Research Technical Completion Report

ASSESSMENT OF NEEDS AND APPROACHES FOR EVALUATING GROUND WATER AND SURFACE WATER INTERACTIONS FOR HYDROLOGIC UNITS IN THE SNAKE RIVER BASIN

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ABSTRACT

The Snake River Basin, located in Idaho, Wyoming, Oregon, Nevada, and Utah, is experiencing increasing demands on a finite amount of water. The complexity of water allocation is magnified by the size of the basin and the varied types of interests competing for water. Irrigation interests, municipalities, flood control operators, tribal needs, industrial uses, domestic supply, recreation and species habitat requirements are all exerting demands on the water system. To enhance decision making abilities as related to water allocation, the United States Bureau of Reclamation initiated the Snake River Resources Review (SR3). The SR3 project involves all Snake River drainage areas upstream from Brownlee Dam, located on the Idaho-Oregon border. In support of the SR3 study, this report addresses the ground-water surface water interactions between the tributary basins and Snake River.

The entire study area was subdivided into geographic areas utilizing the hydrologic unit boundaries (HUCs) established by the U. S. Geological Survey (USGS). Data were accumulated to identify areas where ground water use may be sufficient to materially impact surface water flow. The data sets include: (1) ground water-rights (location, amount, priority date), (2) water table fluctuations, (3) agricultural land use, and (4) recorded stream flow measurements. Current rules for conjunctive management of the surface water and ground water systems were also reviewed.

Aquifers in much of the Snake River basin in Idaho have been modeled by previous efforts. In this study, individual HUCs were compared to one another utilizing the criteria suggested by the Idaho Department of Water Resources (IDWR) for prioritizing areas where additional or more detailed ground water modeling should be performed. From this basin wide approach, 6 areas

received a High Priority ranking: Teton, Raft, Big Lost, Big Wood, Portneuf, and Salmon Falls. Areas receiving a Medium Priority include Middle-Snake Succor, Bruneau, C. J. Strike Reservoir, Camas, and Blackfoot.

Water table fluctuations observed in wells, measured by the USGS, indicate that not all wells in a given region show an equal response to stresses on the water system. Basin-wide changes in the water table seem to correlate with climatic periods of drought or non-drought.

Some of the suggestions for further studies in the Snake River basin area include:

1. Creation of a regional ground water model that would tie together the entire Eastern Snake River Plain and its associated tributary basins;
2. An incorporation of ‘time-lags’ within the rules of conjunctive management used by the State of Idaho to address the degree and timing of impacts that justify subsequent regulation of ground water rights based on impacts to surface water flow;
3. Incorporate detailed review of historical surface water use and diversions with all ground water modeling efforts; and
4. Investigate the use of analytical element models for a basin-wide modeling approach, and their possible use as a preliminary modeling effort.

ACKNOWLEDGMENTS

Funding for this project was provided by the U.S. Bureau of Reclamation (Reclamation) through Snake River Resources Review (SR3). Personnel at federal and state agencies were very cooperative providing information and assistance in the data acquisition phase of the study. Digital elevation model images, hydrologic unit boundaries, stream gages, rivers, and state boundaries data sets were made available by Reclamation. Data sets representing the location of Idaho Ground Water Districts, Ground Water Management Areas, and Administrative Basins were made available by the Idaho Department of Water Resources.

Assistance and support from individuals at the Idaho Falls location of the Idaho Water Resources Research Institute were appreciated. Donna Cosgrove provided technical help in working with the large data bases, assisted in reviewing this report, and provided a helpful exchange of ideas and concepts. Sherry Laney provided support and instruction enabling the use of Arcview as a tool for data management and helped build GIS data sets and construct many of the figures.

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INTRODUCTION

The Snake River in Idaho, Wyoming, and Oregon is a treasured resource for those who live in the region. It represents life to the arid northwest through which it passes. The Snake River, and its associated aquifers and tributaries, supports a broad range of uses. However, as water demands increase, competition for a finite amount of water also increases. To assist in water allocation decisions among the competing interests, the Snake River Resources Review (SR3) study was initiated by the U.S. Bureau of Reclamation (Reclamation) in 1995.

Greater understanding of the Snake River Basin hydrologic system, and the creation of a common data platform provided through SR3, should help facilitate allocation and timely distribution of water resources within the Snake River Basin. The study area for SR3 includes all drainages associated with the Snake River, from its headwaters in Wyoming at Jackson Lake, to Brownlee Dam on the Idaho-Oregon border (Figure 1). In support of the SR3 study, this report assesses the ground water-surface water interactions for hydrologic units in the Snake River basin. More information on SR3 is available at: www.pn.usbr.gov/sr3/index.html.

Within the Snake River Basin, many of the hydrologic study efforts have addressed only regional or local needs and concerns. Knowledge gained from these studies implies that decisions concerning water use, especially consumptive use, affect the outflow of the Snake River. Consider the following statement:

> “Every acre-foot of water consumptively used in basins tributary to the Snake River ultimately reduces the flow of the Snake River” (Ralston and others, 1984, p. 10).

Accepting the premise set forth in the previous quotation, issues dealing with water quantity in the Snake River system should also involve management of water within the tributary basins.

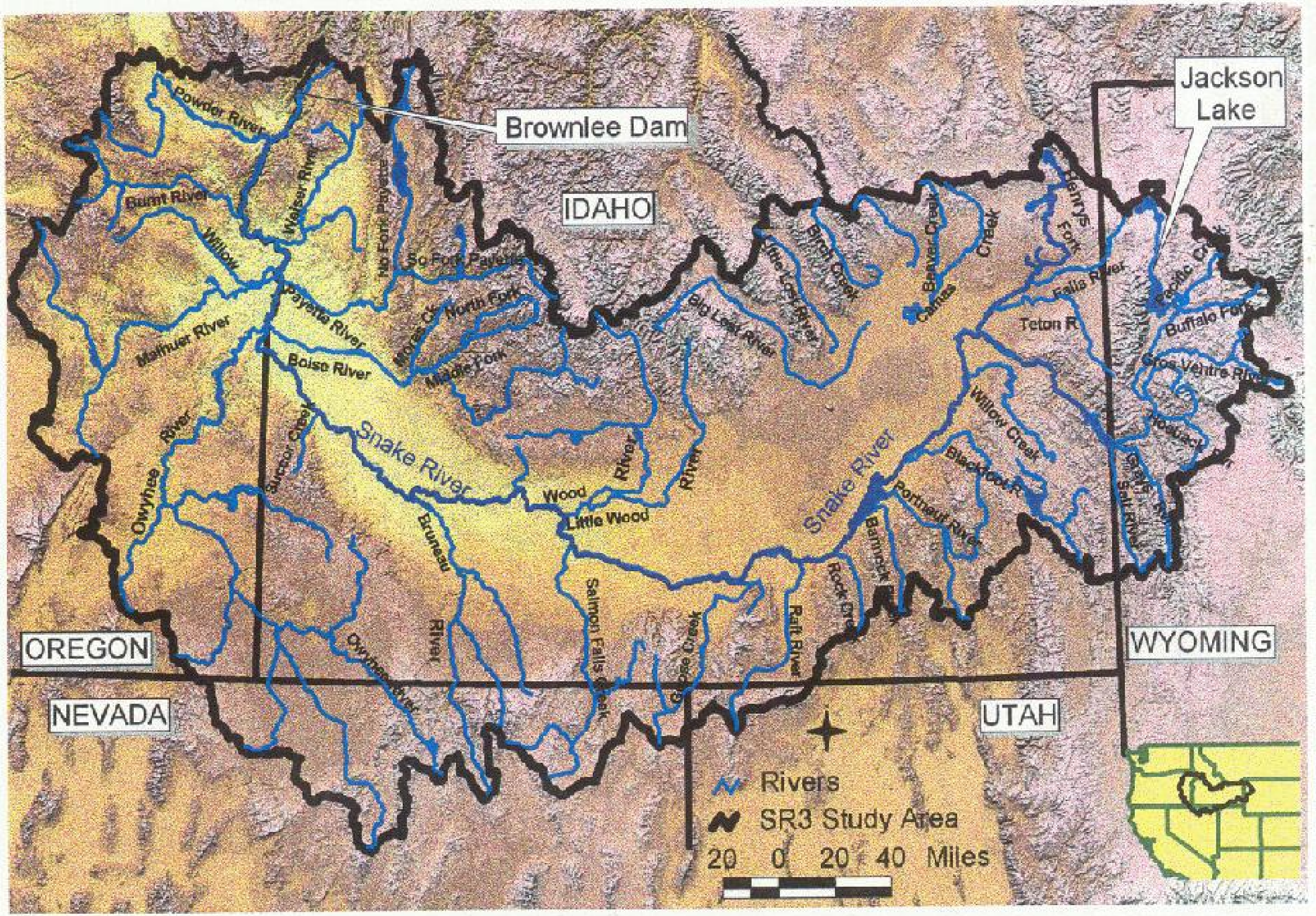


Figure 1. Map showing the SR3 Study Area, the Snake River, and its major tributary streams.

OBJECTIVES AND SCOPE

Within the Eastern Snake River Plain and most tributary basins, surface water and ground water systems are considered hydraulically interconnected (Kjelstrom, 1995; IDWR, 1997). Within the Snake River basin, any stress (pumping, recharge, drought, etc.) that is applied to either the surface water or the ground water affects the entire water system. To support the modeling efforts used to quantify the interconnected relationship, this study attempts to identify available data and methodology useful to describing the surface water-ground water interactions within the hydrologic units. The following objectives are addressed within the subsequent sections:

- Procedures - Establish methodologies to be implemented in the study;
- Snake River Basin - Promote a more regionally integrated view of the Snake River Basin with a water quantity perspective;
- Conjunctive Management - Discuss uses of conjunctive management to address surface water-ground water systems that are interconnected;
- Concepts Involved in Ranking Tributary Basins - Establish why ranking is needed;
- Ranking of Tributary Basins - Identify available data, develop a suggested ranking of tributary basins for further studies;
- Identification and Comparison of Tools - Identify and compare some of the tools or methodologies that could be used to quantify the impacts of ground water discharge and recharge on flow in the Snake River;
- Conclusions and Recommendations - Summarize information gained and provide a discussion recommending future studies for identified areas of interest.

PROCEDURES

To accomplish the objectives set forth for this study the following procedures were adopted.

1. Where feasible, obtain water rights data from the respective state agencies and establish the spatial distribution of ground water pumping within the respective hydrologic units.
2. Acquire applicable GIS data such as location and quantity of irrigated acres, applicable administrative units, precipitation data, location of ground water diversions, and the location of wells used to monitor water table fluctuations.
3. Obtain available monitoring well information from the U.S. Geological Survey and create ground water hydrographs for the different tributary basins.
4. Retrieve stream gage information from the U.S. Geological Survey for active stream gage locations. Compare mean annual flow for water years 1980-96 with historical data (1934-1980, Kjelstrom, 1986).
5. Establish which areas in the Snake River Basin are experiencing ground water pumping in significant quantities and rank the hydrologic units on that basis.
6. Implement a decision-making strategy to determine which areas should be considered for additional studies.
7. Do a literature search for models or management schemes used to administer ground water and surface water in large basin systems.
8. Compare applicable models with proposed studies.

THE SNAKE RIVER BASIN

The basins and streams tributary to the Snake River are numerous and with a few exceptions, generally less well known than the River itself. Yet, for reasons set forth in this paper, all the tributary areas should be included in any regional study dealing with issues of water quantity.

Basins tributary to the Snake River in the study area cover parts of Idaho, Wyoming, Utah, Nevada, and Oregon. The Snake River from Jackson Lake, Wyoming to Brownlee Dam, on the Idaho-Oregon border, is nearly 700 miles long. The tributary basins, combined with the east and west parts of the Snake River Plain, drain more than 72,000 square miles (46,000,000 acres) (Figure 1). Depending on the scale or detail with which the Snake River drainage system is examined, there are at least 60 separate streams or drainages that connect to the main stem of the river or at least deliver water to the Snake River Plain (Kjelstrom, 1986; Peterson, 1988). To aid in understanding this basin in its regional setting, this section includes discussions of the following subjects:

- The Regional Nomenclature
- The Physical Setting of the Snake River Basin
- Hydrologic Unit Codes (HUCs)

Regional Nomenclature

The Snake River, within the State of Idaho, is such a dominant feature, and so varied in its nature, it is generally described in at least three segments: (1) Upper or Eastern Snake (upstream from Milner), (2) Middle Snake (King Hill to Milner), and (3) Western Snake (downstream from King Hill, including the Weiser River drainage) (Figure 2). Respectively, the drainage area in square miles for each of these three regions are roughly (1) 24,100, (2) 5,800, (3) 32,600.

The Henrys Fork (sometimes called the North Fork of the Snake River) located in the northeastern portion of the Snake River Plain is one of many unique tributaries. This river reach begins at Henrys Lake, where the river travels south through the Island Park caldera before flowing onto the Snake River Plain. In regional terminology, it is considered part of the Eastern or Upper Snake River Valley.

The U. S. Bureau of Reclamation (Reclamation) uses the term, “Central Snake River

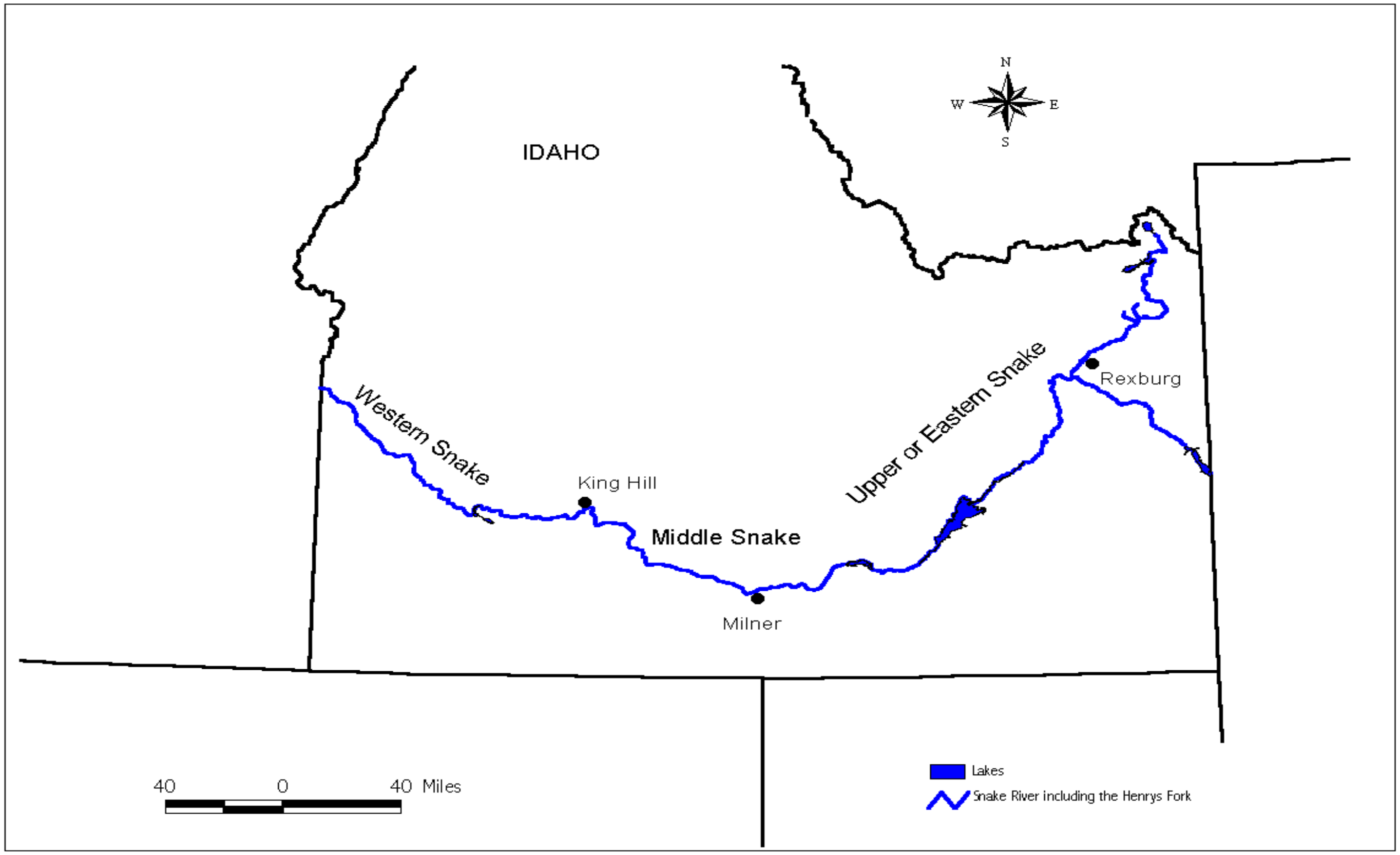


Figure 2. Map showing common terminology for the Snake River.

to include the Boise, Payette, Owyhee, Malheur, Weiser (Mann Creek), Burnt, and Powder Rivers. Except for Burnt and Powder, these rivers are tributary to the Western Snake Plain in Figure 2. Describing operations above Milner Dam, Reclamation uses the term “The Upper Snake River Basin”, which is consistent with the nomenclature in Figure 2.

Relying strictly on local terminology can be confusing. Utilizing the hydrologic unit terminology established by the USGS (which is presented later in this section) can help minimize the confusion.

The Physical Setting of the Snake River Basin

Jackson Lake is the beginning of the Snake River. The lake is nestled at the base of the Teton Mountains within Grand Teton National Park (Figure 3). About 15,300 square miles of the study area is associated with the Snake River Plain with an additional 56,000 square miles within the hydrologic units that extend up the tributary basins.

Water in the Snake River begins its journey flowing south through Jackson Hole. The Jackson Hole valley is more than forty miles long and up to eight miles wide. The Snake River Canyon, between the southern end of Jackson Hole and Palisades Reservoir, is an entrenched section of the river with sufficient gradient to provide excellent white-water experiences (Wyoming Water Resources Center, 1998). The major tributaries in this region include the Gros Ventre River, Hoback River, Greys River, and the Salt River (Figure 3). Within the 69-mile stretch of the Snake River from Jackson Lake to Palisades Reservoir, the elevation of the river drops from 6800 feet to 5600 feet.

After leaving Palisades Reservoir, flowing through Swan Valley, Idaho, the Snake River enters a second canyon section before flowing out onto the Snake River Plain. The 64-mile long river reach from Palisades Dam to the confluence with the Henrys Fork is sometimes called the South Fork of the Snake River. The Snake River drops almost 600 feet between Palisades Reservoir and the Heise, Idaho stream gage.

The Snake River Plain is an arcuate topographic feature that extends across the entire southern portion of Idaho. It is approximately 350 miles long and ranges from 30 to 75 miles wide with a surface area of approximately 15,300 square miles (Lindholm, 1996). The Snake River in eastern Idaho generally follows the southern boundary of the plain.

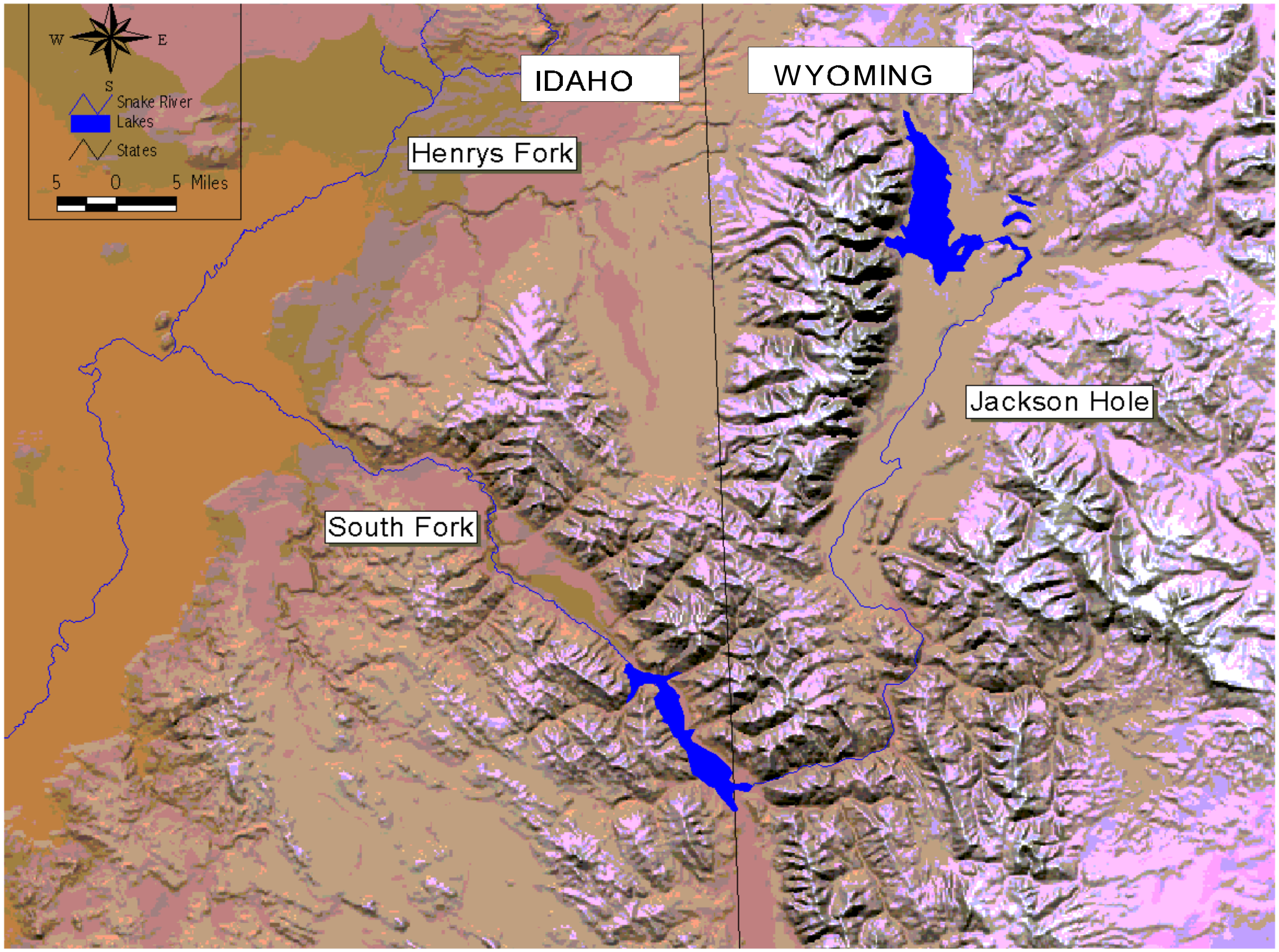


Figure 3. Map showing the Headwaters area of the Snake River.

The transition within the Snake River Plain from east to west marks a change in the lithologic character of the associated aquifers. The origin of the Eastern Snake River Plain is often associated with a mantle plume or hot spot theory. The Eastern Snake River Plain is primarily underlain by volcanic material (mostly basalt near the surface, with increasing proportions of rhyolite with depth) and minor amounts of intercalated lake and fluvial sediments. The Snake River Plain in western Idaho is interpreted as a graben structure, underlain predominantly by sediments (Lindholm, 1996). Whitehead (1992) summarizes the physical nature of the aquifer system associated with the Snake River Plain, and describes it as an unconfined aquifer with locally confined areas. In an unconfined aquifer, the surface of the water table is considered the top of the aquifer.

The Snake River, after passing Milner Dam, becomes entrenched with the resulting canyon over 150 miles long. Near King Hill, the river is almost 700 feet below the adjacent land surface (Lindholm, 1996). Upstream from King Hill, the eastern Snake River Plain aquifer discharges large volumes of ground water to the Snake River. The discharge takes place through the many springs flowing from the canyon walls or directly into the river.

More than twenty tributary streams feed into the Snake River in the eastern portion of the Snake River basin. The larger tributaries in this area include: Henrys Fork, Teton River, Falls River, Big Wood River, Blackfoot River, Big Lost River, and Portneuf River. The Snake River drops in elevation from more than 5,015 feet on the eastern side of the plain, to about 2,100 feet on the western edge near Weiser, Idaho.

The most downstream reach for this study, the Middle Snake-Boise sub-basin, extends from King Hill to Brownlee Dam and includes the western Snake River Plain. The western Snake River Plain is about 50 miles wide and 145 miles long (Newton 1991). The major tributaries in this region include: Payette River, Boise River, Weiser River, Owhyee River, Bruneau River, Malheur River, Powder River, and Burnt River.

For further information on the origin of the Snake Plain, suggested readings include Leeman (1982), Whitehead (1992), Pierce and Morgan (1992), and Geist and Richards (1993).

Hydrologic Units (HUCs)

The USGS, as part of the National Water-Quality Assessment (NAWQA) Program, describes the Upper Snake River Basin as including all drainage areas associated with the Snake River upstream of King Hill (Low, 1997). This follows the nomenclature set forth by the USGS in 1972 when a series of maps was initiated to standardize reporting and discussion of hydrologic features. Seaber (1987) provides the history of this effort and explains the concept of hydrologic unit maps in detail.

The system of nomenclature that was put into place by the USGS divides the United States into several large geographic basins or regions that represent hydrologic systems. Each large basin or region is then subdivided into smaller sub-basins with the smallest unit referred to as a cataloging unit. Each designated area has a unique identifying number and name.

Within the framework of hydrologic unit maps, the SR3 study area is located within the Pacific Northwest Region and consists of two sub-regions. The two digit numerical code for the Pacific Northwest Region is 17. The two sub-regions and their respective numerical codes are the Upper Snake-1704, and Middle Snake-1705, (Figure 4). The boundary between the two sub-regions crosses the Snake River near King Hill. Thus, the Middle Snake sub-region includes the area from King Hill downstream to Brownlee Dam. This puts the region from Milner to King Hill (locally called the Middle Snake) within the Upper Snake sub-region.

Each sub-region, or basin, is subdivided into accounting units. Within the SR3 study area there are four accounting units. These four accounting units or sub-basins (Figure 5), with their respective numerical codes include:

1. Snake Headwaters-170401,
2. Upper Snake-170402,
3. Middle Snake-170501, and
4. Middle Snake-Powder-170502.

The Middle Snake-Powder accounting unit, by definition, extends to the Hells Canyon Dam. The SR3 project extends as far as Brownlee Dam and does not include the Hells Canyon area.

The accounting units may be subdivided into cataloging units. The cataloging unit, as a geographical area, is the smallest subdivision within the terminology established by the USGS

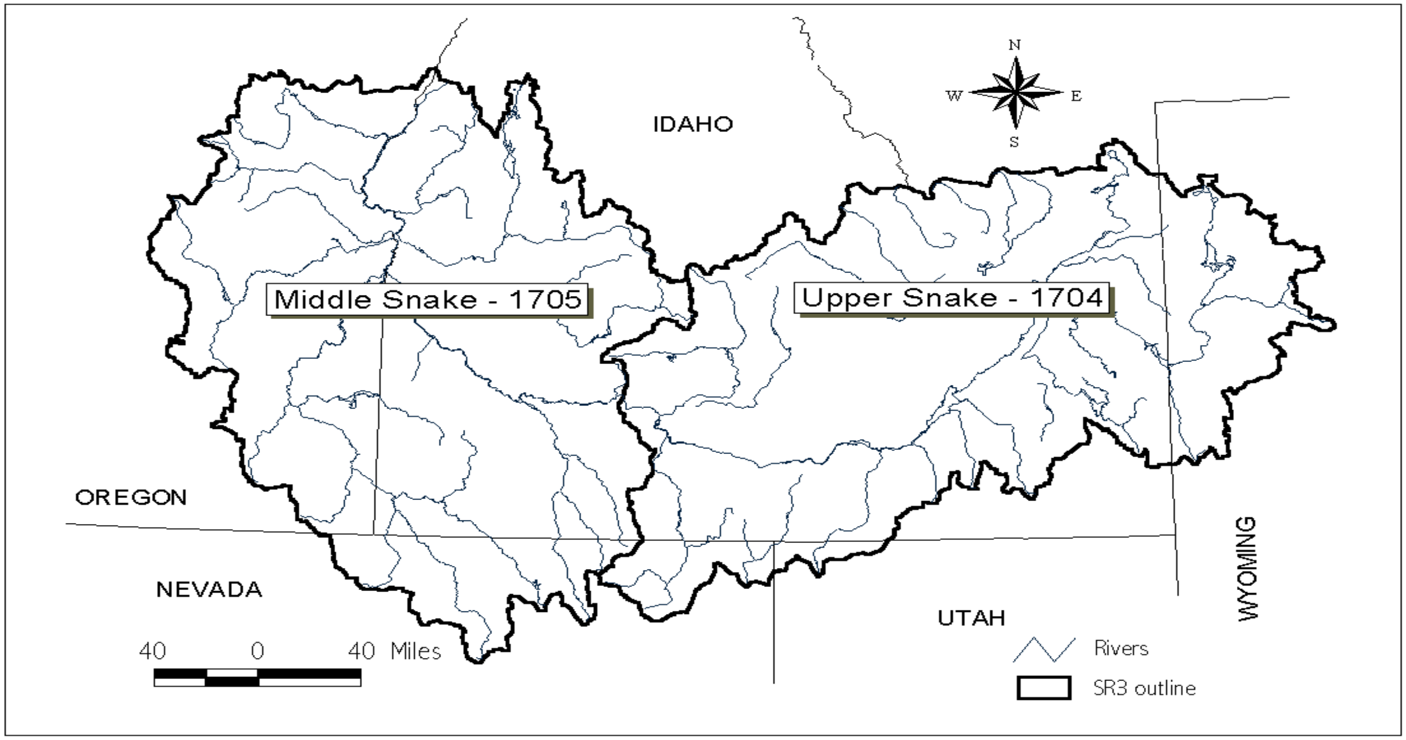
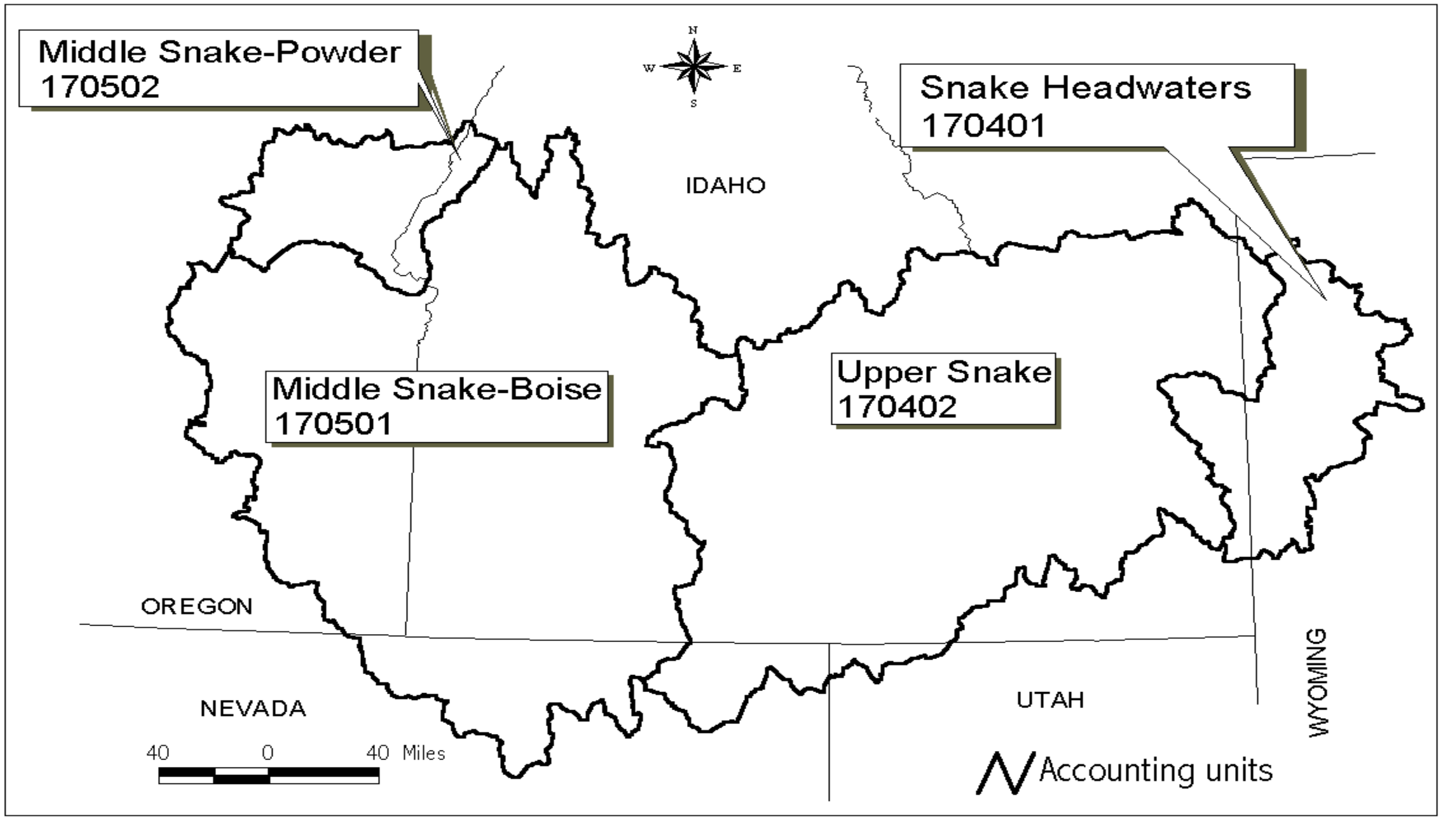


Figure 4. Map showing the location of the Middle and Upper Snake sub-regions.


Middle Snake-Powder
170502
Snake Headwaters
170401
N
W
E
S
IDAHO
Middle Snake-Boise
170501
Upper Snake
170402
OREGON
NEVADA
UTAH
WYOMING
40
0
40 Miles
Accounting units

(Tables 1 and 2). Within cataloging units, watersheds may be designated to identify each individual stream drainage. A cataloging unit may represent a portion of a basin (example - Upper Henrys), an entire catchment or basin (example - Little Lost), or a combination of drainage basins (example - Upper Snake-Rock).

In the SR3 study area, there are fifty-three cataloging units; twenty-six in the Upper Snake sub-basin (Figure 6) and twenty-seven in the Middle Snake sub-basin (Figure 7). Each of the various hydrologic entities, whether a region, sub-region, accounting unit, or cataloging unit, has a unique numeric hydrologic unit code. Regions have a 2 digit code, sub-regions a 4 digit code, accounting units a 6 digit code, and cataloging units an 8 digit code. The hydrologic unit codes gives rise to the acronym 'HUCs'. Often, HUCs are used synonymously with cataloging units.

McCammon (1994), suggests avoiding the terms accounting unit and cataloging unit all together, and in their place using, "River Basin and Sub-basin" respectively. The terms region, sub-region, accounting unit, and cataloging unit do not easily lend themselves to represent a hierarchy of biggest to smallest.

Ponce (1989) writes that the terms *basin* and *watershed* are used to describe catchment areas. A catchment is a geographical area that collects runoff and concentrates it at the most distant downstream point. Ponce makes the distinction that basin usually refers to large catchments, such as the Snake River Basin, while the term watershed represents smaller catchments, an example being the Henrys Fork watershed. Many of the watershed reaches within the SR3 study area are such well defined topographic basins that for much of the SR3 area, the term basin can be used interchangeably with watershed.

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Table 1. Upper Snake sub-region hydrologic units with numeric codes (after Seaber, 1987).

Sub-region 1704		Upper Snake: The Snake River Basin to and including the Clover creek Basin. Idaho, Nevada, Utah, Wyoming.		35,600 sq. mi.
	Accounting unit 170401	Snake Headwaters: The Snake River Basin above Kelly Mountain. Idaho, Wyoming		5,690 sq. mi.
		Cataloging Unit 17040101	Snake Headwaters, WY	1,680 sq. mi.
		Cataloging Unit 17040102	Gros Ventre, WY	638 sq. mi.
		Cataloging Unit 17040103	Greys-Hoback, WY	1,570 sq. mi.
		Cataloging Unit 17040104	Palisades, ID-WY	915 sq. mi.
		Cataloging Unit 17040105	Salt, ID-WY	887 sq. mi.
	Accounting Unit 170402	Upper Snake: The Snake river Basin from Kelly Mountain to and including the Clover Creek Basin. ID, NV, UT, WY		29,900 sq. mi.
		Cataloging Unit 17040201	Idaho Falls, ID	1,140 sq. mi.
		Cataloging Unit 17040202	Upper Henry's, ID-WY	1,090 sq. mi.
		Cataloging Unit 17040203	Lower Henry's, ID-WY	1,040 sq. mi.
		Cataloging Unit 17040204	Teton, ID-WY	1,130 sq. mi.
		Cataloging Unit 17040205	Willow, ID	645 sq. mi.
		Cataloging Unit 17040206	American Falls, ID	2,850 sq. mi.
		Cataloging Unit 17040207	Blackfoot, ID	1,080 sq. mi.
		Cataloging Unit 17040208	Portneuf, ID	1,320 sq. mi.
		Cataloging Unit 17040209	Lake Walcott, ID	3,670 sq. mi.
		Cataloging Unit 17040210	Raft, ID-UT	1,470 sq. mi.
		Cataloging Unit 17040211	Goose, ID-NV-UT	1,150 sq. mi.
		Cataloging Unit 17040212	Upper Snake-Rock, ID	2,440 sq. mi.
		Cataloging Unit 17040213	Salmon Falls, ID-NV	2,120 sq. mi.
		Cataloging Unit 17040214	Beaver-Camas, ID	982 sq. mi.
		Cataloging Unit 17040215	Medicine Lodge, ID	952 sq. mi.
		Cataloging Unit 17040216	Birch, ID	692 sq. mi.
		Cataloging Unit 17040217	Little Lost, ID	957 sq. mi.
		Cataloging Unit 17040218	Big Lost, ID	1,900 sq. mi.
		Cataloging Unit 17040219	Big Wood, ID	1,460 sq. mi.
		Cataloging Unit 17040220	Camas, ID	672 sq. mi.
		Cataloging Unit 17040221	Little Wood, ID	1,120 sq. mi.

Table 2. Middle Snake sub-region hydrologic units with numeric codes (after Seaber, 1987).

Sub-region 1705		Middle Snake: The Snake River Basin below the Clover Creek Basin to Hells Canyon Dam. Idaho, Nevada, Oregon.		36,700 sq. mi.
	Accounting Unit 170501	Middle Snake-Boise: The Snake River Basin below the Clover Creek Basin to and including the Weiser River Basin. Idaho, Nevada, Oregon.		32,600 sq. mi.
		Cataloging Unit 17050101	C.J. Strike Reservoir, ID	2,150 sq. mi.
		Cataloging Unit 17050102	Bruneau, ID-NV	3,290 sq. mi.
		Cataloging Unit 17050103	Mid. Snake-Succor, ID-OR	2,280 sq. mi.
		Cataloging Unit 17050104	Upper Owyhee, ID-NV	2,110 sq. mi.
		Cataloging Unit 17050105	South Fork Owyhee, ID-NV-OR	1,860 sq. mi.
		Cataloging Unit 17050106	East Little Owyhee, ID-NV-OR	910 sq. mi.
		Cataloging Unit 17050107	Middle Owyhee, ID-NV-OR	1,460 sq. mi.
		Cataloging Unit 17050108	Jordan, ID-OR	1,270 sq. mi.
		Cataloging Unit 17050109	Crooked-Rattlesnake, OR	1,340 sq. mi.
		Cataloging Unit 17050110	Lower Owyhee, OR	2,000 sq. mi.
		Cataloging Unit 17050111	North & Middle Forks Boise, ID	761 sq. mi.
		Cataloging Unit 17050112	Boise-Mores, ID	620 sq. mi.
		Cataloging Unit 17050113	South Fork Boise, ID	1,300 sq. mi.
		Cataloging Unit 17050114	Lower Boise, ID	1,300 sq. mi.
		Cataloging Unit 17050115	Middle Snake-Payette, ID-OR	294 sq. mi.
		Cataloging Unit 17050116	Upper Malheur, OR	2,430 sq. mi.
		Cataloging Unit 17050117	Lower Malheur, OR	927 sq. mi.
		Cataloging Unit 17050118	Bully, OR	577 sq. mi.
		Cataloging Unit 17050119	Willow, OR	773 sq. mi.
		Cataloging Unit 17050120	South Fork Payette, ID	813 sq. mi.
		Cataloging Unit 17050121	Middle Fork Payette, ID	338 sq. mi.
		Cataloging Unit 17050122	Payette, ID	1,240 sq. mi.
		Cataloging Unit 17050123	North Fork Payette, ID	912 sq. mi.
		Cataloging Unit 17050124	Weiser, ID	1,660 sq. mi.
	Accounting Unit 170502	Middle snake-Powder: The Snake River Basin below the Weiser River Basin to Hells Canyon Dam. Idaho, Oregon.		4,100 sq. mi.
		Cataloging Unit 17050201	Brownlee Reservoir, ID-OR	1,290 sq. mi.
		Cataloging Unit 17050202	Burnt, OR	1,090 sq. mi.
		Cataloging Unit 17050203	Powder, OR	1,720 sq. mi.

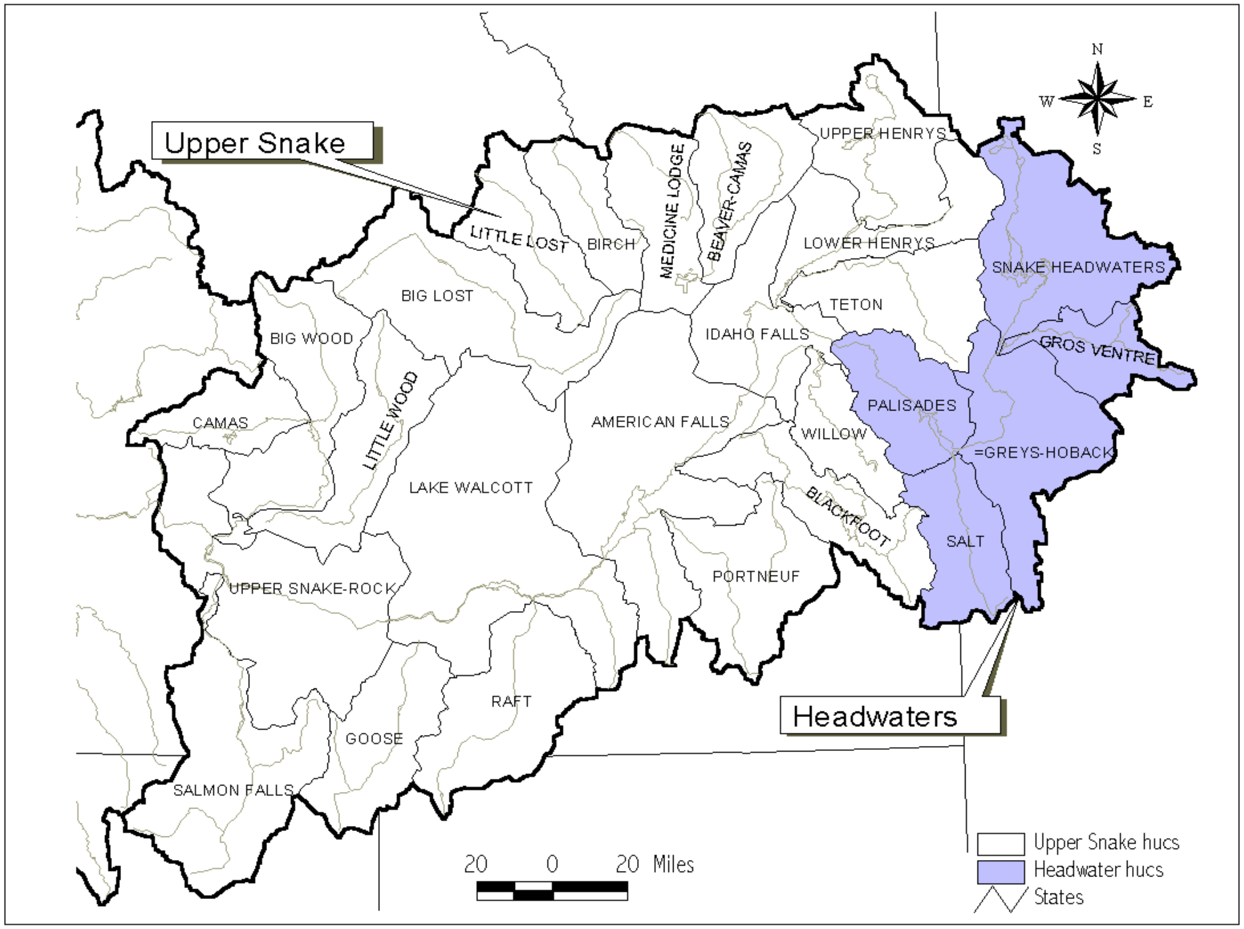

Figure 6. Map showing the cataloging units of the Upper Snake sub-region.

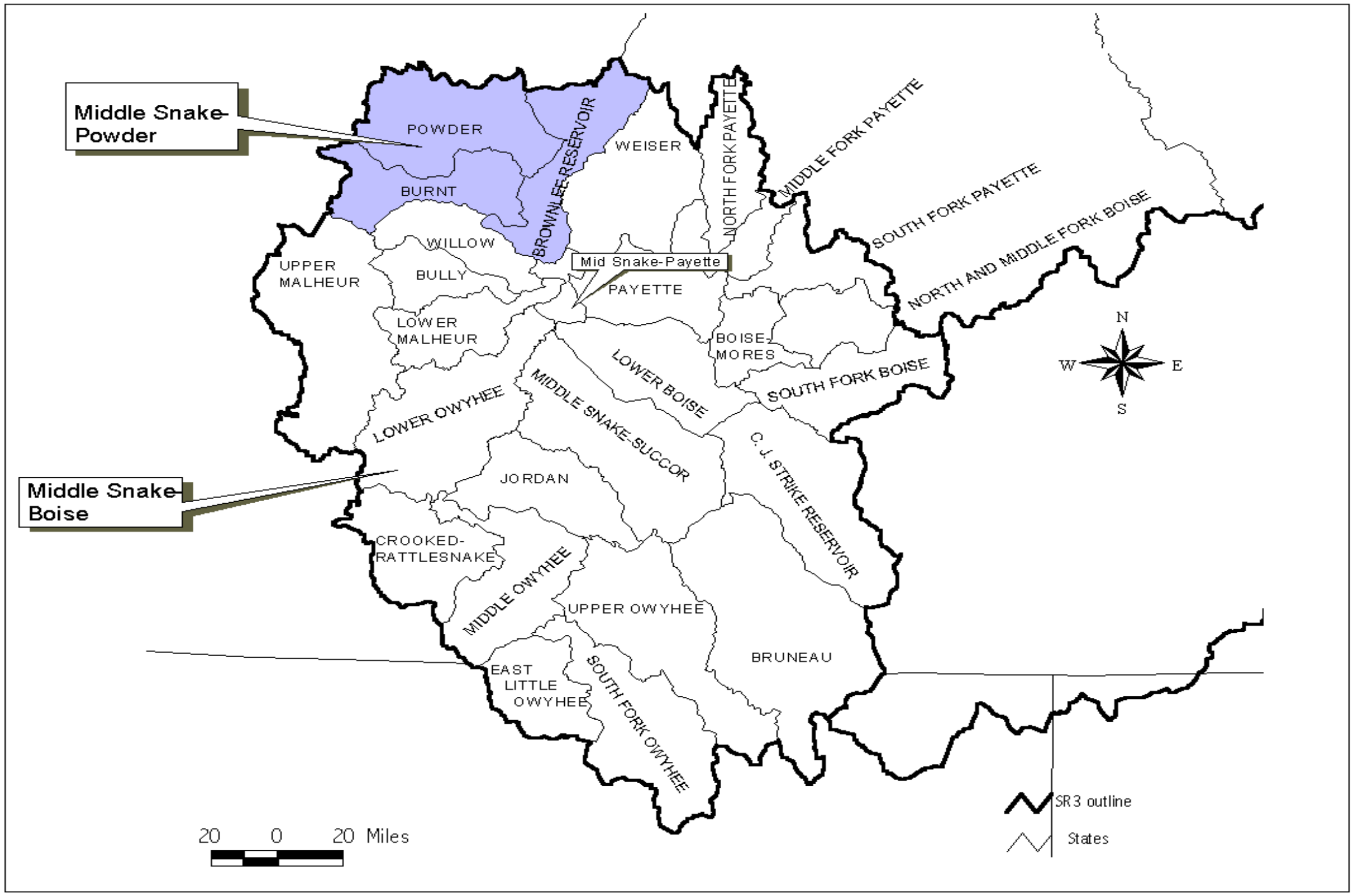

Figure 7. Map showing the cataloging units of the Middle Snake sub-region.

THE IMPORTANCE OF TRIBUTARY BASINS TO THE SNAKE RIVER

While the flow of water within the Snake River receives a tremendous amount of attention, it is necessary to take a closer look at the areas where the flow originates. Precipitation is the sole source of recharge in tributary basins. The Oregon Climate Service (Daly, 1998) created an average annual precipitation map for the Western United States covering the time period 1961-1990 (Figure 8). This map shows that within the Snake River Plain precipitation is less than 15 inches per year with some areas receiving less than 10 inches per year. Precipitation totals in the tributary basins can exceed 60 inches per year. These maps were created using the Parameter-Elevation Regressions on Independent Slopes Model (PRISM).

Two factors stand out as reasons to include tributary basins when discussing the flow of water within the Snake River. First, the majority of recharge occurs within the tributary basins. Second, the large areas associated with the tributary basins provide opportunities for development and use of water within the tributary basins themselves. Use of water within a tributary basin can affect the quantity and timing of water availability to the Snake River. The Tributary Basin Concept and various basin-river relationships are presented in this section to aid in understanding the relationship between the Snake River and its associated tributary basins.

Tributary Basin Concept

Consider what constitutes a tributary basin. Are the drainage area and the water contributions associated with any stream tributary to the Snake River considered a tributary

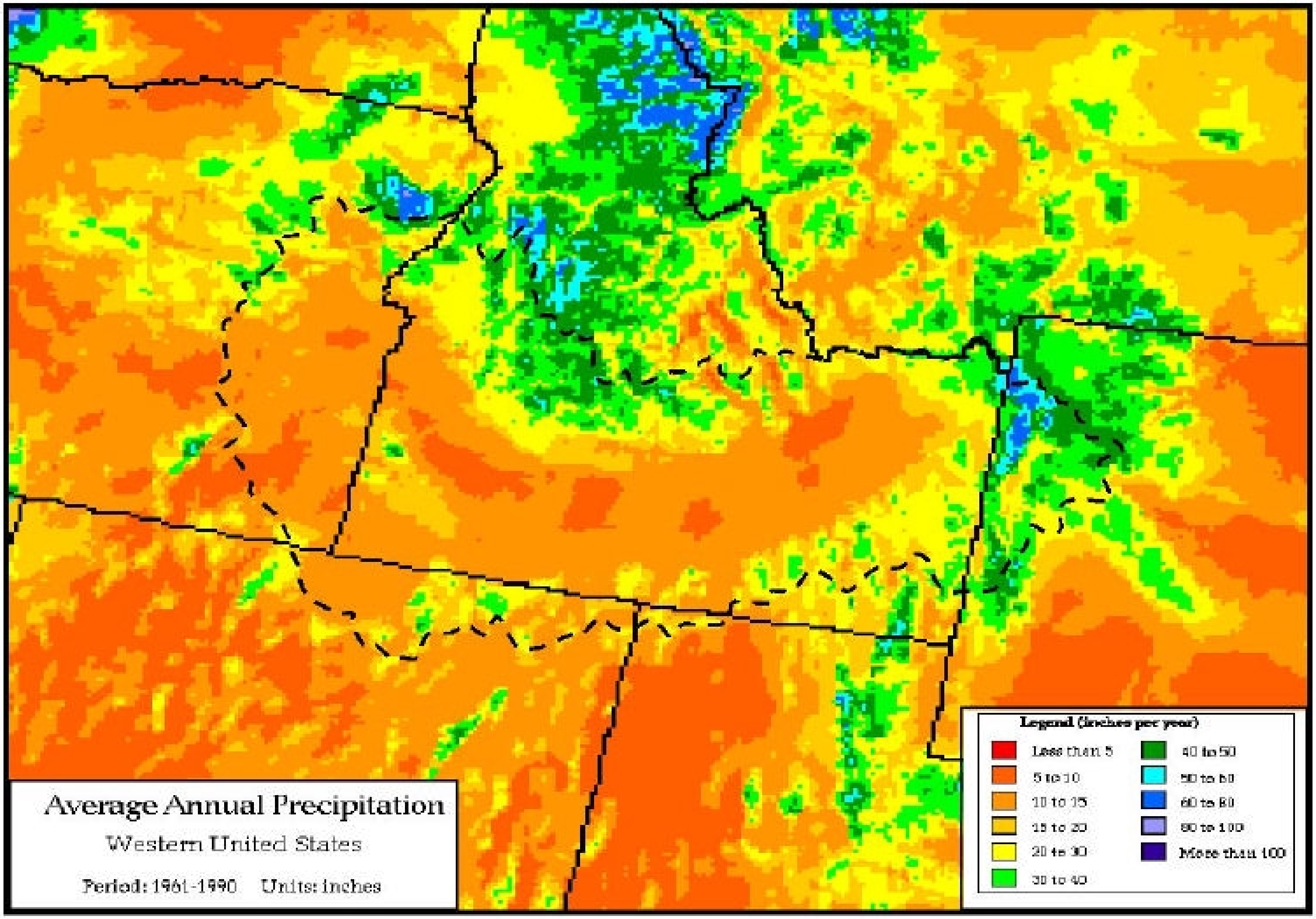

Figure 8. Map showing mean annual precipitation (PRISM) after Daly, 1998.

basin? Accessible through the State of Nevada home page (www.state.nv.us/) the Nevada Division of Water Planning has posted a “Water Words Dictionary,” including the following definitions of BASIN and TRIBUTARY:

- “BASIN— A geographic area drained by a single major stream; consists of a drainage system comprised of streams and often natural or man-made lakes. Also referred to as Drainage Basin, Watershed, or Hydrographic Region.
- TRIBUTARY—(1) A stream which joins another stream or body of water. (2) A stream or other body of water, surface or underground, which contributes its water, even though intermittently and in small quantities, to another and larger stream or body of water.”

Using the two definitions above, a basin tributary to the Snake River represents a geographical area with a stream or other body of water, surface or underground, that contributes water to the Snake River, even in small or intermittent quantities. With so many streams and rivers that deliver water to the Snake River, the scale or size of a basin has to be considered in allocating resources for studies or management programs.

Snake River Basin: River-Tributary Basin Relationships

In a natural system, prior to any man-made developments, the amount of water that enters a ground water system is equal to the amount of water that leaves the system, plus or minus any change in storage. Sources of water which replenish the aquifer or ground water system, referred to as recharge, include: (1) precipitation that infiltrates down to the water table, (2) stream losses, and (3) underflow contributions. In seasons where precipitation is higher than normal, the increased supply of water would increase the amount of water in storage (raising the water table, or the potentiametric surface) and thus increase the amount of water leaving the system (higher spring discharge, stream flows, evapotranspiration, ground water underflow).

A great deal of concern exists about the effects of ground water pumping on a given hydrologic system. Newton (1991, p. G22-23) describes how water table fluctuations can affect stream flow for a river-aquifer system that is hydraulically interconnected:

> “Rivers may contribute water to or receive water from the ground-water system, depending on whether ground-water levels are above or below river stage. A river loses water when aquifer head is below river stage and gains water when aquifer head is above river stage.”

Ground water pumping in the interconnected Snake River Basin can reduce stream flow in several ways. If that portion of the Snake River (or tributary stream) in question is a losing stream and is hydraulically interconnected with the aquifer, pumping would result in an increase in the amount of water leaving the river and flowing into the aquifer. This would reduce the amount of flow in the river. If the section of the river in question is a gaining stream, the pumping effects would reduce the amount of river gain, still causing a reduction in flow.

Many different hydrologic relationships could exist between a river and its tributaries. Within the Snake River Basin, three main categories are readily identified:

A. A tributary stream that is not connected to the Snake River.

B. A tributary stream that is connected to the Snake River. Surface water and ground water are not hydraulically interconnected.

C. A tributary stream connected to the Snake River. Surface water and ground water are at least partially interconnected.

Ground water withdrawal or recharge within a tributary basin can affect the amount of flow within the Snake River. The effects of pumping or recharge in categories A and B would generally have a long lag time. Lag time refers to the time difference from when a stress on the system begins until the effects of that stress are observed. In this example, the effects of consumptive use of ground water would not be fully manifested on flow of the Snake River for a long time. Depending on the distance between the well and the river reach in question, the full impact of the pumping may not be observed for a hundred years or more (Johnson and others, 1993).

Impacts on flow in the Snake River, associated with long time lags, can continue to increase in magnitude for a long time, even after pumping has ceased (Jenkins, 1968). This means that if pumping were causing an undesirable response, turning off the pump would not immediately resolve the problem. This necessitates caution in long term planning.

Different areas within the eastern Snake River Plain have been identified which correspond to the three categories mentioned. The following are examples of tributaries assigned to these different categories.

> **Category A-Examples** In the northeastern portion of the Snake River Plain, located within the State of Idaho, there are several streams which Reclamation grouped in their SR3 Blueprint (1996) under the heading “Streams that disappear into the Snake Plain Aquifer” (Figure 9). These streams, located on the northern portion of the Upper Snake sub-basin, are not tiny ephemeral streams. The largest of the group, the Big Lost River, annually delivers more than 200,000 acre-feet of water that travels down the river to “disappear” or infiltrate into the Snake River Plain. Others in this group include Camas-Beaver Creek, Medicine Lodge Creek, Birch Creek, and Little Lost River. Combined, these basins are the source for over 9 percent (945,000 ac-ft) of the annual water contributions to the Upper Snake River Basin (data from Kjelstrom, 1986).

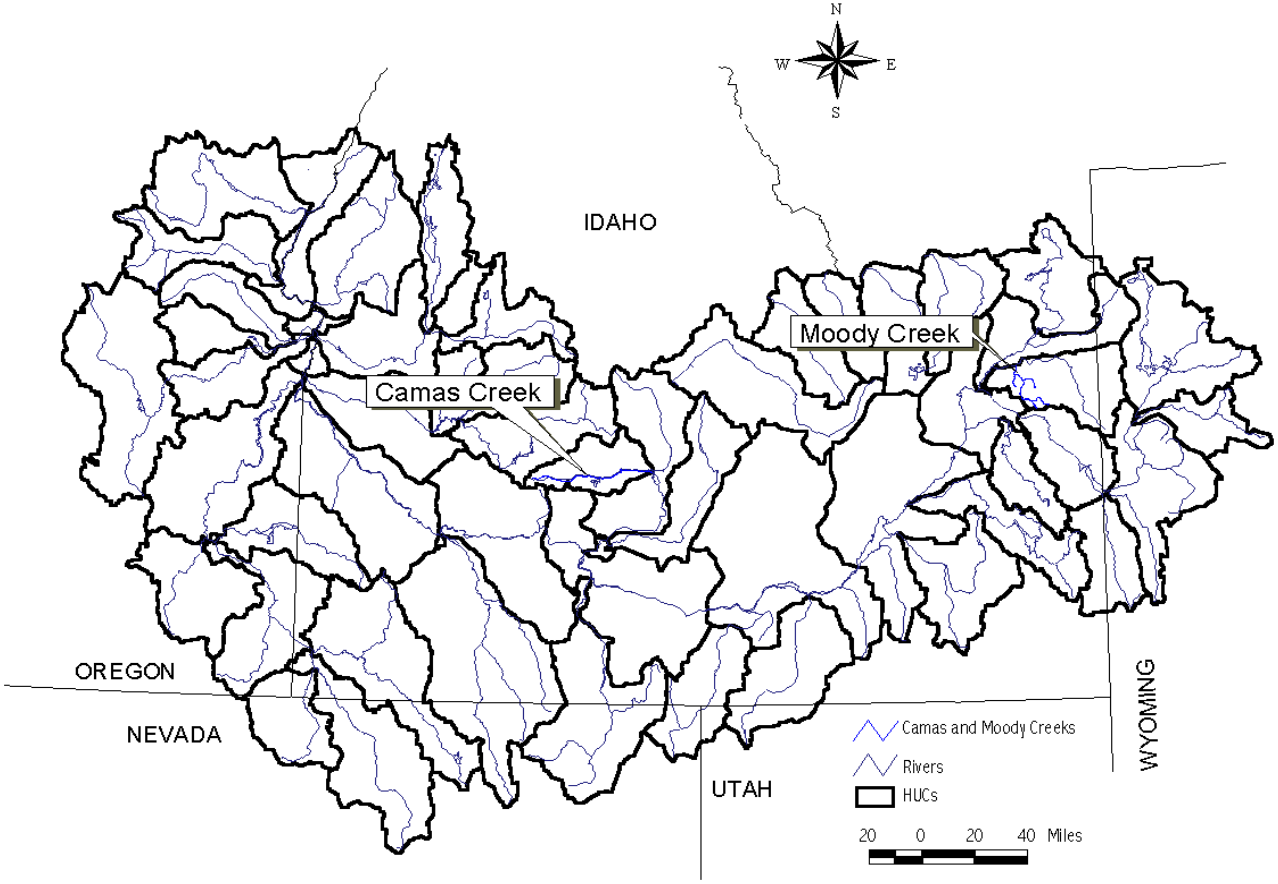

Figure 10. Map showing the location of Camas Creek and Moody Creek, Idaho.

Category B-Examples: IDWR (1997) has described the Rexburg Bench-Moody Creek region as an area that is not hydraulically interconnected with the regional aquifer. In another example, Horn and Jeong (1989), have suggested a similar interpretation describing the Camas Creek basin, Idaho (Figure 10). In the Camas Creek basin, located in central Idaho, ground water pumping from a possible deeper aquifer level does not seem to have a diminishing effect on stream flows. On the contrary, their conclusions indicated that return flows from irrigation practices served to augment stream flows, especially in the fall of the year.

Category C-Examples: The third category represents most of the tributary basins. Most of the tributary streams are considered to have at least some degree of interconnectedness with their associated aquifers. It may be difficult in some areas to determine if the associated ground water is the regional system or a perched zone.

Adverse impacts from ground water pumping in these areas would affect flows in the Snake River in two ways. First, any reduction in tributary stream flows as a result of ground water withdrawals would have an immediate negative impact on flow of the Snake River. The second type of impact is associated with propagation of the pumping effects through the aquifer to the Snake River. This less direct connection provides effects that are greatly attenuated. Johnson and others (1993) showed that a well pumping in the lower reaches of the Big Lost River tributary basin would have time lags of 10 to 25 years prior to affecting flows in the Snake River.

Some beneficial uses seem to be mutually exclusive. While in-stream flows in the Snake River serve to maintain a healthy aquatic environment, this reduces the amount of water that could have been used to increase the volume of water stored in the Snake River Plain aquifer. At the same time, when water is diverted for agriculture, the remaining quantity of water in the river may not be adequate to meet the needs of the aquatic plants and animals. All uses of water have a resulting impact on other associated uses or applications of water in the system.

CONJUNCTIVE MANAGEMENT

Conjunctive management is the tool used by administrators to manage surface water and ground water that is hydraulically interconnected as one complete system. Surface water reached a high level of appropriation in many areas of the western states prior to any significant ground water development. Consequently, under the Prior Appropriation Doctrine, conjunctive management sets the stage to address conflicts between senior surface water users and junior ground water users.

Three events seem to have brought conjunctive management into the forefront at this time. First, the general understanding of hydrologic systems and the ability to convey that understanding to water managers and public officials has increased through the use of computer models. Second, changes in irrigation practices and increased ground water pumping have resulted in profound impacts on stream flow and ground water levels. It was only after many years of implementation of these practices that the impacts became apparent. Third, successive years of drought and resulting shortages of surface water have contributed to increasing concerns among water users.

Western states have been developing their individual rules for conjunctive management. Some examples from the states of Colorado, Oregon, and Idaho are presented to demonstrate the importance of considering ground water and surface water interactions.

Colorado

Colorado entered into conjunctive management practices in the late 1960's. As their water management evolved, Colorado established two categories for ground water; tributary and non-tributary (Spronk, 1994; Getches, 1994). As presented by Spronk (1994, p. 19) non-tributary ground water was defined in 1985 by the Colorado Legislature as:

> “...ground water outside any designated basin, the withdrawal of which will not in 100 years

deplete stream flow at an annual rate greater than 0.1% of the rate of withdrawal."

Getches (1994) suggests that most ground water in Colorado is considered tributary, stating that the courts adopted a "presumption of tributariness". Even if an area could be shown to be non-tributary, there still exists some control over pumping. In some of these areas, appropriations were limited to deplete "40% of available underlying ground water over a 100-year period" (Spronk 1994, p. 19,21).

Oregon

Within the section of Oregon's Administrative Rules entitled, "GROUND WATER INTERFERENCE WITH SURFACE WATER," are the rules for areas that are hydraulically connected. Section 2 under heading 690-009-0040 states:

> "All wells located a horizontal distance less than one-fourth mile from a surface water source that produce water from an unconfined aquifer shall be assumed to be hydraulically connected to the surface water source, unless the applicant or appropriator provides satisfactory information or demonstration to the contrary..."

In addition, the rules continue to expound on potential impacts on surface waters from wells in a hydraulically interconnected system. Section 4 in the same location of the rules, establishes that wells are:

> "...assumed to have the potential to cause substantial interference with the surface water source if the existing or proposed ground water appropriation is within one of the following categories:
>
> a. The point of appropriation is a horizontal distance less than one-fourth mile from the surface water source; or
> b. The rate of appropriation is greater than five cubic feet per second, if the point of appropriation is a horizontal distance less than one mile from the surface water source; or
> c. The rate of appropriation is greater than one percent of the pertinent adopted minimum perennial streamflow or instream water right with a senior priority date, if one is applicable, or of the discharge that is equaled or exceeded 80 percent of time, as determined or estimated by the Department, and if the point

> of appropriation is a horizontal distance less than one mile from the surface water source; or
>
> d. The ground water appropriation, if continued for a period of 30 days, would result in stream depletion greater than 25 percent of rate of appropriation, if the point of appropriation is a horizontal distance less than one mile from the surface water source. Using the best available information, stream depletion shall be determined or estimated by the Department, employing at least one of the following methods...”

The approved methods for establishing stream depletion effects include published computational or graphical techniques such as Jenkins (1968), or the use of computer programs or ground water models that are based on the same accepted theory. These rules tend to put the burden of proof on the appropriator, for those wells less than one-fourth mile from a stream, to show they are not impacting surface flow. The requirements in Category d. would seem to exclude impact assessment for most wells that may have significant effects but with a long time lag.

The State of Oregon has provided public access to their Administrative Rules by way of the Internet. The location for these rules is: http://arcweb.sos.state.or.us/rules/.

Idaho

At the present time, Idaho has not yet adopted rules to quantify stream depletion impacts from individual wells. Also, Idaho has not addressed whether tributary or non-tributary conditions exist outside of the Snake River Plain aquifer. The Idaho Department of Water Resources has addressed conjunctive management on a more regional scale and employed several levels of designations or categories to address the different needs associated with ground water management (IDWR, 1996). Currently, there exist four different types of ground water management designations:

- Critical Ground Water Areas,

- Ground Water Management Areas,
- Ground Water Measurement Districts, and
- Ground Water Districts.

Critical Ground Water and Ground Water Management Area designations provide the director of IDWR increased authority to help manage ground water and, if necessary, reduce diversions on a time priority basis to meet the sustainable capacity of the area. The following sections and Figures 11 and 12 explain the use of the different designations, and where they currently exist. Definitions for Critical Ground Water Areas and the Ground Water Management Areas are from Grant, (part two of Ralston and others, 1984).

Critical Ground Water Areas

A Critical Ground Water Area is defined by the State of Idaho as:

> "any ground water basin, or designated part thereof, not having sufficient ground water to provide a reasonably safe supply for irrigation of cultivated lands, or other uses in the basin at the then current rates of withdrawal, or rates of withdrawal projected by consideration of valid and outstanding applications and permits, as may be determined and designated from time to time, by the Director of the Department of Water Resources" (Ralston and others, 1984, p. 113).

South of the Snake River, management of available water has required more stringent regulations. At the present time, seven out of eight designated Critical Ground Water Areas are located south of the river (Figure 11.)

Ground Water Management Areas

Ground Water Management Areas were created as a tool to help regions avoid achieving critical status (Figure 11). They are defined as:

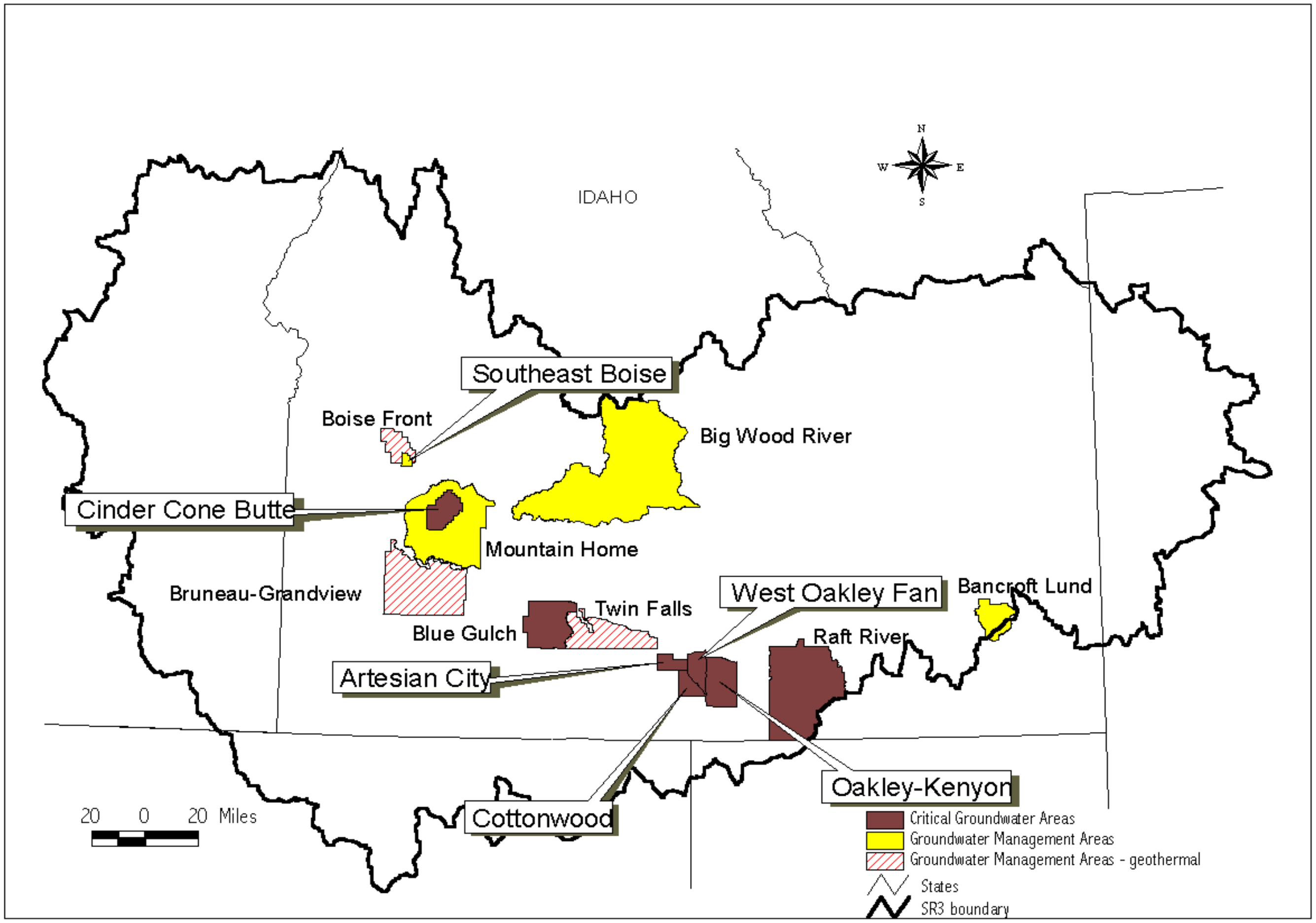

Figure 11. Map showing the location of Ground Water Management Areas, Idaho.

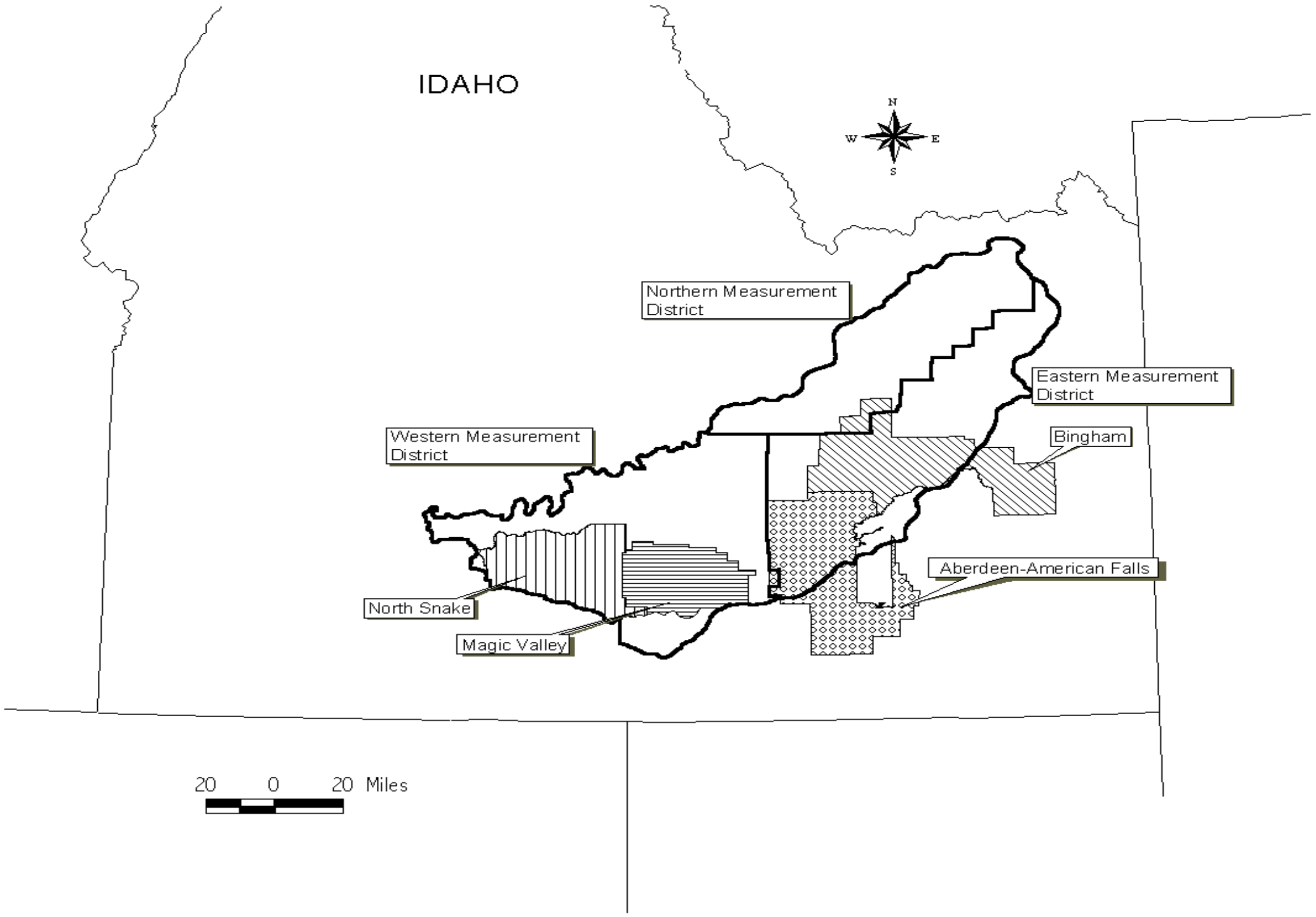

Figure 12. Map showing the location of Groundwater Districts and Groundwater Measurement Districts.

> "any ground water basin or designated part thereof which the Director of the Department of Water Resources has determined may be approaching the conditions of a Critical Ground Water Area." (Ralston and others, 1984, p. 113).

Ground Water Districts

Ground Water Districts are entered into voluntarily. They are required to measure and report all ground water diversions permitted in excess of 0.24 cfs. In addition, these entities have broader authorities including; the ability to own property (e.g. water rights), manage and operate recharge projects, and to develop and enter into mitigation plans. Figure 12 shows the location of the four current Ground Water Districts associated with the Snake River Plain aquifer. Table 3 is a summary of the name and date of designation for the different water district areas (IDWR, 1996).

Table 3. Ground Water Districts and Ground Water Measurement Districts, Idaho.

Ground Water Districts		
	Date Formed	Location (counties)
North Snake	Nov. 1995	Gooding, Jerome, Lincoln
Magic Valley	Dec 1995	Minidoka, Jerome, Lincoln, Cassia
Aberdeen-American Falls	Feb. 1996	Bingham, Power
Bingham	Aug. 1996	Bingham
Ground Water Measurement Districts (East Snake Plain Aquifer) Created 10/24/96		
East	Fremont, Madison, Jefferson, Bingham, Bonneville, Caribou, Bannock, Power, and Blaine	
North	Fremont, Clark, Jefferson, and Butte	

Ground Water Measurement Districts

Ground Water Measurement Districts have been created by the State of Idaho for the Eastern Snake River Plain. These measurement districts were created to ensure that all water diversions within the boundary of the Snake River Plain aquifer are measured, especially all ground water diversions. Inclusion of all ground water users within the districts, pumping in excess of 0.24 cfs, was mandated by the state unless users were part of a Ground Water District. Measurement of water is the exclusive function of this entity (Figure 12).

Conjunctive management allows managers to address impacts of junior ground water users on senior surface water appropriators. While these impacts have been recognized within the Snake River Plain, they also exist within the extended tributary basins.

Ground Water Models

Since the early 1970's, numerical ground water models have been applied to aid in understanding aquifer systems. All of the numerical ground water models applied within the Snake River Plain are finite difference models.

Ground water models provide a means of representing the complex interactions between surface water and ground water. In general, the models are a very simplified representation of the actual ground water-surface water system. Ground water models can be created on different scales. Large regional studies, such as Garabedian’s (1992) Eastern Snake River Plain model, can cover many thousands of square miles. Local, and generally more detailed models, such as Cosgrove and others (1997) Twin Falls model may cover on the order of 700 to 800 square miles.

Recent models generated for areas within the Snake River Basin are summarized below. The location of each model is shown on Figure 13.

- Oakley Fan Area – The model consists of two layers and included a transient state calibration (Young and Newton, 1989).
- Mud Lake Area – This model used five layers and was calibrated to steady state conditions for the calendar year 1980 (Spinazola, 1994).
- Twin Falls Area - The University of Idaho, through the Idaho Water Resources Research Institute (IWRRI), has recently completed a single layer ground water model with transient state calibration for the Twin Falls, Idaho area (Cosgrove and others, 1998).
- Eastern Snake Plain Aquifer - The University of Idaho, through IWRRI, contracted by the U.S. Bureau of Reclamation, is working with the Idaho Department of Water Resources to extend and upgrade the ground water model for the Snake River Plain aquifer.
- Treasure Valley Hydrologic Project - Located in the Boise, Idaho area. The Treasure Valley Hydrologic Project is a four layer model and is currently undergoing transient state calibration (personal communication with Scott Urban, IDWR). Additional information regarding location of the project, project participants, funding, status, etc., is available at their web site: www.idwr.state.id.us/idwr/info/tec/tvhpmain.htm .
- Silver Creek - This ground water model, by University of Idaho, through IWRRI , is under development in the Silver Creek area (personal communication with Clarence Robison).

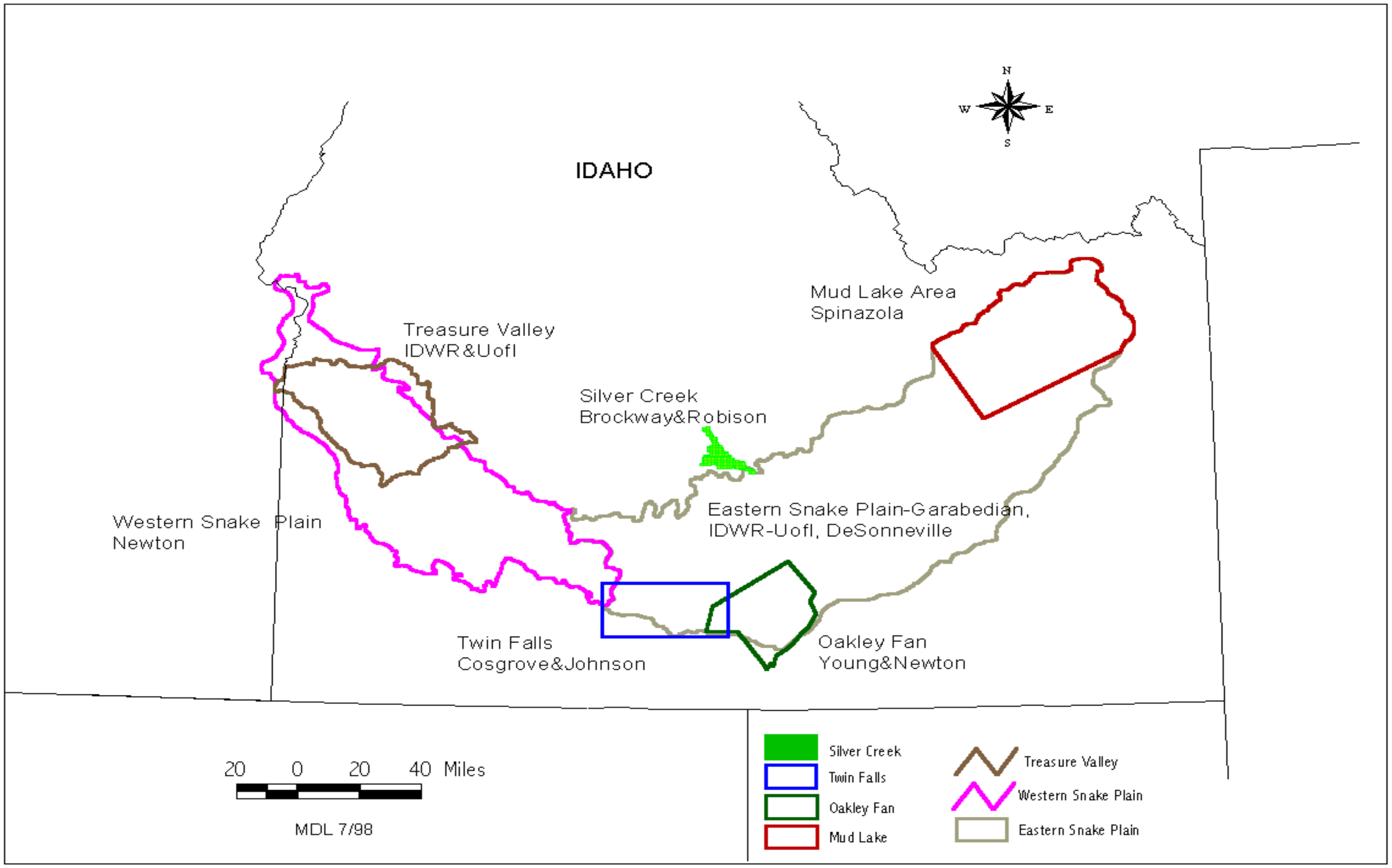

Figure 13. Map showing the location of recent groundwater models.

Included on Figure 13 is the location of the ground water model for the Western Snake River Plain by Newton (1991). Newton built a three layer model with a transient state calibration. The ground water model for the Eastern Snake River Plain that was created by Garabedian (1992) is not shown because it is essentially in the same location as the updated IDWR - University of Idaho model. Garabedian’s model is four layers with a transient state calibration. The IDWR-University of Idaho model is one layer with a transient state calibration. Table 4 is a partial summary of recent ground water models and the authors.

Table 4. Partial list of recent ground water models within the Snake River Plain, Idaho.

LOCATION	DATE	AUTHOR
Rigby Fan/Snake Plain	1972-74	DeSonneville
Henry’s Fork and Rigby Fan	1980	Wytzes
Eastern Snake Plain Aquifer	1985	Johnson and others
Oakley Fan Area	1989	Young and Newton
Western Snake Plain Aquifer	1991	Newton
Eastern Snake Plain Aquifer	1992	Garabedian
Mud Lake (Upper Snake River)	1994	Spinazola
Twin Falls	1998	Cosgrove and others
Silver Creek	in progress	Brockway and Robison
Treasure Valley Hydrologic Project	in progress	IDWR and others

CONCEPTS USED FOR RANKING OF THE TRIBUTARY BASINS

Due to the size of the Snake River Basin, managers must be judicious in deciding where to assign resources for further studies. Most investigations are performed to increase ability to more efficiently manage water resources, resolve disputes over water allocation, and to address concerns relating to water quality. The next area of focus in this study is how to categorize or rank the tributary basins for future investigations.

The Need to Prioritize

The resources (money and labor) at the disposal of federal agencies such as the U.S. Bureau of Reclamation and the U.S. Geological Survey, plus the various state agencies, are subject to ever-increasing competition. At the same time, pressures exerted by demands on the natural resources, especially water, continue to grow. Whether the needs are for agriculture, wildlife, logging, fish habitat, mining, ranching, recreation, industry or domestic use; Idaho and its neighboring states are experiencing increasing demands on natural resources. The reality of limited funding to address the needs of such a mammoth area, with the potential for almost endless numbers of useful studies, mandates that some means be established to help determine where the resources should be expended.

Several methodologies to classify or rank the tributary basins have been proposed within the Upper Snake River Basin in Idaho (IDWR, 1997; Ralston and others, 1984). Applying these ideas on a larger, basin-wide scale, as compared with the more local region in which they were proposed, is discussed below.

Tributary Basin Classification Concepts

The characteristics of the tributary basins vary greatly across the study area. The following is a list of attributes by which basins could be classified:

1. Amount of water discharged
2. Level of development (amount of diversions and consumptive use)
3 .Geographical location (state, eastern plain, western plain, etc.)
4. Elevations and timing of water release
5. Drainage area of the basin
6. Water quality (salmonid spawning, cold water biota, etc.)
1. Hydraulic connection of surface water and ground water
2. Time lags (time required for pumping effects to be observed at a designated place such as: less than 1 month, less than 1 yr, less than 5 yrs, etc.)
3. Basins without surface water discharge to the Snake River.

Most studies are “needs driven” meaning that the resources are expended when motivated by a need or a problem. The distribution of monitoring wells is a good example of this concept (Figure 14). Where water availability has been in question, more effort has been expended to better define the problem. The demand for additional studies with limited resources requires that a prioritization of needs be established. The various tools and levels of investigation must be considered in connection with establishing priorities of which basins to study.

The IDWR utilizes a system of Administrative Basins to segment the state into areas of common hydrologic conditions for management purposes. In many regions, the Administrative Basins cover similar geographic areas as the cataloging units (HUCs) of the USGS.

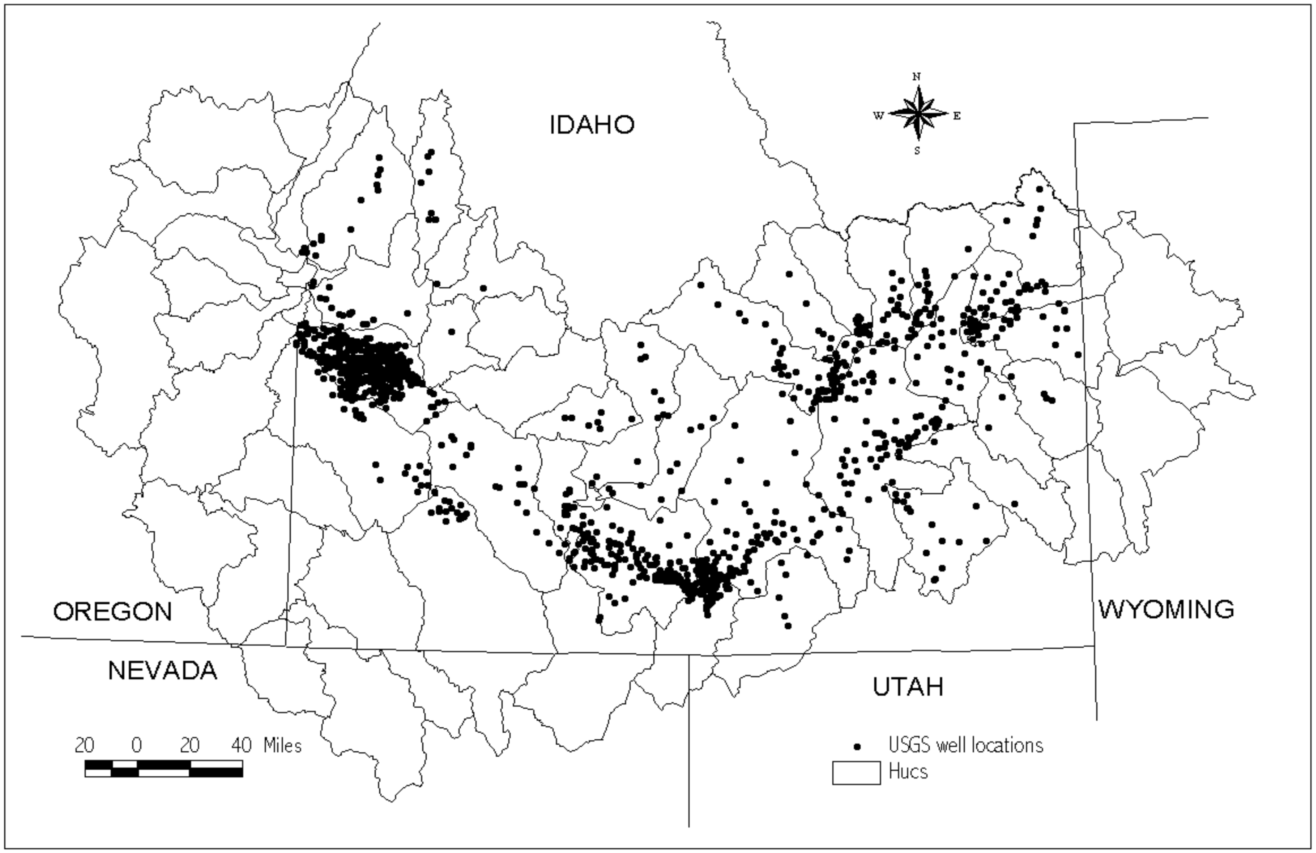

Figure 14. Map showing the location of all active USGS monitoring wells.

The Teton Basin is an example where the USGS (HUC 17040204) and IDWR (BASIN 22) are in close agreement up to the state line (Figure 15). In general, IDWR basins not directly associated with the Snake River Plain are larger than the HUCs in the same location.

IDWR has performed preliminary studies for twenty of the tributary basins associated with the Eastern Snake River Plain (IDWR, 1997). The twenty basins do not necessarily follow IDWR's own administrative basin designations. For example, Administrative Basin 22 is the Teton River-Moody Creek area in eastern Idaho. In IDWR's study of the tributary valleys, the Rexburg bench (Moody Creek) area was separated from the rest of the Teton Basin.

The Rexburg bench example is mentioned only to emphasize that defining what constitutes a tributary basin, and at what scale a study should be undertaken is not trivial. The Rexburg bench, with the expanse of irrigated agriculture, is a more active participant in water use than many of the other better defined basins.

In presenting their preliminary study, IDWR (1997) invoked a ranking system with the following three categories based on the level of ground water development:

1. *High Priority* – Total authorized ground water diversion rate exceeds 500 cfs, and a high growth rate based on historic trends (water rights, land use, and water levels).
2. *Medium Priority* – Total authorized ground water diversion rate between 100 cfs and 500 cfs, and a medium growth rate based on historic trends (water rights, land use, and water levels).
3. *Low Priority* – Total authorized ground water diversion rate less than 100 cfs,

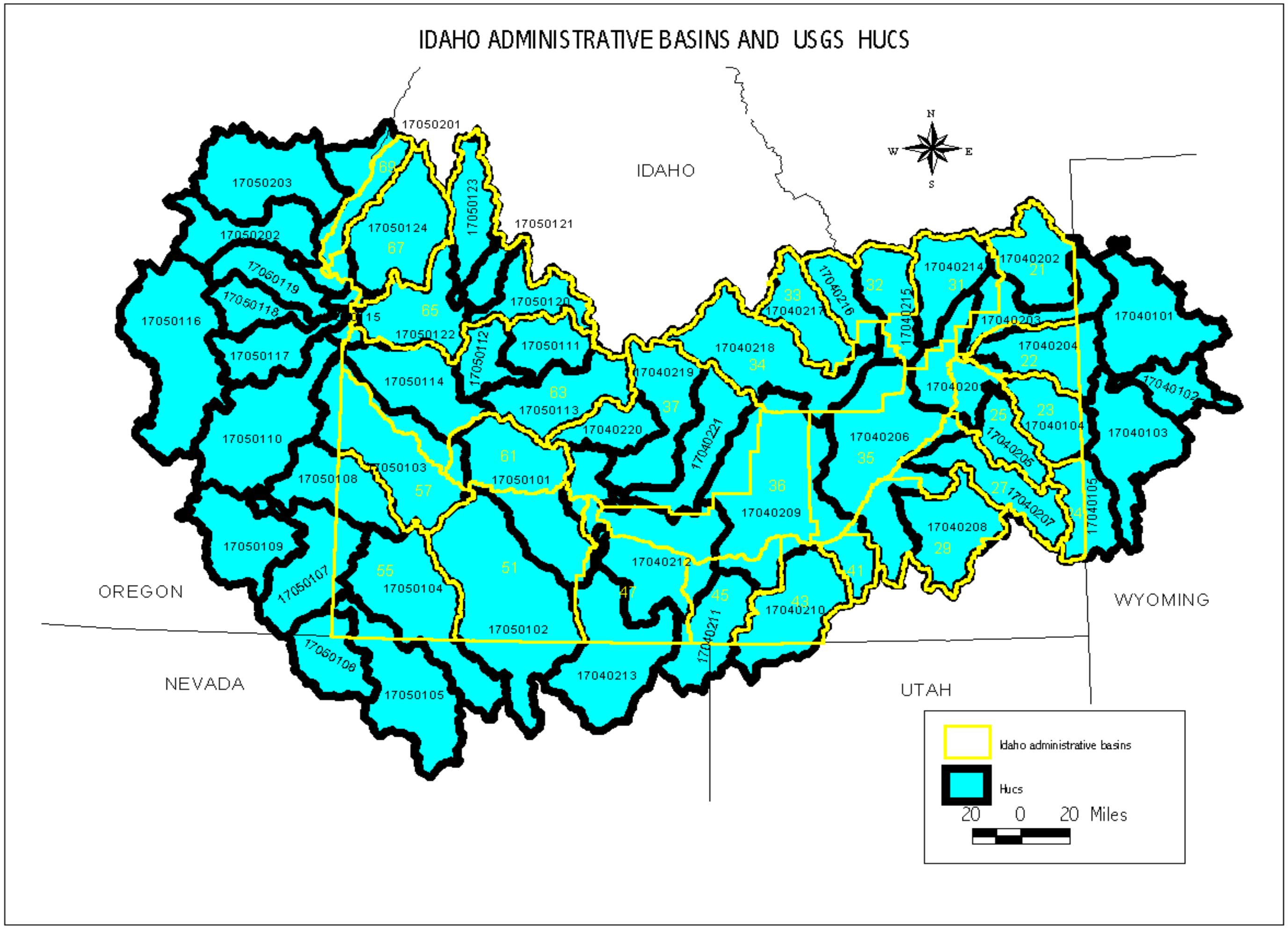

Figure 15. Map showing cataloging units (HUCs) and Idaho Administrative Basins.

and a low growth rate based on historic trends (water rights, land use, and water levels).

This method of prioritization focuses on potential problems with water quantity. This approach addresses the disputes over water allocation which have prompted many of the recent studies. This technique may not adequately address the water quality problems that seem to be developing in the shallow ground water areas associated with domestic or municipal growth, industrial growth, and associated agricultural activities.

Ralston and others (1984) looked at the time lag between ground water withdrawals and a reduction in discharge to the Snake River. The time lag, as well as the magnitude of the pumping effects are also useful qualifiers for ranking basins as shown in the section on Conjunctive Management.

The following criteria were identified by Ralston and others (1984) as being necessary to evaluate the effects of water use in tributary basins on stream flow within the Snake River:

- The amount of water each tributary basin contributes to the flow of the Snake River,
- The size and extent of the basin,
- The major aquifers and their geologic properties,
- Aquifer properties of transmissivity and storativity,
- Any surface water and ground water interconnections,
- Annual water yield for the basin,
- Information on ground water pumpage, and
- Information related to surface and ground water discharge.

Methodologies used to establish these criteria are set forth in the same paper.

Understanding the reliability of the data or how well the data represents reality is important. The first item listed above represents the sum of stream flow and or ground water underflow. Stream gage measurements can provide reliable data for measuring surface flows. It is more difficult to determine the amount of water recognized as underflow.

Kjelstrom (1986) ranked the accuracy of all discharge data as good, fair, and poor. Most stream gage data was considered good while all estimates of ground water discharge were considered poor. The ranking doesn’t imply that ground water discharge data are of no value. Estimating the quantity of ground water that is discharging out of a basin is difficult. The estimates require accurate data on aquifer transmissivity, hydraulic gradient, and/or accurate water budget information.

In the Ralston and others (1984) study, a water budget was developed to determine the amount of water available in each tributary basin. A water budget is a means of accounting for all water that enters into or leaves a basin (recharge and discharge). Often it is through this accounting process that an estimate of ground water discharge is established. More precise precipitation and land use (crop types) data will allow more accurate water budget assessments of ground water discharge.

Basin-Wide Versus Regional Ranking

The criteria proposed for ranking tributary basins should be considered in the context of the entire Snake River Basin located within the SR3 study area. There are at least four natural divisions or breaks in the continuity of the Snake River and its associated tributary basins. These geohydrologic features were probably the logic behind the initial establishment of the four accounting units. Each of these regions can be viewed as large gathering systems with a smaller defined outlet, similar to a funnel (Figure 16). It is at these ‘funnel ends’ that the relative proportion of ground water to total discharge is minimized, consequently

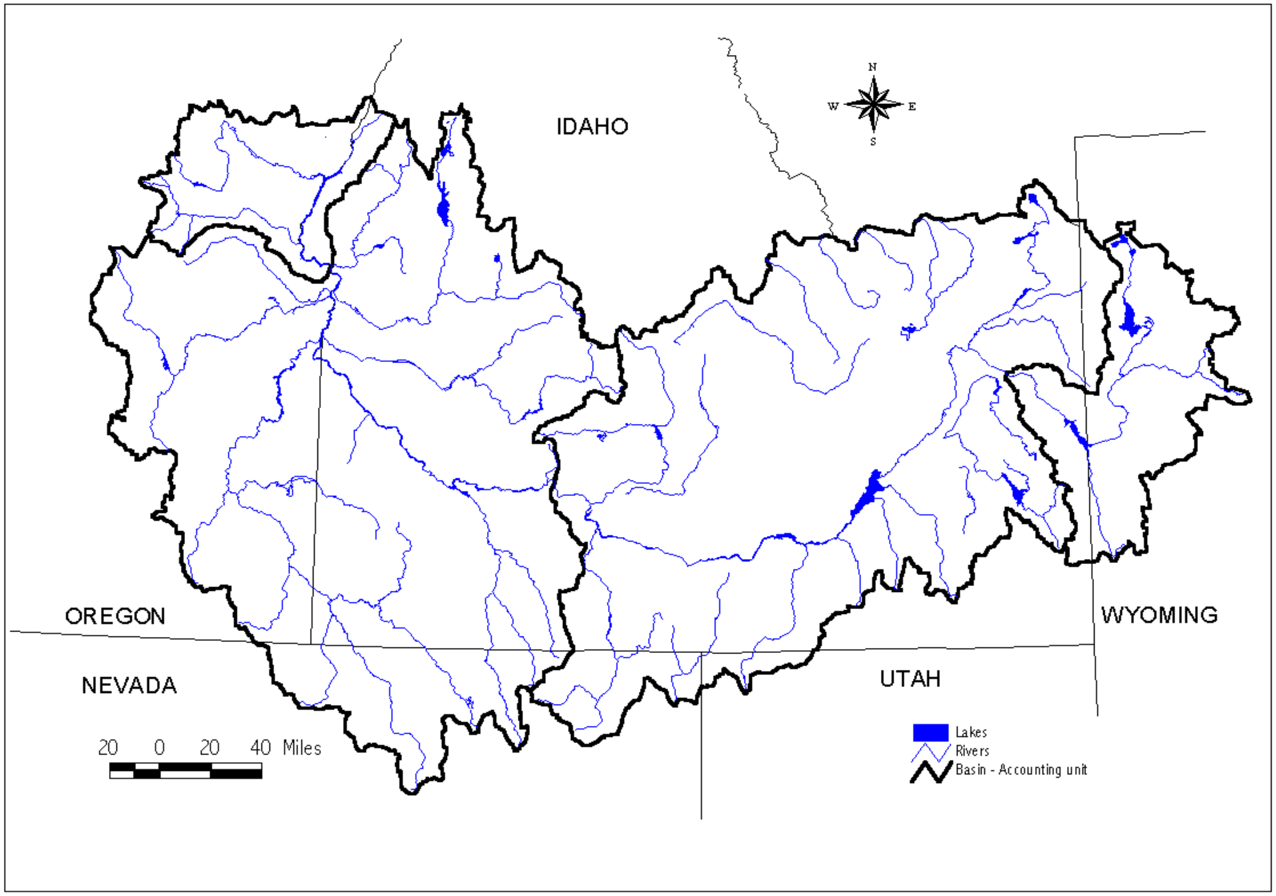

Figure 16. Map showing the accounting units - basins, and major rivers.

minimizing uncertainty in flow estimation.

The Headwaters sub-region, which includes all drainage areas of the Snake River from its beginnings in Wyoming down to the sub-region discharge area near Heise, Idaho, has considerable surface flow with “negligible” ground water discharge (Kjelstrom, 1986). This same concept applies to the Upper Snake Basin in eastern Idaho. The stream flows in the Snake River near King Hill represent essentially all the water that is discharged from eastern Idaho, again with “negligible” amounts of ground water discharge. In western Idaho (Middle Snake sub-basin) the physical setting down stream from Weiser serves to concentrate the great majority of the water, from the Snake River and its tributaries, into surface flow.

Recognizing these naturally occurring divisions or segments of the Snake River Basin leads to the following observations:

1. Water budgets on a regional scale, such as those of Kjelstrom (1986), are useful to identify the availability and use of water within each region.
2. Water uses within a sub-basin can impact stream flows. The impacts are most readily detectable where stream flows represent essentially all of the basin discharge such as near Heise, King Hill, and downstream past the confluence of the Weiser and Snake Rivers. The impacts could affect either gains or losses such as experienced in the Upper Snake Basin.
3. A ranking of basins to prioritize allocation of resources for studies should take place on a sub-basin level (within accounting units) and then compare the

different sub-basins. This would allow criteria for establishing the need for studies to be basin-specific. For example, problems relating to ground water pumping and water allocation, supply, and water quality are driving issues for water studies in the Middle and Upper Snake sub-basins. In the Headwaters sub-basin in Wyoming, effects of ground water pumping may not be the driving issue. Other concerns such as minimum stream flows, and water quality may be those issues which should receive greater attention.

RANKING OF TRIBUTARY BASINS

The process of ranking the tributary basins required obtaining data that would allow discrimination between the basins on different properties. Data that seemed useful and readily available for this study included:

- Water level measurements
- Land use
- Water Rights
- Stream Flow

Discussion on each of these data sets and its relative use in ranking basins is presented in this section.

Water Level Measurements

Evaluation of water level fluctuations can be a useful tool for qualifying a basin’s need for additional study. A significant amount of interest has been focused on the fluctuations of the water level within the Upper Snake River Basin and its associated tributary basins (IDWR, 1997).

Annual fluctuation of the water level occurs both because of variation in precipitation and impacts from man’s activities. Investigation is needed if the elevation of the water level fluctuates with increasing magnitude or shows a steady change in elevation (rising or falling). Such changes would indicate new stresses are acting upon the system and these stresses should be identified and quantified.

The water table data from monitoring wells, provided by the USGS, varies depending on when monitoring began, the sampling time interval, and most recent sampling activity. This database contains measurements from more that 1300 wells within that portion of the Snake River Basin located in Idaho (Figure 14). Some of the wells have multiple observation points with piezometers at differing elevations within the same borehole. This allows monitoring of different zones at the same location. A summary of the information obtained from these wells is published by the U.S. Geological Survey in cooperation with the State of Idaho and other agencies in their annual report entitled Water Resources Data-Idaho. The majority of wells are located within those regions where competition for water has been more intense, such as the Eastern Snake River Plain. While the competition for funding within government agencies seems to be increasing, it is important to maintain an adequate number of observation wells. Of the 53 HUC units within the SR3 study area, only 32 have active U.S. Geological Survey monitoring wells within their borders (Figure 14).

The amount of data available for each well varies from a minimum of one observation or measurement per well, to wells with thousands of measurements spanning nearly half a century. In the Willow Creek area (HUC - 17040205), there are two wells with one measurement each. These provide information on current water level but provide no information relative to historical changes that may have occurred. A well located just across the boundary into the Idaho Falls HUC is used to depict the water level changes near the Willow Creek area.

The Palisades area (HUC-17040104) contains four wells, each with two records or observations. Again, the data have meaning, but are not useful in terms of representing historical trends.

Forty wells were chosen and ground water hydrographs were created to show water level changes within the study area. These wells were then grouped into thirteen areas defined on the basis of hydrologic unit boundaries and regional proximity (Figure 17). Each group, and its respective hydrographs, is located on individual sheets in Appendix A. The horizontal

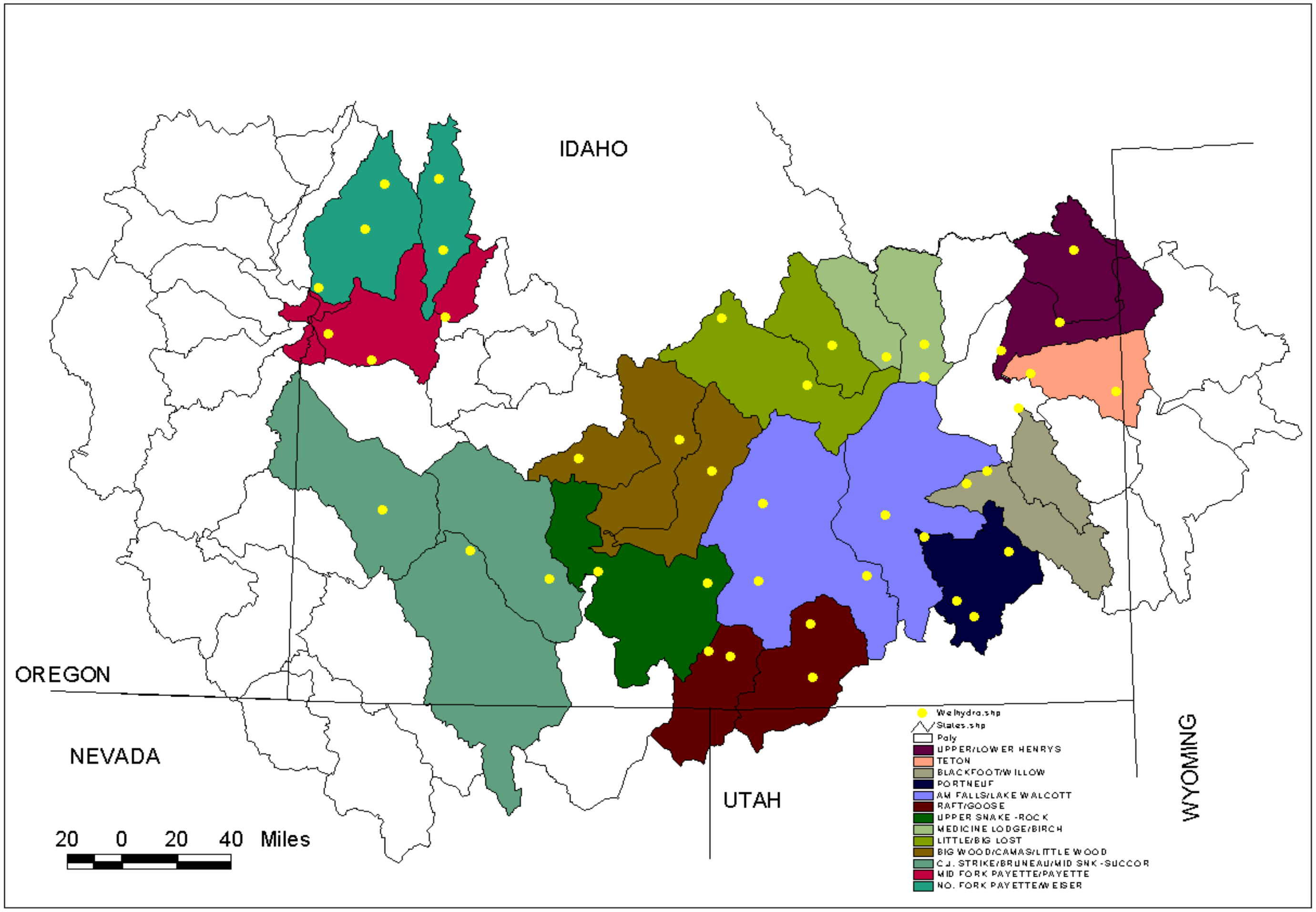

Figure 17. Map showing the location of wells used to create ground water hydrographs.

time axis on the hydrographs was scaled from the year 1945 to the most current reading. Whenever possible, vertical scales were held constant within a given area to allow comparison between wells. This was not always possible as some hydrographs showed fluctuations of only a few feet, while others varied by tens of feet.

Some basin-wide changes in water levels are shown in the hydrographs. These events include three water table declines that started about 1954, 1973, and 1986. At least two regional rises in water levels occurred, beginning about 1982, and more recently in 1993. Figure 18 summarizes the fluctuations observed in the various wells throughout the basin.

Most wells show annual fluctuations of less than ten feet. Notable exceptions include wells in Bruneau, Willow, and Teton where annual fluctuations can vary to a maximum of 50 to 65 feet (Figure A.3). In the Willow well, any drought related declines were short lived with a fairly constant base level maintained after the initial rise in the late 1950s to late 1960s. The Blackfoot well shows an attenuation of the annual fluctuations occurring at different times.

In the Middle Fork Payette and Payette wells, only minor effects, if any, are observed from the droughts in the late 1970s and again in the 1980s (Figure A.12). Seasonal variations in the upper reaches are minimal with greater water level changes toward the discharge area. Wells located with in similar regions don’t always have similar hydrographs. The hydrographs of wells located in the North Fork of the Payette and in the Weiser HUCs (Figure A.13) provide an example of dissimilar hydrographs in a similar region. The northern most wells in both HUCs show effects of the drought that began in 1986.

HUC	NAME_BASIN	HYDRO_WELL	MAX ANNUAL FLUCTUATION (FT)
17040201	WILLOW	08BAA1	55
17040202	UPPER HENRYS	15ADC1	7
17040203	LOWER HENRYS	23DBA1	6
17040203	LOWER HENRYS	34DDA1	8
17040204	TETON	13ADA1	65
17040204	TETON	01CCD1	6
17040206	AMERICAN FALLS	36ABA1	1
17040208	PORTNEUF	20CBB2	2
17040208	PORTNEUF	10CCD1	30
17040208	PORTNEUF	08DDD1	3
17040208	PORTNEUF	16BBB1	4
17040209	LAKE WALCOTT	06BBC1	2
17040209	LAKE WALCOTT	31DAC1	2
17040209	LAKE WALCOTT	23DCC1	23
17040210	RAFT	29AAA1	10
17040210	RAFT	33CDD1	8
17040211	GOOSE	18BBC1	20
17040211	GOOSE	21CCD2	20
17040212	UPPER SNAKE-ROCK	16CBB1	3
17040212	UPPER SNAKE-ROCK	01DAA1	8
17040215	MEDICINE LODGE	09BDA1	7
17040215	MEDICINE LODGE	04CDC1	30
17040217	LITTLE LOST	16DDD1	21
17040216	BIRCH	34BDD1	3
17040218	BIG LOST	23CDA1	10
17040218	BIG LOST	14BBC1	6
17040219	BIG WOOD	01DAA1	15
17040220	CAMAS	13BAA1	4
17040221	LITTLE WOOD	01ACC2	20
17050101	C. J. STRIKE RESERVOIR	33BCD1	2
17050102	BRUNEAU	09BAD2	50
17050103	MIDDLE SNAKE-SUCCOR	30BBB1	55
17050121	SOUTH FORK PAYETTE	22BDD1	3
17050122	PAYETTE	18DAA2	4
17050122	PAYETTE	33ACA1	12
17050123	NORTH FORK PAYETTE	16BAD1	15
17050123	NORTH FORK PAYETTE	36BCD1	8
17050124	WEISER	35DCB1	20
17050124	WEISER	10BCA1	3
17050124	WEISER	15AAC1	5

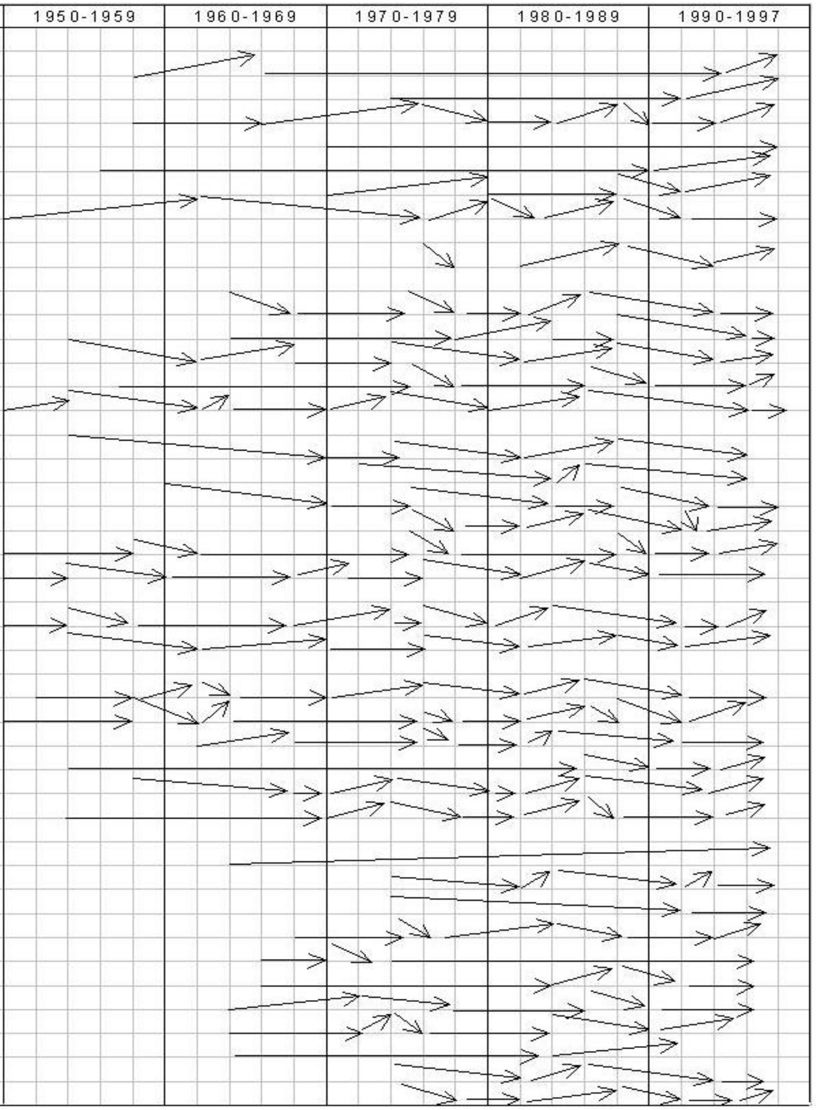

Figure 18. Summary of relative changes in water level observed in well data.

The North Fork Payette well shows a trend of decreasing water levels since the early 1970s while the Weiser well shows declines followed by recoveries. The southernmost well in the Weiser HUC is located in the discharge region. This well shows a rising water table over the same time period with the magnitude of yearly variations increasing from 10 to nearly 20 feet.

With the water rights data set used in this study, there were no reported ground water permits for the Weiser-North Fork Payette area (Figure A.13). Even without ground water withdrawals, seasonal variations are observed and long term declines can take place.

Caution should be exercised when making interpretations based on changes in water level in any single well. As mentioned in Freeze and Cherry (1979), there are many different factors that can influence water table fluctuations observed in a given well. Floods, droughts, earthquakes, changes in irrigation practices, and addition or deletion of ground water diversions are just some of the factors that could cause significant changes in the elevation of the water table.

Land Use Data

Recent land use GIS data were obtained from the respective state agencies of Idaho, Wyoming, and Oregon and used to identify presently irrigated lands (Figure 19). Oregon is in the process of converting older data sets to useable GIS files; however, they did provide that portion of the data currently available. There are more areas of agricultural use than shown in Oregon and that data should be available to incorporate into a data set in the near future. The data provided from Wyoming and Oregon did not allow for computation of irrigated area by HUC.

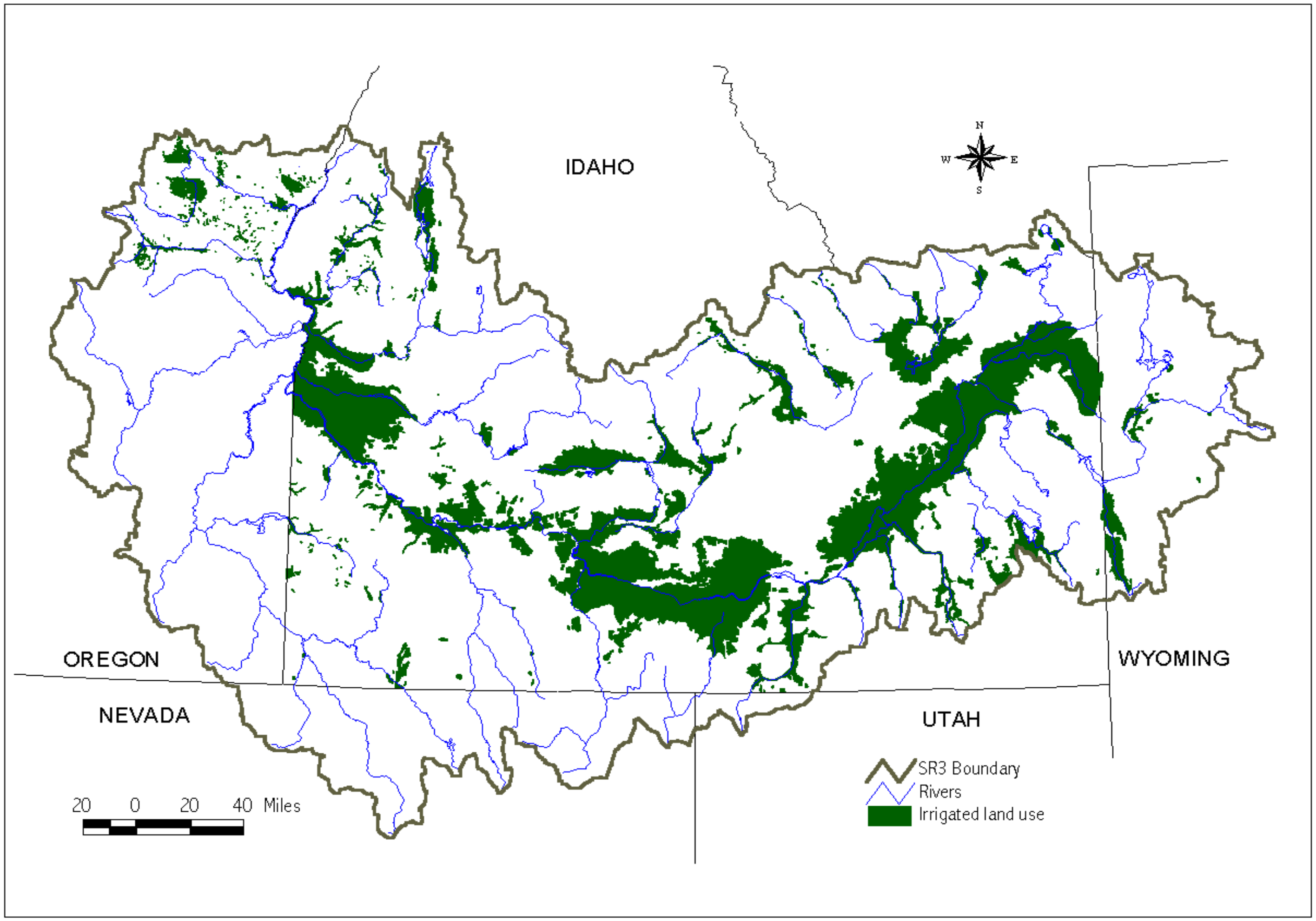

Figure 19. Map showing the distribution of irrigated lands within the SR3 area.

Data from Idaho did enable acreage tabulation of the irrigated and non-irrigated lands within the respective HUCs. The land use data set Snake_ag was selected among available data sets because it appeared to give the most complete coverage of the tributary areas.

Table 5 provides a summary of the distribution of irrigated and non-irrigated acres for HUCs in Idaho. Teton, Raft, Portneuf, and Blackfoot are those HUCs which contain significant non-irrigated lands with potential for conversion to irrigation. Of the eight HUCs with the largest irrigated acreage, seven are located primarily on the Snake River Plain.

More accurate agricultural data probably exist on the county level. These data are generally in tabular form and difficult to include in a GIS-based analysis. Consequently, county data were not used.

Water Rights Data

Water rights information is useful in ranking tributary basins, helping to identify locations where significant volumes of ground water diversions take place. Access to water rights information is available through the appropriate agency within each state. Wyoming and Idaho are currently working towards a more user-friendly database for their water rights information. Oregon and Utah presently are able to respond directly to water rights queries via the Internet (Utah at - http://nrwrt1.nr.state.ut.us/ ; Oregon at - http://www.wrd.state.or.us/).

Currently, to verify the status of any single water right within the entire study area is fairly straightforward, requiring some combination of computer usage, Internet access and/or manual effort, for any state. Such is not the case when working with groups of water rights from different areas. Within the next few years, it should become a simpler task to obtain

Table 5. Summary of Irrigated and Non-Irrigated Acres in Idaho.

Basin Name	HUC	Irrigated Agriculture		Non-irrigated Agriculture		Total Acres	Total Square Miles
		Acres	Square Miles	Acres	Square Miles		
UPPER SNAKE-ROCK	17040212	820,645	1,282	16,325	26	836,969	1,307
AMERICAN FALLS	17040206	692,858	1,082	182,627	285	875,485	1,368
LAKE WALCOTT	17040209	502,446	785	214,971	336	717,417	1,121
LOWER BOISE	17050114	472,309	738	9,230	14	481,539	752
IDAHO FALLS	17040201	426,891	667	67,520	105	494,411	772
TETON	17040204	333,784	521	67,774	106	401,558	627
MIDDLE SNAKE-SUCCOR	17050103	269,442	421	856	1	270,298	422
C. J. STRIKE RESERVOIR	17050101	232,809	364	20,124	31	252,933	395
LOWER HENRYS	17040203	182,185	285			182,185	285
LITTLE WOOD	17040221	170,745	267			170,745	267
MEDICINE LODGE	17040215	161,979	253			161,979	253
CAMAS	17040220	155,545	243			155,545	243
RAFT	17040210	155,020	242	97,321	152	252,341	394
PORTNEUF	17040208	130,687	204	234,609	367	365,296	571
BIG WOOD	17040219	129,927	203			129,927	203
PAYETTE	17050122	127,203	199			127,203	199
BIG LOST	17040218	122,620	192			122,620	192
GOOSE	17040211	114,192	178			114,192	178
BLACKFOOT	17040207	104,811	164	22,630	35	127,442	199
NORTH FORK PAYETTE	17050123	100,755	157			100,755	157
WEISER	17050124	86,460	135			86,460	135
BEAVER-CAMAS	17040214	85,826	134			85,826	134
BRUNEAU	17050102	63,184	99			63,184	99
MIDDLE SNAKE-PAYETTE	17050115	51,294	80			51,294	80
UPPER HENRYS	17040202	45,700	71			45,700	71
SALMON FALLS	17040213	38,878	61			38,878	61
UPPER OWYHEE	17050104	35,823	56			35,823	56
LITTLE LOST	17040217	34,572	54			34,572	54
PALISADES	17040104	23,051	36	65,556	102	88,607	138
SOUTH FORK BOISE	17050113	17,907	28			17,907	28
JORDAN	17050108	16,995	27			16,995	27
BROWNLEE RESERVOIR	17050201	14,447	23			14,447	23
BIRCH	17040216	10,163	16			10,163	16
MIDDLE OWYHEE	17050107	7,474	12			7,474	12
MIDDLE FORK PAYETTE	17050121	4,839	8			4,839	8
SALT	17040105	3,587	6			3,587	6
WILLOW	17040205	2,071	3	117,572	184	119,643	187
SOUTH FORK PAYETTE	17050120	1,047	2			1,047	2
SOUTH FORK OWYHEE	17050105	873	1			873	1
EAST LITTLE OWYHEE	17050106	654	1			654	1
LOWER OWYHEE	17050110	135	0			135	0
BOISE-MORES	17050112	74	0			74	0

Those HUCs which extend into other states may have additional acreage not shown here.

water rights data for a given region, or specific water use in the form of a computer data base, making projects with a large regional scope more feasible. For example, Oregon currently allows queries to be made on a stream or basin level.

Most of the states were able to provide information by means of an electronic transfer of data, generated through use of computer searches. The information provided by the Idaho Department of Water Resources was the most versatile in terms of data manipulation. A wealth of information has been accumulated as a result of water resources investigations, studies resulting from litigation, and the Snake River Basin adjudication. However, the data are still incomplete. There still exists a tremendous amount of work to be done due to the vast geographical areas included within the Snake River Basin and the geologic-hydrologic complexities that appear to exist.

A brief summary of Snake River Basin ground water water rights for the states of Utah and Nevada are presented next. Following those states, the remainder of water rights discussion is focused on Idaho.

Utah

Utah allows Internet access and subsequent queries pertaining to water rights information by township, range, and section. This is a convenient mechanism for a small data search. Using a criteria of selecting only those rights with a permitted flow greater than 0.24cfs, there were only six ground water rights within the Utah portion of the study area that showed up on the queries made. Those water rights represented a total permitted flow of almost 9.5 cfs. The Utah water rights information is summarized in Figure 20.

The portions of the Snake River Basin located in Utah are within the Raft HUC. The ground water hydrographs from these areas show the most drastic declines of water tables in the entire study area. Idaho designated the Raft River Critical Ground Water Management

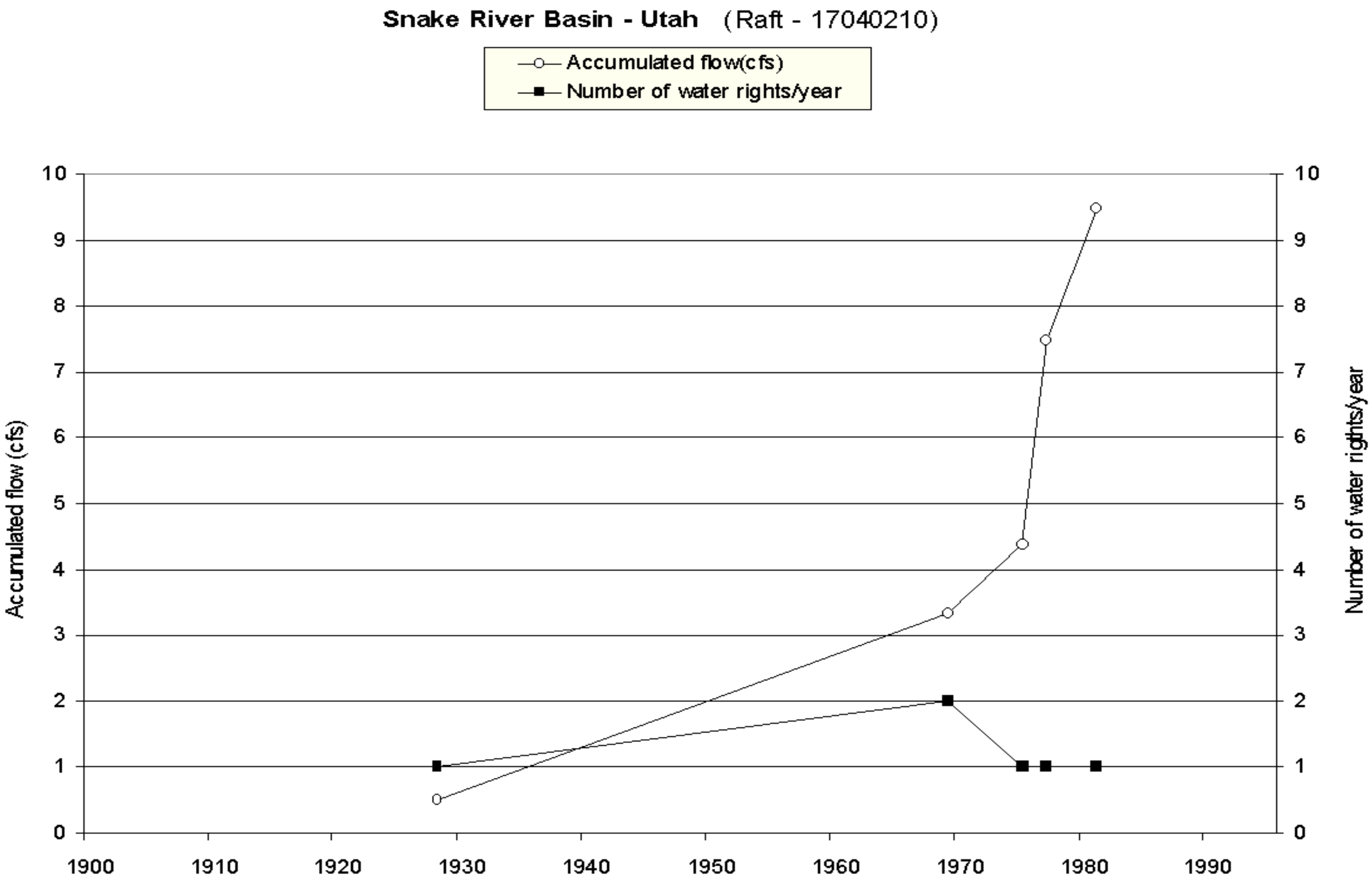

Figure 20. Chart summarizing the number of water rights and permitted flow within the Snake River Basin, Utah.

Area in 1963, greatly restricting any further development. According to the summary information for that portion of Utah within the Snake River drainage, available from the State of Utah, provided through their web site at: www.state.ut.gov/ ,“The State Engineer believes that there is unappropriated water available from the underground resource in valley locations.”

There seems to exist a difference in interpretation as to whether or not water is available for additional development in this region. This may be the result of each state maintaining separate data sets that are defined by state boundaries, not on the basis of hydrology.

Nevada

For at least the Snake River Basin area, the Nevada Division of Water Resources did not have a way to provide the requested water rights data electronically. Photo-copies were made of water rights data from the study area. The copies were then searched manually to identify permits for ground water diversions with flow rates greater than 0.24 cfs. The results of the search indicated approximately 60 water rights with an accumulated flow of 134 cfs. The data are presented in Figure 21. These numbers should be considered preliminary and only used as an indicator of the accumulated amount of permitted diversions that currently exist in this area.

Idaho

In terms of water rights information, this study focused on ground water withdrawals. It is beyond the scope of this study to address the impacts on ground water availability resulting from changes in the administration and consumptive use of surface water. The

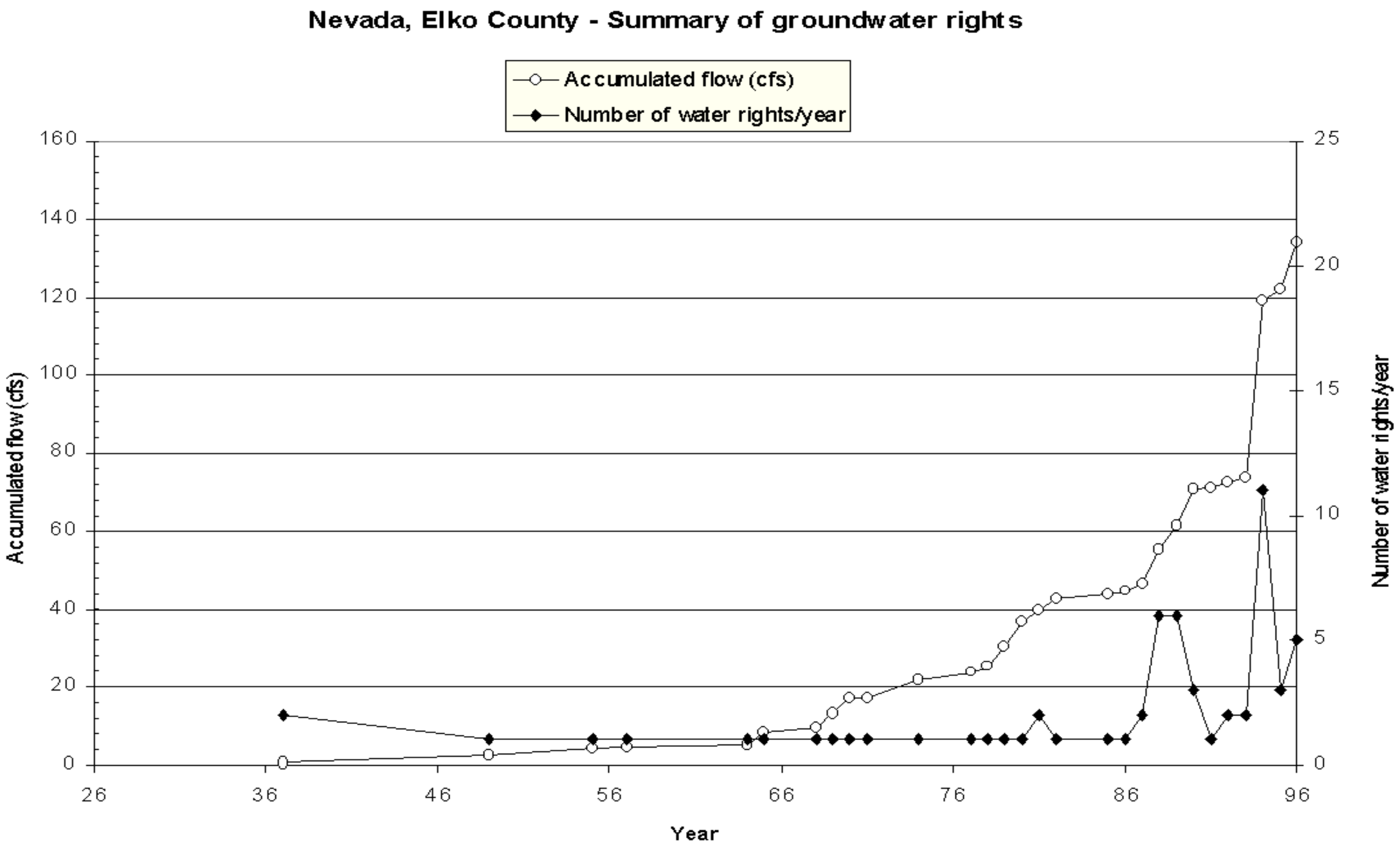

Figure 21. Chart summarizing the number of water rights and permitted flow within the Snake River Basin, Nevada.

historical aspects of surface water use and diversions should be considered when evaluating the effects of ground water pumping. The combined surface water-ground water approach was used in a study on the Big Lost River where changes in surface water diversions such as expansion of total acres irrigated and reduction in total volume of water diverted were encountered (Johnson and others, 1991).

The locations of Idaho ground water claims are shown in Figure 22. The resolution of the presentation only allows identification of those sections in which a point of diversion is located. A summary of the ground water claim information by HUC is shown in Figure 23. It needs be noted that, in terms of claimed flow, many of the ground water claims are considered supplemental, to be used to augment surface water usage.

The water rights information, linked to the individual HUCs, identifies those areas experiencing the greatest demand for ground water. Charts showing the history of water rights claims and associated permitted flow volumes were made for each HUC that contained a ground water claim. These figures are presented in Appendix B. A summary of the same information is provided in Table 6. The HUCs have been sorted by highest claimed flow volumes to lowest.

Stream Flow Data

Stream flow data are used in two ways to help in ranking the tributary basins. First, since most tributary streams are considered to be at least somewhat hydraulically interconnected with the aquifer, changes in stream flow can affect the amount of water available for aquifer recharge. Second, significant changes in the quantity of ground water diverted or the amount of surface water consumptively used might be indicated by a reduction in stream flow relative to other nearby tributaries.

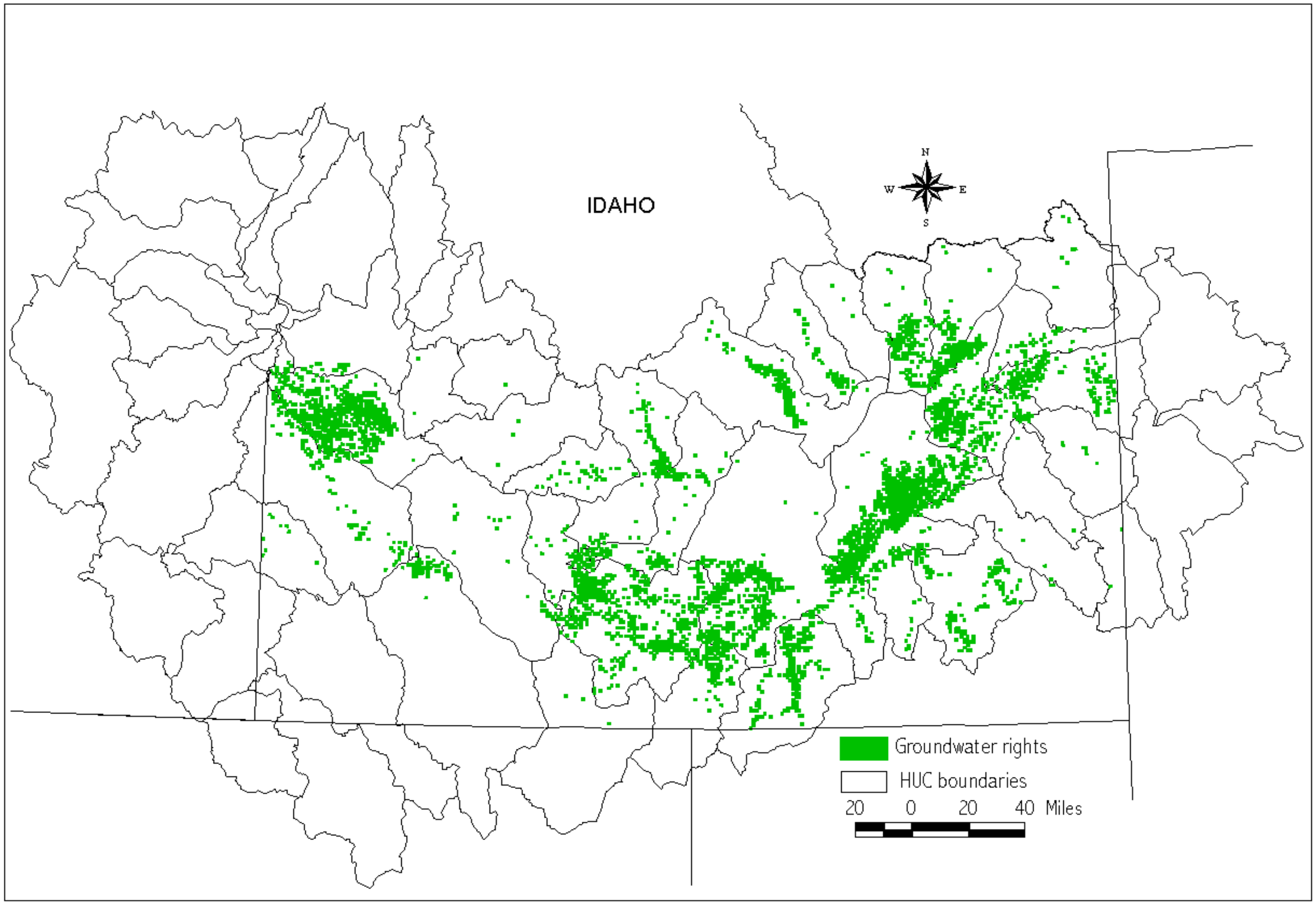

Figure 22. Map showing the distribution of ground water rights, Idaho.

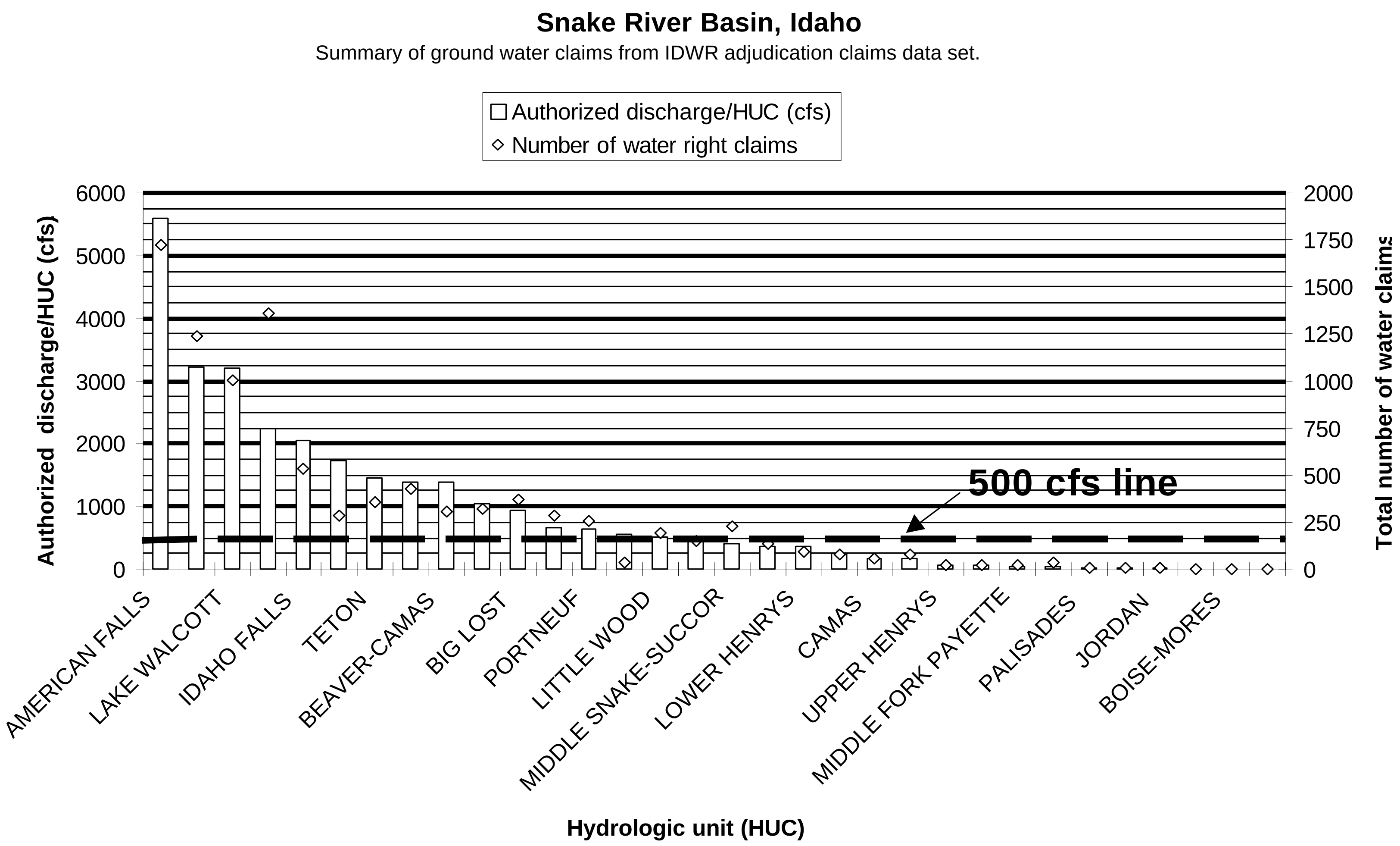

Figure 23. Chart summarizing the number of ground water claims and authorized discharge for Idaho.

Table 6. Summary of water rights data by HUC.

Basin Name	HUCs	Total volume of diversions (cfs)	Number of water claims
AMERICAN FALLS	17040206	5602	1722
UPPER SNAKE-ROCK	17040212	3234	1241
LAKE WALCOTT	17040209	3211	1006
LOWER BOISE	17050114	2248	1358
IDAHO FALLS	17040201	2049	536
MEDICINE LODGE	17040215	1739	285
TETON	17040204	1450	355
RAFT	17040210	1395	426
BEAVER-CAMAS	17040214	1380	304
GOOSE	17040211	1039	318
BIG LOST	17040218	942	367
BIG WOOD	17040219	658	283
PORTNEUF	17040208	635	259
SALMON FALLS	17040213	552	37
LITTLE WOOD	17040221	516	193
LITTLE LOST	17040217	481	151
MIDDLE SNAKE-SUCCOR	17050103	415	230
BRUNEAU	17050102	368	136
LOWER HENRYS	17040203	364	94
C. J. STRIKE RESERVOIR	17050101	261	75
CAMAS	17040220	172	58
BLACKFOOT	17040207	169	76
UPPER HENRYS	17040202	65	19
BIRCH	17040216	62	19
MIDDLE FORK PAYETTE	17050121	43	21
PAYETTE	17050122	40	35
PALISADES	17040104	25	10
WILLOW	17040205	19	7
JORDAN	17050108	15	9
SALT	17040105	4	2
BOISE-MORES	17050112	1	2
NORTH AND MIDDLE FORK BOISE	17050111	1	1

Kjelstrom (1986) developed water budgets for both the eastern and western portions of the Snake River Plain for the period 1934 to 1980. As a part of that process, he tabulated stream gage information to show annual contributions from the different tributary areas. For the Headwaters basin, including the Palisades HUC, the mean annual discharge to the Upper Snake basin was 4.95 million acre-feet (MAF) as measured at the Heise, Idaho stream gage.

This is almost half of the annual net yield of 10.21 MAF of water yielded to the Snake River in the Upper Snake sub-basin. The other 5.26 MAF comes from a combination of tributaries and ground water underflow within the Upper Snake sub-basin.

Mean annual discharge out of the Upper Snake to the Middle Snake sub-basin was 7.57 MAF of water as measured at the stream gage near King Hill, Idaho. The 7.57 MAF of flow minus the 4.95 MAF of flow measured at Heise, indicates that about 2.62 MAF of flow comes from those triubtary basins associated with the Upper Snake River sub-basin. The 10.21 MAF of net yield to the Upper Snake River sub-basin, minus the 7.57 MAF of flow measured at King Hill, indicates diversion and consumptive irrigation use of 2.64 MAF. Thus, about one fourth of the water input to the Upper Snake River sub-basin is diverted and consumptively used while the remainder is discharged into the Middle Snake sub-basin.

Mean annual net water yield to the Middle Snake basin was 14.605 MAF of water. Similar to the Upper Snake, just over half of the net water yield to the Middle Snake sub-basin (7.57 MAF) was stream flow of the Snake River. Kjelstrom (1986) did not include the Middle Snake-Powder sub-basin in his study.

In summary, 4.95 MAF are yielded from tributary basins above Heise (Upper Snake Headwaters sub-basin), 5.26 MAF yielded from tributaries between Heise and King Hill (Upper Snake sub-basin), and 7.03 MAF yielded from tributaries below King Hill (Middle Snake sub-basin).

A stream hydrograph was plotted for the Snake River near Alpine, Wyoming (Figure 24). This figure shows the more abundant water years prior to water year 1986-87, and the increase in water that seems to be occurring in the early to mid 1990's. Hydrographs for stream gages used in comparison with Kjelstrom (1986) are provided in Appendix C.

Of the forty-eight separate regions for which Kjelstom (1986) tabulated data, nineteen have historical stream gage information for water years 1981 to 1996, available from the USGS on the Internet. Locations of these stream gages are shown in Figure 25. Table 7 summarizes the mean annual flows of Kjelstrom as compared with mean annual flows for water years 1981 through 1996.

The majority of the streams show an increase in flow. Willow Creek (13058000), Beaver Creek (13113000), Silver Creek (13150430), and Bruneau River (13168500) all showed decreases in flow. Reduced flows in Willow Creek may have been offset by increased ground water contributions since operation of the Ririe Reservoir began in 1977.

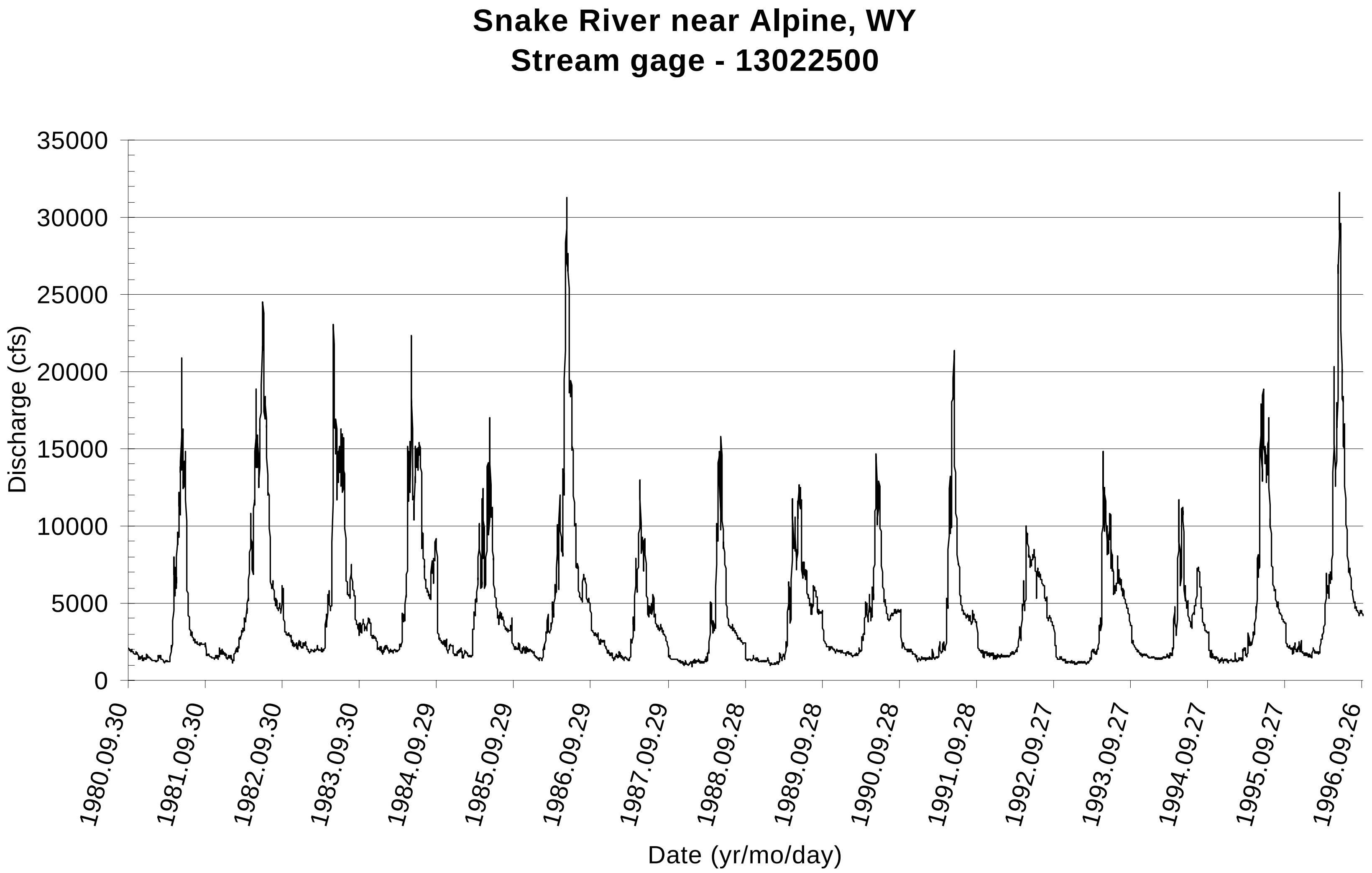

Figure 24. Stream hydrograph, Snake River near Alpine, Wyoming, above Palisades Reservoir (USGS stream gage).

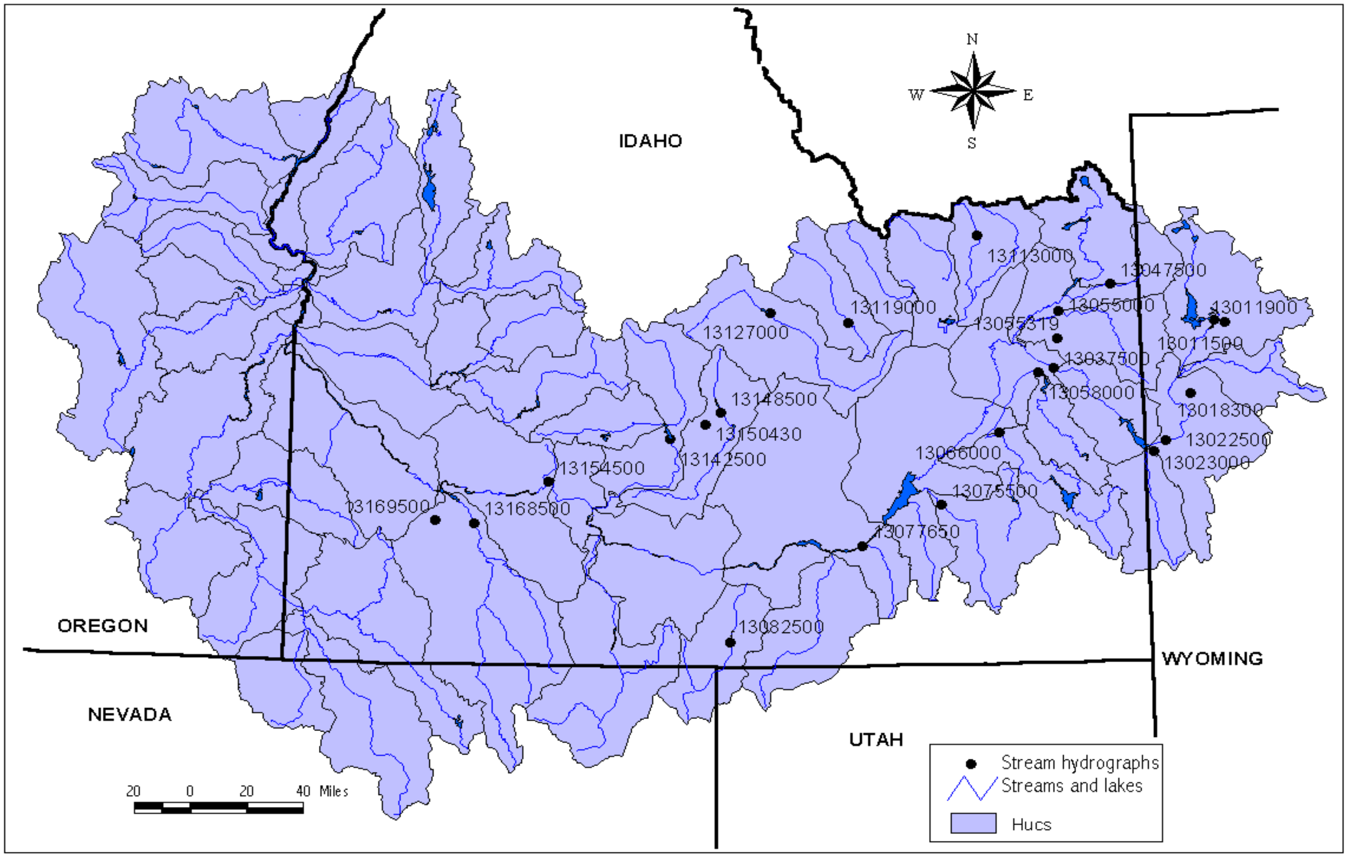

Figure 25. Map showing the location of stream gage sites used for comparisons.

Table 7. Comparisons of mean annual discharge, Kjelstrom (1986) and 1980 to 1996.

Update of stream flow data from 1981 to 1996 (Mean annual discharge in thousands of acre-feet.)				
		Kjelstrom		This study
Gaging station	Stream /Area description	Mean for period of record	Mean or adjusted mean for 1934-80 period	Mean for current study 1980-96
13037500	Snake River near Heise	5,024	4,953	5,067
13046000	Henry's Fork near Ashton	1,054	1,072	1,218
13047500	Falls River near Squirrel	562	570	544
13055000	Teton River near St. Anthony	586	584	643
13055319	Moody Creek near Rexburg	11	10	21
13058000	Willow Creek near Ririe	126	126	66
13066000	Blackfoot River near Shelley	253	253	276
13075500	Portneuf River near Pocatello	194	193	228
13077650	Rock Creek near American Falls	24	17	23
13082500	Goose Creek above Trapper Creek near Oakley	34	33	33
13113000	Beaver Creek near Spencer (current 4/85-9/93)	31	31	15
13119000	Little Lost River near Howe (current 4/85-9/90)	55	52	57
13127000	Big Lost River near Mackay	219	228	240
13148500	Little Wood River near Carey	109	114	118
13150430	Silver Creek at Sportsman Access near Picabo	123	140	107
13142500	Big Wood River below Magic Reservoir near Richfield	332	352	356
13154500	Snake River at King Hill	7,788	7,571	7,812
13168500	Bruneau River near Hot Spring	286	297	269
13169500	Big Jacks Creek near Bruneau	3	3	5
	TOTALS	16,814	18,533	19,078

Summary of Ranking

Those areas of the Snake River Basin within the State of Idaho which are most likely to impact stream flow can be identified by analyzing the information available from water level measurements, land use data, water right permits, and stream flow data. IDWR’s priority ranking scheme (*High, Medium*, and *Low*) based on the level of ground water development is utilized. This methodology does not include consideration of lag times, yet still provides a useful basis for ranking.

The HUCs identified as high and medium priority should be considered for additional water resources studies. HUCs are ranked based on information in Figure 22 that shows the distribution of ground water diversions, HUC boundaries, and the location of current ground water models. The information displayed in Figure 23, showing the sum of flow allowed under existing water claims by HUC, along with Table 6, which provides a summary of the available acreage for agricultural development, is also used in the ranking.

Most areas with high levels of ground water development currently have an associated numerical ground water model. These areas include:

- Medicine Lodge-Beaver Camas, Lower Henrys (Mud Lake Model)
- Idaho Falls, American Falls, Lake Walcott, Upper Snake (IDWR-U of I, USGS Model)
- Goose (Oakley Fan Model)
- Upper Snake-Rock (Twin Falls Model)
- Lower Boise (Treasure Valley Model).

The regional ground water models, along with the more site-specific models, cover most of the regions that have experienced extensive ground water development. HUCs with significant ground water development not included within a numerical ground water model at this time include:

High Priority

- Teton (this could be split into two model areas; 1-Rexburg Bench, 2-Teton Basin)
- Raft
- Big Lost
- Big Wood
- Portneuf
- Salmon Falls

Medium Priority

- Middle Snake-Succor
- Bruneau
- C.J. Strike Reservoir
- Camas
- Blackfoot

Low Priority

- Little Wood
- Little Lost

The first six areas listed above, including Salmon Falls, are all above the 500 cfs accumulated diversion criteria proposed by IDWR to be considered as *High Priority.* The Big Wood and Camas HUCs have already been designated by IDWR as the Big Wood River Ground Water Management Area. An exception to the High Priority group may be Salmon Falls. Table 7 shows Salmon Falls as having accumulated diversions totaling 552 cfs with only 37 water rights listed. Figure B.15 shows that a 1900 priority permit, claiming a diversion right of about 450 cfs, accounts for the majority of permitted flow in this area. The permit belongs to a canal company with a designated beneficial use of irrigation. While there has been some recent ground water development in the area, this HUC does not seem to warrant a *High Priority* rating.

Areas that warrant a *Medium Priority* ranking include; Middle Snake-Succor, Bruneau, C.J. Strike Reservoir, Camas, and Blackfoot. Within the Middle Snake-Boise sub-basin, IDWR has designated the Cinder Cone Butte and Blue Gulch Critical Ground Water Areas, the Mountain Home Ground Water Management Area, and the Bruneau-Grandview Geothermal Ground Water Management Area. If there is sufficient cause for special management designation, some of the above listed areas may be deserving of *High Priority* status. The remaining HUCs (Little Wood, and Little Lost) would be considered *Low Priority* until new information or other needs (such as water right disputes) are identified.

SURVEY OF TOOLS FOR USE IN FUTURE STUDIES

As an introduction to this section, a few comments on computer modeling seem appropriate. The mathematical and physical theories that are employed in computer models are not in question. Texts such as Groundwater (Freeze and Cherry, 1979) and Physical and Chemical Hydrogeology (Domenico and Schwartz, 1990) provide discussion and reference information on the development and application of ground water modeling.

With the development of faster and more powerful computers, accompanied by color printers and plotters that make computer generated simulations look so convincing, it is important to consider the limitations associated with modeling. The following statements should be remembered: “All models are wrong. Some are useful” (anonymous), and “Ground Water models model our perception of the system, not the system itself” (personal communication with Dr. Christian Petrich, 1998). As knowledge and understanding of a specific hydrologic system increases, model concepts are refined, and the model more closely represents the actual system. Different models do not always have the same limitations or provide the same results. It is important to determine what type of information is expected from a given modeling effort.

A variety of tools are available that quantitatively evaluate ground water and surface water interactions. Those tools may be generally classified as either (a) analytical models-consisting of explicitly solved equations or, (b) numerical models-which require an iterative solution.

Analytical models are much easier and less costly to apply but operate under many assumptions. These assumptions generally include:

- The water table is flat and draw-down is minor compared to the aquifer thickness,
- The temperature of the stream is constant and the same temperature as water in the aquifer,
- The aquifer is isotropic, homogeneous, and infinite in areal extent,

- The stream is straight and fully penetrates the aquifer,
- Water is released instantaneously from storage, and
- The pumping (or recharging) well is fully penetrating.

Numerical methods require fewer assumptions. To operate with fewer assumptions, more effort is required to describe the system in greater detail.

To help identify some of the more useful tools for modeling ground water flow, a list and a brief discussion of some of the accepted techniques is presented here. The models listed have different uses and produce different types of results.

Analytical Models

a. Theis

b. Glover/Jenkins

Numerical Models

a. Finite Difference-Finite Element

b. Analytical Element Models

c. Physically Based Distributed Parameter Models

Other Tools

a. Response Functions

b. Multi-Variate Models

Analytical Models

Theis-- Ralston and others (1984) utilized the Theis analytical solution to look at effects of ground water diversions in tributary valleys on flow in the Snake River, comparing the results with Jenkins and the numerical model of Prickett and Vorhees. Ralston and others (1984) estimated that maximum lag times between pumpage and impacts on the Snake River ranged from one year to over 90 years, depending on the basin and its location. As previously mentioned, the Theis method requires that numerous assumptions be made. This method provides useful information, even recognizing that there are few real world examples that approximately meet the theoretical conditions imposed by Theis.

Glover/Jenkins--This analytical method, used to determine depletion of stream flow as a result of pumping, has been discussed as the Glover method (Glover, 1974; MacDonnell, 1988), and as the Jenkins' stream depletion solution (Jenkins, 1968; Ralston and others, 1984). With the advent of hydraulically interconnected systems coming under the rules of conjunctive management, states such as Colorado and Kansas have incorporated the use of this technique to determine the effects of ground water pumping on stream flow (Sophocleous and others, 1995; MacDonnell, 1988).

Jenkins (1968, p. 2) defines stream depletion as "either direct depletion of the stream or reduction of ground water flow to the stream". As with the Theis approach, this method operates under many assumptions.

Sophocleous and others (1995) attempted to evaluate this type of model and its application to conjunctive management decisions, comparing the results with solutions derived using the numerical model MODFLOW. MODFLOW has the ability to address more complex environments, thus not requiring all the assumptions that go with the Glover/ Jenkins method. Of the assumptions associated with Glover/Jenkins, some caused more significant deviation from the numerical response provided by MODFLOW. These included: 1) streambed clogging, less than direct communication between the stream and the aquifer, 2) the degree to which the stream fully penetrates the aquifer, and 3) the heterogeneity of the aquifer.

While the Glover/Jenkins approach is capable of providing an estimate of the stream depletion effects from ground water pumping, it was noted that this method most commonly over-estimated the effects, especially if the governing assumptions were violated (Sophocleous and others, 1995).

Numerical Methods

Early references to numerical models often mentioned computing time or computing capabilities as a limiting factor. With the increased capabilities of today’s computers this is no longer the case. Ground water modeling capabilities are expanding as software development tries to keep up with the expanding capabilities allowed through increased computing power.

Finite Difference-Finite Element--The two most basic types of ground water models are the finite difference and the finite element. Both of these models require that the area of interest be discretized (divided into a grid system) and that aquifer properties be assigned for each grid cell or element.

While there are similarities between finite difference and finite element models such as both requiring the descritization of the entire model area, there are significant differences too. Some of the differences between these two types of models include the following (Anderson and Woessner, 1992; Johnson and others, 1998) :

Finite Difference

- Easier to understand and to program
- In general, fewer input data are needed to construct a grid
- Computes a value for the head at a node, equal to the average head for the cell

- More commonly used

Finite Element

- Better able to approximate irregularly shaped boundaries
- Easier to adjust the size of individual elements and the location of boundaries
- Defines the variation of head within an element using interpolation functions
- Heads are calculated at nodes for convenience, but defined everywhere using "basis functions"
- Better able to approximate internal boundaries (e.g., faults)
- Better able to simulate point sources and sinks, seepage faces, and moving water tables.

Finite difference and finite element models can be highly useful tools in the conjunctive-management, decision-making process. These models generally include features that allow adequate representation of the system characteristics that govern ground water and surface water interaction. The models are normally limited by our knowledge of the system and its representative properties, not by the features of the model.

Reliability of model predictions is directly related to the level of understanding associated with the system. Without adequate funding to define the controlling characteristics of the system (such as hydraulic conductivity, transmissivity, aquifer thickness, recharge quantities, degree of stream-aquifer inter–connectedness, return flows, etc.) the usefulness of the model is diminished. These modeling tools may be very effective provided adequate resources can be dedicated toward their development and application.

Analytical Element Method--A different type of numerical analysis is the Analytical Element (AE) method. Haitjema (1992) used the AE approach to model ground water movement in Foulton County, Indiana, constructing a model 20 by 25 miles in areal extent. A brief history of AE models is presented below, summarized from Haitjema (1992).

This method was developed by Otto Strack at the University of Minnesota in the late 1970's. In contrast to finite difference or finite element methods, this method does not require the discretization of the study area. According to Haitjema (1992, p. 662);

> “...only the surface-water features in the domain are discretized, broken up in sections, and entered into the model as input data. Each of these stream sections or lake sections are represented by closed-form analytic solutions: the analytic elements. The comprehensive solution to a complex, regional ground water flow problem is obtained by superposition of all, a few hundred, analytic elements in the model.”

Haitjema (1992) suggests that by formulating the problem with the “appropriately chosen discharge potentials”, this method is applicable to confined, unconfined, homogeneous, and heterogeneous aquifers. In this method, analytic elements are chosen to represent various hydrologic features. Items such as rivers and streams, ponds and lakes, partially penetrating streams and lakes, variations in aquifer thickness and hydraulic conductivity can all be represented by different analytical elements.

One of the advantages of this method is that it allows construction of a model focusing on the information available and can easily accommodate new information as it becomes available enabling step-wise modeling. The construction of large regional models with a finite element or finite difference model requires using a technique called “telescoping mesh grid,” (Anderson and Woessner, 1992). The telescoping is the process of embedding a more detailed, local model inside a larger model. Haitjema suggests that AE models allow for different scales to be used within the same model, making it unnecessary to use a telescoping mesh grid approach. For more information on AE models, see Strack (1989).

Physically Based Distributed Parameter Models

There have been several ‘physically based distributed parameter models’ created in recent years. Different models identified by Yu and Schwartz (1998) utilizing this concept include SHE (European Hydrological System-Systeme Hydrologique European), SWRRB (Simulator for Water Resources in Rural Basins), TOPMODEL, and THALES. Yu and Schwartz explain that this type of model uses “process-based partial differential equations (PDEs) to describe the spatial variability of hydrologic parameters and processes”. BSHM (Basin-Scale Hydrologic Model) is a new model of this type, authored by Yu and Schwartz (1995). The BSHM model contains four main components:

1. Digital Elevation Generator,
2. Versatile Soil-Moisture Budget Model,
3. Surface-Runoff Delay-Time Model, and
4. Ground-water Flow Model.

Similar to products such as GMS (Brigham Young University, 1998), the BSHM model cited above is designed to take advantage of spatially distributed data. Unknown parameters such as storativity, hydraulic conductivity, and streambed permeability are determined by “trial and error calibration.” Whenever possible, measured data representing climate, soils, topography, land use, and ground water are input.

The authors present the BSHM model as having the ability to model various hydrologic processes including; evapotranspiration, infiltration, overland flow, and ground water flow within a basin. Similar to finite difference and finite element models, building a BSHM model involves descretizing the study area. The grid is created by the digital elevation generator sub-routine within the model. As a tool for conjunctive management, the ability to incorporate climatic data and soil moisture information into the surface water and ground water modeling efforts could be useful.

Careful consideration must be given to the balance between gains from greater model sophistication and unnecessary complexity and excessive data requirements.

Other Tools

Response Functions- Response functions incorporate the concept of superposition. Superposition is the principle or concept that "... for linear systems, the solution to a problem involving multiple inputs (or stresses) is equal to the sum of the solutions to a set of simpler individual problems that form the composite problem" (Reilly and others, 1987, p. 2). Effects of pumping any given well is considered independent of all other aspects of recharge or discharge. The sum of impacts from the individual wells would then represent the total effects pumping would have upon the stream.

Superposition concepts can be applied to numerical models to generate cause and effect relationships for specific locations within a model domain. The relationships have been referred to as response functions (Maddock and Lacher, 1991), discrete kernals (Morel-Seytoux and Daly, 1975), influence coefficients (Illangasekare and Morel-Seytoux, 1982) and algebraic technologic functions (Maddock, 1972).

The University of Idaho is currently developing response functions for the eastern Snake River Plain aquifer for the U.S. Bureau of Reclamation SR3 project. The response functions are created for selected ground water pumping or recharge locations and express the impacts on gains or losses of selected reaches of the Snake River. They are based on a calibrated model of the Snake River Plain aquifer most recently documented by IDWR (1997). These response functions provide a relatively easy and accurate means for quantitatively evaluating impacts of ground water use or recharge on gains and losses of the Snake River.

This concept can also be employed to assess the impacts of ground water recharge or discharge on streams in the tributary basins. IDWR (1997, p. 51) has proposed building individual finite difference models for each of the tributary basins in the Upper Snake River Basin and utilizing the superposition concept to look at “the effects of ground water withdrawal ... on tributary stream flow and underflow leaving the basin.”

The assumption of the system being linear may not be valid in tributary basins where the relative proportion of drawdown to aquifer thickness is large. In addition, perched or layered aquifers could exist within the tributaries increasing the complexity of the system. Caution should be exercised to make sure that assumptions do not significantly affect the validity of the results.

Multi-Variate Models --Horn and Jeong (1989) addressed the effects of ground water pumping in the Camas area (HUC 17040220) without using a ground water model. The goal was to determine if a model could be developed using historical stream flow records for basins prior to ground water development, and correlating with stream flow records from adjacent basins that still have not undergone development of ground water resources.

Results of this study indicate that the sensitivity of the model was inadequate to make quantitative assessments associated with the ground water withdrawals. In general, the study predicted lower streamflows than were observed. A possible reason for difference between the predicted and observed streamflows suggested by Horn and Jeong (1989, p. 89) follows:

> “This may be attributed to the fact that most of the large wells have pumped (mainly in the summer season) from deep aquifers with no connection to the surface stream system”.

Statistically, they did not see a change in annual stream flow attributable to ground water pumping. However, they did observe an apparent increase of stream flow for the summer and fall seasons. The source of the increase was attributed to irrigation return flows.

While this method does not appear to have the ability to define surface/ground water interactions quantitatively, it still is a useful tool. An understanding of the relationship between seasonal ground water pumping and irrigation return flows to the stream, sustaining higher than normal stream flows later in the season, could be useful information to water managers. This study implies that reductions in ground water use, or increases in irrigation efficiencies could result in a reduction in stream flows in Camas Creek. The costs of this approach are likely to be lower than costs associated with development of a numerical ground water model.

PROCEDURE FOR EVALUATING LEVEL OF EFFORT

Having identified and prioritized those HUCs which merit additional studies, the next step is to determine the level of additional study warranted. To address that issue, a flow chart (Figure 26) was created which can be used by water managers to assist in identifying those tributary basins which warrant further study. The flowchart logic is applied to the tributary basins in the section entitled “Conclusions and Recommendations.” A detailed explanation of the questions in the flowchart are presented here, along with a summary of its application.

Modeling Needs Assessment Flowchart

1. Create Basin Wide Model?

The first decision step is to determine if a basin wide model could or should be constructed and whether it would provide the desired results. At present, there are regional ground water models that cover the eastern and western Snake River Plain. These regional models do not include most of the tributary basins. Of the four hydrologic sub-basins, the Upper or Eastern Snake River Basin is the most likely candidate for a basin-wide model. With numerous areas of ground water development outside the Snake River Plain, management would benefit from having a numerical model for this area.

Creating a basin wide model for the Upper Snake Basin could be accomplished utilizing a finite element or finite difference model, incorporating embedded models if needed within areas requiring higher resolution. A finite element model may be more functional, allowing more flexibility in grid construction dealing with the irregular shapes of the tributary basins. The advantages of such a basin wide model would be to:

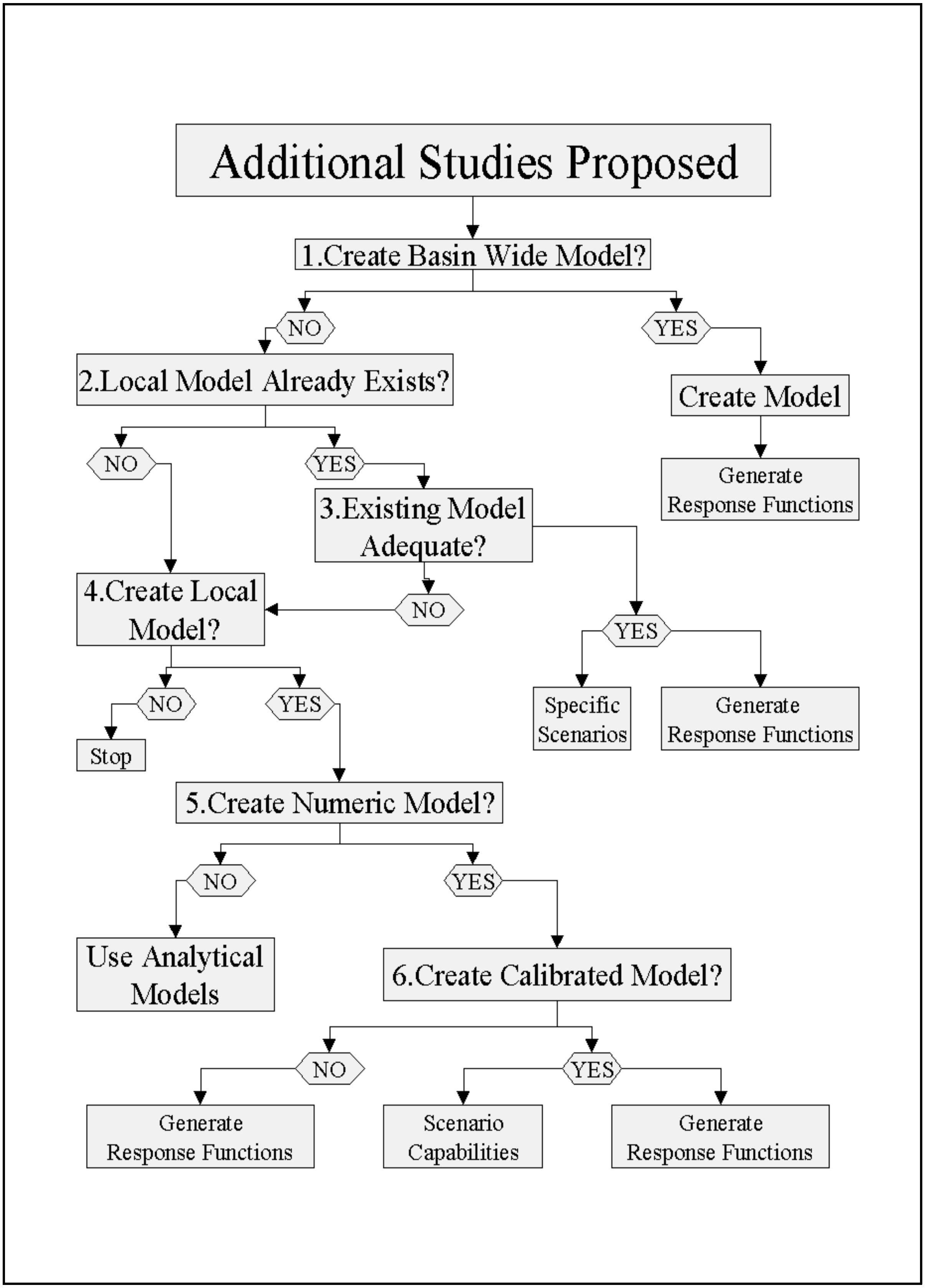

Figure 26. Flowchart showing decision making process for additional studies.

- Allow response functions to be generated anywhere in the basin,
- Provide a consistent approach throughout the area of interest,
- Create and maintain a single data platform, facilitating data storage and retrieval,
- Develop the ability to utilize information from existing models, capable of expansion if needed, and
- Allow construction of a model using fewer resources than required for creating numerous individual models.

Developing a basin-wide model can be a phased approach. Initially, the model would use only information that is currently available. In building a basin-wide model, data sets representing aquifer properties can be populated from the existing models. In areas where no model exists, the data sets can be populated based on estimates of lithology and/or test data. Model calibration, although desirable, could occur in a later phase.

In the Middle Snake sub-basin, which includes the Western Snake River Plain, there are two areas of significant ground water development. These include the Treasure Valley area which has recently been modeled, and the Bruneau and Middle Snake-Succor HUCs. A basin-wide model of this area does not seem warranted at this time because of limited development pumping effects.

2. Local Model Already Exist?

If construction of a basin-wide model is rejected, then it should be determined if a numerical model has already been constructed for the area of interest. Most of the existing models are located within the Snake River Plain area (Figure 13).

3. Existing Model Adequate?

Some models may not be capable of performing time-variant simulations or may not incorporate the necessary features for conjunctive use evaluations. In general, local models in the study area were made to address specific issues even though they overlie portions of the regional models created by the USGS work (Garabedian, 1992; Newton, 1991) and the IDWR - U of I model (Johnson and others, 1983; and IDWR, 1997). If ground water flow models exist in the area of interest, those models may be used to either (1) directly simulate surface water impacts from ground water use and recharge, or (2) develop response functions.

4. Create Local Model?

There are numerous tributary basins without ground water development that may not need to be modeled, either analytically or numerically, at this time. If modeling is not performed, it implies there are insufficient impacts to warrant expending resources required for a modeling effort. The response for this question could be yes or no.

5. Create Numerical Model?

There may be occasions where a model is needed but available resources do not permit construction of a full numerical model. Analytical techniques are normally much simpler to apply. Generally, they operate under many assumptions, yet they can still provide useful information. Analytical Element models can provide a cost effective yet useful alternative, especially with regional efforts.

6. Create Calibrated Model?

It is normally assumed that ground water models will be calibrated. Calibration involves simulation of some historic period and comparing simulated to measured quantities (most often aquifer water level) for that period. Although this procedure is commonly accepted, numerical models may also be used in an un-calibrated state. Calibration refines estimates of aquifer properties and, therefore, produces more reliable model predictions. When fiscal resources are severely limited, however, the question should be: “What is the best tool that can be developed with the available funding?" In some cases, an un-calibrated numerical model can be developed and applied that will give improved predictive capabilities relative to alternative tools such as the Theis equation. Development and use of an un-calibrated model may also be a interim step, allowing time to acquire the necessary funding or data needed to build a fully calibrated model.

Evaluation of Snake River Basin HUCs Using the Flowchart

Table 9 summarizes how each HUC would be treated as it passes through the decisions posed by the flow sheet. For each of the sub-basins, the first question asked is wether or not to create a basin-wide model. Because there are so many areas of *High* and *Medium* priority status, the Upper Snake is recommended for a basin-wide model at this time. Without a basin-wide model, the need for additional tributary basin ground water models still exists. A basin-wide model can provide useful information prior to calibration. A finished calibrated model, providing a higher level of confidence, could be considered a second phase of the model.

The following information summarizes the evaluation of each HUC by sub-basin. Question marks indicate insufficient information to make a recommendation at this time.

Upper Snake Headwaters: No models recommended at this time.

Upper Snake: A basin-wide model is recommended. Should a basin-wide model not be endorsed at this time, studies should continue on the individual tributary basins that have been identified as *High Priority*.

Middle Snake-Boise: Because of limited significant ground water development, a basin-wide model is not recommended at this time. The Bruneau, C.J. Strike Reservoir, and Middle Snake-Succor region all ranked *Medium Priority*. The ground water management designations by IDWR in this region suggest that there may be other needs not identified through this process that would warrant rating the above mentioned HUCs with a *High Priority*.

Middle Snake-Powder: No models recommended at this time.

Table 8. Summary of Decisions from Flowchart

Count	HUC	BASIN_NAME	Questions and Response from Decision Flow Chart					
			1. Create Basin Wide Model?	2. Local Model Exists?	3. Existing Model Adequate?	4. Create Local Model?	5. Create Numeric Model?	6. Create Calibrated Model?
Upper Snake Headwaters			No					
1	17040101	SNAKE HEADWATERS		No		No		
2	17040102	GROS VENTRE		No		No		
3	17040103	GREYS-HOBACK		No		No		
4	17040104	PALISADES		No		No		
5	17040105	SALT		No		No		
Upper Snake			Yes					
6	17040201	IDAHO FALLS		Yes	Yes			
7	17040202	UPPER HENRYS		No		No		
8	17040203	LOWER HENRYS		Yes	No	Yes	Yes	Yes
9	17040204	TETON		No		Yes	Yes	Yes
10	17040205	WILLOW		No		No		
11	17040206	AMERICAN FALLS		Yes	No	Yes	Yes	Yes
12	17040207	BLACKFOOT		No		Yes	Yes	Yes
13	17040208	PORTNEUF		No		Yes	Yes	Yes
14	17040209	LAKE WALCOTT		Yes	No	Yes	Yes	Yes
15	17040210	RAFT		No		Yes	Yes	Yes
16	17040211	GOOSE		Yes	No	Yes	Yes	Yes
17	17040212	UPPER SNAKE-ROCK		No		?		
18	17040213	SALMON FALLS		No		No		
19	17040214	BEAVER-CAMAS		Yes	Yes			
20	17040215	MEDICINE LODGE		Yes	Yes			
21	17040216	BIRCH		No		Yes	Yes	Yes
22	17040217	LITTLE LOST		No		Yes	Yes	Yes

Count	HUC	BASIN_NAME	Questions and Response from Decision Flow Chart					
			1. Create Basin Wide Model?	2. Local Model Exists?	3. Existing Model Adequate?	4. Create Local Model?	5. Create Numeric Model?	6. Create Calibrated Model?
23	17040218	BIG LOST		No		Yes	Yes	Yes
24	17040219	BIG WOOD		No		Yes	Yes	Yes
25	17040220	CAMAS		No		Yes	Yes	Yes
26	17040221	LITTLE WOOD		No		Yes	Yes	Yes
Middle Snake-Boise			No					
27	17050101	C. J. STRIKE RESERVOIR		Yes	No	Yes	Yes	Yes
28	17050102	BRUNEAU		Yes	No	Yes	Yes	Yes
29	17050103	MIDDLE SNAKE-SUCCOR		Yes	No	Yes	Yes	Yes
30	17050104	UPPER OWYHEE		No		No		
31	17050105	SOUTH FORK OWYHEE		?		?		
32	17050106	EAST LITTLE OWYHEE		?		?		
33	17050107	MIDDLE OWYHEE		?		?		
34	17050108	JORDAN		?		?		
35	17050109	CROOKED-RATTLESNAKE		?		?		
36	17050110	LOWER OWYHEE		?		?		
37	17050111	NORTH AND MIDDLE FORK BOISE		No		No		
38	17050112	BOISE-MORES		No		No		
39	17050113	SOUTH FORK BOISE		No		No		
40	17050114	LOWER BOISE		Yes	Yes			
41	17050115	MIDDLE SNAKE-PAYETTE		?		?		
42	17050116	UPPER MALHEUR		?		?		
43	17050117	LOWER MALHEUR		?		?		
44	17050118	BULLY		?		?		
45	17050119	WILLOW		?		?		
46	17050120	SOUTH FORK PAYETTE		No		No		

Count	HUC	BASIN_NAME	Questions and Response from Decision Flow Chart					
			1. Create Basin Wide Model?	2. Local Model Exists?	3. Existing Model Adequate?	4. Create Local Model?	5. Create Numeric Model?	6. Create Calibrated Model?
47	17050121	MIDDLE FORK PAYETTE		No		No		
48	17050122	PAYETTE		No		No		
49	17050123	NORTH FORK PAYETTE		No		No		
50	17050124	WEISER		No		No		
Middle Snake-Powder			No					
51	17050201	BROWNLEE RESERVOIR		No		No		
52	17050202	BURNT		No		No		
53	17050203	POWDER		No		No		

CONCLUSIONS AND RECOMMENDATIONS

The conclusions or observations are divided into two groups. First, some general observations that apply to the Snake River Basin as a whole. Second, subject-specific observations or conclusions made as a result of this study. Recommendations are presented for model use in future studies.

Conclusions

General

- Availability of water as stream flow in the Snake River can be impacted by water management decisions in the tributary basins.
- In addition to ground water use, Snake River flows may be impacted by other stresses such as variations in precipitation, and changes in the use of surface water.
- Any consumptive use of water in the tributary basins ultimately affects the amount of water available to the Snake River.

Specific

- Ranking of Basins: Water rights, land use, and water level measurements are all useful for indicating areas that should be considered for further studies.
    1. <u>Water Rights</u>: Using IDWR’s proposed ranking levels, the data in this report indicates that six HUCs (Teton, Raft, Big Lost, Big Wood, Portneuf, and Salmon Falls) should be considered high priority for additional studies. As mentioned previously, because of some unique water rights, Salmon Falls should not be considered high priority at this time. Five HUCs (Middle Snake-Succor,

Bruneau, C.J. Strike Reservoir, Camas, and Blackfoot) should be considered medium priority, and the remainder as low priority (see Summary of Ranking).

2. <u>Land Use</u>: These data indicated that most HUCs with large amounts of irrigated agriculture and additional non-irrigated lands that could be converted to irrigation are already covered by current ground water models. Those HUCs where additional studies may be warranted include Teton, Raft, Portneuf, and Blackfoot. From the water rights analysis Teton, Raft, and Portneuf are already considered high priority while Blackfoot is listed as medium priority.
3. <u>Water Level Measurements</u>: The data indicates the Raft and Goose HUCs have experienced the most severe declines in water table elevation. Raft and Goose would be considered as a high priority area from water rights analysis. Much of the Goose area is already within the Oakley Fan model area. Other areas of concern where annual water table fluctuations occur include Teton, Willow, Blackfoot, and Bruneau. Only Willow is not currently considered as a high or medium priority study area. The well used to identify the water table fluctuations in this area is within the boundaries of the Snake River Plain aquifer. At present, ground water development within the Willow HUC does not justify a high or medium rating at this time.

- The Most Discriminating Data For Prioritizing Future Studies

1. <u>Water Rights</u>: The most useful data for identifying areas in need of further study appears to be the water rights information. Even though the same level of information is not readily available from all states involved, there were sufficient

data to indicate which pertinent areas had been addressed, and where additional studies would be useful.

2. Lag Times: Within the Snake River Basin, usage of lag times (attenuation of pumping effects) to discriminate between ground water users has not been incorporated by management officials. While water rights data provide an indicator of those areas most likely to have an effect on surface water flows, the timing and magnitude of those effects should be considered in water management decisions. As stated by Ralston and others (1984), all diversions within the Snake River Basin that have a consumptive use will ultimately impact surface flows. Response functions will help to determine when impacts from pumping should be considered to interfere with surface water.

- Accessibility of the different types of data.
  1. GIS Data: GIS data were provided by the U.S. Bureau of Reclamation, Idaho Department of Water Resources, Wyoming Water Resources Center, and the Oregon Water Resources Department. All data that were not from IDWR required more effort to achieve the needed common projection properties.
  2. Water Rights: Water rights information provided by the Idaho Department of Water Resources and the Wyoming State Engineer’s Office were obtained through electronic transfers of databases by way of the Internet. Water rights information from IDWR contained two unanticipated problems in terms of incorporating the data into this study. First, there was not a direct way to import the information into a GIS data set. Second, working with Excel, and Arcview

software, if the numerical data representing the priority date was prior to 1900, that number was not recognized as a date. This necessitated a few extra steps when trying to sort and manipulate the data. The water rights information received for Idaho was derived from a data set of those rights filed under compliance with the adjudication process. While this represents most of the water rights associated with the Snake River Basin, it is not complete. Summaries of information derived from these records should be considered only as indicators in terms of development and potential water use, not as absolutes.

3. Monitoring Wells: Monitoring well information, including water level measurements, was provided by means of electronic file transfer using the Internet, by the U.S. Geological Survey office in Boise, Idaho. Latitude and longitude data had to be converted for projection in Idaho Transverse Mercator.
4. Land Use: It is difficult to get accurate data that is collected by counties and convert it to hydrologic units. Discussions with personnel at IDWR indicated that land classification data (Snaklc92) were probably more accurate than the agricultural data (Snake_ag). Comparing the two data sets, it appeared that outside of the Snake River Plain, the agricultural data were more complete. Since the tributary basins are the primary focus of this study, the agricultural data were used for this report. For projects working strictly with the western or eastern portions of the Snake River Plain, the land classification data would probably be the preferred data set.

5. Stream Gage: Steam gage data were easily accessible for USGS stream gage sites that are currently being measured, however, many stations are not active. Without additional work, it is not possible to compare mean average discharge volumes for previous studies and more recent years. Stream gage information is important to help identify changes that might occur in streamflows with changing water table elevations and levels of diversion.
6. Hydrologic Unit Boundaries: Many wells are located in close proximity to the HUC boundaries. The HUC boundary data that were used in this study were provided to the public by the U.S. Environmental Protection Agency (EPA), taken from 1:100,000 scale base maps. The Idaho Department of Water Resources has re-digitized the boundaries in the same general locations with an effort to honor detailed hydrologic and topographic data (meta-data associated with HUC data from IDWR). In some places the boundaries vary by several miles. As this project crosses or incorporates areas from five state, the data set from the EPA was used to maintain continuity across state lines. No attempt was made to change or redefine the associated HUC for a given well in areas of boundary definition contradictions.

Recommendations

Develop a basin-wide model for the Upper Snake sub-basin.

Of the four sub-basins within the SR3 study area (Headwaters, Upper Snake, Middle Snake-

Boise, and Middle Snake-Powder), the Upper Snake region should be considered for a basin-wide model. There are so many areas in the Upper Snake not yet included within the modeling effort, a two-phased approach is proposed. The first phase would include the design and construction of a model for all areas of interest, incorporating data sets from existing models where applicable. The second, a calibration phase would be done to increase the level of confidence for model output.

Construct needed data sets.

Regardless of the approach taken (basin-wide model vs. numerous local models), construction of data sets necessary for the modeling effort should be initiated. The usefulness of the models is reduced without adequate funding to define the controlling characteristics of the system. Some of the aquifer properties needed for modeling include hydraulic conductivity, transmissivity, aquifer thickness, recharge quantities, degree of stream-aquifer inter–connectedness, return flow quantities, and evapotranspiration. The more information available for defining the system, the higher the level of confidence which can be associated with management tools such as response functions.

Address the implications of lag times in water management.

The application of a time-response qualifier for ranking basins in terms of impacts to stream flow, as proposed by Ralston and others (1984) should be considered. Within the Snake River Basin most of the water travels from one sub-basin to the next by means of surface flow with negligible amounts of ground water flow. The consumptive use of ground water within the individual sub-basins affects the amount of surface flow exiting the sub-basin. Most of the models and tools discussed, including response functions, provide a measure of the timing and magnitude of impacts from the various basins. Incorporation of this concept could help with questions such as the following:

- Do the current regulations take into account the potential lag times that vary from a few years to possibly hundreds of years?
- Are water calls against junior diversions justified when lag times may indicate a truly negligible response at the point of the call for a period of time spanning several decades?

Making the rules for conjunctive management is not a simple task. The responsibility of water management decisions often must be made with inadequate information.

Incorporate historical review of surface water diversions with ground water studies.

The information presented in this report gives a general idea of ground water development trends. With the high degree of inter-connectedness observed between surface and ground water systems, it is important to incorporate a thorough understanding of surface water diversions, uses, and changes in use. The modeling concept of superposition can identify the theoretical effects of pumping; however, other factors such as changes in rates of diversion, or expansion of acreage irrigated may cause the observed impacts to not match the theoretical impacts and the discrepancy will still need to be reconciled.

Consider analytical element models as a tool for regional assessment.

Development of analytical element (AE) models within the tributaries and creation of a basin-wide model may be useful, cost-effective tools. Whereas the Snake River Basin is so immense, and the size and types of tributary basins vary so much, it does not seem likely that one approach will work for all areas. Use of an AE model or models could serve as a precursor to more rigorous numerical models.

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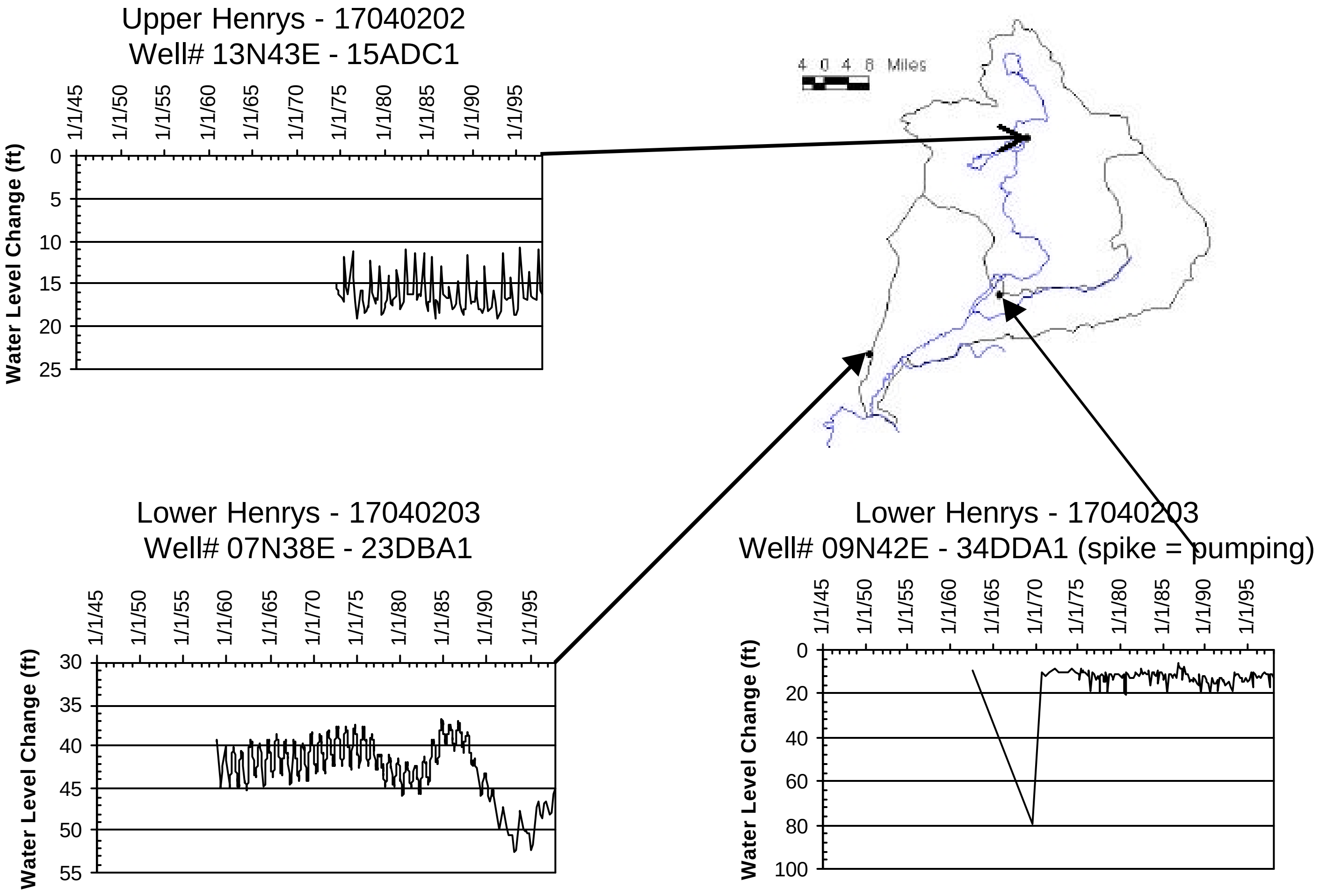
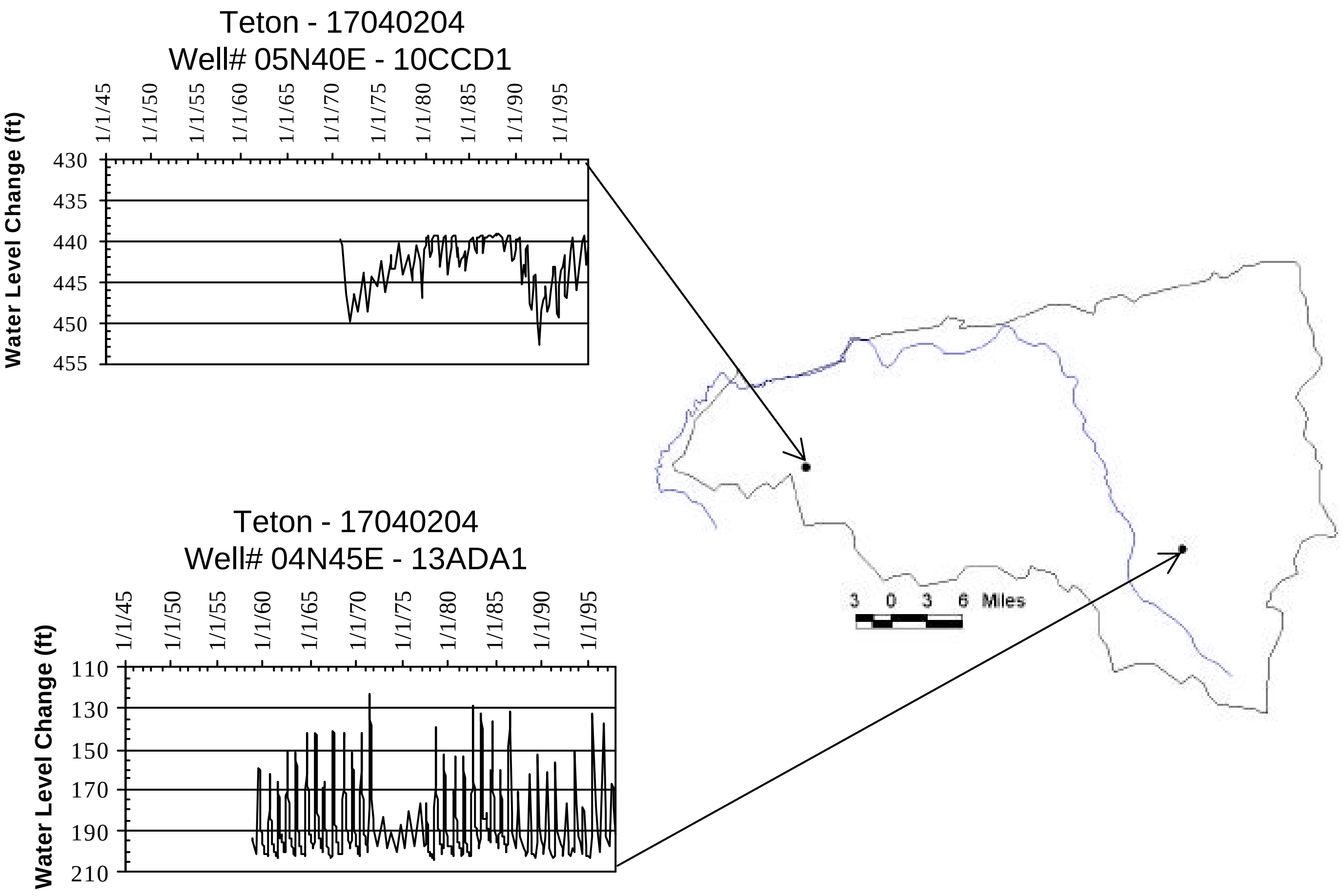
Appendix A

Water Table Hydrographs



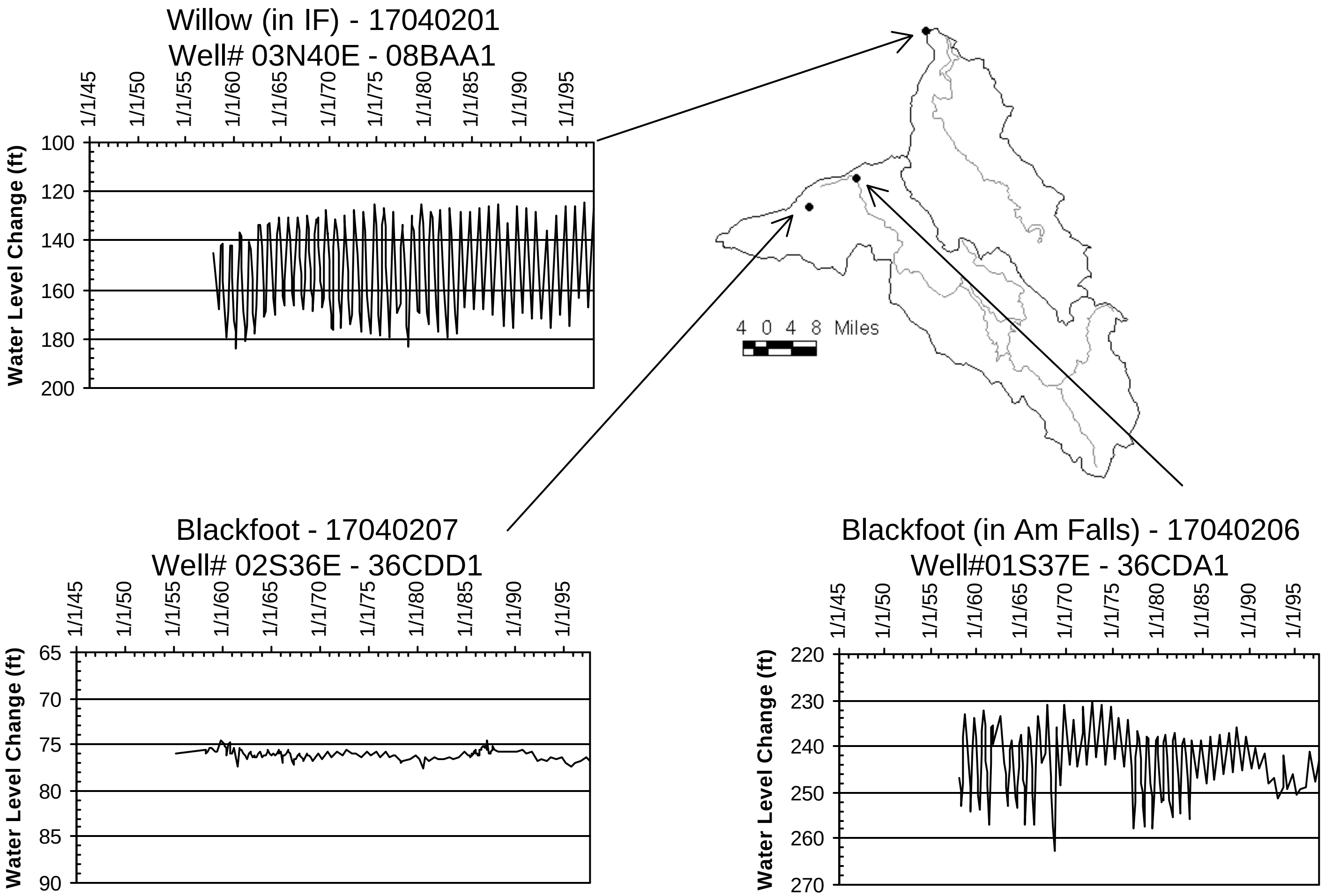
Water level change represents depth to water.

Figure A.1 Hydrographs for wells in Upper Henrys and Lower Henrys HUCs.



Water level change represents depth to water.

Figure A.2. Hydrographs for wells in Teton HUC.

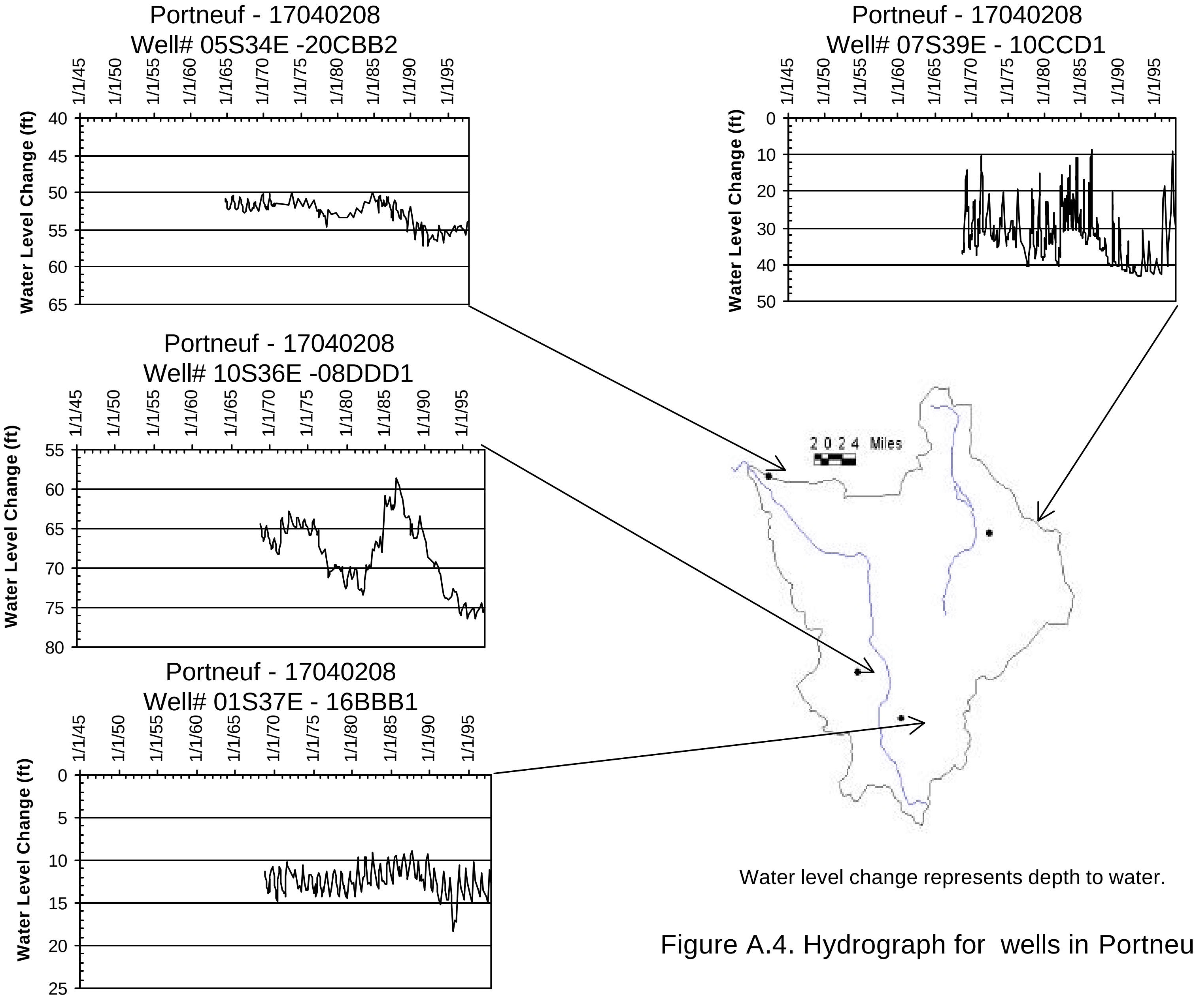

Willow (in IF) - 17040201
Well# 03N40E - 08BAA1

Blackfoot - 17040207
Well# 02S36E - 36CDD1

Blackfoot (in Am Falls) - 17040206
Well#01S37E - 36CDA1

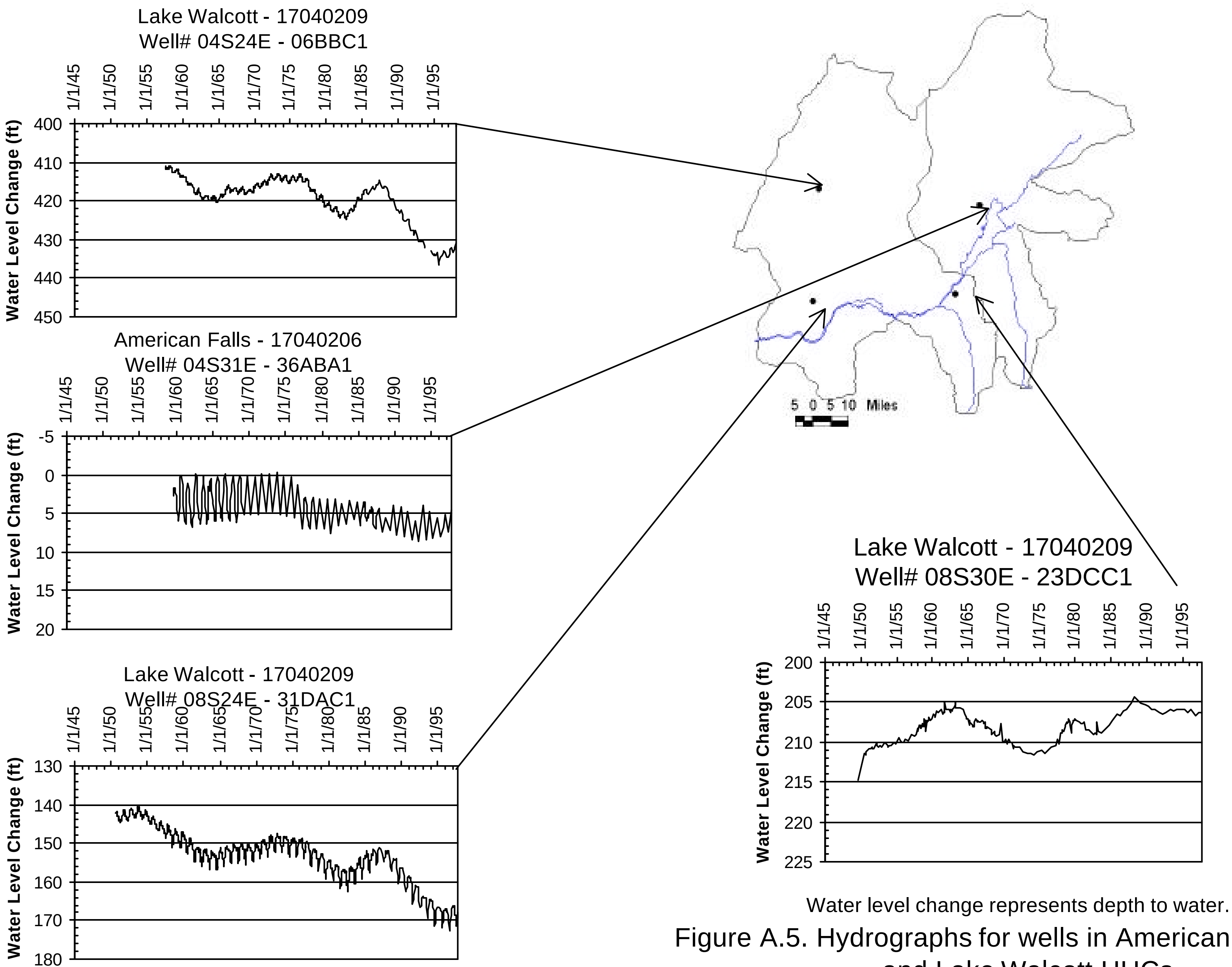
Water level change represents depth to water.

Figure A.3. Hydrographs for wells in Willow and Blackfoot HUCs.



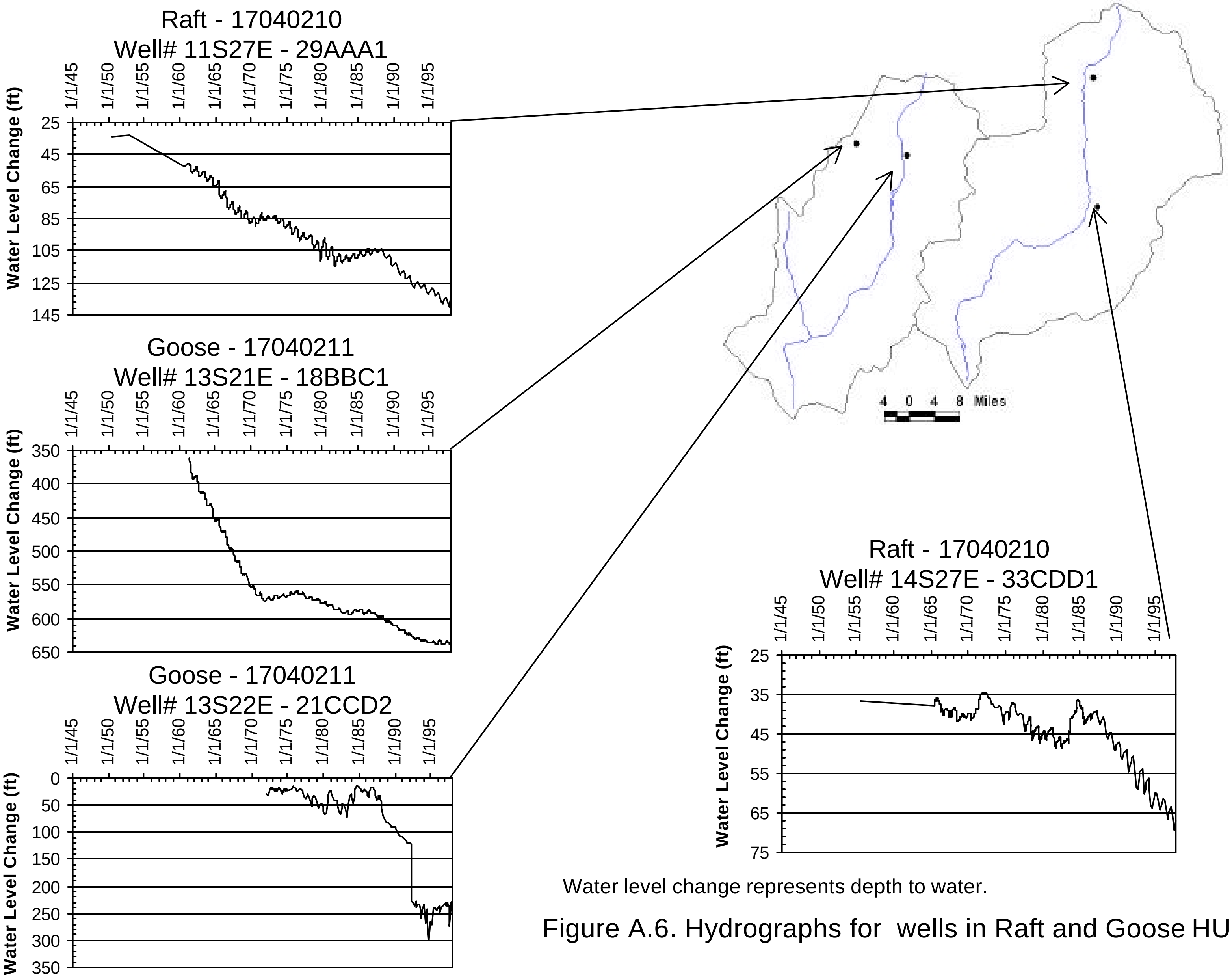
Water level change represents depth to water.

Figure A.4. Hydrograph for wells in Portneuf HUC.



Water level change represents depth to water.

Figure A.5. Hydrographs for wells in American Falls and Lake Walcott HUCs.


Raft - 17040210
Well# 11S27E - 29AAA1

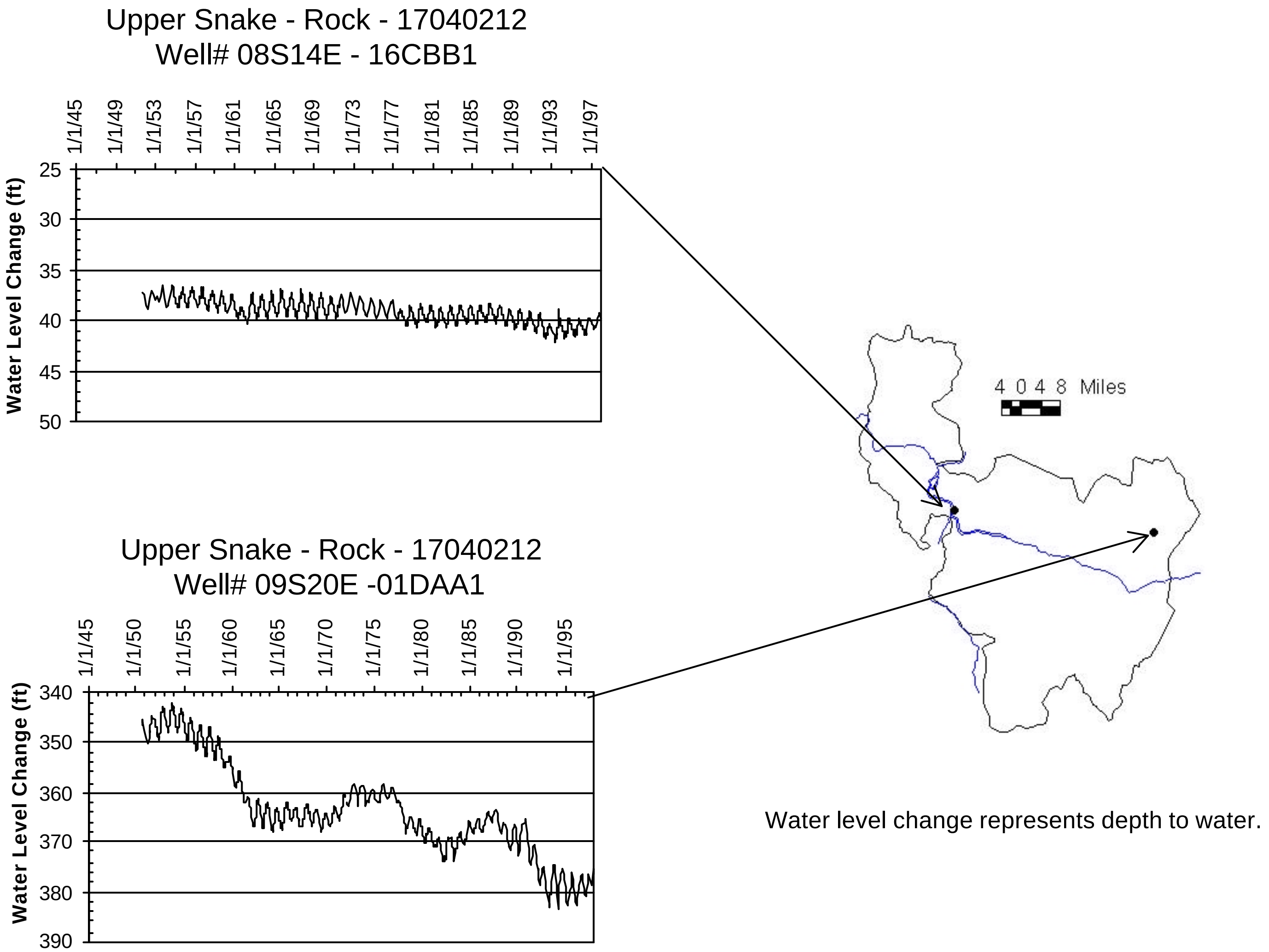
Goose - 17040211
Well# 13S21E - 18BBC1

Goose - 17040211
Well# 13S22E - 21CCD2

Raft - 17040210
Well# 14S27E - 33CDD1

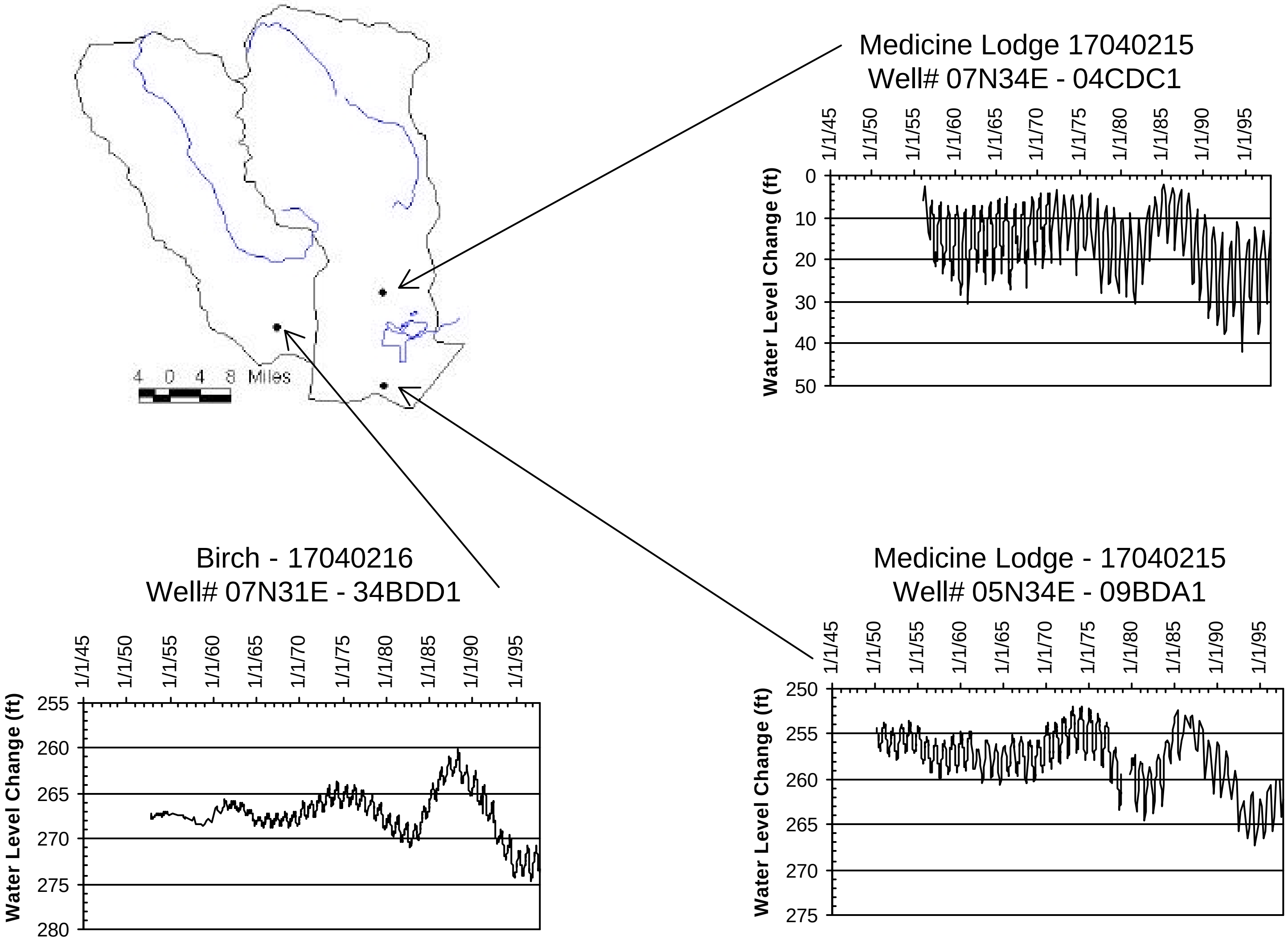
Water level change represents depth to water.

Figure A.6. Hydrographs for wells in Raft and Goose HUCs.



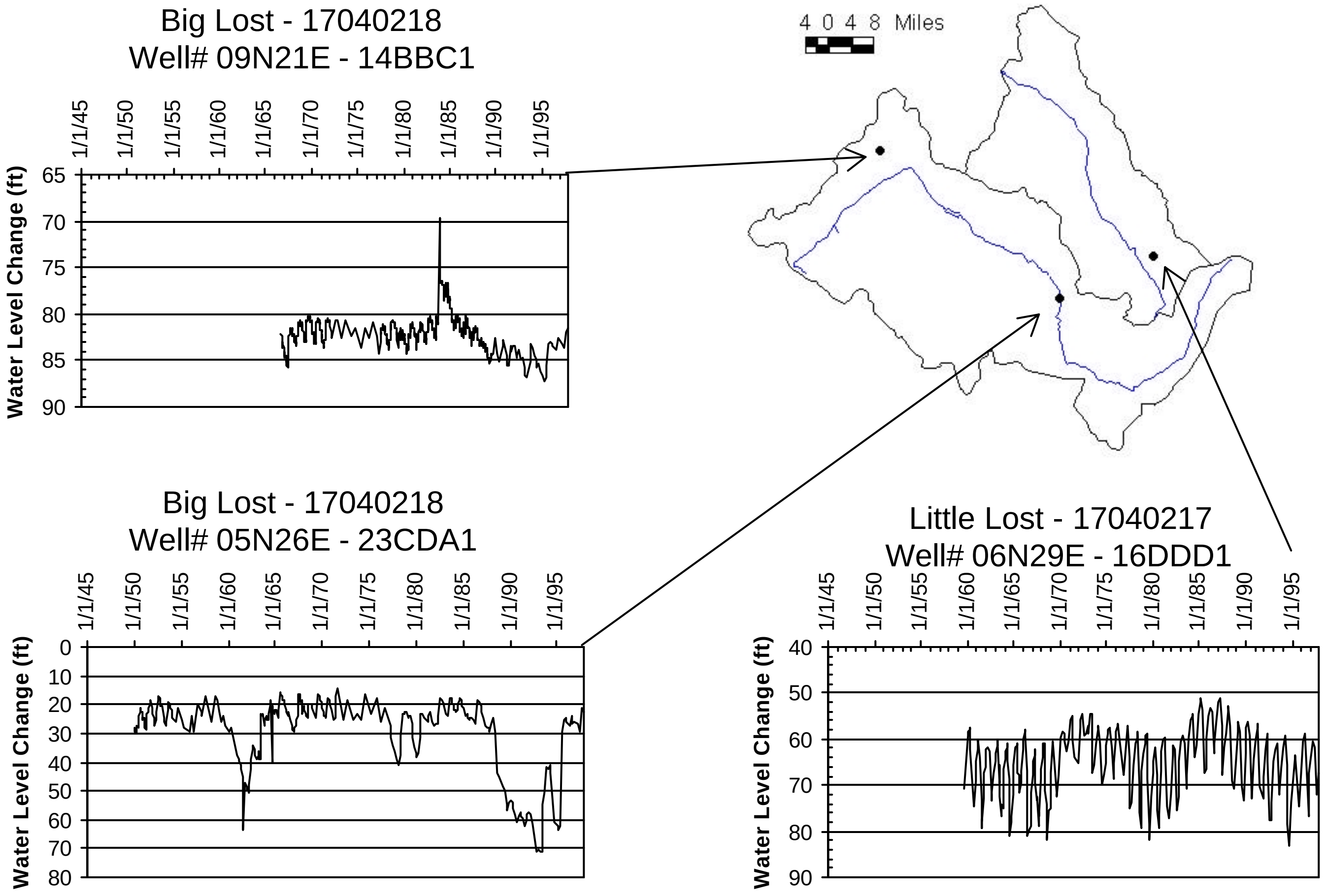
Water level change represents depth to water.

Figure A.7. Hydrographs for wells in Upper Snake - Rock HUC.



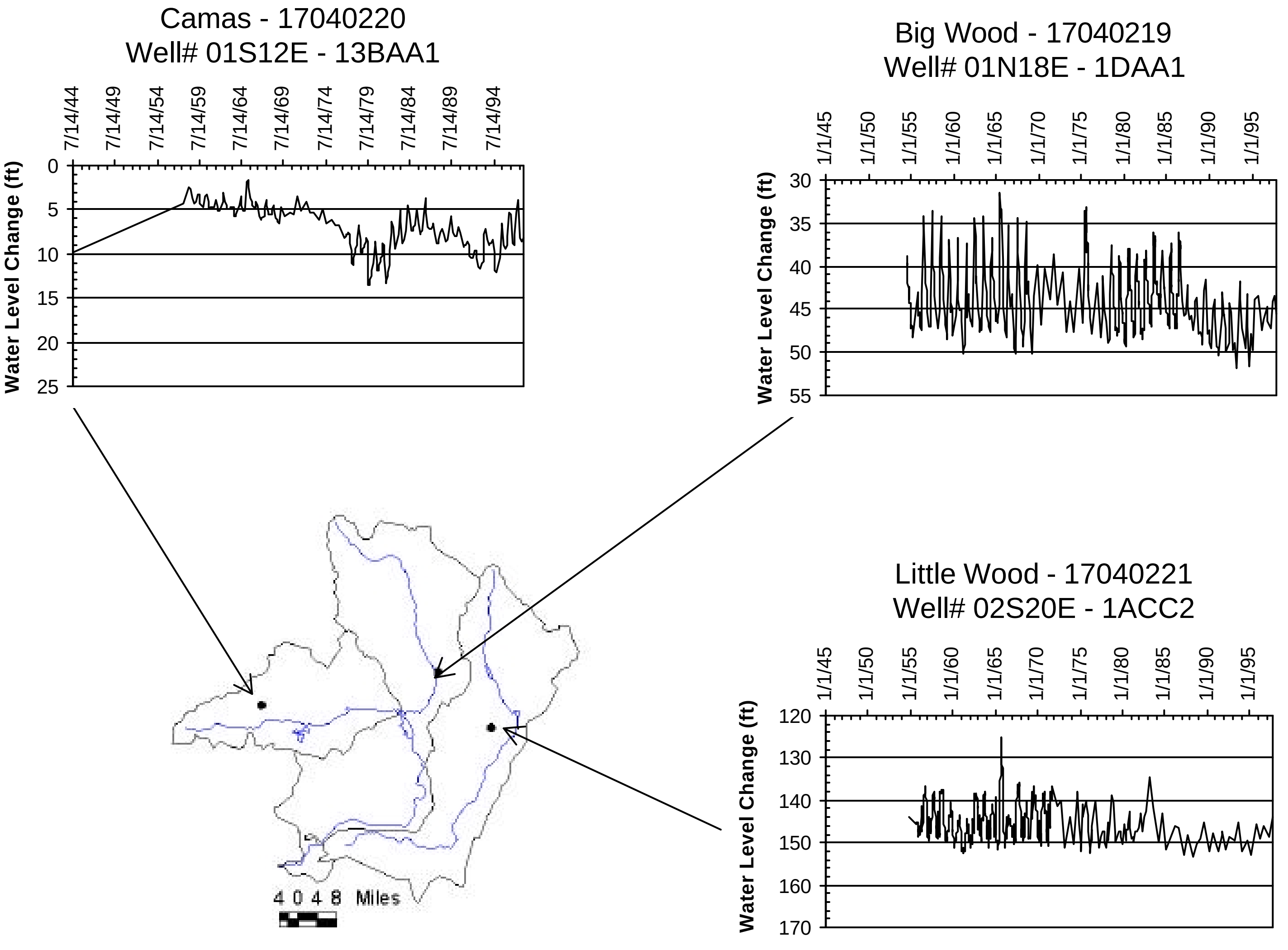
Water level change represents depth to water.

Figure A.8. Hydrographs for wells in Birch and Medicine Lodge HUCs..



Water level change represents depth to water.

Figure A.9. Hydrographs for wells in the Little Lost and Big Lost HUCs.



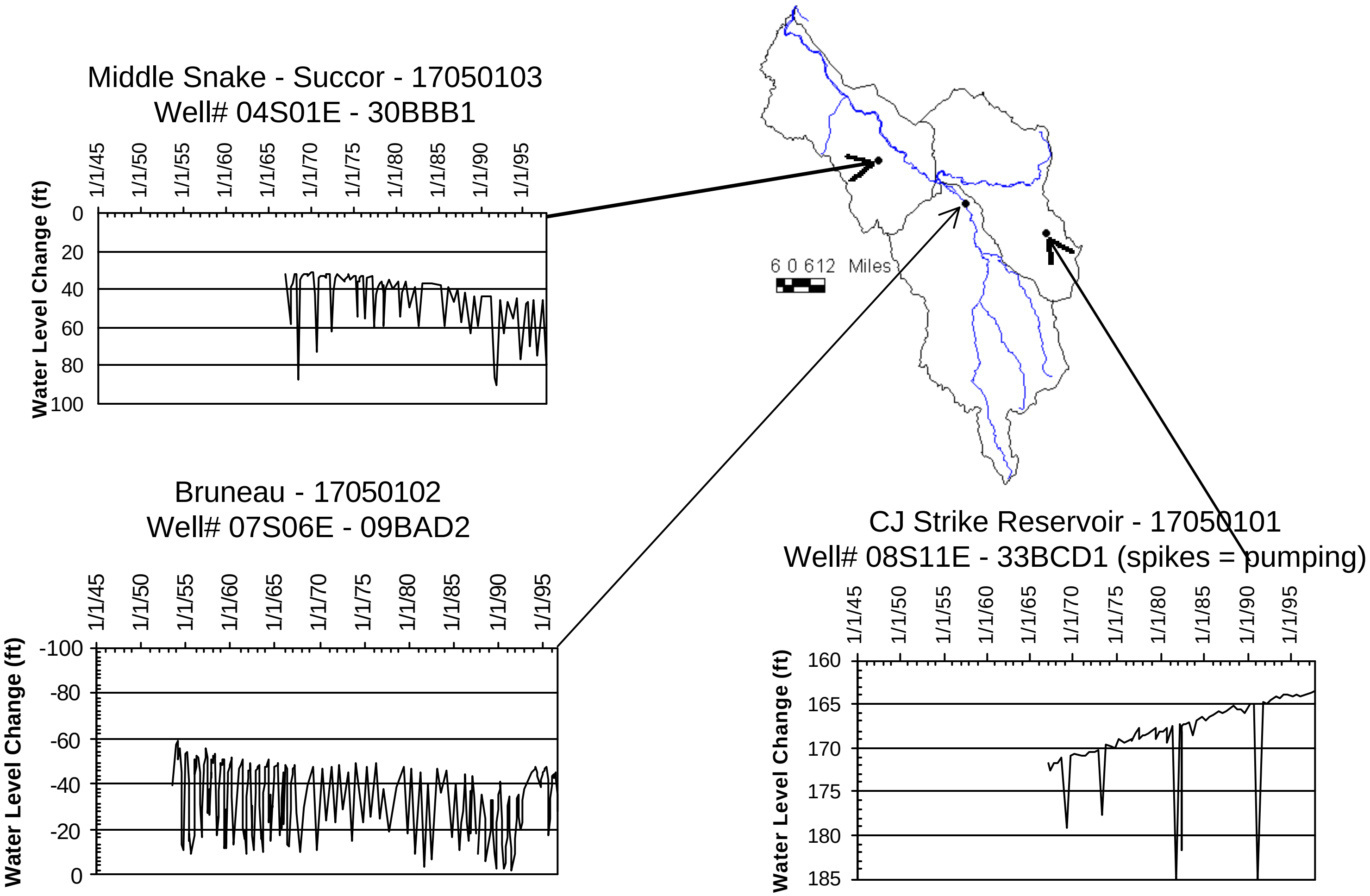
Camas - 17040220
Well# 01S12E - 13BAA1

Big Wood - 17040219
Well# 01N18E - 1DAA1

Little Wood - 17040221
Well# 02S20E - 1ACC2

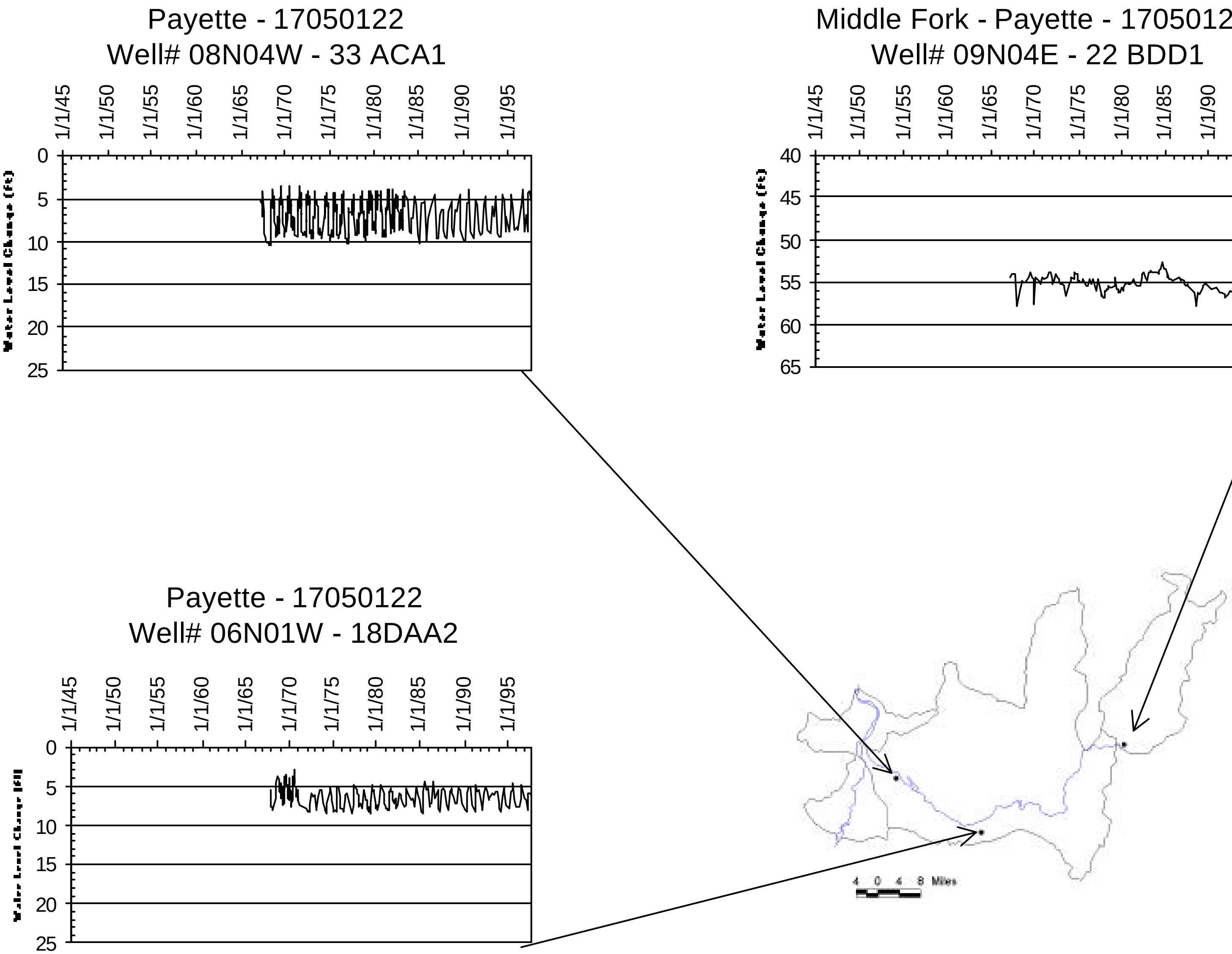
Water level change represents depth to water.

Figure A.10. Hydrographs for wells in Big Wood, Camas, and Little Wood HUCs.



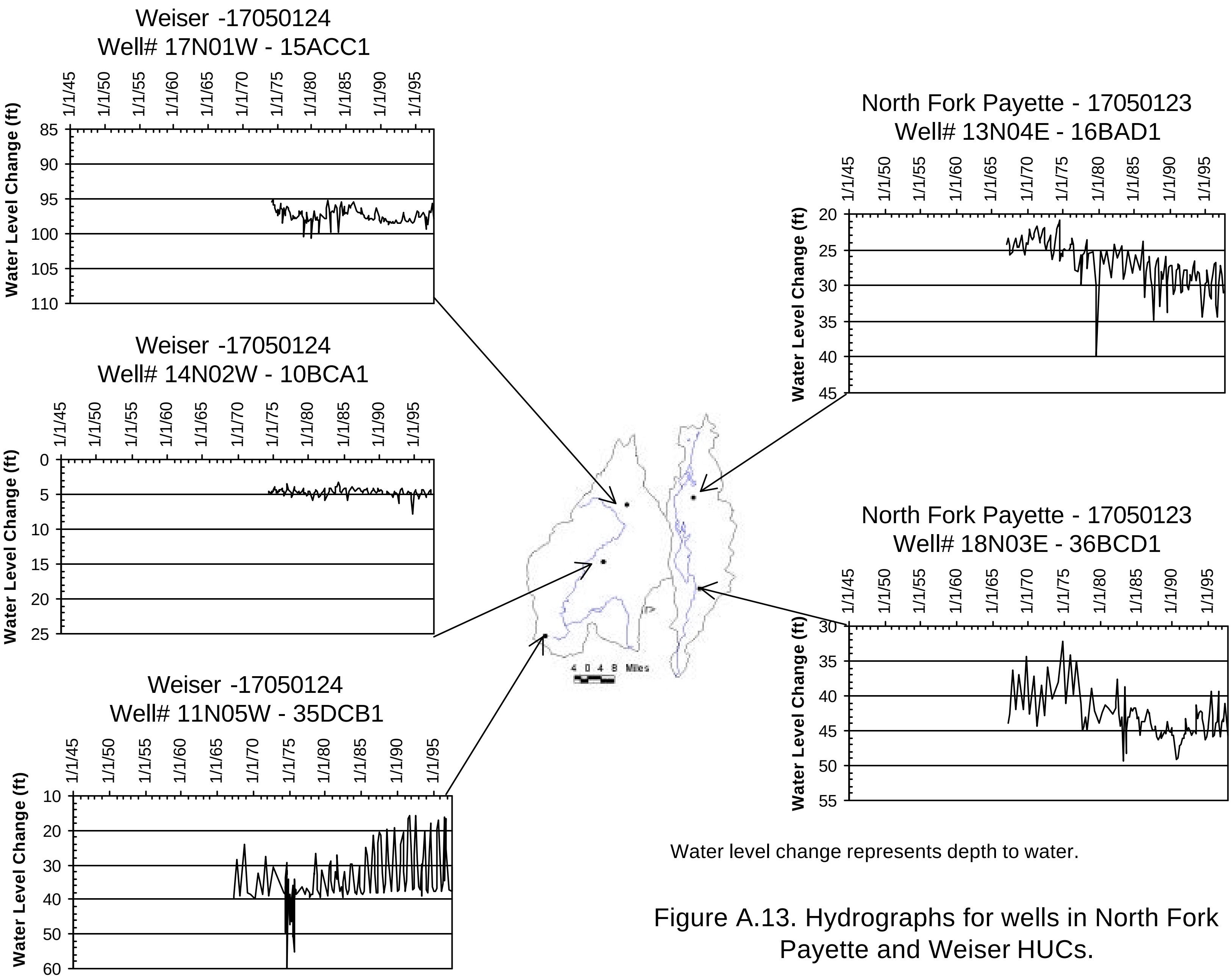
Water level change represents depth to water.

Figure A.11. Hydrographs for wells in Middle Snake - Succor, Bruneau and C.J. Strikes Reservoir HUCs.



Water level change represents depth to water.

Figure A.12. Hydrographs for wells in Middle Fork Payette and Payette HUCs.



Water level change represents depth to water.

Figure A.13. Hydrographs for wells in North Fork Payette and Weiser HUCs.

Appendix B

Number of Water Right Claims and Authorized Discharge by HUC

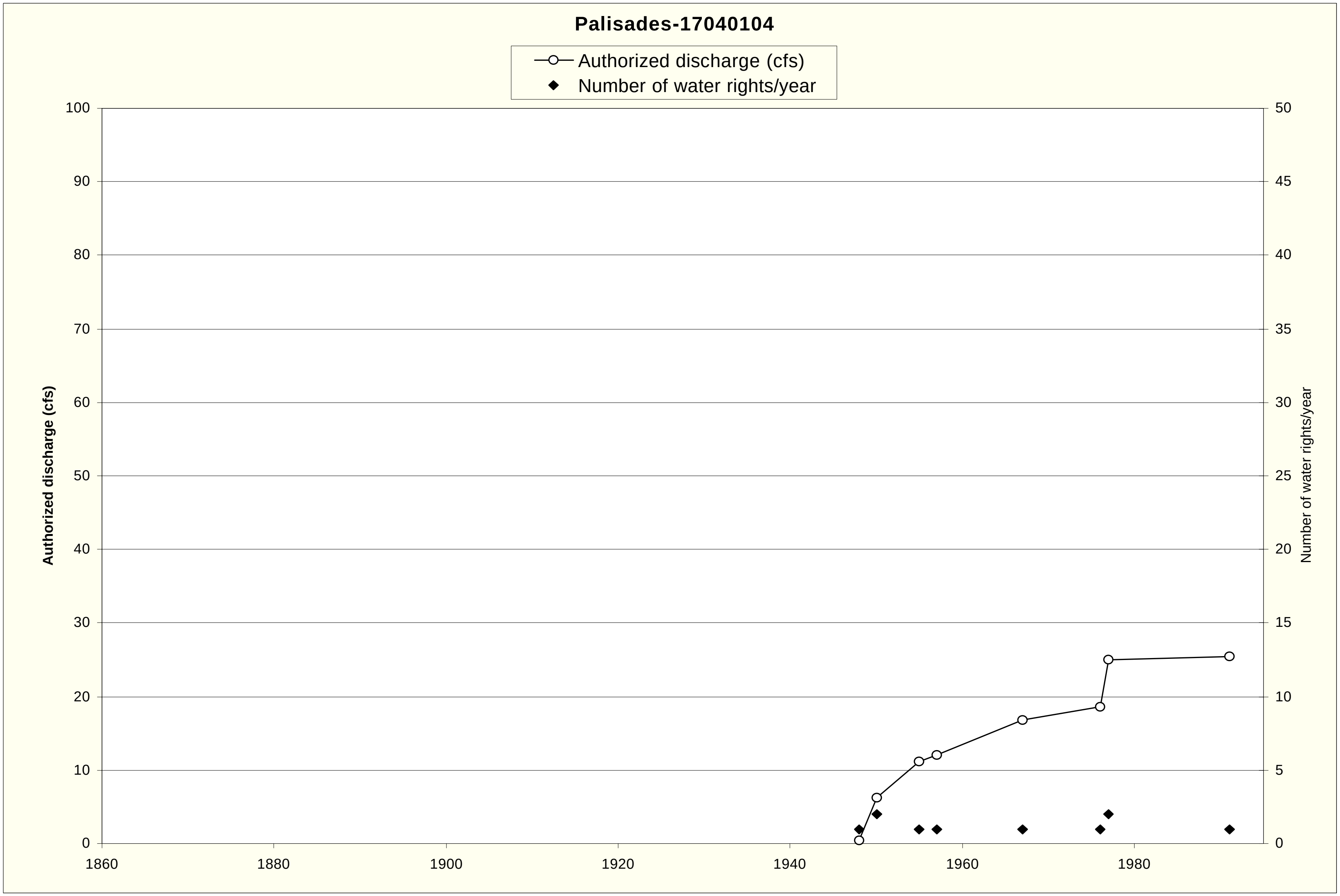


Figure B.1. Palisades (17040104) - summary of ground water claims and authorized discharge (cfs).

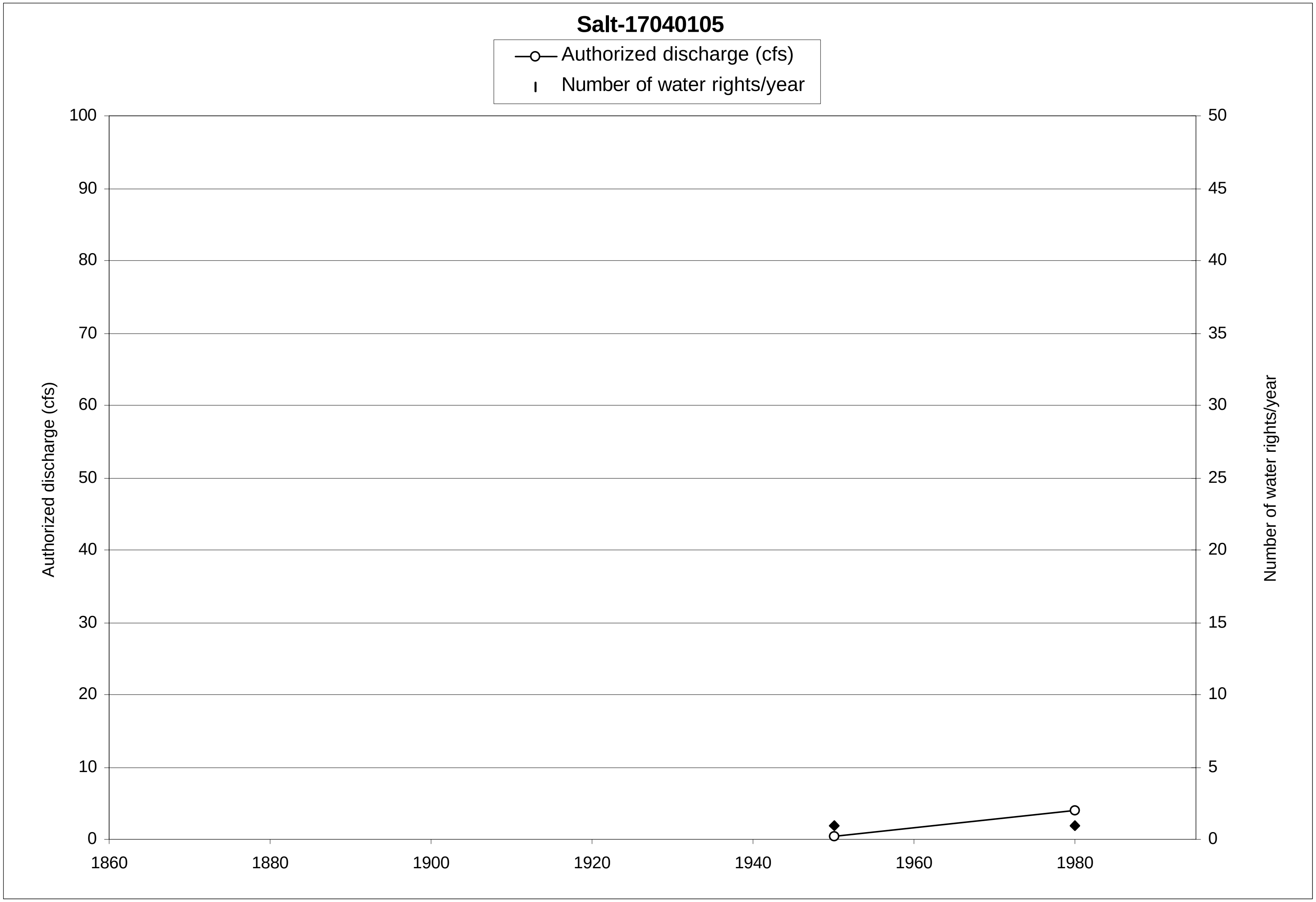


Figure B.2. Salt (17040105) - summary of ground water claims and authorized discharge (cfs).

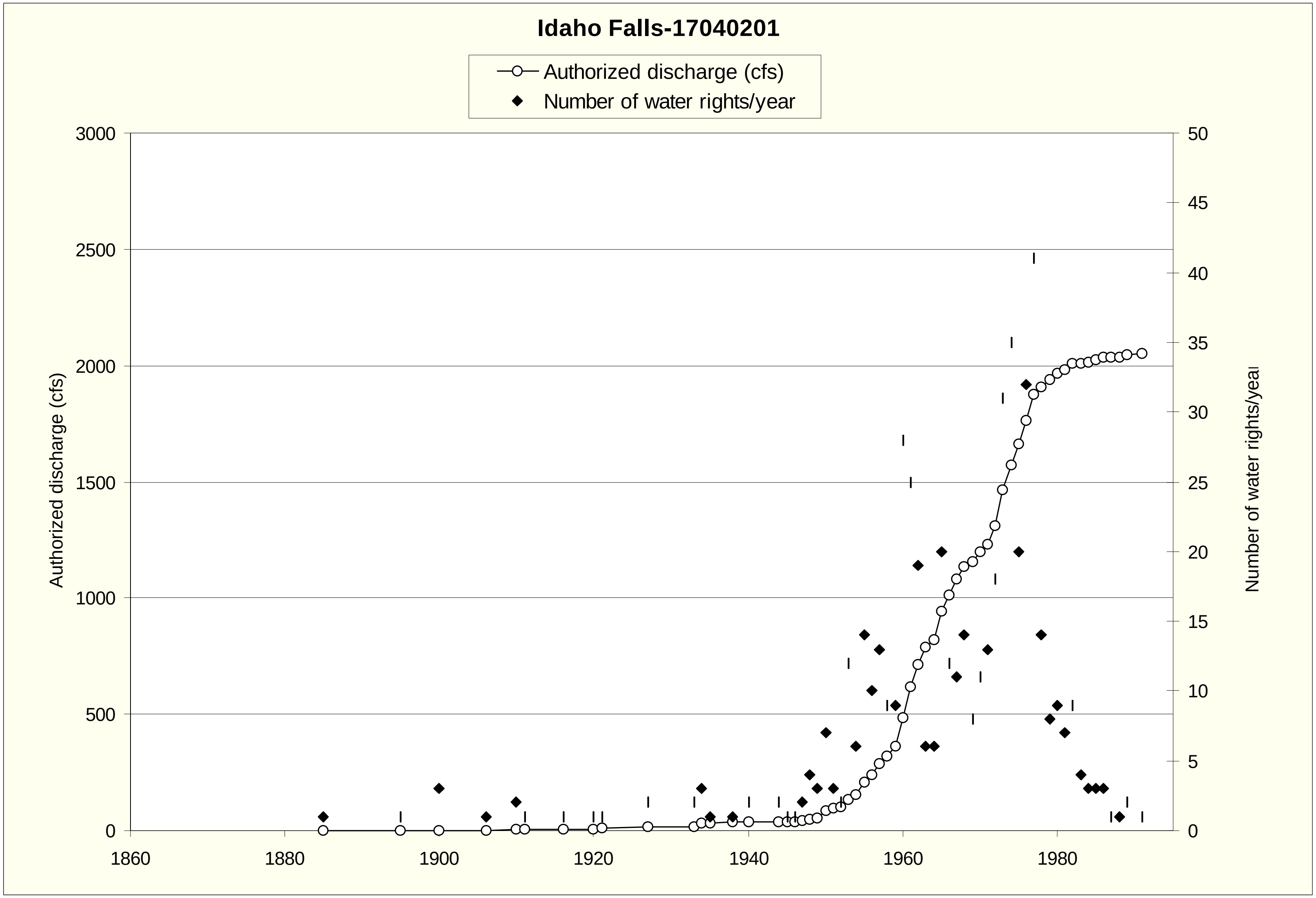


Figure B.3. Idaho Falls (17040201) - summary of ground water claims and authorized discharge (cfs).

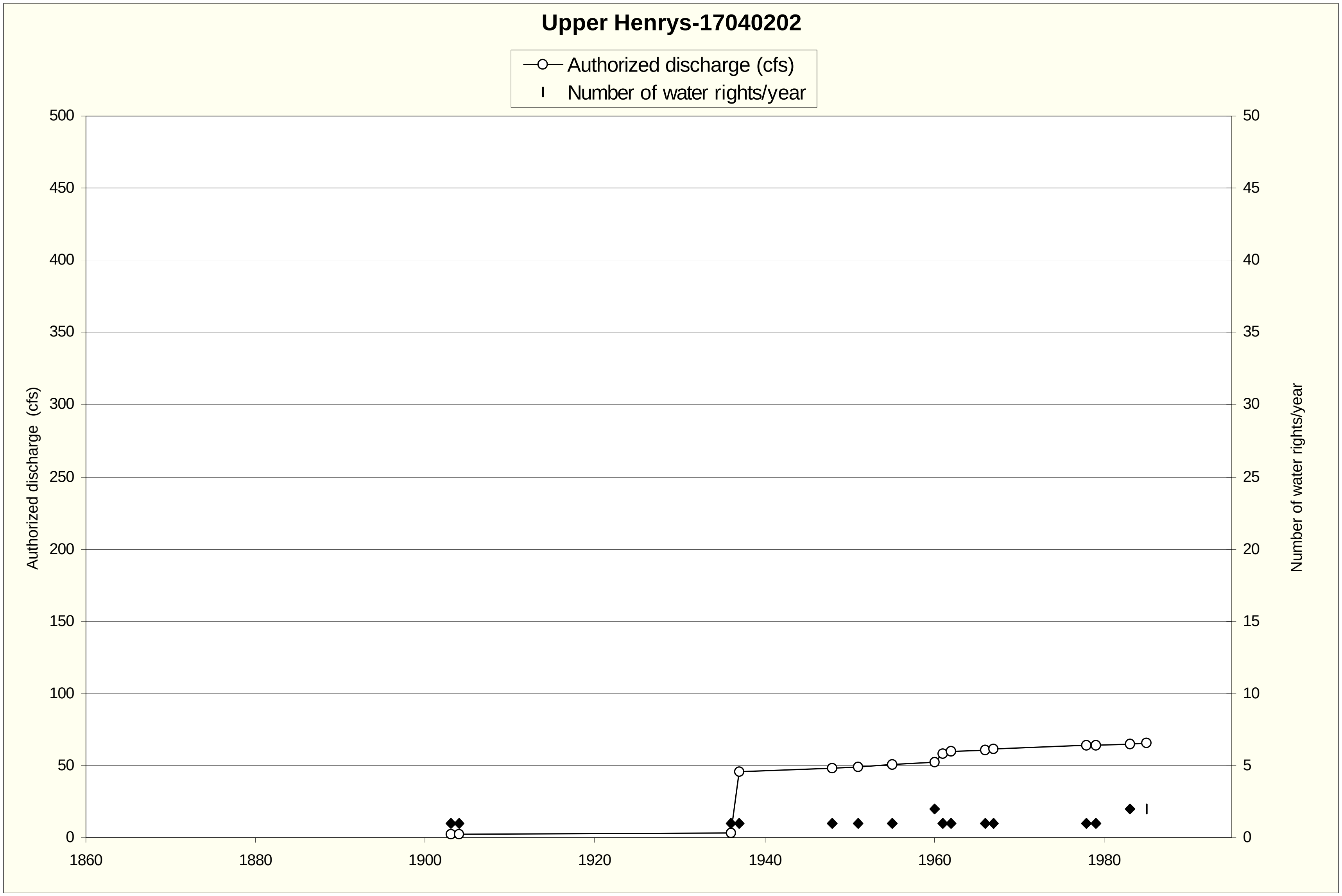


Figure B.4. Upper Henrys (17040202) - summary of ground water claims and authorized discharge (cfs).

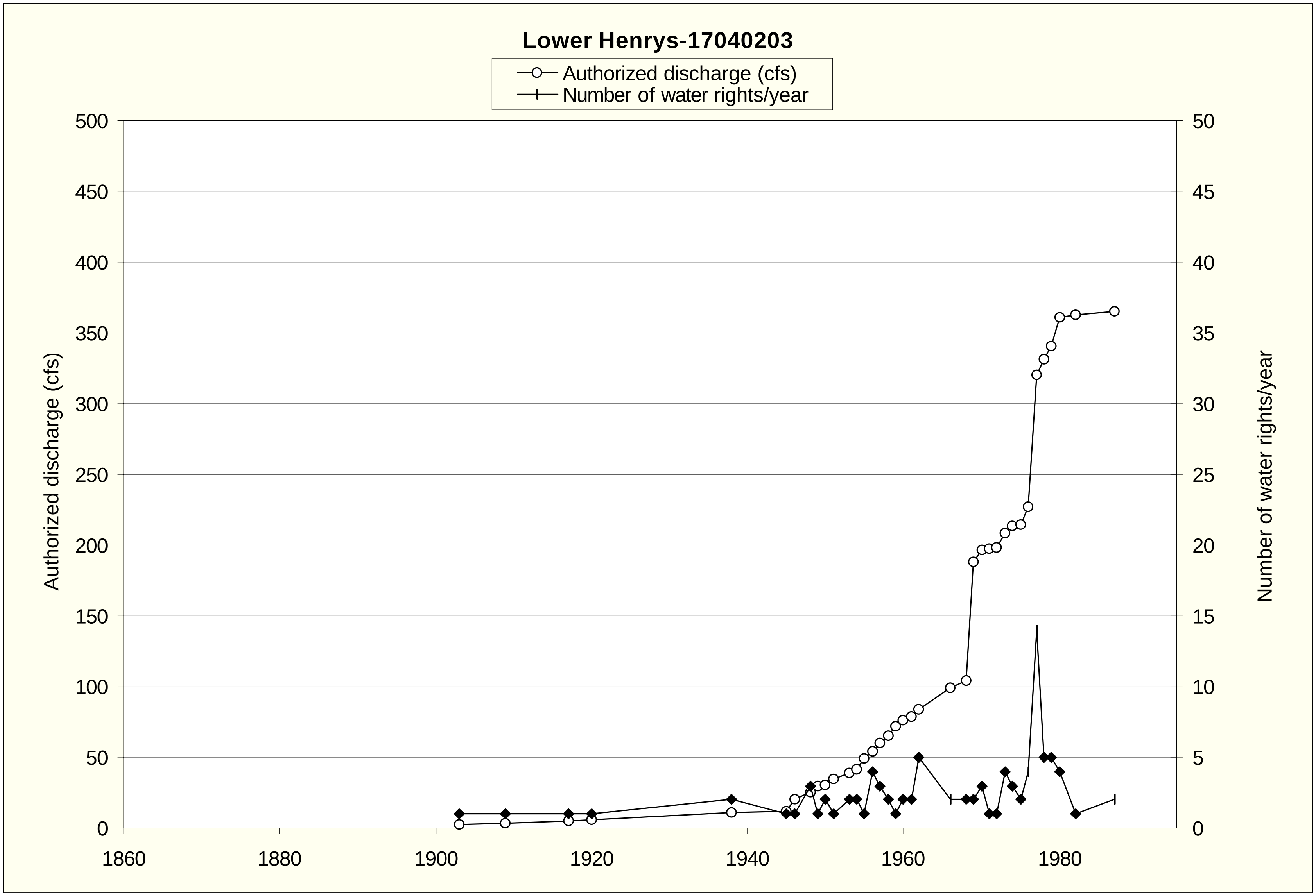


Figure B.5. Lower Henrys (17040203) - summary of ground water claims and authorized discharge (cfs).

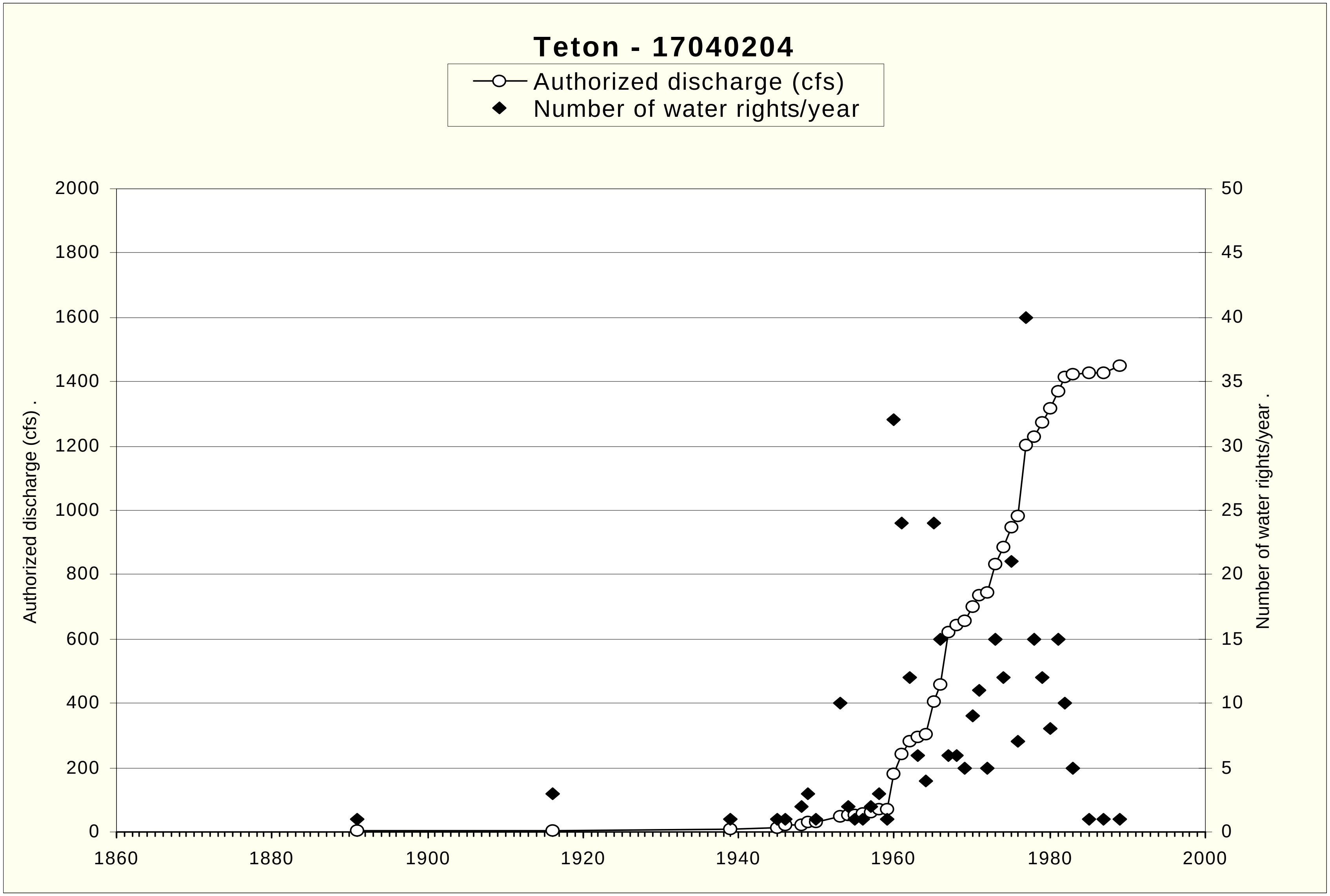


Figure B.6. Teton (17040204) - summary of ground water claims and authorized discharge (cfs).

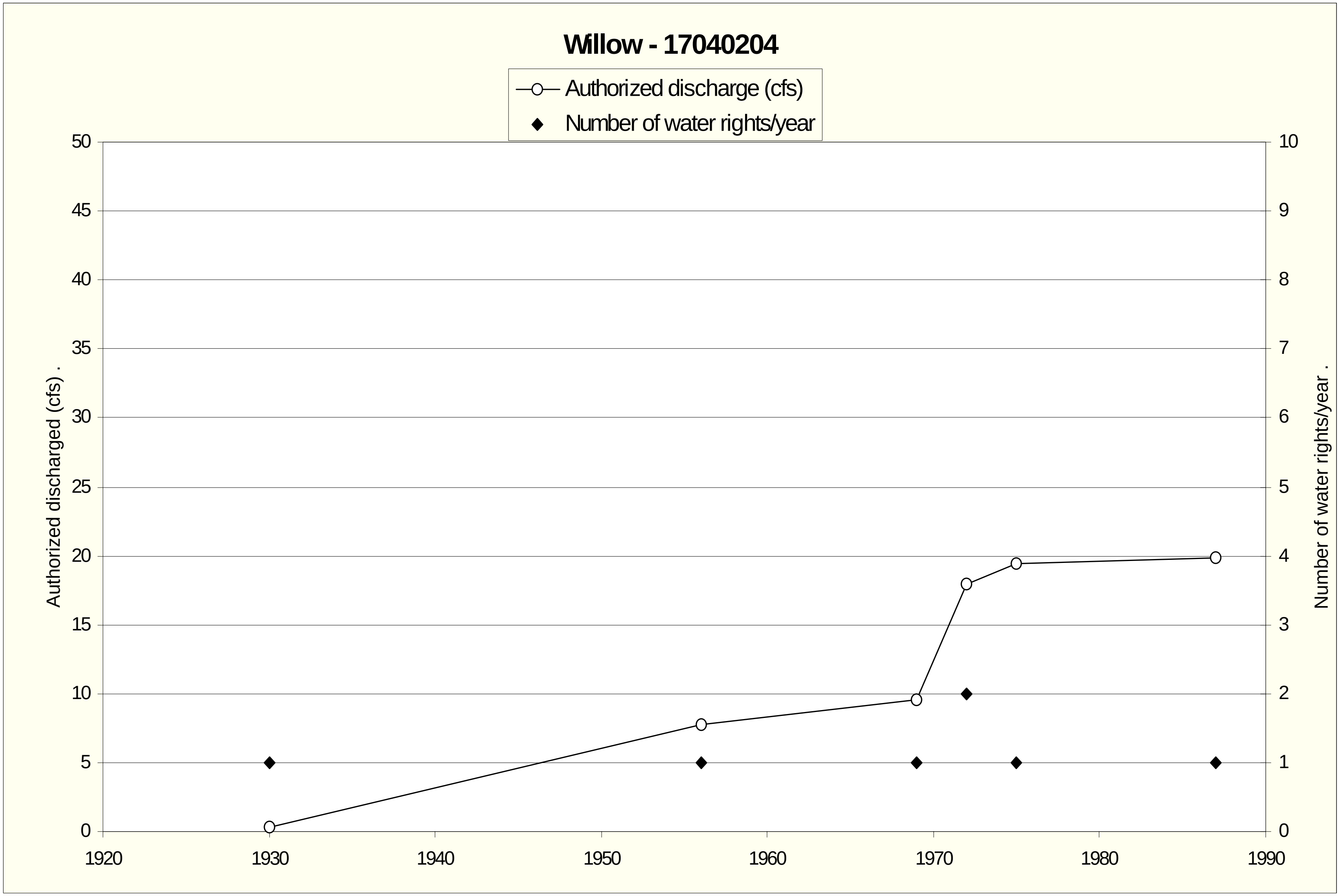


Figure B.7. Willow (17040205) - summary of ground water claims and authorized discharge (cfs).

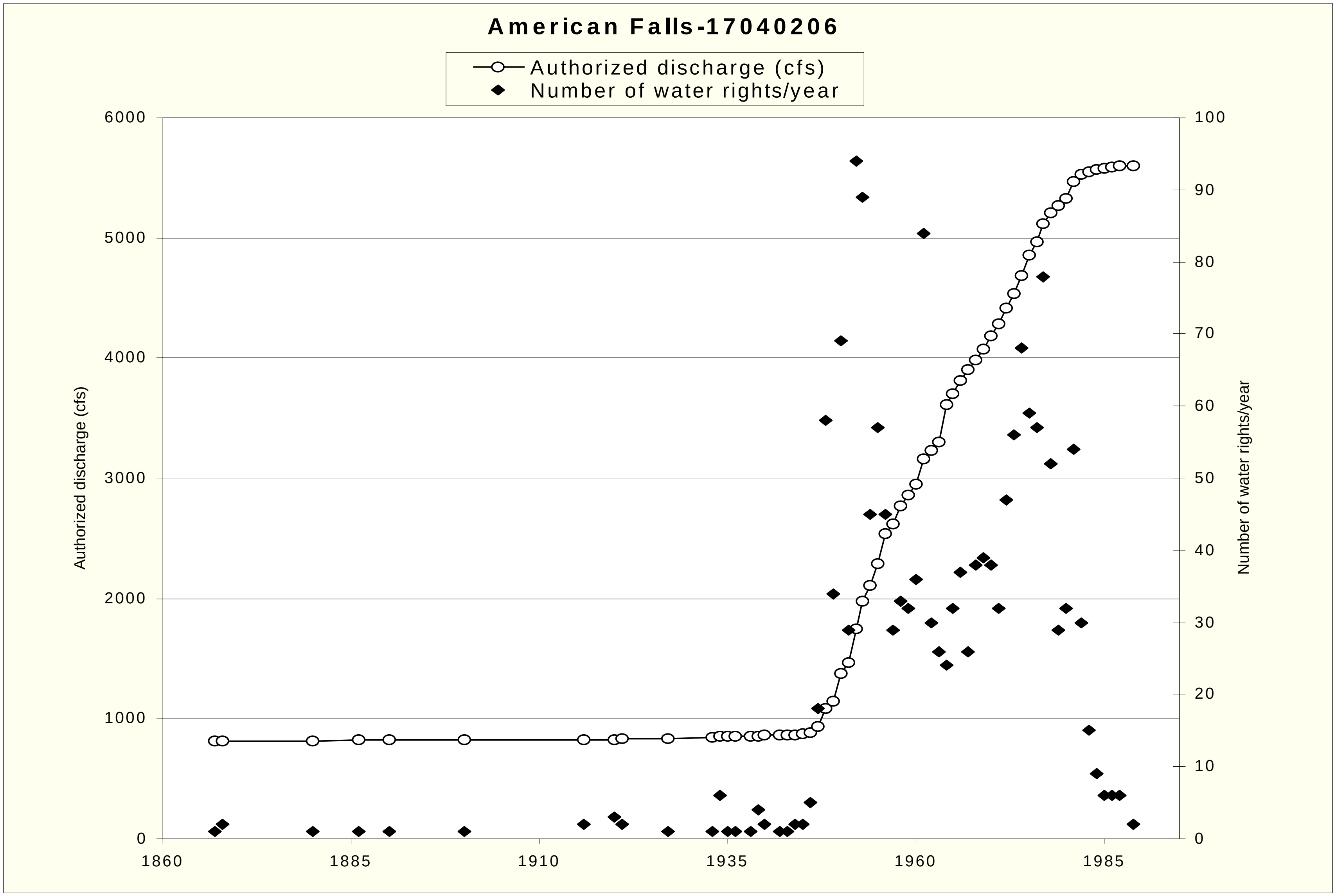


Figure B.8. American Falls (17040206) - summary of ground water claims and authorized discharge (cfs).

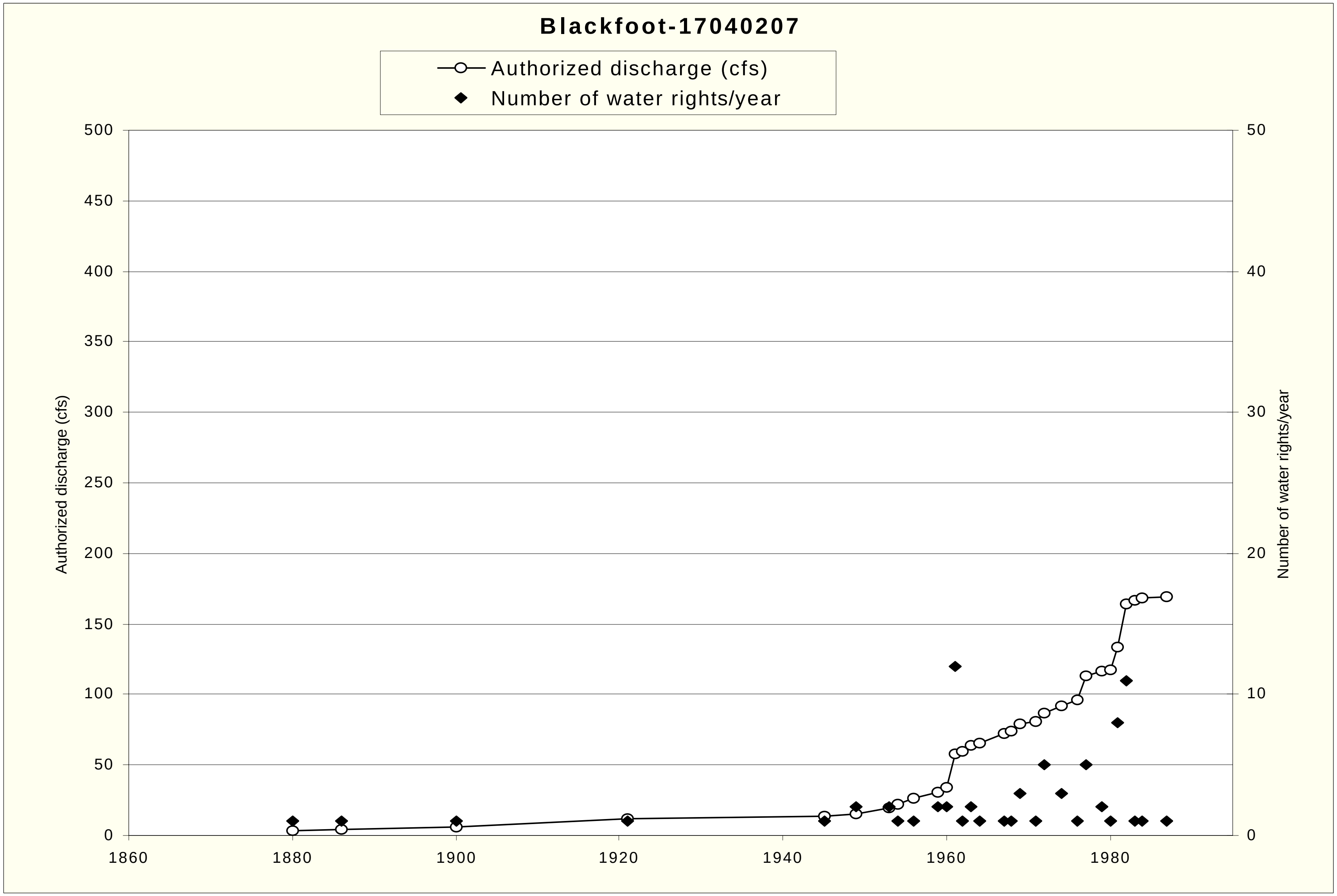


Figure B.9. Blackfoot (17040207) - summary of ground water claims and authorized discharge (cfs).

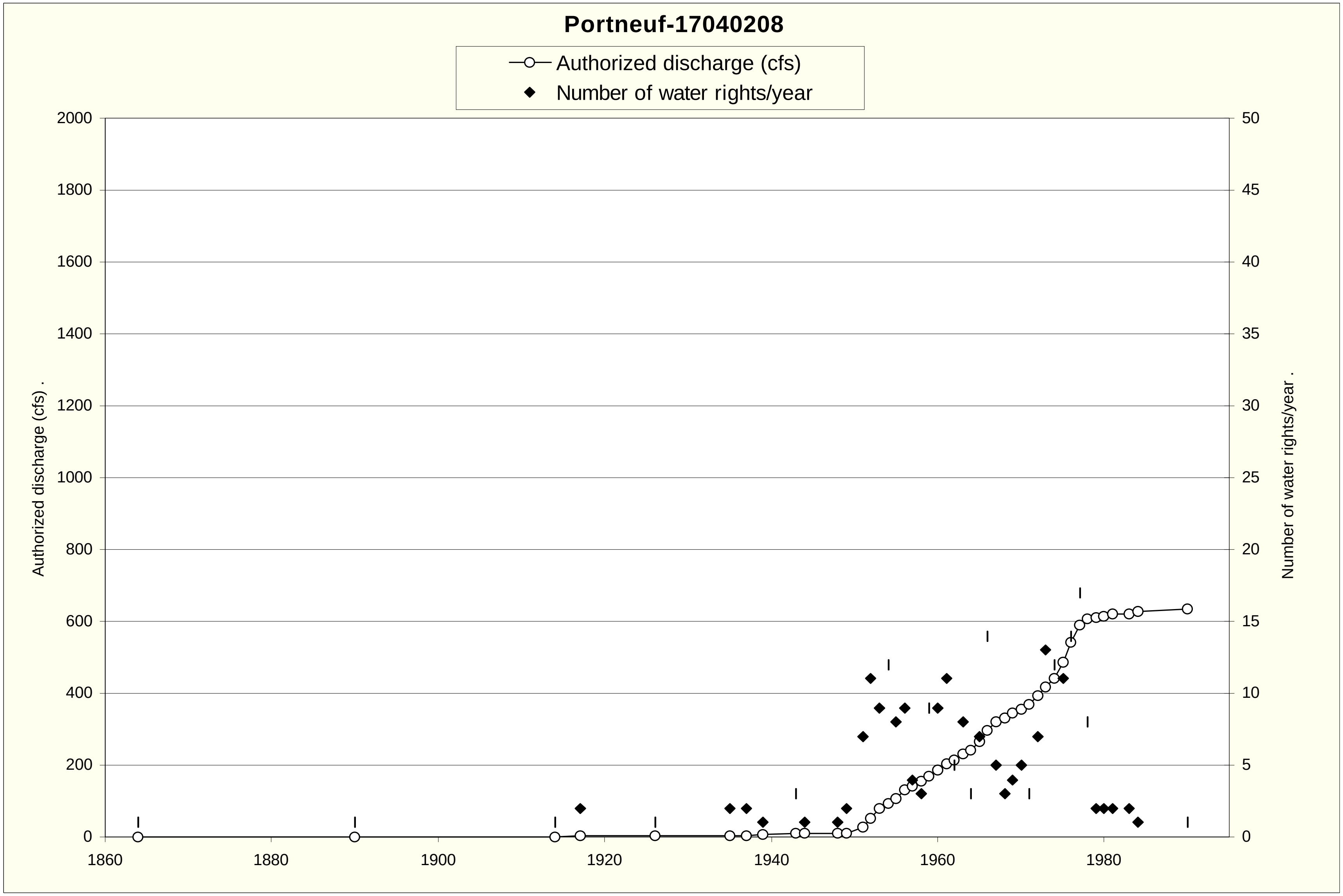


Figure B.10. Portneuf (17040208) - summary of ground water claims and authorized discharge (cfs).

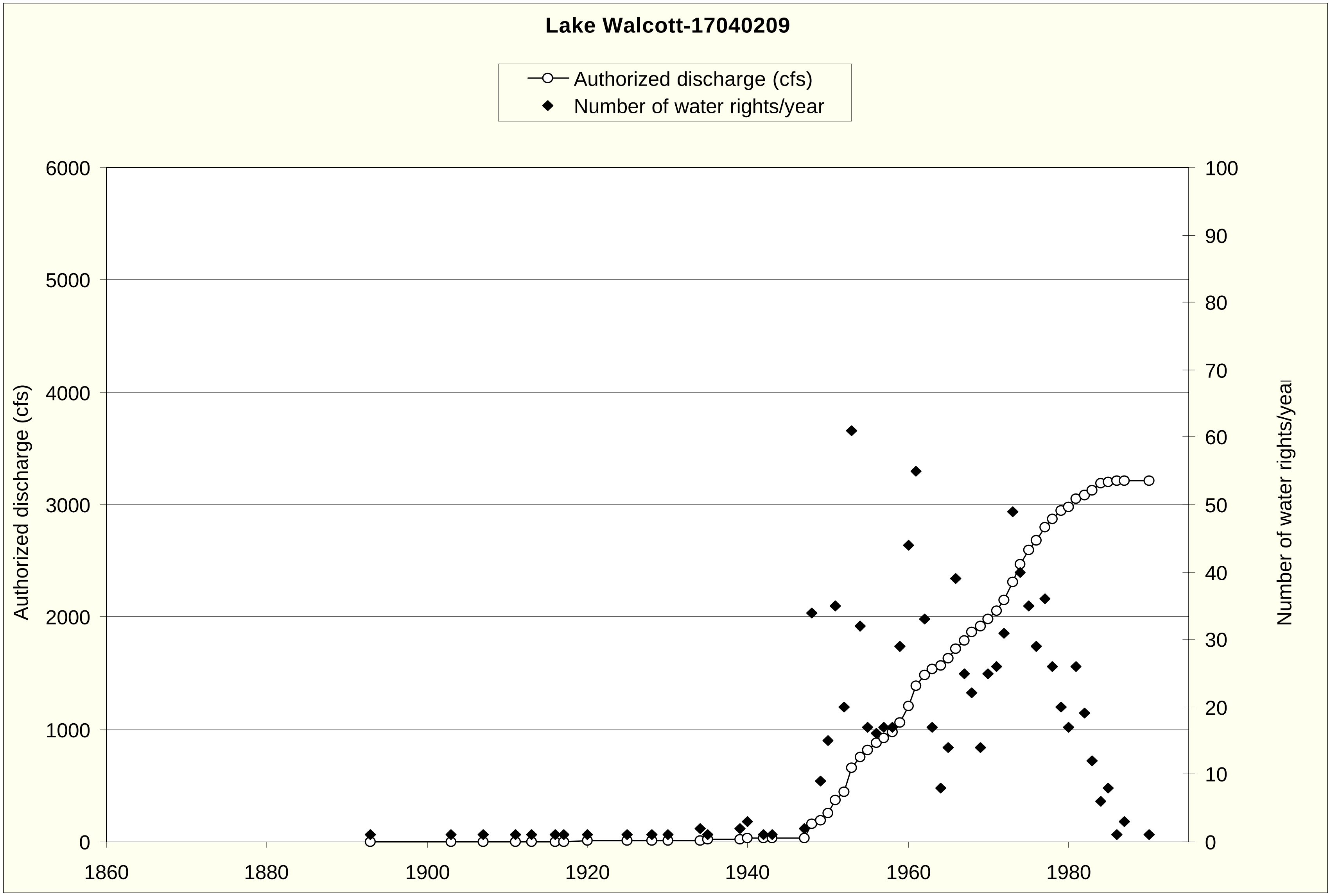


Figure B.11. Lake Walcott (17040209) - summary of ground water claims and authorized discharge (cfs).

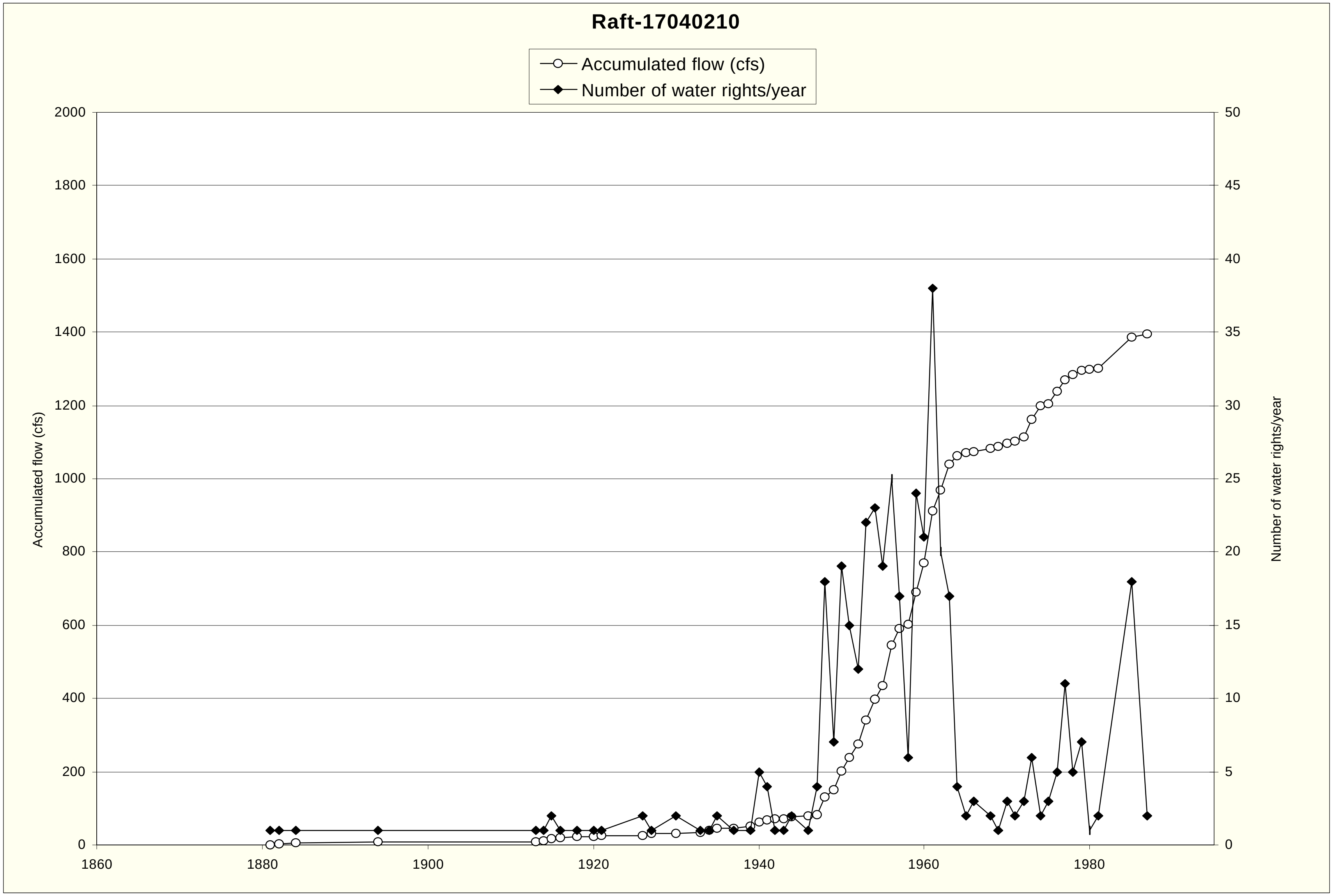


Figure B.12 Raft (17040210) - summary of ground water permits and accumulated flow (cfs).

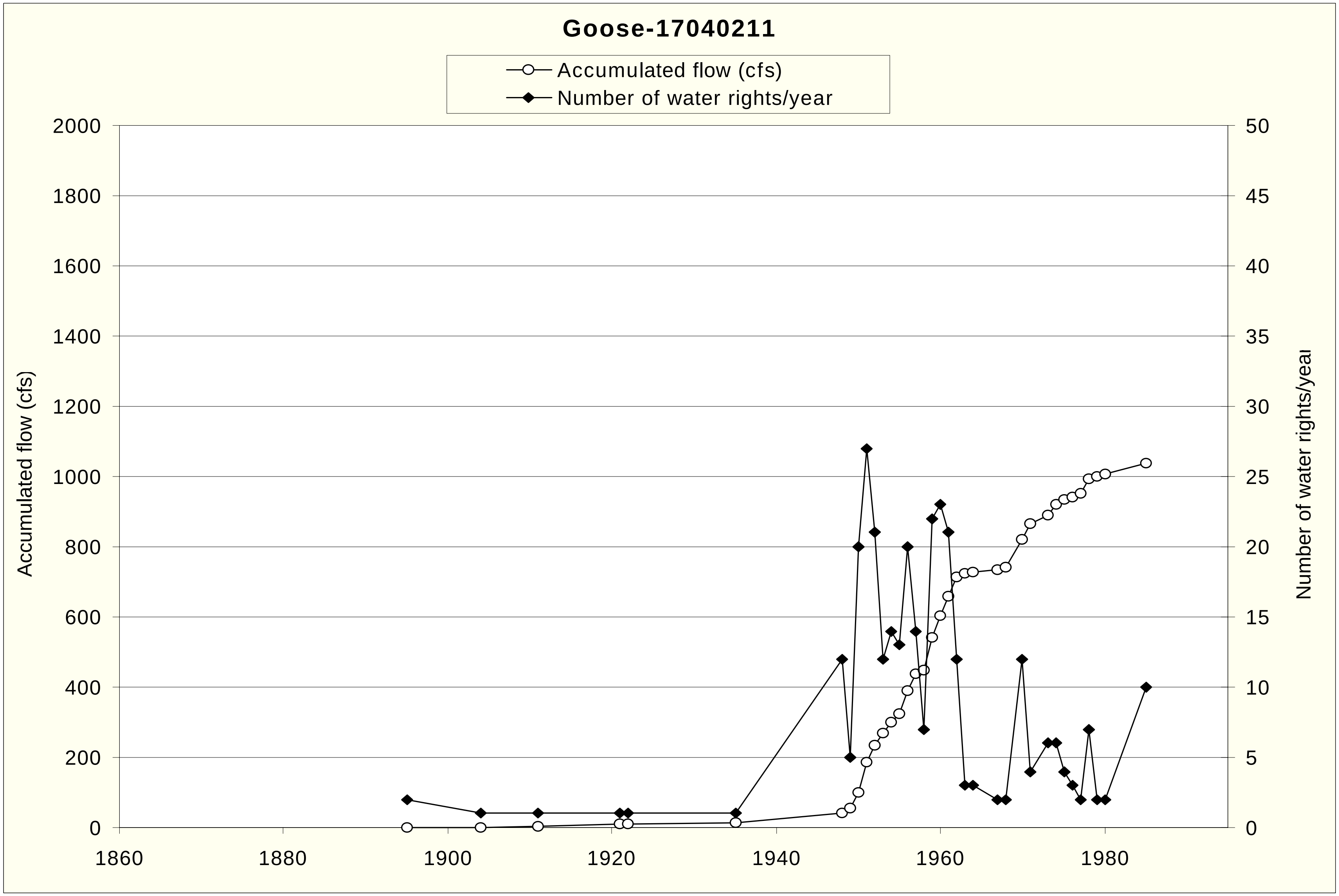


Figure B.13 (17040211) - summary of ground water permits and accumulated flow (cfs).

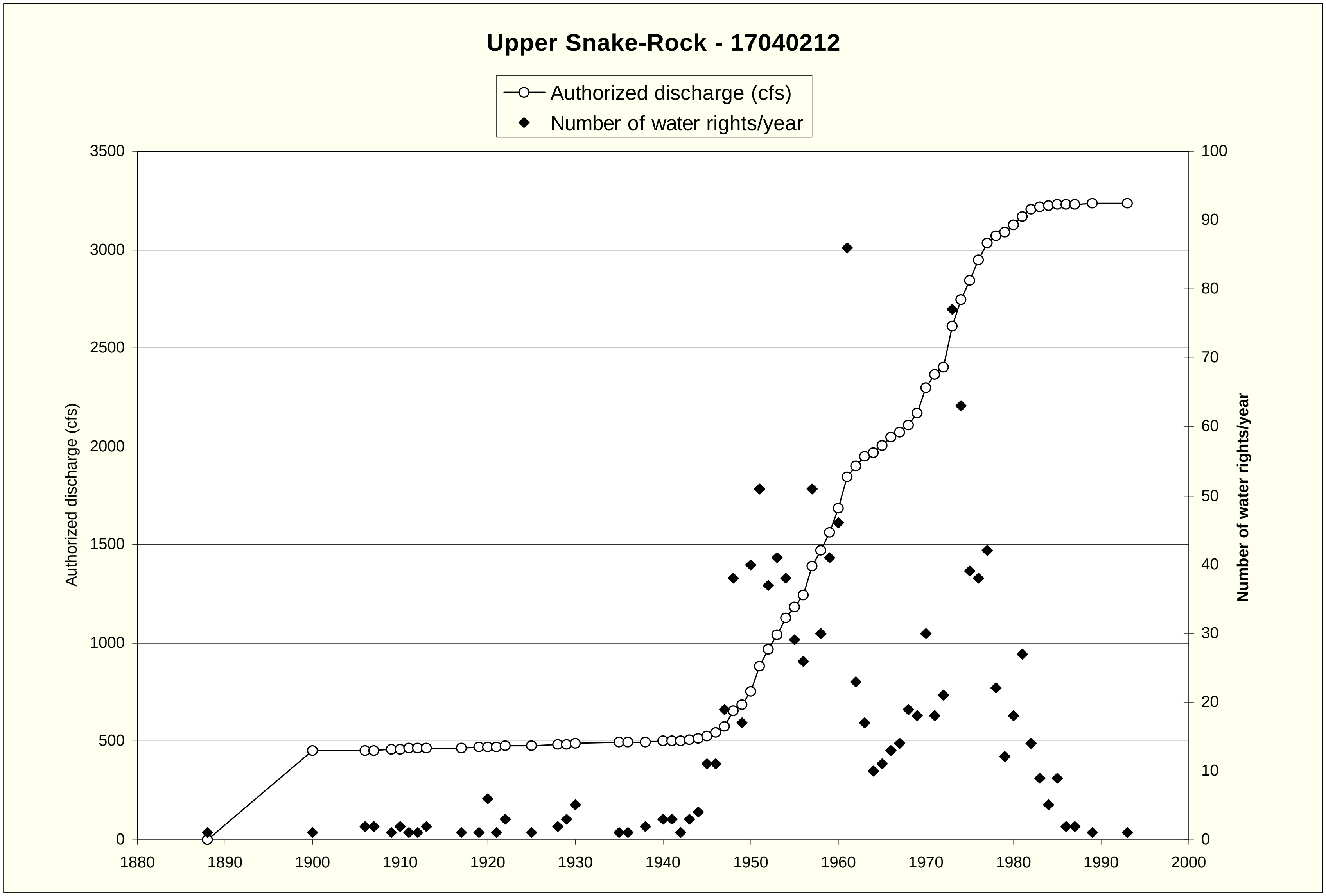


Figure B.14. Upper Snake-Rock (17040212) - summary of ground water claims and authorized discharge (cfs).

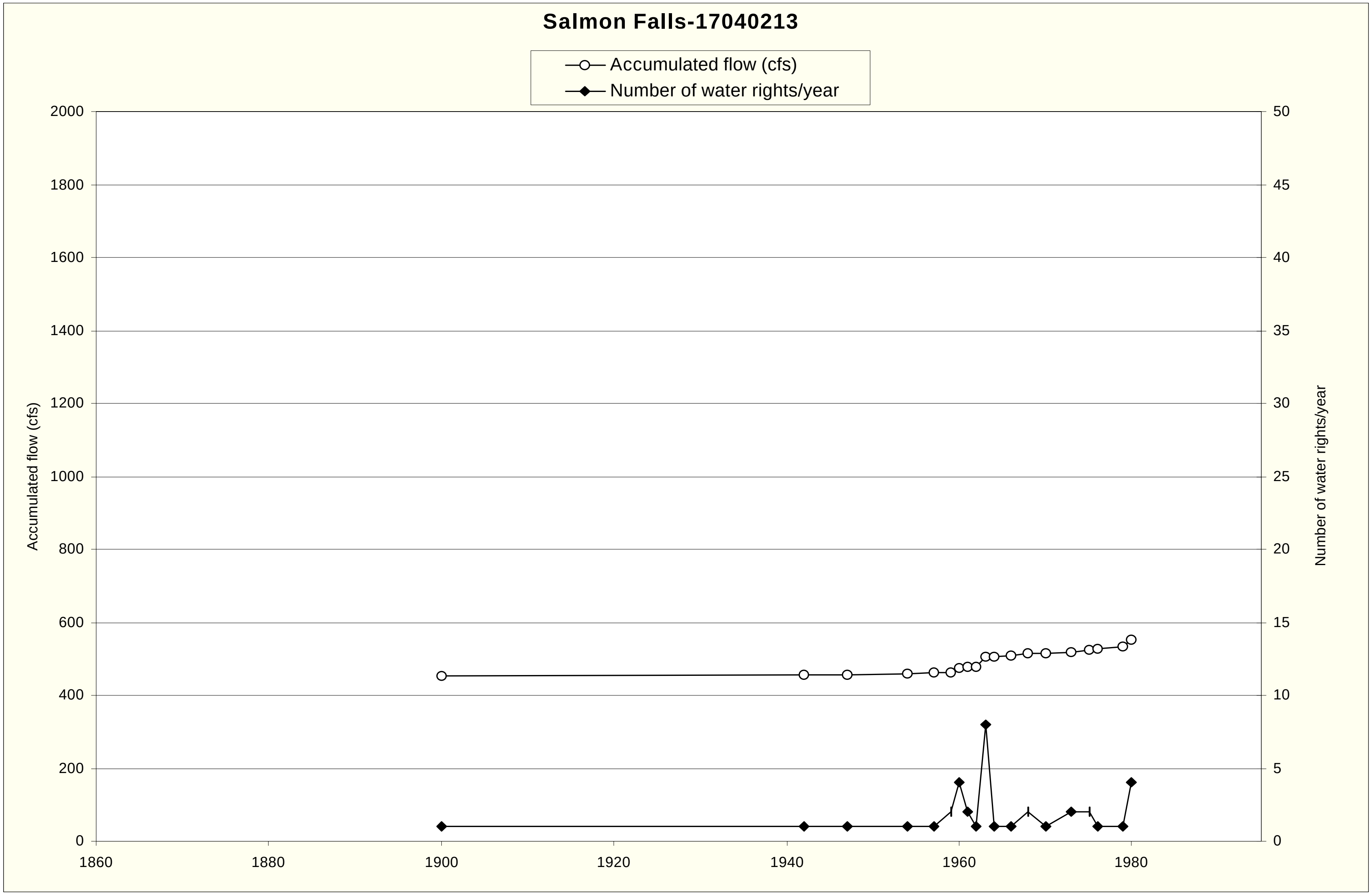


Figure B.15 Salmon Falls (17040213) - summary of ground water permits and accumulated flow (cfs).

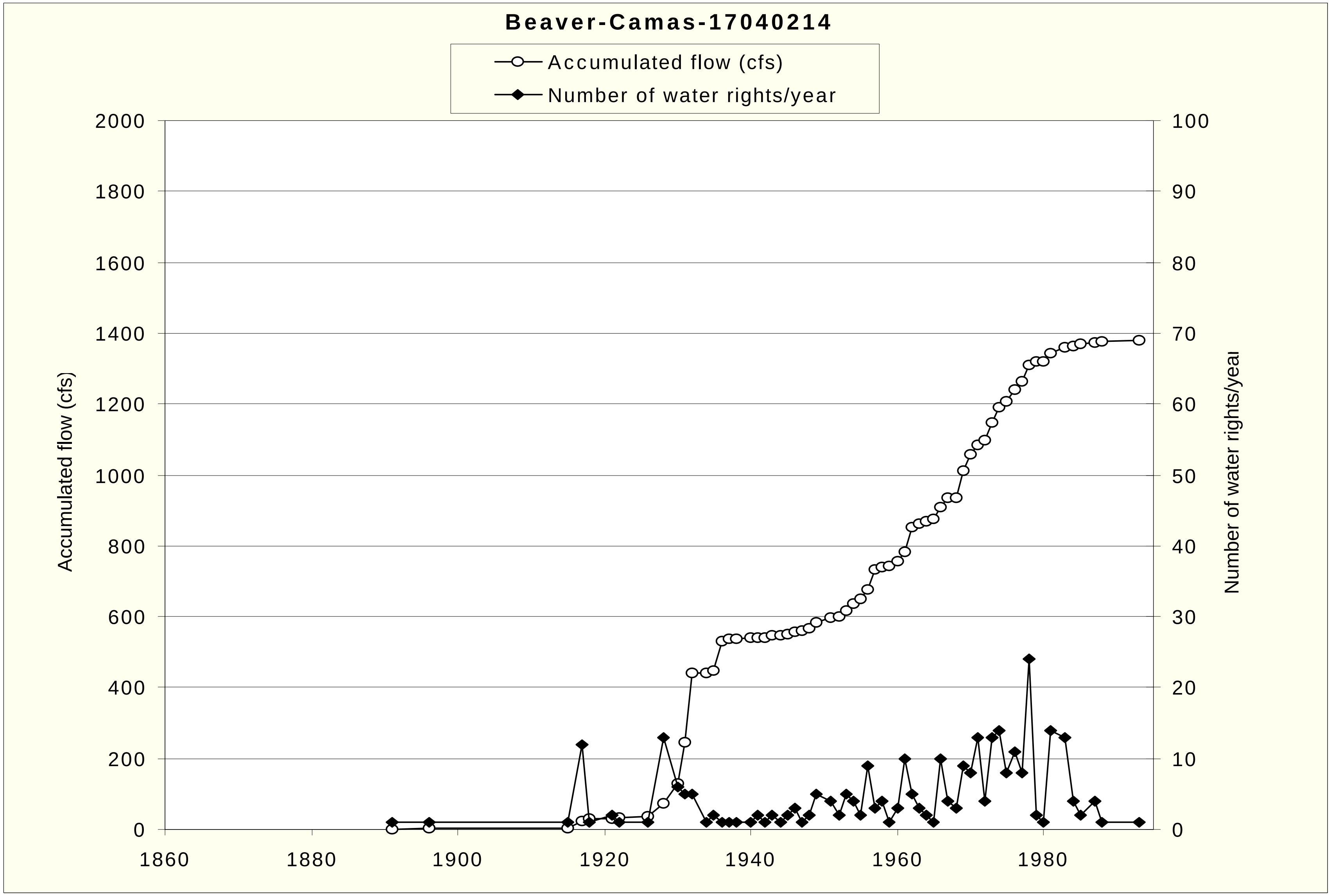


Figure B.16 Beaver-Camas (17040214) - summary of ground water permits and accumulated flow (cfs).

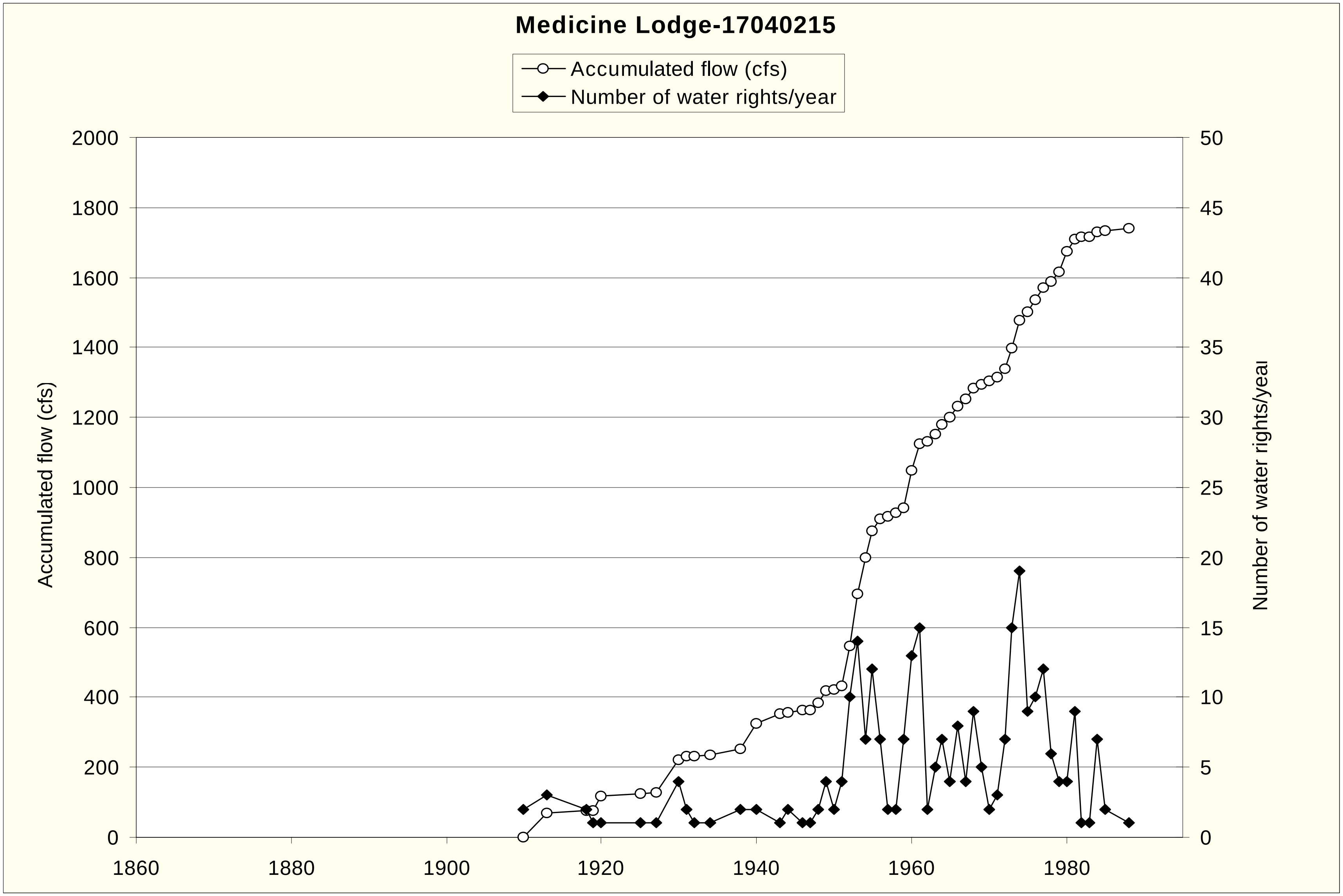


Figure B.17 Medicine Lodge (17040215) - summary of ground water permits and accumulated flow (cfs).

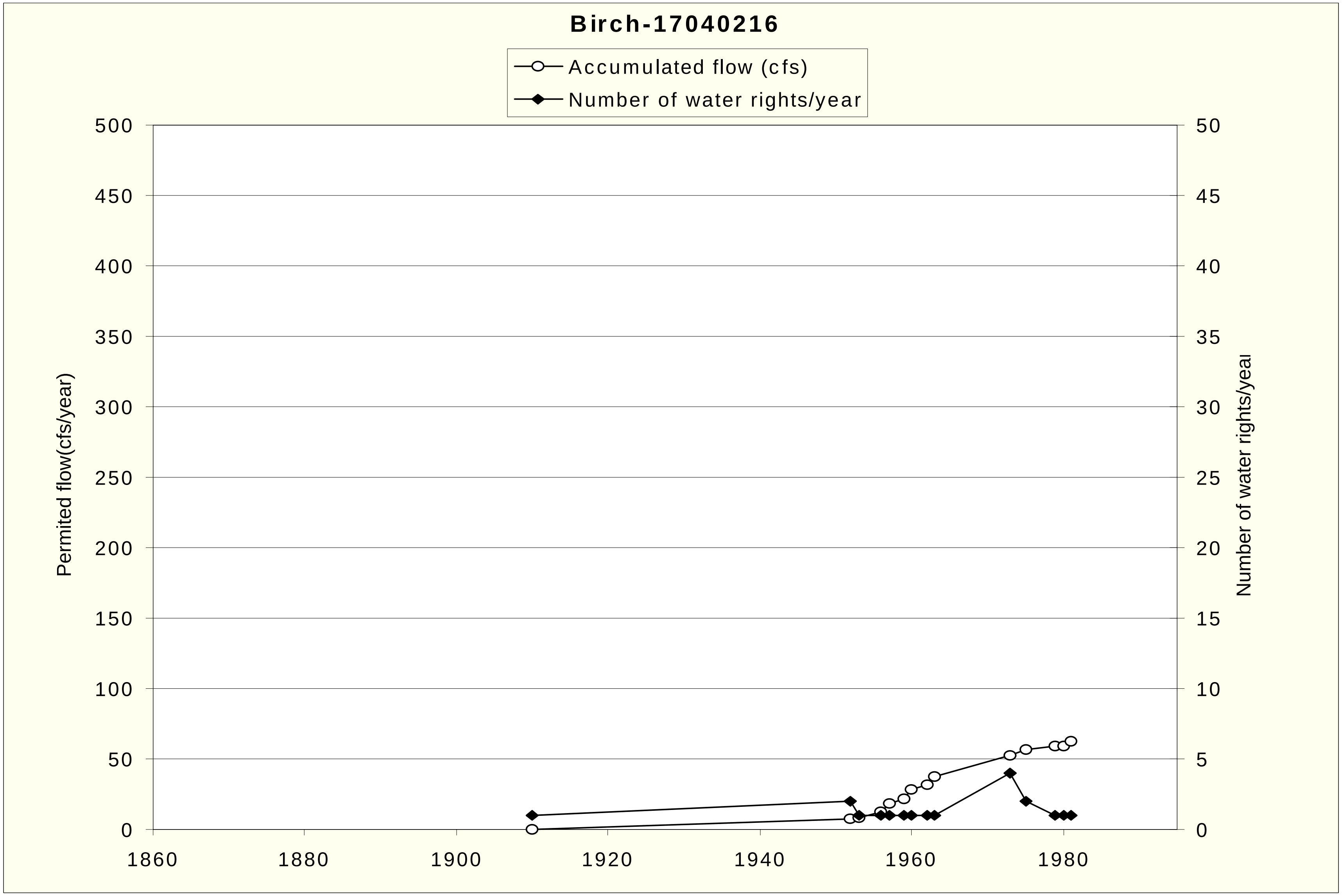


Figure B.18 Birch (17040216) - summary of ground water permits and accumulated flow (cfs).

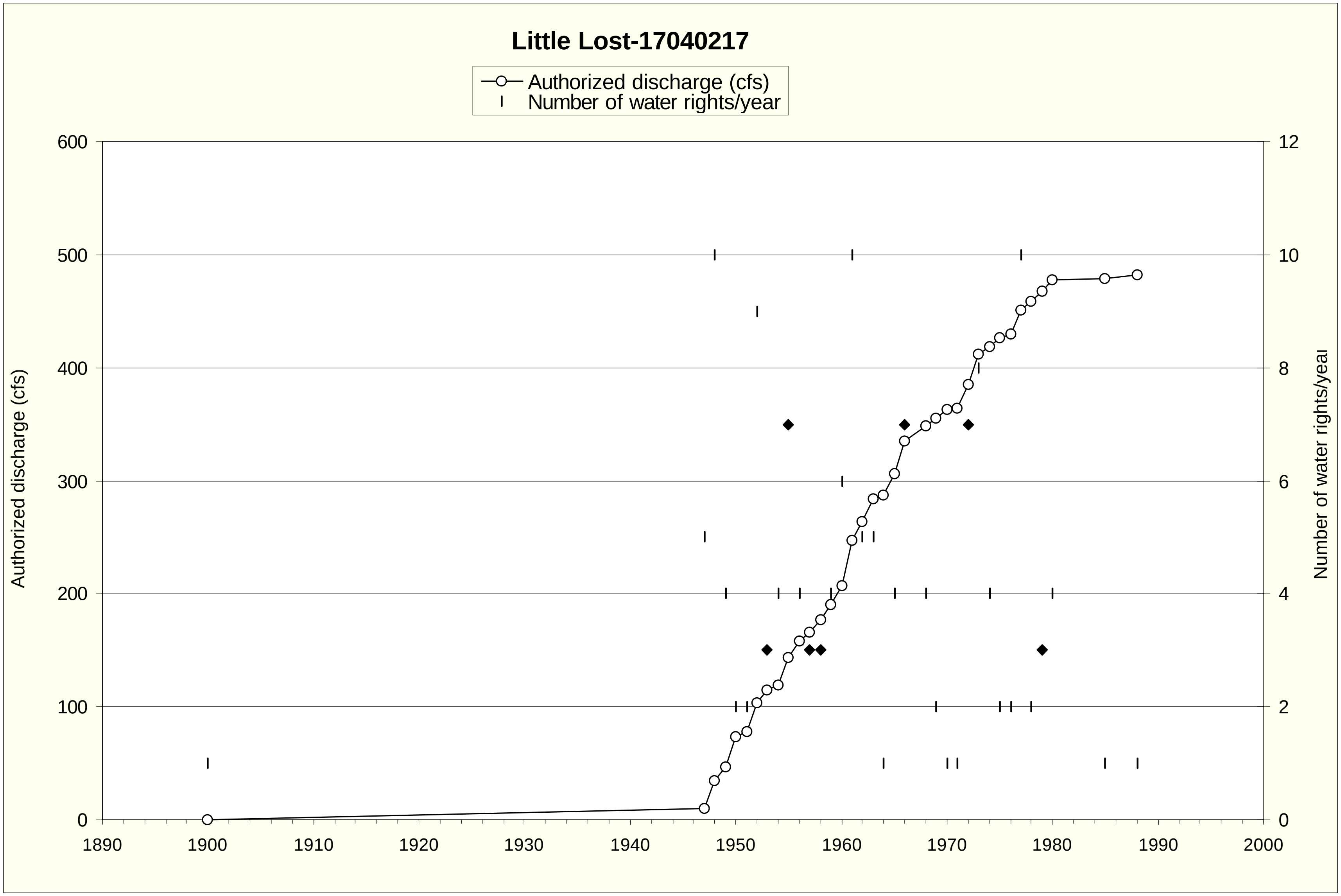


Figure B.19. Little Lost (17040217) - summary of ground water claims and authorized discharge (cfs).

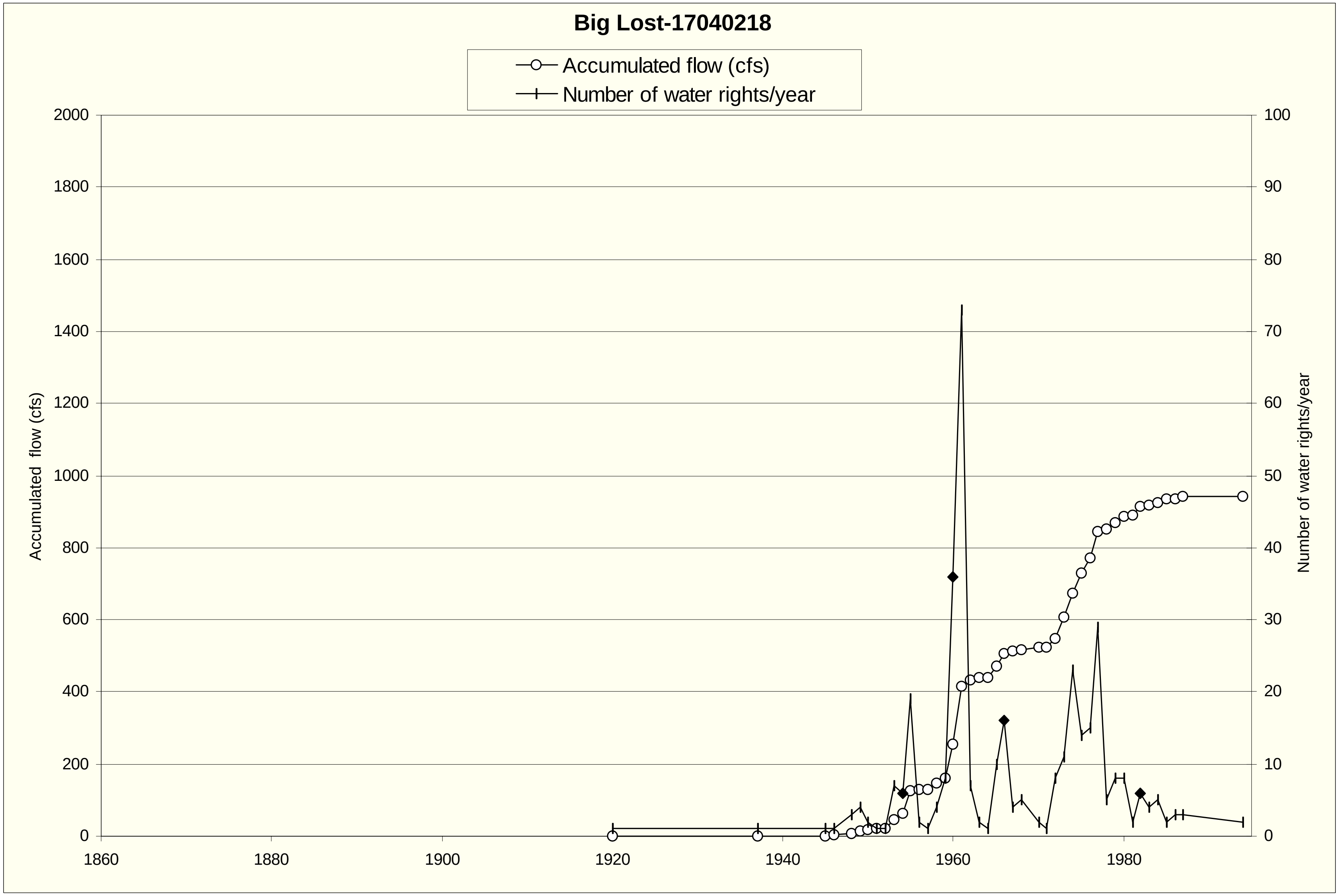


Figure B.20 Big Lost (17040218) - summary of ground water permits and accumulated flow (cfs).

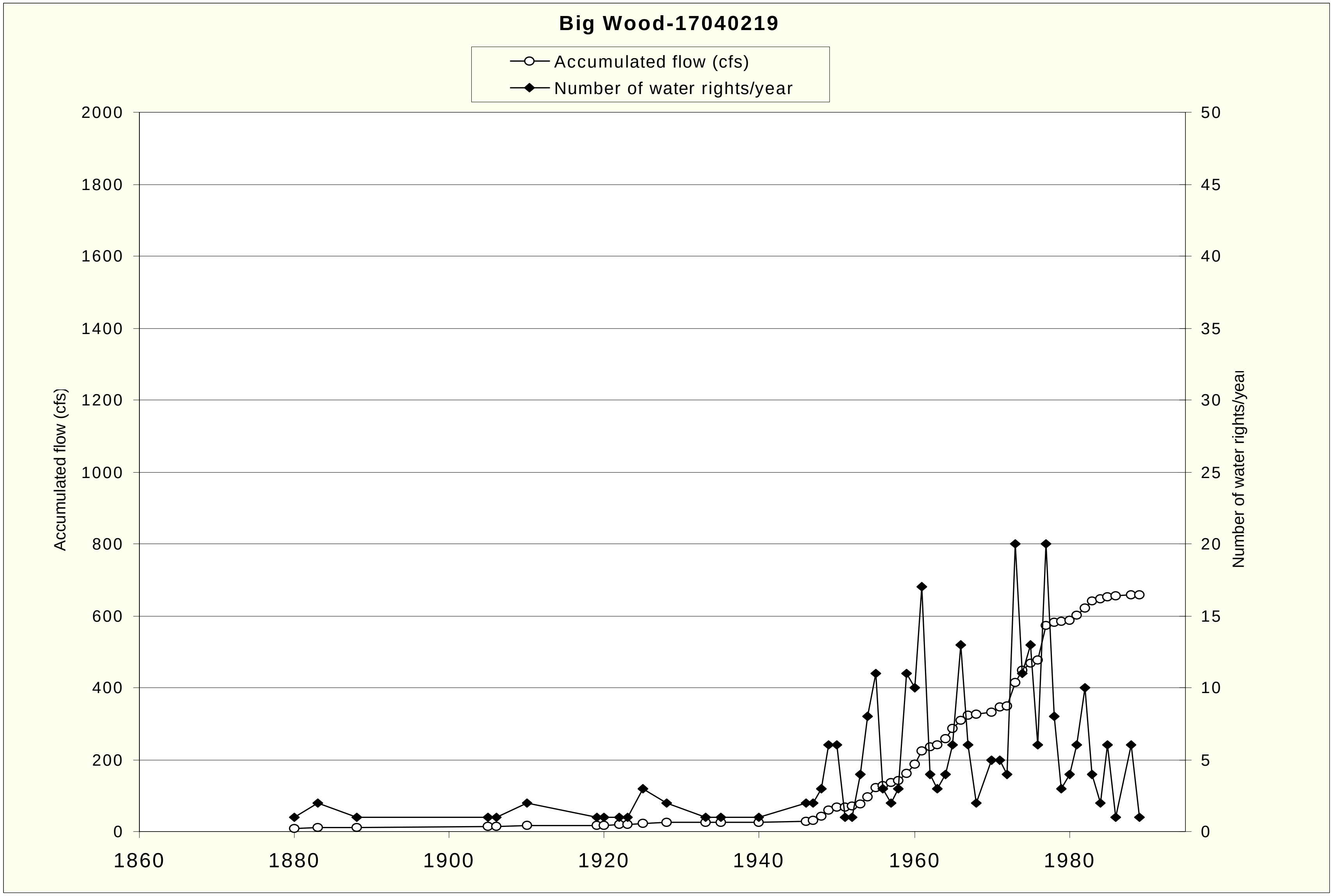


Figure B.21 Big Wood (17040219) - summary of ground water permits and accumulated flow (cfs).

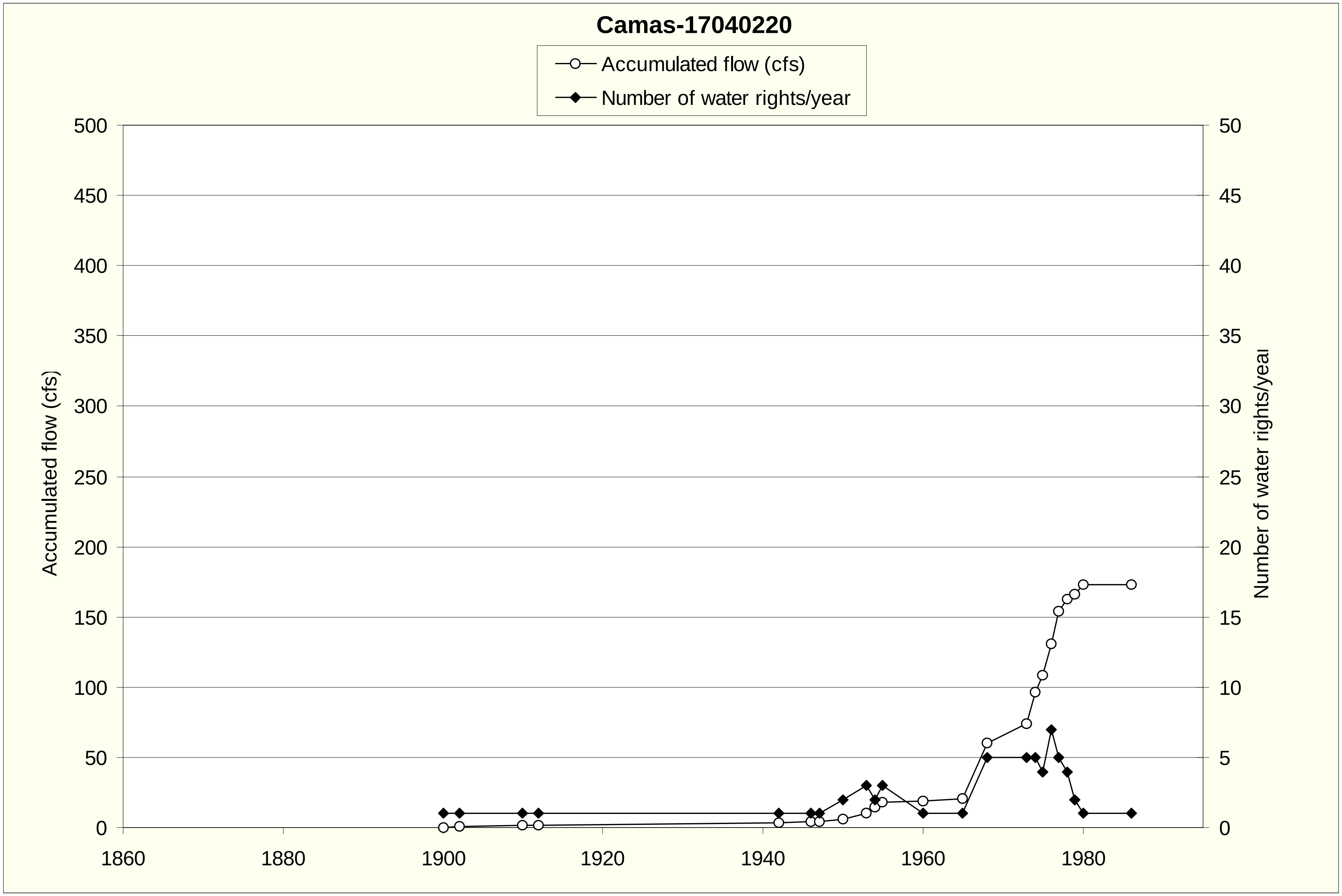


Figure B.22 Camas (17040220) - summary of ground water permits and accumulated flow (cfs).

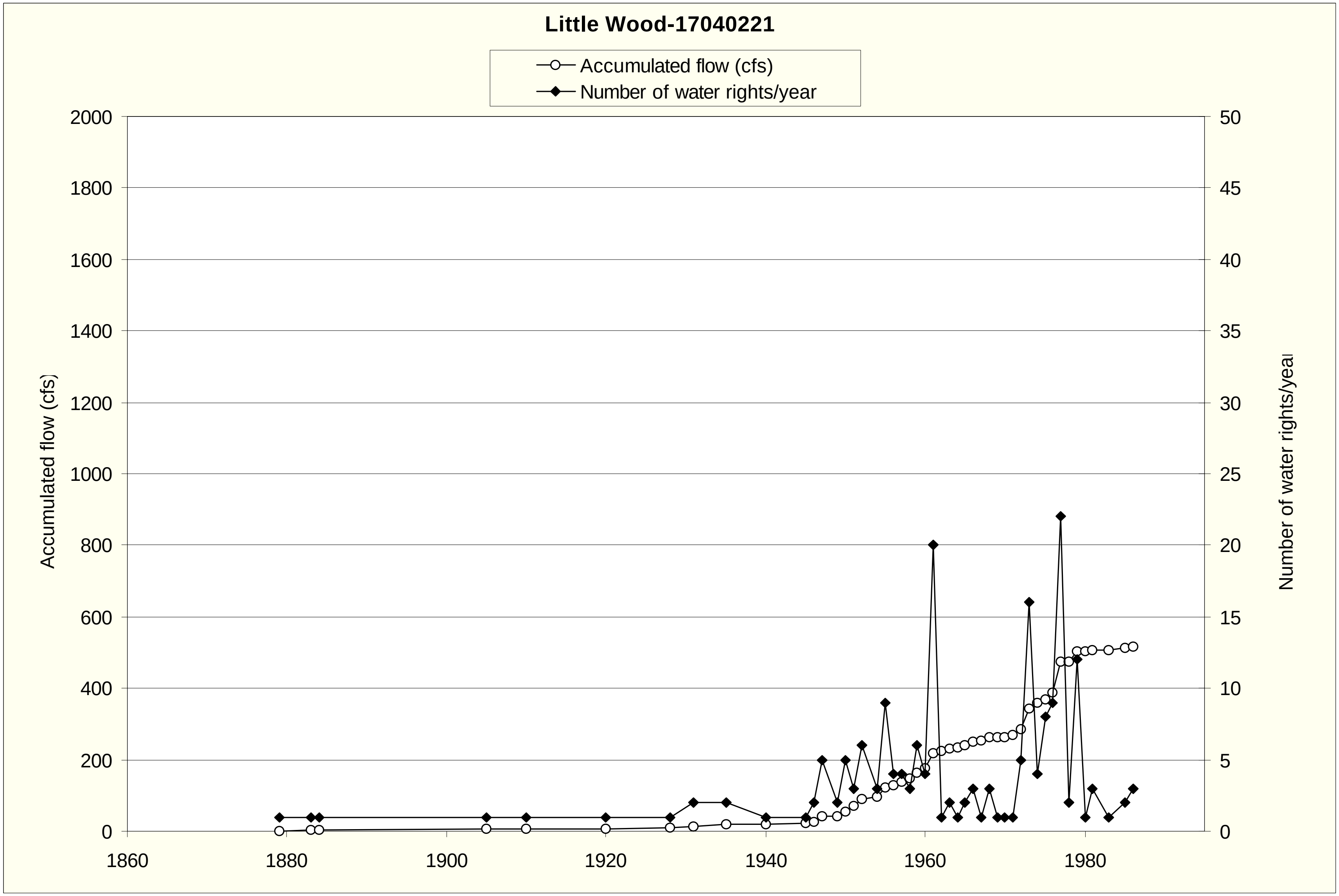


Figure B.23 Little Wood (17040221) - summary of ground water permits and accumulated flow (cfs).

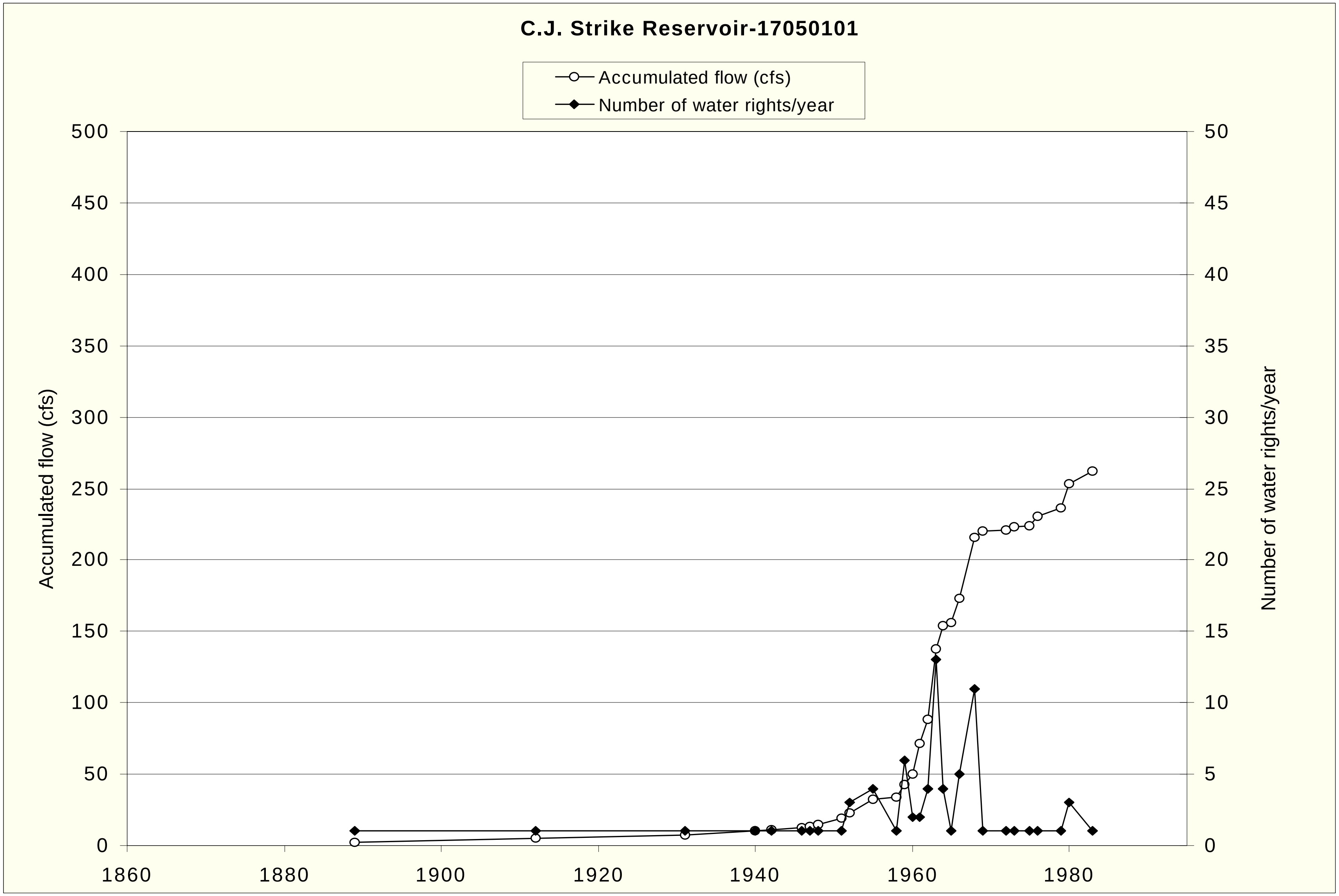


Figure B.24 C.J. Strike Reservoir (17050101) - summary of ground water permits and accumulated flow (cfs).

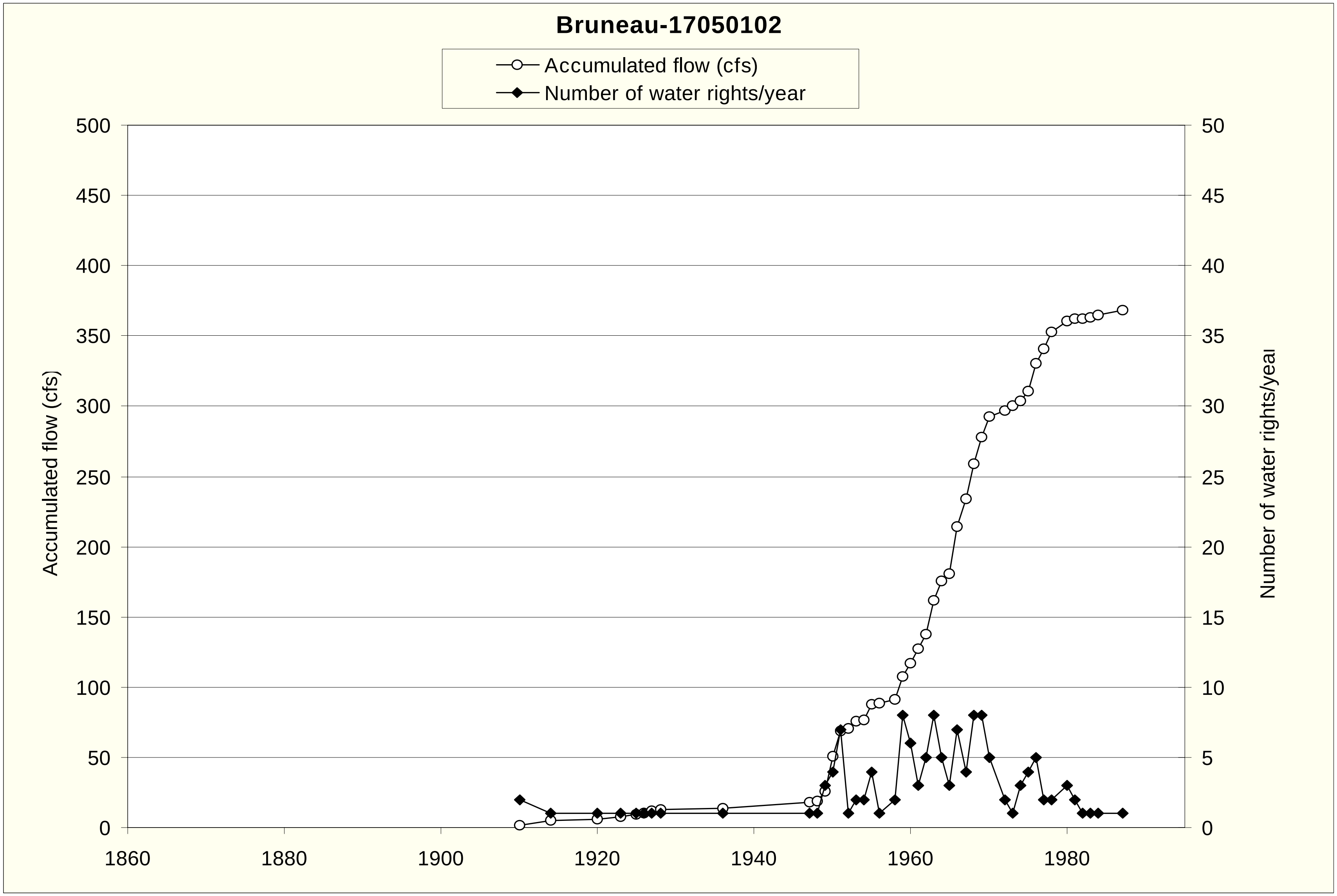


Figure B.25 Bruneau (17050102) - summary of ground water permits and accumulated flow (cfs).

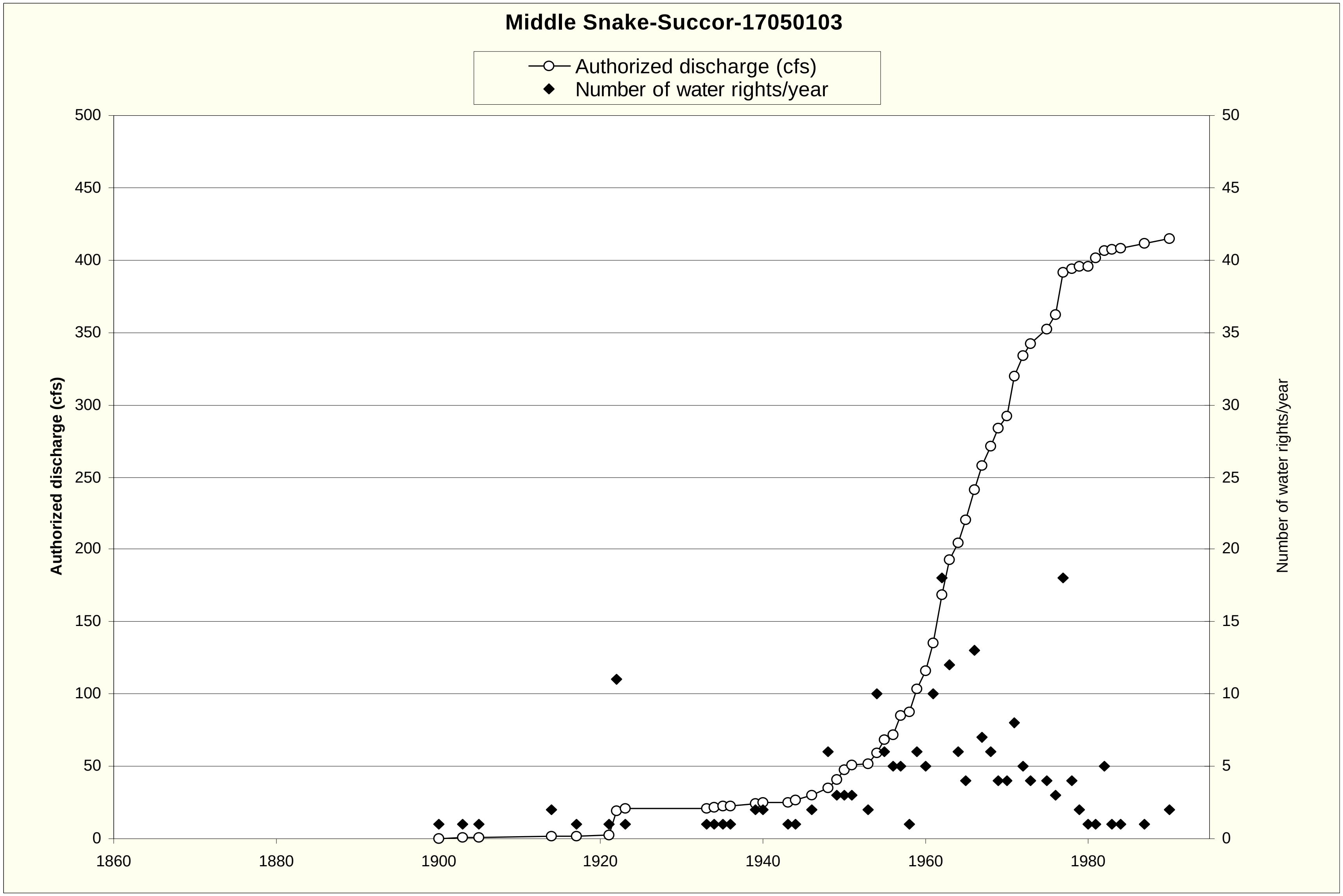


Figure B.26. Middle Snake-Succor (17050103) - summary of ground water claims and authorized discharge (cfs).

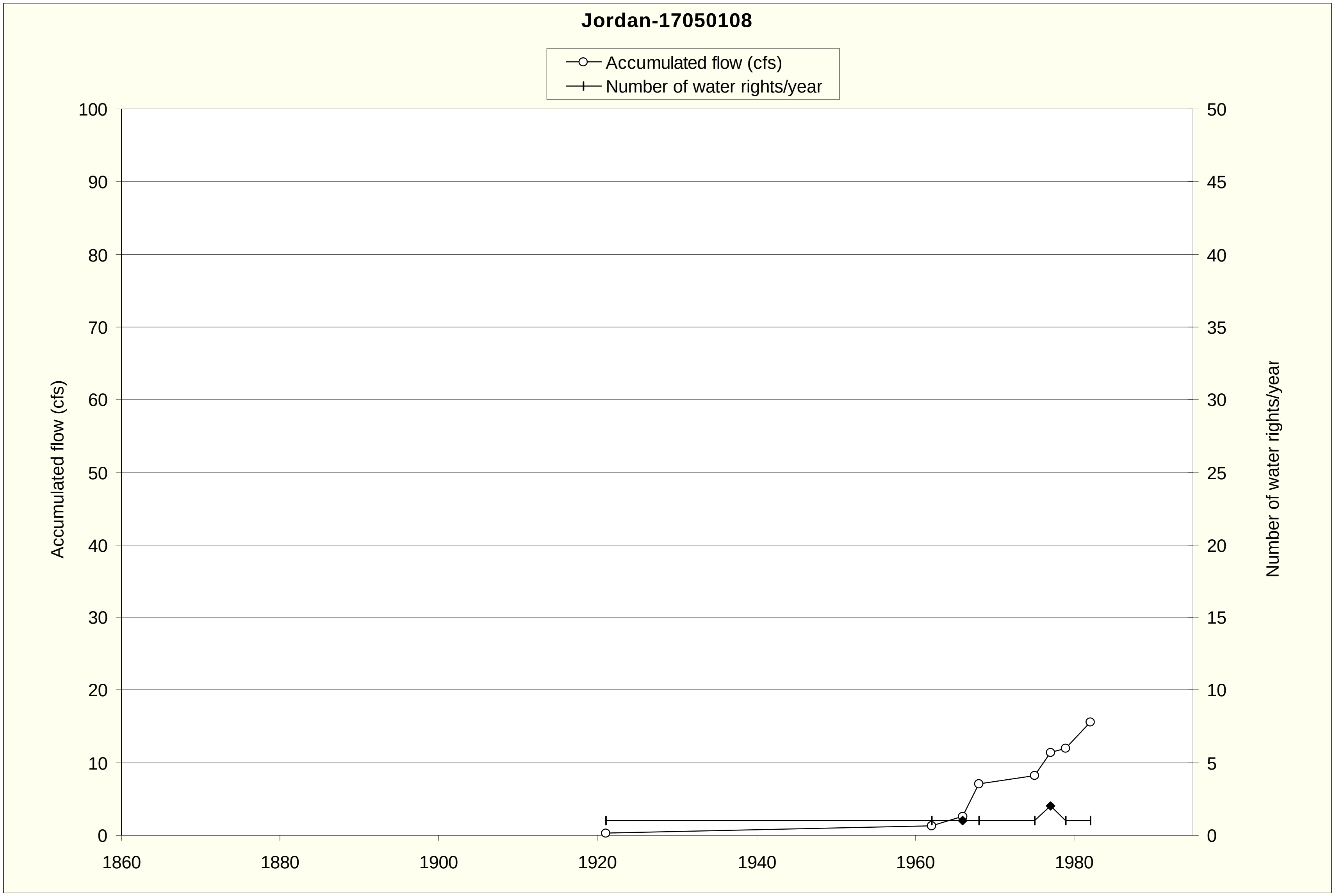


Figure B.27 Jordan (17050108) - summary of ground water permits and accumulated flow (cfs).

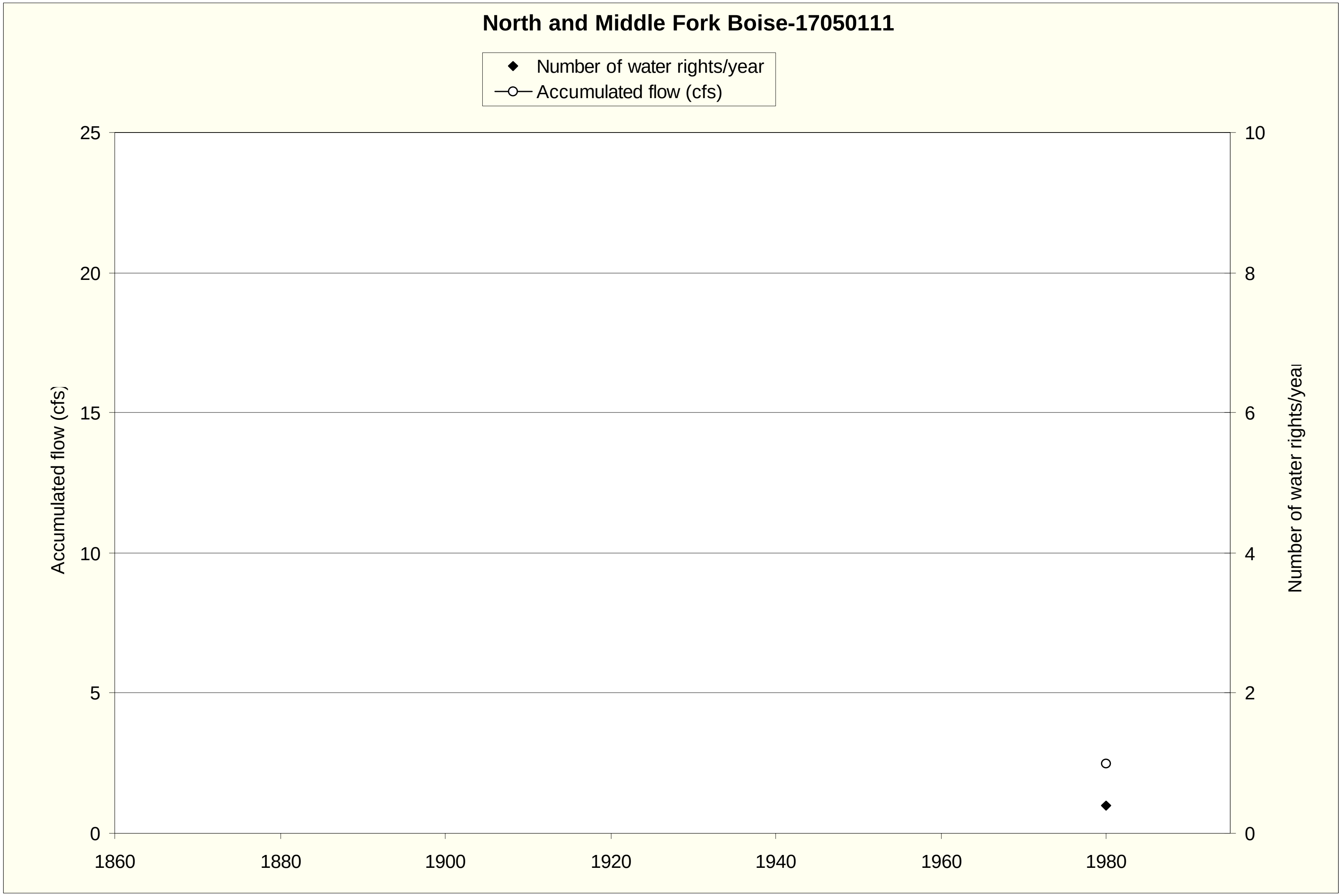


Figure B.28 North and Middle Fork Boise (17050111) - summary of ground water permits and accumulated flow (cfs).

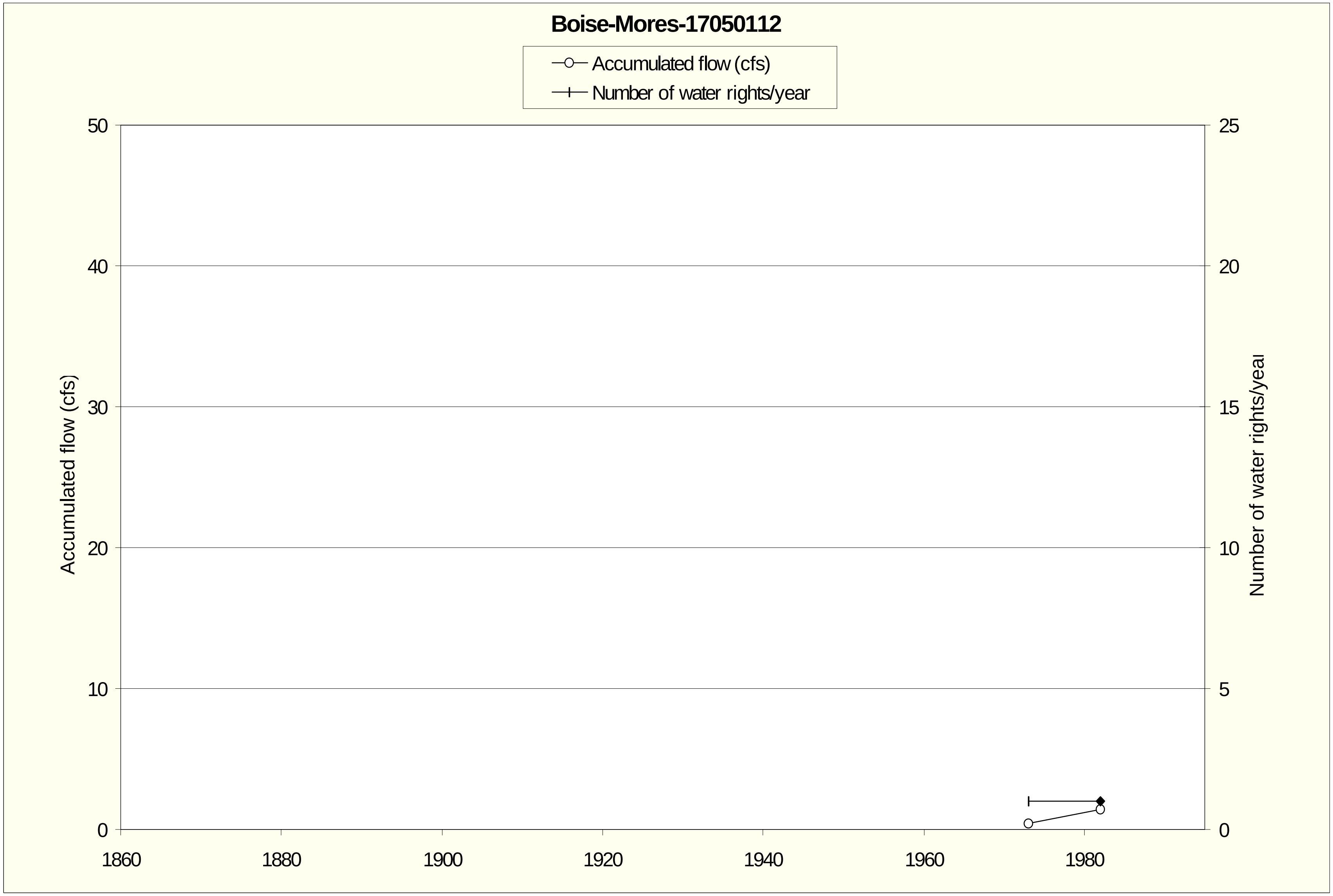


Figure B.29 Boise-Mores (17050112) - summary of ground water permits and accumulated flow (cfs).

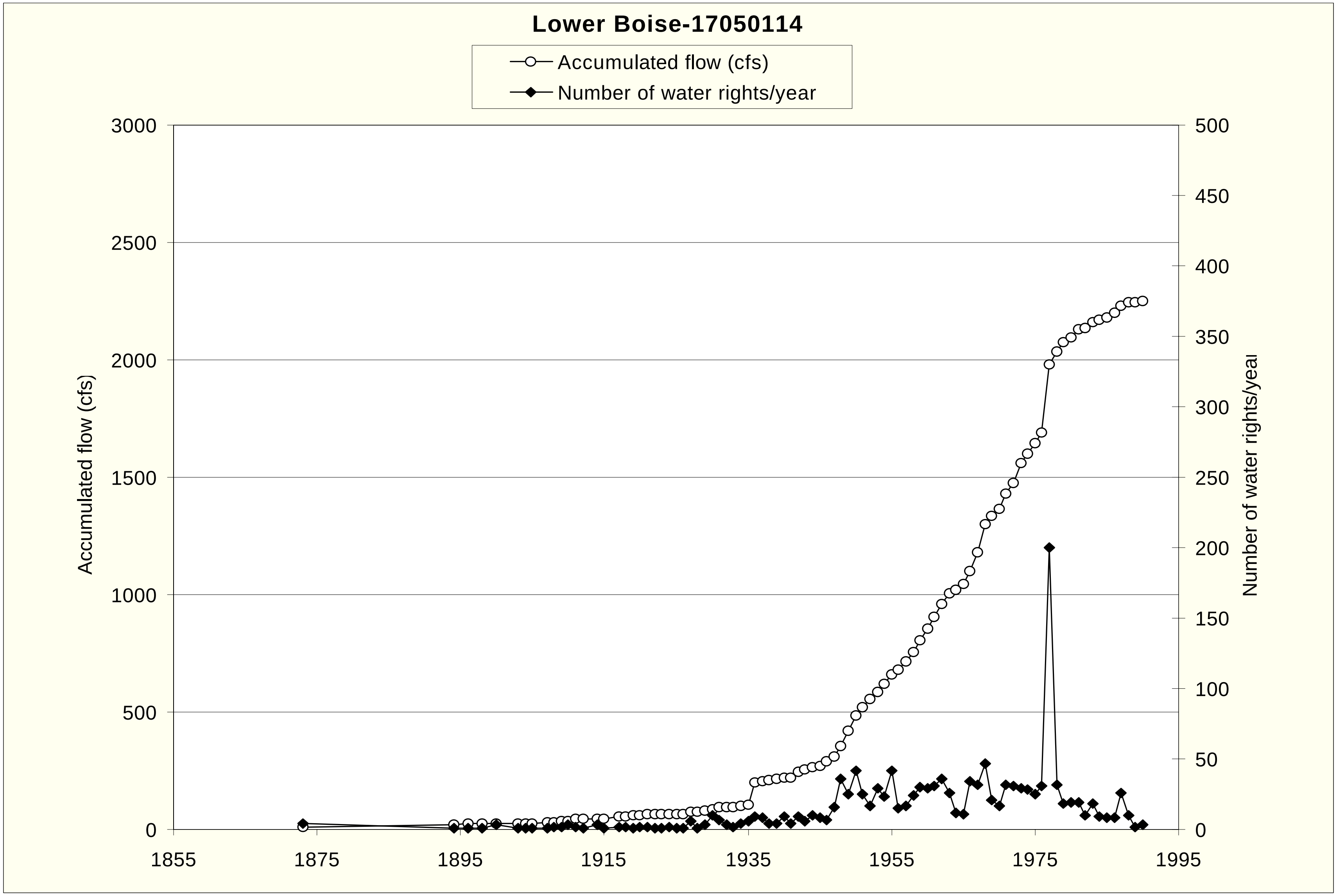


Figure B.30 Lower Boise (17050114) - summary of ground water permits and accumulated flow (cfs).

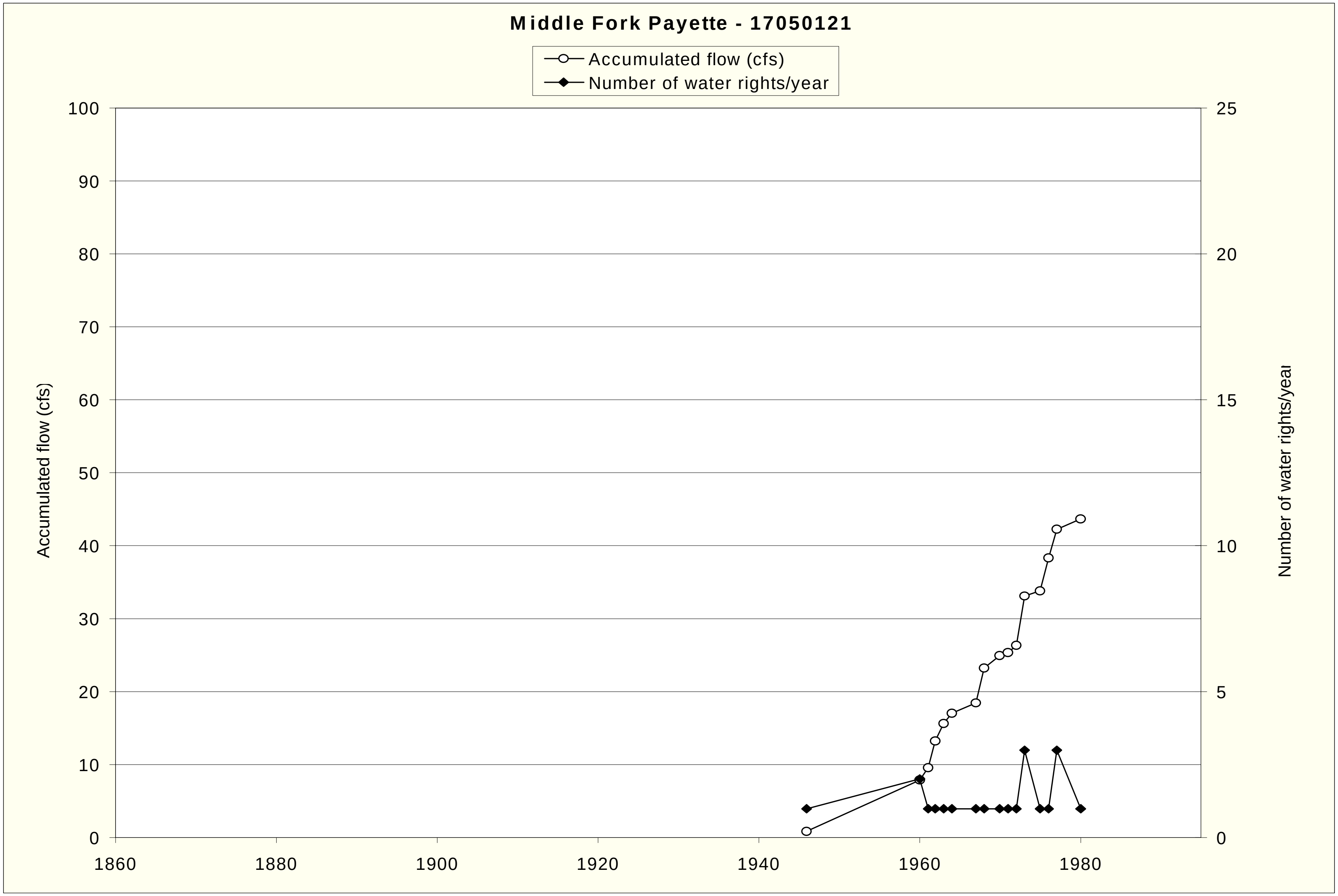


Figure B.31 Middle Fork Payette (17050121) - summary of ground water permits and accumulated flow (cfs).

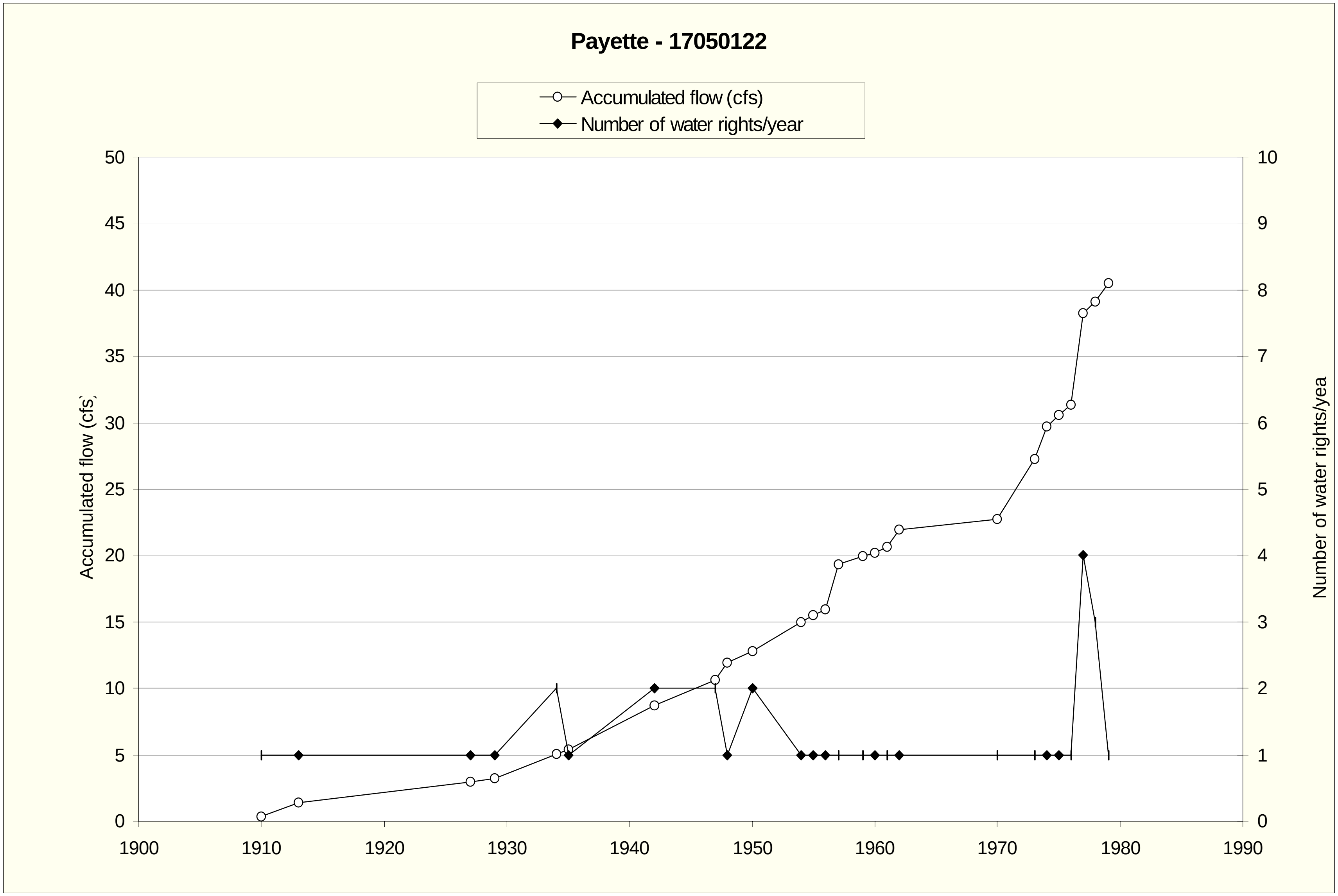


Figure B.32 Payette (17050122) - summary of ground water permits and accumulated flow (cfs).

Appendix C

Stream Flow Hydrographs

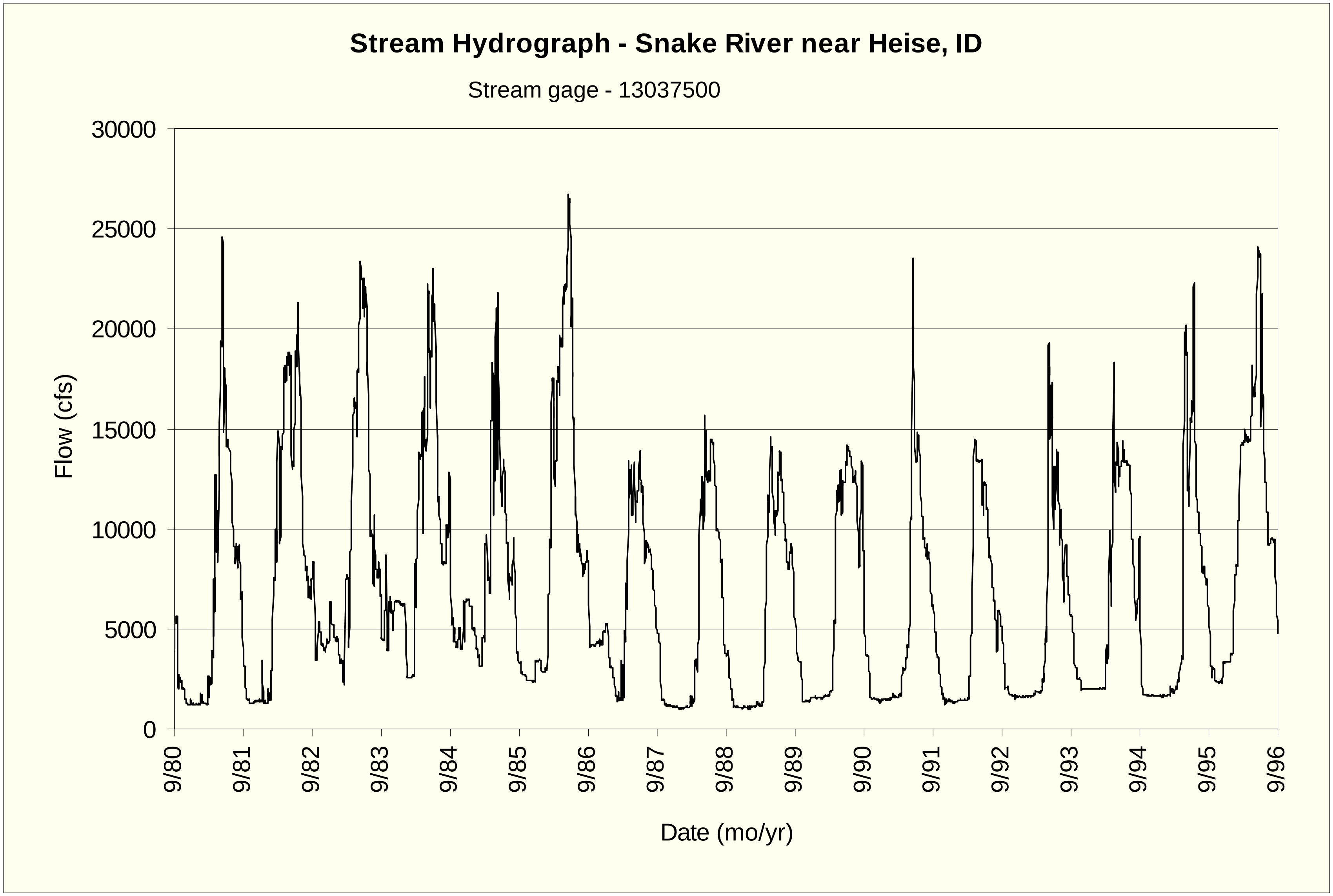


Figure C.1. Stream hydrograph for the Snake River near Heise, Idaho.

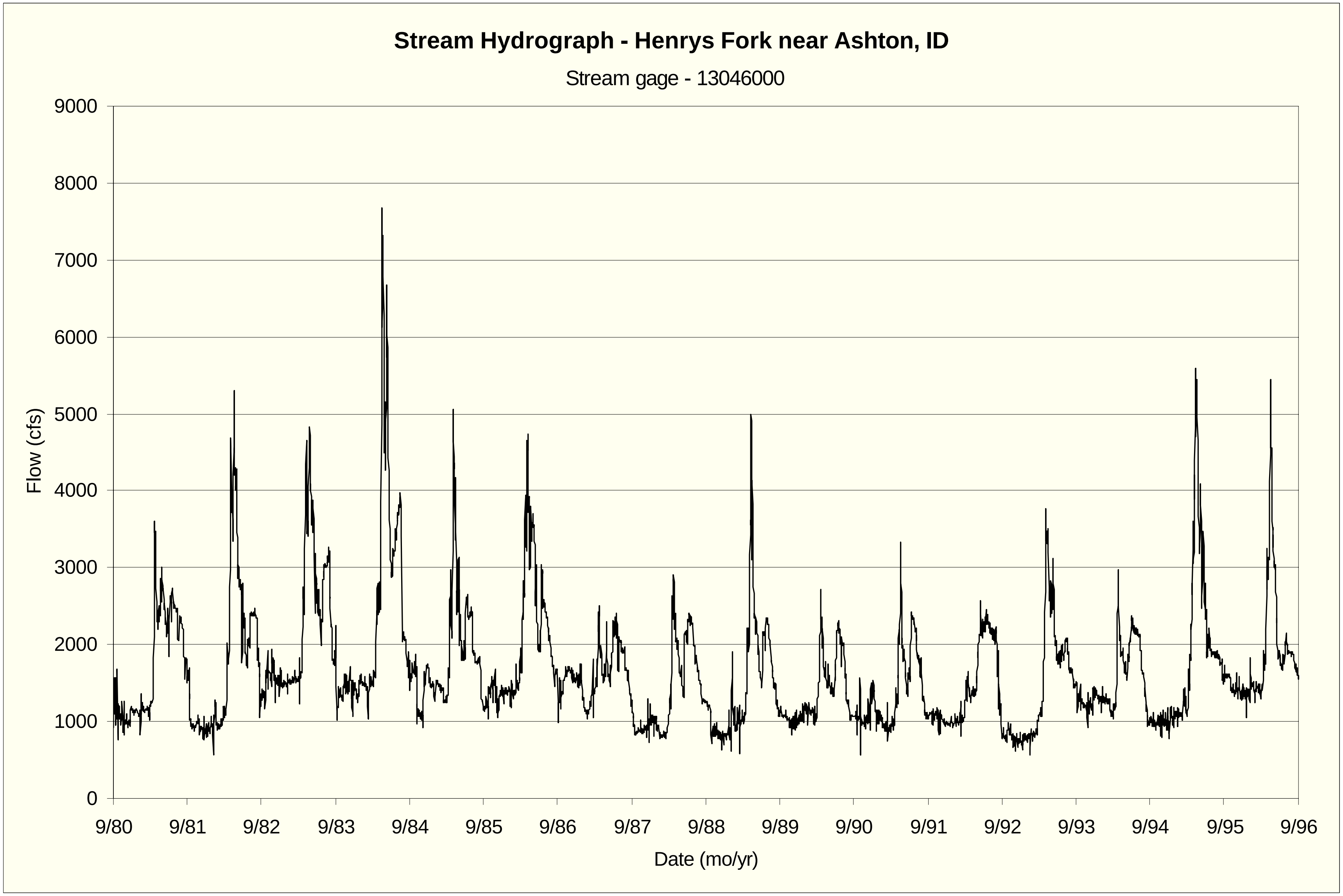


Figure C.2. Stream hydrograph for the Henrys Fork near Ashton, Idaho.

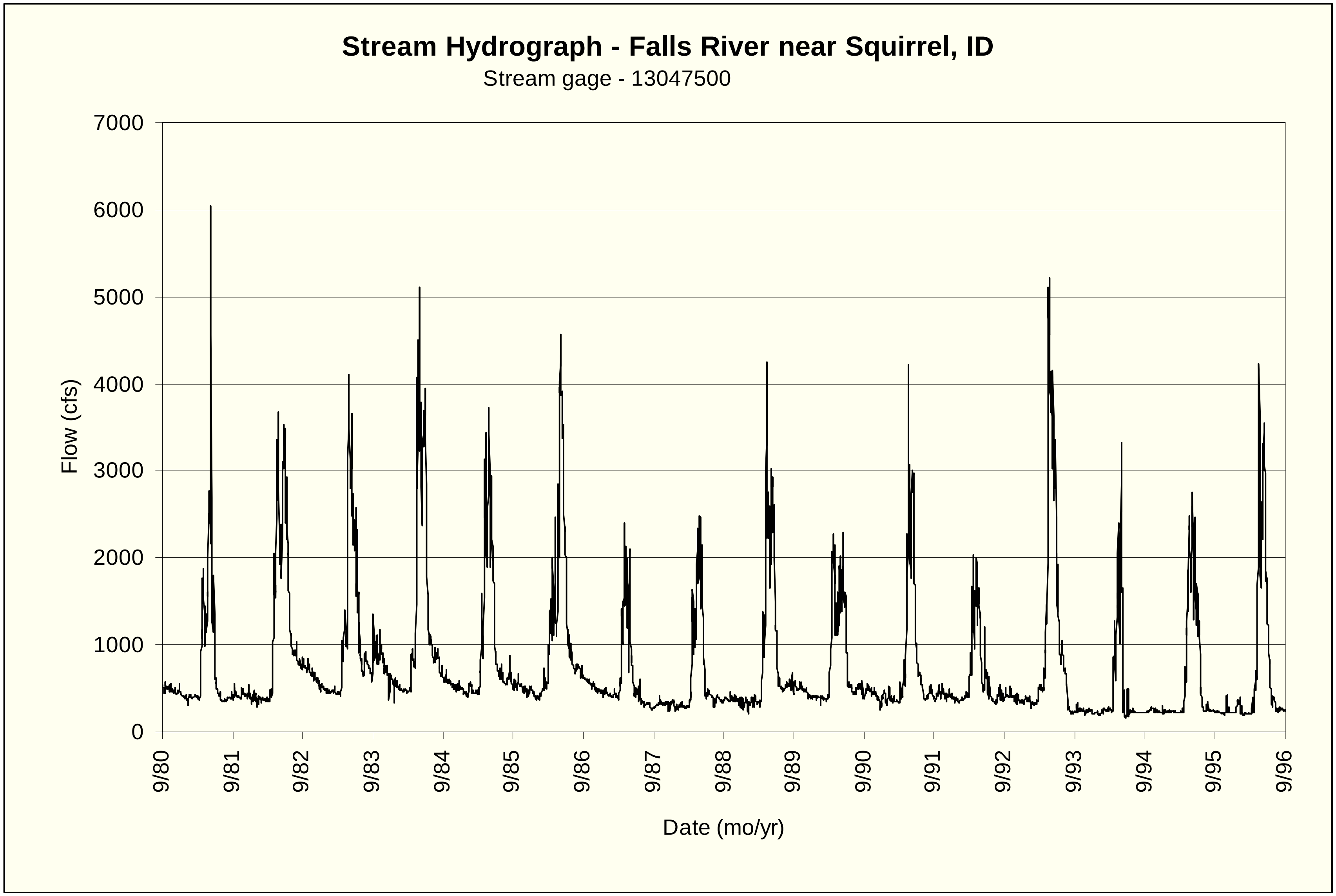


Figure C.3. Stream hydrograph for Falls River near Squirrel, Idaho.

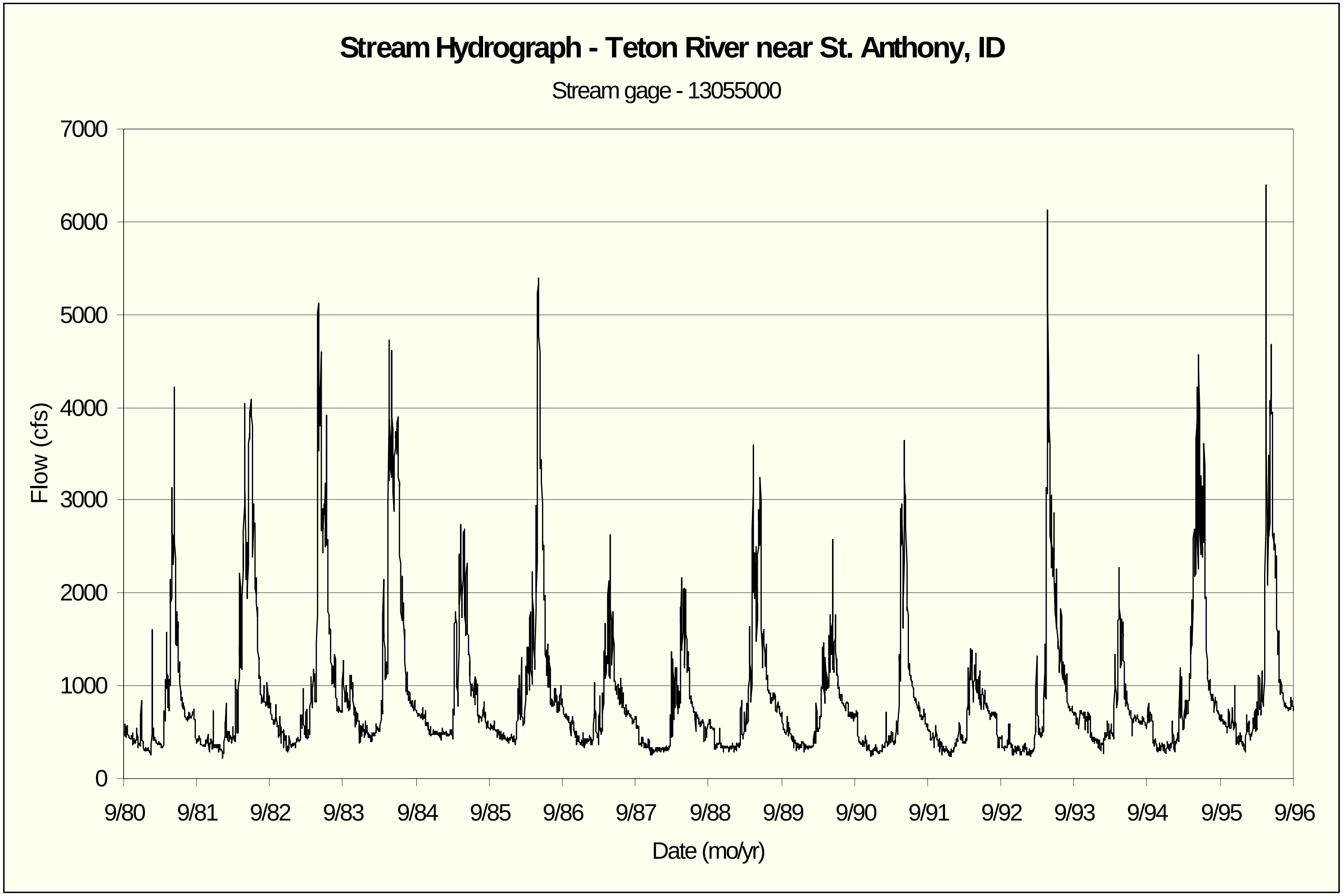


Figure C.4. Stream hydrograph for the Teton River near St. Anthony, Idaho.

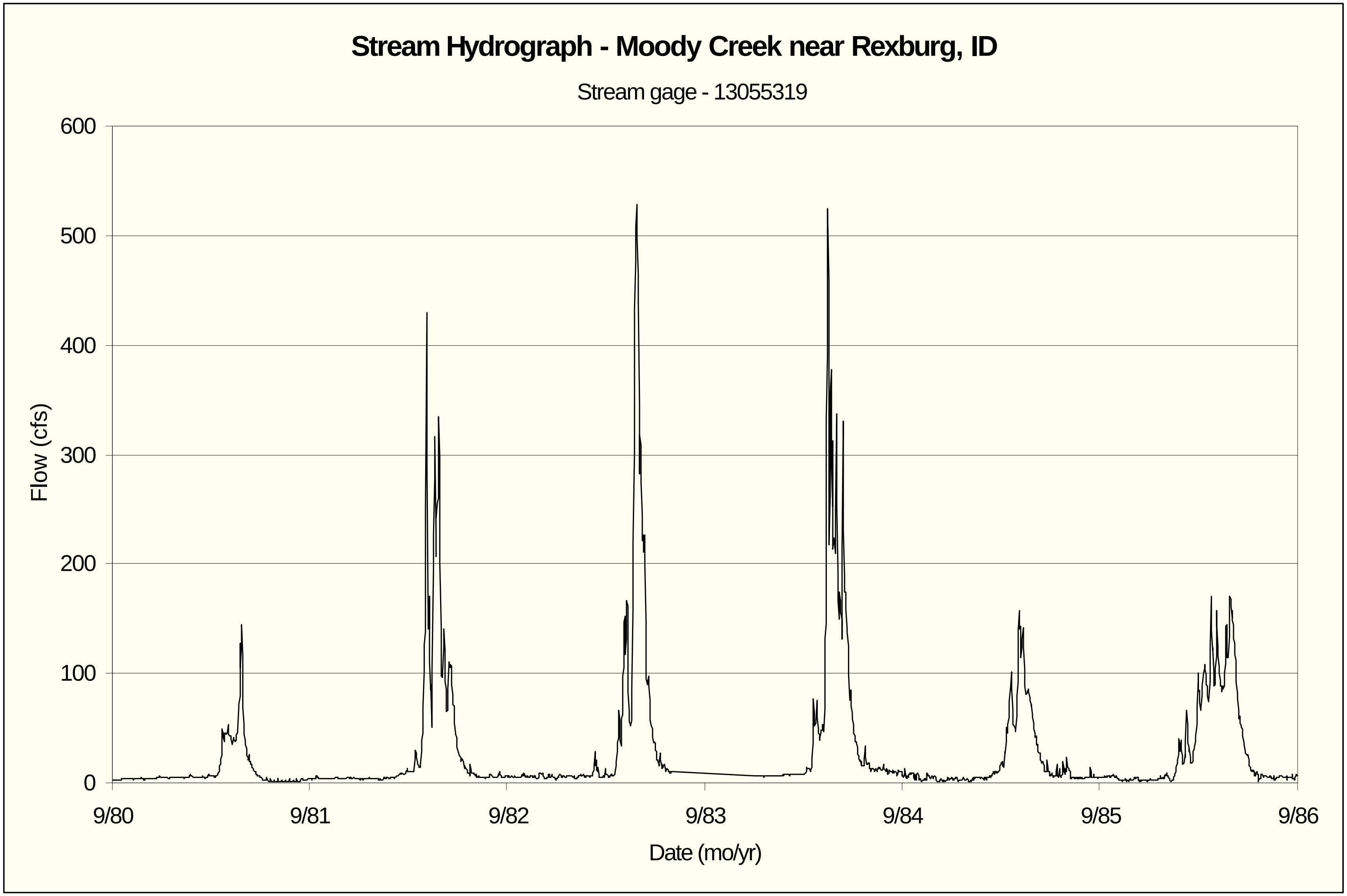


Figure C.5. Stream hydrograph for Moody Creek near Rexburg, Idaho.

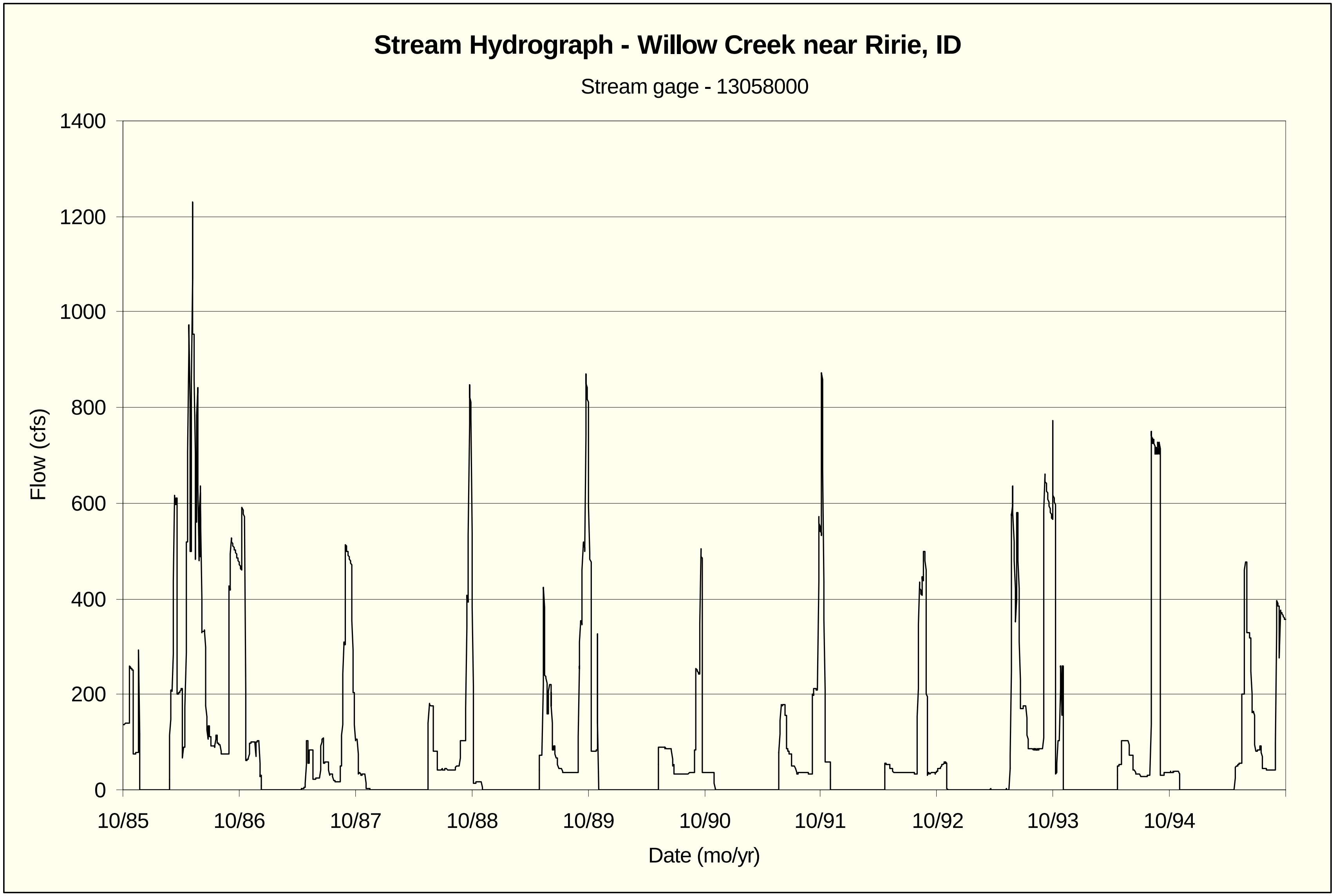


Figure C.6. Stream hydrograph for Willow Creek near Ririe, Idaho.

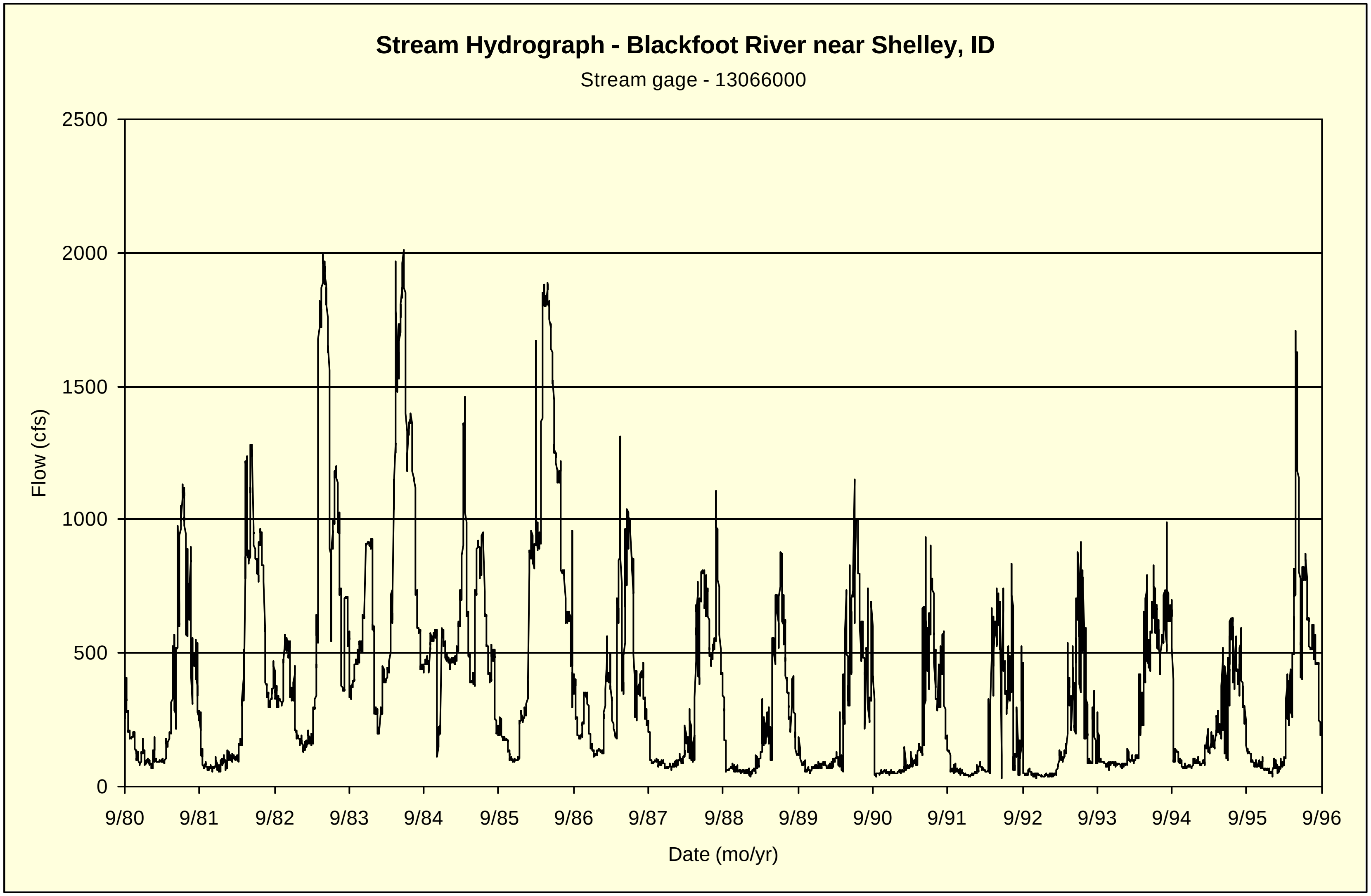


Figure C.7. Stream hydrograph for the Blackfoot River near Shelley, Idaho.

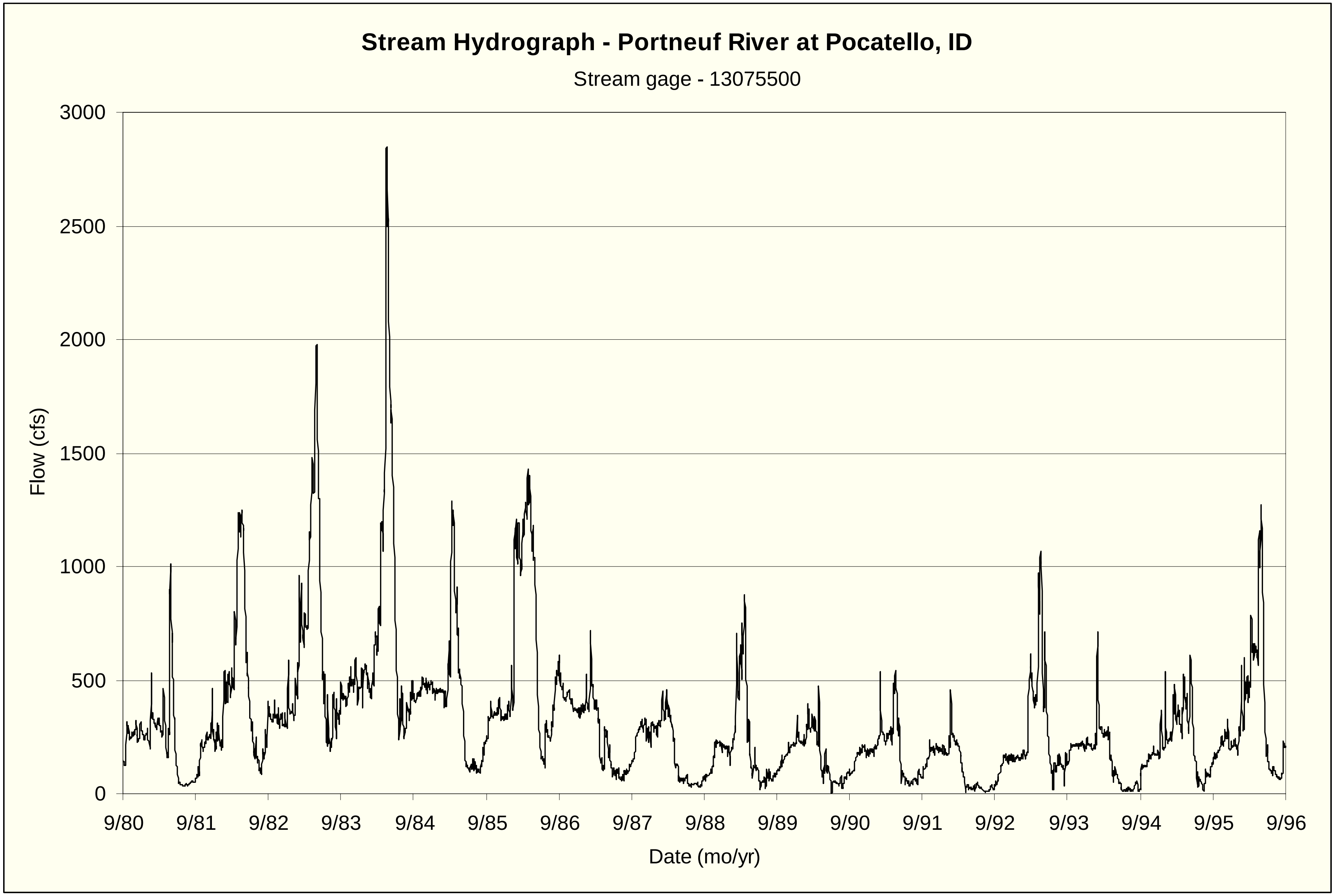


Figure C.8. Stream hydrograph for the Portneuf River near Pocatello, Idaho.

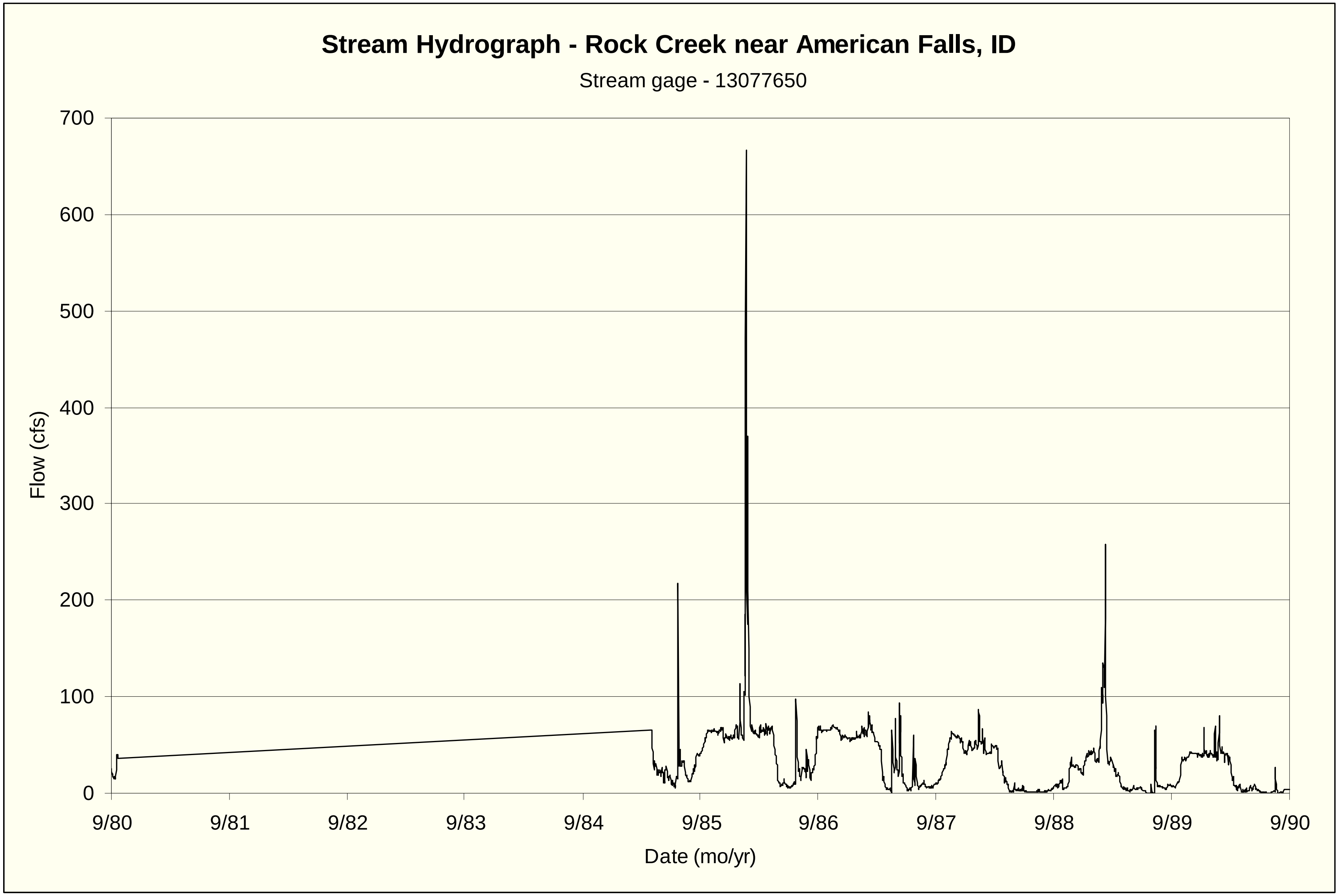


Figure C.9. Stream hydrograph for Rock Creek near American Falls, Idaho.

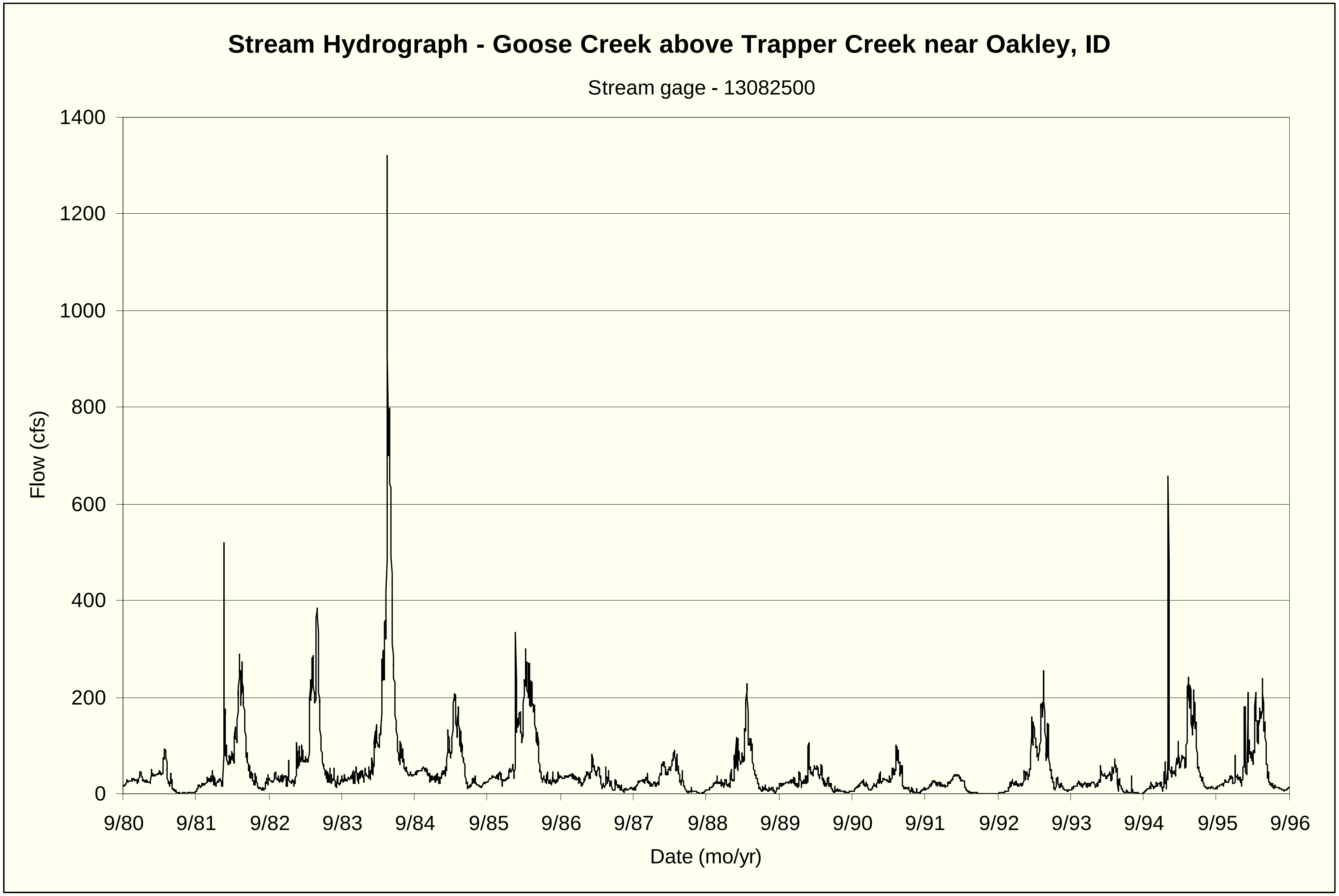


Figure C.10. Stream hydrograph for Goose Creek above Trapper Creek, near Oakley, Idaho.

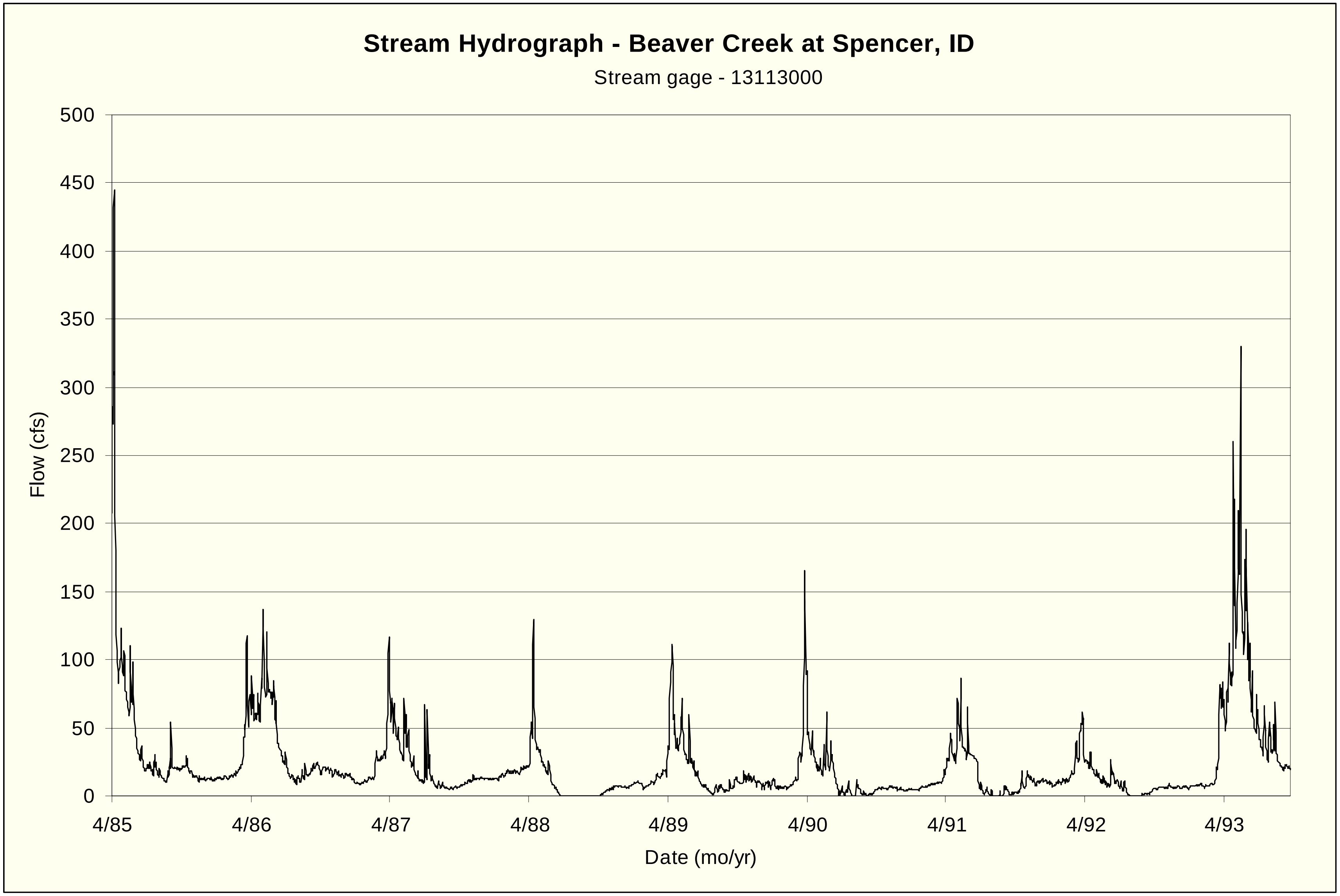


Figure C.11. Stream hydrograph for Beaver Creek near Spencer, Idaho.

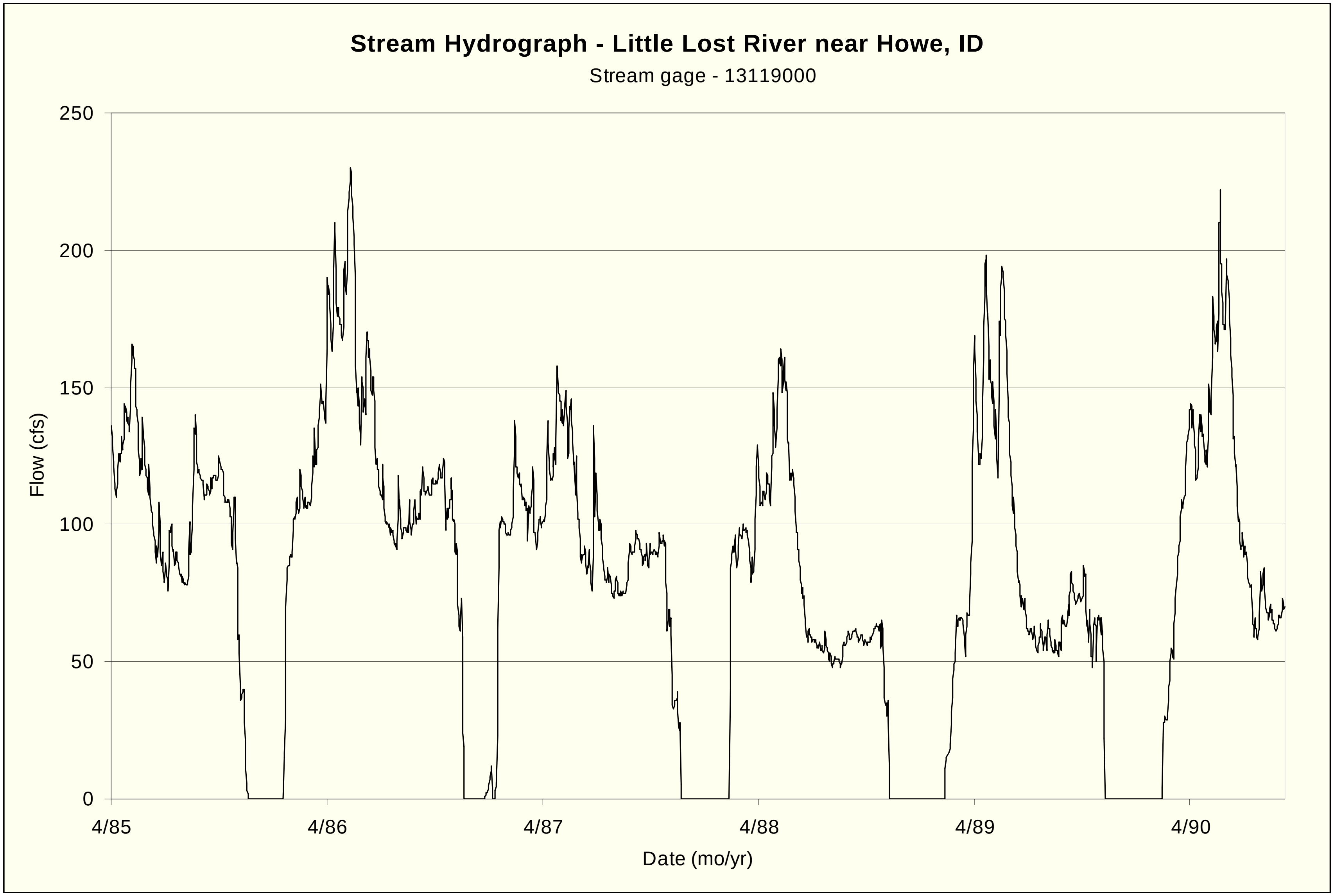


Figure C.12. Stream hydrograph for the Little Lost River near Howe, Idaho.

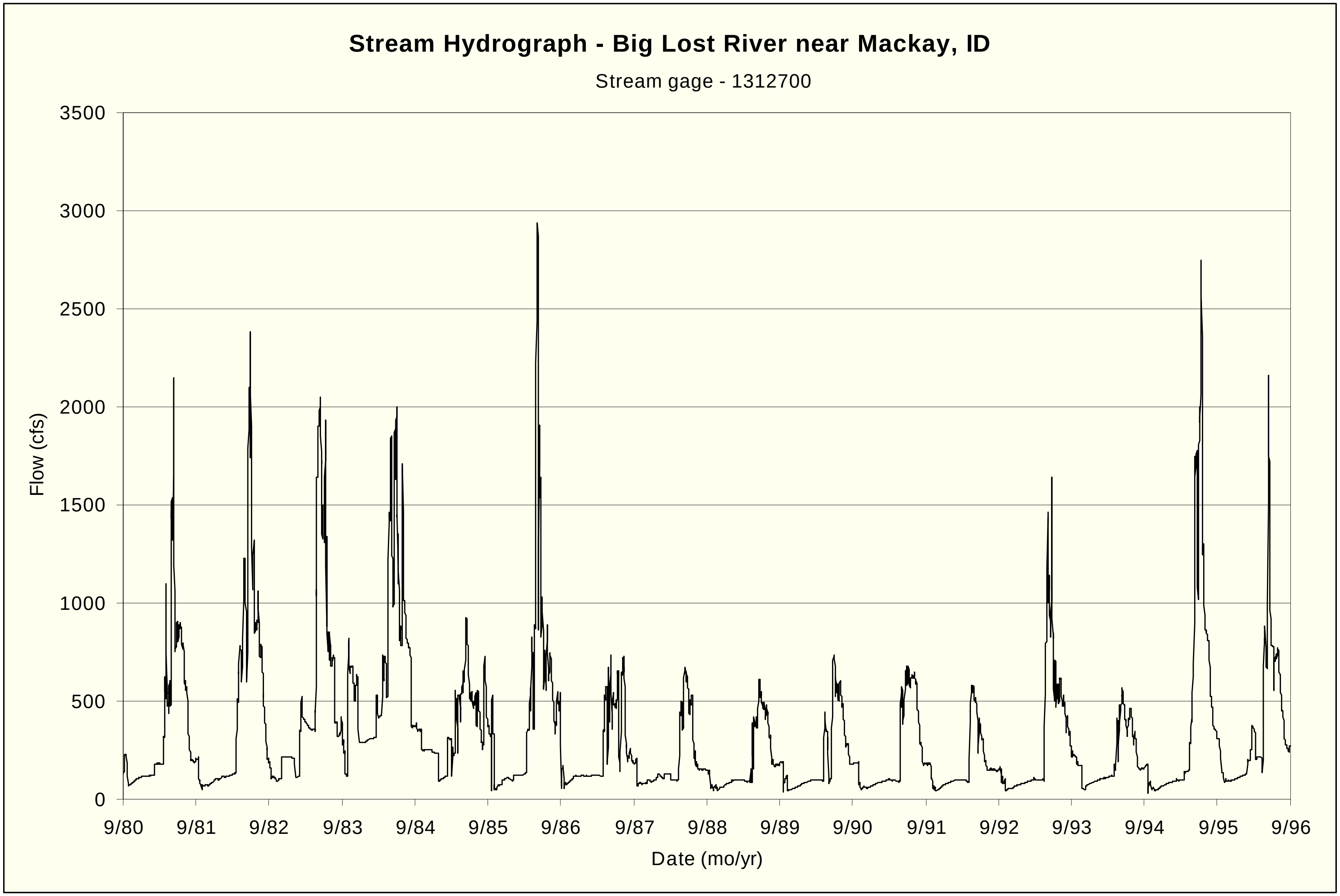


Figure C.13. Stream hydrograph for the Big Lost River below Mackay Reservoir near Mackay, Idaho.

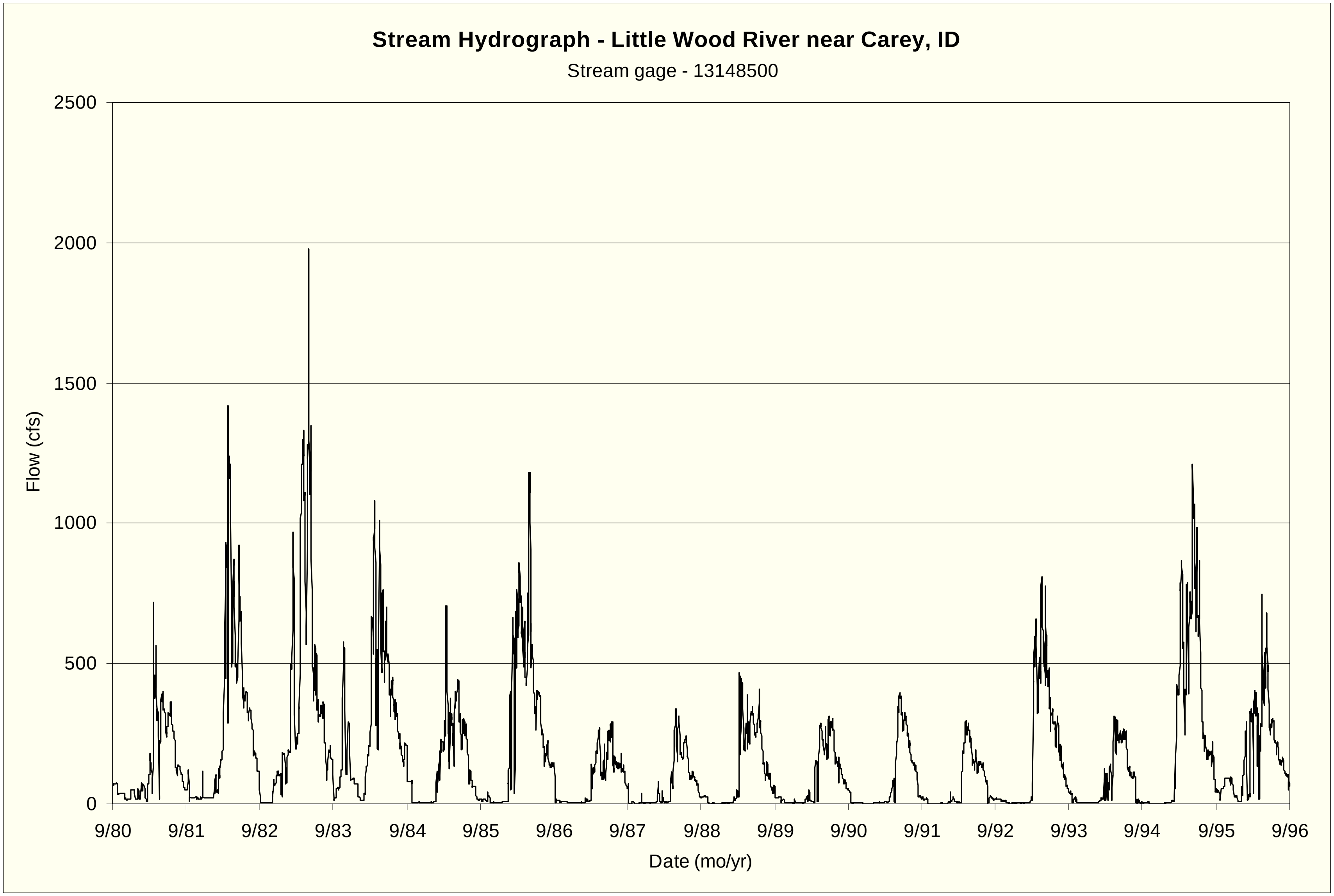


Figure C.14. Stream hydrograph for the Little Wood River near Carey, Idaho.

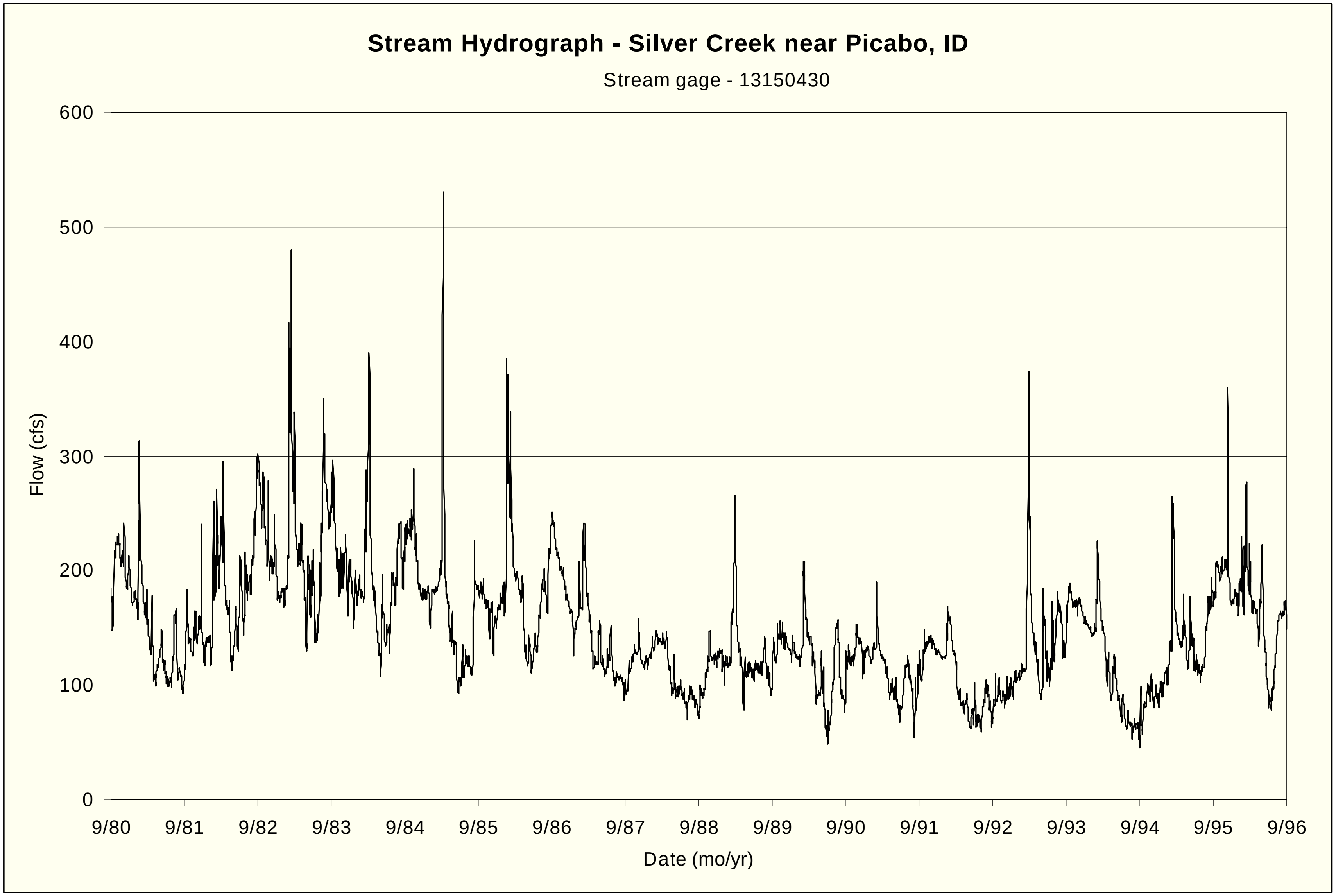


Figure C.15. Stream hydrograph for Silver Creek at Sportsman Access near Picabo, Idaho.

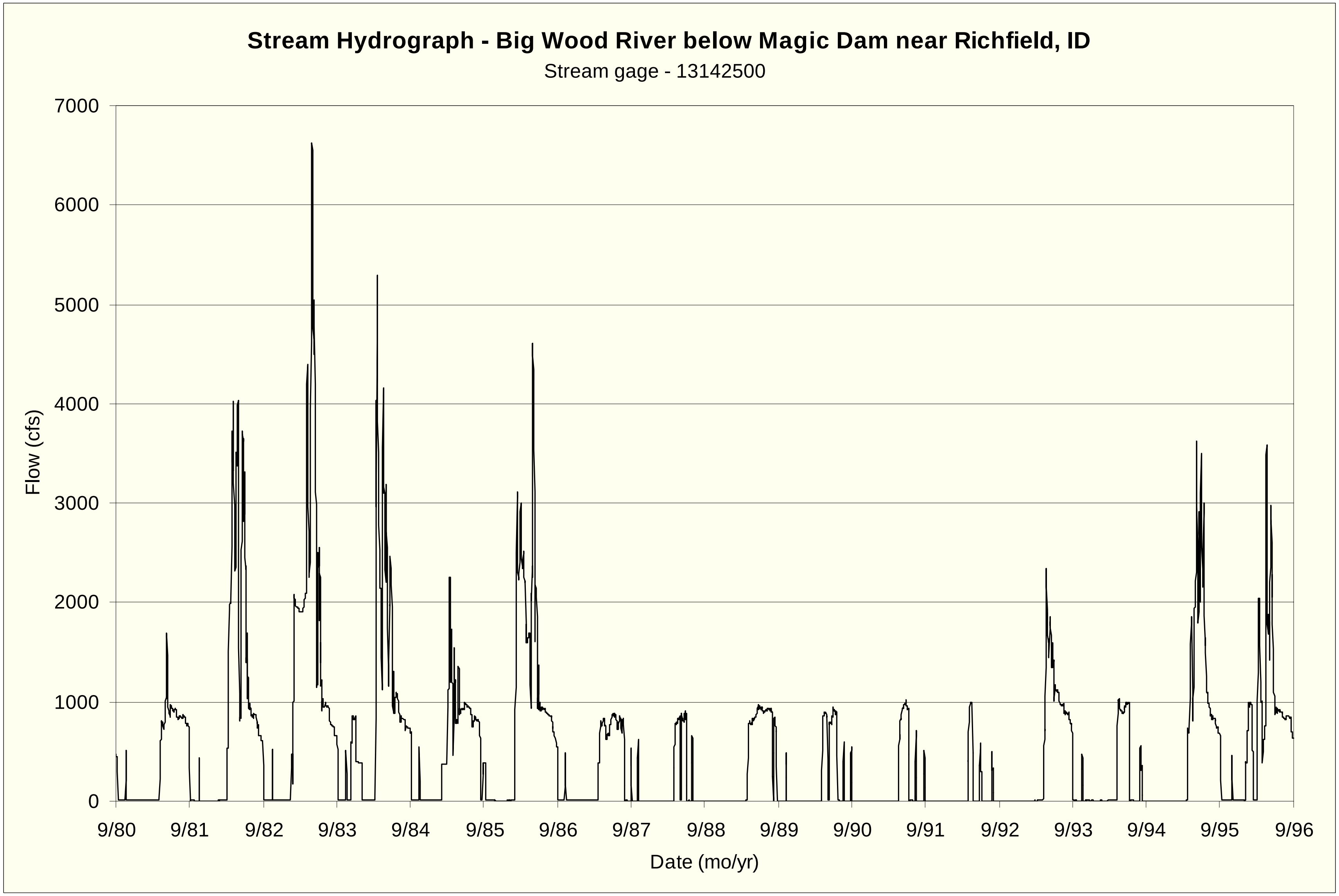


Figure C.16. Stream hydrograph for the Big Wood River below Magic Reservoir near Richfield, Idaho.

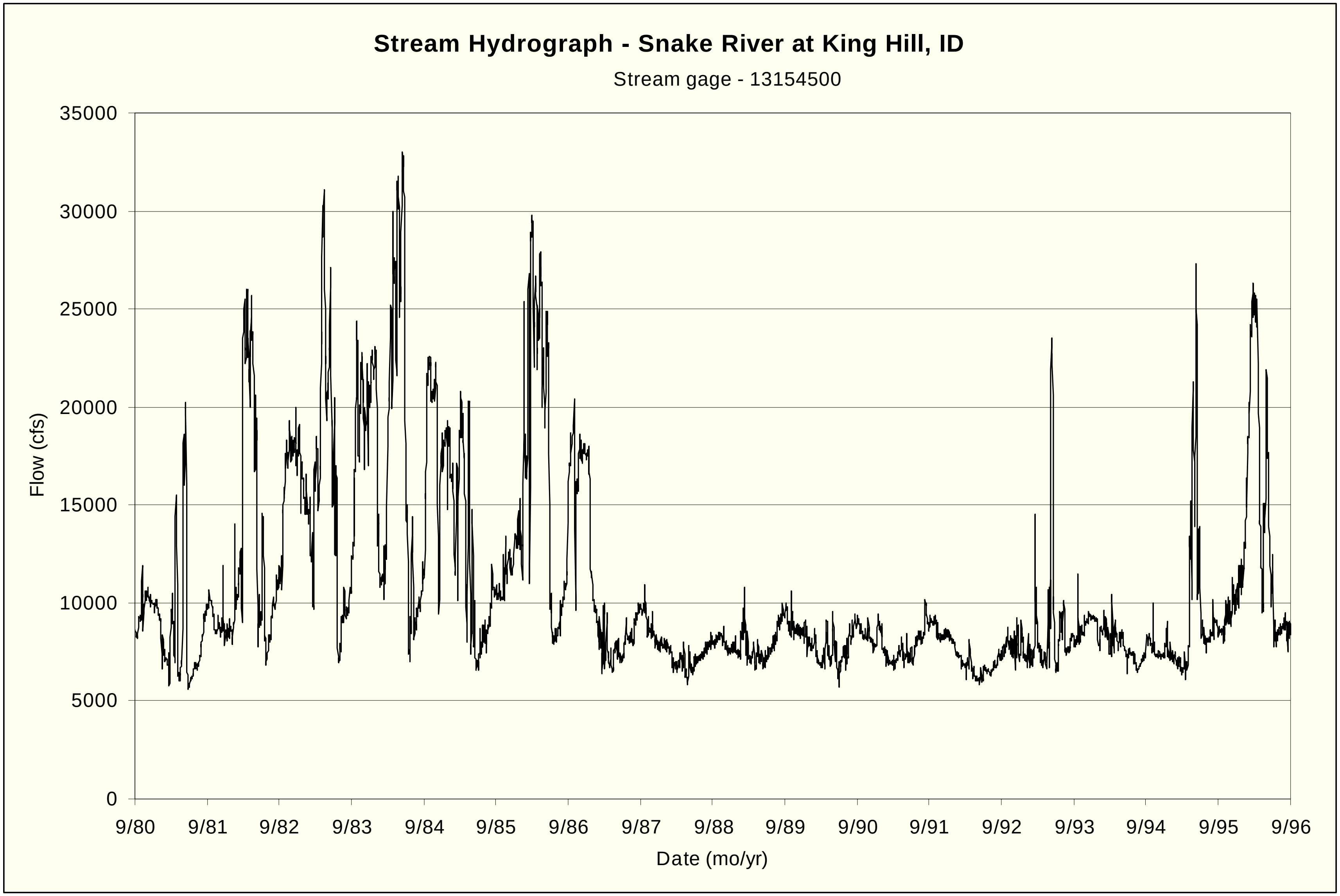


Figure C.17. Stream hydrograph for the Snake River near King Hill, Idaho.

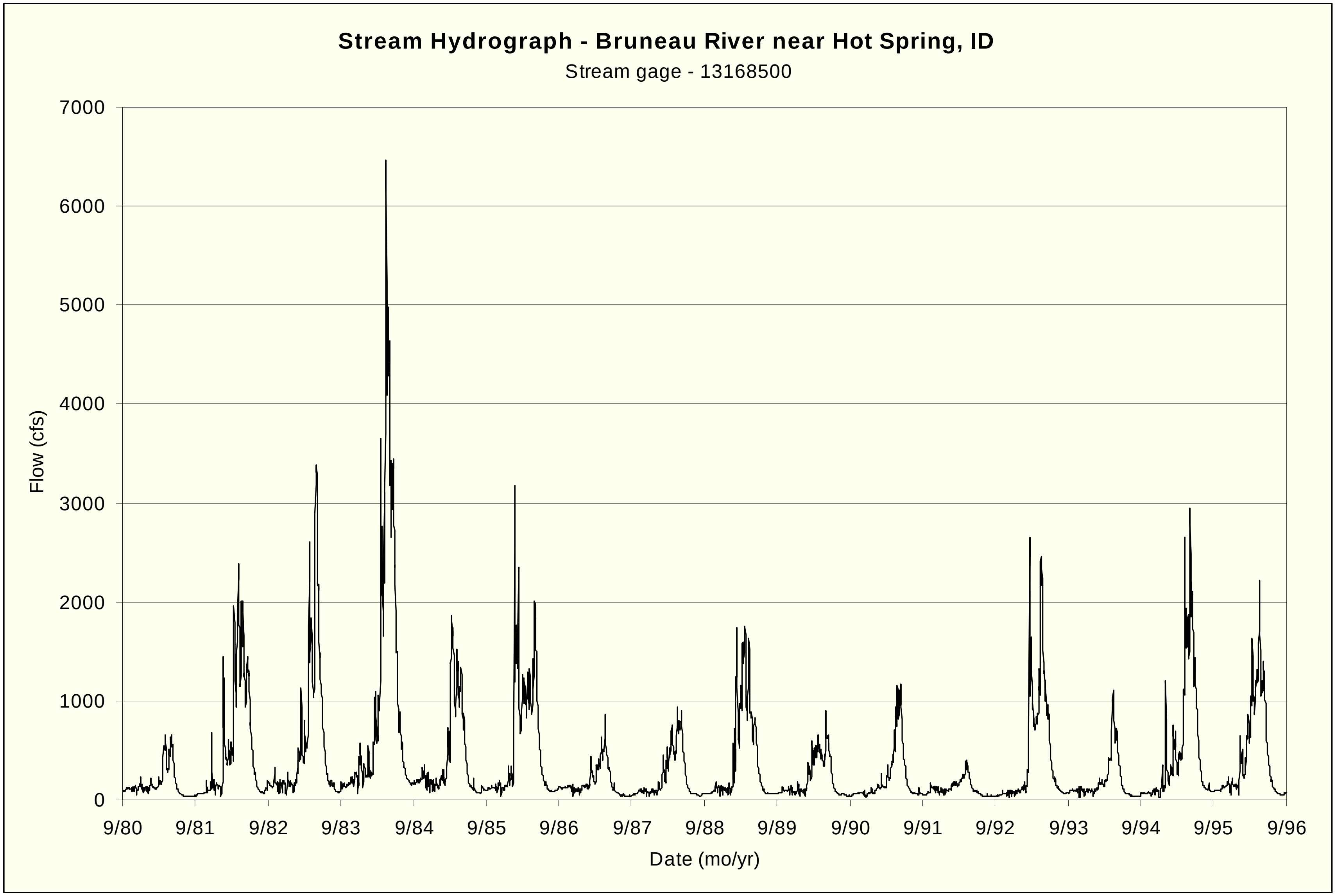


Figure C.18. Stream hydrograph for the Bruneau River near Hot Spring, Idaho.

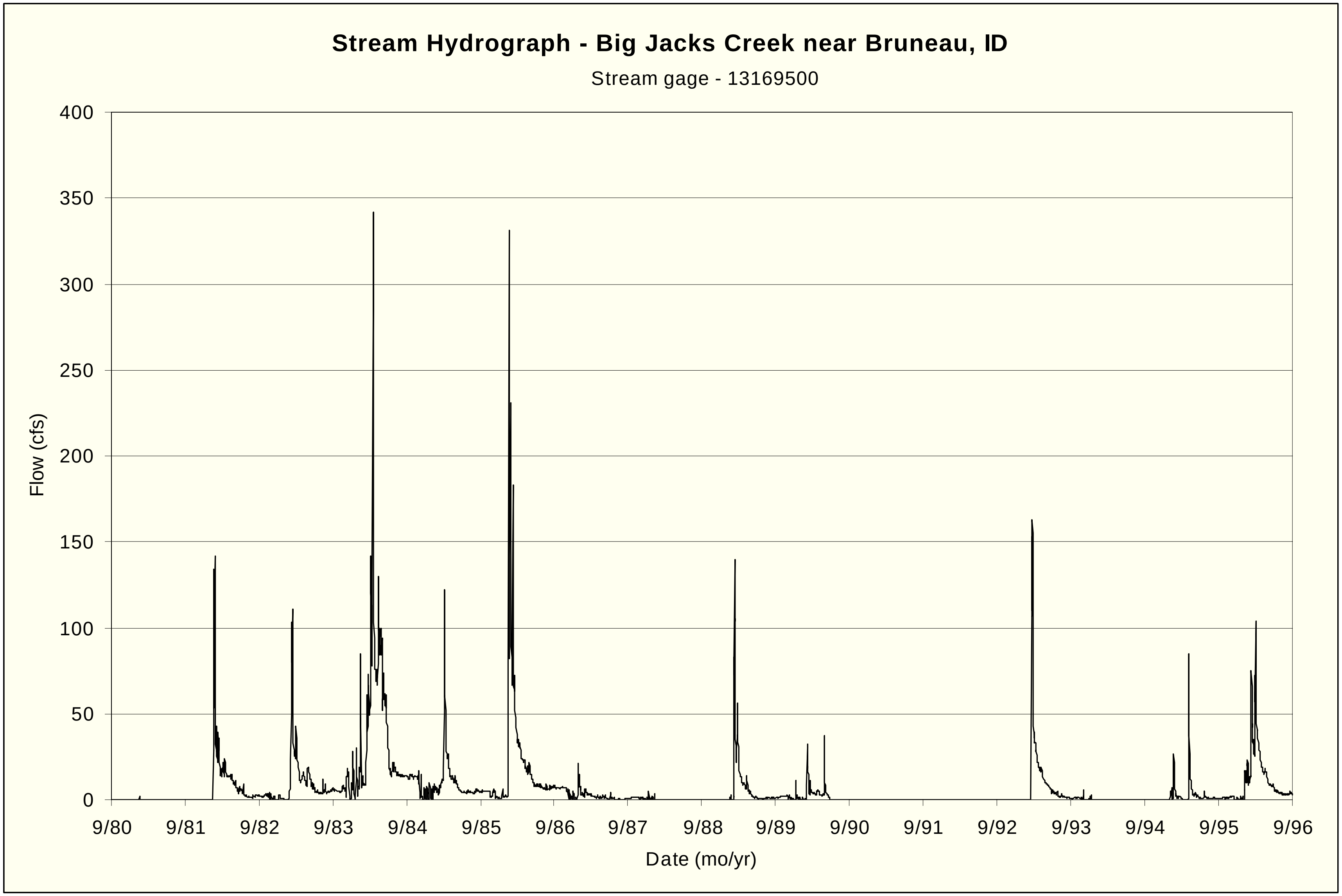


Figure C.19. Stream hydrograph for Big Jacks Creek near Bruneau, Idaho.