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HYDROGEOLOGIC ANALYSIS OF THE NEAR BLACKFOOT TO NEELEY REACH OF THE SNAKE RIVER

Prepared for the

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INTRODUCTION

The Enhanced Snake Plain Aquifer Model (ESPAM) is an important tool used by the Idaho Department of Water Resources (IDWR) in estimating impacts between ground water use and surface water resources to support water management decisions (Cosgrove and others, 2006). A significant portion of the water that discharges from the aquifer is from springs that are located along the Snake River. The Near Blackfoot to Neeley reach of the Snake River (defined by two stream gauging stations) includes large springs that discharge into the Snake River and the Portneuf River (Figure 1).

The objectives of this report are as follows: 1) describe the hydrogeology in the general vicinity of the Near Blackfoot to Neeley reach of the Snake River, 2) describe how the model represents the hydrogeology of this area and 3) provide recommendations relative to model changes to better represent the field conditions. The report is based on a review of available reports (citations provided in the text), discussions with individuals who work for the IDWR, the University of Idaho (UI) and have worked with the U.S. Geological Survey (USGS) and field site visits in March and October of 2007.

OVERVIEW OF THE AREA

The Near Blackfoot to Neeley reach of the Snake River includes the American Falls Reservoir and is located adjacent to the south margin of the of the Snake River Plain of eastern Idaho. Mundorff (1967, page 7) describes the geologic setting of the area as follows.

> "The Snake River Plain is underlain by a thick sequence of basaltic lava flows, interbedded pyroclastics and sedimentary deposits. The sequence accumulated in a structural trough between much older rocks of the mountain ranges that flank the trough along the northwest and southeast. The total thickness of the fill in the trough is not known, but it is believed, on the basis of geophysical evidence, to exceed 10,000 feet in some places.…
>
> The central part of the plain is generally higher than the margins and contains many lava domes and cones, indicating that at least in the late stages of volcanism, the basalt spread from the central part of the plain towards the northwest and southeast flanks. In the process, the Snake River was crowded against the southeast flank of the plain. Sedimentary interbeds, deposited in stream channels, flood plains and lakes, are thick and extensive along and adjacent to the present course of the Snake River, whereas they are thin or absent toward the central part of the plain."

Mundorff (1967, pages 7-8) provides the following description of the ground-water system.

> "The uppermost few thousand feet of basalt flows, pyroclastics and sedimentary interbeds compose the Snake River Group. These rocks form a great aquifer system – the Snake Plain aquifer – that stores and transmits large amounts of water … Chief sources of recharge to the aquifer are percolation from the channels of the Snake River, Henrys Fork and other streams; percolation from canals and irrigated tracts; and underflow from peripheral valleys and highlands…. The margin of the Snake Plain aquifer is the contact between the

> basalt and the consolidated rocks or the sedimentary deposits of lower permeability….The aquifer discharges to the Snake River chiefly in two reaches: between the mouth of the Blackfoot River and American Falls (American Falls Reservoir reach), and between Milner Dam and Bliss (Hagerman Valley reach). Discharge in these two reaches is caused by the specific spatial relationships of the aquifer to aquitards (geologic units of low permeability) in the reach. In the Hagerman Valley reach, the contact between the aquifer and the underlying aquitard intersects the canyon of the Snake River at an altitude generally 100-200 feet above river level, and springs issue at or above that contact. In the American Falls Reservoir reach the contact is generally 20-45 feet above maximum reservoir level."

GEOLOGIC SETTING

Regional Geologic Setting

The Near Blackfoot to Neeley reach of the Snake River including the American Falls Reservoir is underlain mostly by sediments with a large mass of basalt located to the north and northwest. Figure 2 is a geologic map of the area taken from Whitehead (1992) that shows the sediments as alluvium (Qa), wind blown deposits (Qw) and older alluvium (Qts). The basalt shown northwest of the river is identified as younger basalt (Qb) or basalt (Qtb). The general relationship between basalt and sediment is shown on two figures taken from Whitehead (1992). Figure 3 shows the thickness of Quaternary basalt whereas Figure 4 shows the thickness of sedimentary rocks. The two figures show the transition from a basalt-dominated subsurface in the center of the Snake Plain to a sedimentary-dominated subsurface in the vicinity of American Falls Reservoir. In addition, Figure 3 shows that the thickness of Quaternary basalt is greater northeast of the American Falls Reservoir than in the immediate vicinity of the reservoir.

Local Geologic Setting

The local geologic setting includes Tertiary and Quaternary basalt, mostly fine-grained sediments associated with deposition in a lacustrine environment (Raft Formation and American Falls lake beds) and gravel deposits associated with the Snake and Portneuf Rivers. Information on the local geologic setting is provided from four primary papers. Trimble and Carr (1961) describe the geology of the southern portion of the American Falls Reservoir and the surrounding area. Mundorff (1967) provides geologic cross sections and a description of ground water conditions within an area that includes the southern portion of the reservoir. Pierce and Scott (1982) describe alluvial-gravel deposition along the Snake River northeast of the reservoir. Houser (1992) describes the Quaternary stratigraphy of the area northeast of the reservoir and includes a plan map and cross sections.

The geologic history provided by Trimble and Carr (1961) provides an understanding of the relationship of geologic units in the vicinity of the American Falls Reservoir.

> "Rocks exposed along the Snake River include rhyolitic and welded tuff of Pliocene age; basalt and basaltic tuff of probable early Pleistocene age; clay silt, sand and gravel of middle to late Pleistocene age, mostly lucustrine and fluvial;

basalt of middle to late Pleistocene age; and alluvium and dune sand of Recent age" (page 1741).

"The oldest rocks prominently exposed in the Snake River canyon are the Pliocene Neeley Lake Beds … and the Walcott Tuff… These two conformable formations crop out mainly along the south side of the Snake River from American Falls southwestward to Rock Creek" (page 1741).

"The next youngest formation… is named the Raft Formation…. The Raft is mainly light-colored poorly bedded to nearly massive silt in the upper part and tan and gray clay, silt and fine sand in the lower part" (page 1742).

"Above the Raft, but possibly intertonguing with it, is a widespread group of nearly contemporaneous basalt flows from several vents northwest of the Snake River. These flows are restricted to the northwest side of the Snake River valley… These basalts are part of what has been mapped as Snake River Basalt… Cedar Butte Basalt..., which is younger than most of the Snake River Basalt, … occurs in an area about 8 or 10 miles long by 4 or 5 miles wide, almost entirely west of the present Snake River Canyon" (page 1742).

"The American Falls Lake Beds, which were deposited immediately after emplacement of the Cedar Butte Basalt, overlie the Snake River Basalt or the Raft Formation … where the basalt is absent… Above the American Falls Lake Beds are deltaic sand and gravel deposits, and several terrace deposits of silt, sand and gravel, all mainly north and east of American Falls" (pages 1742 - 1743).

Mundorff (1967) depicts the subsurface geology of the southwestern portion of the American Falls area, based on information from water wells, in a series of cross-sections that he combined into a fence diagram. A location map and selected portions of the fence diagram are presented in Figures 5a, 5b and 5c. The following points can be drawn from the Mundorff (1967) cross sections.

- The wells in Township 7 South Range 30 East (T7S R30E 29aa1, 20da1 and 20ab1) penetrate a considerable thickness of basalt overlying sediments, shown as the Raft Formation (Figure 5b). The basalt thins considerably to the southeast as is shown by wells 7S 30E 23cc1. The American Falls Lake Beds directly overlie the Raft Formation in this area.
- The basalt penetrated in wells along the northwest side of the reservoir is thinner with basalt flows interlayered with the American Falls Lake Beds and the Raft Formation as shown by well 7S 30E 11aa1 (Figure 5c). Only limited basalt was penetrated by well 6S 31E 32cd1 near the shore of the reservoir.
- Only thin basalt layers are penetrated by wells on the southeast side of American Falls Reservoir (not shown on Figure 5).
- The Mundorff (1967) fence diagram shows that the basalt, which is thick to the northwest in the center of the plain, thins and interfingered with mostly fine-grained sediments (Raft Formation and American Falls Lake Beds) near and likely under at least the southern portion of the reservoir.

Houser (1992) provides the most complete understanding of the subsurface geologic setting of the northeast portion of the American Falls area. Lithologic logs from 240 water wells were analyzed as part of the study and used to prepare a plan map and a number of cross sections. The geologic map prepared by Houser (Figure 6) shows the mapped surface geology and the well locations. The geologic notation used by Houser (1992) is as follows: 1) the American Falls Lake beds is noted as Ql with the Raft Formation as Qr; 2) Pleistocene basalt is noted as Qby or Qb with Snake River Gravel units identified as Qb; and 3) Tertiary basalt is shown as Tb The geologic map (Figure 6) shows the locations of ten cross sections (A-A' through J-J') The geologic cross sections are based on lithologic information from well logs. Selected cross sections are reproduced as Figures 7a, 7b, 7c and 7d. The following points can be drawn from the Houser (1992) map and cross sections.

- The geologic map (Figure 6) shows that the American Falls Lake Beds (Ql) outcrops in a discontinuous pattern over a large area northeast of the reservoir and north of the Snake River.

- The northeast maximum extent of the Raft Formation in the subsurface (subcrop) is shown on Figure 6. This line trends mostly west-northeast across the Fort Hall Bottoms past the town of Springfield. Houser (1992) did not identify the Raft Formation in the subsurface any further to the northeast.

- Geologic cross sections A-A' and B-B' are oriented approximately north-south and extend into the reservoir. The cross sections show that the American Falls Lake Beds (Ql) are present near land surface over much of the area (Figure 7a). The Raft Formation sediments (Qr) underlie the American Fall Lake beds, separated in places by a basalt layer. Either gravel (Qg) or basalt (Qb) underlies the Raft Formation (Qr). The low hydraulic conductivity units, particularly the Raft Formation, are important because they likely limit the hydraulic connection between deeper ground-water flow systems and shallow ground water and the reservoir.

- Cross-sections D-D' and E-E' are oriented northwest-southeast and are located northeast of the reservoir. In cross section D-D' (Figure 7b), the Raft Formation is depicted as extending continuously under the northeast end of the reservoir, the Snake River and the southwest portion of the Fort Hall bottoms. Cross section E-E' shows the Raft Formation as laterally continuous over the area but thinner. Either gravel (Qg) or basalt (Qb) is shown as both underlying and overlying the Raft Formation in sections D-D' and E-E'. The American Falls Lake Beds is a thin, near-surface unit in both of these sections

- Cross sections F-F' and G-G' are parallel to sections D-D' and E-E' but are located up river to the northeast. The American Falls Lake beds are still present as a near-surface unit but the Raft Formation unit is missing (Figure 7c). In section F-F', the Snake River and Fort Hall Bottoms are shown to be underlain by Snake River Gravel deposits (Qg).

- Cross section I-I' trends in a southwest-northeast direction from the northeastern corner of the reservoir to north of Ferry Butte. Cross section J-J' trends from south-southwest to north-northeast on the east side of Ferry Butte (Figure 6). Cross section I-I' shows that a thick section of the Raft Formation is present under American Falls Reservoir but missing to the northeast (Figure 7d). Houser (1992) shows that a thin clay layer is present between the Quaternary basalt (Qb) and the gravel over about half of the section. Cross section J-J' shows a thinner section of the Raft Formation in the southwest with a considerable thickness of gravel (Qb) overlying Tertiary basalt in much of the area.

- Houser (1992) shows the presence of Tertiary basalt (Tb) under the Snake River Gravel (Qb) at the southwestern (right) end of the four east-west cross sections (D-D', E-E', F-F' and G-G'). The Tertiary basalt is also shown over most of the length of cross section J-J'.
- The Houser (1992) study shows that the fine-grained sedimentary units (American Falls Lake Beds and the Raft Formation) likely are present under the northeast end of the American Falls Reservoir. The Raft Formation is not present in the surbsurface northeast of a line roughly half way between the reservoir and Ferry Butte. The gravel and basalt units likely act as unconfined aquifers northeast of the subcrop line for the Raft Formation and as confined aquifers where they are overlain by the Raft Formation.

Pierce and Scott (1982) provide a description of gravel deposits along the Snake River northeast of the American Falls Reservoir. Their plan view map is reproduced as Figure 8.

> "An extensive gravel deposit of late Pleistocene age, about 15 kilometers wide and at least 10 meters thick, occurs along the Snake River from St. Anthony to American Falls Reservoir (see Figure 8)… Two complimentary effects fostered its accumulation. First, American Falls Lake was dammed by the Cedar Butte Basalt 72,000 +/- 14,000 years ago, resulting in elevated base levels upstream until about 14,000 to 15,000 years ago when the Bonneville Flood drained the lake… Second, conditions that favored deposition in other areas of nonglacial and glacial gravels at this time also existed along the Snake River… Following the drainage of American Falls Lake and the change in stream regimen between late Pleistocene and Holocene time, this gravel fill was incised by the Snake River and its tributaries" (page 695).

The shallow gravel zones shown in the Houser (1992) cross sections near the Snake River and underlying the Fort Hall Bottoms likely are the gravel deposits described by Pierce and Scott (1982). Figure 8 shows that gravel deposits are present northeast of the American Falls Reservoir for a considerable distance beyond Blackfoot.

Summary of Geologic Setting

Four aspects of the geologic setting of the Near Blackfoot to Neely Reach of the Snake River are of particular importance with respect to ground-water flow and the hydraulic interconnection of ground water and surface water.

- The general area of the American Falls Reservoir is underlain by basalt layered with fine-grained sediments. The deposition of fine-grained sediments in this area resulted from damming of the ancestral Snake River by basalt in Quaternary time.

The spatial distribution of the fine-grained sediments, particularly the Raft Formation, provides important control on ground-water flow. The Raft Formation thins generally to the east and northeast and can be identified in the subsurface only to a line approximately half way between the upper end of the reservoir and Ferry Butte. Upward ground-water flow from basalt aquifers into the American Falls Reservoir is likely limited by the presence of the fine-grained sediments of the Raft Formation and the American Falls Lake Beds.

- Gravel associated with the Snake River is present in the subsurface approximately along the present alignment of the river starting above Idaho Falls and continuing down river to thin and terminate against fine-grained sediments near the upper end of the American Falls Reservoir. The fine-grained sediments (Raft Formation and American Falls Lake Beds) in this area effectively block southwestward movement of ground water in the shallow sediments and result in ground-water discharge in the form of springs and river gains, generally northeast of the subcrop of the Raft Formation.
- The presence of the fine-grained sediments at depth in the vicinity of the American Falls Reservoir likely also limits southwestward flow of ground water in the deeper basalt units. This results in upward ground-water flow and discharge of water in the form of springs and river gains.
- The presence of Tertiary basalt at shallow depths in the vicinity of Ferry Butte may also be important relative to controlling ground-water flow. The Tertiary basalt, if less permeable than Quaternary basalt or Quaternary gravel, would be an additional impediment to ground-water flow. Knowledge of the hydraulic properties of the Tertiary basalt is limited.

HYDROGEOLOGIC CONCEPTUAL MODEL

The Quaternary basalt near the center of the Snake Plain generally is considered to host a single, unconfined aquifer. Water producing zones within the Quaternary basalt occur mostly at flow contacts which are present at depth intervals of about 15 to 20 feet. The average hydraulic conductivity of the basalt is extremely high.

The inter-fingering of Quaternary basalt flows with fine-grained sediments in the general vicinity of the American Falls Reservoir likely creates a subsurface environment composed of individual aquifers and confining units (aquitards). The transmissivity of the subsurface in the vicinity of the American Falls Reservoir is postulated to be much lower than the transmissivity of the aquifer to the northwest where fine-grained sediments generally are absent. The hydrogeologic environment in the area northeast of the reservoir is complicated by the presence of a shallow gravel unit roughly parallel to the Snake River. An additional complication is the presence of what is mapped as Tertiary basalt underlying the Quaternary gravel in the vicinity of Ferry Butte. The role that the Tertiary basalt plays in controlling ground-water flow patterns is unknown.

The presence of the fine-grained sediments in the subsurface (Raft Formation and American Falls Lake Beds) likely acts as a restriction for southwestward ground-water flow in both the basalt and the gravel along the Snake River. This results in upward hydraulic gradients and ground-water discharge in the form of springs and river gains.

As noted by previous investigators, most of the ground-water discharge occurs in areas northeast of the reservoir above maximum reservoir level. The sedimentary units likely are present under all but the southwestern end of the American Falls Reservoir. The amount of ground water moving vertically upward through the fine-grained sediments to discharge into the reservoir is believed to be small. The southwestern end of the reservoir is believed to act as a recharge source for ground water. Leakage likely is occurring through basalt that is present in this area.

Two major sources of information are available to combine with the hydrogeologic conceptual model to develop an improved understanding of the ground-water surface water interconnection in the Near Blackfoot to Neeley reach of the Snake River: 1) the locations and temporal variations of ground water discharges (i.e. springs, reach gains) to the river; and 2) the spatial and temporal variations in ground-water levels. Information on ground-water discharges and ground-water levels is described in the following sections.

GROUND-WATER DISCHARGE CHARACTERISTICS

Ground water discharge to the Snake River in the Near Blackfoot to Neeley reach occurs both in the form of identified springs and in the form of river gains that have not been attributed to specific springs. Information on ground-water discharge in the Near Blackfoot to Neeley reach is available from a number of different sources. The following sections provide a summary of information from each specific source.

Stearns and Others (1938)

The springs in the Fort Hall bottoms are described by Stearns and others (1938, pages 137-139) as follows.

> "Springs rise at intervals for a distance of 10 miles or more along the Fort Hall bottoms and adjacent to the Portneuf River near its mouth. Most of these springs rise on the valley floor at heights of 10 to 15 feet above the river. They have a fairly uniform aggregate discharge of about 1,400 second-feet (cfs), and most of them issue from basalt which underlies the alluvium in this area. The flow and the names of 30 of the larger springs in vicinity of the American Falls Reservoir are given below (given in this report in Table 1). The locations of the stations where the flow from these springs were measured are shown in figure … (given in this report as Figure 9)."
>
> "The ground-water contours … indicate that the springs bordering the Fort Hall bottoms should be divided into two groups. Batise Spring, Fish Hatchery Spring, and Wide Creek, in the Portneuf Valley form one group, and Big Spring Creek, Clear Creek, and Kinney Creek, the waters of which come from the valley of the Snake River north and east of Fort Hall, form the other group."
>
> "In addition to these springs, 230 second-feet (cfs) of water is discharged by 13 springs in the Aberdeen-Springfield area. These springs issue from the basalt of Gibson Butte, which collects the water from under the irrigated areas to the northeast and from seepage from the Snake River. At most of the spring vents this basalt is overlain by the American Falls lake beds or by alluvium…"

> “The Portneuf and Snake Rivers are also augmented by smaller springs and by inflow rising in the stream channels themselves.…. The Snake River between the mouth of the Blackfoot River and American Falls, a distance of about 30 miles, has a total gain, exclusive of surface run-off from the upper Portneuf of about 2,500 second-feet (cfs), nearly all of which is supplied by springs.”

Table 1 Spring Discharge Values Reported by Stearns and others (1938)

Number	Name	Discharge		Number	Name	Discharge
1	Rich	18.6		16	Artesian	5.5
2	Johannes	7.2		17	Sterling	6.2
3	Thorn	20.2		18	Colburn	3.2
4	Log Cabin	34.9		19	Ruger	23.9
5	Indian No. 1	47.4		20	Davis	
6	Indian No. 2	21.9		21	Franklin	
7	Indian No. 3	163.5		22	Big Jimmy	37.6
8	Indian No. 4	3.8		23	Big Spring	448.0
9	Indian No. 5	19.3		24	Kinney	29.3
10	Pyle	14.0		25	Clear	130.0
11	McTucker	26.4		26	Ford	7.4
12	Hull	7.1		27	Pocatello City	
13	Tanner	2.2		28	Batise	50.0
14	Crystal	32.8		29	Fish Hatchery	75.0
15	Danielson	51.1		30	Wide	60.0

Stearns and others (1938) discuss the possible sources of inflow to the Snake River in the reach in question. Approximate water balances are prepared for the three identified sources: 1) ground-water flow down the valley of the Portneuf, 2) precipitation on the lava beds north of the Snake River and 3) underflow along the Snake River. Stearns and others (1938, pages 141 and 142) note the following.

> “Thus it appears evident that the springs in the Fort Hall bottoms are mainly supplied by this great underflow of the Snake River Valley. Coarse clean gravel deposits and basalt suitable for the accumulation of ground water underlie the river and the irrigated tracts upstream from the springs, but near Blackfoot the gravel deposits grade into relatively impermeable lake-bed silts and clays of the American Falls Basin. As a consequence the ground water that is carried by the gravel deposits tends to be forced into the basalt, which is the only available material of sufficient permeability, and practically all the springs issue from basalt.”

Mundorff (1967)

Mundorff (1967) spends a number of pages dealing with a water-budget analysis of the American Falls reservoir reach. He reports the following relative to early flow measurements of the inflow (page 24).

> "Continuous records of flow in the Snake river at the two gaging stations used in the analysis are available only since 1911. Spring inflow at earlier dates can be obtained only by analysis of earlier miscellaneous records. Discharge measurements were made at different places along the Snake River in the vicinity of the American Falls Reservoir reach between 1902 and 1910. By estimating inflow from some tributaries, gains and losses in several reaches, and evapotranspiration losses from the reservoir reach, rough estimates of spring discharge were made for a period in August in three different years. These estimates are 2,000 cfs …in 1902; 1,840 cfs … in 1905 and 1,830 cfs in 1908. Although the records are incomplete and the quantities determined may be considerably in error, the records do indicate that spring inflow in the reach was considerably less before 1908 than in the years since 1911."

Mundorff (1967) presents calculated ground-water inflow to the American Falls reach of the Snake River on an annual basis from 1911 through 1960. The variability in his calculated inflow rates is small with a maximum of 2,055 cfs in 1952 and a minimum of 1,654 in 1916. The range in values from 1940 to 1960 is smaller with a minimum of 1,830 in 1956. Mundorff (1967, page 28) shows that a positive correlation exists between the calculated ground-water inflow to the American Falls reach and the 5-year progressive average of irrigation diversions to the area above American Falls Dam. Mundorff (1967, page 45) states the following in his conclusions.

> "Ground-water inflow in the American Falls Reservoir reach was probably about 1.2-1.4 million acre-feet a year (1,700-1,900 cfs) before irrigation began in eastern Idaho. Inflow increased with the increasing diversions of surface water to land adjoining the Snake River and in the late forties and early fifties averaged about 1.95 million acre-feet annually (2,600 cfs). About 1952 increased withdrawals of ground water apparently became large enough to prevent further increases of ground-water inflow. Between 1922 and 1952 the ground water inflow increased roughly 2.5 acre-feet for every 10 acre-feet of surface water diverted to lands on the Snake River Plain upstream from American Falls Dam."

Mundorff (1967) shows that his calculated monthly ground-water inflow to the American Falls reach correlates reasonably well in the period of 1952 to 1960 with water levels in a shallow well (46-feet deep) located in section 27 of township 5 south and range 31 east. A well driller's report for this well is not available on the IDWR website but other wells in this section penetrate basalt in the depth range of about 20 to about 60 feet.

Balmer and Noble (1979)

Balmer and Noble (1979) present an analysis of the water resources of the Fort Hall Indian Reservation. The study included measurement of water levels in wells and discharge from springs in the Fort Hall Bottoms. The mean flow of major springs on the

Fort Hall Bottoms, as compiled by Balmer and Noble (1979, page 17) is presented in Table 2. Some of the springs identified in Table 2 are the same as included in Table 1 from Stearns and others (1938). It is impossible to know whether flow measurements were taken at the same locations.

Table 2 Discharge of Major Springs on the Fort Hall Bottoms (Balmer and Noble, 1979)

Station	Mean flow in cfs
Hatchery Springs	103
Diggie Creek	263
Jeff Cabin Creek	21.1
Spring Creek	466
Big Jimmy Creek	30.5
Clear Creek	134
Kinney Creek	28.1
Wide Creek	57.4
Jimmy Drinks - East	103
Jimmy Drinks - West	35.4
Ross Fork	58.4

The Balmer and Noble (1979) study includes development of a water budget for the Fort Hall Bottoms. The graphical depictions of their water budget are reproduced as Figures 10A and 10B, a Snake River portion and a Portneuf River portion.

- The Snake River discharge of 4,800 cfs below the Blackfoot River (Near Blackfoot gage) increases to 5,450 cfs where it discharges into the American Falls Reservoir (Figure 10A). About 184 cfs of the total gain of about 650 cfs is noted as “groundwater to channel”. The remaining gain is from identified sources with the largest being Diggie Creek at 263 cfs.
- The Portneuf River flow increased from 270 cfs at the USGS Pocatello gage to 1,744 cfs where it discharges into the American Falls Reservoir (Figure 10B). Specific springs and creeks make up much of the gain. The combined flow of Spring Creek and Jimmie Creek (496 cfs), Clear Creek (134 cfs), Ross Fork (55 cfs), Jimmie Drinks (103 and 35 cfs) plus Wide Creek (57 cfs) is 880 cfs. Unmeasured ground-water inflow makes up an additional 428 cfs.
- Balmer and Noble (1979, page 18) note that the total identified gain to the rivers is about 2,100 cfs. Almost 70 percent of this gain is discharge to the Portneuf River with slightly less than 30 percent of the gain discharging into the Snake River.

Balmer and Noble (1979, page 156) established several temporary gaging stations to quantify inflow to the lower Portneuf River. One station was established at the Michaud Pumping Station near Siphon Road with a second station about one-half mile below Jimmy Drinks East Branch. The approximate locations of these stations are shown on Figure 10B. Six sets of measurements were obtained (dates not given). The river gain was about 619 cfs in this reach with 398 cfs accountable by individual spring inflows. Several measurements near the mouth of the Portneuf River were made during the low water period of 1977 (September 29 and November 1). The measurements indicated river gains of 671 and 637 cfs in the reach below Jimmy Drinks East Branch and the mouth. Discounting the flows in the three measured springs, the unaccounted for gain was 156 and 120 cfs for the two dates.

Kjelstrom (1995)

Kjelstrom (1995, page C17) provides the following summary of information on the gain between the Near Blackfoot and Neeley gages.

> "The Snake River gained about 1.9 million acre-ft of ground-water, largely from springs, between the gaging stations near Blackfoot and Neeley … in water year 1980. Annual streamflow gains in the reach varied little during water years 1912-80… The mean gain from ground water from 1912 to 1980 was 1.8 million acre-ft, or 2,540 ft^3/s; the standard deviation was 80,000 acre-ft, or 110 ft^3/s."

The reservoir was drawn down for dam reconstruction in 1977, providing an opportunity for measurement of the Snake and Portneuf Rivers upstream and downstream from major springs. Kjelstrom (1995, page C18) reports that the total streamflow gain from ground water in the Blackfoot to Neeley reach was estimated to be 2,560 cfs and 2,570 cfs on September 8 and 28, 1977 respectively.

Kjelstrom (1995, page C18) notes that ground-water discharge to the natural channel of the Portneuf River is about 65 percent of the total ground-water discharge to the Blackfoot to Neeley reach. He describes field measurements as follows.

> "Streamflow measurements of the Portneuf River at Pocatello and upstream from Bannock Creek were made on September 9 and 17, 1977. After these measurements adjusted for a measured diversion and estimated surface-water inflow, the average difference between outflow (measured at the downstream gage) and inflow was 1,650 ft^3/s (assumed to be ground-water discharge)".

Kjelstrom (1995), page C21) says that springs issuing from basalt north of the Snake River and American Falls Reservoir discharge about 200 cfs. The largest of these springs is tributary to Danielson Creek. Kjelstrom (1995, page C23) shows that temporal variations in discharge in Danielson Creek correlate well with water-level elevations in well 5S 31E 27aba1 (using data from 1980-81). This is the same well that Mundorff (1967) used to correlate with his calculated ground-water discharge to the American Falls Reservoir reach.

Hortness and Vidmar (2003)

Hortness and Vidmar (2003) present the results of seepage studies that were conducted jointly by the U.S. Geological Survey and the Idaho Power Company for three reaches of the Snake River: 1) lower reach from Minidoka to King Hill, 2) middle reach from Shelley to Minidoka and 3) upper reach from Ashton to the mouth of the Henrys Fork and Snake River from Heise to Shelley. The seepage studies were conducted in 2001 and 2002. The approach used by Hortness and Vidmar (2003) is described below.

> "Data collected in each reach included discharge values from the USGS and/or IPCo (Idaho Power Company) gaging stations, discharge values at several intermediate locations obtained using acoustic Doppler instrumentation … and measured and/or inspected discharge values for several miscellaneous inflows (mostly tributaries) along the entire length of each reach obtained by field personnel" (page 1).

The Near Blackfoot to Neeley portion of the middle reach of the Snake River was divided into three subreaches using four gaging sites (Figure 11). Station M9 at the upper end of the reach is the USGS stream gaging station entitled Snake River near Blackfoot. Station M12 at the lower end of the reach is the USGS stream gaging station entitled Snake River at Neeley. Acoustic Doppler discharge measurement data were taken at two intermediate stations: M10 – Snake River near Pingree; and M11 – Snake River above McTucker Creek near Pingree. Additionally, measurements or observations were taken at a number of tributaries within the reach. The seepage studies were done twice in 2001 and three times in 2002.

Appendix B of the Hortness and Vidmar (2003) report include tables of discharge data for each of the four stations (discharge readings were not obtained from stations M10 and M11 for all of the seepage runs) plus estimates of selected inflows between the stations and changes in storage in American Falls Reservoir. Table 3 provides a summary of the seepage run results in cfs. Figure 11 shows the seepage run results for the April 9-10, 2002 data collection effort.

Figure 11 show a gain of 460 cfs from station M9 (Near Blackfoot gage) to M11 (head of the reservoir) with a 1,232 cfs gain over the length of the reservoir (station M12 minus station M11). The Hortness and Vidmar (2003) data in Table 3 show a range of stream flow gains of 1,390 to 2,186 cfs from the Near Blackfoot gage (M9) and Neeley gage (M12). The largest calculated gain was in November 2002 with the smallest in July 2002.

The study results shown on Table 3 are different from the results provided in the Hortness and Vidmar (2003) because two errors were discovered in the original document. The first error is in the calculated inflow between stations M11 and M12 for the July 23-24, 2002 seepage run. Two sites are included in estimated inflow for the July 2002 calculations that are not included in analysis of the other four seepage runs. The inflow for the other four seepage runs between stations M11 and M12 is the sum of discharge at the following sites (Hortness and Vidmar 2003, Table B20).

- Portneuf River near Tyhee
- Bannock Creek near Michaud
- Aberdeen Waste Drain near Aberdeen
- Tarter Waster near American Falls
- Seagull Bay near American Falls
- Falls Irrigation Pump near American Falls

Table 3 Summary of Seepage Run Results (cfs) (Hortness and Vidmar, 2003)

Station	April 3-6, 2001	Oct 31-Nov 1, 2001	April 9-10, 2002	July23-24, 2002	Nov 5-6, 2002
M9	2,190	1,810	1,750	3,960	2,060
Est. Inflow	0	0	0	0	0
Est. Outflow	0	0	0	0	0
M10	2,520	2,410			2,430
Est. Inflow	0	0	0	0	0
Est. Outflow	0	0	0	0	0
M11	2,820		2,190		2,550
Est. Inflow	588	481	538	246	421
Est. Outflow	0	0	0	96	0
Res. Storage	800	4,000	2,300	-4,900	4,300
M12	3,920	354	1,660	10,400	367
M10-M9	**330**	**600**			**370**
M11-M10	**300**				**120**
M12-M11	**1,312**		**1,232**		**1,696**
M12-M10	**1,612**	**1,463**			**1,816**
M12-M9	**1,942**	**2,063**	**1,672**	**1,390**	**2,186**

The following two additional sites are included by Hortness and Vidmar (2003) in the calculated inflow between stations M11 and M12 for the July 23-24, 2002 seepage run.

- McTucker Creek Springfield
- Danielson Creek near Springfield

The calculated inflow for the July 23-24, 2002 seepage run is reported in Table B13 of Hortness and Vidmar (2003) is 246 cfs rather than 506 cfs if the two additional stations are not included (see Table 3). Table B13 and Figure B5 in Hortness and Vidmar (2003) show a streamflow gain of 1,131 cfs from the Near Blackfoot gage to the Neeley Gage (M9 to M12). This number is not comparable to the other reach gains presented in the report because of the inclusion of the two additional sites in the calculated inflow between stations M11 and M12. The corrected calculated gain is 1,390 cfs.

The second error is in the calculated reach gain from M11 to M12 for the November 5-6, 2002 seepage run. As is shown on Table 3, the gain between the Near Blackfoot and the Neeley gaging stations (M9 and M12) was 2,186 cfs. Table B17 and Figure B5 of the Hortness and Vidmar (2003) report show this gain as occurring between M11 and M12 rather than M9 and M12. The correct gain across the American Falls Reservoir (M12-M11) for the November 2002 seepage run is 1,696 cfs.

Hortness and Vidmar (2003) obtained flow measurements at 18 surface water sites that discharge directly into the American Falls Reservoir. Seven of the sites, including the Portneuf River and Bannock Creek, are included in their inflows in the M11 to M12 reach (Table 3). The total discharge of these seven sites ranges from a low of 246 cfs in July 2002 to a high of 588 cfs in April 2001. The eleven remaining surface water sites are: 1) Ross Fork, 2) Clear Creek, 3) Spring Creek, 4) McTucker Creek, 5) Danielson Creek, 6) Sterling Waste, 7) Spring #1 Sterling, 8) Crystal Spring, 9) Spring #2 Sterling, 10) Spring #3 Sterling and 11) Spring Hallow. The combined discharge of these sites was 541.5 cfs in October-November 2001, 634 cfs in July 2002 and 604 cfs in November 2002. Not all of the sites were measured in April 2001 and April 2002. Table 3 shows that the calculated gain across the American Falls Reservoir (M12-M11) was 1,696 cfs in November 2002. Thus, the eleven additional measured inflows to the reservoir (604 cfs) account for about 36 percent of the calculated gain in the American Falls Reservoir reach in November 2002. Most of the remainder of the calculated gain likely is discharge from the spring-fed creeks described by Balmer and Noble (1979) and Kjelstrom (1995) that discharge to the lower Portneuf River. The presence of the sedimentary formations (American Falls Lake Bed and Raft Formation) makes it difficult for large quantities of water to discharge directly into the bottom of the reservoir.

<u>IDWR Reach Gain/Loss Program (2006)</u>

The IDWR Reach Gain/Loss Program is used to develop estimates of historical river gains and losses for various reaches. Cosgrove and others (2006) describe the program as follows.

> "The Reach Gain/Loss Program uses gaged reach inflows and outflows, measured diversions and estimated irrigation returns and reservoir storage and evaporation to calculate a (monthly) water balance for the reach. The residual of the water balance is the estimated river reach gain from or loss to the aquifer" (page 92).

Most of the ground-water discharge to the Snake River occurs in two reaches: 1) Milner to King Hill and 2) Near Blackfoot to Neeley. Cosgrove and others (2006) present calculated average annual river gains in these reaches starting in the early 1900's. A plot of these data is presented in Figure 12. Their description of the temporal pattern of discharge in these two locations is presented below.

> "Natural discharge from the Snake River Plain aquifer is primarily to the Snake River along two reaches: Kimberly to King Hill and Near Blackfoot to Neeley … Spring discharge has varied in response to changes in precipitation, irrigated acreage, and irrigation practices. Overall, discharge in the Kimberly to King Hill

reach appears to have been impacted more than in the Near Blackfoot to Neeley reach…Historically, aquifer water levels and corresponding discharges to the Snake River rose significantly at the onset of surface water irrigation. This is particularly apparent in the historic discharge in the Milner to King Hill reach… Aquifer water levels peaked about 1950 and have been declining since that time. The declines are attributed to the onset of ground-water irrigation, more efficient surface water irrigation practices such as conversion to sprinkler irrigation and canal lining, and the recent seven years of drought. Historic discharge in the Near Blackfoot to Neeley reach shows a less dramatic response to historic changes in irrigation practices, however the reach does exhibit more dramatic seasonal variation since the 1950s" (pages 15-16).

Monthly average river gains, calculated using the IDWR Reach Gain/Loss Program, were obtained from Wylie (2007). The calculated monthly river gains from Near Blackfoot to Neeley results (Figure 13) show a greater data scatter than the annual gains shown on Figure 12. There are some longer-term trends in the river gain with a high in about 1987, a low in about 1995, a high in about 2000 and a low in 2006 that continues into 2007. The average calculated river gain for the reach decreases with time as follows: 2,559 cfs for the period of January 1970 through August 2007, 2,341 cfs for the period of January 2000 through August 2007 and 2,104 cfs for the period of January 2001 through August 2007.

TEMPORAL WATER-LEVEL PATTERNS IN WELLS

The comparison of temporal water-level data from wells from within the basalt-dominated portion of the Snake Plain aquifer to wells near the Near Blackfoot to Neeley reach of the river provides information of hydraulic connection of the ground-water systems. The water-level data were obtained from the U.S. Geological Survey web site.

Hydrographs for selected single completion wells (Figure 14) are presented in Figures 15 through 19. The order of presentation starts with wells completed in basalt north of American Falls Reservoir followed by wells located nearer the reservoir.

- Wells 2N 31E 35dcc1 and 1S 30E 15bca1 (Figure 15) have similar hydrographs and represent the temporal water-level pattern that is typical of the basalt portion of the Snake Plain aquifer northwest of the Near Blackfoot to Neeley reach. Both wells are deep (636 and 751 feet) and the static depth to water is considerably below land surface (594 and 721 feet in 2007). Both wells show a downward overall water-level trend with recent highs in November 1984 and January 1999 and recent lows in August 1981 and August 1994. The water-level rise between August 1981 and November 1984 was about six feet. The seasonal water-level changes in both wells were generally less than two feet with seasonal lows in late spring or summer and seasonal highs in late fall or winter.
- Wells 2S 32E 23bbb1 and 4S 31E 20bbb1 (Figure 16) show a similar water-level pattern as the previous pair of wells. These two wells are 194 and 201 feet deep and have water levels about 171 and 127 feet below land surface. The water-level rise between August 1981 and November 1984 was about five feet in both wells. There is more seasonal scatter in the data points in these wells as compared to wells to the north, probably related to pumping and irrigation application. The

seasonal water-level changes in both wells were generally less than two feet with seasonal lows in spring and seasonal highs in fall.

- Wells 4S 31E 36aba1 and 5S 31E 27aba1 (Figure 17) are both shallow (17 and 51 feet) located in areas irrigated using surface water. The wells show a rapid response to surface water irrigation practices. There is considerable scatter to water-level in both wells with lower water levels in the spring and higher water levels in the fall. The water-level rise from 1981 to 1984, noted in the wells to the north, is not evident in the data from these two shallow wells. The water-level elevation in both wells was lowest in the period of record in 2004-2005.
    - For well 4S 31E 36aba1, the annual water level fluctuation was five to seven feet with no long-term pattern of water-level change from the start of records through the mid 1970's. There is a significant change in the water-level pattern in well 36aba1 starting in about 1978 with lower water level highs and less annual water-level change. Care must be taken to differentiate changes in water-level patterns from apparent changes caused by decreases in frequency of measurement or changes in dates when measurements were taken. The data show a pattern of water-level decline with several multi-year trends (low in 1993 and high in 1999). The water level pattern seen in well 36aba1 is a reflection of change in surface water irrigation practices in the area (such as change from gravity to sprinkler irrigation or lining of canals) and possibly the impacts from ground-water pumping.
    - The overall pattern of the hydrograph for well 5S 31E 27aba1 is similar to well 4S 31E 36aba1 except for larger annual water-level fluctuations. The annual water-level fluctuation was up to 15 feet in the 1950's and 1960's. The range in annual water-level changes lessened (less than nine feet) in the mid 1970's and 1980's with both lower highs and higher lows. Again, some of the change in water-level pattern is from changes in the frequency and/or timing of measurements. An overall downward trend in water levels is evident in the record starting in the early 1980's. The water-level pattern in this shallow well likely is a combination of impacts from changes in surface water irrigation practices and possible impacts from ground-water pumping.
- Well 6S 31E 16bab1 (Figure 18) is located near the northwest shore of American Falls Reservoir. The hydrograph for this 134-foot well has characteristics of the nearby two shallow wells (Figure 17) and the deeper wells to the north (Figures 15 and 16). Seasonal water-level changes were less than about five feet in the 1950's and 1960's, except for scattered low water level readings. According to the USGS record for this well, the pump in the well was operating when the scattered low water-level readings were taken.
- Well 2S 34E 33bba1 (Figure 19) is located near the Aberdeen-Springfield Canal northeast of the American Falls Reservoir. This is 40 feet deep and has high water levels in the fall and low water levels in the spring, which is typical of surface water irrigated areas. The seasonal water-level change generally is five to

six feet. The hydrograph for well 33bba1 is similar to the shallow wells shown on Figure 17. The most likely causes for the water-level pattern in well 33bba1 are changes in surface water irrigation practices in the area and possible impacts from ground-water pumping.

A number of locations have clusters of wells completed to different depths. These wells allow characterization of vertical hydraulic gradients and temporal changes in water-level elevation with depth. Water-level data are available for these wells since about 1980. The locations of the wells are shown on Figure 14.

- Wells 4S 32E 1cba1, 1cba2, 1cba3 and 1cba4 are constructed to depths of 90, 53, 242 and 433 feet respectively and are located near the Aberdeen-Springfield Canal at a site north of the northeast end of the American Falls Reservoir (Figure 14). The water-level patterns for the two shallow wells (Figure 20) are similar with seasonal changes of about 7 to 9 feet and lows in the spring and highs in the fall. The seasonal changes are likely from surface-water irrigation activities. The two deeper wells have much smaller seasonal changes. Figure 20 shows that there was an upward hydraulic gradient between the two deeper completions from the start of the record through about 2002 when the wells had about the same water-level elevation. The scatter in data for the 242-foot well starting in 2005 is difficult to explain. The overall water-level pattern, evident in the three wells with long-term records likely stems from a combination of changes in surface-water irrigation practices in the area and impacts from ground-water pumping.
- Wells 4S 33E 20cbb1, 20cbb2, 20cbb3 and 20cbb4 are located northeast of American Falls Reservoir near the Snake River and are completed at depths of 62, 108, 365 and 738 feet (Figure 14). An upward vertical gradient is evident from the water-level data from all four of these wells (Figure 21). The water-level elevation in the 108-foot well is about 10 feet higher than in the 62-foot deep well. These data indicate an upward vertical gradient of about 0.2 ft/ft. The upward gradient persists deeper in the section but is smaller. The long-term water-level pattern in the 738-foot well is typical of the basalt aquifer to the northwest. This well has one to two feet of seasonal water-level changes with water-level highs generally in early winter and water-level lows in July. This well likely reflects the seasonal impacts of ground-water pumping. The long-term water-level pattern in the 365-foot well is dissimilar from any of the other hydrographs in the area with a high water-level elevation in November 1989 and very small seasonal fluctuations. Reasons for the uniqueness of the hydrograph for the 365-foot well are unknown. The hydrograph for the 108-foot completion has considerable seasonal variation but does not fit the seasonal patterns of other shallow wells in areas of irrigation by surface water. Several significant water level changes (such as 4.5-foot drop between January and March 1992 and a 3.7-foot drop between January and March 1998) are difficult to explain. There are about two-feet of seasonal water-level change in the 62-foot completion well; water-level highs are either in May or September, probably reflecting high river conditions in May and surface-water irrigation impacts in September.
- Wells 4S 33E 25ddb1-2 and 4S 34E 8dbd1-3 are located south of the Snake River and between Ferry Butte and the American Falls Reservoir (Figure 14). Wells

25dbb1 and 25dbb2 have completions at depths of 21 and 117 feet and are located is down gradient (southwest) of wells 8dbd1, 8dbd2 and 8dbd3 which have completions at depths of 38, 99 and 232 feet. Water-level data for these wells are only available during the period of 1985 to 1994 (Figure 22). The water-level data from the 21 and 117-foot completions at 4S 33E 25ddb show an upward vertical gradient of about 0.2 ft/ft with a greater rate of decline during the period of record in the 117-foot completion than in the 21-foot completion. The three completions at 4S 34E 8dbd also show upward ground-water flow but the vertical gradient is smaller (about 0.05 ft/ft). The declining water-level trend in all five of these wells is consistent with this period of record for other wells in the area. The 232-foot completion at 25dbb has a consistent seasonal water-level pattern with low levels in late spring and a high in early winter. A consistent seasonal trend is not as identifiable in the other wells.

- Wells 3S 34E 22dab1 and 22dab2 are located northeast of Ferry Butte and are completed at depths of 85 and 569 feet (Figure 14). Limited water-level data for the 569-foot well are similar in pattern to the 85-foot well with a small downward hydraulic gradient (Figure 23). The overall water-level pattern in both wells is similar to that found in the Snake Plain aquifer to the northwest. The 569-foot well has a seasonal fluctuation of about two to three feet with low water levels in the winter and spring and high water levels in the fall. The 85-foot well has a similar seasonal range in water levels with high water levels generally in the fall.
- Wells 2S 35E 11ddd1-4 are located north-northeast of the City of Blackfoot and are completed at depths of 97, 376, 570 and 682 feet (Figure 14). Note that the scale on the right side of the Figure 24 is for well 11ddd1 (97-foot completion) is three times the range for the other three wells. The hydrograph for the 97-foot well (11ddd1) shows very large seasonal water-level changes (35 to 50 feet), water-level highs and lows that are consistent with surface-water irrigation effects and does not have long-term pattern of water-level decline. There is a downward hydraulic gradient of about 0.18 ft/ft from the 97-foot well to the 376-foot well. The deeper wells at this site have a water-level pattern that is similar to wells located north of American Falls Reservoir with a fairly large seasonal water-level change (three to seven feet). An upward hydraulic gradient was present from the 682-foot completion to the 376-foot completion in the early 1980's. However, these two wells show a downward hydraulic gradient based on the few data points in 2001 and 2002.

Mundorff (1967) notes that shallow wells respond to the large annual range in lake stage only near the southwest end of the American Falls Reservoir. The locations of wells identified by Mundorff (1967) as responding to reservoir stage are shown on Figure 25. A temporal plot of reservoir stage and water-level elevations for one of the wells (7S 30E 24ddc1) for a period of time in the 1960's is presented in Figure 26. The plot shows that the water-level in the well is lower than the surface water at high reservoir stage and higher than the surface water at low reservoir stage. Leakage of water from the west end of the reservoir is likely related to basalt present near land surface in this area.

ANALYSIS OF DATA

Geologic Controls for Ground-Water Discharge

Ground water discharges in an area northeast of the American Falls Reservoir because of changes in geology that result in lower aquifer transmissivity in this area. The gravel zone that hosts a shallow ground-water flow system along the Snake River essentially terminates against the fine-grained sediments of the American Falls Lake Beds and the Raft Formation. In the same way, basalt that makes up most of the Snake Plain aquifer occurs only as individual flows within a sequence of mostly fine-grained sediment. The lower transmissivity in the immediate vicinity of the American Falls Reservoir acts similar to a subsurface dam and results in ground-water levels at or above ground surface in shallow aquifers northeast of the reservoir. Springs occur in these areas. There is also a significant upward hydraulic gradient which indicates ground-water flow occurs from deeper aquifers to shallow aquifers and then to discharge locations.

Studies by Balmer and Noble (1979) and Kjelstrom (1995) plus other authors are sufficient to conclude that the vast majority of ground-water discharge occurs upstream of the American Falls Reservoir, probably controlled by the subcrop of the Raft Formation. The amount of ground-water discharge directly into the bottom of the reservoir is unknown but believed to be small.

Estimation of Ground-Water Discharge

The amount of ground-water that discharges to the Snake River in the Near Blackfoot to Neeley reach has been estimated by a number of investigators using a variety of direct measurement and mass balance approaches. The mass balance approach involves measurement of the flow in the river at an upstream site (often the Near Blackfoot site) and subtracting that number from the flow in the river at a downstream site (often below the American Falls Dam at the Neeley site) and adjusting for known inputs and known outputs. Changes in storage within the American Falls Reservoir are also taken into account. The accuracy of the calculated river gain depends on the accuracy of flow measurements and the detail taken in accounting for all inputs and outputs and the change in storage in the reservoir.

The following sections describe the results of the selected investigation efforts.

- Studies conducted by Balmer and Noble (1979) are particularly important because flow measurements were obtained on a large number of springs and tributary streams near the northeast end of the reservoir. Their studies, conducted in the late 1970's, indicate that the Snake River gains about 650 cfs from the Near Blackfoot gage to the reservoir with about 70 percent of the gain from documented sources (individual springs and creeks) and 30 percent from ground-water discharge to the channel. Balmer and Noble (1979) calculated a gain in the Portneuf River from the Pocatello gage to the reservoir of about 1,470 cfs with about 70 percent from documented sources and about 30 percent from ground-water discharge to the channel. This gives a total gain to the rivers of about 2,100 cfs (rounded to two significant digits). Kjelstrom (1995, page C21) says that springs issuing from basalt north of the Snake River and American Falls

Reservoir discharge about 200 cfs. The largest of these springs is tributary to Danielson Creek. Combining the two sources of information, the estimated ground-water discharge to the Snake River in the Near Blackfoot to Neeley reach in the late 1970's was about 2,300 cfs.

- Kjelstrom (1995, page C17) used data from U.S. Geologic Survey stations, measurements of diversions and return flows and changes in reservoir storage to calculate ground-water discharge in the reach using the mass balance approach. He reports the mean gain from ground water between the Near Blackfoot and Neeley from 1912 to 1980 was 2,540 cfs with a standard deviation of 110 ft^3/s.
- The Hortness and Vidmar (2003) seepage run data in a mass balance approach show a range of streamflow gains of 1,390 to 2,186 cfs from the Near Blackfoot gage (M9) and Neeley gage (M12). The largest calculated gain was in November 2002 with the smallest in July 2002.
- The average calculated river gains for the reach for different time periods using the IDWR Reach Gain/Loss Program are as follows: 1) 2,559 cfs for the period of January 1970 through August 2007, 2) 2,341 cfs for the period of January 2000 through August 2007 and 3) 2,104 cfs for the period of January 2001 through August 2007. These values show that the calculated river gains have decreased with time.

Relationship of Ground-Water Levels and Ground-Water Discharge

As with any ground-water system, temporal variations in the discharge from springs in the Near Blackfoot to Neeley reach of the Snake River are related to water-level changes in the source aquifer. Higher discharge from the springs occurs because of higher ground-water levels. The converse is also true. The relationship of ground-water levels to ground-water discharge is described in this section using a well located near Aberdeen and several wells located northeast of the reservoir as compared to calculated ground-water inflow and the discharge of Spring Creek.

Mundorff (1967) compared his calculated monthly values of ground-water inflow to American Falls Reservoir to well 5S 31E 27ab1, located north of Aberdeen (Figure 14). As Mundorff shows (Figure 27), the water-level pattern in the well, which responds to surface irrigation in the area, is similar to the temporal pattern of calculated ground-water inflow to the reservoir.

Water-level data from well 5S 31E 27aba1 (the same well used by Mundorff) are plotted with the monthly reach gains calculated using the IDWR Reach Gain/Loss Program in Figure 28. The seasonal range in water levels in the well was about 15 feet in the 1950's and 1960's and decreased to less than nine in the mid 1970's and 1980's with both lower highs and higher lows. The seasonal range in water levels has been less than seven feet since about 1990. An overall downward trend in water levels is evident in the record starting in the mid 1980's although the frequency of measurement also decreased starting in the late 1980's. Ground-water levels in well 5S 31E 27aba1 show a similar pattern as the calculated reach gain starting about 1990. The drop in water level in the well after about 1998 is very similar to the decrease in the calculated river gain in the same period. The water-level pattern in this shallow well likely is a combination of impacts from changes in surface water irrigation practices and possible impacts from ground-water pumping. This suggests that the decrease in calculated gains using the IDWR Reach Gain/Loss Program also is a result of the combined impacts of changes in surface water irrigation practices and possible impacts from ground-water pumping.

The analysis of the discharge of Spring Creek with ground-water levels in the area provides an additional opportunity to understand the relationship between ground-water levels and ground-water discharge. Spring Creek heads in a group of springs located west of Ferry Butte and is fed nearly all from ground-water discharge. According to Nathan Jacobson of the U.S. Geological Survey (Jacobson, 2008), the contribution of irrigation return flow to Spring Creek during the irrigation season is a small part (less than 5%) of the total flow. Figure 29 shows the locations of the gaging station on Spring Creek, the springs near Ferry Butte that are the primary source for the stream flow and the locations of nearby observation wells.

The temporal pattern of the discharge of Spring Creek is shown in Figure 30 along with water-level elevations in well 4S 33E 20cbb1. Well 4S 33E 20cbb1 is the shallowest (62 feet) of four wells of various depths that are located about four miles west-northwest of the gaging station location on Spring Creek and about seven miles southwest of the primary springs that feed the stream near Ferry Butte. Daily discharge data are available from the U.S. Geological Survey station Spring Creek at Sheepskin Road starting in the early 1980's. The multi-year temporal changes in the Spring Creek discharge are very similar to the long-term hydrograph for well 20cbb1. There is a high in the mid 1980's, a low in the mid 1990's, a high in the late 1990's and then the lowest discharge and water level in the period of record in 2004-2005. The seasonal features in the two records are harder to correlate, in part because of the different frequency of data points (daily for the creek and every other month for the well). In Figure 30, well 4S 33E 20cbb1 has a seasonal change of about two feet for most of the period of record with highest water levels in the fall. The seasonal water-level pattern in the well appears to change significantly in the period of March 2001 to March 2003 (almost no seasonal water level changes). Reasons for this change are unknown.

The discharge pattern for Spring Creek is compared with hydrographs of two clusters of wells located on the southeast side of the Snake River (the nearest observation wells with temporal records to the gaging station and springs) in Figure 31. Wells 4S 33E 25ddb1 and 25ddb2 are located less than a mile southeast of the Spring Creek gaging station (Figure 29). Both wells are shallow with depths of 117 and 21 feet. Wells 4S 34E 8dbd1, 8dbd2 and 8dbd3 are located south of Ferry Butte and about one mile from the springs that are the primary source of water for Spring Creek. Well depths are 232 feet, 98 feet and 38 feet respectively. Water-level data for these wells are available only from 1985 to 1994. The seasonal change in water levels is small in all five of these wells. The lack of significant seasonal water-level changes fits with the locations of the wells away from irrigated lands and near a ground-water discharge area. The downward water-level trend in the wells is similar to that shown for well 4S 33E 20cbb1 on Figure 30 and correlates with the discharge record from Spring Creek.

The variations in discharge pattern of Spring Creek during on a calendar-year basis over the period of record provide important information relative to ground-water levels and possible causes for changes in both ground-water levels and spring discharge.

Complete year discharge records are available for Spring Creek for the years 1981 through 2007. Figure 32 presents the flow data as average discharge for five-year periods (1981-1985, 1986-1990, 1991-1995, 1996-2000, 2001-2005) and the average of years 2006 and 2007. The entire discharge record for Spring Creek is shown on Figure 30.

- The calendar-year plot of average daily flow of Spring Creek during the period of 1981-1985 (Figure 32) shows a low of 344 cfs on January 1st and July 9th and a high of 414 cfs on October 11th. The discharge steadily increased from the low in July to the high in October with a gradual decrease through the end of the year.
- The average daily flow of Spring Creek during the period of 1986-1990 varied from a low flow of 340 cfs on July 7th to high flows of 390 cfs on May 31st and 387 on October 6th (Figure 32). The flow-rate pattern in 1986-1990 is similar to 1981-1985 except for the lack of a higher peak in the fall.
- The pattern of average daily flows of Spring Creek in 1991-1995 was similar to previous five-year periods only the discharge magnitude was considerably lower. The low flow was 301 cfs on July 9th with high flow rates of 354 cfs on June 6th and 356 cfs on October 7th.
- The 1996-2000 time period includes several years of higher stream flow including the peak flow in the period of record at 605 cfs on June 8, 1998 (Figure 30). The average daily flows of Spring Creek for the 1996-2000 time period (Figure 32) were similar to the 1981-1985 and 1986-1990 periods in shape and magnitude except for the spring high flow period. The average daily high flow value was 419 cfs on June 8th with an average daily low of 337 on July 25th.
- The 2001-2005 time period has much lower average daily discharges than any of the four preceding five-year periods. The average daily high flow was 314 cfs on January 1st with an average daily low flow of 253 cfs on July 3rd.
- The average daily flow of Spring Creek during calendar years 2006 and 2007 are lower than any of the preceding five-year averages with the exception of several short periods. The average daily high flow was 302 cfs on May 5th and October 10th. The average daily low flow was 239 cfs on June 30th.

The average daily discharge plots for Spring Creek, presented in Figure 32, may be used to identify several patterns that are reasonably consistent over the 27 years of record. First, the lowest average daily flow generally occurs in July with a range from June 30th to July 25th. Second, the highest average daily flow mostly occurs either in the spring (May or June) or in October (from 6th to 11th). Third, the July low flow is followed by an October high flow reflects a combination of the impacts of surface water irrigation and the impacts from cessation of ground-water pumping.

Relationship of Surface Water Irrigation and Ground-Water Discharge

Irrigation using both ground water and surface water occurs in the Near Blackfoot to Neeley reach of the Snake River. Figure 33, taken from Cosgrove and others (2006) shows irrigated ground from three sources: 1) ground water, 2) mixed ground water and surface water and 3) surface water.

The Aberdeen-Springfield Canal is the major supply source for surface-water irrigation on the northwest side of the Snake River in the Near-Blackfoot to Neeley reach. As such, the canal diversion records, presented in Figure 34, provide a general temporal view of this water supply source (diversion data obtained from B.A. Contor, 2007). Figure 34 shows an increase in annual diversion per water year from the 1930's into the early 1970's with a peak diversion of about 406,000 acre feet in the 1969 water year. A decrease in diversion rate occurred starting in the 1975 water year with most years less than 350,000 acre-feet per water year. Diversions during the 2000 water year were an exception to the decreasing trend with about 400,000 acre-feet diverted. The diversions during the 2001 through 2005 water years were all less than 300,000 acre feet.

The relationship between annual canal diversions and ground-water levels in a portion of the service area of the Aberdeen-Springfield Canal also is shown on Figure 34. The average annual (taken on a water-year basis) water-level elevations in well 5S 31E 27aba1 are shown along with canal diversions. Water-level data from this well have been presented three times previously in this report: 1) on Figure 17 to represent shallow ground water conditions north of the reservoir; 2) on Figure 27 to show Mundorff's (1967) relationship between calculated river gains and ground-water levels; and 3) on Figure 28 to show the relationship of ground-water levels to river gains calculated using the IDWR Reach Gain-Loss Program. Water-level data from well 5S 31E 27aba1 are presented in Figure 34 as an average over each water year (October 1 through the following September 30). The average values are based on a range in number of data points (weekly measurements in some years ranging to quarterly measurement after 1988). Figure 34 shows that average annual ground-water levels were in the range of 4,380 to 4,383 feet for the period of record up through 1988. With the exception of 1998, all of the average ground-water levels were lower than 4,380 feet. The lowest average ground-water level was 4,375 feet in 2004.

The ground-water levels in well 5S 31E 27aba1 do not immediately follow the decline in diversions in the canal that occurred starting in 1975. The general increase in diversions (with the exception of 1993) that occurred from 1984 to 2000 is also not directly replicated in the ground-water data. There are a number of possible reasons for the differences noted between canal diversion rates and shallow ground-water levels in a portion of the service area. These are: 1) changes in surface water application rates across the service area and in the general vicinity of the well; 2) changes in leakage rates from water delivery systems across the service area and in the general vicinity of the well; and 3) impacts from ground water pumping in the general vicinity of the well. Information is not available at the time of preparation of this report to develop a more detailed cause-effect relationship between canal diversions and ground-water levels in this single well. Sufficient data are available to say with certainty that changes in surface water irrigation practices in the general vicinity of the well 5S 31E 27aba1 have impacted shallow ground-water levels. It is likely that at least a portion of the water-level decline evident in the well hydrograph on Figure 34 is a result of ground-water pumping.

<u>Relationship of Ground-Water Pumping and Ground-Water Discharge</u>

Ground-water pumping from the Snake Plain aquifer is a major portion of the regional water budget. Figure 35, taken from Cosgrove and others (2006), shows that large areas are irrigated using ground water west and north of the Near Blackfoot to

Neeley reach. Other major ground-water pumping centers are located further west, southwest and northeast within the aquifer. The cumulative ground-water irrigation rights on the aquifer, as presented by Contor and others (2006) are presented in Figure 36. This plot shows a dramatic increase in ground-water irrigation rights starting in the 1950's and ending in the 1990's.

The seasonal hydrograph signature for a ground-water pumping area is a water-level high in the spring prior to the starting of pumping and a water-level low in the fall at the end of the pumping season. This is opposite to the signature of a surface-water irrigated area where ground-water levels are low in the spring prior to the start of irrigation and high in the fall at the end of the irrigation season.

None of the observation wells presented and discussed in the report section entitled *"Temporal Water-level Patterns in Wells"* has a seasonal ground-water pumping signature in the water-level record. The presence of the large tracts of land irrigated with surface water between the ground-water pumping areas and the Near Blackfoot to Neeley reach of the river appears to mask out any seasonal water-level changes from pumping wells. However, long-term water level trends such as those shown for wells 2N 31E 35dcc1 and 1S 30E 15bca1 on Figure 15 are detectable in deep wells in the area of interest. Examples are well 4S 33E 20cbb4 which is 738 feet deep (Figure 21) and well 3S 34E 22 dab2 which is 569 feet deep (Figure 23).

Ground-water pumping can impact ground-water discharge in the area northeast of the American Falls Reservoir via the following steps. First, there is a documented upward hydraulic gradient and thus upward ground-water flow from deep zones to shallow zones in the ground-water discharge area. An example of the upward hydraulic gradient is shown on Figure 21. Second, pumping impacts from throughout the aquifer are propagated through the aquifer to the discharge area. Deep wells near the discharge area have hydrographs similar to those near the center of the plain. Third, a decreased upward hydraulic gradient occurs because of greater water-level decline in the deeper zones than in the shallow zones. This is shown on Figure 21 by the comparison of the hydrographs for 4S 33E 20cbb1 at a depth of 62 feet to 20cbb4 at a depth of 738 feet. Fourth, the decreased upward hydraulic gradient results in a reduction in spring discharge.

The magnitude of upward ground-water flow from deep zones to shallow zones and then to discharge areas (such as springs) has not been directly estimated by any of the previous investigators. The magnitude of upward ground-water flow depends on the hydraulic gradient (for which some data are available) and the vertical hydraulic conductivity of the basalt and sediments in the area (for which essentially no data are available). The impacts of ground-water pumping on ground-water discharge also have not been estimated by any of the previous investigators except for model predictions presented in Cosgrove and others (2006).

MODEL REPRESENTATION OF THE HYDROGEOLOGIC SETTING

Characteristics of the ESPAM

ESPAM is a single layer, fixed transmissivity model with 104 rows and 209 columns constructed using the MODFLOW code (Cosgrove and others, 2006). All model cells are 1 mile x 1 mile with a 31.4 degree counter-clockwise rotation relative to east-west. Several types of boundaries were used in the model: 1) no flow, 2) specified flux and 3) head dependent.

The Snake River in the Near Blackfoot to Neeley reach is represented using the River Package. Cosgrove and others (2006) describe the function of river cells as follows.

> "Flow between the aquifer and river or drain cells is governed by equations which are based on Darcy's law (discharge is equal to the product of hydraulic conductivity times cross-sectional area times hydraulic gradient).. In a numerical model, for both river and drain cells, the hydraulic conductivity term represents the conductivity of the river-bed or drain sediments which controls the flow between the river/drain and the aquifer. The gradient … represents the head differential between river stage … and aquifer level" (pages 20-21).
>
> "The flow between the aquifer and a hydraulically connected surface water body is governed by (Darcy's Law)… In the MODFLOW River Package, (Darcy's Law) is implemented in terms of a) stage of the surface water body, b) aquifer water level and c) a conductance term describing the hydraulic conductivity of the riverbed … sediments and the wetted areas of the river bed. The user specifies river stage, elevation of the bottom of the river sediments and conductance of the riverbed sediments. As long as the water level in the aquifer is above the elevation of the bottom of the river sediments, the discharge to (or from) the river is calculated as (discharge is equal to the conductance multiplied by the difference of the river water-level elevation and the aquifer water-level elevation)… (page 30).
>
> "Since riverbed conductance is a lumped parameter (i.e. It represents multiple physical attributes) and impossible to measure, it is commonly estimated during model calibration" (page 32).

The area of the river and reservoir in the Near Blackfoot to Neeley reach is represented using river cells as is shown on Figure 37. Cosgrove and others (2006, Table 3) provide the following information for each of the river cells: 1) row and column (location in the model), 2) stage (for river or reservoir), 3) riverbed conductance in units of square feet per day and 4) riverbed elevation in feet. The stage information was given to represent field conditions. The riverbed elevation was in the range of about 39 to 53 feet lower than stage elevation. The riverbed conductance was held at 99,000 square feet per day for all of the river cells in the reach. As a comparison, the conductance term was set at 157,000 square feet per day for the cells in the Shelley to Near Blackfoot reach and 35,100 square feet per day for the cells in the Neeley to Minidoka reach.

The calibrated transmissivity values for the nodes in the portion of the model near the Near Blackfoot to Neeley reach were obtained from IDWR (Wylie, personal communication, 2008). Figure 38 shows transmissivity values for this portion of the model in terms of ranges of values. The map shows that high transmissivity values (> 10,000,000 ft^2/day) are included in the model to represent aquifer characteristics north of the east end the American Falls Reservoir.

Calibration of the model was done using automated parameter estimation tools. Cosgrove and others (2006, page 90) describe the process as follows.

> "The goal of model calibration was to adjust model parameters (transmissivity, aquifer storage, riverbed conductance and drain conductance and elevation) until model-predicted values of aquifer water levels and discharges to the river matched observed values. The calibration was done in two steps. An initial steady state calibration was done to establish initial aquifer transmissivity and riverbed and drain conductance. After the initial steady state calibration, a coupled steady state and transient calibration was done. During the coupled steady state and transient calibration, the parameter estimation software would adjust aquifer storage and drain elevation during the transient portion, followed by a check of the steady state model fit. This forced the transient calibration to not only provide a 'best fit' to the transient data but to also honor the steady state observations. Changes to the transmissivity field and riverbed and drain conductance were allowed during the coupled steady state/transient calibration."

Cosgrove and others (2006) show comparisons of model predicted ground water levels as compared to field data. They also show model predicted river gains or losses in comparison to observed or calculated river gains or losses. Model output was compared to ground-water levels in selected wells and to calculated or measured reach gains or losses. The comparison of model predicted gain to calculated gain for the Near Blackfoot to Neeley reach is presented in Figure 39. The model predicted gains are a reasonable representation of the calculated gains over time, although with slightly less variability.

Model Representation of Site Hydrogeology

The Snake Plain aquifer model is of necessity a simplification of a complex ground-water flow system with complex interactions with surface water systems. The primary question is whether changes in the model are needed to make it better represent field conditions. Three topics are presented relative to representation of the Near Blackfoot to Neeley hydrogeology within the model.

- The general construction of the model in the vicinity of the Near Blackfoot to Neeley reach is appropriate for the intended uses of the model. However, construction of a single layer model with one-square mile node spacing does not allow assessment of vertical flow within the aquifer or discharge characteristics of individual springs or stream-gain areas.
- Representation of the Snake River including the American Falls Reservoir using the River Package is appropriate. Hydrogeologic conditions are such that higher riverbed conductance values should be applied to the area between the northeastern end of the reservoir and the Near Blackfoot gage than are applied for the body of the reservoir. The conductance value assigned for the reservoir should be low enough relative to the conductance value for the upper portion of the reach to limit direct discharge into the reservoir to a small value.

- The transmissivity array used in the model does not fit the general hydrogeologic setting of a basalt and gravel dominated system north and northeast of the American Falls Reservoir transitioning into a fine-grained, sedimentary-dominated system under the reservoir. Consideration should be given to making changes in model calibration to achieve a transmissivity array that better fits the hydrogeologic conceptual model. Care must be taken in that the transmissivity values of the single layer model need to represent not just the near-surface sediments and basalt but also the deeper basalt units.
- Consideration of multiple layers for the model should be taken carefully. A multiple layer model can provide an improved representation of areas such as upstream of the American Falls Reservoir where vertical hydraulic gradients are present. However, adding multiple layers increases complexity and thus increased uncertainty in model predictions. Also, data may not be currently available to support the construction and application of a multiple layer model.

CONCLUSIONS AND RECOMMENDATIONS

There is little doubt that ground water discharges to the Snake River in the Near Blackfoot to Neeley reach because the transmissivity in the general vicinity of the American Falls Reservoir is lower than in upstream areas. The gravel zone that hosts a shallow ground-water flow system along the Snake River essentially terminates against the fine-grained sediments of the American Falls Lake Beds and the Raft Formation. In the same way, basalt that makes up most of the Snake Plain aquifer occurs only as individual flows within a sequence of mostly fine-grained sediment. The lower transmissivity in the immediate vicinity of the American Falls Reservoir acts similar to a subsurface dam and results in ground-water levels in shallow and deep aquifers northeast of the reservoir at or above ground surface. The springs occur in these areas. There is a significant upward hydraulic gradient which indicates ground-water flows from deeper aquifers to shallow aquifers and then discharges as springs and stream gains.

The majority of ground-water discharge occurs upstream of the American Falls Reservoir, probably controlled dominantly by the subcrop of the Raft Formation. The amount of ground-water discharge directly into the bottom of the reservoir is unknown but believed to be small.

The ground water that discharges to the Snake River in the Near Blackfoot to Neeley reach is a combination of water from the shallow aquifer in gravel zones along the Snake River and upward flow from deeper aquifers that are hydraulically connected to the basalt system of the main Snake Plain aquifer. The percentage of the discharge that originates from the shallow gravel aquifer likely is higher than the percentage that originates from the deeper aquifer, but the relative amounts are unknown.

As with any ground-water system, temporal variations in the ground-water discharge in the Near Blackfoot to Neeley reach of the Snake River are related to water-level changes in the source aquifer. Higher discharge from the springs occurs because of higher ground-water levels. The converse is also true.

Changes in surface-water irrigation practices in recent years have decreased ground-water levels in shallow aquifers and thus have resulted in reduced ground-water discharge in the Near Blackfoot to Neeley reach. Ground-water pumping has caused ground-water level declines in the main Snake Plain aquifer and is also a factor in reduced ground-water discharge in the Near Blackfoot to Neeley reach. The well hydrographs and the discharge hydrograph for Spring Creek represent a multiple overlay of impacts from changes in surface water irrigation practices combined with the impacts from ground-water pumping.

The Enhanced Snake Plain Aquifer Model (ESPAM) is a work in progress. Model construction and operation and then modification and improvement are part of a repetitive process that is tied to improved data collection and analysis. Specific recommendations with respect to the model include the following.

- Modify the transmissivity array in the Near Blackfoot to Neeley reach to better represent the subsurface hydrogeologic conditions. The changes should be made with the objective of forcing ground-water discharge from the model to occur primarily in the area between the American Falls Reservoir and Ferry Butte.
- Modify the ground-water conductance such that ground-water discharge occurs upstream from the northeast end of the reservoir and little discharge occurs directly to the American Falls Reservoir. The conductance can be modified to allow leakage from the southwestern end of the reservoir.
- To the extent possible, ground-water discharge to the Portneuf River should be represented in the model.

A revision to the existing water resource data collection network is needed in order to provide an improved basis for understanding the interaction of surface and ground-water systems in the Near Blackfoot to Neeley reach of the Snake River. Suggested improvements to the data collection network are noted below.

- Long-term discharge monitoring stations should be established on one or more additional spring/stream sites upstream from the American Falls Reservoir that have no direct impacts from irrigation return flows or diversions. Data analysis should include comparison to data from the Spring Creek station.
- Routine water-level measurement should be reinitiated on observations wells 4S 33E 25ddb and 4S 34E 8dbd. The measurement program should include either monthly measurements or preferably installation of data loggers.
- Additional collection of water-level data from shallow wells in the immediate vicinity of the Snake and Portneuf Rivers and near major springs is needed to develop a better understanding of ground-water levels and spring discharge and/or river gains.

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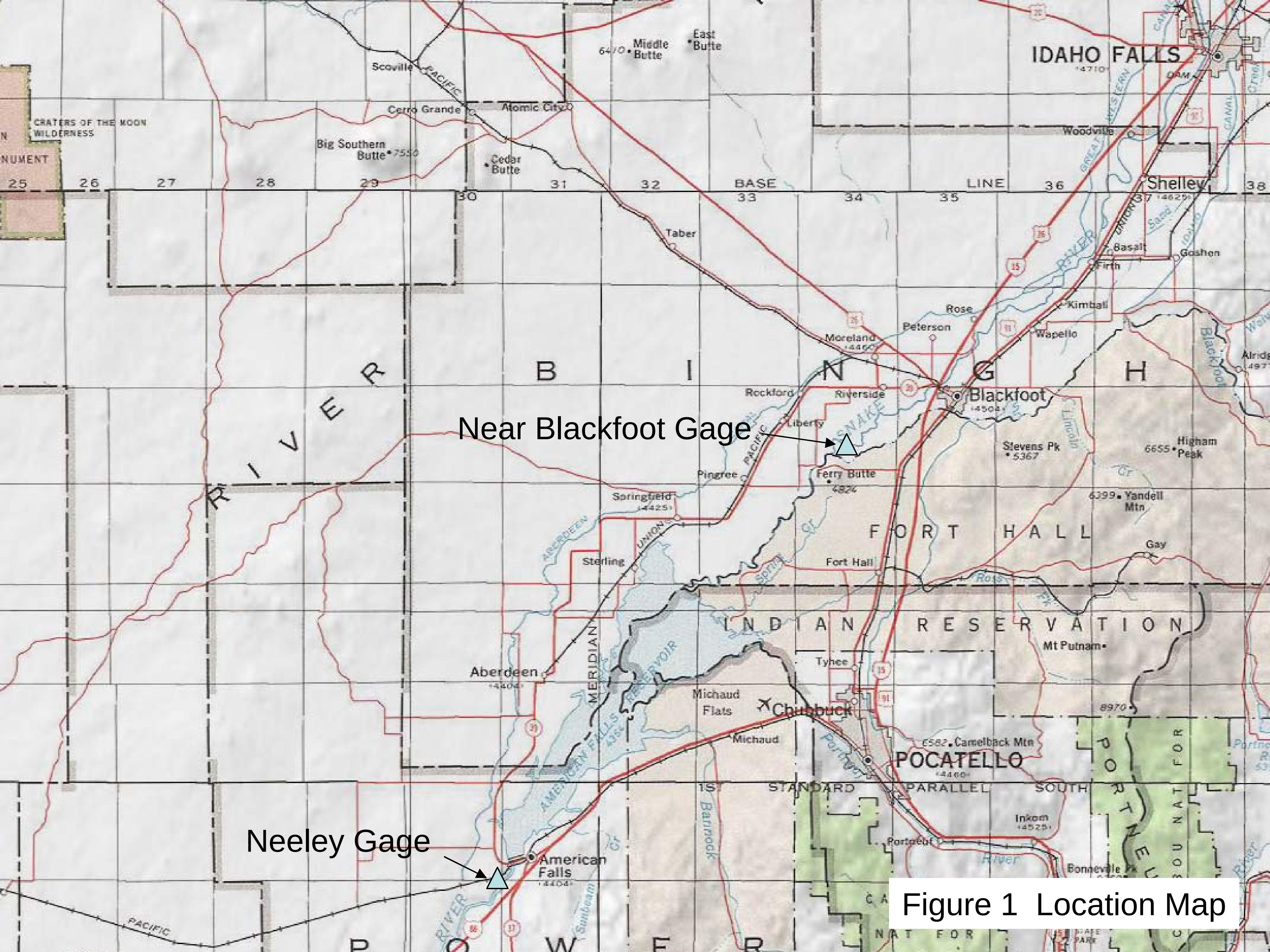


Figure 1 Location Map

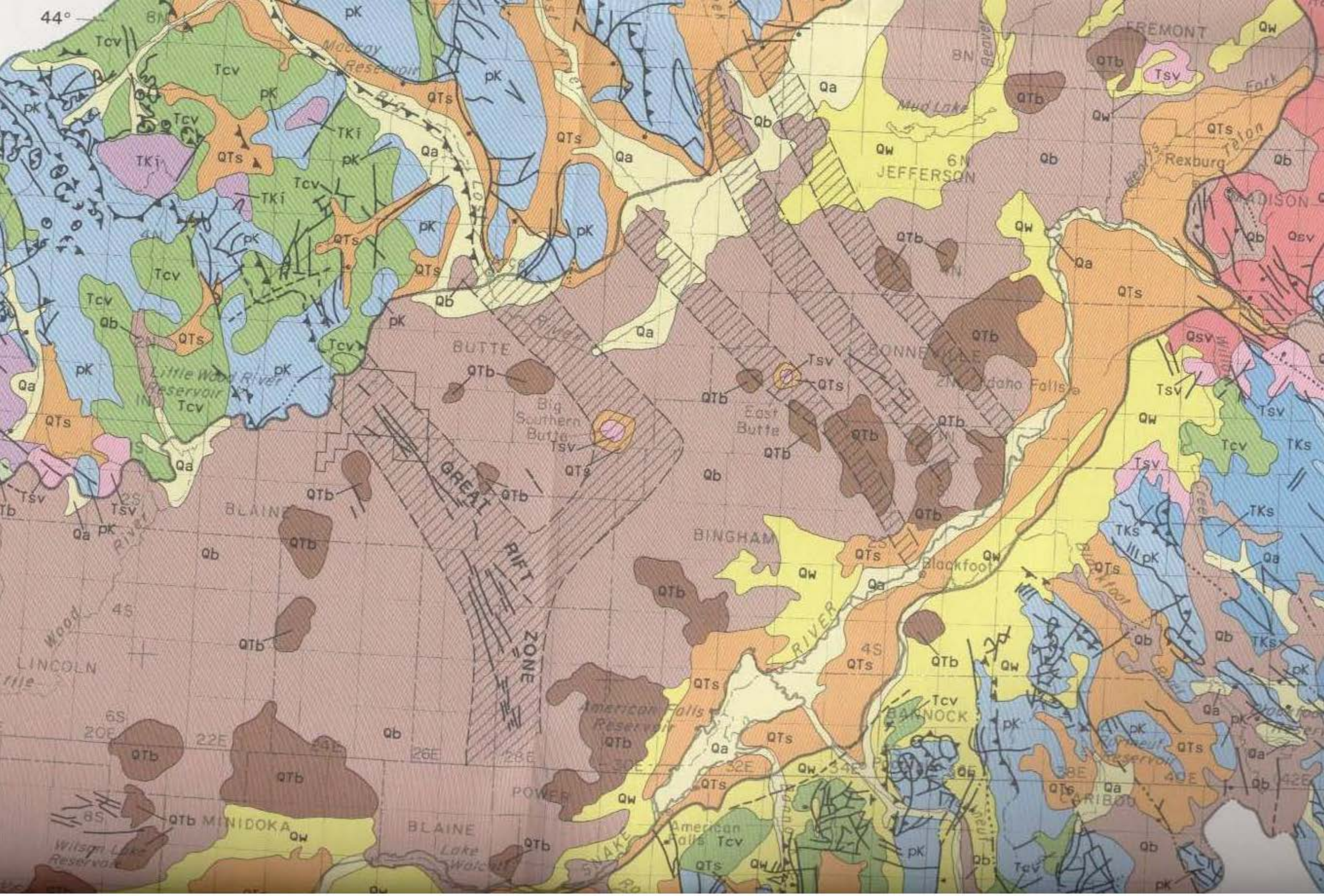


Figure 2a Regional Geologic Map (Whitehead, 1992)

EXPLANATION AND DESCRIPTION OF MAP UNITS

	Rock unit and map symbol		Physical characteristics and areal distribution	Water-yielding characteristics	Known thickness (ft)
QUATERNARY — Holocene	Alluvium	Qa	Chiefly flood-plain deposits. May contain some glacial deposits and colluvium in the uplands. Clay, silt, sand, gravel, and boulders; unconsolidated to well compacted; unstratified to well stratified. Alluvium floors the tributary valleys and flood plains of the main streams and forms fans at mouths of some valleys.	Hydraulic conductivity variable, moderately high in coarse-grained deposits. Sandy and gravelly alluvium yields moderate to large quantities of water to wells. Transmissivity ranges from about 16,000 to more than 160,000 ft²/d (Nace and others, 1957, p. 55). Specific capacities commonly range from 20 to 100 (gal/min)/ft. An important aquifer.	<250 (?)
QUATERNARY — Holocene	Windblown deposits	Qw	Chiefly windblown deposits, include some lake and glacial-flood deposits; mantle much of the lowland areas; include active sand dunes in places, generally in northern Owyhee County and in northern part of eastern plain.	Generally above the water table.	<100 (?)
QUATERNARY — Holocene and Pleistocene	Younger basalt	Qb	Olivine basalt, dense to vesicular, aphanitic to porphyritic; irregular to columnar jointing; thickness of individual flows variable, but averages about 20-25 ft (Mundorff and others, 1964, p. 143). Includes beds of basaltic cinders, rubbly basalt, and interflow sedimentary rocks. Chiefly basalt of the Snake River Group. Crops out in much of Snake River Plain; mantled in many places with alluvium, terrace gravel, and windblown deposits.	Hydraulic conductivity variable but extremely high in places; formational conductivity high because of jointing and rubbly contacts between numerous flows; rock conductivity low. Unit constitutes the Snake River Plain aquifer east of King Hill (Mundorff and others, 1964, p. 8). Specific capacities of 500-1,000 (gal/min)/ft are common. Transmissivity determined from aquifer tests ranges from about 100,000 to more than 1,000,000 ft²/d in much of the Snake River Plain (Mundorff and others, 1964, p. 159; Nace and others, 1957, p. 55).	>4,000 includes QTb below
QUATERNARY — Pleistocene	Younger silicic volcanic rocks	Qsv	Rhyolitic ash-flow tuff, occurs as thick flows and blankets of welded tuff with associated fine- to coarse-grained ash and pumice beds. Include rocks of upper part of the Yellowstone Group and Plateau Rhyolite. Mantle much of Yellowstone Plateau in northeastern part of basin.	Hydraulic conductivity generally unknown but may be high as indicated by rapid percolation of surface runoff (Whitehead, 1978, p. 10). Tightly welded in places. Specific capacities range from 2 to 60 (gal/min)/ft. An important aquifer locally.	>3,000
[QUATERN]ARY / [TERT]IARY — Pliocene, [Pleisto]cene	Basalt	QTb	Olivine basalt similar to Qb above. Included as part of the Snake River Plain aquifer. Tentatively assigned to upper part of Idaho Group. Exposures generally have well-developed soil cover.	Hydraulic conductivity slightly lower than Qb above. It decreases with increasing age.	Included with Qb above

Figure 2b Regional Geologic Map (Whitehead, 1992)

QUATERNARY AND TERTIARY	Pleistocene, Pliocene, and Miocene	Basalt	QTb	Olivine basalt similar to Qb above. Included as part of the Snake River Plain aquifer. Tentatively assigned to upper part of Idaho Group. Exposures generally have well-developed soil cover.	Hydraulic conductivity slightly lower than Qb above. It decreases with increasing age.	Included with Qb above
		Older alluvium	QTs	Subaerial and lake deposits of clay, silt, sand, and gravel. Compacted to poorly consolidated; poorly to well stratified; beds somewhat lenticular and intertongued; contains beds of ash and intercalated basalt. Widespread tuffaceous sedimentary rocks and tuff in western part of basin. Includes upper part of Idaho Group and Payette and Salt Lake Formations. In places, underlies the older basalt (Tb).	Hydraulic conductivity highly variable; generally contains water under confined conditions; yields to wells range from a few gallons per minute from clayey beds to several hundred gallons per minute from sand and gravel. Specific capacities range from 5 to 60 (gal/min)/ft. In places, an important aquifer.	>5,500
TERTIARY	Pliocene and Miocene	Older basalt	Tb	Flood-type basalt, dense, columnar jointing in many places; folded and faulted (except for the Banbury Basalt); may include some rhyolitic and andesitic rocks; some flows of vesicular olivine basalt (Banbury), interbedded locally with minor amounts of stream and lake deposits. Includes Columbia River Basalt Group or equivalent (Miocene) and the Banbury Basalt of the Idaho Group (Miocene).	Hydraulic conductivity variable, may be high in places. Locally yields small to moderate amounts of water to wells from fractures and faults; some interbedded zones of sand and silt yield good supplies of water under confined or unconfined conditions. Specific capacities range from 3 to 900 (gal/min)/ft. An important aquifer.	>7,000 (The Banbury Basalt is generally <1,000. The older basalt may be >7,000 in the western plain)
	Pliocene to Oligocene	Older silicic volcanic rocks	Tsv	Rhyolitic, latitic, and andesitic rocks, massive and dense; jointing ranges from platy to columnar; occur as thick flows and blankets of welded tuff with associated fine- to coarse-grained ash and pumice beds (commonly reworked by flowing water) and as clay, silt, sand, and gravel; locally folded, tilted, and faulted. Include Idavada Volcanics.	Hydraulic conductivity highly variable. Joints and fault zones in flows and welded tuff and interstices in coarse-grained ash, sand, and gravel yield small to moderate, and rarely large, amounts of water to wells. Commonly contain thermal water under confined conditions. Specific capacities range from 1 to >2,000 (gal/min)/ft and are generally <400 (gal/min)/ft. An important aquifer.	>3,000
	Eocene and Paleocene	Volcanic rocks, undifferentiated	Tcv	Extrusive rocks range in composition from rhyolite to basalt; include welded tuff, pyroclastic, tuffaceous, and other clastic and sedimentary rocks. Chiefly Challis Volcanics; mainly crop out in mountains and foothills north of the eastern plain; may include some intrusive rocks.	Hydraulic conductivity generally low. Little information available on yields to wells. May be an important aquifer locally for domestic and stock use.	>5,000
TERTIARY AND CRETACEOUS		Sedimentary rocks, undifferentiated	TKs	Undifferentiated shale, siltstone, sandstone, and freshwater limestone of Tertiary and Cretaceous age. Younger rocks composed chiefly of breccia, conglomerate, and sandstone. Exposed in eastern part of basin. May include a few small outcrops of Jurassic age.	Hydraulic conductivity generally low. Little information available on yields to wells; weathered zones and fractures may yield moderate quantities of water to wells; large yields may be obtained in places. May be an important aquifer locally.	>10,000
		Intrusive rocks	TKi	Chiefly granitic rocks of the Idaho batholith; include older and younger crystalline rocks; crop out in a few places south of Snake River in Idaho and northern Nevada.	Hydraulic conductivity generally low. Faults, fractures, and weathered zones may yield small quantities of water to wells. Not an important aquifer.	Unknown
PRE-CRETACEOUS		Pre-Cretaceous rocks, undifferentiated	pK	Well-indurated sedimentary and metamorphic rocks that have been folded, faulted, and intruded by igneous rocks. Crop out in mountainous areas. Include extrusive rocks of Permian and Triassic age in western part of basin. May include Cretaceous or younger sedimentary rocks.	Hydraulic conductivity low. Faults, fractures, and weathered zones may yield small quantities of water to wells. Little information available on yields to wells. Not an important aquifer.	>12,000

Figure 2c Regional Geologic Map (Whitehead, 1992)

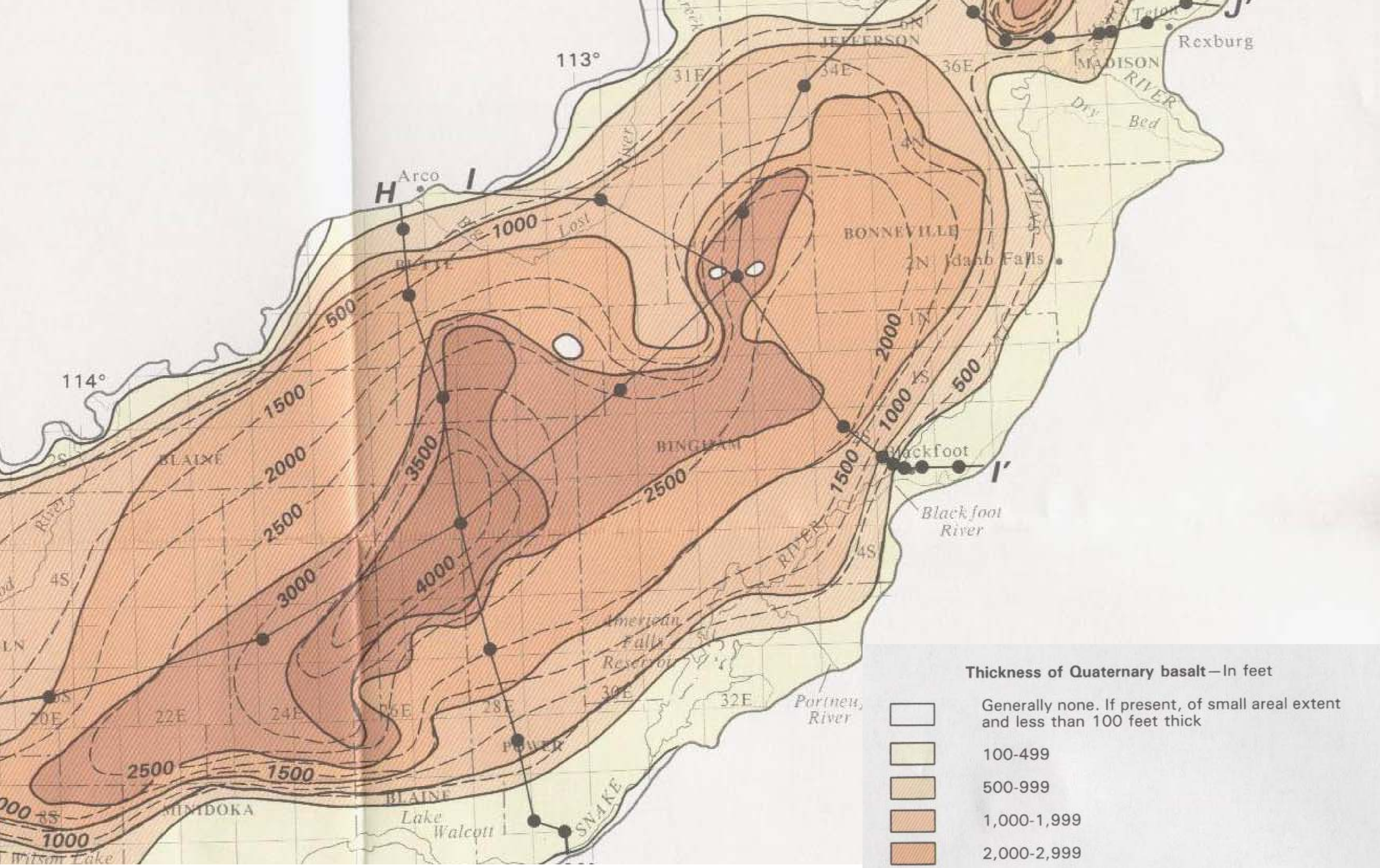


Figure 3 Thickness Map of Quaternary Basalt (Whitehead, 1992)

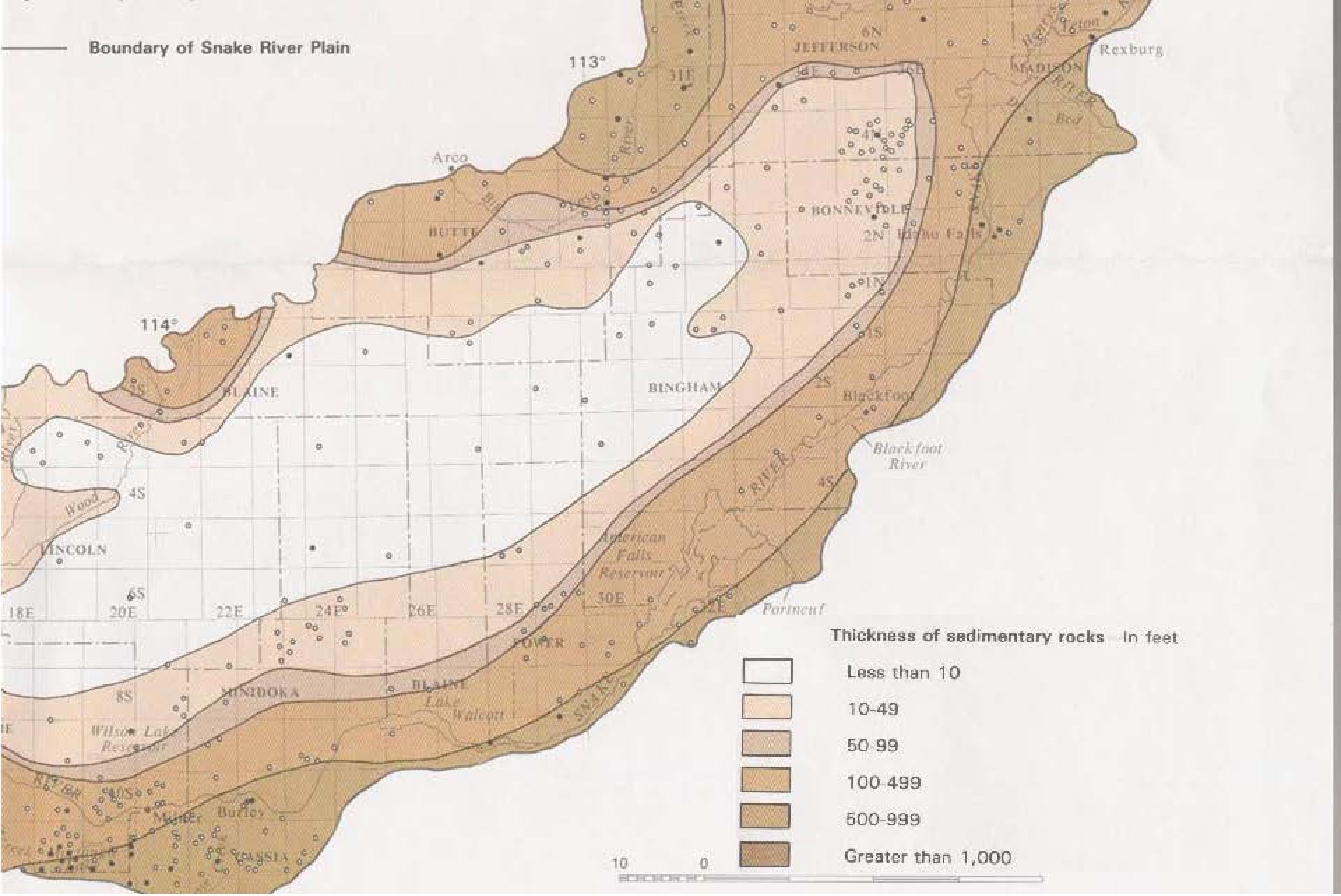


Figure 4 Thickness Map of Sediment (Whitehead, 1992)

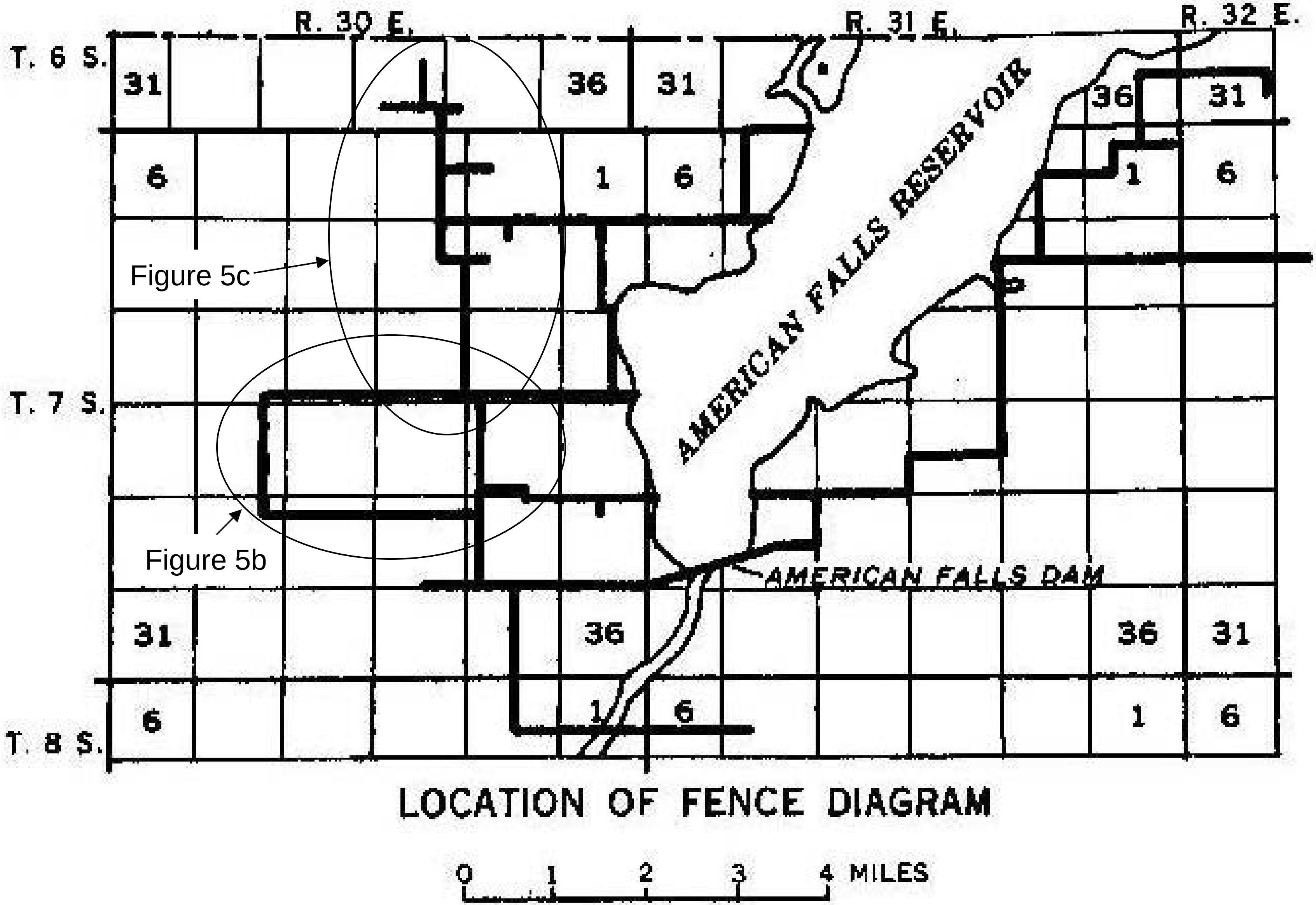


Figure 5a Fence Diagram – Location Map (Mundorff, 1967)

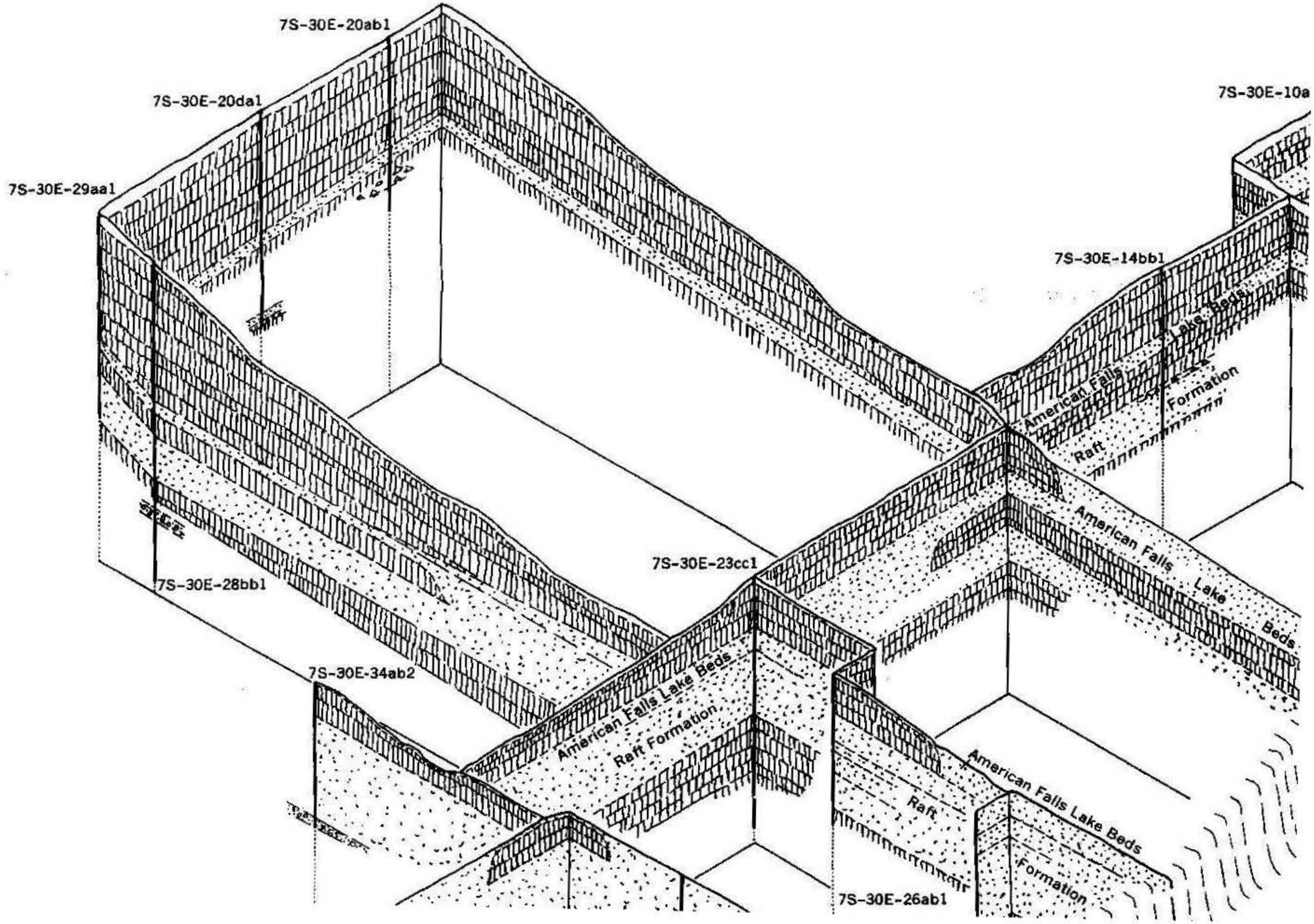


Figure 5b Fence Diagram – West Portion (Mundorff, 1967)

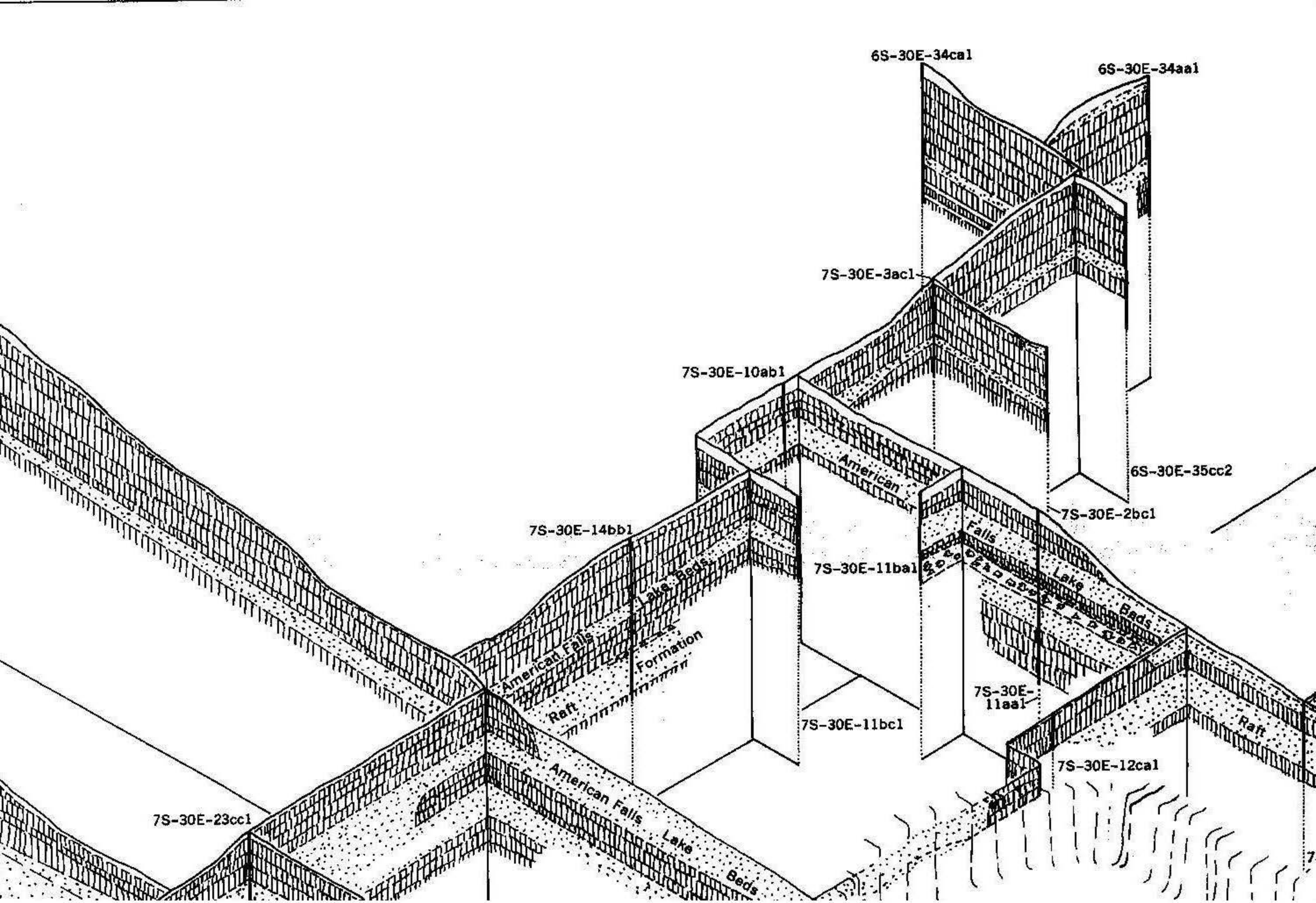


Figure 5c Fence Diagram – Northwest Portion (Mundorff, 1967)

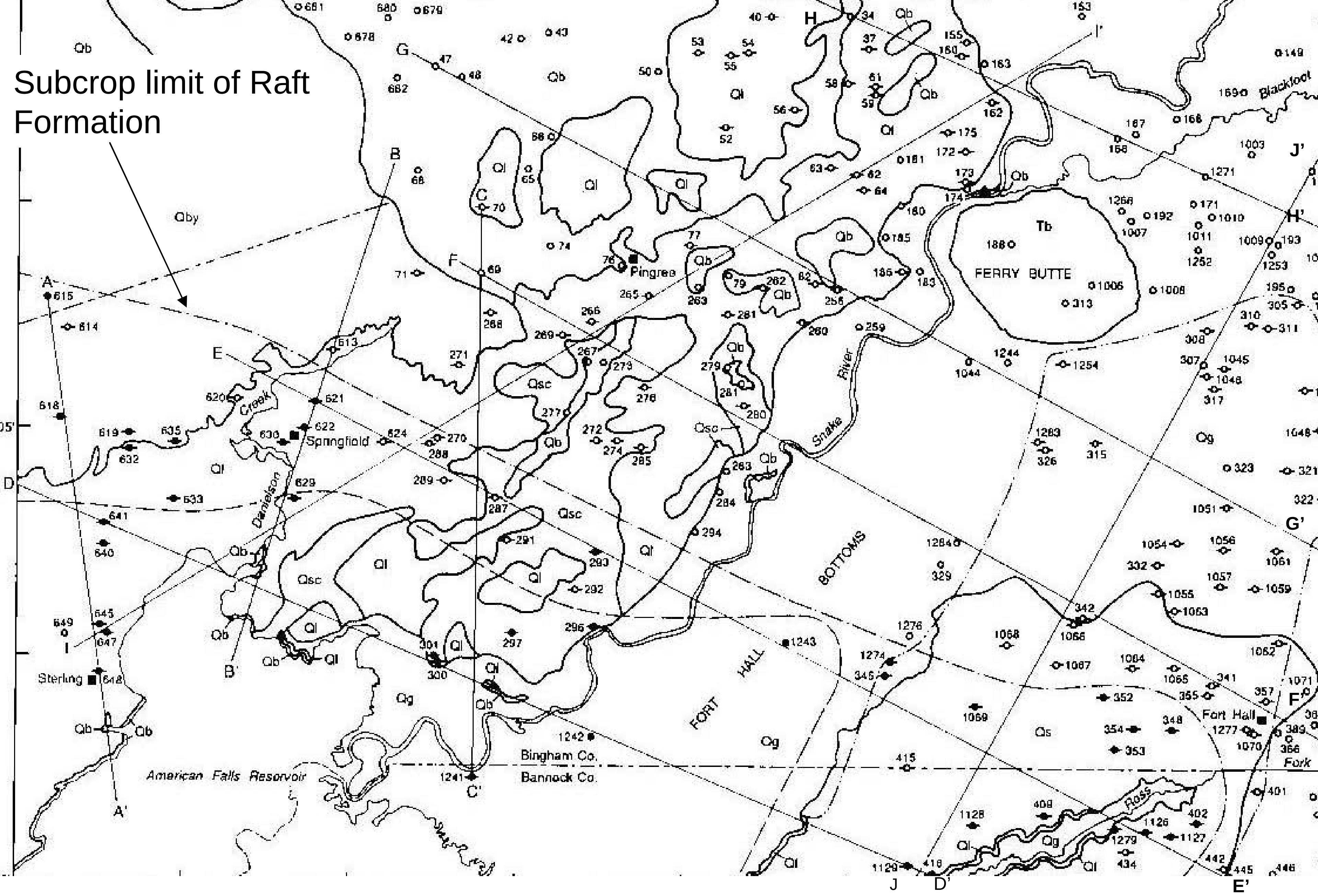
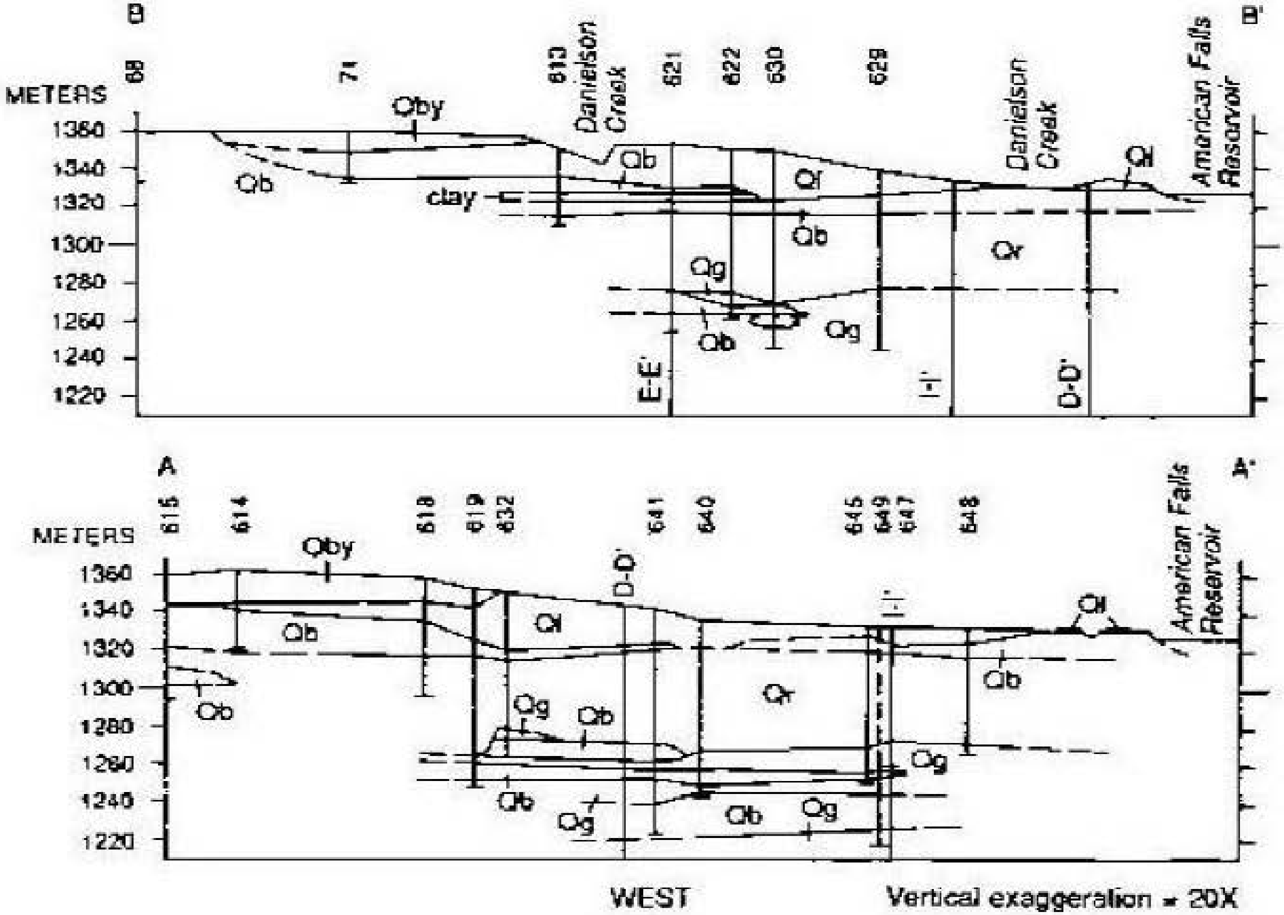
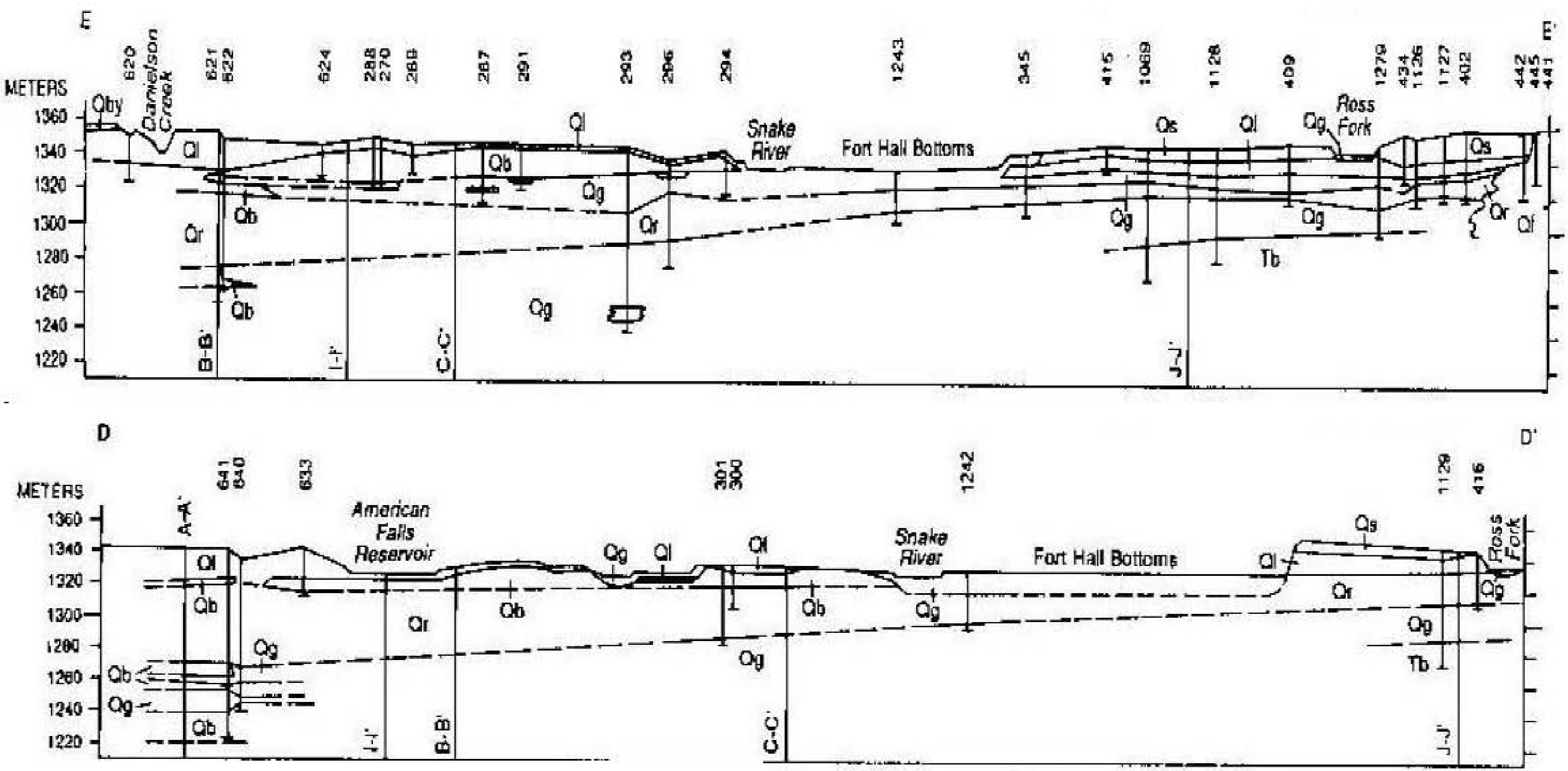


Figure 6 Geologic Map of Area Northeast of American Falls Reservoir Showing Locations of Cross Sections (Houser, 1992)



Qf	Alluvial fan deposits (Holocene and Pleistocene)
Qg	Snake River gravel deposits (Holocene and Pleistocene)
Qsc	Scabland deposits (upper Pleistocene)
Qs	Sand (upper Pleistocene)
Ql	American Falls Lake Beds (upper Pleistocene)
Qby	Young basalt (upper Pleistocene)
Qb	Basalt (Pleistocene)
Qr	Raft Formation (middle and lower? Pleistocene) - cross sections only
Tb	Basalt of Buckskin Basin (Pliocene)
Tvu	Undifferentiated volcanic rocks (Miocene)

Figure 7a Geologic Cross Sections A-A' and B-B' (Houser, 1992)



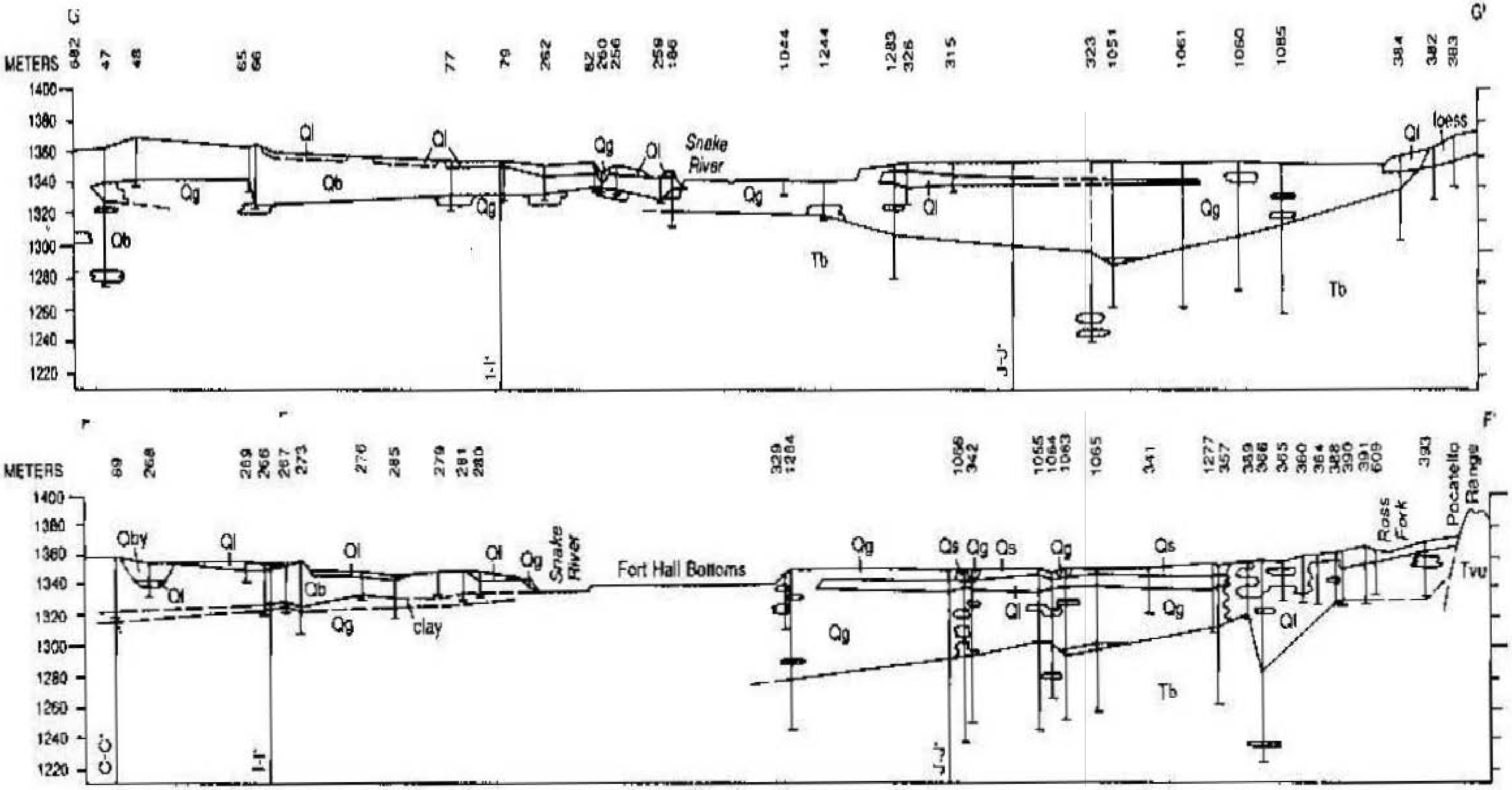
SOUTHWEST

Vertical exaggeration = 20X

LIST OF MAP UNITS

Qf	Alluvial fan deposits (Holocene and Pleistocene)
Qg	Snake River gravel deposits (Holocene and Pleistocene)
Qsc	Scabland deposits (upper Pleistocene)
Qs	Sand (upper Pleistocene)
Ql	American Falls Lake Beds (upper Pleistocene)
Qby	Young basalt (upper Pleistocene)
Qb	Basalt (Pleistocene)
Qr	Raft Formation (middle and lower? Pleistocene) - cross sections only
Tb	Basalt of Buckskin Basin (Pliocene)
Tvu	Undifferentiated volcanic rocks (Miocene)

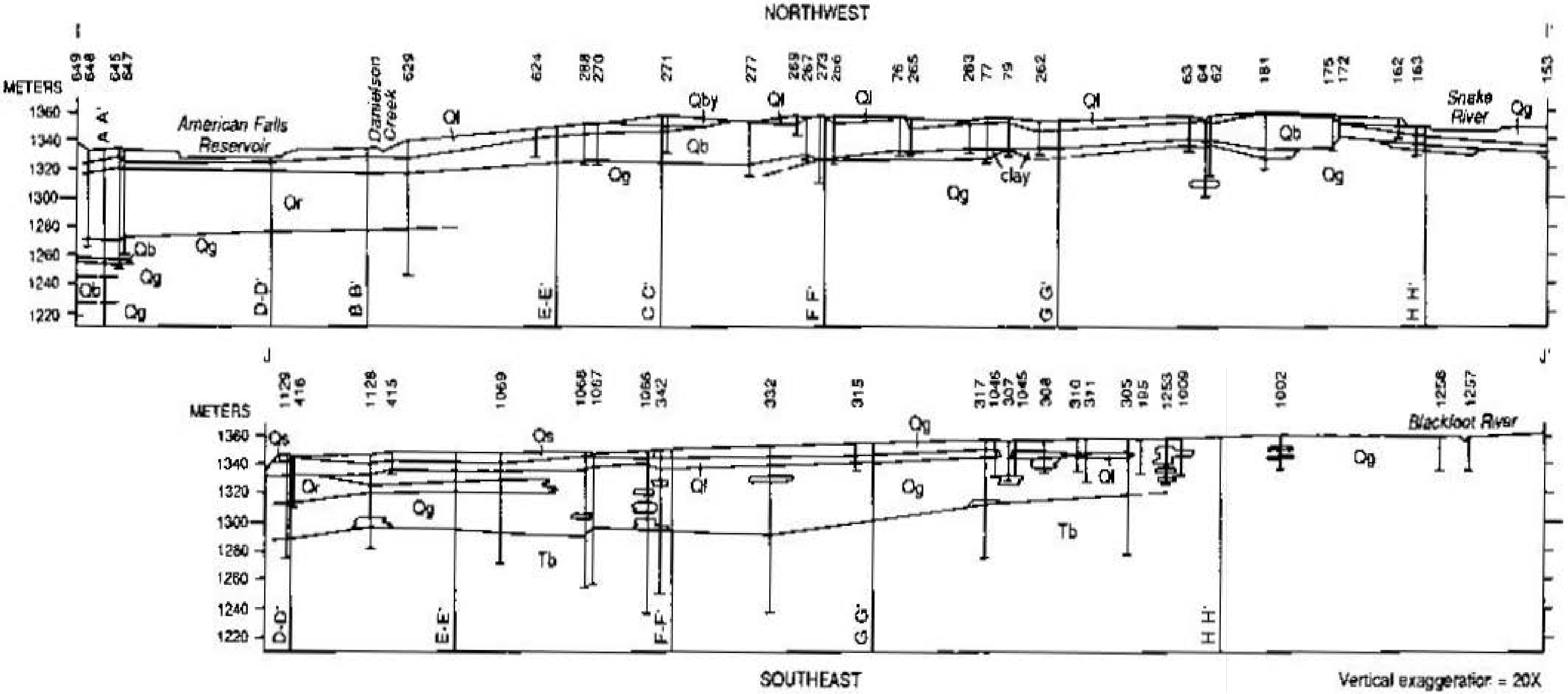
Figure 7b Geologic Cross Sections D-D' and E-E' (Houser, 1992)



LIST OF MAP UNITS

Qf	Alluvial fan deposits (Holocene and Pleistocene)
Qg	Snake River gravel deposits (Holocene and Pleistocene)
Qsc	Scabland deposits (upper Pleistocene)
Qs	Sand (upper Pleistocene)
Ql	American Falls Lake Beds (upper Pleistocene)
Qby	Young basalt (upper Pleistocene)
Qb	Basalt (Pleistocene)
Qr	Raft Formation (middle and lower? Pleistocene) - cross sections only
Tb	Basalt of Buckskin Basin (Pliocene)
Tvu	Undifferentiated volcanic rocks (Miocene)

Figure 7c Geologic Cross Sections F-F' and G-G' (Houser, 1992)



LIST OF MAP UNITS

Qf	Alluvial fan deposits (Holocene and Pleistocene)
Qg	Snake River gravel deposits (Holocene and Pleistocene)
Qsc	Scabland deposits (upper Pleistocene)
Qs	Sand (upper Pleistocene)
Ql	American Falls Lake Beds (upper Pleistocene)
Qby	Young basalt (upper Pleistocene)
Qb	Basalt (Pleistocene)
Qr	Raft Formation (middle and lower? Pleistocene) - cross sections only
Tb	Basalt of Buckskin Basin (Pliocene)
Tvu	Undifferentiated volcanic rocks (Miocene)

Figure 7d Geologic Cross Sections I-I' and J-J' (Houser, 1992)

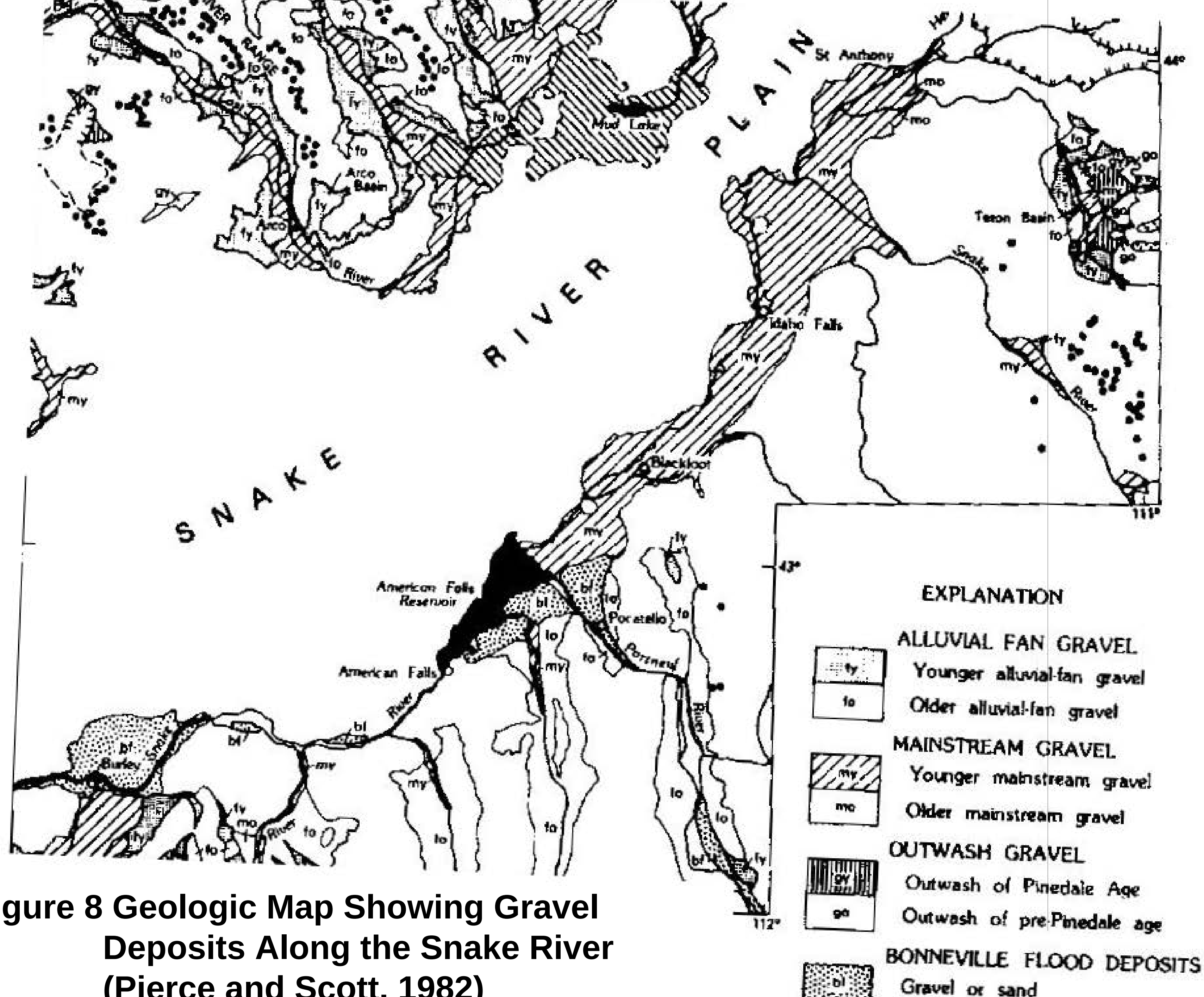
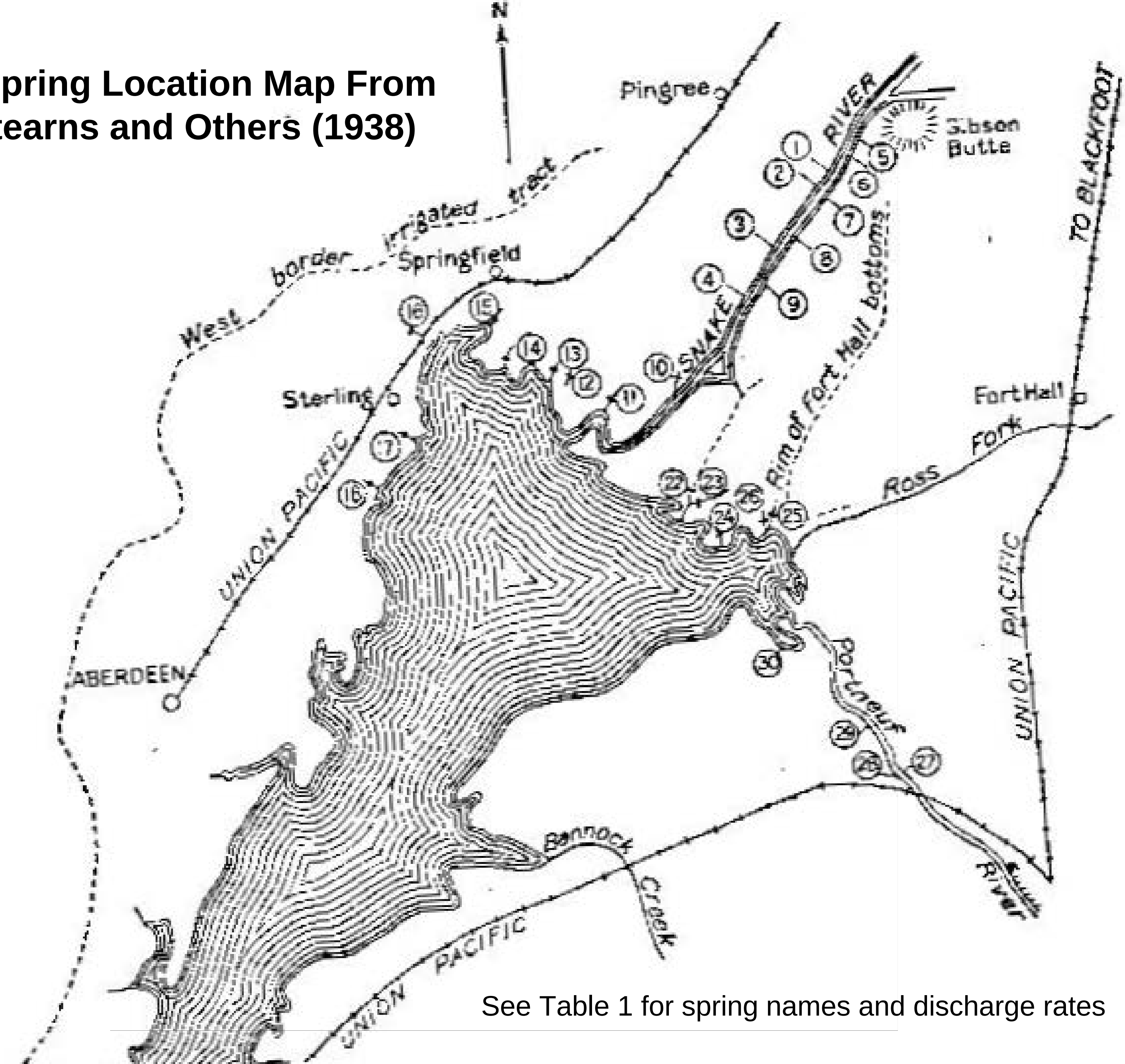


Figure 8 Geologic Map Showing Gravel Deposits Along the Snake River (Pierce and Scott, 1982)

Figure 9 Spring Location Map From Stearns and Others (1938)



See Table 1 for spring names and discharge rates

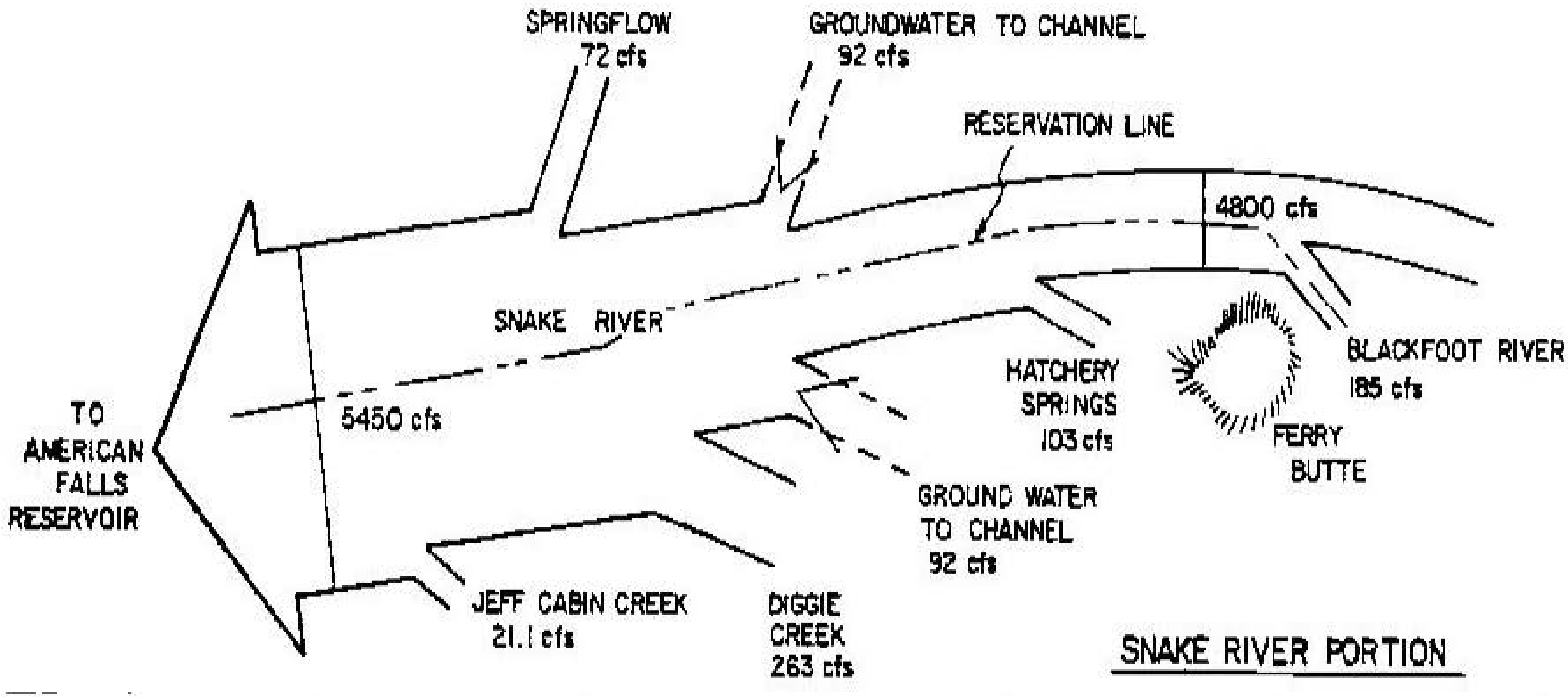


Figure 10A Fort Hall Bottoms Water Budget –Snake River Portion (Balmer and Noble, 1979)

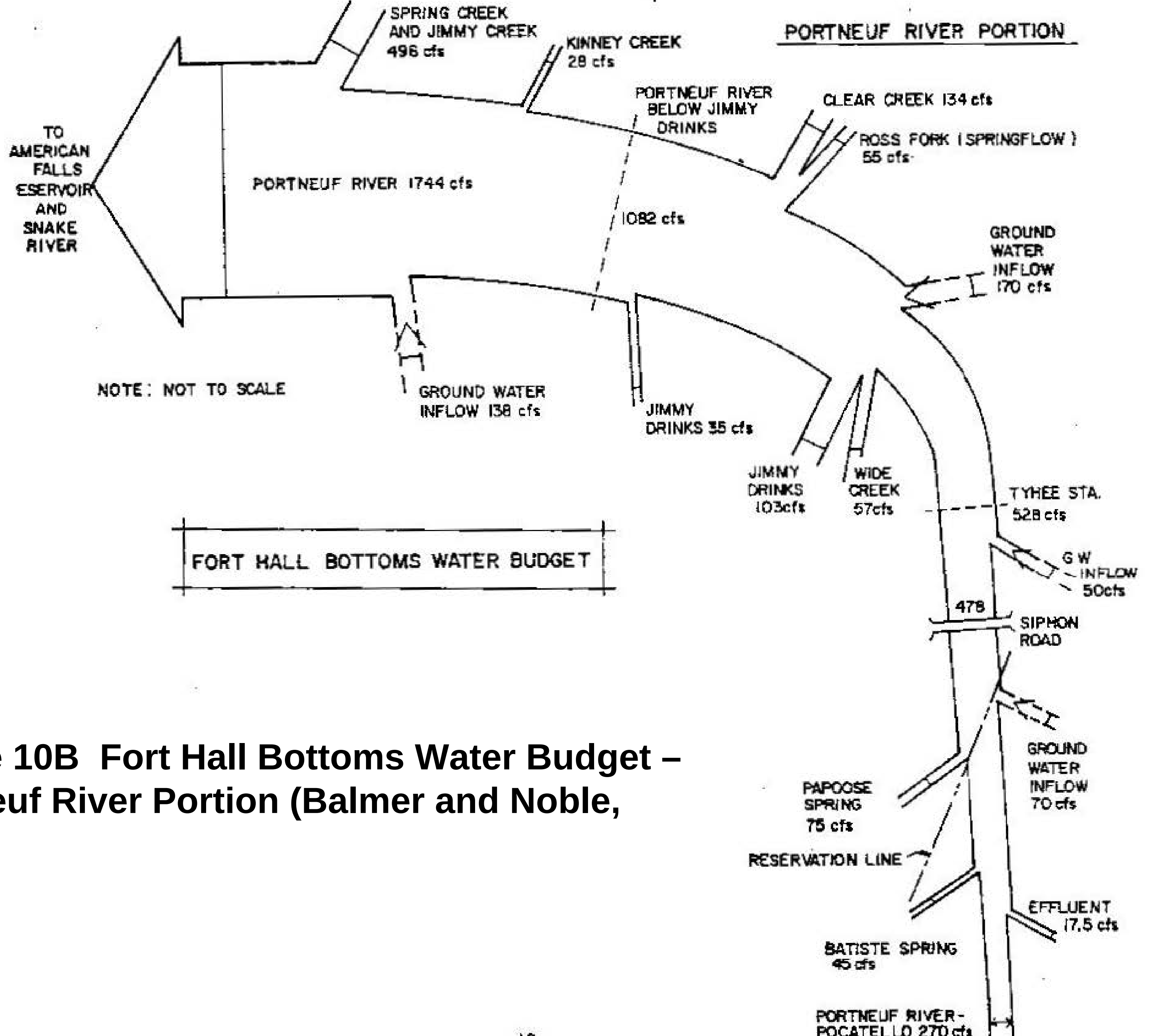


Figure 10B Fort Hall Bottoms Water Budget – Portneuf River Portion (Balmer and Noble, 1979)

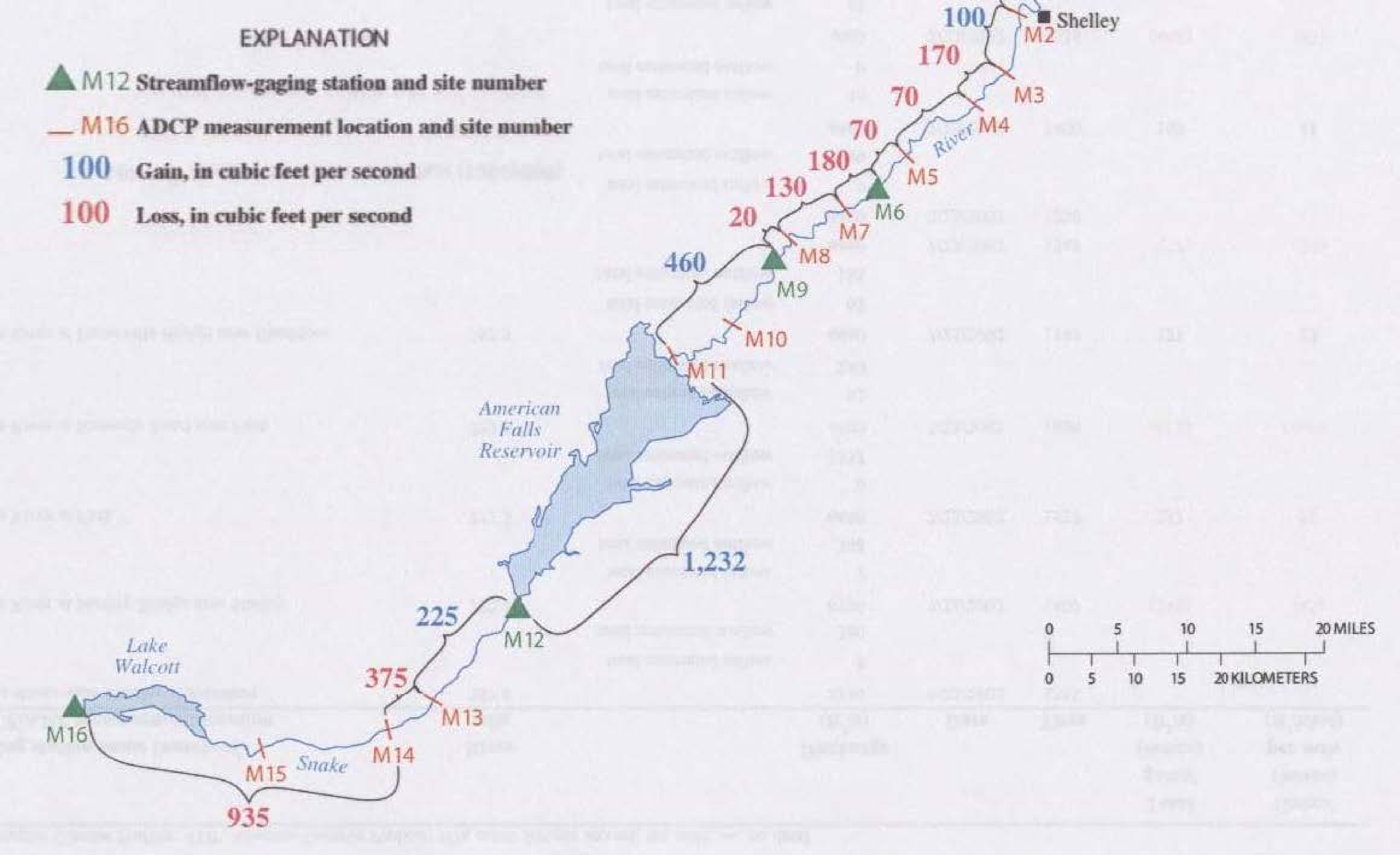


Figure 11 Seepage Run Results for April 2002 (Hortness and Vidmar, 2003)

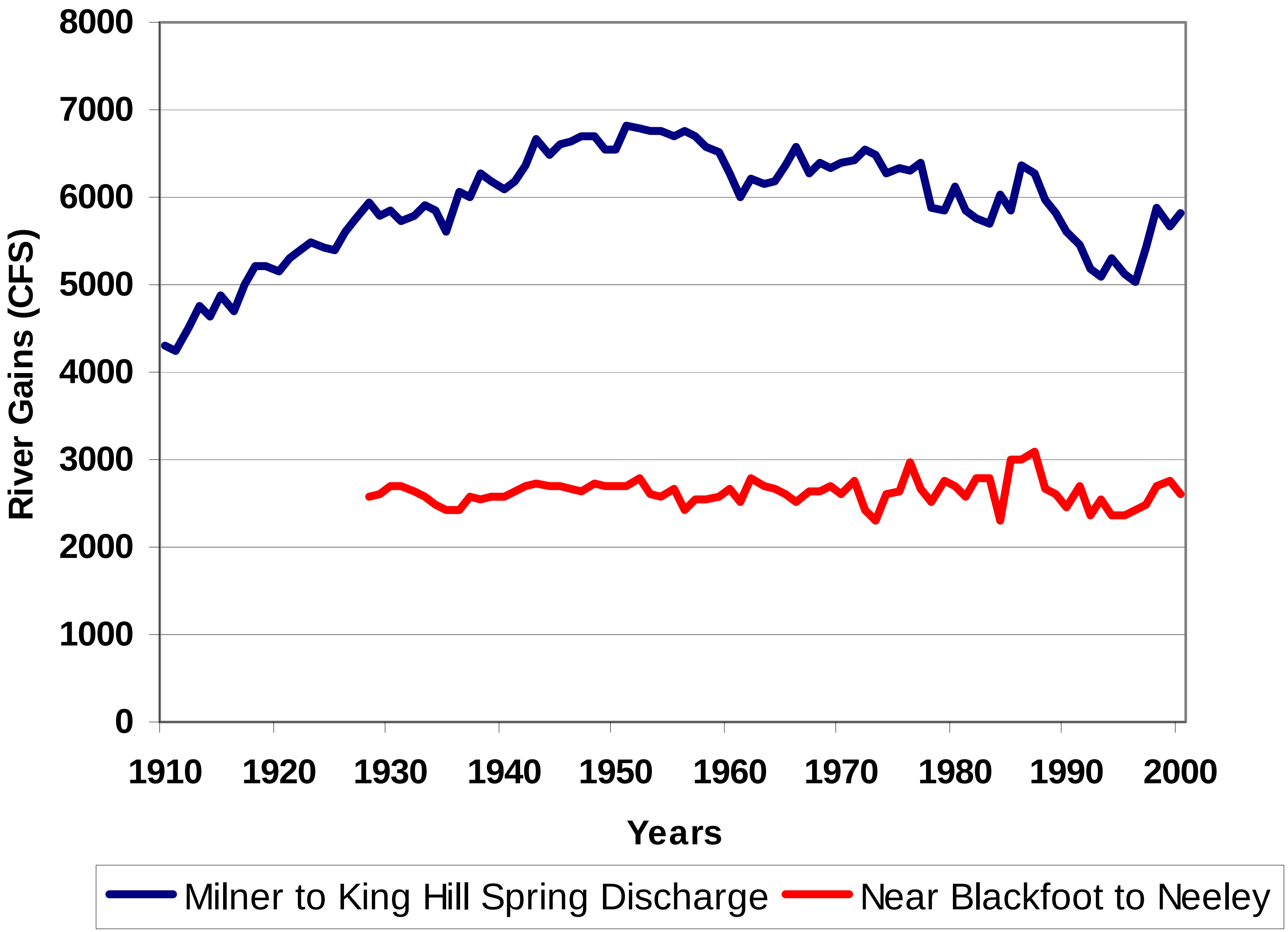


Figure 12 Average Annual River Gains from Near Blackfoot to Neeley Calculated by the IDWR Reach Gain/Loss Program (from Cosgrove and others 2006)

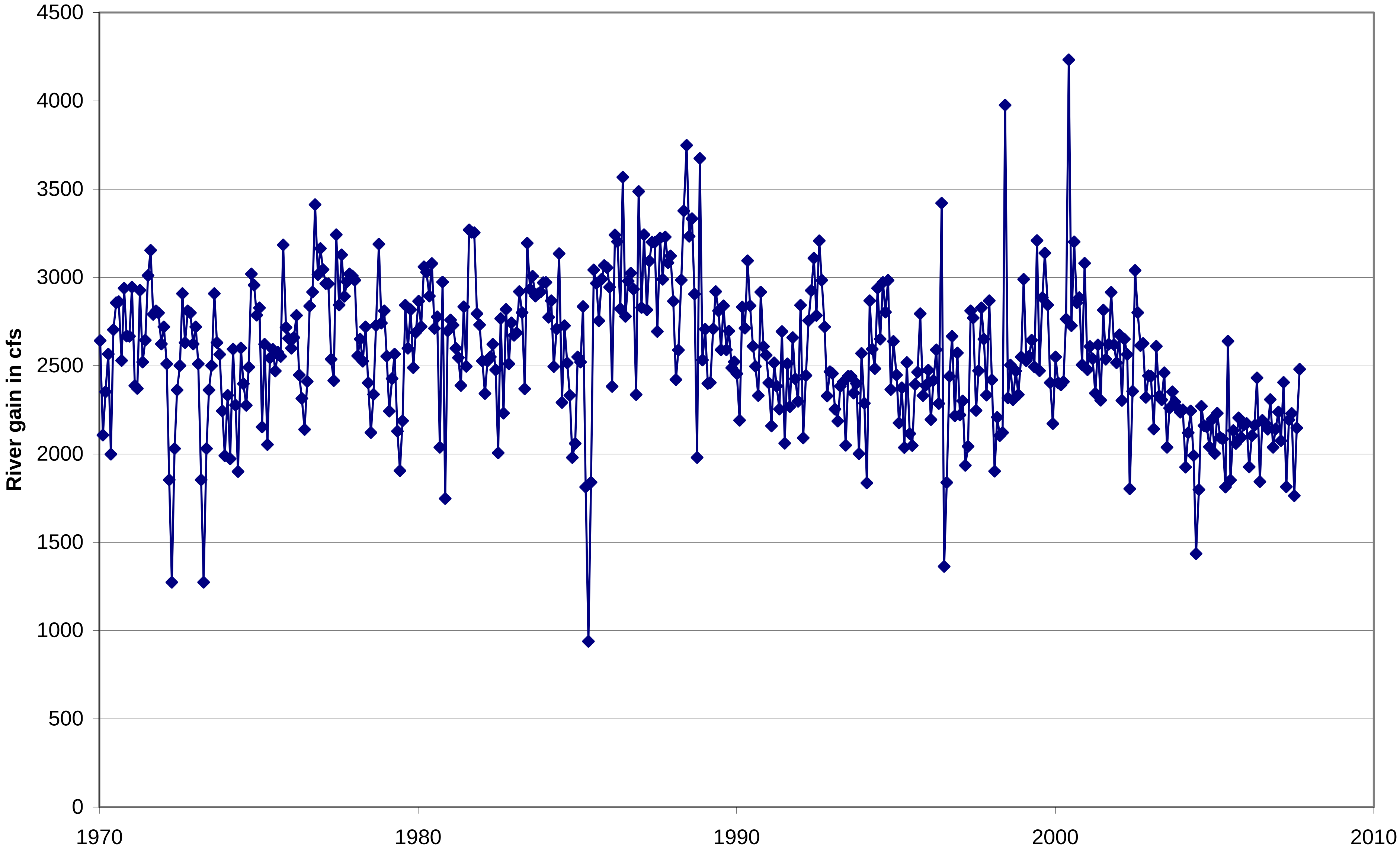


Figure 13 Average Monthly Calculated Snake River Gain -- Near Blackfoot to Neeley Reach

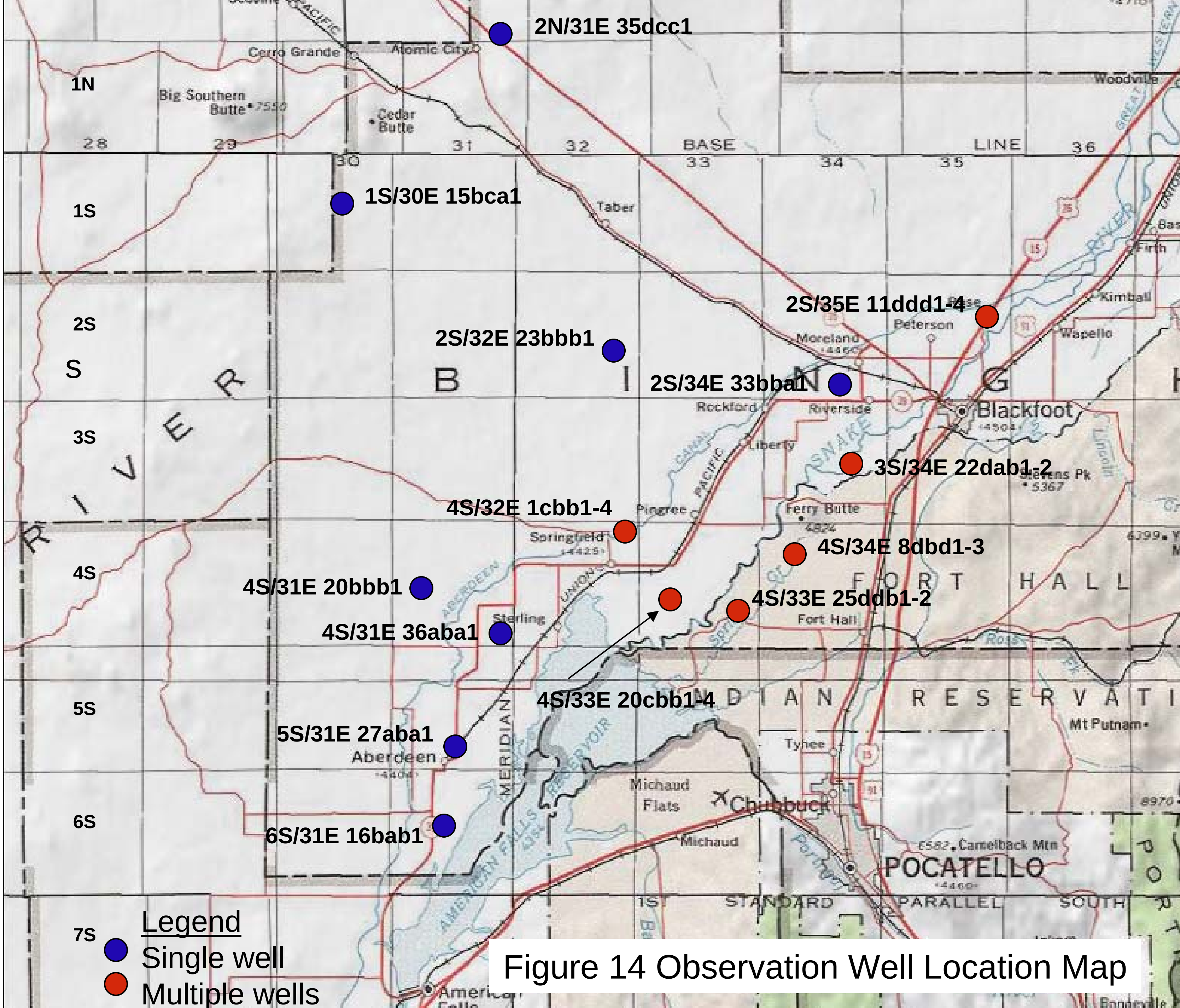


Figure 14 Observation Well Location Map

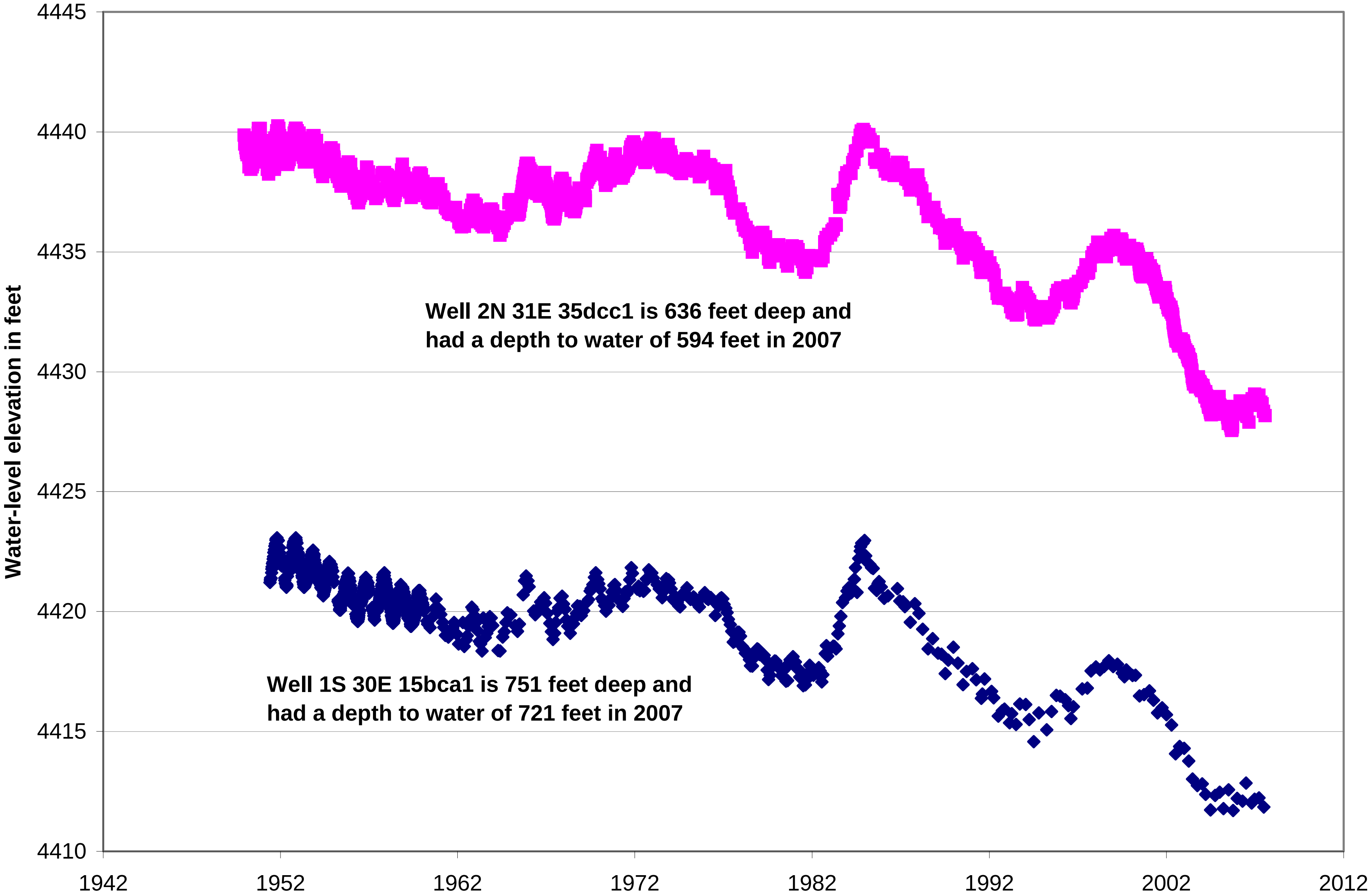


Figure 15 Hydrographs for Wells 2N 31E 35dcc1 and 1S 30E 15bca1

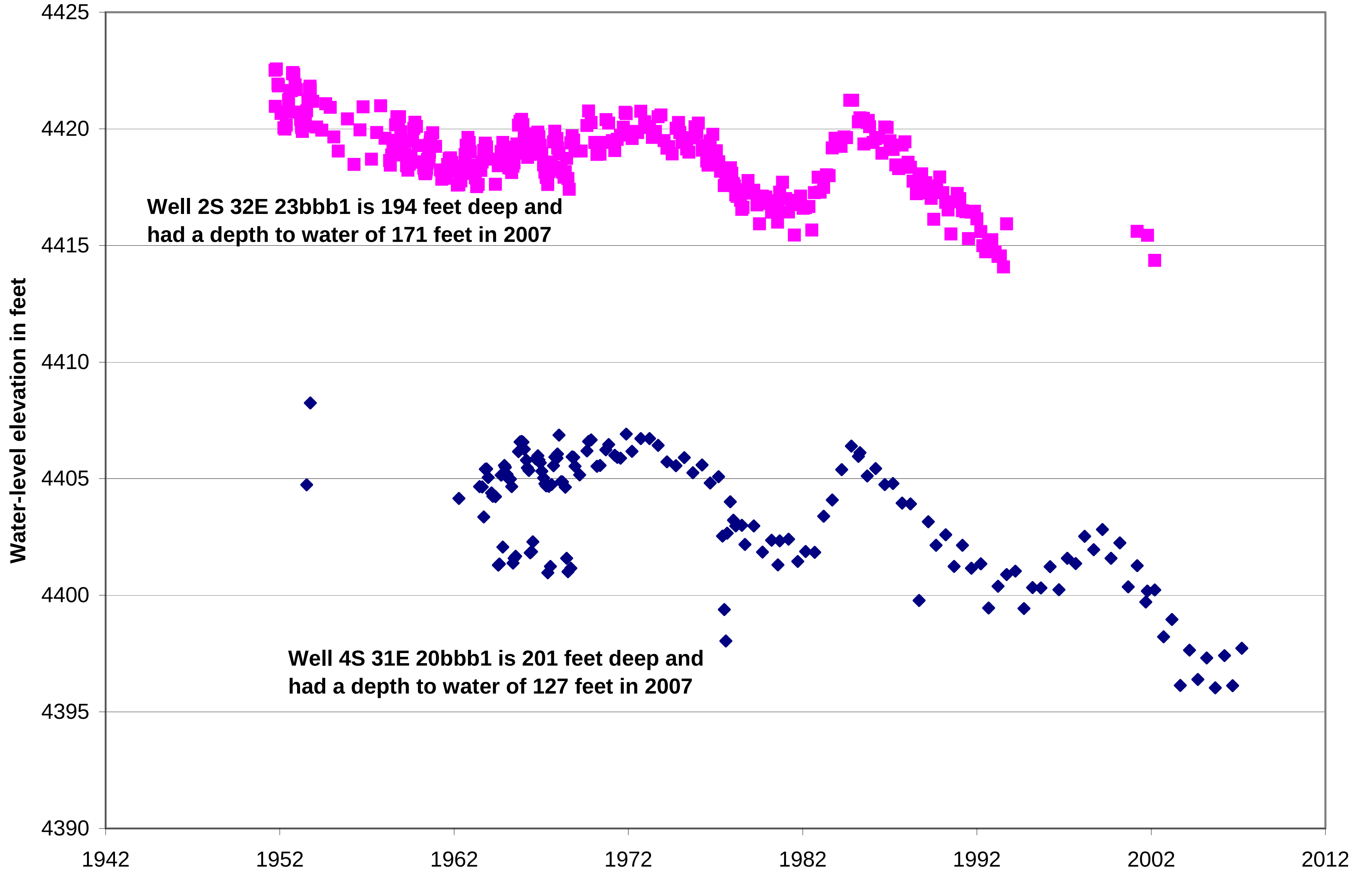


Figure 16 Hydrographs for Wells 2S 32E 23bbb1 and 4S 31E 20bbb1

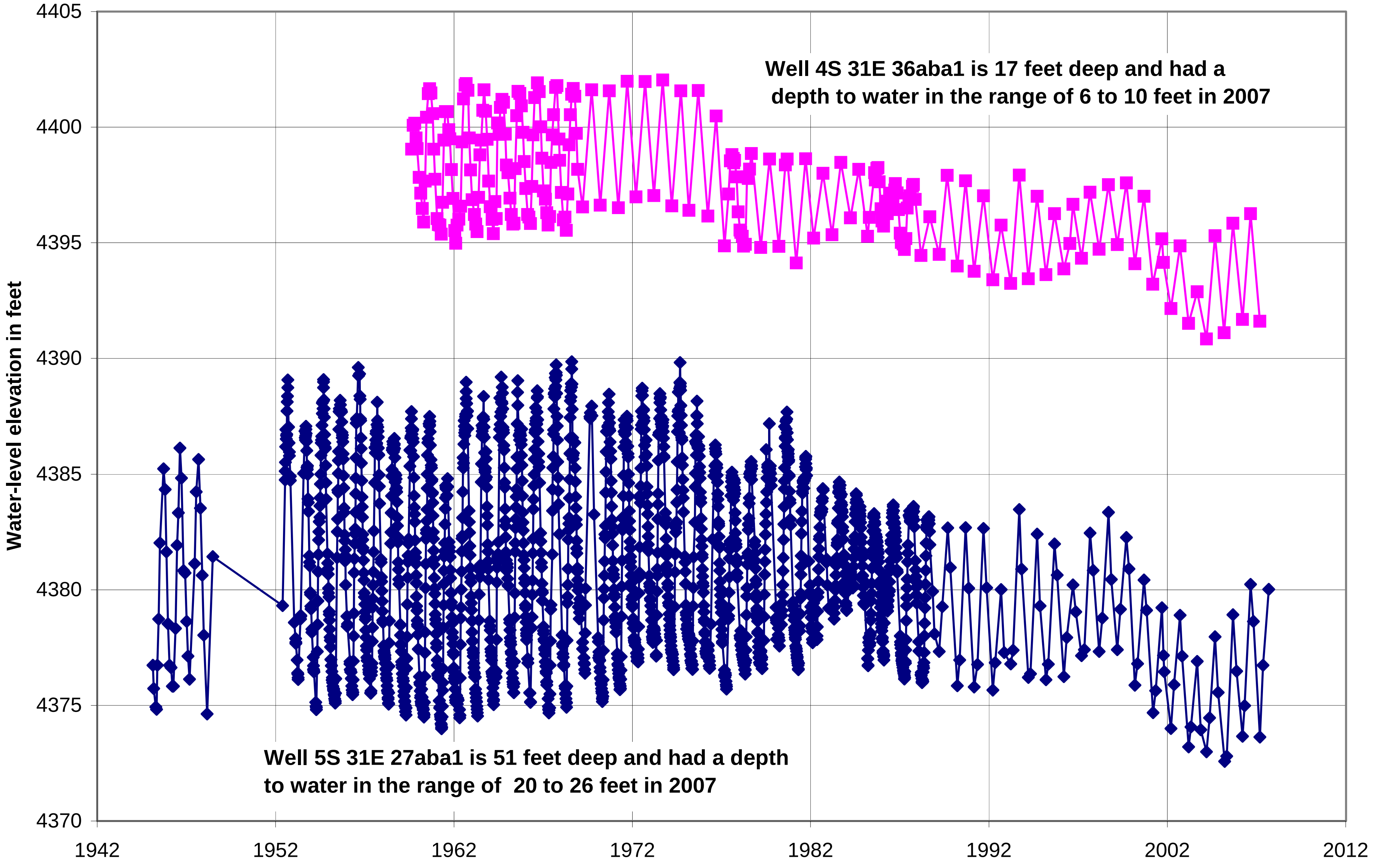


Figure 17 Hydrographs for Wells 4S 31E 36aba1 and 5S 31E 27aba1

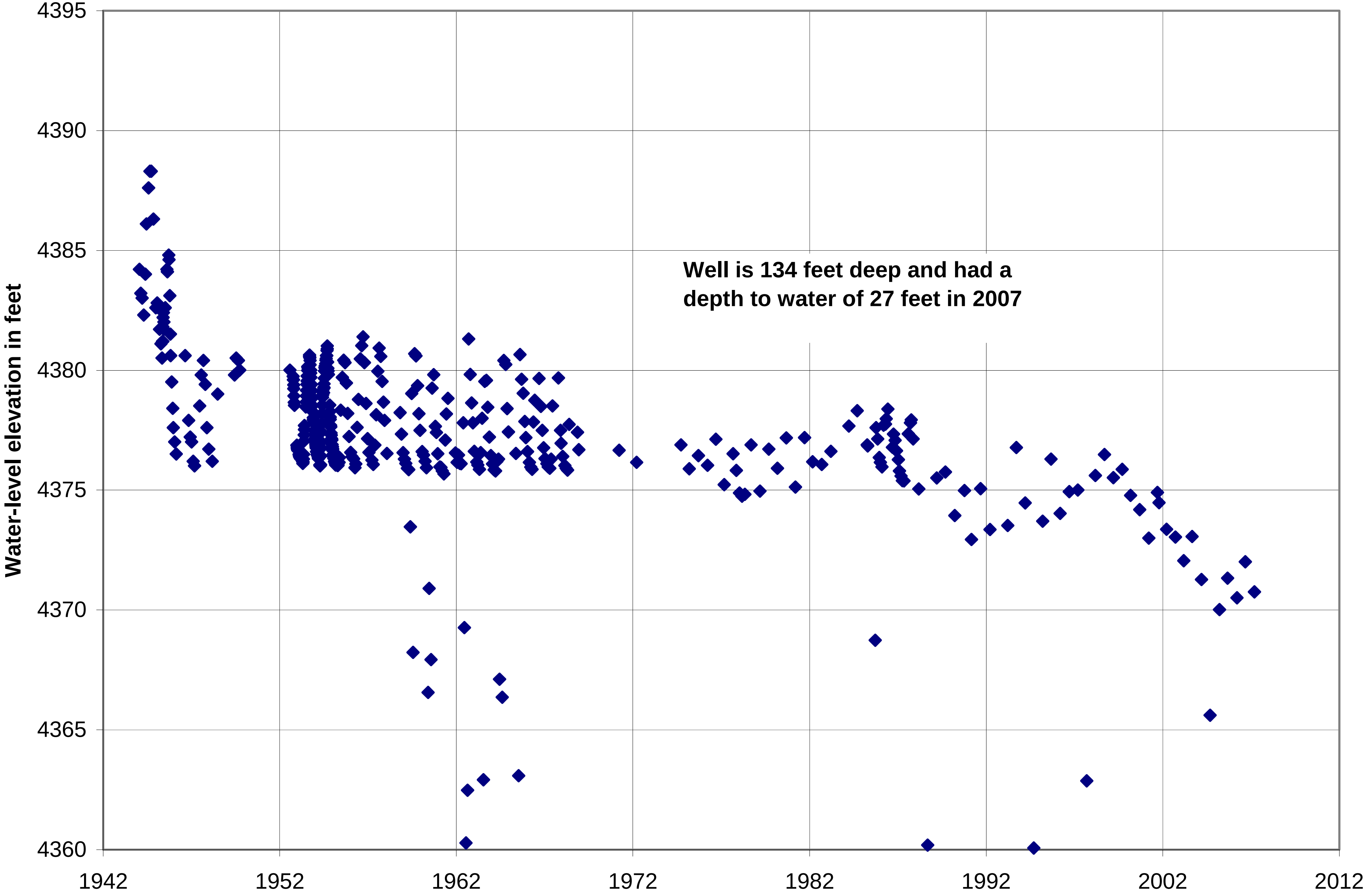


Figure 18 Hydrograph for Well 6S 31E 16bab1

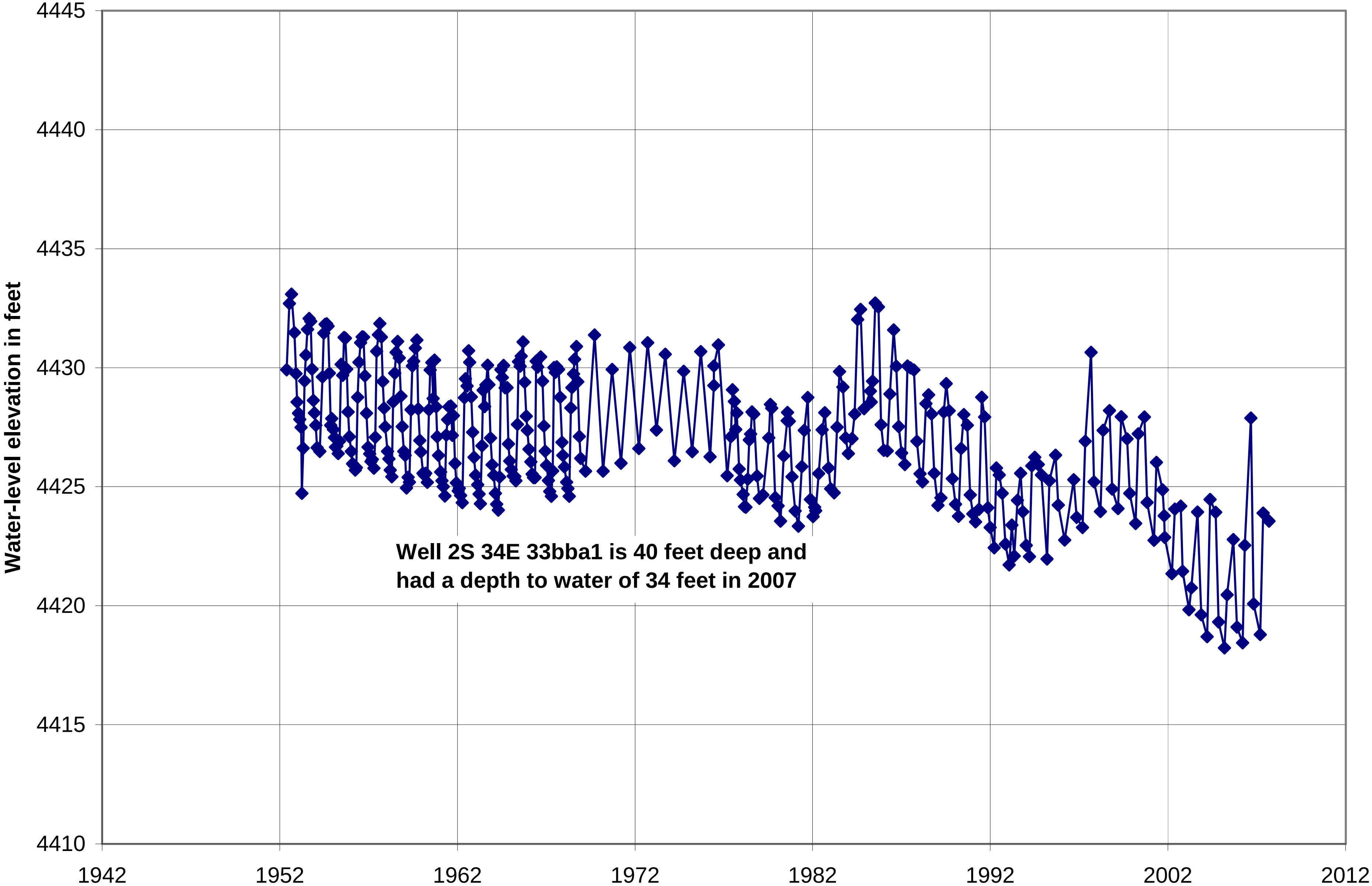


Figure 19 Hydrograph for Well 2S 34E 33bba1

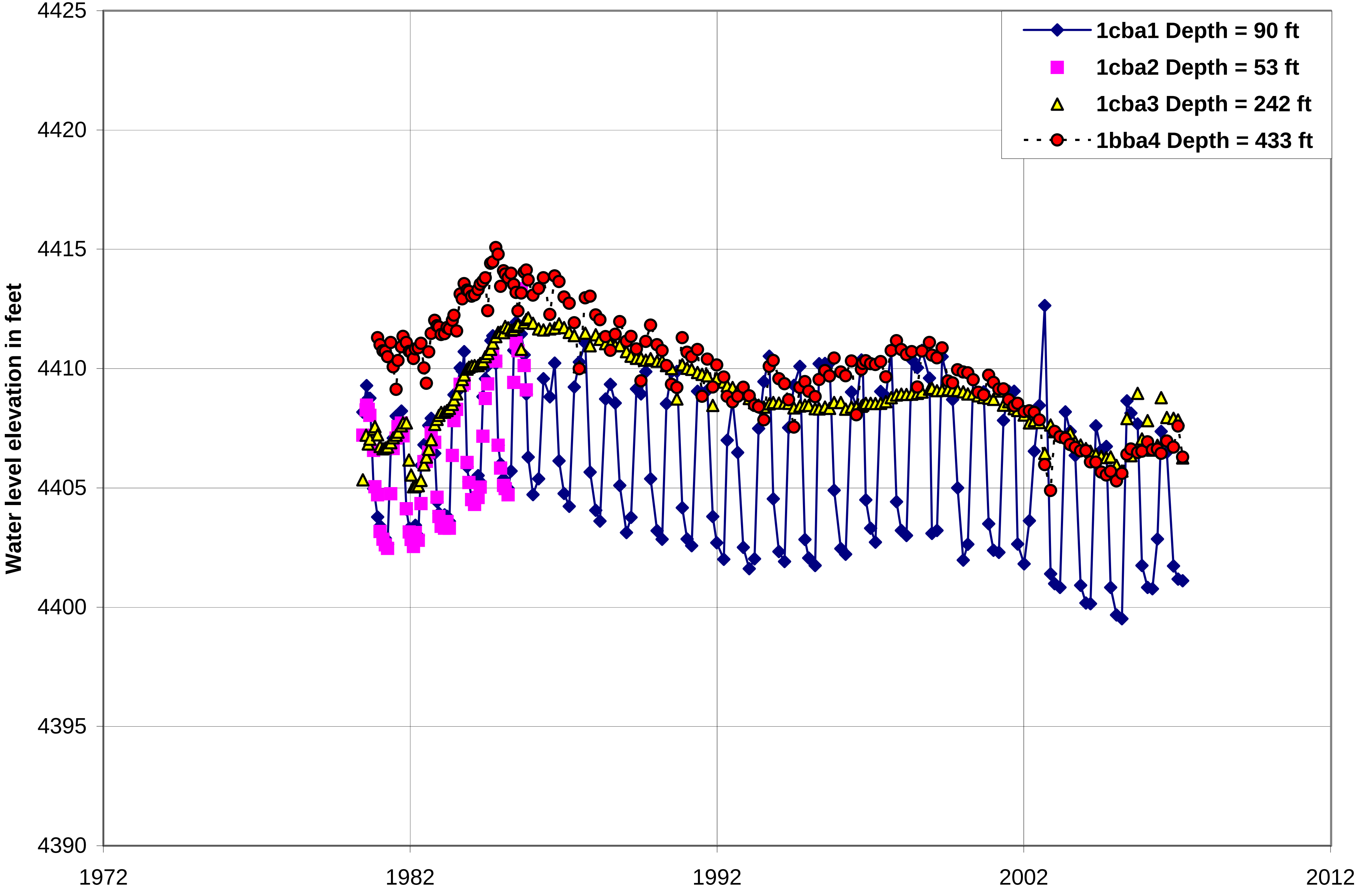


Figure 20 Hydrographs for Wells 4S 32E 1cba1-4

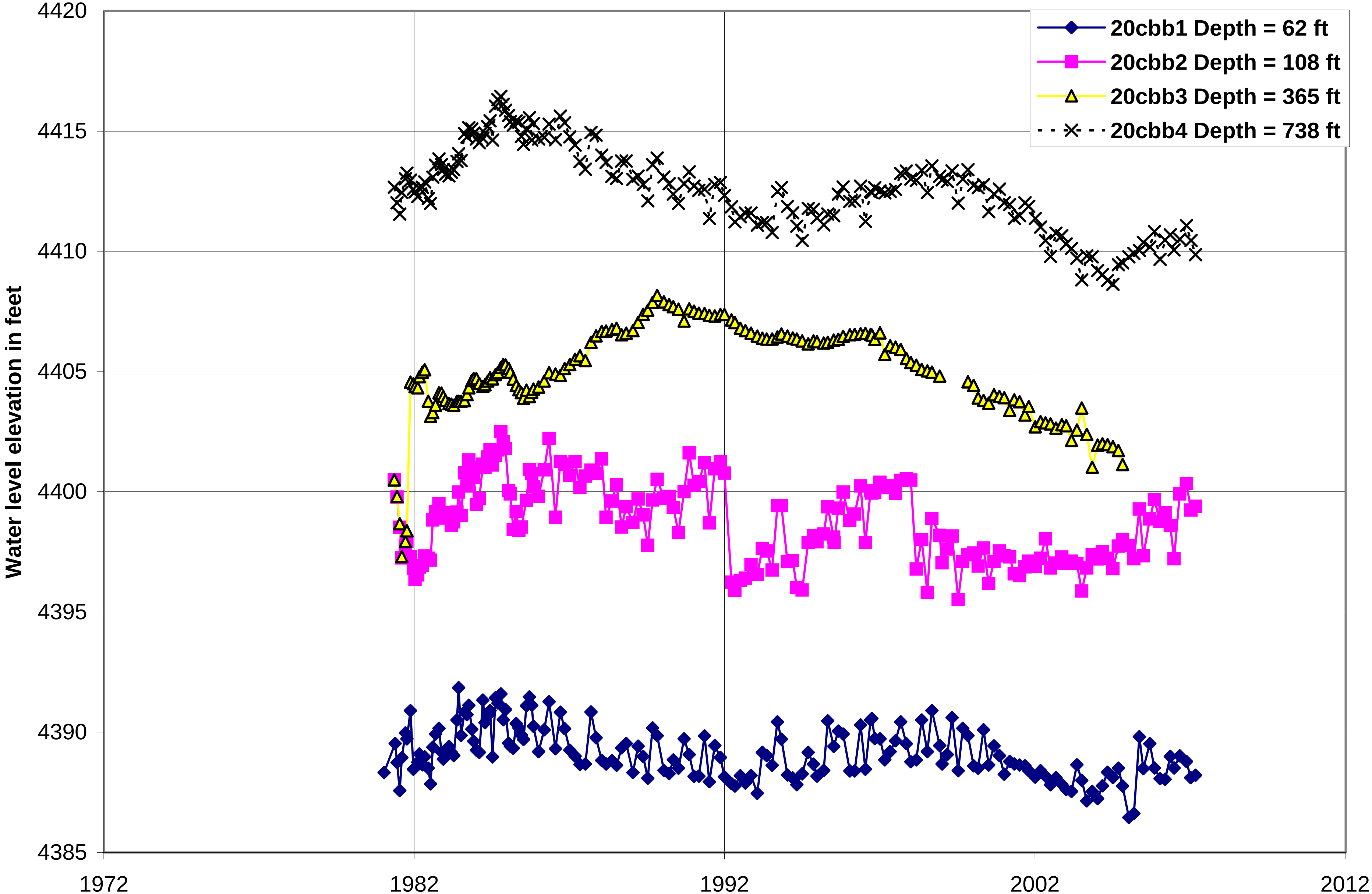


Figure 21 Hydrographs for Wells 4S 33E 20cbb1-4

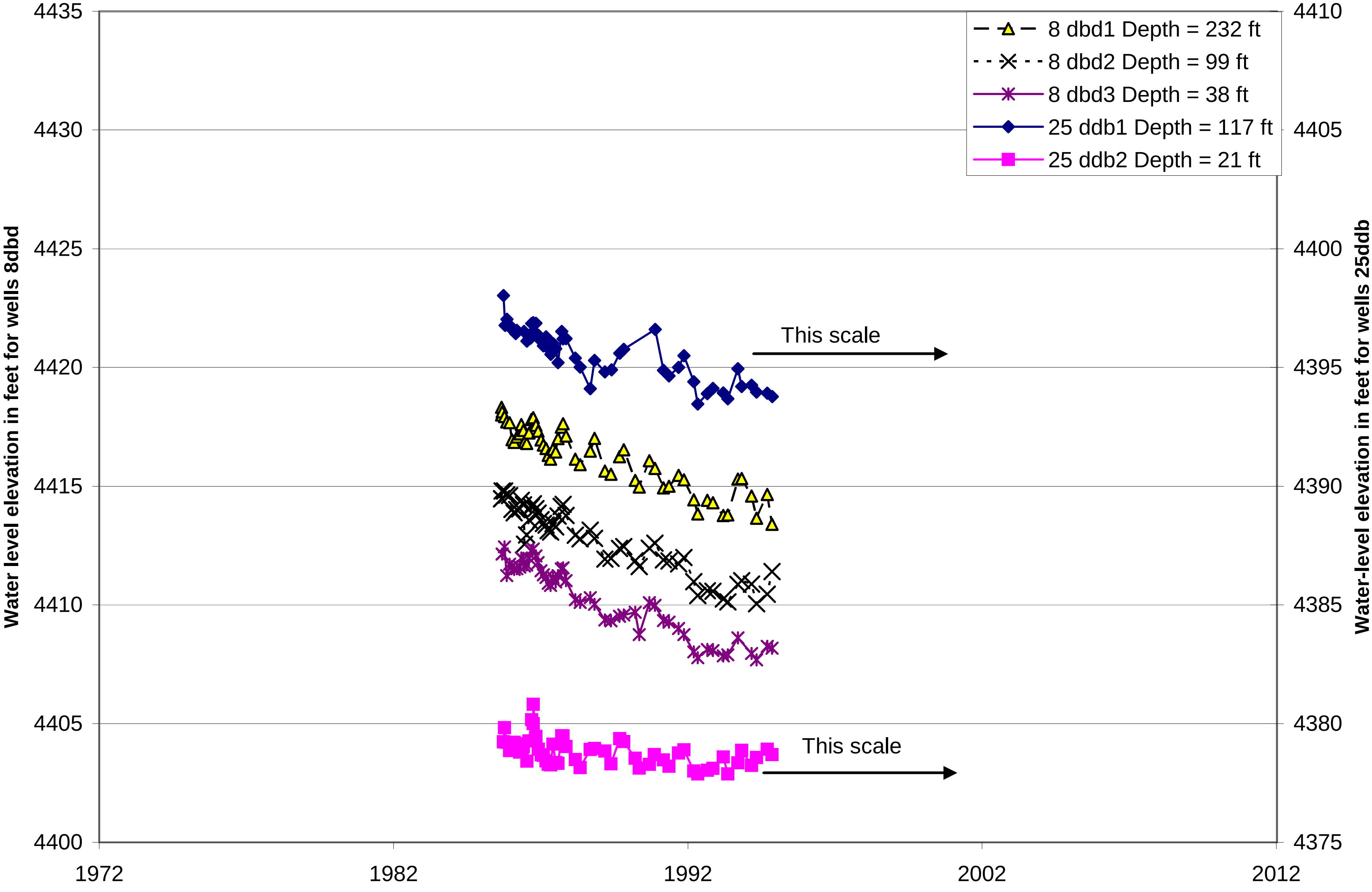


Figure 22 Hydrographs for Wells 4S 33E 25ddb1-2 and 4S 34E 8dbd1-3

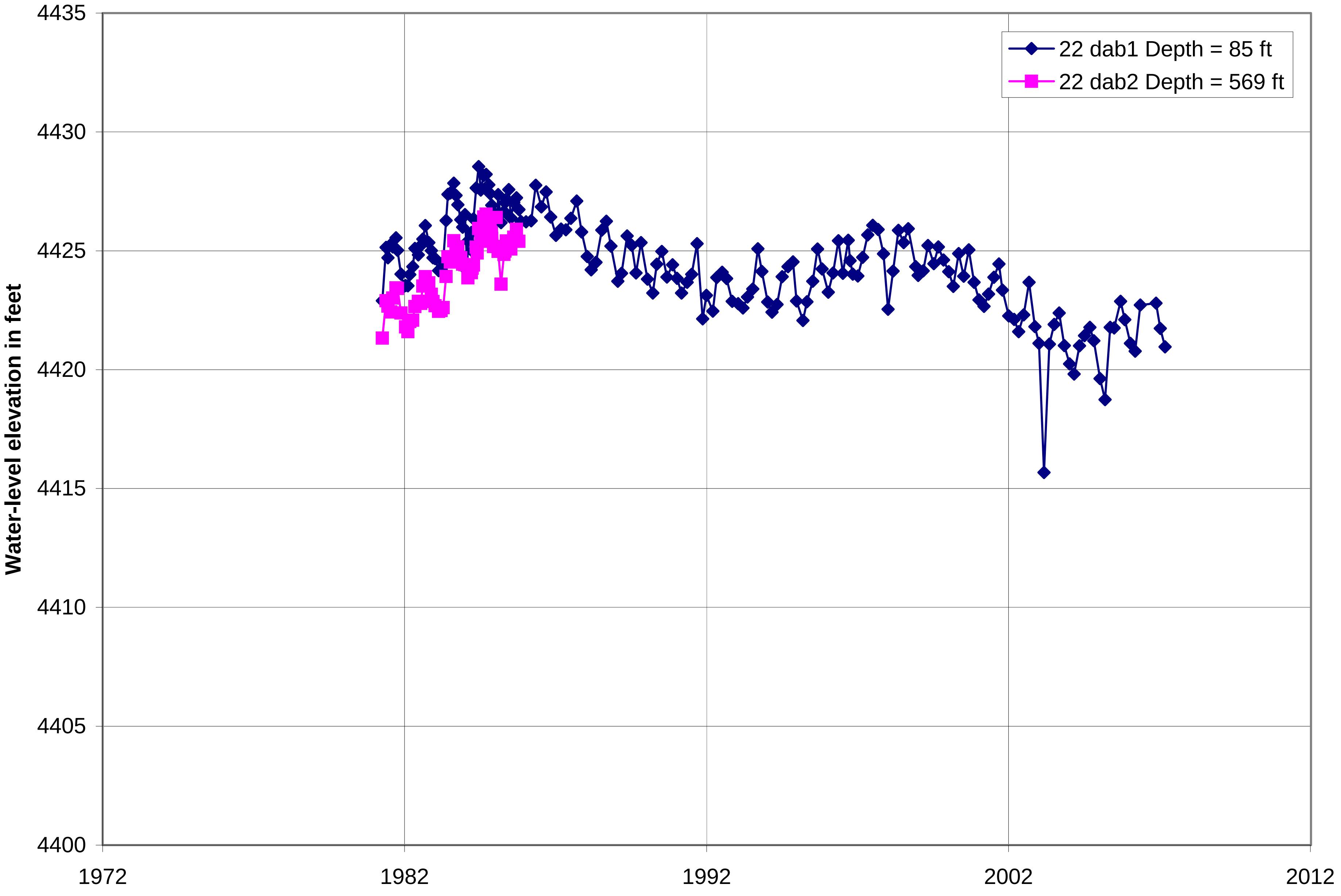


Figure 23 Hydrographs for Wells 3S 34E 22dab1-2

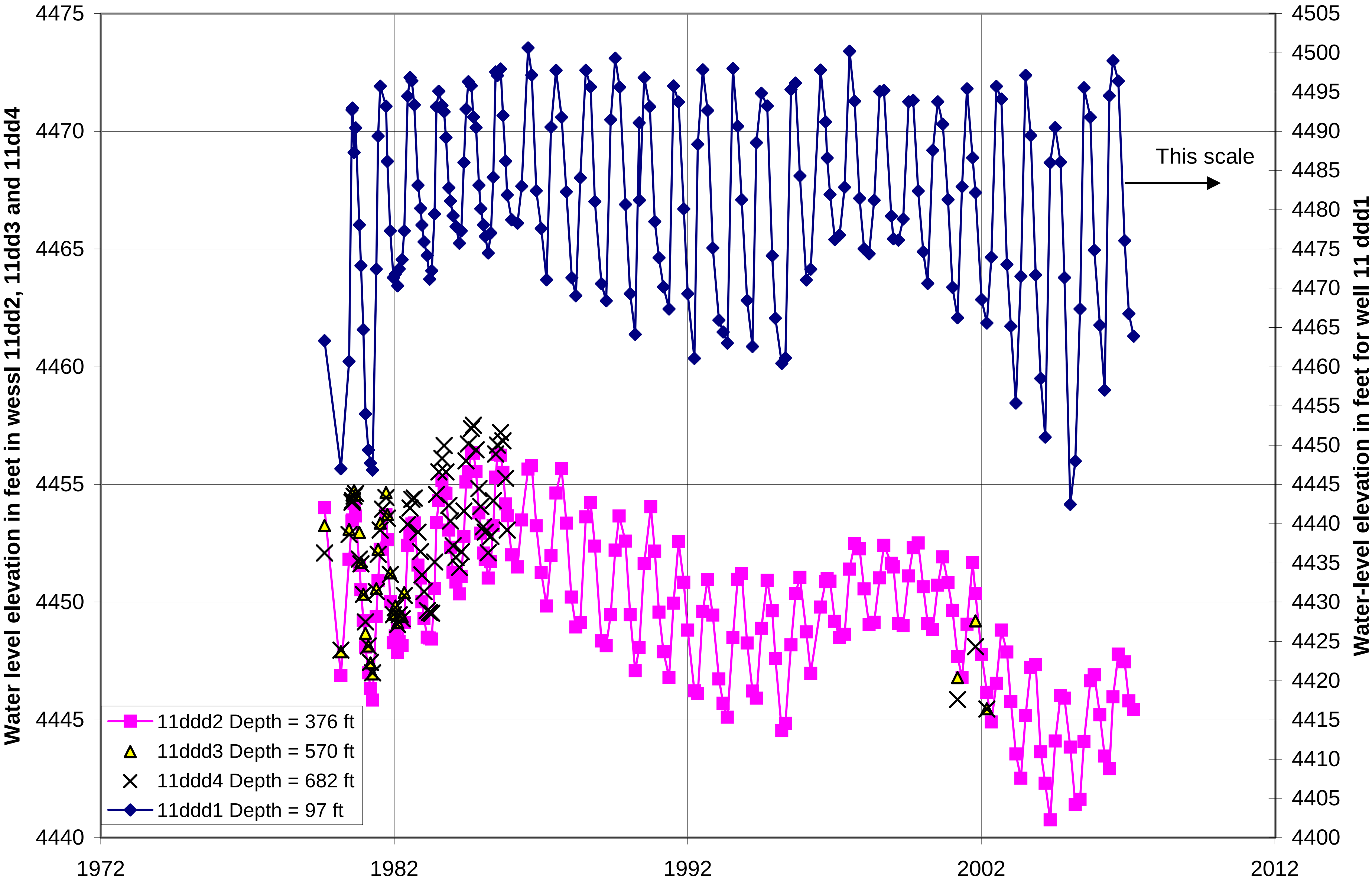


Figure 24 Hydrographs for Wells 2S 35E 11ddd1-4

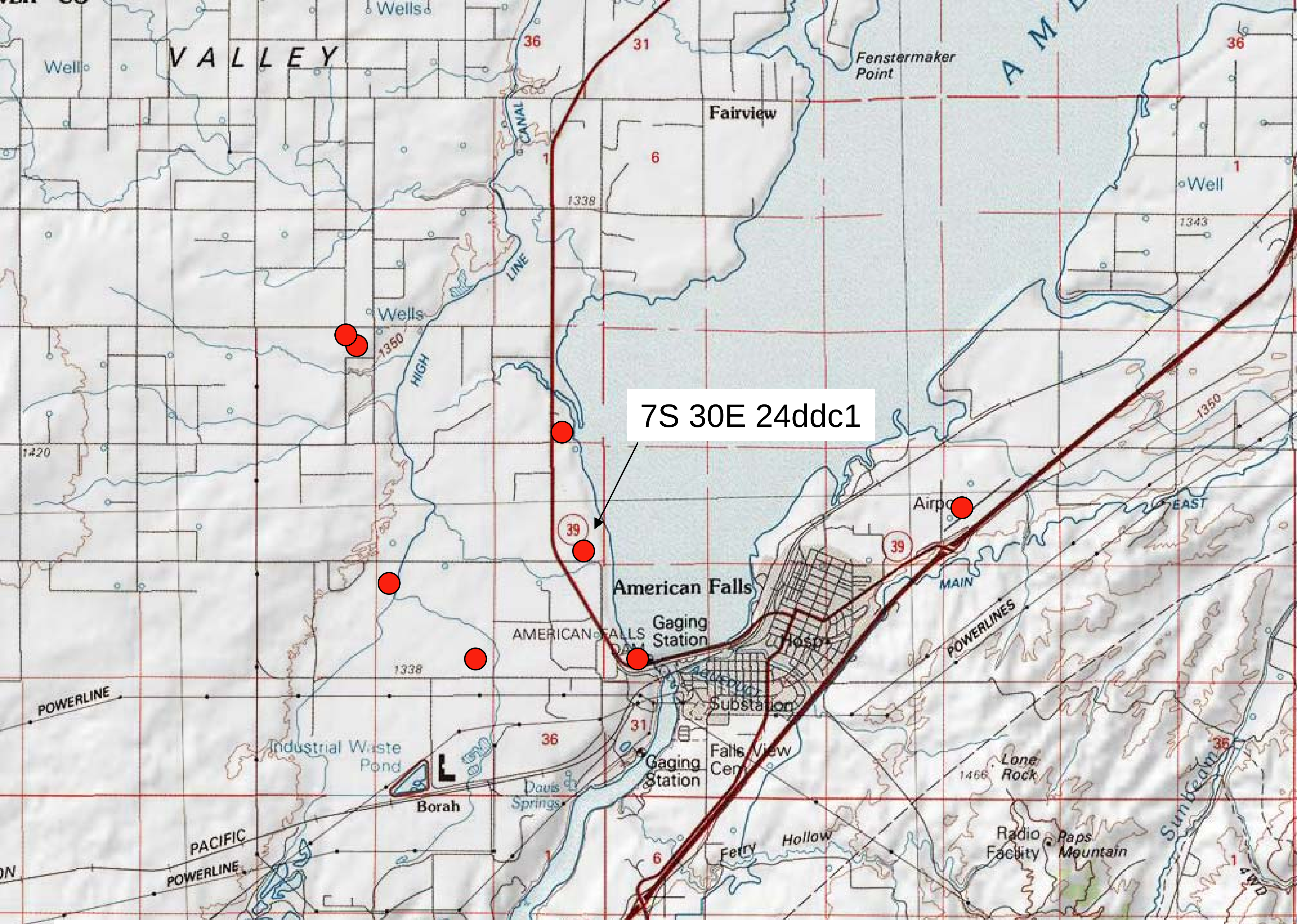


Figure 25 Locations of Wells That Respond to Stage Changes in the Reservoir

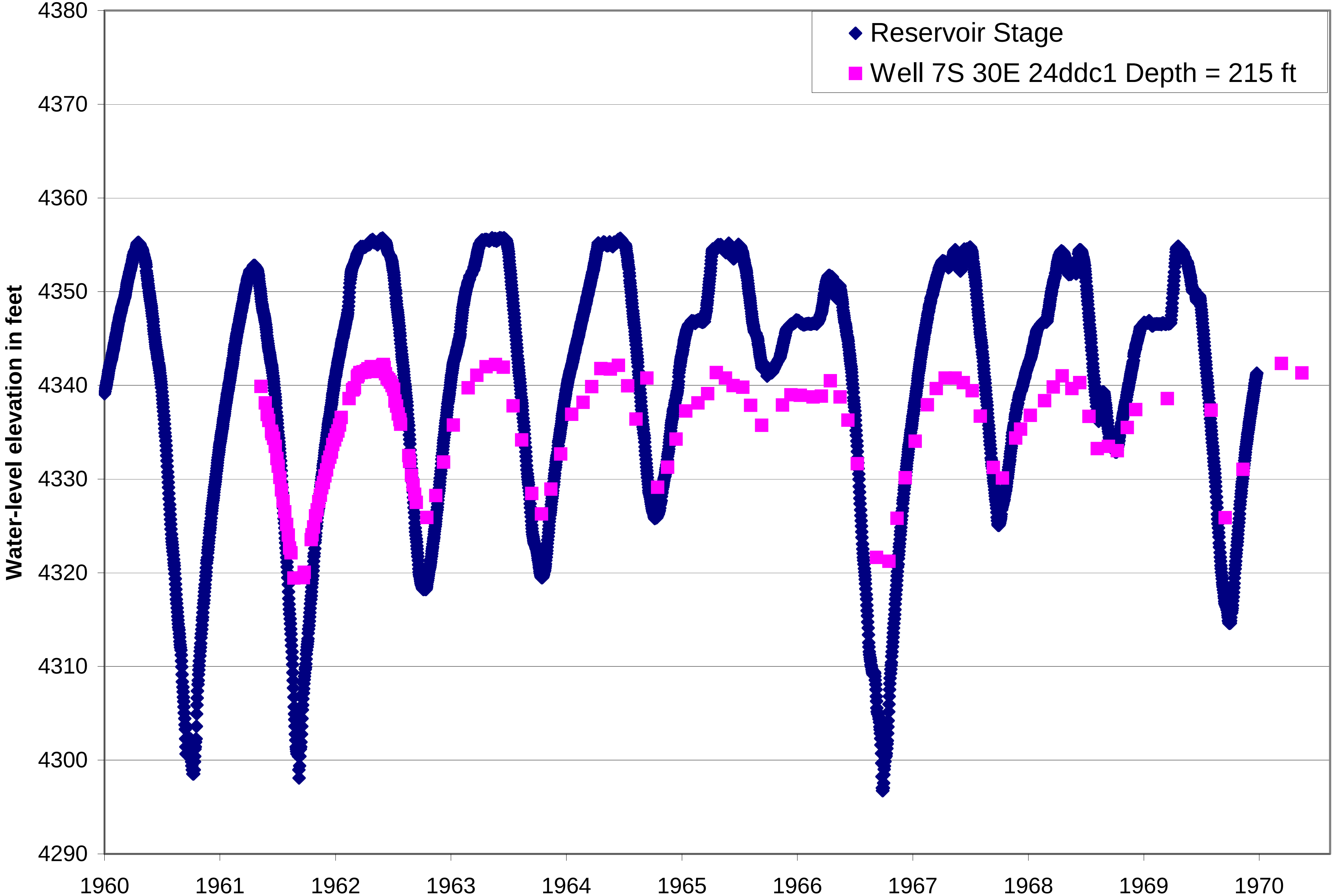


Figure 26 Comparison of Reservoir Stage and Water Level in Well 7S 30E 24ddc1

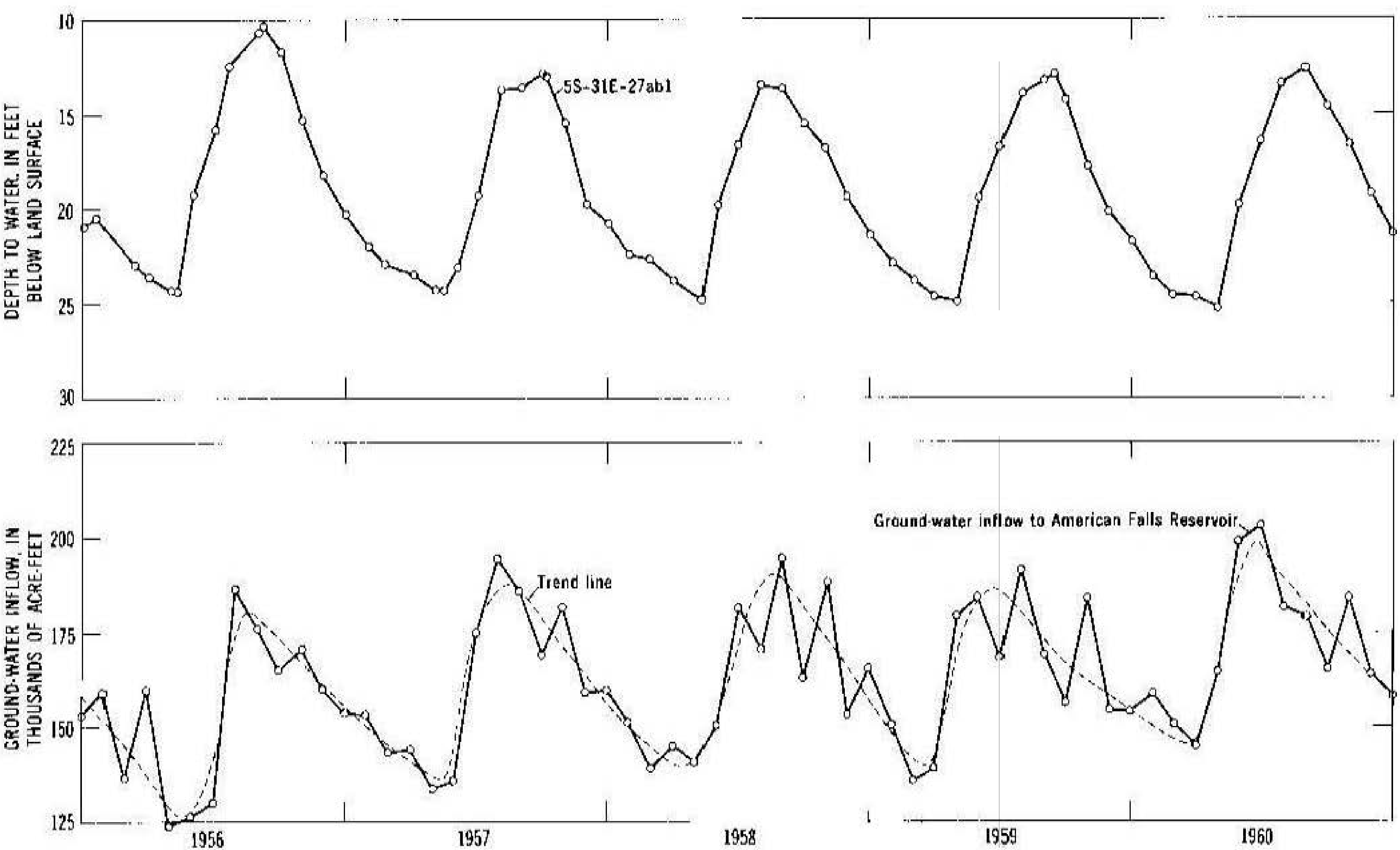


Figure 27 Comparison of Water-Level Patterns in Well 5S 31E 27ab1 to Ground-Water Inflow to American Falls Reservoir (Mundorff, 1967, page 33)

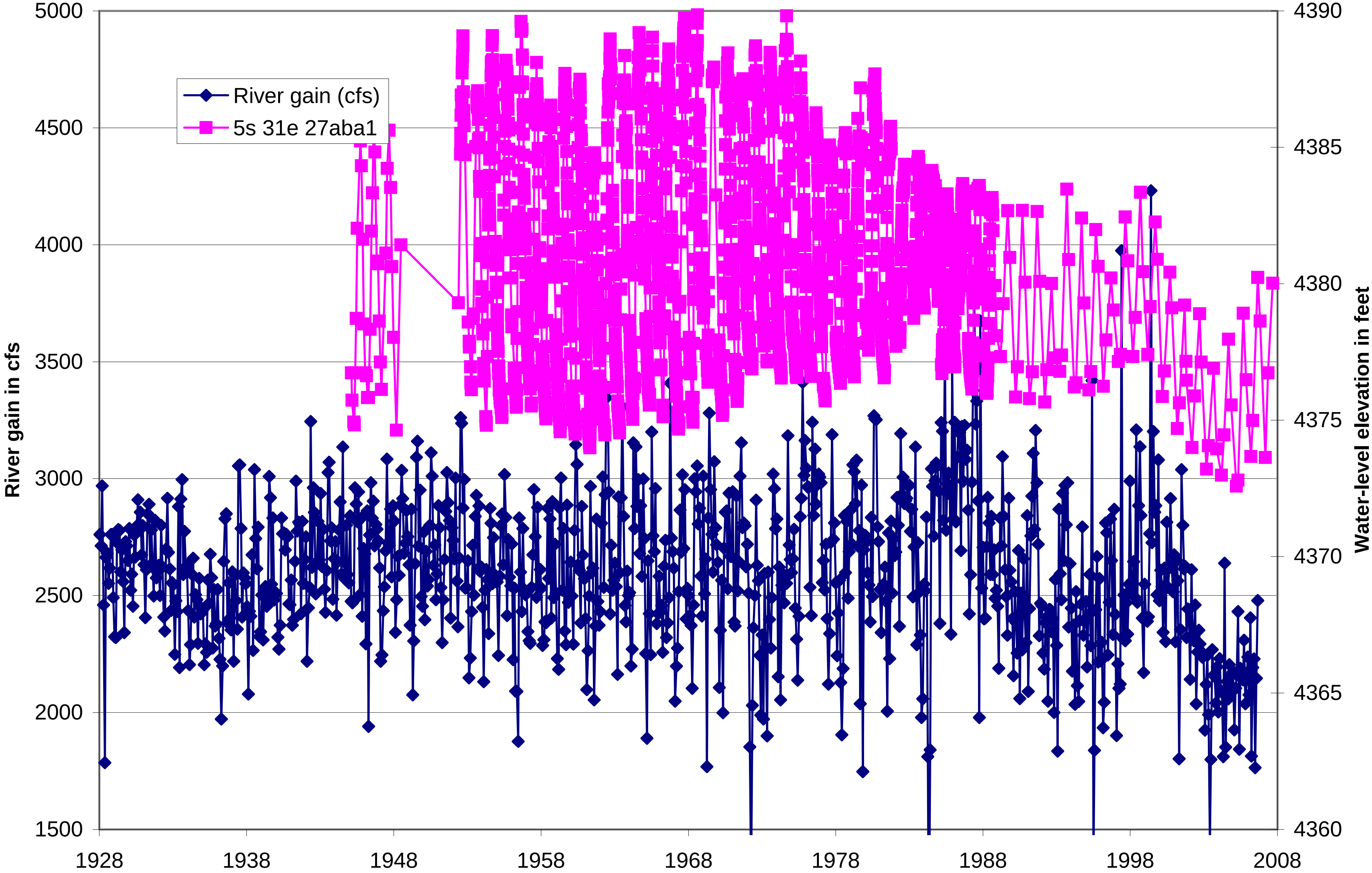


Figure 28 Plot of Calculated River Gain and Water-Level Elevation in Well 5S 31E 27aba1

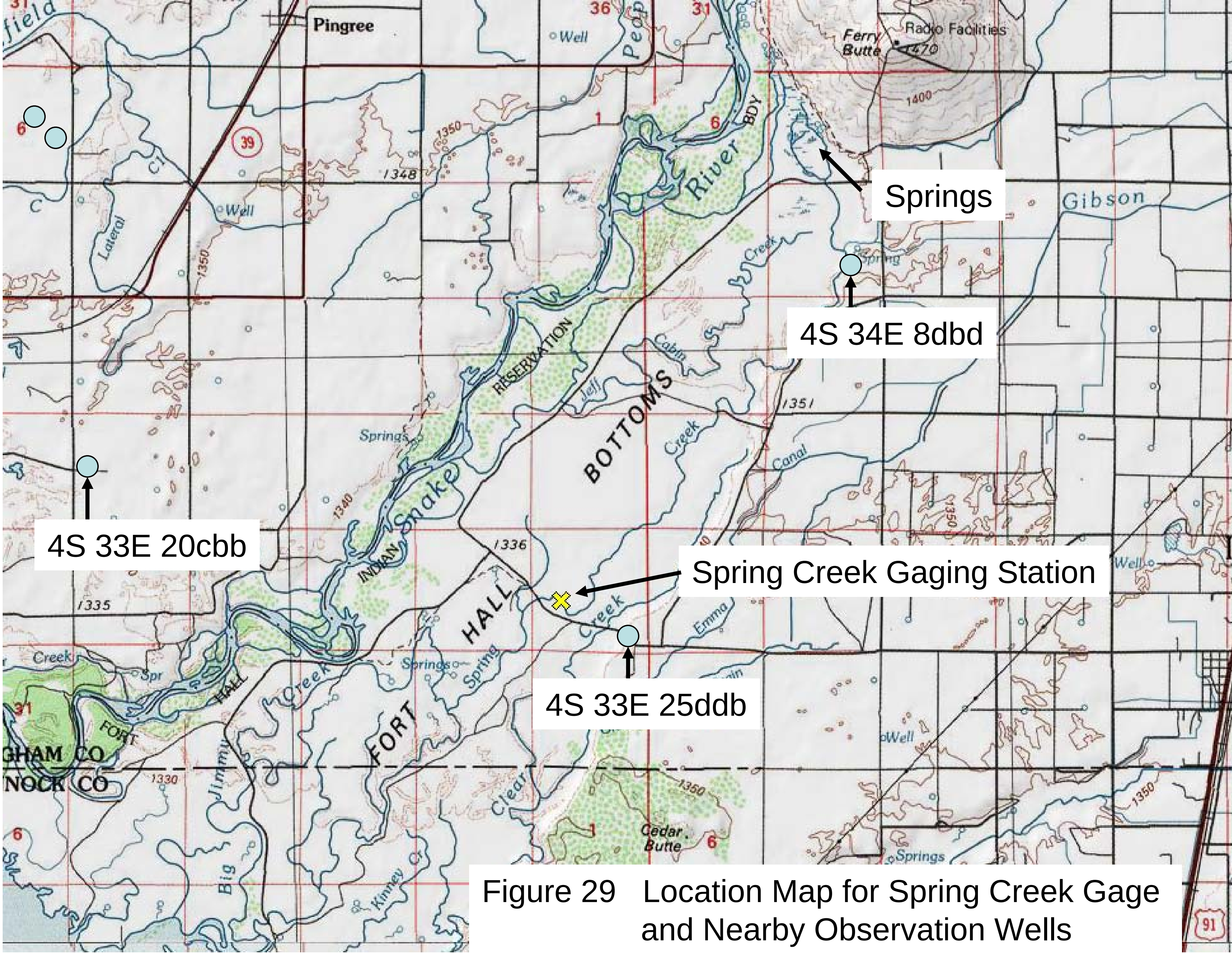


Figure 29 Location Map for Spring Creek Gage and Nearby Observation Wells

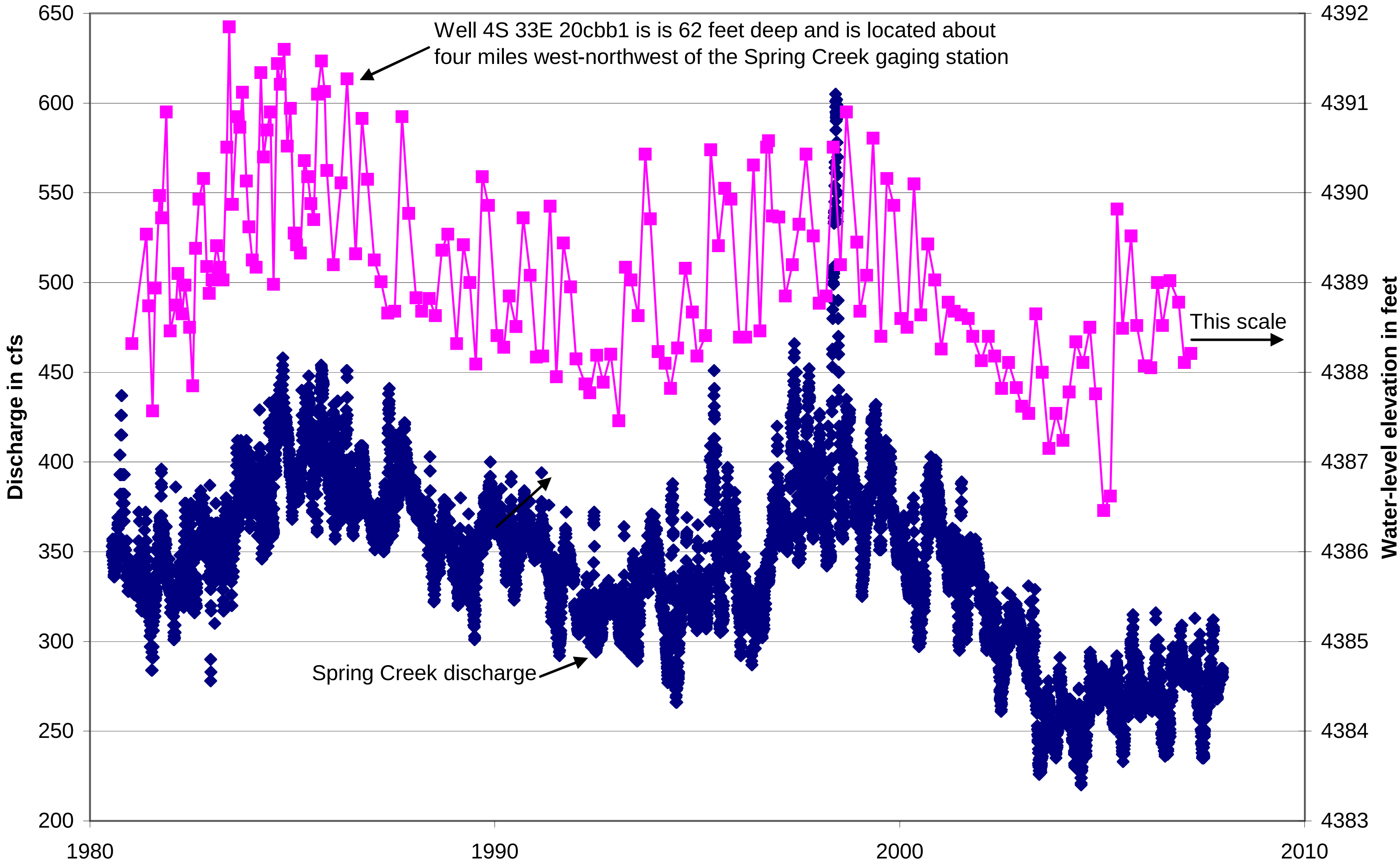


Figure 30 Discharge Plot for Spring Creek and Hydrograph for Well 4S 33E 20cbb1

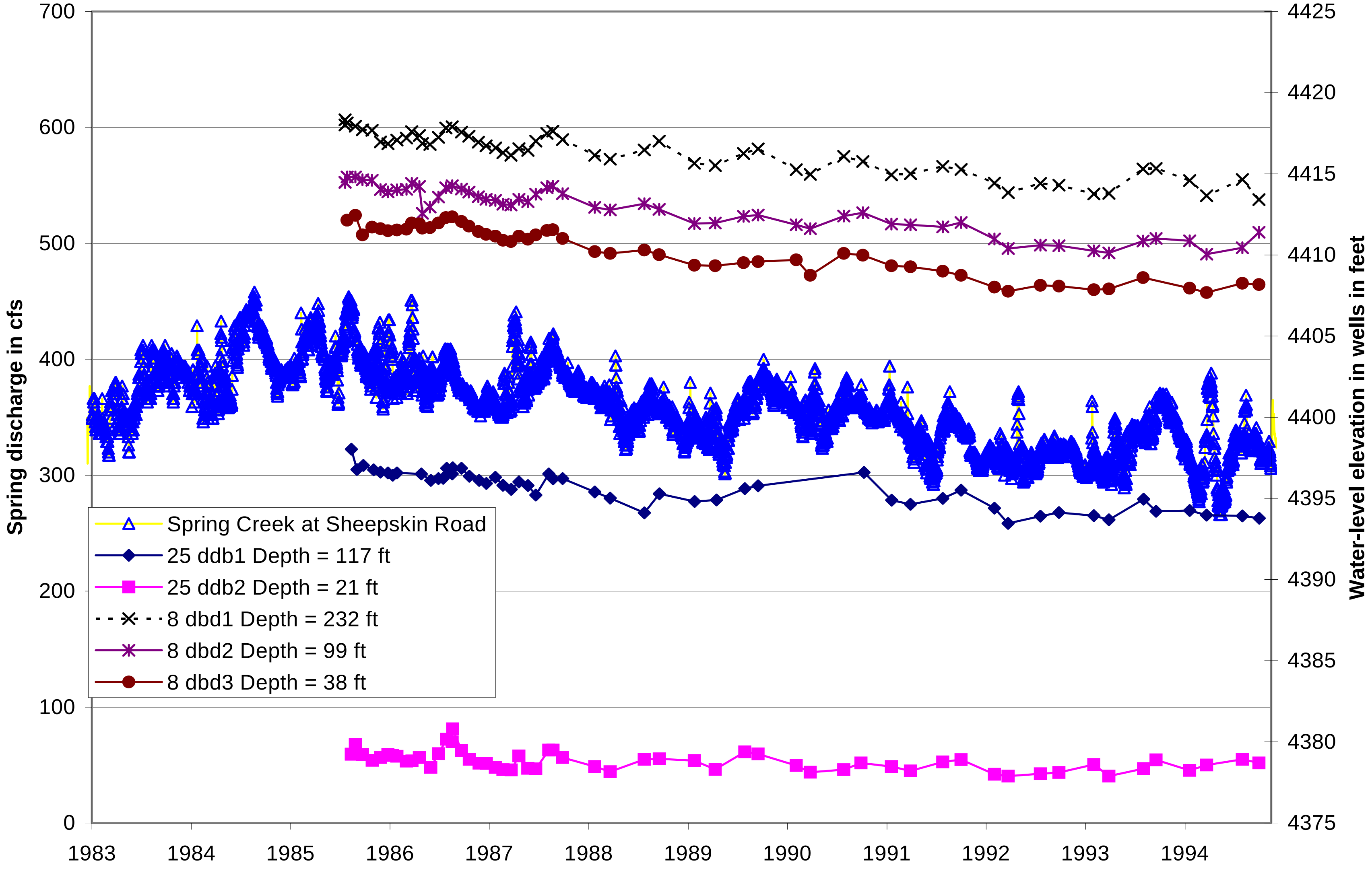


Figure 31 Discharge Plot for Spring Creek and Hydrographs for Nearby Wells

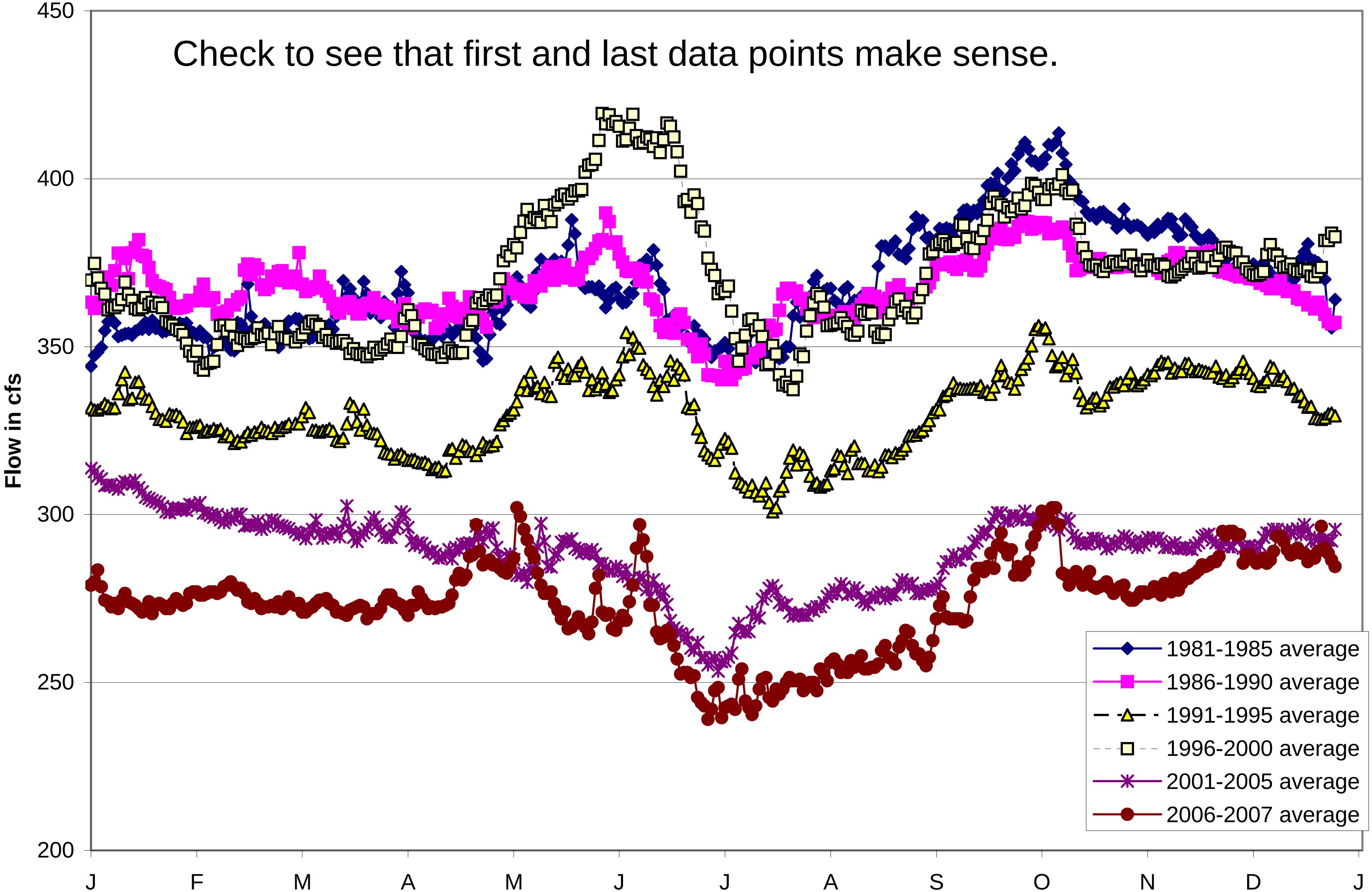


Figure 32 Spring Creek Average Flow Patterns

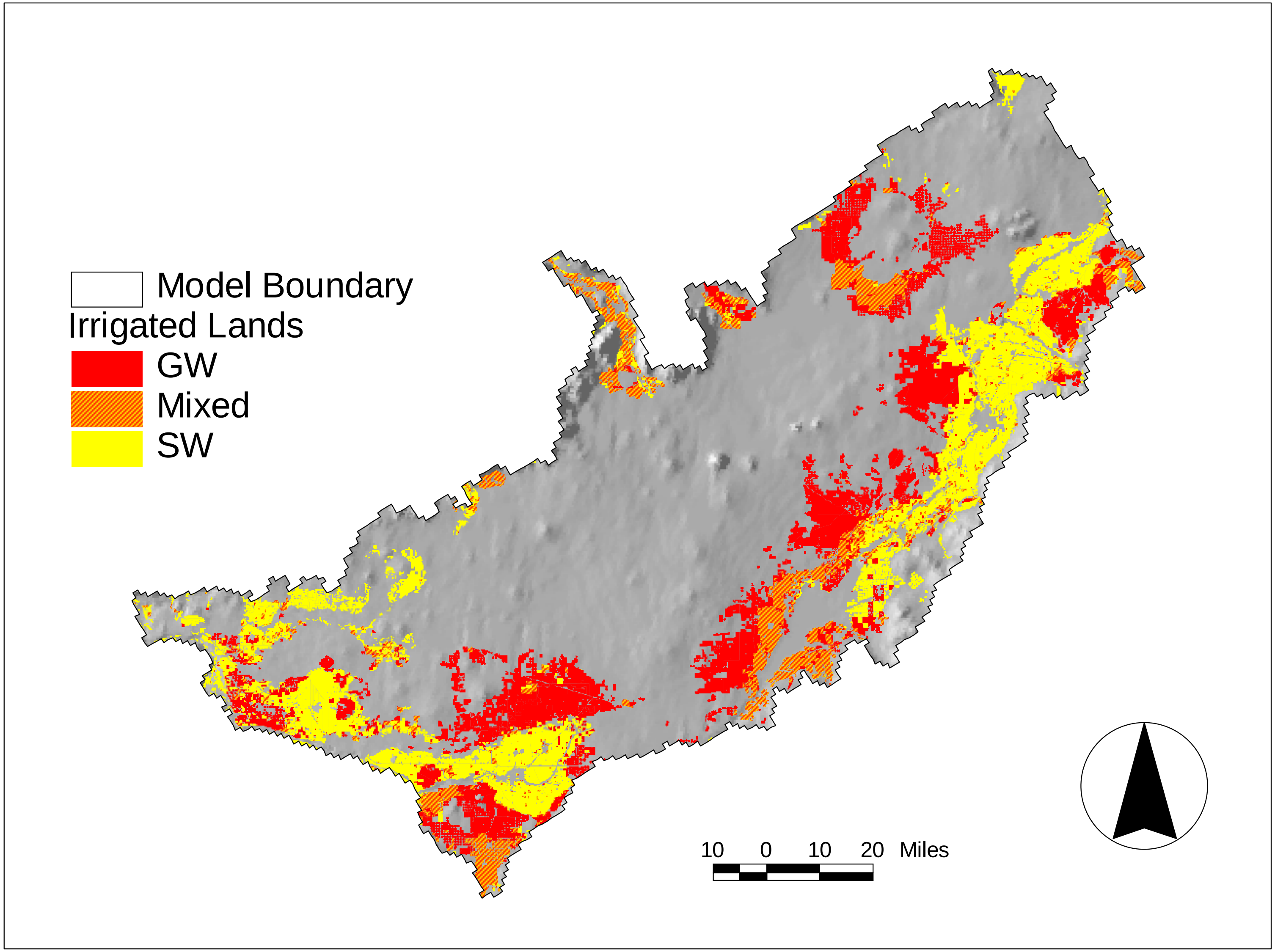


Figure 33 Irrigation Water Source Determined from Adjudication Data (from Cosgrove and others, 2006)

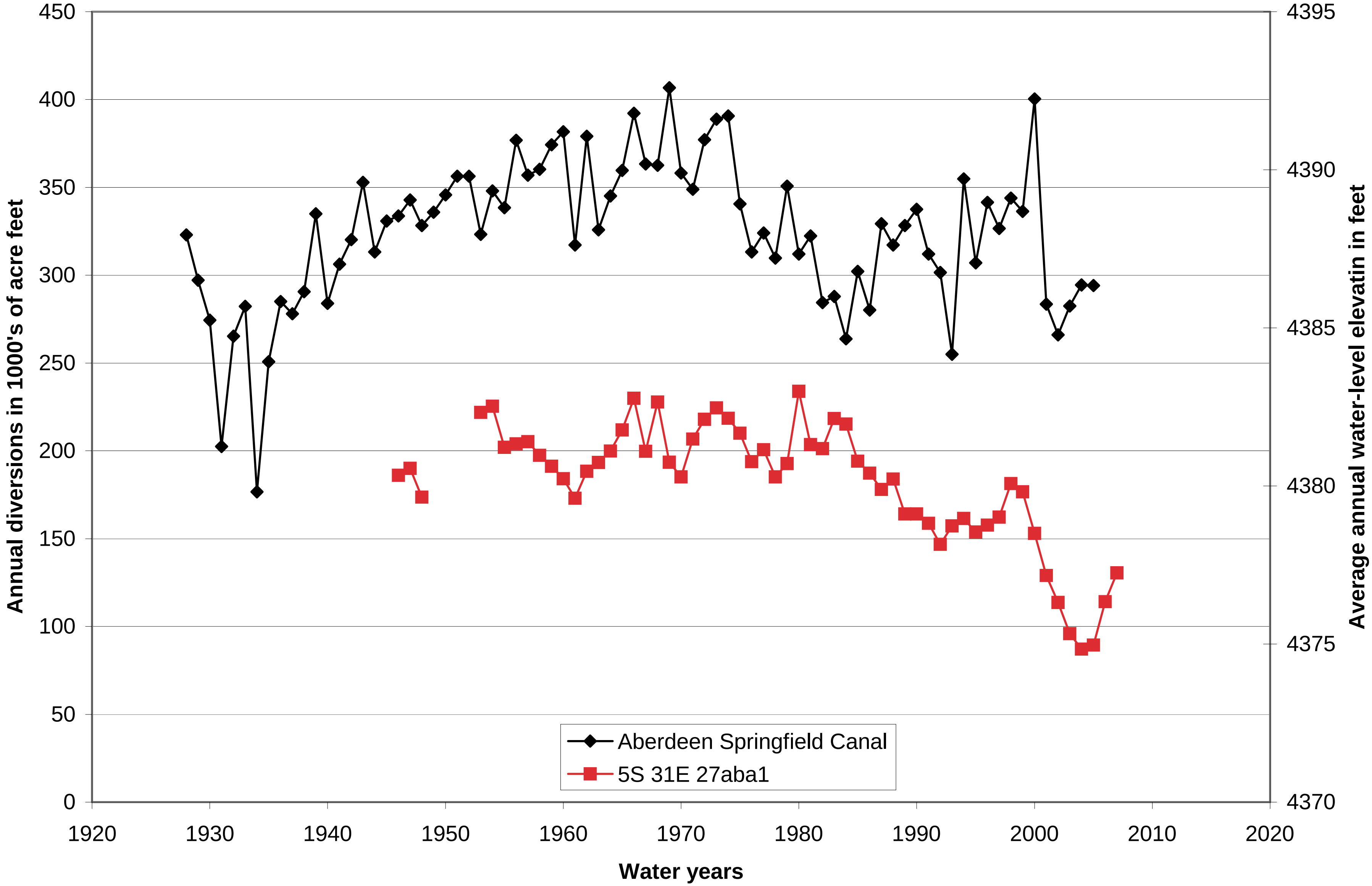


Figure 34 Aberdeen Springfield Canal Annual Diversions and Average Annual Water-Level Elevation in Well 5S 31E 27aba1

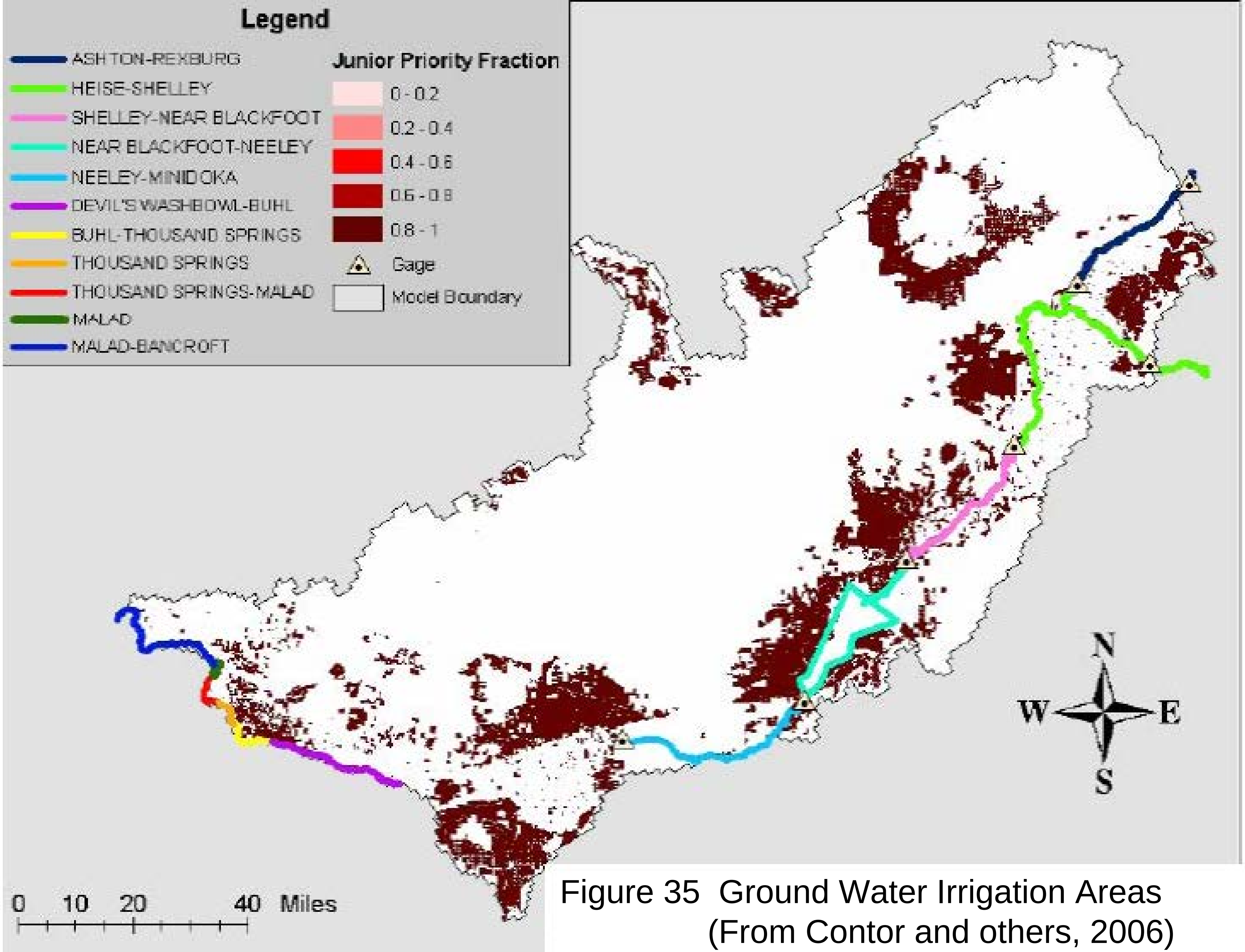


Figure 35 Ground Water Irrigation Areas
(From Contor and others, 2006)

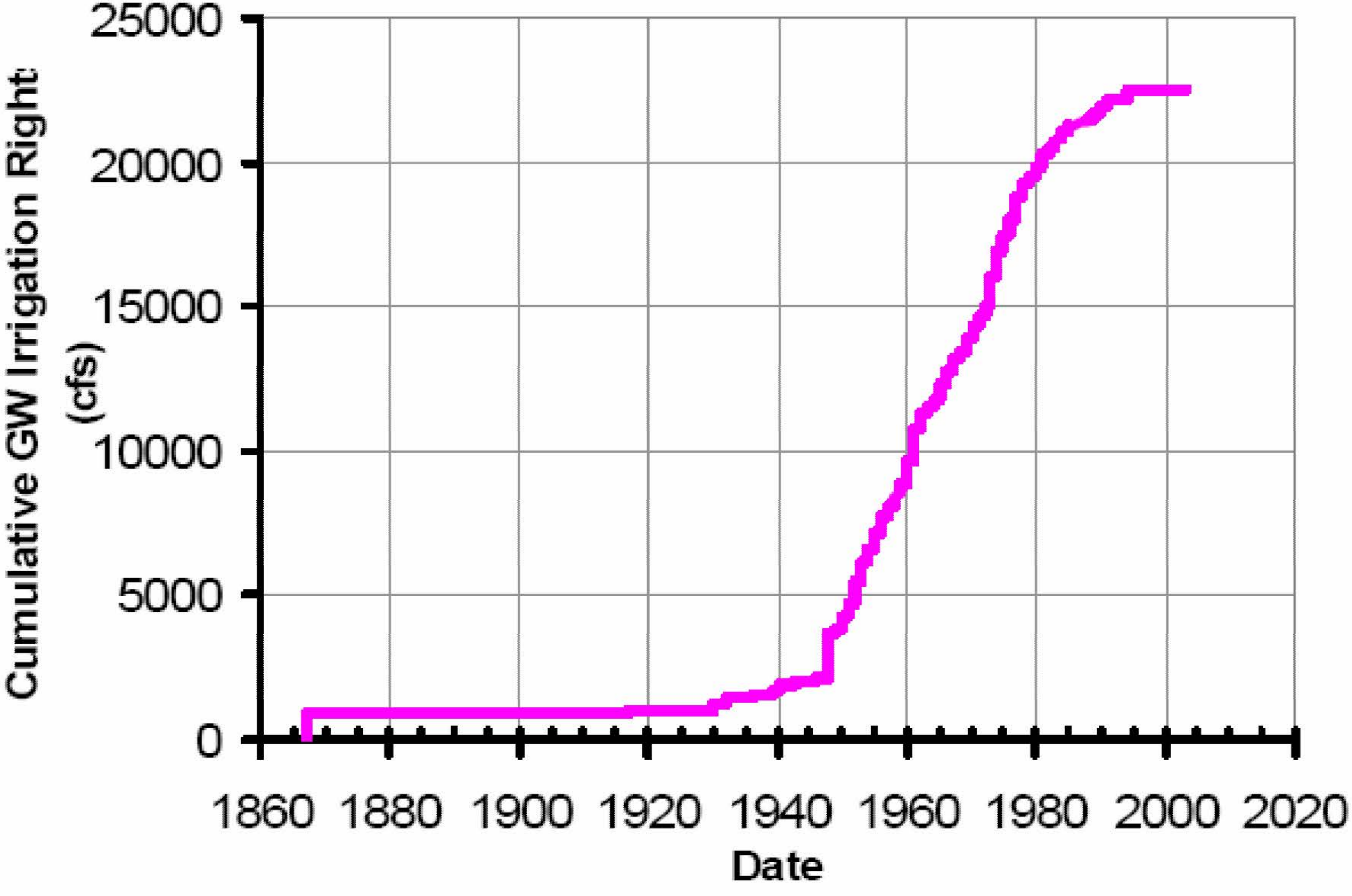


Figure 36 Ground-Water Priorities on the Eastern Snake River Plain
(from Contor and others, 2006)

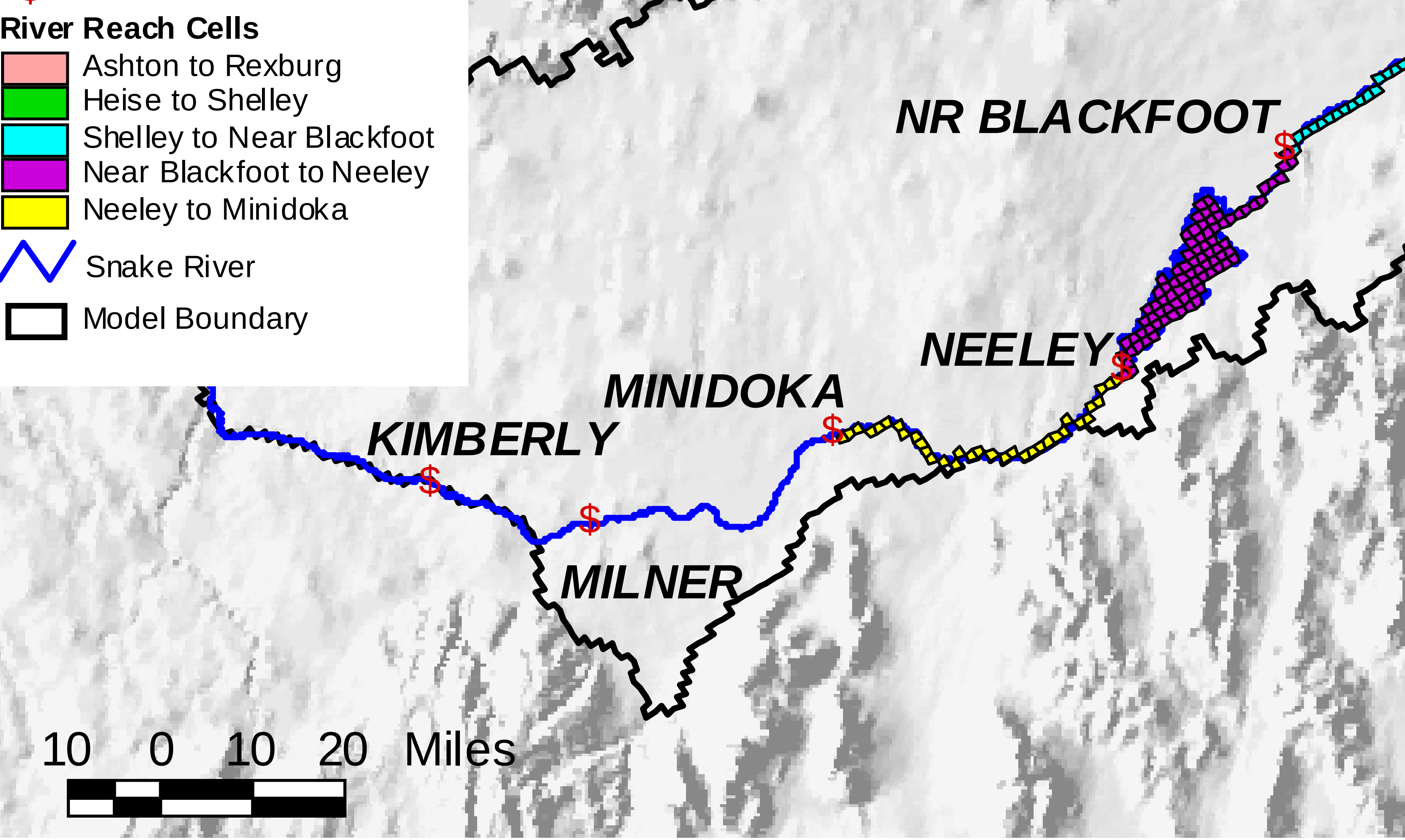


Figure 37 Location Map for River Reach Cells in the Near Blackfoot to Neeley Reach (from Cosgrove and others 2006)

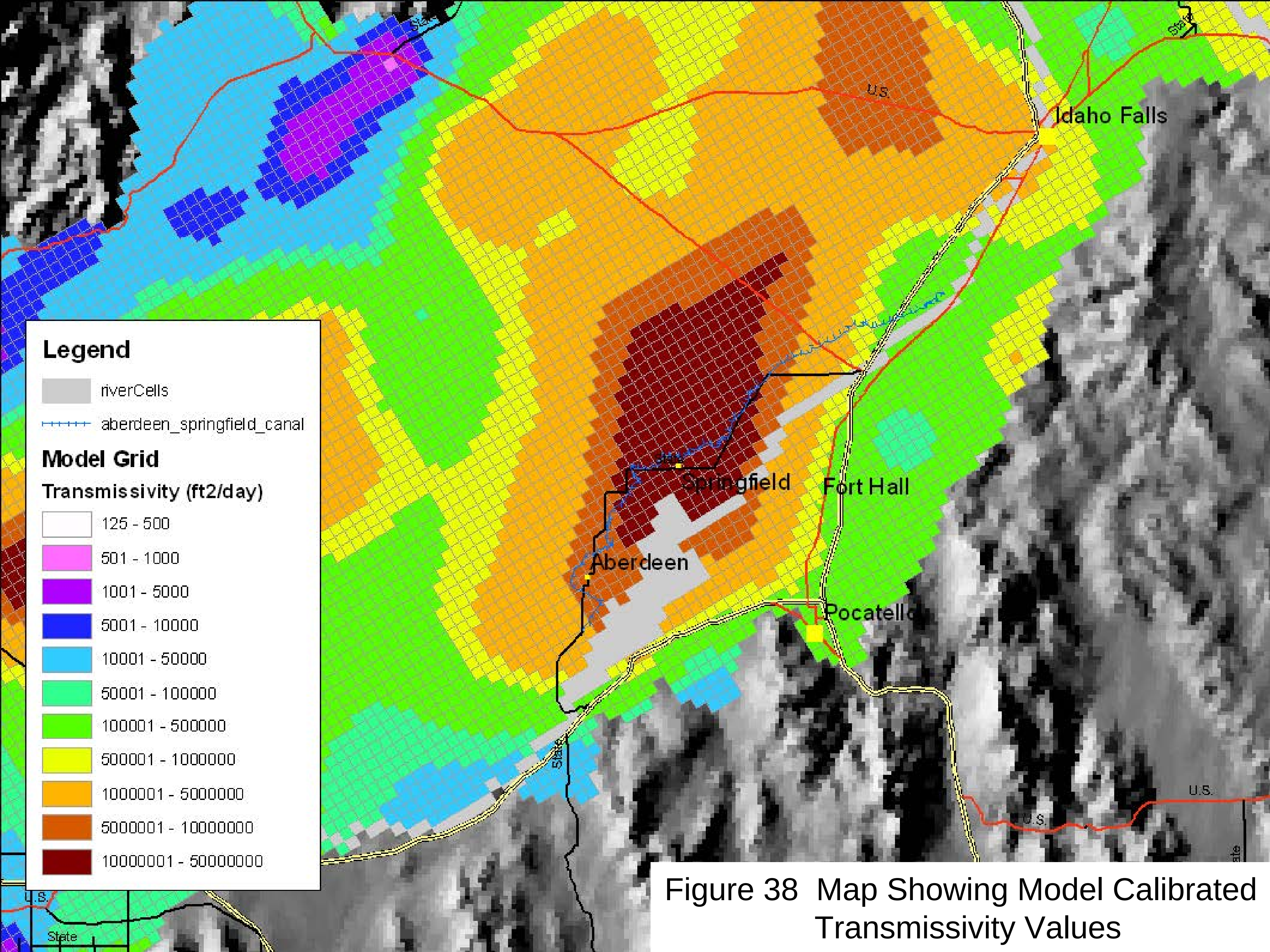


Figure 38 Map Showing Model Calibrated Transmissivity Values

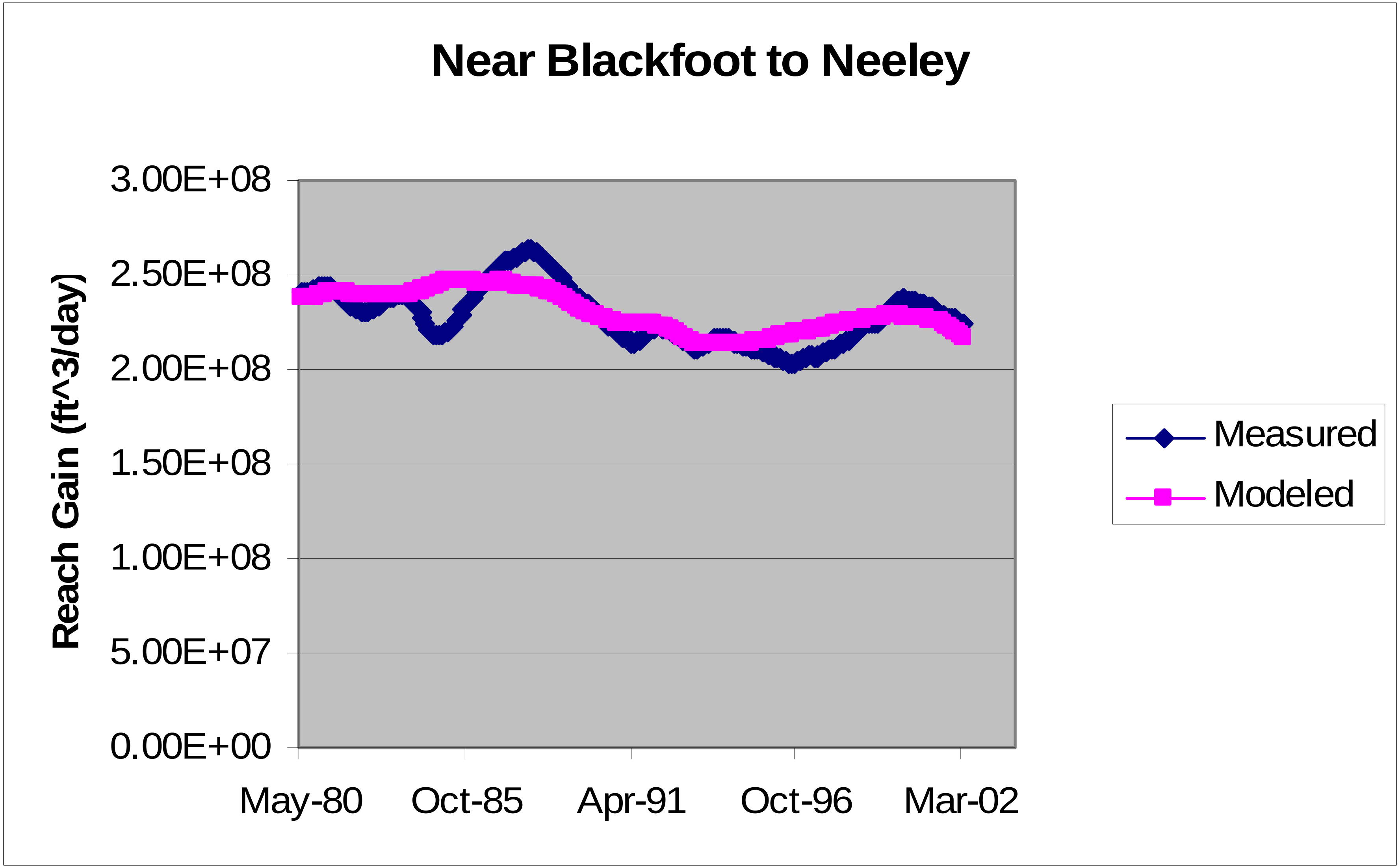


Figure 39 Modeled Versus Observed Gain for the Near Blackfoot to Neeley Reach (from Cosgrove and others 2006)