# HYDROSTRATIGRAPHIC MODEL FOR THE PERCHED AQUIFER SYSTEMS LOCATED NEAR HAGERMAN FOSSIL BEDS NATIONAL MONUMENT, IDAHO.

A Thesis

Presented in Partial Fulfillment of the Requirements for the

Degree of Master of Science

with a

Major in Geology

in the College of Graduate Studies

University of Idaho

by

Charles Neal Farmer

1998

Major Professor:

Dr. Dale Ralston, Ph.D.

*(some graphs, figures and minor verbiage have been updated for this copy as of March, 2005)*

# AUTHORIZATION TO SUBMIT

# THESIS

This thesis of Charles Neal Farmer, submitted for the degree of Master of Science with a major in Geology and titled "A Hydrostratigraphic Model for the Perched Aquifer Systems Located near Hagerman Fossil Beds National Monument, Idaho," has been reviewed in final form, as indicated by the signatures and dates given below. Permission is now granted to submit final copies to the College of Graduate Studies for approval.

Major Professor ________________________________Date__________
Dr. Dale Ralston

Committee Members ________________________________Date__________
Dr. John Bush

________________________________Date__________
Dr. Lee Sappington

Department Administrator ________________________________Date__________
Dr. John Oldow

Discipline's College Dean ________________________________Date__________
Dr. Earl Bennett

Final Approval and Acceptance by the College of Graduate Studies

________________________________________________Date__________
Jean'ne M. Shreeve

# ABSTRACT

Perched aquifer systems are causing slope failures within the Hagerman Fossil Beds National Monument in northwestern Twin Falls County, Idaho. Six large slope failures have occurred since 1979, which are damaging natural resources and private property. In 1987 a slope failure destroyed a million-dollar irrigation pumping facility and nearly killed two workers. Numerous studies have been conducted since 1984 in an attempt to define the aquifer systems but none have resulted in a document that integrates all of the results. This study includes an analysis of all the previous data in addition to field mapping and investigations with the general objective to construct a hydrostratigraphic model for the site.

A geologic model of the study site was developed based on existing studies and literature, field investigations, drill logs and geophysical data. The proposed geologic model has six layers, three of the layers are aquifers and three are aquitards.

A hydrologic model was developed using existing surface water, monitor well, water chemistry and geophysical data. Recharge to the perched aquifers occurs dominantly from irrigation on the plateau. A ground water pressure wave propagates through the perched aquifer systems starting at the recharge area and moving down gradient to the discharge zones causing cyclic fluctuations in monitor well water levels along the flow path.

A hydrostratigraphic model was developed based on the geologic and hydrologic models. The model shows how three perched aquifer systems (upper, middle and lower) flow in the plateau and the implications of each system has for slope stability problems. Paleo stream channels control the upper and lower systems while the middle system is flowing primarily through fractured basalt. The flow regimes are dynamic; exhibiting both unconfined and confined characteristics.

The hydrostratigraphic model explains the spatial distribution of perched aquifer discharge zones and it will aid the development of a mitigative plan for slope stability problems. Results indicate recharge to the upper system is primarily near the canal inlet, while recharge to the middle basalt aquifer occurs in the area near the Fossil Gulch Pond. The lower system is receiving drainage from the middle system. Canal lining mitigative efforts will have the greatest impact to the middle aquifer system if applied near the Fossil Gulch Pond area. It is recommended to start ground water tracer tests, continue focused data collection and long term monitoring to establish trends and define specific flow regimes.

# ACKNOWLEDGEMENTS

It is difficult to convey in words the magnitude of resources from many individuals this project has required to be completed; opportunity, time, moral and physical support, advice, assistance, guidance, curiosity, initiative, perseverance, skills, knowledge and a little luck have been key elements. It has been one of the most challenging yet rewarding adventures I have embarked on. Most importantly, I have gained personal growth, insight, knowledge, experience and friends; some of which are the most outstanding people I have ever met and I will always be grateful, indebted, and a mentor to them. Thank you.

I have often made the statement that I would have never made it *into* graduate school without the opportunity, guidance and support of Dr. John Bush; and I would have never made it *out* of graduate school without the opportunity, guidance and support of Dr. Dale Ralston. I am very fortunate and especially thankful for their time, effort, patience and professionalism with this project.

I am also very grateful to Bob Willhite (Hagerman Fossil Beds National Monument) and Dr. Lee Sappington for their efforts and support. I would also like to thank Neil King and Dena Easterday, as well as the rest of the staff at Hagerman Fossil Beds National Monument.

I appreciate the efforts from individuals who have assisted me with field data collection; Mike & Heidi Casten (tracer tests), Jim Degenhardt (water levels), Eric Foemmel (water levels), Summer Hinton (tracer tests), Bob Lorkowski & Jay Hauser (paper shale mapping), BJ Mountford (water levels), Vicki Murphy (surveying), Bob Willhite (canal geology) and Amy Wolf (tracer tests).

Finally, I would like to express a special thank you to my friends, family and loved ones for their continued support and encouragement.

# TABLE OF CONTENTS

# LIST OF ILLUSTRATIONS

# LIST OF TABLES

# INTRODUCTION

## Description of the Problem

Perched ground water aquifers are causing slope stability problems within the Hagerman Fossil Beds National Monument located in northwestern Twin Falls County, Idaho. The slope failures are located on the hillside of the Bruneau Plateau along the Snake River and they typically range in size from 300 to 800 feet wide and up to 1000 feet long. River water is pumped onto the Bruneau Plateau and distributed by canal systems to agricultural crops. Irrigation water percolates down through the unconsolidated sediments and forms shallow perched ground water systems. Historical photos from paleontological expeditions during the 1930's to present support initial aquifer development and discharge during the 1970's and slope failures have occurred about every two years since 1979. The aquifers and landslides are related to the development of Bell Rapids Irrigation District in 1970 on the plateau adjacent to monument property (Young 1984, Summer 1986, Riedel 1992, Vector 1994). In 1987, workers were starting the Bell Rapids irrigation pumps in preparation for the irrigation season when a large slope failure occurred, completely destroying the station while the workers escaped on foot.

Many studies have addressed the slope stability problem (Table 1) and the following paragraphs provide a summary of the contribution from each study. In 1984 the first investigation of the slope stability problem was completed by Young (1984) with the United States Geological Survey (U.S.G.S.) in cooperation with the Bureau of Land Management (B.L.M.). This study provided quantitative data for canal leakage and perched aquifer discharge, which set in motion a series of succeeding studies for the next eleven years. A detailed discussion of Young (1984) is provided in Appendix C.

| Year | Type of Study | Agency | Author of Report |
|---|---|---|---|
| 1984 | Hydrogeologic/Canal Leakage | U.S.G.S. | Bill Young |
| 1985 | Hydrogeologic/Canal Leakage | Private | Robert Worstell |
| 1986 | Hydrogeologic/Landslide | B.L.M. | Paul Summers |
| 1986 | 11 monitor wells installed | U.S.G.S. | |
| 1988 | Hydrogeologic/Canal Leakage | Private | James Montgomery |
| 1992 | Hydrologic/Landslide | N.P.S. | Jon Riedel |
| 1992 | Canal Leakage Study | N.P.S. | Larry Martin |
| 1993 | Landslide Volume | U.S.G.S. | Photogrammetric Lab |
| 1993 | Geophysics | B.S.U. | J. Pelton & M. Petteys |
| 1994 | 6 monitor wells installed | U.S.G.S. | |
| 1994 | Geophysics | B.S.U. | P. Michaels & P. Donaldson |
| 1994 | Geophysics/Groundwater | Private | Vector Engineering, Inc. |
| 1995 | Review of Geophysical Study | Private | J. R. Pelton |
| 1995 | Monitoring Protocol | U.S.G.S. | A. Chleborad & R. Schuster |
| 1998 | Hydrogeology | N.P.S. | Neal Farmer |
| 2001 | Bacteria & Nutrient Transport | U.S.D.A.&N.P.S. | Jim Entry & Neal Farmer |
| 2002 | Reservoir Landslides | U.of I. & I.W.R.R.I. | Rick Allen |
| 2003 | Groundwater Tracer Test | U.of I. & I.W.R.R.I. | Jim Osiensky |
| 2004 | Groundwater Chemistry | U.of I. & I.W.R.R.I. | Rick Allen |
| 2004 | Slope Failures | Japan Landslide Soc. | Osamu Nagai & Neal Farmer |

Table 1. Chronological listing of studies.

In 1985 a second investigation was performed by a private consultant for the Bell Rapids Irrigation District. Worstell (1985) measured canal leakage using a different technique than the U.S.G.S.. This data shows an order of magnitude less water leaking from the canal than the previous study by Young (1984). A detailed discussion of Worstell (1985) is provided in Appendix C.

In 1986 one report was produced and eleven monitor wells were installed. The report by Summers (1986) discussed general geologic and ground water conditions related to the slope stability problems. Eleven monitor wells were installed by the U.S.G.S. which was contracted by the B.L.M.. This marked the first ground water data collection for the perched aquifers.

In October 1987 a third canal leakage study was conducted by Montgomery (1988) by constructing a water impoundment in the first one-half mile of the Fossil Gulch Canal. This study provided a canal leakage value similar to Worstells' (1985) reported value. A detailed discussion of Montgomery (1988) is provided in Appendix C.

In spring 1988 the first one-half mile of the Fossil Gulch Canal was straightened and lined with concrete. The 'old' segment of canal, where previous leakage tests had been performed (Young, 1984; Worstell, 1985; Montgomery, 1988) was filled with excavated material from the newly aligned segment located just a few hundred feet to the north.

In 1992 a detailed site characterization report was produced by Riedel (1992) and a canal/pond leakage test was performed by Martin (1992). Martin also performed a leakage test on the Fossil Gulch Pond. The Fossil Gulch Canal leakage test was performed on the concrete lined segment as well as two unlined segments immediately downstream separated by earthen dams. The report by Martin is incomplete and there is a detailed discussion of these studies in Appendix C.

In 1993 two investigations were conducted, one by the U.S.G.S. and one by Pelton and Petteys (1993). The U.S.G.S. conducted a photogrammetric analysis that provided quantitative data on volumes of slope failures. Pelton and Petteys (1993) performed a preliminary seismic and magnetic field study used as a basis for an in-depth seismic study in 1994.

The National Park Service (N.P.S.) contracted U.S.G.S. to install six additional monitor wells in 1994. Michaels and Donaldson (1994) performed a seismic refraction investigation identifying the surface of the Shoestring Basalt flow at locations within the plateau. Vector Engineering, Inc. performed surface geoelectric and hydrologic studies that were compiled in a site characterization report, which is discussed in Appendices A and C.

In 1995 reports were produced by Pelton (1995), and Chleborad and Schuster (1995). Pelton analyzed the report produced by Vector Engineering (1994) for correctness and accepted standard methodologies. Chleborad and Schuster produced a report that describes specific procedures for monitoring slope movement and aquifer seepage.

Purpose and Objectives

The purpose of this report is to aid development of a mitigative plan for slope stability problems located at the Hagerman Fossil Beds National Monument. The general objective is to formulate a conceptual hydrostratigraphic model of the study area based on a review and compilation of results from existing studies, recently collected hydrogeologic data and focused field mapping. Specific objectives of the study include:

1) Use available geologic and geophysical data to develop a geologic conceptual model of the site.

2) Use available canal leakage and ground water level data to develop an understanding of the flow systems.

3) Combine the geologic and hydrologic models to present a general hydrostratigraphic model of the site.

4) Use the hydrostratigraphic model to explain spatial distribution of perched aquifer discharge zones, aid mitigation efforts and explain observed field data.

Geographic Setting

The Hagerman Fossil Beds National Monument and study site are located at the eastern edge of the Western Snake River Plain (Figure 1). The monument boundary is illustrated as slanted lines and the general study site area as a rectangle with horizontal lines. The monument is located about 90 miles southeast of Boise and 30 miles downstream of Twin Falls along the Snake River.

West of the town of Hagerman are fossil bearing sediments exposed in a 600 foot high bluff that forms the western wall of the Hagerman Valley. The bluff is part of the Bruneau Plateau with the Snake River located at the base. The river is held at a constant elevation of 2,800 feet by the Lower Salmon Falls hydroelectric dam.

The surface of the bluff has an average elevation of 3,400 feet (600 feet above the river) and it is the northeastern extent of the Bruneau Plateau. The monument boundary effectively traces the edge of the bluff (Figure 1). The deeply incised canyons range from a half to one mile in length and have slope angles commonly exceeding $35^0$ with a few up to $70^0$. Native vegetation on the bluff is dominated by sagebrush, which is more abundant on north aspect slopes. Non-native vegetation types grow at the perched aquifer discharge zones that include cattails, Tamarisk trees, rye grass, willows, Russian Olive trees and thistle.

The study site covers an area of approximately 10 square miles and includes parts or all of sections 4, 5, 8, 9, 16, 17, T.7S. R.13E., section 31 T.6S.

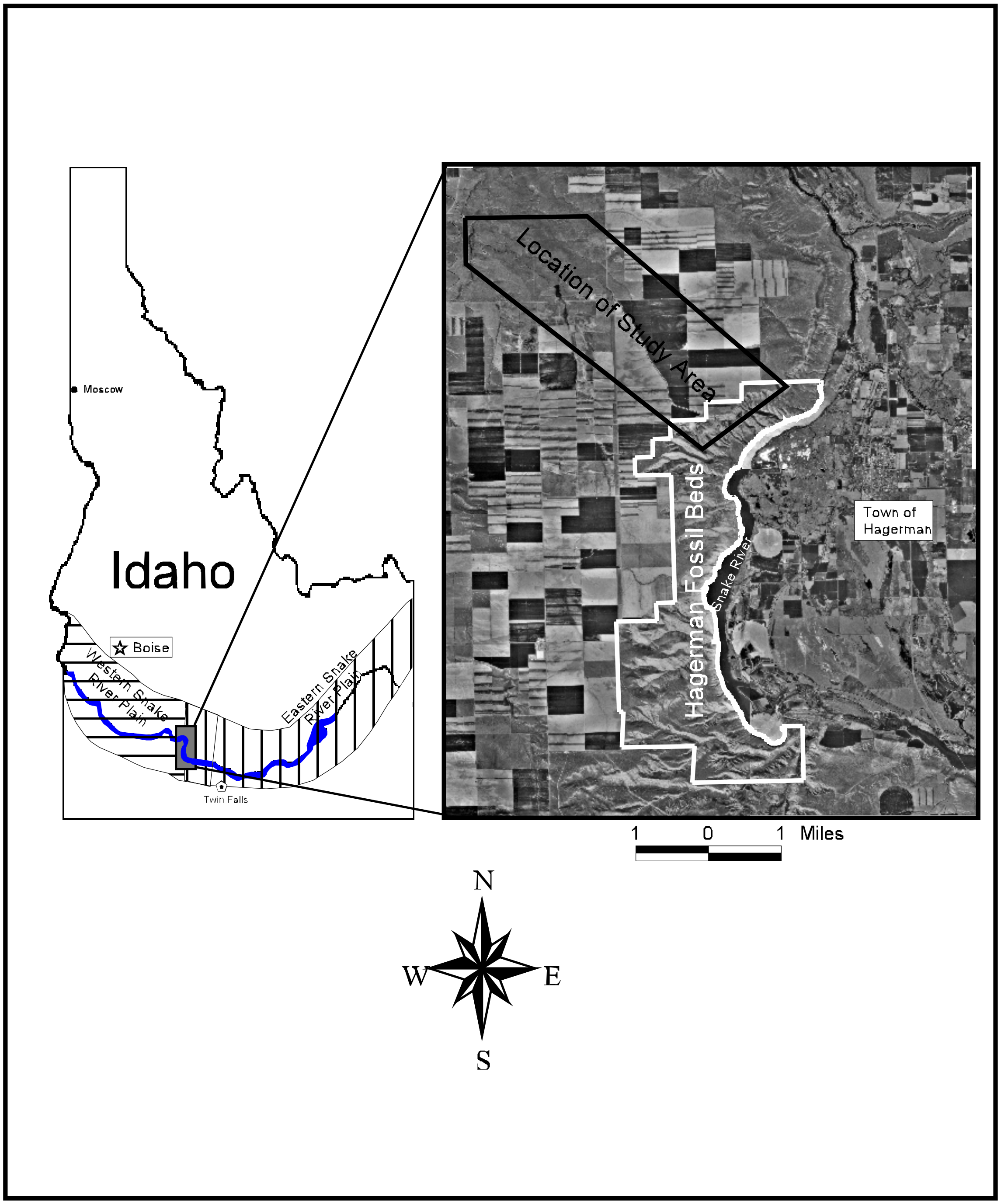



Figure 1. Location of study.

R.13E., sections 35, 36, T.6S. R.12E. and sections 6, 7, T.7S. R.12E., Twin Falls County, Idaho. The general location of the study area is illustrated in Figure 1 and lies primarily on the plateau surface but extends partially down the bluff face where perched aquifers are discharging in the northwest area of the monument.

The basis for the study area boundary is to capture areas of recharge, discharge, monitor wells and geophysical studies. The northwest/southeast orientation of the study area correlates to the same orientation of the Fossil Gulch Canal. The southeast boundary is located at aquifer discharge areas and the northwest boundary extends to recharge areas ending where the Fossil Gulch Canal enters an aqueduct and crosses a small canyon. The northeast and southwest boundaries extend far enough to enclose locations of monitor wells and geophysical studies.

# GENERAL GEOLOGY

## Geologic Setting

The study site is located at the eastern edge of the western Snake River Plain in southern Idaho. A series of sediments named the Idaho and Snake River Groups have been deposited non-conformably on the Idavada volcanics (Figure 2). The Idaho Group is composed of seven formations identified by Malde and Powers (1962), and covers several thousand square miles in a wide

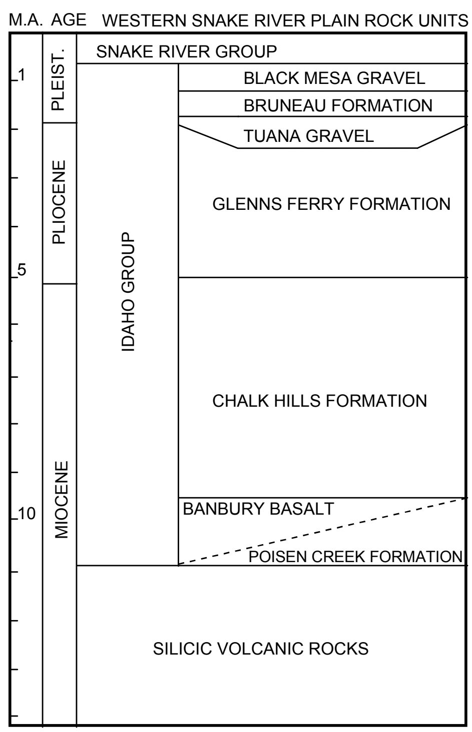



Figure 2. Sequence of upper Cenozoic rocks in the western Snake River Plain, Owyhee County, Idaho (modified from Malde, 1991)

area of the western Snake River Plain. The Glenns Ferry and Tuana Formations crop out within the study site along the west side of the Snake River. These Cenozoic sediments are a combination of lake, stream and flood plain deposits inter-bedded with an occasional basalt flow, silicic volcanic ash and basaltic pyroclastic deposits. The following paragraphs provide a more thorough description of the geologic setting.

The Snake River Plain is a major late Cenozoic tectonic/volcanic feature in the northern portion of the Basin and Range geologic region (Bonnichsen and Breckenridge, 1982). The plain extends across southern Idaho for roughly 300 miles in a crescent shape. It is divided into two main sections identified as the western and eastern Snake River Plain. The western portion is about 40 miles wide, bounded by normal faults and has a northwest-southeast trend. Malde and Powers (1958) recorded at least 9,000 feet of displacement between the highlands to the north and the elevation of the plain today and concluded about 5,000 feet of displacement occurred in the early and middle Pliocene. The displacement started about 17 million years ago by rifting and down warping of the plain. The subsequent stretching of the crust produced a basin that began filling with sedimentary and volcanic rocks of considerable thickness during the Miocene, Pliocene and Pleistocene.

Explosive rhyolitic volcanism associated with the Yellowstone-Snake River Plain hotspot deposited the Idavada Volcanics from 14 to 9 MA (Figure 2) in southwestern and south-central Idaho during middle Miocene time (Malde and Powers, 1962). The Snake River Plain near Hagerman subsided in the wake of thermal uplift associated with the hotspot and also due to northeast/southwest extension that formed the southeast propagating western Snake River Plain graben or rift (Malde, 1991). These eruptions continued through much of the Miocene epoch and filled the basal portion of the western Snake River Plain with silicic lavas, welded and vitric tuffs. The Idavada Volcanics are commonly exposed to the north and south of the plain as local highlands. The Mount Bennett Hills north of the city of Hagerman are primarily composed of Idavada Volcanics (Maley, 1987).

Eleven million years ago deposition of the Idaho Group began on the Idavada Volcanics. Cope (1883) identified and named these sediments “The Idaho Group” and the body of water where these sediments collected “Lake Idaho”. He correctly dated a portion of the Idaho Group as Pliocene based on fish fossils. The Idaho Group was deposited in lakes, flood plains and streams. The base level and sediment load in this environment was affected by local basaltic volcanism and subsidence of the western Snake River Plain as well as silicic volcanism in the eastern Snake River Plain (Malde, 1991).

Malde and Powers (1962) divided the Idaho Group into seven formations ranging in age from 11 million to 700,000 years old. In ascending order they are Poison Creek/Banbury Basalt, Chalk Hills, Glenns Ferry, Tuana Gravel, Bruneau and Black Mesa Gravel (Figure 2). These formations are composed of clastic sedimentary lithologies and inter-bedded olivine basalt flows, silicic volcanic ashes and basaltic pyroclastic material with an aggregate thickness up to 1500m (Malde and Powers, 1962). Most of the sediments are poorly consolidated and range in texture from clays to gravels. Only the Glenns Ferry and Tuana Formations of the Idaho Group, along with a thick caliche cap and overlying soils are exposed at the study site. Figure 3 illustrates a generalized geologic map in the vicinity of the study area based on a map by Malde (1972).

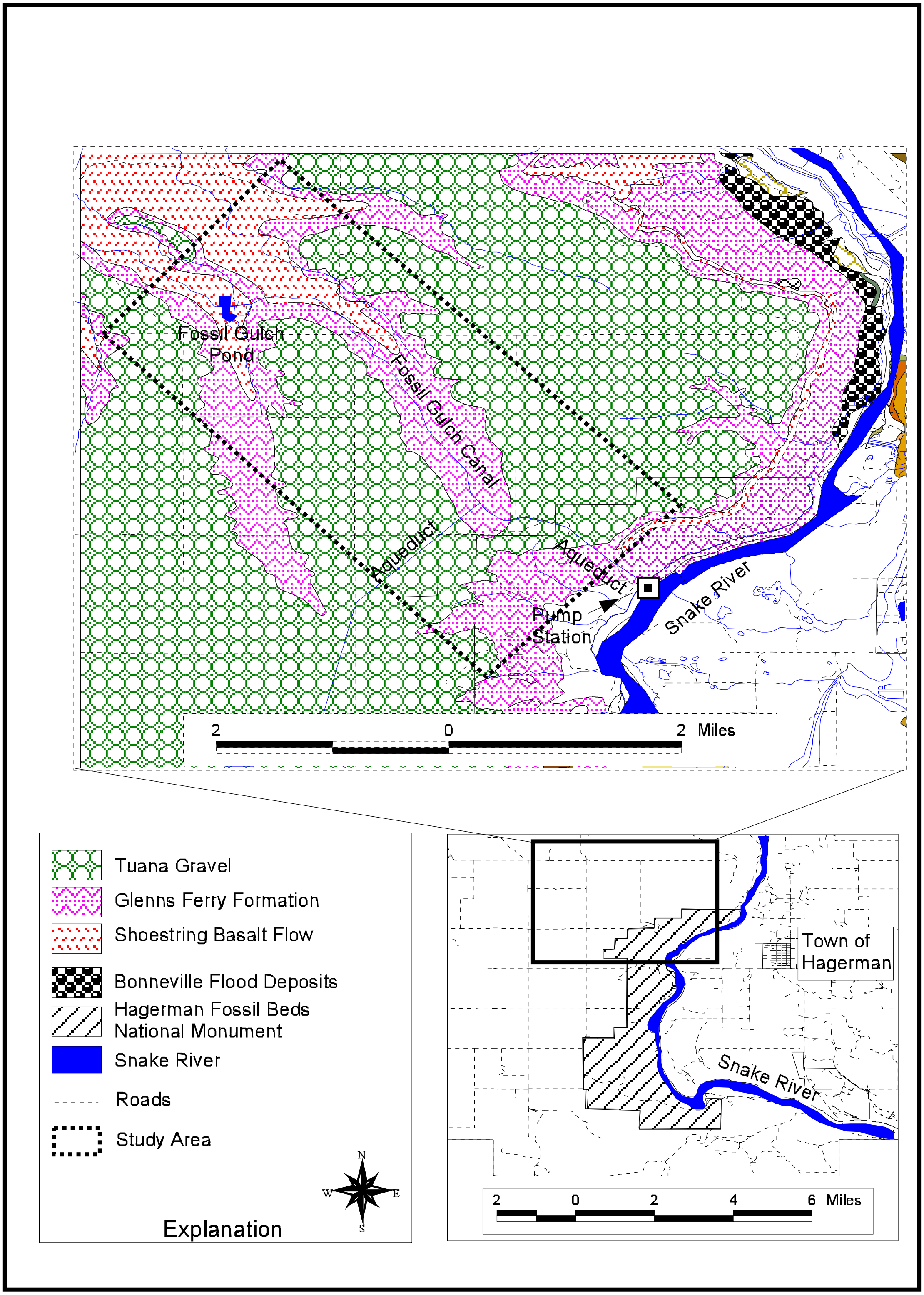



Figure 3. Geologic map of study site (modified from Malde, 1972).

The age of the Glenns Ferry Formation is broadly constrained from Pliocene to early Pleistocene or 5 to 1.5 MA. (Malde, 1991). It exhibits four major environments including sandy fluviatile, muddy flood plain, lacustrine and valley border facies (Malde, 1972). Primarily fluviatile and flood plain

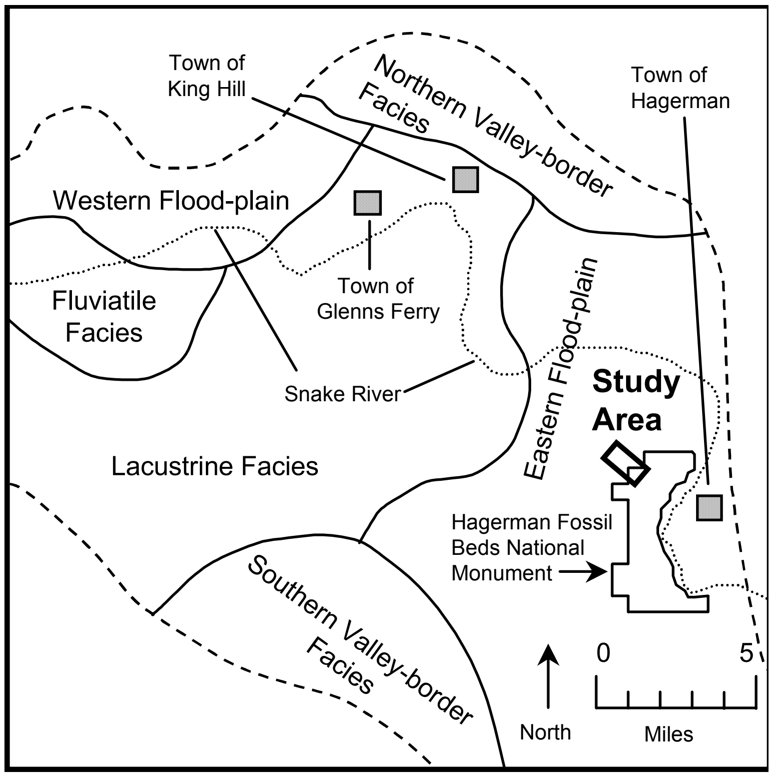



Figure 4. Study area location and distribution Glenns Ferry Formation sedimentary facies in the Glenns Ferry/Hagerman area (after Malde, 1972).

environments are represented in the study area. The flood plain deposits of the Hagerman area are marginal to and east of the lacustrine facies that crop out near the town of Glenns Ferry and continue westward as illustrated in Figure 4 (Malde, 1972; Malde, 1991). Lacustrine deposits consist of massive tan silt and fine-grained sand forming monotonous outcrops and were deposited in ancient "Lake Idaho". The outcrops of fluvial facies are predominately found east of the town of Glenns Ferry. Coarse-grained arkosic sands and cobble gravels of the valley border facies are present at both the northern and southern margins of the western Snake River Plain (Figure 4) (Malde, 1972).

Malde (1972) describes the depositional setting as a highly sinuous meandering stream and flood plain which formed the delta plain marginal to a perennial lake to the west. The climate was predominately humid but also semi-arid at times.

> "... the river flowed in a wide valley marked by temporary lakes and by broad stretches that were seasonally flooded. As the river shifted its course, the sedimentary environments changed correspondingly. Even so, the persistence of rather uniform environments in certain areas is shown by surprisingly thick sequences of fairly uniform deposits (Malde, 1972, page D13)."

Lee (1995) recognized two lithofacies associations, sandy and muddy. These are equated to represent a channel and flood plain environment within a meandering stream system. Sandy associations make up about 25% of the Glenns Ferry Formation at the northern end of the Hagerman Fossil Beds National Monument (Lee, 1995). The sandy fluviatile association contains lithofacies of gravely sand, trough cross-bedded sand, ripple-marked and scour-fill sand generally arranged in upward-fining successions. These are interpreted to represent point bar deposits in a mixed-load, highly sinuous meandering stream system. Bjork (1968) described these channel sands as grey, micaceous quartz sand that is uniformly fine-grained.

Muddy facies sequences with local organic rich and pedogenic facies make up about 75% of the Glenns Ferry Formation (Lee, 1995). The muddy facies association accumulated vertically in flood plains periodically inundated by water from floods in the fluvial system and consists mainly of pale olive colored silty clays and clayey silt beds arranged in upward fining cycles at a scale of decimeters to meters (Lee, 1995). These deposits are commonly characterized by monotonous fine-grained, graded, calcareous, pale-olive silt beds from one to three feet thick capped with a dark, carbonaceous clay from one to several inches thick (Malde, 1965).

The Tuana Gravel Formation rests on the Glenns Ferry Formation. Saddler (1997) describes the composition of the Tuana Gravels as coarser grained sediments in the silt, sand and gravel fractions. Thickness of the gravel varies up to 200 feet but is commonly about 50 feet thick within the study site (Bjork, 1968). Malde (1965) describes the Tuana as gradually rising in elevation and thickening southward and suggests that the ancestral Snake River deposited the gravels across the valley. The exposed base of the Tuana Gravel exhibits cut and fill stream channels in the underlying silts and clays of the Glenns Ferry Formation. These stream channels are commonly filled with fine sand.

A caliche layer has formed several feet below overlying soil horizons. It covers most of the study site but no formal mapping or characterization has been performed specifically to determine its areal extent, continuity, structure or thickness. The caliche does reflect a climatic change from the Tuana environment and is considered to have formed during an interglacial dry cycle of the Pleistocene (Bjork, 1968). Outcrop observations indicate the caliche is a very dense layer averaging several feet thick, but thins to less than one foot in thickness at some locations. It contains vertical fractures that are re-cemented in some places and not in others. It is resistant to weathering and forms a cap rock near the top of the hillsides in most of the study site and surrounding area.

<u>Geologic Model</u>

A six layer geologic model of the study site was developed and provides the foundation for the hydrostratigraphic model. The model is based on literature research and review, examination of geologic outcrops located at perched aquifer discharge zones and recharge areas and an investigation of geologic conditions for the Fossil Gulch Canal base. Geologic units within the plateau were inferred from geophysics and drill logs, discussed in Appendices A and C. Literature research and review is based on the following sources.

1) General geology (Malde, 1972), (Bonnichsen and Breckenridge, 1982), (Malde, 1991), and (Malde and Powers, 1958).
2) Stratigraphy (Bjork, 1968), (Lee, 1995), (Malde, 1972) and (Malde and Powers, 1962).
3) Carbonaceous Paper Shales (Lorkowski and Hauser, 1996).
4) Tuana Gravel Formation (Saddler, 1997).
5) Drill logs and borehole geophysics (U.S.G.S., 1986 and 1994).
6) Seismic data (Michaels and Donaldson, 1994).

Outcrop elevations for the model layers were collected at the southeast end of the study site. There is a southerly dip to the formations based on the U.S.G.S geologic map (Malde, 1972) and stratigraphy studies (Bjork, 1968). A gradient of 0.006 (0.6%) was calculated for the Shoestring Basalt flow from the Fossil Gulch Pond (Elev. 3,280 feet) to outcrops located at the southeast end of the study site (Elev. 3,180 feet). It is assumed the other geologic units generally follow this trend within the plateau.

An investigation of the canal base geology was performed from the end of the concrete lined segment to an aqueduct approximately 2.5 miles downstream from the Fossil Gulch Pond (Figure 5). The canal base was sampled every 200 feet with several holes drilled from a power auger that has a 2.5-foot depth capability. The sampling occurred after Bell Rapids Irrigation Company cleaned the canal by scraping sediments out of the base.

Results indicate a layer of caliche in the base of the canal extending from the concrete lined section of canal, downstream to 1/3 mile before Fossil Gulch Pond. Then very dense silty clay was recorded to the pond. One 200-foot long area did reveal coarse sand with no caliche down to 2.5 feet. Caliche was observed in the sides of the canal at this location indicating that heavy equipment had broken through the layer of caliche during construction of the canal. Fossil Gulch Pond is in direct contact with the Shoestring Basalt flow based on observations made in February 1998. Basalt outcrops were exposed under approximately four feet of sediments during a dredging operation performed by the Bell Rapids Irrigation Co. to remove 28 years of sedimentation in Fossil Gulch Pond. Dense, partially cemented olive colored silty clays were recorded in the base of the canal from the Fossil Gulch Pond to 0.75 mile downstream. Basalt was observed in the base of the canal from 0.75 mile downstream of the pond, to 1.5 miles downstream from Fossil Gulch Pond.

Layers of the geologic model have been identified at locations within the plateau from drill logs, borehole geophysics and surface geophysics. Appendix

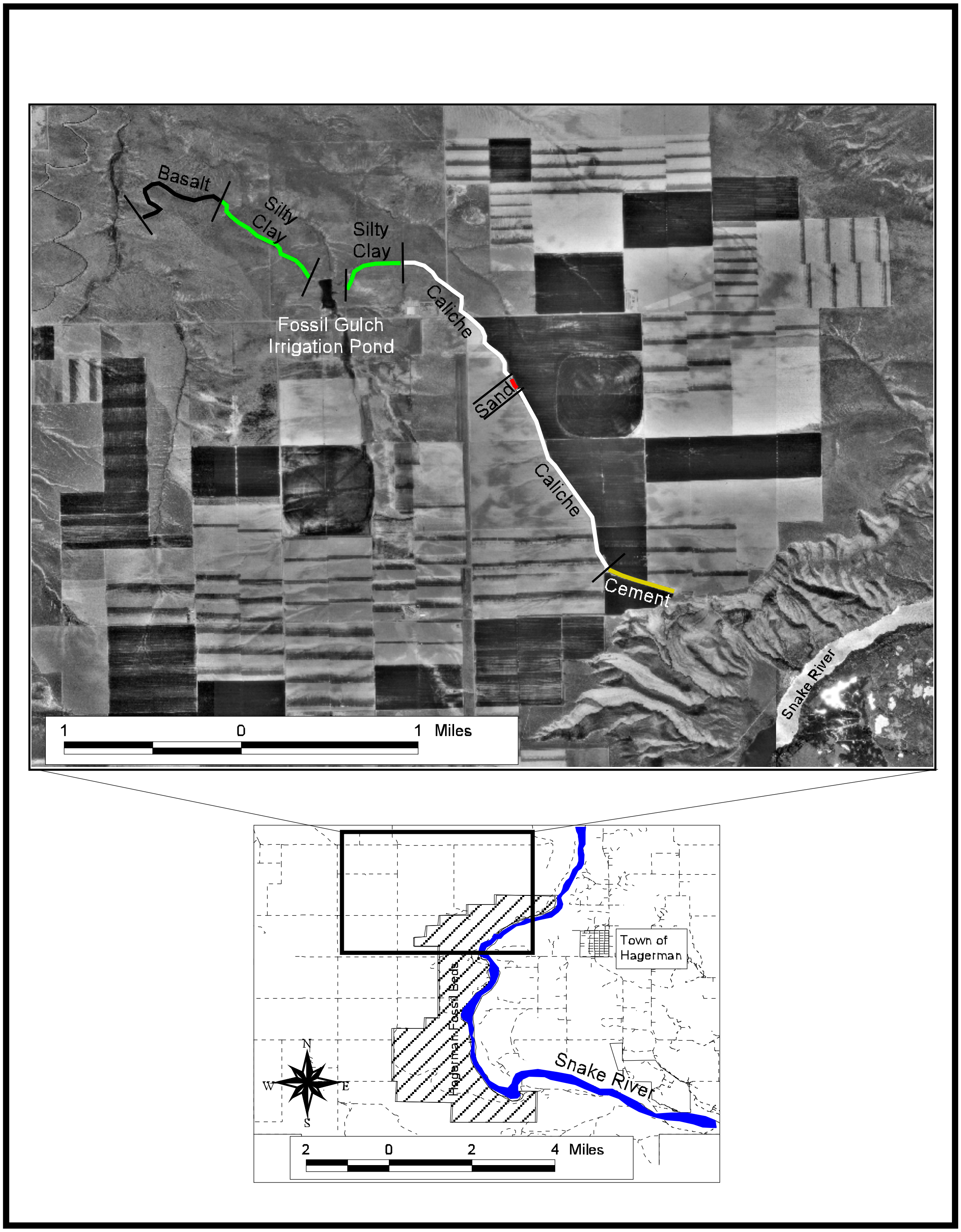



Figure 5. Canal base geology.

C provides illustrations of monitor well geologic logs and locations in Figure 10. The Shoestring Basalt has been inferred between the drill log locations within the plateau from a seismic geophysical study.

In 1994 Idaho Power Company mapped the surface of the Shoestring Basalt flow using seismics. The primary objectives were to determine the areal extent of the basalt flow in proximity to the Fossil Gulch Irrigation Canal to aid in assessment of ground water flow paths. White dashed lines with a line number mark the location of the seismic traverses illustrated in Figure 6. The surface of the Shoestring Basalt was identified from seismics along lines 1, 2, 4, 5 and 6. The basalt was not observed seismically near the canyon rim with line 3 but is known to exist from drill logs and outcrops in this area. Overall the surface of the Shoestring Basalt flow is continuous and smooth with a composite apparent dip to the south and southwest (Michaels and Donaldson, 1994).

The individual hydrostratigraphic layers of the model are described in the following paragraphs and illustrated in Figure 7. Layer 1 of the model is the Tuana Gravel Formation that is composed of gravel, sand, and subordinate silt and clay. Paleo-stream channels have cut and filled into the underlying Glenns Ferry Formation at an elevation of about 3,325 feet (Saddler, 1997). Layer 1 is acting as an aquifer and transmitting water through paleo-stream channels, which show as localized point discharge locations on the hillsides.

Layer 2 of the model is part of the Glenns Ferry Formation which consists of 75% silty clays (Lee, 1995) with the remaining 25% composed of mostly stream facies. This layer is about 125 feet thick and extends from an elevation

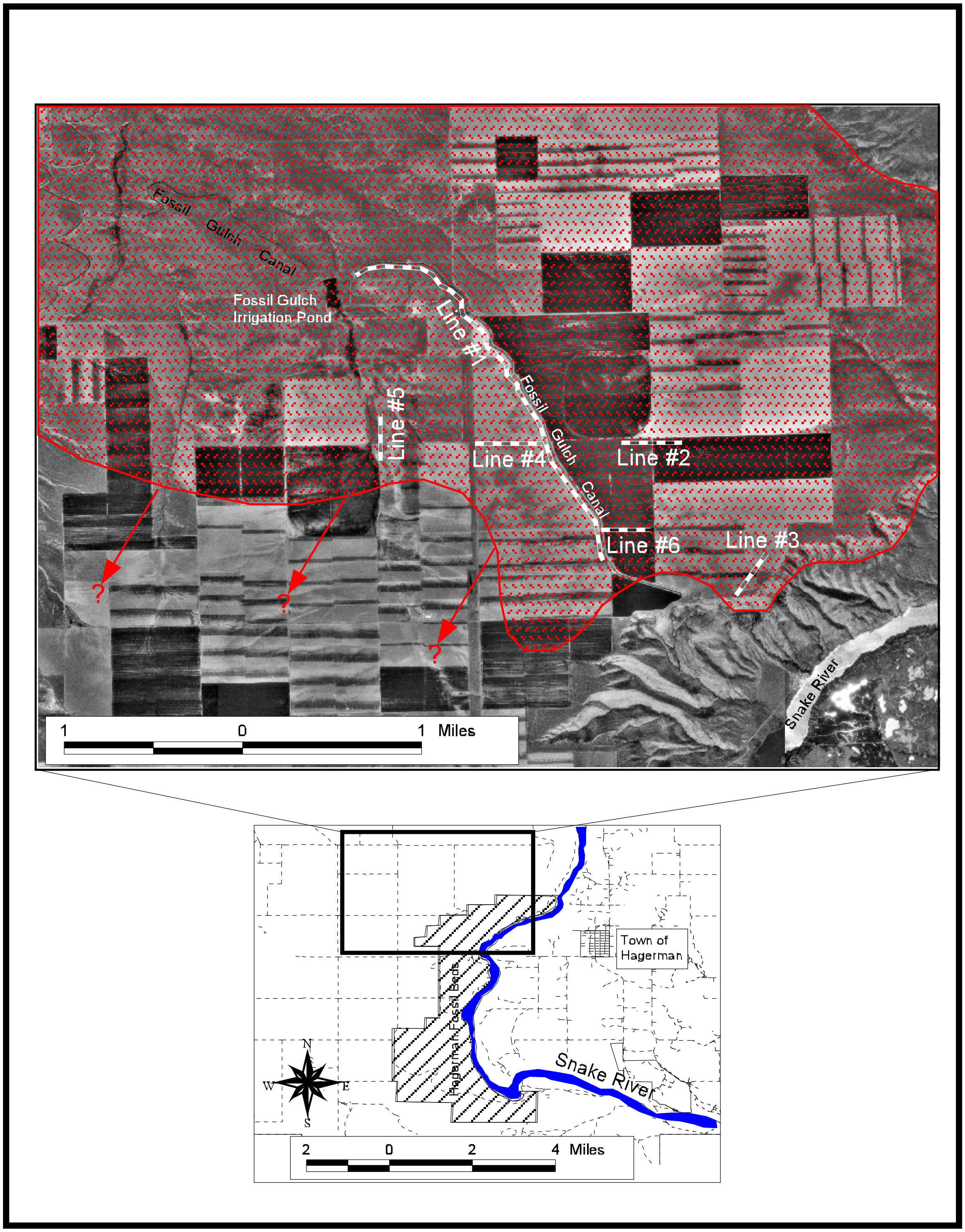



Figure 6. Seismic line locations and inferred extent of the basalt flow noted by the hachured pattern.

of 3,325 feet down to the top of the basalt flow at about 3,200 feet elevation (Lee, 1995). Layer 2 of the model is acting as an aquitard separating the Tuana Gravel Formation from Layer 3.

Layer 3 is the Shoestring Basalt flow, which averages 20 feet thick in outcrops and exhibits a one-half foot thick basal baked zone forming an aquitard. The fractured basalt flow is acting as an aquifer discharging up to 300 gallons per minute in one area. The basalt base crops out at an elevation of 3,180 feet at the southeastern side of the study site and near Fossil Gulch pond it is inferred to be at about 3,280 feet. Well logs and geophysics have identified the basalt at locations within the plateau. Layer 4 extends from the base of the basalt flow down to an elevation of about 3,110 feet and consists of more silty clays, typical of the Glenns Ferry Formation and forms an aquitard. Layer 5, from 3,110 feet to 3,100 feet elevation is dominated by a stream facie acting as an aquifer. The stream facie dominates this layer but it is not laterally continuous. Paleo-stream channels have cut into the underlying carbonaceous paper shale and filled with fine sand. Lorkowski and Hauser (1996) mapped this layer and the underlying carbonaceous paper shale unit.

Layer 6 is composed of carbonaceous paper shales that form an aquitard and probable failure plane for slope failures. The unit is about 20 feet thick, crops out from 3,100 feet to 3,080 feet in elevation, and is composed primarily of finely laminated clays with deposits of diatoms and ash (Lorkowski and Hauser, 1996). These deposits likely have low shear strengths and their elevations correspond to the inferred lower rotational failure planes for the 1991 and ca.

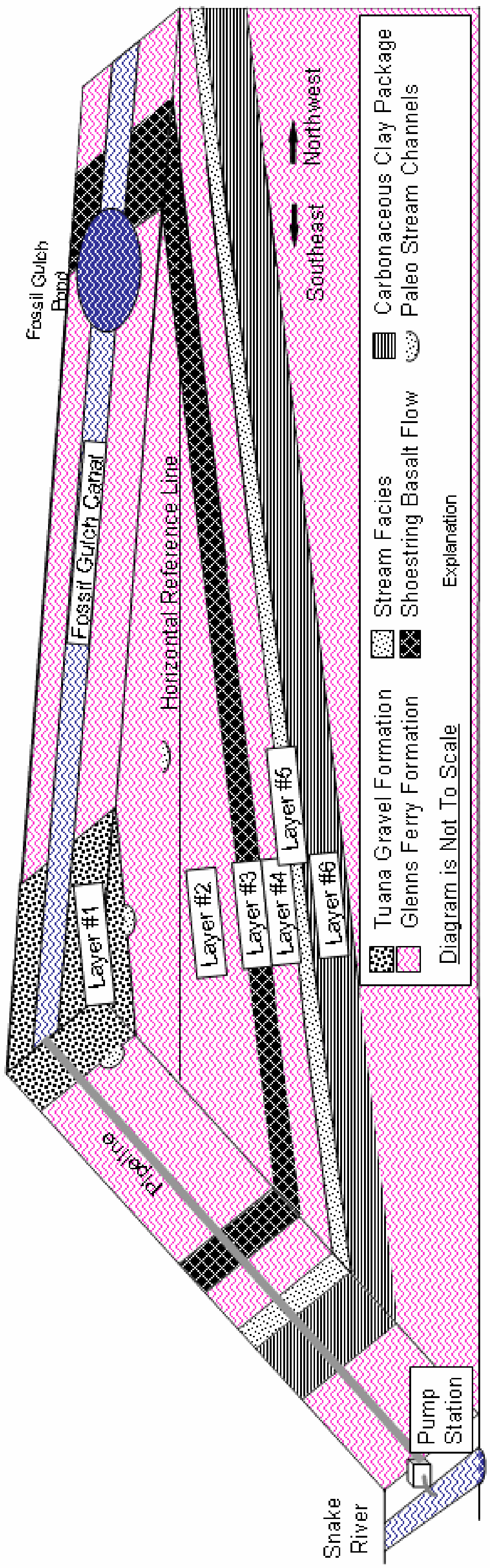



Figure 7. Geologic Model

1979 slope failures.

# HYDROLOGIC MODEL

The hydrologic model describes how water moves through the geologic materials within the study site. The primary elements of the model are recharge, ground water flow and perched aquifer discharge with supporting data from hydrographs, water chemistry and geophysics. Recharge to the model occurs during mid-April through mid-October from irrigation water. Natural precipitation effects surface water flows primarily during December, January and February but is likely not significant source of recharge to the perched aquifers. Ground water and perched aquifer discharge hydrographs exhibit cycles that closely correlate to seasonal irrigation. Water chemistry illustrates how chemical concentrations increase as ground water flows from recharge areas to discharge zones and high electrical responses from geophysics indicate locations of recharge areas.

## Irrigation As A Recharge Source

Landuse change on the plateau from sagebrush desert to irrigated farmland has coincided with the formation of perched ground water systems, which discharge along the hillsides of the Bruneau Plateau. The Bell Rapids Mutual Irrigation District is located adjacent to the Hagerman Fossil Beds National Monument and operates and maintains an irrigation system that pumps water from the Snake River to irrigate approximately 19,000 acres of land on the plateau. The water license priority for Bell Rapids Irrigation Company is dated December 16, 1963 and construction of the irrigation facilities began in 1969 with the first irrigation season in 1970 (Vector, 1994).

The following paragraphs provide a chronology for irrigation activities. The main pumps lift water from the Snake River up 600 feet in elevation where it is emptied into the Fossil Gulch Canal. Water is pumped from the canal system for field application using sprinkler system technology. The Irrigation season starts in mid April and ends in mid October. The total amount of water pumped into the irrigation system averages 45,000 acre-feet per year and Figure 8 illustrates yearly volumes of water pumped from the Snake River into the irrigation system (U.S.G.S.).

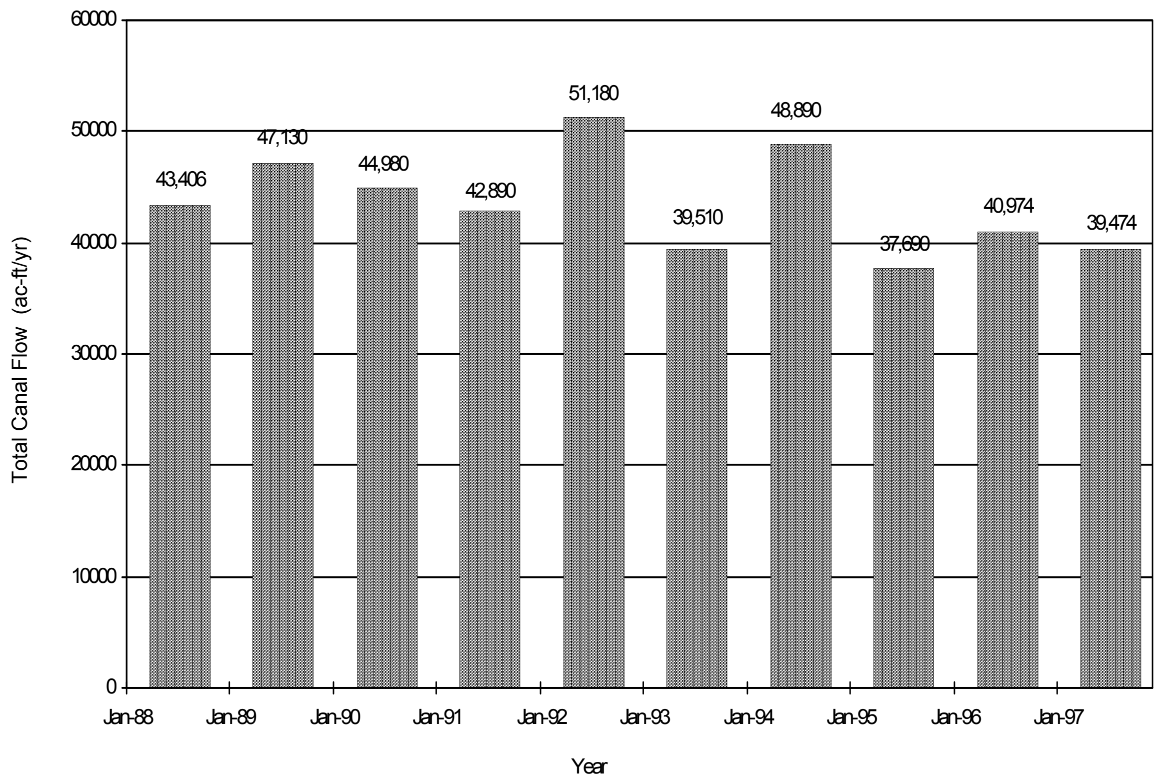



Figure 8. Total volume of water (acre-feet/year) pumped into Fossil Gulch Canal.

The first irrigation season and recharge to the perched aquifers began in spring 1970. Perched ground water began to discharge on the hillsides during mid 1970's and the first large slope failure occurred in ca. 1979. Slope stability problems are a function of several elements that include ground water, steep slopes up to 70 degrees, poorly consolidated sediments and at some locations over-steeping of slopes from road building. In 1983 a second slope failure put at risk a portion of the Bell Rapids Canal. In spring 1987, a third slope failure occurred that destroyed the Bell Rapids Pumping Station while workers were turning on pumps. During the 1987 irrigation season the Fossil Gulch Canal carried larger volumes of water in response to the non-usable Bell Rapids Canal so lateral line aqueducts could transfer water to the areas previously supplied by the Bell Rapids Canal. After the 1987 season the first one-half mile of Fossil Gulch Canal was realigned to straighten it and lined with concrete.

The 1983 slope failure set in motion a series of actions and canal leakage studies addressing the perched ground water conditions within the plateau. Studies have been conducted by both private and government agencies since that time. Results from these studies indicate the source of recharge to the perched aquifers is the irrigation system.

Summary of Canal Leakage Studies

Recharge to the perched aquifers from the canal and pond has been studied during five different leakage investigations. A discussion of each hydrologic study is provided in Appendix B and Figure 9 illustrates the locations of each study. The first study by Young (1984) measured flow within the Fossil Gulch Canal at two locations and then indirectly calculated the amount of water leaking from the canal based on the difference between the two flow rates. Young (1984) reports about 1,900 acre-feet of water leaks from the first mile of the Fossil Gulch Canal per 120 day irrigation season, before it was lined with

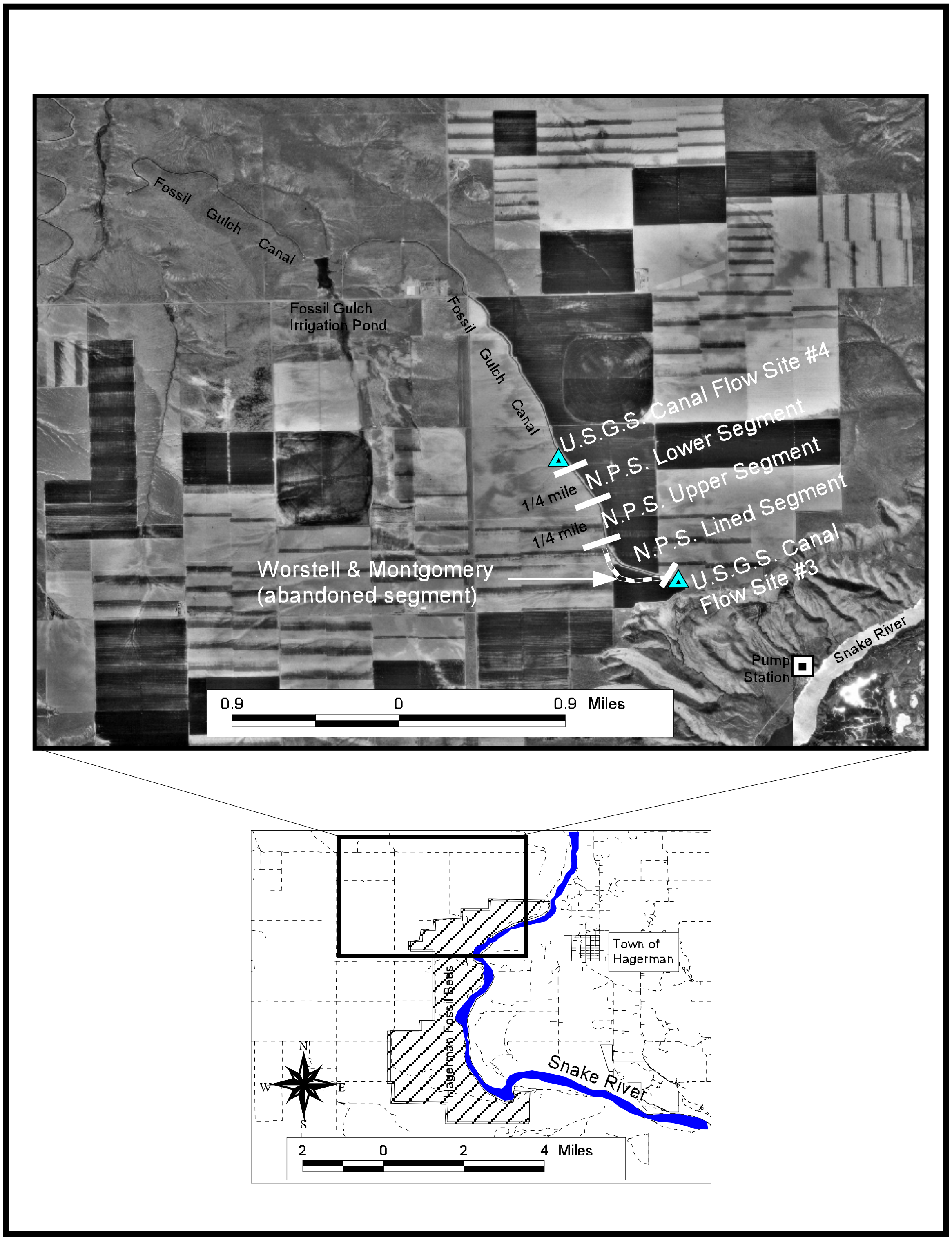



Figure 9. Locations of canal leakage studies.

concrete in 1988. The second study by Worstell (1985) measured the first half-mile of canal with a seepage meter that is commonly used for such studies. His results indicate a lower leakage rate of 193 acre-feet per 180-day irrigation season.

A third canal leakage study, conducted by Montgomery (1987), involved constructing a water impoundment in the first one-half mile of Fossil Gulch Canal. The calculated leakage was reported at 299 acre-feet per season. The fourth canal leakage study, performed by Martin (1994), tested three sections of the Fossil Gulch Irrigation Canal and two irrigation holding ponds. The results from his study show 360 acre-feet of water per irrigation season is lost from the first one-half mile segment of unlined canal. Leakage for the cement lined segment was determined to be 7,000 gallons per day. Vector Engineering, Inc. (1994) performed the fifth leakage study. This study was designed to measure the canal flow at 500-foot intervals for the entire length and use this flow rate data to indirectly calculate canal leakage similar to Young's study in 1984. The results of the Vector study were stated as inconclusive, but a leakage rate of 5,000 acre-feet/season for the **entire canal system** was reported. Canal leakage estimates for an average irrigation season are summarized in Table 2.

Assuming a constant leakage rate along the canal may not be accurate because of changing geologic and hydraulic head conditions. For instance, the Tuana Gravel Formation is below the canal at the inlet area near the edge of the bluffs where most of the leakage tests were performed. The canal crosses the contact between the Tuana Gravel and the finer grained Glenns Ferry Formation within the first mile segment of canal according to the U.S.G.S. geologic map (Malde, 1972).

| Year | Research Entity | Average Leakage Rate (ft./day /first **unlined** 1/2 mile) | Leakage Rate (ft./day **lined** section | Leakage Volume (acre-feet/ /180 day season/ /first **unlined** 1/2 mile) | Leakage Volume (acre-feet/ /180 day season/ /first **unlined** mile) | Leakage (acre-feet/ /180 day season/ /**entire system**) |
|---|---|---|---|---|---|---|
| 1984 | Young | | | 1,425 | 2,850 | |
| 1985 | Worstell | 0.8 | | 193 | 386 | |
| 1987 | Montgomery | | | 293 | 586 | |
| 1992 | Martin | 1.45 | 0.015 | 360 | 720 | |
| 1994 | Vector Eng. | | | | | 5000 ( = 10% loss) |

Table 2. Volume of water lost to leakage from the Fossil Gulch Canal system determined from different studies.

The Fossil Gulch Irrigation Pond leakage study performed by Martin (1994) indicated a water leakage of 140 acre-feet per season. If this value is correct it would be roughly equal to 33% of the annual discharge from the perched aquifer as estimated by Young (1984). A degree of uncertainty is associated with the reported pond leakage data due to surveying problems during data collection.

<u>Monitor Wells</u>

Ground water monitoring in the Fossil Gulch area started in 1986 with the installation of six monitor wells. In 1994 six additional wells were constructed for a total of 12. Table 3 provides construction information and Figure 10 illustrates the location of the monitor wells. All of the wells drilled in 1986 were constructed with six inch diameter PVC casing with 20 feet of 0.030-inch slot sized screen. The sand packs extend up to within 30 feet of ground surface then a cement grout surface seal was placed (Young, 1997). The 1986 wells that encountered basalt only penetrated a short distance into the upper surface of the basalt while the 1994 wells drilled completely through the basalt into the underlying Glenns Ferry Formation.

| Monitor Well Identification (Fossil Gulch Area) | Year of Completion | Depth of Well (feet) | Elevation of Land Surface (feet) | Elevation of Effective Screen (Top) | Elevation of Effective Screen (Bottom) |
|---|---|---|---|---|---|
| 7S 13E 17ABB1 | 1986 | 172 | 3374 | 3344 | 3202 |
| 7S 13E 17AAB1 | 1986 | 165 | 3346 | 3316 | 3181 |
| 7S 13E 9CCC1 | 1986 | 209 | 3342 | 3312 | 3133 |
| 7S 13E 9CDC1 | 1986 | 169 | 3374 | 3344 | 3205 |
| 7S 13E 9CBB1 | 1986 | 114 | 3345 | 3315 | 3231 |
| 7S 13E 9DCC1 | 1986 | 212 | 3401 | 3371 | 3189 |
| NPS-1 | 1994 | 235 | 3402 | 3262 | 3167 |
| NPS-2 | 1994 | 240 | 3401 | 3221 | 3161 |
| NPS-3 | 1994 | 224 | 3402 | 3213 | 3178 |
| NPS-4 | 1994 | 250 | 3379 | 3319 | 3128 |
| NPS-5 | 1994 | 249 | 3395 | 3285 | 3145 |
| NPS-6 | 1994 | 252 | 3403 | 3235 | 3151 |
| NPS-7 | 2003 | 215 | 3390 | open hole 173 - 215 | NA |
| NPS-8 | 2004 | 163 | 3350 | open hole 103 - 163 | NA |
| 7S 13E 9CDC1 (redrilled) | 2004 | 190 | 3374 | open hole 169 - 190 | NA |

Table 3. Monitor well information.

The wells constructed in 1994 are more complex and variable than the 1986 wells. The 1994 wells were constructed with six-inch diameter PVC casing with variable lengths of 0.040-inch slot sized screen. Gravel pack lengths are also more variable ranging from 35 feet in NPS-3 to 190 feet in NPS-4. The rest of the 1994 wells have gravel pack intervals of about 90 feet. All of the 1994 wells penetrated below the Shoestring Basalt to varying depths ranging from 72 feet in NPS-4 to 38 feet in NPS-5 with the rest averaging about 14 feet below the basalt. Bentonite grout was used to seal from the sand pack up to about 10 to 20 feet from ground surface and then a cement grout seal placed up to ground surface.

Well completion diagrams and drill logs for the wells are located in Appendix C. Long effective screen intervals have likely interconnected different

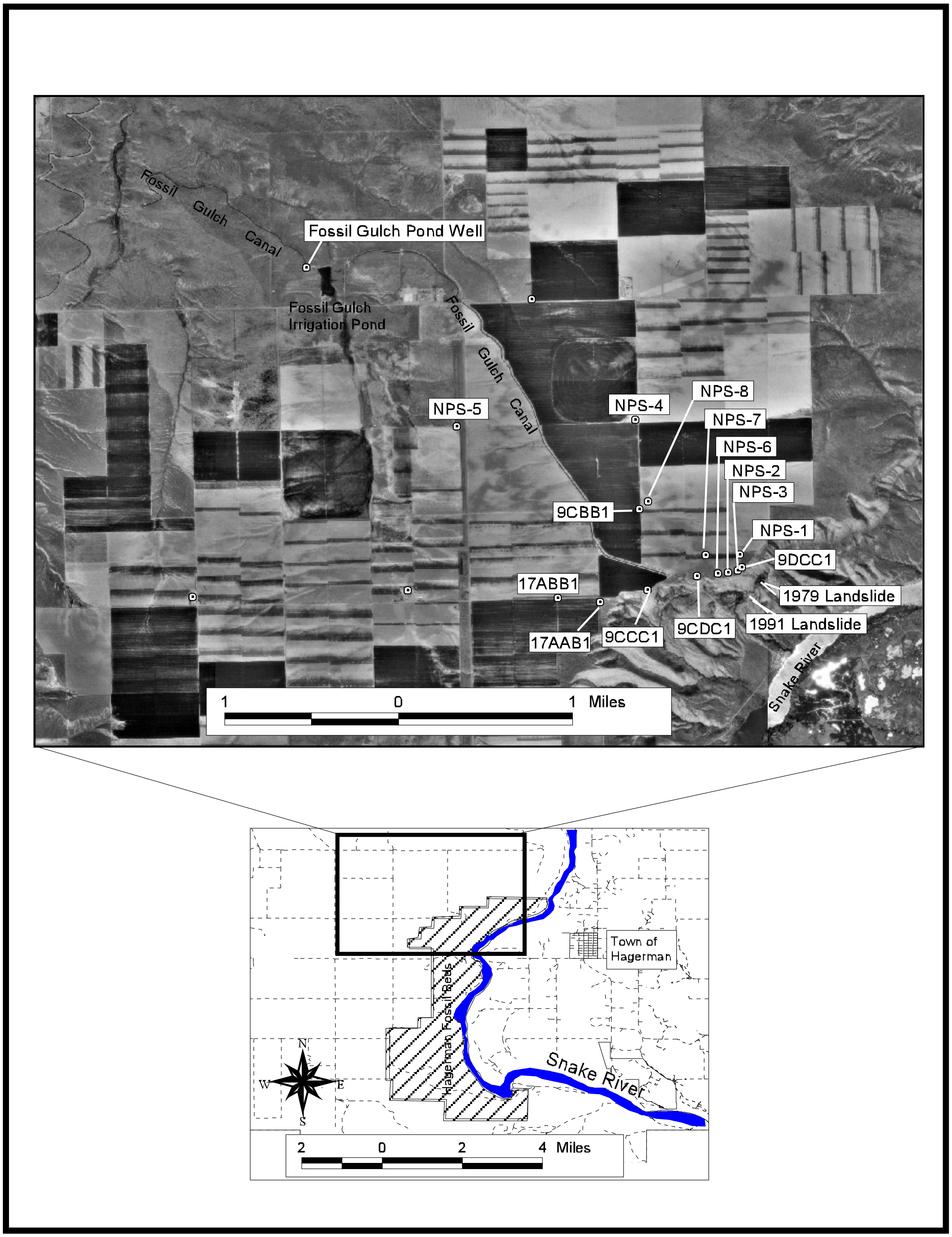



Figure 10. Locations of monitor wells and slope failures.

perched aquifers producing a composite affect for some of the monitor well hydrographs. The U.S.G.S. collected water level measurements in wells from March 1986 through May 1987 and January 1992 through April 1996. National Park Service staff has collected water level data since April 1996. Hydrographs for each of the wells are located in Appendix C.

<u>Ground Water Hydrographs and Contours</u>

Ground water levels are responding to temporal changes in recharge due to seasonal irrigation practices. Monitor well hydrographs for NPS-5, NPS-4 and NPS-3 (Figure 11) have been chosen because they clearly demonstrate how changes in recharge conditions effect water levels in the middle perched aquifer.

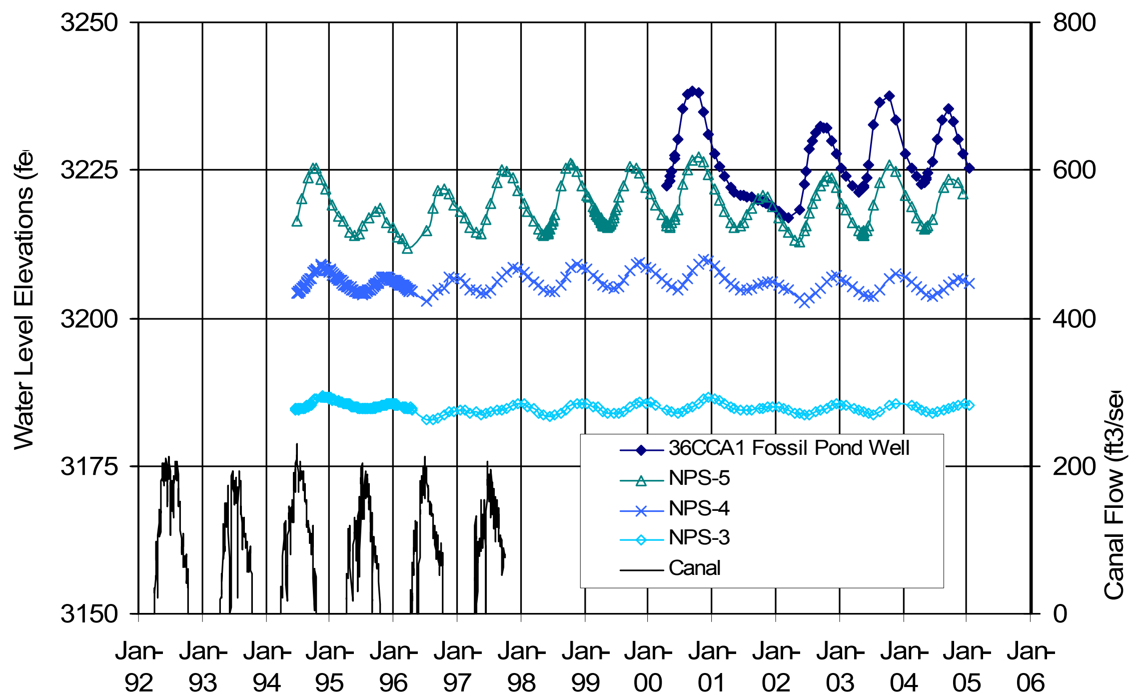



Figure 11. The hydrologic model illustrates a cyclic relation between the canal flow hydrographs and ground water hydrographs for NPS-5, NPS-4 and NPS-3.

The wells are completed in the Shoestring Basalt flow (geologic model layer 3). Other monitor wells in the Fossil Gulch area were not used in the demonstration in the interest of simplicity and to eliminate redundancy because some wells (NPS-6) have nearly identical hydrographs to other wells (NPS-3). Others have complex hydrographs attributed partially to well construction and design. Appendix C provides a discussion of these wells.

Well NPS-3 is located furthest down gradient near the perched aquifer discharge zones. Water levels in this well begin to rise in August. Figure 12 hydrograph amplitude of wells completed in the basalt flow. Figure 11 illustrates water levels starting to rise during the early part of June for NPS-5. Well NPS-4 is located further from the recharge area than NPS-5 and water levels start to rise during July as the effects of the recharge pressure wave propagate down gradient.

Well NPS-5 is located nearest to the source of recharge evident from the earliest rise in water levels, highest water level elevation and greatest illustrates the interpreted progression of seasonal recharge events moving through the basalt system noted by hachured lines located at NPS-5, NPS-4 and NPS-3. The water level response of these wells indicate a source area near the Fossil Gulch Irrigation Pond. The pressure response takes about 100 days to travel a horizontal distance of 15,000 to 20,000 feet from the recharge area to the discharge zones; this equates to a range from 150 to 200 feet/day.

Ground water contours are illustrated in Figure 12, which are based on hydrographs for monitor wells NPS-5, NPS-4, NPS-3 and NPS-6. These wells

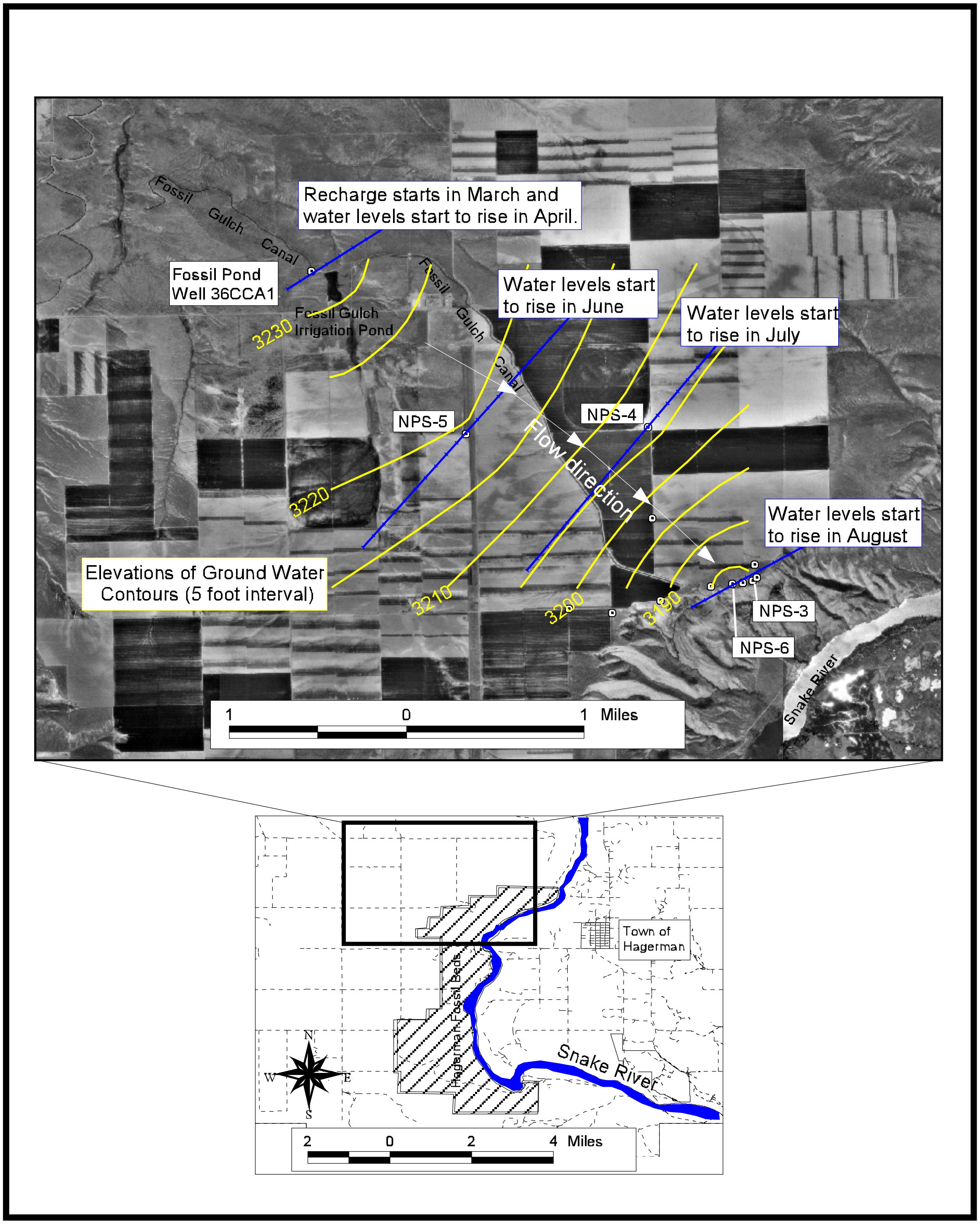



Figure 12. Ground water contours for the basalt aquifer. Only the monitor wells used for contouring are shown. Interpreted location of the recharge pressure wave is noted by blue hachured lines.

were selected because they are completed in the middle basalt aquifer. Water level data from October 15, 1997 was used for the contours; this is when the hydrograph for NPS-5 is at its greatest height each year. There is a 36-foot loss in head from NPS-5 to NPS-3 over a distance of 9,000 feet. This equates to a hydraulic gradient of 0.004 (0.4 percent) compared to a gradient of 0.006 (0.6 percent) for the basalt flow. The downward hydraulic gradient from NPS-5 to NPS-3 indicates water flowing from the northwest to the southeast in the basalt aquifer.

Ground Water Chemistry

Water chemistry data for the Fossil Gulch Canal, monitor wells NPS-5 and NPS-4, and aquifer discharge are consistent with the model. As water enters the ground water systems it dissolves ions. An increase in chemical concentrations occurs as ground water flows further from the recharge area. The U.S.G.S. collected water quality data in 1993 and the trilinear diagram in Figure 13 illustrates water chemistry for the Fossil Gulch Canal, NPS-5, NPS-4 and a discharge stream. Total dissolved solids progressively increase from the lowest concentration in canal water, to NPS-5, to NPS-4 and ultimately the perched aquifer discharge, which has the greatest concentrations. The increase in chemical concentrations as ground water flows further from a recharge area to a discharge zone is consistent with the hydrologic model.

Geophysics

Two surface geophysical studies were conducted in 1994 by Vector Engineering to investigate relations between the irrigation canal system and the

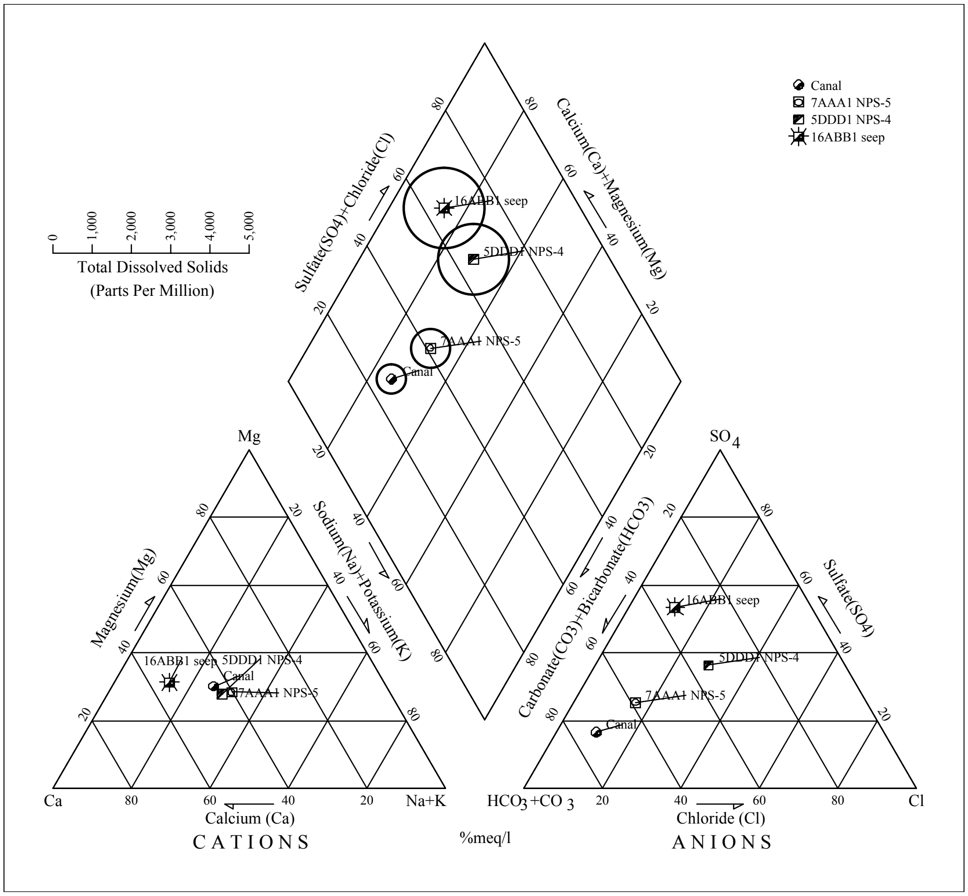



Figure 13. Trilinear diagram illustrating an increase of dissolved ions noted by the increase in circle diameters as water flows from recharge area to discharge area.

perched aquifers. Mise-a'-la-masse and Schlumberger studies (Figures 14 and 15) were employed to determine if there is a correlation between canal water and the perched aquifers. Appendix A provides a detailed discussion for each study.

High electrical potential responses are shown in figure 12 for the Mise-a'-la-masse study and they are inferred to be indicative of ground water recharge from the canal and low potential charges equate to little or no canal water connection with ground water. Pelton (1995) states that Vector (1994) used an incorrect method of moving the current electrode during the Mise-a'-la-masse

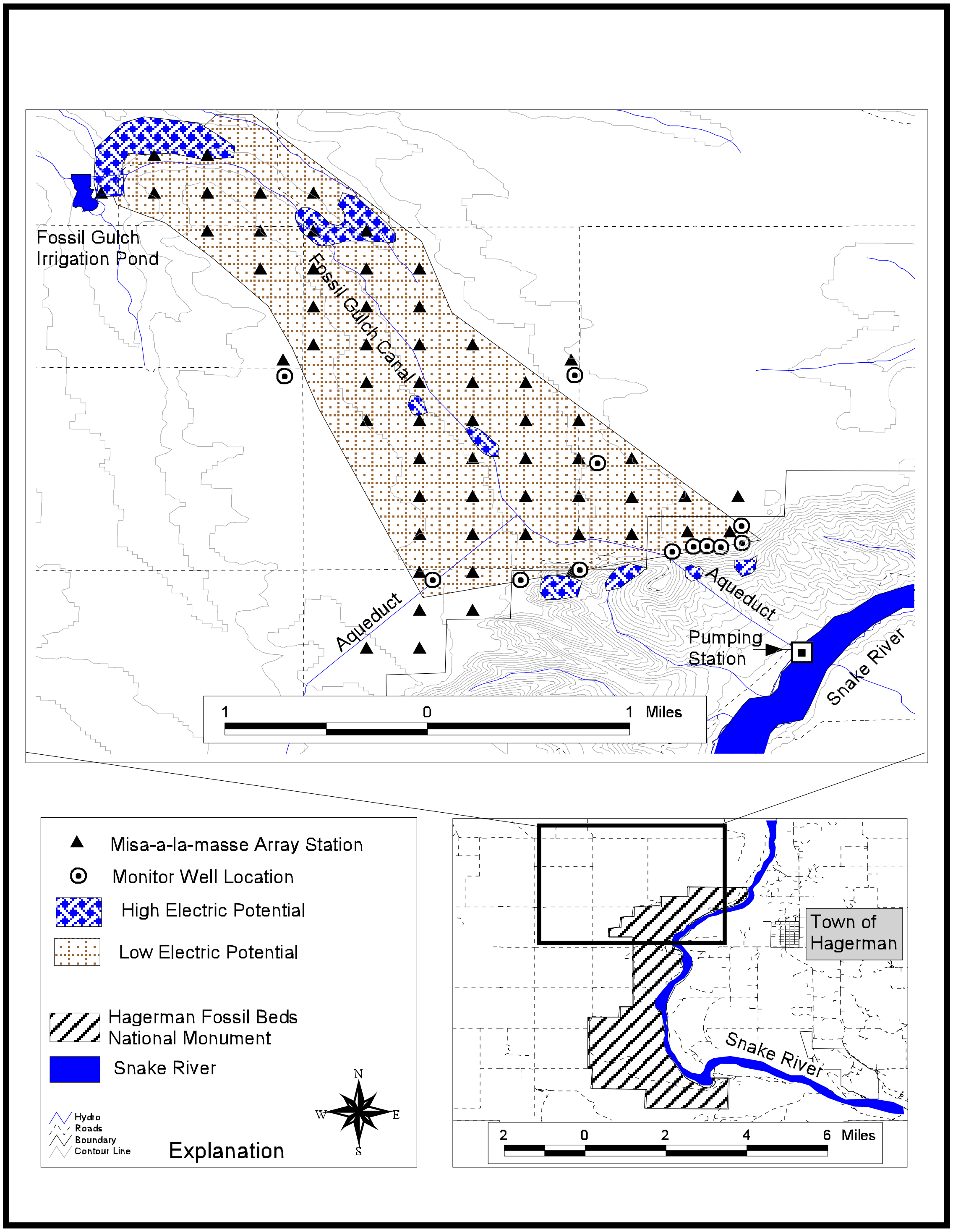



Figure 14. Misa-a-la-masse results illustrating high and low electrical potential zones (Modified from Vector Engineering, 1994).

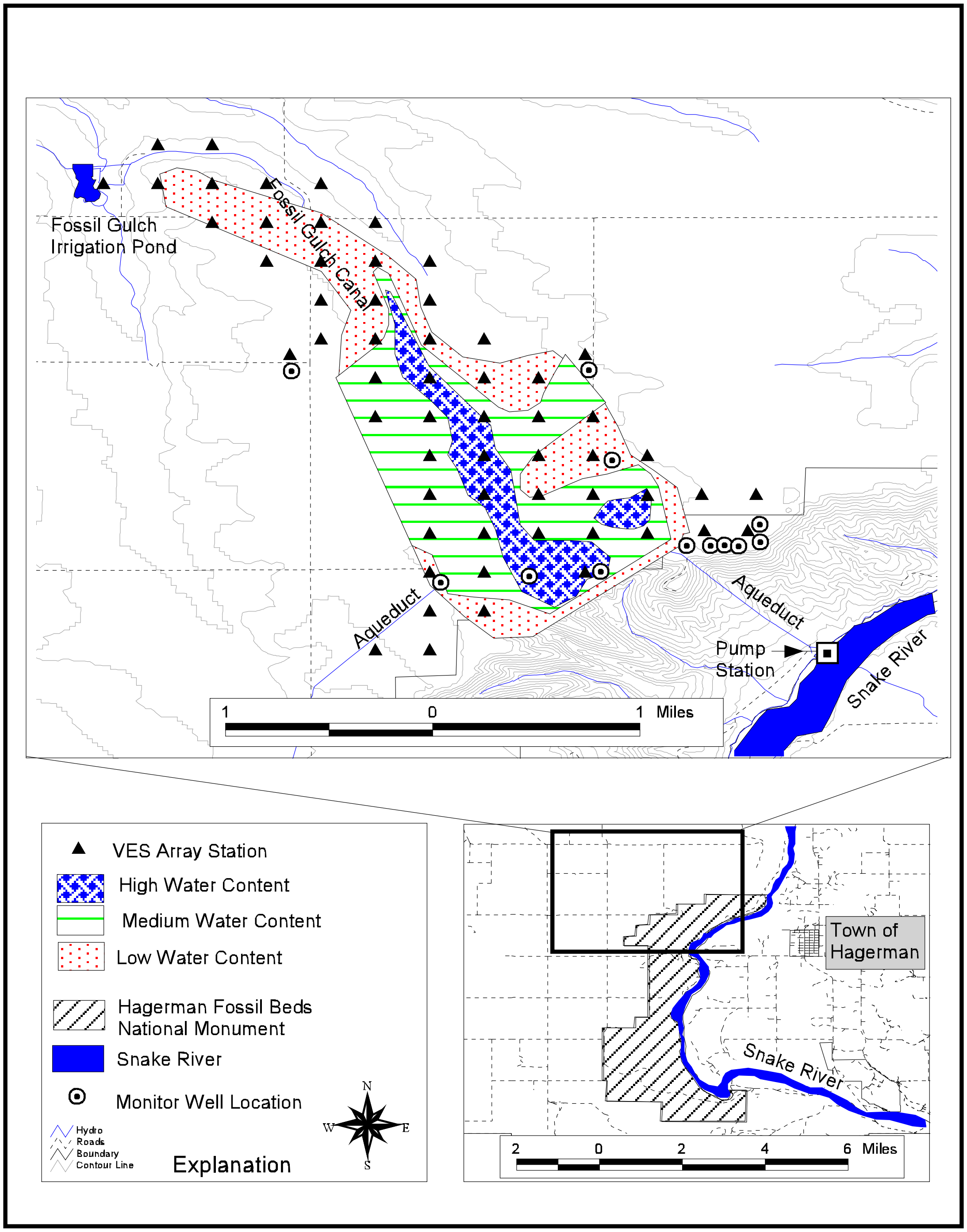



Figure 15. 'Vertical Electrical Sounding' results illustrating different resistivity zones at 100 '
below land surface (Modified from Vector Engineering, 1994).

data collection and because of this the data are suspect. The high electrical response located near the Fossil Gulch Pond (Figure 14) is interpreted to reflect recharge in this area that is consistent with the hydrologic and geologic model from this study.

The crosshatch pattern in Figure 15 is interpreted as high water content from the Schlumberger study. There is a general northwest/southeast trend to the patterns, which progress toward the Fossil Gulch Pond area. Pelton (1995) states that Vector (1994) used a unique computer program to process data collected from the survey and this should be taken into account while interpreting the results. This study reviewed the Schlumberger data and generally concurs with Pelton's (1995) statements. The computer program did not take into account the geology of the plateau or discriminate raw data between different perched aquifers. The program incorrectly connected high responses at different elevations into one layer and then interpreted this layer as one aquifer. Other cross sections appear to be reasonable and so the results of the Schlumberger study are debatable.

Perched Aquifer Discharge

The majority of aquifer discharge comes from the basalt aquifer. Young (1984) calculated a discharge rate of 420 acre-feet (AC-FT) of water per year. Included in this value are aquifer discharge locations noted in Figure 16 but also two discharge locations 2 miles south of the study area in sections 29 and 32. Aquifer discharge in sections 29 and 32 are not part of the same perched aquifer system located within the study site. If these two locations are subtracted from the 420 AC-FT calculated by Young (1984) then discharge from the study site area is 360 AC-FT per year. Low surface water flow rates occur in April, May and June and the high flow rates occur during November, December and January.

Discharge rates have been measured monthly by the U.S.G.S. and N.P.S. using weirs and flumes placed in surface water flows below aquifer discharge zones. Figure 16 illustrates weir and flume locations and Figure 17 illustrates the hydrographs for surface flows and the Fossil Gulch Canal. The purpose of collecting discharge measurements is to aid water balance calculations, record surface flow trends, correlate with recharge events and monitor well data. The N.P.S. staff started collecting surface water measurements in the same streams as the U.S.G.S. in October of 1996 using volumetric measurement methods instead of weir and staff gauge. The N.P.S. placed metal square notch type weirs into the streams and then used a calibrated bucket and stopwatch to collect measurements.

Most of the aquifer discharge hydrographs in Figure 17 show a cyclic pattern associated with the seasonal irrigation. The irrigation system starts filling with water in mid-April and four months later in August, discharge flows 16ABB2s and 16ABA1s respond with increased surface water flow. The drop in the hydrograph for 16ABA1s in late 1995 is due to a channel shift from debris flows shedding off the 1991 landslide. Some flow rates change because mud/rock debris flows originating from the landslides alter the stream channels and flow regime.

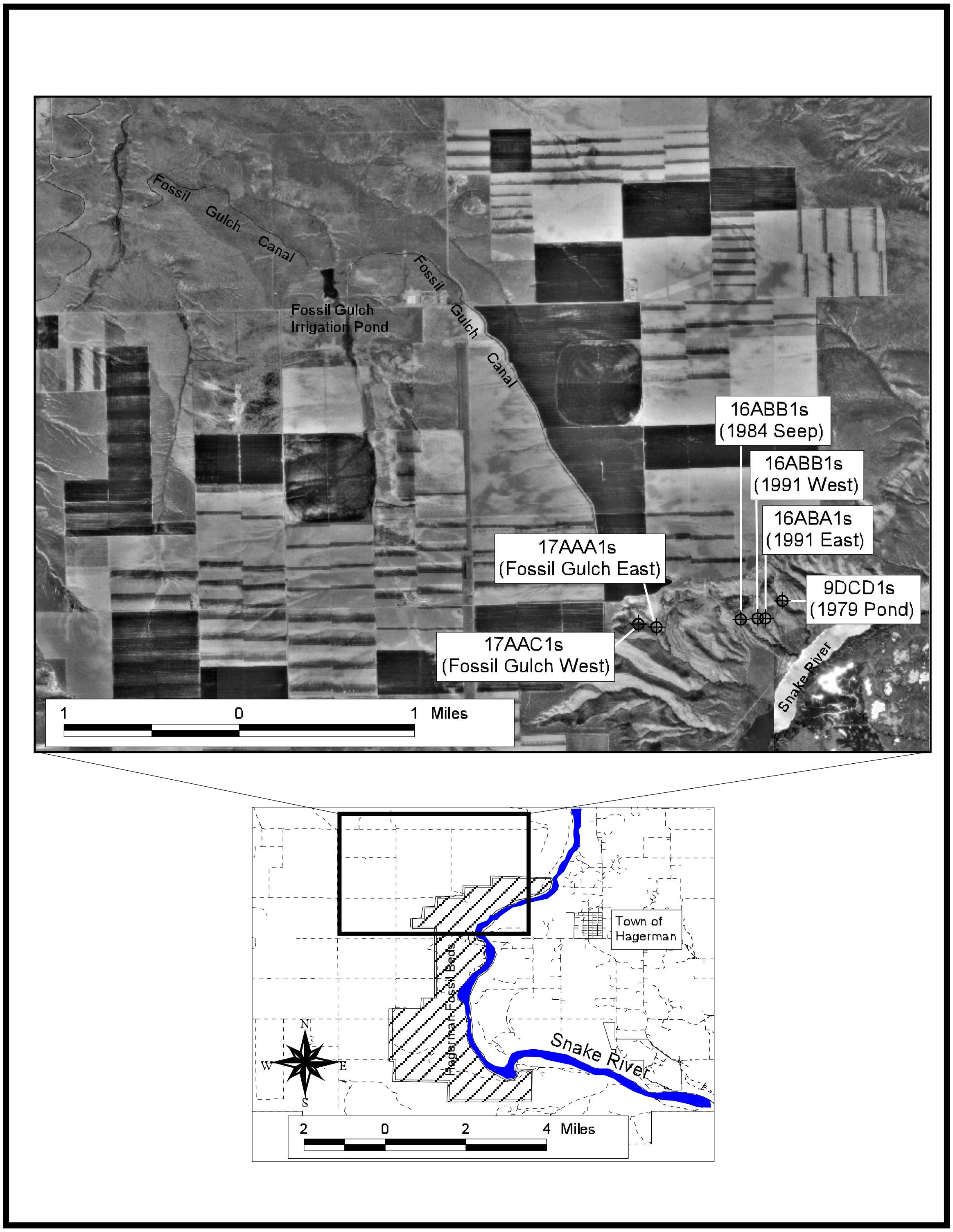



Figure 16. Weir Locations noted by legal descriptions and common titles.

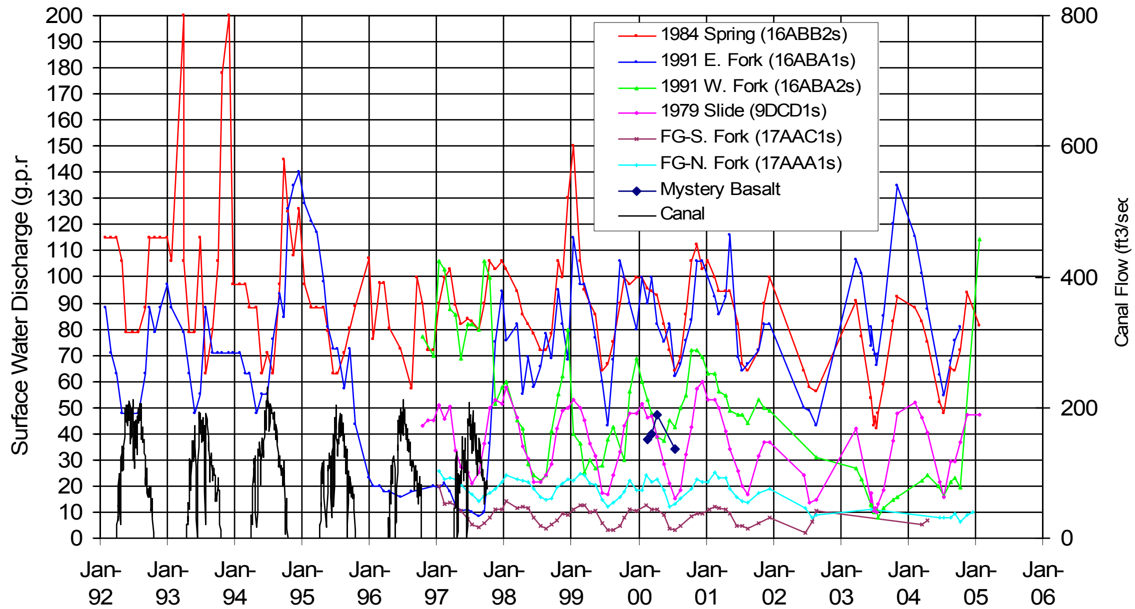



Figure 17. Hydrographs of perched aquifer discharge streams and Fossil Gulch Canal illustrating a cyclic relation between recharge events and aquifer discharge.

## Conclusions

The hydrologic model illustrates a hydraulic correlation between the seasonal irrigation, ground water flow within the Shoestring Basalt flow and perched aquifer discharge along the hillsides. Hydrographs support a ground water pressure response occurring from seasonal irrigation, which starts in mid-April. It reaches monitor well NPS-5 in June, NPS-4 in July, NPS-3 August and causes increased surface water flow in August. The lag time between the start of the recharge event in April and a response in perched aquifer discharge is about four months. Ground water contours indicate a hydraulic gradient from NPS-5 to NPS-3, which supports water flowing from the northwest to the southeast. The Mise-a'-la-masse, Schlumberger and water chemistry data also indicate recharge occurring near the pond area and flowing down gradient to the discharge zones.

## HYDROSTRATIGRAPHIC MODEL

Introduction

A six-layer hydrostratigraphic model is proposed for the study site based on the geologic and hydrologic models. The six layers are composed of three aquifers and three aquitards and are listed below.

Layer #1 - Upper Perched Aquifer (Tuana Gravel Formation).
Layer #2 - Aquitard (Glenns Ferry Formation).
Layer #3 - Middle Perched Aquifer (Shoestring Basalt flow).
Layer #4 - Aquitard (Baked zone at base of Shoestring Basalt flow and underlying Glenns Ferry Formation).
Layer #5 - Lower Perched Aquifer (Glenns Ferry Formation stream facie).
Layer #6 - Aquitard (Carbonaceous Paper Shales).

Figure 18 illustrates a detailed and accurate vertical scale fence diagram of the hydrostratigraphic model showing the six main geologic layers, monitor well designs and water levels. Figure 19 illustrates a generalized block diagram of the hydrostratigraphic model with three perched aquifers identified as the upper, middle and lower systems. These aquifers flow through layers #1, #3 and #5. Paleo-stream channels control ground water flow in the upper system while the middle system is primarily controlled by the Shoestring Basalt flow. The lower perched system is controlled by a fine-grained stream facie resting on a package of carbonaceous clays. Figures 20, 21 and 22 illustrate photographs of three aquifer discharge areas compared to the model, which explains the discharge spatial distribution on the hillside.

Upper Perched Aquifer System

The upper system is characterized by paleo-stream channels composed of primarily fine sand (Saddler, 1997) along localized, sinuous and meandering paleo-stream channels. Figures 20 and 21 exhibit these localized point discharge paleo-stream channels noted by heavy isolated vegetation growth surrounded by sagebrush. Most of the ground water filled channels are located at the contact (about 3,300 feet above sea level) between the coarser grained Tuana Gravel Formation and underlying fine-grained Glenns Ferry Formation. This system has the shallowest depth below ground surface and shortest ground water flow paths from recharge to discharge. Based on field observations these channels exhibit unconfined flow conditions with discharge rates typical of seeps.

Middle Perched Aquifer System

The middle system is primarily constrained to the Shoestring Basalt flow at an elevation of about 3,200 feet in the discharge area and transmits ground water through fractures and joints. General ground water flow likely follows the geologic dip of the flow that was determined from the seismic study to be southerly. The basalt flow is not areally extensive and where the flow pinches out fine-grained sediments control ground water flow.

The geologic and hydrologic models indicate the area of recharge to the basalt aquifer system is primarily in the vicinity of the Fossil Gulch Irrigation Pond. Basalt is observed in direct contact with irrigation water at an elevation of about 3,300 feet in this area. Hydrographs for NPS-5, NPS-4 and NPS-3 illustrate how a recharge pressure wave propagates through the basalt system from recharge areas to the discharge. Geophysical evidence of recharge for the pond area is based on the Mise-a'-la-masse and Schlumberger studies performed by Vector Engineering (1994). The high response of Mise-a'-la-masse

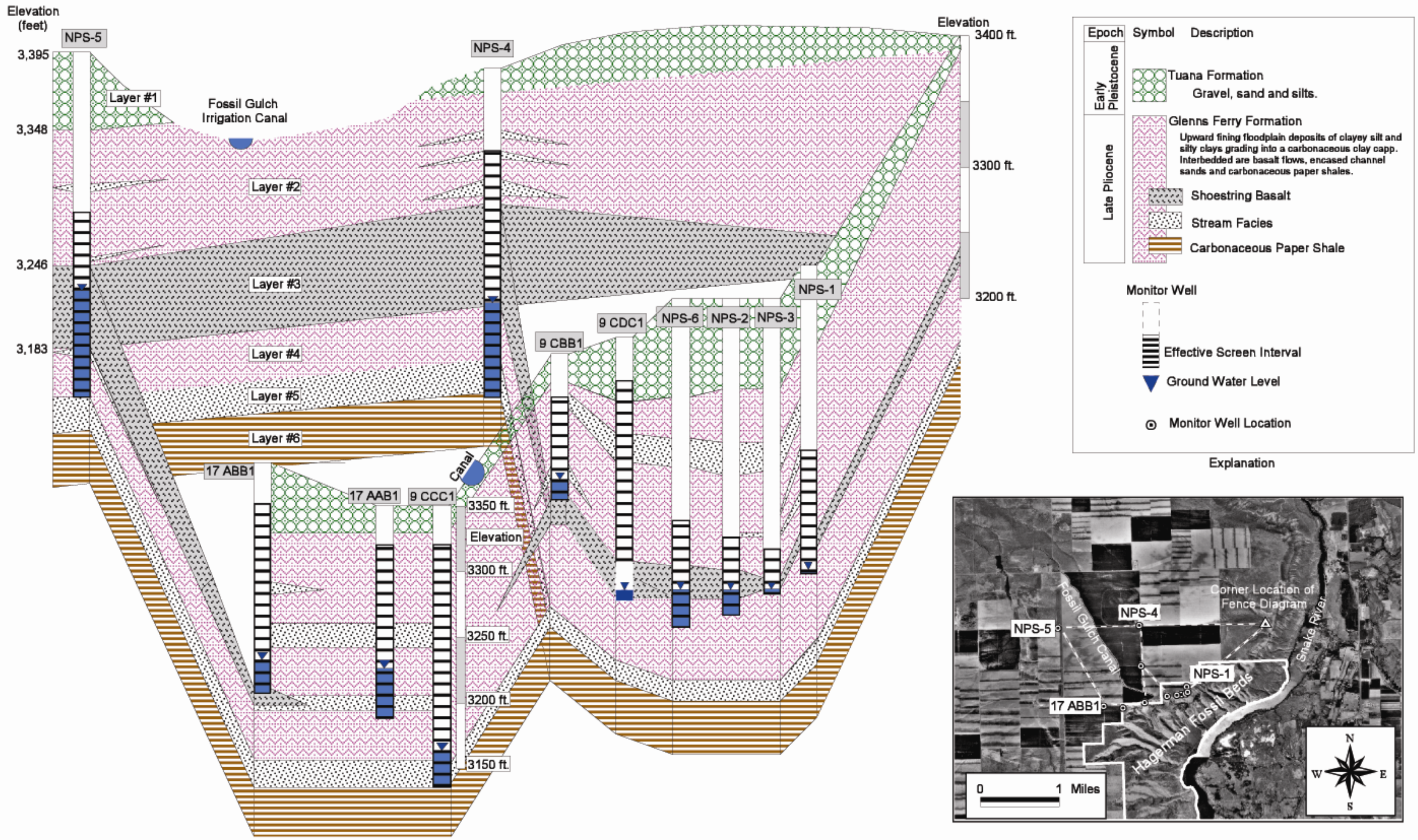



Figure 18. Fence diagram of the hydrostratigraphic model illustrating the six main geologic layers, monitor well designs and water levels.

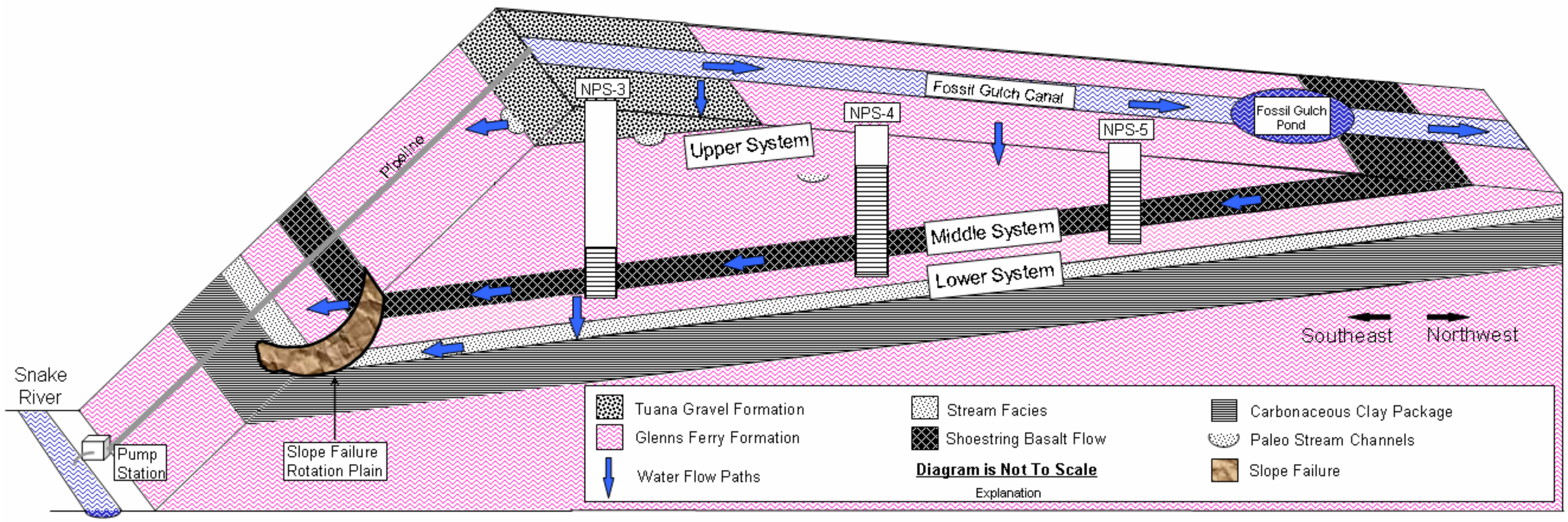



Figure 19. Block diagram of the hydrostratigraphic model illustrating main geologic layers controlling the upper, middle and lower perched aquifer systems. The upper and lower systems flow through paleo-stream channels while the middle system flows primarily through basalt. Recharge reaches monitor well NPS-5 first, followed by NPS-4 and NPS-3 before discharging out the hillside.

and Schlumberger data near the Fossil Gulch Pond area correlates with the geology and the hydrographs from monitor wells.

This system has intermediate length ground water flow paths from recharge to discharge zones. The basalt flow has the greatest hydraulic conductivity of the three perched systems and it discharges the greatest volume of ground water. Figure 22 illustrates how the greatest vegetation growth correlates to discharge from this aquifer system. The basalt has a basal baked zone that is well lithified but fractured. This baked zone and underlying silty clays are acting as an aquitard to the basalt aquifer. Saturated thickness of the flow is a few feet near the discharge areas but at monitor well N.P.S.-5 it is has a thickness of 60 feet.

Lower Perched Aquifer System

The lower perched aquifer system is characterized by a fine-grained paleo-stream facie resting on a 20-foot thick package of carbonaceous paper shales. In some areas the stream facie exhibits preferential flow paths through paleo-channels as shown on Figures 20 and 22. The lower perched system is the least defined due to a lack of data. However, this system correlates with the elevation of the rotational failure planes for the 1991 and ca. 1979 slope failures (Figure 22).

Ground water recharge to the lower system likely encompasses a larger area and flow paths are the longest of the three perching systems. Additional water may be draining from monitor wells into the lower system due to long effective screen intervals (Appendix C). The discharge volume of the lower system is significantly less than the basalt system and at most locations evapotranspiration is greater than discharge. There is evidence for the expansion of the lower system in recent years. The green vegetation located at a paleo-stream channel in the lower perched system on Figure 20 did not exist a few years ago based on historical photos. Also, water levels in monitor well 9CCC1, which is completed in the lower system, continue to increase (Appendix C).

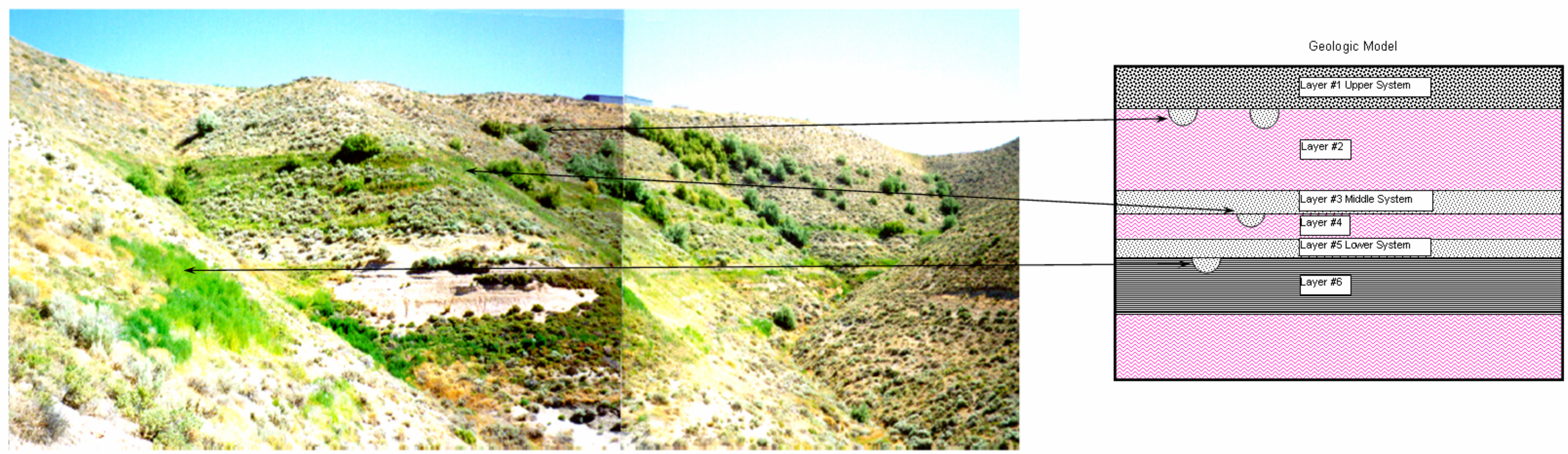



Figure 20. The photograph shows three aquifer systems and the geologic model explains the spatial distribution of discharge patterns. The upper system discharges from individual paleo-stream channels as seen by the two green areas just below the horizon. The middle system exhibits a broad band of green vegetation in the center. The basalt does not outcrop in this area but during field investigations a basalt boulder was found embedded in fine sediments at this elevation. It also has the greatest discharge volumes of all the seeps typical of the basalt system. The discharge locations of the lower system have green vegetation growing at the paleo-stream channel locations.

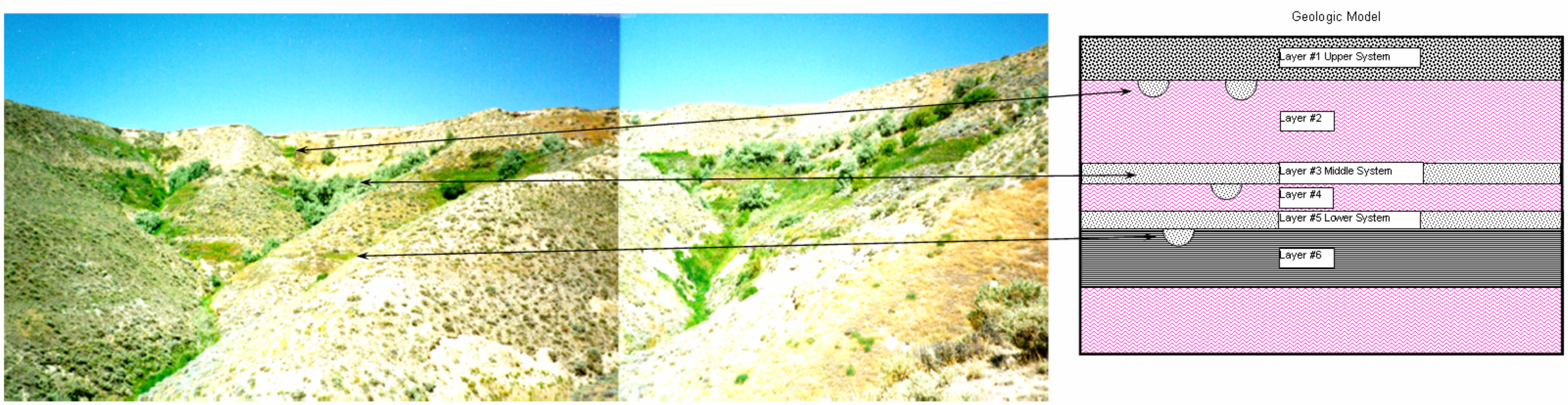



Figure 21. The photograph shows three aquifer systems and the geologic model explains the spatial distribution of discharge patterns. The upper system discharges from individual paleo-stream channels as seen by the two green areas just below the horizon. The middle system exhibits a broad band of green vegetation in the center. The basalt does not outcrop in this area but the middle system still discharges the greatest volume of water typical of the middle basalt system. The discharge locations of the lower system have green vegetation growing at the paleo-stream channel locations.


Figure 22. Photograph of perched aquifer discharge zones and slope failures. The middle basalt and lower systems are dominant in this area. Ground water discharge locations are noted by green vegetation growth. The lower system is flowing through paleo-stream channels and the elevation correlates to the rotational failure plane of the 1991 and ca. 1979 slope failures.

## CONCLUSIONS AND RECOMMENDATIONS

The hydrostratigraphic model developed from this investigation provides for:

1.) Identification of three perched aquifer systems and an explanation for the perched aquifer discharge patterns and spatial distribution on the hillsides.

2.) Location of the main recharge area for the middle perched system based on geologic, hydrologic and geophysical data.

3.) Association between the failure planes for the 1991 and ca. 1979 landslides and the carbonaceous paper shale package.

4.) Potential of each aquifer system for slope stability problems.

5.) Explanation of well hydrographs responding to a recharge pressure wave.

Three perched aquifer systems (upper, middle and lower) occur within the plateau and have different implications for slope failures. Paleo-stream channels control ground water flow of the upper system that causes point discharge locations on the hillsides. They have very low discharge rates typical of seeps. Any slope failure associated with these individual channels will likely be small relative to the magnitude of failures associated with the middle and lower systems.

The middle system has the greatest discharge rates and lateral extent. Recharge to the middle basalt system is primarily from the irrigation system with unknown quantities recharging from field application of water. Recharge to the middle system occurs in the Fossil Gulch Pond area based on the hydrostratigraphic model. The main component of ground water flow is likely following the southerly dip of the basalt flow. Hydrographs for wells NPS-5, NPS-4 and NPS-3 and water chemistry illustrate a recharge pressure wave propagating through the basalt aquifer. It takes approximately four months for the pressure wave to travel from the recharge area in mid-April to the discharge zones reaching NPS-5 in June, NPS-4 in July and NPS-3 (near the discharge area) in August. The volume of water discharging from the basalt flow saturates sediments in the discharge zones and erodes the slope face causing over-steepened slopes.

The third and lowest perched aquifer system is controlled by paleo-stream channels. This system is particularly susceptible to slope failures because of the presence of a finely laminated paper shale package with occasional deposits of diatomite and volcanic ash. The existing 1991 and ca. 1979 slope failure planes are about 40 feet below the Shoestring Basalt flow which corresponds to the elevation of carbonaceous paper shale package of the lower system. Sparse data exists for this system but recharge likely occurs from leakage of the middle basalt aquifer system and water draining from upper systems into lower systems from monitor wells constructed with long effective screen intervals.

Recommendations for further study are presented below.

1.) Continue ground water monitoring on a monthly basis.

2.) Continue water quality data collection for all wells and specific perched aquifer discharge locations.

3.) Perform ground water tracer tests to define ground water parameters and identify flow paths with discharge locations that will aid mitigative efforts.

4.) Based on field data, canal lining efforts need to be focused near the Fossil Gulch Pond area to impact the middle system.

5.) Drill a series of drain wells upgradient from the perched aquifer discharge zones down to the regional aquifer. Construct the wells to capture water flowing toward the slope face effectively diverting it down to the regional aquifer. A problem with drain wells will be water quality implications from draining perched aquifer water into lower aquifers (aquifer interconnection). The advantages to this option are:

A.) Provides a permanent long term solution with little or no maintenance compared to relatively short life spans (30 yrs.) for canal/pond synthetic liners.

B.) Eliminates potential problems with future irrigation dredging activities to remove sediments in the canal/pond and synthetic liners.

C.) Lower costs than canal/pond lining. The least expensive option of lining the canals/ponds using HDPE flexible membrane is calculated to be $3.6 million.

D.) No de-watering pumps which require capitol, maintenance and electrical costs.

E.) Drain wells can be constructed on federal lands, compared to canal/pond lining that will occur on private land.

# Appendix A

## DISCUSSION OF GEOELECTRIC STUDIES

## INTRODUCTION

In 1994 Vector Engineering, Inc. was hired to conduct geophysical and engineering studies for assessing the relation between the Bell Rapids Irrigation District canal system and the perched aquifer discharge on the hillside. Vector hypothesized if the canal water was the recharge source then an electrical continuity between the canal water and perched aquifer discharge water would be evident. The Vector study employed electrical techniques to determine if there is a correlation between the aquifer discharge and the canal water.

Pelton (1995) then evaluated these surveys for accuracy and acceptable methodology. According to Pelton, Vector Engineering does not provide complete information on the data acquisition and reduction procedures for any of these electrical studies in its report. Pelton (1995) states that despite the lack of detail it appears the Wenner and Schlumberger data were acquired and reduced using procedures acceptable to most professional geophysicists although the data post-processing for the Schlumberger study using a computer model produced skeptical results.

## MISE-A'-LA-MASSE STUDY

Description/Purpose

In 1994 Vector Engineering conducted a Mise-a'-la-masse study near the Fossil Gulch Canal with the goals of collecting data for identifying ground water flow geometry and establishing an electrical connection between the perched aquifer discharge zones at the hillside and the canal. Figure 23 illustrates the locations of each Mise-a'-la-masse array station marked with a triangle where voltage potential was measured lateral to the canal while the canal water was charged with an electrical current.

Results/Conclusion

The seeps at the bluff face exhibit high electrical potential indicating the perched aquifer discharge zones are hydraulically connected to the canal. Perched aquifer discharge water always exhibited higher voltage potentials than other areas at the bluff face, which had no water discharging and were apparently 'dry' (Vector Engineering, 1994). Pelton (1995) states the current electrode placed at 3,000 to 5,500 feet from the canal may not have been far enough away due to zones of elevated potential difference at the margins of the survey area. Also, the procedure used by the Vector Mise-a'-la-masse study differs with the procedure described by Parasnis 1973 in two fundamental ways.

1.) The access point of the current source to the conductive mass was not fixed.

2.) A roving electrical potential difference measurement was made rather than the electrical potential measured relative to a fixed base.

Additionally, the current electrode located at the canal was not fixed and so it is incorrect to combine all of the Mise-a'-la-masse data together on a single map. The experiment design is not described completely and the exact locations of the current electrodes is unknown but, the results are consistent with an electrical connection between the canal and perched aquifer discharge zones (Pelton, 1995).

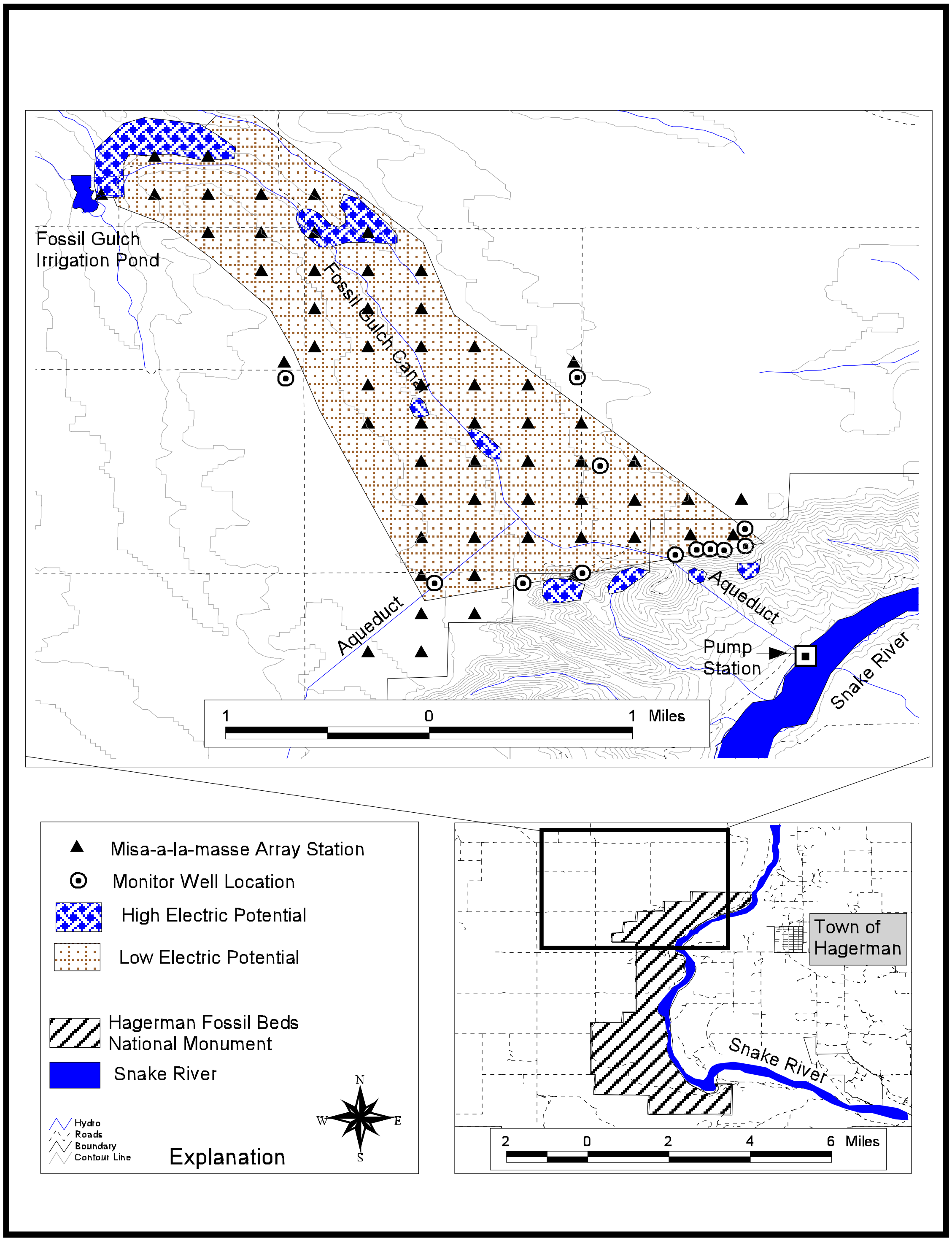



Figure 23. Misa-a-la-masse results illustrating high and low electrical potential zones (Modified from Vector Engineering, 1994).

## WENNER STUDY

Description/Purpose

In 1994 Vector Engineering conducted a Wenner array study along the Fossil Gulch Canal with the goal of collecting data to aid assessment with the relation between the Fossil Gulch Canal and the underlying perched aquifers. Figure 24 illustrates the location of the Wenner array. The scope of the study includes a segment of the Fossil Gulch Canal between the inlet and Fossil Gulch Pond about 2.8 miles downstream. The Wenner array is very commonly used to identify flat-lying interfaces between lithologies. Resistivity data was collected directly below the canal to map subsurface anomalies. Pelton (1995) evaluated the Wenner study for accuracy and acceptable methodology.

Results

Vector Engineering 1994, states that from the start of the unlined canal and progressing 9,000 feet downstream resistivity decreases with depth indicating an increase in moisture content as illustrated in Figure 25. Resistivity increases with depth from 9,000 feet onward to the Fossil Gulch Pond indicating a decrease in moisture content suggesting this portion of the canal is not leaking as much as the previous 9,000 feet. Low resistivities are inferred by Vector to have high permeability even though saturated clay-rich units are known to have a low resistivity. Vector states that the low permeability of clay-rich units is believed to act as an aquitard inhibiting saturation of the clays and resulting in high resistivities for the ‘dryer’ clays. Also, a large resistivity difference between shallow and deep measurements indicate lower permeability while if the geologic

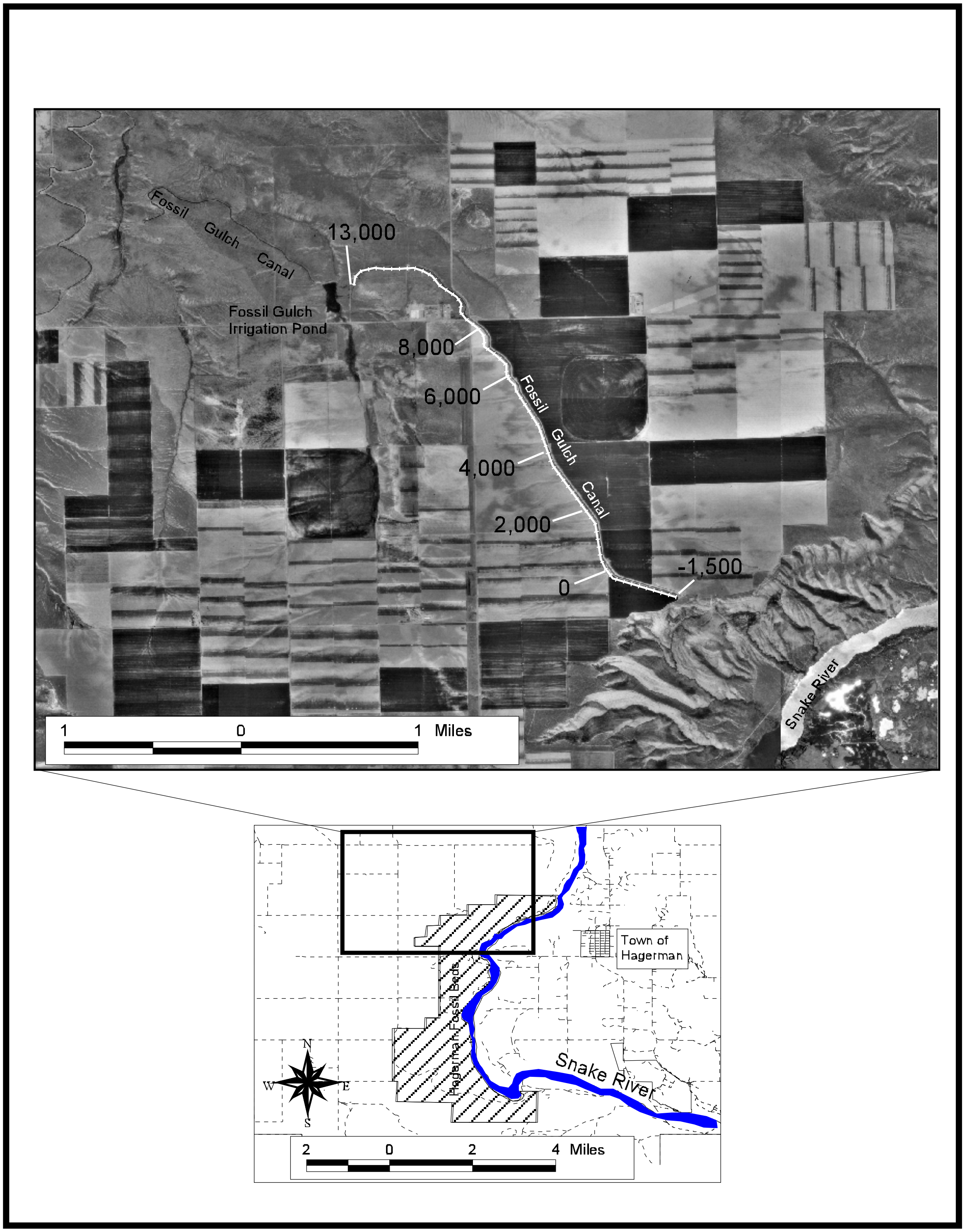



Figure 24. Wenner array location noted by the hachured line. The numbers indicate distance in feet from the canal inlet to the pond and correlate with the Wenner profile.

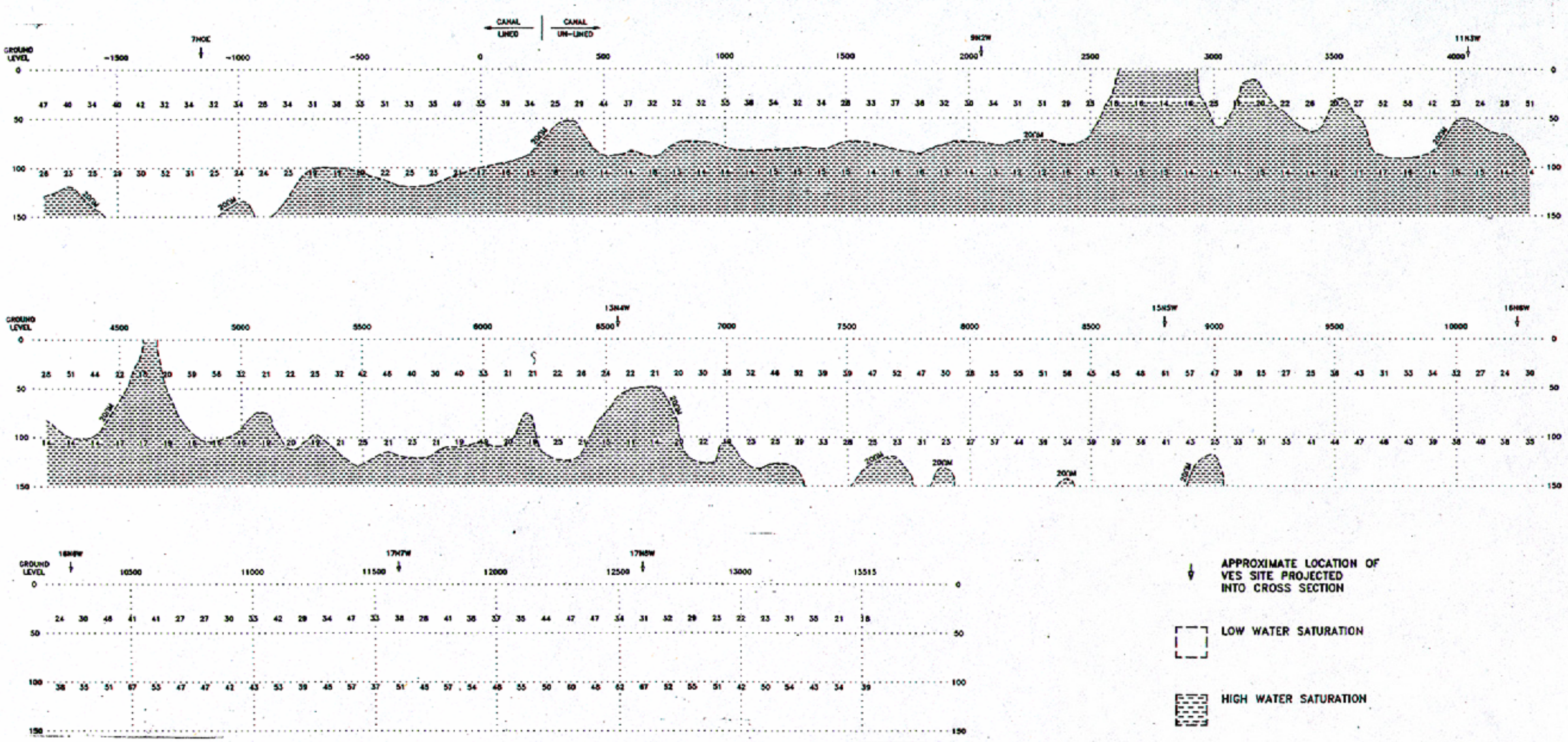



Figure 25. Wenner profile along the Fossil Gulch Canal illustrating layers with high and low saturation. Vector interpreted areas with high water saturation to be leaky canal segments composed of a material other than clay (from Vector Engineering, 1994).

unit has high permeability the resistivity values would be similar indicating the same percentage of water saturation (Vector Engineering, 1994).

Wenner array data at one location correlates with an anomaly from the Mise-a'-la-masse data. Figure 23 illustrates a location with high electrical potential from the Mise-a'-la-masse study and correlates with low resistivity from the Wenner study. Resistivity drops below 20 OHM-Meters between stations 2,500 and 3,000 from the Wenner array while electrical potential from the Misa-a-la-masse study was measured at 59 millivolts near the same location (Vector Engineering, 1994).

Conclusions

Vector Engineering claims that resistivity measurements collected along the canal are effective for representing zones with high water saturation and high water saturation implies a lithology, other than clay, transmitting water; the clays would inhibit downward migration of water thus high saturated conditions will not occur in the clays. These interpreted zones of high water saturation are assumed to be associated with canal leakage.

One flaw, according to Pelton (1995), in the Wenner study is the basic premise stated by Vector Engineering as:

> "As the water saturation of a given porous medium increases, it has a larger and larger affect (sic) on the resistivity of the material. By measuring the resistivity at two different depths the degree of water saturation is evaluated at the two separate depths. In the same medium (e.g. sand) low resistivities indicate a higher water saturation and high resistivities indicate a lower water saturation (Vector Engineering, 1995)".

The intention of the Vector study was to map the estimated apparent resistivity at two different depths and then, based on the Archie water saturation equation, qualitatively infer the water saturation in the shallow subsurface. The Archie water saturation equation can be used to relate water saturation to measured resistivity in a porous medium if clay is not present (Schlumberger Educational Services, 1987). If clay is present then the Archie water saturation equation cannot be used. Lithology and water resistivity of the shallow subsurface need to be constant along the canal in order to use the Archie equation to interpret the data in terms of lateral changes in water saturation. It is common for low resistivities to be associated with low permeable clay rich lithologies and even slightly moist clay conducts well due to ion active clay minerals (Milsom, 1989). A change in apparent resistivity would accompany any lateral facies change or chemical change in a sedimentary unit (Pelton, 1995).

## VERTICAL ELECTRICAL SOUNDINGS STUDY

Description/Purpose

The goals of the VES study were to collect geophysical data to aid assessment with the relation between the Fossil Gulch Canal and the underlying perched aquifers. Figure 26 illustrates the location of each VES station marked with a triangle and defines the scope of the study which includes a segment of the Fossil Gulch Canal between the inlet and Fossil Gulch Pond about 2.8 miles downstream. Data was collected using an expanding electrode array to map subsurface resistivities and construct geoelectric cross sections and plan view maps. Pelton (1995) then evaluated this survey for accuracy and acceptable methodology.

Results

Considerable variation exists in the subsurface resistivity data throughout the study area likely due to the complex paleo-flood plain deposits and ground water flow geometry. There are low resistivities at one hundred feet below the Fossil Gulch Canal but the Shoestring Basalt flow is very resistive and variations within the flow are inversely proportional to porosity (i.e., low resistivities correlate to higher porosity) (Vector Engineering, 1994). Processing of the raw data was performed with a computer program named ABEM's "Super VES" to generate a multi-layered model for each VES station. The computer model suggests various geo-electric units between stations which are interpreted as sandy and clay-rich inter-fingering lithologic units with a relatively continuous basalt layer throughout most of the survey area (Vector Engineering, 1994).

The raw resistivity data was computer processed and used to produce cross section diagrams. When the computer program is anchored to well logs the cross section diagrams appear to be reasonable. Debatable results occur when the model is not anchored to well logs and the program has connected three separate resistivity responses at different elevations into one lithology. If the same data processing methods were used to create the plan view maps of resistivity as the vertical cross sections (which is likely the case) then there is a high degree of uncertainty in the VES maps.

Figures 26 and 27 illustrate the plan view VES study results after computer processing for 100 and 150-foot depths respectively below land surface. The triangle symbols mark the location of each VES station and the crosshatch pattern is interpreted as high water content by Vector Engineering. In both figures there is a general northwest/southeast trend to the high water content patterns along with apparent northeast/southwest trending axes from the low and medium water content patterns.

Conclusions

According to Pelton 1995, it is important to realize the unique methodology used to create layered resistivity models from the computer program ABEM's 'Super VES' which produced debatable results. Also, a typical VES curve (apparent resistivity versus AB/2) may be fit by more than one layered resistivity model and each model must be considered one of many possible models that could fit the data equally well (Pelton, 1995). The vertical electrical sounding diagrams from the array study are suspect due to the data post-processing by the computer program.

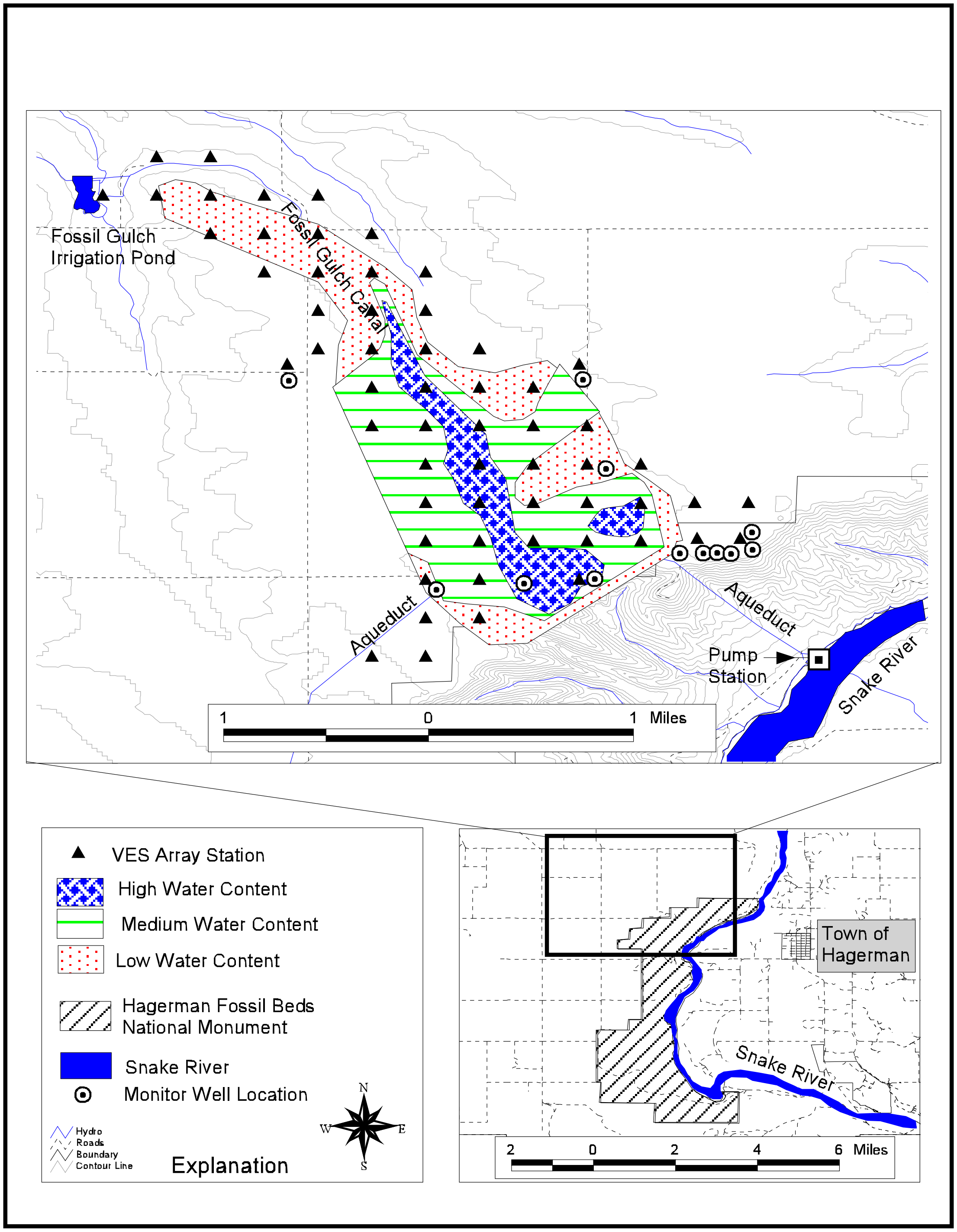



Figure 26. 'Vertical Electrical Sounding' results illustrating different resistivity zones at 100 fe below land surface inferred as water content (Modified from Vector Engineering, 1994)

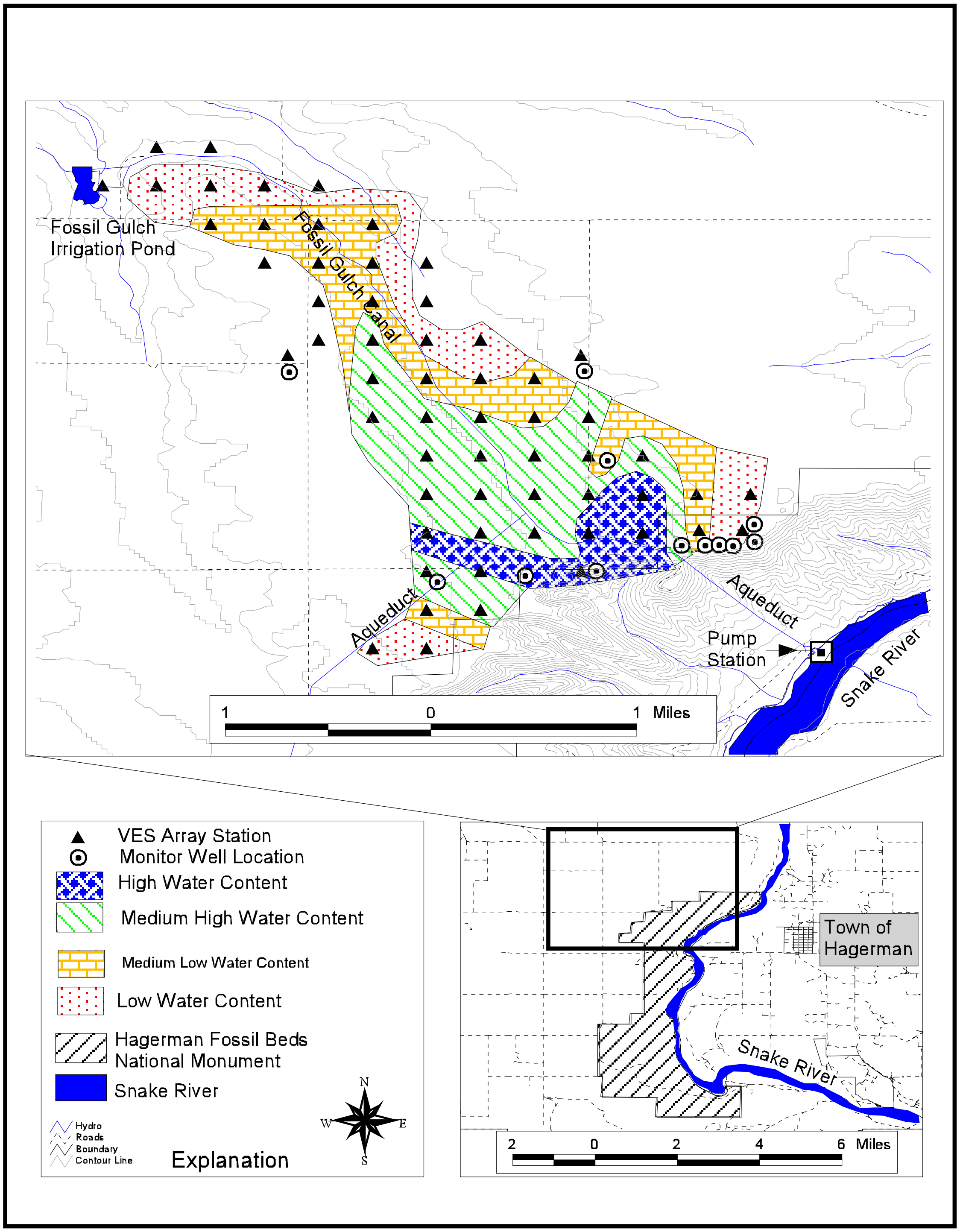



Figure 27. 'Vertical Electrical Sounding' results illustrating different resistivity zones at 175 fe below land surface inferred as water content (Modified from Vector Engineering, 1994).

# Appendix B

## DISCUSSION OF SURFACE WATER

# INTRODUCTION

The Bell Rapids Mutual Irrigation District is located adjacent to the Hagerman Fossil Beds National Monument on the Bruneau Plateau. The irrigation company operates and maintains an irrigation system that pumps water from the Snake River to irrigate approximately 19,000 acres of land on the plateau. The water license priority for Bell Rapids Irrigation Company is dated December 16, 1963 and construction of the irrigation facilities began in 1969 with the first irrigation season in 1970 (Vector Engineering, 1994).

The irrigation system consists of river pumps, three penstocks, 10 miles of delivery canal system, a canal transfer pump station, regulating ponds, canal lateral line pumps, and over 110 miles of lateral and mainline distribution pipe. The main pumps lift water from the Snake River up 600 feet in elevation where it is emptied into the Fossil Gulch Canal and lateral lines along the remainder of the canal system pump water out of the canal for field application using sprinkler system technology (Vector Engineering, 1994). This system provides pressurized irrigation water to approximately 25 individual farms. The original irrigation project had two main pump stations named the Fossil Gulch and Bell Rapids pump stations. In 1987 a massive landslide eliminated the Bell Rapids pump station.

As a result of the landslide the Fossil Gulch station increased pumping rates and additional lateral lines were constructed to distribute water to areas formerly supplied by the Bell Rapids Canal. The Fossil Gulch Canal was realigned, straightened and lined with concrete for the first one-half mile after the

1987 irrigation season due to an increase in demand. The now buried first one-half mile canal segment was part of all the canal leakage studies prior to the realignment. The rest of the Fossil Gulch Canal system and storage ponds are unlined with synthetic materials but do have natural calcium carbonate (caliche) in segments that may act as a natural liner.

The landuse change of the plateau from sagebrush desert to farmland has also coincided with formation of multiple perched aquifer systems that discharge at various locations. The largest discharge volumes and most numerous discharge sites are located near Fossil Gulch Basin on the hillside about 250 feet below the plateau surface. Many studies have been conducted since 1984 indicating the source of recharge to the perched aquifers is the Bell Rapids Irrigation System.

Five separate seepage studies have been performed on the Fossil Gulch Irrigation Canal and pond. The first study was completed by the U.S.G.S. (Young, 1984) in cooperation with the B.L.M. in 1984. This study measured flow in the Fossil Gulch Canal at two locations. The amount of water leaking from the canal was calculated based on the difference between two flow rates. About 1,900 AC-FT of water leaks from the first mile of the Fossil Gulch Canal per irrigation season. A second study by Worstell (1985) was performed in response to a request from the Bell Rapids Irrigation District. Worstell measured canal leakage by a seepage meter technique that is commonly used for such studies. The first half-mile of canal length was analyzed using this technique and results indicate 193 AC-FT of water leak from the canal per irrigation season.

Montgomery (1987) conducted a third canal leakage study in October 1987 by constructing a water impoundment in the first one-half mile of Fossil Gulch Canal. Montgomery (1987) calculated leakage at 299 AC-FT per season.

In 1992 the fourth study was implemented by the National Park Service (N.P.S.) Water Resources Division (Martin, 1992). Leakage tests were conducted on three sections of the Fossil Gulch Irrigation Canal and two irrigation holding ponds. The results from the N.P.S. study show 360 AC-FT of water per irrigation season is lost from the first one-half mile segment of unlined canal. The fifth study was performed in 1994 by Vector Engineering, Inc.. This study was designed to measure the canal flow directly every 500 feet for the entire length and use this flow rate data to indirectly calculate canal leakage similar to the U.S.G.S. study. The results of the Vector study were stated as inconclusive but a leakage rate of 5,000 AC-FT per season for the entire canal system was reported.

## SUMMARY OF CANAL LEAKAGE STUDIES

Table 4 lists estimates from the five different studies for the volume of water leaking from the Fossil Gulch Canal for an average irrigation season. Changing geologic conditions in the canal base will influence extrapolation of canal leakage data. For instance, the Tuana Gravel Formation is below the canal at the inlet area near the edge of the bluffs. Conversely, near the end of the canal the Tuana Formation is observed higher in elevation on the hillsides above the canal where active gravel pits are located in section 31. Drill well logs from monitor wells N.P.S.- 4 and 5 lateral to the canal support this geologic condition. It is probable the canal crosses the contact between the Tuana Gravel and underlying finer grained Glenns Ferry Formation somewhere within the first mile segment of canal.

| | | Leakage Volume (acre-feet/ /180 day season/ /first unlined one-half mile) | Leakage Volume (acre-feet/ /180 day season/ /first unlined mile) | Leakage (acre-feet/ /180 day season/ /Entire system) |
|---|---|---|---|---|
| Year Performed | Research Entity | | | |
| | | | | |
| 1984 | U.S.G.S. | 1,425 | 2,850 | |
| 1985 | Worstell | 193 | 386 | |
| 1987 | Montgomery | 293 | 586 | |
| 1992 | N.P.S. | 360 | 720 | |
| 1994 | Vector Eng. | | | 5,000 |

Table 4. Comparison of canal leakage rates. The measured data from short segments of the unlined canal was extrapolated for the entire length of the canal with the leakage rate assumed to be constant for an average length irrigation season of 180 days.

Young (1984), Worstell (1985) and N.P.S. (1994) canal leakage tests on the Fossil Gulch Canal were performed in proximity to this geologic contact. Young's (1984) flow measurement site #3 is located near the start of the canal and test site #4 is about one mile downstream (Figure 9). It is likely that somewhere between #3 and #4 flow measurement sites is the Tuana/Glenns Ferry contact. The study by Martin (1994) indicates a decrease of water leakage from the middle unlined test impoundment to the lower unlined test impoundment. This may be a function of the Tuana/Glenns Ferry Formation Contact. It is conceivable that the lower leakage test impoundment may have been performed in the finer grained Glenns Ferry Formation. Worstell (1985) notes gravel at the first two test sites which indicates Tuana Formation in this area. It appears most of the leakage studies have been performed within the Tuana Formation and therefore biasing the projected results for the remainder of the canal system. The Fossil Gulch Irrigation Pond leakage study performed by Martin (1994) indicated a water leakage of 140 acre-feet per season. A degree of uncertainty is associated with the reported pond leakage data due to problems with data collection.

Generally speaking there may be a bias in the reported canal leakage data due to changing geologic conditions along the canal. This would effect extrapolation of the data to other segments of canal. The Fossil Gulch Canal appears to intercept the Glenns Ferry Formation for most of its length base on the canal geology investigation.

## VECTOR ENGINEERING WATER BUDGET STUDY (1995)

### Description/Purpose

In 1995 Vector Engineering conducted a water budget analysis for the total Bell Rapids irrigation system. The system was assessed as a single unit that includes approximately ten miles of canal and four ponds. Water loss due to infiltration was calculated at 10 percent of the total volume of water pumped into the irrigation system during 1991 (Vector Engineering, 1995).

### Results

The results of the water balance study are illustrated in Table 5. Inflows to the canal system were calculated at 48,600 acre-feet while irrigation outflows were calculated to be approximately 43,400 acre-feet. Evaporation was estimated to be 150 acre-feet and precipitation 30 acre-feet for the Bell Rapids Irrigation District in 1991. Canal leakage estimate for the entire Bell Rapids Irrigation District amounts to 5,080 acre-feet for the 1991 season.

Conclusions

Vector Engineering (1995) calculated that 10 percent of the total volume of water pumped into the Bell Rapids irrigation system is lost to infiltration. This loss amounts to about 5,000 acre-feet of water. It is important to note this amount is for the entire irrigation system consisting of ten miles of canals and four ponds and not just the first three miles of canal and Fossil Gulch Pond.

| System Balance Factors | Acre-Feet | |
|---|---|---|
| | (1991 Irrigation Season) | |
| | | |
| Canal Inflow (Snake River Pump Station) | 48,600 | |
| Canal Inflow (Precipitaion) | 30 | |
| | Inflow Sub-Total | 48,630 |
| | | |
| Canal Outflow (Irrigation Pumping) | 43,400 | |
| Canal Outflow (Evaporation) | 150 | |
| | Outflow Sub-Total | 43,550 |
| | | |
| Canal Water Lost To Infiltration | | 5,080 |

Table 5. Results of water balance study from the Vector Engineering illustrating estimates of water inflows and outflows for the total Bell Rapids Irrigation District (modified from Vector Engineering, 1995).

# Appendix C

## DISCUSSION OF GROUND WATER

## INTRODUCTION

Ground water data has been collected since 1986 when six monitor wells were installed and 1994 with additional 6 wells. Interpretation of the hydrographs needs to take into account the well construction because of multiple perching ground water conditions. There are two general trends illustrated in the hydrographs; one type is cyclic and the other is nearly level. Hydrograph characteristics are mainly a function of recharge events, aquifer parameters, lengths of flow paths and monitor well design. Figure 28 illustrates the hydrographs for each monitor well discussed in the following paragraphs. The identification number applied to the wells is the standard legal description used by the U.S.G.S. of range, township, section and 1/4,1/4,1/4 referenced to the Boise base line and meridian. All of the wells and springs have the same state, county, range (R13East) and township (T7South) so just the section and 1/4's will be referenced. The six wells constructed in 1994 are noted with the acronym NPS-# for clarification.

Monitor Well 17ABB1

The hydrograph for 17ABB1 illustrates a cyclic water level response from March 1986 through October 1988. Water levels generally rise from 145 feet below ground surface (B.G.S.) in March 1986 up to 139 feet B.G.S. in 1988 where they appear to stabilize and then generally start dropping down to 148 feet B.G.S. in January 1992. The water level shift in January 1992 is attributed to the change from B.L.M. to U.S.G.S. monitoring. Starting in January 1992 the cyclic pattern is no longer observed and water levels drop only slightly from 146 feet

B.G.S. to 148 feet B.G.S. in April of 1996.

Monitor Well 17AAB1

Water levels remain stable at about 111 feet B.G.S. from March 1986 through April 1987 but start to increase reaching a peak of 107 feet B.G.S. on January 1988 and a cyclic pattern starts to develop with water levels dropping again to 110 feet B.G.S. in August of 1988. Levels drop from 110 feet in 1990

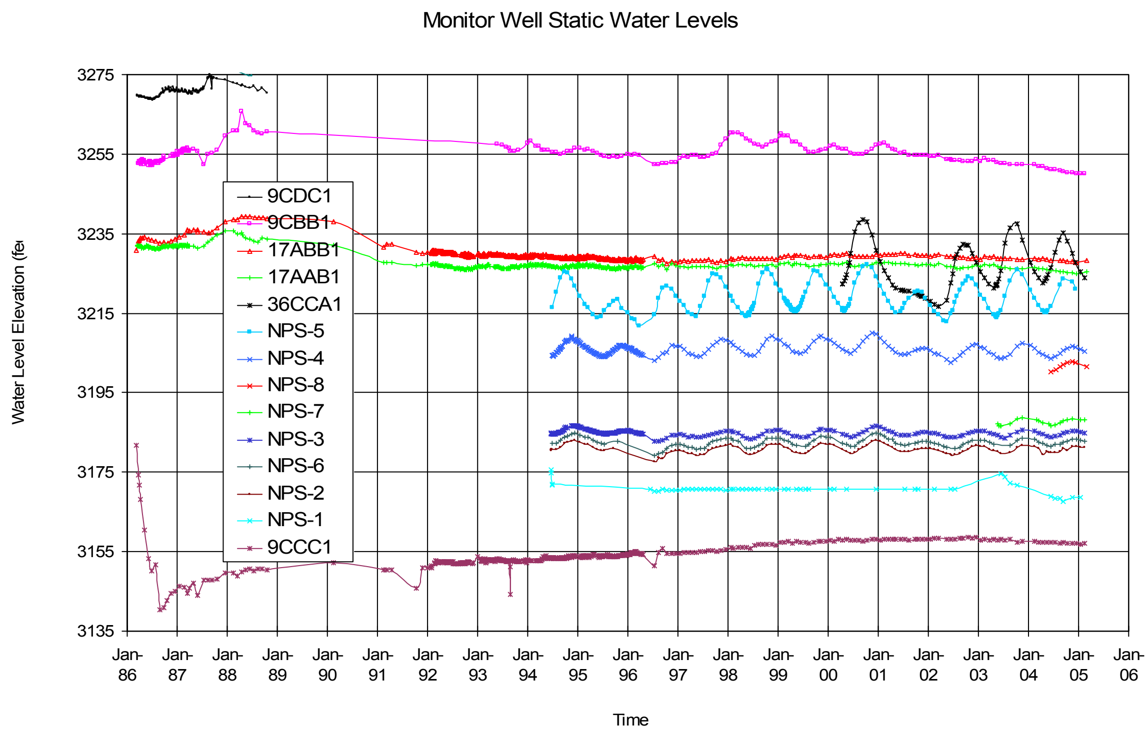



Figure 28. Static water level hydrographs for monitor wells in Fossil Gulch area (data from U.S.G.S. and N.P.S.).

down to 115 feet B.G.S. in January 1992 where they level off with only a slight cyclic pattern until August 1993 when the well was pumped by the U.S.G.S. The water level shift in January 1992 is attributed to the change from B.L.M. to U.S.G.S. monitoring. Water levels never recovered from pumping the well and levels remained at about 121 feet B.G.S. through April 1996.

Monitor Well 9CCC1

Water levels decrease significantly from 161 feet B.G.S. in March 1986 to 202 feet B.G.S. in September 1986. The levels rebound in a broad arch reaching a peak of 191 feet B.G.S. in January 1990 and then decrease again to 197 feet B.G.S. in October 1991. The water levels then rise again to 189 feet B.G.S. in January 1992 and then steadily increase through April 1996 by three feet to 186 feet B.G.S.. The water level shift in January 1992 is attributed to the change from B.L.M. monitoring to U.S.G.S. monitoring.

Monitor Well 9CDC1

Water levels from March 1986 through October 1988 exhibit a cyclic pattern and generally increase from 109 feet B.G.S. in March 1986 to 103 feet B.G.S. in September 1987. Two peaks occur in November 1986 and September 1987 and then a steady decline through October 1988 when monitoring stopped until 1990. The 1990 measurement indicated a dry well and it has been dry since. Water levels appear to have dropped in response to the concrete lining of the Fossil Gulch Canal after the 1987 irrigation season.

Monitor Well 9CBB1

Water levels exhibit cyclical patterns and generally increase from 95 feet B.G.S. in March 1986 to 82 feet B.G.S. in April 1988. Levels then generally decrease from 90 feet B.G.S. in May 1993 to 93 feet B.G.S. in March 1996. The general decrease in water levels from 1988 through 1996 may be due to the concrete canal lining constructed after the 1987 irrigation season. This well may have a leaky surface seal based on inconsistent water levels and a high concentration of nitrates in the water.

Monitor Well 9DCC1

This well was a dry hole and is known to have remained dry until 1994. In 1994 the N.P.S. allowed the Boise State University seismic study team to discharge an explosive in the bottom of the well for the study. The well has remained in this condition.

Monitor Well NPS-1 (9DCB1)

Only a few water levels have been collected for NPS-1. Based on very sparse data, water levels have remained very constant at 233 feet B.G.S. from 1994 to present. The constant water levels may be explained by water filling the PVC end cap on the casing, then overflowing through the screen and moving downward out of the bottom of the well.

Monitor Well NPS-2 (9CDD1)

The static water levels exhibit a low amplitude wave characteristic of the cyclic pattern observed more prominently in other well hydrographs. Water levels have risen from about 220 feet B.G.S. in June 1994 to 218 feet B.G.S. in December 1994 and then back down to 221 feet B.G.S. in July 1995.

Monitor Well NPS-3 (9DCC2)

The hydrograph for NPS-3 exhibits a very low amplitude cycle ranging from a low of 221 feet B.G.S. up to 219 feet B.G.S.. The cycle peaks in December and reaches its low during August. The water level pattern is nearly identical to the hydrograph for monitor well NPS-2 in both amplitude and time of cycle highs and lows. There are no significant long-term changes in water levels.

Monitor Well NPS-4 (5DDD1)

The hydrograph for NPS-4 exhibits a very smooth cyclic pattern with greater amplitude than either NPS-3 or NPS-2. The cycle peaks at 174 feet B.G.S. in November and reaches its low of 179 feet during July where NPS-2 and NPS-3 hydrographs show a water level peak during December and a low during August. The amplitude difference for NPS-4 is about five feet where NPS-2 and NPS-3 is about two feet. There are no significant long-term changes in water levels from 1994 through 1996.

Monitor Well NPS-5 (7AAA1)

The hydrograph for NPS-5 exhibits a very smooth cyclic pattern with greater amplitude than NPS-4, NPS-3 or NPS-2. The cycle peaks at 176 feet B.G.S. in October and reaches its low of 187 feet during mid-May. The amplitude difference for NPS-5 is about 10 feet where NPS-4 is about five feet and NPS-2 and NPS-3 have about two feet of amplitude change. There are no significant long-term changes in water levels from 1994 through 1996.

Monitor Well NPS-6 (9CDD2)

The hydrograph for NPS-6 is very similar to NPS-2 and NPS-3 characterized by a smooth low amplitude cyclic water level pattern observed more prominently in other well hydrographs such as NPS-4 and NPS-5. The cycle peaks at 218 feet B.G.S. in December and reaches its low of 221 feet during August. The amplitude difference for NPS-6 is about three feet, which is similar to NPS-2 and NPS-3.

## SUMMARY OF FOSSIL GULCH AREA MONITOR WELLS

Hydrographs for the monitor wells generally show two trends. One type is a cyclic rise and fall attributed to seasonal recharge events to the aquifers. The other is a generally flat hydrograph with some exhibiting a slight decrease in water levels and some a slight increase. The cyclic hydrographs suggest a better hydrologic connection to the recharge source with shorter ground water flow paths. The greater the amplitude of the cycle the better the hydraulic connection to the recharge source. The longer the flow paths are the greater the energy loss in the system which result in lower amplitude cycles, or even flat hydrographs. The basalt flow aquifer usually has cyclic hydrographs associated with it which are also a function of basalt aquifer properties of low storage and high transmissivity.

Flat hydrographs are usually exhibited in wells that encountered only fine-grained sediments. Sediment properties have higher storage and lower transmissivity than basalt and so the recharge pressure wave looses energy at a greater rate resulting in nearly flat hydrographs. Very low amplitude cycles can still be observed in some of these flat hydrographs. The challenge in hydrograph interpretation is from long effective screen intervals in the monitor wells, which can interconnect aquifers.

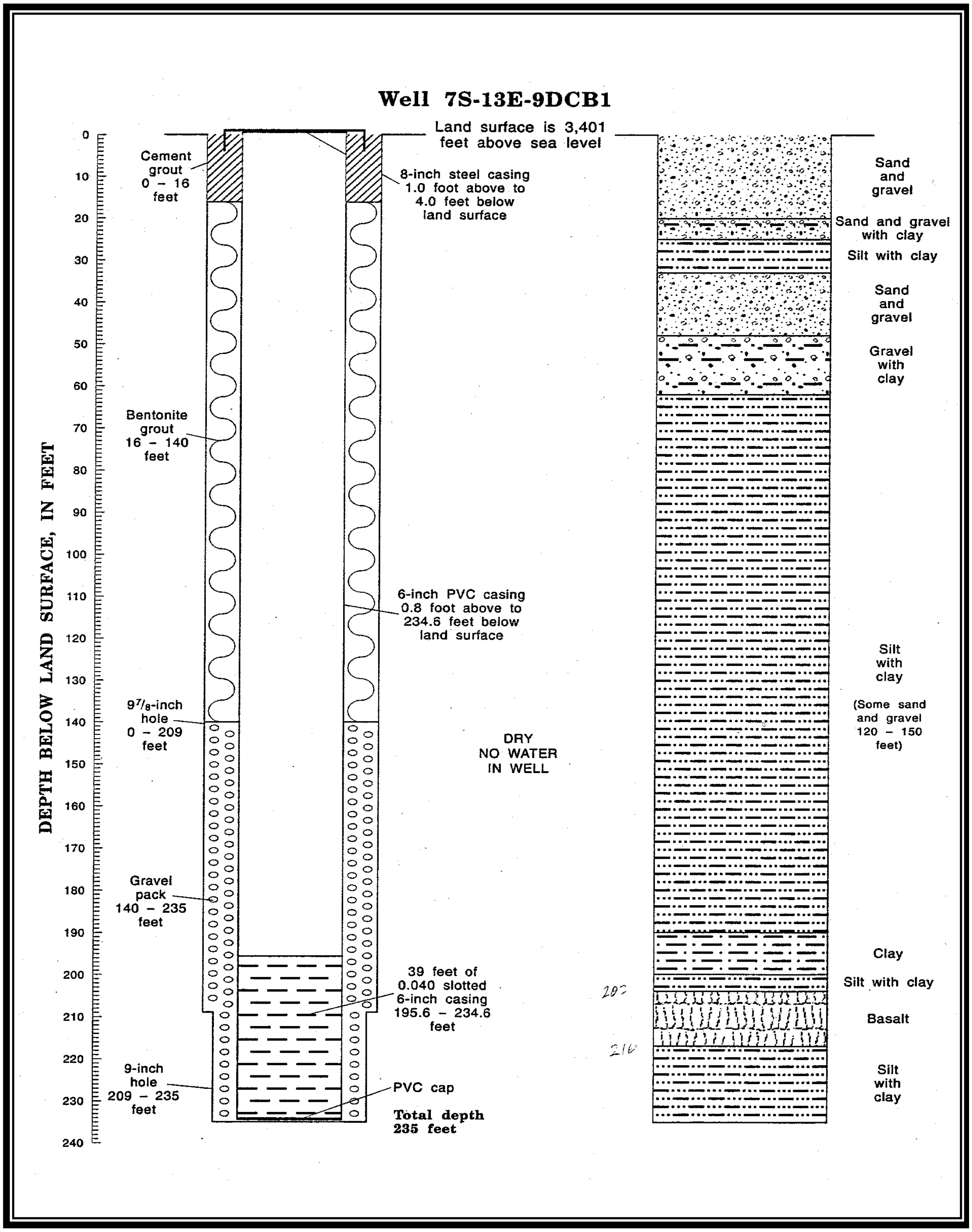



Figure 29. Monitor well 9DCB1 (NPS-1) construction and geologic log

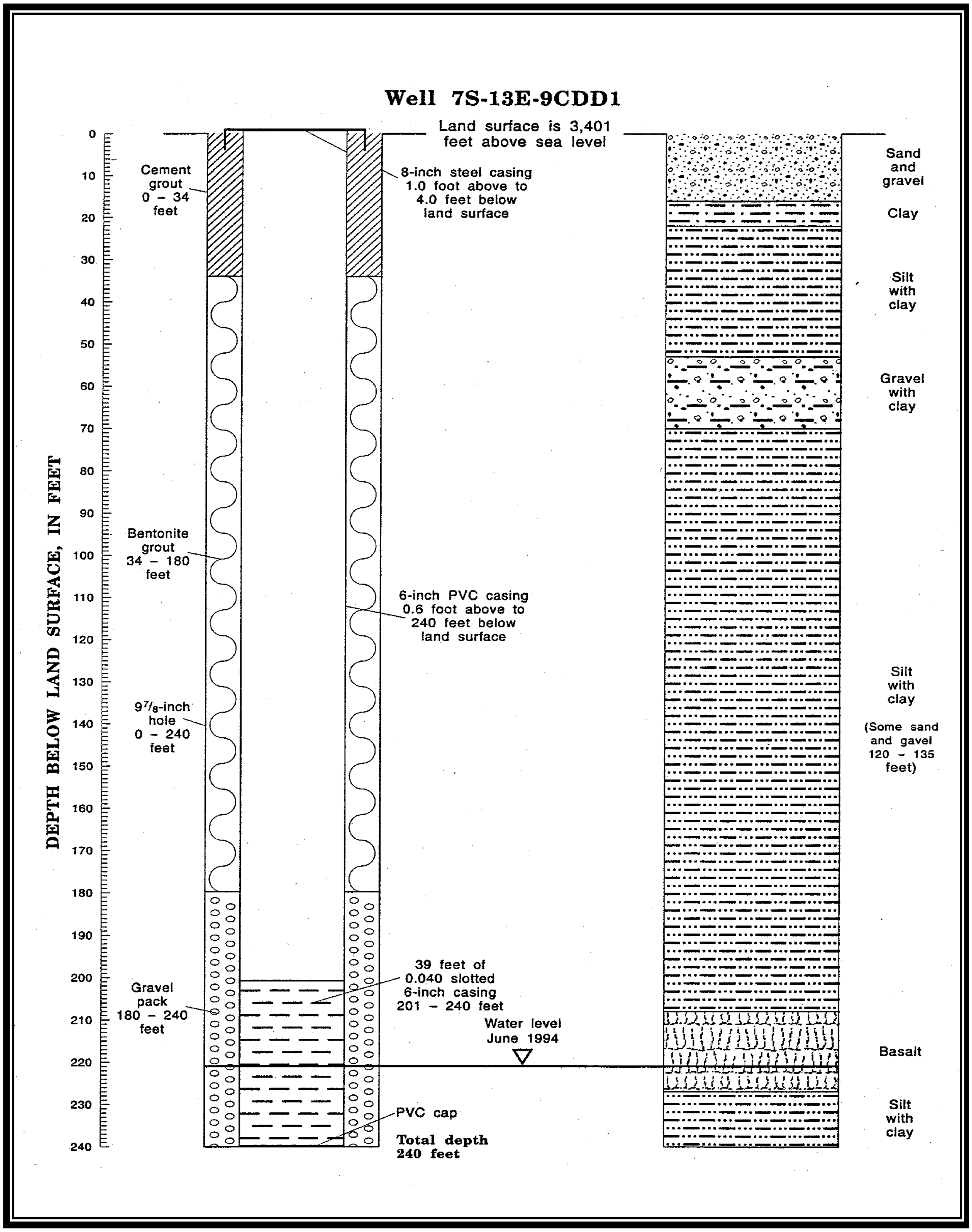



Figure 30. Monitor well 9CDD1 (NPS-2) construction and geologic log

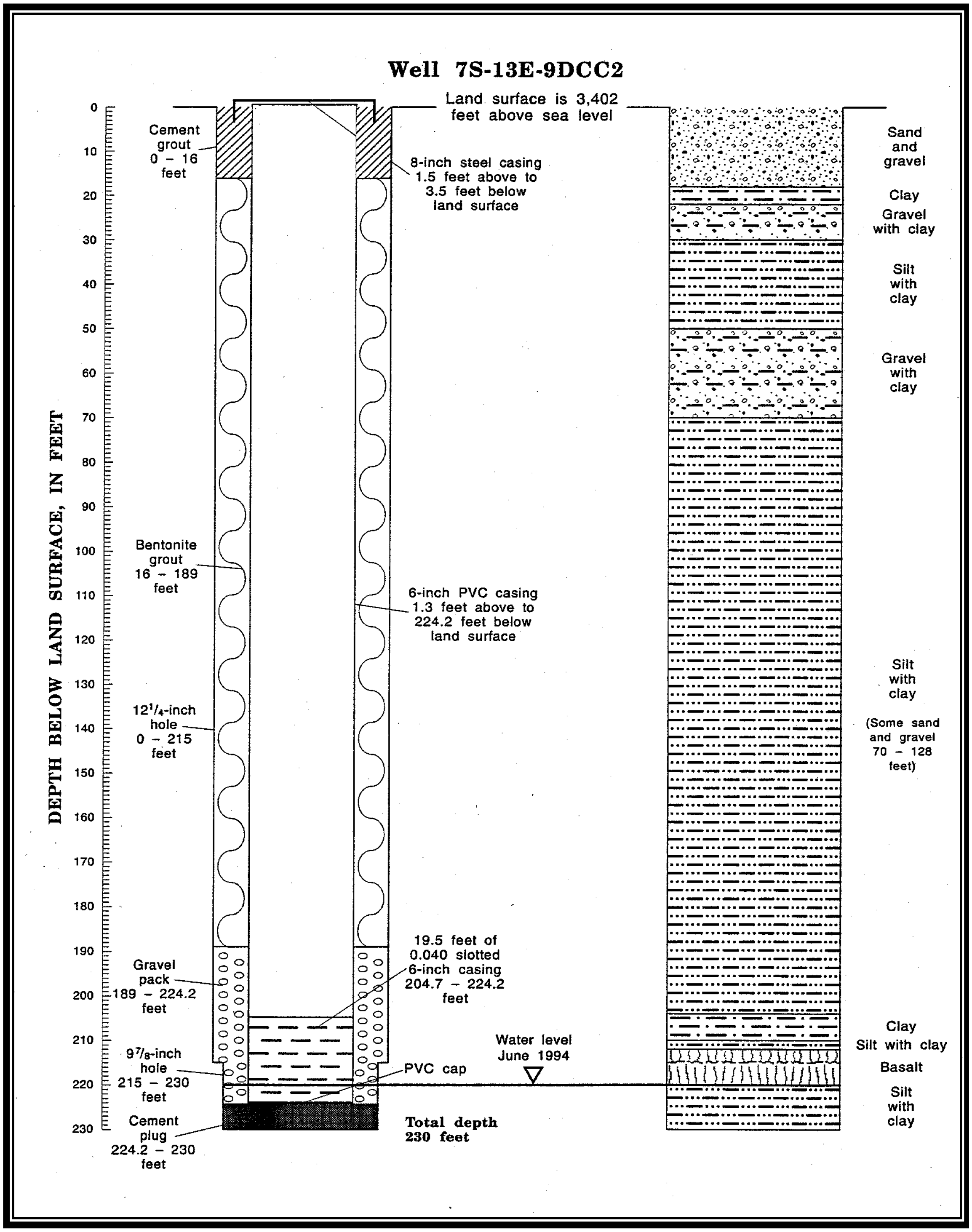



Figure 31. Monitor well 9DCC2 (NPS-3) construction and geologic log

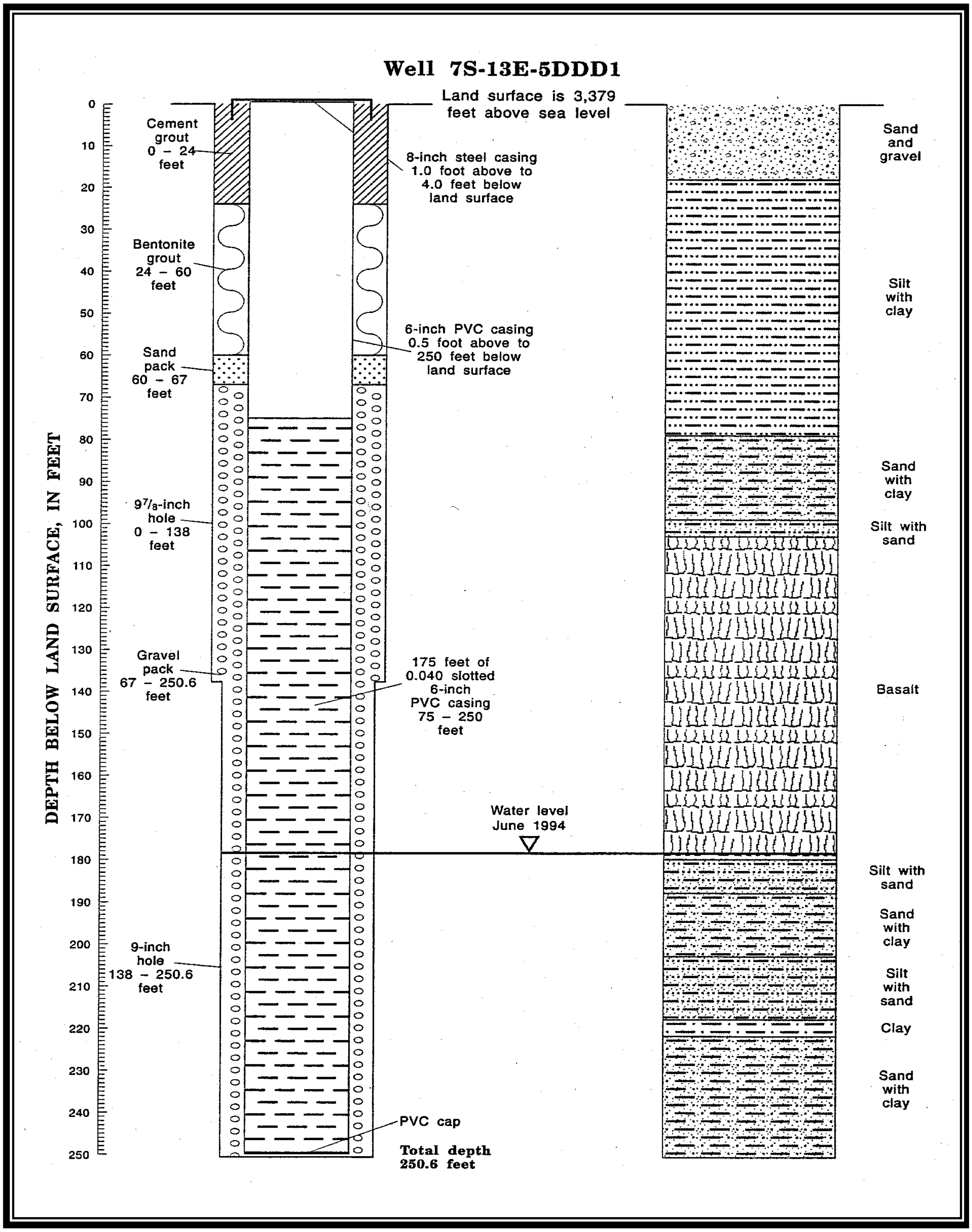



Figure 32. Monitor well 5DDD1 (NPS-4) construction and geologic log

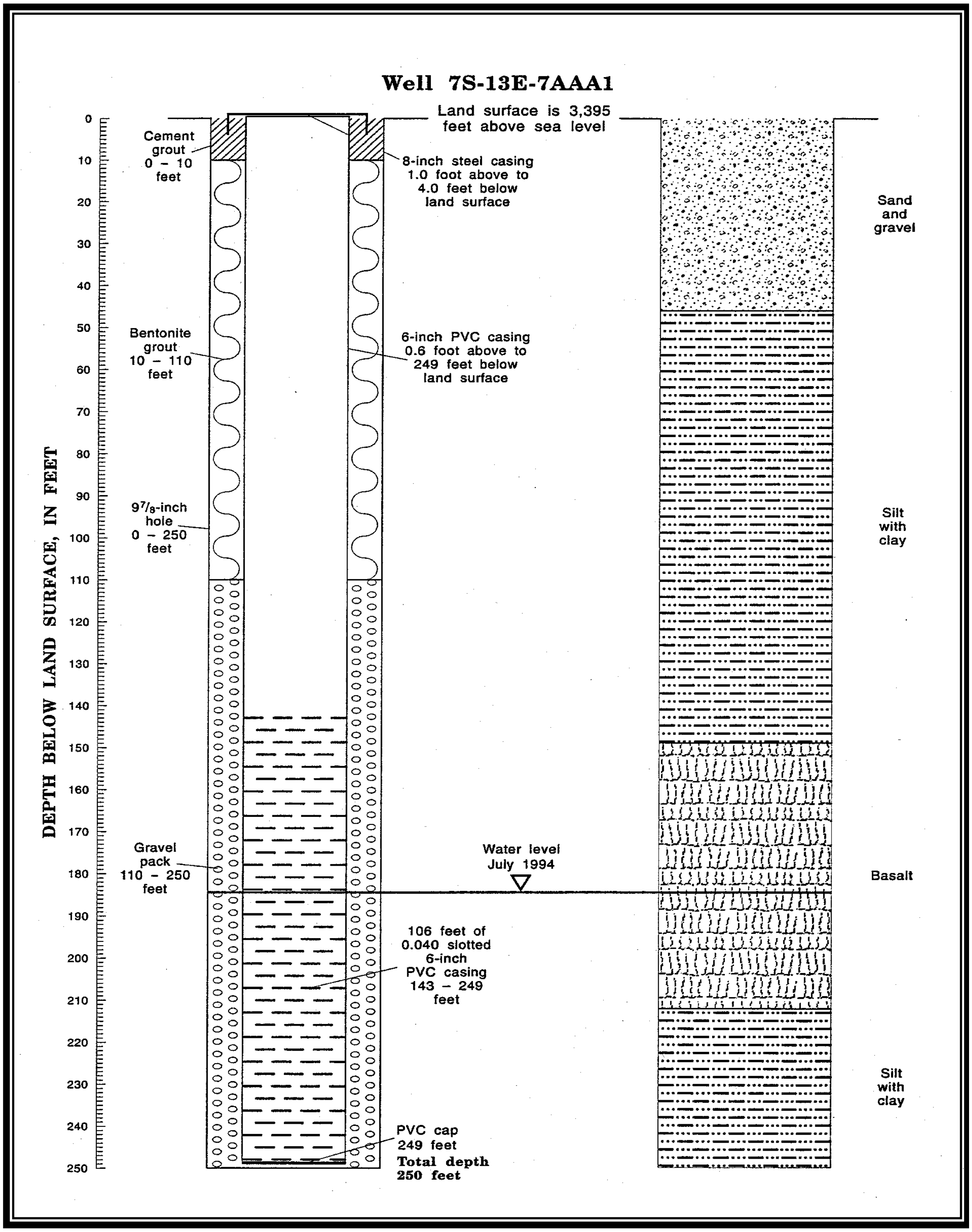



Figure 33. Monitor well 7AAA1 (NPS-5) construction and geologic log

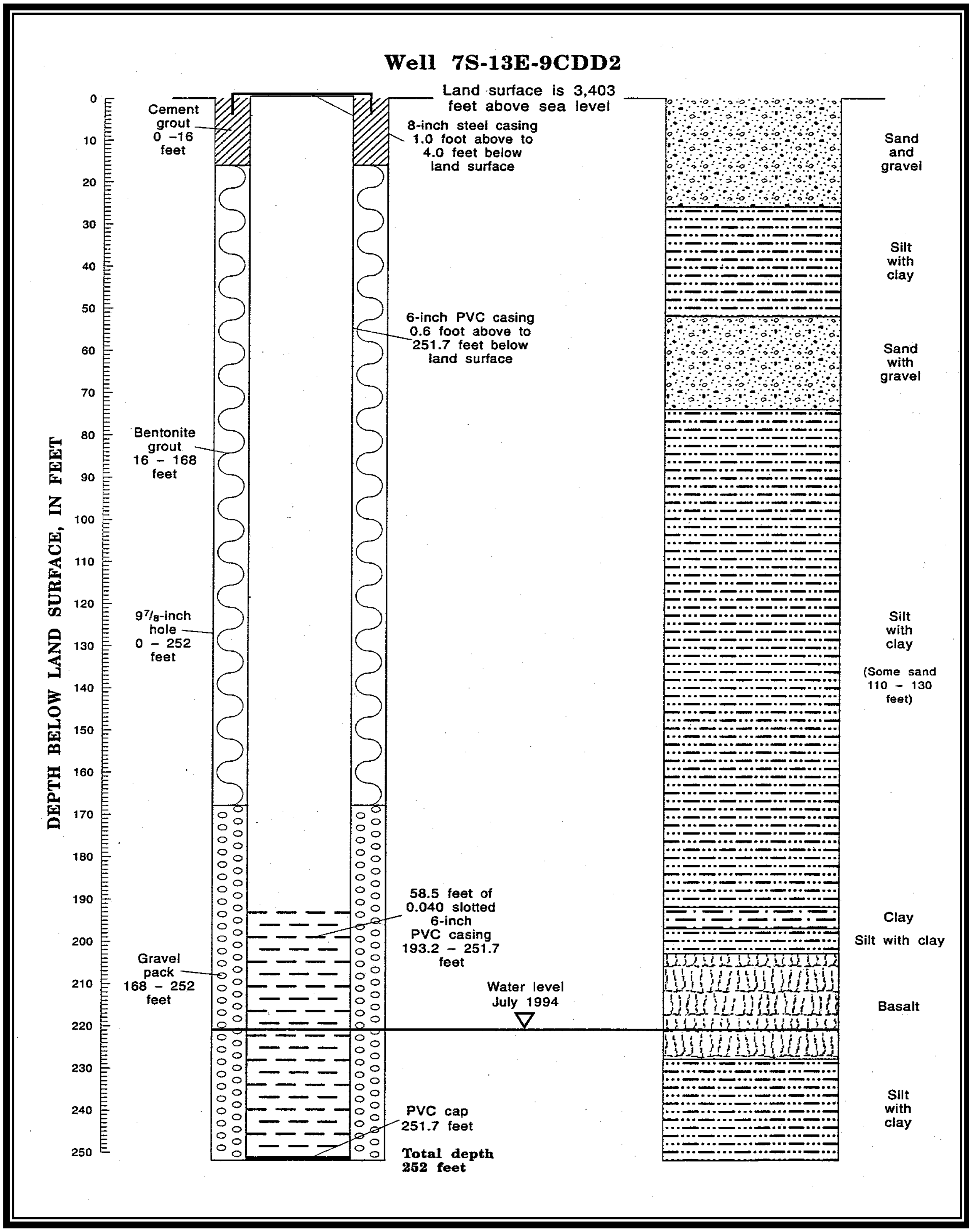



Figure 34. Monitor well 9CDD2 (NPS-6) construction and geologic log

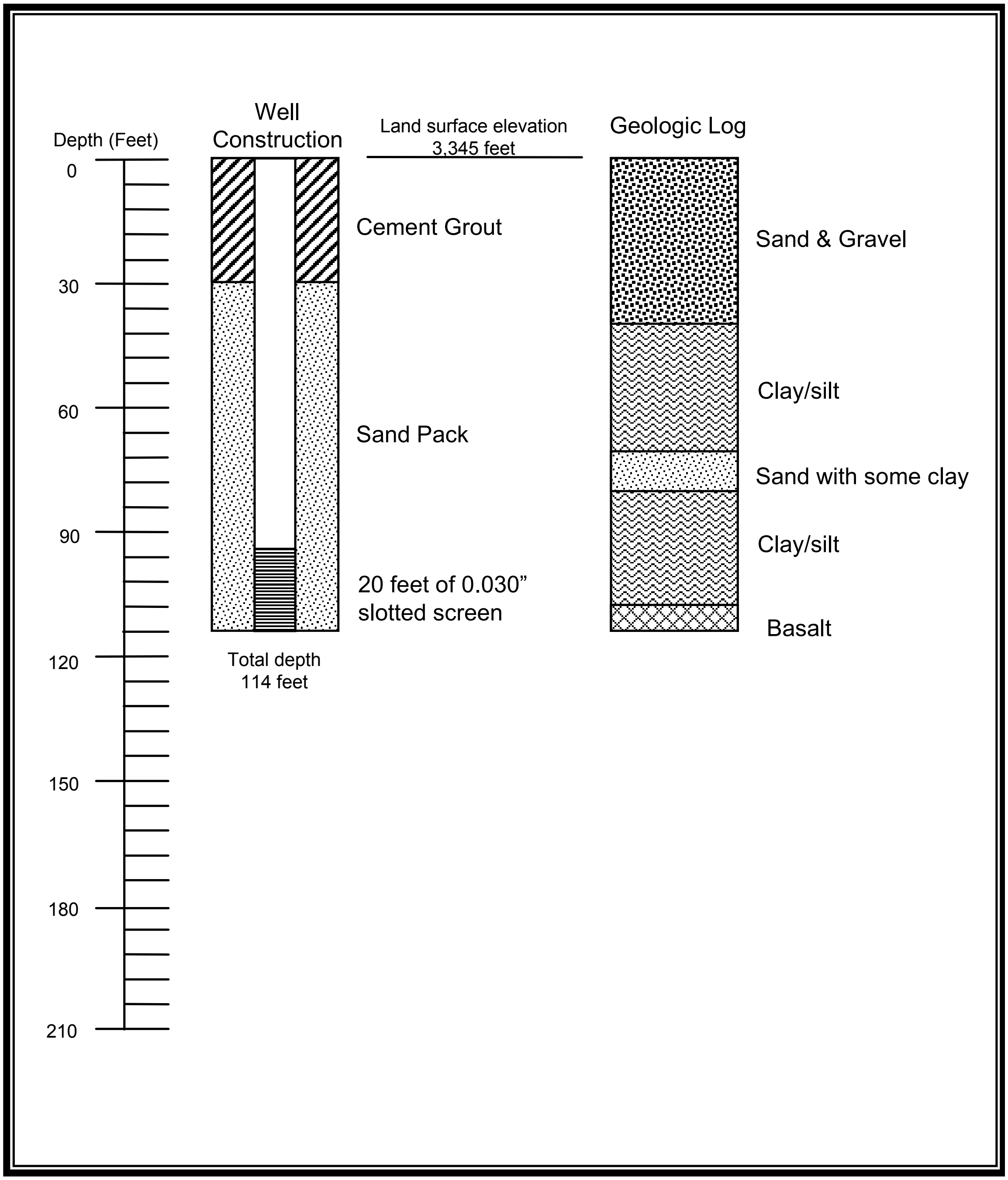



Figure 35. Monitor well 9CBB1 construction and geologic log

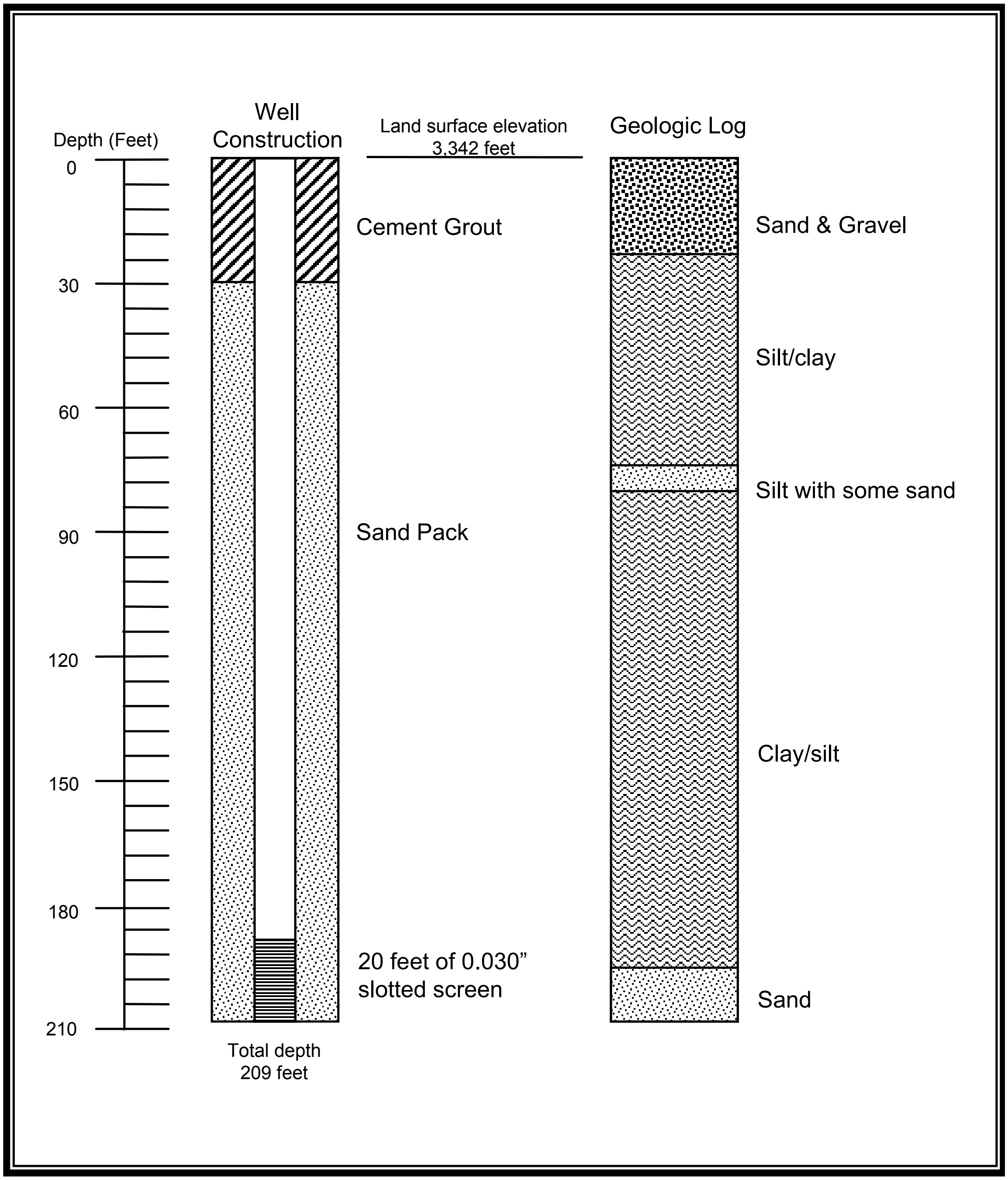



Figure 36. Monitor well 9CCC1 construction and geologic log

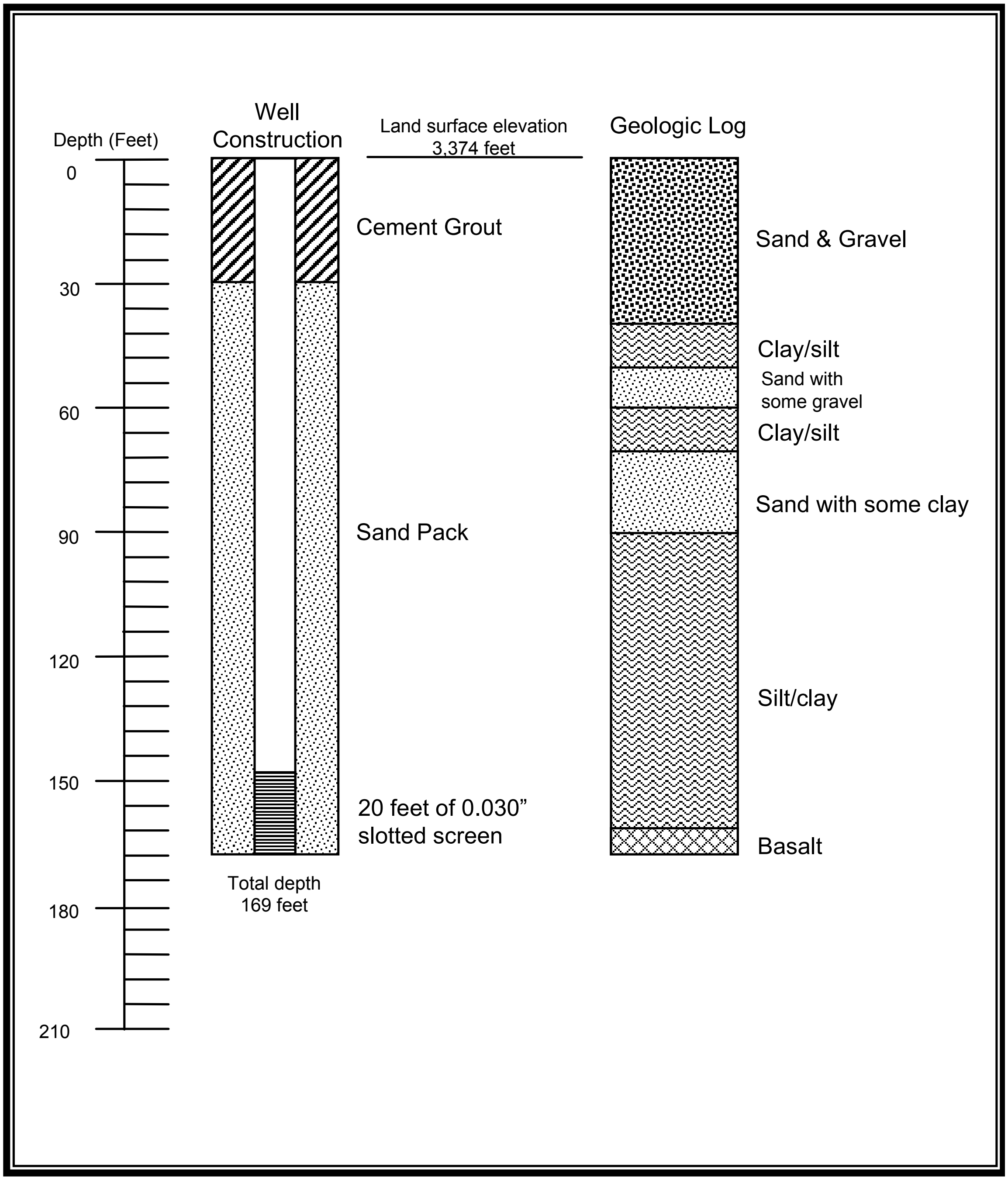



Figure 37. Monitor well 9CDC1 construction and geologic log

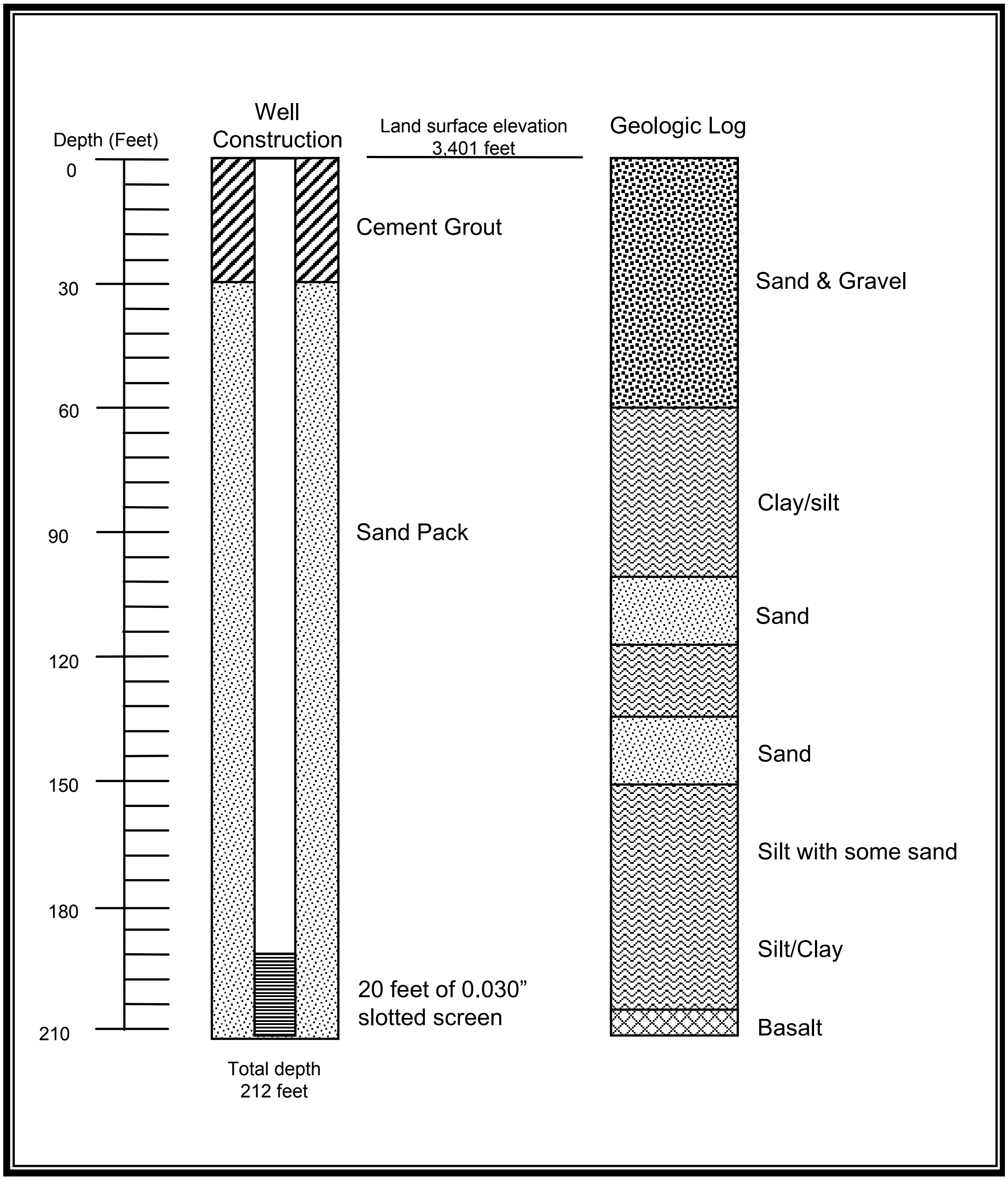



Figure 38. Monitor well 9DCC1 construction and geologic log

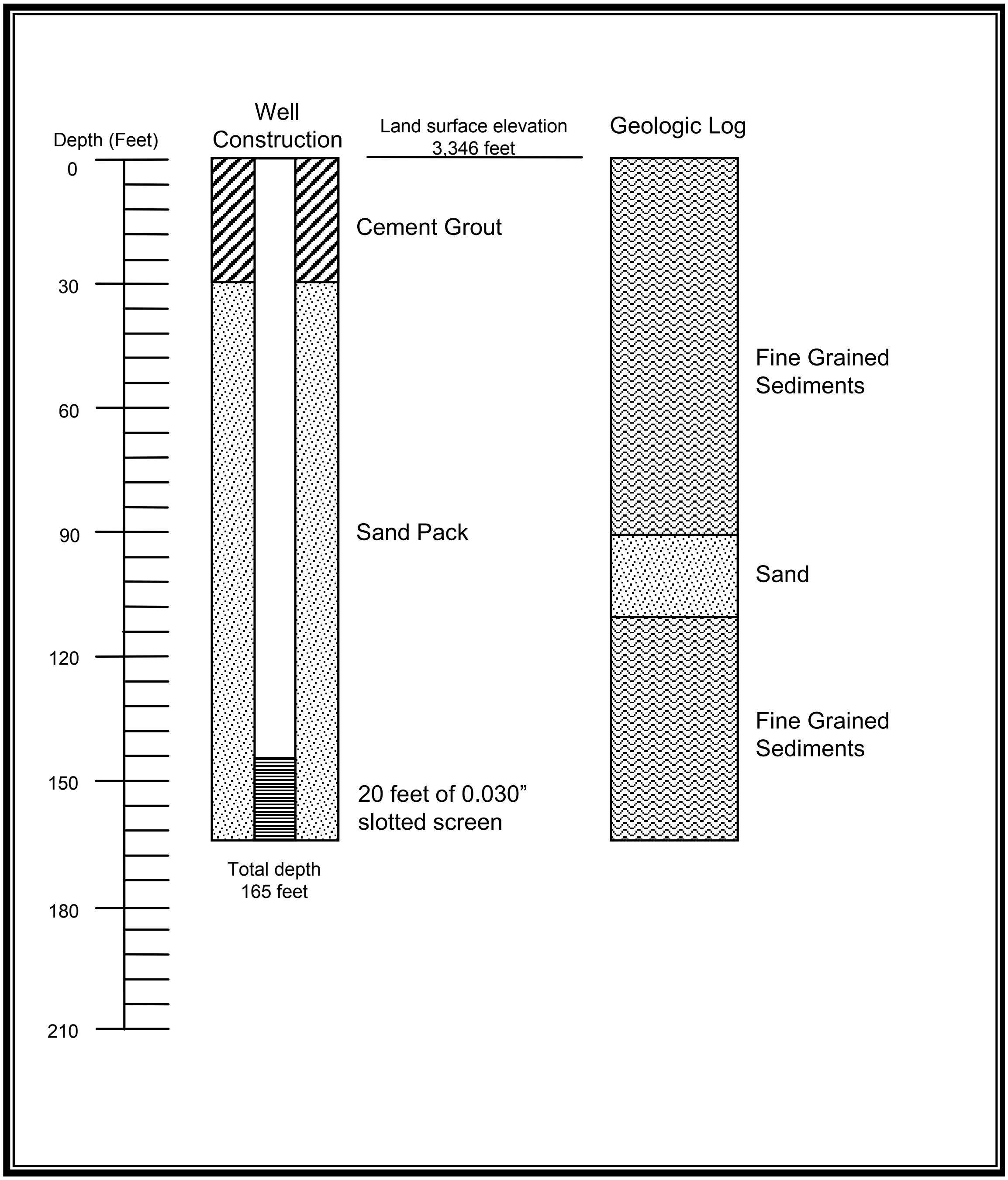



Figure 39. Monitor well 17AAB1 construction and geologic log

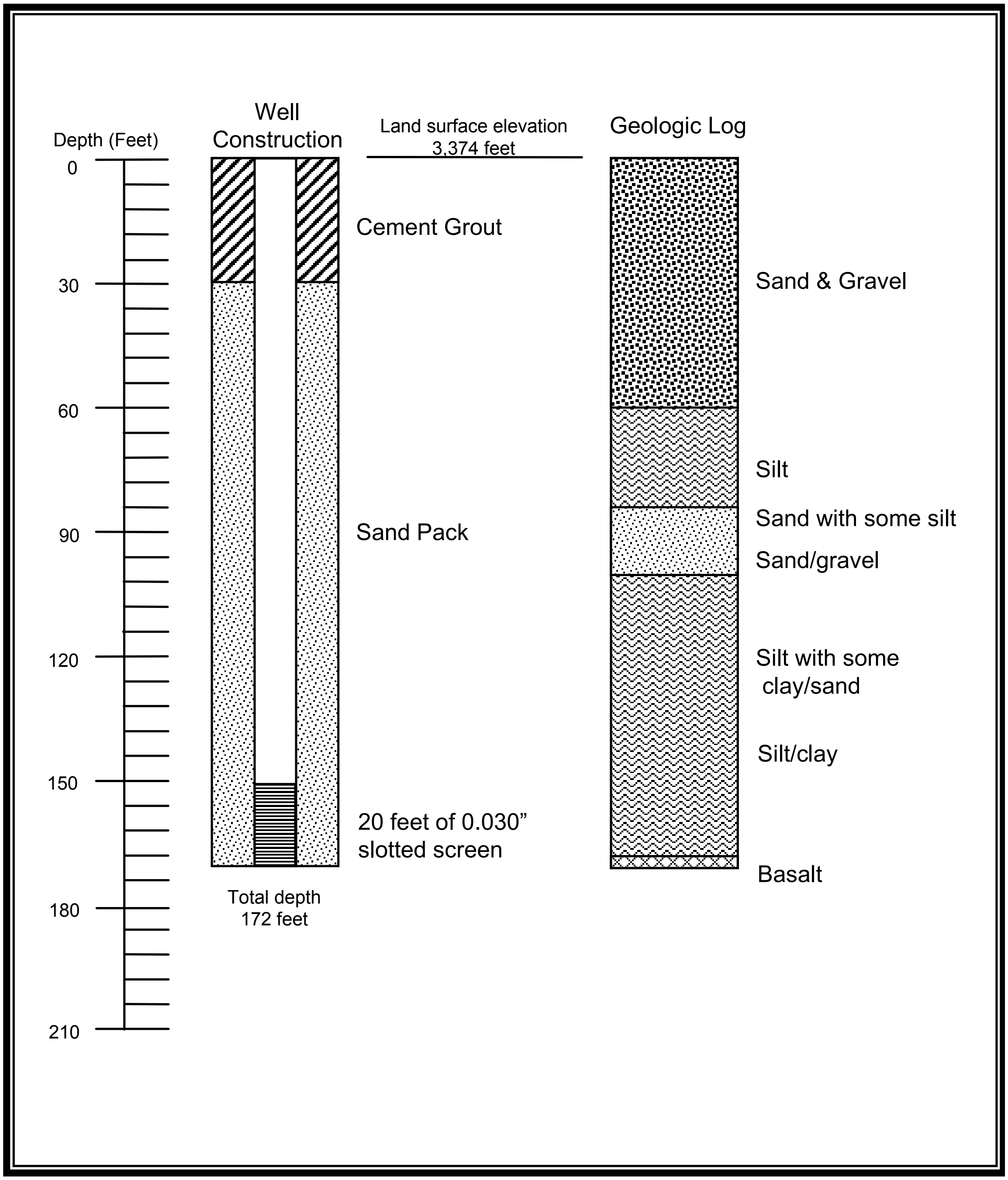
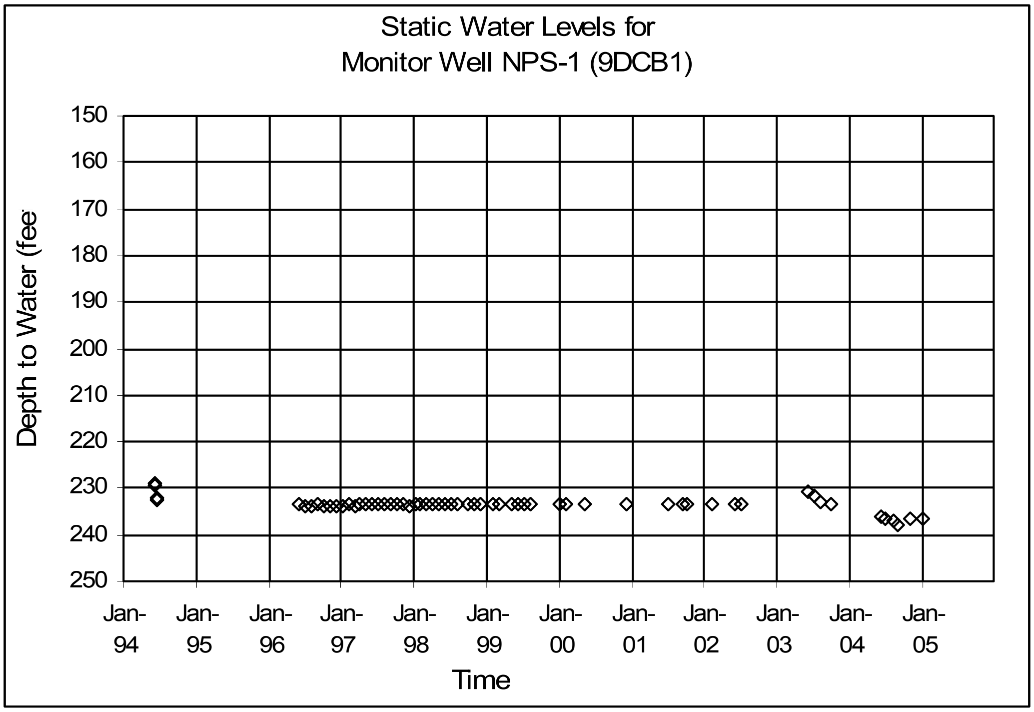



Figure 40. Monitor well 17ABB1 construction and geologic log



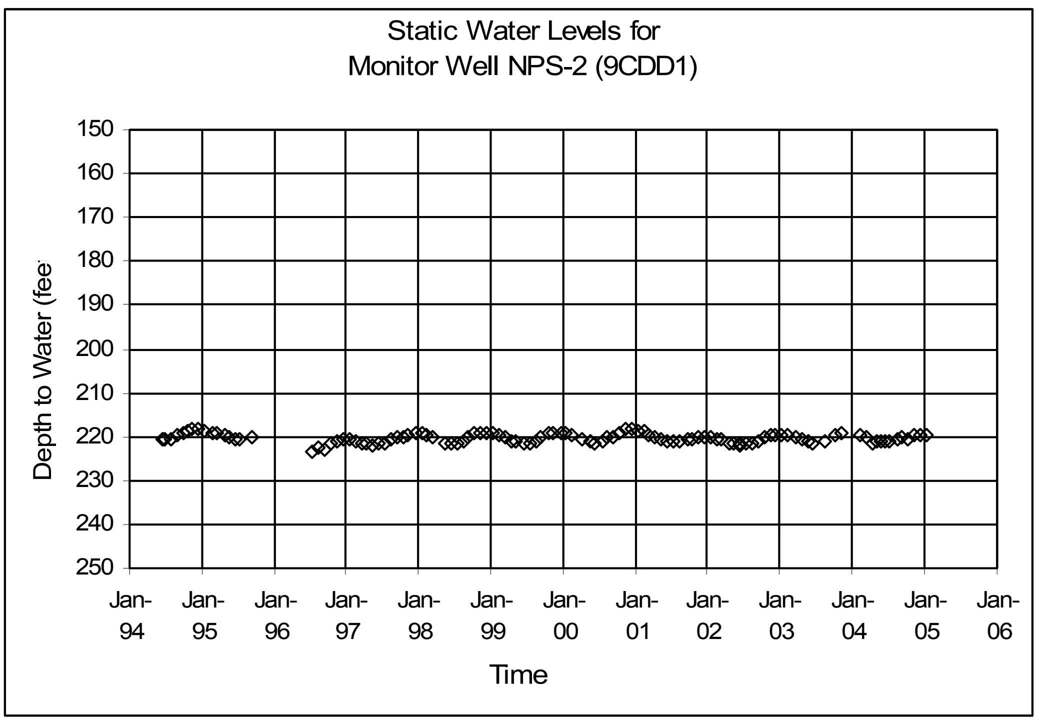
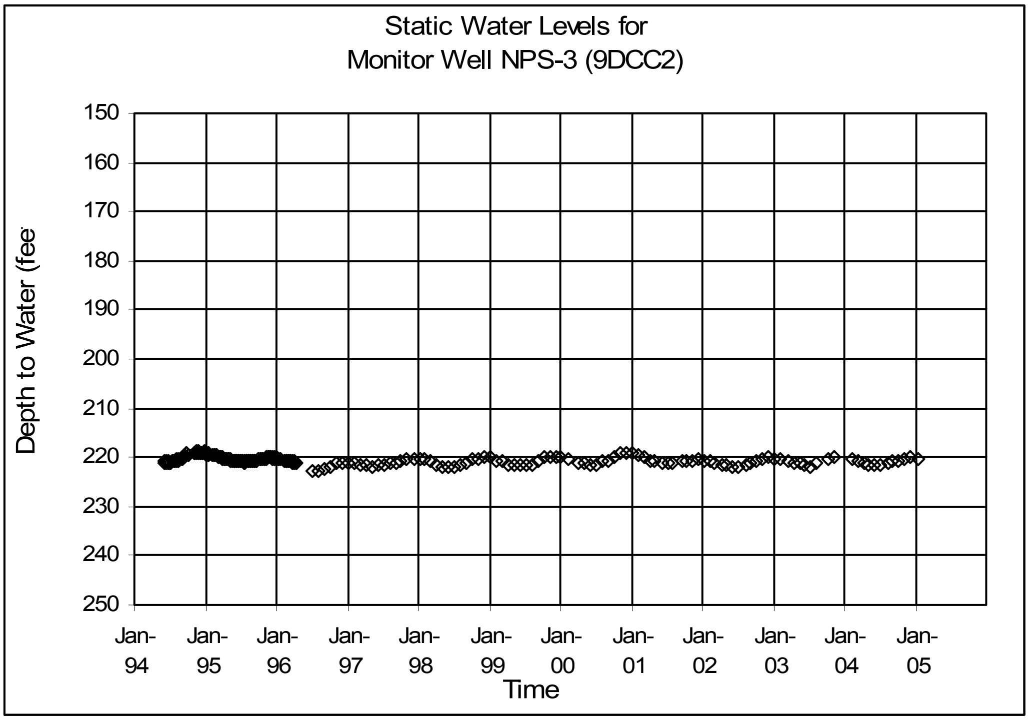




Figure 41. Static water levels for monitor wells NPS-1 and NPS-2.



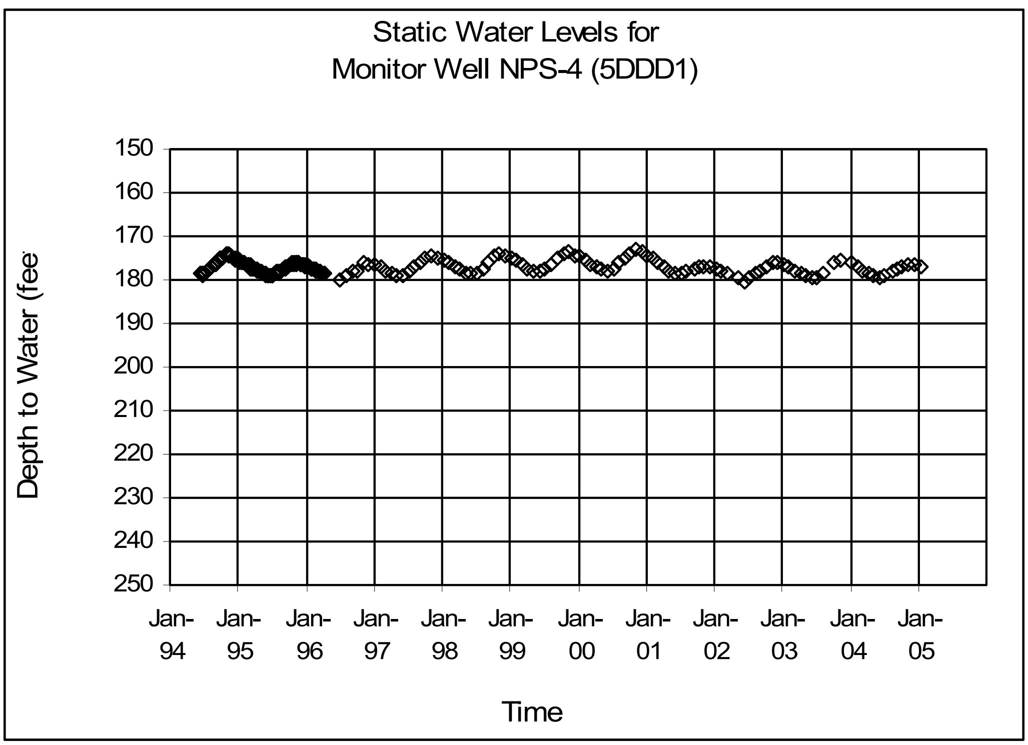
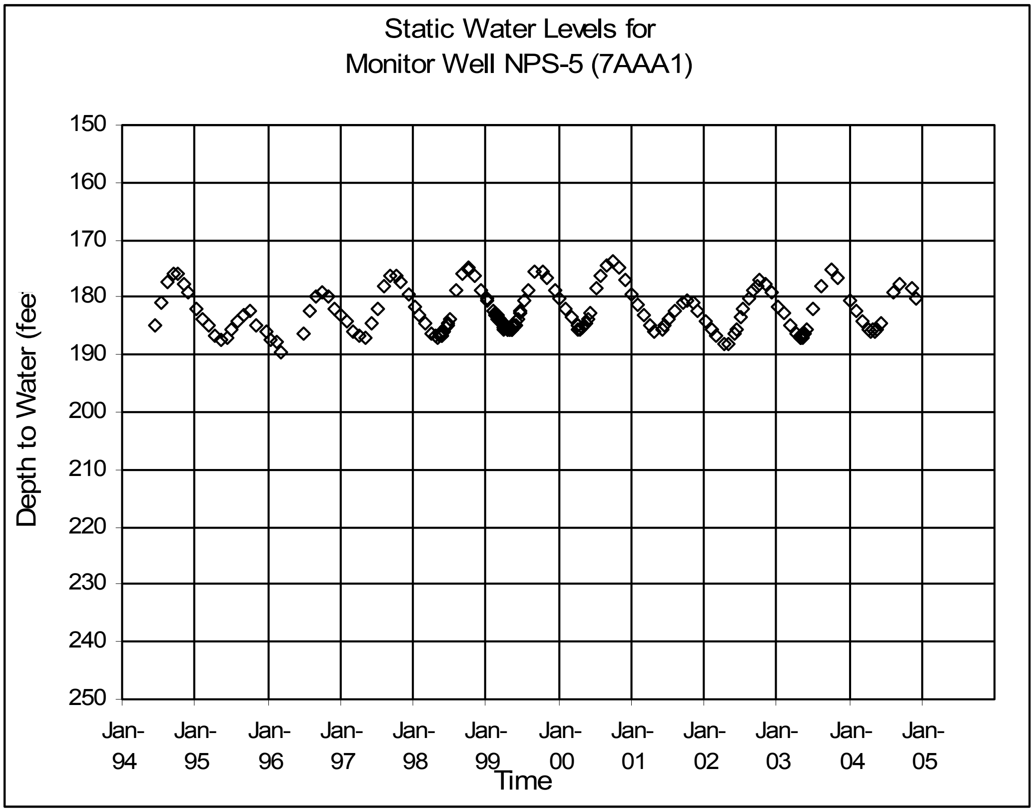




Figure 42. Static water levels for monitor wells NPS-3 and NPS-4.



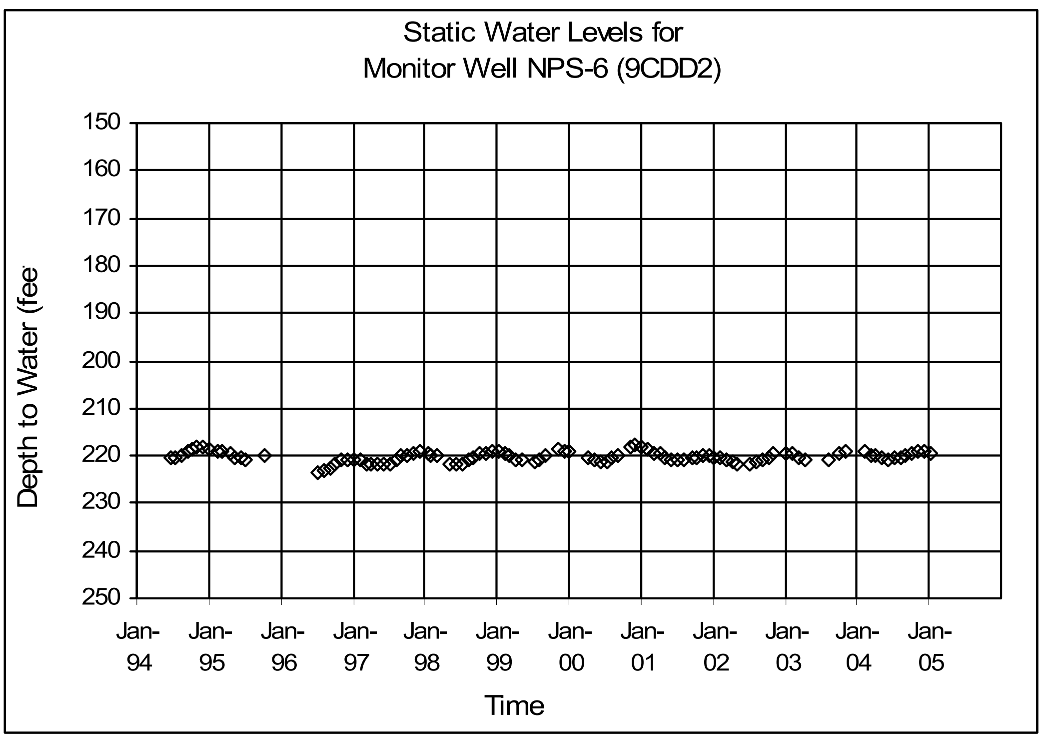
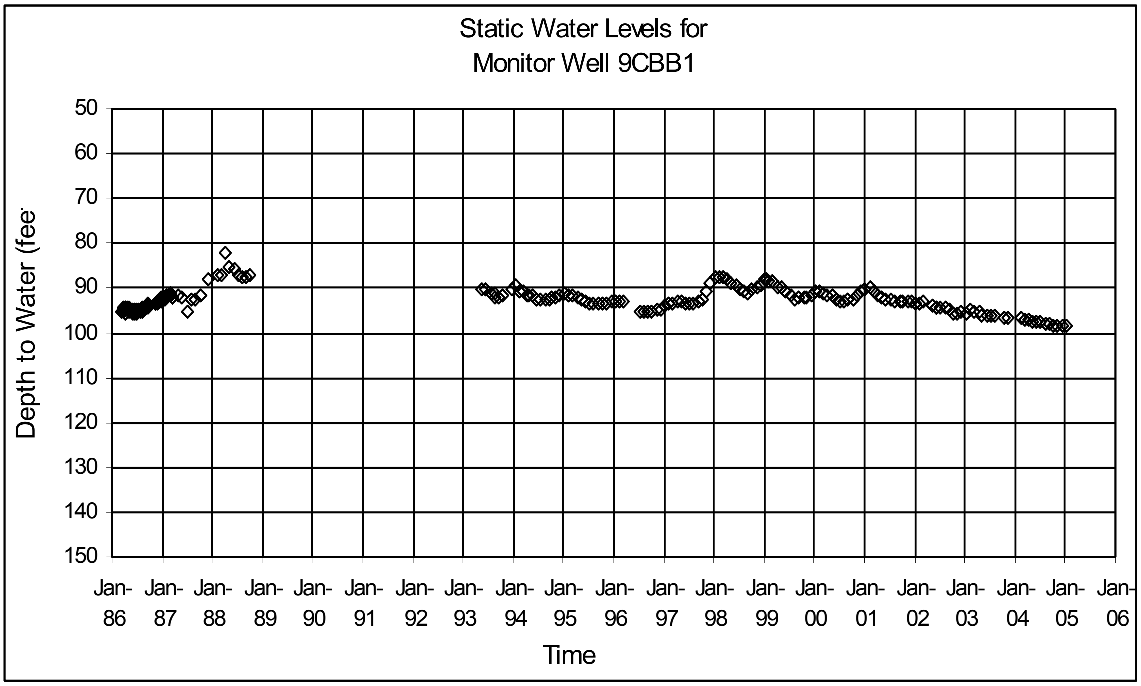




Figure 43. Static water levels for monitor wells NPS-5 and NPS-6.



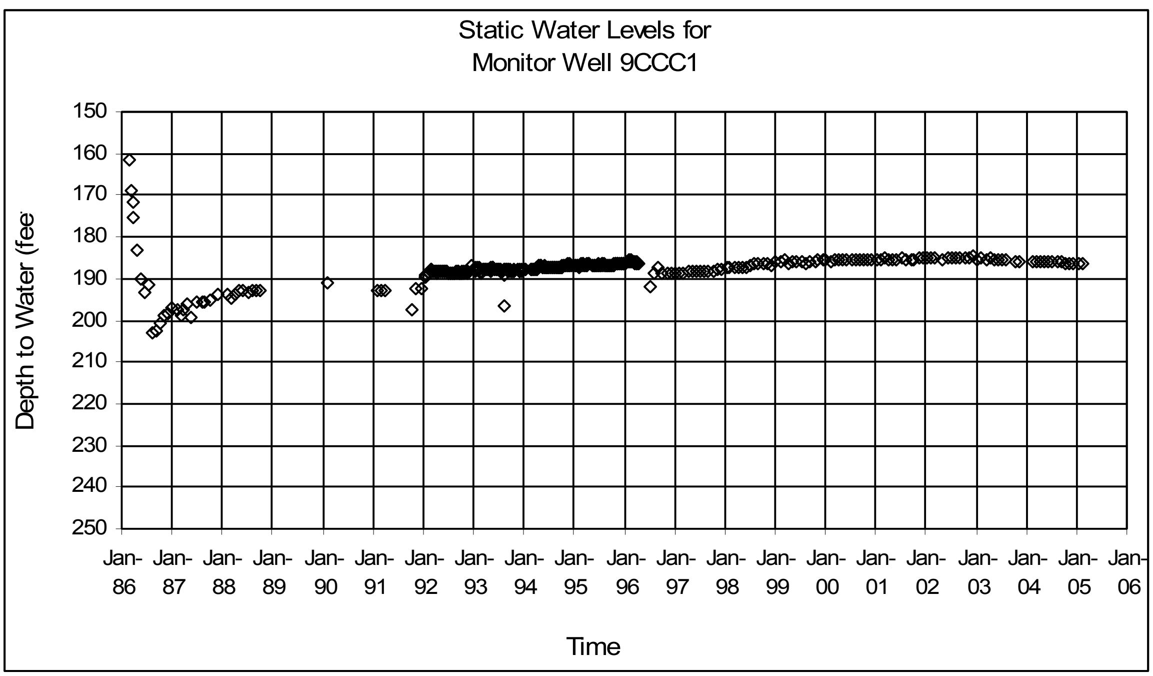
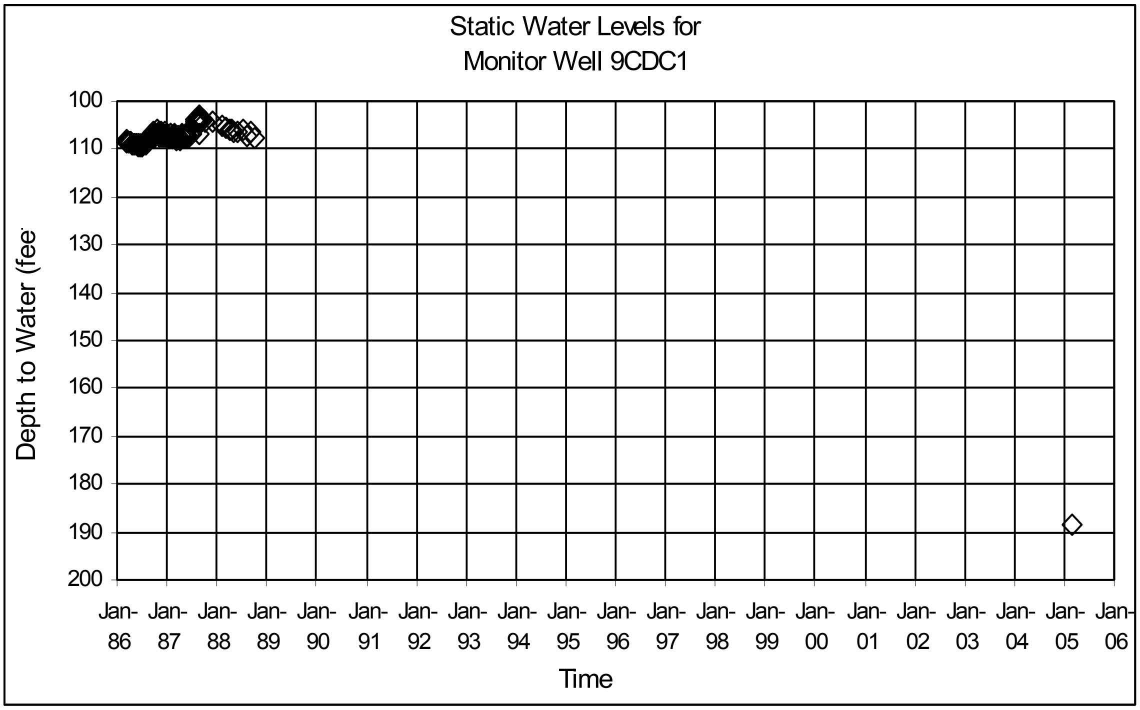




Figure 44. Static water levels for monitor wells 9CBB1 and 9CCC1.



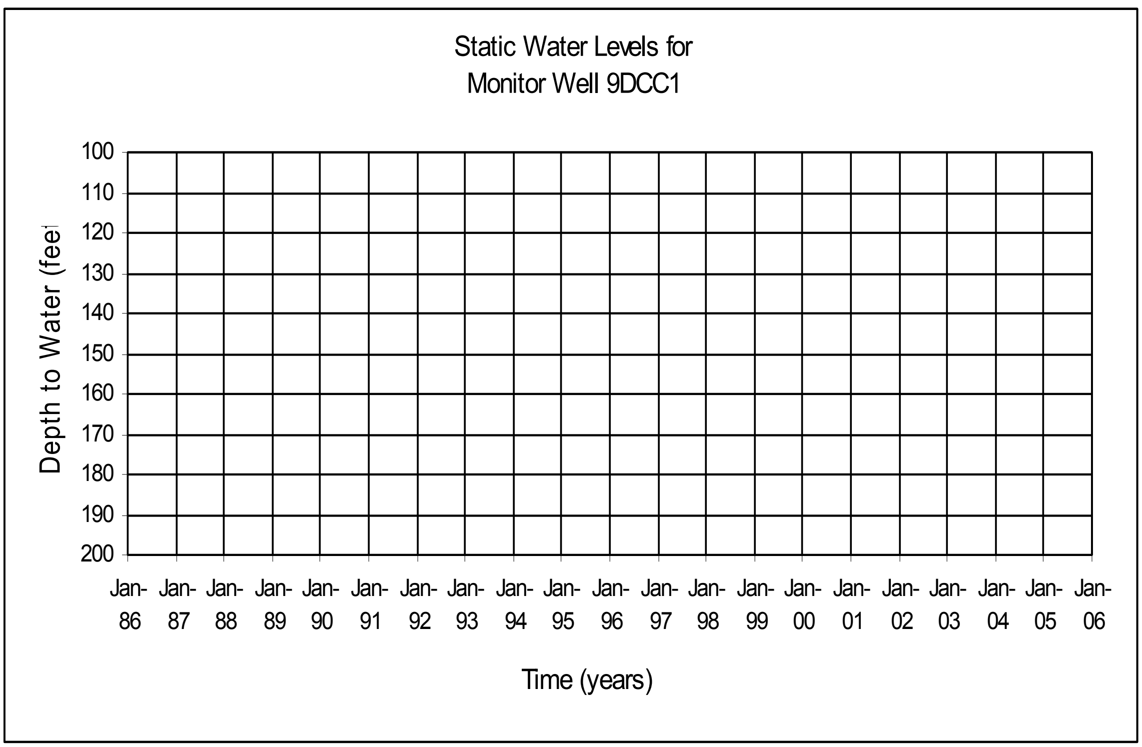
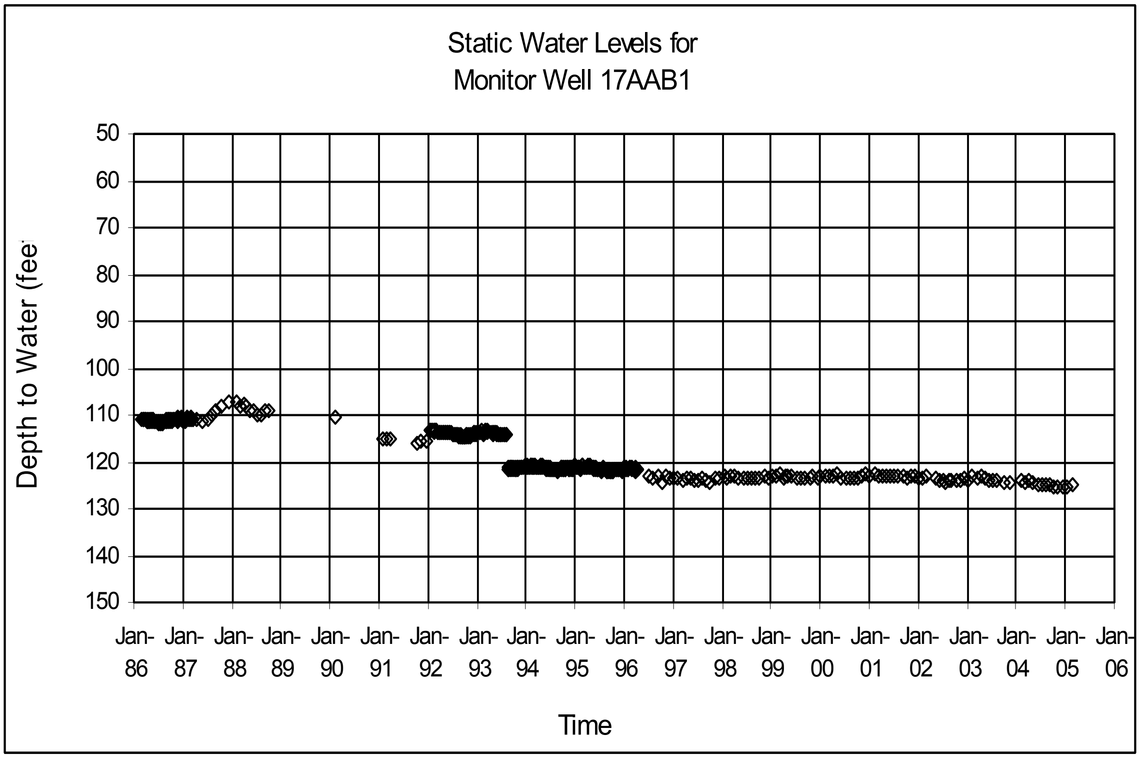




Figure 45. Static water levels for monitor wells 9CDC1 and 9DCC1 (dry).



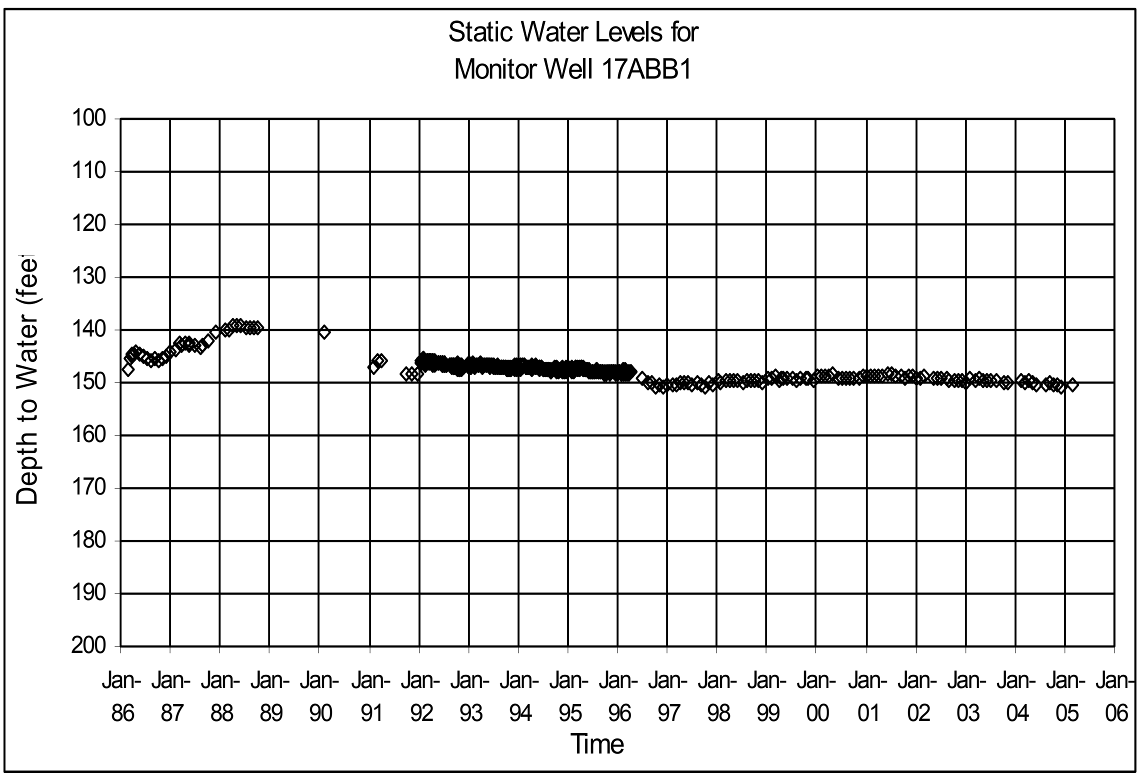




Figure 46. Static water levels for monitor wells 17AAB1 and 17ABB1.

# Appendix D

## DISCUSSION OF DISSOLVED NITROGEN

## INTRODUCTION

In 1993 and 1994 the U.S.G.S. collected water samples from selected monitor wells, Fossil Gulch Canal and perched aquifer discharge springs to be analyzed for a suite of chemical constituents. Dissolved nitrogen (NO2+NO3) concentrations in all of the wells and springs tested are above the concentrations of the canal and Snake River water. Figure 47 illustrates the location and concentration of nitrogen in the monitor wells, Fossil Gulch Canal and the Snake River.

### Results

Nitrogen (NO2+NO3) concentrations are elevated above the canal and Snake River water in all of the wells tested. Ground water nitrogen concentrations range from 3.0 to 39.0 mg/l (milligrams per liter) but most are in the range of 4.0 to 10.0 mg/l while the canal water tested at 1.4 mg/l (U.S.G.S., 1993). Snake River water samples were collected by the University of Idaho Water Resources Research Institute about five miles upstream of the study area and tested for nitrogen. Nitrogen (NO2+NO3) concentrations of the Snake River ranged from 0.75 to 1.98 mg/l and averaged about 1.46 mg/l (Brockway and Robison, 1992). This value corresponds with the U.S.G.S. canal water test of 1.4 mg/l.

### Conclusions

Dissolved nitrogen concentrations from monitor wells are elevated above the canal and river water suggesting there are other sources of recharge to the perched aquifer systems besides the Fossil Gulch Canal. Generally, the lower

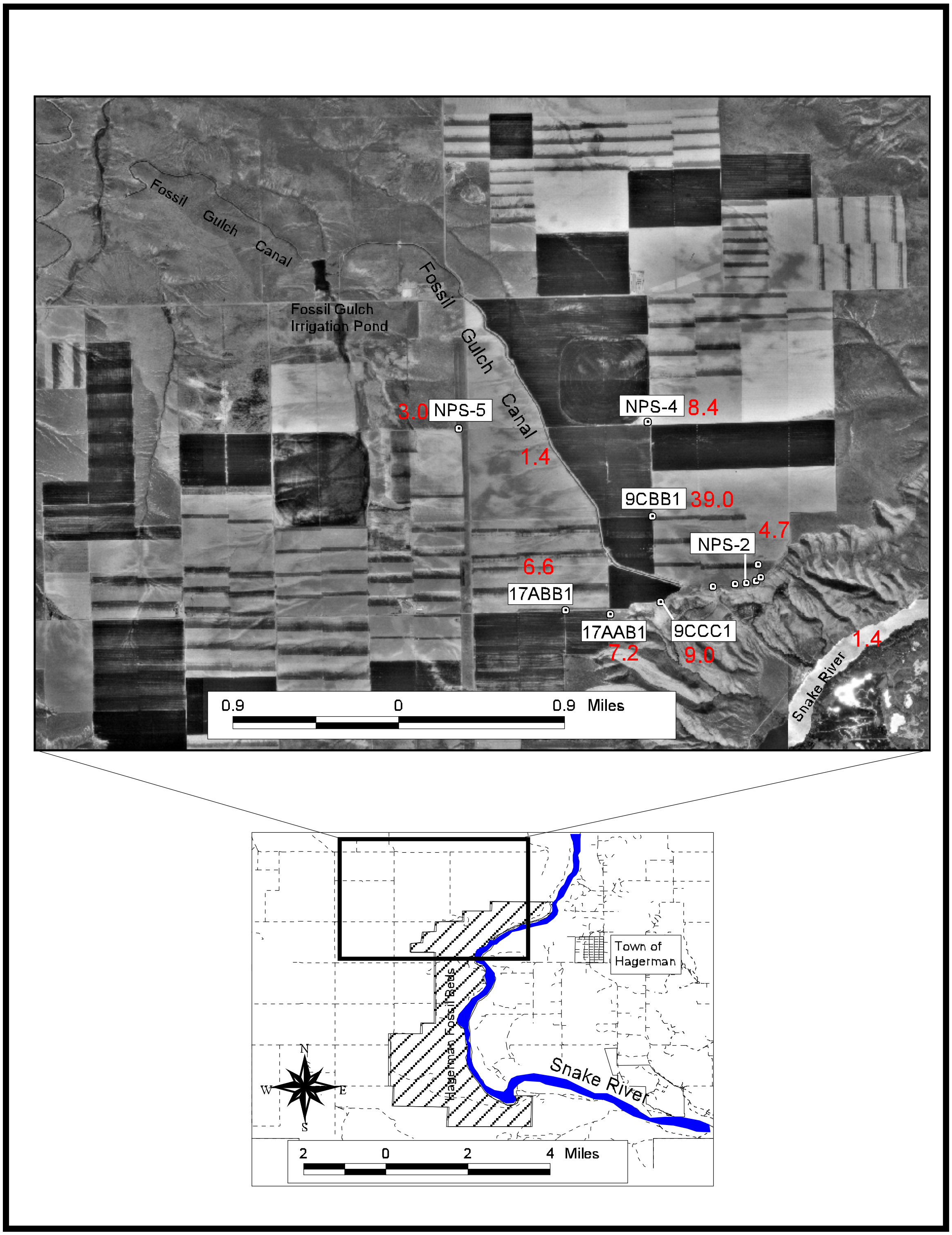



Figure 47. Nitrate concentration map. Concentrations (mg/l) are in the form of nitrite/nitrate (NO2+NO3). Only the wells that were sampled are labled.

the nitrogen concentrations in a particular well the better the hydrologic connection with the canal water. A mixing effect is probably taking place in some monitor wells due to long effective screen intervals. For example, water that has percolated down from agricultural crops (i.e. high in nitrate concentrations) may be perched at the base of the Tuana Gravel Formation. This water may be draining into lower perching systems (i.e. low in nitrate concentrations) through monitor well screen intervals and influencing nitrate concentrations.

## References

Bjork, P.R., 1968, The carnivora of the Hagerman local fauna (late Pliocene) of southwestern Idaho, University of Michigan, Ph.D. dissertation, 165 p.

Bonnichsen, B., and Breckenridge, R.M., 1982, Cenozoic Geology of Idaho, Idaho Geological Survey, Moscow, Idaho, Bulletin 26, 725 p.

Bouwer, H., 1965, Theoretical aspects of seepage from open channels, Journal of Hydraulics Division, Proceedings of the american society of civil engineers, Vol. 91, No. HY3, 17 p.

Brockway, C.E., and Robison, C.W., 1992, Middle Snake River water quality study phase 1 final report, University of Idaho Water Resources Research Institute, Kimberly Research and Extension Center, 70 p.

Chleborad, A.F., and Schuster, R.L., 1995, A protocol for monitoring slope movement and seepage conditions at the Hagerman Fossil Beds National Monument, south central Idaho, U.S. Geological Survey Administrative Report, 20 p.

Cope, E.D., 1883, On the fishes of the Recent and Pliocene lakes of the western part of the Great Basin, and the Idaho Pliocene lake: Philadelphia Academy of Natural science Proceedings, v. 35, 134-166 p.

Freeman, G.E., Allen, R.G. and Brockway, C.E., 1981, Management and systems for water and energy savings - Bruneau Project, Idaho, Idaho Department of Water Resources supplementary report No. 3, 20 p.

Lee, D.E., 1995, Characterization of the Glenns Ferry Formation in the Fossil Gulch area, Hagerman Fossil Beds National Monument, Idaho: Geology Reports, Idaho Museum of Natural History, Geology Report #1, 59 p.

Lorkowski, R. M. and Hauser, J., 1996, Carbonaceous shale facies of the Glenn's Ferry Formation, Hagerman Fossil Beds National Monument, Idaho: National Park Service unpublished report.

Malde, H.E., 1991, Quaternary geology and structural history of the Snake River Plain, Idaho and Oregon in Morrison, R.B., ed., Quaternary nonglacial geology; conterminous U.S.: Boulder, CO, Geological Society of America, The Geology of North America, v. K-2.

Malde, H.E., 1972, Geologic Map of the Glenns Ferry-Hagerman Area, west-central Snake River Plain, Idaho, U.S. Geological Survey Miscellaneous Investigations Map I-169, scale 1:48,000, 2 sheets.

Malde, H.E., 1972, Stratigraphy of the Glenns Ferry Formation from Hammett to Hagerman, Idaho: U.S. Geological Survey Bulletin 1331-D, 19 p.

Malde, H.E., and Powers, H.A., 1962, Upper Cenozoic stratigraphy of western Snake River Plain, Idaho: Geological Society of America Bulletin, v. 73. no. 10, 1197-1220 p.

Malde, H.E., 1965, Snake river plain, *in* The Quaternary of the United States, A review volume for the VII congress of the international association for Quaternary research, Wright, H.E. and Frey D.G., editors, Princeton University Press, Princeton, New Jersey.

Malde, H.E., and Powers, H. A., 1958, Flood-plain origin of the Hagerman Lake Beds, Snake River Plain, Idaho (abs.): Geological Society of America Bulletin, v. 69, 1608 p.

Maley, T., 1987, Exploring Idaho geology: Mineral Land Publications, 232 p.

Martin, L., 1992, Analysis of data collected during a field investigation of leakage from canals and ponds of the Bell Rapids irrigation district near Hagerman Fossil Beds National Monument, National Park Service Water Resource Division, Fort Collins, Colorado, 10 p.

Martin, L., 1994, Notes, comments, and summary of results for the canal and pond leakage experiments Bell Rapids irrigation canals, Hagerman Fossil Beds, National Park Service Water Resource Division, Fort Collins, Colorado, 26 p.

Michaels, P., and Donaldson, P., 1994, Seismic refraction investigation fossil gulch and bell rapids canal areas, Technical Report BSU CGISS 94-05, Center for Geophysical Investigation of the Shallow Subsurface, Boise State University, Idaho, 20 p.

Milsom, J., 1989, Field Geophysics: Geological Society of London Handbook , Open University Press, 182 p.

Moffatt, R. L., and Jones, M.L., 1984, Availability and chemistry of ground water on the Bruneau plateau and adjacent eastern plain in Twin Falls county, south-central Idaho, U. S. Geological Survey, Water-Resources Investigations Report 84-4065, 43 p.

Montgomery, J.M., 1988, Interim report on ground-water conditions: Fossil Gulch pump station, Bell Rapids Irrigation District, Hagerman, Idaho; Montgomery, Consulting Engineers, Boise, Idaho, 9 p.

Parasnis, D.S., 1973, Mining Geophysics, Elsevier Scientific Publishing

Company, Amsterdam, 395 p.

Pelton, J.R., and Petteys, M.P., 1993, Preliminary seismic and magnetic investigations at Hagerman Fossil Beds National Monument, Technical Report BSU CGISS 93-02, Center for Geophysical Investigation of the Shallow Subsurface, Boise State University, Idaho, 13 p.

Pelton, J.R., 1995, Review of the report prepared by Vector Engineering, Inc., entitled: "Geophysical investigations of the Fossil Gulch Canal at the Hagerman Fossil Bed National Monument, Hagerman, Idaho", 10 p.

Riedel, J.L., 1992, Existing conditions of large landslides at Hagerman Fossil Beds National Monument, final report to the National Park Service; North Cascades National Park Geologist, Marblemount, Washington, 26 p.

Saddler, J.L., 1997, Sedimentology and stratigraphy of the Pleistocene Tuana gravel at Hagerman Fossil Beds National Monument, Idaho: Idaho State University, M.S. thesis, 62 p.

Schlumberger Educational Services, 1987, Log interpretation principles/applications, Schlumberger Educational Services, Houston, Texas, 198 p.

Summer, P., 1986, Groundwater evaluation of geologic hazards at the Hagerman Fossil Beds, Twin Falls county, Idaho, Bureau of Land Management Report, 9 p.

Vector Engineering, Inc., 1994, Geophysical investigation of the Fossil Gulch canal at the Hagerman Fossil Bed National Monument, Idaho, Vector Engineering, Inc. report No. 94-5020.00, Carson City, NV., 25 p.

Worstell, R.V., 1985, Report of canal seepage loss measurements made on the Bell Rapids irrigation district, Board of Directors of Bell Rapids Irrigation District, 12 p.

Young, H.W., 1984, Evaluation of hydrologic processes affecting soil movement in the Hagerman Fauna area, Hagerman, Idaho, U. S. Geological Survey, Water-Resources Investigations Report 84-4137, 16 p.

Young, H.W., 1993, Work activities summarization report with raw data, U.S. Geological Survey, Water Resources Division, Boise, Idaho, 19 p.

Young, H.W., (1997, April). Personal communication.