16	7.93	6.1	1198	0	87210	810	<5.0 P	74.7	<5.0
2003Q5084	188435	MBMG RESEARCH SITE * HS16		526	12000	27100		0.08	7.87								
2003Q0433	188435	MBMG RESEARCH SITE * HS16	39100	530	11400	21500	36.8	<0.25	8.45	7.66	1220	0	94900	<50	<5. P	<5	<5
2002Q0745	188436	MBMG RESEARCH SITE * HS17	40400	536	9900	19100	49.2	2.27	5.14	5.66	1671.4	0	77291	67.9	<5.0 P	92.9	<25.0
2003Q5090	188436	MBMG RESEARCH SITE * HS17		525	10500	28200		0.07	3.19								
2003Q0430	188436	MBMG RESEARCH SITE * HS17	40100	524	10200	23500	46.8	<0.25	3.26	<5.0	1354.2	0	89500	39	<13.0	<100	<13.0
2002Q0754	188437	MBMG RESEARCH SITE * HS18	36500	433	2500	17500	39.6	1.92	2.61	9.38	1588.4	0	45807	973	<5.0 P	59.7	<25.0
2003Q5080	188440	MBMG RESEARCH SITE * HS20		522	13000	19400		0.02	0.82								
2003Q0442	188440	MBMG RESEARCH SITE * HS20	35400	521	12174	17300	42.1	<0.25	0.807	<5.0	883.3	0	82900	<1000	<13.0 P	<5.0	<5.0
2002Q0747	188441	MBMG RESEARCH SITE * HS21	38400	510	8000	19500	51.5	2.42	4.33	6.73	1434.7	0	72751	1310	<5.0	78.7	<25.0
2003Q5081	188441	MBMG RESEARCH SITE * HS21		543	7530	30700		<0.01	3.65								
2003Q0439	188441	MBMG RESEARCH SITE * HS21	37200	550	6992	22500	54.6	0.492	3.64	6.12	1507.9	0	77000	1120	<13.0 P	<100	<100
2003Q5083	188442	MBMG RESEARCH SITE * HS22		464	3850	20300		6.05	8.47								
2003Q0435	188442	MBMG RESEARCH SITE * HS22	34800	469	3810	17000	47.5	4.12	8.83	13	1141.9	0	50500	<50	<13.0 P	<5.0	<5.0
2003Q5082	188443	MBMG RESEARCH SITE * HS23		491	4260	26500		0.04	2.62								
2003Q0440	188443	MBMG RESEARCH SITE * HS23	36200	489	4147	21250	59	0.856	2.68	8.27	1117.5	0	60900	1170	<13.0 P	<5.0	<5.0
2002Q0750	188444	MBMG RESEARCH SITE * HS24	28300	416	5238	7510	43.2	2.25	1.47	7.6	470.9	0	35710	644	<5.0 P	48.3	<25.0

Appendix A.

Analytical results of surface and groundwater samples

Sample	Gwic Id	Site Name	Ag (µg/l)	Al (µg/l)	As (µg/L)	B (µg/L)	Ba (µg/l)	Be (µg/l)	Br (µg/l)	Cd (µg/l)	Co (µg/l)	Cr (µ/l)	Cu (µg/l)	Hg (µg/l)	Li (µg/l)	Mo (µg/l)
Groundwater below																
transition																
2002Q0748	188419	MBMG RESEARCH SITE * HS01	<50	<1500	<50	<1500	<100	<100	<5000	<100	<100	<100	<100		2260	<500
2003Q5086	188419	MBMG RESEARCH SITE * HS01	<10.	311	<20.	1550	8	<0.5		<2.	<5.	<5.	15	<0.02		50
2003Q0441	188419	MBMG RESEARCH SITE * HS01		<1500	<500	<1500	<100	<100	<5000	<50	<100	<500	<250		2330	<500
2002Q0749	188420	MBMG RESEARCH SITE * HS02	<50	<1500	<50	<1500	<100	<100	<5000	<100	<100	<100	<100		2260	<500
2003Q5078	188420	MBMG RESEARCH SITE * HS02	<10.	317	<20.	1760	9	<0.5		<2.	<5.	<5.	16	0.04		50
2003Q0438	188420	MBMG RESEARCH SITE * HS02		<1500	<500	<1500	<100	<100	<3000	<50	<100	<500	<250		2300	<500
2003Q5079	188421	MBMG RESEARCH SITE * HS03	<10.	326	<20.	1360	9	<0.5		<2.	13	<5.	8	0.03		60
2003Q0434	188421	MBMG RESEARCH SITE * HS03		<1500	<500	<1500	<100	<100	<5000	<50	<100	<500	<250		2440	<500
2002Q0744	188422	MBMG RESEARCH SITE * HS04	<50	<1500	<50	3410	<100	<100	<5000	<100	<100	<100	<100		2300	<500
2003Q5088	188423	MBMG RESEARCH SITE * HS05	<10.	328	<20.	1960	10	<0.5		<2.	<5.	<5.	19	<0.02		50
2003Q0428	188423	MBMG RESEARCH SITE * HS05		<1500	<500	1810	<100	<100	<5000	<50	<100	<500	<250		1110	<500
2003Q5065	188424	MBMG RESEARCH SITE * HS06	<10.	331	<20.	1950	11	<0.5		<2.	<5.	<5.	21	0.04		40
2003Q0437	188424	MBMG RESEARCH SITE * HS06		<1500	<500	1780	<100	<100	<3000	<50	<100	<500	<250		1080	<500
2002Q0755	188425	MBMG RESEARCH SITE * HS07	<25	<750	<25	1510	<50	<50	<5000	<50	<50	<50	<50		909	<250
2002Q0752	188426	MBMG RESEARCH SITE * HS08	<50	<1500	<50	1840	<100	<100	<5000	<100	<100	<100	<100		1310	<500
2003Q0429	188426	MBMG RESEARCH SITE * HS08		<1500	<500	1610	<100	<100	<5000	<50	<100	<500	<250		1130	<500
2003Q5087	188426	MBMG RESEARCH SITE * HS08	<10.	315	<20.	1780	8	<0.5		<2.	<5.	<5.	7	<0.02		20
2002Q0753	188427	MBMG RESEARCH SITE * HS09	<50	<1500	<50	<1500	<100	<100	<5000	<100	<100	<100	123		2420	<500
2002Q0740	188429	MBMG RESEARCH SITE * HS11	<50	<1500	<50	<1500	<100	<100	<5000	<100	<100	<100	141		2090	<500
2002Q0746	188430	MBMG RESEARCH SITE * HS12	<50	<1500	<50	<1500	<100	<100	<5000	<100	<100	<100	141		1580	<500
2003Q5091	188430	MBMG RESEARCH SITE * HS12	<10.	328	<20.	594	13	<0.5		<2.	17	<5.	29	<0.02		80
2003Q0431	188430	MBMG RESEARCH SITE * HS12		<1500	<500	<1500	<100	<100	<13000	<50	<100	<500	<250		1680	<500
2002Q0741	188431	MBMG RESEARCH SITE * HS13	<50	<1500	<50	<1500	<100	<100	<5000	<100	<100	<100	181		1980	<500
2003Q5089	188431	MBMG RESEARCH SITE * HS13	<10.	325	<20.	824	15	<0.5		<2.	20	<5.	53	<0.02		30
2003Q0436	188431	MBMG RESEARCH SITE * HS13		1860	<500	<1500	<100	<100	<13000	<50	<100	<500	<250		2220	<500
2002Q0742	188433	MBMG RESEARCH SITE * HS15	<50	<1500	<50	<1500	<100	<100	<5000	<100	<100	<100	323		1160	<500
2003Q5084	188435	MBMG RESEARCH SITE * HS16	<10.	334	<20.	480	24	<0.5		<2.	16	<5.	20	<0.02		158
2003Q0433	188435	MBMG RESEARCH SITE * HS16		<1500	<500	<1500	<100	<100	<5000	<50	<100	<500	<250		1570	<500
2002Q0745	188436	MBMG RESEARCH SITE * HS17	<50	<1500	<50	<1500	<100	<100	<5000	<100	<100	<100	266		1490	<500
2003Q5090	188436	MBMG RESEARCH SITE * HS17	<10.	335	<20.	550	16	<0.5		<2.	11	<5.	88	<0.02		102
2003Q0430	188436	MBMG RESEARCH SITE * HS17		<1500	<500	<1500	<100	<100	<13000	<50	<100	<500	<250		1430	<500
2002Q0754	188437	MBMG RESEARCH SITE * HS18	<50	<1500	<50	<1500	<100	<100	<5000	<100	<100	<100	121		2920	<500
2003Q5080	188440	MBMG RESEARCH SITE * HS20	<10.	338	<20.	820	12	<0.5		<2.	6	<5.	31	0.03		70
2003Q0442	188440	MBMG RESEARCH SITE * HS20		1570	<500	<1500	<100	<100	<5000	<50	<100	<500	<250		2010	<500
2002Q0747	188441	MBMG RESEARCH SITE * HS21	<50	<1500	<50	<1500	<100	<100	<5000	<100	<100	<100	147		1190	<500
2003Q5081	188441	MBMG RESEARCH SITE * HS21	<10.	341	<20.	1100	11	<0.5		<2.	27	<5.	18	<0.02		50
2003Q0439	188441	MBMG RESEARCH SITE * HS21		<1500	<500	<1500	<100	<100	<100000	<50	<100	<500	<250		1210	<500
2003Q5083	188442	MBMG RESEARCH SITE * HS22	<10.	3510	<20.	1150	32	<0.5		<2.	21	<5.	8	0.03		<10.
2003Q0435	188442	MBMG RESEARCH SITE * HS22		1790	<500	<1500	<100	<100	<5000	<50	<100	<500	<250		2470	<500
2003Q5082	188443	MBMG RESEARCH SITE * HS23	<10.	342	<20.	644	14	<0.5		<2.	11	<5.	<5.	<0.02		20
2003Q0440	188443	MBMG RESEARCH SITE * HS23		<1500	<500	<1500	<100	<100	<5000	<50	<100	<500	<250		3340	<500
2002Q0750	188444	MBMG RESEARCH SITE * HS24	<50	<1500	<50	<1500	<100	<100	<5000	<100	<100	<100	<100		1500	<500

Appendix A.

Analytical results of surface and groundwater samples

Sample	Gwic Id	Site Name	Ni (µg/l)	Pb (µg/l)	Sb (µg/l)	Se (µg/l)	Sr (µg/l)	Ti (µg/l)	Tl (µg/l)	U (µg/l)	V (µg/l)	Zn (µg/l)	Zr (µg/l)	Total Dissolved Solids(mg/L)
Groundwater below transition														
2002Q0748	188419	MBMG RESEARCH SITE * HS01	<100	<100	<100	<50	13600	<50	<250	370	<250	<100	<100	53483
2003Q5086	188419	MBMG RESEARCH SITE * HS01	13	<20.		10.6	12900	<5.			<10.	<5.		
2003Q0441	188419	MBMG RESEARCH SITE * HS01	<100	<500	<500	<750	14000	<50	<1000		<500	<100	<100	55608
2002Q0749	188420	MBMG RESEARCH SITE * HS02	<100	<100	<100	<50	13800	<50	<250	349	<250	<100	<100	48610
2003Q5078	188420	MBMG RESEARCH SITE * HS02	6	<20.		15.4	13300	5			<10.	5		
2003Q0438	188420	MBMG RESEARCH SITE * HS02	<100	<500	<500	<750	12900	<50	<1000		<500	<100	<100	50122
2003Q5079	188421	MBMG RESEARCH SITE * HS03	13	<20.		1.36	13800	5			<10.	6		
2003Q0434	188421	MBMG RESEARCH SITE * HS03	<100	<500	<500	<750	14100	<50	<100		<500	<100	<100	66618
2002Q0744	188422	MBMG RESEARCH SITE * HS04	<100	<100	<100	<50	15100	<50	<250	200	<250	<100	<100	49416
2003Q5088	188423	MBMG RESEARCH SITE * HS05	9	<20.		13.3	13000	5			<10.	27		
2003Q0428	188423	MBMG RESEARCH SITE * HS05	<100	<500	<500	<750	13100	<50	<1000		<500	<100	<100	56396
2003Q5065	188424	MBMG RESEARCH SITE * HS06	13	<20.		0.76	11900	5			<10.	20		
2003Q0437	188424	MBMG RESEARCH SITE * HS06	<100	<500	<500	<750	11600	<50	<1000		<500	<100	<100	54846
2002Q0755	188425	MBMG RESEARCH SITE * HS07	<50	<50	<50	<25	9830	<25	<125	63.2	<125	<50	<50	25362
2002Q0752	188426	MBMG RESEARCH SITE * HS08	<100	<100	<100	<50	11600	<50	<250	155	<250	<100	<100	45179
2003Q0429	188426	MBMG RESEARCH SITE * HS08	<100	<500	<500	<750	9790	<50	<100		<500	<100	<100	35854
2003Q5087	188426	MBMG RESEARCH SITE * HS08	15	<20.		0.16	9290	6			<10.	13		
2002Q0753	188427	MBMG RESEARCH SITE * HS09	<100	<100	<100	<50	13600	<50	<250	278	<250	<100	<100	85462
2002Q0740	188429	MBMG RESEARCH SITE * HS11	<100	<100	<100	<50	14600	<50	<250	241	<250	<100	<100	77683
2002Q0746	188430	MBMG RESEARCH SITE * HS12	<100	<100	<100	<50	16000	<50	<250	645	<250	100	<100	119640
2003Q5091	188430	MBMG RESEARCH SITE * HS12	44	<20.		5.59	15300	6			<10.	34		
2003Q0431	188430	MBMG RESEARCH SITE * HS12	<100	<500	<500	<750	16300	<50	<1000		<500	<100	<100	119546
2002Q0741	188431	MBMG RESEARCH SITE * HS13	<100	817	<100	62.2	16600	<50	<250	541	<250	128	<100	121161
2003Q5089	188431	MBMG RESEARCH SITE * HS13	91	3250		4.41	15500	6			<10.	28		
2003Q0436	188431	MBMG RESEARCH SITE * HS13	<100	3060	<500	<750	16100	<50	<1000		<500	<100	<100	125465
2002Q0742	188433	MBMG RESEARCH SITE * HS15	<100	<100	<100	<50	18300	<50	<250	1100	<250	105	<100	120295
2003Q5084	188435	MBMG RESEARCH SITE * HS16	40	<20.		4.54	16000	7			<100.	32		
2003Q0433	188435	MBMG RESEARCH SITE * HS16	<100	<500	<500	<750	17200	<50	<1000		<500	<100	<100	128984
2002Q0745	188436	MBMG RESEARCH SITE * HS17	<100	<100	<100	<50	18300	<50	<250	1080	<250	105	<100	107874
2003Q5090	188436	MBMG RESEARCH SITE * HS17	49	<20.		6.84	17100	6			<10.	33		
2003Q0430	188436	MBMG RESEARCH SITE * HS17	<100	<500	<500	<750	16100	<50	<100		<500	<100	<100	124480
2002Q0754	188437	MBMG RESEARCH SITE * HS18	<100	<100	<100	<50	11600	<50	<250	93	<250	<100	<100	68109
2003Q5080	188440	MBMG RESEARCH SITE * HS20	17	<20.		9.35	16200	5			<10.	7		
2003Q0442	188440	MBMG RESEARCH SITE * HS20	<100	<500	<500	<750	15600	<50	<1000		<500	<100	<100	113375
2002Q0747	188441	MBMG RESEARCH SITE * HS21	<100	<100	<100	<50	17700	<50	<250	514	<250	<100	<100	102922
2003Q5081	188441	MBMG RESEARCH SITE * HS21	65	<20.		2.17	17300	6			<10.	7		
2003Q0439	188441	MBMG RESEARCH SITE * HS21	<100	<500	<500	<750	16100	<50	<1000		<500	<100	<100	108970
2003Q5083	188442	MBMG RESEARCH SITE * HS22	57	<20.		0.44	12700	36			<10.	32		
2003Q0435	188442	MBMG RESEARCH SITE * HS22	<100	<500	<500	<750	12500	<50	<1000		<500	<100	<100	72417
2003Q5082	188443	MBMG RESEARCH SITE * HS23	38	<20.		0.45	14400	<5.			<10.	10		
2003Q0440	188443	MBMG RESEARCH SITE * HS23	<100	<500	<500	<750	14300	<50	<1000		<500	<100	<100	88577
2002Q0750	188444	MBMG RESEARCH SITE * HS24	<100	<100	<100	<50	11800	<50	<250	71.4	<250	<100	<100	49853

Appendix A.

Analytical results of surface and groundwater samples

Sample	Gwic Id	Site Name	Latitude	Longitude	Location (TRS)	Site Type	Depth (ft)	Agency	Sample Date	Water Temp (°C)	Field pH (S.U.)	Field S.C. (µS/cm)	Lab	Lab pH (S.U.)
Halfbreed NWR														
2003Q5066	197332	MBMG RESEARCH WELL * HB01	45.9676	-109.1176	03N21E33BDCB	WELL	23	USFWS	8/26/2002	11.1	7.16	34820	TERL	
2003Q0354	197332	MBMG RESEARCH WELL * HB01	45.9676	-109.1176	03N21E33BDCB	WELL	23	MBMG	8/26/2002	11.1	7.16	34820	MBMG	7.71
2003Q5069	197333	MBMG RESEARCH WELL * HB02	45.9657	-109.1202	03N21E33CBAA	WELL	18	USFWS	8/26/2002	13.8	7.40	45100	TERL	
2003Q0349	197333	MBMG RESEARCH WELL * HB02	45.9657	-109.1202	03N21E33CBAA	WELL	18	MBMG	8/26/2002	13.8	7.40	45100	MBMG	7.59
2003Q5068	197334	MBMG RESEARCH WELL * HB03	45.9635	-109.1097	03N21E34CCBB	WELL	18	USFWS	8/26/2002	11.2	7.03	34620	TERL	
2003Q0355	197334	MBMG RESEARCH WELL * HB03	45.9635	-109.1097	03N21E34CCBB	WELL	18	MBMG	8/26/2002	11.2	7.03	34620	MBMG	7.56
2003Q5074	197335	MBMG RESEARCH WELL * HB04	45.9520	-109.1103	02N21E03CBBB	WELL	28	USFWS	8/27/2002	10.2	7.29	29750	TERL	
2003Q0348	197335	MBMG RESEARCH WELL * HB04	45.9520	-109.1103	02N21E03CBBB	WELL	28	MBMG	8/27/2002	10.2	7.29	29750	MBMG	7.73
2003Q5067	197336	MBMG RESEARCH WELL * HB05	45.9438	-109.1084	02N21E03CCCC	WELL	18	USFWS	8/26/2002	14.3	7.20	44670	TERL	
2003Q0356	197336	MBMG RESEARCH WELL * HB05	45.9438	-109.1084	02N21E03CCCC	WELL	18	MBMG	8/26/2002	14.3	7.20	44670	MBMG	7.67
2003Q5071	197338	MBMG RESEARCH WELL * HB06	45.9437	-109.1118	02N21E09AAAB	WELL	28	USFWS	8/27/2002	10.2	7.24	47790	TERL	
2003Q0347	197338	MBMG RESEARCH WELL * HB06	45.9437	-109.1118	02N21E09AAAB	WELL	28	MBMG	8/27/2002	10.2	7.24	47790	MBMG	7.71

Appendix A.

Analytical results of surface and groundwater samples

Sample	Gwic Id	Site Name	Lab S.C. µS/cm	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Fe (mg/L)	Mn (mg/L)	SiO2 (mg/L)	HCO3 (mg/L)	CO3 (mg/L)	SO4 (mg/L)	Cl (mg/L)	NO3 (mg/L)	F (mg/L)	OPO4 (mg/L)
Halfbreed NWR																	
2003Q5066	197332	MBMG RESEARCH WELL * HB01		432	3200	9600		<0.01	3.39								
2003Q0354	197332	MBMG RESEARCH WELL * HB01	26200	402	3229	9190	50.8	0.767	3.21	6.97	754	0	30100	388	<5.0 P	<50	<5.0
2003Q5069	197333	MBMG RESEARCH WELL * HB02		467	4040	13300		<0.01	3.84								
2003Q0349	197333	MBMG RESEARCH WELL * HB02	30500	456	4060	12100	44.1	0.881	3.86	9.05	741.8	0	38100	430	<5.0 P	<5.0	<5.0
2003Q5068	197334	MBMG RESEARCH WELL * HB03		428	2400	10000		<0.01	13.7								
2003Q0355	197334	MBMG RESEARCH WELL * HB03	25700	409	2300	9170	34.9	0.729	13.6	7.56	1210.2	0	27100	100	<5.0 P	<50	<5.0
2003Q5074	197335	MBMG RESEARCH WELL * HB04		419	1710	8130		0.127	2.14								
2003Q0348	197335	MBMG RESEARCH WELL * HB04	23200	406	1680	7730	52.1	0.594	2.04	7.16	771	0	22500	844	<5.0 P	<50	<5.0
2003Q5067	197336	MBMG RESEARCH WELL * HB05		468	3430	15200		0.02	2.41								
2003Q0356	197336	MBMG RESEARCH WELL * HB05	31000	471	3312	12700	48.8	0.751	2.35	7.55	1488.4	0	36100	1649	<13.0 P	<100	<13.0
2003Q5071	197338	MBMG RESEARCH WELL * HB06		451	2870	17100		<0.01	2.1								
2003Q0347	197338	MBMG RESEARCH WELL * HB06	32400	446	2907	14500	52	0.756	2.1	7.64	1278.6	0	39600	944	<5.0	<100	<5.0

Appendix A.

Analytical results of surface and groundwater samples

Sample	Gwic Id	Site Name	Ag (µg/l)	Al (µg/l)	As (µg/L)	B (µg/L)	Ba (µg/l)	Be (µg/l)	Br (µg/l)	Cd (µg/l)	Co (µg/l)	Cr (µ/l)	Cu (µg/l)	Hg (µg/l)	Li (µg/l)	Mo (µg/l)
Halfbreed NWR																
2003Q5066	197332	MBMG RESEARCH WELL * HB01	<10.	302	<20.	462	11	<0.5		<2.	7	<5.	5	<0.02		<10.
2003Q0354	197332	MBMG RESEARCH WELL * HB01		<1500	<500	<1500	<100	<100	<5000	<50	<100	<500	<250		1160	<500
2003Q5069	197333	MBMG RESEARCH WELL * HB02	<10.	329	<20.	575	25	<0.5		<2.	26	<5.	7	<0.02		30
2003Q0349	197333	MBMG RESEARCH WELL * HB02		<1500	<500	<1500	<100	<100	<5000	<50	<100	<500	<250		779	<500
2003Q5068	197334	MBMG RESEARCH WELL * HB03	<10.	309	<20.	722	8	<0.5		<2.	34	<5.	<5.	<0.02		10
2003Q0355	197334	MBMG RESEARCH WELL * HB03		<1500	<500	<1500	<100	<100	<5000	<50	<100	<500	<250		244	<500
2003Q5074	197335	MBMG RESEARCH WELL * HB04	<10.	314	<20.	982	10	<0.5		<2.	<5.	<5.	6	<0.02		100
2003Q0348	197335	MBMG RESEARCH WELL * HB04		<1500	<500	<1500	<100	<100	<5000	<50	<100	<500	<250		266	<500
2003Q5067	197336	MBMG RESEARCH WELL * HB05	<10.	322	<20.	1420	22	<0.5		<2.	5	<5.	12	0.02		50
2003Q0356	197336	MBMG RESEARCH WELL * HB05		<1500	<500	<1500	<100	<100	<13000	<50	<100	<500	<250		328	<500
2003Q5071	197338	MBMG RESEARCH WELL * HB06	<10.	322	<20.	1030	15	<0.5		<2.	<5.	<5.	7	0.02		30
2003Q0347	197338	MBMG RESEARCH WELL * HB06		<1500	<500	<1500	<100	<100	<5000	<50	<100	<500	<250		268	<500

Appendix A.

Analytical results of surface and groundwater samples

Sample	Gwic Id	Site Name	Ni (µg/l)	Pb (µg/l)	Sb (µg/l)	Se (µg/l)	Sr (µg/l)	Ti (µg/l)	Tl (µg/l)	U (µg/l)	V (µg/l)	Zn (µg/l)	Zr (µg/l)	Total Dissolved Solids(mg/L)
Halfbreed NWR														
2003Q5066	197332	MBMG RESEARCH WELL * HB01	19	<20.		0.55	12200	5			<10.	8		
2003Q0354	197332	MBMG RESEARCH WELL * HB01	<100	<500	<500	<750	12100	<50	<1000		<500	<100	<100	43742
2003Q5069	197333	MBMG RESEARCH WELL * HB02	30	<20.		1.32	13200	5			<10.	23		
2003Q0349	197333	MBMG RESEARCH WELL * HB02	<100	<500	<500	<750	14600	<50	<1000		<500	<100	<100	55569
2003Q5068	197334	MBMG RESEARCH WELL * HB03	31	<20.		0.34	9540	<5.			<10.	19		
2003Q0355	197334	MBMG RESEARCH WELL * HB03	<100	<500	<500	<750	9580	<50	<1000		<500	<100	<100	39732
2003Q5074	197335	MBMG RESEARCH WELL * HB04	<5.	<20.		1.23	9750	<5.			<10.	8		
2003Q0348	197335	MBMG RESEARCH WELL * HB04	<100	<500	<500	<750	9880	<50	<1000		<500	<100	<100	33602
2003Q5067	197336	MBMG RESEARCH WELL * HB05	24	<20.		1.5	13700	5			<10.	12		
2003Q0356	197336	MBMG RESEARCH WELL * HB05	<100	<500	<500	<750	13600	<50	<1000		<500	<100	<100	55025
2003Q5071	197338	MBMG RESEARCH WELL * HB06	12	<20.		1.85	12200	6			<10.	6		
2003Q0347	197338	MBMG RESEARCH WELL * HB06	<100	<500	<500	<750	12300	<50	<1000		<500	<100	<100	59089

Appendix B. Analytical Results of Sediment, Soils, and Biota.
Concentrations in ppm.

Sample	Sample	Sample	Species	Sample	Al		As		B		Ba	
Location	Date	Number	Name	Matrix	dw	ww	dw	ww	dw	ww	dw	ww
Hailstone Dam	5/24/2001	HD0524S		Sediments	7690	5275	3.41	2.34	13.9	9.54	20.6	14.1
Hailstone Dam	8/1/2001	HD0801S		Sediments	9610	6381	5.25	3.49	17	11.3	33.7	22.4
Below Dam	5/24/2001	BD0524S		Sediments	3990	1001	1.12	0.281	28.9	7.25	47.6	11.9
Below Dam	8/1/2001	BD0801S		Sediments	4360	1264	0.878	0.255	18.5	5.36	44	12.8
East Hailstone	5/24/2001	EH0524S		Sediments	7790	4105	3.74	1.97	41.2	21.7	31.8	16.8
East Tributary	5/24/2001	ET0524S		Sediments	18500	9583	4.84	2.51	57	29.5	43.2	22.4
West Hailstone	5/24/2001	WH0524S		Sediments	9150	5508	4.4	2.65	41.8	25.2	33.6	20.2
Hailstone Dam	5/9/2001	HD0509A	Brine Shrimp	Invertebrate	464	84	11.9	2.15	51.7	9.36	4.75	0.86
Hailstone Dam	8/1/2001	HD0801A	Brine Shrimp	Invertebrate	1290	264	16.6	3.4	32.9	6.74	10.2	2.09
Below Dam	5/7/2001	BD0507C	Ephydridae	Invertebrate	2130	345	3.26	0.528	13.5	2.19	32.3	5.23
Below Dam	8/1/2001	BD0801C	Ephydridae	Invertebrate	584	416	1.4	0.998	8.52	6.07	12.8	9.13
East Hailstone	5/8/2001	EH0508A	Brine Shrimp	Invertebrate	569	105	13.5	2.48	47.2	8.68	4.94	0.909
East Tributary	5/7/2001	ET0507A	Brine Shrimp	Invertebrate	1090	213	17.7	3.45	48.3	9.42	8.54	1.67
West Hailstone	5/7/2001	WH0507E	Brine Shrimp	Invertebrate	1480	363	6.14	1.5	85.1	20.8	12.3	3.01
West Hailstone	5/9/2001	WH0509A	Brine Shrimp	Invertebrate	497	97.9	11.6	2.29	58.6	11.5	4.09	0.806
Hailstone NWR	4/26/2001	H0426AW	American Wigeon	Liver	< 5.48	< 1.74	< .548	< .174	1.45	0.46	< .110	< .0349
Hailstone NWR	5/30/2001	H0530A	American Avocet	Liver	14.9	4.5	0.763	0.23	1.13	0.341	0.271	0.0818
Hailstone NWR	5/30/2001	H0530W	Willet	Liver	8.56	2.84	0.936	0.311	1.21	0.402	0.707	0.235
Hailstone NWR	7/26/2001	H0726C1	Curlew	Liver	9.45	2.93	< .529	< .164	< 1.06	< .329	0.544	0.169
Hailstone NWR	7/26/2001	H0726C2	Curlew	Liver	7.91	2.5	< .517	< .163	< 1.03	< .325	0.381	0.12
Hailstone NWR	7/26/2001	H0726P1	Phalarope	Liver	15.1	4.89	6.13	1.99	< 1.03	< .334	0.29	0.094
Hailstone NWR	7/26/2001	H0726P2	Phalarope	Liver	23.7	9.03	2.38	0.907	< 1.01	< .385	0.313	0.119
Hailstone NWR	7/26/2001	H0726P3	Phalarope	Liver	22.3	7.8	12.4	4.34	1.18	0.413	0.272	0.0952
Hailstone NWR	7/26/2001	H0726P4	Phalarope	Liver	10	3.19	1.23	0.392	< .998	< .318	0.276	0.088
Hailstone NWR	7/26/2001	H0726P5	Phalarope	Liver	48.3	17.1	1.27	0.451	< .997	< .354	0.788	0.28
Hailstone NWR	7/26/2001	H0726P6	Phalarope	Liver	18.3	5.51	2.9	0.873	< .950	< .286	0.376	0.113

Appendix B. Analytical Results of Sediment, Soils, and Biota.
Concentrations in ppm.

Sample Location	Sample Date	Sample Number	Species Name	Sample Matrix	Be dw	Be ww	Ca dw	Ca ww	Cd dw	Cd ww	Co dw	Co ww
Hailstone Dam	5/24/2001	HD0524S		Sediments	0.364	0.25	15800	10839	0.0861	0.0591	3.61	2.48
Hailstone Dam	8/1/2001	HD0801S		Sediments	0.456	0.303	25200	16733	0.108	0.0717	5.17	3.43
Below Dam	5/24/2001	BD0524S		Sediments	0.264	0.0663	76500	19202	0.402	0.101	53.1	13.3
Below Dam	8/1/2001	BD0801S		Sediments	0.257	0.0745	62600	18154	0.449	0.13	57.9	16.8
East Hailstone	5/24/2001	EH0524S		Sediments	0.355	0.187	41200	21712	0.114	0.0601	3.75	1.98
East Tributary	5/24/2001	ET0524S		Sediments	0.763	0.395	49200	25486	0.255	0.132	6.26	3.24
West Hailstone	5/24/2001	WH0524S		Sediments	0.404	0.243	36500	21973	0.12	0.0722	4.04	2.43
Hailstone Dam	5/9/2001	HD0509A	Brine Shrimp	Invertebrate	< .0531	< .00961	3130	567	0.155	0.0281	< .531	< .0961
Hailstone Dam	8/1/2001	HD0801A	Brine Shrimp	Invertebrate	< .0518	< .0106	3770	773	0.0591	0.0121	0.527	0.108
Below Dam	5/7/2001	BD0507C	Ephydridae	Invertebrate	0.0654	0.0106	55400	8975	0.303	0.0491	19.3	3.13
Below Dam	8/1/2001	BD0801C	Ephydridae	Invertebrate	< .0540	< .0385	26400	18823	0.126	0.0898	4.14	2.95
East Hailstone	5/8/2001	EH0508A	Brine Shrimp	Invertebrate	< .0540	< .00994	2780	512	0.181	0.0333	< .540	< .0994
East Tributary	5/7/2001	ET0507A	Brine Shrimp	Invertebrate	< .0550	< .0107	4100	800	0.204	0.0398	< .550	< .107
West Hailstone	5/7/2001	WH0507E	Brine Shrimp	Invertebrate	< .0536	< .0131	14200	3479	0.148	0.0363	0.573	0.14
West Hailstone	5/9/2001	WH0509A	Brine Shrimp	Invertebrate	< .0548	< .0108	5600	1103	0.161	0.0317	< .548	< .108
Hailstone NWR	4/26/2001	H0426AW	American Wigeon	Liver	< .0548	< .0174	272	86.2	8.79	2.79	< .548	< .174
Hailstone NWR	5/30/2001	H0530A	American Avocet	Liver	< .0536	< .0162	330	99.7	2.8	0.846	< .536	< .162
Hailstone NWR	5/30/2001	H0530W	Willet	Liver	< .0484	< .0161	171	56.8	6.36	2.11	< .484	< .161
Hailstone NWR	7/26/2001	H0726C1	Curlew	Liver	< .0529	< .0164	220	68.2	0.0886	0.0275	< .529	< .164
Hailstone NWR	7/26/2001	H0726C2	Curlew	Liver	< .0517	< .0163	220	69.5	0.0824	0.026	< .517	< .163
Hailstone NWR	7/26/2001	H0726P1	Phalarope	Liver	< .0513	< .0166	267	86.5	4.16	1.35	< .513	< .166
Hailstone NWR	7/26/2001	H0726P2	Phalarope	Liver	< .0503	< .0192	246	93.7	1.58	0.602	< .503	< .192
Hailstone NWR	7/26/2001	H0726P3	Phalarope	Liver	< .0478	< .0167	254	88.9	5.33	1.87	< .478	< .167
Hailstone NWR	7/26/2001	H0726P4	Phalarope	Liver	< .0499	< .0159	252	80.4	12	3.83	< .499	< .159
Hailstone NWR	7/26/2001	H0726P5	Phalarope	Liver	< .0498	< .0177	633	225	6.88	2.44	< .498	< .177
Hailstone NWR	7/26/2001	H0726P6	Phalarope	Liver	< .0475	< .0143	466	140	6.07	1.83	< .475	< .143

Appendix B. Analytical Results of Sediment, Soils, and Biota.
Concentrations in ppm.

Sample	Sample	Sample	Species	Sample	Cr		Cu		Fe		Hg	
Location	**Date**	**Number**	**Name**	**Matrix**	**dw**	**ww**	**dw**	**ww**	**dw**	**ww**	**dw**	**ww**
Hailstone Dam	5/24/2001	HD0524S		Sediments	8.21	5.63	5.93	4.07	11300	7752	0.00621	0.00426
Hailstone Dam	8/1/2001	HD0801S		Sediments	10.2	6.77	7.71	5.12	14900	9894	0.007	0.00465
Below Dam	5/24/2001	BD0524S		Sediments	5.59	1.4	4.56	1.14	9320	2339	0.0355	0.00891
Below Dam	8/1/2001	BD0801S		Sediments	6.23	1.81	4.17	1.21	10100	2929	0.0282	0.00818
East Hailstone	5/24/2001	EH0524S		Sediments	8.26	4.35	8.22	4.33	10600	5586	0.0132	0.00696
East Tributary	5/24/2001	ET0524S		Sediments	17	8.81	16.4	8.5	18700	9687	0.0171	0.00886
West Hailstone	5/24/2001	WH0524S		Sediments	9.26	5.57	7.74	4.66	11500	6923	0.00792	0.00477
Hailstone Dam	5/9/2001	HD0509A	Brine Shrimp	Invertebrate	1.67	0.302	3.89	0.704	335	60.6	< .0106	< .00192
Hailstone Dam	8/1/2001	HD0801A	Brine Shrimp	Invertebrate	1.37	0.281	4.93	1.01	1090	223	0.0142	0.00291
Below Dam	5/7/2001	BD0507C	Ephydridae	Invertebrate	3.1	0.502	5.15	0.834	3500	567	0.0268	0.00434
Below Dam	8/1/2001	BD0801C	Ephydridae	Invertebrate	1.73	1.23	3.58	2.55	796	568	< .0159	< .0113
East Hailstone	5/8/2001	EH0508A	Brine Shrimp	Invertebrate	< .540	< .0994	4.93	0.907	357	65.7	0.0132	0.00243
East Tributary	5/7/2001	ET0507A	Brine Shrimp	Invertebrate	1.03	0.201	5.73	1.12	738	144	< .0111	< .00216
West Hailstone	5/7/2001	WH0507E	Brine Shrimp	Invertebrate	1.62	0.397	3.94	0.965	1390	341	< .0116	< .00284
West Hailstone	5/9/2001	WH0509A	Brine Shrimp	Invertebrate	< .548	< .108	4.71	0.928	422	83.1	< .0116	< .00229
Hailstone NWR	4/26/2001	H0426AW	American Wigeon	Liver	< .548	< .174	155	49.1	1000	317	0.105	0.0333
Hailstone NWR	5/30/2001	H0530A	American Avocet	Liver	< .536	< .162	23.4	7.07	746	225	3.39	1.02
Hailstone NWR	5/30/2001	H0530W	Willet	Liver	< .484	< .161	38.9	12.9	1670	554	10.3	3.42
Hailstone NWR	7/26/2001	H0726C1	Curlew	Liver	< .529	< .164	16.3	5.05	1260	391	0.0285	0.00884
Hailstone NWR	7/26/2001	H0726C2	Curlew	Liver	< .517	< .163	21.4	6.76	1480	468	0.025	0.0079
Hailstone NWR	7/26/2001	H0726P1	Phalarope	Liver	< .513	< .166	19.9	6.45	1400	454	2.28	0.739
Hailstone NWR	7/26/2001	H0726P2	Phalarope	Liver	< .503	< .192	17.9	6.82	770	293	2.88	1.1
Hailstone NWR	7/26/2001	H0726P3	Phalarope	Liver	< .478	< .167	18.8	6.58	857	300	4.89	1.71
Hailstone NWR	7/26/2001	H0726P4	Phalarope	Liver	< .499	< .159	27.4	8.74	1090	348	1.19	0.38
Hailstone NWR	7/26/2001	H0726P5	Phalarope	Liver	< .498	< .177	18.8	6.67	1210	430	3.56	1.26
Hailstone NWR	7/26/2001	H0726P6	Phalarope	Liver	< .475	< .143	23.6	7.1	1210	364	3.4	1.02

Appendix B. Analytical Results of Sediment, Soils, and Biota.
Concentrations in ppm.

Sample Location	Sample Date	Sample Number	Species Name	Sample Matrix	K		Mg		Mn		Mo	
					dw	ww	dw	ww	dw	ww	dw	ww
Hailstone Dam	5/24/2001	HD0524S		Sediments	1270	871	13700	9398	179	123	< .620	< .425
Hailstone Dam	8/1/2001	HD0801S		Sediments	1470	976	13200	8765	261	173	< .700	< .465
Below Dam	5/24/2001	BD0524S		Sediments	1400	351	24500	6150	26500	6652	8.36	2.1
Below Dam	8/1/2001	BD0801S		Sediments	1230	357	23400	6786	29000	8410	4.89	1.42
East Hailstone	5/24/2001	EH0524S		Sediments	2100	1107	26200	13807	212	112	1.27	0.669
East Tributary	5/24/2001	ET0524S		Sediments	4960	2569	33300	17249	300	155	2.42	1.25
West Hailstone	5/24/2001	WH0524S		Sediments	2390	1439	20800	12522	170	102	0.96	0.578
Hailstone Dam	5/9/2001	HD0509A	Brine Shrimp	Invertebrate	6950	1258	55400	10027	518	93.8	< 1.06	< .192
Hailstone Dam	8/1/2001	HD0801A	Brine Shrimp	Invertebrate	7070	1449	23300	4776	48.4	9.92	< 1.04	< .213
Below Dam	5/7/2001	BD0507C	Ephydridae	Invertebrate	6990	1132	17600	2851	11000	1782	2.27	0.368
Below Dam	8/1/2001	BD0801C	Ephydridae	Invertebrate	5250	3743	27300	19465	4360	3109	< 1.08	< .770
East Hailstone	5/8/2001	EH0508A	Brine Shrimp	Invertebrate	6810	1253	49300	9071	556	102	< 1.08	< .199
East Tributary	5/7/2001	ET0507A	Brine Shrimp	Invertebrate	8530	1663	37300	7274	622	121	< 1.10	< .214
West Hailstone	5/7/2001	WH0507E	Brine Shrimp	Invertebrate	2080	510	59100	14480	758	186	< 1.07	< .262
West Hailstone	5/9/2001	WH0509A	Brine Shrimp	Invertebrate	6090	1200	48100	9476	529	104	< 1.10	< .217
Hailstone NWR	4/26/2001	H0426AW	American Wigeon	Liver	9530	3021	849	269	8.26	2.62	3.25	1.03
Hailstone NWR	5/30/2001	H0530A	American Avocet	Liver	9400	2839	845	255	13.5	4.08	1.99	0.601
Hailstone NWR	5/30/2001	H0530W	Willet	Liver	9660	3207	839	279	16.8	5.58	1.99	0.661
Hailstone NWR	7/26/2001	H0726C1	Curlew	Liver	9420	2920	888	275	14.5	4.5	3	0.93
Hailstone NWR	7/26/2001	H0726C2	Curlew	Liver	9450	2986	824	260	13.1	4.14	2.56	0.809
Hailstone NWR	7/26/2001	H0726P1	Phalarope	Liver	9320	3020	991	321	22.6	7.32	2.12	0.687
Hailstone NWR	7/26/2001	H0726P2	Phalarope	Liver	7810	2976	1310	499	19.6	7.47	1.67	0.636
Hailstone NWR	7/26/2001	H0726P3	Phalarope	Liver	10000	3500	1070	374	14.1	4.94	1.81	0.634
Hailstone NWR	7/26/2001	H0726P4	Phalarope	Liver	8710	2778	943	301	22.7	7.24	2.05	0.654
Hailstone NWR	7/26/2001	H0726P5	Phalarope	Liver	8420	2989	957	340	21.4	7.6	1.78	0.632
Hailstone NWR	7/26/2001	H0726P6	Phalarope	Liver	8970	2700	1170	352	35.9	10.8	1.25	0.376

Appendix B. Analytical Results of Sediment, Soils, and Biota.
Concentrations in ppm.

Sample Location	Sample Date	Sample Number	Species Name	Sample Matrix	Na dw	Na ww	Ni dw	Ni ww	P dw	P ww	Pb dw	Pb ww
Hailstone Dam	5/24/2001	HD0524S		Sediments	28700	19688	7.2	4.94	320	220	6.1	4.18
Hailstone Dam	8/1/2001	HD0801S		Sediments	18900	12550	9.98	6.63	377	250	8.59	5.7
Below Dam	5/24/2001	BD0524S		Sediments	50000	12550	28.4	7.13	579	145	5.06	1.27
Below Dam	8/1/2001	BD0801S		Sediments	41000	11890	23.5	6.82	373	108	5.1	1.48
East Hailstone	5/24/2001	EH0524S		Sediments	48800	25718	8.46	4.46	437	230	6.08	3.2
East Tributary	5/24/2001	ET0524S		Sediments	41300	21393	15.8	8.18	634	328	10.9	5.65
West Hailstone	5/24/2001	WH0524S		Sediments	37000	22274	8.22	4.95	380	229	6.58	3.96
Hailstone Dam	5/9/2001	HD0509A	Brine Shrimp	Invertebrate	90700	16417	2.03	0.367	4800	869	0.193	0.0349
Hailstone Dam	8/1/2001	HD0801A	Brine Shrimp	Invertebrate	71800	14719	1.71	0.351	5220	1070	0.542	0.111
Below Dam	5/7/2001	BD0507C	Ephydridae	Invertebrate	39800	6448	11.8	1.91	5050	818	1.55	0.251
Below Dam	8/1/2001	BD0801C	Ephydridae	Invertebrate	65500	46702	2.85	2.03	3590	2560	0.501	0.357
East Hailstone	5/8/2001	EH0508A	Brine Shrimp	Invertebrate	94200	17333	2.08	0.383	5180	953	0.235	0.0432
East Tributary	5/7/2001	ET0507A	Brine Shrimp	Invertebrate	70800	13806	2.77	0.54	6520	1271	0.405	0.079
West Hailstone	5/7/2001	WH0507E	Brine Shrimp	Invertebrate	111000	27195	2.35	0.576	1060	260	0.732	0.179
West Hailstone	5/9/2001	WH0509A	Brine Shrimp	Invertebrate	92800	18282	1.61	0.317	4730	932	0.346	0.0682
Hailstone NWR	4/26/2001	H0426AW	American Wigeon	Liver	5250	1664	< .548	< .174	10800	3424	0.132	0.0418
Hailstone NWR	5/30/2001	H0530A	American Avocet	Liver	4470	1350	< .536	< .162	10500	3171	0.19	0.0574
Hailstone NWR	5/30/2001	H0530W	Willet	Liver	3300	1096	< .484	< .161	10600	3519	0.104	0.0345
Hailstone NWR	7/26/2001	H0726C1	Curlew	Liver	3800	1178	< .529	< .164	10300	3193	0.211	0.0654
Hailstone NWR	7/26/2001	H0726C2	Curlew	Liver	3580	1131	< .517	< .163	10200	3223	0.171	0.054
Hailstone NWR	7/26/2001	H0726P1	Phalarope	Liver	4070	1319	< .513	< .166	11100	3596	0.084	0.0272
Hailstone NWR	7/26/2001	H0726P2	Phalarope	Liver	3900	1486	< .503	< .192	8890	3387	0.0716	0.0273
Hailstone NWR	7/26/2001	H0726P3	Phalarope	Liver	3140	1099	< .478	< .167	11000	3850	0.119	0.0416
Hailstone NWR	7/26/2001	H0726P4	Phalarope	Liver	3620	1155	< .499	< .159	10300	3286	0.0751	0.024
Hailstone NWR	7/26/2001	H0726P5	Phalarope	Liver	2770	983	< .498	< .177	9480	3365	0.139	0.0493
Hailstone NWR	7/26/2001	H0726P6	Phalarope	Liver	3500	1054	< .475	< .143	10800	3251	0.185	0.0557

Appendix B. Analytical Results of Sediment, Soils, and Biota.
Concentrations in ppm.

Sample	Sample	Sample	Species	Sample	S		Se		Sr		Ti	
Location	Date	Number	Name	Matrix	dw	ww	dw	ww	dw	ww	dw	ww
Hailstone Dam	5/24/2001	HD0524S		Sediments	30600	20992	1.77	1.21	163	112		
Hailstone Dam	8/1/2001	HD0801S		Sediments	26000	17264	3.36	2.23	334	222		
Below Dam	5/24/2001	BD0524S		Sediments	73700	18499	2.33	0.585	1790	449		
Below Dam	8/1/2001	BD0801S		Sediments	63400	18386	1.86	0.539	1320	383		
East Hailstone	5/24/2001	EH0524S		Sediments	55500	29248	4.44	2.34	603	318		
East Tributary	5/24/2001	ET0524S		Sediments	57300	29681	6.67	3.46	643	333		
West Hailstone	5/24/2001	WH0524S		Sediments	47800	28776	4.2	2.53	610	367		
Hailstone Dam	5/9/2001	HD0509A	Brine Shrimp	Invertebrate	115000	20815	15.4	2.79	94.3	17.1	12.5	2.26
Hailstone Dam	8/1/2001	HD0801A	Brine Shrimp	Invertebrate	65700	13468	26.1	5.35	115	23.6	18.6	3.81
Below Dam	5/7/2001	BD0507C	Ephydridae	Invertebrate	41700	6755	2.46	0.399	1600	259	44.6	7.23
Below Dam	8/1/2001	BD0801C	Ephydridae	Invertebrate	68100	48555	1.62	1.16	875	624	16.1	11.5
East Hailstone	5/8/2001	EH0508A	Brine Shrimp	Invertebrate	112000	20608	17.1	3.15	72.9	13.4	15.8	2.91
East Tributary	5/7/2001	ET0507A	Brine Shrimp	Invertebrate	85000	16575	23.2	4.52	84.8	16.5	13.3	2.59
West Hailstone	5/7/2001	WH0507E	Brine Shrimp	Invertebrate	132000	32340	5.63	1.38	238	58.3	17.2	4.21
West Hailstone	5/9/2001	WH0509A	Brine Shrimp	Invertebrate	109000	21473	14.7	2.9	102	20.1	5.3	1.04
Hailstone NWR	4/26/2001	H0426AW	American Wigeon	Liver	11100	3519	6.64	2.1	0.82	0.26	< .548	< .174
Hailstone NWR	5/30/2001	H0530A	American Avocet	Liver	9650	2914	34.5	10.4	0.766	0.231	0.582	0.176
Hailstone NWR	5/30/2001	H0530W	Willet	Liver	9870	3277	14.6	4.85	0.472	0.157	< .484	< .161
Hailstone NWR	7/26/2001	H0726C1	Curlew	Liver	8710	2700	2.97	0.921	0.952	0.295	< .529	< .164
Hailstone NWR	7/26/2001	H0726C2	Curlew	Liver	8410	2658	2.58	0.815	0.774	0.245	< .517	< .163
Hailstone NWR	7/26/2001	H0726P1	Phalarope	Liver	9720	3149	15.6	5.05	3.58	1.16	< .513	< .166
Hailstone NWR	7/26/2001	H0726P2	Phalarope	Liver	9590	3654	13.5	5.14	3.71	1.41	0.72	0.274
Hailstone NWR	7/26/2001	H0726P3	Phalarope	Liver	10100	3535	19.3	6.76	2.25	0.788	0.891	0.312
Hailstone NWR	7/26/2001	H0726P4	Phalarope	Liver	9470	3021	10.9	3.48	3.57	1.14	0.687	0.219
Hailstone NWR	7/26/2001	H0726P5	Phalarope	Liver	8570	3042	7.94	2.82	4.48	1.59	1.33	0.472
Hailstone NWR	7/26/2001	H0726P6	Phalarope	Liver	8850	2664	11	3.31	8.45	2.54	0.697	0.21

Appendix B. Analytical Results of Sediment, Soils, and Biota.
Concentrations in ppm.

Sample	Sample	Sample	Species	Sample	V		Zn	
Location	**Date**	**Number**	**Name**	**Matrix**	**dw**	**ww**	**dw**	**ww**
Hailstone Dam	5/24/2001	HD0524S		Sediments	14.5	9.95	31.5	21.6
Hailstone Dam	8/1/2001	HD0801S		Sediments	19.3	12.8	41.9	27.8
Below Dam	5/24/2001	BD0524S		Sediments	6.66	1.67	22.5	5.65
Below Dam	8/1/2001	BD0801S		Sediments	7.75	2.25	21.6	6.26
East Hailstone	5/24/2001	EH0524S		Sediments	19.5	10.3	35.6	18.8
East Tributary	5/24/2001	ET0524S		Sediments	42.9	22.2	68.7	35.6
West Hailstone	5/24/2001	WH0524S		Sediments	20.6	12.4	35.9	21.6
Hailstone Dam	5/9/2001	HD0509A	Brine Shrimp	Invertebrate	1.3	0.235	25.9	4.69
Hailstone Dam	8/1/2001	HD0801A	Brine Shrimp	Invertebrate	3.08	0.631	39.1	8.02
Below Dam	5/7/2001	BD0507C	Ephydridae	Invertebrate	4.31	0.698	29.8	4.83
Below Dam	8/1/2001	BD0801C	Ephydridae	Invertebrate	1.24	0.884	18	12.8
East Hailstone	5/8/2001	EH0508A	Brine Shrimp	Invertebrate	1.31	0.241	29.7	5.46
East Tributary	5/7/2001	ET0507A	Brine Shrimp	Invertebrate	2.55	0.497	36.3	7.08
West Hailstone	5/7/2001	WH0507E	Brine Shrimp	Invertebrate	3.5	0.858	15.8	3.87
West Hailstone	5/9/2001	WH0509A	Brine Shrimp	Invertebrate	1.27	0.25	27.7	5.46
Hailstone NWR	4/26/2001	H0426AW	American Wigeon	Liver	< 1.10	< .349	164	52
Hailstone NWR	5/30/2001	H0530A	American Avocet	Liver	< 1.07	< .323	96.7	29.2
Hailstone NWR	5/30/2001	H0530W	Willet	Liver	< .968	< .321	114	37.8
Hailstone NWR	7/26/2001	H0726C1	Curlew	Liver	< 1.06	< .329	84.7	26.3
Hailstone NWR	7/26/2001	H0726C2	Curlew	Liver	< 1.03	< .325	77.7	24.6
Hailstone NWR	7/26/2001	H0726P1	Phalarope	Liver	< 1.03	< .334	86.5	28
Hailstone NWR	7/26/2001	H0726P2	Phalarope	Liver	< 1.01	< .385	72.3	27.5
Hailstone NWR	7/26/2001	H0726P3	Phalarope	Liver	< .956	< .335	104	36.4
Hailstone NWR	7/26/2001	H0726P4	Phalarope	Liver	< .998	< .318	107	34.1
Hailstone NWR	7/26/2001	H0726P5	Phalarope	Liver	< .997	< .354	81	28.8
Hailstone NWR	7/26/2001	H0726P6	Phalarope	Liver	< .950	< .286	123	37

Appendix B. Analytical Results of Sediment, Soils, and Biota.
Concentrations in ppm.

Sample Location	Sample Date	Sample Number	Species Name	Sample Matrix	Al dw	Al ww	As dw	As ww	B dw	B ww	Ba dw	Ba ww
Hailstone Dam	6/18/2002	HD61802		Sediments	11400	6281	2.45	1.35	35.6	19.6	73.9	40.7
Below Dam	6/18/2002	BD61802		Sediments	8440	3207	9.72	3.69	28.1	10.7	88	33.4
East Tributary	6/19/2002	ET61902		Sediments	6020	3359	3.05	1.7	45.1	25.2	61.1	34.1
Hailstone Dam	6/18/2002	HD61802A	Brine Shrimp	Invertebrate	298	67.3	10.2	2.31	53.2	12	6.52	1.47
Below Dam	6/18/2002	BD61802A	Brine Shrimp	Invertebrate	365	59.5	6.16	1	8.17	1.33	4.97	0.81
East Tributary	6/19/2002	ET61902A	Brine Shrimp	Invertebrate	293	70.3	9.53	2.29	43.2	10.4	4.82	1.16
Hailstone NWR	7/11/2002	H71102A	American Avocet	Liver	7.3	2.3	< 1.88	< .592	< .939	< .296	< .0940	< .0296
Hailstone NWR	7/11/2002	H71102A2	American Avocet	Liver	12.2	3.72	< 2.07	< .631	< 1.04	< .317	0.311	0.0949
Hailstone NWR	7/11/2002	H71102A3	American Avocet	Liver	8.23	2.35	< 1.87	< .535	< .936	< .268	0.187	0.0535
Hailstone NWR	7/11/2002	H71102A4	American Avocet	Liver	13.6	4.07	< 1.82	< .544	< .911	< .272	0.255	0.0762
Hailstone NWR	7/11/2002	H71102K	Killdeer	Liver	5.42	1.93	< 1.88	< .669	< .941	< .335	0.151	0.0538
Hailstone NWR	7/11/2002	H71102K2	Killdeer	Liver	8.04	2.68	< 1.85	< .616	< .924	< .308	0.166	0.0553
Hailstone NWR	7/11/2002	H71102K3	Killdeer	Liver	4.76	1.27	< 1.87	< .499	< .936	< .250	0.112	0.0299
Hailstone NWR	7/11/2002	H71102R	Redhead	Liver	5.33	1.75	< 1.93	< .633	< .963	< .316	< .0960	< .0315
Hailstone NWR	7/11/2002	H71102R2	Redhead	Liver	6.5	2.13	< 1.85	< .607	1.3	0.426	0.111	0.0364
Hailstone NWR	7/23/2002	H72302DM	mallard	Liver	5.29	1.59	< 1.95	< .585	1.07	0.321	0.467	0.14
Hailstone NWR	7/23/2002	H72302DR	Redhead	Liver	5.87	2.01	< 1.89	< .646	< .943	< .323	0.17	0.0581
Hailstone NWR	7/23/2002	H71102DS	Lesser Scaup	Liver	4.87	1.62	< 1.85	< .614	< .926	< .307	< .0930	< .0309

Sample Location	Sample Date	Sample Number	Sample Matrix	Al dw	Al ww	As dw	As ww	B dw	B ww	Ba dw	Ba ww
Dry lake bed on		B197333S	Soils	34000	22032	7.08	4.59	44.1	28.6	296	192
Halfbreed NWR		B197334S	Soils	37500	20662	7.36	4.06	38.4	21.2	315	174
Halfbreed NWR		B197335S	Soils	42700	22716	6.51	3.46	39.7	21.1	393	209
Halfbreed NWR		B197336S	Soils	46400	22040	6.06	2.88	27.7	13.2	374	178
Halfbreed NWR		B197338S	Soils	46600	23067	5.94	2.94	25.3	12.5	338	167
seep @HNWR		H188419S	Soils	8960	5510	7.44	4.58	11.9	7.32	97.1	59.7

Appendix B. Analytical Results of Sediment, Soils, and Biota.
Concentrations in ppm.

Sample Location	Sample Date	Sample Number	Species Name	Sample Matrix	Be dw	Be ww	Ca dw	Ca ww	Cd dw	Cd ww	Co dw	Co ww
Hailstone Dam	6/18/2002	HD61802		Sediments	0.537	0.296	40800	22481	0.166	0.0915	4.58	2.52
Below Dam	6/18/2002	BD61802		Sediments	0.464	0.176	81800	31084	0.398	0.151	258	98
East Tributary	6/19/2002	ET61902		Sediments	0.252	0.141	102000	56916	0.109	0.0608	2.18	1.22
Hailstone Dam	6/18/2002	HD61802A	Brine Shrimp	Invertebrate	< .0532	< .0120	5300	1198	< .213	< .0481	0.597	0.135
Below Dam	6/18/2002	BD61802A	Brine Shrimp	Invertebrate	< .0507	< .00826	3900	636	0.344	0.0561	12.7	2.07
East Tributary	6/19/2002	ET61902A	Brine Shrimp	Invertebrate	< .0479	< .0115	3890	934	< .0960	< .0230	< .479	< .115
Hailstone NWR	7/11/2002	H71102A	American Avocet	Liver	< .0469	< .0148	185	58.3	3	0.945	< .469	< .148
Hailstone NWR	7/11/2002	H71102A2	American Avocet	Liver	< .0518	< .0158	389	119	< .104	< .0317	0.798	0.243
Hailstone NWR	7/11/2002	H71102A3	American Avocet	Liver	< .0468	< .0134	302	86.4	< .0940	< .0269	< .468	< .134
Hailstone NWR	7/11/2002	H71102A4	American Avocet	Liver	< .0456	< .0136	380	114	< .0910	< .0272	0.718	0.215
Hailstone NWR	7/11/2002	H71102K	Killdeer	Liver	< .0471	< .0168	172	61.2	2.91	1.04	< .471	< .168
Hailstone NWR	7/11/2002	H71102K2	Killdeer	Liver	< .0462	< .0154	190	63.3	1.29	0.43	< .462	< .154
Hailstone NWR	7/11/2002	H71102K3	Killdeer	Liver	< .0468	< .0125	137	36.6	1.16	0.31	< .468	< .125
Hailstone NWR	7/11/2002	H71102R	Redhead	Liver	< .0481	< .0158	212	69.5	3.58	1.17	< .481	< .158
Hailstone NWR	7/11/2002	H71102R2	Redhead	Liver	< .0463	< .0152	304	99.7	2.74	0.899	< .463	< .152
Hailstone NWR	7/23/2002	H72302DM	mallard	Liver	< .0487	< .0146	1450	435	1.2	0.36	< .487	< .146
Hailstone NWR	7/23/2002	H72302DR	Redhead	Liver	< .0472	< .0161	310	106	2.23	0.763	< .472	< .161
Hailstone NWR	7/23/2002	H71102DS	Lesser Scaup	Liver	< .0463	< .0154	171	56.8	1.34	0.445	< .463	< .154

Sample Location	Sample Date	Sample Number		Sample Matrix	Be dw	Be ww	Ca dw	Ca ww	Cd dw	Cd ww	Co dw	Co ww
Dry lake bed on		B197333S		Soils	1.13	0.732	29600	19181	0.335	0.217	9.33	6.05
Halfbreed NWR		B197334S		Soils	1.31	0.722	26300	14491	0.322	0.177	10.4	5.73
Halfbreed NWR		B197335S		Soils	1.38	0.734	41000	21812	0.376	0.2	11.2	5.96
Halfbreed NWR		B197336S		Soils	1.36	0.646	46600	22135	0.327	0.155	11.9	5.65
Halfbreed NWR		B197338S		Soils	1.59	0.787	12400	6138	0.346	0.171	13.4	6.63
seep @HNWR		H188419S		Soils	0.426	0.262	14200	8733	0.218	0.134	3.33	2.05

Appendix B. Analytical Results of Sediment, Soils, and Biota.
Concentrations in ppm.

Sample	Sample	Sample	Species	Sample	Cr		Cu		Fe		Hg	
Location	Date	Number	Name	Matrix	dw	ww	dw	ww	dw	ww	dw	ww
Hailstone Dam	6/18/2002	HD61802		Sediments	10.2	5.62	9.24	5.09	12900	7108	0.0115	0.00634
Below Dam	6/18/2002	BD61802		Sediments	7.99	3.04	7.19	2.73	29000	11020	0.019	0.00722
East Tributary	6/19/2002	ET61902		Sediments	4.67	2.61	5.77	3.22	6400	3571	0.00588	0.00328
Hailstone Dam	6/18/2002	HD61802A	Brine Shrimp	Invertebrate	0.581	0.131	4.03	0.911	508	115	0.0103	0.00233
Below Dam	6/18/2002	BD61802A	Brine Shrimp	Invertebrate	< .507	< .0826	6.25	1.02	1470	240	0.0578	0.00942
East Tributary	6/19/2002	ET61902A	Brine Shrimp	Invertebrate	< .479	< .115	2.68	0.643	497	119		
Hailstone NWR	7/11/2002	H71102A	American Avocet	Liver	< .469	< .148	19.2	6.05	3370	1062		
Hailstone NWR	7/11/2002	H71102A2	American Avocet	Liver	< .518	< .158	4.44	1.35	755	230		
Hailstone NWR	7/11/2002	H71102A3	American Avocet	Liver	< .468	< .134	4.73	1.35	558	160		
Hailstone NWR	7/11/2002	H71102A4	American Avocet	Liver	10.4	3.11	5.68	1.7	954	285		
Hailstone NWR	7/11/2002	H71102K	Killdeer	Liver	< .471	< .168	47.1	16.8	990	352		
Hailstone NWR	7/11/2002	H71102K2	Killdeer	Liver	< .462	< .154	56.4	18.8	2360	786		
Hailstone NWR	7/11/2002	H71102K3	Killdeer	Liver	< .468	< .125	56.2	15	562	150		
Hailstone NWR	7/11/2002	H71102R	Redhead	Liver	< .481	< .158	427	140	1680	551		
Hailstone NWR	7/11/2002	H71102R2	Redhead	Liver	< .463	< .152	741	243	6190	2030		
Hailstone NWR	7/23/2002	H72302DM	mallard	Liver	< .487	< .146	50	15	5580	1674		
Hailstone NWR	7/23/2002	H72302DR	Redhead	Liver	< .472	< .161	237	81.1	3970	1358		
Hailstone NWR	7/23/2002	H71102DS	Lesser Scaup	Liver	< .463	< .154	98	32.5	2770	920		

Sample	Sample	Sample	Sample	Cr		Cu		Fe		Hg	
Location	Date	Number	Matrix	dw	ww	dw	ww	dw	ww	dw	ww
Dry lake bed on		B197333S	Soils	30.8	20	23	14.9	26900	17431	0.0143	0.00927
Halfbreed NWR		B197334S	Soils	35.2	19.4	25	13.8	30100	16585	0.0117	0.00645
Halfbreed NWR		B197335S	Soils	36.7	19.5	28.9	15.4	31700	16864	0.0179	0.00952
Halfbreed NWR		B197336S	Soils	42.2	20	28.5	13.5	31800	15105	0.0191	0.00907
Halfbreed NWR		B197338S	Soils	49.4	24.5	30.1	14.9	36300	17968	0.0136	0.00673
seep @HNWR		H188419S	Soils	9.69	5.96	10.6	6.52	13200	8118	0.0111	0.00683

Appendix B. Analytical Results of Sediment, Soils, and Biota.
Concentrations in ppm.

Sample Location	Sample Date	Sample Number	Species Name	Sample Matrix	Mg		Mn		Mo	
					dw	ww	dw	ww	dw	ww
Hailstone Dam	6/18/2002	HD61802		Sediments	33400	18403	219	121	1.69	0.931
Below Dam	6/18/2002	BD61802		Sediments	23200	8816	79800	30324	10.2	3.88
East Tributary	6/19/2002	ET61902		Sediments	25500	14229	180	100	1.98	1.1
Hailstone Dam	6/18/2002	HD61802A	Brine Shrimp	Invertebrate	65100	14713	89	20.1	< 1.06	< .240
Below Dam	6/18/2002	BD61802A	Brine Shrimp	Invertebrate	12400	2021	2270	370	< 1.01	< .165
East Tributary	6/19/2002	ET61902A	Brine Shrimp	Invertebrate	68000	16320	61.2	14.7	< .959	< .230
Hailstone NWR	7/11/2002	H71102A	American Avocet	Liver	835	263	26.9	8.47	2.56	0.806
Hailstone NWR	7/11/2002	H71102A2	American Avocet	Liver	1290	393	176	53.7	1.27	0.387
Hailstone NWR	7/11/2002	H71102A3	American Avocet	Liver	1280	366	98.1	28.1	< .936	< .268
Hailstone NWR	7/11/2002	H71102A4	American Avocet	Liver	1340	401	129	38.6	1.32	0.395
Hailstone NWR	7/11/2002	H71102K	Killdeer	Liver	756	269	23.8	8.47	2.81	1
Hailstone NWR	7/11/2002	H71102K2	Killdeer	Liver	872	290	36.8	12.3	2.97	0.989
Hailstone NWR	7/11/2002	H71102K3	Killdeer	Liver	656	175	10.4	2.78	1.95	0.521
Hailstone NWR	7/11/2002	H71102R	Redhead	Liver	1000	328	17	5.58	3.38	1.11
Hailstone NWR	7/11/2002	H71102R2	Redhead	Liver	884	290	17.4	5.71	5.18	1.7
Hailstone NWR	7/23/2002	H72302DM	mallard	Liver	3010	903	15.5	4.65	6.18	1.85
Hailstone NWR	7/23/2002	H72302DR	Redhead	Liver	846	289	8.37	2.86	1.9	0.65
Hailstone NWR	7/23/2002	H71102DS	Lesser Scaup	Liver	687	228	13.2	4.38	2.69	0.893

Sample Location	Sample Date	Sample Number	Sample Matrix	Mg		Mn		Mo	
				dw	ww	dw	ww	dw	ww
Dry lake bed on		B197333S	Soils	16100	10433	395	256	1.47	0.953
Halfbreed NWR		B197334S	Soils	16900	9312	435	240	1.88	1.04
Halfbreed NWR		B197335S	Soils	16300	8672	536	285	1.78	0.947
Halfbreed NWR		B197336S	Soils	16100	7648	620	294	1.74	0.826
Halfbreed NWR		B197338S	Soils	17800	8811	1030	510	1.8	0.891
seep @HNWR		H188419S	Soils	19500	11992	163	100	2.3	1.41

Appendix B. Analytical Results of Sediment, Soils, and Biota.
Concentrations in ppm.

Sample Location	Sample Date	Sample Number	Species Name	Sample Matrix	Na dw	Na ww	Ni dw	Ni ww	P dw	P ww	Pb dw	Pb ww
Hailstone Dam	6/18/2002	HD61802		Sediments	34500	19010	9.74	5.37	499	275	8.65	4.77
Below Dam	6/18/2002	BD61802		Sediments	25200	9576	100	38	516	196	17.5	6.65
East Tributary	6/19/2002	ET61902		Sediments	31500	17577	4.98	2.78	554	309	3.54	1.98
Hailstone Dam	6/18/2002	HD61802A	Brine Shrimp	Invertebrate	99100	22397	1.25	0.282	3830	866	< .160	< .0362
Below Dam	6/18/2002	BD61802A	Brine Shrimp	Invertebrate	42700	6960	7.74	1.26	11200	1826	0.695	0.113
East Tributary	6/19/2002	ET61902A	Brine Shrimp	Invertebrate	101000	24240	1.41	0.338	2720	653		
Hailstone NWR	7/11/2002	H71102A	American Avocet	Liver	2720	857	< .469	< .148	10600	3339		
Hailstone NWR	7/11/2002	H71102A2	American Avocet	Liver	3880	1183	0.523	0.16	11200	3416		
Hailstone NWR	7/11/2002	H71102A3	American Avocet	Liver	4360	1247	0.476	0.136	12100	3461		
Hailstone NWR	7/11/2002	H71102A4	American Avocet	Liver	5060	1513	4.97	1.49	11200	3349		
Hailstone NWR	7/11/2002	H71102K	Killdeer	Liver	2740	975	0.565	0.201	10100	3596		
Hailstone NWR	7/11/2002	H71102K2	Killdeer	Liver	2630	876	< .462	< .154	11000	3663		
Hailstone NWR	7/11/2002	H71102K3	Killdeer	Liver	2790	745	< .468	< .125	9120	2435		
Hailstone NWR	7/11/2002	H71102R	Redhead	Liver	3850	1263	< .481	< .158	10900	3575		
Hailstone NWR	7/11/2002	H71102R2	Redhead	Liver	4750	1558	< .463	< .152	10700	3510		
Hailstone NWR	7/23/2002	H72302DM	mallard	Liver	12900	3870	< .487	< .146	7420	2226		
Hailstone NWR	7/23/2002	H72302DR	Redhead	Liver	4460	1525	< .472	< .161	8690	2972		
Hailstone NWR	7/23/2002	H71102DS	Lesser Scaup	Liver	3730	1238	< .463	< .154	10300	3420		

Sample Location	Sample Date	Sample Number	Sample Matrix	Na dw	Na ww	Ni dw	Ni ww	P dw	P ww	Pb dw	Pb ww
Dry lake bed on		B197333S	Soils	3850	2495	23	14.9	919	596	16.7	10.8
Halfbreed NWR		B197334S	Soils	6350	3499	26.4	14.5	895	493	17.1	9.42
Halfbreed NWR		B197335S	Soils	4510	2399	29.2	15.5	933	496	18.4	9.79
Halfbreed NWR		B197336S	Soils	1460	694	32.9	15.6	860	408	17.6	8.36
Halfbreed NWR		B197338S	Soils	1520	752	36.1	17.9	997	494	19.3	9.55
seep @HNWR		H188419S	Soils	44300	27244	9.02	5.55	831	511	9.46	5.82

Appendix B. Analytical Results of Sediment, Soils, and Biota.
Concentrations in ppm.

Sample Location	Sample Date	Sample Number	Species Name	Sample Matrix	S dw	S ww	Se dw	Se ww	Sr dw	Sr ww	Ti dw	Ti ww
Hailstone Dam	6/18/2002	HD61802		Sediments			2.74	1.51	390	215		
Below Dam	6/18/2002	BD61802		Sediments			3.14	1.19	806	306		
East Tributary	6/19/2002	ET61902		Sediments			3.74	2.09	1060	591		
Hailstone Dam	6/18/2002	HD61802A	Brine Shrimp	Invertebrate	122000	27572	13.6	3.07	119	26.9	4.21	0.951
Below Dam	6/18/2002	BD61802A	Brine Shrimp	Invertebrate	43000	7009	5.26	0.857	91.7	14.9	4.92	0.802
East Tributary	6/19/2002	ET61902A	Brine Shrimp	Invertebrate	118000	28320	10.2	2.45	107	25.7	5.77	1.38
Hailstone NWR	7/11/2002	H71102A	American Avocet	Liver	9650	3040	20.6	6.49	4	1.26	< .469	< .148
Hailstone NWR	7/11/2002	H71102A2	American Avocet	Liver	9950	3035	10.3	3.14	5.98	1.82	< .518	< .158
Hailstone NWR	7/11/2002	H71102A3	American Avocet	Liver	10500	3003	11.6	3.32	6.18	1.77	< .468	< .134
Hailstone NWR	7/11/2002	H71102A4	American Avocet	Liver	10500	3140	13.8	4.13	8.36	2.5	< .456	< .136
Hailstone NWR	7/11/2002	H71102K	Killdeer	Liver	8870	3158	6.5	2.31	0.969	0.345	< .471	< .168
Hailstone NWR	7/11/2002	H71102K2	Killdeer	Liver	9160	3050	8.85	2.95	1.82	0.606	< .462	< .154
Hailstone NWR	7/11/2002	H71102K3	Killdeer	Liver	6940	1853	6.63	1.77	0.206	0.055	< .468	< .125
Hailstone NWR	7/11/2002	H71102R	Redhead	Liver	9510	3119	24	7.87	0.973	0.319	< .481	< .158
Hailstone NWR	7/11/2002	H71102R2	Redhead	Liver	11300	3706	7.3	2.39	0.713	0.234	< .463	< .152
Hailstone NWR	7/23/2002	H72302DM	mallard	Liver	20600	6180	25.4	7.62	16.1	4.83	< .487	< .146
Hailstone NWR	7/23/2002	H72302DR	Redhead	Liver	8800	3010	5.8	1.98	1.11	0.38	< .472	< .161
Hailstone NWR	7/23/2002	H71102DS	Lesser Scaup	Liver	8850	2938	8.7	2.89	0.231	0.0767	< .463	< .154

Sample Location	Sample Date	Sample Number	Sample Matrix	Se dw	Se ww	Sr dw	Sr ww
Dry lake bed on		B197333S	Soils	0.37	0.24	326	211
Halfbreed NWR		B197334S	Soils	0.228	0.126	275	152
Halfbreed NWR		B197335S	Soils	0.662	0.352	515	274
Halfbreed NWR		B197336S	Soils	0.457	0.217	515	245
Halfbreed NWR		B197338S	Soils	0.136	0.0673	141	69.8
seep @HNWR		H188419S	Soils	0.767	0.472	46.3	28.5

Appendix B. Analytical Results of Sediment, Soils, and Biota.
Concentrations in ppm.

Sample Location	Sample Date	Sample Number	Species Name	Sample Matrix	V dw	V ww	Zn dw	Zn ww
Hailstone Dam	6/18/2002	HD61802		Sediments	21.9	12.1	45.2	24.9
Below Dam	6/18/2002	BD61802		Sediments	21.7	8.25	41.7	15.8
East Tributary	6/19/2002	ET61902		Sediments	15.2	8.48	20.9	11.7
Hailstone Dam	6/18/2002	HD61802A	Brine Shrimp	Invertebrate	< 1.06	< .240	29.8	6.73
Below Dam	6/18/2002	BD61802A	Brine Shrimp	Invertebrate	< 1.01	< .165	67.5	11
East Tributary	6/19/2002	ET61902A	Brine Shrimp	Invertebrate	< .959	< .230	22.5	5.4
Hailstone NWR	7/11/2002	H71102A	American Avocet	Liver	< .939	< .296	122	38.4
Hailstone NWR	7/11/2002	H71102A2	American Avocet	Liver	< 1.04	< .317	83.9	25.6
Hailstone NWR	7/11/2002	H71102A3	American Avocet	Liver	< .936	< .268	81.7	23.4
Hailstone NWR	7/11/2002	H71102A4	American Avocet	Liver	< .911	< .272	74.5	22.3
Hailstone NWR	7/11/2002	H71102K	Killdeer	Liver	< .941	< .335	89.6	31.9
Hailstone NWR	7/11/2002	H71102K2	Killdeer	Liver	< .924	< .308	91.9	30.6
Hailstone NWR	7/11/2002	H71102K3	Killdeer	Liver	< .936	< .250	85.4	22.8
Hailstone NWR	7/11/2002	H71102R	Redhead	Liver	< .963	< .316	225	73.8
Hailstone NWR	7/11/2002	H71102R2	Redhead	Liver	< .926	< .304	295	96.8
Hailstone NWR	7/23/2002	H72302DM	mallard	Liver	< .974	< .292	150	45
Hailstone NWR	7/23/2002	H72302DR	Redhead	Liver	< .943	< .323	156	53.4
Hailstone NWR	7/23/2002	H71102DS	Lesser Scaup	Liver	< .926	< .307	189	62.7

Sample Location	Sample Date	Sample Number	Sample Matrix	V dw	V ww	Zn dw	Zn ww
Dry lake bed on		B197333S	Soils	57.3	37.1	94.8	61.4
Halfbreed NWR		B197334S	Soils	61.9	34.1	106	58.4
Halfbreed NWR		B197335S	Soils	61	32.5	111	59.1
Halfbreed NWR		B197336S	Soils	56.7	26.9	102	48.4
Halfbreed NWR		B197338S	Soils	69.2	34.3	117	57.9
seep @HNWR		H188419S	Soils	27.7	17	46.3	28.5

Appendix B. Analytical Results of Sediment, Soils, and Biota.
Concentrations in ppm.

Sample Location	Sample Number	Sample Date	Species Name	Sample Matrix	Se Dry Wt. (ppm)	Se Wet Wt. (ppm)
East Trib.	ET0625AA	6/25/2003	A. Avocet	Avian Egg	26.8	6.86
East Trib.	ET0716AA	7/16/2003	A. Avocet	Avian Egg	46.8	14.5
East Trib.	ET0716A	7/16/2003	Brine Shrimp	Invertebrate	14.4	2.75
East Trib.	ET0716S	7/16/2003		Sediments	2.27	1.42
East Trib.	ET0716W	7/16/2003		Water		0.0292
East Trib.	ETR0418W	4/18/2003		Water		0.682
H. Dam	HD0418W	4/18/2003		Water		0.0909
H. Dam	HD0716W	7/16/2003		Water		0.0216
East Trib.	HNWR06060(	6/6/2006	A. Avocet	Avian Egg	32.7	8.27

* sample maticies collected to complete the Lemely protocol.