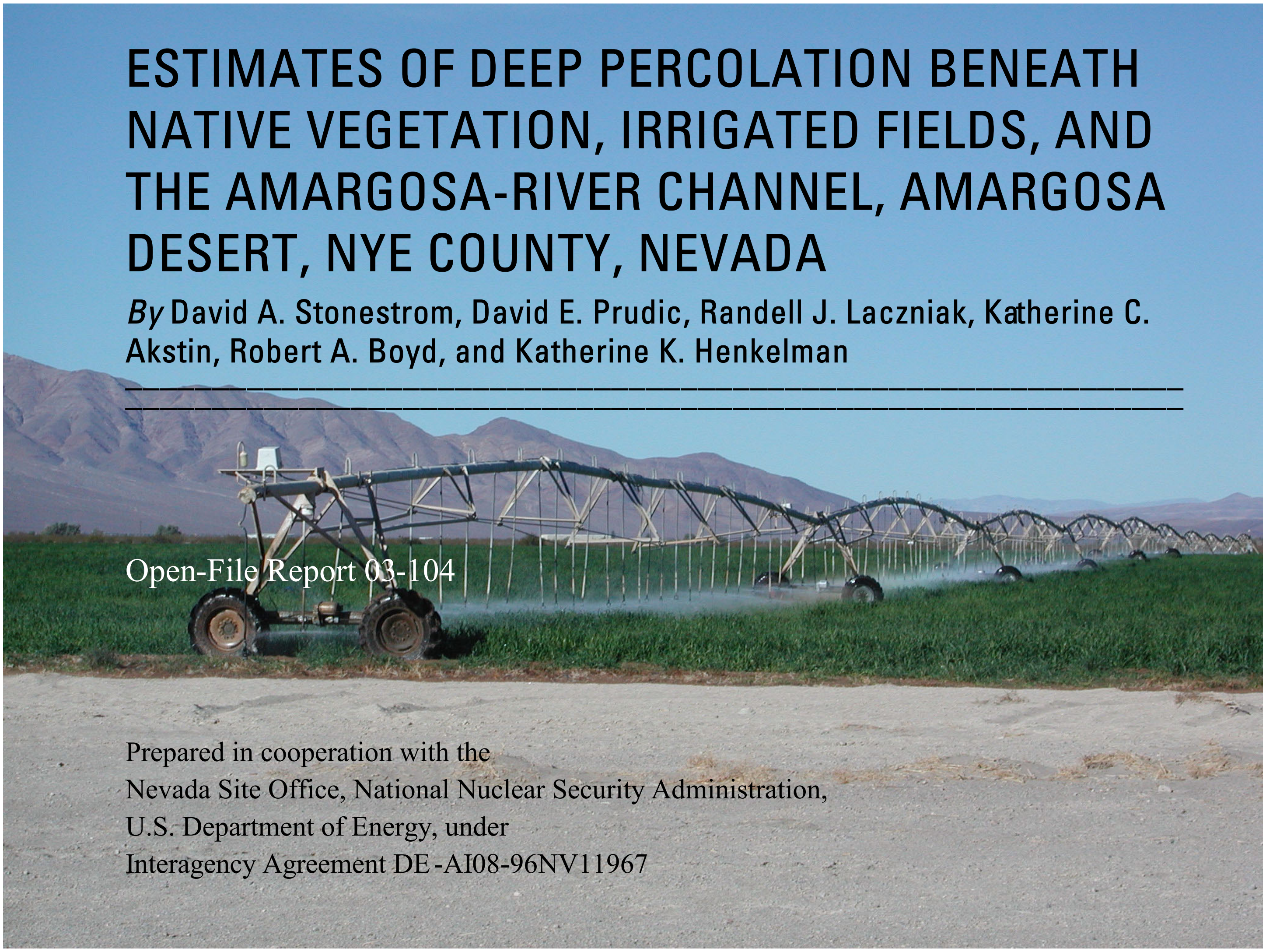

ESTIMATES OF DEEP PERCOLATION BENEATH NATIVE VEGETATION, IRRIGATED FIELDS, AND THE AMARGOSA-RIVER CHANNEL, AMARGOSA DESERT, NYE COUNTY, NEVADA

By David A. Stonestrom, David E. Prudic, Randell J. Laczniak, Katherine C. Akstin, Robert A. Boyd, and Katherine K. Henkelman

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U.S. DEPARTMENT OF THE INTERIOR

GALE A. NORTON, Secretary

U.S. GEOLOGICAL SURVEY

Charles G. Groat, Director

For additional information write to:

District Chief
U.S. Geological Survey
333 W. Nye Lane, Suite 203
Carson City, NV 89706-3810

email: GS-W-NVpublic-info@usgs.gov

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CONTENTS

FIGURES

TABLES

CONVERSION FACTORS, ABBREVIATIONS, AND VERTICAL DATUM

Multiply	By[1]	To obtain
Area		
hectare (ha)	2.47104	acre (acre)
square kilometer (km^2)	247.104	acre (acre)
square kilometer (km^2)	0.386102	square mile (mi^2)
Density		
megagrams per cubic meter (Mg/m^3)	1.	grams per cubic centimeter (g/cm^3)
megagrams per cubic meter (Mg/m^3)	62.4280	pounds per cubic foot (lb/ft^3)
Length		
kilometer (km)	0.621371	mile (mi)
meter (m)	3.28084	foot (ft)
meter (m)	39.3701	inch (in)
millimeter (mm)	3.93701	hundreths of an inch (1/100 in)
Mass		
gram (g)	0.0352740	ounce (oz)
kilogram (kg)	2.20462	pound (lb)
milligram (mg)	0.0000352740	ounce (oz)
Rate		
cubic meter per minute (m^3/min)	0.588578	cubic foot per second (ft^3/s)
cubic meter per second (m^3/s)	35.3147	cubic foot per second (ft^3/s)
meter per hour (m/hr)	78.7402	foot per day (ft/day)
meter per hour (m/hr)	3.28084	foot per hour (ft/hr)
meter per year (m/yr)	3.28084	foot per year (ft/yr)
millimeter per year (mm/yr)	0.0393701	inch per year (in/yr)
Volume		
liter (L)	0.264172	gallon (gal)
million cubic meters (106 m^3)	810.710	acre feet (acre-ft)
Water Potential (Volumetric)		
megapascal (MPa)	10.	bar
megapascal (MPa)	145.038	pounds per square inch (psi)

[1] Conversion factors given to six significant figures, unless exact.

Temperature: Degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) by using the formula °F = [1.8×(°C)]+32.

Concentration Units: Concentrations of constituents in water samples are given in milligrams of solute per liter of solution (mg/L). At concentrations and analytical accuracies reported herein, milligrams per liter are equivalent to parts per million (ppm).

Sea Level: In this report, “sea level” refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929, formerly called “Sea-Level Datum of 1929”), which is derived from a general adjustment of the first-order leveling networks of the United States and Canada.

ABSTRACT

The presence and approximate rates of deep percolation beneath areas of native vegetation, irrigated fields, and the Amargosa-River channel in the Amargosa Desert of southern Nevada were evaluated using the chloride mass-balance method and inferred downward velocities of chloride and nitrate peaks. Estimates of deep-percolation rates in the Amargosa Desert are needed for the analysis of regional ground-water flow and transport. An understanding of regional flow patterns is important because ground water originating on the Nevada Test Site may pass through the area before discharging from springs at lower elevations in the Amargosa Desert and in Death Valley. Nine boreholes 10 to 16 meters deep were cored nearly continuously using a hollow-stem auger designed for gravelly sediments. Two boreholes were drilled in each of three irrigated fields in the Amargosa-Farms area, two in the Amargosa-River channel, and one in an undisturbed area of native vegetation. Data from previously cored boreholes beneath undisturbed, native vegetation were compared with the new data to further assess deep percolation under current climatic conditions and provide information on spatial variability.

The profiles beneath native vegetation were characterized by large amounts of accumulated chloride just below the root zone with almost no further accumulation at greater depths. This pattern is typical of profiles beneath interfluvial areas in arid alluvial basins of the southwestern United States, where salts have been accumulating since the end of the Pleistocene. The profiles beneath irrigated fields and the Amargosa-River channel contained more than twice the volume of water compared to profiles beneath native vegetation, consistent with active deep percolation beneath these sites. Chloride profiles beneath two older fields (cultivated since the 1960's) as well as the upstream Amargosa-River site were indicative of long-term, quasi-steady deep percolation. Chloride profiles beneath the newest field (cultivated since 1993), the downstream Amargosa-River site, and the edge of an older field were indicative of recently active deep percolation moving previously accumulated salts from the upper profile to greater depths.

Results clearly indicate that deep percolation and ground-water recharge occur not only beneath areas of irrigation but also beneath ephemeral stream channels, despite the arid climate and infrequency of runoff. Rates of deep percolation beneath irrigated fields ranged from 0.1 to 0.5 m/yr. Estimated rates of deep percolation beneath the Amargosa-River channel ranged from 0.02 to 0.15 m/yr. Only a few decades are needed for excess irrigation water to move through the unsaturated zone and recharge ground water. Assuming vertical, one-dimensional flow, the estimated time for irrigation-return flow to reach the water table beneath the irrigated fields ranged from about 10 to 70 years. In contrast, infiltration from present-day runoff takes centuries to move through the unsaturated zone and reach the water table. The estimated time for water to reach the water table beneath the channel ranged from 140 to 1000 years. These values represent minimum times, as they do not take lateral flow into account. The estimated fraction of irrigation water becoming deep percolation averaged 8 to 16 percent. Similar fractions of infiltration from ephemeral flow events were estimated to become deep percolation beneath the normally dry Amargosa-River channel. In areas where flood-induced channel migration occurs at sub-centennial frequencies, residence times in the unsaturated zone beneath the Amargosa channel could be longer. Estimates of deep percolation presented herein provide a basis for evaluating the importance of recharge from irrigation and channel infiltration in models of ground-water flow from the Nevada Test Site.

INTRODUCTION

The U.S. Department of Energy, regulatory agencies, and others are concerned about the potential for contaminant migration away from areas of past underground weapons testing at the Nevada Test Site (NTS) and from a proposed high-level nuclear-waste repository at Yucca Mountain (fig. 1). The potential for subsurface transport by ground water from areas of underground testing at the NTS (primarily Yucca Flat and Pahute Mesa) and Yucca Mountain toward lower-elevation areas of ground-water discharge is being evaluated with coupled ground-water-flow and transport models (D'Agnese and others, 1999; Tiedeman and others, 2003). Necessary inputs for these models include reasonably accurate estimates of ground-water recharge and discharge. Although studies are underway to quantify recharge and discharge at regional and sub-regional scales (Walker and Eakin, 1963; Osterkamp and others, 1994; Flint and others, 2001; Hevesi and others, 2002) few data exist to assess these components locally or to determine their temporal and spatial character. Two processes likely to affect the rate and direction of radionuclide movement away from source areas on and near the NTS are: (1) ground-water pumpage for irrigation (and associated return flow), primarily in the Amargosa-Farms area and (2) percolation beneath stream channels that flow intermittently, primarily in the Amargosa-River and Fortymile-Wash drainage systems (fig. 1).

Figure 1

The primary mechanisms by which ground water becomes available to living things down gradient of the NTS are through naturally occurring spring flow and evapotranspiration, and through ground-water pumpage. Much of the natural discharge in the Amargosa Desert occurs in the Ash Meadows area, a desert oasis managed as a National Wildlife Refuge (fig. 1). Virtually all of the ground-water discharge at Ash Meadows becomes evapotranspiration. Micrometeorologically based mean annual evapotranspiration at Ash Meadows was estimated to be 22 to 26 × 10^6 m^3 (18,000-21,000 acre-ft) (Laczniak and others, 1999). This range is 6 to 24 percent higher than previous estimates of about 21 × 10^6 m^3 (17,000 acre-ft), which were based primarily on measurements of spring discharge (Walker and Eakin, 1963; Winograd and Thordarson, 1975; Dudley and Larson, 1976).

The other large component of discharge in the basin is the withdrawal of ground water for irrigation in the Amargosa-Farms area (fig. 1). Irrigation began around 1917 with the drilling of a single well at the T&T Ranch in the southern part of the Amargosa-Farms area. This well supplied water for a field providing fruits and vegetables to employees of the Tidewater and Tonopah Railroad. Irrigation continued on a modest scale until about 1954. Between 1954 and 1965 more than 150 additional wells were drilled in the Amargosa-Farms area to support agricultural production. Records show that by 1966, about 5 × 10^6 m^3 (4,000 acre-ft) of ground water were pumped per year for irrigation (Nevada State Engineer’s Office, Las Vegas, NV, written commun.). The amount of annual irrigation withdrawals increased steadily to about 20 × 10^6 m^3 (15,000 acre-ft) in 1980. Between 1980 and 1989, ground-water withdrawals for irrigation dropped to about 2 × 10^6 m^3 (1,500 acre-ft) per year, due to economic factors. Irrigation increased again after 1989, reaching about 15 × 10^6 m^3 (12,000 acre-ft) in 1998.

Local recharge and discharge, including ground-water pumpage, affect the rate and direction of ground-water flow in the Amargosa Desert. Any recent changes in ground-water flow patterns would most likely be caused by changes in local discharge or recharge. The amount and time lag of return flow to ground water from local irrigation is a main source of uncertainty in ground-water models, as is the amount and time lag of ground-water recharge beneath channels that flow intermittently (Tiedeman and others, 2003).

Purpose and Scope

This study was undertaken to: (1) estimate the approximate percentage of irrigation water returning to the water table in the Amargosa-Farms area, (2) estimate the rates of deep percolation beneath cultivated fields and the attendant time lag for return flow to reach the water table, (3) determine the presence and approximate magnitude of localized recharge beneath the normally dry Amargosa-River channel, and (4) determine the presence and approximate magnitude of recharge beneath undisturbed native vegetation. Results of the study are being used to support the development and calibration of a transient model of the Death-Valley regional ground-water flow system. Although the study focused on areas down-gradient of the NTS (specifically, the Amargosa-Farms area and the Amargosa-River channel), results may be generalizable to other regions in the desert southwest.

Acknowledgements

Residents of Amargosa Valley provided information on the farming history of the Amargosa-Farms area, allowed access to their properties, and extended cordial hospitality to the drillers and scientists working in the area. In particular, the authors thank Michael DeLee of T&T Ranch, Ronel and LaVonne Selbach of Funeral Mountain Ranch, Dave Hall of Ponderosa Dairies, and Ken Gary of Bar BQ Ranch. The authors also thank the Southern Nye County Conservation District (SNCCD) for providing project personnel the opportunity to promote the study at two regularly scheduled SNCCD meetings, and the Tonopah Field Office of the Bureau of Land Management (BLM) for granting permission to drill and sample in the channel of the Amargosa River.

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METHODS OF ESTIMATING DEEP PERCOLATION

Theory and Assumptions

Profiles of environmental tracers were determined beneath irrigated fields, the Amargosa-River channel, and undisturbed areas of native vegetation. Where applicable, rates of deep percolation were estimated assuming that chloride is a conservative tracer of liquid water movement. Under suitable conditions, the rate of deep percolation can be estimated from average chloride concentrations beneath the root zone using the following equation:

$$D_p = (C_e P + C_r R + C_i I + C_f F) / C \qquad (1)$$

where

D_p is the rate of deep percolation, in meters per year;

C_e is the effective chloride concentration in precipitation, including dry fallout, in milligrams per liter;

P is the annual volume of precipitation per unit area, in meters per year;

C_r is the concentration of chloride in Amargosa-River water, in milligrams per liter;

R is the net annual volume of runoff that percolates, per unit area of riverbed, in meters per year;

C_i is the concentration of chloride in irrigation water, in milligrams per liter;

I is the annual volume of applied irrigation water per unit area, in meters per year;

C_f is the concentration of chloride in applied fertilizer, in milligrams per liter;

F is the annual volume of applied fertilizer per unit area, in meters per year; and

C is average chloride concentration in deep percolation (that is, in pore water below the zone influenced by evapotranspiration), in milligrams per liter.

The product of the average concentration of chloride and the annual volume of water that passes through the land surface from a given source is referred to herein as the chloride deposition rate, expressed in grams of chloride per square meter of horizontal area per year. The rate of deep percolation at a given location, in cubic meters of water per square meter of horizontal area per year (m^3/m^2 yr = m/yr), is the sum of the annual chloride deposition from all sources (in g/m^2 yr) divided by the average chloride concentration in deep percolation (in g/m^3). For example, the annual chloride deposition from the atmosphere is simply the product of C_e and P. Note that the concentration units of mg/L and g/m^3 are identical.

Application of equation 1 assumes: (1) steady, uniform downward flow of water (no change in water content with time), (2) negligible preferential flow (or sufficient sampling to provide meaningful averaging of preferential flow paths), and (3) transport of chloride with negligible retardation or anion-exclusion effects. Other assumptions are that: (4) annual chloride inputs at the land surface are known and constant, (5) there are no sources or sinks of chloride within the sediments, (6) chloride is not taken up by crops or native vegetation, (7) the land surface is neither aggrading nor eroding, and (8) chloride fluxes beneath the depth of seasonal influences are in approximate equilibrium with long-term average fluxes of chloride across the land surface (Wood, 1999; Scanlon, 2000).

Where applicable, rates of deep percolation can also be determined from apparent travel velocities of a solute “marker,” using

$$D_p = \overline{\theta}(z_2 - z_1)/(t_2 - t_1) \qquad (2)$$

where $\bar{\theta}$ is the average volume fraction of water between z_1 and z_2, and z_1 and z_2 are the depths of a solute marker at times t_1 and t_2, respectively. Like the chloride mass-balance method (equation 1), the tracer-velocity method requires that the marker moves conservatively with the water, and that water contents between z_1 and z_2 are constant through time.

The chloride mass-balance method has been used to estimate deep percolation beneath undisturbed areas of native vegetation (for example, Stone, 1984; Edmunds and others, 1988; Allison and others, 1994; Phillips, 1994; Stonestrom and Akstin, 1998). In particular, the method has been applied to areas of undisturbed vegetation at the Nevada Test Site (Tyler and others, 1996) and the Amargosa Desert Research Site (ADRS) (Fouty, 1989; Prudic, 1994). The method has also been used to estimate deep percolation beneath irrigated fields in both the Roswell Basin, New Mexico (Roark and Healy, 1998) and in Eagle Valley, Nevada (Maurer and Thodal, 2000). Additionally, the method has been used to estimate deep percolation beneath ephemeral washes in the eastern Mojave Desert (Izbicki, and others, 2000; Izbicki, 2002).

Applicability of assumptions

Rarely is there continuous uniform downward flow throughout the entire unsaturated zone. Alternating periods of infiltration and evapotranspirative discharge result in large changes in moisture content near land surface. Even though large changes in the magnitude and direction of water flux occur at the land surface, the unsaturated zone rapidly attenuates these temporal fluctuations with depth (Gardner, 1964). Beneath the interval affected by evapotranspiration, fluxes are sufficiently damped that the assumption of steady flow below the root zone is often a reasonable approximation (Nimmo and others, 1994).

The assumption of approximately steady-state conditions seems reasonable for areas beneath irrigated fields where nearly constant irrigation rates are imposed. The assumption might also apply beneath ephemeral stream channels, if episodic flows occur frequently enough to sustain deep percolation beneath the zone influenced by evapotranspiration. On the other hand, the assumption of steady-state conditions is questionable for undisturbed areas of native vegetation in the Amargosa Desert. Numerous studies have concluded that there has been little to no deep percolation below the creosote bushes that populate the basin floor under current climatic conditions (Nichols, 1987; Fischer, 1992; Prudic, 1994; Tyler and others, 1996; Andraski, 1997; Stonestrom and others, 1999; Andraski and Jacobson, 2000; Hartsough and others, 2001). Recent modeling studies of heat and water flow (as both vapor and liquid) have shown that profiles beneath undisturbed creosote communities are not at steady state; rather, they are still responding slowly to the change from pluvial to arid conditions that occurred at the end of the Pleistocene (Walvoord, Plummer, and others, 2002; Walvoord, Phillips, and others, 2002).

Data collected from several alluvial basins in the southwestern United States indicate that preferential flow is not a dominant transport process in unconsolidated, unfractured sediments at relatively flat sites (Phillips, 1994; Scanlon and others, 1997). Flow is, however, concentrated beneath sources of water and diverted laterally by stratigraphic contrasts. For example greater infiltration beneath ephemeral stream channels compared to adjacent areas receiving only precipitation was documented on an alluvial fan in the Mojave Desert (Izbicki and others, 2000). The Mojave study also produced evidence of lateral flow that detoured around fine-grained, clayey deposits within the fan (Izbicki, 2002; Nimmo and others, 2002). Since the alluvial sediments in the Amargosa Basin are largely unfractured, the types of preferential flow expected are those due to stratigraphy and geomorphic concentrations of water.

Collection and Analysis of Sediments

A series of shallow (10 to 16 m deep) holes were drilled at nine locations in the Amargosa Desert (fig. 2). Profiles of sediment type, water content, and anion concentrations (including chloride, sulfate, and nitrate) were determined from cores collected at each hole. One hole was drilled in an undisturbed area of native vegetation in the Amargosa-Farms area, two holes were located in the Amargosa-River channel, and two holes were located in each of three different irrigated fields (fig. 2). Each field had a different irrigation history as detailed by landowners, farmers, and other residents. Field 1, the newest field, was converted from creosote to agriculture eight years prior to drilling (beginning in 1993). Field 2, the oldest field, was put into production in 1961 but used only intermittently during the 1980's. The third field (Field

3) went into production one or two years after Field 2 and was cultivated continuously for at least 14 years prior to sampling. In addition to the nine holes drilled for this study, test holes extending to a maximum depth of 115 m had previously been drilled at the ADRS in an undisturbed area of native vegetation (Prudic, 1994). Data on cores from these holes that had been analyzed for water content and chloride concentration were included in this study to assess the variation of profiles beneath native vegetation.

Figure 2

The new holes for this study were drilled using a heavy-duty hollow-stem auger capable of recovering 75-mm diameter cores in gravelly sediments. A 1.5-m long split-tube core barrel was placed down the hollow stem auger so that the cutting shoe of the core barrel matched or extended slightly below the cutting bits of the lead auger. Occasionally 1.5-m long cores were collected, but more often, alternating 0.6- and 0.9-m long cores were collected. Core samples were collected in 120-mm sections and immediately transferred to sealed, 1-liter glass bottles. Each hole was backfilled with bentonite pellets to within 1 m of land surface. The remainder of the hole was filled with sediment. A summary of boreholes is given in table 1. A listing of cored intervals and sediment descriptions appears in appendix A. Photographs of the drilling and coring are shown in figure 3.

Table 1

Figure 3

Jars were tared prior to adding samples and reweighed after filling. The potential energy of pore water in each depth interval was determined by removing small sediment samples from jars and placing them into a water-activity meter (Gee and others, 1992). The water-activity meter measures the relative humidity of air in equilibrium with a sample. Readings from three aliquots were averaged for each jar. The water-activity meter is relatively inaccurate for water potentials greater (less negative) than -0.3 MPa (-3 bars), corresponding to relative humidities greater than 0.998 (Gee and others, 1992). Water potentials as measured include the energy due to solutes in pore water (Jury and others, 1991, p. 50). The gradient of the sum of the water potential and elevation potential indicates the direction of water movement. In regions with high salt-concentration gradients (in this study, just below the root zone of native vegetation), or high temperature gradients (near the land surface at all sites), much of the movement may occur in the gas phase (Fischer, 1992; Scanlon, 1992; Walvoord, Plummer, and others, 2002). Over most of the profiles at depth, however, solute concentrations, solute-concentration gradients, and temperature gradients were small. Hence gradients in water potential (plus elevation potential) were useful for inferring the direction and relative magnitude of water movement beneath areas of undisturbed vegetation, irrigated fields, and ephemeral channels.

The gravimetric water contents of cores were determined by drying sediment samples at 105° C to constant weight. Some of the finer-grained samples required as long as 3 days to dry. After drying, the samples were mixed with an equal mass of deionized water and shaken periodically for 24 hours. Supernatant liquid was decanted, filtered through a 0.45 µm membrane, and analyzed for pH and specific conductance. Filtered water was also analyzed for chloride, nitrite, nitrate, and sulfate using ion chromatography. Measured supernatant concentrations were converted to pore-water concentrations by dividing by the gravimetric water content and multiplying by the density of pore water, assumed to be 1.00 Mg/m^3.

Gravimetric water contents, water potentials, pH values, specific conductances, and concentrations of chloride, nitrate, nitrite, and sulfate in water extracts are listed in appendix B. Anion concentrations are reported per mass of oven-dry sediment and per volume of pore water in appendix C. Chloride, nitrate, and sulfate profiles are detailed in subsequent sections. Although means were not available to determine carbonate species in pore water as they existed underground, variable concentrations of bicarbonate were evidenced by scattered occurrences of secondary calcite mineralization. Nitrite was generally below analytical detection levels, except in shallow sediments.

The specific electrical conductance of extracts did not correlate consistently with either chloride alone or with the sum, in milliequivalents per liter, of chloride, nitrite, nitrate, and sulfate (fig. 4). The inconsistent correlations were probably caused by variable concentrations of bicarbonate ions and colloids. The dependence of specific conductance on the sum of measured anions was weaker at the upstream-Amargosa-River site than elsewhere (appendix A). Extracts from the upstream sediments had noticeably higher concentrations of colloids than other sediments. Specific conductance is of limited usefulness as a proxy for chloride in unsaturated-zone water in Amargosa sediments due to variable amounts of difficult-to-measure constituents that contribute to electrical conductivity.

Figure 4

ANALYSIS OF DEPOSITIONAL SOURCES AND UNCERTAINTY

Chloride and other water-soluble constituents reach the land surface everywhere in the Amargosa Desert through atmospheric deposition of precipitation and dust. In the irrigated fields, dissolved constituents are also delivered by ground water used for irrigation, and by fertilizer. In the Amargosa-River channel, dissolved constituents enter the land surface through infiltration of runoff as well as atmospheric deposition.

Atmospheric Deposition

The Amargosa Desert is one of the driest regions in the United States. Annual precipitation from 1966 to 2001 at Amargosa Farms averaged 113 mm, with a low of 18 mm in 1989 and a high of 263 mm in 1983 (NOAA, National Climatic Data Center, station 260150, data obtained May 2002 from http://lwf.ncdc.noaa.gov/oa/climate/climatedata.html). Average annual precipitation from 1981 to 2000 at the ADRS was nearly the same, at 108 mm (Johnson and others, 2002, p. 6). Two periods of higher precipitation are evident from consideration of monthly averages (fig. 5). More than half of the annual precipitation falls in the four-month period from December through March. More than a third falls in the three-month period from July through September. Winter precipitation is dominated by storms from the west and northwest. Summer precipitation is dominated by storms from the south and southwest (Houghton, 1967). Winter storms typically originate in the Pacific Ocean, off the west coast of the United States. Summer storms typically originate farther south, in the Gulf of California and in the Pacific Ocean off Mexico (Brenner, 1974).

Figure 5

The current hot and dry climate has been prevalent for at least the last 9,000 to 11,000 years (Grayson, 1993; Ettinger, 2002) and perhaps as long as 18,000 to 20,000 years, as suggested by water levels at Devils Hole (fig. 1; Szabo and others, 1994, p. 59).

Estimates of the annual chloride deposition from the atmosphere were determined from five years of chloride concentrations in bulk precipitation (including dryfall) collected at the ADRS (fig. 2), from November 1997 to November 2002. Concentrations of nitrite, nitrate, and sulfate were also determined. Precipitation was accumulated for roughly six-month periods (summer and winter) in duplicate collectors, although samples were picked up after shorter intervals during the first year due to large amounts of precipitation related to a strong El Niño sea-surface temperature pattern. Precipitation and dryfall impinging on two funnels one meter above land surface and one meter apart drained into glass collectors sharing a common underground chamber. A layer of vacuum-pump oil floated on the accumulating sample in each collector to minimize evaporation. Two additional glass tubes in the underground chamber contained deionized water under vacuum-pump oil, as controls for contamination and evaporation. Effective volume-averaged concentrations of chloride, nitrite, nitrate, and sulfate in precipitation are given in table 2. The (effective) volume-weighted concentration of chloride in precipitation (that is, including chloride from dryfall) was about 0.5 mg/L (table 2). While individual samples ranged from 0.2 to 6 mg/L, the cumulative volume-weighted average chloride concentration converged to 0.5 ± 0.05 within 18 months. This value is in general agreement with a mean value of 0.4 mg/L for 74 sites in Nevada reported by Dettinger (1989). Multiplying the effective chloride concentration in precipitation times the annual average precipitation yields an annual average chloride deposition of 0.06 g/m^2. Although atmospheric deposition rates are unlikely to have been constant since the late Pleistocene, the ADRS data are consistent with regional trends and allow a first approximation of current conditions in the Amargosa Desert.

Table 2

Irrigation Water

Mild winter temperatures on the basin floor allow for extended growing seasons—from February through November. Three cultivated fields at Amargosa Farms were chosen for study (fig. 2). Irrigation histories were obtained from farm owners. Field 1 is about 12 hectares and is irrigated with a center-pivot sprinkler. Irrigation began in June 1993. The field was dormant from November 2000 until the boreholes were drilled in February 2001. No precipitation was recorded in November and December 2000; 74 mm was recorded in January and February 2001. Field 1 has been used to grow alfalfa since going into production. While in production, an average of 7 mm of water per day was applied from March through November. About 0.8 mm of water per day was applied from December through February. The total application was about 2 m per year.

Field 2 is about 53 hectares and is one of the oldest fields in the area. Irrigation began sometime between 1960 and 1962. Wheel-line sprinklers were used to irrigate alfalfa until 1978. A center-pivot sprinkler was installed in 1979, but production (hence irrigation) was sporadic from 1979 through 1983. The field lay dormant from 1983 through 1991. The field was returned to alfalfa production in spring 1992. Since 1992, water has been applied at about the same rate as that for field 1.

Field 3 is also about 53 hectares. It was put into production in the early 1960's, shortly after field 2. Until the early 1970's, the field was used to grow turf. The field was used occasionally between the early 1970's and the early 1980's. Oats were grown in 1981 and 1982. Barley and vegetables were grown in 1983 and 1984. Since 1987, the field has been used continuously for the production of organic alfalfa. The earliest irrigation techniques were not documented. Since 1987, the field has been irrigated with a center pivot nearly continuously from February through November, except for two to three days per month for maintenance. No irrigation was applied from December through January. On average, about 9 mm of water per day was applied during the 300-day irrigation season, for a total application of about 2.7 m per year.

Irrigation water for each field was supplied from individual wells. Ground water from the wells used to supply fields 1, 2, and 3 were analyzed for chloride, nitrate, nitrite, and sulfate as part of this study. The well for field 1 was sampled in February 2001. The well for field 2 was sampled in January 2002. The well for field 3 was sampled in February 2001 and again in January 2002. Each well was pumped at least 30 minutes prior to sampling. The same laboratory that analyzed soil-water extracts (U.S. Geological Survey, Menlo Park) also analyzed ground-water samples collected in February 2001. Replicate splits of samples collected in January 2002 were sent to the U.S. Geological Survey's Central Laboratory in Arvada, Colorado. Concentrations of dissolved chloride and sulfate determined by the two laboratories were in close agreement (table 2). Archived data for a water sample collected in March 1974 from the field-3 well showed nearly the same concentrations of dissolved chloride and sulfate as obtained 27 and 28 years later, in February 2001 and January 2002 (table 2). The average concentration of chloride in ground water was

6.9 mg/L, which implies an annual chloride deposition from irrigation water of about 14 g/m^2 for fields 1 and 2, and about 19 g/m^2 for field 3.

Commercial fertilizer containing 11 percent nitrogen and 52 percent phosphorous was applied in spring and summer to fields 1 and 2. Approximately 9 g of fertilizer per m^2 of field was applied each time. Additionally, liquid fertilizer was applied to field 2 in the spring of 1992 when the field was put back into production. Compost was used to fertilize field 3. The compost consisted of undigested feed (oats, corn, and hay separated from manure). Approximately 0.4 to 0.7 kg/m^2 of compost was applied to the field every two years. The compost contained about 10 to 15 g of nitrogen per kg of compost. The concentration of chloride in compost was not measured, but is probably close to that of sodium, which is about 3 g/kg (0.3 percent) (Loney Ashcraft, U.S. Department of Agriculture, Natural Resources Conservation Service, Roswell, New Mexico, oral commun., 2002). Thus the annual chloride deposition from fertilizer on field 3 is about 0.6 to 1 g/m^2. Commercial fertilizers generally contain much less than 2% chloride by weight. The maximum amount of chloride applied in fertilizer on fields 1 and 2 was thus less than 0.2 g/m^2 per year. This is less than one percent of the estimated annual chloride deposition from irrigation. Rounding to 2 significant figures, the total annual chloride deposition on irrigated fields, including fertilizer and atmospheric sources, was still about 14 g/m^2 for fields 1 and 2, and 19 g/m^2 for field 3. Gypsum ($CaSO_4$) was also applied to field 3 at a rate of 100 g/m^2 every two to three years, for an annual deposition rate of 33 to 50 g/m^2. Gypsum was not applied to fields 1 or 2. The gypsum probably contained trace quantities of chloride, but these amounts would be negligible in comparison to other sources.

Amargosa-River Water

The Amargosa River downstream of Beatty, Nevada (fig. 1) is usually dry. Flow is infrequent because precipitation averages less than 150 mm per year over much of the drainage area (Tanko and Glancy, 2001). Flow in the channel is primarily generated by runoff from the mountains upstream of Beatty, but local runoff from Bare Mountain (which forms the northeast side of the Amargosa basin), the Bullfrog Hills (north side), and the Funeral Mountains (southwest side) can also contribute runoff to the channel (fig. 1). Flows that extended continuously from the headwaters upstream of Beatty, Nevada all the way past Amargosa Farms into Death Valley were documented for the floods of March 11, 1995 and February 23-24, 1998 (Tanko and Glancy, 2001; Beck and Glancy, 1995). Peak flows associated with the 1998 flood were estimated not only at Beatty, but also near Big Dune, about 35 km downstream of Beatty (fig. 2). The estimated peak flow rate was 90 cfs (2.6 m^3/s) at Beatty and 20 cfs (0.6 m^3/s) near Big Dune (Tanko and Glancy, 2001). These estimates indicate that 70 cfs (2.0 m^3/s) of flow was lost along the reach, assuming lateral inflows were negligible. Assuming a uniform loss rate, the average loss was 70 cfs (2.0 m^3/s) in 35 km, or 2.0 cfs (0.057 m^3/s) per km. Thus at least 1.4 m^3/s of flow at Beatty would be needed to reach the Ashton site, about 25 km downstream (ARAS1; fig. 2). Similarly, at least 0.7 m^3/s would be needed to reach the radio-beacon site (ARRB1), midway between Ashton and Beatty (13 km downstream of Beatty). The days in which peak flow exceeded 0.5 m^3/s near Beatty are listed in table 3 for the period of record (October 1963 through September 2001). Peak flow equaled or exceeded 0.7 m^3/s on at least 26 days, and equaled or exceeded 1.4 m^3/s on at least 16 days. These values represent minimum counts because only annual peak discharges at the crest-stage gage were recorded in most years.

Table 3

As shown in table 3, large flows occur most frequently during two periods, January through March and July through September. These two periods correspond to the periods of higher precipitation (fig. 5). About 70 percent of peak flows that equaled or exceeded 0.7 m^3/s occurred in January, February, or March. The remaining 30 percent occurred in July, August, or September. Maximum flow estimated at or near Beatty was 450 m^3/s on February 24, 1969. This flow far exceeded any other on record.

Flow durations were estimated using data from the Beatty gage, where stage was recorded every 15 minutes from August 1993 to April 1995 and from January 1996 to October 2001. Flow was divided into 4 categories: 0 to 0.1 m^3/s, 0.1 to 0.7 m^3/s, 0.7 to 1.4 m^3/s, and greater than 1.4 m^3/s. Flow at the Beatty gage was less than or equal to 0.1 m^3/s about 99 percent of the time. Flows greater than 0.7 m^3/s occurred only 0.13 percent of the time. Flows greater than 1.4 m^3/s occurred only 0.04 percent of the time. Thus, in any given year, flow at ARRB1 can be expected for a total of 11 hours, on average, whereas flow at ARAS1 can be expected for a total of only 3.5 hours. Assuming a channel loss rate of 0.057 m^3/s (3.4 m^3/min) per km (on the basis of the February 1998 peak-flow estimates at Beatty and Big Dune, discussed above), and assuming an average width of 3 m (on the basis of channel morphology), the channel infiltration rate is about 1.1 mm/min (68 mm/hr). Multiplying by 11 hours of flow per year results in an average cumulative infiltration of about 0.75 m per year at ARRB1. Similarly, multiplying by 3.5 hours results in an average cumulative infiltration of about 0.24 m per year at ARAS1. These estimates represent minimum values because they do not consider highly localized runoff from the valley floor or from tributaries draining the Bull Frog Hills to the north, the Funeral Mountains to the southwest, or Bare Mountain to the northeast (fig. 2). It is therefore clear that despite the low frequency of runoff in the Amargosa Desert, infiltration from infrequent flows of the Amargosa River substantially exceeds direct precipitation and potentially produces ground-water recharge.

The chemical composition of streamflow in the Amargosa River downstream of Beatty is difficult to assess because of the rare occurrence of runoff. Storms between February 13 and February 27, 2001 produced a combined total of 34 mm of precipitation. The latter storm produced intense local precipitation accompanied by brief periods of flow at ARRB1 and ARAS1 February 24–25 and February 26–27 on the basis of field observations of channel bed-forms, debris strandlines, and stream-surface temperatures. The peak flow at Beatty was relatively small (0.53 m^3/s), suggesting that part of the flow at ARRB1 and ARAS1 was generated locally. Infiltrating water was observed in channel depressions when ARAS1 was drilled on the morning of February 27. Perched water was encountered in several shallow hand-dug pits near ARAS1. Water from a shallow hand-dug pit several meters from ARAS1 was collected and subsequently analyzed for chloride, nitrite, nitrate, and sulfate (table 2). This sample had a chloride concentration of about 15 mg/L. Similarly, the core sample collected from a depth of 0 to 0.15 m, immediately above the perched water, had a chloride concentration of 9 mg/L (appendix C). Due to the cold, rainy conditions (see fig. 3F) and the fact that only several hours had elapsed between the time of flow and the time of collection, there was little chance for evaporative enrichment of the samples. Additionally, because several pore volumes had flushed the sediments prior to collection, shallow pore water was assumed to represent relatively unaltered channel water. A similar, saturated sample collected at ARRB1 from a depth of 0 to 0.15 m had a chloride concentration of 18 mg/L; however, this sample was collected more than a full day after flow had occurred. All of these chloride concentrations were much less than chloride concentration deeper in the profiles at ARRB1 and ARAS1. The concentrations are also less than the 20 to 50 mg/L of chloride found in pore water at the ADRS below a depth of 15 m (Prudic, 1994, p. 5) and the 70 to 80 mg/L of chloride in ground water at the ADRS (Prudic, 1998, U.S. Geol. Survey, Carson City, NV, written commun.). Assuming that the chloride concentration of storm-produced runoff in the Amargosa River downstream of Beatty, NV was 12 mg/L (the average of chloride concentrations in water from the shallow pit and shallowest ARAS1 core), and assuming that 0.75 m and 0.24 m of water infiltrate annually into the streambed at ARRB1 and ARAS1, respectively, the estimated annual chloride deposition from runoff is about 9.0 g/m^2 at ARRB1 and 2.9 g/m^2 at ARAS1. The lower chloride-deposition rate at ARAS1 results from less frequent flow due to channel losses between ARRB1 and ARAS1.

Uncertainty In Deep-Percolation Estimates

Uncertainties in chloride-mass-balance based deep-percolation rates arise primarily from fairly large uncertainties in total chloride deposition from atmospheric, irrigation, and runoff processes. Uncertainties from errors in water content and pore-water composition, estimated to be about five percent, are small in comparison. The remainder of this section characterizes the uncertainty of the three depositional sources of water and chloride. Uncertainties in tracer-velocity based estimates of deep-percolation rates arise primarily from assumptions about initial conditions and about the conservative, one-dimensional nature of flow. Although these assumptions cannot be readily tested, comparisons of estimates from tracer velocities with largely independent estimates from chemical mass-balance calculations provide a likely indication of actual errors.

Uncertainty in atmospheric deposition

Although there are large differences in precipitation patterns among storms, long-term average precipitation at Amargosa Farms (36 years of record) and at the ADRS (20 years of record) are relatively close, agreeing within 5 percent (5 mm). Thus the main source of uncertainty in the atmospheric chloride source is the effective chloride concentration. As shown on table 2, the effective chloride concentration in precipitation based on 5 years of data was 0.51 mg/L. An analysis of data from the nearest National Atmospheric Deposition Network (NADP) station with more than five years of data (station NV00, Red Rock Canyon, about 125 km to the southeast of the ADRS, 17 years of record) shows that 5-year sampling periods produced an average error of 12% when used to estimate the 17-year average (data downloaded from http://nadp.sws.uiuc.edu/ on February 3, 2003). Because the NADP protocol excludes dry deposition, and because the time periods of interest are often considerably in excess of 17 years, 12% represents a minimum uncertainty. Extrapolation to longer timeframes and consideration of dryfall increases the uncertainty. For present purposes the uncertainty in atmospheric chloride deposition over decadal time scales based on a single five-year sample was assumed to be ± 25%. Thus, the current average annual atmospheric chloride deposition rate was estimated to range from 0.04 (= 75% $\times$ 0.5 g/m^3 $\times$ 0.108 m) to 0.07 g/m^2 (= 125% $\times$ 0.5 g/m^3 $\times$ 0.113 m). Extrapolating this rate to millennial timescales could produce larger errors. Thus, the estimated time required to accumulate chloride beneath native vegetation contains relatively more uncertainty than the decadal-scale estimates of deep percolation beneath irrigated fields. Nevertheless, relative comparisons of accumulation times for different locations in the Amargosa Desert will be unaffected by temporal shifts in deposition, as long as spatial variations in chloride deposition in the past were comparable to current variations proxied by precipitation.

Uncertainty in agricultural deposition

The annual chloride deposition from ground water used for irrigation (14 g/m^2 to 19 g/m^2) greatly exceeds the annual chloride deposition from the atmosphere (< 0.1 g/m^2) and from fertilizers (< 1 g/m^2). Uncertainty in the estimate of annual chloride deposition from irrigation water is therefore assumed to be the main source of uncertainty in irrigated fields. The chemical composition of ground water in the Amargosa-Farms area has been uniform and steady, as indicated by similarities among wells and sample dates (table 2). Historical records of water quality from wells in the immediate vicinity of fields 1, 2 and 3 further indicate that chloride concentrations have been at current levels since the 1950’s (A.S. Van Denburgh, 2002, U.S. Geological Survey, retired, written commun.). Thus, the main uncertainty in the rates of chloride deposition for irrigated fields is the uncertainty associated with the volumes and uniformity of irrigation water. Volumes were estimated from pumping rates and irrigation periods. Estimated errors in pumping rates and irrigation periods are ten and five percent, respectively. Total annual application rates could thus range from 1.7 to 2.3 m^3/m^2 for fields 1 and 2 and 2.3 to 3.1 m^3/m^2 for field 3. These ranges imply total annual chloride deposition rates (from all sources) of 12 to 16 g/m^2 for fields 1 and 2 and 17 to 22 g/m^2 for field 3.

Uniformity of water-application rates within individual fields is controlled by varyingly the size of spray nozzles along pivot lines in combination with active pressure regulation. Regular maintenance is required to maintain uniform application (Briggs and others, 1992). Because pumping is a major part of production costs, levels of maintenance tend to be high. Assuming typical to above average levels of maintenance, uncertainties due to spatial variations in water application are probably smaller than the uncertainties in total pumpage. Thus the overall uncertainty in application was assumed to be approximated by the uncertainty in the total volume of irrigation water applied to each field.

Uncertainty in channel deposition

The uncertainty in the average annual rate of chloride deposition from channel flow is relatively large due to limited data on infiltration rate, flow chemistry, and flow duration. The infiltration rate was estimated on the basis of a single flow-loss study. Although the rate obtained here was close to rates measured in an ephemeral channel with similar sediments (Ronan and others, 1998), for present purposes the uncertainty in infiltration rate was assumed to be ± 25 percent.

The concentration of chloride in runoff was likewise estimated on the basis of a single flow event. Although the sampled flow event might not have been representative, the chloride concentrations obtained here were close to values obtained for ephemeral flows in four different channels on the Nevada Test Site (NTS). Chloride in ephemeral flows of these channels ranged from 3 to 10 mg/L (Stockade Wash at Airport Road, station number 102512484; Yucca Wash near mouth, station number 10251252; Cane Spring Wash tributary below Skull Mountain, station number 102512654; and unnamed tributary to Stockade Wash near Rattlesnake Ridge, station number 10251248; sampled January through March, 1993; Emmet and others, 1994, p. 132 and 550). Concentrations of chloride in ephemeral runoff in the Amargosa River as well as at the NTS are high relative to concentrations in precipitation due to the large drainage areas and infrequency and short durations of flows. Ephemeral flows readily dissolve effervescent salts that form in the channel between flow events. Large quantities of effervescent salts form perennially in the Amargosa-River channel from Oasis Valley to several km downstream of Beatty. Base flow near Beatty (representing ground-water discharge) had a chloride concentration of 76 mg/L (ppm) on Dec. 12, 1965 (U.S. Bureau of Reclamation, 1968). Chloride concentrations during flows of less than 0.14 m^3/s in early 1993 were 180 to 290 mg/L (Emmet and others, 1994, p 122); however, these concentrations were possibly affected by up-gradient sewage lagoons installed in the 1970's. All data indicate that ground-water fed base flow has a much higher concentration of dissolved salts than ephemeral flow. Thus base-flow concentrations were not used in estimating the concentration of chloride in ephemeral runoff, which was assumed to be bounded by the samples collected during ephemeral flow in the Amargosa channel (9 to 15 mg/L).

The method of estimating average-annual-flow duration assumed that specific threshold flows at the Beatty gage produced flows at the sampling sites farther down the channel. This method ignores tributary and basin-floor inputs to the channel and therefore likely underestimates cumulative flow durations. Field reconnaissance supplemented by stream-bed temperatures suggest that the actual durations of runoff at each site might be greater than threshold-based estimates by as much as three hours per year.

Only broad ranges can be assigned to chloride deposition at the two channel sites, ARRB1 and ARAS1. Assuming that: (1) the channel infiltration rate ranged from 54 to 82 mm/hr (= 68 mm/hr ± 25%), (2) the chloride concentration of ephemeral runoff ranged from 9 to 15 mg/L, and (3) the duration of flow ranged from 11 to 14 hrs/yr at ARRB1 and from 3.5 to 6.5 hrs/yr at ARAS1, the combined uncertainties yield ranges for average annual chloride deposition from infiltration of ephemeral flow plus atmospheric deposition of 5 to 18 g/m^2 at ARRB1 and 2 to 8 g/m^2 at ARAS1.

ANALYSIS OF UNSATURATED-ZONE PROFILES

Vertical Profiles of Sediments, Water Status, and Selected Anions

Sediments

Sediments in the Amargosa-Farms area consisted almost entirely of thin layers (< 2 m thick) of moderately sorted sand and gravel separated by thin layers of sand and sandy silt (appendix A). Gravel ranged from 4 mm to 64 mm in diameter. The sand and gravel layers were evidently deposited by Fortymile Wash and, at depth, possibly also the Amargosa River. The intervening layers of sandy silt and fine sand appeared to represent wind-reworked fluvial deposits.

A layer of volcanic ash was encountered at a depth of 13.5 to 13.8 m beneath field 3 (appendix A). This material was identified as "Lava Creek B" ash from a caldera eruption in the Yellowstone-Park area about 650,000 years ago (Andrei Sarna-Wojcicki, U.S. Geological Survey tephrachronology laboratory, Menlo Park, written commun., 2002; Sarna-Wojcicki and others, 2001). The ash has the same mineralogical composition as ash exposed in former lakebeds of Lake Tecopa near Shoshone, California, about 60 km south of Amargosa Farms. The ash indicates that alluvial sediments in the Amargosa-Farms area have accumulated at a net rate of two meters per 100,000 years (0.02 mm/yr) for roughly the last half of the Quaternary. The low deposition rate supports the chloride-mass-balance requirement of land-surface stability, especially when Holocene aridity is taken into account.

Sediments beneath the Amargosa-River channel differed from those in the Amargosa-Farms area. Sediments beneath the channel at the upstream site (ARRB1) consisted of a 2-m thick layer of sand and gravel beneath a surface strewn with boulders and cobbles (appendix A; fig. 2). The sand and gravel layer ended abruptly at 2 m. Sediments in the remainder of the hole were a poorly sorted mixture of clay, silt, sand and gravel that resembled weathered deposits from debris flows (Patrick A. Glancy, U.S. Geological Survey, Carson City, Nevada, personal commun., 2001; Glancy, 1994). Cobbles up to the size of the 75-mm diameter core barrel were recovered in the cores. The Amargosa-River channel at the upstream site has incised at least 2 m into the general surface. In contrast, the sediments beneath the channel at the downstream site (ARAS1) consisted of unweathered, moderately sorted sand and gravel to a depth of at least 14 m (appendix A). The active channel of the river at this location is incised less than 1 m into the general surface and is part of an anastomosing network of shallow channels. The lack of incision and the braided nature of the channel suggest that this reach actively migrates during large flows.

Calcite veins and nodules occurred at various depths beneath the irrigated fields and native vegetation (appendix A). In contrast, secondary calcite was largely absent from sediments beneath the stream channel of the Amargosa River (appendix A).

Water potential and water content

The distributions of water potential and water content in each profile are shown in figure 6. Sub-root-zone water potentials were extremely low beneath native, undisturbed vegetation (AFCA1; fig. 6*A*). Water potentials were lower (more negative) than –5 megapascals (MPa) for most of the profile, indicating little downward movement of water below the 1-m deep root zone. The profile was similar to those measured beneath native vegetation at the ADRS (Stonestrom and others, 1999), where calculated fluxes indicated virtually no deep percolation under current climatic conditions (Fischer, 1992; Prudic, 1994; Andraski, 1997). Water potentials beneath irrigated fields and the Amargosa-River channel were higher. Water potentials generally exceeded –3 MPa beneath field 1 (fig. 6*B*; note horizontal scale change here and elsewhere) and –1 MPa beneath fields 2 and 3 (fig. 6*C-D*) as well as the Amargosa-River channel (fig. 6*E*). The greater variation in water potential beneath field 1 presumably reflects the shorter period of irrigation. Conversely, the higher (less negative) and more uniform water potentials beneath fields 2 and 3 and beneath the Amargosa-River channel reflect longer periods of deep percolation during which the sediments have reached nearly constant water potentials associated with quasi-steady fluxes.

Figure 6A *Figure 6B* *Figure 6C* *Figure 6D* *Figure 6E*

Water contents showed the same general patterns as water potentials, with higher variations that reflected textural heterogeneities. Gravimetric water contents beneath the undisturbed area of native vegetation were generally less than 0.07 g/g (mass of water per mass of dry soil) (fig. 6*A*). Many samples were drier than 0.05 g/g. The water content beneath fields 1 and 2 were generally much higher, but exhibited considerable variation (fig. 6*B&C*). Higher water contents correlated with higher amounts of fine-grained sediments (appendices A and B). The water content beneath field 3 (fig. 6*D*) was slightly higher than that beneath fields 1 and 2, consistent with its higher irrigation rate. Water contents beneath the Amargosa-River channel were similarly elevated (fig. 6*E*). Water contents were more uniform than in the Farms area, reflecting more uniform sediments at channel sites. The elevated, uniform water contents are further evidence of active deep percolation beneath the channel.

Chloride, nitrate, and sulfate

As previously mentioned, measured nitrite concentrations in all profiles were generally below detection thresholds, except near land surface in irrigated fields (appendix B). Nitrite is clearly taken up by plants or converted to other nitrogen forms before exiting the root zone. The lack of nitrite beneath the root zone is consistent with models showing that, absent high levels of ammonia, nitrite is readily converted to other forms of nitrogen at shallow depths (Smith and others, 1997).

At the undisturbed native-vegetation site, chloride, nitrate, and sulfate showed similarly shaped concentration profiles with large accumulations (bulges) just below the root zone (AFCA1, fig. 6*A*). The chloride bulge is similar to that found in sediments at the ADRS (Prudic, 1994) and is a common feature beneath the roots of desert vegetation in the western United States (Phillips, 1994; Murphy and others, 1996). Chloride bulges have been attributed to a major change in climate from cooler and wetter (pluvial) conditions to the hot and dry conditions prevailing today. Low precipitation during the Holocene led to a succession of xerophytes efficient at extracting soil moisture, minimizing percolation below the root zone and initiating the accumulation of chloride (Phillips, 1994; Walvoord, Plummer, and others, 2002; Walvoord, Phillips, and others, 2002). The change from pluvial to arid conditions in the Amargosa Desert may have started as early as 18,000–20,000 years ago on the basis of vegetational changes at the Nevada Test Site (Spaulding, 1985) and the sudden decline in water level at Devils Hole (Szabo and others, 1994; fig. 2). High stands of nearby ancient lakes (Mojave, Manly, and Tonopah), however, suggest that the most recent pluvial conditions in the area culminated about 9,000 to 11,000 years ago (Grayson, 1993; Ettinger, 2002).

Peaks in chloride concentrations beneath field 1 were measured at depths of about 9 m in borehole AFCA2 and 13 m in borehole AFCA3 (fig. 6*B*). These peaks suggest that deep percolation from irrigation water is moving previously accumulated chloride from just below the root zone to greater depths. Deep percolation since conversion to cultivation, 7.7 years prior to sampling, has been insufficient to flush the accumulated salts from the sampled profile. The concentrations of chloride, nitrate, and sulfate at AFCA3 were generally lower than at AFCA2, implying greater percolation at AFCA3 (assuming both profiles prior to irrigation were similar to the profile at AFCA1). Although sediments at AFCA1, AFCA2, and AFCA3 are similar, AFCA3 lies on the projection of a distributory channel of Fortymile Wash (visible in fig. 2). Chloride, nitrate, and sulfate may not have accumulated as much at AFCA3 as elsewhere due to past flows in this channel.

Chloride concentrations beneath the root zone in field 2 (AFCA4 and AFCA5, fig. 6*C*) were nearly uniform except for a peak at 0.8 m depth in AFAC5, indicating that deeply percolating irrigation water has flushed the presumed pre-irrigation chloride bulge from the profile. Sub-root-zone nitrate concentrations beneath irrigated fields and the Amargosa-River channel were generally lower than chloride concentrations at comparable depths, except for an interval in the field-2 profiles (AFCA4 and AFCA5) at a depth of about 8 m, where nitrate concentrations were more than twice the chloride concentrations. AFCA4 revealed a nitrate peak in the 8.3 to 9.8-m interval. Similarly, AFCA5 revealed a nitrate peak in the 6.9 to 8.3-m interval (fig. 6*C*, appendix C). These peaks are presumably due to the liquid fertilizer applied in 1992, when the field was brought back into production.

Near the center of field 3, at AFPL2, chloride, nitrate and sulfate concentrations decreased to low, nearly constant values below 3 m (fig. 6*D*). Chloride concentrations in the interior of the field (AFPL2) were less than 25 mg/L at depths greater than 5 m. In contrast, chloride concentrations near the edge of the field (AFPL1) were similarly low near land surface, but increased sharply between 10 and 12 m before dropping again at greater depths (fig. 6*D*). Nitrate and sulfate showed similar patterns. The elevated anion concentrations in the deep profile at AFPL1 occurred just above a semi-indurated layer overlying the volcanic ash (appendix A). The semi-indurated and ash layers clearly impeded downward flow. The overall pattern is consistent with stratigraphically induced lateral flow towards drier sediments beyond the edge of the field. High concentrations of sulfate in the upper 2 m were consistent with the periodic application of gypsum to field 3. Sulfate levels at depths greater than 2 m were no higher in field 3 than in fields 1 and 2, where gypsum was not applied, suggesting almost complete consumption in the root zone.

Profiles of chloride, nitrate, and sulfate beneath the Amargosa-River channel (ARRB1 and ARAS1) showed no accumulation of salts in the 1–6-m depth interval (fig. 6*E*). Channel profiles contrasted sharply with profiles beneath the undisturbed vegetated site (fig 6*A*). Chloride profiles beneath the river channel were much closer in shape to profiles beneath the roots of irrigated crops. Sub-root-zone chloride, nitrate, and sulfate concentrations at ARRB1 were relatively low and uniform throughout the profile. Similarly, sub-root-zone chloride, nitrate, and sulfate concentrations at ARAS1 were relatively low through most of the profile; however, sulfate concentrations increased sharply at about 7 m and reached a peak at about 8 m (fig. 6*E*). Similarly, nitrate concentrations at ARAS1 increased below 10 m, and chloride concentrations increased below 11 m. This suggests that the active channel at ARAS1 moved to its current location relatively recently. The sharp increases in sulfate, nitrate, and chloride concentrations all suggest downward displacement of previously accumulated near-surface salts at ARAS1. The overall pattern is similar to that revealed, for example, by AFCA2 in field 1 (fig. 6*B*). The pattern also suggests higher mobility for chloride than for nitrate and sulfate, with sulfate being retarded somewhat more than nitrate.

Cumulative Water and Cumulative Chloride

Cumulative water

Cumulative water was estimated for each hole by summing the product of gravimetric water content and bulk density for each depth interval starting at land surface, assuming that the water content of individual samples represented the entire interval defined by midpoints between samples (fig. 7). The bulk density of sediments in the Amargosa-Farms area and the upper 2 m at ARRB1 ranged from 1.5 to 1.7 Mg/m^3 on the basis of similar sediments at the ADRS from 0 to 2 m and 6 to 8 m (Fischer, 1992, p. 21). A value of 1.6 Mg/m^3 was assigned to these sediments. Similarly, the poorly sorted sediments below 2 m at ARRB1 were assigned a bulk density of 1.7 Mg/m^3 on the basis of similar sediments at the ADRS at depths of 2 to 5 m and 9 to 14 m (Fischer, 1992, p. 21).

Figure 7

As previously discussed, sediments beneath undisturbed native vegetation in the Amargosa-Farms area (AFCA1) were relatively dry. Irrigation and ephemeral flows have increased the volume of water in sediments underlying the cultivated fields and the Amargosa channel. Profiles beneath the cultivated fields and channel contained greater than 0.125 m (m^3/m^2) more water in the 0 to 14 m interval than corresponding profiles beneath native vegetation (fig. 7*A*). Of the irrigated fields, the profile with the highest cumulative water was near the center of field 3 (AFPL2). This is not surprising, given that field 3 has the highest application rate and longest history of irrigation. The cumulative water beneath the channel sites is slightly higher than beneath irrigated fields, despite lower estimates of cumulative infiltration. Channel infiltration may be more efficient at increasing the water content of the profile due to the lower evapotranspiration from the channel as compared to irrigated fields. Vegetation that invades the channel between flows tends to be stripped away in subsequent flows. Because channel vegetation is sparse and small to non-existent, transpiration losses are relatively low. Furthermore, flows generally occur during cool, humid periods. Evaporation losses from the channel are therefore relatively smaller than evaporation losses from irrigated fields.

The high amounts of cumulative water beneath the irrigated fields and Amargosa-River channel, relative to undisturbed native vegetation, together with the nearly linear profiles, support the idea that irrigation and ephemeral flows are sufficient to sustain quasi-steady, deep percolation beneath the zone of evapotranspiration. Departures from linearity in the cumulative-water profiles (mainly inflections), as well as differences between members of replicate profile pairs, primarily represent textural heterogeneities.

For example, the cumulative water at both sampling locations in field 1 (AFCA2 and AFCA3) is nearly the same to a depth of 6 m (fig. 7*A*). From 6 to 9 m, more water is stored at AFCA2 than at AFCA3. Below 9 m, however, the sediments at AFCA2 become drier, so that by 12 m both profiles have about the same cumulative water. Similarly, in field 2, the cumulative volume of water to 10 m depth is about the same at AFCA4 as at AFCA5 (fig. 7*B*) even though there are different intervals of wetter and drier sediments in each profile. Note, however, that in field 3 the volume of water is consistently greater near the center (AFPL2) than near the edge of the field (AFPL1). The lower volume of water near the edge of the field may be affected by lateral movement towards dry sediments beyond the field.

Cumulative chloride

Profiles of cumulative chloride in the sampled locations were estimated by summing the product of chloride concentration and water content for each interval, starting at the land surface (fig. 8). Profiles beneath native vegetation had little chloride in the upper meter, followed by large amounts of chloride in the 1 to 6-m interval (AFCA1) and 1 to 8-m interval (ADRS), followed by little additional chloride at greater depths (fig. 8*A*). These profiles are consistent with observations that in areas of undisturbed creosote plants, most precipitation penetrates to depths of less than 1-m before returning to the atmosphere as evapotranspiration (Fischer, 1992; Andraski, 1997). Chloride accumulates just below the root zone because virtually all of the liquid water that penetrates this zone returns to the atmosphere as vapor (Andraski, 1997; Johnson and others, 2002; Walvoord, Phillips, and others, 2002).

Figure 8

Cultivation of field 1 since 1993, when native creosote was replaced with irrigated crops, has displaced the chloride bulge to a depth of 6 m at AFCA2 and 11 m at AFCA3 (fig. 8*A*). The abrupt increase in chloride at the bottom of the sampled profile suggests almost piston-like displacement. According to this interpretation, the peak chloride concentration approximately represents the leading edge of deeply percolating irrigation-return flow. Lower water contents in underlying sediments at AFCA2 support this interpretation (fig. 6*A*). As already mentioned, differences between profiles at AFCA2 and AFCA3 indicate that deep percolation is not uniform across the field.

Cumulative chloride profiles beneath fields 2 and 3 suggest that the presumed pre-irrigation chloride bulges have been flushed below the bottoms of the boreholes except near the edge of field 3, at AFPL1 (fig. 8*B*). Rather than representing a bulge that moved directly downward from above, this bulge may represent chloride that initially moved downward closer to the center of the field. Flow at the depth of the bulge may be principally horizontal due to diversion by the underlying semi-indurated sediments just above the ash, as already explained.

The cumulative-chloride profiles beneath the two Amargosa-channel sites, while similar, reveal significant differences at depth (fig. 8*A*). Chloride at ARRB1 accumulates linearly with depth throughout the profile, suggesting long-established fluxes of chloride (and water) beneath the channel. Chloride at ARAS1 also accumulates linearly to 11 m depth, although the rate of accumulation is slightly lower than at ARRB1. The rapid increase in chloride below 11 m at ARAS1 suggests that initiation of deep percolation was relatively recent (fig. 8*A*). The present location of the active channel at ARAS1 was probably established during the 1969 flood (table 3). This flood produced ample flow to cause channel migration. Aerial photographs support this idea, showing the active channel in 1948 about 0.5 km east of its present location at ASAR1. In contrast, the active channel at ARRB1 was in its present location in 1948. Photos taken since the 1969 flood show the active channel in its current location at both sites.

Cumulative chloride versus cumulative water

The non-linear relation between accumulated chloride and accumulated water beneath native vegetation shows a steep buildup of chloride in the shallow unsaturated zone followed by little additional chloride at greater depths (fig. 9). This pattern is indicative of extremely low sub-root-zone water fluxes and is typical of arid sites in the western United States where salts have been accumulating since the last pluvial period (Phillips, 1994; Murphy and others, 1996). Of the profiles showing evidence of deep percolation (that is, the profiles beneath irrigated fields and the Amargosa-River channel) only the profiles beneath field 2 (AFCA4 and AFCA5), the center of field 3 (AFPL2), and the upstream site on the Amargosa River (ARRB1) show a simple linear increase in cumulative chloride with cumulative water content. A simple linear increase is consistent with the assumptions of equation 1. Profiles at the other sites with active deep percolation all show a break in slope at one or more depths, suggesting that the initiation of deep percolation was sufficiently recent that accumulated salts, while displaced downward, still remain in the measured profile.

Figure 9

Estimated Rates of Deep Percolation

Beneath native vegetation

The accumulation of large amounts of nitrate, chloride, and sulfate just below the root zone at AFCA1 (fig. 6*A*) indicates little to no deep percolation of present-day precipitation. The time needed to accumulate the 570 g/m^2 of chloride between the land surface and 6.2 m at AFCA1 (fig. 8) ranges from about 8,000 to 14,000 years, assuming that average annual atmospheric chloride deposition from precipitation and dryfall ranges from 0.04 to 0.07 g/m^2. The accumulation of chloride is larger at the ADRS than at AFCA1. With the same annual chloride deposition, the time needed to accumulate the 2,580 g/m^2 of chloride between land surface and 7.8 m at the ADRS (fig. 8) ranges from about 36,000 to 60,000 years. As discussed in the section on uncertainty, projecting present-day estimates of chloride deposition rates thousands of years into the past involves errors that are hard to quantify. Neither precipitation nor chloride-deposition rate has likely remained constant for millennia. Nevertheless, even if the current atmospheric chloride-deposition rate was tripled , the time needed to accumulate the observed chloride budges would still be at least 2,700 years at AFCA1 and 12,000 years at the ADRS. The observed sub-root-zone accumulations of chloride beneath undisturbed native vegetation in the Amargosa Desert support previous studies that concluded that there has been little to no deep percolation at the Nevada Test Site for thousands of years (Tyler and others, 1996; Walvoord, Plummer, and others, 2002; Walvoord, Phillips, and others, 2002).

The difference in accumulation at AFCA1 and the ADRS may indicate a longer period with little to no deep percolation at the ADRS. The ADRS is located on an older geomorphic surface that is elevated with respect to the current floodplain of the Amargosa River. Its elevated position may be such that increased precipitation alone during the last pluvial period was insufficient to flush accumulated salts from the sediments. In contrast, AFCA1 is located on a younger, low-lying geomorphic surface near the confluence of Fortymile Wash and the Amargosa River (fig. 1; Slate and others, 2000). Sediments in this area have slowly been accumulating for at least the last 650,000 years, as indicated by the volcanic ash found beneath field 3 (AFPL2; appendix A). Flushing of accumulated salts in the Farms area by deep percolation from runoff in Fortymile Wash as well as the Amargosa River during the most recent pluvial period(s), after the ADRS surface was elevated, might explain the lower amount of accumulated salts at AFCA1. Deep percolation from repeated surface inundations may be required to remove (or prevent) salt accumulations beneath xeric vegetation.

Pore water beneath native vegetation at depths well below the chloride bulges probably represents relict recharge from pluvial times (Tyler and others, 1996). Modeling studies suggest that the concentration of chloride in deep pore water may be little changed since pluvial times, (Walvoord, Phillips, and others, 2002). Thus, an estimate of (paleo-) ground-water recharge rates could be derived if rates of infiltration and chloride deposition during pluvial times were known. While estimates of precipitation and temperatures for pluvial conditions exist (Spaulding, 1985; Grayson, 1993, p. 126), corresponding paleo-chloride-deposition rates are highly speculative.

Isotopic evidence argues against preferential flow as an explanation for the dilute pore-water concentrations at depth. Oxygen-18 and deuterium values measured for unsaturated-zone pore water at the ADRS indicate evaporation of water from a source that is isotopically *lighter* than present-day precipitation, but similar to ground water (Prudic and others, 1997). If preferential flow were occurring (bypassing the chloride bulges), deep unsaturated zone water would have an isotopic composition *equal to or heavier than* modern precipitation (due to evaporative enrichment near land surface). Ground water at the ADRS has an unadjusted carbon-14 age of about 11 thousand years before present, consistent with a lack of present-day recharge (Stonestrom and others, 1999).

Beneath fields

Rates of deep percolation (D_p) beneath the root zones of irrigated crops in fields 1, 2, and 3 were estimated using the chloride-mass-balance method by summing the total chloride deposition from all sources (atmospheric, irrigation, and fertilizer) and dividing by the average chloride concentration in deep pore water. Chloride deposition in cultivated fields comes primarily from irrigation water, which supplied

12–16 g/m^2 to fields 1 and 2 and 16–22 g/m^2 to field 3, and secondarily from fertilizer, which supplied about 0.1 g/m^2 to fields 1 and 2 and 0.6–1 g/m^2 to field 3 (see previous section on chloride sources). Chloride from runoff and atmospheric deposition were negligible in comparison. Average pore-water chloride concentrations at depth were determined for each profile in the irrigated fields. The interval over which the pore-water chloride concentration was averaged, hereinafter called the transmission zone, was limited to the linear portion of the cumulative water versus cumulative chloride curve (this portion being consistent with the application of equation 1). Ranges of annual chloride deposition, average transmission-zone chloride concentrations, and deep-percolation estimates are summarized in table 4.

Table 4

Chloride-mass-balance rates of deep percolation for field 1 ranged from 0.10 to 0.14 m/yr at AFCA2 and 0.17 to 0.23 m/yr at AFCA3 (table 4). Similar variability beneath an irrigated field in Australia was reported by Cook and others (1989). The higher chloride-mass-balance rates for AFCA3 were consistent with the greater depth of displacement of the chloride bulge (to 13.3 m at AFCA3 versus 8.9 m at AFCA2; fig. 6*B*). Assuming that at AFCA2 the center of mass of chloride moved from a depth of 1.8 m (on the basis of AFCA1) to 8.9 m in 7.7 years, the rate at which the chloride bulge moved through the sediments was about 0.9 m/yr. Multiplying this rate times the average water content (0.21 m^3/m^3) in the transmission zone (1.8 to 8.9 m, table 4) yields a rate of deep percolation of 0.19 m/yr. Similarly, assuming that the chloride bulge at AFCA3 moved from 1.8 to 13.3 m in 7.7 years, the bulge velocity (1.5 m/yr) times the average water content in the transmission zone (0.20 m^3/m^3) yields a rate of deep percolation of 0.30 m/yr. Rates of deep percolation estimated from equation 2 using chloride-bulge velocities are 30 to 90 percent higher than the maximum rates of deep percolation from chloride-mass-balance (equation 1; table 4). Comparing the travel-time and chloride-mass-balance estimates provides a good measure of uncertainty because the methods are largely independent.

Chloride-mass-balance estimates of deep-percolation rates for field 2 ranged from 0.40 to 0.53 m/yr at AFCA4 and from 0.17 to 0.23 m/yr at AFCA5 (table 4). The higher rates beneath AFCA4 reflect generally lower chloride concentrations in the profile. Secondary peak concentrations of nitrate at depth in both holes (fig. 6*C*) are presumably from the application of liquid fertilizer when the field was put back into production, in 1992. The midpoint of the peak nitrate concentration at AFCA4 occurred at a depth of 8.9 m; the peak at AFCA5 occurred at 7.6 m (appendix C). Assuming that these nitrate peaks stemmed from surface applications in 1992, the average velocities of nitrate movement were about 1.0 m/yr in AFCA4 (9.2 m divided by 8.7 years) and 0.85 m/yr in AFCA5 (7.4 m divided by 8.7 years). Multiplying these velocities by the average water content in the transmission zone (0.16 m^3/m^3), yields rates of deep percolation of 0.17 m/yr at AFCA4 and 0.13 at AFCA5 (table 4). Nitrate-based estimates may be lower than chloride-based estimates partly due to adsorption on organics or biogeochemical cycling in the root zone (Jury and Nielsen, 1989; Tindall and others, 1995; Smith and others, 1997; Birkinshaw and Ewen, 2000). Conceivably, the nitrate bulges at depth could be from an application later than 1992, if nitrate from 1992 has moved entirely beyond the sampled depths.

Chloride-mass-balance estimates of deep-percolation rates for field 3 ranged from 0.25 to 0.33 m/yr at AFPL1 and from 0.28 to 0.38 m/yr at AFPL2 (table 4). The profile at AFPL1, near the edge of the field, included a chloride bulge at a depth of 11.5 m. As already discussed, no bulge was present in the interior of the field, at AFPL2 (fig. 6D). Relatively low chloride concentrations above the bulge at AFPL1 indicate that irrigation water has flushed the upper portion of the profile at the edge of the field, just as in the interior of the field. Sediments underlying the bulge (between 11.6 and 12.6 m) consisted of dense, calcite-cemented silty sediment that was difficult to sample (appendix A). This layer immediately overlies the volcanic ash (appendix A). The cemented layer has apparently induced lateral flow towards drier sediments beyond the edge of the field. The chloride bulge at the edge of the field probably represents high-chloride pore water being swept laterally from the interior of the field above the impeding layer, as opposed to a bulge being transported strictly vertically downwards. The center of the field would be flushed first, accounting for the lack of a chloride budge at AFPL2. One-dimensional downward movement of chloride at AFPL1, if it started in 1962, would imply an anomalously low deep-percolation rate of 0.04 m/yr (from equation 2 with $z_1 = 1.8$ m, $z_2 = 11.5$ m, $t_1 = 1962$, $t_2 = 2001$, and $\theta = 0.16$ m^3/m^3). However, the chloride bulge at AFPL1 does not appear to represent one-dimensional vertical flow. Because the actual travel distance is potentially much greater than the vertical offset, the travel-time estimate represents a lower bound.

For steady-state conditions, the time for irrigation water to reach a depth L is given by $t = (L\theta)/D_p$, where θ is the average water content in the transmission zone and D_p is the rate of deep percolation calculated from chloride-mass balance or displacement of chloride and nitrate bulges. Depth to ground water beneath the irrigated fields is about 35 m, on the basis of static water levels in the area (Kilroy, 1991). At current rates, assuming vertical one-dimensional flow, the time required for return flow to reach the water table is 23 to 70 years for the newest field (field 1), 11 to 43 years for field 2, and 12 to 19 years for field 3 (table 4). Although these return times are approximate, they suggest that after initiation of irrigation, water percolating below the root zone in the Amargosa-Farms area takes on the order of several decades to reach the water table.

Beneath the Amargosa-River channel

Rates of deep percolation (D_p) beneath the Amargosa-River channel were estimated by summing the chloride deposition from runoff and the atmosphere, and dividing the total deposition by the average chloride concentration in the transmission zone. Estimated chloride-mass-balance rates of deep percolation beneath the Amargosa-River channel range from 0.04 to 0.15 m/yr at ARRB1 and 0.02 to 0.08 m/y at ARAS1 (table 4). These rates exceed estimated vapor fluxes at the ADRS by several orders of magnitude (Andraski, 1997). Since the ADRS estimates are for drier sediments in which vapor fluxes will be relatively large, it is likely that nearly all deep percolation beneath the channel becomes ground-water recharge.

Chloride concentrations below 9.5 m were not included in the analysis of ARAS1 because the chloride bulge below this depth evidently represented a near-surface accumulation that began moving downward when the active channel moved to its current location during the 1969 flood. The rate of deep percolation, estimated from the displacement of the chloride bulge from an assumed depth of 1.8 m to the observed depth of 14.4 m in the 32 years since the flood, is 0.07 m/yr (table 4). The travel-time estimate lies within the range of rates estimated with the chloride mass-balance method (0.02 to 0.08 m/yr). Chloride bulges may occur at various depths in the vicinity of ARAS1, judging by the many inactive channels near this site. Along distributory reaches of ephemeral channels there may be many places where water has percolated to considerable depths but failed to reach the water table before the active channel shifted to a new location.

Estimated percolation rates beneath the Amargosa-River channel are relatively uncertain. Nevertheless, water-content, water-potential, and anion profiles all provide clear evidence that deep percolation is occurring beneath the channel because of ephemeral flow. The nearly constant anion concentrations at depth suggest that the assumptions of the chloride-mass-balance method are approximately satisfied (fig. 9, appendix C). Because the channel at ARRB1 is deeply incised into older sediments and evidently long established, moisture contents and percolation rates at depth have probably remained more or less constant for decades. Estimates of the time required for channel infiltration to reach the water table ranged from 140 to 500 years at ARRB1 and from 200 to 1000 years at ARAS1, assuming depth to ground water at both sites is approximately 100 m. This value is based on a measurement of 103 m in a well near the channel three kilometers west of the ADRS (W.D. Nichols, deceased, while with the U.S. Geological Survey, Carson City, Nev., unpub. data, 1985). The time required for channel infiltration to reach ground water may be somewhat higher due to the effects of lateral flow.

As a percentage of irrigation

The percentage of applied irrigation that percolates below the root zone, eventually returning to the water table, is simply the ratio of effective chloride concentration in irrigation water to chloride concentration in deeply percolating pore water (fig. 10). The concentration of chloride in deeply percolating pore water was calculated as the average value in the profile below the root zone (about 1 m) and above translocated bulges, where present (for example, in AFCA2 and AFCA3, fig. 6A). Effective chloride concentrations of irrigation water applied to fields 1, 2, and 3 averaged 6.9 mg/L (table 2).

Average transmission-zone chloride concentrations were 92 mg/L (field 1), 50 mg/L (field 2), and 45 mg/L (field 3) (table 4). Using these values, the percentage of return flow was 8 percent for field 1, 14 percent for field 2, and 16 percent for field 3. Differences correlate with irrigation histories. For example, field 3 had the longest duration and highest rate of irrigation, and hence had the highest percentage of return flow. The lower percentage for field 1 may be due in part to residual chloride from the translocated bulge that is still being flushed from the profile.

Figure 10

As a percentage of channel infiltration

The average concentration of chloride in transmission-zone pore water at the channel sites was 121 mg/L (ARRB1; 1–14 m) and 97 mg/L (ARAS1; 2–10 m) (table 4). Assuming that the concentration of chloride in runoff ranged from 9 to 15 mg/L, 7 to 12 percent of the water infiltrating into the channel became deep percolation at ARRB1 and 9 to 15 percent at ARAS1. The greater percentage of infiltration becoming deep percolation at ARAS1 is consistent with the better sorting and lack of fine sediments at this site (appendix A). The percentage of deep percolation is less certain for the Amargosa-River sites than for the irrigated fields due to the lack of data on flow frequency and chemical composition of runoff.

SUMMARY AND CONCLUSIONS

Ground water from the Nevada Test Site and Yucca Mountain flows toward areas of discharge in the Amargosa Desert and adjacent Death Valley. The potential for subsurface transport of radionuclides from areas of past underground weapons testing on the Nevada Test Site and from a proposed repository for high-level radioactive waste at Yucca Mountain is being evaluated using ground-water flow and transport models. Necessary inputs for these models include estimates of ground-water recharge and discharge rates. These rates include ground-water withdrawals and associated return flows in irrigated areas as well as deep percolation beneath stream channels and areas of native vegetation. The purpose of this study was to estimate and compare rates of deep percolation in the Amargosa Desert for areas of native vegetation, cultivated fields, and the Amargosa-River channel. Rates of deep percolation were evaluated using the chloride-mass-balance method, where applicable, and transport velocities of chloride and nitrate markers, where available.

Located between Death Valley and the Nevada Test Site, the Amargosa Desert is one of the driest regions in the United States. Annual precipitation at Amargosa Farms, about 20 km from the Nevada Test Site, averaged 113 mm from 1966 through 2001. Irrigation began in 1917. Under current practices, fields are irrigated continuously from February through November. Stream channels in the Amargosa Desert are almost always dry; nevertheless, storm runoff occasionally causes flow. The Amargosa River has flowed uninterrupted from its headwaters on and around the Nevada Test Site to its distal end in Death Valley at least twice since 1995.

Nine boreholes 10-16 m deep were cored nearly continuously using a hollow-stem auger designed for gravelly sediments. One hole was drilled in an undisturbed area of native vegetation. Two holes were drilled in each of three irrigated fields with contrasting irrigation histories. Two holes were drilled in the Amargosa-River channel, about 21 and 33 km northwest of the irrigated fields. Water content and chloride data from a previously drilled borehole beneath undisturbed vegetation, 27 km northwest of the farms area, were compared with data from the new boreholes to provide information on spatial variability. Comparing profiles beneath native vegetation with their irrigated counterparts allowed evaluation of the effects of converting native vegetation to agriculture.

Sediments beneath irrigated fields in the Amargosa-Farms area consist almost entirely of interbedded layers (each less than 2 m thick) of moderately sorted sand and gravel separated by layers of well sorted sand and sandy silt. A layer of volcanic ash at 13.5–13.8 m beneath one of the irrigated fields was identified as the Lava Creek B ash from a caldera eruption in the Yellowstone-Park area about 650,000 years ago. This implies that the Amargosa-Farms area has been accumulating sediments at a net rate of about two meters per 100,000 years (0.02 mm/yr) during the latter half of the Quaternary. The nature of the sediments beneath the channel at the two Amargosa-River borehole locations differed considerably. Sediments through most of the profile at the upstream site were moderately weathered, poorly sorted mixtures of sand, gravel, silt, and clay; sand and gravel being dominant. The channel was incised at least two meters into the surrounding surface, suggesting long-term stability of the existing channel location. Sediments at the downstream site were unweathered, moderately sorted sand and gravel. The channel here was minimally incised and part of a network of shallow indistinct channels, suggesting active migration of the channel during large floods.

Vertical profiles beneath native vegetation were characterized by large amounts of accumulated chloride just below the root zone with almost no further accumulation at greater depths. This pattern is typical of profiles beneath interfluvial areas in the southwestern United States and other arid regions where salts have been accumulating since at least the last pluvial period. Chloride profiles beneath the older fields (irrigated since the early 1960's) as well as the upstream Amargosa-River site were indicative of long-term, quasi-steady, deep percolation. Chloride profiles beneath the newest field (irrigated since 1992) and the downstream Amargosa-River site were indicative of recently active deep percolation moving previously accumulated salts from the upper profile to greater depths. The volume of water in sediments beneath irrigated fields and the Amargosa-River channel was much higher than beneath native vegetation, consistent with active deep percolation beneath these sites.

Estimated rates of deep percolation beneath irrigated fields ranged from 0.1 to 0.3 m/yr beneath the newest field (field 1) and 0.1 to 0.5 m/yr beneath the two older fields (fields 2 and 3). Assuming that current rates continue into the future and assuming vertical, one-dimensional flow, the estimated time for irrigation-return flow to reach the 35-m deep water table beneath the irrigated fields is 11 to 43 years for the older fields and 23 to 70 years for the newest field. Estimated rates of deep percolation beneath the Amargosa-River channel ranged from 0.02 to 0.08 m/yr at the downstream site and from 0.04 to 0.15 m/yr at the upstream site. The lower rate at the downstream site is attributable to fewer flows of shorter duration. The estimated time for water to reach the roughly 100-m deep water table beneath the channel ranged from 200 to 1000 years at the downstream site and 140 to 500 years at the upstream site. These values represent minimum times, as they do not take lateral flow into account. The estimated fraction of irrigation water becoming deep percolation averaged 8 percent for the newest field, 14 percent for the oldest field (field 2), and 16 percent for the field with the highest irrigation rate (field 3). The percentages are based on the ratio of chloride concentration in the applied irrigation water to the chloride concentrations in the sediments beneath the root zone and above any translocated chloride accumulations. The estimated fraction of channel infiltration becoming deep percolation at the Amargosa-River sites ranged from 9 to 15 percent at the downstream site and from 7 to 12 percent at the upstream site.

Low water contents and the accumulation of large amounts of chloride within a few meters of land surface indicate that precipitation has been insufficient to cause deep percolation beneath areas of undisturbed native vegetation for thousands of years. In contrast, high water contents, low water potentials, and low chloride concentrations suggest focused recharge and deep percolation beneath irrigated fields and the active channel of the Amargosa River. Estimates of deep-percolation rates were better constrained for irrigated fields than for the Amargosa-River channel, because the amount and composition of infiltrating water was better constrained for irrigation than for ephemeral flow. Variations in deep-percolation rates for individual fields were ascribed mainly to heterogeneities in sediment properties. Due not only to these variations, but also to conceptual inaccuracies, estimates of deep percolation are somewhat uncertain even for the irrigated fields. Nevertheless, tracer-based calculations uniformly suggest that between 8 and 16 percent of applied irrigation water becomes deep percolation beneath the irrigated fields. On the basis of available data, an approximately equal percentage of channel infiltration from ephemeral flow becomes deep percolation beneath the normally dry channel of the Amargosa River.

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Table 1. Location, land-surface altitude, depth, and brief description of holes used in study, Amargosa Desert, Nye County, Nevada

Drill Hole or Site Designation[1]	West Longitude[2]	North Latitude[2]	Land-Surface Altitude[3] (meters)	Hole Depth[4] (meters)	Date Drilled (yyyy/mm/dd)	Brief Description	General Location[1]
AFCA1	116°31’34”	36°33’56”	724	15	2001/02/21	Undisturbed area, native vegetation	North of Field 1, Amargosa Farms
AFCA2	116°31’34”	36°33’53”	723	12	2001/02/22	Newest field, continuously irrigated	Field 1, Amargosa Farms
AFCA3	116°31’39”	36°33’44”	722	15	2001/02/22	Newest field, continuously irrigated	Field 1, Amargosa Farms
AFCA4	116°31’35”	36°33’13”	719	10	2001/02/23	Oldest field, intermittently irrigated	Field 2, Amargosa Farms
AFCA5	116°31’57”	36°32’59”	717	10	2001/02/23	Oldest field, intermittently irrigated	Field 2, Amargosa Farms
AFPL1	116°29’23”	36°32’46”	717	15	2001/02/24	Older field, continuously irrigated	Field 3, Amargosa Farms
AFPL2	116°29’30”	36°32’39”	718	16	2001/02/25	Older field, continuously irrigated	Field 3, Amargosa Farms
ARRB1	116°45’09”	36°47’53’	889	14	2001/02/26	Incised river channel	Amargosa River, 13 km south of Beatty, Nev.
ARAS1	116°40’35”	36°42’47”	808	14	2001/02/27	Braided river channel	Amargosa River, 25 km south of Beatty, Nev.
ADRS[5]	116°41’37”	36°45’56”	847	48	1992/11/19	Undisturbed area, native vegetation	ADRS, 17 km south of Beatty, Nev.

[1] Borehole and other named locations shown on figures 1 and 2.

[2] Geographic coordinates referenced to North American Datum of 1927 (NAD27).

[3] Land-surface altitude referenced to sea level, estimated from U.S. Geological Survey 1:24,000-scale topographic maps, and reported to nearest meter.

[4] Hole depth referenced to land surface and reported to nearest meter.

[5] ADRS stands for the U.S. Geological Survey’s Amargosa Desert Research Site (Andraski and Stonestrom, 1999). Water-content and chloride data were composited from boreholes UZB1, IB1, and shallow hand-dug pits near UZB1 [Prudic, 1994]. Tabulated data are for borehole UZB1.

Table 2. Summary of chloride, sulfate, nitrate, and nitrite in precipitation, ground water and Amargosa-River water, Amargosa Desert, Nye County, Nevada

		Concentrations, in milligrams per liter			
Location shown on figure 2	Date Sampled	Chloride	Sulfate as SO_4	Nitrate as NO_3	Nitrite as NO_2
		Precipitation			
ADRS [1]	11/1997-11/2002	0.51	1.8	4.1	0.0
		Ground Water			
Field 1 [2]	02/25/2001	7.3	26	7.1	0.0
Field 2 [2]	01/25/2002	6.9	26	6.6	0.0
Field 2 [3]	01/25/2002	6.5	26	--[6]	--
Field 3 [4]	03/05/1974	6.6	33	7.0	--
Field 3 [2]	02/25/2001	7.0	27	7.1	0.0
Field 3 [2]	01/25/2002	6.9	32	7.4	0.0
Field 3 [3]	01/25/2002	7.0	32	--	--
Averages (± standard errors)		6.9 (± 0.1)	29 (± 1)	7.0 (± 0.1)	0.0 (± 0.0)
		Amargosa-River Water			
Ashton Site [5]	02/27/2001	15	26	41	0.0

[1] Effective chloride concentration in volume weighted precipitation for the period 11/19/1997 through 11/20/2002. Samples include dust that falls on collector, 1-meter above ground. Samples analyzed at U.S. Geological Survey research laboratory in Menlo Park, California.

[2] Ground-water sample analyzed at the U.S. Geological Survey research laboratories in Menlo Park, California.

[3] Ground-water sample analyzed at the U.S. Geological Survey Central Laboratory in Arvada, Colorado. Data available from National Water Information System (http://waterdata.usgs.gov/nwis/) under site identification numbers 363254116313901 (field 2) and 363237116292901 (field 3).

[4] Archived water-quality data analyzed at U.S. Geological Survey. Data available from National Water Information System (http://waterdata.usgs.gov/nwis/) under site identification number 363249116291900. Note that this site identification number refers to the same well as site identification number 363237116292901.

[5] Water sample collected February 27, 2001 at Ashton site on Amargosa River. Water from shallow pit excavated into streambed following brief flows that occurred just prior to drilling borehole ARAS1 on February 27. The perched water was gone shortly thereafter; by April the surface sediments were dry.

[6] Sample not analyzed for constituent.

Table 3. Documented peak-flow estimates exceeding 0.5 cubic meters per second, Amargosa River near Beatty, Nye County, Nevada for period of record (October 1963- September 2001)[1]

Location	Date	Peak discharge[2], in m^3/s
Highway bridge, 3 km south of Beatty, Nev.[3]	July 26, 1964	0.7
Highway bridge, 3 km south of Beatty, Nev.	Sept. 7, 1965	0.6
Highway bridge, 3 km south of Beatty, Nev.	Aug. 30, 1967	120
Highway bridge, 3 km south of Beatty, Nev.	Feb. 10, 1968	2.6
Airport road, 5 km south of Beatty, Nev.[4]	Feb. 24, 1969	450
Airport road, 5 km south of Beatty, Nev.	Sept. 10, 1975	12
Airport road, 5 km south of Beatty, Nev.	Feb. 1976	2.8
Airport road, 5 km south of Beatty, Nev.	March 1, 1978	18
Airport road, 5 km south of Beatty, Nev.	March 3, 1983	3.4
Airport road, 5 km south of Beatty, Nev.	March 21, 1987	1.7
Airport road, 5 km south of Beatty, Nev.	July 15, 1990	5.2
Highway bridge, 3 km south of Beatty, Nev.	March 21, 1991	0.5
Gage at Beatty, Nev.[5]	Jan. 25, 1995	0.8
Gage at Beatty, Nev.	Jan. 26, 1995	0.6
Gage at Beatty, Nev.	March 6,1995	2.7
Gage at Beatty, Nev.	March 11, 1995	28
Highway bridge, 3 km south of Beatty, Nev.	March 11, 1995	31
Gage at Beatty, Nev.	March 12, 1995	2.7
Gage at Beatty, Nev.	Feb. 4, 1998	0.6
Gage at Beatty, Nev.	Feb. 15, 1998	0.7
Gage at Beatty, Nev.	Feb. 23, 1998	2.6
Gage at Beatty, Nev.	Feb. 24, 1998	1.0
Gage at Beatty, Nev.	July 9, 1999	2.0
Gage at Beatty, Nev.	July 13, 1999	2.4
Gage at Beatty, Nev.	July 14, 1999	1.1
Gage at Beatty, Nev.	Aug. 10, 1999	0.6
Gage at Beatty, Nev.	Jan. 26, 2000	0.6
Gage at Beatty, Nev.	Feb. 21, 2000	0.9
Gage at Beatty, Nev.	Feb. 23, 2000	0.6
Gage at Beatty, Nev.	Feb. 24, 2000	0.9
Gage at Beatty, Nev.	March 6, 2000	0.6
Gage at Beatty, Nev.	March 9, 2000	0.9
Gage at Beatty, Nev.	Aug. 30, 2000	2.1
Gage at Beatty, Nev.	Jan. 11, 2001	0.9

[1] Data from: U.S. Geological Survey (no dates, surface water records for Nevada, 1964-66); U.S. Geological Survey (1968; 1969); Moosburner (1978); U.S. Geological Survey (1979, 1980, 1982a, and 1982b); Nichols (1987); Pabst and others (1993); Emett and others (1994); Kane and others (1994), Clary and others (1995); Bauer and others (1996); Bostic and others (1997); and Bonner and others (1998).

[2] Peak flows less than 0.5 m^3/s not listed. Annual peak flows only, October 1968 through September 1990. All peak flows (> 0.5 m^3/s), October 1990 through September 2001. Flow at the Beatty gage was perennial throughout the period of record but usually less than 0.1 m^3/s. Gages south of Beatty recorded no flow most of the time.

[3] Streamflow gage at Highway 95 bridge south of Beatty, Nevada (U.S. Geological Survey station number 10251218; 15-minute stage gage) operated from October 1963 through September 1968, and March 1991 through September 1995.

[4] Crest-stage gage at airport-access road, five kilometers south of Beatty, Nevada (U.S. Geological Survey station number 10251220) operated from October 1968 through September 1995.

[5] Streamflow gage at Beatty, Nevada (U.S. Geological Survey station number 10251217; 15-minute stage gage) was operated from August 1993 to April 1995, and January 1996 through September 2001. Since October 1998 the gage has operated with minimal maintenance. Accordingly, flow estimates after October 1998 are less accurate.

Table 4. Estimated rates of deep percolation from chloride and nitrate concentrations in pore water beneath irrigated fields in the Amargosa-Farms area and beneath the Amargosa-River channel, Amargosa Desert, Nye County, Nevada

Hole name[1]	Range in annual chloride deposition rate, grams per square meter[2]	Depth interval used in equation 1, meters below land surface[3]	Average chloride concentration in interval, grams per cubic meter	Rate of deep percolation (D_p) from chloride-mass balance, meters per year	Water content in transmission zone (θ), cubic meter per cubic meter[4]	Rate of deep percolation (D_p) from chloride or nitrate displacement, meters per year[5]	Estimated time for water to reach water table (t), years[6]
			Field 1 (Newest field; continuously irrigated)				
AFCA2	12 – 16	1.49 – 5.87	116	0.10 – 0.14	0.21	0.19 (Cl)	40 – 70
AFCA3	12 – 16	1.22 – 11.0	69	0.17 – 0.23	0.20	0.30 (Cl)	23 – 40
			Field 2 (Oldest field; intermittently irrigated)				
AFCA4	12 – 16	0.84 – 9.77	30	0.40 – 0.53	0.16	0.17 (N)	11 – 33
AFCA5	12 – 16	1.16 – 9.65	70	0.17 – 0.23	0.16	0.13 (N)	25 – 43
			Field 3 (Older field; continuously irrigated)				
AFPL1	17 – 22	0.87 – 9.86	48	0.25 – 0.33	0.16	--[7]	12 – 17
AFPL2	17 – 22	0.78 – 16.0	42	0.28 – 0.38	0.22	--	14 – 19
			Amargosa-River Channel (Intermittent; normally dry)				
ARRB1	5 – 18	1.14 – 14.4	121	0.04 – 0.15	0.21	--	140 – 500
ARAS1	2 – 8	1.60 – 9.53	97	0.02 – 0.08	0.18	0.07 (Cl)	200 – 1000

[1] Locations of holes are shown in figure 2.

[2] Annual chloride deposition rate includes sum of all sources described in section "Sources of Chloride, Nitrate, and Sulfate." For irrigated fields, the annual chloride deposition from atmosphere and runoff was assumed negligible. For Amargosa-River channel, annual chloride deposition from applied irrigation water and from application of fertilizers was zero.

[3] Depth interval used in averaging chloride concentrations; depths are from midpoint of 0.12-m long cores collected in each hole. Interval includes several cores.

[4] Average water content in interval used to estimate average chloride concentration except for those holes in which deep chloride bulge was observed. Water content in holes with deep chloride bulge was averaged to the peak concentration in deep chloride bulge. Average water content is arithmetic average of gravimetric water content from all samples in interval multiplied by a bulk density of 1.6 g/cm^3 except for samples below a depth of 2 m in ARRB1, which was multiplied by a bulk density of 1.7 g/cm^3.

[5] Rate of deep percolation using equation 2 and displacement of chloride bulges (Cl) found at depth in holes AFCA2, AFCA3, AFPL1, and ARAS1 and displacement of nitrate bulges (N) found at depth in holes AFCA4 and AFCA5. Chloride bulge beneath each site was originally assumed at a depth of 1.8 m, whereas nitrate was applied at land surface. Time since displacement began to when samples collected was 7.7 years at AFCA2 and AFCA3; 8.7 years at AFCA3 and AFCA4; 14 years at AFPL1; and 33 years at ARAS1.

[6] Time for irrigation return flow to reach a depth L is given by $t = (L\theta)/D_p$, where L is depth to water table beneath land surface, θ is average water content in transmission zone (see footnote 3), and D_p is rate of deep percolation (estimated from chloride-mass balance considerations and from downward displacement of chloride and nitrate peaks). Depth to water table beneath irrigated fields is approximately 35 m on basis of depth to water in wells (Kilroy, 1991). Depth to water table beneath Amargosa River at ARRB1 and ARAS1 is about 100 m on basis of depth to water in well near channel, ~3 km west of the ADRS (fig. 1; W.D. Nichols, 1985, U.S. Geological Survey, written commun.).

[7] Not applicable.

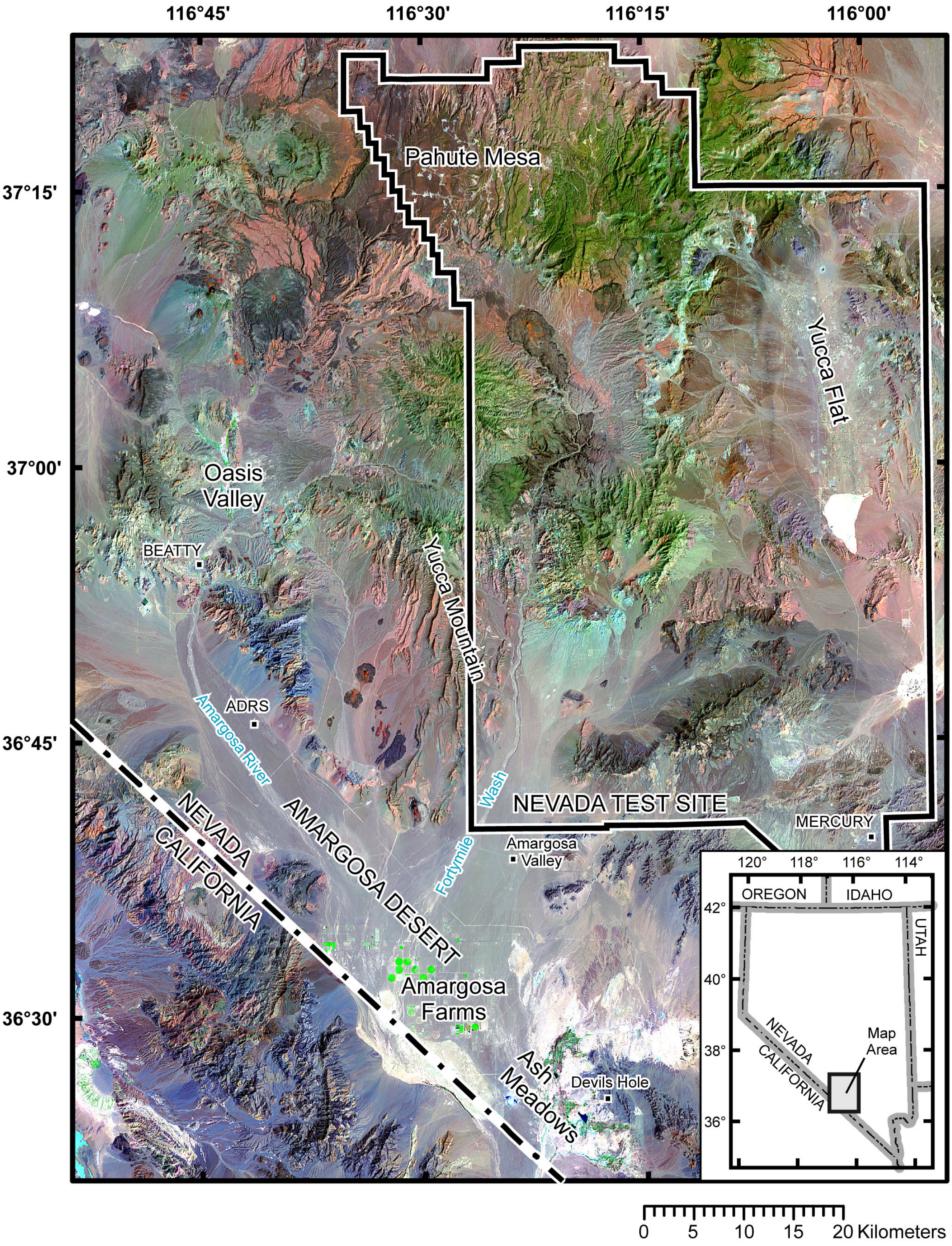

Figure 1. Amargosa Farms, the Amargosa River, and other features in the Amargosa Desert and vicinity, Nye County, Nevada and Inyo County, California. ADRS is the Amargosa-Desert Desert Research Site (Andraski and Stonestrom, 1999).

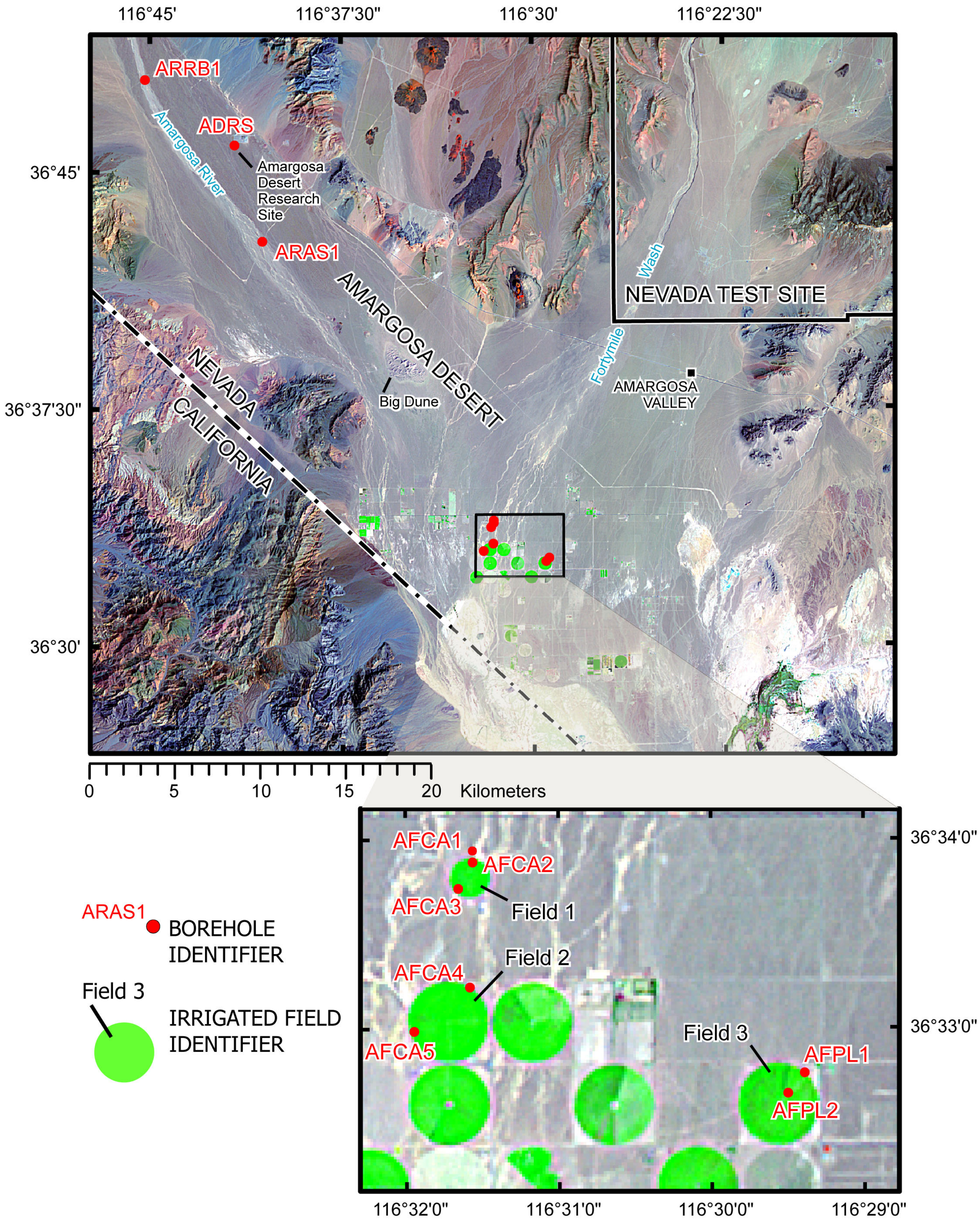

Figure 2. Locations of boreholes in the Amargosa-Farms area, the Amargosa-River channel, and at the Amargosa Desert Research Site, Nye County, Nevada.

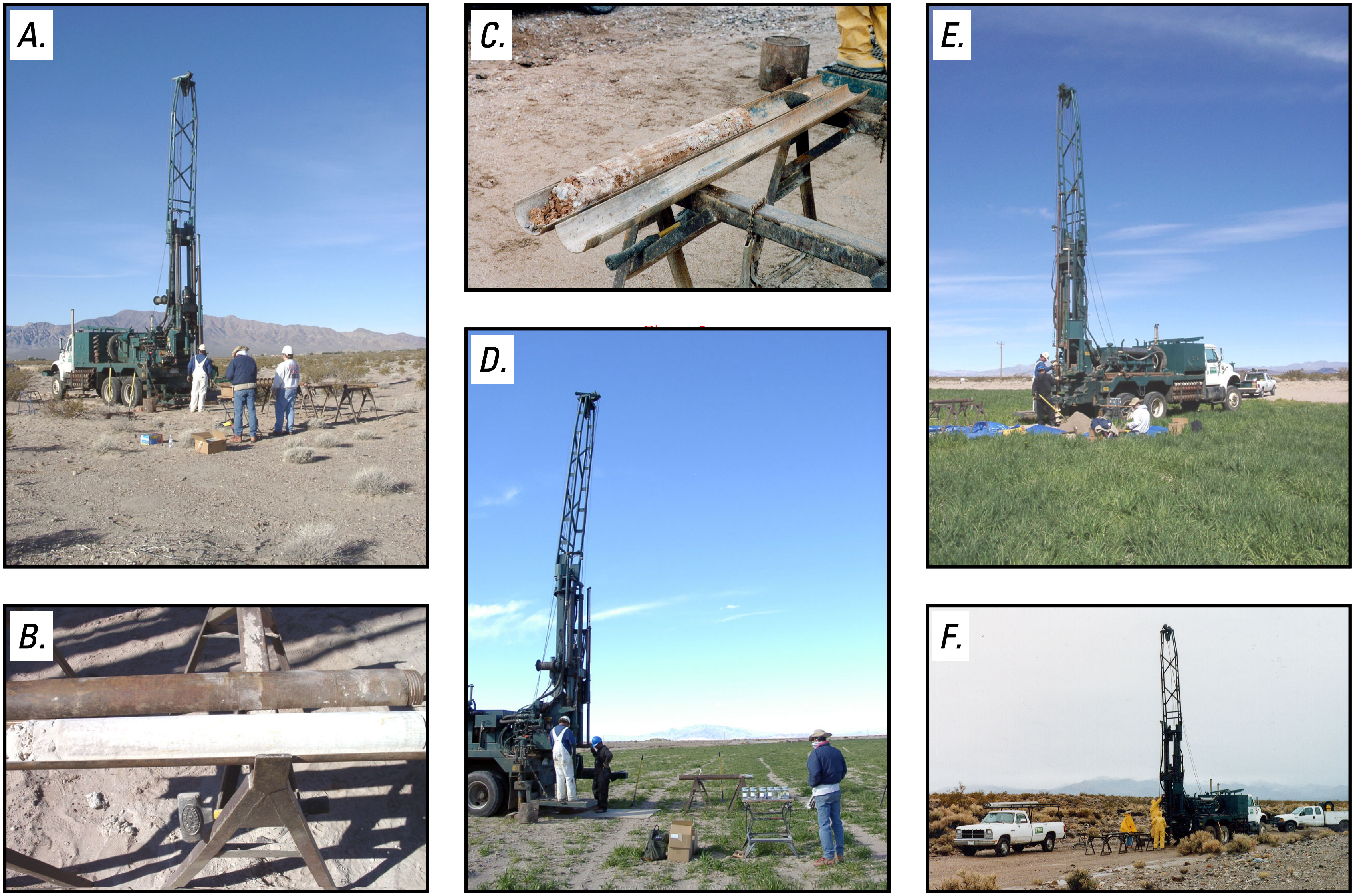

Figure 3. Photographs of drilling and sampling during February 2001 in the Amargosa-Farms area and Amargosa-River channel, Amargosa Desert, Nye County, Nevada. (A) Drilling AFCA1 at the native-vegetation site; (B) core from AFCA1; (C) core from river-channel site (borehole ARRB1); (D) drilling AFCA4 (Field 2, irrigated intermittently since the 1960's); (E) drilling AFPL1 (Field 3, irrigated continuously since the 1960's; and (F) drilling ARRB1 (Amargosa-River channel). See fig. 2 for locations.

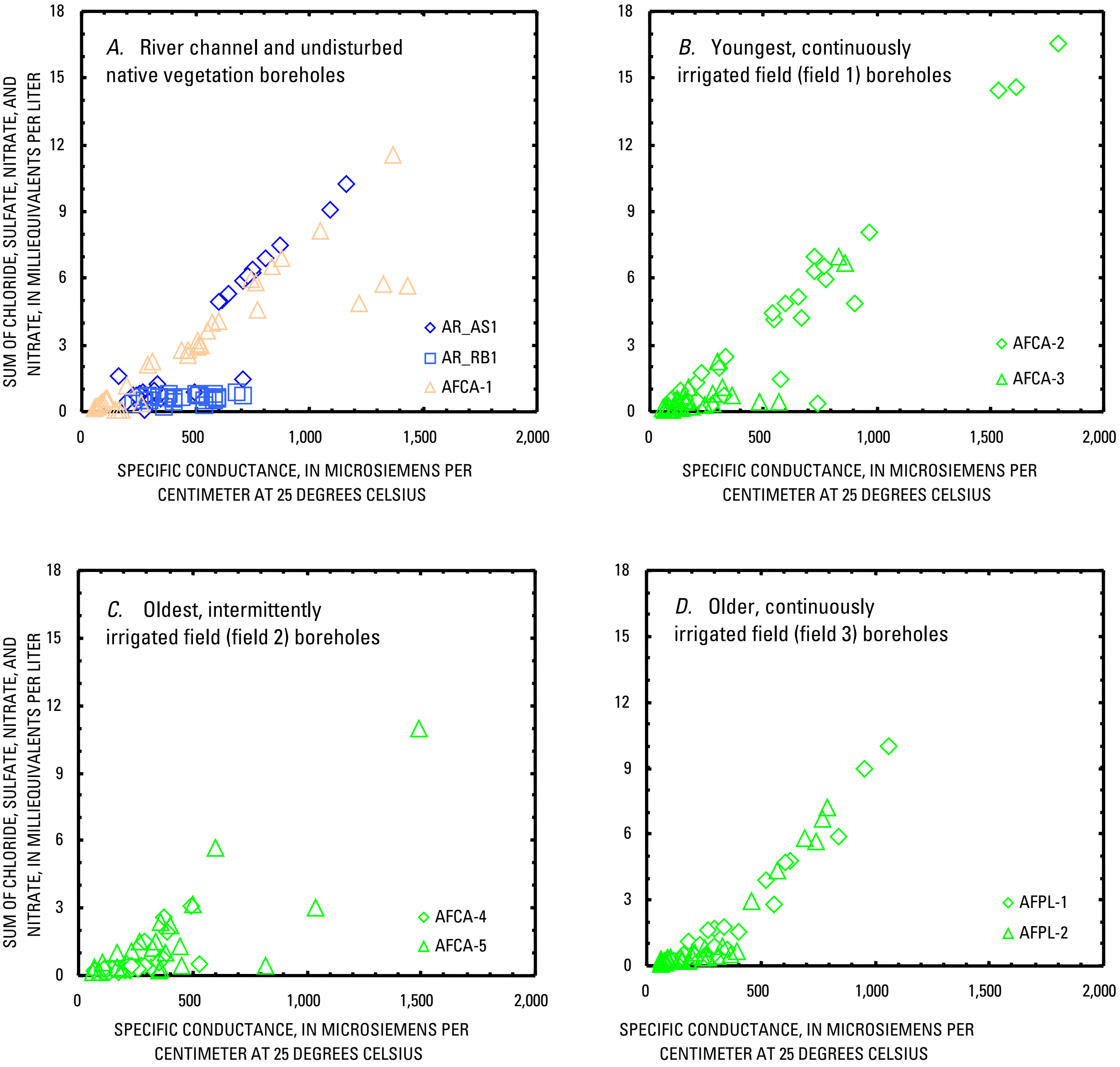

Figure 4. Relation between specific conductance and the sum of chloride, sulfate, nitrate, and nitrite in water extracts from core samples collected from boreholes in the Amargosa Desert, Nye County, Nevada. See fig. 2 for locations.

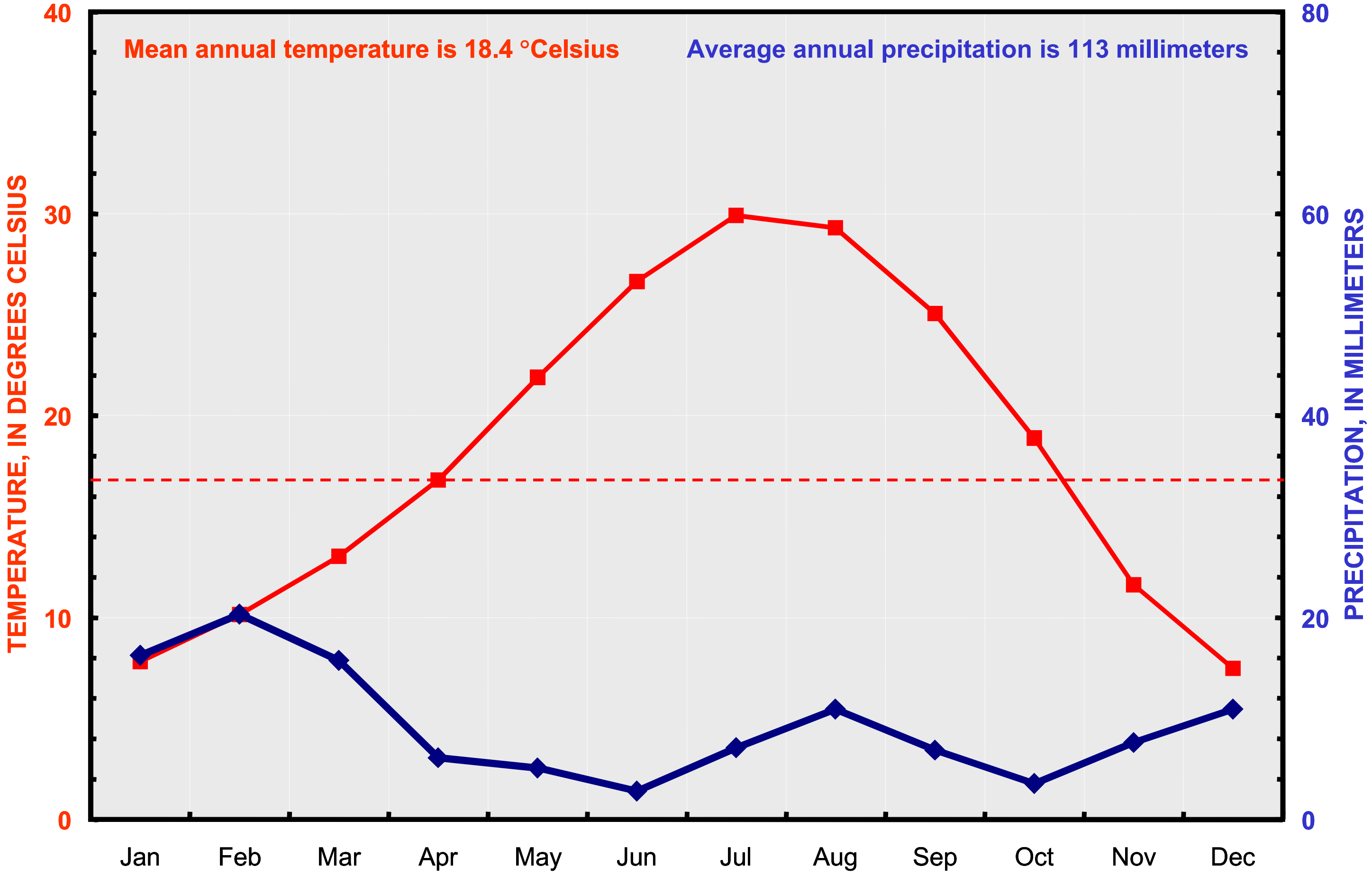

Figure 5. Mean monthly temperature and precipitation for December 1965 – December 2001, Amargosa Desert, Nye County, Nevada. Data are from National Weather Service (NWS) Amargosa Farms Garey Cooperative Station.

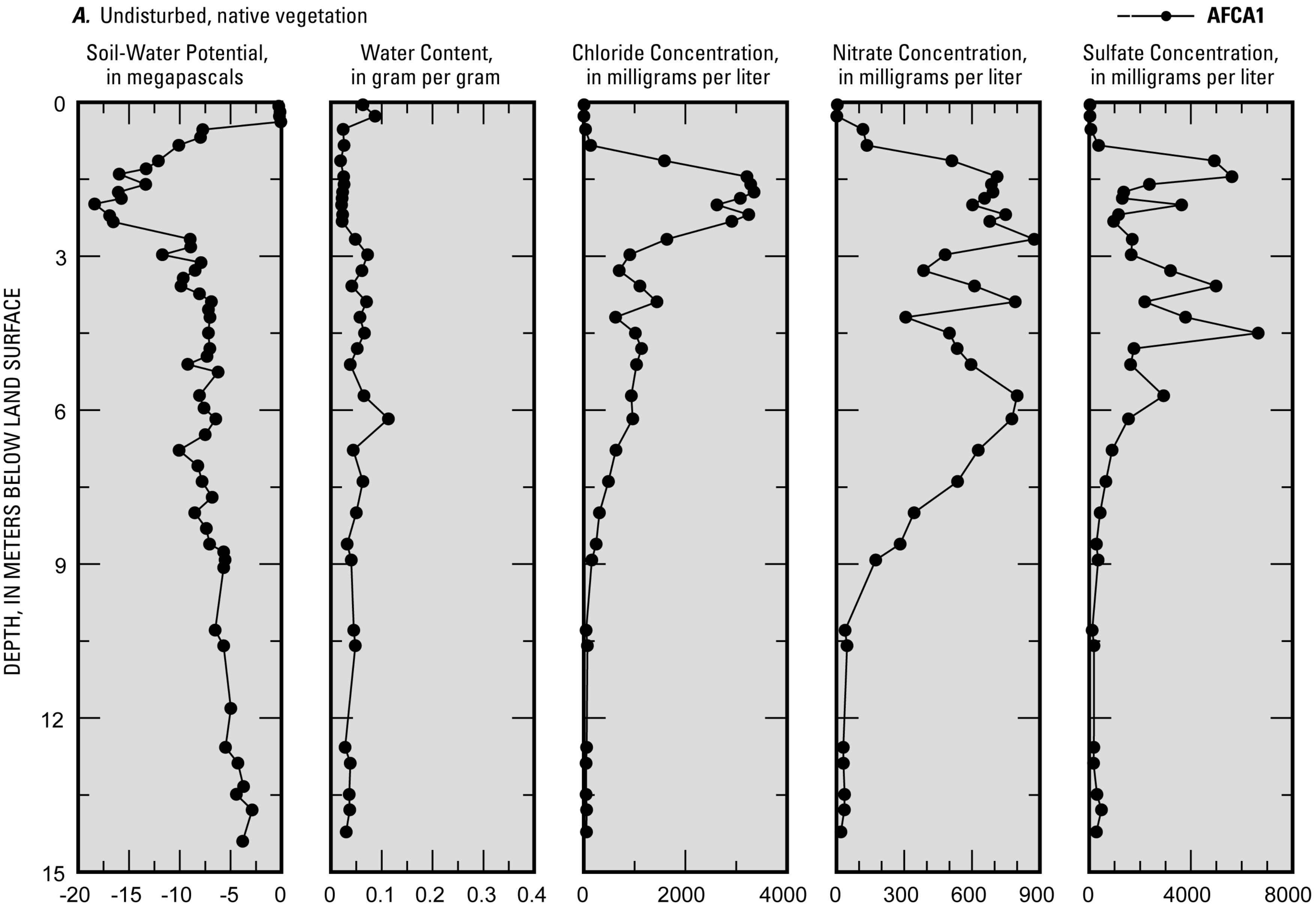

Figure 6. Profiles of water potential, water content, and chloride, sulfate, and nitrate concentrations in pore water beneath sites in the Amargosa Desert, Nye County, Nevada (fig. 2). The meter used to determine water potential had an upper detection threshold of -0.3 megapascals (MPa). Water potentials >-0.3 MPa are plotted as -0.15 MPa, representing half the upper detection threshold.

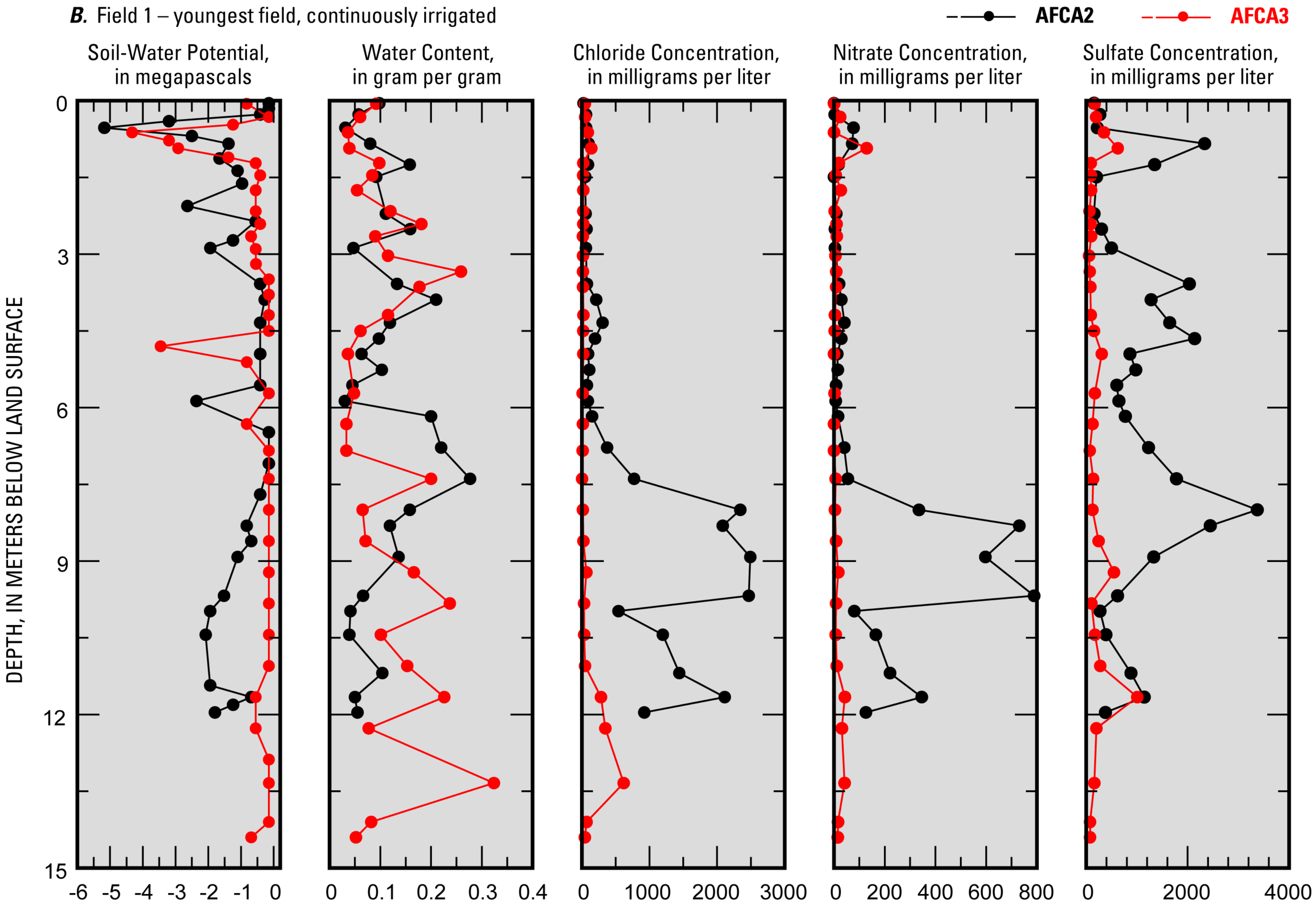

Figure 6 – continued Profiles of water potential, water content, and chloride, sulfate, and nitrate concentrations in pore water beneath sites in the Amargosa Desert, Nye County, Nevada (fig. 2). The meter used to determine water potential had an upper detection threshold of -0.3 megapascals (MPa). Water potentials >-0.3 MPa are plotted as -0.15 MPa, representing half the detection threshold.

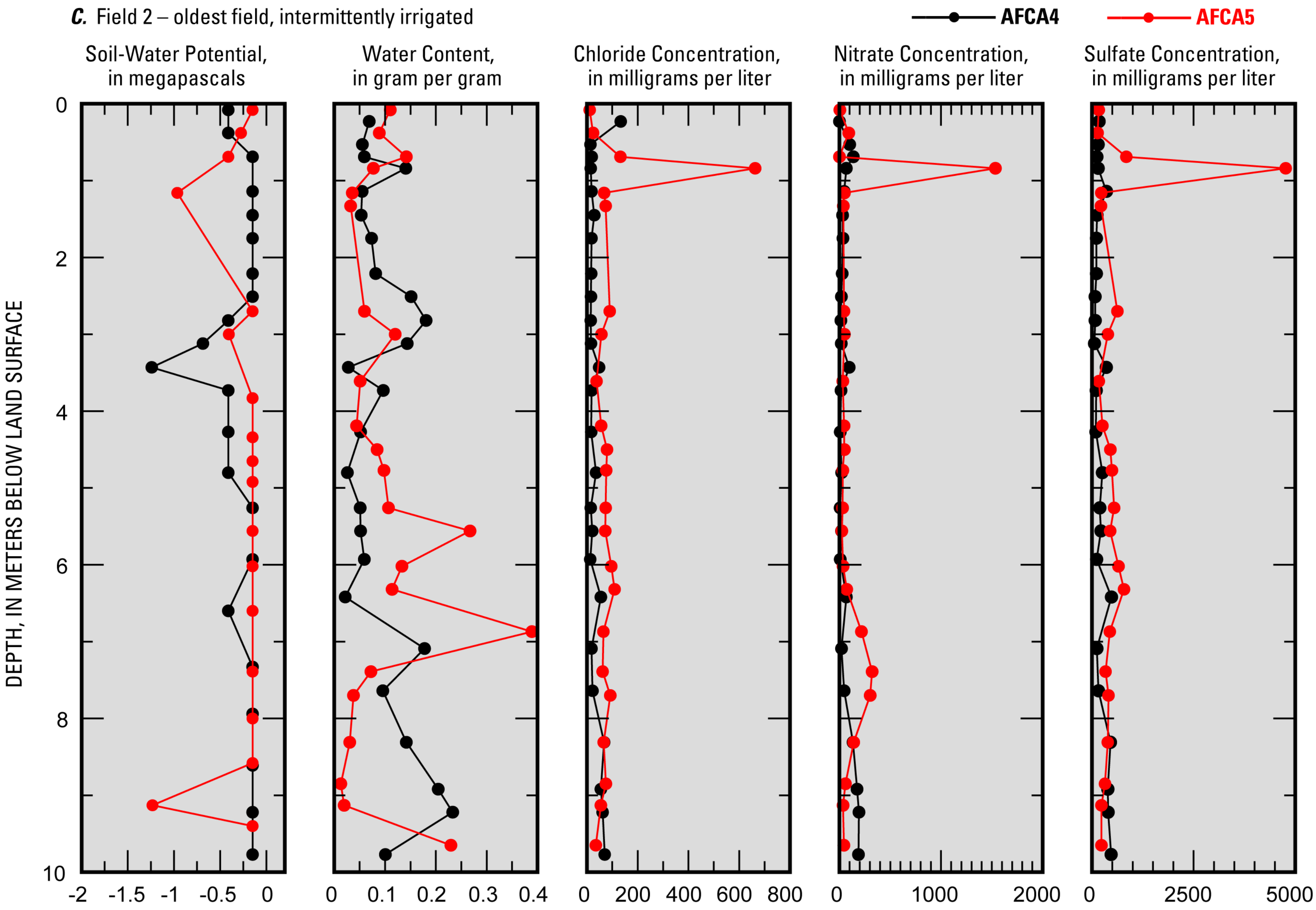

Figure 6 – continued Profiles of water potential, water content, and chloride, sulfate, and nitrate concentrations in pore water beneath sites in the Amargosa Desert, Nye County, Nevada (fig. 2). The meter used to determine water potential had an upper detection threshold of -0.3 megapascals (MPa). Water potentials >-0.3 MPa are plotted as -0.15 MPa, representing half the upper detection threshold.

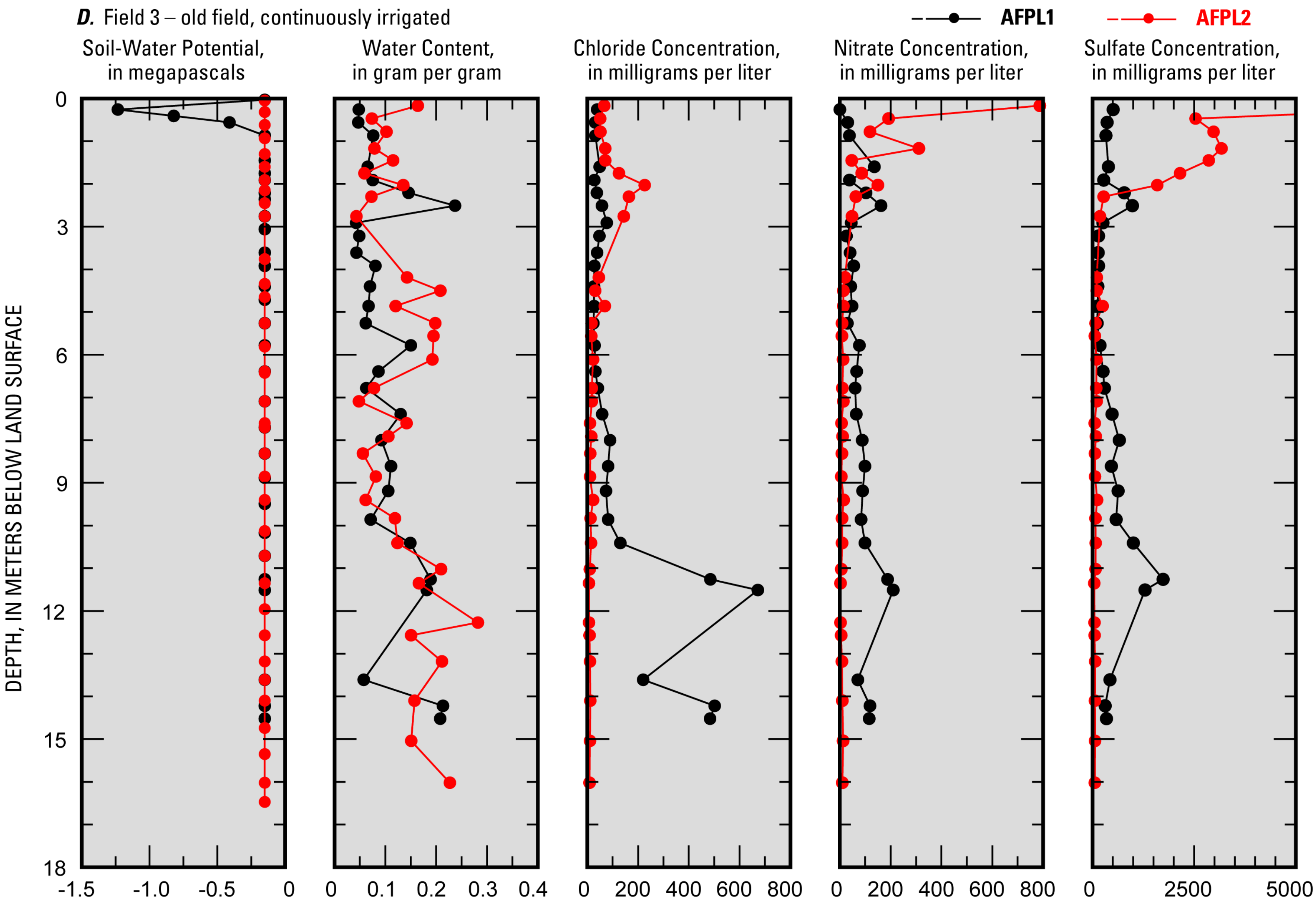

Figure 6 – continued Profiles of water potential, water content, and chloride, sulfate, and nitrate concentrations in pore water beneath sites in the Amargosa Desert, Nye County, Nevada (fig. 2). The meter used to determine water potential had an upper detection threshold of -0.3 megapascals (MPa). Water potentials >-0.3 MPa are plotted as -0.15 MPa, representing half the upper detection threshold.

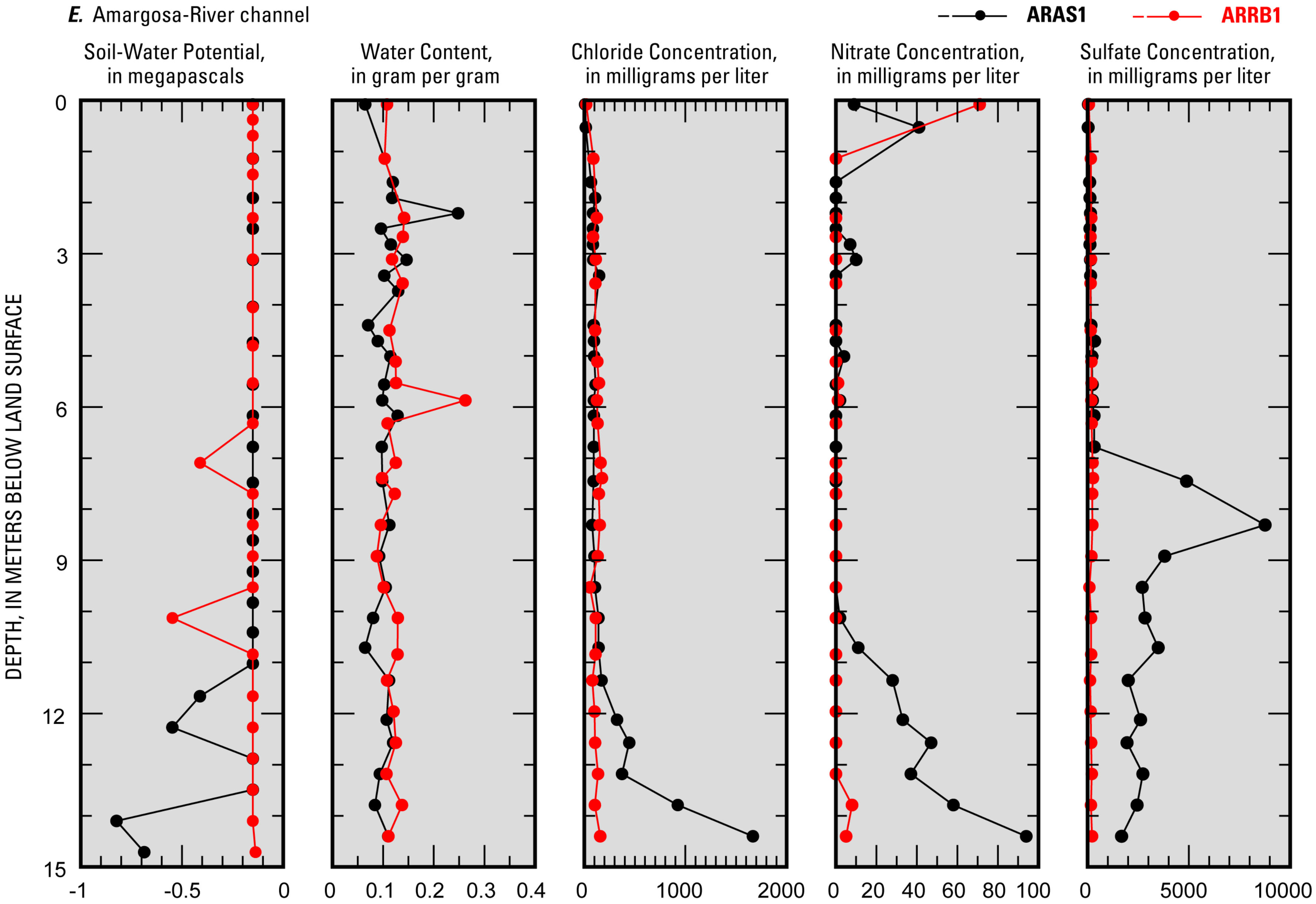

Figure 6 – continued Profiles of water potential, water content, and chloride, sulfate, and nitrate concentrations in pore water beneath sites in the Amargosa Desert, Nye County, Nevada (fig. 2). The meter used to determine water potential had an upper detection threshold of -0.3 megapascals (MPa). Water potentials >-0.3 MPa are plotted as -0.15 MPa, representing half the upper detection threshold.

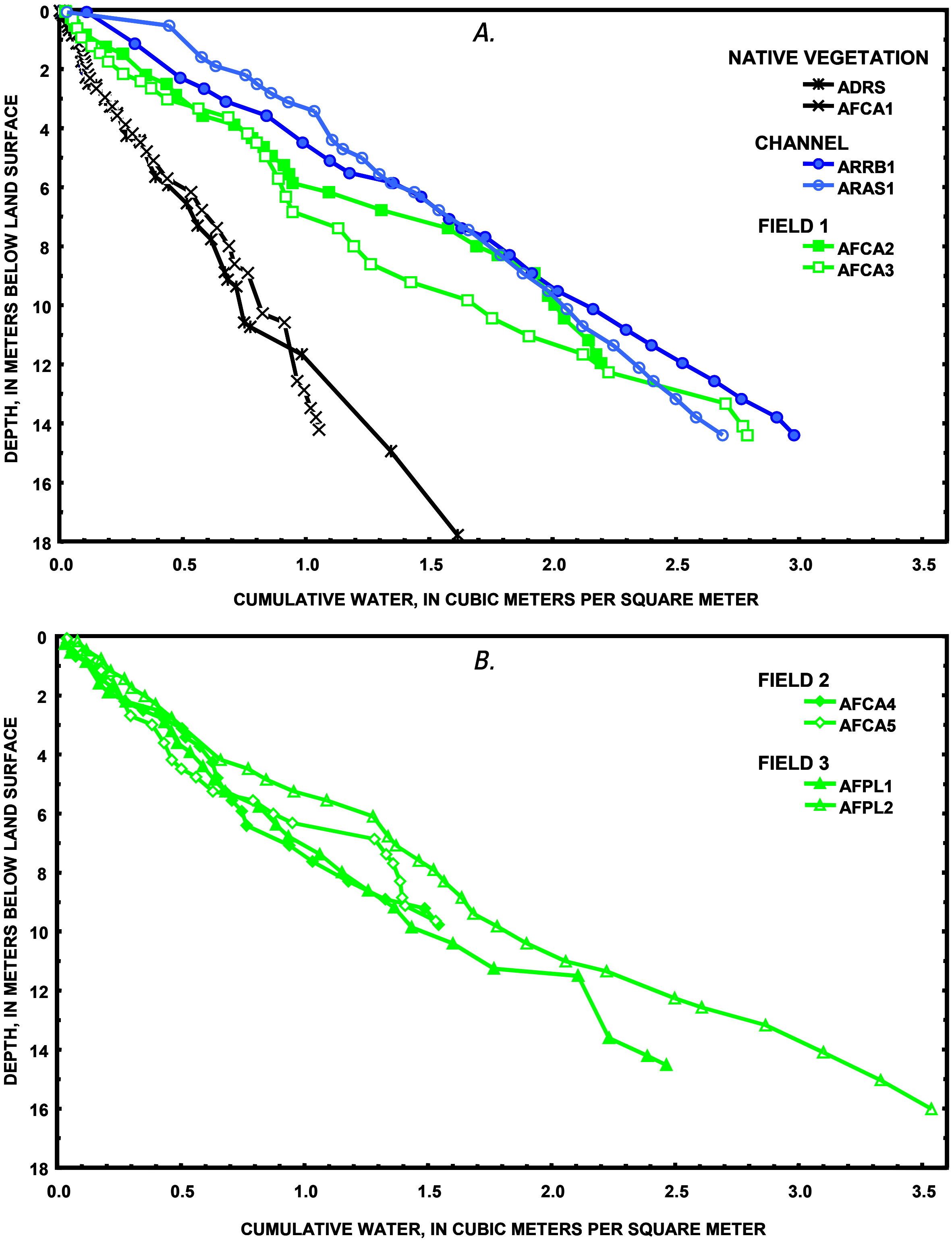

Figure 7. Profiles of cumulative water beneath irrigated fields, the Amargosa-River channel, and native vegetation, Amargosa Desert, Nye County, Nevada. *A.* Native-vegetation, channel, and newest-field (irrigated since 1993) boreholes. *B.* Older-field (irrigated since the 1960's) boreholes. See fig. 2 for locations.

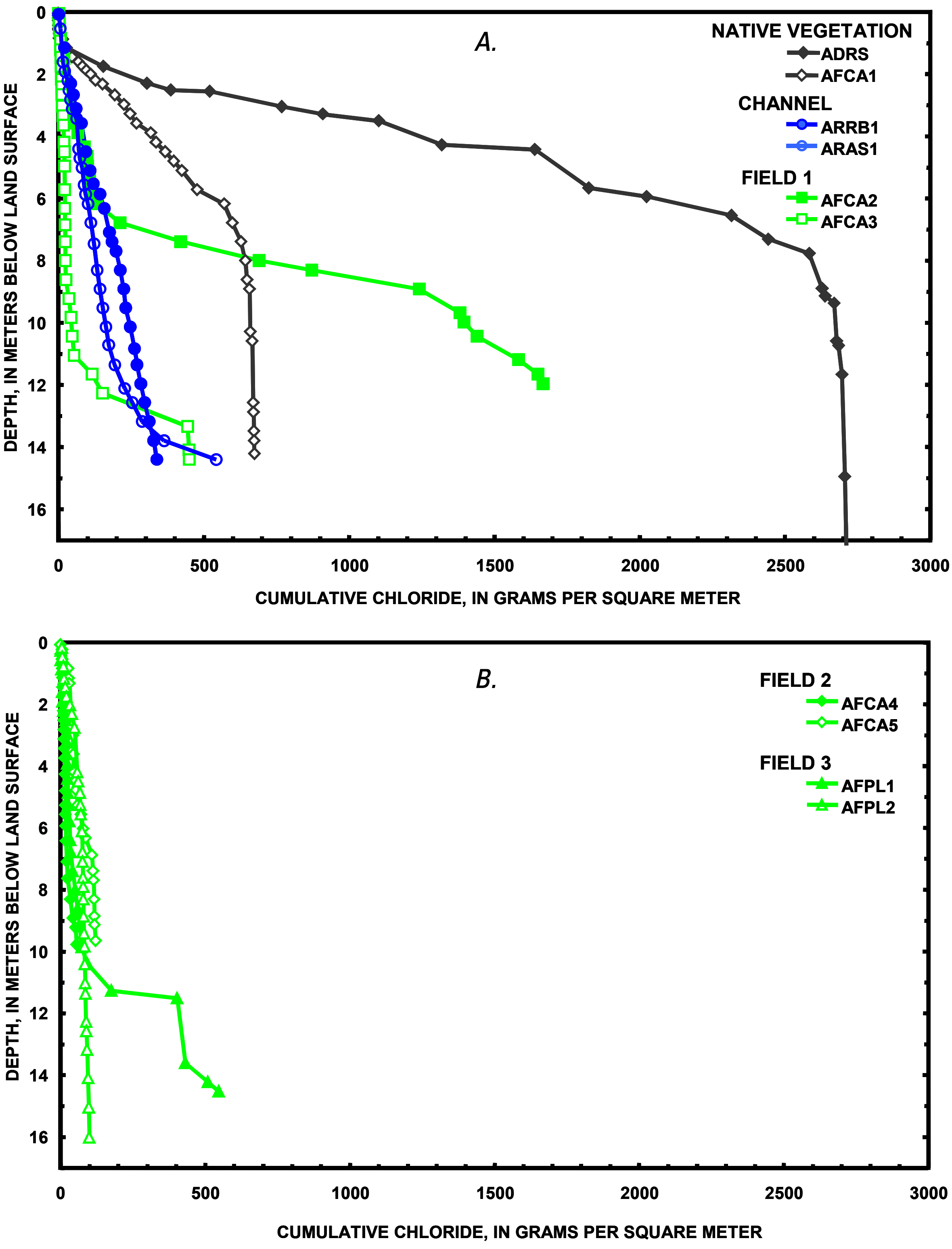

Figure 8. Profiles of cumulative chloride beneath irrigated fields, the Amargosa-River channel, and native vegetation, Amargosa Desert, Nye County, Nevada. *A.* Native-vegetation, channel, and newest-field (irrigated since 1993) boreholes. *B.* Older-field (irrigated since the 1960's) boreholes. See fig. 2 for locations.

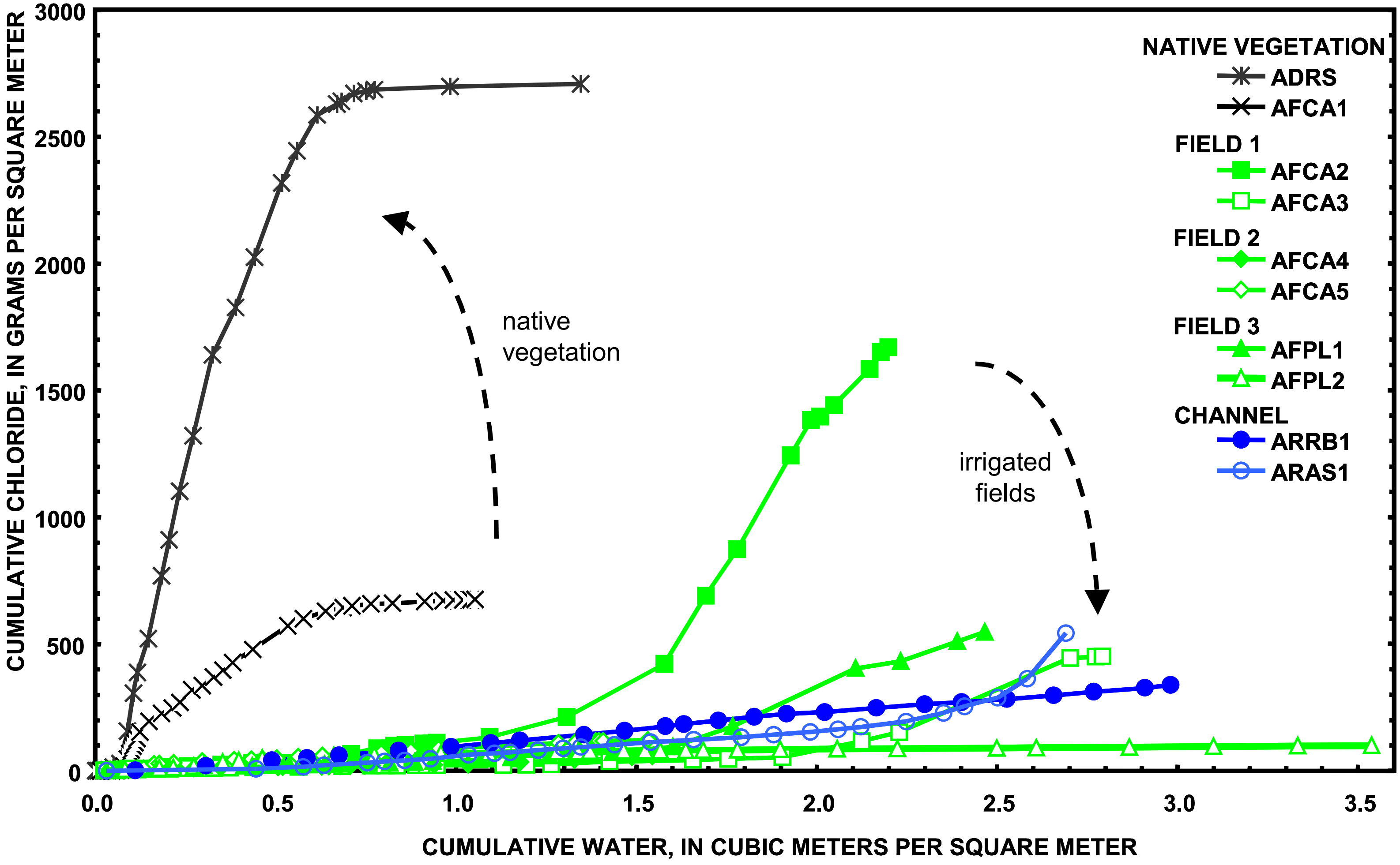

Figure 9. Relation between cumulative chloride and cumulative water content beneath irrigated fields, the Amargosa-River channel, and native vegetation, Amargosa Desert, Nye County, Nevada. Arrows show inferred profile evolution under current conditions. See fig. 2 for locations.

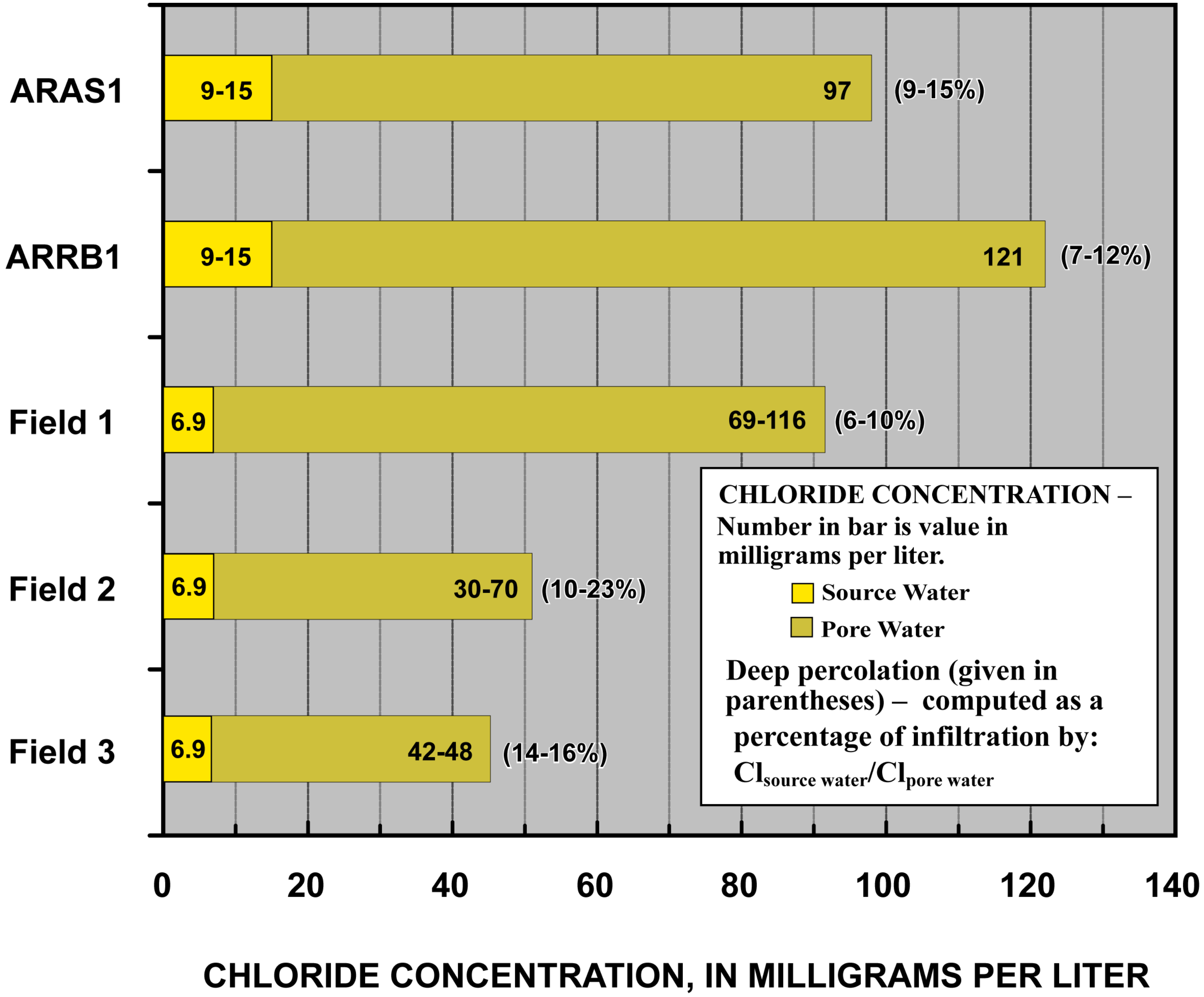

Figure 10. Deep percolation as a percentage of irrigation and channel infiltration, Amargosa Desert, Nye County, Nevada. ARAS1 and ARRB1 are sites in the Amargosa-River channel. Fields 1, 2, and 3 are irrigated with ground water. See fig. 2 for site locations.

APPENDIX A. – DESCRIPTION OF SEDIMENTS

Description of sediments from boreholes drilled in undisturbed vegetation and irrigated fields of the Amargosa-Farms area, and in the Amargosa-River channel, Amargosa Desert, Nye County, Nevada, February 2001

Lithologic log for hole: AFCA1

Date: February 21, 2001

Location: Funeral Mountain Ranch near intersection of Casada Road and Amargosa Farms Road, Amargosa Farms, Amargosa Desert, Nye County, Nevada. Hole is on undeveloped land 45 meters north of northernmost field (field 1 on figure 2).

UTM Zone 11, NAD 27, Easting 0542415; Northing 4046485; elevation 731 meters; error 3.4 meters

Depth below land surface, meters		Lithologic Description
From	To	
0.0	0.49	Sand, fine, moist, windblown, and occasional volcanic gravel and cobbles embedded in sand, moderate yellowish brown (10YR5/4). Gravel and cobbles commonly coated with calcite.
0.49	0.61	Boulders and cobbles mixed with sand, dry.
0.61	0.70	Pavement of cobbles and boulders.
0.70	0.91	Sand and gravel, mostly sand, gravel as large as 4 centimeters, roots around cobbles, fewer roots at 0.9 meter, grayish orange pink (5YR7/2).
1.07	1.40	Sand with few stones, fine, powdery, very dry. Cored from 1.07 to 2.59 meters, recovered 33 centimeters of sample.
2.59	3.11	Silt with fine sand, partly cemented, occasional fine gravel and coarse sand, pinkish gray (5YR8/1). Cored from 2.59 to 3.20 meters, recovered 52 centimeters
3.20	4.08	Silt with fine sand, partly cemented, dry very pale orange (10YR8/2). Cored from 3.20 to 4.11 meters, recovered 88 centimeters.
4.11	5.03	Silt with fine sand, compacted, dry, very pale orange (10YR8/2). Roots with oxidization rings are throughout core. Many dark colored pebbles embedded in sandy silt. Bottom 15 centimeters has more sand. Overall look is like marl. Cored from 4.11 to 5.03, recovered 92 centimeters.
5.03	5.35	Sand, medium to fine, dry from 5.03 to 5.18 meters, very pale orange (10YR8/2). Grades to fine sand and silt from 5.18 to 5.33 meters. Silt is dense and cemented with fossilized roots—almost a siltstone. Cored from 5.03 to 5.58, recovered 30 cm.
5.58	6.55	Silt with fine sand, dense and partly cemented, almost a siltstone, very pale orange (10YR8/2). Sample is mottled with grayish green sandy silt and contains many nearly vertical streaks of yellow orange oxidation with fossilized roots. Calcite nodules are present and seem to have formed around old root traces or in small burrows. Cored from 5.58 to 6.55 meters, recovered 97 centimeters.
6.55	7.16	Silt with fine sand, dense and partly cemented, almost a siltstone, very pale orange (10YR8/2). There are fewer zones of oxidation and fossilized roots. Cored from 6.55 to 7.16 meters, recovered 61 centimeters.
7.16	8.23	Silt with fine sand, dense and partly cemented from 7.16 to 8.23 meters, almost a siltstone, very pale orange (10YR8/2). There are only occasional zones of oxidation. Black pebbles at 8.23 meters. Cored from 7.16 to 8.69 meters, recovered 1.52 meters.

Lithologic log for hole: AFCA1

Date: February 21, 2001

Location: Funeral Mountain Ranch near intersection of Casada Road and Amargosa Farms Road, Amargosa Farms, Amargosa Desert, Nye County, Nevada. Hole is on undeveloped land 45 meters north of northernmost field (field 1 on figure 2).

UTM Zone 11, NAD 27, Easting 0542415; Northing 4046485; elevation 731 meters; error 3.4 meters

Depth below land surface, meters		Lithologic Description
From	To	
8.23	8.30	Sand and gravel, gravel as large as 6.3 millimeters, loose and dry.
8.30	8.69	Sand, coarse, loose and slightly damp. Sand is mottled gray, brown, black and pink.
8.69	9.14	Sand and gravel with gravel a dark red volcanic rock, cemented. Cored from 8.69 to 9.14 meters, recovered 30 cm. Cored again and collected 15 centimeters of sample, called it 8.99 to 9.14 meters.
9.14	10.21	No core, drilled hard from 9.14 to 9.60 meters; easy from 9.60 to 9.75 meters; hard again from 9.75 to 10.21 meters.
10.21	10.68	Silt with sand, minor gravel, dry and partly cemented. No fossilized roots, oxidation, or calcite nodules observed. Cored from 10.21 to 11.73 meters, recovered 42 centimeters.
11.73	11.89	Sand and gravel with some cobbles, coarse sand, dry and loose. Stones commonly quartzite and carbonate. Cored from 11.73 to 12.65 meters, recovered 15 centimeters.
12.65	13.20	Sand, coarse, well sorted for entire core. Individual grains are gray, brown, pink and black. Cored from 12.65 to 13.26 meters, recovered 53 centimeters.
13.26	14.20	Sand, fine to coarse. Cored from 13.26 to 14.20, recovered 64 centimeters.
14.20	14.51	Sand, coarse, well sorted; gravelly at 14.48 meters. Cored from 14.20 to 14.94 meters, recovered 30 centimeters. End of hole.

Lithologic log for hole: AFCA2

Date: February 22, 2001

Location: Funeral Mountain Ranch near intersection of Casada Road and Amargosa Farms Road, Amargosa Farms, Amargosa Valley, Nye County, Nevada. Hole is on north side of northernmost field (field 1 in table 1 and figure 2) about 45 meters from edge.

UTM Zone 11, NAD 27, Easting 0542412; Northing 4046485; elevation 731 meters; error 3.4 meters

Depth below land surface, meters		Lithologic Description
From	To	
0.0	0.34	Silt with fine sand and some gravel, numerous roots, moist, dark yellowish brown (10YR 4/2). Sandy silt is windblown.
0.34	0.88	Sand and gravel, gravel as large as 61 centimeters, mostly volcanic, one large stone of obsidian, some roots, loose, and damp but not as moist as overlying sandy silt, grayish orange pink (5YR7/2).
1.07	1.22	Silt with minor gravel, some clay and roots, minor oxidation, damp, grayish orange pink (5YR7/2). Cored from 1.07 to 1.98 meters, recovered 61 centimeters.
1.22	1.68	Sand, medium to fine, well sorted, minor gravel, loose, an occasional root, damp, grayish orange pink (5YR7/2).
1.98	2.13	Sand, with silt, no roots or oxidation observed, moist, grayish orange pink (5YR7/2). Cored from 1.98 to 2.59 meters, recovered 61 centimeters.
2.13	2.59	Silt with sand, pea-size gravel at 2.56 meters, moist yet readily falls apart, grayish orange pink (5YR7/2).
2.59	2.96	Sand and gravel, stones 6 millimeters, damp, grayish orange pink (5YR7/2). Cored from 2.59 to 3.44 meters, recovered 37 centimeters. Driller noted gravel at 3.35 meters.
3.44	3.65	Sand with silt, no roots or oxidation, loose and damp, grayish orange pink (5YR7/2). Cored from 3.44 to 4.11, recovered 67 centimeters.
3.65	4.11	Silt with fine sand, partly cemented, mottled with oxidation and manganese nodules, moist, grayish orange pink (5YR7/2).
4.11	4.72	Sand, fine to medium, gravelly from 4.57 to 4.72 meters, moist, light brown (5YR5/4). Cored from 4.11 to 5.64 meters, recovered 152 centimeters.
4.72	5.18	Sand, medium to coarse, an occasional pebble, streaks of bright yellow orange oxidation, moist, grayish orange (10YR7/4).
5.18	5.64	Sand, fine, well sorted, moist, grayish orange (10YR7/4).
5.64	6.04	Sand, medium to coarse, no pebbles, well sorted, moist, grayish orange (10YR5/4). Cored from 5.64 to 7.16, recovered 152 centimeters.
6.04	7.16	Silt with fine sand, streaks of bright yellow orange oxidation, very pale orange (10YR8/2).
7.16	8.08	Silt with fine sand, an occasional pebble, partly cemented, vertical traces of faintly oxidized zones, some relic root hairs and traces of light gray calcite along old root traces, moist, very pale orange (10YR8/2). Cored from 7.16 to 8.08, recovered 91 centimeters.
8.08	8.23	Silt with fine sand (similar to preceding core), moist, very pale orange (10YR8/2). Cored from 8.08 to 8.78 meters, recovered 70 centimeters..

Lithologic log for hole: AFCA2

Date: February 22, 2001

Location: Funeral Mountain Ranch near intersection of Casada Road and Amargosa Farms Road, Amargosa Farms, Amargosa Valley, Nye County, Nevada. Hole is on north side of northernmost field (field 1 in table 1 and figure 2) about 45 meters from edge.

UTM Zone 11, NAD 27, Easting 0542412; Northing 4046485; elevation 731 meters; error 3.4 meters

Depth below land surface, meters		Lithologic Description
From	To	
8.23	8.78	Sand, fine to medium, an occasional pebble, moist, yellowish gray (5Y7/2).
8.78	9.24	Sand, fine to medium, gravelly from 9.02 to 9.24 meters, moist, yellowish gray (5Y7/2). Cored from 8.78 to 10.21 meters, recovered 137 centimeters.
9.24	10.15	Sand, coarse, and gravel, gravel as large as 5 centimeters and more abundant near 10.06 meters, moist, pale red (10R6/2).
10.21	10.52	Sand, coarse, and gravel, gravel as large as 4 centimeters, thin layers of moisture, pale red (10R6/2). Cored from 10.21 to 11.13 meters, recovered 31 centimeters, sediment at bottom of shoe on core was cemented and hard.
11.13	11.58	Sand, fine to medium, with an occasional pebble, well sorted, damp, moderate yellowish brown (10YR5/4). Cored from 11.13 to 11.73 meters, recovered 60 centimeters.
11.58	11.73	Sand, coarse, and gravel, gravel as large as 4 centimeters, moist, pale red (10R5/2).
11.73	12.03	Sand, coarse, and gravel, gravel as large as 3 centimeters, thin zones of moisture between drier sediments, pale red (10R5/2). Cored from 11.73 to 12.65 meters, recovered 30 centimeters. Last meter was in sand and gravel. Drilling difficult. End of hole.

Lithologic log for hole: AFCA3

Date: February 22, 2001

Location: Funeral Mountain Ranch near intersection of Casada Road and Amargosa Farms Road, Amargosa Farms, Amargosa Valley, Nye County, Nevada. Hole is on southwest side of northernmost field (field 1 in table 1 and figure 2) about 27 meters in from edge.

UTM Zone 11, NAD 27, Easting 0542273; Northing 4046225; elevation 736 meters; error 4 meters.

Depth below land surface, meters		Lithologic Description
From	To	
0.00	0.40	Sand, fine, with silt, numerous roots, moist, pale yellowish brown (10YR 6/2).
0.40	1.00	Sand, fine, with silt, pebbles common near 0.98 meter, numerous roots and drier than at surface, grayish orange pink (5YR7/2).
1.07	1.16	Sand and silt with pebbly gravel, loose and much less moisture than near surface, grayish orange pink (5YR7/2). Cored from 1.07 to 1.98 meters, recovered 76 centimeters.
1.16	1.83	Sand, medium to fine, well sorted, with only an occasional root, more moisture than at 1.16 meters, Grayish orange pink (5YR7/2).
1.98	2.56	Sand and silt, well sorted, minor amount of coarse sand, moist, partly cemented with web-like secondary calcite and root hairs at 2.29 meters, grayish orange pink (5YR7/2). Cored from 1.98 to 2.59 meters, recovered 58 centimeters.
2.59	3.11	Sand, medium to coarse, and fine gravel, some silt, occasional roots, moist, pale yellowish brown (10YR6/2). Gravel well sorted and reddish. Cored from 2.59 to 4.11 recover 143 centimeters.
3.11	4.02	Sand and gravel with some silt, gravel as large as 3 centimeters, partly cemented, several roots with oxidation around roots, damp, pale yellowish brown (10YR6/2).
4.11	4.42	Sand and silt with few pebbles, no roots, moist, moderate yellowish brown (10YR5/4). Cored from 4.11 to 5.64 meters, recovered 122 centimeters.
4.42	4.57	Sand, fine to medium, well sorted with thin layers of coarse sand and pebbles, moist, grayish orange pink (5YR7/2).
4.57	5.33	Sand, coarse, and gravel, gravel as large as 5 centimeters, moist, grayish orange pink (5YR7/2).
5.64	5.79	Sand, medium to coarse, and gravel, gravel as large as 1 centimeter, moist, grayish orange pink (5YR7/2). Cored from 5.64-6.55 meters, recovered 76 centimeters.
5.79	6.40	Sand, fine to medium well sorted, no roots or oxidation, moist, grayish orange pink (5YR7/2).
6.55	7.07	Sand, medium to coarse, well sorted, occasional pebble, no roots or oxidation, moist, grayish orange pink (5YR7/2). Cored from 6.55 to 7.16 meters, recovered 61 centimeters.
7.07	7.16	Silt and fine sand, with rust colored blobs (weathering around pebbles?), compact, some calcite webbing, moist, grayish orange pink (5YR7/2).
7.17	8.08	Silt and fine sand, occasional dark red to black pebbles, some staining of grayish yellow (5Y8/4) that may be relic oxidation, calcite nodules, partly cemented, moist, yellowish gray (5YR7/2). Higher content of fine sand from 7.17 to 7.47 meters. Cored from 7.16 to 8.08 meters, recovered 91 centimeters.
8.08	8.66	Sand and gravel with silt, gravel as large as 5 centimeters, moist, grayish orange pink (5YR7/2). Cored from 8.08 to 8.69 meters, recovered 58 centimeters.

Lithologic log for hole: AFCA3

Date: February 22, 2001

Location: Funeral Mountain Ranch near intersection of Casada Road and Amargosa Farms Road, Amargosa Farms, Amargosa Valley, Nye County, Nevada. Hole is on southwest side of northernmost field (field 1 in table 1 and figure 2) about 27 meters in from edge.

UTM Zone 11, NAD 27, Easting 0542273; Northing 4046225; elevation 736 meters; error 4 meters.

Depth below land surface, meters		Lithologic Description
From	To	
8.69	8.84	Sand, coarse, and gravel, gravel as large as 3 centimeters, loose, moist, grayish orange pink (5YR7/2). Cored from 8.69 to 10.21 meters, recovered 122 centimeters.
8.84	9.14	Sand, medium, well sorted, moist, grayish orange pink (5YR7/2).
9.14	9.75	Silt with fine sand, compacted and partly cemented, occasional calcite nodule, moist, grayish red (10R4/2).
9.75	9.91	Sand, fine to coarse, moist, grayish red (10R4/2).
10.21	10.82	Sand, fine, and silt with vertical calcite stringers, moist, grayish red (10R4/2). Cored from 10.21 to 11.73 meters, recovered 152 centimeters.
10.82	11.13	Sand, fine, with silt and minor clay, moist, grayish red (10R4/2) .
11.13	11.73	Sand, fine, with silt, vertical calcite stringers, moist, grayish red (10R4/2).
11.73	13.26	Sand, fine, alternates with 15-centimeter thick layers of silt and fine sand, occasional pebbles, moist, grayish red (10R4/2). Cored from 11.73 to 13.26 meters, recovered 153 centimeters.
13.26	13.44	Marl(?) with clay and silt, smears, gravel at 13.41 to 13.44 meters, gravel as large as 3 centimeters, moist, very pale orange (10YR8/2). Cored from 13.26 to 14.48 meters, recovered 122 centimeters.
13.44	13.62	Sand, medium to coarse, well sorted, moist, dusky red (10R3/2). Sand grains are red and black.
13.62	14.48	Sand, fine to medium, well sorted, one large white calcite nodule, moist, grayish orange pink (5YR7/2). End of hole

Lithologic log for hole: AFCA4

Date: February 24, 2001

Location: Funeral Mountain Ranch near intersection of Casada Road and Amargosa Farms Road, Amargosa Farms, Amargosa Valley, Nye County, Nevada. Hole is at north end of field about 15 meters in from edge (field 2 in table 1 and figure 2).

UTM Zone 11, NAD 27, Easting 0542386; Northing 4045260; elevation 728 meters; error 5.8 meters.

Depth below land surface, meters		Lithologic Description
From	To	
0.0	0.94	Sand, fine, with silt and gravel, gravel as large as 1 centimeter, numerous roots in uppermost 60 centimeters, moist, moderate yellow brown (10YR5/4). Cored from 0.0 to 1.07 meters, recovered 94 centimeters.
1.07	1.37	Sand, coarse, and gravel, gravel as large as 6 millimeters, occasional roots, moist. Cored from 1.07 to 1.98 meters, recovered 79 centimeters.
1.37	1.68	Sand, medium to coarse, minor gravel; occasional roots; moist
1.68	1.86	Sand, coarse, and gravel, gravel as large as 3 centimeters, occasional roots, moist.
1.98	2.13	Sand, coarse, and gravel, gravel as large as 3 centimeters, occasional roots, moist. Cored from 1.98 to 2.59 meters, recovered 61 centimeters.
2.13	2.29	Sand, medium to coarse, well sorted, occasional roots, moist.
2.29	2.59	Silt with fine sand, numerous whitish root hairs and some decomposing woody roots, moist, moderate brown (5YR5/4).
2.59	3.20	Sand, very fine, uniform, possibly wind blown, no roots, moist. Cored from 2.59 to 4.11 meters, recovered 1.37 meters.
3.20	3.90	Sand, medium to coarse, larger grains reddish black, moist.
3.90	3.96	Sand, fine, well sorted, layered with 6- to 12-millimeter thick yellowish green silt and clay, moist.
4.11	4.87	Sand, coarse, and gravel, gravel as large as 1 centimeter, less gravel from 4.42 to 4.72 meters, no roots, moist. Cored from 4.11 to 4.94, recovered 76 centimeters.
4.94	5.18	Sand, fine, with some gravel, gravel as large as 2 centimeters, moist. Cored from 4.94 to 5.64, recovered 70 centimeters.
5.18	5.64	Sand, coarse, well sorted, occasional gravel to 3 centimeters, moist.
5.64	6.49	Sand, coarse, well sorted, occasional gravel, gravel as large as 1 centimeter, no roots, moist. Cored from 5.64 to 6.55 meters, recovered 85 centimeters.
6.55	6.86	Sand, coarse, and gravel, gravel as large as 5 centimeters, moist. Cored from 6.55 to 7.16 meters, recovered 61 centimeters.
6.86	7.16	Silt, with fine sand, partly cemented, streaks of dark red oxidation, no calcite or fossil roots observed, moist, moderate brown (5YR5/4).
7.16	7.86	Silt, with sand, and gravel, poorly sorted, gravel as large as 3 centimeters, moist. Cored from 7.16 to 8.02 meters, recovered 86 centimeters.
7.86	8.01	Silt with fine sand and no gravel, lacey white calcite, moist, moderate brown (5YR5/4).
8.01	8.23	Silt with very fine sand, occasional pebble less than 3 millimeters, moderate brown (5YR5/4), Cored from 8.01 to 8.68 meters, recovered 67 centimeters.
8.23	8.44	Silt with very fine sand, well sorted, pale yellowish brown (10YR6/2), layered with thin beds of medium gray (N6) calcite (freshwater limestone?) and one 5-

Lithologic log for hole: AFCA4

Date: February 24, 2001

Location: Funeral Mountain Ranch near intersection of Casada Road and Amargosa Farms Road, Amargosa Farms, Amargosa Valley, Nye County, Nevada. Hole is at north end of field about 15 meters in from edge (field 2 in table 1 and figure 2).

UTM Zone 11, NAD 27, Easting 0542386; Northing 4045260; elevation 728 meters; error 5.8 meters.

Depth below land surface, meters		Lithologic Description
From	To	
		centimeter thick layer of very light gray (N8) calcite.
8.44	8.68	Silt with very fine sand, an occasional pebble as large as 3 millimeters, loose; zones of dark reddish brown oxidation, calcite stringers follow relic root traces, pale yellowish brown (10YR6/2).
8.68	9.60	Silt with very fine sand, thin layers of cemented siltstone, pale yellowish brown (10YR6/2). Cored from 8.68 to 9.60 meters, recovered 92 centimeters.
9.60	9.85	Silt with very fine sand, thin layers of cemented siltstone, pale yellowish brown (10YR6/2) with minor yellowish oxidation streaks. Cored from 9.60 to 9.85 meters, recovered 25 centimeters. Stopped coring because could not penetrate cemented interval with core barrel.
9.85	10.06	Drilled slowly to 10.06 meters, drilling through something hard. Decided to stop drilling and move to another location. End of hole.

Lithologic log for hole: AFCA5

Date: February 24, 2001

Location: Funeral Mountain Ranch near intersection of Casada Road and Amargosa Farms Road, Amargosa Farms, Amargosa Valley, Nye County, Nevada. Hole is at west side of field about 29 meters in from edge (field 2 in table 2 and figure 2).

UTM Zone 11, NAD 27, Easting 0541844; Northing 4044830; elevation 734 meters; error 5.2 meters.

Depth below land surface, meters		Lithologic Description
From	To	
0.0	0.91	Sand, fine and silt, windblown, roots numerous to 0.46 meter, less common below, dry uppermost 6 centimeters, moist below, moderate yellow brown (10YR5/4). Cored from 0.0 to 1.07 meters, recovered everything except what was in shoe at end of core barrel.
0.91	1.07	Sand and gravel, gravel as large as 4 centimeters, damp.
1.07	1.40	Sand with silt and gravel, gravel decreases toward bottom, no roots observed, considerably drier than above. Cored from 1.07 to 2.59 meters, recovered 33 centimeters.
2.59	3.02	Sand, coarse, and gravel, gravel as large as 1 centimeter, some roots, calcite veins in upper foot, moist. Cored from 2.59 to 3.51 meters, recovered 49 centimeters.
3.02	3.08	Silt, with clay in layers less than 6 millimeters thick, very pale orange (10YR8/2).
3.51	3.90	Sand, coarse, and gravel, no roots, no calcite, loose, moist. Cored from 4.11 to 5.00 meters, recovered 89 centimeters.
4.11	4.27	Sand, coarse, and gravel, no roots, no calcite, loose, moist. Cored from 4.11 to 5.00 meters, recovered 89 centimeters.
4.27	5.00	Sand, fine to medium, with thin layers of cemented silt, some veins of dark reddish oxidation near bottom of interval.
5.00	5.64	Sand, fine, with silt and an occasional pebble, calcite veins prevalent from 5.33 to 5.64 meters, streaks of dark reddish brown oxidation. Cored from 5.00 to 5.64 meters, recovered 64 centimeters.
5.64	5.82	Sand, coarse, and gravel, gravel less than 6 millimeters, no noticeable calcite or oxidation, moist. Cored from 6.64 to 7.16 meters, recovered 131 centimeters.
5.82	6.85	Sand, fine, with silt, also thin layers of silt, abundant calcite veins, moist.
6.85	6.95	Silt with clay, moist, highly mottled—grayish orange, bright yellow orange, and dark reddish brown.
7.16	7.22	Silt with clay, highly mottled, similar to silt from 6.85 to 6.95 meters. Cored from 7.16 to 8.69 meters, recovered 143 centimeters.
7.22	7.47	Sand, medium, well sorted, abundant oxidation, moist.
7.47	8.38	Sand, medium, well sorted, minor oxidation and occasional large calcite nodule, moist.
8.38	8.66	Sand, medium, well sorted, loose, wet to touch.
8.69	8.99	Sand, medium, well sorted, loose; wet to touch. Cored from 8.69 to 9.75 meters, recovered 104 centimeters.
8.99	9.14	Silt, wet to touch, yellowish gray (5Y7/2).

Lithologic log for hole: AFCA5

Date: February 24, 2001

Location: Funeral Mountain Ranch near intersection of Casada Road and Amargosa Farms Road, Amargosa Farms, Amargosa Valley, Nye County, Nevada. Hole is at west side of field about 29 meters in from edge (field 2 in table 2 and figure 2).

UTM Zone 11, NAD 27, Easting 0541844; Northing 4044830; elevation 734 meters; error 5.2 meters.

Depth below land surface, meters		Lithologic Description
From	To	
9.14	9.72	Silt, yellowish gray (5Y7/2), transitioning into mottled yellow gray and gray marl(?), wet.
9.72	10.06	Drilled into hard material, suspect material is a cemented siltstone or marl. End of hole.

Lithologic log for hole: AFPL1

Date: February 25, 2001

Location: T&T Ranch field on west side of Powerline Road south of Amargosa Farms Road, Amargosa Farms, Amargosa Desert, Nye County, Nevada. Hole is on northeast side of field of oats and alfalfa about 10 meters in from edge (field 3 in table 1 and figure 2).

UTM Zone 11, NAD 27, Easting 0545661; Northing 4044432; elevation 724 meters; error 4 meters.

Depth below land surface, meters		Lithologic Description
From	To	
0.0	0.06	Sand, fine with silt and abundant organic matter, moist, moderate yellowish brown (10YR5/4). Cored from 0.0 to 0.94 meter, recovered 94 centimeters.
0.06	0.73	Sand, fine with silt and an occasional pebble, fewer roots than at surface, drier, grayish orange (10YR5/4).
0.73	0.94	Sand, fine to coarse with silt and pebbles, pebbles more common than above, pale yellowish brown (10YR6/2).
0.94	1.37	Drilled because too hard to core; cobble was in way of coring.
1.37	1.98	Sand, coarse, and gravel, gravel as large as 4 centimeters, no roots or oxidation observed, moderate yellowish brown (10YR5/4). Cored from 1.37 to 1.98 meters, recovered 61 centimeters.
1.98	2.53	Silt with fine sand, no roots, slightly cemented, moist, pale yellowish brown (10YR6/2). Short oxidized staining along fractures or old root traces. Calcite veins present throughout silt. Cored from 1.98 to 2.59 meters, recovered 61 centimeters.
2.53	2.59	Sand, coarse, and gravel, gravel as large as 2 centimeters, no roots, loose, moist.
2.59	3.29	Sand, coarse, and gravel, gravel as large as 5 centimeters, stones often rounded, no roots, moist, pale yellowish brown (10YR6/2). Cored from recovered 2.59 to 3.51 meters, recovered 70 centimeters.
3.51	3.66	Sand, coarse, and gravel, gravel as large as 3 centimeters, no roots, moist, pale yellowish brown (10YR6/2). Cored from 3.51 to 4.11 meters, recovered 49 centimeters.
3.66	3.93	Silt with fine sand and occasional pebble, no roots, moist, moderate yellowish brown (10YR5/4). Several veins and nodules of calcite, faint oxidation.
3.93	4.00	Silt, with sand and gravel, stones as large as 3 centimeters, no roots, moist.
4.11	4.94	Silt and fine to medium sand, poorly sorted, occasional gravel near top of interval, no roots, moist, moderate yellowish brown (10YR5/4). Cored from 4.11 to 5.03 meters, recovered 82 centimeters.
5.03	5.64	Sand, coarse, and gravel, gravel as large as 5 centimeters common. Rusty-red stain around stones below 5.49 meters, moist, moderate yellowish brown (10YR5/4). Cored from 5.03 to 5.64 meters, recovered 61 centimeters.
5.64	5.72	Sand, coarse, and gravel, similar to previous core, moderate yellowish brown (10YR5/4). Cored from 5.64 to 6.46 meters, recovered 82 centimeters.
5.72	6.46	Sand, fine and silt, occasional gravel as large as 1 centimeter, moderate yellowish brown (10YR5/4). Calcite nodules and veins common, no roots, moist, some oxidation.
6.46	6.71	Sand, fine, and silt, numerous calcite nodules, moist, moderate yellowish brown (10YR5/4). Cored from 6.46 to 7.16 meters, recovered 70 centimeters.

Lithologic log for hole: AFPL1

Date: February 25, 2001

Location: T&T Ranch field on west side of Powerline Road south of Amargosa Farms Road, Amargosa Farms, Amargosa Desert, Nye County, Nevada. Hole is on northeast side of field of oats and alfalfa about 10 meters in from edge (field 3 in table 1 and figure 2).

UTM Zone 11, NAD 27, Easting 0545661; Northing 4044432; elevation 724 meters; error 4 meters.

Depth below land surface, meters		Lithologic Description
From	To	
6.71	6.92	Sand, medium to coarse, and gravel, gravel as large as 1 centimeter, moist, moderate yellowish brown (10YR5/4).
6.92	7.16	Sand, fine, uniform, moist, moderate yellowish brown (10YR5/4).
7.16	8.02	Silt and fine sand with occasional pebble, numerous calcite nodules and thin calcified layers, moist, grayish orange pink (5YR7/2). Cored from 7.16 to 8.08 meters, recovered 92 centimeters.
8.02	8.08	Sand, fine, and silt, no noticeable calcite nodules, moist, moderate yellowish brown (10YR5/4).
8.08	8.69	Sand, fine, occasional gravel as large as 1 centimeter, numerous calcite nodules and veins, thin layers of partly cemented silt, moist, moderate yellowish brown (10YR5/4). Cored from 8.08 to 8.69 meters, recovered 61 centimeters.
8.69	8.81	Sand, fine, several calcite nodules and veins, moist, moderate yellowish brown (10YR5/4). Cored from 8.69 to 9.57 meters, recovered 88 centimeters.
8.81	9.11	Silt and fine sand, occasional pebble, grayish orange pink (5YR7/2), thin layers of mottled moderate yellowish brown (10YR5/4) to light gray (N7) siltstone (cemented).
9.11	9.57	Sand, fine, occasional gravel as large as 1 centimeter, loose, numerous calcite nodules and veins, moist, moderate yellowish brown (10YR5/4).
9.57	10.24	Sand and gravel, gravel (mostly volcanic) as large as 6 centimeters, occasional calcite nodule near top, moist, moderate yellowish brown (10YR5/4). Cored from 9.57 to 10.24 meters, recovered 67 centimeters.
10.24	11.09	Silt and very fine sand, occasional pebble and coarse sand, moist, laced with fine calcite, numerous nodules and thin layers of calcified siltstone, gradual color change from top to bottom—moderate yellow brown (10YR5/4) to grayish orange pink (5YR7/2). Cored from 10.24 to 11.09 meters, recovered 85 centimeters.
11.09	11.58	Sand, very fine, slightly drier than overlying sediment, calcite nodules and veins throughout, numerous thin layers of calcified siltstone, grayish orange pink (5YR7/2), color lightens near bottom. Could not core complete interval because materials too hard. Cored from 11.09 to 11.58 meters, recovered 46 centimeters. Sample at end of shoe was dense siltstone with pervasive light gray calcite.
11.58	13.26	Augured without coring. Drilling easier from 12.64 to 13.26 meters.
13.26	13.69	Sand, coarse, and gravel, stones as large as 1 centimeter, damp, pale yellowish brown (10YR6/2). Cored from 13.26 to 14.60 meters, recovered 134 centimeters.
13.69	13.96	Silt and fine sand with very few pebbles, damp, grayish orange pink (5YR7/2). Includes thin layer of light gray (N7) silt to very fine sand (possibly volcanic ash?), compact.
13.96	14.60	Sand, very fine, and silt with an occasional pebble, well sorted, damp, grayish orange pink (5YR7/2). End of hole.

Lithologic log of hole: AFPL2

Date: February 25, 20001

Location: T&T Ranch field on west side of Powerline Road south of Amargosa Farms Road, Amargosa Farms, Amargosa Desert, Nye County, Nevada.

Hole is on northeast side of field of oats and alfalfa about 60 meters northeast of center pivot (field 3 in table 1 and figure 2).

UTM Zone 11, NAD 27, Easting 0545501; Northing 4044236; elevation 715 meters; error 6 meters.

Depth below land surface, meters		Lithologic Description
From	To	
0.0	0.24	Sand, fine, and silt, abundant organic matter and numerous roots, loose, moist, dark yellowish brown (10YR4/2).
0.24	0.91	Sand, fine, and silt, occasional gravel, gravel as large as 1 centimeter, decreased organic matter and fewer roots, loose, moist, moderate yellowish brown (10YR5/4).
0.91	1.00	Sand, coarse, and gravel, gravel as large as 3 centimeters, partly cemented, no roots observed, grayish orange pink (5YR7/2). Cored from 0.0 to 1.0 meter, recovered 1 meter. Encountered cemented interval at 1 meter.
1.00	1.13	Drilled without core through a 7-centimeter layer of cemented materials.
1.13	1.22	Sand, coarse, and gravel, moist, color grades from grayish orange pink (5YR7/2) to dark yellowish brown (10YR4/2). Cored from 1.13 to 1.98 meters, recovered 85 centimeters.
1.22	1.37	Sand, coarse, and gravel, partly cemented, no roots observed, moist, grayish orange pink (5YR7/2).
1.37	1.52	Sand, coarse, and gravel, no roots observed, moist, moderate brown (5YR4/4).
1.52	1.98	Sand, coarse, and gravel, gravel as large as 5 centimeters, no roots observed, moist, vertical wispy veins of a white mineral, moderate yellowish brown (5YR7/2). Cored from 1.98 to 2.59 meters, recovered 56 centimeters.
1.98	2.07	Sand and gravel, some silt, cemented, moist, grayish orange pink (5YR7/2).
2.07	2.22	Sand, coarse, and gravel, little cementation, loose, pale yellowish brown (10YR6/2) .
2.22	2.54	Sand, coarse, and gravel, gravel as large as 6 centimeters, numerous black pebbles and coarse sand, little cementation, loose, some roots present, pale yellowish brown (10YR6/2).
2.59	2.83	Sand, coarse, and gravel, gravel as large as 5 centimeters, mostly volcanic, white mineral nodules within sand and gravel, whitish coating on larger stones. Cored from 2.59 to 2.83 meters, recovered 24 centimeters. Stopped coring because gravel too large.
2.83	3.71	Drilled to get past large gravel and cobbles.
3.71	3.80	Attempted core but cobble in way. Collected only 9 centimeters at end of core barrel. Sand, coarse, and gravel, gravel as large as 4 centimeters, moist, pale yellowish brown. Drilled to 4.11 meters
4.11	4.57	Sand, medium, well sorted, moist, moderate brown (5YR4/4). Sand grades first to fine sand then to silty fine sand with depth. Cored from 4.11-4.94 meters, recovered 83 centimeters.

Lithologic log of hole: AFPL2

Date: February 25, 20001

Location: T&T Ranch field on west side of Powerline Road south of Amargosa Farms Road, Amargosa Farms, Amargosa Desert, Nye County, Nevada.

Hole is on northeast side of field of oats and alfalfa about 60 meters northeast of center pivot (field 3 in table 1 and figure 2).

UTM Zone 11, NAD 27, Easting 0545501; Northing 4044236; elevation 715 meters; error 6 meters.

Depth below land surface, meters		Lithologic Description
From	To	
4.57	4.94	Sand, fine and silt, well sorted, moderate yellowish brown (5YR5/4). Several vertical veins of a white mineral extend through interval.
4.94	5.61	Sand, fine and silt, occasional gravel as large as 6 millimeters, moist, moderate yellowish brown (10YR5/4). Several vertical veins of a white mineral along with a few small lenses measuring about 6 millimeters thick by 2 centimeters long. Cored from 4.94 to 5.64 meters, recovered 67 centimeters.
5.64	6.49	Sand, fine, and silt, occasional gravel as large as 3 centimeters, gravel more common near bottom of interval, moist, moderate yellowish brown (10YR5/4). Several vertical white veins less than 1 millimeter thick. Few thin intervals of cemented siltstone. Cored from 5.64 to 6.55 meters, recovered 85 centimeters.
6.55	6.71	Sand, fine and silt, minor whitish mineral, little cementation, moist, moderate yellowish brown (10YR5/4). Cored from 6.55 to 7.16 meters, recovered 61 centimeters.
6.71	6.86	Sand, medium, and gravel, moist.
6.86	7.16	Sand, fine, moderate yellowish brown (10YR5/4). Grades to coarse sand and gravel at 7.16 meters, no observed mineral veins or nodules, moist.
7.16	7.32	Sand, coarse and fine gravel. Cored from 7.16 to 7.99 meters, recovered 82 centimeters.
7.32	7.99	Sand, fine, and silt, occasional gravel as large as 2 centimeters, moist, moderate yellowish brown (10YR5/4). A cylindrical vein of a white mineral (calcite?) measured less than 1 mm in diameter and was more than 3 centimeters long (old root trace?).
7.99	8.23	Sand, fine, and silt, occasional gravel as large as 1 centimeter, loose, some white mineral veins, moist, moderate yellowish brown (10YR5/4). Cored from 7.99 to 8.69 meters, recovered 70 centimeters.
8.23	8.38	Sand, medium, and gravel, gravel as large as 3 centimeters, no mineral veins, moist, moderate yellowish brown (10YR5/4).
8.38	8.69	Sand, fine, grading to sand and gravel, gravel as large as 1 centimeter, loose, occasional white nodules in fine sand, moist, moderate yellowish brown (10YR5/4).
8.69	8.72	Sand, fine, and silt, occasional pebble, white mineral (calcite?) laced through core, moist, moderate yellowish brown (10YR5/4). Cored from 8.69 to 9.51 meters, recovered 79 centimeters.
8.72	9.14	Sand, coarse, and gravel, gravel as large as 2.5 centimeters, thin layer of white mineral at 9.14 meters, moist.
9.14	9.48	Sand, fine, occasional gravel as large as 1 centimeter, white mineral laced through

Lithologic log of hole: AFPL2

Date: February 25, 20001

Location: T&T Ranch field on west side of Powerline Road south of Amargosa Farms Road, Amargosa Farms, Amargosa Desert, Nye County, Nevada.

Hole is on northeast side of field of oats and alfalfa about 60 meters northeast of center pivot (field 3 in table 1 and figure 2).

UTM Zone 11, NAD 27, Easting 0545501; Northing 4044236; elevation 715 meters; error 6 meters.

Depth below land surface, meters		Lithologic Description
From	To	
		core, moist, moderate yellowish brown (10YR5/4).
9.51	10.21	Sand, fine, and silt, occasional pebble, some minor yellow orange oxidation near top, numerous thin weakly cemented layers, white mineral laced through core, moderate yellowish brown (10YR5/4). Cored from 9.51 to 10.21 meters, recovered 70 centimeters.
10.21	10.51	Sand, fine, well sorted, no white minerals, moist, moderate yellowish brown (10YR5/4). Cored from 10.21 to 11.06 meters, recovered 85 centimeters.
10.51	10.82	Sand and gravel, some silt, gravel as large as 1 centimeter, moist, occasional bleb of white mineral.
10.82	10.97	Sand, fine, and silt, occasional pebble, considerable calcite (?) and thin lenses of cemented sandstone, moist, grayish orange pink (5YR7/2).
10.97	11.06	Sand, fine, and silt, occasional pebble, minor white mineral (calcite?), moist, moderate yellowish brown (10YR5/4).
11.06	11.73	Sand, fine, and silt, occasional gravel, damp, thin layers of cemented sandstone, moderate yellowish brown (10YR5/4). Cored from 11.06 to 11.73 meters, recovered 67 centimeters.
11.73	11.86	Siltstone, occasional small pebble, highly cemented, occasional veins of a whitish mineral, dry to damp, moderate yellowish brown (10YR5/4). Cored from 11.73 to 12.65 meters, recovered 89 centimeters.
11.86	12.34	Sand and gravel, Gravel as large as 1 centimeter, thin layers of a light gray mineral, moist, moderate brown (5YR4/4).
12.34	12.62	Sand, fine, and silt, weakly cemented, numerous veins and blebs of a whitish mineral, moist, moderate yellowish brown (10YR5/4).
12.65	12.95	Sand, fine, and silt, occasional pebble and bleb of whitish mineral, moist, moderate yellowish brown (10YR5/4). At 42.5, two thin layers of siltstone, cemented, occasional pebble, very pale orange (10YR8/2). Cored from 12.65 to 13.26 meters, recovered 61 centimeters.
12.95	13.26	Sand, very fine, well sorted, occasional small pebble and coarse sand, moist, light brown (5YR6/4).
13.26	13.50	Sand, very fine, well sorted, occasional vertical vein of whitish mineral, moist, very pale orange (10YR8/2). Cored from 12.95 to 14.14 meters, recovered 88 centimeters.
13.50	13.78	Volcanic ash, very fine sand, well sorted and uniform, loose, moist, very light gray (N8). Ash identified as Lava Creek B with an age of 0.64 Ma (Andrei Sarna-Wojcicki, U.S. Geological Survey, Menlo Park, written commun., 2002).
13.78	14.04	Sand, very fine, 1-centimeter thick layers of cemented sand, moist, pale yellowish

Lithologic log of hole: AFPL2

Date: February 25, 20001

Location: T&T Ranch field on west side of Powerline Road south of Amargosa Farms Road, Amargosa Farms, Amargosa Desert, Nye County, Nevada.

Hole is on northeast side of field of oats and alfalfa about 60 meters northeast of center pivot (field 3 in table 1 and figure 2).

UTM Zone 11, NAD 27, Easting 0545501; Northing 4044236; elevation 715 meters; error 6 meters.

Depth below land surface, meters		Lithologic Description
From	To	
		brown (10YR6/2).
14.04	14.14	Sand, very fine, occasional bleb of whitish mineral, loose, moist, pale yellowish brown (10YR6/2).
14.14	14.63	Sand, fine, well sorted, occasional bleb of whitish mineral, loose, moist, pale yellowish brown (10YR6/2). Cored from 14.14 to 14.81 meters, recovered 67 centimeters.
14.63	14.81	Sand, fine, well sorted, occasional bleb of whitish mineral, loose, moist, very pale orange (10YR8/2).
14.81	15.11	Sand, fine, well sorted, occasional pebble, occasional bleb of whitish mineral, loose, moist, very pale orange (10YR8/2). Cored from 14.81 to 15.73 meters, recovered 92 centimeters.
15.11	15.42	Sand, fine, well sorted, occasional pebble, occasional cemented zone, moist, grayish yellow (5Y8/4) with oxidized yellowish orange streaks.
15.42	15.73	Sand, fine to coarse, and gravel, gravel as large as 6 millimeters, occasional vertical vein and bleb of whitish mineral, yellowish gray (5Y7/2).
15.73	15.94	Sand, fine, and silt, occasional pebble, occasional bleb of whitish mineral, oxidized streaks, moist, grayish yellow (5Y8/4). Cored from 15.73 to 16.56 meters, recovered 83 centimeters
15.94	16.39	Sand, medium with numerous pebbles, moist, occasional bleb of whitish mineral, occasional cemented layer.
16.39	16.56	Sand, medium to coarse, and gravel, gravel weathered, some crumble easily, reddish oxidation halos around stones, occasional bleb of whitish mineral, moist. End of hole.

Lithologic log for hole: ARRB1

Date: February 26, 2001

Location: In Amargosa River channel about 18 meters downstream of unnamed road where road crosses Amargosa-River channel, west of FAA airplane guidance beacon (dirt road informally called “radio beacon road”). The road intersects Highway 95 about 13 kilometers south of Beatty, Nevada.

UTM Zone 11, NAD 27, Easting 0521815; Northing 4072299; elevation 886 meters; error 6 meters.

Depth below land surface, meters		Lithologic Description
From	To	
0.0	0.76	Sand and gravel, loose, no roots, some streaks of oxidation, wet.
1.07	1.52	Sand and gravel, gravel mostly volcanic with some quartzite and dolomite, loose. Cored from 1.07 to 1.98 meters, recovered 46 centimeters. Large stone wedged at end of shoe on core barrel.
1.98	2.32	Sand and gravel poorly sorted with clay and silt, gravel as large as 7.5 centimeters, wet, pale yellowish brown (10YR6/2). Cored from 1.98 to 2.59 meters, recovered 34 centimeters.
2.59	3.17	Sand and gravel poorly sorted with clay and silt, wet, pale yellowish brown (10YR6/2). Cored from 2.59 to 3.47 meters, recovered 58 centimeters.
3.47	4.11	Sand and gravel poorly sorted with clay and silt, gravel greater than 5 centimeters, wet, pale yellowish brown (10YR6/2). Cored from 3.47 to 4.11 meters, recovered 64 centimeters.
4.11	4.89	Sand and gravel poorly sorted with clay and silt, gravel greater than 7.5 centimeters, compact yet not cemented, moist, multicolored. In middle of core (at about 4.57 meters), a large quartzite stone, same size as the 7.5-centimeter diameter core barrel except the edges had been rounded to fit tightly in barrel. Cored from 4.11 to 5.03 meters, recovered 76 centimeters.
5.03	5.61	Sand and gravel poorly sorted with clay and silt, gravel highly weathered, moist, multicolored. Cored from 5.03 to 5.61 meters, recovered 58 centimeters.
5.61	6.40	Sand and gravel poorly sorted with clay and silt, compact yet not cemented, gravel highly weathered, moist, light brown (5YR5/6). Stopped coring because shoe grinding on large stone. Bottom of shoe had a 3-centimeter thick piece of freshly broken basalt. Cored from 5.61 to 6.40 meters, recovered 79 centimeters.
6.40	7.13	Sand and gravel poorly sorted with silt and minor clay, gravel moderately weathered, moist, light brown (5YR5/6). Matching piece of freshly broken basalt at 6.40 meters. Cored from 6.40 to 7.16 meters, recovered 73 centimeters.
7.16	8.08	Sand and gravel poorly sorted with silt and minor clay, gravel moderately weathered, moist but drier and warmer than above, light brown (5YR5/6). Cored from 7.16 to 8.08 meters, recovered 92 centimeters.
8.08	8.69	Sand and gravel poorly sorted with clay and silt, damp and warm, light brown (5YR5/6). Cored from 8.08 to 8.69 meters, recovered 61 centimeters.
8.6	9.60	Sand and gravel poorly sorted with clay and silt, damp and warm, light brown (5YR5/6). Cored from 8.69 to 9.60 meters, recovered 0.91 centimeters.
9.60	10.21	Sand and gravel poorly sorted with clay and silt, wetter than above, light brown (5YR5/6). Cored from 9.60 to 10.21 meters, recovered 61 centimeters.
10.21	10.91	Sand and gravel poorly sorted with clay and silt, gravel moderately weathered,

Lithologic log for hole: ARRB1

Date: February 26, 2001

Location: In Amargosa River channel about 18 meters downstream of unnamed road where road crosses Amargosa-River channel, west of FAA airplane guidance beacon (dirt road informally called "radio beacon road"). The road intersects Highway 95 about 13 kilometers south of Beatty, Nevada.

UTM Zone 11, NAD 27, Easting 0521815; Northing 4072299; elevation 886 meters; error 6 meters.

Depth below land surface, meters		Lithologic Description
From	To	
		moist, light brown (5YR5/6). Cored from 10.21 to 10.91 meters, recovered 70 centimeters. Stopped on a boulder—could not continue coring. Drilled through boulder with inner bit.
11.13	11.73	Sand and gravel poorly sorted with silt and minor clay, gravel as large as 7.5 centimeters and moderately weathered, damp, light brown (5YR5/6). Cored from 11.13 to 11.73 meters, recovered 60 centimeters.
11.73	12.65	Sand and gravel poorly sorted with silt and minor clay, gravel as large as 7.5 centimeters, gravel mostly volcanic with occasional quartzite and moderately weathered, crumbly, damp, light brown (5YR5/6). Cored from 11.73 to 12.65 meters, recovered 92 centimeters.
12.65	13.26	Sand and gravel poorly sorted with silt and minor clay, gravel as large as 7.5 centimeters, gravel mostly volcanic with occasional quartzite and moderately weathered, damp, light brown (5YR5/6). Cored from 12.65 to 13.26 meters, recovered 61 centimeters.
13.26	14.17	Sand and gravel poorly sorted with silt and minor clay, gravel as large as 7.5 centimeters, loose, damp, light brown (5YR5/6). Color fades gradually to a pale yellowish brown (10YR6/2) at 14 meters with more silt below. Cored from 13.26 to 14.17 meters, recovered 91 centimeters.
14.17	14.78	Sand and gravel poorly sorted with silt and minor clay, gravel greater than 7.5 centimeters, loose, damp, pale yellow brown (10YR6/2). Cored from 14.17 to 14.78 meters, recovered 61 centimeters. End of hole.

Lithologic log for hole: ARAS1

Date: February 27, 2001

Location: In Amargosa River channel about 100 meters downstream of dirt road where it crosses channel west of the old Ashton site along the Tonopah and Tidewater Railroad bed. The dirt road intersects Highway 95 about 20 kilometers south of Beatty, Nevada.

UTM Zone 11, NAD 27, Easting 0528846; Northing 4062684; elevation 807 meters; error 6 meters.

Depth below land surface, meters		Lithologic Description
From	To	
0.0	0.76	Sand, coarse, and gravel, loose, gravel as large as 4 centimeters, gravel mostly volcanic with some quartzite and dolomite, no roots, saturated from 0.46 to 0.76 meter. Information from hand dug pit near drill rig.
1.07	1.98	Sand and gravel, some silt, moderately sorted, moist. Cored from 1.07 to 1.98 meters, recovered 91 centimeters.
1.98	2.59	Sand and gravel, some silt, moderately sorted, moist. Cored from 1.98 to 2.59 meters, recovered 61 centimeters.
2.59	3.51	Sand and gravel, some silt, moderately sorted, wet. Perched water. Cored from 2.59 to 3.51 meters, recovered 92 centimeters.
3.51	4.11	Sand and gravel, some silt, moderately sorted, moist. Cored from 3.51 to 4.11 meters, recovered 60 centimeters.
4.11	5.09	Sand and gravel, some silt, moderately sorted, moist. Cored from 4.11 to 5.09 meters, recovered 98 centimeters.
5.09	5.64	Sand and gravel, some silt, moderately sorted, moist. Cored from 5.09 to 5.64 meters, recovered 55 centimeters.
5.64	6.40	Sand and gravel, some silt, moderately sorted, moist. Cored from 5.64 to 6.55 meters, recovered 76 centimeters.
6.55	7.00	Sand and gravel, some silt, moderately sorted, moist. Cored from 6.55 to 7.22 meters, recovered 45 centimeters.
7.22	8.14	Sand and gravel, some silt, moderately sorted, moist. Cored from 7.22 to 8.14 meters, recovered 92 centimeters.
8.14	8.69	Sand and gravel, some silt, moderately sorted, moist. Cored from 8.14 to 8.69 meters, recovered 55 centimeters.
8.69	9.60	Sand and gravel, some silt, moderately sorted, moist. Cored from 8.69 to 9.60 meters, recovered 91 centimeters.
9.60	10.21	Sand and gravel, some silt, moderately sorted, moist. Cored from 9.60 to 10.21 meters, recovered 61 centimeters.
10.21	11.09	Sand and gravel, some silt, moderately sorted, moist. Cored from 10.21 to 11.13 meters, recovered 88 centimeters.
11.13	11.73	Sand and gravel, some silt, moderately sorted, moist. Cored from 11.13 to 11.73 meters, recovered 60 centimeters.
11.73	12.65	Sand and gravel, some silt, moderately sorted, moist. Cored from 11.73 to 12.65 meters, recovered 92 centimeters.
12.65	13.26	Sand and gravel, some silt, moderately sorted, moist. Cored from 12.65 to 13.26 meters, recovered 61 centimeters.

Lithologic log for hole: ARAS1

Date: February 27, 2001

Location: In Amargosa River channel about 100 meters downstream of dirt road where it crosses channel west of the old Ashton site along the Tonopah and Tidewater Railroad bed. The dirt road intersects Highway 95 about 20 kilometers south of Beatty, Nevada.

UTM Zone 11, NAD 27, Easting 0528846; Northing 4062684; elevation 807 meters; error 6 meters.

Depth below land surface, meters		Lithologic Description
From	To	
13.26	14.17	Sand and gravel, some silt, moderately sorted, moist. Cored from 13.26 to 14.17 meters, recovered 91 centimeters.
14.17	14.78	Sand and gravel, some silt, moderately sorted, moist. Cored from 14.17 to 14.78 meters, recovered 61 centimeters. End of hole.

APPENDIX B. – WATER CONTENT AND WATER POTENTIAL OF SEDIMENTS, AND SELECTED CHEMICAL PROPERTIES OF WATER EXTRACTS

Water content and water potential of sediments, and selected chemical properties of 1:1 water extracts from cores collected in an area of undisturbed native vegetation, the channel of the Amargosa River, and irrigated fields, Amargosa Desert, Nye County, Nevada, February 2001. Locations of holes are given in table 1 and figure 2.

Hole AFCA1

Depth of core midpoint, (meters below land surface)	Gravimetric water content (gram per gram)	Total potential (megapascals)	Chemistry of water extract from cores					
			Specific conductance (micro-siemens)	pH (units)	Concentrations in milligrams per liter			
					Chloride	Sulfate	Nitrate	Nitrite
0.05	0.063	-0.27	180	7.69	0.41	1.59	0.25	0.00
0.27	0.087	-0.21	165	8.46	0.31	2.29	0.13	1.59
0.53	0.024	-7.76	151	8.73	0.87	1.60	2.79	0.00
0.84	0.026	-10.11	260	8.91	3.60	9.70	3.55	0.00
1.14	0.019	-12.12	524	8.52	30.10	93.01	9.67	0.00
1.45	0.025	-15.97	763	7.67	79.92	157.09	17.71	0.00
1.60	0.026	-13.36	601	7.59	84.03	68.09	17.55	0.00
1.75	0.021	--	509	7.48	68.88	33.87	14.29	0.00
1.75	0.023	-16.07	509	7.46	78.39	35.69	16.20	0.00
1.87	0.022	-15.76	467	7.36	67.11	31.90	14.28	0.00
2.00	0.021	-18.40	556	7.41	56.25	87.91	12.93	0.00
2.19	0.023	-16.93	515	7.44	75.37	30.11	17.37	0.00
2.32	0.022	-16.56	465	7.43	64.66	24.02	15.05	0.00
2.67	0.048	-9.00	776	8.29	77.80	80.32	41.63	0.00
2.97	0.072	-7.11	1220	8.17	65.26	118.67	34.56	0.00
3.28	0.061	-8.51	1430	7.64	42.88	196.08	23.66	0.00
3.58	0.041	-9.89	744	7.58	45.59	205.53	25.22	0.00
3.89	0.070	-6.90	879	7.64	100.32	152.09	55.15	0.00
4.19	0.057	-7.05	1320	7.47	35.50	214.76	17.38	0.00
4.50	0.066	-7.19	1370	7.60	67.09	438.48	33.02	0.00
4.80	0.052	-7.05	573	7.74	58.87	91.20	27.67	0.00
5.11	0.038	-9.23	439	7.77	39.42	61.66	22.56	0.00
5.72	0.065	-8.07	840	7.71	61.29	191.32	52.29	0.00
6.17	0.113	-6.47	1050	7.65	109.26	174.77	88.01	0.00
6.78	0.044	-10.08	294	7.46	28.13	40.01	27.89	0.00
7.39	0.063	-7.81	313	7.75	30.72	41.17	33.91	0.00
8.00	0.050	-8.54	201	7.62	15.35	21.28	17.07	0.00
8.61	0.032	-7.07	108	7.62	7.90	9.11	9.08	0.00
8.92	0.040	-5.55	117	7.72	6.31	13.91	6.90	0.00
10.29	0.045	-6.53	69	7.91	2.11	5.29	1.71	0.00
10.59	0.048	-5.70	850	7.93	3.56	9.12	2.27	0.00
12.57	0.028	-5.51	54	7.99	1.65	5.12	0.85	0.00
12.88	0.038	-4.29	60	7.94	1.83	6.50	1.18	0.00
13.49	0.036	-4.45	81	8.06	1.69	10.86	1.30	0.00
13.79	0.037	-2.89	96	7.84	2.13	17.54	1.29	0.00
14.22	0.030	-3.82	62	6.53	1.57	8.42	0.59	0.00

Hole AFCA2

Depth of core midpoint, (meters below land surface)	Gravimetric water content(gram per gram)	Total potential (megapascals)	Chemistry of water extract from cores					
			Specific conductance (micro-siemens)	pH (units)	Concentrations in milligrams per liter			
					Chloride	Sulfate	Nitrate	Nitrite
0.05	0.098	-0.27	739	7.23	2.40	15.09	0.01	0.00
0.27	0.057	-0.41	330	8.25	3.58	15.52	0.16	12.32
0.53	0.031	-5.18	269	9.17	1.96	6.79	2.41	3.34
0.84	0.080	-1.38	670	9.20	7.97	186.24	5.77	0.00
1.13		-1.66						
1.25	0.158		904	8.65	14.44	213.19	2.92	0.00
1.37		-1.10						
1.49	0.092		208	8.71	4.70	18.71	0.00	0.00
1.62		-0.97						
2.06		-2.64						
2.21	0.111		157	8.63	6.20	17.08	1.01	0.00
2.36		-0.55						
2.51	0.159		577	9.19	10.90	48.08	0.64	4.65
2.73		-1.24						
2.88	0.047	-1.94	102	8.59	2.79	23.19	0.21	0.00
3.58	0.133	-0.41	774	8.27	9.86	269.99	2.69	0.00
3.89	0.210	-0.28	728	8.10	44.84	269.03	6.13	0.00
4.34	0.119	-0.41	652	8.01	36.27	195.29	4.89	0.00
4.65	0.097		597	8.14	18.84	206.82	2.77	0.00
4.95	0.063	-0.41	206	8.12	5.86	54.56	0.81	0.00
5.26	0.103		332	8.40	11.44	100.82	1.55	0.00
5.56	0.045	-0.41	125	8.16	3.28	26.87	0.37	0.00
5.87	0.030	-2.36	95	8.29	2.62	19.04	0.21	0.00
6.17	0.200		548	7.91	30.22	154.33	3.15	0.00
6.48		-0.28						
6.78	0.220		968	8.16	81.88	269.77	8.87	0.00
7.39	0.277		1800	7.75	213.88	492.75	15.24	0.00
7.70		-0.41						
8.00	0.158		2310	7.50	369.27	531.34	52.71	0.00
8.31	0.119	-0.83	1540	7.52	247.89	290.55	86.87	0.00
8.92	0.136	-1.11	1620	7.24	337.63	180.26	80.93	0.00
9.68	0.066	-1.52	725	7.37	163.35	40.95	52.18	0.00
9.98	0.041	-1.94	132	7.68	22.32	11.24	3.30	0.00
10.44	0.039	-2.08	229	7.46	46.35	15.06	6.38	0.00
11.19	0.104		769	7.38	149.82	91.69	22.95	0.00
11.66	0.050	-0.69	540	7.18	104.95	56.77	17.20	0.00
11.96	0.055	-1.80	306	8.39	50.60	20.74	6.89	0.00

Hole AFCA3

Depth of core midpoint, (meters below land surface)	Gravimetric water content (gram per gram)	Total potential (megapascals)	Chemistry of water extract from cores					
			Specific conductance (micro-siemens)	pH (units)	Concentrations in milligrams per liter			
					Chloride	Sulfate	Nitrate	Nitrite
0.06	0.092	-0.83	569	6.74	4.08	15.31	0.049	0.00
0.32	0.060	>-0.30	361	7.43	2.94	11.69	1.430	16.01
0.62	0.036	-4.33	277	8.04	3.10	12.47	0.000	0.00
0.93	0.039	-2.92	281	7.64	5.38	23.98	4.978	1.98
1.22	0.098	-0.55	240	7.95	1.99	8.77	1.838	0.00
1.46	0.084	-0.41	116	7.93	1.49	7.98	0.613	0.00
1.75	0.054	-0.55	142	8.3	1.12	5.20	1.423	0.00
2.16	0.120	-0.55	184	8.27	2.28	7.76	0.374	0.00
2.41	0.181	-0.41	486	8.43	3.85	15.84	1.771	0.00
2.65	0.090	-0.69	112	8.22	1.37	8.69	0.999	0.00
2.90		-0.55						
3.03	0.115		86	7.62	1.95	6.62	0.734	0.00
3.19		-0.55						
3.34	0.259		160	7.79	4.43	18.09	2.220	0.00
3.49		>-0.3						
3.64	0.177		160	7.88	3.05	14.64	1.621	0.00
3.79		>-0.3						
4.19	0.115	>-0.3	137	7.89	2.63	10.41	0.431	0.00
4.50	0.061	>-0.3	111	8.04	1.20	9.43	0.167	0.00
4.80		-3.46						
4.95	0.036		84	7.74	0.76	11.14	0.000	0.00
5.11		-0.82						
5.72	0.048	>-0.30	108	7.89	0.53	8.09	0.084	0.00
6.32	0.033	-0.82	97	8.05	0.47	4.18	0.000	0.00
6.84	0.033	>-0.30	64	7.85	0.39	2.24	0.000	0.00
7.39	0.200	>-0.30	124	7.56	0.79	27.09	1.481	0.00
8.00	0.065	>-0.30	74	7.79	0.94	7.99	0.237	0.00
8.61	0.071	>-0.30	162	8.16	1.61	17.19	0.574	0.00
9.22	0.166	>-0.30	299	7.44	10.88	90.39	2.839	0.00
9.83	0.237	>-0.30	152	7.79	7.69	24.61	1.891	0.00
10.44	0.101	>-0.30	121	7.85	3.46	17.42	0.745	0.00
11.05	0.153	>-0.30	321	8.22	7.20	42.40	1.735	0.00
11.66	0.226	-0.55	861	8.91	63.51	227.32	9.800	0.00
12.27	0.077	-0.55	173	7.75	26.82	15.60	2.431	0.00
13.34	0.324	>-0.30	832	7.89	199.98	51.44	13.597	0.00
14.10	0.082	>-0.30	77	8.23	5.62	6.18	1.331	0.00
14.40	0.052	-0.69	58	8.24	2.26	3.92	0.779	0.00

Hole AFCA4

Depth of core midpoint, (meters below land surface)	Gravimetric water content (gram per gram)	Total potential (megapascals)	Chemistry of water extract from cores					
			Specific conductance (micro-siemens)	pH (units)	Concentrations in milligrams per liter			
					Chloride	Sulfate	Nitrate	Nitrite
0.08		-0.41						
0.23	0.069		530	6.59	9.17	12.13	0.017	0.00
0.38		-0.41						
0.53	0.055		275	8.1	0.80	8.36	5.518	5.56
0.69	0.059	>-0.30	263	8.41	1.14	7.06	8.10	1.90
0.84	0.141		366	8.31	2.12	21.36	9.584	5.79
1.14	0.055	>-0.30	210	8.48	1.00	19.29	2.561	0.00
1.45	0.053	>-0.30	208	8.59	1.55	6.59	1.662	0.00
1.75	0.073	>-0.30	226	8.64	1.30	7.93	2.593	0.00
2.21	0.082	>-0.30	233	8.56	1.36	8.93	2.233	0.00
2.51	0.151	>-0.30	316	8.44	2.45	11.41	2.922	0.00
2.82	0.181	-0.41	290	8.42	2.70	14.09	2.687	0.00
3.12	0.144	-0.69	262	8.45	2.25	8.65	2.530	0.00
3.43	0.028	-1.24	111	8.41	1.32	9.68	2.639	0.00
3.73	0.096	-0.41	124	8.27	1.69	9.80	1.576	0.00
4.27	0.052	-0.41	180	8.86	0.90	4.93	0.449	0.00
4.80	0.026	-0.41	133	8.64	0.91	6.48	0.564	0.00
5.26	0.051	>-0.30	69	8.06	0.79	9.77	0.341	0.00
5.56	0.052		151	8.57	1.10	11.29	1.011	0.00
5.93	0.059	>-0.30	115	8.44	0.74	6.67	0.520	0.00
6.42	0.022		112	8.31	1.20	10.38	1.464	0.00
6.60		-0.41						
7.09	0.178		350	8.65	3.21	20.97	3.690	0.00
7.33		>-0.30						
7.64	0.096		232	8.56	2.08	15.29	4.378	0.00
7.94		>-0.30						
8.31	0.142		388	8.18	9.62	64.55	19.077	0.00
8.61		>-0.30						
8.92	0.205		374	7.68	11.33	79.57	35.735	0.00
9.22	0.233	>-0.30	492	7.55	14.50	92.48	44.795	0.00
9.77	0.100	>-0.30	291	8.37	7.02	47.01	18.815	0.00

Hole AFCA5

			Chemistry of water extract from cores					
					Concentrations in milligrams per liter			
Depth of core midpoint, (meters below land surface)	Gravimetric water content (gram per gram)	Total potential (megapascals)	Specific conductance (micro- siemens)	pH (units)	Chloride	Sulfate	Nitrate	Nitrite
0.08	0.110	>-0.30	819	7.14	1.22	18.06	0.42	0.00
0.38	0.089	>-0.30	455	7.74	2.11	12.23	8.10	0.00
0.69	0.142	-0.41	1040	8.93	18.79	119.62	0.00	0.00
0.84	0.077		1492	9.04	50.96	366.54	118.07	0.00
1.16	0.036	-0.97	362	9.53	2.43	8.07	1.74	0.00
1.33	0.032		356	9.4	2.41	7.05	1.27	0.00
2.70	0.059	>-0.30	380	9.13	5.34	37.23	2.63	0.00
3.00	0.120	-0.41	446	9.04	6.89	46.58	5.94	0.00
3.61	0.051		188	8.92	1.92	8.59	1.67	0.00
3.83		>-0.30						
4.19	0.044		172	8.54	2.45	11.29	1.98	0.00
4.34		>-0.30						
4.50	0.084		233	8.06	6.68	38.07	4.14	0.00
4.65		>-0.30						
4.77	0.098		322	8.38	7.41	47.64	3.18	0.00
4.92		>-0.30						
5.26	0.107		269	7.83	7.91	58.14	3.29	0.00
5.56	0.267	>-0.30	503	7.72	19.15	118.92	6.46	0.00
6.02	0.133	>-0.30	405	7.87	12.76	86.90	4.99	0.00
6.32	0.114		360	7.73	12.45	89.58	8.25	0.00
6.60		>-0.30						
6.87	0.389		600	7.48	25.41	170.83	84.25	0.00
7.39	0.072	>-0.30	167	6.93	4.52	24.06	23.26	0.00
7.70	0.038		104	6.94	3.47	15.32	11.46	0.00
8.00		>-0.30						
8.31	0.030		72	7.21	2.03	11.84	4.33	0.00
8.58		>-0.30						
8.85	0.013		95	7.91	0.99	4.16	0.78	0.00
9.13	0.019		64	7.39	1.07	4.52	0.71	0.00
9.40		-1.23						
9.65	0.230	>-0.30	341	8.25	8.03	53.70	10.03	0.00

Hole AFPL1

Depth of core midpoint, (meters below land surface)	Gravimetric water content (gram per gram)	Total potential (megapascals)	Chemistry of water extract from cores					
			Specific conductance (micro-siemens)	pH (units)	Concentrations in milligrams per liter			
					Chloride	Sulfate	Nitrate	Nitrite
0.03		0.00						
0.26	0.048	-1.24	277	7.86	1.88	24.33	0.00	0.00
0.41		-0.82						
0.56	0.047	-0.41	271	7.87	1.45	16.70	1.45	2.75
0.87	0.076	0.00	302	8.32	2.46	25.16	2.89	7.03
1.45		0.00						
1.60	0.065		351	9.07	3.18	25.45	8.88	0.00
1.75		0.14						
1.91	0.075	0.27	298	9.21	2.12	20.74	2.89	0.00
2.21	0.146	0.00	557	9.16	5.53	113.51	14.98	0.00
2.36		0.00						
2.51	0.237		840	8.66	13.73	233.16	38.44	0.00
2.76		0.14						
2.91	0.043		154	8.93	3.28	10.92	1.94	0.00
3.06		0.41						
3.22	0.049		148	8.84	2.33	7.26	1.26	0.00
3.61	0.043	-0.14	122	8.72	1.69	5.90	1.74	0.00
3.92	0.080	-0.14	154	7.81	2.27	12.02	4.45	0.00
4.40	0.070	0.00	96	7.96	1.90	9.18	2.99	0.00
4.86	0.067		93	7.91	1.82	8.65	3.24	0.00
5.26	0.061	0.14	109	7.93	1.47	6.96	1.82	0.00
5.78	0.150	-0.14	299	8.39	4.39	27.66	11.60	0.00
6.39	0.086	0.00	199	8.71	2.75	22.42	5.73	0.00
6.78	0.062		164	8.83	2.63	18.23	3.74	0.00
7.39	0.130	-0.14	297	8.38	7.65	62.79	8.52	0.00
8.00	0.092		272	8.52	8.33	61.01	8.11	0.00
8.31		0.00						
8.61	0.111		400	7.81	9.06	51.66	11.04	0.00
9.19	0.106		340	8.22	7.82	66.60	9.47	0.00
9.49		-0.14						
9.86	0.071		182	7.96	5.82	41.39	5.96	0.00
10.17		0.00						
10.41	0.149		526	8.25	19.39	150.45	14.82	0.00
11.26	0.189	0.00	1059	7.98	91.94	328.71	35.64	0.00
11.51	0.182	0.00	957	8.29	122.52	235.42	38.37	0.00
13.61	0.058	0.14	231	7.86	12.69	24.87	4.11	0.00
14.22	0.213	-0.14	627	7.81	106.65	66.34	25.26	0.00
14.52	0.208	0.00	611	7.75	100.51	71.08	24.02	0.00

Hole AFPL2

Depth of core midpoint, (meters below land surface)	Gravimetric water content (gram per gram)	Total potential (megapascals)	Chemistry of water extract from cores					
			Specific conductance (micro-siemens)	pH (units)	Concentrations in milligrams per liter			
					Chloride	Sulfate	Nitrate	Nitrite
0.17	0.164	>-0.30	3320	7.12	11.00	34.715	129.13	177.20
0.47	0.074	>-0.30	570	7.76	3.80	3.895	14.20	4.38
0.78	0.102	>-0.30	767	8.09	5.34	6.333	12.19	0.00
1.17	0.078	>-0.30	693	7.95	5.56	5.177	24.36	4.51
1.45	0.115	>-0.30	794	8.29	8.25	6.873	5.44	0.00
1.75	0.059	>-0.30	459	8.96	7.33	2.639	5.08	0.00
2.03	0.135	>-0.30	741	8.7	30.59	4.482	20.30	0.00
2.30	0.073	>-0.30	251	9.05	11.94	0.413	4.58	0.00
2.76	0.043	>-0.30	267	9.37	6.18	0.165	2.06	0.00
4.19	0.143	>-0.30	369	9.02	6.63	0.313	2.90	0.00
4.50	0.208	>-0.30	395	8.91	6.52	0.442	2.96	0.00
4.86	0.120	>-0.30	334	9.01	8.32	0.625	1.63	0.00
5.26	0.198	>-0.30	312	8.98	3.34	0.313	1.80	0.00
5.56	0.195	>-0.30	145	8.58	3.10	0.226	1.64	0.00
6.11	0.193	>-0.30	212	8.56	4.51	0.396	2.46	0.00
6.78	0.078	>-0.30	185	8.78	1.37	0.151	0.75	0.00
7.09	0.048	>-0.30	61.9	8.52	0.87	0.103	0.70	0.00
7.60	0.142	>-0.30	87.9	8.3	1.52	0.159	1.03	0.00
7.91	0.106	>-0.30	96.1	8.51	1.71	0.180	1.14	0.00
8.31	0.056	>-0.30	64.7	8.41	0.68	0.069	0.43	0.00
8.85	0.081	>-0.30	84.3	8.26	0.93	0.106	0.52	0.00
9.40	0.061	>-0.30	152	8.84	1.39	0.145	0.92	0.00
9.83	0.119	>-0.30	187	8.92	1.50	0.180	1.13	0.00
10.41	0.124	>-0.30	156	8.35	1.84	0.205	1.08	0.00
11.02	0.210	>-0.30	198	8.82	2.14	0.330	1.31	0.00
11.35	0.166	>-0.30	183	8.52	1.14	0.152	0.49	0.00
12.27	0.282	>-0.30	249	8.56	2.09	0.288	0.75	0.00
12.57	0.151	>-0.30	79.5	7.88	1.38	0.161	0.70	0.00
13.18	0.211	>-0.30	106	8.1	2.22	0.288	1.62	0.00
14.10	0.157	>-0.30	89.3	7.89	1.91	0.194	1.51	0.00
15.04	0.151	>-0.30	67	7.93	1.68	0.198	1.89	0.00
16.02	0.227	>-0.30	91.2	7.81	2.05	0.263	2.37	0.00

Hole ARRB1

Depth of core midpoint, (meters below land surface)	Gravimetric water content (gram per gram)	Total potential (megapascals)	Chemistry of water extract from cores					
			Specific conductance (micro-siemens)	pH (units)	Concentrations in milligrams per liter			
					Chloride	Sulfate	Nitrate	Nitrite
0.08	0.108	>-0.30	362	8.93	2.01	6.41	7.67	0.124
0.38		>-0.30						
0.69		>-0.30						
1.14	0.103	>-0.30	401	9.12	9.25	15.98	0.01	0.000
1.45		>-0.30						
2.30	0.141	>-0.30	712	9.14	17.32	24.88	0.00	0.000
2.67	0.139		542	9.16	12.04	19.27	0.00	0.000
3.11	0.118	>-0.30	594	8.96	13.43	19.90	0.00	0.000
3.58	0.139		595	8.98	15.21	20.32	0.00	0.000
4.05		>-0.30						
4.50	0.113		581	9.11	12.02	16.95	0.00	0.000
4.80		>-0.30						
5.11	0.125		516	8.88	16.07	23.28	0.00	0.000
5.53	0.125	>-0.30	585	8.7	18.16	24.70	0.10	0.002
5.87	0.263				32.77	47.84	0.36	0.006
6.32	0.109	>-0.30	440	8.63	14.31	21.53	0.00	0.000
7.09	0.125	-0.41	684	8.88	20.11	30.15	0.00	0.000
7.39	0.098		293	8.23	17.13	26.05	0.00	0.000
7.70	0.123	>-0.30	506	8.71	17.70	27.24	0.00	0.000
8.31	0.096	>-0.30	379	8.42	14.51	22.47	0.00	0.000
8.92	0.087	>-0.30	299	7.76	11.62	16.62	0.00	0.000
9.53	0.101	>-0.30	537	8.35	5.70	8.98	0.00	0.000
10.13	0.129	-0.55	341	7.97	14.65	21.68	0.00	0.000
10.84	0.128	>-0.30	340	7.81	14.27	21.96	0.00	0.000
11.35	0.108		225	7.68	8.60	13.07	0.00	0.000
11.66		>-0.30						
11.96	0.121	>-0.30	278	7.9	12.28	18.61	0.00	0.000
12.27		>-0.30						
12.57	0.125		402	8.04	13.34	21.61	0.00	0.000
12.88		>-0.30						
13.18	0.107		556	8.45	14.51	22.33	1.07	0.017
13.49		>-0.30						
13.79	0.137		257	7.58	14.40	23.96	0.61	0.010
14.10		>-0.30						
14.40	0.110	>-0.30	382	7.68	17.45	28.23	0.00	0.000

Hole ARAS1

Depth of core midpoint, (meters below land surface)	Gravimetric water content (gram per gram)	Total potential (megapascals)	Chemistry of water extract from cores					
			Specific conductance (micro-siemens)	pH (units)	Concentrations in milligrams per liter			
					Chloride	Sulfate	Nitrate	Nitrite
0.08	0.065	>0.30	278	8.66	0.60	2.54	0.56	0.00
0.53			165	8.41	15.48	25.92	40.70	0.00
1.60	0.119		250	8.29	8.02	11.65	0.00	0.00
1.91	0.118	>0.30	285	7.72	12.59	13.72	0.00	0.00
2.21	0.248		706	8.25	21.32	34.39	0.09	6.92
2.51	0.096	>0.30	248	7.91	8.14	10.75	0.00	0.00
2.82	0.115		351	8.22	9.79	13.12	0.84	0.00
3.12	0.146	>0.30	495	8.3	13.01	20.12	1.39	2.20
3.43	0.102		228	7.73	15.03	15.10	0.01	0.00
4.40	0.070		197	7.82	6.59	11.35	0.00	0.00
4.74	0.089	>0.30	272	7.74	8.59	30.58	0.00	0.00
5.01	0.114		257	7.7	11.10	23.97	0.41	0.00
5.56	0.102	>0.30	347	7.84	11.38	22.97	0.00	0.00
5.87	0.098		243	7.75	9.35	22.95	0.17	0.00
6.17	0.129	>0.30	331	7.33	12.26	41.27	0.00	0.00
6.78	0.097	>0.30	316	7.66	9.15	31.51	0.01	0.00
7.45	0.098	>0.30	1161	7.38	8.99	479.91	0.00	0.00
8.31	0.112		2050	7.36	8.85	978.26	0.00	0.00
8.92	0.092		870	7.41	9.20	345.98	0.02	0.00
9.22		>0.30						
9.53	0.105		750	7.41	11.10	283.66	0.05	0.00
10.13	0.080		619	7.28	11.16	226.22	0.20	0.00
10.41		>0.30						
10.71	0.065		606	7.25	9.23	223.26	0.72	0.00
11.35	0.112		750	7.35	19.10	276.73	3.17	0.00
11.66		-0.41						
12.12	0.107		708	7.34	34.29	231.95	3.50	0.00
12.27		-0.55						
12.57	0.120		811	7.35	52.92	256.20	5.60	0.00
12.88		>0.30						
13.18	0.094		643	7.35	35.04	204.40	3.50	0.00
13.49		>0.30						
13.79	0.084		731	7.26	77.22	184.46	4.83	0.00
14.10		-0.82						
14.40	0.110		1092	7.65	183.38	177.84	10.30	0.00
14.71		-0.69						

APPENDIX C. – CHLORIDE, SULFATE, AND NITRATE CONCENTRATIONS IN PORE WATER

Chloride, sulfate, and nitrate concentrations in pore water from beneath undisturbed vegetation and irrigated fields of the Amargosa-Farms area, and in the Amargosa-River channel, Amargosa Desert, Nye County, Nevada. Sample locations are given in table 1 and figure 2.

Hole AFCA1

Depth of core midpoint, (meters below land surface)	Gravimetric water content (gram per gram)	Mass of anion to mass of dry sediment, milligram per gram			Anion concentration in pore water, milligrams per liter		
		Chloride	Sulfate	Nitrate	Chloride	Sulfate	Nitrate
0.05	0.063	0.0004	0.0016	0.0003	7	25	4
0.27	0.087	0.0003	0.0023	0.0001	4	26	2
0.53	0.024	0.0009	0.0016	0.0028	36	67	117
0.84	0.026	0.0036	0.0097	0.0035	136	369	135
1.14	0.019	0.0301	0.0931	0.0097	1590	4920	511
1.45	0.025	0.0799	0.1397	0.0177	3210	5610	711
1.60	0.026	0.0840	0.0606	0.0175	3280	2370	685
1.75	0.021	0.0689	0.0301	0.0143	3210	1400	667
1.75	0.023	0.0784	0.0317	0.0162	3350	1360	693
1.87	0.022	0.0671	0.0283	0.0143	3080	1300	656
2.00	0.021	0.0562	0.0780	0.0129	2620	3630	602
2.19	0.023	0.0754	0.0268	0.0174	3250	1150	749
2.32	0.022	0.0647	0.0213	0.0151	2910	961	678
2.67	0.048	0.0778	0.0803	0.0416	1640	1690	875
2.97	0.072	0.0653	0.1186	0.0346	909	1650	481
3.28	0.061	0.0429	0.1961	0.0237	699	3190	385
3.58	0.041	0.0456	0.2057	0.0252	1100	4980	611
3.89	0.070	0.1003	0.1520	0.0551	1440	2180	792
4.19	0.057	0.0355	0.2149	0.0174	626	3790	307
4.50	0.066	0.0671	0.4387	0.0330	1020	6650	500
4.80	0.052	0.0589	0.0912	0.0277	1140	1760	534
5.11	0.038	0.0394	0.0617	0.0226	1040	1630	595
5.72	0.065	0.0613	0.1914	0.0523	937	2930	800
6.17	0.113	0.1093	0.1748	0.0880	964	1540	776
6.78	0.044	0.0281	0.0400	0.0279	633	900	628
7.39	0.063	0.0307	0.0412	0.0339	486	651	536
8.00	0.050	0.0153	0.0213	0.0171	309	428	343
8.61	0.032	0.0079	0.0091	0.0091	245	283	282
8.92	0.040	0.0063	0.0139	0.0069	159	350	173
10.29	0.045	0.0021	0.0053	0.0017	47	118	38
10.59	0.048	0.0036	0.0091	0.0023	74	188	47
12.57	0.028	0.0017	0.0051	0.0008	58	181	30
12.88	0.038	0.0018	0.0065	0.0012	48	170	31
13.49	0.036	0.0017	0.0109	0.0013	47	301	36
13.79	0.037	0.0021	0.0175	0.0013	58	479	35
14.22	0.030	0.0016	0.0084	0.0006	53	283	20

Hole AFCA2

Depth of core midpoint, (meters below land surface)	Gravimetric water content (gram per gram)	Mass of anion to mass of dry sediment, milligram per gram			Anion concentration in pore water, milligrams per liter		
		Chloride	Sulfate	Nitrate	Chloride	Sulfate	Nitrate
0.05	0.098	0.0024	0.0151	0.0000	25	155	0
0.27	0.057	0.0036	0.0155	0.0002	62	270	3
0.53	0.031	0.0020	0.0068	0.0024	63	218	77
0.84	0.080	0.0080	0.1863	0.0058	100	2336	72
1.25	0.158	0.0145	0.2135	0.0029	91	1349	18
1.49	0.092	0.0047	0.0187	0.0000	51	204	0
2.21	0.111	0.0062	0.0171	0.0010	56	154	9
2.51	0.159	0.0109	0.0481	0.0006	69	303	4
2.88	0.047	0.0028	0.0232	0.0002	60	498	4
3.58	0.133	0.0099	0.2700	0.0027	74	2034	20
3.89	0.210	0.0448	0.2690	0.0061	213	1280	29
4.34	0.119	0.0363	0.1953	0.0049	306	1645	41
4.65	0.097	0.0188	0.2068	0.0028	195	2139	29
4.95	0.063	0.0059	0.0546	0.0008	93	862	13
5.26	0.103	0.0114	0.1008	0.0015	111	977	15
5.56	0.045	0.0033	0.0269	0.0004	74	603	8
5.87	0.030	0.0026	0.0190	0.0002	88	644	7
6.17	0.200	0.0302	0.1544	0.0031	151	772	16
6.78	0.220	0.0819	0.2698	0.0089	373	1228	40
7.39	0.277	0.2139	0.4928	0.0152	772	1779	55
8.00	0.158	0.3694	0.5315	0.0527	2345	3374	335
8.31	0.119	0.2479	0.2906	0.0869	2086	2445	731
8.92	0.136	0.3376	0.1803	0.0809	2492	1330	597
9.68	0.066	0.1634	0.0410	0.0522	2469	619	789
9.98	0.041	0.0223	0.0112	0.0033	542	273	80
10.44	0.039	0.0464	0.0151	0.0064	1197	389	165
11.19	0.104	0.1498	0.0917	0.0230	1441	882	221
11.66	0.050	0.1050	0.0568	0.0172	2114	1143	346
11.96	0.055	0.0506	0.0207	0.0069	923	379	126

Hole AFCA3

Depth of core midpoint, (meters below land surface)	Gravimetric water content (gram per gram)	Mass of anion to mass of dry sediment, milligram per gram			Anion concentration in pore water, milligrams per liter		
		Chloride	Sulfate	Nitrate	Chloride	Sulfate	Nitrate
0.06	0.092	0.0041	0.0153	0.0000	44	166	1
0.32	0.060	0.0029	0.0117	0.0014	49	195	24
0.62	0.036	0.0031	0.0125	0.0000	87	349	0
0.93	0.039	0.0054	0.0240	0.0050	140	623	129
1.22	0.098	0.0020	0.0088	0.0018	20	90	19
1.46	0.084	0.0015	0.0080	0.0006	18	96	7
1.75	0.054	0.0011	0.0052	0.0014	21	97	27
2.16	0.120	0.0023	0.0078	0.0004	19	65	3
2.41	0.181	0.0039	0.0158	0.0018	21	87	10
2.65	0.090	0.0014	0.0087	0.0010	15	97	11
3.03	0.115	0.0019	0.0066	0.0007	17	57	6
3.34	0.259	0.0044	0.0181	0.0022	17	70	9
3.64	0.177	0.0031	0.0146	0.0016	17	83	9
4.19	0.115	0.0026	0.0104	0.0004	23	90	4
4.50	0.061	0.0012	0.0094	0.0002	20	154	3
4.95	0.036	0.0008	0.0112	0.0000	21	307	0
5.72	0.048	0.0005	0.0081	0.0001	11	170	2
6.32	0.033	0.0005	0.0042	0.0000	14	126	0
6.84	0.033	0.0004	0.0022	0.0000	12	69	0
7.39	0.200	0.0008	0.0271	0.0015	4	136	7
8.00	0.065	0.0009	0.0080	0.0002	15	123	4
8.61	0.071	0.0016	0.0172	0.0006	23	244	8
9.22	0.166	0.0109	0.0906	0.0028	66	547	17
9.83	0.237	0.0077	0.0246	0.0019	32	104	8
10.44	0.101	0.0035	0.0174	0.0007	34	173	7
11.05	0.153	0.0072	0.0424	0.0017	47	277	11
11.66	0.226	0.0635	0.2274	0.0098	282	1008	43
12.27	0.077	0.0268	0.0156	0.0024	347	202	31
13.34	0.324	0.2001	0.0515	0.0136	618	159	42
14.10	0.082	0.0056	0.0062	0.0013	69	75	16
14.40	0.052	0.0023	0.0039	0.0008	43	76	15

Hole AFCA4

Depth of core midpoint, (meters below land surface)	Gravimetric water content (gram per gram)	Mass of anion to mass of dry sediment, milligram per gram			Anion concentration in pore water, milligrams per liter		
		Chloride	Sulfate	Nitrate	Chloride	Sulfate	Nitrate
0.23	0.069	0.0092	0.0121	0.0000	133	177	0
0.53	0.055	0.0008	0.0084	0.0055	14	151	100
0.69	0.059	0.0011	0.0070	0.0081	19	120	137
0.84	0.141	0.0021	0.0214	0.0096	15	152	68
1.14	0.055	0.0010	0.0194	0.0026	18	353	47
1.45	0.053	0.0016	0.0066	0.0017	29	125	31
1.75	0.073	0.0013	0.0079	0.0026	18	108	35
2.21	0.082	0.0014	0.0089	0.0022	17	109	27
2.51	0.151	0.0025	0.0114	0.0029	16	75	19
2.82	0.181	0.0027	0.0141	0.0027	15	78	15
3.12	0.144	0.0022	0.0087	0.0025	16	60	18
3.43	0.028	0.0013	0.0097	0.0026	48	351	96
3.73	0.096	0.0017	0.0098	0.0016	18	102	16
4.27	0.052	0.0009	0.0049	0.0004	17	95	9
4.80	0.026	0.0009	0.0065	0.0006	36	253	22
5.26	0.051	0.0008	0.0098	0.0003	15	192	7
5.56	0.052	0.0011	0.0113	0.0010	21	219	20
5.93	0.059	0.0007	0.0067	0.0005	13	113	9
6.42	0.022	0.0012	0.0104	0.0015	55	479	68
7.09	0.178	0.0032	0.0210	0.0037	18	118	21
7.64	0.096	0.0021	0.0153	0.0044	22	160	46
8.31	0.142	0.0096	0.0644	0.0190	68	454	134
8.92	0.205	0.0113	0.0793	0.0356	55	388	174
9.22	0.233	0.0145	0.0925	0.0448	62	397	192
9.77	0.100	0.0070	0.0471	0.0189	70	469	188

Hole AFCA5

Depth of core midpoint, (meters below land surface)	Gravimetric water content (gram per gram)	Mass of anion to mass of dry sediment, milligram per gram			Anion concentration in pore water, milligrams per liter		
		Chloride	Sulfate	Nitrate	Chloride	Sulfate	Nitrate
0.08	0.110	0.0012	0.0181	0.0004	11	164	4
0.38	0.089	0.0021	0.0123	0.0081	24	139	92
0.69	0.142	0.0188	0.1196	0.0000	132	843	0
0.84	0.077	0.0510	0.3665	0.1181	663	4765	1535
1.16	0.036	0.0024	0.0081	0.0017	68	227	49
1.33	0.032	0.0024	0.0070	0.0013	74	218	39
2.70	0.059	0.0053	0.0371	0.0026	90	625	44
3.00	0.120	0.0069	0.0465	0.0059	57	388	49
3.61	0.051	0.0019	0.0086	0.0017	38	168	33
4.19	0.044	0.0024	0.0113	0.0020	56	256	45
4.50	0.084	0.0067	0.0381	0.0041	79	452	49
4.77	0.098	0.0074	0.0476	0.0032	76	488	33
5.26	0.107	0.0079	0.0581	0.0033	74	544	31
5.56	0.267	0.0191	0.1189	0.0065	72	445	24
6.02	0.133	0.0127	0.0867	0.0050	96	651	37
6.32	0.114	0.0124	0.0896	0.0082	109	787	72
6.87	0.389	0.0254	0.1708	0.0842	65	439	217
7.39	0.072	0.0045	0.0240	0.0232	62	333	322
7.70	0.038	0.0035	0.0153	0.0115	92	405	303
8.31	0.030	0.0020	0.0118	0.0043	66	387	141
8.85	0.013	0.0010	0.0042	0.0008	75	318	59
9.13	0.019	0.0011	0.0045	0.0007	55	233	36
9.65	0.230	0.0080	0.0535	0.0100	35	233	44

Hole AFPL1

Depth of core midpoint, (meters below land surface)	Gravimetric water content (gram per gram)	Mass of anion to mass of dry sediment, milligram per gram			Anion concentration in pore water, milligrams per liter		
		Chloride	Sulfate	Nitrate	Chloride	Sulfate	Nitrate
0.26	0.048	0.0019	0.0242	0.0000	39	507	0
0.56	0.047	0.0015	0.0168	0.0015	31	360	31
0.87	0.076	0.0025	0.0251	0.0029	32	330	38
1.60	0.065	0.0032	0.0255	0.0089	49	391	136
1.91	0.075	0.0021	0.0207	0.0029	28	276	38
2.21	0.146	0.0055	0.1137	0.0150	38	781	103
2.51	0.237	0.0137	0.2327	0.0384	58	981	162
2.91	0.043	0.0033	0.0109	0.0019	77	256	45
3.22	0.049	0.0023	0.0073	0.0013	48	149	26
3.61	0.043	0.0017	0.0059	0.0017	39	137	40
3.92	0.080	0.0023	0.0120	0.0044	28	149	55
4.40	0.070	0.0019	0.0092	0.0030	27	131	43
4.86	0.067	0.0018	0.0086	0.0032	27	129	48
5.26	0.061	0.0015	0.0070	0.0018	24	114	30
5.78	0.150	0.0044	0.0276	0.0116	29	184	77
6.39	0.086	0.0028	0.0224	0.0057	32	259	66
6.78	0.062	0.0026	0.0182	0.0037	42	292	60
7.39	0.130	0.0076	0.0626	0.0085	59	481	65
8.00	0.092	0.0083	0.0609	0.0081	90	660	88
8.61	0.111	0.0091	0.0517	0.0111	82	465	99
9.19	0.106	0.0078	0.0665	0.0095	74	630	90
9.86	0.071	0.0058	0.0413	0.0059	82	580	84
10.41	0.149	0.0193	0.1501	0.0148	130	1006	99
11.26	0.189	0.0917	0.3279	0.0356	485	1736	188
11.51	0.182	0.1220	0.2344	0.0382	672	1291	210
13.61	0.058	0.0127	0.0248	0.0041	220	431	71
14.22	0.213	0.1072	0.0667	0.0254	502	312	119
14.52	0.208	0.1006	0.0712	0.0241	484	342	116

Hole AFPL2

Depth of core midpoint, (meters below land surface)	Gravimetric water content (gram per gram)	Mass of anion to mass of dry sediment, milligram per gram			Anion concentration in pore water, milligrams per liter		
		Chloride	Sulfate	Nitrate	Chloride	Sulfate	Nitrate
0.17	0.164	0.0110	1.6647	0.1289	67	10159	787
0.47	0.074	0.0038	0.1866	0.0142	51	2535	192
0.78	0.102	0.0053	0.3044	0.0122	52	2978	119
1.17	0.078	0.0056	0.2489	0.0244	71	3172	311
1.45	0.115	0.0082	0.3295	0.0054	71	2859	47
1.75	0.059	0.0073	0.1267	0.0051	125	2155	86
2.03	0.135	0.0306	0.2154	0.0203	226	1591	150
2.30	0.073	0.0119	0.0198	0.0046	164	273	63
2.76	0.043	0.0062	0.0079	0.0021	144	184	48
4.19	0.143	0.0066	0.0151	0.0029	46	105	20
4.50	0.208	0.0065	0.0212	0.0030	31	102	14
4.86	0.120	0.0083	0.0300	0.0016	69	250	14
5.26	0.198	0.0033	0.0150	0.0018	17	76	9
5.56	0.195	0.0031	0.0109	0.0016	16	56	8
6.11	0.193	0.0045	0.0190	0.0025	23	99	13
6.78	0.078	0.0014	0.0072	0.0007	18	93	10
7.09	0.048	0.0009	0.0050	0.0007	18	103	14
7.60	0.142	0.0015	0.0076	0.0010	11	54	7
7.91	0.106	0.0017	0.0086	0.0011	16	82	11
8.31	0.056	0.0007	0.0033	0.0004	12	59	8
8.85	0.081	0.0009	0.0051	0.0005	11	63	6
9.40	0.061	0.0014	0.0070	0.0009	23	114	15
9.83	0.119	0.0015	0.0086	0.0011	13	73	9
10.41	0.124	0.0018	0.0098	0.0011	15	79	9
11.02	0.210	0.0021	0.0159	0.0013	10	76	6
11.35	0.166	0.0011	0.0073	0.0005	7	44	3
12.27	0.282	0.0021	0.0138	0.0007	7	49	3
12.57	0.151	0.0014	0.0077	0.0007	9	51	5
13.18	0.211	0.0022	0.0138	0.0016	11	66	8
14.10	0.157	0.0019	0.0093	0.0015	12	59	10
15.04	0.151	0.0017	0.0095	0.0019	11	63	13
16.02	0.227	0.0020	0.0126	0.0024	9	56	10

Hole ARRB1

Depth of core midpoint, (meters below land surface)	Gravimetric water content (gram per gram)	Mass of anion to mass of dry sediment, milligram per gram			Anion concentration in pore water, milligrams per liter		
		Chloride	Sulfate	Nitrate	Chloride	Sulfate	Nitrate
0.08	0.108	0.0020	0.0064	0.0077	19	60	71
1.14	0.103	0.0093	0.0160	0.0000	90	155	0
2.30	0.141	0.0174	0.0250	0.0000	123	177	0
2.67	0.139	0.0120	0.0193	0.0000	87	139	0
3.11	0.118	0.0134	0.0199	0.0000	114	169	0
3.58	0.139	0.0152	0.0203	0.0000	110	147	0
4.50	0.113	0.0120	0.0170	0.0000	107	151	0
5.11	0.125	0.0161	0.0233	0.0000	129	187	0
5.53	0.125	0.0182	0.0247	0.0001	145	197	1
5.87	0.263	0.0328	0.0479	0.0004	125	182	1
6.32	0.109	0.0143	0.0216	0.0000	132	198	0
7.09	0.125	0.0201	0.0302	0.0000	161	241	0
7.39	0.098	0.0171	0.0261	0.0000	175	266	0
7.70	0.123	0.0177	0.0273	0.0000	144	222	0
8.31	0.096	0.0145	0.0225	0.0000	152	235	0
8.92	0.087	0.0116	0.0166	0.0000	133	190	0
9.53	0.101	0.0057	0.0090	0.0000	56	89	0
10.13	0.129	0.0147	0.0217	0.0000	113	168	0
10.84	0.128	0.0143	0.0220	0.0000	111	171	0
11.35	0.108	0.0086	0.0131	0.0000	80	121	0
11.96	0.121	0.0123	0.0186	0.0000	102	154	0
12.57	0.125	0.0133	0.0216	0.0000	107	173	0
13.18	0.107	0.0145	0.0216	0.0000	136	203	0
13.79	0.137	0.0144	0.0223	0.0011	105	163	8
14.40	0.110	0.0175	0.0240	0.0006	158	218	5

Hole ARAS1

Depth of core midpoint, (meters below land surface)	Gravimetric water content (gram per gram)	Mass of anion to mass of dry sediment, milligram per gram			Anion concentration in pore water, milligrams per liter		
		Chloride	Sulfate	Nitrate	Chloride	Sulfate	Nitrate
0.08	0.065	0.0006	0.0025	0.0006	9	39	9
0.53[1]	--	--	--	--	15	26	41
1.60	0.119	0.0080	0.0117	0.0000	67	98	0
1.91	0.118	0.0126	0.0137	0.0000	107	116	0
2.21	0.248	0.0213	0.0344	0.0001	86	139	0
2.51	0.096	0.0081	0.0108	0.0000	85	112	0
2.82	0.115	0.0098	0.0131	0.0008	85	114	7
3.12	0.146	0.0130	0.0202	0.0014	89	138	10
3.43	0.102	0.0151	0.0151	0.0000	147	148	0
4.40	0.070	0.0066	0.0113	0.0000	93	161	0
4.71	0.089	0.0086	0.0306	0.0000	96	342	0
5.01	0.114	0.0111	0.0240	0.0004	97	210	4
5.56	0.102	0.0114	0.0229	0.0000	111	225	0
5.87	0.098	0.0094	0.0230	0.0002	95	234	2
6.17	0.129	0.0123	0.0413	0.0000	95	321	0
6.78	0.097	0.0092	0.0316	0.0000	94	325	0
7.45	0.098	0.0090	0.4807	0.0000	92	4888	0
8.31	0.112	0.0089	0.9822	0.0000	79	8761	0
8.92	0.092	0.0093	0.3503	0.0000	101	3805	0
9.53	0.105	0.0111	0.2838	0.0001	106	2700	0
10.13	0.080	0.0112	0.2271	0.0002	140	2833	2
10.71	0.065	0.0092	0.2250	0.0007	142	3487	11
11.35	0.112	0.0191	0.2238	0.0032	171	2004	28
12.12	0.107	0.0346	0.2791	0.0035	323	2609	33
12.57	0.120	0.0531	0.2327	0.0056	444	1944	47
13.18	0.094	0.0350	0.2559	0.0035	373	2731	37
13.79	0.084	0.0775	0.2052	0.0048	924	2445	58
14.40	0.110	0.1836	0.1847	0.0103	1667	1677	94

[1] Free water from hand-dug pit near borehole.