

Hydrology and Geochemistry of Yucca House National Monument and Surrounding Area, Southwestern Colorado



Southwest Hydro-Logic

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Hydrological Studies Report 2006-1

*Prepared in Cooperation with the National Park Service,
Mesa Verde National Park*



Cover Photo: Ismay Spring, September 24, 2002. As a result of drought, the pipe did not flow during 2003; samples were collected from inside of the spring-capture box.

CONVERSION FACTORS AND ABBREVIATIONS USED IN THIS REPORT

CONVERSION FACTORS:

Multiply	By	To obtain
cubic foot per second (ft ³ /s)	0.02832	cubic meter per second (m ³ /sec)
foot (ft)	0.3048	meter (m)
gallon	3.78	liter (L)
inch	25.40	millimeter (mm)

Degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) by using the following equation:

$$^{\circ}\text{F} = 9/5(^{\circ}\text{C}) + 32$$

ABBREVIATIONS:

The following terms and abbreviations may be used in this report:

ft (feet)
mi² (square miles)
ft³/sec (cubic feet per second)
gal/d (gallons per day)
inches per year (in/yr)
acre-feet per year (acre-ft/yr)
acre-feet per month (acre-ft/mo)
milligrams per liter (mg/L)
micrograms per liter (µg/L)
micrograms per liter (ug/L)
milliliter (mL)
millimeter (mm)
kilometer (km)
microsiemens per centimeter at 25 degrees Celsius (uS/cm@25°C)

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EXECUTIVE SUMMARY

The spring at Yucca House National Monument was used as a water source for an ancient village of Anasazi people during A.D. 1100-1300. There are no analogs for water-quality conditions of the spring during that period; only the current conditions can be studied, and historic water-quality conditions at the spring may be inferred from recent analyses.

For the current conditions, the ground-water flow conditions are described as follows:

- Water recharged in the Sleeping Ute Mountains flows downgradient through an alluvial fan and discharges in small springs such as Ismay Spring. The water from Ismay Spring is drinkable because of contact with alluvium and colluvium, which is not highly mineralized. Additional recharge for the Yucca House area springs occurs on the alluvial fan.
- Water from the alluvial fan percolates through Mancos Shale to form water at Gate Marsh Spring, which is hypothesized to have the quality of a spring that might have existed during the occupation and drought of A.D. 1276-1300. Water from Gate Marsh Spring is highly mineralized.
- Water from the alluvial fan mixes with water in the Mancos Shale, and then is mixed with irrigation water to form water that discharges at Yucca House Spring. Evidence supporting the fact that Yucca House Spring is affected by man's activities include flow path diagrams indicating geochemical evolution of ground water, the presence of nitrate in water from the spring, saturation indices of mineral speciation, and ground-water flow path modeling.
- Water from the alluvial fan mixes with irrigation-affected water and discharges into South Sunfish Pond. If there was a spring at the

location of the pond during the occupation period, we might expect to see signs of ancient human activity (pottery sherds, etc.) at the site.

Geochemical modeling indicates that minerals are precipitating from ground water into the solid phases. Such chemical precipitation could seal fractures through which the ground water moves, thereby causing the water to seek other discharge locations. The locations of springs can migrate in this manner, and this may be the case for the springs at Yucca House. Ground water currently discharging at Gate Marsh Spring and South Sunfish Pond may have, at one time, all been discharging from Yucca House Spring. It is possible that during the extended drought of 1276-1300, the springs went entirely dry.

If the water from Gate Marsh Spring is representative of the quality of water that the occupants might have experienced during A.D. 1276, the water would have been of poor quality. Drinking water should have a maximum total dissolved solids (TDS) of about 1,000 mg/L. TDS concentrations above 1,000 mg/L create water that is undesirable to drink. Regarding suitability for cultivation and irrigation, water-quality samples from the springs at Yucca House National Monument had high salinity and low sodium-alkali hazard ratings; however, water from Navajo Wash had high and very high salinity and sodium-alkali hazard ratings. Beans and corn might have been grown by the Anasazi that once occupied Yucca House. The values for specific conductance (SC) for water from Yucca House and Gate Marsh Springs ranged from 1,260 to 2,460 $\mu\text{S}/\text{cm}$ or 1.26 to 2.46 mS/cm. Crops such as beans would have a salinity threshold of 1.0 mS/cm, and crop yield losses would occur for SC values between 1.5 and 3.6 mS/cm. Crops such as corn would have a salinity threshold of 2.7 mS/cm, and crop yield losses would occur for SC values between 3.7 and 7.0 mS/cm.

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INTRODUCTION

Yucca House National Monument is an ancestral Puebloan site located in Southwestern Colorado (Figure 1) where a spring played a prominent role in the history of the site and its use by ancient people. The first written documentation of Yucca House was by William H. Holmes in 1877 as part of a U.S. Geological Survey report (Holmes, 1878). Holmes sketched and drew a general floorplan of the Yucca House site based upon fallen walls and the piles of stone (Figure 2). Pioneers and ranchers believed that the ancient village was built by the Aztec people of Mexico; therefore, Holmes named the site and the spring "Aztec Springs." After the establishment of Aztec National Monument in Aztec, New Mexico, the site was renamed "Yucca House."

In 1919, Henry Van Kleeck, a Denver pioneer and the original landowner, donated Yucca House to the federal government, hoping that it would be excavated in the near future. On December 19, 1919, Woodrow Wilson set aside Yucca House and the surrounding acreage to be forever preserved and protected. Despite letters urging the National Park Service to excavate the site, lack of funding prevented it from being unearthed. Van Kleeck sold the surrounding land to the late owners Ray and Hallie Ismay in 1921.

Although there has not been extensive excavation and interpretation of the Yucca House site, artifacts recovered from similar sites in the Four Corners region suggest a Pueblo III (A.D. 1100-1300) period occupation (<http://www.nps.gov/yuho/home.htm>, accessed January 2, 2006). Drought, climatic shifts, deforestation, depletion of soils, social factors, and over-population all could have contributed to their move away from the area. Around A.D. 1276, a long drought began that continued until the end of the century, and the area was completely abandoned by A.D. 1300. Recent studies have shown that abandonment actually began before the drought set in

(Varien, 1999). Even more telling is evidence that the Anasazi had weathered many severe droughts in the past; therefore, the role of the drought in abandonment of the Yucca House site is unclear (Van West and Dean, 2000). It is clear, however, that at one time there was a thriving community at Yucca House, and a large spring would be necessary to support such a community. At the present time (A.D. 2006), the spring is very small, and it would not support a large community. What are the possible factors for the use of the site by the ancient people? What are the possible factors for abandonment of the spring site?

Yucca House National Monument is managed by the National Park Service and administered by staff at Mesa Verde National Park (located east of Yucca House). Resource assessments are needed for Yucca House National Monument, and include inventory of invertebrate fauna, control of non-native weeds, geologic surveys, and descriptions of spring water source and quality. Of particular interest to this report is the source of the water and water quality related to the main Yucca House spring, which discharges in the middle of the ancient village (Figure 3). In addition, source descriptions and water-quality characterization are needed for other springs in the area, Navajo Wash, the Ismay drinking water spring, and runoff from irrigation and snowmelt.

Purpose and Scope

The purpose of this report is to describe the source of water and water-quality characteristics for springs and streams at Yucca House National Monument and surrounding area. Characteristics of major ions and trace elements are described, and geochemical speciation is presented for water-quality samples. Results of geochemical modeling are presented which indicates possible flow paths and source waters for the springs.

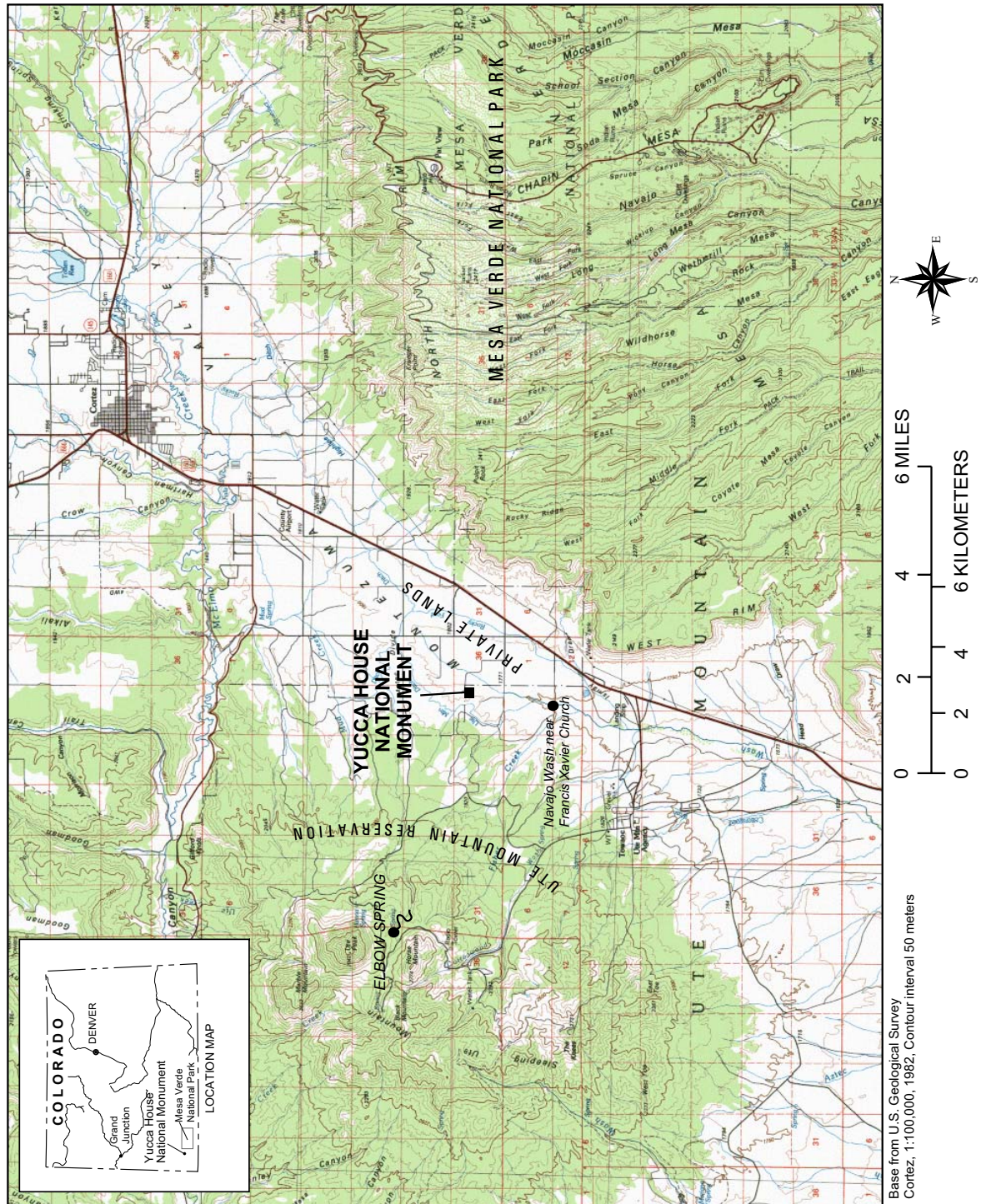


Figure 1. Location of Yucca House National Monument, southwestern Colorado.

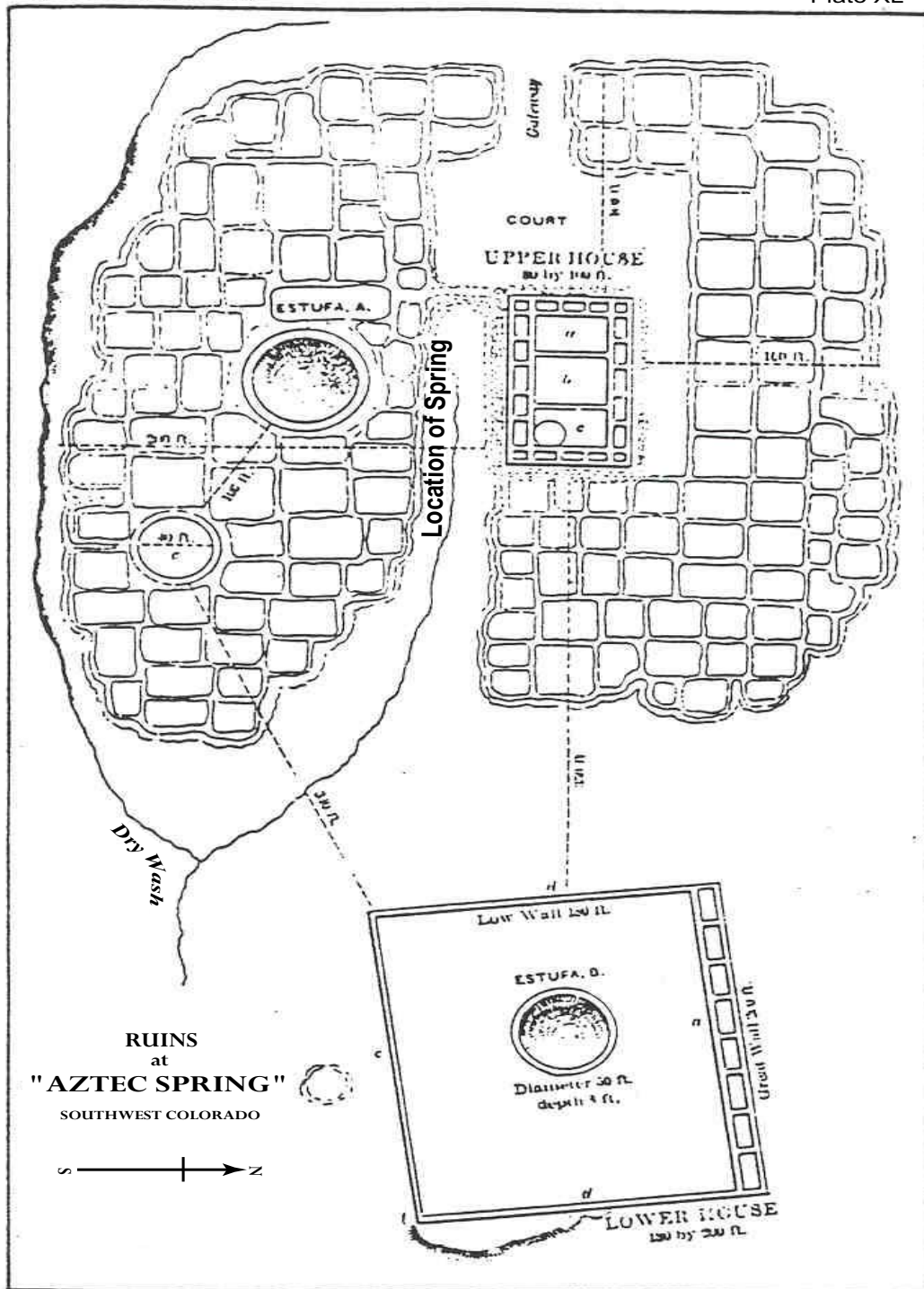
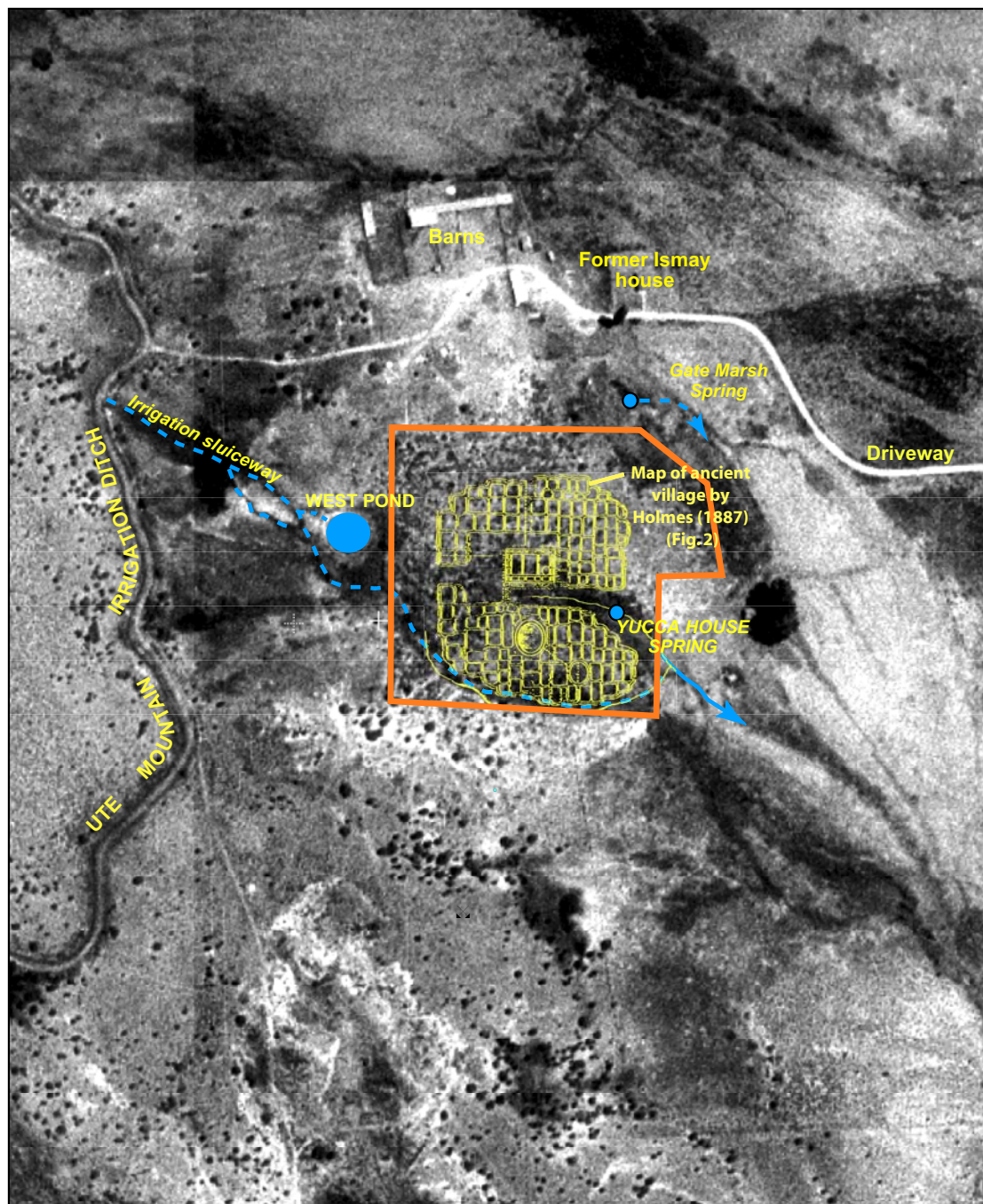


Figure 2. Sketch map showing possible layout of the ancient village at Aztec Spring (Yucca House) by W.H. Holmes, 1878.



Base from National Park Service
 Six-inch resolution imagery acquired April 2002
 UTM Projection, Zone 12, 1983 North American Datum

0 150 300 600 Feet



Figure 3. Aerial photograph of Yucca House Spring and surrounding area. The sketch map made by Holmes (1878) is superimposed on the aerial photograph and shows the possible layout of the ancient village.

Water-quality samples were collected by the author while employed as a hydrologist with the U.S. Geological Survey during 2002-2003. Data compilation and interpretation for this report was done by Southwest Hydro-Logic between September 2005 and February 2006. Sites where water-quality samples were collected were located in the immediate area of Yucca House, upgradient from Yucca House (to the west), on the Ute Mountain Ute Reservation, at selected locations on the Ismay Farm, and at selected locations along Navajo Wash (Appendixes 1 and 2; selected sites are shown on Figure 1).

Methods of Investigation

Trace-element sampling protocols were followed for sample collection (Horowitz and others, 1994). A disposable 0.45 micrometer filter and a length of new tubing were used at each site. Powderless surgical gloves were worn during water sample collection. Discharge was measured using a pygmy current meter or by volumetric method. Polyethylene bottles (pre-rinsed and cleaned) were used for collection of water samples for dissolved-constituent analyses. All samples were analyzed for dissolved cations and anions (calcium, magnesium, sodium, potassium, silica, chloride, fluoride, and sulfate) and selected dissolved trace elements (arsenic, boron, iron, manganese, selenium, uranium, vanadium, and zinc). Selected samples were analyzed for filtered and unfiltered nutrients (ammonia, ammonia plus organic nitrogen, nitrite plus nitrate, phosphorus, and orthophosphate).

Field meters were calibrated in the field each day of sample collection. Since field-meter measurements are temperature dependent, calibration standards were placed in the site water to reach the ambient temperature of the water to be measured. Specific conductance and pH meters were calibrated to standards that bracket the range of expected values. Dissolved-oxygen (DO) meters were calibrated to the saturated DO of water, and the DO meters also were checked with a solution of zero dissolved oxygen. Water temperature was measured with a digital thermometer calibrated in the laboratory to a certified ASTM thermometer. Filtration of water samples was performed in a portable glove box. Samples for dissolved-cation and dissolved trace-metal analyses were preserved using ultrapure nitric acid ampules;

samples for anions were not preserved. Alkalinity titrations were performed in the field at the time of sample collection. Site locations were determined by Global Positioning System (GPS) and verified by map location.

The quality assurance of the data were verified by collection of replicate and blank samples and by calculation of the cation and anion balances. Replicate samples collected from Ismay Spring on 09/04/2003, and analyzed separately in the laboratory, indicated differences of 0 to 11 percent between the two samples. Cation and anion balances performed on the laboratory analyses indicated balances of less than 5 percent for all samples.

The water-quality data were downloaded from the U.S. Geological Survey National Water Information System (<http://nwis.waterdata.usgs.gov/nwis>). Downloaded data were supplemented with the hard-copy laboratory analysis sheets available in the USGS Field Office in Durango, Colorado.

Permission was obtained from the Ute Mountain Ute Tribe to collect a water-quality sample from Elbow Spring on Sleeping Ute Mountain (Figure 1), part of the Ute Mountain Ute Reservation. During July 2003, the author was joined by Scott Clow, Water-Quality Specialist with the Ute Mountain Ute Tribe, to collect water-quality samples in the Sleeping Ute Mountains. We very much appreciate access to the spring site; this water sample represents the source of water for the Yucca House area, and the analysis was very helpful for this report.

Water-quality data were tabulated in a spreadsheet (Microsoft Excel™), and x-y plots were generated in Excel. Site locations and data were displayed using ArcGIS 9™. Water-quality data were displayed on a trilinear diagram (Piper diagram) using HC-Gram Version 3.0.1 (U.S. Department of Interior, Office of Surface Mining, http://www.tips.osmre.gov/tips_html/downloads.asp, accessed January 26, 2006). Geochemical speciation modeling was done using WATEQ4F, the USGS equilibrium chemical speciation computer program (Ball and Nordstrom, 1991). Water-quality data for the Yucca House hydrochemical system were input into a geochemical modeling system called NETPATH which interprets net geochemical mass balance reactions between an initial and final water along a hydrologic flow path (Plummer and others, 1994). NETPATH also computes the mixing proportions of two to five initial waters and net geochemical

reactions that can account for the observed composition of a final water.

PHYSICAL SETTING

Yucca House National Monument encompasses 31 acres of moderately rolling terrain in the foothills of Sleeping Ute Mountain in southwestern Colorado (Figure 4). The Sleeping Ute is said to resemble a Ute Chief lying on his back with arms folded across his chest. The mountains were valued as a sacred place by the Weeminuche Ute band. It is still a sacred place to their descendants, the Ute Mountain Ute Tribe, and still plays a role in their ceremonies as indicated by the “Sundance Ground” on some topographical maps nestled between The Knees and Horse Peak (Wikipedia, The Free Encyclopedia, http://en.wikipedia.org/wiki/Sleeping_Ute, accessed January 27, 2006).

Physical setting of the study area is described by Fenneman (1931) as the Great Sage Plain of the Colorado Plateau physiographic province. Altitudes within the monument boundary range from 5,865 to 5,930 feet above sea level, and altitudes of water-quality sites range from 5,735 to 7,871 feet above sea level.

The influence of altitude on the character of the vegetation is plainly marked on the landscape. In the higher terrain west of Yucca House (on the Ute Mountain Ute Reservation), vegetation consists of

spruce, ponderosa pine, aspen groves, oak brush, and subalpine grass meadows mixed with piñon and juniper. Below about 7,000 feet, bare soil dominates and the vegetation is dramatically different consisting of sage, clump grasses, piñon, and juniper; cottonwoods, willows, and tamarisk grow along irrigation ditches and in the bottoms of seasonal streambeds. Wild flowers are present that indicate high trace-element concentrations in soil (Figure 5).

Geology

Rocks of the area surrounding Yucca House have a varied background, including tertiary age igneous intrusive rocks of the Sleeping Ute Mountain Range, sedimentary rocks of the Morrison Formation of Jurassic age, and the Mesa Verde, Dakota, and Burro Canyon Formations of Cretaceous age (Figure 6). The rocks in the immediate area of Yucca House are comprised of Mancos Shale of upper Cretaceous age (Haynes and others, 1972; Griffiths, 2001). The Mancos Shale is comprised of dark gray to black shale and silty shale, dark-gray to blue-gray argillaceous limestone, and thin beds of bentonite. The Mancos Shale is full of fossils from the deep marine environment when the shale was deposited around 81 to 94 million years ago (Griffiths, 2001).

In near-surface environments, Mancos Shale weathers to shale residuum, which resembles soil in its

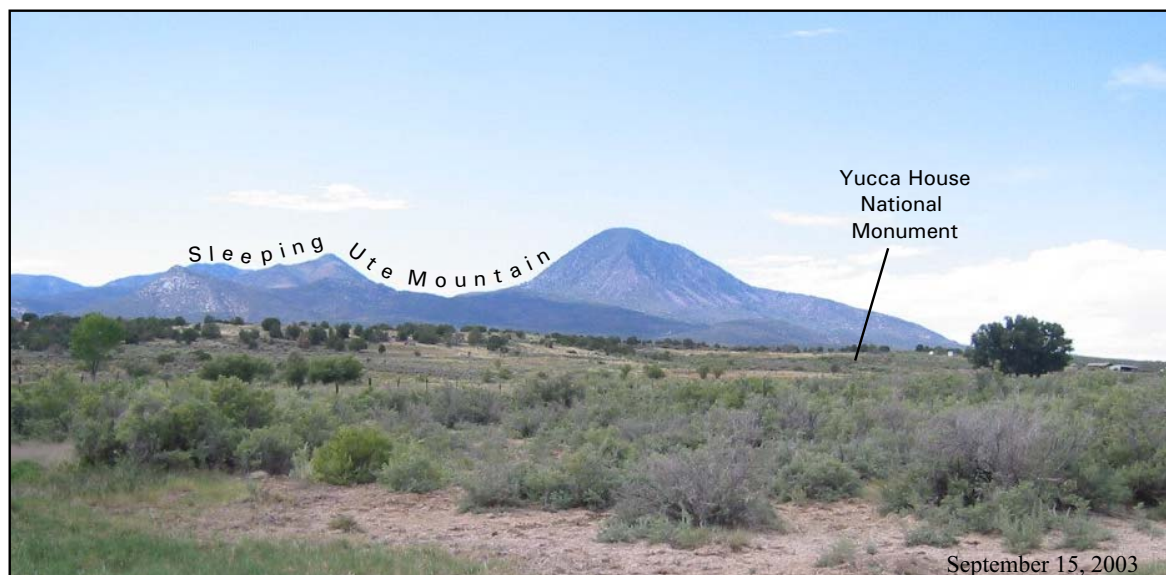


Figure 4. Photograph showing Sleeping Ute Mountain and location of Yucca House National Monument (view looking west).



Figure 5. Photograph showing bare soil, sage, and prince's plume which is a primary indicator of high selenium concentrations in soil.

characteristics but retains the physical structure of the shale (Whittig and others, 1982). Residuum profiles in the Mancos Shale can range from several feet to tens of feet thick (Cole and Young, 1991).

There are no faults known in the Yucca House area; however, there are indications of faults across Montezuma Valley, southeast of Yucca House (Figure 6). Fracturing of the bedrock has likely occurred because of the uplift of the rocks caused by the intrusive Sleeping Ute Mountains. Fractures can act as conduits for the movement of ground water.

Climate and Drought

Annual precipitation at Cortez, Colorado (north of Yucca House), averaged 12.9 inches during the period of 1929-2005, with a high annual precipitation of 26.34 inches in 1957, and a low of 5.23 inches in 1989 (Western Regional Climate Center, <http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?cocort>, accessed January 28, 2006). Precipitation has varied throughout time, but the area has been, and remains, a semi-arid to arid region. Using tree-ring chronology, Van West and Dean (2000) reconstructed precipitation departure from the average for the Mesa Verde region during the period when the area was occupied by the Anasazi (Figure 7). Precipitation departures from the average also are tabulated as part of this study (Figure

7). The departures were both fitted with a LOWESS curve which is a data analysis technique for producing a “smooth” set of values from a time series. Both the tree-ring data and the recent Cortez data show similar frequency of fluctuation around the average; however, the values of departure from the average (amplitudes) appear to be subdued in the tree-ring data. It appears that the area experienced sustained drought conditions during A.D. 1125-1175 (50-year drought period), and the drought of A.D. 1276-1300 was, at one time, hypothesized as the reason for abandonment of the region by the Anasazi (Van West and Dean, 2000). In the recent record there appears to be only slight drought conditions sustained during A.D. 1954-1968, and the negative departures were not substantial. There is not enough data to indicate whether the current drought cycle compares with the A.D. 1125-1175 drought; however, other studies have indicated that precipitation during 2002 was as low as during the A.D. 1276-1300 drought period (Doesken and Pielke, 2004).

HYDROLOGY

The hydrology of the area surrounding Yucca House National Monument is typical for a semi-arid region where local water supplies would not be adequate to support a substantial population. Spring-



Base from U.S. Geological Survey
Cortez 1:250,000, 1956
Geology from USGS Map I-629

EXPLANATION

Qa	-- Alluvium
Qap	-- Alluvium, pediment gravels
Qc	-- Colluvium
Qct	-- Colluvium, talus deposits
Kdb	-- Dakota and Burro Canyon Formations
Kmij	-- Mancos Shale, Juana Lopez Member
Km	-- Mancos Shale
Kpl	-- Mesa Verde Group, Point Lookout Sandstone
Jmb	-- Morrison Formation, Brushy Basin Member
Jmw	-- Morrison Formation, Westwater Canyon Member
TKdu	-- Sleeping Ute, quartz diorite
TKus	-- Sleeping Ute, stock

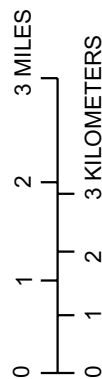
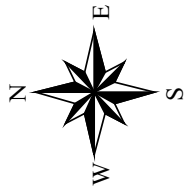


Figure 6. Geologic map of Yucca House National Monument and surrounding area (from Haynes and others, 1972).

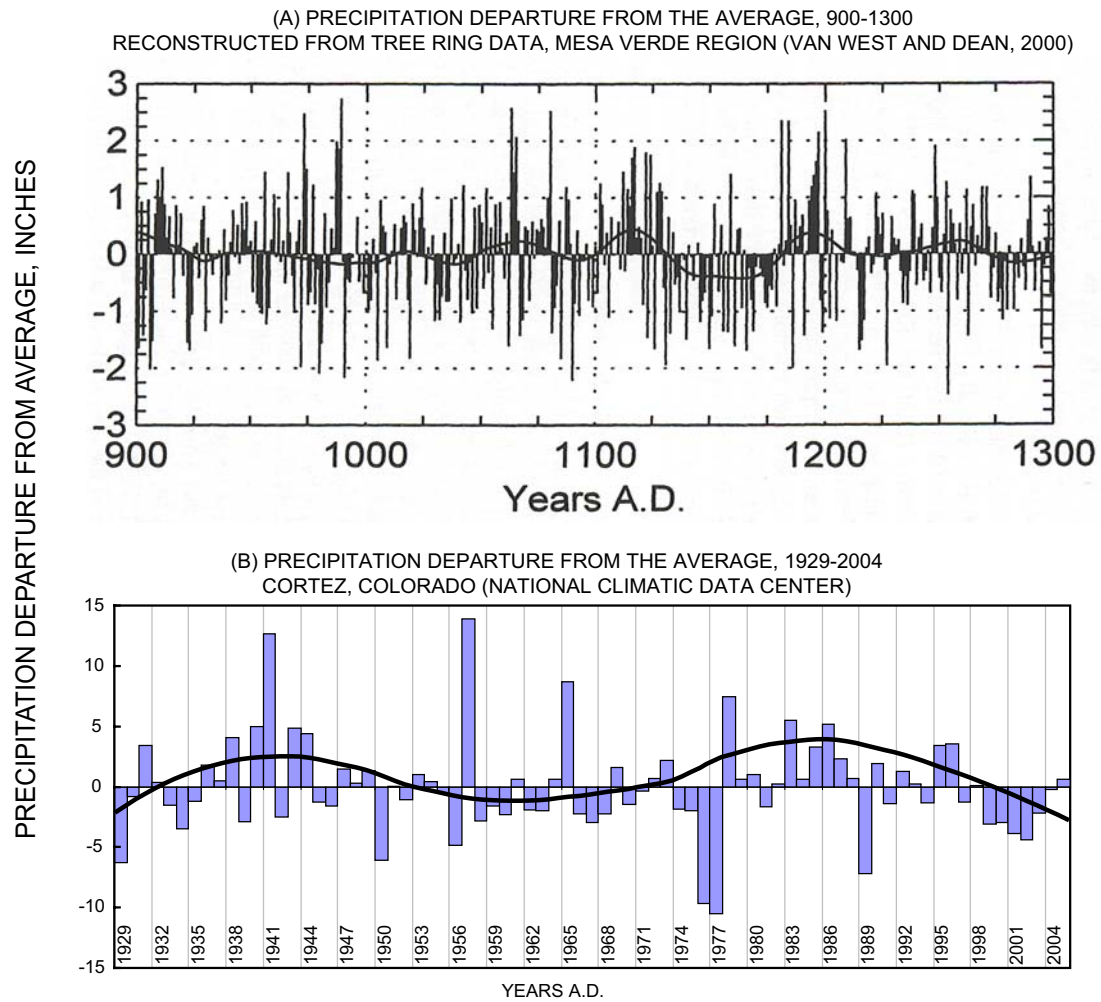


Figure 7. (A) Precipitation departure from average during A.D. 900-1300 for the Mesa Verde region from tree-ring chronology (Van West and Dean, 2000), and (B) Precipitation departure from average during A.D. 1929-2005 for the meteorological station at Cortez, Colorado.

fed washes draining Sleeping Ute Mountain are ephemeral and intermittent in nature, gaining recharge from rainfall and snowmelt (Geldon, 1985). In contrast, the washes can turn into raging torrents of rainfall runoff during monsoonal thunderstorms of July through October. Shale layers in Mancos Shale have low permeabilities (Irwin, 1966), and are poor ground-water aquifers. Limestone beds in the Mancos Shale may have slightly greater permeabilities due to solutional enlargement of fractures and fissures; however, the quality of water in the limestone beds is poor (Irwin, 1966). During most months of the year evaporation and plant transpiration exceed precipitation (Butler and others, 1995). If not for irrigation water from the Dolores River transported to the area by canals and pipeline, there would be little water present in the streams and drains. Imported irrigation water also affects springs, and may create ephemeral springs, in the area.

Springs

Three springs occur in the Yucca House area--the Yucca House Spring, Ismay Spring, and Gate Marsh Spring (Figure 8, Table 1). Discharges from these springs are very small and range from 0.001 to 0.002 ft³/sec (cubic feet per second) (Appendix 2); discharge from Gate Marsh Spring is intermittent. Since the Yucca House and Gate Marsh Springs are located downgradient from irrigation water sources (Figure 8), it is uncertain whether these springs have been affected by irrigation water. The Ismay Spring is located upgradient from the effects of irrigation (Figure 8), and is not affected by irrigation water.

The recharge area for the springs occurs upgradient from the Yucca House area in the foothills of Sleeping Ute Mountain. Color infrared (IR) imagery of the study area shows bright red colors where water-loving plants (phreatophytes) are located (Figure 9). The irrigated acres are clearly marked by red colors on the IR imagery. Upgradient (to the west) from Yucca House, there is a relatively flat area comprised of alluvium and pediment gravels on top of Mancos Shale where several red colors appear in the IR imagery (Figure 9). These red colors may represent phreatophyte plants, wetlands, and saturated soils. These red colors also may represent ground-water

recharge zones for springs at Yucca House National Monument.

Streams

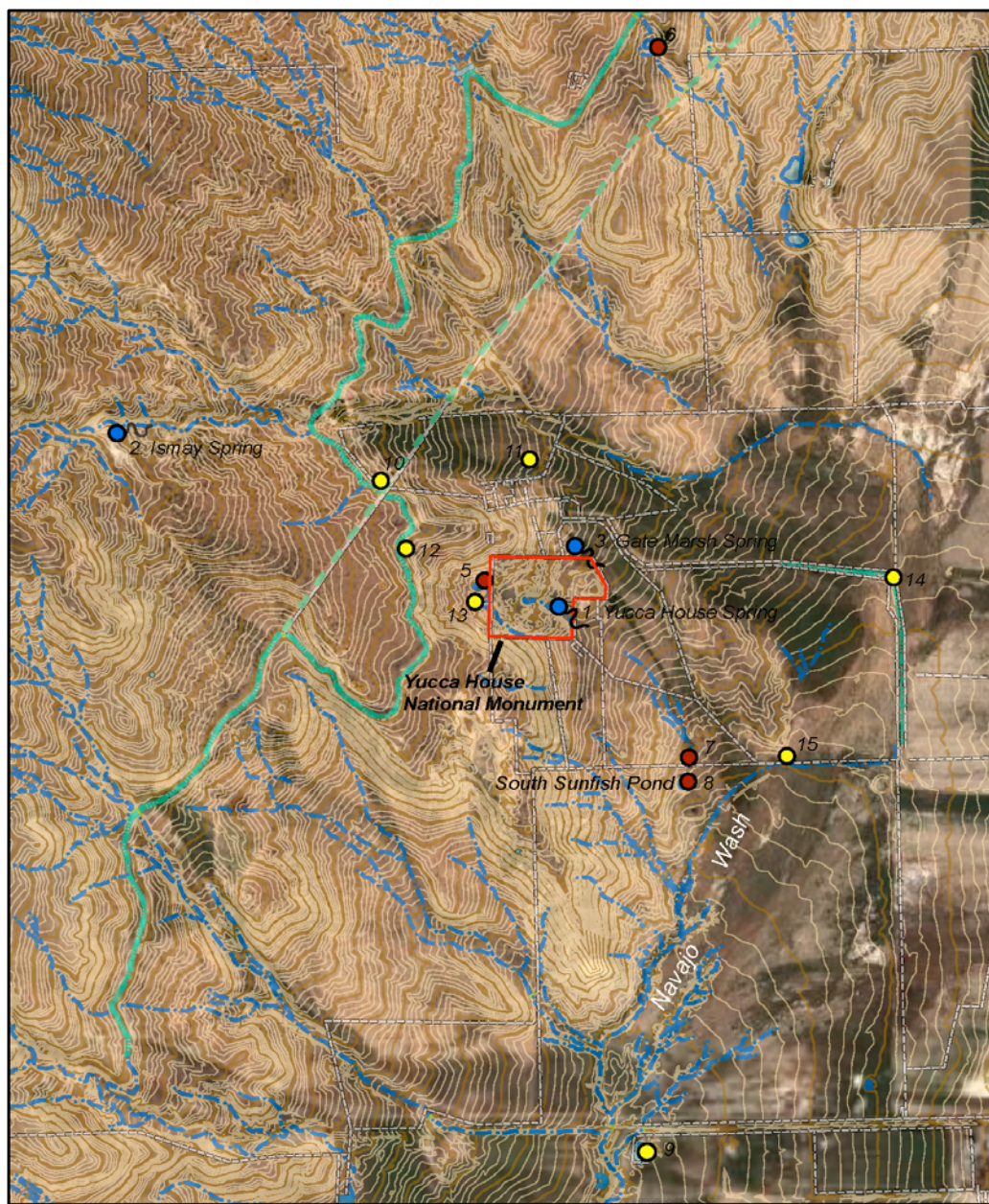
Streamflows in the area surrounding Yucca House are influenced by imported irrigation water which is delivered to the area through canals and pipelines during April through October of each year. Streamflow discharges in Navajo Wash near Towaoc can fluctuate widely during the irrigation season (Figure 10). Some of the larger discharges that occurred during the non-irrigation season are caused by rainfall runoff from thunderstorms or snowmelt/rainfall-runoff events (Figure 10). During the non-irrigation season, discharges in Navajo Wash are sourced from seepage caused by irrigation drainage. If not for the irrigation water, Navajo Wash would probably be dry most of the time, except during periods of high precipitation and snowmelt.

Irrigation

Many of the fields in the area surrounding Yucca House National Monument are irrigated on a seasonal basis every year (Figure 11). Application of irrigation water to soils derived from Mancos Shale is known to increase percolation rates and seepage in shallow aquifer systems (Wright and Butler, 1993; Butler and others, 1996). Permeability values for Mancos Shale residuum were shown by Butler and others (1996) to be as low as 4.5 ft/d. At these low permeabilities, and at a relatively low-gradient location such as Yucca House, it could take 2,000 days for ground water to travel 400 feet. Fractures may occur in the shale which provide for faster ground-water flow rates; however, the aquifers in the study area are not sufficient to withdraw water for domestic use (Irwin, 1966; Geldon, 1985).

GEOCHEMISTRY

The composition of rocks and minerals, solubilities of minerals, and reaction times are controlling factors in the resulting chemical composition of natural waters. Different minerals weather at different rates, and saturation of mineral



Base from Google Earth, 3.0.0762, Nov 15, 2005
 Contours from National Park Service
 Contour interval 2 feet, bold contours 10 feet

0 750 1,500 3,000 Feet



EXPLANATION

- | | | |
|--|-------------------------------------|----------------------------|
| ● 1 | SPRING AND SITE NUMBER | ===== FENCE |
| ● 7 | POND AND SITE NUMBER | - - - - - EPHEMERAL STREAM |
| ● 15 | IRRIGATION DRAINAGE AND SITE NUMBER | IRRIGATION CANAL OR DITCH |
| | | — IRRIGATION PIPELINE |

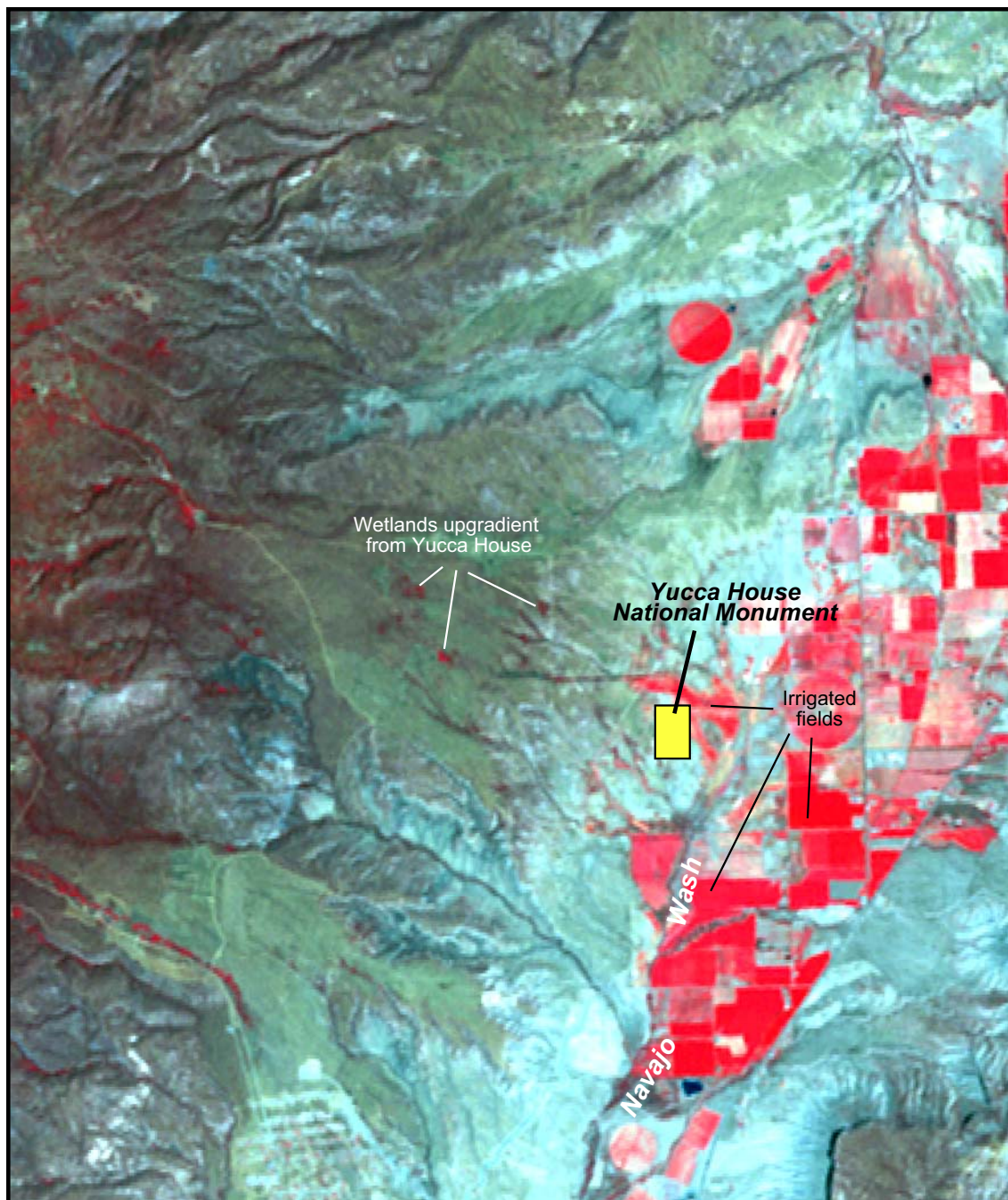
Figure 8. Locations of water-quality sampling sites in the Yucca House National Monument area.

Table 1. Site information and location data for water-quality samples at Yucca House National Monument

YUHO Site	Site Name	Sample Years	USGS Site Number	Field Number	Data source	Site Type	Hydrologic Unit Code	Latitude, dd mm ss	Longitude, ddd mm ss
1	Yucca House Spring	2002, 2003	371500108410801	YUCW06	USGS	SP	14080107	37°15'00.5"	108°41'08.8"
2	Ismay Spring	2002, 2003	371514108414601	YUCW01	USGS	SP	14080107	37°15'14.0"	108°41'46.7"
3	Gate Marsh Spring	2002	371504108410601	YUCW04	USGS	SP	14080107	37°15'04.7"	108°41'06.3"
4	Elbow Spring, east slope of Sleeping Ute Mountain	2003	371634108455701	Elbow Spring	USGS	SP	14080107	37°16'34.30"	108°45'57.80"
5	West Pond at Yucca House National Monument	2003	371502108411301	YUCW02	USGS	LW	14080107	37°15'02.67"	108°41'13.45"
6	South Highline Pond near Yucca House National Monument	2003	371541108405801	YUCW10	USGS	LW	14080107	37°15'41.40"	108°40'58.50"
7	Middle Sunfish Pond	2002	371447108405701	YUCW22	USGS	LW	14080107	37°14'47.9"	108°40'57.6"
8	South Sunfish Pond	2002	371446108405701	YUCW17	USGS	LW	14080107	37°14'46.7"	108°40'57.6"
9	Pond near B Road and Navajo Wash--Gordanier Pond	1994	371415108410001	Gordanier Pond	USGS	LW	14080107	37°14'15"	108°41'00"
10	Ismay Main Headgate	2003	371509108412401	Ismay Headgate	USGS	IW	14080107	37°15'09.7"	108°41'24.5"
11	Irrigation runoff below main headgate	2003	371510108411001	YUCR2	USGS	IW	14080107	37°15'10.90"	108°41'10.90"
12	Headgate above West Pond	2003	371504108412201	YUCHG1	USGS	IW	14080107	37°15'04.90"	108°41'22.10"
13	Irrigation runoff west of Yucca House Natl Monument	2003	371500108411501	YUCR1	USGS	IW	14080107	37°15'00.90"	108°41'15.80"
14	Navajo Wash near Yucca House National Monument	2003	371501108403601	YUCW13	USGS	SW	14080107	37°15'01"	108°40'36"
15	Navajo Wash at Ismay property line, southern boundary	2003	371448108404801	Navajo Wash	USGS	SW	14080107	37°14'48.60"	108°40'48.70"
16	Navajo Wash near Francis Xavier Church	1975	371329108411900	Navajo nr FX Church	USGS	SW	14080107	37°13'29"	108°41'19"

Table 1. Site information and location data for water-quality samples at Yucca House National Monument--continued

YUHO Site	Latitude, dd	Longitude, dd	Lat/Long source	Horizontal Datum	Altitude, ft	Altitude Source	Altitude Digital map	County	Geologic Setting	Site Description
1	37.25013889	-108.6857778	GPS	NAD83	5,898	Digital map	NGVD29	Montezuma	Mancos Shale	Main spring at Yucca House National Monument
2	37.25388889	-108.6963056	GPS	NAD83	6,032	Digital map	NGVD29	Montezuma	Dakota Formation	Spring in Ismay Draw, fills stock tank
3	37.25130556	-108.6850833	GPS	NAD83	5,905	Digital map	NGVD29	Montezuma	Mancos Shale	Spring near gate entrance to Yucca House Natl Mon
4	37.27619444	-108.7660556	GPS	NAD83	7,871	Digital map	NGVD29	Montezuma	Mancos Shale	Spring discharging from the "elbow" of the Sleeping Ute, upgradient from Yucca House National Monument
5	37.25074167	-108.6870694	GPS	NAD83	5,938	Digital map	NGVD29	Montezuma	Mancos Shale	Pond west of Yucca House receiving irrigation water from Headgate Source (YUCHG1)
6	37.2615	-108.6829167	GPS	NAD83	5,735	Digital map	NGVD29	Montezuma	Mancos Shale	Pond receiving water from Ute Mountain Ditch, north of Yucca House
7	37.24663889	-108.6826667	GPS	NAD83	5,837	Digital map	NGVD29	Montezuma	Mancos Shale	Pond collecting drainage from Yucca House spring and upgradient irrigated fields
8	37.24630556	-108.6826667	GPS	NAD83	5,830	Digital map	NGVD29	Montezuma	Mancos Shale	Pond collecting drainage from Yucca House spring and upgradient irrigated fields
9	37.2375	-108.6833333	Topo map	NAD27	5,800	Topo map	NGVD29	Montezuma	Mancos Shale	Pond on Gordanier property
10	37.25269444	-108.6901389	GPS	NAD83	5,970	Digital map	NGVD29	Montezuma	Mancos Shale	Headgate source for irrigation of land north of Ismay house, Ute Mountain Ditch water
11	37.25302778	-108.6863611	GPS	NAD83	5,925	Digital map	NGVD29	Montezuma	Mancos Shale	Irrigation water draining fields north of barns, north of Yucca House
12	37.25136111	-108.6894722	GPS	NAD83	5,960	Digital map	NGVD29	Montezuma	Mancos Shale	Headgate source near West Pond, Ute Mountain Ditch water
13	37.25025	-108.6877222	GPS	NAD83	5,937	Digital map	NGVD29	Montezuma	Mancos Shale	Irrigation runoff near West Pond
14	37.25027778	-108.6766667	GPS	NAD83	5,843	Digital map	NGVD29	Montezuma	Mancos Shale	Navajo Wash downstream from irrigated land east and northeast of Yucca House
15	37.24683333	-108.6801944	GPS	NAD83	5,830	Digital map	NGVD29	Montezuma	Mancos Shale	Irrigation runoff from Ismay property, collected into Navajo Wash
16	37.22472222	-108.6886111	Topo map	NAD27	5,800	Topo map	NGVD29	Montezuma	Mancos Shale	Navajo Wash downstream from Yucca House National Monument



Base from U.S. Geological Survey,
Landsat Thematic Mapper Imagery for the
Conterminous United States, July 2002,
<http://seamless.usgs.gov>.

0 0.5 1 2 Miles
0 0.5 1 2 Kilometers



Figure 9. Color infrared imagery showing water-loving plants (phreatophytes) in bright red colors.

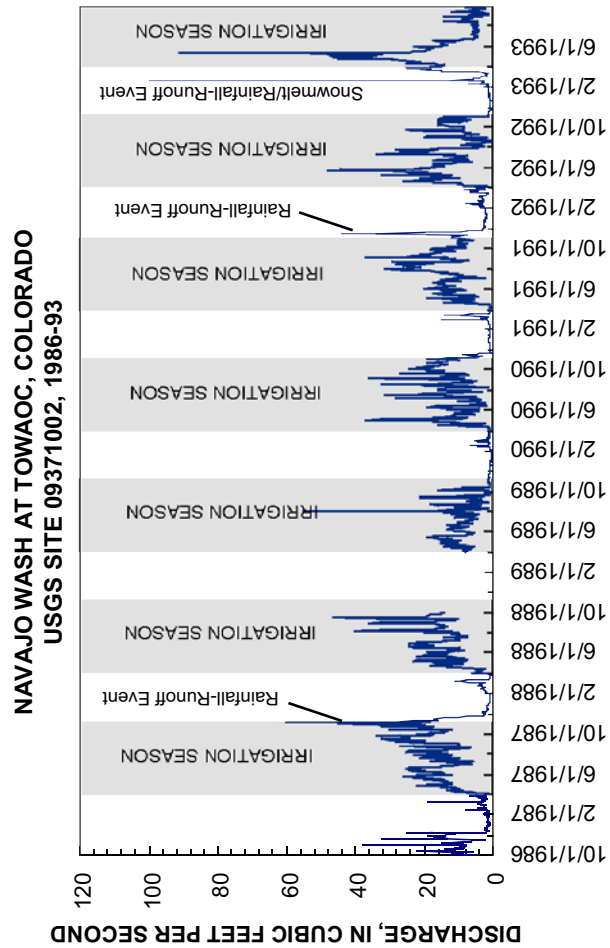
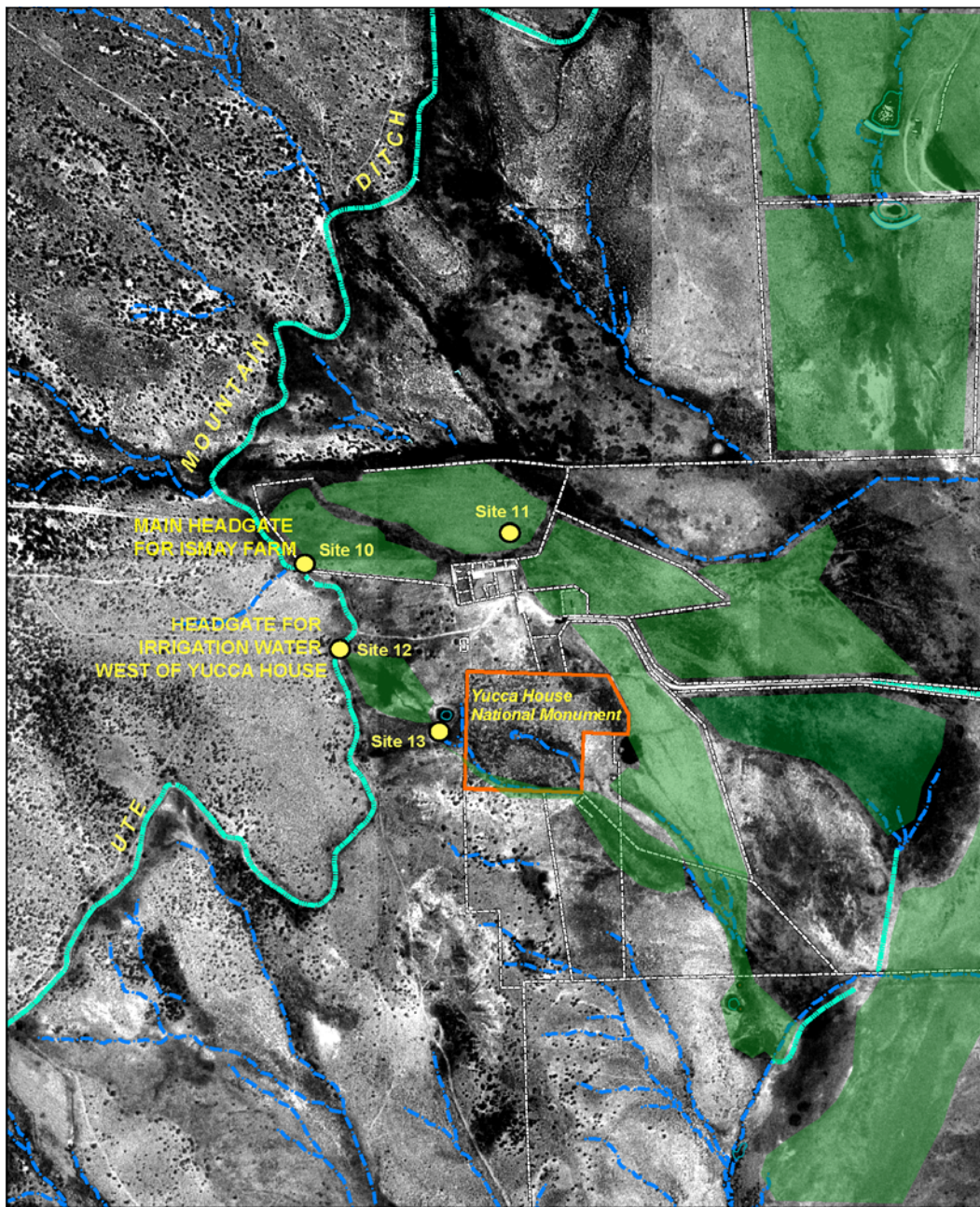


Figure 10. Hydrograph of Navajo Wash at Towaoc, Colorado, showing the influences of irrigation water on discharges in the stream.



UTM Projection, Zone 12, 1983 North American Datum
Six-inch resolution imagery acquired by NPS April 2002

0 375 750 1,500 Feet



EXPLANATION

- AREA AFFECTED BY IRRIGATION
IN THE VICINITY OF YUCCA HOUSE
NATIONAL MONUMENT
- FENCE
- IRRIGATION CANAL OR DITCH
- Site 13 IRRIGATION WATER-QUALITY SITE

Figure 11. Areas affected by irrigation in the vicinity of Yucca House National Monument.

species can result in chemical precipitation or reduction of dissolved mineral concentration.

Water-quality data from Yucca House National Monument and surrounding area can reveal the geochemistry of the rocks through which the water passed. In addition, flow paths and source areas can be described through evaluation of geochemical data. The composition of the solid-phase minerals controls the resulting water-quality and aqueous geochemical characteristics.

Analytical results from solid-phase samples of Mancos Shale are presented from the Grand Valley and Uncompahgre River valley (west-central Colorado). The exact composition of the shale may differ between the Yucca House area and west-central Colorado. However, the solid-phase data are presented as an idea of the minerals that may play a role in geochemical reactions and evolution of ground water in the Yucca House area.

Solid-Phase Minerals

Mancos Shale bedrock itself consists of many different minerals such as silicate (quartz), calcium carbonate, dolomite, ash layers (bentonite), trace pyrite, kerogen (organic matter), trace elements (chromium, iron, manganese, nickel, selenium,

uranium, vanadium, zinc), and fossils. The shale weathers to residuum and shale-derived alluvium, and clay minerals are partly the result of shale weathering (Table 2). After weathering, minerals are more available for geochemical reactions in shale residuum and alluvium than the shale bedrock, partly due to increased porosity. Silicate minerals are dominant in shale residuum and alluvium (Table 2). Calcite (CaCO_3) and dolomite (MgCO_3) also are present in the shale residuum and alluvium (Table 2).

Gypsum and other evaporite salts can be dominant minerals in surface outcrops of shale residuum (Table 3). In general, pyrite (iron sulfide) in the shale bedrock oxidizes to release dissolved sulfate and iron. Dissolved sulfate combines with calcium, magnesium, and sodium which then can precipitate as efflorescent salts (efflorescent for “flower”). There may be primary gypsum in some parts of the Mancos Shale; however, it is not a widespread feature (Cole and Young, 1991). These efflorescent salts are very soluble, and can dissolve quickly during rainstorms, thereby presenting high dissolved mineral loads in rainfall runoff. Efflorescent salts are present in the Yucca House area, mostly in the valley near Navajo Wash where irrigation occurs on Mancos Shale.

Table 2. Minerals in Mancos Shale residuum and alluvium identified by X-ray diffraction from Butler and others (1994)

[nd, not detected; tr, less than 7 percent of intensity of dominant phase; min, 7 to 30 percent of intensity of dominant phase; mod, 30 to 70 percent of intensity of dominant phase; dom, predominant mineral in X-ray pattern; sdom, 70 to 99 percent of intensity of dominant phase; cdom, predominant minerals have same relative intensities; K, potassium; ft BLS, feet below land surface]

	Minerals Identified by X-ray Diffraction										
	Illite	Kaolinite	Smectite	Chlorite	Quartz	Plagioclase feldspar	K feldspar	Calcite	Dolomite	Gypsum	Pyrite
Mancos Shale residuum, Delta, Colorado, 5 ft BLS	cdom	cdom	min	tr	sdom	tr	tr	min	min	dom	nd
Mancos Shale residuum, Delta, Colorado, 15.5 ft BLS	cdom	cdom	min	tr	dom	tr	tr	min-mod	min	nd	nd
Alluvium derived from Mancos Shale, Loma, Colorado, 6 ft BLS	cdom	cdom	tr	tr	dom	min	tr	min	min	nd	nd
Alluvium derived from Mancos Shale, Loma, Colorado, 24.5 ft BLS	cdom	cdom	tr	tr	dom	tr	nd	mod	min-mod	tr	nd

Table 3. Evaporite mineral species and salt efflorescence associated with the Mancos Shale and shale residuum in the Grand Valley from Whittig and others (1982)

Evaporite species	Formula	Occurring in Mancos Shale	Occurring in efflorescence
Gypsum	$\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$	X	X
Epsomite	$\text{MgSO}_4 \cdot 10\text{H}_2\text{O}$	--	X
Hexahydrite	$\text{MgSO}_4 \cdot 6\text{H}_2\text{O}$	--	X
Pentahydrite	$\text{MgSO}_4 \cdot 5\text{H}_2\text{O}$	--	X
Starkeyite	$\text{MgSO}_4 \cdot 4\text{H}_2\text{O}$	--	X
Kieserite	$\text{MgSO}_4 \cdot \text{H}_2\text{O}$	--	X
Mirabilite	$\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$	--	X
Thenardite	Na_2SO_4	--	X
Loewite	$\text{Na}_4\text{Mg}_2(\text{SO}_4)_4 \cdot 5\text{H}_2\text{O}$	--	X
Bloedite	$\text{Na}_2\text{Mg}(\text{SO}_4)_2 \cdot 4\text{H}_2\text{O}$	--	X

Major Ions and Nutrients

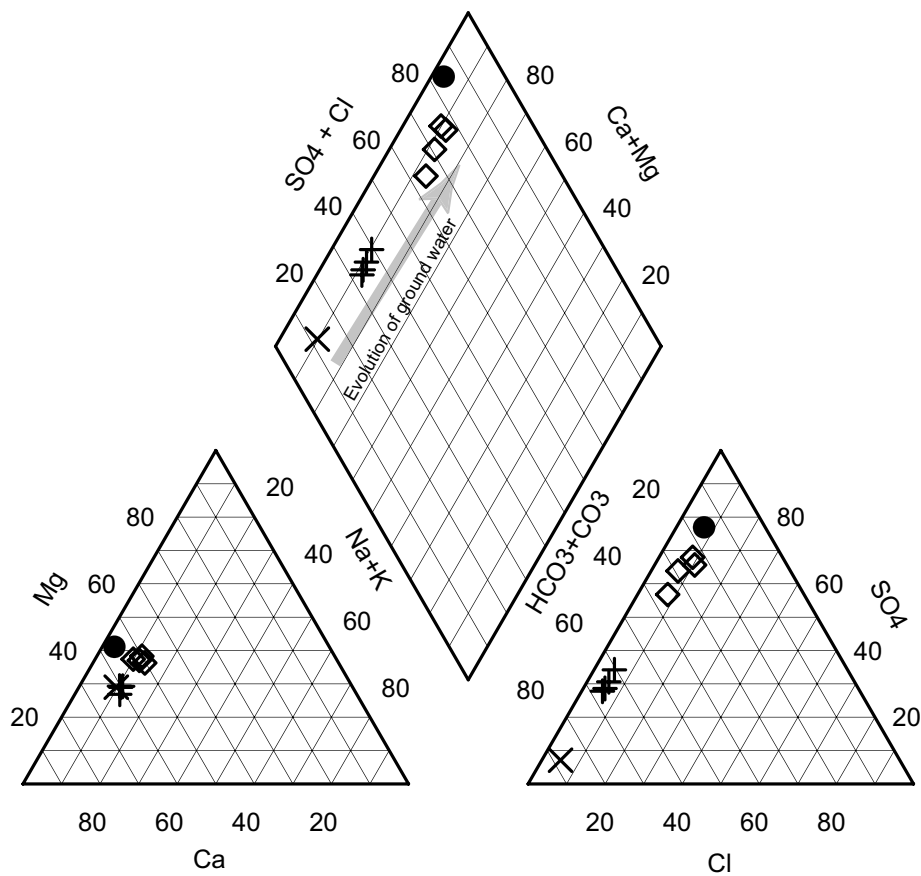
Observations of the general characteristics of water quality in the study area can be described using a water-analysis diagram (Figure 12). This diagram, sometimes referred to as a trilinear diagram or Piper diagram, shows the relations among concentrations of cations (positively charged ions) and anions (negatively charged ions). The values are expressed as percentages of the total milliequivalents per liter of cations (lower left triangle) or of anions (lower right triangle) and are not shown as actual concentrations. The central quadrilinear graph shows the combined cationic and anionic chemical quality of the water by a third point, which is at the intersection of the rays projected from the points on the cation and anion plots.

The water sample from Elbow Spring (on Sleeping Ute Mountain) was a calcium bicarbonate type water, water samples from Ismay spring were a calcium bicarbonate type water, and water samples from the Yucca House and Gate Marsh Springs were dominantly a calcium sulfate type water. The total dissolved solids (TDS) concentration in water from Elbow Spring was 206 mg/L (milligrams per liter). TDS concentrations in the Ismay Spring ranged from 474 to 491 mg/L, and TDS concentrations in Yucca House Spring ranged from 885 to 1,570 mg/L. The highest TDS concentration of 2,000 mg/L was in water from Gate Marsh Spring.

As ground water flows along a flow path from recharge areas to discharge areas, the water acquires dissolved constituents by water-rock interaction. The further along the flow path, the water generally has

higher dissolved constituent concentrations. This is called the evolution of ground water along a flow path. In the Piper diagram (Figure 12), an example of ground-water evolution is shown, where the water at Elbow Spring is a calcium bicarbonate type water with a TDS of 206 mg/L. At Ismay Spring, the water is still a calcium bicarbonate type water with a relatively low TDS concentration of about 474 mg/L. At Yucca House Spring, the water has evolved into a calcium sulfate type water with TDS concentrations of about 1000 mg/L due to water-rock interaction with the Mancos Shale. Gate Marsh Spring also is a calcium sulfate type water with a high TDS concentration of 2000 mg/L. Yucca House and Gate Marsh Springs appear to be similar types of waters; however, there are higher dissolved-constituent concentrations in Gate Marsh Spring than in Yucca House Spring. It is possible that water in the Yucca House Spring is influenced (or diluted) by irrigation water in the field near West Pond and by seepage from West Pond.

Further evidence of the evolution of natural waters can be displayed by X-Y plots of dissolved-constituent data (Figure 13). Elbow Spring, Yucca House, and Gate Marsh Springs all had silica concentrations of about 22-25 mg/L. Waters in Elbow Spring interact with quartz diorite of the Sleeping Ute Mountains and acquire dissolved silica. As the water flows downgradient from Sleeping Ute Mountain to the Yucca House area, the dissolved silica concentrations are similar to Elbow Spring, almost acting as a tracer (Figure 13). In contrast, the irrigation water had silica concentrations of about 3 to 4 mg/L. Water in West Pond and Middle Sunfish Pond appear to be similar to the irrigation water, except



EXPLANATION

- ✕ Elbow Spring
- + Ismay Spring
- ◇ Yucca House Spring
- Gate Marsh Spring

Figure 12. Water analysis diagram showing percentages of major ions in water samples from springs in the Yucca House National Monument area. On the top-central diagram, the arrow indicates evolution of ground water as it flows from the Sleeping Ute Mountains (Elbow Spring), to Ismay Spring, the Yucca House spring, and Gate Marsh Spring.

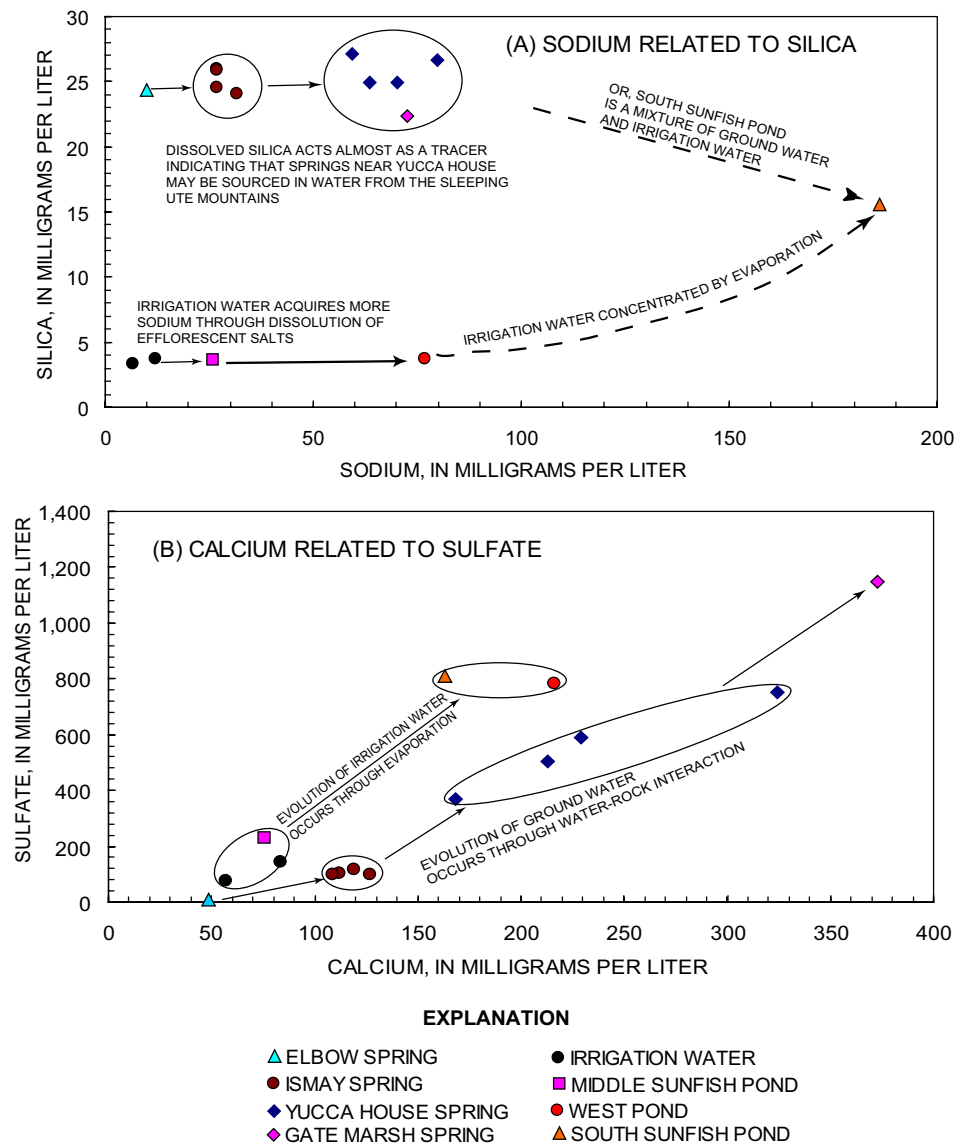


Figure 13. X-Y plots of (A) sodium related to silica, and (B) calcium related to sulfate in water from springs, irrigation ditches, and ponds in the Yucca House National Monument area.

sodium was probably acquired from the dissolution of efflorescent salts (Figure 13). Water in South Sunfish Pond had higher silica and sodium concentrations, which may have been caused by evaporation from the ponds and subsequent concentrating of the dissolved solutes. It is also possible that South Sunfish Pond represents a mixture of sources--irrigation water and ground water.

Nutrients in water can include nitrate, nitrite, ammonia, and phosphorus. The compounds are called nutrients because their presence in ponds and lakes can stimulate algal and other vegetative growth, which can be detrimental to the overall quality of water. Nutrients are sourced in fertilizers and in human and animal (livestock) wastes. Nitrogen is known to occur in bedrock formations such as the Mancos Shale (Holloway and others, 1998); however, naturally occurring concentrations are generally very low. Nutrient concentrations occur in water samples collected from springs, irrigation ditches, and ponds in the Yucca House area (Figure 14). Nutrient concentrations in Ismay Spring--about 0.05 to 0.08 mg/L--are representative of naturally occurring concentrations. The highest nutrient concentrations were in water from Navajo Wash, especially during March 2003 (Appendix 2). All of the irrigation runoff samples had relatively high nutrient concentrations (Figure 14).

The Yucca House Spring has nutrient concentrations that are higher than naturally occurring concentrations. During September 2003, the dissolved nitrite plus nitrate concentration was 3.76 mg/L. The field west of Yucca House had horses and other livestock grazing in the field at the time, West Pond was filled with the irrigation source water, and runoff from the field above West Pond drains into the pond. It is possible that the Yucca House Spring was affected by nutrient sources in the field to the west of the site.

Increased concentrations of dissolved mineral species can result in increased "activity" of the mineral in solution. When the activity of the mineral species becomes greater than the solubility product, the mineral is "saturated" or "supersaturated" and may precipitate from the dissolved to the solid phase. From the water-quality data, the saturation index (SI) for each site in the study area was calculated using the mineral speciation model WATEQ4F (Ball and Nordstrom, 1991). SI values less than zero indicate

undersaturation, and the mineral species would be dissolving in a water-rock interaction environment. SI values greater than zero indicate supersaturation, and the mineral would be precipitating from the dissolved phase into the solid phase (Figure 15). SI values can help describe whether the geochemical system is dissolving bedrock as ground water moves through fractures in the rock (undersaturated SI values), or whether the system is precipitating minerals in the fractures in rock (supersaturated SI values), possibly filling up the fractures. Filling of fractures through chemical precipitation contributes to the migration of springs from one discharge point to another. The SI values also can be used to compare sites, and the data are useful for describing possible flow paths.

Looking at the Yucca House area data in Figure 15, it is interesting that water from Ismay and Gate Marsh Springs are undersaturated with respect to calcite, aragonite, and dolomite, but water from Yucca House Spring is supersaturated with respect to these minerals. Application of irrigation water west of Yucca House, and the effects of irrigation on the Yucca House Spring, may contribute to these differences in SI values of the spring sites.

Effects of Irrigation on Water Quality

Application of irrigation water to Cretaceous shales in the western US is known to contribute salinity and trace element contamination to receiving waters (Seiler and others, 2003). Conditions suitable for mobilization of trace elements from these irrigated shales include application of oxygenated irrigation water and nitrogen fertilizers (Wright, 1999). Irrigation of soils derived from the Mancos Shale contributes to many irrigation-induced water-quality problems in western Colorado (Butler and others, 1994; Butler and others, 1995; Butler and others, 1996). Application of irrigation water to soils derived from the Mancos Shale in the Yucca House National Monument and surrounding area also contributes concentrations of major ions, trace elements, and nutrients to the environment. Two sites were studied in the Yucca House area (Figure 11): (1) fields below the main headgate for the Ismay Farm where water is diverted from the Ute Mountain Ditch to the fields around the Ismay Farm; and (2) the field below the headgate west of Yucca House National Monument.

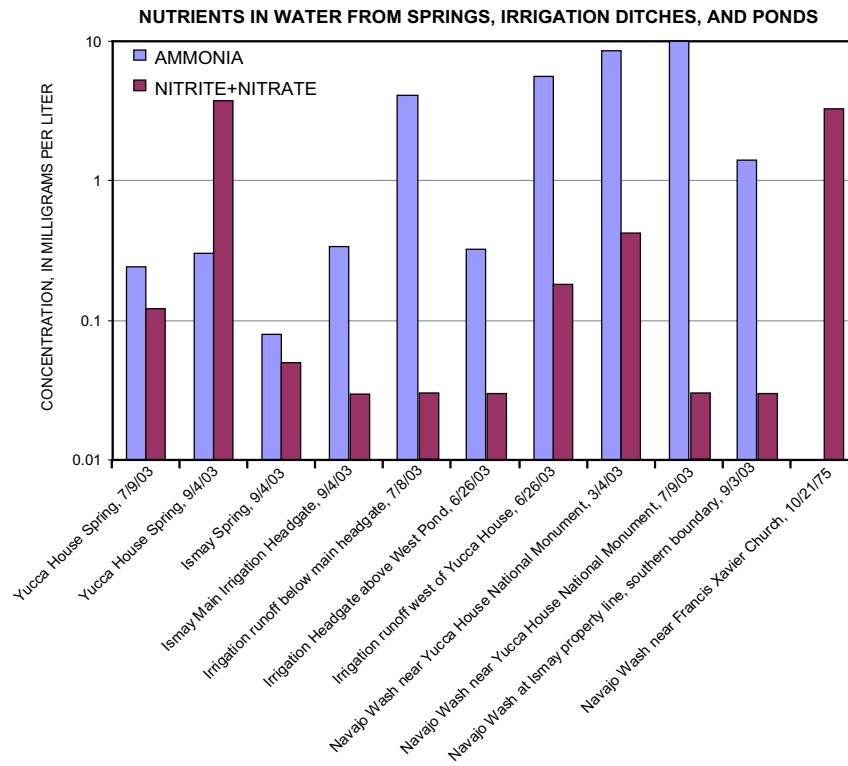
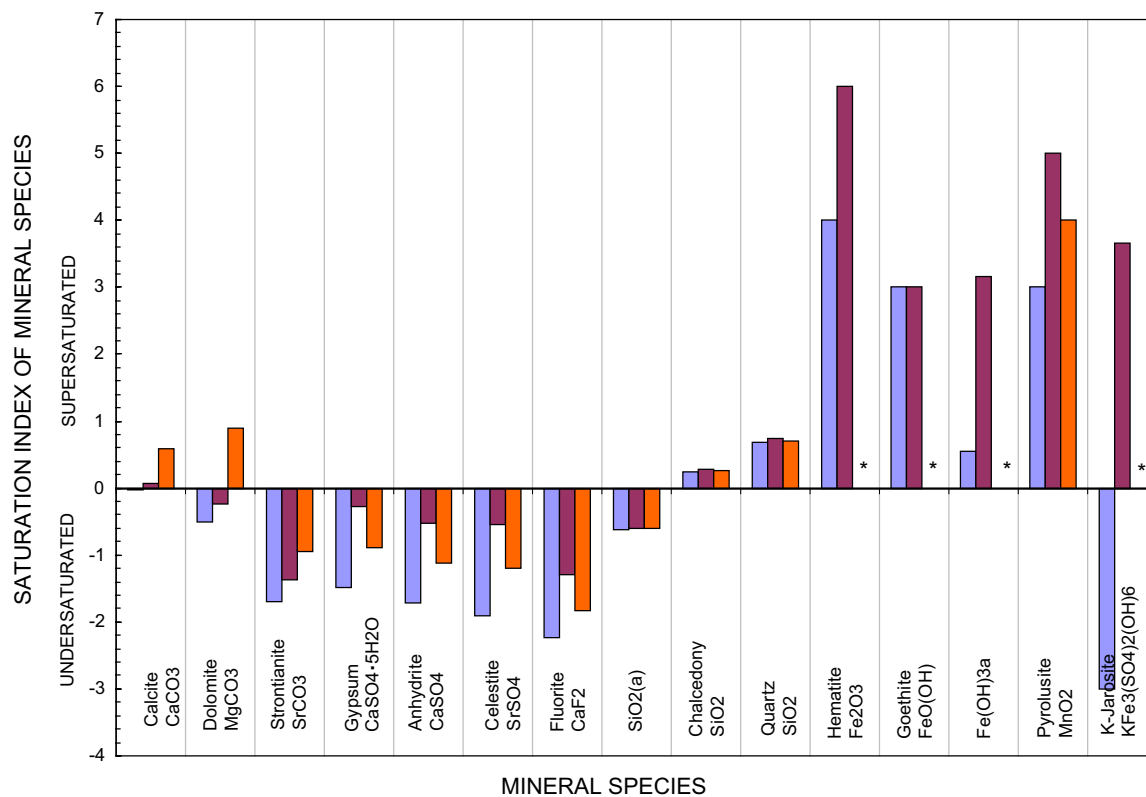


Figure 14. Concentrations of nutrients (total ammonia and dissolved nitrite plus nitrate) in water from springs, irrigation ditches, and ponds in the Yucca House National Monument area.



EXPLANATION

■ ISMAY SPRING

■ GATE MARSH SPRING

■ YUCCA HOUSE SPRING

* IRON CONCENTRATIONS WERE NOT REPORTED IN WATER FROM YUCCA HOUSE SPRING; ACTIVITY OF IRON MINERAL SPECIES WERE NOT CALCULATED.

Figure 15. Saturation index of mineral species for springs in the Yucca House area. Saturation index less than zero indicates undersaturation, and the mineral species would be dissolving in a water-rock interaction environment. Saturation index greater than zero indicates saturation, and the mineral would be precipitating from the dissolved phase into the solid phase.

At both sites, water-quality samples were collected of the irrigation source water, and water-quality samples were collected on the same day of the irrigation runoff downgradient from the source water. At both sites, concentrations of almost all constituents increased from the source water to the irrigation runoff water (Figure 16). Significant increases were reported for ammonia and phosphorous concentrations in the irrigation runoff (Figure 16). The irrigation source water already contains relatively high concentrations of some constituents because the Ute Mountain Ditch receives irrigation tailwater and runoff from other irrigated fields upstream from the Yucca House area.

Toxicity

Toxicity standards for drinking water and for survival of aquatic life have been promulgated by the U.S. Environmental Protection Agency (EPA) and the Colorado Department of Public Health and Environment (CDPHE) for all streams and waters in the United States and in the State of Colorado. The drinking water standards discussed in this report apply to secondary maximum contaminant limits (SMCLs). Toxicity standards for aquatic life in streams may vary by hardness, temperature, or pH, and some of the standards are fixed values (<http://www.cdphe.state.co.us/wq/wqhom.asp>, accessed February 2, 2006). Concentrations of selected constituents are shown for waters in the Yucca House area. The drinking water standards and the toxicity thresholds for aquatic life are compared to the constituent concentrations in Figure 17. Water from Ismay Spring is of fair to good quality, and this explains the reason that the spring has been used for drinking water at the Ismay Farm. Three of the four sites shown (Yucca House Spring, Gate Marsh Spring, and Navajo Wash near Yucca House), have total dissolved solids (TDS) and sulfate values that are above the drinking water standard, and the standards are greatly exceeded at Gate Marsh Spring and Navajo Wash (Figure 17). Gastrointestinal disorders and diarrhea may be associated with the ingestion of water containing sulfate greater than 1,000-1,200 mg/L (World Health Organization, 2004).

Ammonia exceeded the aquatic-life toxicity standard at some of the sites (Figure 17). Arsenic

concentrations were below the standard at all sites, and selenium was above the standard at Yucca House Spring and Navajo Wash near Yucca House (site 14). Zinc concentrations did not exceed the standard at any of the sites (Figure 17). These standards are a simple measure of the ability of the waters to support human and aquatic life. More specific studies of toxicity are needed to address aquatic toxicity in the Yucca House area.

Suitability for Cultivation

Assessment of the suitability of water for cultivation and irrigation purposes requires consideration of the total dissolved solids (using specific conductance as a substitute) and dissolved-sodium concentrations. Irrigation water that has a high sodium concentration can bring about a displacement of exchangeable cations (Ca^{2+} and Mg^{2+}) from clay minerals in the soil, followed by replacement of the cations by sodium. Sodium-saturated soils peptize (form colloids and disperse) and lose their permeability, so that the suitability for cultivation decreases (Matthess, 1982, p. 347). The ability of a water to expel calcium and magnesium can be estimated with the aid of the sodium adsorption ratio (SAR):

$$\text{SAR} = \text{Na}^+ / \{ \sqrt{(\text{Ca}^{2+} + \text{Mg}^{2+})/2} \}$$

where the concentration of the ions present is given in milliequivalents per liter. High SAR values indicate the risk of displacement of the alkaline earths (Ca^{2+} and Mg^{2+}). Empirical relationships have been established between the specific conductance of water and SAR. Waters were divided into four classes of salinity and alkali hazards based on specific conductance of the water and SAR values (U.S. Salinity Laboratory, 1954, p. 76-78). The diagram has been widely used for evaluating waters for irrigation (Hem, 1985, p. 217).

Specific conductance and SAR values in water from sites at Yucca House National Monument were plotted on the diagram for classification of the waters for the suitability for cultivation (Figure 18). Water-quality samples from Ismay Spring had a high salinity hazard and low sodium-alkali hazard rating. Water-

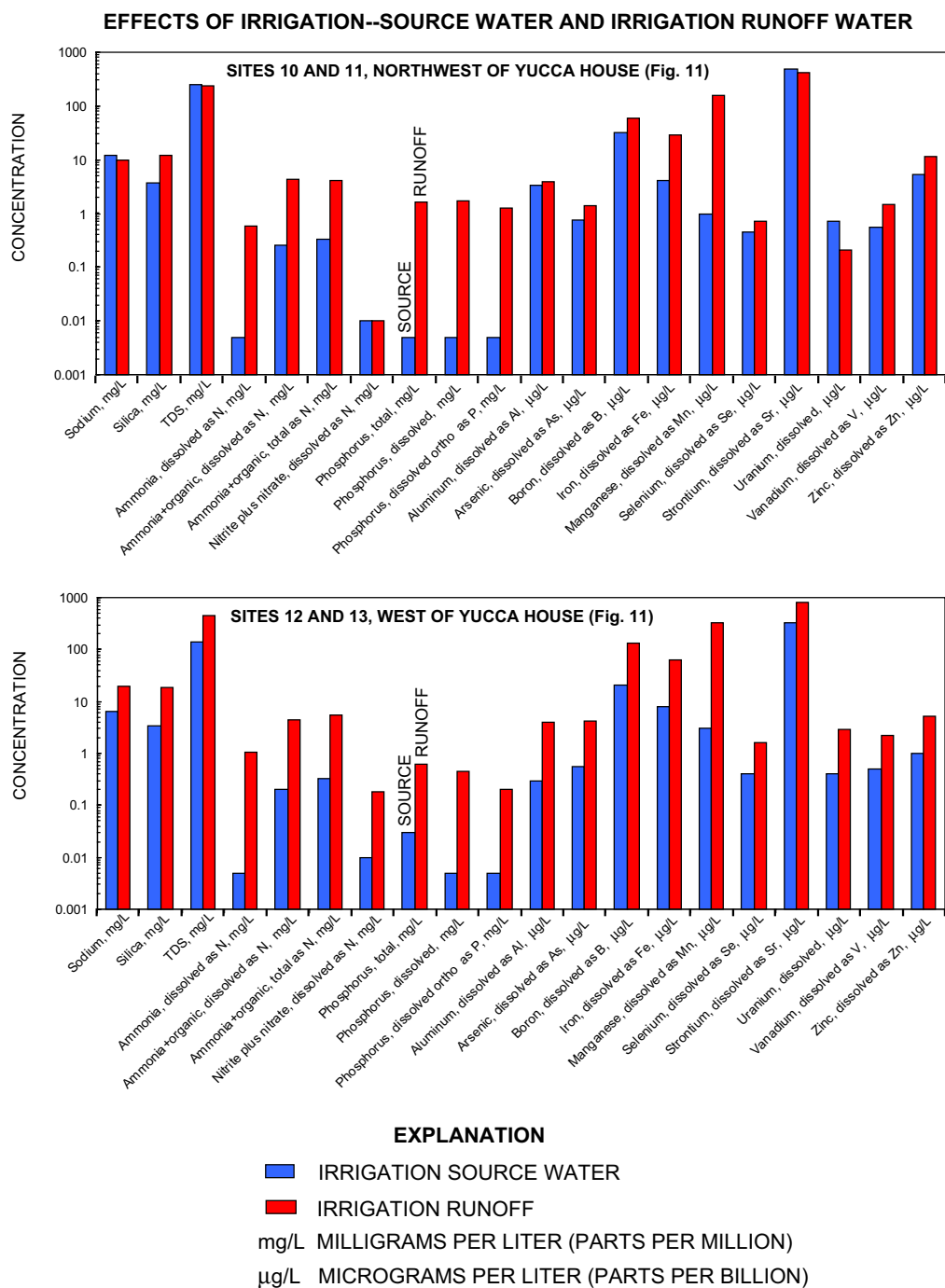


Figure 16. Effects of irrigation on water quality showing concentrations of selected constituents of source water (Ute Mountain Ditch water) and irrigation runoff water (runoff from fields), Yucca House National Monument and surrounding area.

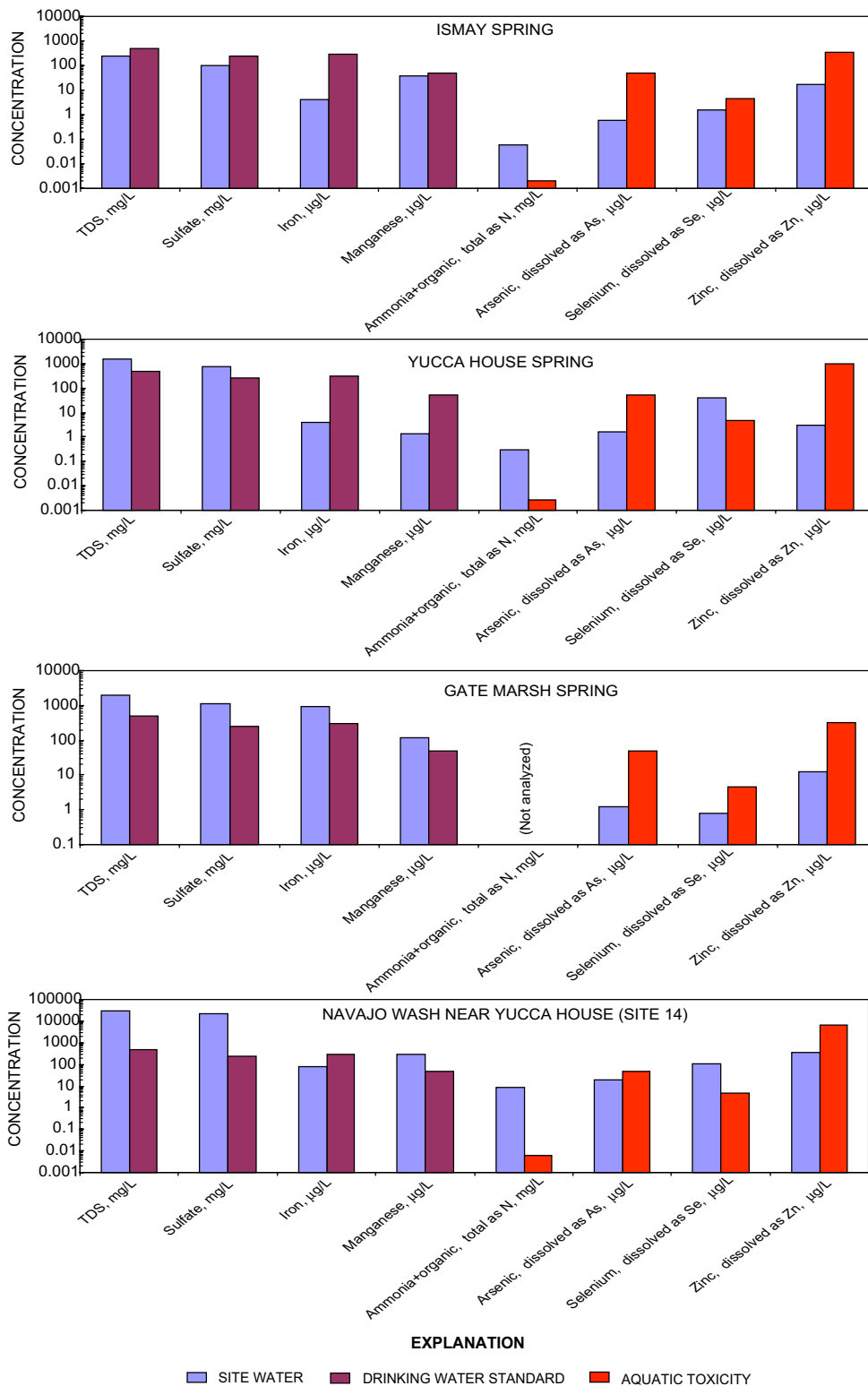


Figure 17. Concentrations of selected constituents in water from sites, drinking water standards, and toxicity threshold for survival of aquatic life.

quality samples from Yucca House Spring had a high salinity hazard and a low sodium-alkali hazard rating. Water-quality samples from Navajo Wash, which resulted from irrigation of Mancos Shale, had a very high salinity hazard and a high to very high sodium-alkali hazard rating (Figure 18).

Soil salinity is a measure of the total amount of soluble salt in soil. As salinity levels increase, plants extract water less easily from soil, aggravating water stress conditions. High soil salinity also can cause nutrient imbalances, and result in the accumulation of elements toxic to plants; therefore, soil salinity can be a factor limiting plant growth (Kotuby-Amacher and others, 1997). Salt-affected plants are stunted with dark green leaves which, in some cases, are thicker and more succulent than normal. In woody species, high soil salinity may lead to leaf burn and defoliation. High salinity causes alfalfa yield to decrease while the leaf-to-stem ratio increases, influencing forage quality. Grasses also appear dark green and stunted with leaf burn symptoms.

Salinity tolerance of common field crops is shown in Table 4. Beans and corn might have been grown by the Anasazi that once occupied Yucca House. The values for specific conductance (SC) for water from Yucca House and Gate Marsh Springs ranged from 1,260 to 2,460 $\mu\text{S}/\text{cm}$ or 1.26 to 2.46 mS/cm . From Table 4, crops such as beans would have a salinity threshold of 1.0 mS/cm , and crop yield losses would occur for SC values between 1.5 and 3.6 mS/cm (Table 4). Crops such as corn would have a salinity threshold of 2.7 mS/cm , and crop yield losses

would occur for SC values between 3.7 and 7.0 mS/cm (Table 4).

Flow Path Modeling

Flow path modeling was done using NETPATH (Plummer and others, 1994) to test hypotheses on the sources of water to springs in the Yucca House area. The hypotheses to be tested include:

- (1) Water for the springs is sourced in the Sleeping Ute Mountains, and flows downgradient to the springs in the Yucca House area.
- (2) Irrigation water mixes with ground water to create the water observed in the Yucca House Spring.
- (3) Water in South Sunfish Pond is a mixture of irrigation water and ground water.

Model parameters include constraints and mineral phases. A constraint is typically a chemical element, and is included in the model to constrain the masses of selected phases (minerals) that can enter or leave the aqueous solution. The constraints selected for the model will determine the number and types of phases that need to be selected to solve the modeling problem. A phase is any mineral that can enter or leave the aqueous solution along the evolutionary flow path in the hydrologic system. Selected phases should be known to occur in the system, such as minerals known to occur in the Mancos Shale.

Table 4. Salinity tolerance of common field crops (Kotuby-Amacher and others, 1997)

Crop	Threshold value	10% yield loss	25% yield loss	50% yield loss
	SC (mS/cm)	SC (mS/cm)	SC (mS/cm)	SC (mS/cm)
Barley	8.0	9.6	13.0	17.0
Beans (field)	1.0	1.5	2.3	3.6
Canola	2.5	3.9	6.0	9.5
Corn (grain)	2.7	3.7	6.0	7.0
Oats (grain)	5.2	6.7	9.0	12.8
Rye (grain)	5.9	7.7	12.1	16.5
Safflower	5.3	8.0	11.0	14.0
Sorghum	4.0	5.1	7.1	10.0
Sugarbeets	6.7	8.7	11.0	15.0
Sunflower	2.3	3.2	4.7	6.3
Triticale (grain)	6.1	8.1	12.0	14.2
Wheat	4.7	7.0	9.5	13.0

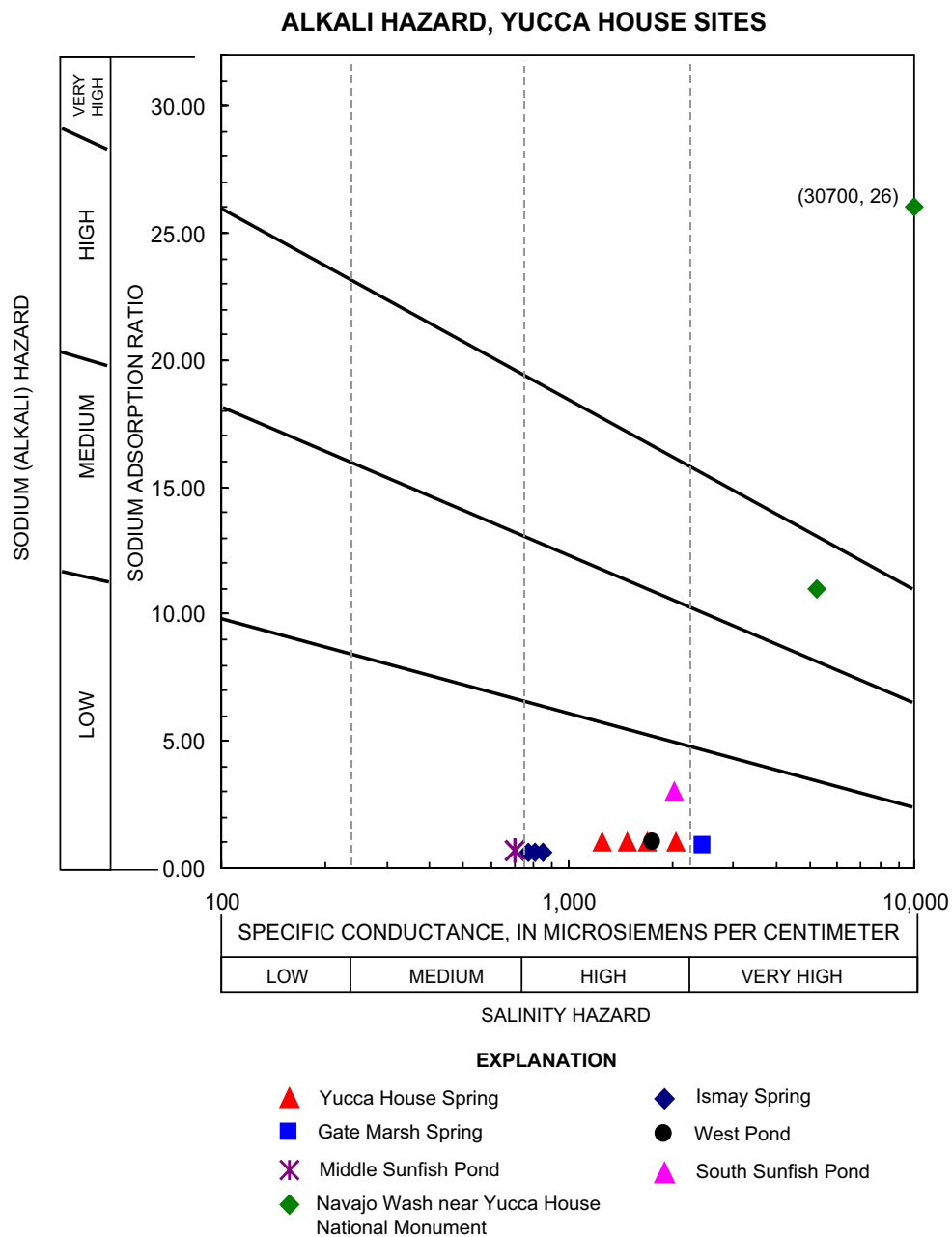


Figure 18. Salinity and sodium (alkali) crop hazard and water-quality results from Yucca House National Monument.

Model parameters for modeling flow paths in the Yucca House area are as follows:

Table 5. List of constraints and phases for geochemical modeling of springs in the Yucca House National Monument area

Constraints:	Related Phases:
• Calcium -----	Calcite (CaCO ₃)
• Chloride -----	Sodium chloride (NaCl)
• Fluoride -----	Fluorite (CaF ₂)
• Iron -----	Pyrite (FeS ₂)
	-----Iron hydroxide (Fe(OH) ₃)
	-----Goethite (FeO(OH))
	-----K-Jarosite (KFe ₃ (SO ₄) ₂ (OH) ₆)
• Magnesium -----	Dolomite (Mg, CaCO ₃)
• Manganese -----	Pyrolusite (MnO ₂)
• Potassium -----	K-Jarosite (KFe ₃ (SO ₄) ₂ (OH) ₆)
• Silica -----	Quartz (SiO ₂)
	-----Chalcedony (SiO ₂)
	-----Amorphous silica (SiO ₂ (a))
• Sodium -----	Sodium chloride (NaCl)
• Strontium -----	Celestite (SrSO ₄)
	-----Strontianite (SrCO ₃)
• Sulfur -----	Pyrite (FeS ₂)
	-----Gypsum (CaSO ₄ ·2H ₂ O)
	-----Celestite (SrSO ₄)

To test the first hypothesis, the water from Elbow Spring was mixed with water from Ismay Spring to see if it could feasibly produce water from Gate Marsh Spring. The results are as follows:

Table 6. Flowpath modeling results for Elbow Spring mixed with Ismay Spring to form water at Gate Marsh Spring

Initial Spring 1: Elbow Spring
Initial Spring 2: Ismay Spring
Final Spring : Gate Marsh Spring

MODEL RESULTS	
Proportions in Gate Marsh Spring	
Elbow Spring	0.84555
Ismay Spring	0.15445
=====	
	Mole transfer
	(+ dissolve;
Mineral species	- precip)
CELESTITE	+0.00770
DOLOMITE	+0.72620
GYP SUM	+3.02528
NaCl	+0.32195
PYRITE	+0.00464
Pyrolusite MnO ₂	-0.00057
CALCITE	-2.63064
SiO ₂	+0.00000
Evaporation factor: 3.643	

The results indicate that it is possible for water at Elbow Spring to mix with water from Ismay Spring to

form water at Gate Marsh Spring. Eighty four percent of the water in Gate Marsh could be from Elbow Spring, and 15 percent could be from Ismay Spring. Celestite, dolomite, gypsum, NaCl, pyrite, and SiO₂ would be dissolving from the rocks into the water. Pyrolusite and calcite would be precipitating from the dissolved into the solid phase. These results are verified by the SI indexes shown in Figure 15. There would be an evaporation factor of 3.643.

To test the second hypothesis, water from Ismay Spring was mixed with irrigation water (West Pond) to form water observed at Yucca House Spring. The results are as follows:

Table 7. Flowpath modeling results for Ismay Spring mixed with West Pond to form water at Yucca House Spring

Initial Spring 1: Ismay Spring
Initial Water 2: West Pond
Final Spring : Yucca House Spring

MODEL RESULTS	
Proportions in Yucca House Spring	
Ismay Spring	0.83227
West Pond	0.16773
=====	
	Mole transfer
	(+ dissolve;
Mineral species	- precip)
CELESTITE	-0.00115
DOLOMITE	-0.13167
GYP SUM	+0.52716
NaCl	+0.04002
PYRITE	-0.00014
Pyrolusite MnO ₂	-0.00057
CALCITE	-1.11526
SiO ₂	-0.20683
Evaporation factor: 2.148	

The results indicate that it is possible for water at Ismay Spring to mix with water from West Pond to form water at Yucca House Spring. These results are consistent with other results (such as the presence of nitrogen species in Yucca House Spring) indicating that Yucca House Spring may be affected by man's activities.

The third hypothesis to be tested is based on the observation that water in South Sunfish Pond has similar quality to that of Yucca House Spring. In particular, the strontium concentration in South Sunfish Pond was similar to the strontium concentrations observed in Yucca House Spring. Since there is irrigation upgradient from South Sunfish

Pond, the geochemical signature would be a mixture of ground water (Isamay Spring), irrigation-affected spring water (Yucca House Spring), and irrigation runoff (Middle Sunfish Pond). The results are as follows:

Table 8. Flowpath modeling results for Ismay Spring mixed with Yucca House Spring and Middle Sunfish Pond to form water at South Sunfish Pond

Initial Spring 1: Ismay Spring
Mixed with spring : Yucca House Spg
Mixed with pond : Middle Sunfish Pond
Final pond : South Sunfish Pond

MODEL RESULTS	
Proportions in South Sunfish Pond	
Isamay Spring	0.19781
Yucca House Spring	0.22416
Middle Sunfish Pond	0.57803
=====	
	Mole transfer (+ dissolve; - precip)
Mineral species	
CELESTITE	-0.01074
DOLOMITE	-0.71254
GYPSUM	-1.29894
NaCl	-0.36715
PYRITE	-0.00002
Pyrolusite MnO ₂	+0.00001
CALCITE	0.00000
SiO ₂	0.00000

Evaporation factor: 7.415	

These results indicate that it is possible for water from Ismay Spring to mix with water from Yucca House Spring and Middle Sunfish Pond to form water at South Sunfish Pond. Celestite, dolomite, gypsum, salt, and pyrite are precipitated along the flow path or left as evaporites along the edges of the pond.

SUMMARY AND CONCLUSIONS

The spring at Yucca House National Monument was used as a water source for an ancient village of Anasazi people during A.D. 1100-1300. There are no analogs for water-quality conditions of the spring during that period; only the current conditions can be studied, and hypotheses can be presented regarding historic water-quality conditions at the spring.

For the current conditions, the inferred ground-water flow conditions are described as follows (Figure 19):

- Water recharged in the Sleeping Ute Mountains flows downgradient through an alluvial fan and discharges in small springs such as Ismay Spring. The water from Ismay Spring is drinkable because of contact with alluvium and colluvium, which is not highly mineralized. Recharge for the Yucca House area springs also occurs on the alluvial fan.
- Water from the alluvial fan percolates through Mancos Shale to form water at Gate Marsh Spring, which is hypothesized to have the quality of a spring that might have existed during the occupation and drought of A.D. 1276-1300. Water from Gate Marsh Spring is highly mineralized.
- Water from the alluvial fan mixes with water in the Mancos Shale, and then is mixed with irrigation water to form water that discharges at Yucca House Spring. Evidence supporting the fact that Yucca House Spring is affected by man's activities include flow path diagrams indicating geochemical evolution of ground water, the presence of nitrate in water from the spring, saturation indices of mineral speciation, and ground-water flow path modeling.
- Water from the alluvial fan mixes with irrigation-affected water and discharges into South Sunfish Pond. If there was a spring at the location of the pond during the occupation period, we might expect to see signs of ancient human activity (pottery sherds, etc.) at the site.

Since the geochemical models indicate supersaturation of mineral species and precipitation of minerals along a flow path, then it is possible that the spring "sealed" itself and migrated to other locations such as Gate Marsh Spring and South Sunfish Pond. It also may be possible that during the extended drought of 1276-1300, the spring went entirely dry.

If the water from Gate Marsh Spring is representative of the quality of water that the occupants might have experienced during A.D. 1276, the water would have been of poor quality. Drinking water should have a maximum total dissolved solids (TDS) of about 500-1,000 mg/L. TDS concentrations above 1,000 mg/L create water that is undesirable to drink. Regarding suitability for cultivation and irrigation, water-quality samples from the springs at Yucca House National Monument had high salinity and low sodium-alkali hazard ratings; however, water from Navajo Wash had high and very high salinity and

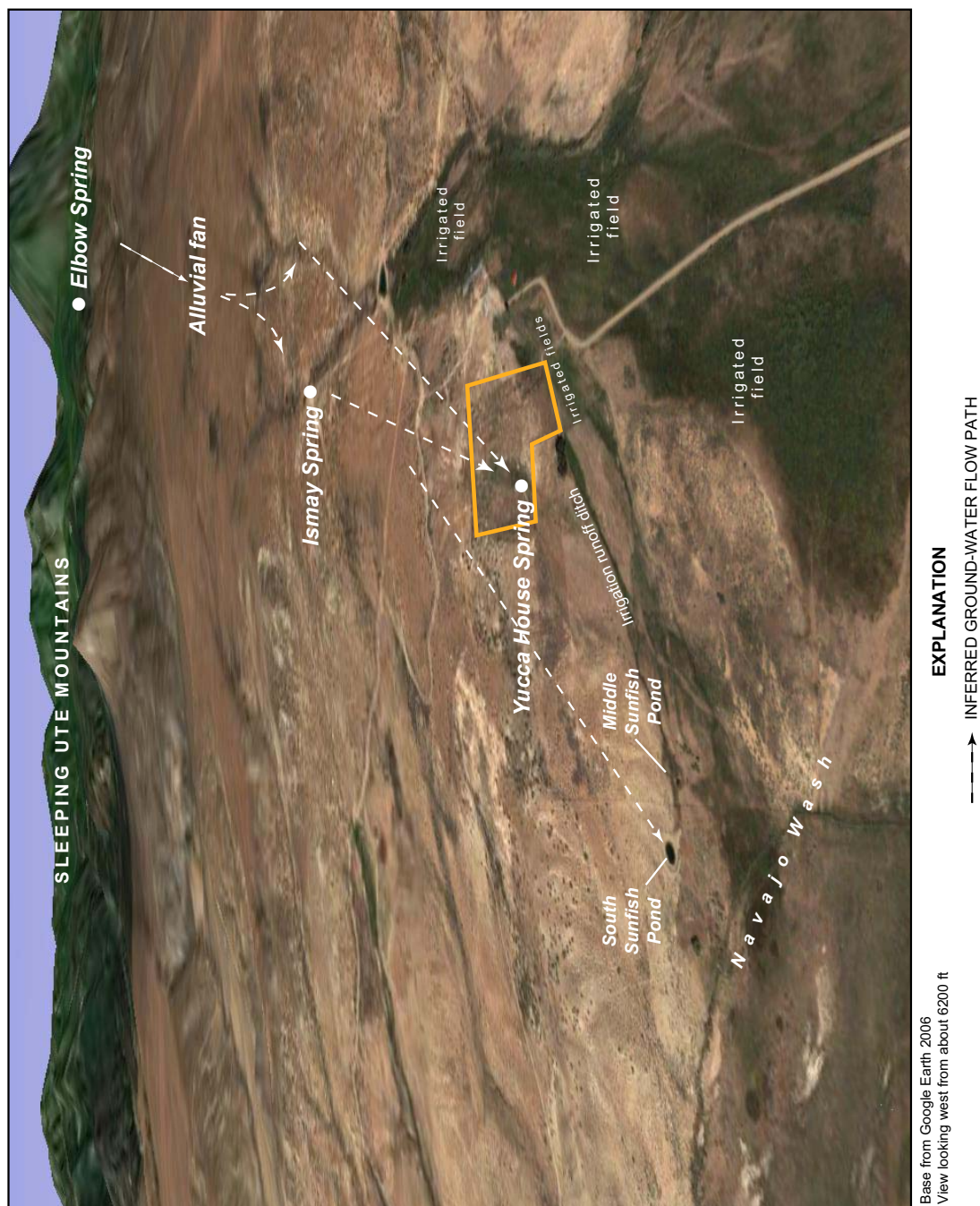


Figure 19. 3D satellite image of the Sleeping Ute Mountain area, Yucca House National Monument, springs and ponds, and inferred ground-water flow paths.

sodium-alkali hazard ratings. Beans and corn might have been grown by the Anasazi that once occupied Yucca House. The values for specific conductance (SC) for water from Yucca House and Gate Marsh Springs ranged from 1,260 to 2,460 $\mu\text{S}/\text{cm}$ or 1.26 to 2.46 mS/cm . Crops such as beans would have a salinity threshold of 1.0 mS/cm , and crop yield losses would occur for SC values between 1.5 and 3.6 mS/cm . Crops such as corn would have a salinity threshold of 2.7 mS/cm , and crop yield losses would occur for SC values between 3.7 and 7.0 mS/cm .

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**APPENDIX. WATER-QUALITY DATA BASE FOR SPRINGS,
LAKES AND PONDS, IRRIGATION WATER, AND STREAMS
AT YUCCA HOUSE NATIONAL MONUMENT AND SURROUNDING AREA,
MONTEZUMA COUNTY, COLORADO**

Compiled by



Southwest Hydro-Logic

EXPLANATIONS

Abbreviation	Definition
USGS	U.S. Geological Survey, National Water Information System data base and data from hard copy files
Site type SP	Spring
Site type LW	Lake or pond
Site type IR	Irrigation water
Site type SW	Surface or stream water
Column heading units	
dd mm ss	degrees minutes seconds
dd	decimal degrees
ft	Feet
ft ³ /sec	cubic feet per second
gal/min	gallons per minute
uS/cm @ 25oC	microsiemens per centimeter at 25 degrees Celsius
oC	degrees Celsius
mg/L	milligrams per liter
ug/L	micrograms per liter
mg/L as CaCO ₃	milligrams per liter as calcium carbonate

Appendix 1. Site information and location data for water-quality samples at Yucca House National Monument

YUHO Site	Site Name	Sample Years	USGS Site Number	Field Number	Data source	Site Type	Hydrologic Unit Code	Latitude, dd mm ss	Longitude, ddd mm ss
1	Yucca House Spring	2002, 2003	371500108410801	YUCW06	USGS	SP	14080107	37°15'00.5"	108°41'08.8"
2	Ismay Spring	2002, 2003	371514108414601	YUCW01	USGS	SP	14080107	37°15'14.0"	108°41'46.7"
3	Gate Marsh Spring	2002	371504108410601	YUCW04	USGS	SP	14080107	37°15'04.7"	108°41'06.3"
4	Elbow Spring, east slope of Sleeping Ute Mountain	2003	371634108455701	Elbow Spring	USGS	SP	14080107	37°16'34.30"	108°45'57.80"
5	West Pond at Yucca House National Monument	2003	371502108411301	YUCW02	USGS	LW	14080107	37°15'02.67"	108°41'13.45"
6	South Highline Pond near Yucca House National Monument	2003	371541108405801	YUCW10	USGS	LW	14080107	37°15'41.40"	108°40'58.50"
7	Middle Sunfish Pond	2002	371447108405701	YUCW22	USGS	LW	14080107	37°14'47.9"	108°40'57.6"
8	South Sunfish Pond	2002	371446108405701	YUCW17	USGS	LW	14080107	37°14'46.7"	108°40'57.6"
9	Pond near B Road and Navajo Wash--Gordaniar Pond	1994	371415108410001	Gordaniar Pond	USGS	LW	14080107	37°14'15"	108°41'00"
10	Ismay Main Headgate	2003	371509108412401	Ismay Headgate	USGS	IW	14080107	37°15'09.7"	108°41'24.5"
11	Irrigation runoff below main headgate	2003	371510108411001	YUCIR2	USGS	IW	14080107	37°15'10.90"	108°41'10.90"
12	Headgate above West Pond	2003	371504108412201	YUCHG1	USGS	IW	14080107	37°15'04.90"	108°41'22.10"
13	Irrigation runoff west of Yucca House Natl Monument	2003	371500108411501	YUCIR1	USGS	IW	14080107	37°15'00.90"	108°41'15.80"
14	Navajo Wash near Yucca House National Monument	2003	371501108403601	YUCW13	USGS	SW	14080107	37°15'01"	108°40'36"
15	Navajo Wash at Ismay property line, southern boundary	2003	371448108404801	Navajo Wash	USGS	SW	14080107	37°14'48.60"	108°40'48.70"
16	Navajo Wash near Francis Xavier Church	1975	371329108411900	Navajo nr FX Church	USGS	SW	14080107	37°13'29"	108°41'19"

Appendix 1. Site information and location data for water-quality samples at Yucca House National Monument

YUHQ Site	Latitude, dd	Longitude, dd	Lat/Long source	Horizontal Datum	Altitude, ft	Altitude Source	Altitude Datum	County	Geologic Setting	Site Description
1	37.25013889	-108.6657778	GPS	NAD83	5,898	Digital map	NGVD29	Montezuma	Mancos Shale	Main spring at Yucca House National Monument
2	37.25388889	-108.6663056	GPS	NAD83	6,032	Digital map	NGVD29	Montezuma	Dakota Formation	Spring in Ismay Draw, fills stock tank
3	37.25130556	-108.6650833	GPS	NAD83	5,905	Digital map	NGVD29	Montezuma	Mancos Shale	Spring near gate entrance to Yucca House Nat Mon
4	37.27619444	-108.7660556	GPS	NAD83	7,871	Digital map	NGVD29	Montezuma	Mancos Shale	Spring discharging from the "elbow" of the Sleeping Ute, upgradient from Yucca House National Monument
5	37.25074167	-108.6870694	GPS	NAD83	5,938	Digital map	NGVD29	Montezuma	Mancos Shale	Pond west of Yucca House receiving irrigation water from Headgate Source (YUCHG1)
6	37.27615	-108.6829167	GPS	NAD83	5,735	Digital map	NGVD29	Montezuma	Mancos Shale	Pond receiving water from Ute Mountain Ditch, north of Yucca House
7	37.24663889	-108.6626667	GPS	NAD83	5,837	Digital map	NGVD29	Montezuma	Dakota Formation	Pond collecting drainage from Yucca House spring and upgradient irrigated fields
8	37.24630556	-108.6626667	GPS	NAD83	5,830	Digital map	NGVD29	Montezuma	Mancos Shale	Pond collecting drainage from Yucca House spring and upgradient irrigated fields
9	37.2375	-108.6833333	Topo map	NAD27	5,800	Topo map	NGVD29	Montezuma	Mancos Shale	Pond on Gordanier property
10	37.25269444	-108.6601389	GPS	NAD83	5,970	Digital map	NGVD29	Montezuma	Mancos Shale	Headgate source for irrigation of land north of Ismay house, Ute Mountain Ditch water
11	37.25302778	-108.6663611	GPS	NAD83	5,925	Digital map	NGVD29	Montezuma	Mancos Shale	Irrigation water draining fields north of barns, north of Yucca House
12	37.25136111	-108.6694722	GPS	NAD83	5,960	Digital map	NGVD29	Montezuma	Mancos Shale	Headgate source near West Pond, Ute Mountain Ditch water
13	37.25025	-108.6677222	GPS	NAD83	5,937	Digital map	NGVD29	Montezuma	Mancos Shale	Irrigation runoff near West Pond
14	37.25027778	-108.6766667	GPS	NAD83	5,843	Digital map	NGVD29	Montezuma	Mancos Shale	Navajo Wash downstream from irrigated land east and northeast of Yucca House
15	37.24683333	-108.6601944	GPS	NAD83	5,830	Digital map	NGVD29	Montezuma	Mancos Shale	Irrigation runoff from Ismay property, collected into Navajo Wash
16	37.22472222	-108.6686111	Topo map	NAD27	5,800	Topo map	NGVD29	Montezuma	Mancos Shale	Navajo Wash downstream from Yucca House National Monument

Appendix 2. Water-quality data for all sites at Yucca House National Monument

YUHO Site	SiteName	Site Number	Field Number	Data source	Sample Type	Date Time	Discharge, instantaneous, ft ³ /sec	Discharge, instantaneous, gal/min
1	Yucca House Spring	371500108410801	YUCW06	USGS	SP	9/25/2002 13:30	0.0011	0.50
1	Yucca House Spring	371500108410801	YUCW06	USGS	SP	4/7/2003 17:00	0.002	0.90
1	Yucca House Spring	371500108410801	YUCW06	USGS	SP	7/9/2003 13:30	0.001	0.45
1	Yucca House Spring	371500108410801	YUCW06	USGS	SP	9/4/2003 14:00	0.001	0.45
2	Ismay Spring	371514108414601	YUCW01	USGS	SP	9/24/2002 11:00	0.0012	0.50
2	Ismay Spring	371514108414601	YUCW01	USGS	SP	5/21/2003 11:30	0.001	0.45
2	Ismay Spring	371514108414601	YUCW01	USGS	SP	7/9/2003 12:00	0.001	0.45
2	Ismay Spring	371514108414601	YUCW01	USGS	SP	9/4/2003 10:30	*	
2	Ismay Spring	371514108414601	YUCW01	USGS	SP	9/4/2003 11:30	*	
3	Gate Marsh Spring	371504108410601	YUCW04	USGS	SP	9/27/2002 10:00	*	
4	Elbow Spring	371634108455701	Elbow Spring	USGS	SP	7/11/2003 15:00	0.004	1.8
5	West Pond	371502108411301	YUCW02	USGS	LW	4/7/2003 16:00	--	--
6	South Highline Pond	371541108405801	YUCW10	USGS	LW	5/19/2003 16:00	--	--
7	Middle Sunfish Pond	371447108405701	YUCW22	USGS	LW	9/25/2002 11:00	--	--
8	South Sunfish Pond	371446108405701	YUCW17	USGS	LW	9/25/2002 12:00	--	--
9	Pond near B Road and Navajo Wash	371415108410001	Gordianer Pond	USGS	LW	3/8/1994 12:00	--	--
10	Ismay Main Headgate	371509108412401	Ismay Headgate	USGS	IW	9/4/2003 16:00	--	--
11	Irrigation runoff below main headgate	371510108411001	YUCIR2	USGS	IW	7/8/2003 11:30	0.5	224
12	Headgate above West Pond	371504108412201	YUCHG1	USGS	IW	6/26/2003 16:00	0.7	314
13	Irrigation runoff west of YuHo	371500108411501	YUCIR1	USGS	IW	6/26/2003 15:00	0.5	224
14	Navajo Wash near Yucca House National Monument	371501108403601	YUCW13	USGS	SW	3/4/2003 14:30	0.002	0.90
14	Navajo Wash near Yucca House National Monument	371501108403601	YUCW13	USGS	SW	7/9/2003 10:30	0.1	45
15	Navajo Wash at Ismay property line, southern boundary	371448108404801	Navajo Wash	USGS	SW	9/3/2003 14:30	0.4	180
16	Navajo Wash near Francis Xavier Church	371329108411900	Navajo nr FX Church	USGS	SW	10/21/1975 9:25	4	1795

Appendix 2. Water-quality data for all sites at Yucca House National Monument

YUHO Site	Date Time	Field specific conductance, uS/cm @ 25oC	Field pH, standard units	Temperature, oC	Dissolved oxygen (DO), mg/L	Dissolved oxygen, percent saturation	Alkalinity, total as CaCO ₃ , mg/L	Bicarbonate (HCO ₃), mg/L	Calcium, dissolved (Ca), mg/L	Magnesium, dissolved (Mg), mg/L	Hardness as CaCO ₃ (Ca, Mg), mg/L
1	9/25/2002 13:30	1700	7.2	13.7	6.3	75	269	328	229	64.5	840
1	4/7/2003 17:00	1490	7.8	8.1	8.2	100	304	371	213	56.6	770
1	7/9/2003 13:30	1260	7.5	20.2	5.5	72	306	373	168	44.5	610
1	9/4/2003 14:00	2050	7.6	14.7	5.6	77	365	445	324	84.5	1200
2	9/24/2002 11:00	808	7.16	15.3	6.2	80	279	340	119	21.3	390
2	5/21/2003 11:30	771	7.27	15.3	8.7	100	290	354	112	19.8	360
2	7/9/2003 12:00	783	6.95	20.7	2.7	35	307	374	109	19.7	350
2	9/4/2003 10:30	773	7.7	19.4	1.8	27	318	388	127	20.4	
2	9/4/2003 11:30	773	7.7	19.4	1.8	27	318	388	120	19.3	
3	9/27/2002 10:00	2460	6.88	13	3.3	39	315	384	373	101	1400
4	7/11/2003 15:00	330	7.28	9.5	7.9	89	166	202	48.3	8.38	160
5	4/7/2003 16:00	1750	8.34	12.7	9.6	128	140	171	216	93.4	930
6	5/19/2003 16:00	268	8.76	20.4	10	125	60	73	23	10.2	100
7	9/25/2002 11:00	706	7.16	14.8	7.93	94	104	127	75.5	25.8	300
8	9/25/2002 12:00	2040	7.45	13.2	8.23	105	312	380	163	85	760
9	3/8/1994 12:00	3860	8.1	10.5							
10	9/4/2003 16:00	400	8.51	20.4	7.05	108	132	161	56.7	10.9	190
11	7/8/2003 11:30	403	7.17	30.8	1.4	20	126	154	48.8	10.1	160
12	6/26/2003 16:00	253	7.87	20.2			86	105	35.1	5.8	110
13	6/26/2003 15:00	709	7.79	31.9			200	244	83.2	22	300
14	3/4/2003 14:30	30700	8.15	6.3	6.6	75			498	2500	12000
14	7/9/2003 10:30	5220	7.59	17.1	0.1	1.43	520	634	226	333	1900
15	9/3/2003 14:30	717	7.93	24.6	3.65	66	144	176	104	20.4	340
16	10/21/1975 9:25	2400	7.9	6	10.4		238	290	270	150	1300

Appendix 2. Water-quality data for all sites at Yucca House National Monument

YUHO Site	Date Time	Sodium, dissolved (Na), mg/L	Sodium Adsorption Ratio	Sodium Percent	Potassium, dissolved (K), mg/L	Chloride, dissolved (Cl), mg/L	Sulfate, dissolved (SO ₄), mg/L	Fluoride, dissolved (F), mg/L	Silica, dissolved (SiO ₂), mg/L	Total Dissolved Solids (TDS), mg/L	Ammonia, dissolved as N, mg/L
1	9/25/2002 13:30	70.3	1	16	0.92	41.6	591	0.22	24.9	1190	
1	4/7/2003 17:00	63.7	1	16	0.87	30.1	502	0.23	24.9	1080	
1	7/9/2003 13:30	59.2	1	18	0.42	28	371	0.3	27.1	885	< .04
1	9/4/2003 14:00	79.7	1	14	1.01	64.2	754	0.2	26.7	1570	0.03
2	9/24/2002 11:00	26.9	0.6	14	0.15	10.1	119	0.21	26	491	
2	5/21/2003 11:30	26.7	0.6	14	0.19	10.6	105	0.2	24.6	474	
2	7/9/2003 12:00	26.8	0.6	15	0.3	10.9	101	0.2	25.9	479	
2	9/4/2003 10:30	31.6			0.69	10.6	100	0.2	24.1		< .04
2	9/4/2003 11:30	30			0.68	10.6	101	0.2	24.2		< .04
3	9/27/2002 10:00	72.7	0.9	11	21.4	59.2	1150	0.42	22.4	2000	
4	7/11/2003 15:00	10	0.3	13	0.46	3.77	10.1	< .2	24.4	206	< .04
5	4/7/2003 16:00	76.7	1	15	21.4	45.7	785	0.41	3.74		
6	5/19/2003 16:00	13.4	0.6	23	2.5	13.5	47.9	0.18	0.59	148	
7	9/25/2002 11:00	25.9	0.7	16	6.5	15.2	228	0.38	3.6	444	
8	9/25/2002 12:00	186	3	35	7.2	31.2	809	0.32	15.6	1490	
9	3/8/1994 12:00										
10	9/4/2003 16:00	11.9	0.4	13	2.3	8.7	74.6	< .17	3.7	249	< .04
11	7/8/2003 11:30	9.8	0.3	11	14.2	11.25	49.5	< .17	12.1	236	0.59
12	6/26/2003 16:00	6.5	0.3	12	1.63	6.65	28.9	< .2	3.34	139	< .04
13	6/26/2003 15:00	19.2	0.5	12	28.6	18.1	145	0.4	18.6	459	1.03
14	3/4/2003 14:30	6488	26	56	3.2	1258	21931	0.35	11.8		0.09
14	7/9/2003 10:30	1085	11	55	38.8	77.4	2690	0.6	20.4	4800	3.85
15	9/3/2003 14:30	21.8	0.5	12	6.54	10.3	210	0.2	17.4	478	0.03
16	10/21/1975 9:25	180	2	23	4.5	34	1300	0.3	6.6	2100	

Appendix 2. Water-quality data for all sites at Yucca House National Monument

YUHO Site	Date Time	Ammonia+organic, dissolved as N, mg/L	Ammonia+organic, total as N, mg/L	Nitrite plus nitrate, dissolved as N, mg/L	Phosphorus, total, mg/L	Phosphorus, dissolved, mg/L	Phosphorus, dissolved ortho as P, mg/L	Aluminum, dissolved as Al, ug/L	Arsenic, dissolved as As, ug/L
1	9/25/2002 13:30							< 20	1.1
1	4/7/2003 17:00							< 20	0.8
1	7/9/2003 13:30	0.24	0.24	0.12	0.04	0.04	< .02	< 2	0.7
1	9/4/2003 14:00	0.29	0.3	3.76	< .04	< .04	< .18	< 2	1.6
2	9/24/2002 11:00							< 20	0.7
2	5/21/2003 11:30							0.2	0.5
2	7/9/2003 12:00							< 2	0.5
2	9/4/2003 10:30	0.07	0.08	0.05	< .04	< .04	< .18	1	0.6
2	9/4/2003 11:30	0.08	0.06	0.05	< .04	< .04	< .18	2	0.6
3	9/27/2002 10:00				0.04	0.03	0.03	< 2	1.2
4	7/11/2003 15:00	< .10	< .10	0.13				9.5	0.4
5	4/7/2003 16:00							7.4	1.2
6	5/19/2003 16:00							< 15	1.5
7	9/25/2002 11:00							< 15	1.2
8	9/25/2002 12:00							< 15	2.1
9	3/8/1994 12:00								
10	9/4/2003 16:00	0.26	0.34	< .06	< .04	< .035	< .18	3.3	0.77
11	7/8/2003 11:30	4.3	4.1	< .06	1.65	1.75	1.27	4	1.4
12	6/26/2003 16:00	0.2	0.32	< .06	0.03	< .04	< .02	0.3	0.56
13	6/26/2003 15:00	4.4	5.6	0.18	0.61	0.45	0.2	4	4.1
14	3/4/2003 14:30	7.9	8.5	0.42	0.37	0.3	0.24	< 220	19.6
14	7/9/2003 10:30	8.4	10	< .06	0.68	0.32	0.14	6	6.8
15	9/3/2003 14:30	0.93	1.4	< .06	0.31	0.25	0.17	1.9	1.8
16	10/21/1975 9:25			3.3			0.01		< 1

Appendix 2. Water-quality data for all sites at Yucca House National Monument

YUHO Site	Date Time	Boron, B, ug/L	Iron, Fe, ug/L	Manganese, Mn, ug/L	Selenium, Se, ug/L	Strontium, Sr, ug/L	Uranium, dissolved, ug/L	Vanadium, V, ug/L	Zinc, Zn, ug/L
1	9/25/2002 13:30	156	< 10	1.6	17.3	2300	10	1.3	< 24
1	4/7/2003 17:00	121	< 10	1.1	12.6	1990	8.54	2.4	< 24
1	7/9/2003 13:30	118	< 8	1.4	6.9	1630	7.46	1.6	< 3
1	9/4/2003 14:00	169	< 8	1.4	38.8	2800	13.1	1.5	3
2	9/24/2002 11:00	73	< 10	14.7	4.5	875	3.14	2.4	< 24
2	5/21/2003 11:30	64	< 8	0.7	3.8	798	3.23	2.6	4.2
2	7/9/2003 12:00	71	5	2.3	3.9	803	3.11	2.2	9
2	9/4/2003 10:30	76	< 8	36.8	1.7	896	3.3	3	16
2	9/4/2003 11:30	72	< 8	37.1	1.5	848	3.27	2.8	17
3	9/27/2002 10:00	172	945	118	0.8	3980	9.03	0.8	< 24
4	7/11/2003 15:00	13	< 8	0.9	0.93	350	1.4	2.3	13.6
5	4/7/2003 16:00	91.5	116.9	9.3	0.8	2429	7.146	1.37	< 24
6	5/19/2003 16:00	46.7	70	3.4	0.5	394	1.446	1.9	4.7
7	9/25/2002 11:00	49.5	23.4	10.1	0.45	1140	1.758	0.21	< 24
8	9/25/2002 12:00	86.5	97.9	47.9	1	1799	1.804	1.65	< 24
9	3/8/1994 12:00				27				
10	9/4/2003 16:00	32.7	4.1	0.97	0.44	483	0.704	0.56	5.2
11	7/8/2003 11:30	58	29.4	156.1	0.7	419	0.21	1.45	11.5
12	6/26/2003 16:00	21.1	7.9	3.1	0.4	324	0.411	0.5	< 3
13	6/26/2003 15:00	134	62	322	1.6	817	2.828	2.2	5.3
14	3/4/2003 14:30	347	< 150	283	104	13800	485	7.1	< 360
14	7/9/2003 10:30	954	1060	1920	13.9	3284	69.4	3.2	6.5
15	9/3/2003 14:30	144	12	63.2	1.3	1184	5.95	1.1	3.3
16	10/21/1975 9:25		< 10	40	6				

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