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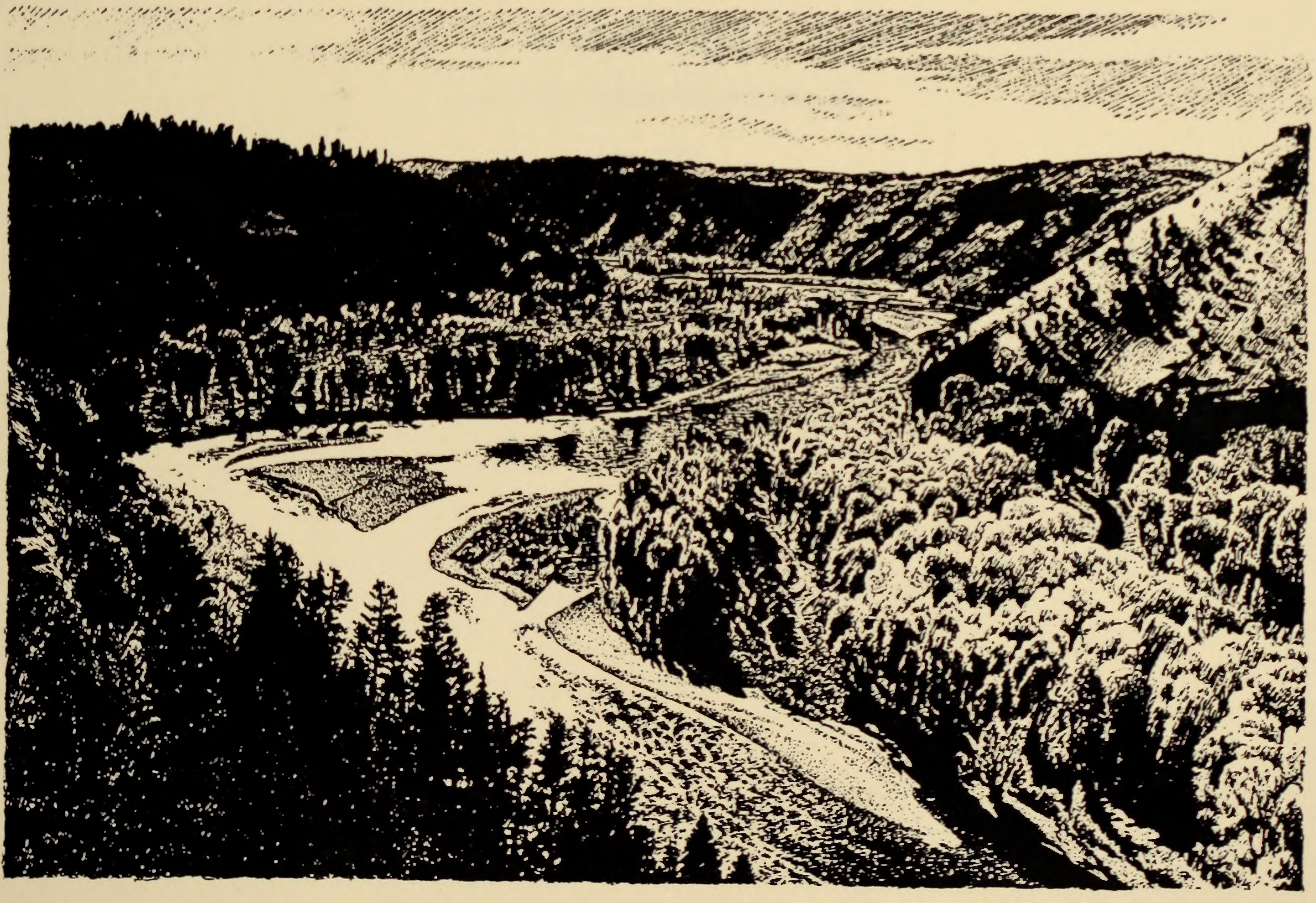
## ECOLOGY AND MANAGEMENT OF THE SOUTH FORK SNAKE RIVER COTTONWOOD FOREST

by
Michael F. Merigliano



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# ECOLOGY AND MANAGEMENT
# OF THE
# SOUTH FORK SNAKE RIVER COTTONWOOD FOREST

by

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Riparian and Wetland Research Program

May 1996

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Idaho State Office, Bureau of Land Management
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## PREFACE

Management of stream-associated vegetation requires an understanding of hydrology, geomorphology, and plant ecology, at least. These three disciplines are typically separated in the literature and among people. By merging them, vegetation and stream dynamic relations may be clearer, and our total understanding will be greater. Perhaps more than anything, this is a prime motivation behind this report. Specialists, such as hydrologists, range ecologists, soil scientists, etc., will likely continue to solve resource problems together, but a knowledge cross-over among them should ease the task by improving communication, sharpening inquiry, and fostering mutual understanding.

A down-side of merging disciplines is an increased patience and effort by the readers. If specialist only read the sections pertinent to their discipline, they should find much basic, familiar information. When writing section germane to one discipline, I had other disciplines in mind. Therefore, hydrologists, for example, may find some tedium in some parts, while those used to vegetation will find the same in other parts. Much of my effort will be wasted and readers may be sleepy if they stay within their comfort areas. The same goes for actual practice.

The bulk of this report is somewhat technical, but basic findings and ideas are brought together for those not interested in technical details. Although this report focuses on only 40 miles of one river, its general approach should be valuable to those dealing with other rivers — especially regulated ones.

## ACKNOWLEDGEMENTS

Several people helped with this project. Many thanks go to the pioneer South Fork riparian ecologists, Karen Rice and Bob Jones of the Bureau of Land Management. Their awareness of many of the problems over 15 years ago highlights the time it can take to even begin to solve them, and their early field efforts were a foundation for this study. Both were instrumental in initiating this study, and Karen continued to be involved to the end, including several field visits, logistical support, and report review.

Many people provided data and their insights. Mike Beus of the Bureau of Reclamation was especially helpful with water management issues and data. Jake Jacobsen of the U.S. Geological Survey lended his expertise and provided unpublished data pertaining to streamflow gages. Dusty Hinks and Karen Rice provided information about livestock grazing. Sonny Spaulding was a well-spring of South Fork history. Stuart Rood, University of Lethbridge, Alberta, visited the study area, and his insight in cottonwood physiology — particularly vegetative reproduction — was a valuable addition. Brian Richter, National Hydrologist for the Nature Conservancy, also visited and his broad perspective on riparian ecosystems put things in a better perspective. Bob Moseley of the Idaho Conservation Data Center provided expertise and data pertaining to Idaho's riparian areas and rare plants.

It's difficult to come up with answers with no questions. Besides those already mentioned, numerous land managers and researchers provided many questions and they include Gregor Auble, Signe Blair, Jonathan Friedman, Karl Gebhardt, Pat Koelsch, Dan Kotansky, Mike McQueen, Victoria Saab, Michael L. Scott, and Michael Whitfield.

I cannot thank Paul Hansen enough for encouragement and guidance throughout this project. Much of this information is part of my graduate work, and Paul was an energetic and thoughtful advisor. Thanks also to the rest of my graduate committee; Robert Pfister, plant ecologist, Donald Potts, hydrologist, David Patterson, statistician, Ragan Calloway, plant ecologist, and Johnnie Moore, geologist.

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This study was generously funded by the Idaho State Office of the Bureau of Land Management, The Idaho Nature Conservancy, Trout Unlimited, and the University of Montana. All information contained herein is the responsibility of M. Merigliano.

Cover art is by Alan McKnight, drawn from a photograph by M. Merigliano.

# ABSTRACT

This report summarizes an investigation of the cottonwood ecosystem along the South Fork Snake River from Palisades Dam to Heise Idaho. Vegetation dynamics in time and space, with an emphasis on the cottonwood component, was the primary focus. Because riparian vegetation is so intricately related to the river's physical processes, these were studied to the extent that available data and rapid field observation allowed.

The South Fork of the Snake River water flow is dominated by snowmelt and its sediment load is strongly influenced by glacial deposits. Its channel form and location on the flood plain is quite stable under most flows. However, the channel can migrate a considerable distance during very high discharges. Due to the inherent stability, sediment budget, and Palisades Dam discharges, the river has changed little since dam closure. This lack of change has two main implications: The river should behave now in a similar manner as it did before dam closure under similar discharges, and the lack of high peak discharges due to flood control has inhibited channel migration. The former allows for easier prediction, the latter has affected the cottonwood forest.

Floods were the dominant disturbance factor before Palisades Dam closure, and most of the cottonwood forest established on sediment deposited during large floods. Species such as cottonwood and willow that require bare, moist, mineral soil in sunlight for regeneration are declining because of flood control. The smaller floods since Palisades Dam closure have created less area conducive to cottonwood and willow regeneration, and total forest area is shrinking and becoming proportionately older.

For the South Fork, the most important island-forming and cottonwood-colonization events are *at least* 36,000 cfs. Annual floods of at least this size recurred about 8 years apart during the pre-Palisades period. Considering the size of stands created since 1910, and assuming a 300-year longevity for cottonwood stands, a 36,000 cfs event is just enough to create new stands large enough to maintain the cottonwood forest, and this assuming an optimistic cottonwood life span of 300 years. Floods in the 45,000 to 50,000 cfs range are much more apt to maintain the forest because islands formed under this regime are considerably larger than those created under flows about 36,000 cfs. The recurrence interval for 45,000 to 50,000 cfs are 27 and 54 years, respectively.

Sediment deposition and water discharge patterns are important for riparian vegetation establishment and survival. Seasonal water levels influence general water availability to plants, while soil characteristics locally influence water availability. Species composition responds to water availability. Dam releases during most of the growing season are similar to the pre-dam condition, and existing vegetation appears to be growing well. However, cattle grazing has impacted vegetation in some places, and recovery will likely be slow in the most heavily-impacted areas.

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# EXECUTIVE SUMMARY

The goal of this study was to gain an understanding of the flow and vegetation dynamics of the South Fork Snake River (herein, South Fork) riparian zone between Palisades Dam and Heise, Idaho. This information can be used to mitigate adverse effects of flow regulation and therefore maintain the cottonwood ecosystem. The main study objectives are to determine the age distribution of the cottonwood forest, correlate cottonwood establishment with flow events, and investigate how time and site relate to some common riparian plant communities found on the South Fork.

There are many aspects to this study, and only the more important examples are included here with a balance between support, understanding, and brevity in mind. The main topics of this report are the physical characteristics of the river — or its form and process over time, riparian vegetation dynamics and its relation to the river, and recommendations. Although grazing impacts on vegetation was not a primary research objective, some discussion of this is included based on my observations, experience of others, and the literature. I include a synopsis of the methodology emphasizing study design and sampling assumptions, but details are left out.

River systems are inherently dynamic, and the South Fork is no exception. Separating natural dynamics from those with a human influence was fundamental to this study, and one should be attentive to this separation when thinking or making a decision about the river.

In contrast to this separation, I considered findings and general land management objectives together when forming recommendations. With a diversity of land ownership, public perception, values, and opinion rivalling the South Fork's natural diversity, general "objectives" are elusive. Based on agency documents incorporating public input, recent land acquisition by conservation-minded people, and informal conversations with residents and visitors, a main theme of at least maintaining the status-quo or improving "riparian values" emerges. Of course, my primary tasks were related to the field setting, but the theme of these objectives help bridge the gap between arcane plots with lines and dots and some possible actions.

Recognizing these general, natural dynamics and land management objectives, three questions form the study's basis, and in turn, some possible management direction: What was the river and its associated vegetation like before the influence of modern humans — the presettlement condition? What are the dominant processes that maintained the ecosystem? Which system processes have been changed, and what will be the result of these changes?

The results of this study can be summarized as follows. The river's form and process has changed little since dam closure, but net channel erosion is occurring very slowly. There has been a cottonwood forest for at least the last 300 years. The system may have looked like it does today at some times in the past, but there are probably more mature and older-aged trees than usual. There are some exotic grasses and forbs, but most of the native flora is intact. The region supported bison, but some present grazing patterns may be different compared to the bison pattern. Dense riparian shrubs and bison apparently coexisted, but these shrubs have been nearly eliminated in some places. Cottonwood and other riparian species depend on new stream deposits for regeneration. Flood control has limited the amount of new deposits, thus severely limiting cottonwood regeneration. If existing reservoir management continues, the cottonwood forest will decline, and the decline will be much faster than changes in river morphology. Planting is a poor option for it will be very expensive, logistically difficult, and water diversion rights may be needed.

The main recommendations are: facilitate steps to allow for larger floods (about 38,000 cfs) that would be spaced approximately 15 years apart. To allow for these floods in the future, flood-plain development should be limited, agency cooperation should continue, and public education and acceptance will be essential. Subtle changes in summer flows will be required during some years, otherwise, typical existing summer flows are acceptable. Do not encourage fire; it was not a dominant disturbance in the cottonwood forest and usually reduces it. Livestock use should be adjusted to plant community and site characteristics.

## AN OVERVIEW

Along the shifting stream of water and sediment called the South Fork Snake River, some sediment stops its downstream journey for a while. No longer part of the moving river, it now defines the river's edge until carried along once again. In the meantime, it supports one of the largest riparian forest in the northern Rocky Mountains.

The cottonwood is aptly-named for its tiny, wind-blown seeds. Highly-mobile, plentiful, and short-lived, these seeds need sunny, moist, and bare earth to take hold. The river occasionally supplies these places when it shifts course, leaving new land in its wake called flood plain. Nearly every place we see cottonwood today, there was river channel, and today's river channel is potentially where future cottonwoods will be.

The South Fork's potential for new cottonwoods has changed since the construction of Palisades Dam. The river is less dynamic now because of flood control. When thinking of floods, one may conjure images of deep, spreading waters. But what happens under water is more fundamental to cottonwood replenishment; it is not so much where the water goes, but where the sediment lands. There are now fewer places for cottonwood seeds to take hold, for the river shifts much less than before. Although very extensive, ninety five percent of today's cottonwood forest is a legacy of pre-dam, natural conditions. Most of the forest is between 50 and 125 years old, but one can still see trees that were here before the first explorers; some trees were born before our nation. Cottonwood has colonized flood plain areas that formed since dam closure, but these areas are much smaller than those formed under natural conditions. The cottonwood forest is getting proportionately older and less extensive.

There is much more to a cottonwood forest than cottonwood trees, of course. Cottonwood is practically the only tree on the flood plain, but many different plants occur under them or in areas without them. Much of the species diversity is due to a wide variety of flood plain ages and site factors. Species have there own life histories and tolerance to site factors; they develop differently over time and a particular species cannot live everywhere, especially if other species are more adaptive and out-compete them. Site factors on a given place change over time, especially within the first few decades after initial formation. The most important site factor is water availability, which depends on soil texture and surface topography. Due to these differences among species and differing site factors over time and space, the flood plain supports many species. Water levels during the growing season are similar for the pre- and post-dam periods, and existing plants appear to be growing well. The biggest change in species diversity will be due to scarcity of sites conducive to cottonwood and willow regeneration.

There is a place the local fisherman call "endless riffle". An extensive haven for fish, this place, like many others, is on the cusp between a water and land environment. In the past, floods have nudged them over the cusp, at the same time eroding other places away, leaving a new watery environment where there may have been magnificent forest. Cottonwoods are pioneers, and the fresh land left by the shifting river is their frontier. Although long-lived, cottonwoods trees do not live forever, but the forest lives on as long as there is a frontier. In order for the river to look the same, it must change.

And so must we. Before water development on the upper Snake River, the cottonwood forest was a free, self-sustaining resource. As long as we control the river, and as long as society wants cottonwood forests, we must change our ways. Without some form of action, this report amounts to a mere history lesson with some dire predictions. The following section outlines some possible actions that should maintain the South Fork ecosystem in a way similar to what it was in the past.

## INTRODUCTION

This report summarizes an investigation of the cottonwood ecosystem along the South Fork Snake River (herein, South Fork) from Palisades Dam to Heise Idaho. Figure 1 shows the river and tributaries in the primary study area. Some aspects of the study were extended to the upper basin. Vegetation dynamics in time and space, with an emphasis on the cottonwood component, was the primary focus.

Because riparian vegetation is so intricately related to the river's physical processes, these were studied to the extent that available data and rapid field observation allowed. Fortunately, there is a considerable amount of data for the Snake River in general and the South Fork in particular, allowing a good understanding of channel dynamics.

The recommendations are based on findings from this study, the experience of others, and the literature. These recommendations are contingent

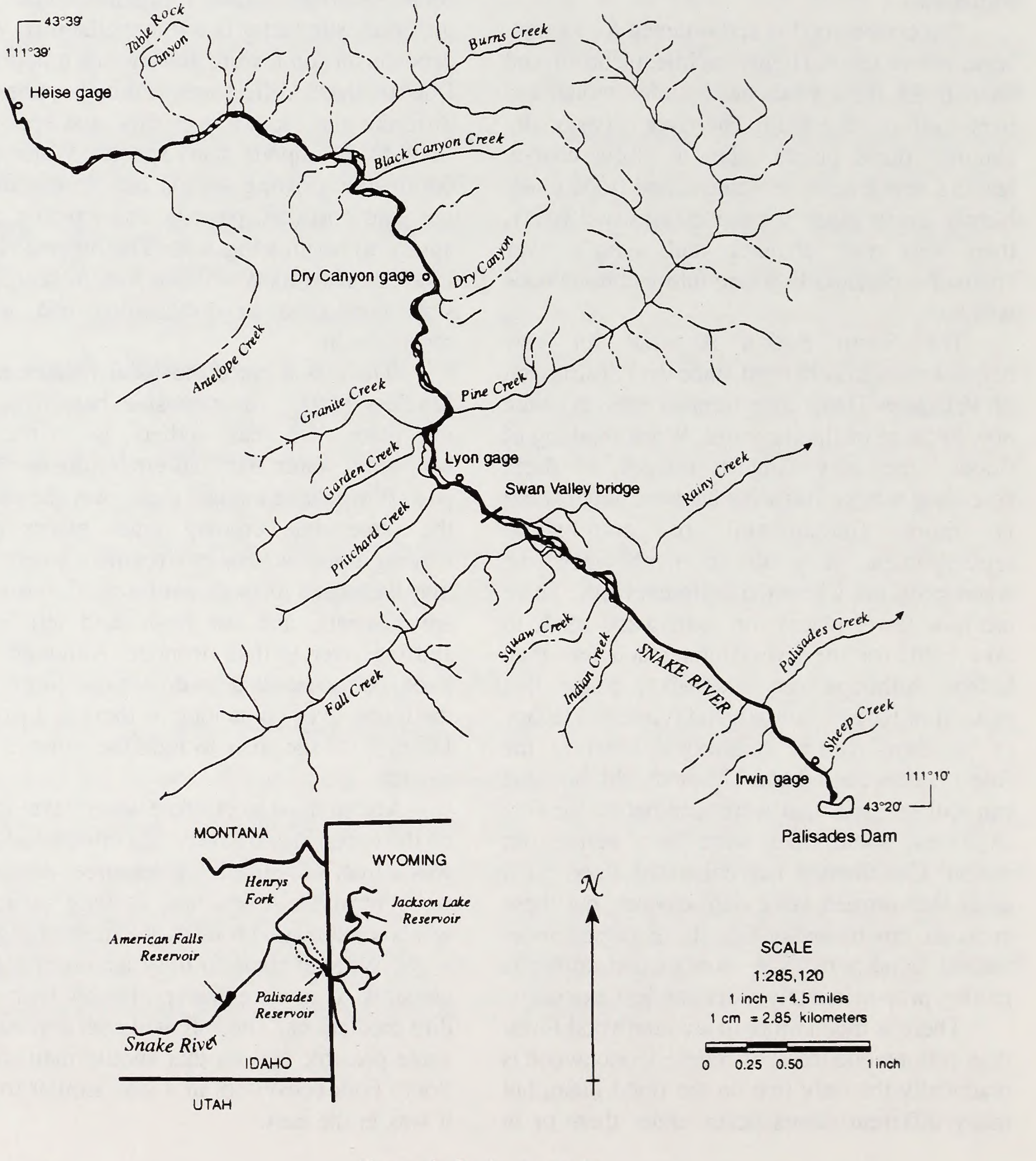


Figure 1. Study area map.

on an overall objective of maintaining the cottonwood ecosystem. The original study objectives as proposed in 1991 were:

1) Compare the temporal and spatial patterns of cottonwood establishment that occurred before and during flow regulation, to assess whether the cottonwood forest is maintaining its size under current management.

2) Determine, as close as possible, the specific flow regime associated with cottonwood stands of pre-and post-dam origin by correlating cottonwood ages with the discharge record.

3) Describe the floristic features of riparian communities, analyze their relationship to site, and determine the successional trends and pathways of riparian plant communities where possible.

As the objectives indicate, the effect of Palisades Reservoir management on cottonwood dynamics is a main focus, and many comparisons are centered around the closure of Palisades Dam. However, I put these comparisons in a broader context.

Below is a conceptual flow chart (Figure 2) that guided the over-all study.The report generally follows the chart in Figure 2, beginning with the physical aspects and concentrating on runoff, channel processes, and flood plain formation. Vegetation dynamics follow this, with an emphasis on temporal changes in the cottonwood forest due to the dominant disturbance regime — flooding. Other disturbances such as herbivory and fire are treated briefly. Pertinent information on ecology based on other work are interspersed where it is most helpful. The study results are incorporated with the discussion, and essential aspects of methodology or data sources are too.

This is followed by my recommendations. Finally, a synopsis of the most important aspects of the methodology is included, followed by references and an appendix. Although methods are important, I de-emphasize them for brevity. Several maps (Plates 1 to 17) are included in a pouch at the back of the report.

## PHYSICAL ENVIRONMENT

### Geology and climate

The Snake River above Heise, Idaho drains about 5,752 square miles (USGS 1954). The dominant, exposed bedrock types are marine sediments (i.e. limestone), sandstone, volcanics, conglomerate, and plutonic-metamorphic complexes. Considerable erosion and deposition occurred during four major glaciations in the late Pleistocene epoch (200,000 to 5,000 years B.P.) As a result of each of these glaciations, the ancestral Snake River transported and deposited glacial debris in a long "tongue" extending at least to the Portneuf River near American Falls Reservoir. Each glaciation had its own tongue of debris, called a valley train or sandur. During the warmer and drier inter-glacial periods, the sediment budget changed so that the river eroded the sandur, leaving a terrace for each of these

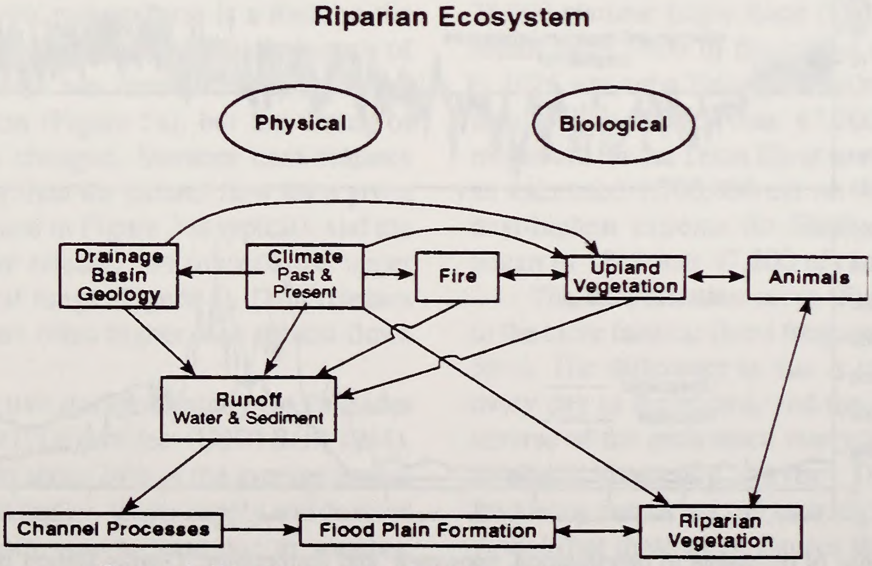


Figure 2. Riparian ecosystem components and interactions.

deposition-erosion cycles. The more recent glaciations were less dramatic and the deposits are smaller and nested within an older one. The terrace sequence can be easily seen near Alpine, Wyoming and one of the best examples of glacial terraces in North America is in the Jackson Hole basin. Walker (1964) traced, aged, and described the terraces along the Snake River above Alpine.

This glacial legacy still greatly influences the river today. Although most of the country rock is sedimentary and easily broken down into small fragments, the South Fork's sediment load is dominated by well-rounded cobbles which resemble those in glacial terraces. The terraces are apparently an important source of sediment; most of the tributaries carry angular gravel, but it is difficult to find this material in the Snake River.

Today, about 92% of the drainage basin is mountainous and forested, and the runoff pattern is dominated by snowmelt. The upland conifer forest may be slightly more expansive now as compared to the late 1800's because of differing fire history(Gruell 1980 a,b), but the effect of this on runoff is probably negligible. Sediment yields from burned landscapes may have been higher, however. Compared to vegetated, unburned glacial till soil, Marston (1990) found a 35-fold increase in sediment yield from simulated rainfall on burned glacial till soils in the Snake River basin. Most of the soil loss was due to raindrop splash; losses were minimal from snowmelt.

The mean annual discharge for the South Fork near Heise is 6,977 cfs for the period 1911 to 1990. This equates to an average 5,054,578 acre-feet per year, or 16.5 inches of runoff per year for the drainage basin. River discharge is sensitive to snowmelt patterns on a daily as well as seasonal basis. Figure 3 shows how the flow pattern varies with temperature, precipitation, and snowmelt. The climate data is from the Phillips Bench station, a subalpine forest area near Teton Pass. The hydrograph is for the South Fork near Heise, Idaho. The reconstructed unregulated flow fluctuates more closely with weather patterns than

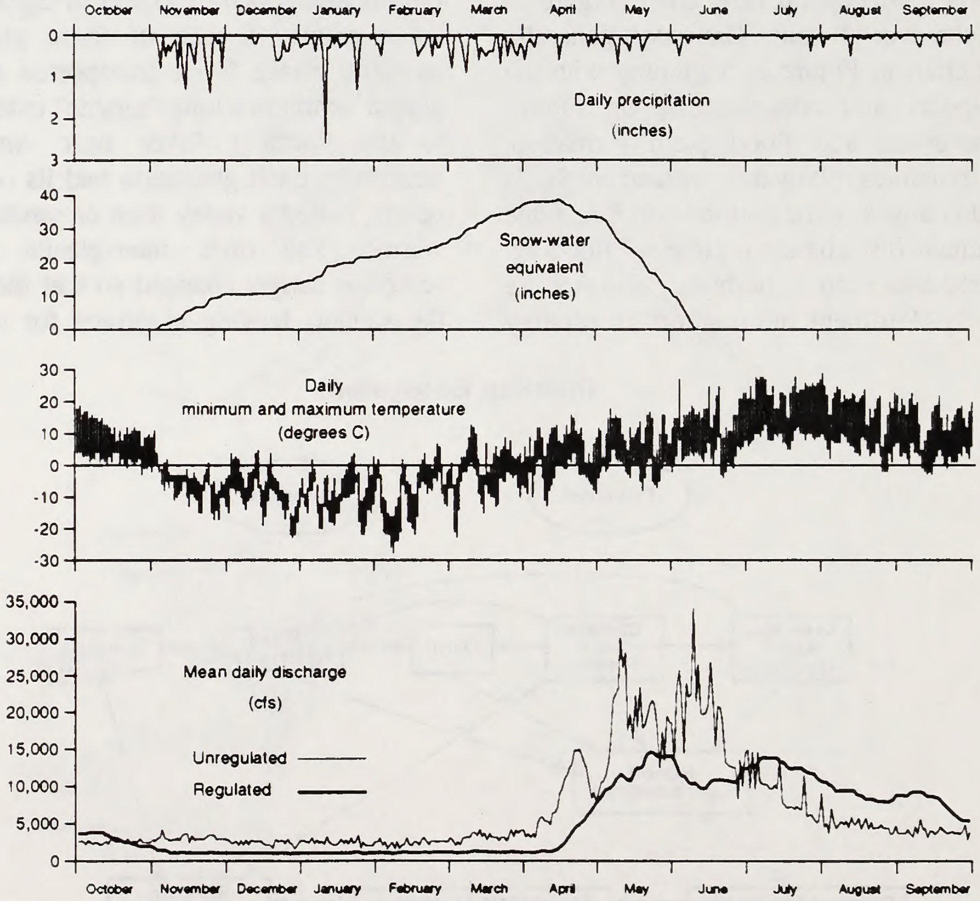


Figure 3. Response of discharge to precipitation, snowmelt, and temperature. Gaging station is Snake River (South Fork) near Heise, Idaho, weather station is Phillips Bench, Wyoming. Water year 1989.

the observed or actual flow, but some of the minor (± 500 cfs) fluctuations are due to rounding errors in reservoir storage values used in calculations. Both Jackson Lake and Palisades Reservoir effects are accounted for; diversions, which are minor above Heise, are not.

Hydrology

Two important hydrologic aspects are water and sediment. Channels adjust to the amount and timing of water and sediment flows. The changes in pattern of these flows over time are described now; the implications of these changes are discussed in the sections on river processes and vegetation dynamics.

The South Fork's water discharge history for the record period can be summarized four ways: composite hydrographs showing daily flows over time (Figure 4), flow duration curves which show the percent of time a given daily discharge is equalled or exceeded (Figure 5a), annual flood frequency (Figure 5b,c), and time series of annual floods (Figure 6). The Heise station has the longest record, starting in September 1910, and represents the study area best. The Heise record is augmented with the earlier Lyon record. This gage was at the Wedikind ferry cable, near the present Forest Service administration site in Conant Valley (Figure 1). Mean daily flows at Irwin are 3% lower than those at Heise, and flows at Lyon are probably within 2% of Heise. Flow regime can be defined as the magnitude and timing of discharge. An important change in flow regime due to Palisades Reservoir management is a limit on the larger flows due to flood control. The frequency of the moderate flows has remained similar to the pre-dam condition (Figure 5a), but the timing of these flows has changed. Summer dam releases tend to be higher than the natural flow for a given year (the difference in Figure 3 is typical), and the range in summer releases are towards the upper end of the natural range (Figure 4). Dam releases in early spring are often higher than natural flows would be.

The total active storage capacity for Palisades Reservoir is 1,200,000 acre-feet (USDI BOR 1961), which amounts to about 24% of the average annual inflow mentioned earlier. Water supply and demand patterns vary from year to year due to weather, holdover storage, and diversion and storage rights, so there is hardly a typical year. Nevertheless, the hydrograph tends to be compressed (Figure 4), with higher early-spring releases to allow space for high inflows, and higher summer releases during hot summers if there is adequate storage. Palisades Reservoir is managed for irrigation, power generation, flood control, recreation, and fish and wildlife conservation (Van Den Berg, personal communication 1990).

Palisades reservoir often physically fills in spring, but much of the water belongs in downstream storage or diversions due to priority water rights. Effects of reservoir management on peak flows are shown in Figure 6. The reduction in peak discharge is usually greater after Palisades Reservoir operation as compared to Jackson Lake alone. The pre-1916 Jackson Lake Dam was much smaller than the present version, and the older reservoir had about half the storage capacity.

The hydrographs show mean daily flows, while instantaneous flow values are used for the flood analysis. Instantaneous flows are usually within 5% of the mean daily flow. The one notable exception occurred during the Gros Ventre flood of May 1927, when the landslide blocking the Gros Ventre River partially failed. This flood destroyed 3 bridges and had an instantaneous peak of 60,000 cfs at Heise. This is the biggest flood in the USGS record for the Heise station. A similar size flood of 65,000 cfs occurred on June 6, 1894, according to Army Corps records (first mentioned in USGS gage records for Heise and Irwin in 1951). This same flood was about 75,000 cfs near Eagle Rock (Idaho Falls). A more recent large flood in the region occurred on June 6, 1976 when the Teton dam failed. The peak flow near Shelly, Idaho was 67,300 cfs, while the maximum for the Teton River near St. Anthony was an estimated 1,700,000 cfs on June 5, 1976. The next-highest extreme for Shelly since the record began in 1915 was 47,200 cfs in 1918.

The flow duration curve (Figure 5a) is similar to the more familiar flood frequency curves (Figure 5b,c). The difference is that it includes flows for every day in the record, and the probability is the inverse of the recurrence interval commonly used in flood frequency curves. The annual flood frequency curves use only the highest flow for each year. What these three figures show are the

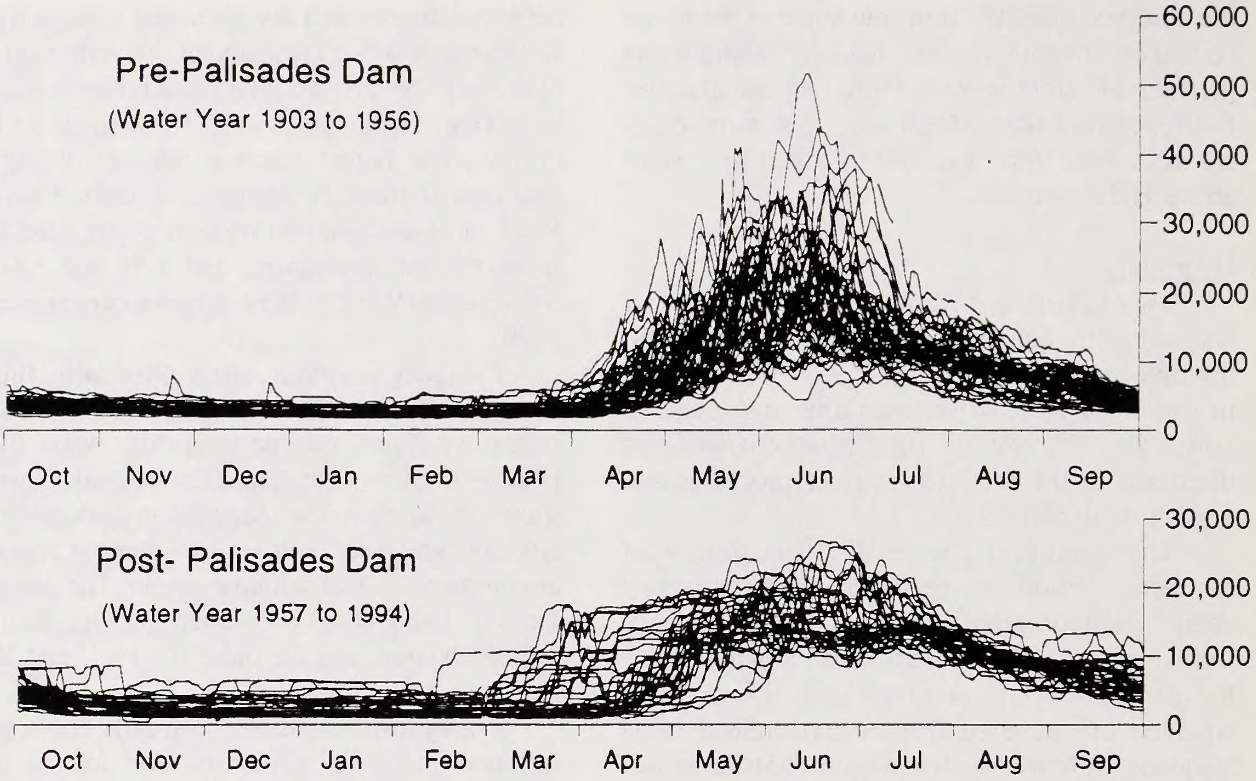


Figure 4. Composite hydrographs for the pre- and post-Palisades Dam periods, South Fork Snake River near Heise, Idaho. The pre-dam graph includes flows measured at the Lyon gaging station, which is comparable to the Heise station and was operated from 1903 to 1910. Flows during 1903 to 1906 and 1910 are unregulated. Units are cubic feet per second (cfs), and values are mean daily discharge.

probability of a given flow being equalled or exceeded. In other words, the probability is cumulative. However, in practice, one discharge value is considered for a given frequency or probability. Figures 5 a, b, and c do not indicate the temporal spacing of flows of a given frequency.Large flows can be clustered (e.g., 10-year floods are not necessarily spaced 10 years apart). Figure 6 shows peak flows over time and flood control effect.

For natural flows, the shape of the duration curve reflects the geology and climate of the drainage basin (Searcy 1959). The steeper the curve's slope, the greater the range in discharge magnitude. The slightly flattened upper-end of the pre-dam curve reflects the snowmelt influence on peak flows, but the natural-flow hydrographs typically have a considerable range in discharge over a few weeks. The flattened lower end indicates ground water storage. The frequency of the moderate flows between 4,000 and 15,000 cfs has changed little between the two periods. The deviations at either end reflect flood control in spring, and reduction of low flows during storage in winter. The much-reduced slope of post-dam curve's upper-end reflects the compressed range of high flows.

The flood frequency curve for observed flows (Figure 5b) shows how flood control has eliminated peaks above 27,000 cfs. An annual peak flow of this size had a recurrence interval of 1.5 years on the reconstructed natural flood curve (Figure 5c). The reconstructed natural flood series (Figure 5c) extends the record to 92 years, and better indicates the natural flood frequency because flow regulation is eliminated, and the clustering effect is lessened with a longer record.

Channel dimensions adjust so that fluid stress on the bed and banks is in balance, and this occurs at bankfull discharge (Langbein and Leopold 1964). There are several ways to define bankfull discharge (Williams 1978). A common approach uses a recurrence interval of 1.5 or 2 years. Using this approach and the observed flood history before Palisades (Figure 5b), the bankfull discharge is about 25,000 cfs, but as will be shown later, the

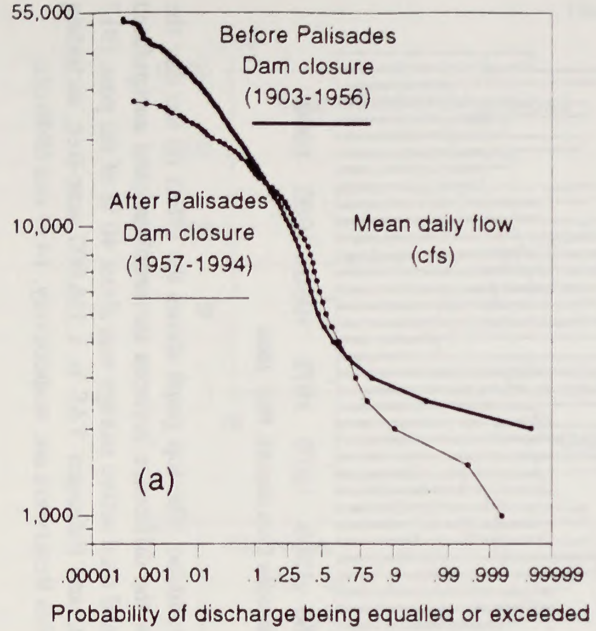
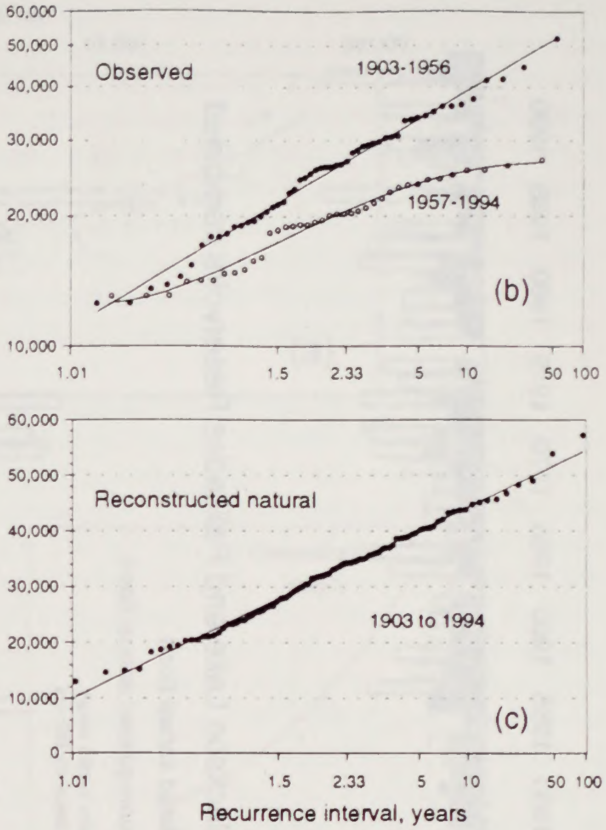


Figure 5. Magnitude and duration of flows, South Fork near Heise, Idaho. Flow duration curves (a); and Annual flood series for actual flows (b); for pre- and post-Palisades dam periods. Reconstructed, natural annual flood series for period of record (c). Annual peaks are instantaneous cubic feet per second (cfs). Gros Ventre flood of 1927 not included in (b) and (c).

geomorphically-defined bankfull discharge is much higher — about 40,000 cfs.

Flows that do the most cumulative work in sediment movement over time and maintain the channel tend to be frequent and moderate (Leopold and Wolman 1957; Wolman and Miller 1960; Dury 1973). The frequency of moderate flows has not changed much with Palisades Dam operation (Figure 5a and 5b). The threshold of bedload movement as indicated by measurements at gaging stations, occurs with moderate peak flows, which are between 20,00025,000 cfs. These moderate peak flows still occur often enough after Palisades Dam closure to maintain channel dimensions. Channel dynamics before and after damming are explained in the next section.

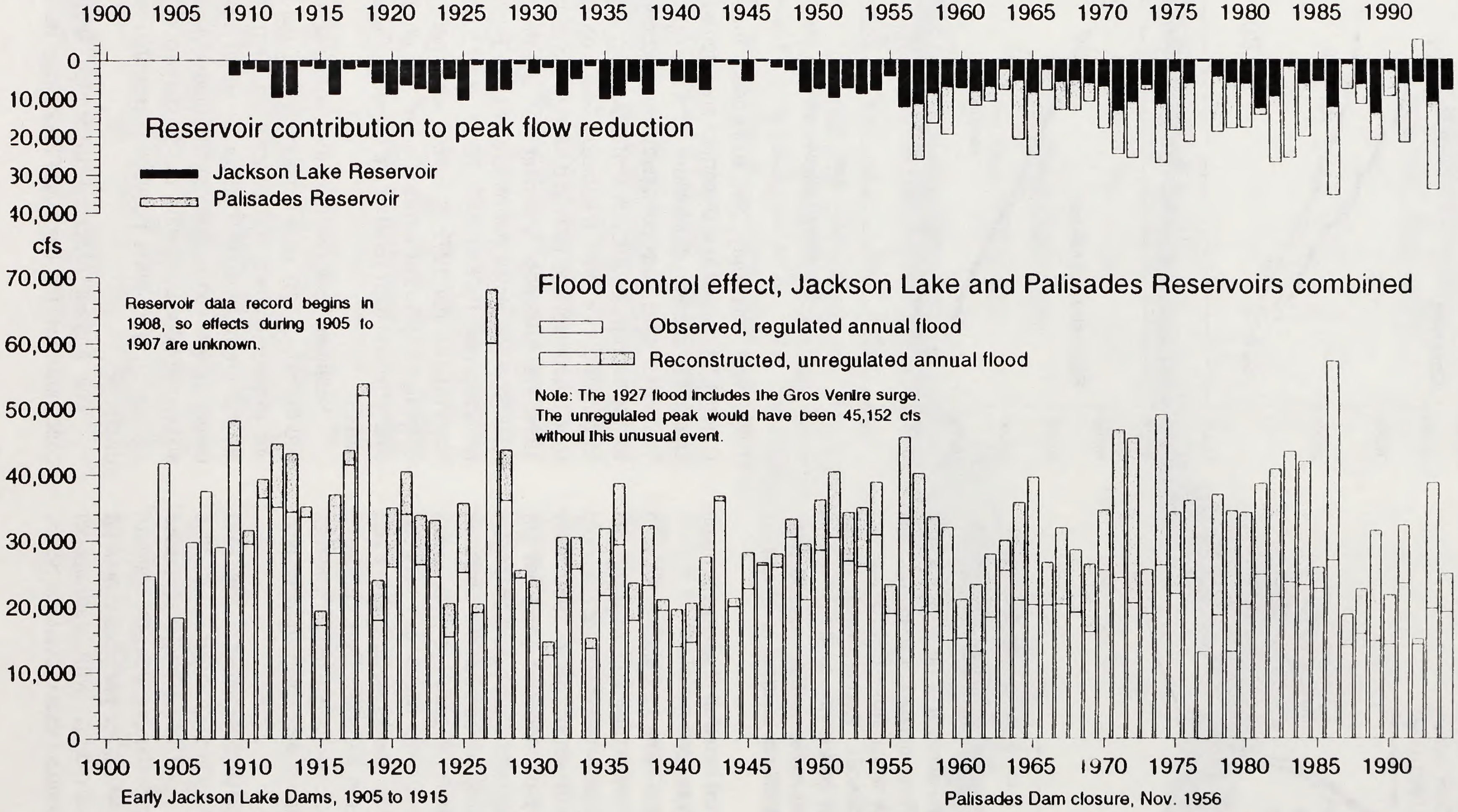
Besides water discharge, sediment size and load are the main factors to which channels adjust. The total load is made up of bed load, particles supported by solid-transmitted stress (bounce along the bottom), and suspended load, which are particles supported by fluid stress (stirred-up with turbulence) (Bagnold1966). No sediment data is available before



1978, and this only for suspended load and concentration. Bed load dynamics are inferred from changes in channel dimensions as water discharge varies over time. Suspended sediment concentrations for the natural condition are inferred from changes in roughness or flow resistence. More on this is found in Merigliano 1994 and Merigliano and Potts 1994. The suspended sediment load and discharge relation at the Heise station is shown in Figure 7a for water year 1978 to 1991. Most years have few observations, but 1979 is a year with more data. Suspended sediment concentration and discharge over time and their relation are shown in Figure 7b and 7c.

Sediment relations tend to be quite scattered and the South Fork data is no exception, but there are apparent patterns that deserve attention. These are the relatively small load for a river of this size (hence the low concentrations), the relative skewness and spread of concentration and discharge over time, and the steep relation between concentration and discharge.

The highest observed suspended sediment concentrations for the South Fork range between



Reservoir contribution to peak flow reduction

Flood control effect, Jackson Lake and Palisades Reservoirs combined

Reservoir data record begins in 1908, so effects during 1905 to 1907 are unknown.

Note: The 1927 flood includes the Gros Ventre surge. The unregulated peak would have been 45,152 cfs without this unusual event.

Early Jackson Lake Dams, 1905 to 1915

Palisades Dam closure, Nov. 1956

Figure 6. Effect of Jackson Lake and Palisades Reservoirs on annual floods, South Fork near Heise, Idaho. The top graph shows the effect on the day the reconstructed peak would have ocurred in a given year. In the bottom graph, the shaded bars show the difference between the regulated and unregulated annual floods; these events can occur on different days. The early Jackson Lake Dams were smaller and total active storage was about 40 % of the post-1917 versions. Total active storage (TAS) for the present Jackson Lake Reservoir is 847,000 acre-feet, and Palisades TAS is 1,356,000 acre-feet, including minimum power head of 199,600 acre-feet. Average annual discharges near Jackson Lake and Palisades Reservoirs are, respectively, 1439 and 6940 cfs.

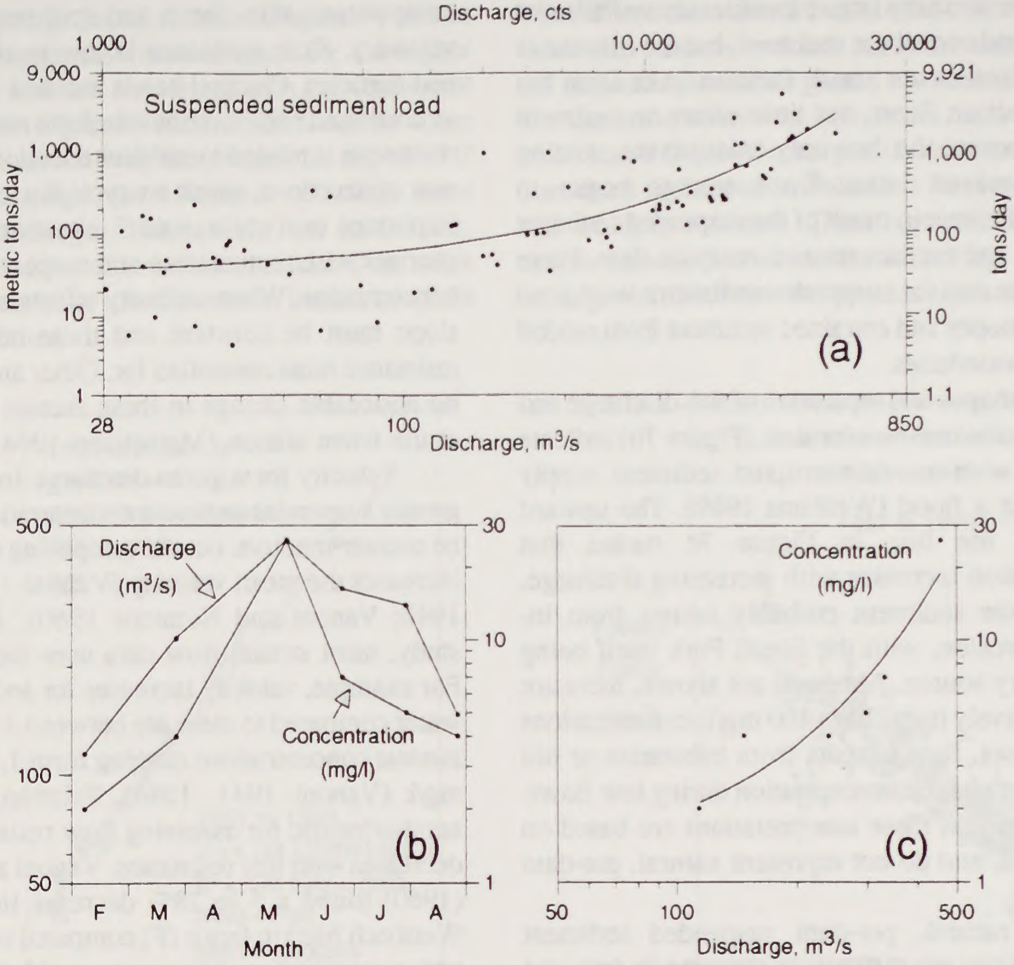


Figure 7. Suspended sediment relations, South Fork near Heise, Idaho. Relation of total load to discharge for water years 1978 to 1991 (a). Change in suspended sediment concentration and discharge over time (b), and relation of concentration to discharge (c) during water year 1979. Note change in units for (b) and (c). Cumecs is cubic meters per second.

100 and 150 mg/l. For comparison, other studied. rivers have higher concentrations. For example, the the Bighorn River near Thermopolis, WY, before closure of the new Boysen dam in 1952, had 20,000 tons/day at 2,000 cfs, which is the mean annual flow (Leopold and Maddock 1953). This equates to about 2,250 mg/l. After the Boysen, and about 90 miles downstream at Kane, WY, the concentration was about 1,000 mg/l for the same discharge (Akashi 1988). Concentration for the South Fork at the mean annual flow of 7,000 cfs is about 10 mg/l. On the White River in Washington, below the active Emmons glacier on Mt. Rainier, concentrations varied from 530 to 17,200 ppm[1] (Fahnestock 1963). These two examples are from drainage basins with considerable sediment yields or potential for in-channel erosion. A more comparable basin to the South Fork with available data is the Yampa in Colorado and Wyoming. Here, concentrations were between 50 and 250 mg/l at bankfull discharges (Andrews 1978). The higher values are for lower-elevation, larger streams such as the Yampa and Little Snake Rivers. The previous examples are convenient, for they have comparable data in terms of units and discharge frequency and I have visited them. My general impression, based on the thickness and texture of the flood plain deposits, is that the pre-dam South Fork carried less suspended sediment than these other streams, including the Yampa. More on the nature of the South Fork flood plain will be discussed in the vegetation section.

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[1] The units ppm and mg/l are interchangeable up to about 7,000 mg/l (Richards 1982), after which the increased density of the mixture becomes more significant.

There are many large tributaries above Palisades which could contribute sediment, but the tributaries below Palisades are small. Jackson Lake Dam has some effect on flows, but little effect on sediment regime because the dam only enlarged the existing natural Jackson Lake. Since storage began in Palisades Reservoir, much of the suspended sediment settles out and the dam releases are quite clear. There are two sources for suspended sediment: wash load from hill slopes and entrained sediment from eroded channel boundaries.

The shapes and separation of the discharge and concentration curves over time (Figure 7b) indicate a stream with an uninterrupted sediment supply throughout a flood (Williams 1989). The upward curve of the line in Figure 7c means that concentration increases with increasing discharge. Most of the sediment probably comes from in-channel erosion, with the South Fork itself being the primary source. Although not shown, there are some relatively high (20 to 100 mg/l) concentrations at low flows. Small inputs from tributaries or hill slopes can raise the concentration during low flows. Be mindful that these interpretations are based on sparse data, and do not represent natural, pre-dam conditions.

The natural, pre-dam suspended sediment characteristics are difficult to reconstruct from the data, but a gross characterization is possible. By combining the work of Vanoni (1941, 1946), Vanoni and Nomicos (1960), the sediment data at Heise, hydraulic geometry, aerial photography flown during natural flows, and field observations, the suspended sediment regime can be approximated. The basis for this analysis is the comparison of flow resistance of the clear-water dam releases with the pre-dam, sediment-laden condition at the Irwin station.

Aerial photography flown during and after a flood in 1951 indicate opaque, sediment-rich flows at 13,700 cfs. At 7,410 cfs, the water is clear, and bottom features are discernable. The post-dam South Fork is still opaque at higher flows (above 17,000 cfs in my experience), but recall that the measured maximum is quite low: 150 mg/l. One can be reasonably certain that concentrations were higher before the dam at Irwin. The following analyisis of flow resistance gives a probable upper limit on what the natural concentration was.

Flow resistance or roughness is made up of 4 components: skin, form, and spill resistances, and viscosity. Skin resistance is due to the texture of bed particles. Channel bends and bed features such as dunes and bars contribute to form resistance. Spill resistance is related to sudden reductions in velocity near obstructions, which are typically local and more important in "white water" situations. Viscosity changes with temperature and suspended sediment concentration. When viscosity effects are of interest, slope must be constant and these other types of resistance must controlled for. Other analysis shows no noticeable change in these factors in the reach at the Irwin station (Merigliano 1994).

Velocity for a given discharge increases with greater suspended sediment concentration. This may be counter-intuitive, but the dampening of turbulence increases the mean velocity (Vanoni 1941; Vanoni 1946; Vanoni and Nomicos 1960). As with this study, most stream-flow data uses mean velocity. For example, velocity increases for sediment-laden water compared to clear are between 4 and 11% for modest concentrations ranging from 1,200 to 3,300 mg/l (Vanoni 1941, 1946). Friction factors are another metric for assessing flow resistance, and it decreases with less resistance. Vanoni and Nomicos (1960) found a 5 to 28% decrease in the Darcy-Weisbach friction factor (**F**) compared to clear water with corresponding concentrations of 3,640 and 8,080 mg/l. **F** is proportional to depth/velocity$^2$ if slope is held constant (Richards 1973). With this basic information in mind, the velocity- and friction-factor relations to discharge are shown in Figure 8 and 9.

The difference in slopes for the velocity and discharge relations is small but statistically significant ($p = 0.0271$, two-tailed, single model test for coincidence). I used only the higher discharges because suspended sediment is quite low below 15,000 cfs for the river in general. What is especially interesting is that the post-dam slope is higher, where we would expect it to be lower if sediment concentration effects were dominant. One explanation for this is the higher hydraulic head with reservoir storage. Jacobson (personal communication, 1992) noticed higher velocities for low flows when storage was high, and lower velocities for the same discharges with low storage. I tested for this using multiple regression but found no effect. The same test at high discharges is not possible, for low storage does not occur during high discharges.

The friction factor relation (Figure 9) shows consistent roughness characteristics for the higher discharges, which is consistent with the very small shift shown in Figure 8. The friction factor for some low flows is much less than would be expected if the pre-dam range was extended to include these very low discharges. Anchor ice may be a factor, but I excluded ice-effects from the data if the notes showed presence of ice. Otherwise, I cannot explain these anomalies.

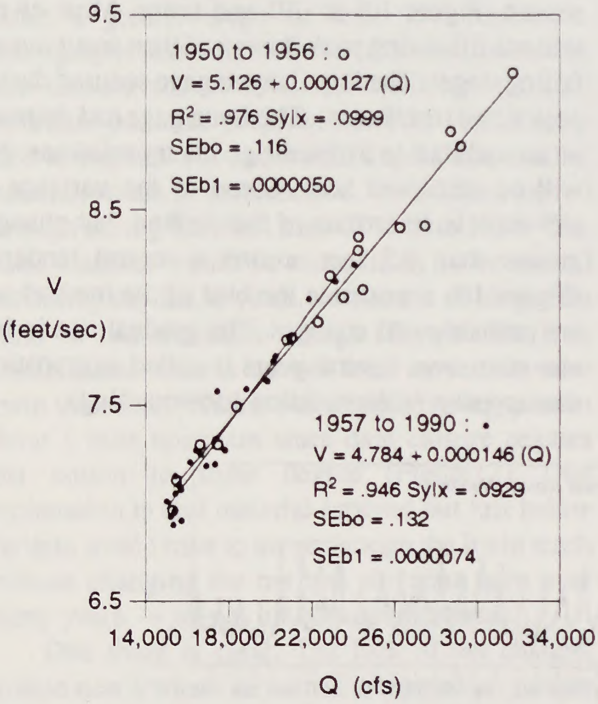


Figure 8. Relation of velocity to discharge, South Fork near Irwin, Idaho, for pre- and post-and Palisades Dam periods. V = velocity, Q = discharge, $R^2$ = coefficient of determination, Sylx = standard error of estimate, SEbo = standard error of Y intercept, SEb1 = standard error of slope.

Based on the roughness characteristics and the work of Vanoni and Nomicos, suspended sediment concentrations were probably mostly below 8,000 mg/l. Amounts above this would likely change the roughness characteristics at high flows in a noticeable way as explained earlier. Leopold and Maddock (1953) measured definite shifts in the velocity-to-discharge relation on southwestern rivers, and they attributed the shift to dampened turbulence from increased suspended loads, which they measured during the shifts.

There is no direct data for the other part of the sediment load — bedload, but some understanding of bedload dynamics is gained by looking at changes in channel dimensions, roughness, and slope over time and different discharges, Like suspended load, bed load is trapped in Palisades Reservoir, except all of it is retained. These dynamics are more conveniently treated in the following section on changes in river form and process since dam closure.

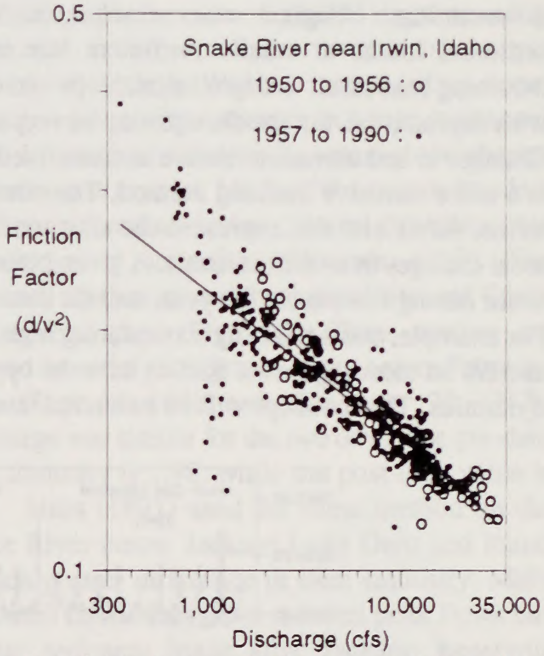


Figure 9. Friction factor and discharge relations, South Fork near Irwin, Idaho for pre-and post-Palisades Dam periods. d = depth, v = velocity.

## River form and process through time

Streams are open systems and adjust their size, shape and energy patterns to inputs of sediment, water, and gravity. There are 8 factors involved in streams and they are water, sediment load, sediment size, slope, width, depth, velocity, and resistance. A change in one or more of these factors results in mutual adjustment of the others. With a change in the magnitude and timing of water flows and sediment load and size — the system inputs — we would expect a change in the South Fork channelbelow the dam. The following is a summary of these changes.

Channel slope tends to be in equillibrium with sediment load and size. Streams in this balanced situation are called graded (Mackin 1948). A perfect balance is probably non-existent, but the concept of stream beds eroding to a slope that is just steep enough to move the usual sediment load is a good reference point. Usual is a key word, for sediment loads and movement are very uneven in time and space. Therefore, it is good to look at sediment dynamics over a range of temporal and spatial scales.

Four key terms are related to sediment dynamics and slope. A gradual rise in bed elevation over several years over appreciable channel distances is aggradation. The opposite is degradation, or downcutting. Higher water discharges, lower sediment loads, or smaller sediment size of the incoming load result in degradation. Slope is reduced with degradation, but the change may be very small. Changes in bed elevation relative to some fixed level is a more sensitive tracking method. The other two terms, scour and fill, represent the short-term and local changes in sediment levels. A given place may scour during one part of the year, and fill thereafter. For example, pools typically scour during high flows and fill on receding flows. Riffles have the opposite dynamics. This concept will be extended later and is very important to vegetation establishment and survival.

Bedload dynamics can be inferred from channel bed changes over time at measured cross sections — in this case gaging stations. Figure 10 shows bed elevation dynamics at three gaging stations. The Alpine station is above the reservoir and serves as a control. The Irwin and Heise stations are about 1.4 river miles (RM) and 42 RM below Palisades Dam, respectively.

The cyclic rise and fall of the bed with each season (Figure 10) is fill and scour. Most of the stations fill during peak flows and then scour during falling stages. The Dry Canyon gage scoured during peak flows (not shown). The Lyon gage had dramatic scour and shift in hydraulic geometry relations; this will be discussed later. Some of the variance in elevation is an artifact of the method, but changes greater than 0.2 feet around a central tendency (Figure 10) are outside the bias of the method and are probably real changes. The gradual rise in bed elevation over several years is called aggradation; the opposite is degradation (downcutting).

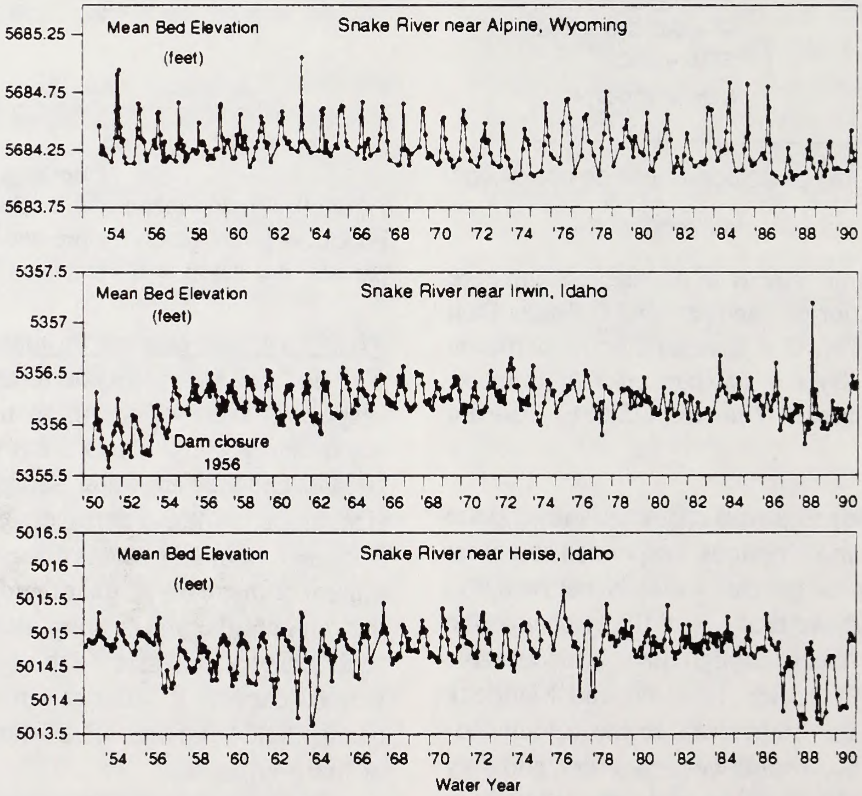


Figure 10. Channel bed elevation dynamics at Snake River gaging stations. Cross-section locations are consistent for each gage throughout the periods shown.

In respect to channel adjustment to damming, the Irwin station is the most interesting. With the limited bed load infusion from tributaries, and flows competent (strong) enough to move bed material, the channel could erode. The channel may widen through bank erosion, or the bed can degrade. Except for some aggradation from 1950 to 1956, there is no obvious trend. This rise in bed elevation may have been due to sediment washing in from dam construction activities. The velocity-to-discharge relation changed gradually during this time, reflecting either a greater slope or less flow resistance. Photographs taken at the Irwin cross-section during dam closure and in 1992 show similar sizes of dominant particles (Figure 11). This similarity is hard to explain, for one would expect that smaller material, which is more mobile, would have moved through during the short time of 1950 to 1956. This same material would be more likely to be moved out during the last 36 years, but there is no long-term trend in bed-elevation change (Figure 10). It is possible that there is no bed load movement near Irwin since dam closure, but the definite degradation about 1 mile upstream since dam closure negates this notion to some degree (Figure12). One explanation is that material scoured out just below the dam would have to move through the Irwin reach without changing the net bed elevation here over many years — this is an odd circumstance.

One thing is clear. The lack of net channel erosion near Irwin is very small compared to changes below other studied rivers below dams. Beds within a few miles of a dam typically degrade on the order of feet or meters 10 years after dam closure (Williams and Wolman 1984).

The channel erosion near Sheep Creek 0.5 miles below the dam (Figure12) will slowly migrate downstream. The maximum rate under present management is about 200 feet per year.

The previous analysis involved bed elevation changes at a few places over nearly continuous time. The gaging stations are good places to look for these changes, because the banks at these places appear more stable or less erodible. Channel migration is negligible at these stations, especially at Irwin. Therefore, erosion is more apt to occur in the vertical direction and if there was general channel bed erosion, it would likely show up at these stations.

The first 8 river-miles of channel below Palisades Dam is nearly straight and entrenched, leaving terraces 10 and 30-feet high above the river, perhaps leaving one with the impression that the channel was artificially channelized. The Irwin station is within the entrenched reach, and the previous analysis shows that degradation from damming is not the cause of entrenchment. Neither is channelization. Photographs from 1911 show this reach to be similar to present conditions. The Hayden survey description also portrays a similar scene (Hayden 1879).

Sinuosity is the ratio of channel length to valley length, but it also represents the ratio of channel slope to valley slope. With a constant valley slope, a change in sinuosity indicates a change in channel slope. I measured sinuosity to assess slope change for the river in general. Much of the river is braided, and I considered all active channel branches: this is called total sinuosity (Richards 1982). The measured reaches extend from near Pritchard Creek to the Heise gage (Figure 1). These reaches are covered by aerial photography taken before Palisades Dam (Sept. 10, 1941) and after (Apr. 22, 1987). Discharge was similar for the two days. The pre-dam total sinuosity is 1.98, while the post-dam value is 2.02. Mills (1991) used the same method on the Snake River below Jackson Lake Dam and found a much greater difference in total sinuosity. Mills attributed the difference to reduced peak flows but similar sediment loads after Jackson Reservoir management changed in the 1950's.

An interesting pattern that these numbers do not reflect is that the post-dam river anabranches (sub-channels) are shorter and more numerous, and a few of the larger anabranches have been cut off since the 1960's. This is probably due to the lack of channel avulsions which typically occur during large peak flows (Leopold et al. 1964; Stewart and LaMarche 1967; Hickin and Sichingabula 1988; Schumann 1989; Brizga and Finlayson 1990). The islands created since dam closure are smaller than those formed under the natural flow regime. This difference has important implications for riparian vegetation establishment, which is discussed later.

Of all factors, width is usually the most responsive to changes in sediment or water regimes (Leopold and Wolman 1957; Andrews 1982). The width:discharge relation can shift in either direction; channels may become wider or narrower for a given

Figure 11a. November 8, 1956. Flow is 19 cfs. P. Merritt USDI BOR

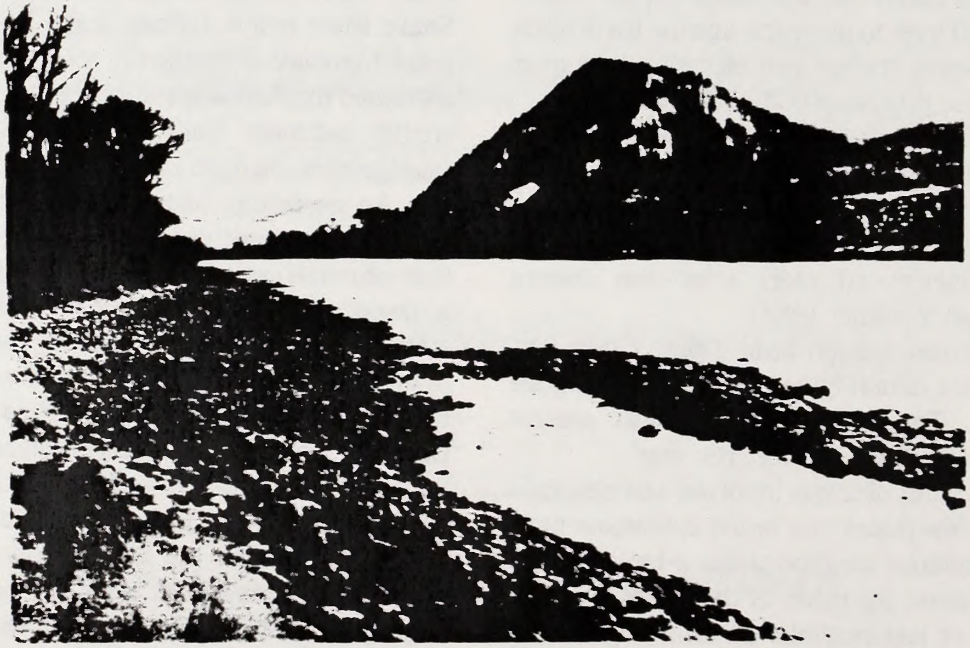


Figure 11b. November 20, 1992. Flow is 1,220 cfs. M. Merigliano U. of Montana

Figure 11. South Fork at the Irwin gaging station, with Palisades Dam in the far-distance. Palisades Dam closed November 3, 1956. Note cobble-dominated bed material in both scenes.

Figure 12a. November 8, 1992. Flow is 19 cfs at Irwin gage. P. Merritt USDI BOR

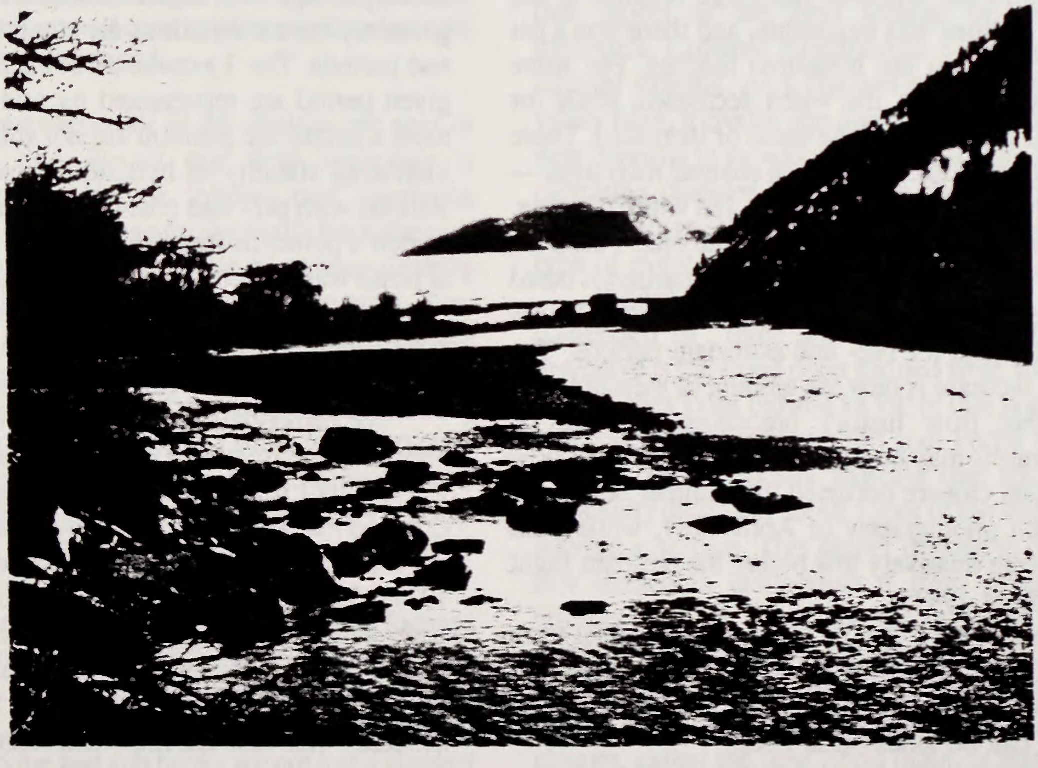


Figure 12b. November 20, 1992. Flow is 1,220 cfs at Irwin gage. M. Merigliano U. of Montana

Figure 12. South Fork above Sheep Creek confluence, with Palisades Dam in the middle-distance. In 12b, note increased prominence of boulders despite higher discharge, indicating local downcutting.

discharge. The direction depends on the relative erodibility of bank and bed material, and the change in sediment and water regimes caused by damming or climate change.

Given the above, it follows that channels below dams do not always erode. In cases where peak flows are much reduced and tributaries entering below the dam inject sediment, width may decrease, slope may increase, or both. Even if conditions lend themselves to net erosion, the direction of width change is difficult to predict (Petts 1979; Williams and Wolman 1984).

With the absence of bed degradation, some bank erosion is expected that would result in a general increased width. However, peak flows are much reduced since dam closure (Figure 5b), so the width may have narrowed in response to this change.

Actually, the above factors may be working in combination and compensate each other. Also, at some distance from the dam, in-channel erosion and minor sediment additions from tributaries may be in balance with the present discharge regime.

In comparing post-dam to pre-dam periods, the changes in the width-to-discharge relation at the gaging stations was negligible, and there was a net 4% increase on the measured reaches. For some individual reaches, the width decreased, while for others it either stayed the same or increased. There was poor correlation between channel migration — which involves bank erosion — and width increase. The measured reaches are the same ones I used for comparing sinuosity. The width comparison is based on water- surface area for a constant channel length and discharge for pre- and post-dam periods. The net 4% increase is near the amount of measurement error, but flow history preceding the time of photography may be a factor. The largest peak flow since dam closure occurred the summer before the post-dam photography of April 1987, while peak flows were relatively low before the pre-dam flight (September 1941).

So far, the 8 factors involved in channel form and process have been presented individually, but by looking at hydraulic geometry, many of these factors can be assessed at once.

Strictly defined, hydraulic geometry is the interrelations between width, depth, velocity, and suspended load, and how these vary with discharge (Leopold and Maddock 1953). Perhaps, hydraulic geometry is the "pulse" of a river, because it concisely integrates form and process. A short summary of the South Fork's geometry follows, concentrating on how width, depth and velocity are related to discharge for 5 gaging stations. The Alpine, Irwin, and Heise station records pre- and post-date the Palisades Dam, and the geometry relations for each of these stations during these times are separated and compared. The Lyon and Dry Canyon stations had short records, but their locations represent reaches supporting extensive cottonwood forests. The basic hydraulic geometry equations are:

$$w = aQ^{b} \qquad d = cQ^{f} \qquad v = kQ^{m}$$

where $w$ = water surface width, $d$ = mean depth, $v$ = mean velocity, $Q$ = discharge, and $a, b, c, f, k$, and $m$ are model parameters which are estimated from discharge measurement data.

The exponents $b$, $f$, and $m$ are slope coefficients and are important for interpretation of channel process and morphology. Because $Q = w \times d \times v$, $b + f + m = 1$. This summation allows us to plot the slope coefficients on a ternary diagram for easy comparison. Figure 13 shows the South Fork geometry for the 5 stations for comparable stations and periods. The 3 exponents of each station for a given period are represented by one symbol. For most stations, the position did not shift very much, indicating stability of hydraulic factors. Of the 3 stations with pre- and post-dam periods, the Heise station's points shifted the most. The cross-section at Heise was moved several times; the 1953 to1990 period had a consistent location, as did the 1934 to 1936 period. The earlier period is shown to compare with the Dry Canyon gage for the same period.

The dashed-line subdivisions in Figure 13 allow interpretation of stream channel behavior (Rhodes 1977). Only the 3 main subdivisions are shown. Considering streams world-wide, stations can plot anywhere within the diagram (Rhodes 1977; Park 1977). Stations plotting to the right of $b = f$ have steep banks. The South Fork in general has steep banks, as represented by these stations. In the diagram's vertical direction, the ratio of $m/f$ increases. This ratio has important sediment transport implications, for competence (the ability to move sediment particle of a given size) increases with this ratio. For stations plotting above the $m = f$ line, velocity increases faster than depth as

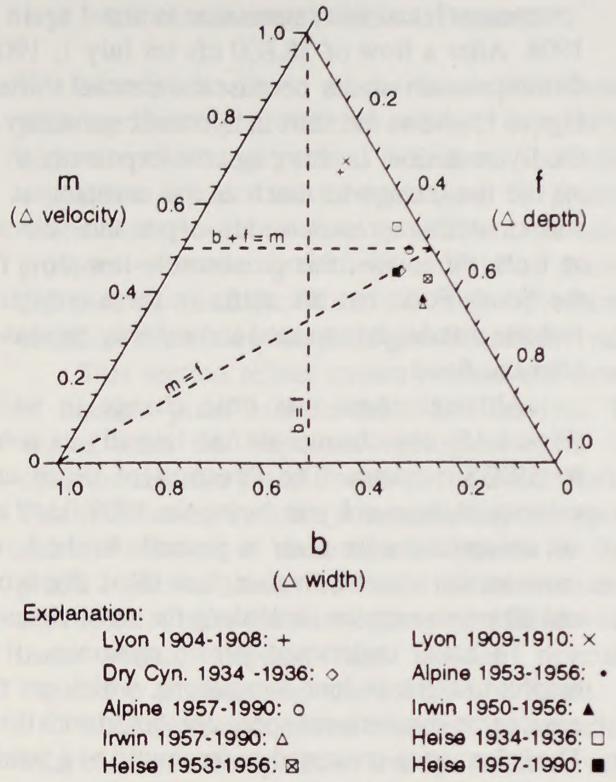


Figure 13. Ternary plot of South Fork hydraulic geometry exponents. All cross-section locations are consistent for a given station and period.

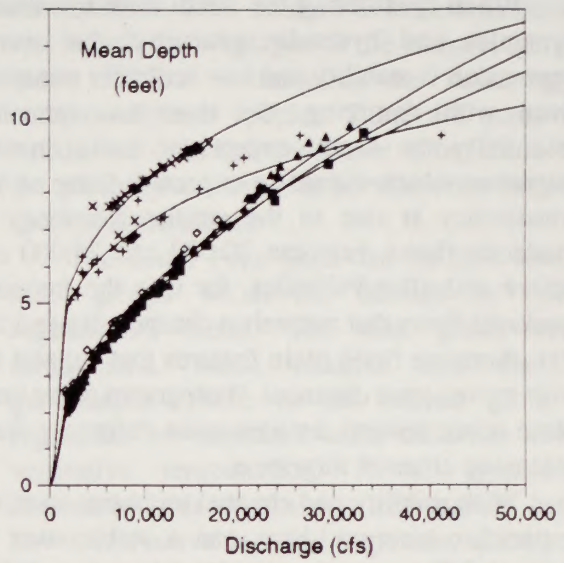


Figure 14. Depth and discharge relations for South Fork gaging stations. Symbols as in Figure 13. The Lyon station curves stand-out from the other stations.

discharge increases. All of the stations are near or above this line. Recall that flow resistance is proportional to $d/v^2$. It follows that roughness decreases with discharge for the South Fork stations. These relations should be kept in mind when thinking about floods. Because of the decreasing flow resistance as flows increase, depths increase more slowly than discharge (Figure 14). The curves in Figure 14 extend beyond the data, and the channel at the Irwin, Dry Canyon, and Heise gage locations are somewhat confined. Thus, depths at the extreme flows could be even lower for many river reaches because the width would increase greatly as the flow expands over the flood plain.

Although most of the discussion has focused on in-channel processes, riparian vegetation grows on the flood plain. But on alluvial streams like the South Fork, the flood plain is not merely a flooded surface, and the bed and banks are not just a channel boundary. These distinctions make communication easier, but in reality, the transition from channel to flood plain is a gradual and dynamic one. This changing transition is very important to riparian vegetation establishment and survival, and although a physical process, it is easier to illustrate and discuss this aspect in the next section on vegetation dynamics. Channel migration is a key process in alluvial streams. As a channel migrates across the valley floor, it erodes into one bank while depositing new deposits in its wake. The actual time scale and migration distance varies from river-to river, and defining this scale was one part of this study. What type of event causes the transition was another.

Recent alluvium along the South Fork is comprised of three general deposits. The most extensive is the flood plain formed from about 1850 to Palisades Dam closure in 1956; this is called the old flood plain. Cottonwood root collar locations within stream deposits indicate that the channel apparently down-cut about 1 foot in the mid-1800's, leaving a terrace. This higher deposit is called the low terrace to distinguish it from much higher terraces that are thousands of years old (Walker 1964). When overbank deposits are included, the low terrace is about 2 feet higher than the old flood plain. Alluvium deposited since Palisades Dam closure, called the new flood plain, is about 2 feet lower than the old flood plain. The new flood plain is lower in elevation because of reduced flood stages rather than downcutting. The relation between deposit elevation relative to flood stages is discussed later.

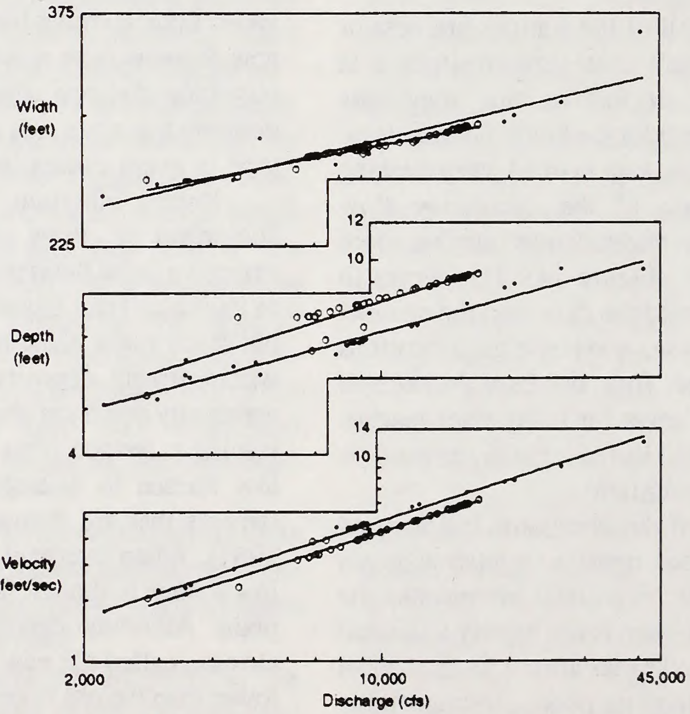
When considering the South Fork's sediment dynamics and hydraulic geometry, the overall impression is stability and low sediment transport. Even with damming, the river has remained essentially the same, except for some channel migration which should be expected. Some of this consistency is due to the similar frequency of moderate flows, between 20,000 and 25,000 cfs, before and after Palisades, for it is the frequent, moderate flows that maintain a channels dimensions. Yet, there are flood plain features that suggest the river moves great distances. Photographs of the same place taken several decades apart definitely show extensive channel migration.

With stability and channel migration in mind, a paradox emerges. How can a stable river be dynamic? There is a threshold to this system, below which the channel moves very little. Above this threshold, there are large changes. To begin to illustrate this, we return to the Lyon gaging station.

Stable channels allows for easier water measurement, because a shifting channel must be constantly corrected for. In 1903, The US Geological Survey described the channel bed at Lyon as being "permanent", and this impression is noted again in 1908. After a flow of 38,800 cfs on July 1, 1909, this impression erodes because the channel shifted. Figure 15 shows the shift in hydraulic geometry at the Lyon station. In this case, the exponents (*b, f, m*) did not change as much as the constants *a, c,* and *k,* which represent width, depth and velocity at 1 cfs. Of course, this an absurdly-low flow for the South Fork, but the shifts in these constants indicate that depth increased and velocity decreased after the flood.

Although there was little change in width (Figure 15), the channel shifted laterally as noted by USGS workers. The direction of depth and velocity changes at Lyon during the 1909 flood are not universal for the river in general. As the Lyon cross-section scoured, another place filled. The scour and fill process repeats itself along the entire channel.

To better understand stream dynamics, it is helpful to think in four dimensions, which are the usual three-dimensional space combined with time. The information presented so far should be a primer on this concept so that vegetation dynamics, a primary concern, is better understood.



Explanation: 23 May 1904 to 1 April 1909: • 1 August 1909 to 26 September 1910: ∘
Large flood (38,800 cfs, 10-year recurrence) on 1 July 1909

Figure 15. Hydraulic geometry, South Fork Snake River near Lyon, Idaho.

## RIPARIAN VEGETATION DYNAMICS

Most plants found on the South Fork flood plain are intricately related to sediment deposition and water discharge patterns over time. Sediment deposition provides the substrate (soil) for plants, while water levels relative to sediment surfaces provides water for growth of established plants and seed germination. Water discharge influences sediment deposition and plant growth and survival.

This section relates stream process and form to riparian plant establishment and survival. It begins with the important ecological traits of common riparian plants found on the South Fork. This is followed by basic stream deposit concepts, and the relation of these stream deposits to the plants found on them. From this information and my results, I infer the flow regime associated with these stream deposits and existing riparian vegetation emphasizing the cottonwood forest.

With these relations as a basis, I then predict what the forest composition and age structure will look like 50 and 100 years from now. Assuming that the river behavior will be similar in the future under comparable discharges, I give the rationale for why periodic, higher flows are important in maintaining this ecosystem.

The final part of this section is a discussion of grazing influences on South Fork riparian vegetation. The discussion incorporates my observations, direct experience of others, and pertinent literature.

### Ecology of common riparian species

The natural occurrence of a given species is largely a result of its physiological traits, site conditions, interactions with other species, (including animals, fungi, etc.) and disturbance. The following is a sketch of these aspects for common plant species found on the South Fork riparian zone. The riparian zone is land outside the channel that is influenced by stream water. This influence includes erosion and deposition, water availability to plants, temperature, and nutrients. For alluvial rivers like the South Fork, the riparian zone is essentially the flood plain and recent, low terraces.

Physiological traits determine the adaptations and behavior of plants in relation to their environment. This relation is called autecology, and it includes all stages of life history, including seeds. Table 1 summarizes the autecology of common riparian species. There are many traits besides the ones listed in Table 1, but those listed are probably the most important ones related to species distributions.

The South Fork flora can be split into two main groups which are defined by primary regeneration mode. The first group require unvegetated, moist mineral soil for seed germination. Those in the second group can regenerate on vegetated areas either by seed or vegetative reproduction. If all species are considered, this dichotomy intergrades, but for now it is a convenient and important split because those species in the first group require disturbance for continued existence, while disturbance is not as important for the second group. Superimposed on these two groups is shade tolerance. There is some plasticity in this trait within a species, but by observing how various species decrease in coverage with increasing shade, relative shade tolerance can be estimated if other factors such as soil moisture are accounted for. These concepts are shown schematically in Figure 16.

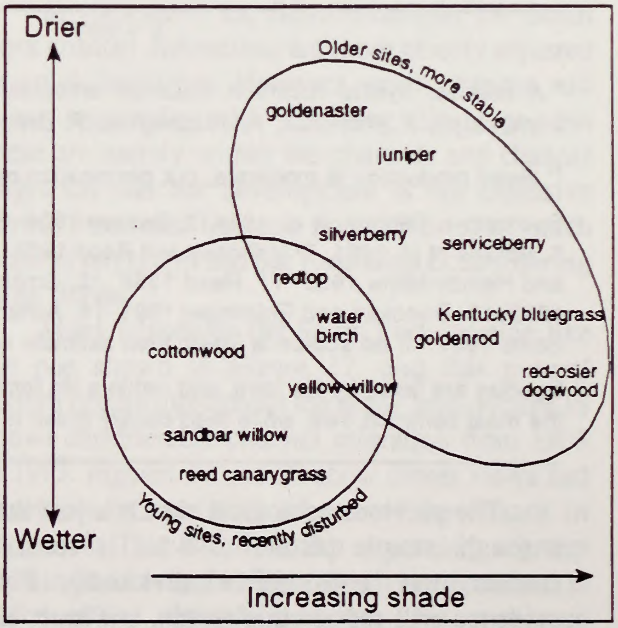


Figure 16. Situations where common riparian plant species usually regenerate.

Table 1. Autecology of common riparian plant species found on the South Fork.

| | Regeneration Strategy | | | | |
|---|---|---|---|---|---|
| | Sexual | Asexual (Vegetative) | | Drought | Shade |
| Species | (Seed production) | Stems | Roots or rhizomes | Tolerance | Tolerance |
| *Populus angustifolia* (narrowleaf cottonwood)* | VH (1,2) | M (3) | M (3) | VL (4-10) | VL (4,11) |
| *Betula occidentalis* (water birch) | VH | M | - | L (12,13) | M |
| *Juniperus scopulorum* (Rocky Mountain juniper) | H | M | - | M | H |
| *Salix exigua* (sandbar willow) | H (14) | M (14) | VH (14) | VL (15) | VL |
| *Elaeagnus commutata* (silverberry) | M | M | VH | VL | L |
| *Cornus stolonifera* (red-osier dogwood)** | L (16) | M | VH | VL | VH (16,17) |
| *Amelanchier alnifolia* (western serviceberry) | M | M | - | L | M |
| *Salix lutea* (yellow willow) | M | M | VL | VL | VL |
| *Crataegus douglasii* (hawthorn) | M | VL | - | M | M |
| *Solidago canadensis* (Canada goldenrod) | M | VL | VH | M | M |
| *Glycyrrhiza lepidota* (licorice root) | M | VL | VH | M | M |
| *Heterotheca villosa* (goldenaster) | M | - | - | VH | VL |
| *Poa pratensis* (Kentucky bluegrass) | L | M | VH | M | M |
| *Agrostis stolonifera* var. *stolonifera* (redtop) | M | M | VH | M | M |
| *Agropyron smithii* (western wheatgrass) | L | M | VH | M | M |
| *Phalaris arundinacea* (reed canary grass) | M (18) | L | VH (18) | VL | VL |

V = very M = moderate L = low H = high

* *A Populus* hybrid occurs in moderate amounts; sources below include other cottonwood species (e.g., *Populus trichocarpa, P. fremontii, P. balsamifera, P. deltoides*) in addition to *P. angustifolia*.

** Seed production is moderate, but germination percent can be low due to seed coat dormancy.

Sources: 1. Fenner, et al. 1984 2. Bessey 1904 3. Schier and Campbell 1976 4. Moss 1938 5. Tyree et al. 1994 6. McGee et al. 1981 7. Mahoney and Rood 1992 8. Segelquist et al. 1993 9. Stromberg and Patten 1992 10. Rood and Heinze-Milne 1989 11. Read 1958 12. Smith et al. 1989 13. Sperry et al. 1993 14. Ottenbreit and Staniforth 1992 15. Donovan and Ehleringer 1991 16. Acharya et al. 1992 17. Sheppard and Pellett 1976 18. Apfelbaum and Sams 1987 If no source is listed, then estimate is based on personal observation.

Species are listed by life form, and within a life form, in descending order of areal extent. For example, cottonwood is the most common tree, while reed canary grass is the least common graminoid of those listed.

The previous ecological sketch is just that — a rough, simple picture of what is seen, with species only considered individually. Further evidence will refine this sketch, but most of the discussion will center on development of various plant communities over time on various sites.

Species with similar traits tend to grow together in communities which reflect their past history and local environment. Disturbance was very important in shaping South Fork vegetation, and succession, or plant community development after disturbance, will be a dominant theme of discussion because it is an important process in vegetation development.

### Stream deposits and vegetation

Sediment is not transported uniformly in time and space by streams, and the collective particles that come to rest are stream deposits or alluvium. Plants will colonize alluvium that is stable enough to allow survival, and situations include aquatic algae on rocks living only a few weeks to trees that live centuries in a complex of sediment ranging from cobbles to clay. The following discussion expands concepts from the previous section on the physical environment and relates it to patterns of vegetation observed on the South Fork, concentrating on non-aquatic plants.

Just as the sediment load is made up of two main constituents — bed load and suspended load, so are stream deposits. Stalled bed load makes up channel deposits, which are laterally accreted. Suspended sediment that settles on the existing flood plain forms overbank deposits, which are vertically accreted. South-Fork channel deposits are predominantly cobbles and pebbles, and overbank deposits are fine sand to clay.

With a very wide discharge range, there can be a continuum between channel, flood plain, and terrace, but a distinct break in process and morphology is related to the bankfull discharge (Wolman and Leopold 1957). On many streams, much of the flood plain's volume is channel deposits (Wolman and Leopold 1957) and this is the case for the South Fork. Terraces are old flood plains formed by the channel before degradation.

A third type of stream deposit is slack-water or eddy deposits. This material is suspended sediment that settles within the channel, below the bankfull stage. These deposits are less common than the other two, and on the South Fork, occur in some side channels (anabranches) just above their confluences with the main channel. After an anabranch is cut-off, overbank deposits can cover the eddy deposits during large floods. The downstream-end of intact bars often have thick, fine-textured deposits on them. This may be due to the influence of existing vegetation that slows down flows (Stromberg, et al. 1993) as well as channel geometry causing eddies. Patton and others (1979) and Rubin and others (1990) describe eddy or slack-water deposits.

The transition of an in-channel surface (such as a riffle or bar) to the flood plain is a critical one for establishment of riparian plants, and the moisture regime during this transition determines the establishment pattern of the earliest species. Further site modification from overbank deposits and a changing relation between river stage, discharge, and the original channel-deposit surface allow other species to invade. Biological interactions between the original species and invaders contribute to changes in species composition over time, or succession. Herbivory (grazing, browsing) also influences succession.

The development of a mid-channel bar typical of many braided rivers is shown in Figure 17. As the bar develops, more surface area emerges. This example is from a flume, which allows control and careful observation of processes that occur in real rivers. However, the initial channel dimensions in the flume were not in adjustment with the sediment and water mixture, and the rapid change is partly due to channel adjustment. One can imagine how the moist, bare surfaces of the emerging bar would be a suitable environment for the wind- and water-dispersed seeds of cottonwood, willow, and other early colonizers that require moist, bare mineral soil for germination and survival. Figures 18, 19, and 20 show the transition from incipient gravel bar to an island supporting mature cottonwoods.

In contrast to the flume example, the South Fork channel dimensions are more closely adjusted to usual discharges. However, small changes still occur seasonally with changing discharge, but these are mainly within the channel, and channel migration and bar development is not extensive during moderate, frequent flows. However, much channel migration and bar formation occurs during large floods.

Many islands on the South Fork develop like the one shown in Figure 17, and this general pattern occurs throughout the study area. Figure 18 shows considerable channel migration from 1908 to 1992. Figures 19 and 20 show closer views and development over time of one of the islands in Figure 18. This island, which is actually a group of islands, is near the Riley Ditch headgate and is called Riley Island complex for reference purposes.

The Riley Islands are unvegetated from 1908 to 1914, but support young vegetation in 1925

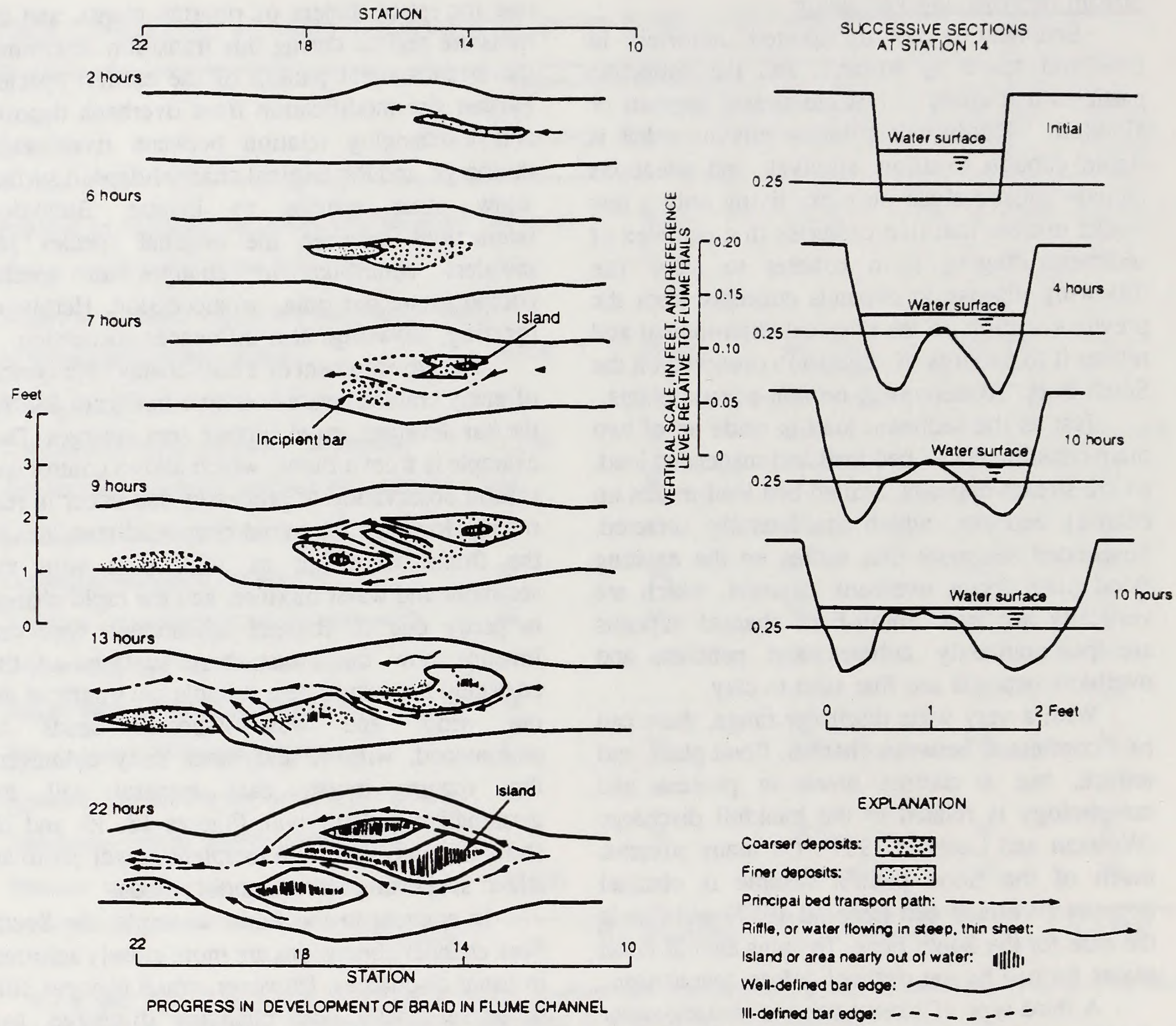


Figure 17. Sketches and cross-sections of a developing braid in flume-river. (From Leopold and Wolman 1957)

(Figures 18 and 19). Aerial views show the vegetation pattern from 1941 to 1987 (Figure 20); cottonwoods dominate most of the bar. The cottonwood forest shows different textures, or signatures, on the aerial views. The differences are due to either disparate tree ages, site quality, or both. The age variance within a uniform patch (Figure 20e) is due to aging errors that yield younger-than-true ages, and seedling establishment the first few years after bar emergence and before the island is fully vegetated. The method section has more detail on aging. Vegetation established on the developing island sometime between 1914 and 1925 (Figures 18a and 19a). The portion that was bare in 1914 supports cottonwoods aged between 62 and 73 years old in 1992. Some of the island supporting shrubs and small trees in 1908 and 1914 (Figures 18a, 19a) had already been eroded by 1941, but on its remainder in 1992, cottonwood ages agree with the stage they were in during 1914 (Figure 20e).

The Riley island complex is the best reference area for cottonwood aging and bar development because photography documents its entire development, and two scenes in particular (Figure 19a,19b) clearly show a crucial period of bar development — plant colonization. There are other areas that have photo coverage nearly as good as the Riley Islands, and I augmented the aging information gained there in a similar manner with

Figure 18a. circa 1908-1911. (W. B. Heroy #28, U.S. Geological Survey)

Figure 18b. June 18, 1992. Flow is 11,340 cfs (M. Merigliano, U. of Montana)

Figure 18. South Fork below Clark hill. The unvegetated bars in left-center in (a) are the developing Riley Islands which are shown in (b) and Figures 19 and 20. The shrubby island in (a) referred to in the text is right of center. This general area shows in Plate 17.

land-based and aerial photography. I used aerial photography from 1951, 1960, 1977, 1984, and 1993, in addition to the 1941 and 1987 flights to augment and corroborate aging data in the study area.

Cottonwood and willow are the first woody species to colonize emerging bar surfaces (Ware and Penfound 1949; Everitt 1968; Wilson 1970; Nanson and Beach 1977; Noble 1979; Barnes 1985; Bradley and Smith 1986; Walker et al. 1986; Baker 1990; Stromberg et al. 1993). Bar emergence can be a result of aggrading surfaces, degrading of adjacent channels, or both (Leopold and Wolman 1957; Fahnestock 1963; Church

Figure 19a. 1914. (R. W. Stone #693, U. S. Geological Survey)

Figure 19b. September 10, 1925. Flow is 5950 cfs. (W. C. Alden #1606, U. S. Geological Survey)

Figure 19c. July 13, 1992. Flow is 10,965 cfs. (M. Merigliano, U. of Montana)

Figure 19. Development of island complex near the Riley Ditch head gate (Riley Islands complex).

Figure 20a. 1941

Figure 20b. 1960

Figure 20c. 1977

Figure 20d. 1987

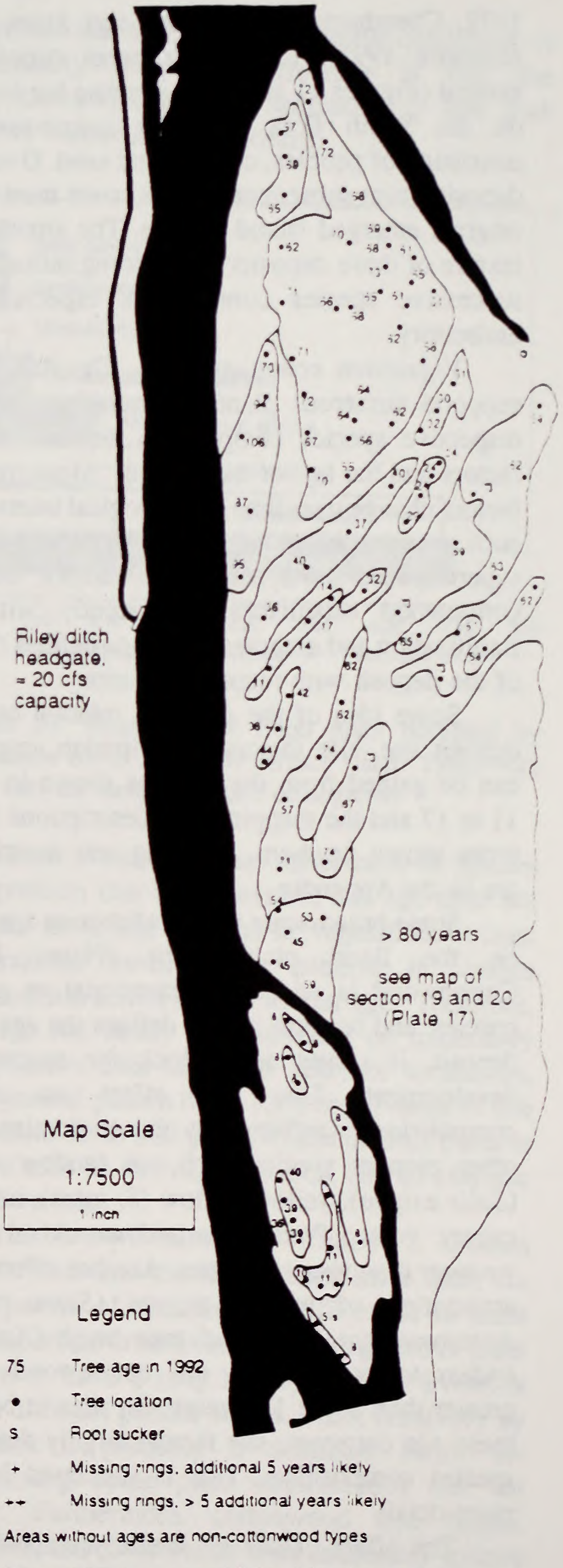


Figure 20e. Age map of Riley Islands complex.

Figure 20. Vegetation on and near Riley Islands complex, and corresponding age map. Photography date and discharges are: September 10, 1941, 6,080 cfs; August 2, 1960, 14,500 cfs; September 6, 1977, 4,880 cfs; April 22, 1987, 6420 cfs. Drawn line in Figure 20d. marks a plot transect shown in Figure 26. Cottonwood is the dominant vegetation and ar the aged trees.

1972; Cheetham 1979; Church and Jones 1982; Ashmore 1991). Like the channel deposits in general (Figures 11 and 12), emerging bar surfaces on the South Fork are very coarse-textured, consisting of pebbles, cobbles and sand. Overbank deposits from subsequent floods cover most of the original emerged island surface. The amount and texture of these deposits has a strong influence on successive species composition, especially the understory.

*Vegetation communities* — The flood plain supports numerous plant communities, and their respective species composition depends on site factors and the age of the deposit. Moreover, site factors change over time, so biological interactions such as competition, facilitation, herbivory, etc. are superimposed on dynamic site factors. Because cottonwood establishes concurrently with bar stabilization and emergence, its age defines the age of the deposit with respect to plants.

Some idea of the complex relation between deposit age, site factors, and riparian vegetation can be gained from the patterns shown in Plates 11 to 17 and the mapping unit descriptions for the types shown on them. Mapping unit descriptions are in the Appendix.

Some broad-scale effects of deposit age show on the flood plain maps (Plates 11-17). Cottonwood is an early-successional or pioneer species, and because its age defines the age of the deposit, it serves as a clock for successional development. One age effect on species composition is reflected by the co-dominance of other pioneer species such as sandbar willow (*Salix exigua*), yellow willow (*S. lutea*), and reed canary grass (*Phalaris arundinacea*) on sites younger than about 30 years. Another effect is the association of upland grasses (*Stipa comata, Agropyron spicatum*) and sage brush (*Artemisia tridentata*) with some old cottonwood stands greater than about 125 years. On sites in between these age extremes, site factors largely determine species composition. This is discussed later in more detail.

The effect of site on species composition is not readily apparent on the maps (Plates 11 to 17), but there are patterns that suggest this effect. On young islands, reed canary grass dominates the wettest, coarse-textured sites. (the RP mapping unit near young (1 to 20 years old) cottonwoods represents this; see appendix for descriptions). Cottonwood, yellow willow, and sandbar willow dominate the higher, drier sites on young islands. These three species colonize similar sites via seed, but sandbar willow invades the lower areas vegetatively, while cottonwood and yellow willow do not. Ottenbreit and Staniforth (1992) describe clonal expansion of sandbar willow. Although I found very little clonal expansion of cottonwood on young sites, Nanson and Beach (1977) found it quite common with balsam poplar (*Populus balsamifera)* in northeastern British Columbia.

On very wet sites with fine deposits, mannagrass (*Glyceria grandis*), cattail (*Typha latifolia*), common forget-me-not (*Myosotis scorpioides*), common spike-rush (*Eleocharis palustris*) softstem bulrush (*Scirpus validus*), water parsnip (*Sium suave*), and water speedwell (*Veronica anagallis-aquatica*) become more common. These latter species occur on old and young sites, and apparently persist for several decades if the site does not change. Although not mapped separately, communities with these species mostly occur in wetter areas in the RP type near old (greater than 80 years) cottonwood stands; standing water often exists with discharges above 15,000 cfs.

The mixed-riparian shrub (MS) type is strongly associated with fine, deep, deposits in old anabranches. This mapping unit contains a variety of plant communities, but the dominant species can regenerate vegetatively (sprout) without disturbance such as beaver cutting. Important species include red-osier dogwood, silverberry, water birch, and sandbar willow. Cottonwood is extremely rare; these sites were probably too wet during initial colonization or under water during cottonwood seed shed. As the surface raises with subsequent overbank deposits, the site becomes more conducive to cottonwood, except competition from existing plants and impeding litter precludes cottonwood establishment. However, yellow willow occurs and can be quite common, but its growth form does not suggest vegetative reproduction. I don't know why yellow willow is more common than cottonwood on these sites; these two species have similar densities on young islands. Communities of the MS mapping unit are found on a broad range of site ages, but are rare on sites younger than 20 years. Site age for anabranches are inferred from adjacent flood plain areas of known age and aerial photography.

There is also a complex of mesic graminoid and forb communities on the flood plain. Their pattern was too fine to map at the scales used, but they occur in old anabranches not dominated by shrubs and on some swales and ridges between cottonwood patches. In general, the RP mapping unit amongst flood plain areas greater than 20 years support these communities. These communities can intergrade with reed canary grass and the wet-site species already described.

*The flood plain mosaic* — The proportion of the flood plain occupied by vegetation mapping units and surface water are shown in Figure 21. The mean proportions and standard errors are derived from 10 flood-plain sampling units which are about 260 acres each (Plates 1, 11 to 17).

A given sampling unit includes recent alluvium and surface water at a flow of 6,000 cfs. Recent alluvium includes the low terrace, old flood plain and new flood plain defined on page 16. I mapped the reed canary grass community and the drier, mesic riparian graminoid/forb community complex separately on larger scale maps, so calculation of their respective proportions was possible.

Although cottonwood forest dominates the flood plain, there are interesting species-composition patterns in the understory that a simple cover type cannot reflect. Various plant communities form a distinct pattern throughout the cottonwood forest understory. The pattern may result from several factors including succession, herbivory, and the physical environment or site. These factors are first treated briefly below, and the patterns are then described and related to important factors in more detail.

*Vegetation succession* — When comparing young cottonwood stands (less than 20 years) to older stands, much of the difference may be due to the time it takes for understory community development, or succession in the traditional sense (Clements 1916). However, the full complement of young sites created after Palisades Dam may be different than the complement created during natural flows, thus confounding a chronosequence approach that assumes similar initial conditions. A potentially important difference is that the deposition rate of fine sediments is less than before Palisades Dam closure.

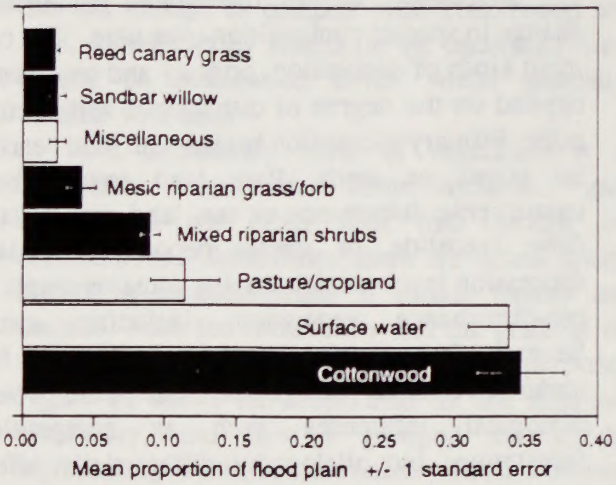


Figure 21. Proportion of flood plain occupied by vegetation cover types and surface water. Types with dark bars are more important ecologically.

Even if there are real differences in species composition due to succession, site age does not explain all of the patterns in vegetation. Forest understories have distinct patterns in species composition across sites of similar age. Therefore, site age has much less influence on understory composition after about 35 years of succession. This general pattern holds for a broad range of site ages from 35 to 300 years. These distinct patterns can be seen on individual islands, and an example is shown later.

Herbivory certainly affects species composition, and this is discussed more later, but one pattern of communities still exists in areas with moderate to no livestock grazing, and in areas known to have a long history of high livestock use, a different pattern shows. Thus, herbivory by livestock is probably a dominant factor for determining some plant communities but not others. Furthermore, cottonwood tree height, diameter, and cover varies with understory species composition, indicating that factors involved in understory development may affect cottonwood growth as well. Site differences may explain community patterns that succession and herbivory do not. With these broad-process distinctions in mind, a discussion of the effects of succession, site factors, and herbivory on cottonwood-forest-understory communities follows, using some examples from the South Fork.

Succession is the directional, cumulative change in species composition over time. The two main kinds of succession, primary and secondary, depend on the degree of disturbance and starting point. Primary succession begins with land bearing no plants or seeds. Bare land results from catastrophic disturbance or new land such as lava flow, landslide, or stream deposit. Secondary succession involves sites having some remnants of pre-disturbance vegetation, including seeds. Several factors drive succession, but they fall under two main categories: *autogenic*, where biological influences such as competition facilitation, and allelopathy differentially affect species survival, and *allogenic*, where physical changes to the site occur that affect on-site vegetation. Primary succession is dominant on the South Fork — at least before flow regulation. Autogenic influences are apparent, but allogenic influences may have a more dominant role shaping South Fork riparian communities.

Competition for light is apparently the dominant autogenic influence. With increasing shade from the cottonwood canopy, early colonizers such as reed canary grass and sandbar willow decrease, and more shade-tolerant species become more common.

For example, most of the shrubs on the young island that formed around 1890 (Figure 19a and 19b) resemble sandbar willow. Today's young bars (less than 20 years old) support sandbar willow and some cottonwood, but also a considerable amount of reed canary grass. If the species composition on the young islands in Figure 19a and 19b is typifies the pre-dam period, then reed canary grass is more common now.

Some consider reed canary grass (*Phalaris arundinacea*) an exotic (e.g., Walton 1983; Apfelbaum and Sams 1987; Angradi 1989). However, J. M. Coulter collected this species along the South Fork in 1872 (Hayden 1873). This species may be more common now as a result of higher summer flows and a slower island-building rate compared to the pre-Palisades Dam period. Its strong rhizomatous habit and ability to survive weeks of inundation allows it to invade lower, wetter areas of new islands. Sandbar willow can invade existing canary grass stands vegetatively, but cottonwood and yellow willow seldom if ever do.

About 4 years after initial colonization, heavy grass litter probably impedes cottonwood and willow seed germination, and shade from reed canary grass, which can be 5 feet tall, would limit any new seedling survival. However, robust cottonwood saplings and willow do occur in heavy reed canary grass stands; these individuals colonized areas before canary grass cover became an impediment. This colonization sequence is evident on recent, sequential aerial photography.

Other, rarer species occur on young islands, but most apparently endure a fate similar to sandbar willow and reed canary grass because of their intolerance to either shade, drought or both. These decreasers, listed by order of occurrence on moist-to-dry sites, are common spike-rush *(Eleocharis palustris)*, alkali butterweed *(Senecio hydrophilus)*, curly dock *(Rumex crispa)*, marsh sow-thistle *(Sonchus ugilinosus)*, meadow barley *(Hordeum depressum)*, and foxtail barley *(Hordeum jubatum)*. The *Sonchus* and *Rumex* species are exotic (Hitchcock and Cronquist 1973). In contrast to these decreasers, other rare species apparently increase with time as the canopy closes. The most notable are silverberry and red-osier dogwood. These two species and many others are common in older cottonwood stands. Few of the species that are common on young sites are common on older (greater than 35 years) sites, while those common on older sites are scarce or absent on younger ones.

A shift in species composition over time is noticeable in the early stages of cottonwood community development. Some of this shift is due to competitive exclusion of shade intolerants as previously discussed, while some of it may be due to changing site factors such as water availability. Plant density and form can influence sediment deposition (Harris 1987; Stromberg et al. 1993), so existing plants can influence site changes and facilitate establishment of other species that would otherwise not occur. In essence, species interactions and changing site factors over time are likely causes of dramatic shifts in species composition during the first few decades after island emergence. This may have been especially true for the pre-Palisades condition, when larger floods and higher sediment loads allowed greater overbank deposition.

*Vegetation and site relations* — Dramatic shifts in species composition occur in older cottonwood stands (greater than 35 years). Most of the shift is in understory species. Unlike the previous shift in species composition in young island development, the range in understory species composition, or coenocline, transcends space rather than time. The coenocline occurs on sites of similar age and it also repeats itself across a wide range of site ages. Therefore, the coenocline does not represent successional stages for a given site. Rather, differing site factors are likely reasons for the species shift across the flood plain. These site factors are due to allogenic influences, specifically, depositional history. As a cottonwood community develops on a given site, a successional plateau is reached as site factors stabilize, and species composition remains relatively stable for several decades barring disturbance or change in site. No other trees are common enough and tall enough to compete with cottonwood for light, so tree-canopy effects on the understory only depend on cottonwood cover, which gradually declines with time.

The community view of vegetation is a convenient one for communication, and coenoclines are often split into groups or communities. Sometimes there are actual sharp breaks in the coenocline if causal factors are discrete. I use the community and the gradient or coenocline views, depending on the purpose. Figure 22 shows the coenocline for the sampled understory, and how I grouped the stands representing it into communities. Table 2 shows average species composition for each community.

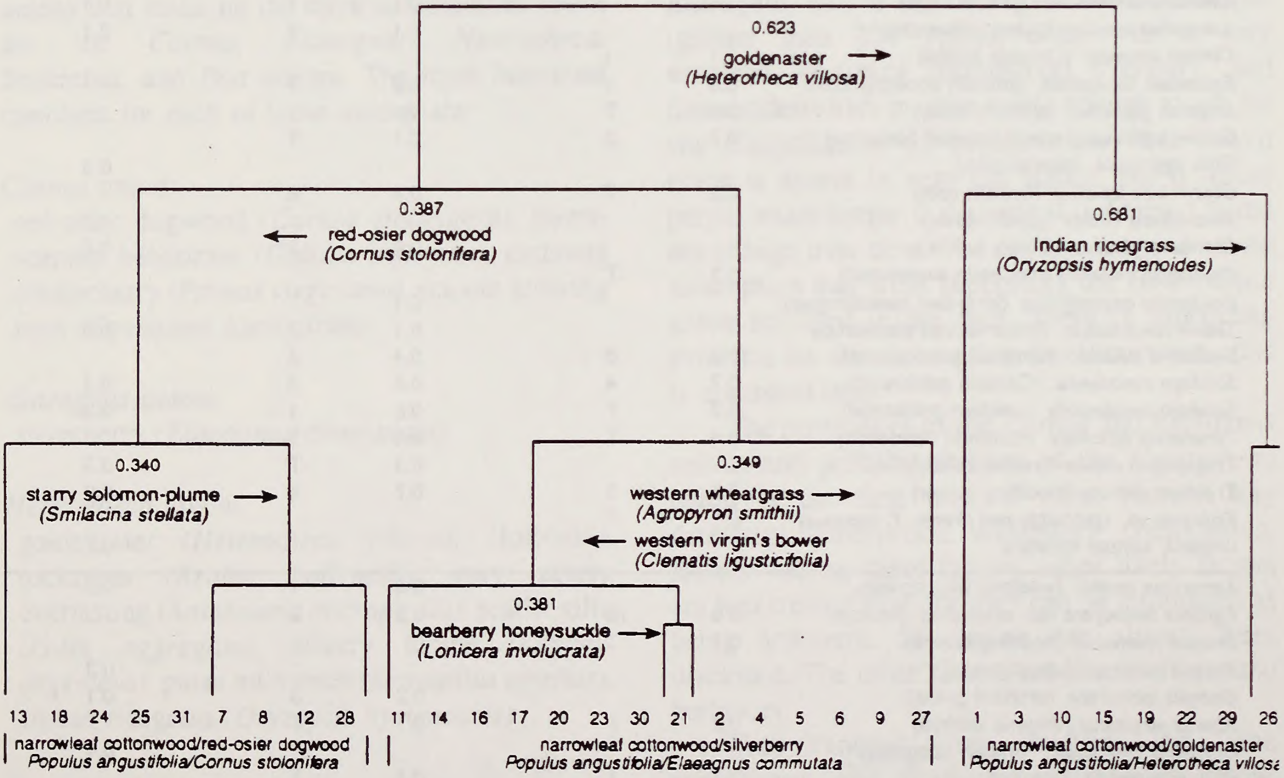


Figure 22. Dendrogram of the cottonwood understory coenocline. Sample stands are numbered along the bottom, with corresponding community names for the stands grouped by similarity using TWINSPAN. Eigenvalues and indicator species for each division are placed at junctions.

Table 2. Constancy (proportion of occurrence) and canopy cover (percent, T if < 1) for plants on sampled flood plain by community type. Blanks = no occurrence. Species grouped as trees, shrubs, forbs, and graminoids.

| Species | POPANG/CORSTO<br>Constancy | Cover | POPANG/ELACOM<br>Constancy | Cover | POPANG/HETVIL<br>Constancy | Cover |
|---|---|---|---|---|---|---|
| *Juniperus scopulorum* (Rocky Mountain juniper) | 0.1 | T | 0.3 | T | | |
| *Populus angustifolia* (narrowleaf cottonwood) | 1.0 | 65 | 1.04 | 46 | 1.0 | 17 |
| *Amelanchier alnifolia* (western serviceberry) | 0.3 | T | 0.1 | T | 0.1 | T |
| *Berberis repens* (Oregon grape) | | | 0.1 | T | | |
| *Chrysothamnus viscidiflorus* (green rabbitbrush) | | | | | 0.1 | T |
| *Clematis ligusticifolia* (western virgin's bower) | 0.2 | T | 0.4 | 4 | | |
| *Cornus stolonifera* (red-osier dogwood) | 1.0 | 38 | 0.3 | T | | |
| *Crataegus douglasii* (black hawthorn) | 0.1 | T | | | | |
| *Elaeagnus commutata* (silverberry) | 0.8 | 8 | 0.9 | 25 | 0.1 | T |
| *Lonicera involucrata* (bearberry honeysuckle) | 0.2 | T | 0.2 | T | | |
| *Prunus virginiana* (common chokecherry) | 0.2 | T | | | | |
| *Rhus trilobata* (skunkbush) | 0.1 | T | 0.1 | T | | |
| *Ribes lacustre* (prickly currant) | 0.2 | T | 0.1 | T | | |
| *Rosa woodsii* (Wood's rose) | 0.6 | 1 | 0.1 | T | | |
| *Salix exigua* (sandbar willow) | 0.1 | T | 0.1 | T | | |
| *Salix lutea* (yellow willow) | 0.6 | 3 | 0.1 | T | | |
| *Symphoricarpos albus* (common snowberry) | 0.3 | T | 0.1 | T | | |
| *Achillea millefolium* (common yarrow) | | | 0.1 | T | | |
| *Arabis holboellii* (Holboell's rockcress) | | | | | 0.4 | T |
| *Antennaria microphylla* (rosy pearly everlasting) | | | | | 0.3 | T |
| *Arnica longifolia* (seep-spring arnica) | | | 0.1 | T | | |
| *Artemisia dracunculus* (tarragon) | | | 0.1 | T | | |
| *Artemisia ludoviciana* (prairie sage) | | | 0.1 | T | 0.1 | T |
| *Astragalus tenellus* (pulse milkvetch) | | | 0.1 | T | 0.1 | T |
| *Cirsium arvensis* (Canada thistle) | 0.1 | 1 | | | | |
| *Equisetum laevigatum* (smooth scouring rush) | 0.8 | 1 | 0.2 | T | | |
| *Erigeron glabellus* (smooth daisy) | 0.1 | T | | | | |
| *Galium triflorum* (sweet-scented bedstraw) | 0.7 | 2 | 0.1 | T | | |
| *Gilia aggregata* (scarlet gilia) | | | | | 0.3 | T |
| *Glycyrrhiza lepidota* (licorice root) | 0.6 | 7 | 0.4 | 6 | | |
| *Heterotheca villosa* (goldenaster) | | | | | 1.0 | 8 |
| *Lupinus argenteus* (silvery lupine) | | | 0.2 | 2 | 0.8 | 2 |
| *Osmorhiza chilensis* (mountain sweet-root) | 0.2 | T | | | | |
| *Penstemon angustifolius* (long-leaf beardtongue) | | | 0.1 | T | | |
| *Sedum lanceolatum* (lance-leaved stonecrop) | | | 0.1 | T | 0.3 | T |
| *Smilacina stellata* (starry solomon-plume) | 0.6 | 8 | 0.4 | 2 | | |
| *Solidago canadensis* (Canada goldenrod) | 0.7 | 4 | 0.5 | 3 | 0.1 | T |
| *Solidago occidentalis* (western goldenrod) | 0.2 | T | 0.6 | 1 | 0.3 | T |
| *Taraxacum officinale* (common dandelion) | 0.4 | T | 0.3 | T | | |
| *Tragopogon dubius* (yellow salsify) | | | 0.1 | T | 0.3 | T |
| *Trifolium dubium* (suckling clover) | 0.6 | 3 | 0.7 | 6 | 0.9 | 3 |
| *Trifolium* sp. (probably red clover, *T. pratense*) | 0.1 | T | | | | |
| unident. annual mustard | | | | | 0.1 | T |
| *Agropyron smithii* (western wheatgrass) | | | 0.3 | 1 | 0.5 | T |
| *Agrostis stolonifera* var. *stolonifera* (redtop) | 0.9 | 16 | 0.2 | 2 | | |
| *Bromus anomalus* (nodding brome) | 0.1 | T | | | | |
| *Bromus tectorum* (cheat grass) | | | | | 0.3 | T |
| *Dactylis glomerata* (orchard grass) | | | 0.2 | 3 | 0.1 | T |
| *Elymus virginicus* (Virginia wildrye) | 0.2 | T | 0.1 | T | | |
| *Oryzopsis hymenoides* (Indian ricegrass) | | | | | 0.4 | T |
| *Phleum pratensis* (timothy) | 0.1 | 1 | 0.1 | T | | |
| *Poa pratensis* (Kentucky bluegrass) | 0.9 | 25 | 1.0 | 35 | 0.6 | 2 |
| unident. grass | 0.1 | T | | | | |

The 6-letter codes denote the communities, which are named after the dominant species in upper and lower stratums: POPANG = *Populus angustifolia* (narrowleaf cottonwood) CORSTO = *Cornus stolonifera* (red-osier dogwood), ELACOM = *Elaeagnus commutata* (silverberry), HETVIL = *Heterotheca villosa* (goldenaster)

About 75% of the cottonwood forest is between 35 and 125 years old, and the following community descriptions and their relation to site factors apply to much of this area if it is not severely grazed. The relation probably extends to stands older than 125 years to the degree that these communities are found, but I did not sample these areas. The three common community types found on non-severely-grazed areas are *Populus angustifolia/Cornus stolonifera* (POPANG/CORSTO), *Populus angustifolia/Elaeagnus commutata* (POPANG/ELACOM), and *Populus angustifolia/Heterotheca villosa* (POPANG/HETVIL). Typical stands showing the general physiognomy of these types are shown in Figure 23. Cottonwood age distributions are presented later.

A further breakdown in vegetation structure, called unions, is useful for communication. Species that occur together with similar phenology and apparent autecology are called unions (Daubenmire 1952). Considering the full complement of understory species, the important unions that make up the three communities above are the *Cornus*, *Elaeagnus*, *Heterotheca*, *Smilacina*, and *Poa* unions. The most important members for each of these unions are:

*Cornus* union:
red-osier dogwood *(Cornus stolonifera)*, sweet-scented beadstraw *(Galium triflorum)*, common chokecherry *(Prunus virginiana)*, smooth scouring rush *(Equisetum laevigatum)*

*Elaeagnus* union:
silverberry *(Elaeagnus commutata)*

*Heterotheca* union:
goldenaster *(Heterotheca villosa)*, Holboell's rockcress *(Arabis holboellii)*, rosy pearly everlasting *(Antennaria microphylla)*, scarlet gilia *(Gilia aggregata)*, silvery lupine *(Lupinus argenteus)*, pulse milkvetch *(Astragalus tenellus)*, Indian ricegrass *(Oryzopsis hymenoides)*

*Smilacina* union:
starry solomon-plume *(Smilacina stellata)*, Canada goldenrod *(Solidago canadensis)*, western goldenrod *(Solidago occidentalis)*

*Poa* union:
Kentucky bluegrass *(Poa pratensis)*, Canada bluegrass *(Poa compressa)*, Orchard grass *(Dactylis glomerata)*, smooth brome *(Bromus inermis)*

The *Cornus*, *Elaeagnus*, *Smilacina* and *Poa* unions are found in the POPANG/CORSTO and POPANG/ELACOM communities. In contrast, the *Heterotheca* union is restricted to the POPANG/HETVIL community. The *Smilacina* and *Poa* unions, which comprise much of the herbaceous layer, respond to shading of shrubs, herbivory, and site factors.

Although I focus on how these communities are related to site factors, which is reminiscent of habitat types, the communities are probably not stable for a long enough time to be considered climax. This is especially true for the cottonwood component. Habitat types, which are units of a site classification system, are based on climax vegetation (Daubenmire and Daubenmire 1968; Pfister and Arno 1980). However, the *Cornus* and *Elaeagnus* unions do occur in very old stands (greater than 200 years), even with a very scattered, declining cottonwood overstory, and these understories may be stable enough to use for site classification. In contrast, the *Heterotheca* union is absent in very old stands, but it would persist much longer if the sites it is adapted to did not change over time. The decline is based on the assumption that areas supporting the *Heterotheca* union occurred in the past. There is supporting evidence for this assumption on other rivers; this is discussed later.

The persistence of the *Cornus* and *Elaeagnus* unions and probable decline of the *Heterotheca* union is the first hint of what factors may determine cottonwood understory composition. Before visiting these factors, other likely factors are best treated first, for they can be eliminated as being dominant. Succession has already been discussed. The other factors are shade effects and herbivory.

Tree canopy cover modifies the light, temperature, and moisture environment below, and understory species composition can respond to the environmental variation induced by varying tree cover (Daubenmire 1952). There is a

*Populus angustifolia/Cornus stolonifera* (POANG/CORSTO)
Community Type

*Populus angustifolia/Elaeagnus commutata* (POANG/ELACOM)
Community Type

*Populus angustifolia/Heterotheca villosa* (POANG/HETVIL)
Community Type

Figure 23. Typical stands of three common community types found on older flood plain sites. The pole is at plot center, and the stripes are 10 decimeters wide. The tatum is placed where most visible. Photo points are from the southerly edge of plot, and the same lens was used for all photos. These plots are on a transect on Riley Island (see Figure 20d), and are 100 feet apart. The plots correspond (from the left) to sample numbers 13, 14, and 15 in Figure 22.

noticeable response to shading in cottonwood understories, but mainly in the herbaceous layer below varying shrub canopy cover. In addition to obvious shifts in herbaceous species composition with varying shrub canopy cover, I also found differences in plant moisture stress in herbs that may be related to shade. However, there is a poor correlation between cottonwood canopy cover and the dominant understory species — red-osier dogwood and silverberry — so cottonwood canopy cover probably has little facilitative effect on them. The most dramatic situation indicating such a lack of facilitation is that red-osier dogwood and silverberry have high canopy cover in dense cottonwood shade as well as areas devoid of cottonwood. Canopy cover apparently limits the *Heterotheca* union, for it never occurs in moderate shade, but many open areas does not support it. Thus, shade limits the distribution of the *Heterotheca* union species because of their apparent shade intolerance, but shade is not the only factor.

A broad view of cottonwood canopy cover and coenocline relations shows in the following examples. Cottonwood canopy cover is consistently low in the POPANG/HETVIL community type; an example of this shows in Figure 20a to 20d. The light-colored areas on the islands are POPANG/HETVIL, and the more heavily-vegetated areas are either shrub-dominated (e.g., sandbar willow, mixed riparian shrub), POPANG/CORSTO or POPANG/ELACOM. (Plate 17 in the Appendix shows the general vegetation here at row G, column 7.) The POPANG/HETVIL type is light-colored because of low cottonwood canopy cover and its very sparse understory, and about 80% of the cobbly-channel deposit is exposed (Figure 23). An extreme case of this occurs near Black Canyon, where there is no vegetation in bare, loose cobble deposits (Plate 15, H9). The mixed riparian shrub type (MS) is essentially the POPANG/CORSTO community without cottonwood. The MS type mainly occurs in old anabranches, as discussed earlier, but also as a result of heavy beaver cutting of cottonwood trees in POPANG/CORSTO.

Herbivory occurs nearly everywhere on the flood plain, and the most common herbivores today are beaver, moose, and domestic cattle. Elk and mule deer concentrate in some areas in winter, while whitetail deer are year-long residents but occur sporadically.

Riparian shrubs were common in the pre-settlement period (Merigliano 1994), so native herbivores, including beaver and bison, coexisted with them. Beaver were common enough to trap in the 1840's (Haines 1955). Bison were numerous in the Swan Valley area in the 1840's and occurred along the canyon corridor as well (Haines 1955). The eastern Snake River Plain was the western limit of bison range in modern times (Roe 1951; Van Vuren 1987). The beaver's diverse diet includes cottonwood, and saplings are preferred (Allen 1980; Hammerson 1994). Saplings are scarce on the South Fork today, and beaver cutting can be severe in young cottonwood stands — probably for this reason. Large trees are occasionally felled, but beaver have little impact in the older cottonwood stands except in a few locales.

Drastic reduction in shrub cover due to cattle grazing is well documented (e.g., Knopf and Cannon 1982; Rickard and Cushing 1982; Kauffman and Krueger 1984; Platts and Nelson 1989; Smith et al. 1992). The same can occur with moose (Chadde and Kay 1988). Moose may be more common today than during the late 1800's, but domestic livestock are more numerous on the South Fork, and they can change plant communities greatly. Some places show signs of severe grazing, and the most obvious effects are a reduction in shrubs, most notably red-osier dogwood, and an increase in some forb species.

Considering the entire coenocline, cattle grazing is probably not a dominant factor in the spatial distribution and cover of mature-understory species. Two opposing lines of evidence suggest this: Stands that have not been grazed (if grazed at all) by cattle since the 1930's (Spaulding, personal communication 1994) are similar to more typical, moderately-grazed areas, while areas with more severe grazing lose much of the typical understory species. The *Poa* union dominates the understory in these latter places. Three plots represent the ungrazed stands. They are 29, 30 and 31 shown in Figure 22. More on cattle grazing is discussed later.

Patterns in cottonwood stand ages.

understory:overstory cover relations, and grazing history suggest that plant succession, cottonwood canopy cover, and herbivory are unimportant in explaining the shift in species composition across the old flood plain (the coenocline). Other factors may explain this shift, and the gross distribution of key species points to physical factors; water and nutrient availability are likely possibilities. One pattern suggesting physical factors is the restriction of the *Heterotheca* union on very cobbly sites (Figure 23), and the general increase in the *Cornus* union as overbank deposits thicken. A broader-scaled pattern shows from above, especially after leaf fall, when the community mosaic is visible and seems to reflect the river's braided pattern.

The gradient in species composition (coenocline) represents a gradient in site factors, assuming that the species are adapted to the sites they grow on. The stands in the TWINSPAN dendrogram (Figure 22) are arranged and split according to species composition. The stands with high *Cornus stolonifera* cover define one end of the coenocline, while those with *Heterotheca villosa* define the other. This general gradation is more detailed in Table 2.

Another way to see the gradient is through ordination, where species and samples (plots) are related to each other in multidimensional space. Figure 24 shows how selected species are arranged and vary in cover along the site gradient. The selection criteria for plotting are dominance, plant morphology that suggest adaptations to site factors, and fidelity. The site gradient (sample scores) is calculated using species composition. The methodology involved in the dendrogram (Figure 22) and ordination (Figure 24) is similar, so the dominant gradients in these figures are likewise similar.

Using a community view point, the POPANG/CORSTO and POPANG/HETVIL communities define the site gradient end-points or extremes, while the POPANG/ELACOM community is towards the middle. Community names ease communication, but they imply a discreetness that may not be real.

A caution is in order when thinking about the relation of species to physical site factors. The relation is not always a direct, simplistic connection between site and species. For example, the POPANG/HETVIL and POPANG/CORSTO communities represent site factor extremes, but the goldenaster's (HETVIL) absence on POPANG/CORSTO sites is probably not due to site factors alone. Goldenaster's morphology suggests adaptation to droughty habitats (Semple et al. 1980), but it could probably survive on moister sites supporting POPANG/CORSTO if competing vegetation is removed. Therefore, competition may limit goldenaster from the POPANG/CORSTO community. The reverse situation involves site factors more directly. The sites supporting goldenaster are probably too dry for red-osier dogwood and other drought-intolerants to survive.

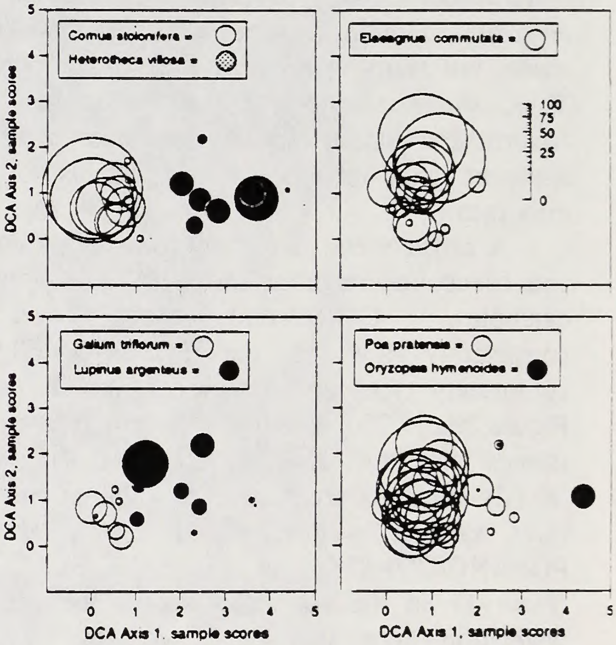


Figure 24. Canopy cover of selected species along ordination gradients using Detrended Correspondence Analysis (DCA). Circle area represents percent canopy cover (note interior scale). Both DCA axes are on the same scale, and units are average standard deviations of species turnover, or SD, which is a standard measure. Gradients longer than 4 SD's are considered long. The first axis is usually more ecologically meaningful than higher axes (Gauch 1982).

Considering the various factors that shape plant communities, physical factors remained as likely dominant ones for those on older flood plain sites. Water and nutrient availability are remaining possibilities. The presence of droughttolerant species on one end of the gradient and drought-intolerants on the other (Figure 22 and 24) suggest that the coenocline follows a gradient of water availability. This pattern does not eliminate nutrients as a factor, but nutrient availability can be strongly correlated with water availability, and separating these two factors completely would be difficult or impossible under field conditions. I only investigated how water availability may be related to the coenocline, but I consider some possible effects due to nutrients later. Defining nutrient effects needs further study.

Water availability with respect to plants depends on its energy status in the soil. This status largely depends on the amount of water in the soil, solute concentration, and soil texture. The amount in flood plain soil depends on precipitation and ground water influences. Except for crown interception, precipitation is equal for a given locale that shows the full coenocline, so ground water is likely more dominant. Shrub-crown interception seemed to affect moisture stress in shallow-rooted herbs and grasses, but I noticed no pattern in the shrub layer due to cottonwood canopy cover. I did not assess solute effects directly, but I found no carbonates or salt concentrations in soil pits, and plant moisture stress patterns suggest it is not differential across the flood plain. So, if precipitation and soil solutes are evenly distributed across the flood plain, water availability depends largely on soil texture and river stage.

Water availability is physically linked to soil texture (Hillel 1980), and this link most-strongly ties plants and soil together when amounts of water and solutes are similar across a range of textures. If precipitation, range in groundwater level, and solute concentrations are similar across a flood plain area, but there is a spatial difference in texture, plant species would likely be located according to water availability due to texture. This is apparently the case for the coenocline on the older flood plain areas. Figure 25 shows how the coenocline, represented by sample scores, is related to soil texture. Figure 26 shows an array of flood plain communities on island surfaces and associated soil profiles.

Measurements of plant water stress also indicate that water is less available on sites supporting the *Heterotheca* union, and more available on sites where the *Cornus* union occurs. Not surprisingly, measurements of soil water content follow the same general pattern (Merigliano 1996). Although not shown, these results support the notion that species composition is related to water availability. The relation between texture and species composition shown in Figure 25 is definite but not very precise. Some imprecision is likely due to the methods, for ordination seldom represents gradients in vegetation perfectly (van Groenewoud 1992), and soil samples may not capture spatial variability in soil. Even if the method was perfect, other variables are likely to have effects.

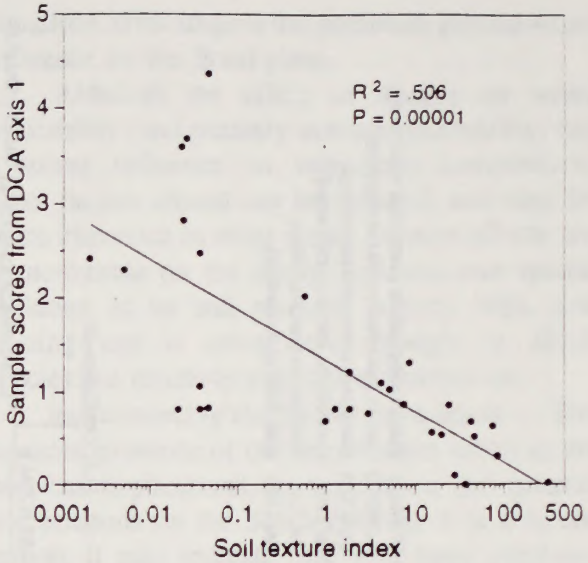
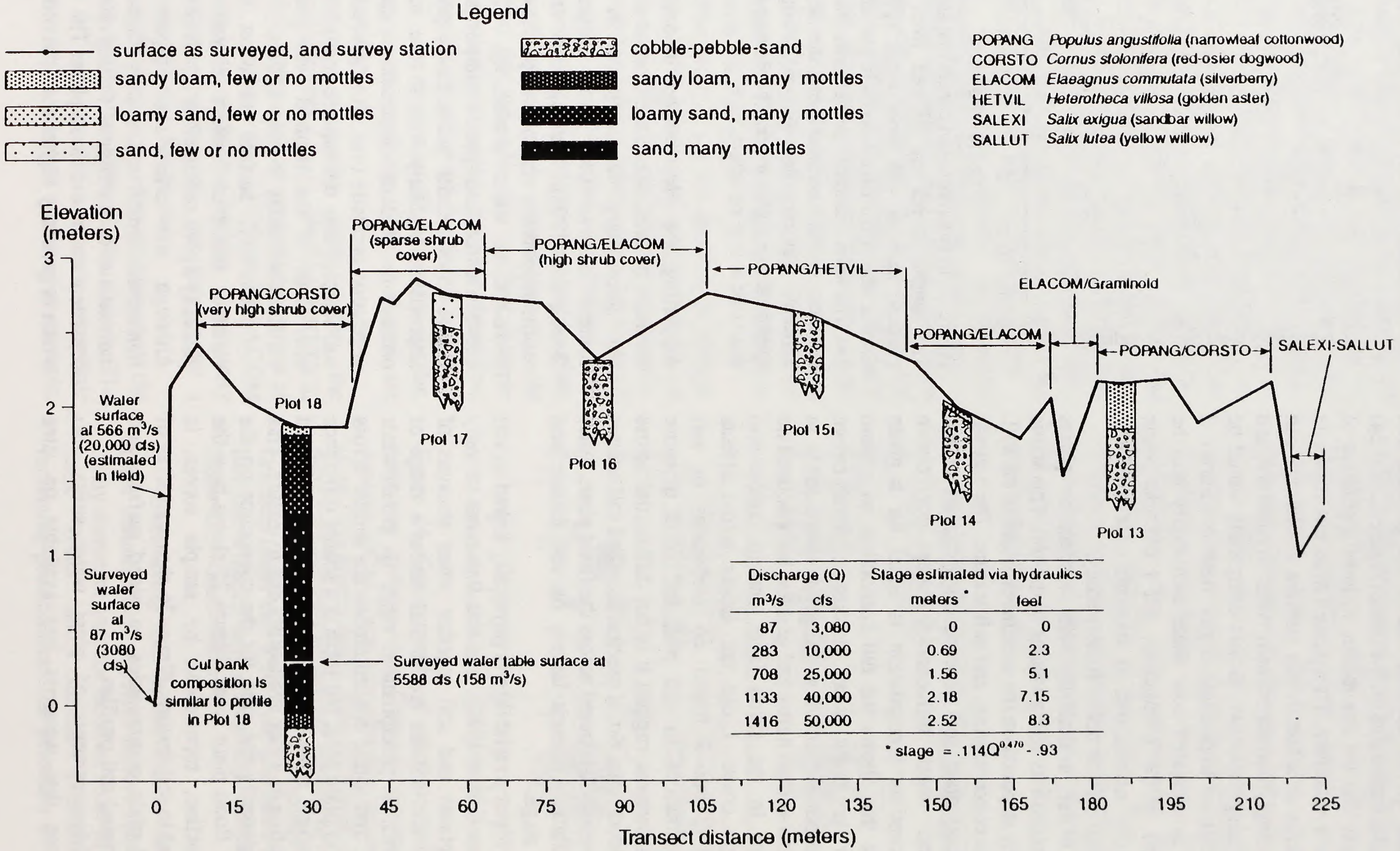


Figure 25. Relation between coenocline and soil texture. The sample scores are derived from the species gradient. Samples with more mesic species such as *Cornus stolonifera* have lower sample scores (see Fig. 24). The index combines particle size distribution and thickness of soil horizons, and the depth of these horizons. Thicker, finer-textured, deeper horizons contribute to a higher index. The P-value is for the test that slope = 0 or no effect.

Intuitively, surface elevation is a likely variable. However, surface elevation alone is generally a poor predictor on South Fork alluvium. Although the drier sites typified by the *Heterotheca* union are usually higher than the moister sites (e. g., Figure 26), this relation is only consistent on the old flood plain. The low terrace, which is generally higher than the old floodplain,



| Discharge (Q) | | Stage estimated via hydraulics | |
|---|---|---|---|
| m³/s | cfs | meters * | feet |
| 87 | 3,080 | 0 | 0 |
| 283 | 10,000 | 0.69 | 2.3 |
| 708 | 25,000 | 1.56 | 5.1 |
| 1133 | 40,000 | 2.18 | 7.15 |
| 1416 | 50,000 | 2.52 | 8.3 |

* slage = $.114Q^{0.470} - .93$

Figure 26. Flood plain cross-section on Riley island complex showing surface elevation, plant communities, and sampled soil profiles. View is downstream, and transect is orthogonal to the channel. The channel deposits left of transect distance 180 stabilized about 74 years ago, those to the right about 65 years ago. The stage relation is derived from the hydraulic geometry at the gaging station near Dry Canyon, and referenced to the surveyed water surface.

supports the mesic *Cornus* union. More extensive surveying reveals that the *Cornus* union can occur on surfaces 2.6 feet higher than nearby surfaces supporting the xeric *Heterotheca* union. This situation, which is common on the South Fork, clearly indicates that depth to water table is not a dominant control of understory species composition here.

Nutrients stocks and availability may also help control the coenocline. The upper soil horizon, or epipedon, varies across the coenocline. Darker colors can indicate higher nutrient stocks due to higher organic matter content. Sampled profiles under the POPANG/CORSTO and POPANG/HETVIL communities were typically darkest. Epipedon thickness varied across community types. Epipedons associated with the POPANG/HETVIL community were between 0.6 and 1.2 cm thick; epipedons associated with POPANG/ELACOM ranged from 1.2 to 15 cm thick, with 10 to 12 cm being more typical, and those associated with the POPANG/CORSTO were generally the thickest, ranging between 3 and 26 cm. Thicker, darker horizons can indicate higher nutrient stocks. A given nutrient stock becomes more available with higher water availability.

Ground water levels within alluvium are strongly related to river stage. Texture influences hydraulic conductivity and thus water table levels. Recall that the bulk of the flood plain is comprised of cobbles, pebbles and sand, and water influenced by gravity (ground water) moves rapidly in this material (Fetter 1994). Even in the relatively fine-textured flood plains along the Platte River, Hurr (1983) found that ground-water levels within a large flood-plain island closely matched river stage. A similarly close tie between stage and flood-plain groundwater level also occurred on the Sangamon River in Illinois (Bell and Johnson 1974), and lower Missouri River Grannemann and Sharp (1979).

Free water within hillsides that are attached to alluvium can influence water levels within alluvium. However, by definition, islands are hydraulically isolated from hillsides, and much of the South Fork's flood plain is comprised of islands. Some South Fork alluvium is attached to canyon slopes, but usually an old channel separates them at higher flows. Therefore, in most situations, river stage is the dominant ground water influence on the flood plain.

Although the effect of texture on water availability (and possibly nutrient availability) has a strong influence on vegetation composition, other factors should not be ignored, and may be more important in other areas. Texture effects are so noticeable on the South Fork because spatial variation of its soil textures is very high, and grazing use is often low enough to allow species:site relations to express themselves.

*Implications of the Heterotheca union* — The assumed presence of the *Heterotheca* union in the past has implications for succession and general site relations on the South Fork. If it is a recent arrival, it may indicate that sites have dried-out since dam closure, or herbivory pressure has favored the unpalatable *Heterotheca* (USDA 1937). Evidence on the South Fork and other places indicate that it is probably not a recent arrival. The South Fork discharge record indicates that under Palisades regulation, the flood plain has a slightly higher moisture regime during summer than under natural conditions (Figure 4). However, the *Heterotheca* union occurs on the highest channel deposits on island surfaces, and these areas receive less water since flood control. Even so, these places may have been too dry for other plants before dam closure. The cobbly-areas show on pre- and post-dam aerial photography, and this union is consistently found on these cobbly-areas (unless heavily trampled) on the South Fork. I have seen *Heterotheca* on young islands along the unregulated Yampa River. Like the South Fork, it grows on the higher, cobbly areas. This plant apparently persists as long as the site remains cobbly and too dry to support many plants that can shade it out or otherwise out-compete it. Although uncommon on the South Fork, it is quite common along the upper Snake River and tributaries in Wyoming where cobbly substrate is the norm. It also occurs many feet above likely flood levels along other rivers on cobbly alluvium.

On the South Fork, the *Heterotheca* union probably disappears after the cobbly channel deposits it inhabits are covered with over-bank deposits. The old *Heterotheca* sites may now support the drier grass types dominated by needle-and-thread *(Stipa comata)* and bluebunch wheatgrass *(Agropyron spicatum)*. Sagebrush *(Artemisia tridentata)* can also occur with these grasses. A good example of this possible transition shows on Plate 17, row C, column 4, where a sagebrush/grass area may have been a POPANG/HETVIL community in the past.

In summary, surface elevation and soil texture result from fluvial processes, so excluding herbivory, depositional history largely determines understory composition by influencing water availability via soil texture. Nutrients may be a factor as well. Early events that shape island surfaces are important in cottonwood establishment, while subsequent overbank deposits strongly influence understory composition. Although water itself is obviously important to plants, spatial variation in texture across the flood plain can explain much of the patterns we see in the field because texture affects water availability.

## Flow regime and the cottonwood forest

The previous section outlined the ecology of common riparian plant species and the stream deposits they grow on. Plant colonization on new stream deposits was also introduced and put in the overall-context of flood plain communities and their development. This section focuses on what discharge patterns created the sites that support today's cottonwood forest.

On the South Fork, a majority of cottonwood trees establish from seed on new stream deposits. Some vegetative reproduction (suckering from roots and coppicing from stumps) occurs and is locally common; this is discussed later. Figure 19 shows cottonwood colonization on a typical island. What events led to this island's development and others like it?

*Some theories* — Two main fluvial processes can lead to the creation of sites suitable for cottonwood establishment. One is through width adjustment, or specifically, channel narrowing. The other is redistribution of sediment in the scour-and-fill, channel-migration process discussed earlier. The former process occurs naturally (e.g., Schumm and Lichty 1963; Andrews 1982; Hereford 1993) and as a response to flow regulation (Bergman and Sullivan 1963; Nadler and Schumm 1981; Williams and Wolman 1984; Johnson 1994). I found very little evidence of cottonwood encroachment on surfaces that may have stabilized after damming or were simply exposed with the change in discharge regime. The channel-migration process is common on nearly every alluvial stream, and is the dominant one creating sites suitable for cottonwood colonization on the South Fork. As explained earlier, cottonwood is not the only species that colonizes new alluvial surfaces.

Channel-migration and flood-plain accretion rates vary from negligible to very rapid. Wolman and Leopold (1957) report annual migration rates of 0 to 2460 feet for a broad range of rivers. This variance is due to many factors, such as bank resistance, sediment load characteristics, channel geometry, and discharge pattern. With a given channel-migration rate for a particular river, the kind of flow event behind migration in general becomes more interesting. This is also a central question in this study.

There are two general lines of evidence and points of view towards the channel-migration process: one is that new flood plain areas may develop gradually over many years during several, moderate floods (e.g., Wolman and Miller 1960; Dury 1973; Harvey et al. 1979); the other is of sudden, rapid development during more extreme events (Stewart and LaMarche 1967; Scott and Gravlee 1968; Desloges and Church 1992). Others assume a gradual rate (Everitt 1968); are not sure (Hickin and Nanson 1975); or have found both situations on one river (Hickin and Sichingabula 1988). Moreover, considerable migration and island development can occur under moderate floods after large, rapid migration caused by a very large flood (Desloges and Church 1987), thus blurring the general dichotomy of ideas. Even more complexity is imbedded in these ideas, for much of the thinking hinges on sediment transport in a channel, which can occur without channel migration (e.g., Maddock 1969; Andrews 1984; Dietrich and Smith 1984). Thus, sediment fluxes can be poorly-linked to channel migration and island development. There is clear evidence supporting both the gradual and sudden shift perspectives; most of the difficulty lies in understanding why some streams behave one way and others another.

*Channel migration and cottonwoods* — The channel-migration problems are emphasized because they allow a basis for proceeding with the island-building dynamics on the South Fork. The above dichotomy figures strongly into the rationale for associating the magnitude and frequency of discharge events with island development and cottonwood colonization. In other words, did most of the South Fork cottonwoods originate with a few very large floods, or many small ones?

To answer this question, I used an empirical and rational approach. Empirical evidence includes establishment years for sample cottonwood trees determined from tree aging, spatial patterns of tree ages on the flood plain, island development visible on sequential photography, flood plain topography, the river's hydraulic characteristics, and the discharge record. Reasoning involves the above and broad-scale evidence related to channel migration and stability.

A logical procedure for finding the flows associated with cottonwood stand origination is by comparing tree ages with the discharge record for the river. If cottonwood trees colonize the year a bar emerges or otherwise stabilizes, this year can be determined by simply subtracting the present age of trees from the year they were cored for aging. This procedure is valid if the island is completely colonized during the summer the discharge event occurred, aging is perfectly accurate, the stems are of seed origin (genets), and all island development important for cottonwood colonization occurs with one event. These requirements were seldom met in this study, but when age data is combined with other information, a good estimate of the flow regime required for maintaining the cottonwood forest is possible. The development of this estimate, using a few examples from the broad sources of information I used, is presented now.

The spatial distribution and variance of tree ages on islands indicate that cottonwoods seldom colonize a fresh surface all at once. The age map in Figure 20 shows typical spread of 3 to 6 years within tree patches that appear uniform. I assessed uniformity on aerial photography and field evidence such as tree height, bark characteristics, bias of the trees, which tend to form rows, and flood plain features such as swales, ridges, and channels, which can help indicate patch borders. Patch uniformity and size is easier to see in Figure 27, where photography years and island dynamics coincide better.

Some of the variance in age is due to aging errors, but most trees were intact enough so that the true age is no more than 2 or 3 years of the ring count on cores. Younger trees (greater than 20 years old) were excavated and sectioned, so ages are exact with few exceptions. The more-disparate ages within a patch are typically due to past beaver activity. To check the degree of age variance due to aging versus a real age spread, I sampled a large young island on the Salmon River near North Fork, Idaho. Here, the Salmon River is very similar to the South Fork in hydrology and morphology, except it is not dammed. The age variance of adjacent (less than 2 meters apart) trees was up to 4 years, and was typically 2 years.

The variance in tree ages makes a simple correlation of establishment years with discrete hydrologic events difficult. However, by looking at more than just tree ages and the discharge record, a definite pattern emerges. The age variance suggests that islands build gradually, perhaps during small floods. However, the spatial distribution of tree ages on islands indicates that patches with a relatively narrow range in age are quite large. This pattern shows in Figures 20, 27, and 28.

Despite the age variance, cottonwood-establishment years can indicate important hydrologic events. If island surfaces emerge suddenly and extensively, and cottonwood seedlings establish the year of surface emergence and a few years after that, the establishment year of the oldest trees should indicate the year that the bar surface emerged or stabilized. Bars emerge to island status when surfaces are above the normal high-water stage, or at least, flows no longer scour the bar surface and plants can survive longer than a few years.

Whether or not island surfaces emerge suddenly is obviously an important distinction to make. The clustering of similarly-aged trees in large intact areas suggest that it is indeed sudden. For example, aerial photographs show that surfaces created during the more recent, pre-dam period are quite large. Figure 27 shows typical, new-island surfaces that were formed in the 1940's. The oval- - and wishbone-shaped surfaces show in

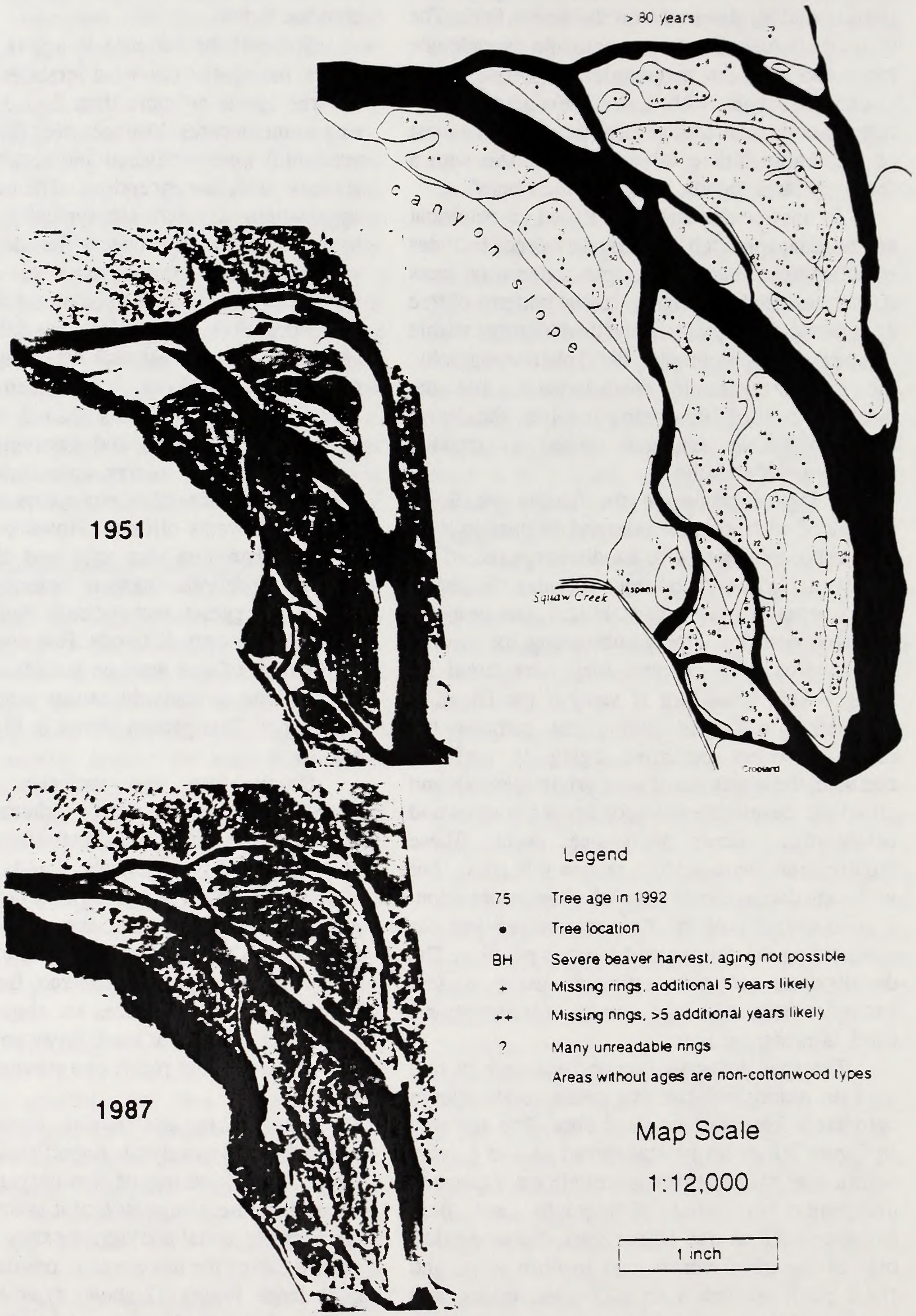


Figure 27. Island development near Squaw Creek confluence. Photography dates and discharges are: September 14, 1951, 7410 cfs (210 m3/s); April 22, 1987, 6420 cfs. New island surfaces of 1951 emerged in 1940's. Downstream is to the left.

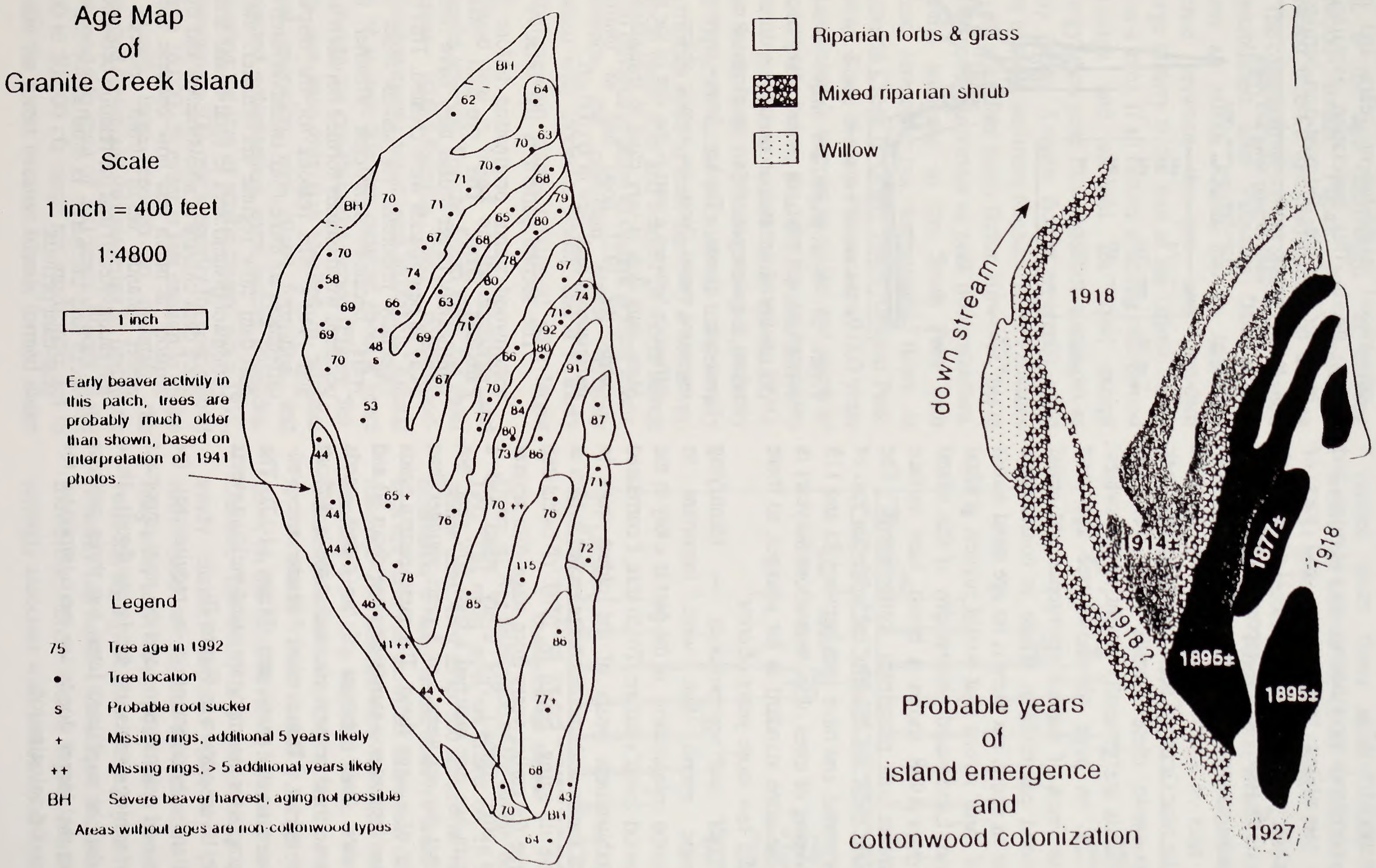


Figure 28. Cottonwood colonization patterns on Granite Creek Island. Trees less than 80 years old are more acurately aged. This island shows on Plate 13.

Figure 27 and are common throughout the study area (Plates 11 to 17).

Some islands have distinct rows of ridges and swales resembling the classic scroll bars of meandering rivers (Thornbury 1957; Leopold et al. 1964). If meander scrolls represent the gradual channel migration idea, one would expect a trend in tree ages on a series of scrolls. One island in particular near Granite Creek (called Granite Creek Island), shows these "scrolls" very well, and cottonwoods are generally absent in the swales. Figure 28, on page 40, shows tree ages and probable years of surface emergence and initial cottonwood colonization. There is considerable variance in aging, but there is no age trend across a set of three scrolls that would suggest gradual accretion. Land-based photography of this island taken circa 1908 shows a broad, bare surface downstream of prominent cottonwoods. The prominent trees are towards the upstream end of today's island, and have ages between 85 and 115 years. Aging of trees older than about 80 years is not to the same standard as for younger, so there may be a few more years of error.

*Floods and cottonwoods* — Identifying hydrologic events that were important to cottonwood colonization in the past is a key to the cottonwood forest's future. To do this, I correlated the establishment years of the oldest trees in uniform stands with the discharge record, which at the time of aging, began in 1910. (I calculated discharge for earlier years from stage data several months after aging.) Not every stand had a maximum age that matched a high flow year, but those that did not were 2 or 3 years younger than the year of a large flood. The same pattern holds for older cottonwood stands between about 80 and 125 years. Only vestiges of the oldest stands remain, so their original size and shape is difficult to reconstruct. These older stands are well-distributed in the study area (Plates 11-17). The hydrographs for the important island-building events since 1910 are shown in Figure 29.

Island development is a requirement for cottonwood colonization, and the most important island-forming events are the larger floods. How large will be explained later, but three patterns indicate that larger floods are more important for cottonwood colonization.

The first pattern is the association between cottonwood establishment years and relatively large floods. This association, explained above, holds for both pre- and post-dam periods.

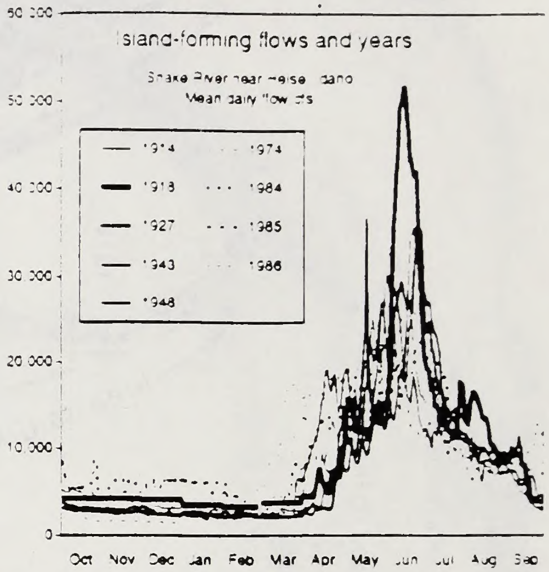


Figure 29. Hydrographs for major island-building events since 1910. Islands created after Palisades Dam closure are much smaller than most of those built before, but these post-1956 events created most of the post-dam islands. Thicker lines represent more important events. Note the similar shapes; the main difference between events is the size of the peak flow. Mean daily flow is very close to instantaneous flow, except the 1927 flood had an unusually-large instantaneous peak flow of 60,000 cfs.

The second pattern is the relative sizes of cottonwood stands originating before and after Palisades Dam. The pre-dam stands are significantly larger unless they have been eroded away as new islands were created. This erosion is especially important for stands older than 125 years, because significant channel migration occurred when islands formed between the 1890's and 1940's. The reasons for the disparate size differences are three-fold: islands created under the post-dam flow regime are smaller, the ratio of cottonwood-stand area to total-island area created since dam closure is also smaller, and flood plain erosion is much less now because the smaller, newer islands result from reduced channel migration. Recall that the relation between channel width and discharge is similar for the pre- and post-dam periods.

The third pattern, which follows from the second, is the age distribution of existing cottonwood stands. Figure 30 shows the cottonwood forest's age distribution on an area basis. The comparatively-small area of cottonwood that established after Palisades Dam closure indicates an effect. Recall that an important difference between the pre- and post-dam discharge history is the size of the largest floods (Figures 4 to 6). If all factors affecting cottonwood colonization and survival are equal except hydrology, then peak flow reduction stands out as a likely factor. Smaller floods apparently yield smaller islands. Sediment retention in the Palisades Reservoir is another likely factor. However, this is probably not as important as peak flow reduction. A natural analogue to the South Fork with sediment retention but unregulated flows is Cottonwood Creek in Grand Teton National Park, Wyoming. Since the late Pleistocene (9,000 years B.P.), sediment is trapped in a lake, but much of the flood plain below the lake has an extensive, regenerating cottonwood forest (Merigliano 1994). On the South Fork, livestock grazing is probably not an important factor because use has generally been constant since at least the 1940's. Moreover, on a local basis, size and density of recent stands bears no obvious relation to current grazing levels. In essence, the post-dam stands certainly originated with moderate floods, and it is likely that the pre-dam stands originated with larger floods.

Flood size is based on its discharge and recurrence interval. For the South Fork, the most important island-forming and cottonwood-colonization events are *at least* 36,000 cfs. Annual floods of at least this size recurred about 8 years apart during the pre-Palisades period (Figure 5b). Floods less than this size resulted in minimal channel migration, new island formation, and cottonwood colonization, even before Palisades. Considering the size of stands created since 1910, and assuming a 300-year longevity for cottonwood stands, a 36,000 cfs event is just enough to create new stands large enough to maintain the cottonwood forest, and this assuming an optimistic cottonwood life span of 300 years. Floods in the 45,000 to 50,000 cfs range are much more apt to maintain the forest because islands formed under this regime are considerably larger than those created under flows about 36,000 cfs. The recurrence interval for 45,000 to 50,000 cfs are 27 and 54 years, respectively (Figure 5b).

The recurrence interval for floods allows comparisons to other rivers. Bradley and Smith (1986) compared cottonwood recruitment and peak flows on the Milk River in Montana and Alberta, Canada. The Milk is a meandering river with sandy channel deposits (Bradley 1982), and cottonwood recruitment (colonization leading to long-term survival on point bars) correlated with years having a peak flow with a 2-year recurrence. (Bradley and Smith 1986). Scott and others (1993) found that floods with a 9-year recurrence was strongly associate with cottonwood establishment

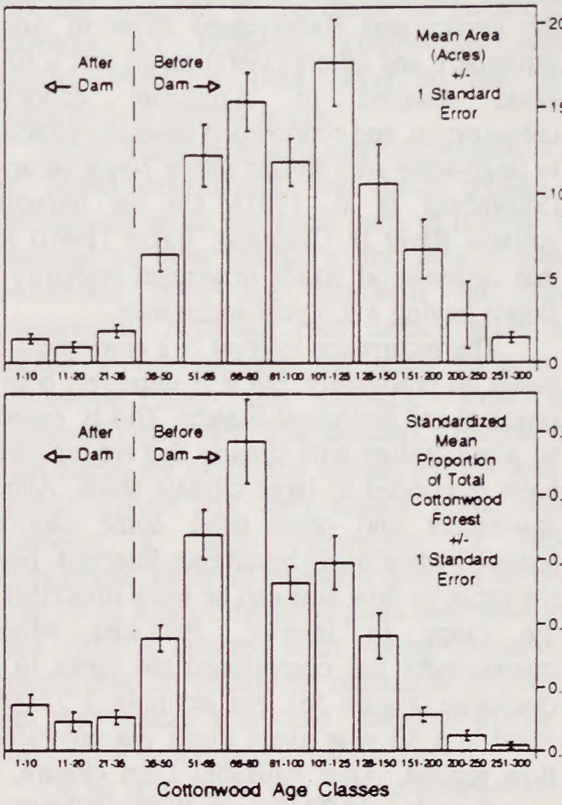


Figure 30. Age distribution of the cottonwood forest in 1993. The mean areas are based on 10 flood-plain sample units, each about 260 acres. The standardized distribution is based on the observed areas (acres) for each age class, but the effect of unequal class-width is removed. The standard error indicates the degree of sampling error in a statistical sense. The error bar indicates the confidence interval for the mean. For an approximate 95% interval, double the bar length.

on the upper Missouri River. The ratio of flood plain-to-channel width is wider on the Milk River compared to the upper Missouri. This differing ratio may reflect a difference in stream power to bank resistance, or overall stability, between the two rivers. Therefore, smaller floods may be adequate for cottonwood colonization on a less-stable river. Flows on the Missouri and Milk Rivers are regulated by dams and diversions. On the unregulated Hassayampa River in Arizona, Stromberg and others (1993) report that a 10-year flood resulted in significant cottonwood colonization, and cottonwood generally established in large-scale after floods with a 7-year recurrence (Stromberg et al. 1991). On the unregulated Animas River in Colorado, Baker (1990) found that cottonwood stands originated primarily with floods having a 3.6 year recurrence.

The recurrence interval is a convenient scale based on probability, but it is imperfect both in a physical and biological context. This is especially so when dealing with streams that are regulated or have responded to large climate shifts. Although convenient and often used, some caution is required when using recurrence intervals, because the range in flow size can be more important than the range in interval. Palisades Reservoir management has compressed the range in peak discharge (Figure 5b). For example, a 52,000 cfs flood is a 50 year event under the pre-Palisades flow regime. After Palisades Dam closure, a 50 year event is only 27,000 cfs. With similar channel dimensions, flow resistance, fluid density, and slope, stream power is proportional to discharge (Bagnold 1977). Bagnold showed how sediment transport rate and stream power are related in a general sense over long channel lengths and years, but his excellent relation breaks down under local and short-term conditions — especially under large floods.

On the South Fork, channel migration and island development becomes disproportionately large with a gradual increase in discharge. For example, for the cottonwood forest as sampled in 1993, the mean stand size for cottonwood stands created between 1918 and 1956 is over 4 times larger than the mean for stands created between 1956 and 1993. The difference is statistically significant ($p < 0.0004$). Assuming that cottonwood stand size is an indicator of channel migration and island-development, this is a drastic reduction. Recall that there should be a systematic reduction in older stands over time as new ones are created, but older stands are still much larger.

There are at least three possible reasons for the threshold, which seems to be around 36,000 cfs. First, local increases in stream power may be disproportionate to general stream power and discharge. Second, stream power may be indeed proportional, but bank resistance may decrease suddenly as water infiltrates the flood plain and weakens internal friction between particles (Thorne 1982). The resistance of channel bed deposits to fluid stress can vary too. Reid and others (1985) found bed material is looser and easier to move by a flood of given size if such a flood occurs a short time after a previous flood. Bed particles are naturally quite loose on the South Fork, so bank resistance is probably more important. Finally, and perhaps most important, shear stress on the bed and banks reaches a close balance at bank full discharge (Langbein and Leopold 1964). The estimated bankfull discharge for the pre-dam condition is about 40,000 cfs. This discharge has a stage that reaches the bank top of the old flood plain (e.g., see Figure 26). As defined earlier, the old flood plain is comprised of alluvium deposited between 1850 and 1956.

*After the flood* — The size of the flood is physically important, but the actual timing of flood events is more important biologically. Seasonal timing of flow is critical; falling stages should occur during seed dispersal so that bare substrates are moist. Fenner and others (1985), Bradley and Smith (1986), and Baker (1990) illustrate this importance. Baker also found that late summer and fall precipitation aided seedling survival. Besides the seasonal timing, the spacing in years between events can affect colonization. Large floods can remove very young seedlings, and a longer time between floods should allow seedlings to withstand larger floods. Flood plain aggradation and general vegetation establishment may also aid stability. This latter aspect has not been refined, but the shape of the falling limb of the hydrograph and its importance to seedling survival has.

Although large floods create the bare surfaces for seeds to germinate, declining stages must be gradual enough to insure seedling survival. Rood and Heinze-Milne (1989) showed how cottonwood forests can decline — even with no flood control — if there are rapid drops in stage during the colonization period. Their study did not establish a direct cause-effect between water table decline and seedling survival, but others have. Studies that tie seedling survival and growth to declining water tables (Mahoney and Rood 1991 and 1992; Segelquist et al. 1993) indicate that a 1 cm/day drop in stage appears optimum, while more than a 3 cm/day decline will probably cause significant mortality. A range in soil textures were used in these experimental studies; I weighed my estimates towards results based on sandy and gravelly soils. Figure 31 shows the actual decline in stage on the South Fork during the more important cottonwood establishment years. The optimum and marginal decline rates are superimposed for reference. Both rate-lines start at about 20,000 cfs, which is reasonable, but a shift in the timing of the peak moves these lines; the slope of the lines are more important for comparisons. The 1943 rate is quite steep; this may explain the rarity of trees dating to this year. The height of the island relative to declining flow stages is also important, but I have no data for this. I used the geometry for the Snake River at Dry Canyon gage (Merigliano 1994) to convert stage to discharge.

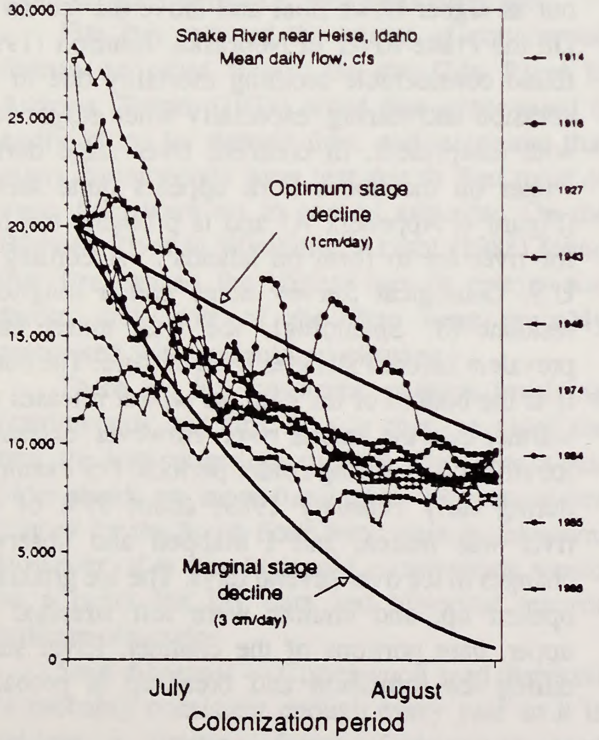


Figure 31. South Fork hydrograph falling limbs and optimum- and marginal-stage declines for cottonwood seedling survival.

Flows during subsequent years of initial island development may also be important. An important island-building year was 1918, and the next year was one of the driest on record (see Appendix A). However, cottonwood stands resulting from the 1918 flood do not show unusually low density today.

*Island topography and early colonizers* — So far, island development has been related to cottonwoods alone, but some parts of islands are colonized by other plants, so the area of young cottonwood does not represent all island development. Although reed canary grass and sandbar willow colonize the same surfaces as cottonwood, they also colonize areas that cottonwood does not. The dynamics behind this colonization are explained earlier, but the area of sandbar willow and reed canary grass, which represents a large proportion of island development, deserves attention now. As of 1993, about 25 to 30% of the flood plain that developed since 1956 is covered with young cottonwood (greater than 36 years); the remainder is covered with reed canary grass and sandbar willow in nearly equal proportion to each other.

On an areal basis, the ratio of cottonwood to other riparian types has changed since closure of Palisades Dam. On the pre-Palisades flood plain, the ratio of cottonwood to other riparian types is about 2:1; the post-Palisades ratio is 1:4.

One possible reason for the difference in ratio is that islands are building more gradually and at a lower elevation under regulated flows. Since Palisades Dam closure, surfaces at the critical height for cottonwood colonization are quite small, not only in respect to the flood plain as a whole, but in proportion to the total area of new islands. Cottonwood tends to survive on the highest parts of islands which may be created episodically in the "larger" floods occurring after the dam. Taking overbank deposits into account, the general height of islands created after Palisades Dam is about 3 feet lower than the general height of pre-Palisades islands.

The difference in elevation between island surfaces created before and after Palisades Dam is likely due to flow regime. The height of large sub-aqueous bed forms tend to be scaled to the depths that form them (Simons and Richardson 1966; Ashley 1978; Pitlick 1992). Large-scale bedforms take on many forms depending on flow and sediment conditions and had many names, but are simply called dunes now (Ashley 1990). If dunes, bars, and islands are formed under similar processes, then the height of islands should be scaled to the depth or stage of the river when the island is formed. I found no detailed work involving stage during island formation and island height (Figure 17, from Leopold and Wolman's work, is the best example). Interestingly, for the respective flows that probably formed the low and high islands on the South Fork, the difference in stage at most gage cross-sections is about 3 feet, which is the elevation difference between the low and high islands. Channel degradation is a doubtful reason for the elevation difference, for none was detected at the two gages downstream of Palisades Dam (Figure 10). The bed material at the gage sections is similar to the general bed material. Moreover, the higher bank resistance at these gages would encourage bed degradation at the gages compared to the channel in general.

Overall channel migration and stability indicate that islands tend to build suddenly during higher, less-frequent floods rather than gradually during many smaller, more frequent floods. If there was high channel migration during smaller, frequent floods, flood plain turn-over would be too high to allow the observed age distribution to exist. Furthermore, high amounts of channel migration with small and moderate floods would require high amounts of sediment transport in the channel. Channels with high sediment transport typically have noticeable, seasonal shifts in flow resistance; as bed forms change, form resistance changes. This is not evident in the hydraulic geometry for the Snake River except during very high flows (Merigliano 1994).

In essence, the main differences between islands formed after Palisades Dam and those formed before is that the new islands are much smaller, less elevated in respect to usual summer flows, and may have formed more gradually.

There are other factors related to cottonwood establishment and survival besides floods, sediment dynamics, and general flow regime. Although these other factors appear to be minor on the South Fork, they deserve some attention so that all likely factors are put in perspective. A brief summary of other factors related to cottonwood dynamics, which may be important concerns on other rivers, follows.

### Other factors related to cottonwood dynamics

Factors that may affect cottonwood dynamics besides those already discussed are ice, fire, cottonwood seed dispersal, and vegetative reproduction. Livestock grazing can be a factor; this is discussed later.

*Ice* — Ice can damage riparian vegetation, especially when it is young. Hansen and Suchomel (1990) describe a variety of ice damage, which seems especially prevalent on the Flathead River below Kerr dam (personal visit to Flathead River with Suchomel in 1993). Operation of Kerr dam causes widely-fluctuating river stages all year; in winter, ice can freeze around plants and tear them out as higher flows float and move the ice away. On the Platte River in Nebraska, Johnson (1994) found considerable seedling mortality due to ice abrasion and tearing, especially when stages rose with ice present. In contrast, river stage during winter on the South Fork appears quite steady (Figure 4, Appendix A) and is probably too low for river ice to form on islands[2]. According to U.S. Geological Survey notes and a long-term resident (S. Spaulding), ice was much more prevalent before Palisades Dam closure. The outlet is at the bottom of the dam, so winter releases are warmer than the natural river. However, extensive ice still occurs during colder periods. For example, during early February 1989, about 95% of the river was frozen, and I mapped and observed changes in ice over several days. The ice gradually opened up, and chunks were left stranded on upper, bare portions of the channel. River stage during ice formation and break-up is probably

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[2] The gage record during winter months is not complete, especially before 1925. Data for missing days were apparently filled in later. See various U.S.G.S. Water Supply Papers for details and Merigliano 1994.

more important than ice amounts. For winters with high ice amounts, Johnson (1994) found much less mortality when base flows were lower during ice formation and break-up compared to a winter with higher stages during these critical times.

Because of the cold climate, natural winter flows on the South Fork are relatively low and stable, and ice damage may not have been prevalent under the current climate. Ice jams can raise river stages and create high discharge surges upon break-up, but I found no evidence of this in the discharge record (but see foot note below) and anecdotal evidence from residents and historical records indicates that significant flooding due to ice is a rarity.

*Fire* — Fire is a minor disturbance on the South Fork flood plain. I found about 2% of the cottonwood forest had scars or mortality due to fire. With one exception, the forest was significantly reduced because mortality was extensive and vegetative reproduction was minimal to non-existent. Most burns were limited in extent; the largest was about 7 acres. Most fires occurred during the last 30 years, but this may be due to more difficult detection with increasing age.

Fire has reduced the extent of cottonwood forests on other rivers. On the Gila River in Arizona, Turner (1974) noted that cottonwood is easily killed by ground fires, and suggested that many cottonwoods were lost due to fire; most of these fires were set to control saltcedar. On the Bighorn River in Wyoming, Akashi (1988) found that fire caused the largest loss in cottonwood forest, and most of the fires were probably associated with agricultural clearing.

There are two consistent patterns involving cottonwoods and fire. One is that the older the tree, the less suckering potential. The other is that older stands are more flammable. The natural fire history for the South Fork flood plain is unknown. However, if it was high, old cottonwoods would be a rarity but my data and historical records indicate otherwise.

*Seed dispersal* — Cottonwood seed dispersal is probably consistent enough every year so it is seldom a limiting factor. Cottonwood seed dispersal was prodigious every year of the study (1991 -1994). In an informal test, I collected about 50 seeds in 1992, and all germinated and grew to seedlings on moist soil. In much more exhaustive work, Bessey (1904) showed how just one tree can produce nearly 28 million seeds in one year. Johnson (1994) trapped seeds on the Platte River, and cottonwood seed influx varied between 0.5 to 15 seeds per trap-hour in traps averaging about 2 feet$^2$. Observed gemination rates on moist surfaces for cottonwood seeds vary between 47% (Segelquist et al. 1993) and in the 90 to 97% range (Fenner 1984; Mahoney and Rood 1991; Johnson 1994).

Another indication of consistent viable seed for cottonwoods in general is the prevalence of very young seedlings on lower flood plain areas. For example, on the Milk River, Bradley (1982) found many young cottonwood seedlings on low portions of the flood plain, but felt that these trees were more apt to die from subsequent flood damage. Scott and others (1993) and Akashi's (1988) studies on the upper Missouri and Bighorn Rivers, respectively, found seedlings on similar surfaces. This seems to be common on sandy meandering rivers. Upon visiting these areas and comparing them to the South Fork, the lower flood plain supporting reed canary grass appears analogous to the low areas supporting young seedlings on the sandy-meandering rivers. Sedgwick and Knopf (1989) report seedling establishment in vegetated areas on the South Platte River — another sandy river — but their descriptions do not allow a comparison, and I have not visited the Platte. On the sandy rivers, seedlings probably colonize the low areas most years, but as indicated by the general forest age structure, do not survive more than a few years. On the South Fork, I never found young seedlings (1 to 3 years old) except on moist surfaces that were mostly bare. These seedlings established in 1991 after a flood of 23,000 cfs. However, this cohort only makes up about 0.2% of the cottonwood forest, and represents the lack of bare, moist surfaces suitable for cottonwood colonization in the last 5 years. The higher prevalence of young seedlings on sandy rivers may be due to channel shape. My impression from field visits is that on the sandy rivers, more active channel is exposed with falling discharges below bankfull compared to the South Fork which has steep banks. The difference in channel shape may also explain higher ice damage on sandy rivers. However, more work is needed to test these ideas.

*Vegetative reproduction* — Cottonwood reproduces vegetatively from roots and cut stems (Schier and Campbell 1976), and the vegetative sprouts are called suckers. Two taxa[3] comprise the South Fork population: narrowleaf cottonwood (*Populus angustifolia* James) and what may be lanceleaf cottonwood (*P. acuminata* Rydberg) (Hitchcock and Cronquist 1973). Both of these taxons produce suckers with or without disturbance such as fire or beaver cutting. With the drastic reduction in sexual reproduction from seed, vegetative reproduction becomes especially interesting from a management perspective.

In the South Fork population, sucker production varies from none to profuse; the highest measured sucker density is 805 live stems/acre. A stem is defined at ground level. Average density of live suckers on 31 plots is 143 stems/acre. Mean density varied by community type; the respective mean stems/acre for the *Populus angustifolia/Heterotheca villosa*, *Populus angustifolia/Elaeagnus commutata*, and *Populus angustifolia/Cornus stolonifera* community types is 161, 184, and 72. However, the within-type variances are high, and these differences are not statistically significant.

Despite these high sucker densities, few stems live long enough to become an important upper-canopy component. Most suckers have very suppressed growth rates, and branches tend to die after 5 to 10 years of growth. Dead standing suckers and decomposing remains on the ground indicate that mortality is high and continuous. However, some suckers live to maturity. The ideal condition appears to be when canopies are open enough for light, site moisture is high — indicated by understory species, and the parent tree is cut or burned when it is less than about 100 years old. Suckers that arise without apparent disturbance to the parent tree typically have low vigor. However, vigor seems to increase if site moisture increases. A good, accessible example of this is on the Osterkamp Ranch in Conant Valley near Route 26. Small patches of vigorous suckers are near small channels that have been backed up. These suckers are associated with very old trees on a low terrace. On the Yampa River near Hayden, Colorado, H. Richter has noticed higher and longer sucker survival in places with higher ground water (H. Richter, personal communication 1995 and personal field visit, 1994). Richter's study is still in progress.

The areal extent of suckers that reach maturity is very small, and I have never seen a closed-canopy forest of apparent sucker origin that is more than 2 tree-heights wide, either on the South Fork or other streams in the region. The highest proportion of stands that appear to be of sprout origin occur along the terrace-confined reach between Palisades Dam and Indian Creek. I identified sprout-origin or clonal stands by leaf phenology (bud-burst and senescence) patterns and by their clumpy nature. Some clumps are multi-aged, with the youngest stems toward the outside. Although common in some places, vegetative reproduction may not be a very promising way to perpetuate cottonwoods on a large scale for a longtime. If cottonwood sprouting ability was perpetual and extensive, it should occur as long-lived, expansive clones on old alluvial surfaces, especially those with low shrubs that do not compete with young suckers for light. More work is needed to further understand vegetative reproduction and its influence on stand and forest structure. Besides H. Richter, at Colorado State University, S. B. Rood, at the University of Lethbridge, Alberta Canada, has on-going projects related to this (S. B. Rood, personal communication 1994).

### Herbivory dynamics

The most obvious herbivores affecting riparian vegetation are beaver, moose, elk, cattle, mule deer and whitetail deer. Their general effects were discussed earlier; this section concentrates on cattle grazing. A detailed account of cattle grazing effects was not a study objective, but grazing is an important land management issue and interested managers requested information that I could provide. By pulling together varied experience and adapting it to South Fork plant communities, more insight may be gained. I combine my observations with others, including the literature and local range conservationists.

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[3] *Populus acuminata* is considered a hybrid between *Populus angustifolia* James and *Populus deltoides* Marsh and as such is written *Populus* x *acuminata* Rydberg. (Eckenwalder 1984).

The main variables related to grazing are climate, inherent site productivity, existing and potential species composition, palatability, duration and amount of use, and animal behavior. Every place has its own mix of these variables, and this is especially true for large rivers. Unless dealing with broad generalities, there is no other place in the world like the South Fork; the same can be said for other large rivers. Therefore, information from other places should be applied cautiously.

A common way to evaluate range condition is to compare existing species composition to what the site can produce at climax (Dyksterhuis 1949), but there are problems with this approach in riparian areas. Dyksterhuis considered communities with climax species composition as excellent, and those far from climax containing mostly invasive species and species that increase with disturbance as poor. Although falling out of favor recently, excellent, good, fair, and poor can be poor terms for describing range condition, for they imply that climax is better when it is just a successional stage of vegetation. Whether a community's condition is "good, "poor" etc. depends on natural disturbance agents and regimes, the resulting mix of successional stages, and management objectives. Dyksterhuis (1949) acknowledged the potential problems with his terminology, especially for sites that do not support grasslands or savannahs at climax, such as coniferous forests. For riparian areas such as the South Fork, where flooding is (was) a dominant natural disturbance agent and early-successional species are so prevalent, many communities would fall into the poor condition class.

A further complication in riparian settings is that sites can change with time in addition to the usual plant succession. Examples of this on the South Fork are discussed in an earlier section. Emphasis is now on communities that have reached a temporary successional plateau and make up most of the forage base. These are the communities defined by the gradient in species composition that occurs in mature cottonwood (about 35 to 125 years old). The species composition of these communities and their relation to site were also discussed. The section on succession and species:site relations (pages 26 to 38) is an important foundation for the following discussion on cattle grazing.

Given a particular site potential, its potential species composition becomes a reference point. For example, one should not expect red-osier dogwood (*Cornus stolonifera*) to occur on all flood plain surfaces, even without grazing. As demonstrated before, water availability, via soil factors, define understory species composition where grazing is not severe. However, there are places where grazing use is or was very high, and species composition was apparently affected. I now consider the range in grazing patterns and its affect on the various communities.

Most of the flood plain in the study area is Public Land administered by the Bureau of Land Management (BLM), while a much smaller portion is National Forest administered by the U.S. Forest Service. According to BLM records, cattle have grazed the flood plain since the early 1940's. Grazing probably occurred before this time, which is the beginning of record keeping and coincides with establishment of the U.S. Grazing Service in 1941 (Muhn and Stuart 1988). These records show similar permitted animal numbers and animal unit months (AUM) for existing allotments since record keeping. I assume that cattle numbers before record keeping were similar to today for BLM and Forest Service allotments. Considering settlement history (Horton et al. 1989), grazing probably began around 1900 in the more accessible areas. Spaulding's impression is that early ranching was largely subsistence (S. Spaulding, personal communication 1994). For cattle and horse allotments, BLM records show animal numbers between 15 and 120 animals for the South Fork allotments. There were two allotments with sheep, but sheep probably stayed on uplands. Although difficult to quantify with available data, cattle use levels seem to be about 5 acres per AUM (2 hectares/AUM); early use levels are the least certain, because the range staff was very low and compliance checks would have been difficult. Recently, some permittees have opted for non-use for the last 5 to 19 years, which allows for observing vegetation changes over a short term. A large proportion of the BLM allotments is on the flood plain, and a minor part is on steep adjacent hill-sides. The above animal density figures are approximate. Documented season of use was typically from May to September, which is nearly the entire growing season. Since 1992 or 1993, the BLM has restricted the use season to spring (May 1 to June 30) on active allotments.

*Grazing levels and indicators* — Kauffman and Krueger (1984) consider 1.35 acres/AUM as heavy stocking and 3.25 acres/AUM as light for western riparian range. With this rating, typical South Fork allotments are very lightly stocked. However, there are noticeable impacts from cattle in some places. These impacts include reduced shrub size and regeneration of red-osier dogwood — a very palatable species, and increase in weedy species such as Canada thistle *(Cirsium arvensis)* yellow salsify *(Tragopogon dubius)*, and dandelion *(Taraxacum officinale)*. With very high use levels, sandbar willow, silverberry, and cottonwood are also severely browsed. In my observations on the South Fork, cattle seldom browse cottonwood. However, cattle can heavily impact cottonwood if other forage is depleted or becomes less palatable (Smith et al. 1992). In Smith's study, animal stocking was 0.2 acres/AUM, which is about 10-times the usual level on the South Fork. Even large mature trees can be girdled and killed, especially when animals are confined (personal observation on other rivers).

For an indication of long-term grazing pressure, I compared the existing extent of the *Cornus* union to what would be expected based on micro-topography. In mature cottonwood (35 to 125 years), the thicker, finer-textured soils that support this union tend to occur in shallow depressions or swales. If red-osier dogwood *(Cornus stolonifera)* is largely absent from swales, I assumed that grazing pressure reduced it, especially if the few existing shrubs are heavily browsed. On the dry extreme dominated by the *Heterotheca* union, Indian rice grass *(Oryzopsis hymenoides)* is common where the surface has appreciable amounts (3 to 5 cm) of soil between the cobbles. This is a cool season grass and cattle prefer it. In areas with higher cattle use (e.g., islands near Woods Canyon), the drier sites were quite trampled and had more weedy species.

There is another gradient involving river birch and skunkbush that one could attribute to herbivory pressure, but other evidence tends to reject this notion. River birch *(Betula occidentalis)* is more common along the lower-Swan Valley and canyon reaches; this is the most conspicuous pattern within the study area. Below Heise, where topography lessens the effect of cold air drainage, birch is less common and skunk bush *(Rhus trilobata)* becomes more common. Cattle grazing is generally higher below Heise, and considering the low palatability of skunkbush, one could argue that birch and skunkbush are responding to grazing pressure. However, birch seldom shows signs of grazing, even in areas with higher grazing pressure; skunkbush is scarce in the cooler reaches, even where grazing pressure is high. If micro-climate is truly an important factor in birch and skunkbush occurrence, birch should be scarce on moist sites in lightly-grazed areas (if they exist) below Heise.

*Grazing season* — Assuming that calculated use levels are approximately correct, or at least consistently wrong, season of use becomes interesting. In addition to animal density and duration, vegetation responds to season of use. As mentioned earlier, most allotments were grazed season-long, and grazing impacts are generally high under this regime. For example, K. Rice and J. Gardetto documented high impacts on riparian shrubs near Pine Creek (BLM files, 5-Ways allotment). A reasonable estimate of use here is 2 acres/AUM. The time since the shift to spring grazing is too short to notice changes, but one allotment (near Falls campground) has been grazed in the fall (September and October) for the last 20 years and probably long before that (D. Hinks, personal communication 1995). Riparian shrubs, including red-osier dogwood, are robust in this allotment. A nearby allotment that has a similar mix of sites has less red-osier dogwood than would be expected. This area (Squaw Creek islands 1 and 3, Plate 1) was grazed in spring for many years until recently (D. Hinks, personal communication 1995).

If maintaining potential structure and species composition of riparian shrubs is important, fall grazing can be effective but risky. Once the herbaceous layer loses its palatability, cattle may shift to shrubs. For example, Kauffman and others (1983) found that cattle used the palatable elderberry *(Sambucus cerula)* and gooseberry *(Ribes* spp.) heavily, and use was often more than

100% of current years growth. The stocking rate in their study was about 3 acres/AUM. In general, cattle primarily used the herbaceous layer, but the common shrubs were Douglas hawthorn *(Crataegus douglasii)*, common snowberry *(Symphoricarpos albus)*, and Wood's rose *(Rosa woodsii)*, which are not very palatable, especially when mature (Kauffman et al. 1983). They also found light-to-moderate use on cottonwood and willow on young gravel bars. In contrast, the cattle I observed in September near Falls campground did not prefer shrubs, and the herbs and grasses were still moist within the *Cornus* union. The herbaceous layer was much drier in the *Elaeagnus* and *Heterotheca* unions. If the drier herbaceous layer is less palatable than the shrubs, shrubs may be more prone to browsing within these latter two unions in the fall. In his observations along Rainy Creek, Hinks noticed that cattle shifted their use from grasses to shrubs after the first hard frost (D. Hinks, personal communication 1995). Despite the risks, fall grazing may have merit for maintaining shrubs on the moister sites along the South Fork, and spring grazing is not risk-free. Recall that the Falls campground area has been fall-grazed for at least 20 years, yet, palatable shrubs are still robust, as well as a young cottonwood stand that is accessible to cattle. On the South Fork, riparian shrubs and trees are mostly dormant by mid-September, and mobile carbohydrates and other essential compounds have been transferred to the roots. Therefore, for a given amount of browsing, shrubs should be less impacted by browsing in fall than during May and June when they are growing. Spring grazing may be more detrimental within the *Heterotheca* union, because many of the species complete most of their growth and seed production by mid-July. However, conditions have improved on some allotments under spring grazing. These are below Heise on drier, warmer sites, and were grazed season-long before the restriction to spring grazing (K. Rice, personal communication 1995).

Although Kauffman and others (1983) noted high use levels on palatable shrubs in the fall, they only compared fall grazing to no grazing for 3 seasons. It would be interesting to compare the effects of spring versus fall grazing on riparian vegetation for several seasons under realistic grazing levels, for the differences may be subtle, cumulative, and chronic over long periods. I found no study that did this. A careful distinction should be made between grazing systems that include fall grazing, such as season-long, and fall-grazing as defined here where use is limited to the fall. Cattle browse more shrubs in the fall, as Myers (1989) indicates, but may be less apt to shift to shrubs in fall if they do not deplete herbaceous forage in the previous months.

*Long-term effects* — Seasonal grazing patterns of the native herbivores can give insight into what the vegetation is adapted to, but today's complement of native ungulates may be different than that of the past. Bison, pronghorn antelope, and bighorn sheep are mentioned more often and seemed quite common according to various journals of early explorers (e.g., Osborne Russell's). Today, elk, mule deer, and moose are the common species, and may use riparian habitat differently. Seasonal use patterns of bison and their preferences may be an important clue to proper management of livestock to maintain species and structural diversity on the South Fork and other areas. However, two introduced grasses, Kentucky blue grass *(Poa pratensis)* and redtop bentgrass *(Agrostis stolonifera* var. *stolonifera)* are quite common on the flood plain now, so response to grazing may be different than before. More on pre- European settlement conditions are found in Merigliano 1994.

Long-term effects are especially important in respect to recovery. Resilience varies by species and degree and duration of disturbance. For example, willow communities can respond differently to complete removal of grazing depending on the degree of use and damage in the past (Knopf and Cannon 1982). In their study of three riparian pastures, willow structure did not vary significantly with rest periods of 1, 2, and 4 years after summer cattle grazing. Most of the difference in structure was due to grazing practices that occurred over a decade before the study. Although all pastures were grazed most of the 12 summers before study, one pasture was grazed in summer for many years previous, and possibly at high stocking rates, while the other two pastures were used as winter feeding areas, and deep snow and supplemental feeding probably limited willow use. Willows in the pasture that was summer-grazed historically were further apart and had more dead branches and less live branches than the willows in the other two pastures. Structure was similar in these latter pastures despite a difference in rest of 3 years prior to measurement. Height class-distributions for the three pastures indicated that willows in the more-impacted pasture were still recovering from grazing practices that occurred over 12 years ago. Apparently, the willows in the winter-feeding areas were essentially ungrazed and robust enough to maintain their structure under high grazing levels (0.4 to 0.8 acres/AUM) for 12 years (Knopf and Cannon 1982).

Vegetation condition before grazing and long-term use may explain some differences in vegetation structure along the South Fork. Recall that if red-osier dogwood is largely absent from sites they would be expected on, grazing may be a responsible agent. This occurs on some island complexes that range between 35 to 75 years old, but adjacent, older areas (150 to 250 years) have robust red-osier dogwood, despite apparently equal access to cattle. In these particular places, cattle grazing began at least 50 years ago and perhaps 80 years ago. Consistent grazing for say the last 50 years may have suppressed development of dogwood and other palatable species on the younger part of the allotment, but the older part may have had well-established, robust shrubs at the onset of cattle grazing that could better-resist the same level of grazing. Community age does not guarantee absolute resistance to cattle grazing, however. There are many older stands that do not have a dogwood component that probably could have supported it.

Assuming that there are places that cattle have drastically changed vegetation structure and composition, recovery of these places to their natural potential demands some attention. Here are a few speculative ideas that may guide any future efforts. One situation is where riparian shrubs, especially red-osier dogwood, have apparently been eliminated. Expansive areas of older-cottonwood with hawthorn, juniper, and birch typify these places. Even if grazing is the cause, red-osier dogwood and other species requiring moist conditions may not re-establish by simply eliminating grazing. If there is no root stock left, the higher surfaces may be too dry for seed establishment for mesic species. Robust stands of riparian shrubs, including red-osier dogwood, occur on high surfaces (over 2 feet higher than the drier goldenaster sites in some cases[4]), but these shrubs may have established early in island history before overbank deposits increased the elevation.

Deep-rooted riparian shrubs and trees may increase moisture at the surface via their root system. These plants have deep roots to the water table and an extensive system of lateral roots. The net movement of water from deep sources to the upper soil profile via roots is called hydraulic lift (Caldwell and Richards 1989). This phenomenon was measured in sagebrush *(Artemisia tridentata)* which has deep and shallow roots, but root structure may not be the only requirement. Efflux of water from shallow roots occurred when stomates closed and drier soil had a lower water potential than the shallow roots (thus, water was drawn out of the roots). At least some riparian plants do not close their stomates (e.g., Williams 1989; Foster and Smith 1991), so water may still transpire rather than leave the roots. More work is needed to assess hydraulic lift in riparian plants and its possible effect on soil moisture. If hydraulic lift augments soil moisture in the upper soil profile, its elimination along with riparian plants may explain the loss of shallow-rooted, mesic species and lack of re-establishment of deep-rooted species via seed. Examples of this type of loss are described in Hansen et al. 1995.

### The cottonwood forest's future

So far, conditions up to the present (1993) have been presented. Using the relations between river flow events and vegetation dynamics, future conditions can be estimated. The following predictions assume that previous reservoir and land management will continue, and channel behavior will remain the same under the regulated flow regime.

Predictions include flood plain forest age structure, some likely successional trends, and physical characteristics of the river.

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[4] These dramatic cases involve a low terrace that formed around 150 years ago, which is about 1 foot high. Younger sites will be lower than sites on this terrace. See Merigliano 1994 for more detail.

Because the cottonwood forest is such a dominant component of the South Fork flood plain, and much of its structure and habitat quality depends on age, future age class distributions are interesting. Figure 32 shows these distributions 50 and 100 years from 1993. The present distribution is the same as in Figure 30, except the age classes were grouped into 50-year classes for easier comparison to the predicted distributions. The predicted distributions are derived from a dynamic model that tracks changes in compartments over time. The compartments are forest age classes on an area basis. Time steps are 50 years, and recruitment, erosion, mortality, and beaver cutting are factors affecting state levels (areas) of compartments over time. A flow chart showing model logic (Figure 33) is included in the methods section. Future age distributions are most sensitive to the existing age distribution. The reduction in cottonwood forest is more sensitive to mortality, beaver cutting, and erosion. I assumed that young islands would not erode until they were 50 years old. This is an optimistic assumption. The exact pattern of future erosion is difficult to predict, but young islands have eroded in the past, and Johnson and others (1976) noticed that erosion rates were highest for youngest forests on the Missouri River.

Many permutations of the model involving different mortality rates, beaver-cutting impacts, and differential erosion rates are possible. An optimistic one is presented. More pessimistic but realistic changes involving mortality rates etc. would hasten the shift towards older trees and reduction of the total cottonwood forest. In other words, even this optimistic scenario will not maintain the cottonwood forest, and there is a good chance the decline will be even faster than shown in Figure 32.

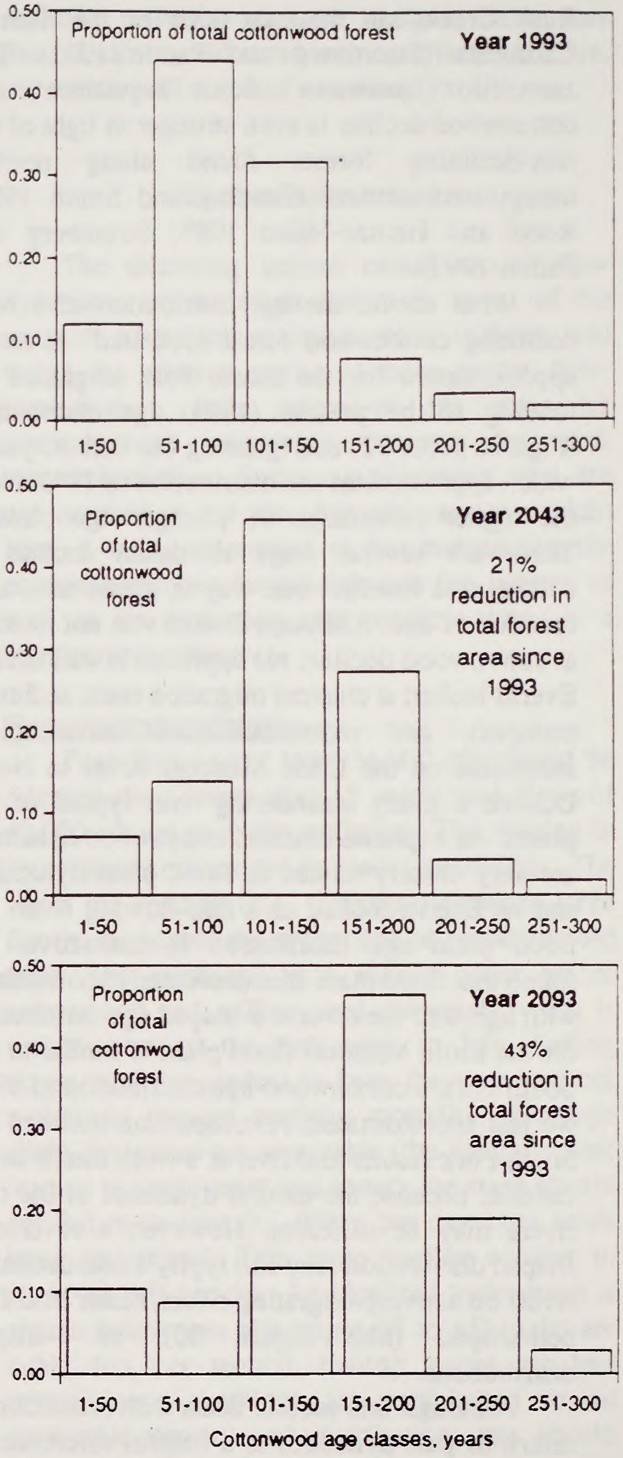


Figure 32. Cottonwood forest age distribution in 1993 and as predicted in 2043 and 2093. Distributions are on an area basis.

The decline of the South Fork cottonwood forest is not unique. Forest decline along several other streams has been documented; all involve some kind of flow regulation and most have flood control. Documented cases include the Missouri River in North Dakota (Johnson et al. 1976; Johnson 1992), the Salt River in Arizona (Fenner et al. 1985), the Milk River in Montana (Bradley and Smith 1986), St. Mary and Waterton Rivers in Alberta, Canada (Rood and Heinze-Milne 1989), the Rio Grande in New Mexico (Howe and Knopf 1991), South Platte and Arkansas Rivers in Colorado (Snyder and Miller 1991), Bishop and

Rush Creeks on the east-slope of the Sierras, California (Stromberg and Patton 1992). The association between flow regulation and cottonwood decline is even stronger in light of the non-declining forests found along nearby, unregulated streams (Bradley and Smith 1986; Rood and Heinze-Milne 1989; Stromberg and Patton 1992).

What should the age distribution of a non-declining cottonwood forest look like? A rough approximation for the South Fork is gained by looking at the present (1993) age distribution (Figures 30 or 32) and ignoring the first 50 years, which approximates the distribution in 1943. Note the higher percentage of younger age classes. There are several ways to detect decline in cottonwood forests; one way is to use area as a function of age. Although Everitt was not looking at cottonwood decline, his approach is still useful. Everitt looked at channel migration rates, sediment transport, and redistribution of flood plain sediments on the Little Missouri River in North Dakota, a sandy meandering river typical of the plains. As explained earlier, cottonwood dynamics are very closely related to flood plain dynamics, and as Everitt looked at a free-flowing river, his flood plain age distribution is instructive. He found that flood plain area decreased exponentially with age, and the reverse-J shaped age distribution for the Little Missouri flood plain is similar to the South Fork's cottonwood age distribution in 1943 we just approximated. A comparison between the South Fork results and Everitt's work merits some caution, because the natural dynamics of the two rivers may be different. However, a reverse-J-shaped distribution may still typify a non-declining forest on actively-migrating rivers, rather than flat, bell-shaped (like Figure 30), or J-shaped distributions.

Although this section deals with prediction, a return to past dynamics is a helpful reference. If islands are created and shaped during large floods, the age structure of the forest is shaped by the spacing of island-forming floods. One can imagine that the South Fork forest would have a higher proportion of young trees and bare islands a few years after very large floods. Early photography during the early 1900's, which followed a series of large floods, shows much less mature forest than today (Merigliano 1994). The hiatus in very large floods in the 1930's and 1940's (Figure 6) allowed trees to mature. The forest may have looked more like it did in the early 1900's today if flows were unregulated during the 1980's (Figure 6). Although large floods were probably more frequent in the past and young stands were more common, old stands were still present. In the 1840's Russell (Haines 1955) noted large cottonwood trees and so did the Hayden Survey in 1877 (Hayden 1879). The upper Snake River has probably supported cottonwoods for a long time. A pollen record from southern Yellowstone National Park indicates that cottonwoods were present in that area 13,000 to 15,000 years ago (Whitlock 1993).

As the cottonwood forest declines, other species and communities will become more prominent via succession and colonization. As old forest dies, mixed riparian shrub understories, which are on the moister sites, will become dominant. Present patterns suggest this. On drier sites, Rocky Mountain juniper *(Juniperus scopulorum)* will gain prominence and the lower stratum will have xeric grasses, forbs, and low shrubs. Juniper was common on the flood plain before fire suppression and flood control (Merigliano 1994); some of these trees are still living. Young islands will probably continue to have higher coverage of reed canary grass *(Phalaris arundinacea)* with initially-small stands of cottonwood and willow. Sandbar willow *(Salix exigua)* will likely invade reed canary grass stands as it has in the past, while cottonwood stands will remain small. Silverberry *(Elaeagnus commutata)* is quite common on young (15 to 30 years) islands and will probably maintain itself in the future. The future of red-osier dogwood *(Cornus stolonifera)* is less certain. Although it will remain on old flood plain for several decades at least, it may not dominate on islands formed since dam closure. This plant is scarce on today's young islands, but it is difficult to say if today's amounts will increase or remain scarce in the future. Robust and extensive dogwood stands occur on some flood plain areas greater than about 40 years. If islands formed since 1975 do not support some dense stands of dogwood by 2000 to 2015, site factors or grazing may be limiting dogwood expansion.

River birch *(Betula occidentalis)* is also very scarce on islands formed since Palisades Dam closure. It usually has a scattered, savannah-like distribution on older flood plain, but I do not know enough about its life history to make a prediction.

Other conifer species besides juniper are rare and most individuals occur on older (greater than 100 years) flood plain. Douglas-fir *(Pseudotsuga menziesii)* is quite common on adjacent uplands, but rarely establishes on the flood plain. Ages of mature individuals pre-date Palisades Dam, and seedlings are widely-scattered but rare. Blue spruce *(Picea pungens)* tends to be more scattered than Douglas-fir. Blue spruce is much more common above Palisades Reservoir and in some of the larger tributaries in the Snake River Range. Most of the spruce on the uplands are Engelmann *(Picea engelmannii)*, but these are very scarce on the flood plain. I estimate between 100 and 200 Douglas-fir and spruce in the study area. Given the present number and recruitment rate of Douglas-fir and spruce, succession to a conifer forest is extremely unlikely within the next two centuries unless the climate becomes cooler and wetter. Browse patterns indicate that ungulate use in winter may also limit conifer survival.

The gradual channel migration pattern will likely continue. However, there may be more dramatic shifts even under moderate floods (say 20,000 to 25,000 cfs) in some locales where the channel erodes through flood plain that blocks old channels. One example of this possibility is near the Falls Campground area. The main channel will likely shift to river-left, and as it cuts through an island (Plate 11, row E column 3), flows will enlarge the active side channels. One of these side channels may become the main channel. With this shift, gravel bars in the present main channel will be exposed and reed canary grass and possibly cottonwood and willow will colonize it. This may happen within the next few years.

As discussed earlier, net channel erosion will slowly occur due to sediment retention in Palisades Reservoir. The best place to monitor this is around Squaw Creek Islands, which is the beginning (furthest up-steam) of the more-easily moved alluvium below the Palisades Dam. Changes in channel width and braiding due to sediment retention are most likely to occur here first. If stability increases with net channel erosion, vegetation will respond accordingly.

## RECOMMENDATIONS

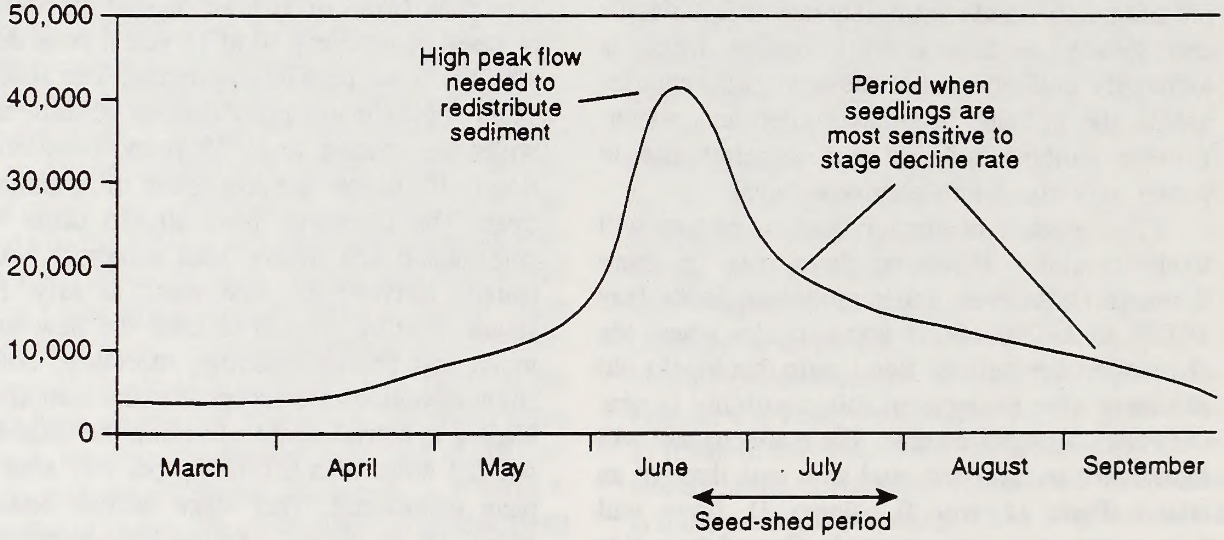
The following actions center around flow dynamics, which reflect the main thrust of the study. I also include some other options, and weigh the relative merits of these to the flow-related ones. Page references are given for rationale and supporting concepts for most recommendations. Some miscellaneous ones are not covered in the text, but are easy to explain here. A main assumption is that maintaining the cottonwood forest for wildlife and fish habitat, as well as its recreation and scenic values, is a management objective.

### Flow recommendations:

Peak flows of at least 36,000 cfs should be released about every 10 to 15 years; peak flows of 40,000 cfs are probably optimum. The spacing in years approximates pre-Palisades conditions. The wider the spacing (e.g., 25 years) between large floods, the higher the proportion of remaining old trees. The discharge peak should occur before cottonwood and willow seed dispersal, which is usually heaviest the first week in July. Falling stages must be gradual to keep the new surfaces moist and prevent seedling mortality. Although slight deviations are acceptable (the natural events leading to recruitment had some), the stage should not fall more than 0.1 ft/day per day after seeds have germinated. This stage decline equates to about 200 cfs per day. An idealized hydrograph is shown below (see also pages 41 to 45); units are cubic feet per second. Falling stages are less critical once seedlings are established to an acceptable density and distribution; this should occur within 2 or 3 seasons.

A peak flow of 38,000 cfs is about 8,000 cfs higher than what would likely occur under unusual circumstances with present reservoir management. The highest peak discharge since dam closure is 27,000 cfs. The gated outlet works of Palisades Dam can allow a combined discharge of 47,500 cfs when the reservoir is full. The spillway capacity adds another 48,500 cfs (USDI BOR 1961).

Although few developments would be threatened in the study area, there is more development downstream, and a flow of 38,000 cfs or more will likely cause problems. Some of the total flow can be routed through canals and ditches. Although preferable, the peak flow may not have to occur during mid-June as shown. As long as sediment is moved and new islands are built before seed dispersal, timing can be adjusted so that peak flow on the Henrys Fork and the South Fork do not coincide. A perfectly smooth falling limb may not be necessary, because natural flows associated with cottonwood stands were not. However, falling stages should be monitored so that new islands are kept moist during seed shed. The two key requirements are peak flows high enough to redistribute sediment and gradually-declining flows so that cottonwood and willow root extension can keep pace with available water.



Stage fluctuations when the channel is heavily-iced can damage young regeneration and should be kept to a minimum (page 45). Ice and its potential effect on vegetation is relatively easy to monitor from road-side vantage points. Thick, extensive ice is unusual on the South Fork.

Relaxing flood control will obviously be politically difficult and legally challenging. This study does not address these obvious difficulties, but in view of them, it would be easy to dismiss the "prescribed flood" approach in favor of manipulative techniques such as planting, channel re-construction, and other engineering feats. These other techniques may work, but the option of using prescribed floods should be kept open in case the other options do not. So far there is very limited experience involving planting and bio-engineering on large rivers. The coarse soils, braided channel, and general inaccessibility of the South Fork will add to the usual difficulty and expense. Some potential problems involved in planting and channel-reconstruction follow.

Some alternatives to prescribed floods:

Planting at-risk species such as cottonwood, sandbar willow and yellow willow is possible but will be expensive. Planting on a scale required for the South Fork has been done in California and Arizona. Costs for these projects are $3,000 per acre in California (using volunteer labor) and $99 per tree in Arizona, which at a minimum stocking level of 250 trees per acre is about $25,000 per acre. The California figure is more recent (T. Griggs, personal communication 1995) and is considered very cheap. The Arizona experience under Robert Ohmart, Arizona State University, is from about 7 years ago. All of this experience involves accessible, sandy deposits that are easy to dig in. The costs include planting stock propagation, site evaluation, planting, and irrigation.

Financial considerations aside, there are some ecological disadvantages and hurdles. Of primary concern is maintaining genetic diversity. Avoid using commercial hybrids, which may grow faster but are unproven for longevity. The safest bet is to use South Fork material because it is adapted to the local climate and other environmental factors. A major hurdle will be the actual planting. The cobbly soils will be very difficult to work with, especially with the usual hand-planting tools, including power augers. In my experience with tree planting, which is extensive, nothing comes close to the difficulties these coarse soils present. The higher the channel deposits are above the seasonal water table (see Figure 26, page 35), the more difficult planting will be to ensure survival. Replacing cottonwood mortality on old surfaces presents the most difficult planting scenario. Stock must be large enough to compete with existing vegetation, which is more competitive (especially for light) on the moister sites. Sparsely-vegetated sites offer less competition, but also less water. The areas dominated by reed canary grass have ample moisture and only shallow digging is needed. However, beavers will likely be a problem. Over the last 8 years, beavers cut most young cottonwoods at least 2 or 3 times near these areas. Planting stock must be robust enough to withstand stress from beaver. Fencing, stem protection, or trapping to eliminate beaver will add to the cost.

Seeding of bare, moist sites has been successful in the Mississippi River Valley (Johnson 1965) and near Boulder, Colorado (Friedman et al. 1995). Existing vegetation will have to be removed and the sites irrigated to ensure seedling germination and survival. Species diversity will obviously be lost unless they re-establish naturally or artificially. Past disturbances indicate that weeds, particularly Canada thistle, will probably increase to incredible amounts.

Channel re-construction is outside my area of expertise, but the degree of success is obvious given the cottonwood stands along constructed irrigation ditches. Options vary from cutting channels within the existing flood plain to creating new islands. Preserving the sedimentation sequence characteristic of fluvial environments will be difficult, so plant diversity which is related to sedimentation patterns may be lost. A common engineering approach is to scale the channel so that the larger dam releases behave like the larger natural floods. The South Fork would have to be narrowed to do this, requiring much earth movement. Also, the usual peak flows would have to be nearly halved to about 15,000 cfs, so that an infrequent dam release of say 25,000 cfs would have relatively high power. The hydrograph in most years would have to be greatly flattened to avoid flows above 15,000 cfs. Palisades releases have maintained a channel width that is similar to pre-dam flows, thus the channel may widen to what it is now without a large reduction in annual peak flows.

With enough money, time, and experience, some semblance of what exists today can probably be made. However, the degree of manipulation required may not be socially acceptable to at least some river users. An important question is not whether we can create a cottonwood forest via planting or other highly-manipulative methods, but whether we should. The South Fork native vegetation is virtually intact — a rarity on large rivers in the United States and other developed nations. The cure may be worse than the disease. Despite the potential drawbacks of planting, small-scale planting projects on representative sites (e.g., old alluvium devoid of cottonwood, reed canary grass patches on young islands) can indicate the degree of success better than my estimates, and are worth pursuing.

Grazing recommendations (pages 26 to 37, and 47 to 51):

This study was not designed to answer specific questions involving livestock grazing. Due to the complexity of sites and uncertain grazing history, I cannot offer firm recommendations for grazing. However, here are some suggestions that should help refine current practices.

Season-long grazing should be shortened to spring- or fall-grazing. Documented stocking levels are about 5 acres/AUM. This is considered a low level, but some areas still show moderate to heavy use on palatable shrubs such as red-osier dogwood. Effective stocking levels may actually be higher due to concentrated use in some parts of an allotment. Better animal distribution or re-evaluation of AUM's to reflect actual use will allow a better match between forage resources and animal use. Fall grazing has been successful on the allotment it occurs on. Timing of fall grazing should occur before herbaceous forage begins to cure, especially before the first hard frost. Fall grazing may be more successful on allotments with a higher-proportion of moist sites. Moist-site indicators are red-osier dogwood *(Cornus stolonifera)*, bearberry honeysuckle *(Lonicera involucrata)*, solomon-plume *(Smilacina stellata)*, sweet-scented bedstraw *(Galium triflorum)*, smooth scouring rush *(Equisetum laevigatum)*, redtop *(Agrostis alba* var. *stolonifera)*, and alkali muhly*(Muhlenbergia asperifolia)*.

Some species can indicate grazing pressure. Shrub regeneration is a useful grazing indicator. Red-osier dogwood and serviceberry *(Amelanchier alnifolia)* are palatable at all stages. Woods rose *(Rosa woodsii)* and hawthorn *(Crataegus douglasii)* seedlings are preferred by cattle or ungulates. These species normally regenerate without disturbance, and seedling absence or severe damage can indicate trends. The Snake River management plan lists tufted hairgrass *(Deschampsia cespitosa)* as an indicator of forage use. This species should not be used to assess forage use because it does not occur (or is extremely rare) along the South Fork, even in places that have not been grazed for decades.

Relative amounts of native and non-native species can be helpful indicators of grazing use. The most common native grasses are western wheatgrass *(Agropyron smithii)*, reed canarygrass *(Phalaris arundinacea)*, needle-and-thread *(Stipa comata)*, Virginia wildrye *(Elymus virginicus)*, and American mannagrass *(Glyceria grandis)*. There is some Canada bluegrass *(Poa compressa)* intermixed with Kentucky bluegrass in some locales. This species is native to the region and seems to be ecologically similar to Kentucky bluegrass *(Poa pratensis)*. There is a considerable amount of the non-native Kentucky bluegrass and redtop *(Agrostis alba* var. *stolonifera)* on mesic sites. It is difficult to say what native species these two species replaced. These two species are common in places with little grazing history, so their amounts are not good indicators of grazing use. The native alkali muhly*(Muhlenbergia asperifolia)* is minor in extent but well-distributed on moist sites; it reaches full development later than the other grass species. It still occurs in areas with late-season grazing. The native Indian rice grass *(Oryzopsis hymenoides)* is common on the drier sites, but appears to be a decreaser. It is most palatable in early-summer. Smooth brome *(Bromus inermis)*, timothy *(Phleum pratensis)* and orchard grass *(Dactylis glomerata)* are exotic pasture grasses; they are apparently more common on mesic sites where livestock use is higher.

Miscellaneous recommendations:

On the South Fork, fire played a very minor role in shaping riparian vegetation in the past. Unlike aspen, fire often reduces cottonwood forests (see page 46). Older stands are more flammable and less apt to regenerate after fire. Campers typically prefer older, more open stands. Fire risk is highest in early spring before green-up. Fire should not be encouraged on the flood plain.

There are a few exotic species that are scarce now but may become problematic in the future. One is Russian olive *(Elaeagnus angustifolia)*, a tall shrub or tree commonly used for windbreaks. It is more common below the study area, where is found on a variety of sites including young islands. It may be ecologically similar to the native silverberry *(Elaeagnus commutata)* and may compete with or displace this species as well as others. It is quite common on Kelly Island, but becomes rare a short distance upstream from there. Its distribution should at least be monitored so that invasion into new areas can be prevented. The other species is leafy spurge *(Euphorbia esula)*. This deep-rooted forb is notoriously difficult to kill and most are familiar with it. Spurge patches occur throughout the study area, especially on canyon slopes. It also occurs sporadically on the flood plain, including young islands. Current efforts to control spurge should be continued.

Finally, the general public's priorities pertaining to the river and riparian resources should be assessed, and they should be informed about present and potential problems related to the South Fork. Rivers connect many kinds of places, but tend to split people with differing values and situations. The ultimate barrier to maintaining this ecosystem is not the Palisades Dam, but the potential lack of cooperation among us. Efforts should be directed towards public awareness through education, keeping in mind that education should go both ways.

## METHODOLOGY

The following is an outline of the most important methods. A complete treatment for the hydrologic and geomorphic analysis is in Merigliano 1994; only the bare essentials and new extensions are mentioned here. Methods pertaining to riparian vegetation dynamics are treated more completely; minor details that are important for repeatability are in Merigliano 1996.

### Hydrology

Data for the observed mean daily flows from 1910 to 1990 are from a CD-ROM of the U.S.G.S. record (Earth Info 1991). Instantaneous annual peak flows for 1914 to 1989 are from published U.S.G.S. records; earlier values are obtained from a regression. Data for 1990 to 1994 were supplied by the Bureau of Reclamation (B.O.R.) and U.S.G.S. Flows for 1903 to 1909 are from the Lyon gage record, which is similar in flow characteristics to Heise. Discharge at Lyon for 1903 to 1908 was obtained from published gage heights and a rating curve I fit to published width, depth, and velocity data. Discharge is published for 1909. I used standard U.S.G.S. methods for flow duration curves (Searcy 1959) and flood frequency analysis (Dalrymple 1960). Unregulated flows were reconstructed using observed mean daily flows at Heise and daily storage data for Jackson Lake and Palisades Reservoirs. As per B.O.R. recommendations, travel times are 1 day for Jackson Lake to Heise and same day for Palisades to Heise. Storage for Jackson Lake reservoir before 1918 was derived from published gage heights and unpublished notes from the U.S.G.S. and a rating table supplied by the B.O.R. I accounted for the change in reservoir geometry in 1917 when the outlet was dredged. I used a 6th-order regression equation to represent the rating table; correlation transformation (Bowerman and O'Connell 1990) eliminated bias due to collinearity.

Suspended sediment analysis follows Williams (1989); I normalized the data (all ranges converted to 0 to 1) and then adjusted scaling so that original units fit the normalized shapes. Normalization is important to check skewness and relations between the various curves. Hydraulic geometry analysis follows Leopold and Maddock (1953) and Rhodes (1977). Channel width changes were derived from aerial photography and U.S.G.S. discharge measurement notes. Bed-elevation changes are derived from U.S.G.S. discharge measurement notes.

### Riparian vegetation

Flood plain vegetation mapping is based on enlarged 1987 color aerial photography and is 100% ground-truthed. Enlarged representative fractions ranged between 1:3360 and 1:6720. Vegetation cover types were delineated as they occurred in 1993 and 1994. Corrections due to channel shifts since 1987 were made using Agriculture Stabilization and Conservation Service compliance photography flown in 1993. Minimum mapping unit size was approximately 0.01 acres. I mapped cottonwood forest canopy gaps if they were greater than about 1 tree-length wide.

Sampling of cottonwood and flood plain ages was two-tiered. The purpose for the first was to gain an understanding of bar and island development and to correlate hydrologic events with cottonwood establishment. For the second tier, the entire flood plain from Indian Creek to the Heise gage was sampled to determine the age distribution of the entire cottonwood forest between these two points. Island complexes were sampled first, and understanding of cottonwood stand structure and island development gained from this spatially-intensive sample was applied to the second, more-extensive sample. Riparian cover types were delineated during cottonwood forest aging.

For the island-complex sample, sample areas were selected from a list of 22 island complexes. Listing criteria was a broad range in tree stand ages up to about 80 years old (estimated from aerial photography and field visits), and no major disturbance that would confound tree-age and flood-plain age interpretations. The area for each island complex varied, but all were defined by major active channels, flood plain obviously older than 100 y, or uplands. Unless a patch was very small, 4 trees within a uniform patch of cottonwoods were spaced systematically within a patch and marked on enlarged aerial photos. I aged these marked trees, or the closest acceptable stem in cases were stem-rot or other obvious damage precluded accurate aging. Obvious root suckers were not selected except when I needed to ascertain stand structure. Patch uniformity was based on aerial photography (1941 and 1987), tree height and bark characteristics, and flood plain microtopography. Trees between 20 and 80 years old were cored as close to the original root collar as possible; excavations were typically between 0.5 and 1.5 feet. I used a 0.5-inch diameter increment corer 18 inches long. Younger trees were excavated and discs were cut out at the root collar. I mounted increment cores on pre-grooved boards and sanded the cores before counting rings. The aging process was iterative. After the original set was aged and mapped, more trees were aged in places where island development and cottonwood stand boundaries were unclear. I aged 11 island complexes; several listed ones were rejected due to excessive age. I did not complete one of the listed areas (#7 — see Plate 1)) due to equipment problems and logistics; this deleted area was not unusual and similar in many respects to sampled areas.

For the extensive sample of cottonwood forest age distribution, 20 equal-sized flood plain sections were delineated and listed. Ten of these were randomly selected. The sampling design was a one-stage cluster sample. Statistical assumptions follow this design. Trees were selected in a similar manner as in the island complex aging, except trees were not excavated and core height was typically 1 foot above ground, and selected trees were typically spaced further apart. One year per foot of core-height above the ground surface was added to the core age. Trees less than 10 years old were ocularly estimated using field characteristics, past experience, and aerial photography. Precise aging was not as important in this sample, because stands were placed into age classes. The age classes are 1-10, 11-20, 21-35, 36-50, 51-65, 66-80, 81-100, 101-125, 126-150, 150-200, 201-250, 251-300. The older the stand, the more difficult it was to find its boundary. These intervals allowed consistent and convenient placement of stands into a class.

The cottonwood aging samples are shown graphically on Plate 1, and the sample selection is summarized. Total trees cored is 1285, with 698 to define island development and flow event: cottonwood establishment relations. The cottonwood forest age distribution is based on 1074 aged trees and 897 acres of sampled forest. There is some overlap between areas selected for the two samples. Conifers were aged to see how their time of origin relates to flow regulation and stream deposit age.

Predictions for cottonwood forest area and age distributions are based on a dynamic, compartmental model incorporating the observed, existing distribution, erosion and deposition under current reservoir management, and estimates of beaver cutting and mortality due to old age. The compartment unit is area, and time steps are 50 years. Mortality due to stand thinning is not considered; mortality means there are no trees left on an area. Figure 33 shows a flow chart of this model.

Field sampling of cottonwood understory vegetation involved tree aging as in above, vegetation sample plots, soil samples, and in some places, topographic surveying and plant moisture stress.

Vegetation sample plots were rectangular and 50 meter$^2$. I used a combination of relevé and transects to place plots. The relevé approach, where representative areas of stands are selected for sampling, insured that important stands of small areal extent (the *Populus angustifolia/Heterotheca villosa* type) were selected. I used the relevé approach for selecting typical stands dominated by either *Cornus stolonifera, Elaeagnus commutata, or Heterotheca villosa.* Relevé plots totaled 9. I used transects with equally-spaced plots to more closely look for possible gradients orthogonal to the channel. Transect plots totalled 22. All plots (31) were combined for classification and gradient analysis. Plot data included canopy cover by species, cottonwood stem density and diameter at breast height, and basal area of cottonwood stems at breast height. I used a densiometer to measure cottonwood canopy cover, and ocularly estimated shrub and herbaceous species canopy cover. I estimated shrub cover at once for the entire 50 m$^2$ plot. Herbaceous cover was estimated in five 0.1-microplots placed systematically across a plot diagonal. I closely followed Daubenmire (1959) for defining individual plant cover and cover classes. I modified the class interval to include trace coverage between 0 and 1 percent.

I collected soil samples from a pit dug at plot center. All overbank deposit horizons were represented with a sub-sample of about 150 grams. Channel deposits (cobbles, pebbles, and sand) were collected from some plots with deep overbank deposits and all plots with channel deposits near the present surface. I followed Day (1965) for texture analysis, except to calculate percent sand, silt and clay. For this I used formulas from individually-fit curves to observed cumulative particle size distributions. This is conceptually-similar but more accurate than Day's graphical technique. After passing the sample through a 2-mm sieve, I removed organic matter with hydrogen peroxide before texture analysis so that organic matter would not confound the relation between the texture of original stream deposits and species composition. The texture index of the overbank deposit is based on the following formula:

$$TI = \sum_{i=1}^{n} \left[ \frac{t_i}{d_{g_i}} (d_i) \right] \qquad (1)$$

where:

$TI$ = texture index
$d_{gi}$ = mean particle diameter, microns
$t_i$ = horizon thickness, centimeters
$d_i$ = depth to bottom of horizon from surface, cm

The geometric mean particle diameter ($d_g$) for a horizon is:

$$d_g = \exp\left[ \left( \sum_{i=1}^{n} w_i \log x_i \right) \Big/ \left( \sum_{i=1}^{n} w_i \right) \right] \qquad (2)$$

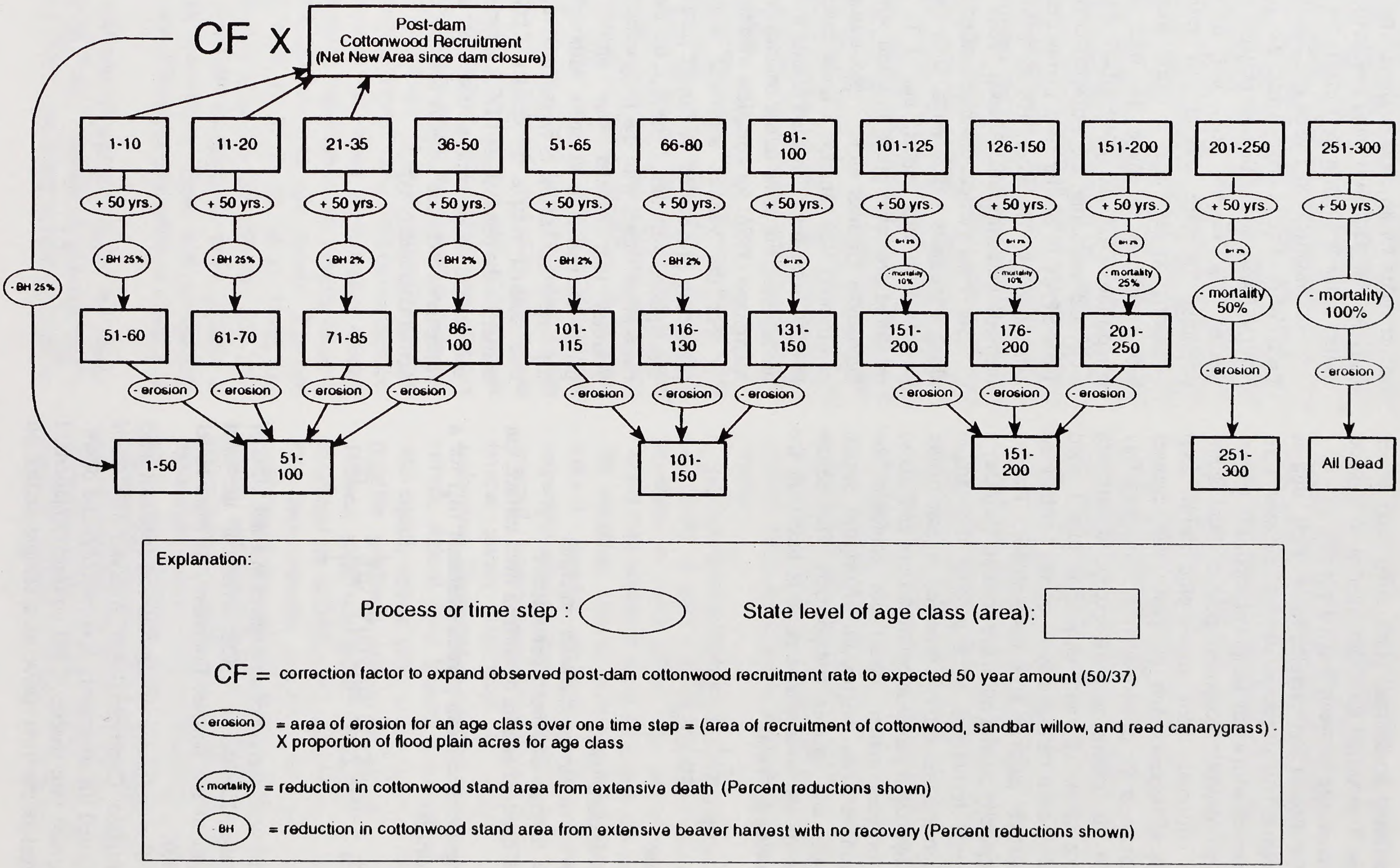
where $w_i$ is weight of aggregates in a size class of average diameter $x_i$ The divisor is the total weight of the sample. Equation 2 is from Hillel (1980).

For ordination of samples and species I used Detrended Correspondence Analysis (DCA). I ordinated the understory species only, and down-weighted rare species. I did no transformations. I regressed the first DCA axis sample scores on texture index for an unconstrained direct gradient analysis. The gradient is water availability, and the texture index is a surrogate variable for this.

For classification I used the complementary Two-Way-Indicator-Species-Analysis (TWINSPAN), and again used only the understory species. TWINSPAN does not allow down-weighting of rare species, so rare species (occurring on less than 3 plots) were deleted before analysis to make the data sets more comparable. DCA and TWINSPAN are based on reciprocal averaging; the extracted coenocline of TWINSPAN is similar to a non-detrended, first axis of DCA. Therefore, results from the two methods are comparable (Gauch 1982).

Surveyed transect distance totaled 6,932 feet along 4 transects and 22 plots. Only one transect is shown in this report, but it is typical. I measured pre-dawn plant moisture stress with a Scholander chamber along 3 plot-transects. Each plot-transect was sampled 5 times from late-May to early September. Detailed results from this are not reported, but some minor conclusions are. See Merigliano (1996) for complete treatment.

For the various statistical tests, I used parametric procedures. Although parametric test assumptions were met, I checked the independent, two-sample t-tests with the nonparametric Mann-Whitney test. Results were similar. I report parametric results in all cases. Although I assume my vegetation sample is representative, it is not a true random sample by design. This does not matter for the regression of DCA sample scores on soil texture index, but it does for my test of differences between cottonwood sucker density across community types.



Explanation:

Process or time step :

State level of age class (area):

CF = correction factor to expand observed post-dam cottonwood recruitment rate to expected 50 year amount (50/37)

- erosion = area of erosion for an age class over one time step = (area of recruitment of cottonwood, sandbar willow, and reed canarygrass) - X proportion of flood plain acres for age class

- mortality = reduction in cottonwood stand area from extensive death (Percent reductions shown)

BH = reduction in cottonwood stand area from extensive beaver harvest with no recovery (Percent reductions shown)

Figure 33. Schematic of the model for predicting cottonwood forest age distribution

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## APPENDICES

## FIGURES

## TABLES

## Appendix A. Annual hydrographs showing observed and reconstructed natural flows for South Fork Snake River .

Note: The pertinent stream-flow record begins with South Fork Snake River near Lyon, Idaho in 1903. The earliest Jackson dam was built in 1905, but promptly washed out (Palmer 1991). The U.S. Geological Survey records state that the earliest dam was built in 1906. These early dams were log-crib, and useable storage capacity was 300,000 acft from 1906 to 1910. The l906 dam washed out in July 1910, and a larger earth-filled dam soon replaced it, increasing storage to 380,000 ac-ft. The earth-filled dam was raised in 1916, and storage increased to 790,000 ac-ft. Dredging in 1917 further increased storage to 847,000 ac-ft. The reservoir storage record begins in 1908.

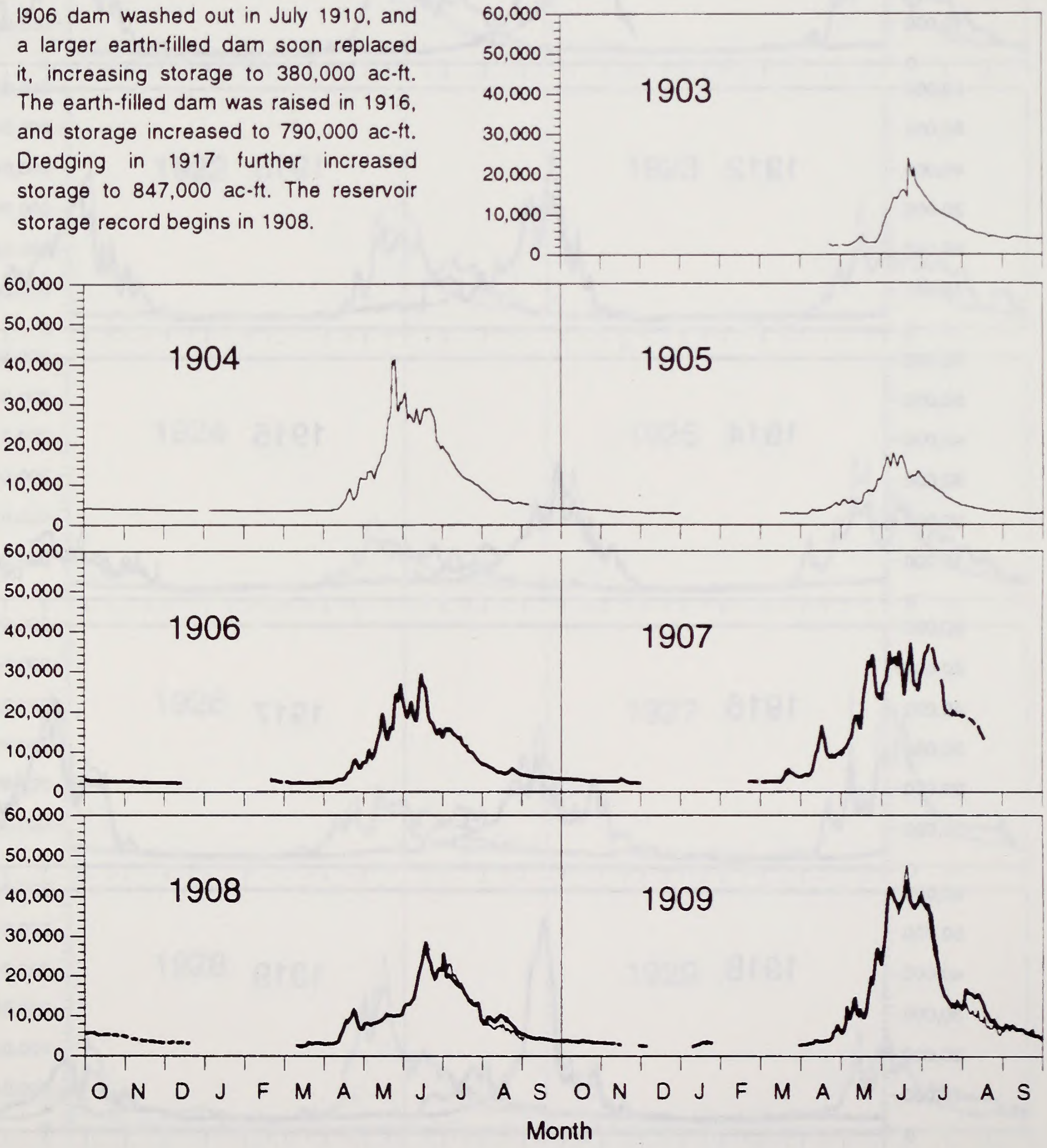


Figure A1. Mean daily discharge, cfs, at Snake River near Lyon, Idaho, for water years 1903 to 1909. Thick line is observed flow. The thin line is natural flow in 1903 to 1905, or reconstructed unregulated flow accounting for storage in Jackson Lake reservoir in 1908 to 1909. Effect of Jackson reservoir storage on flows is unknown for 1906 and 1907. Flows at Lyon are about 1% less than those at the Snake River near Heise, Idaho gage. The Heise record is used for the later years.

Appendix A. Annual hydrographs showing observed and reconstructed natural flows for South Fork Snake River — continued.

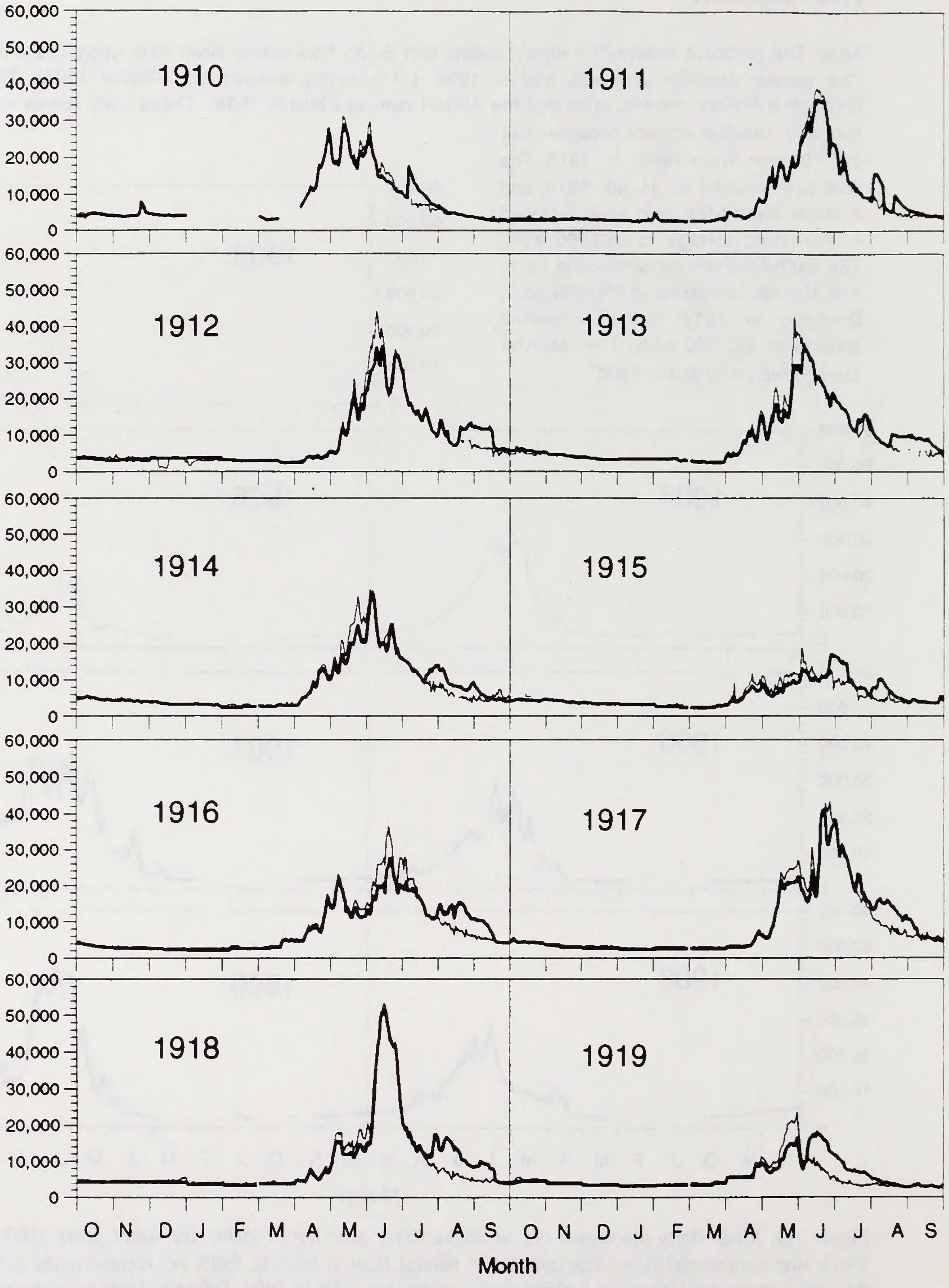


**Figure A2. Mean daily discharge, cfs, at Snake River near Heise, Idaho, for water years 1910 to 1919. Thick line is observed flow, thin line is reconstructed unregulated flow accounting for storage in Jackson Lake reservoir.**

Appendix A. Annual hydrographs showing observed and reconstructed natural flows for South Fork Snake River —continued.

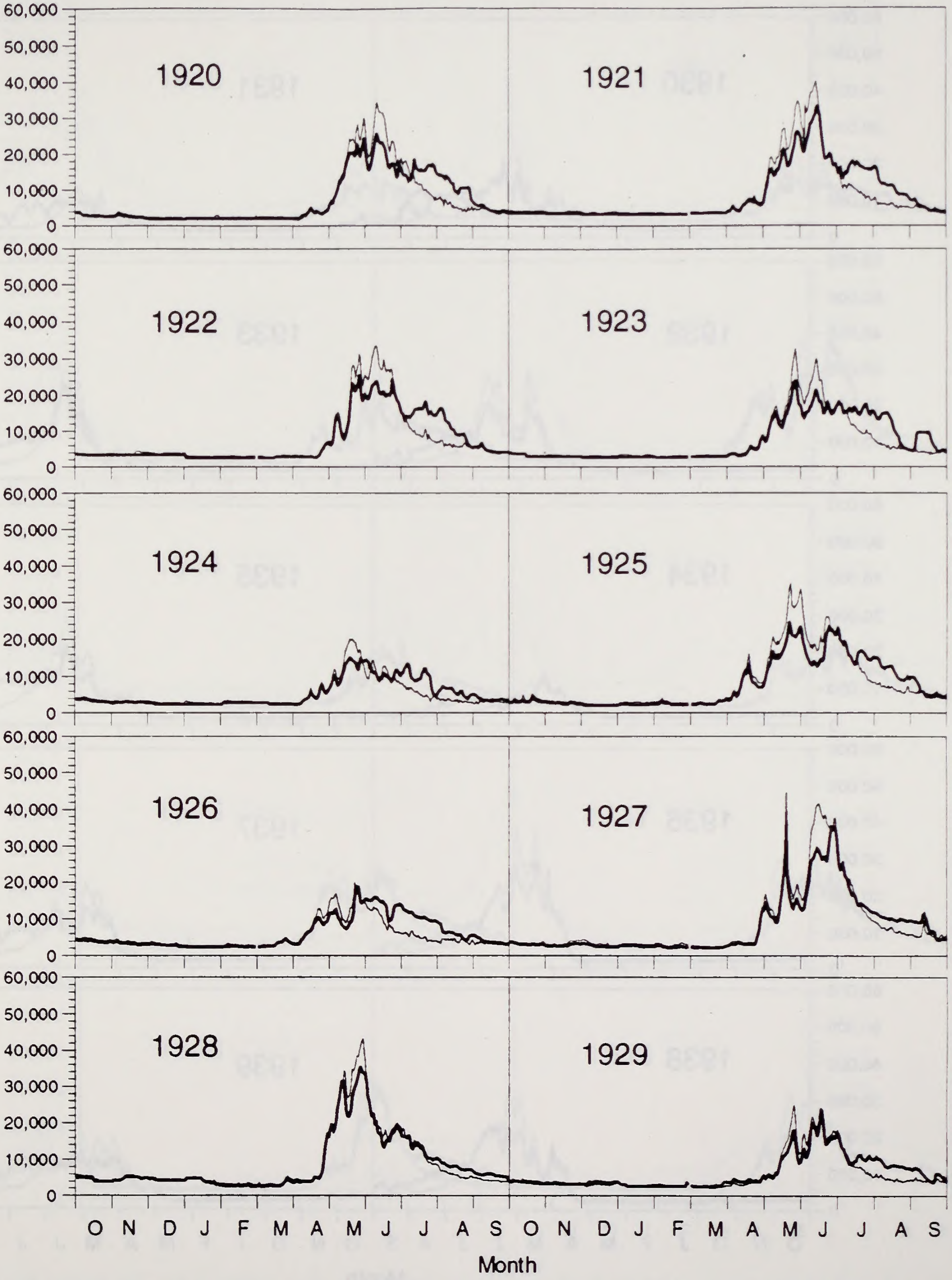


Figure A3. Mean daily discharge, cfs, at Snake River near Heise, Idaho, for water years 1920 to 1929. Thick line is observed flow, thin line is reconstructed unregulated flow accounting for storage in Jackson Lake reservoir.

Appendix A. Annual hydrographs showing observed and reconstructed natural flows for South Fork Snake River — continued.

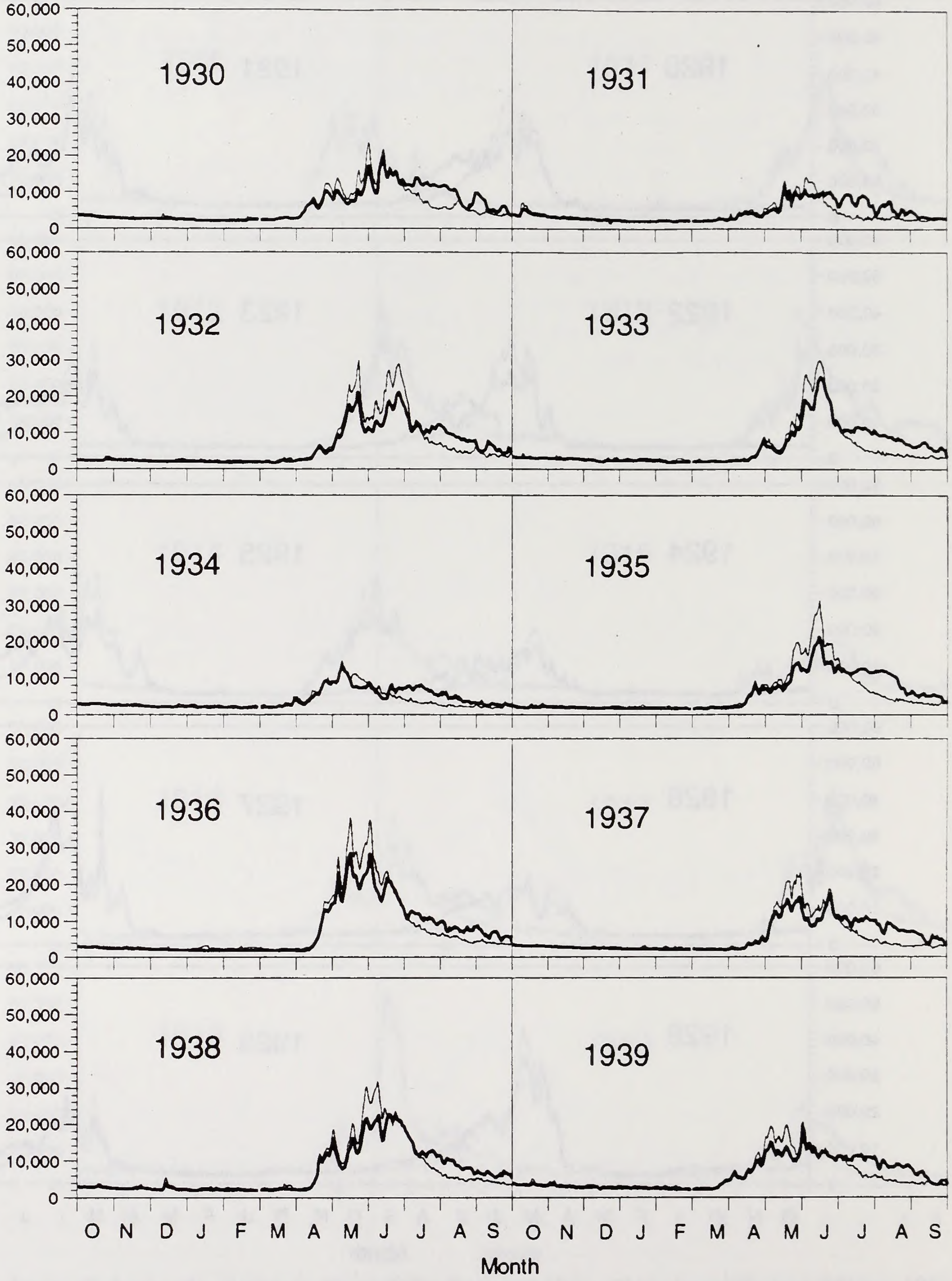


Figure A4. Mean daily discharge, cfs, at Snake River near Heise, Idaho, for water years 1930 to 1939. Thick line is observed flow, thin line is reconstructed unregulated flow accounting for storage in Jackson Lake reservoir.

Appendix A. Annual hydrographs showing observed and reconstructed natural flows for South Fork Snake River — continued.

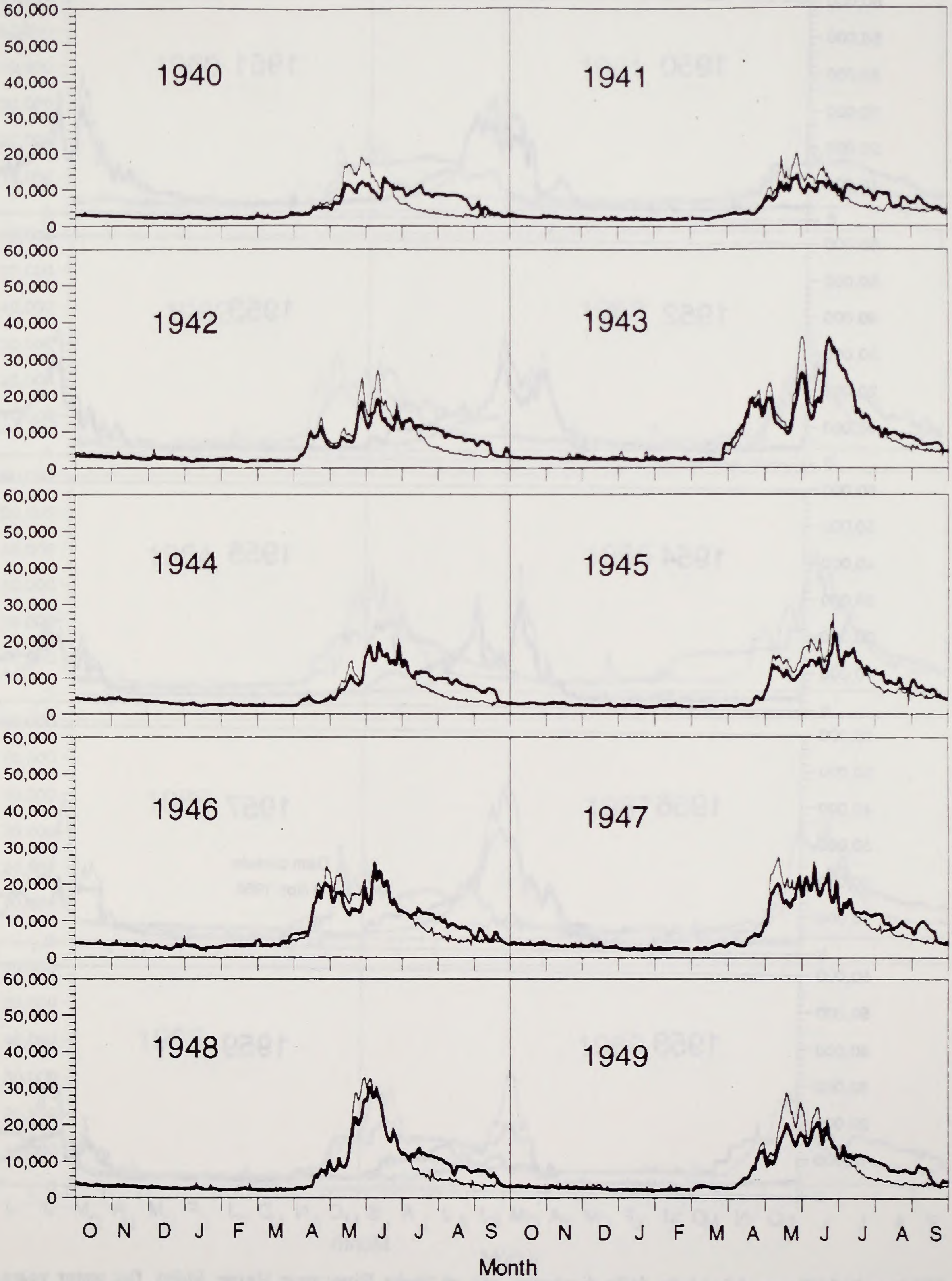


Figure A5.Mean daily discharge, cfs, at Snake River near Heise, Idaho, for water years 1940 to 1949. Thick line is observed flow, thin line is reconstructed unregulated flow accounting for storage in Jackson Lake reservoir.

Appendix A. Annual hydrographs showing observed and reconstructed natural flows for Snake River near Heise, Idaho — continued.

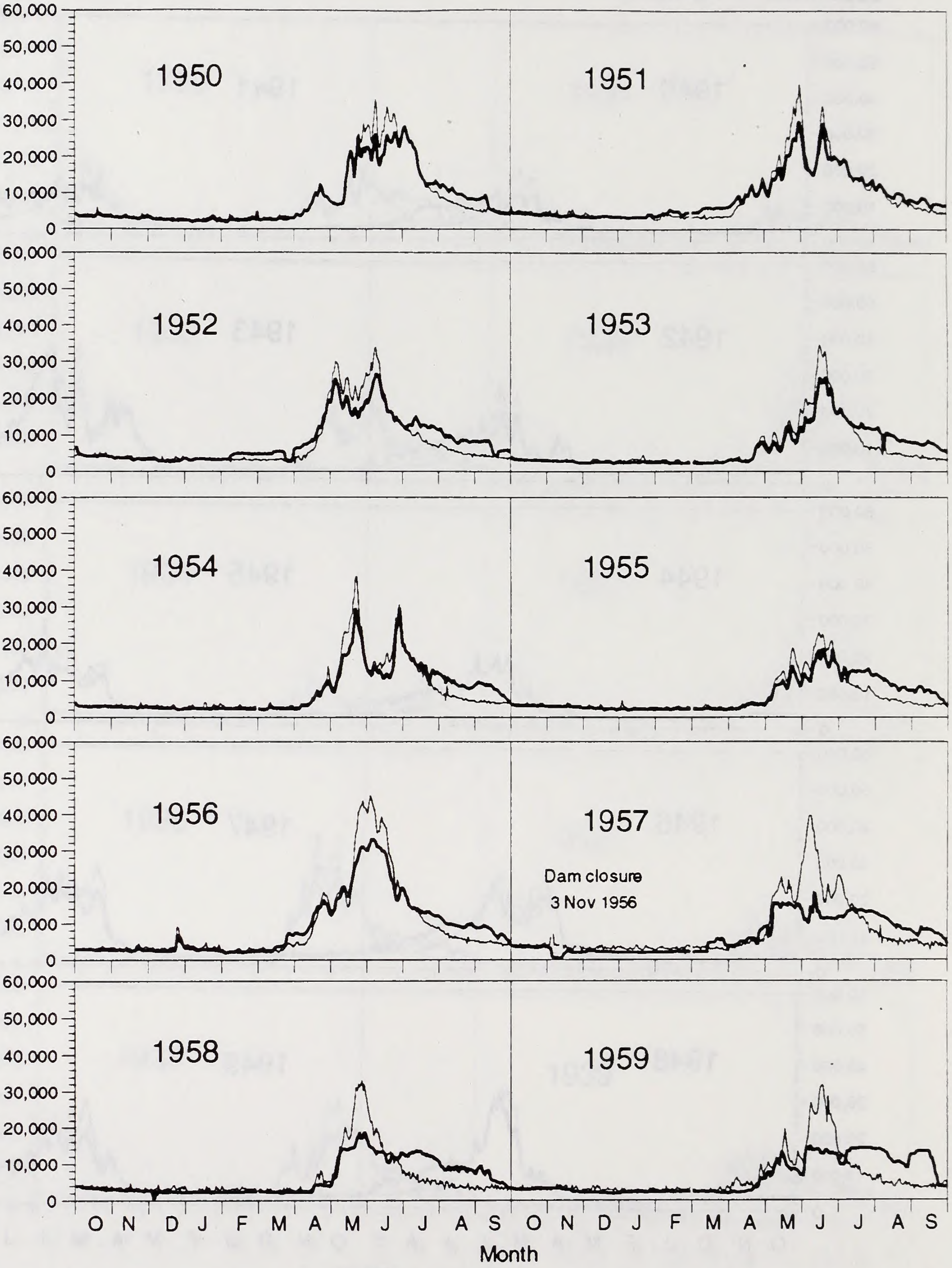


Figure A6. Mean daily discharge, cfs, at Snake River near Heise, Idaho, for water years 1950 to 1959. Thick line is observed flow, thin line is reconstructed unregulated flow accounting for storage in Jackson Lake and Palisades reservoirs. Palisades dam closed in November 1956.

Appendix A. Annual hydrographs showing observed and reconstructed natural flows for South Fork Snake River — continued.

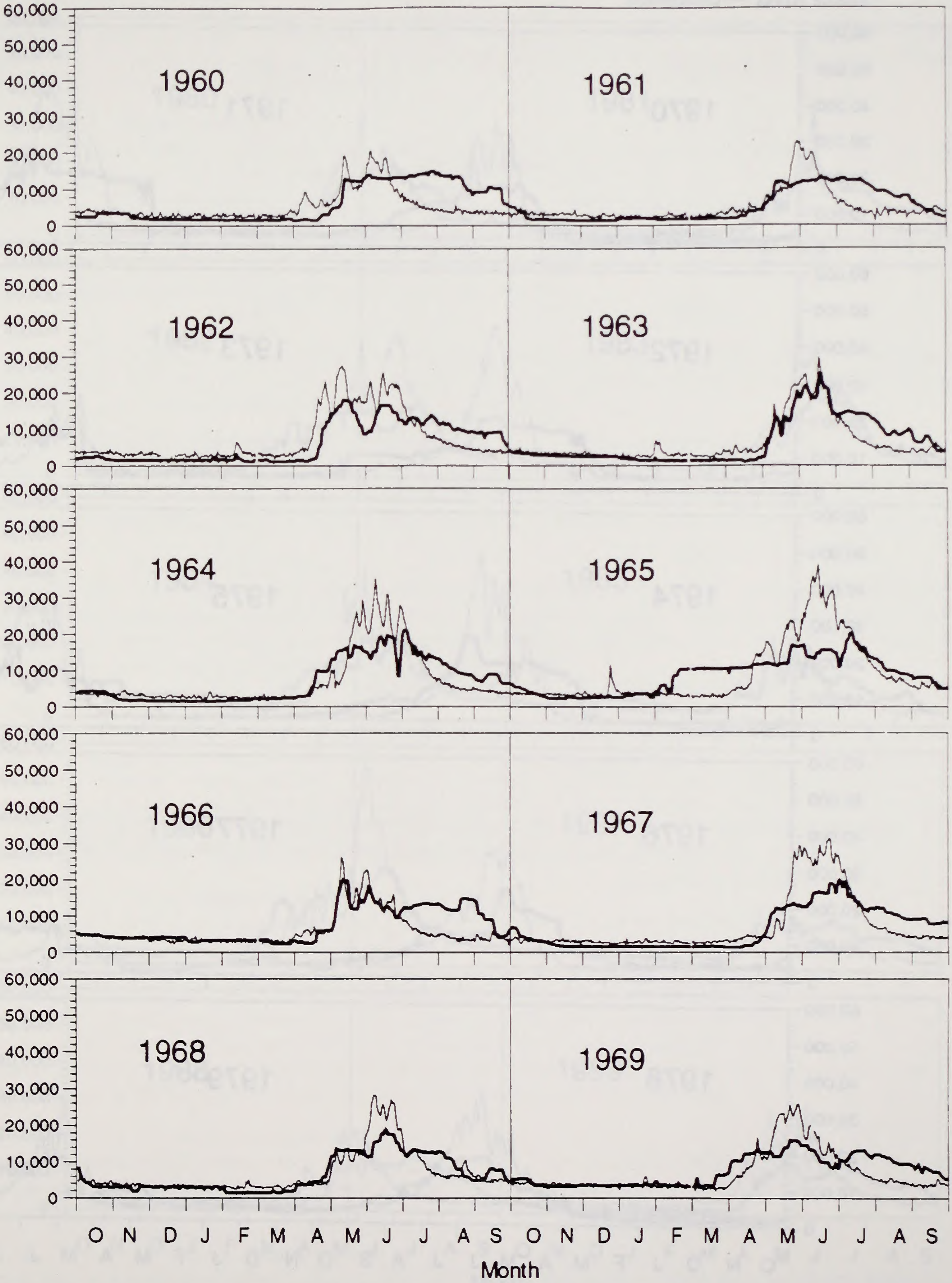


Figure A7. Mean daily discharge, cfs, at Snake River near Heise, Idaho, for water years 1960 to 1969. Thick line is observed flow, thin line is reconstructed unregulated flow accounting for storage in Jackson Lake and Palisades reservoirs.

Appendix A. Annual hydrographs showing observed and reconstructed natural flows for South Fork Snake River — continued.

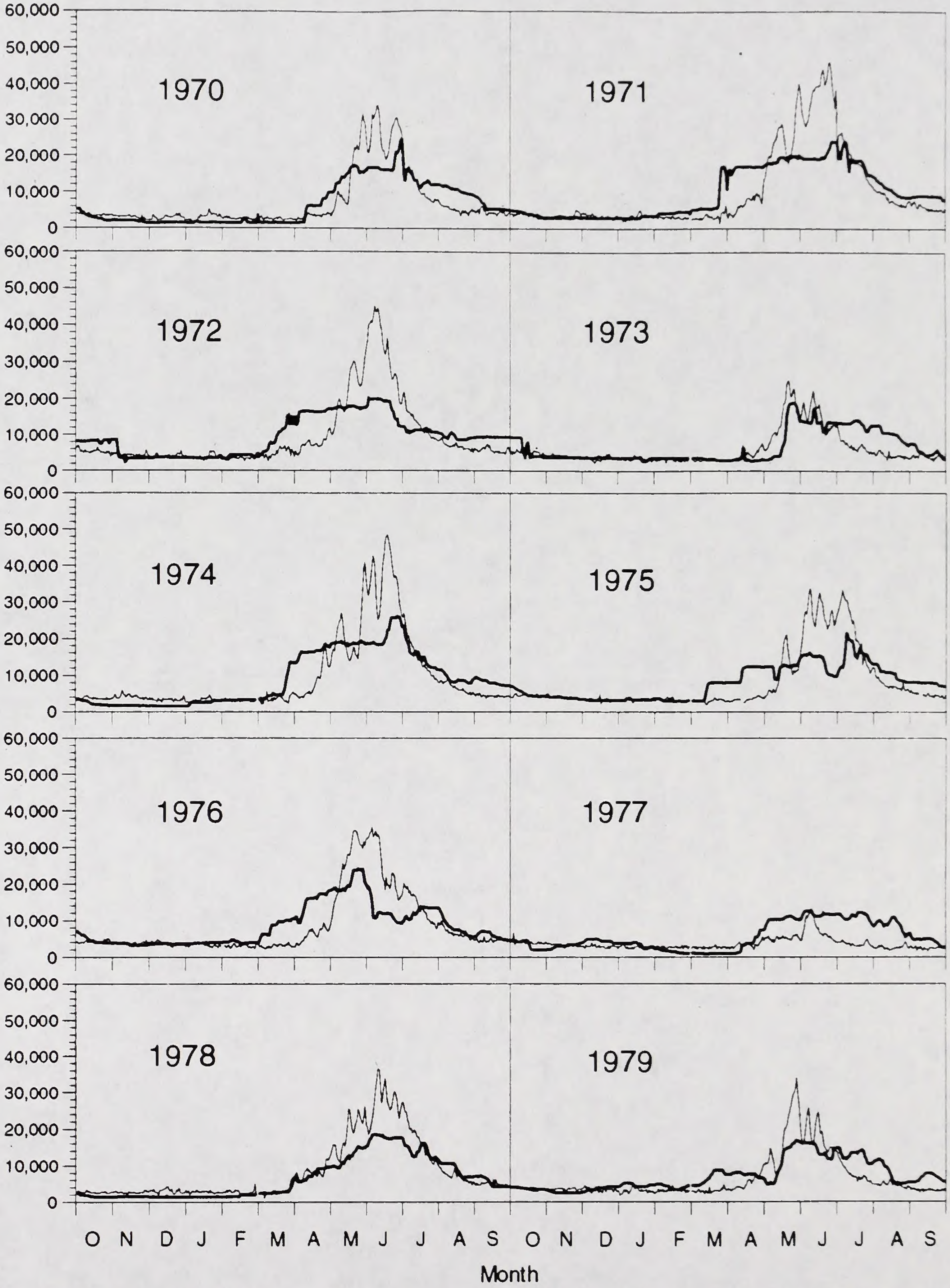


Figure A8. Mean daily discharge, cfs, at Snake River near Heise, Idaho, for water years 1970 to 1979. Thick line is observed flow, thin line is reconstructed unregulated flow accounting for storage in Jackson Lake and Palisades reservoirs.

Appendix A. Annual hydrographs showing observed and reconstructed natural flows for South Fork Snake River — continued.

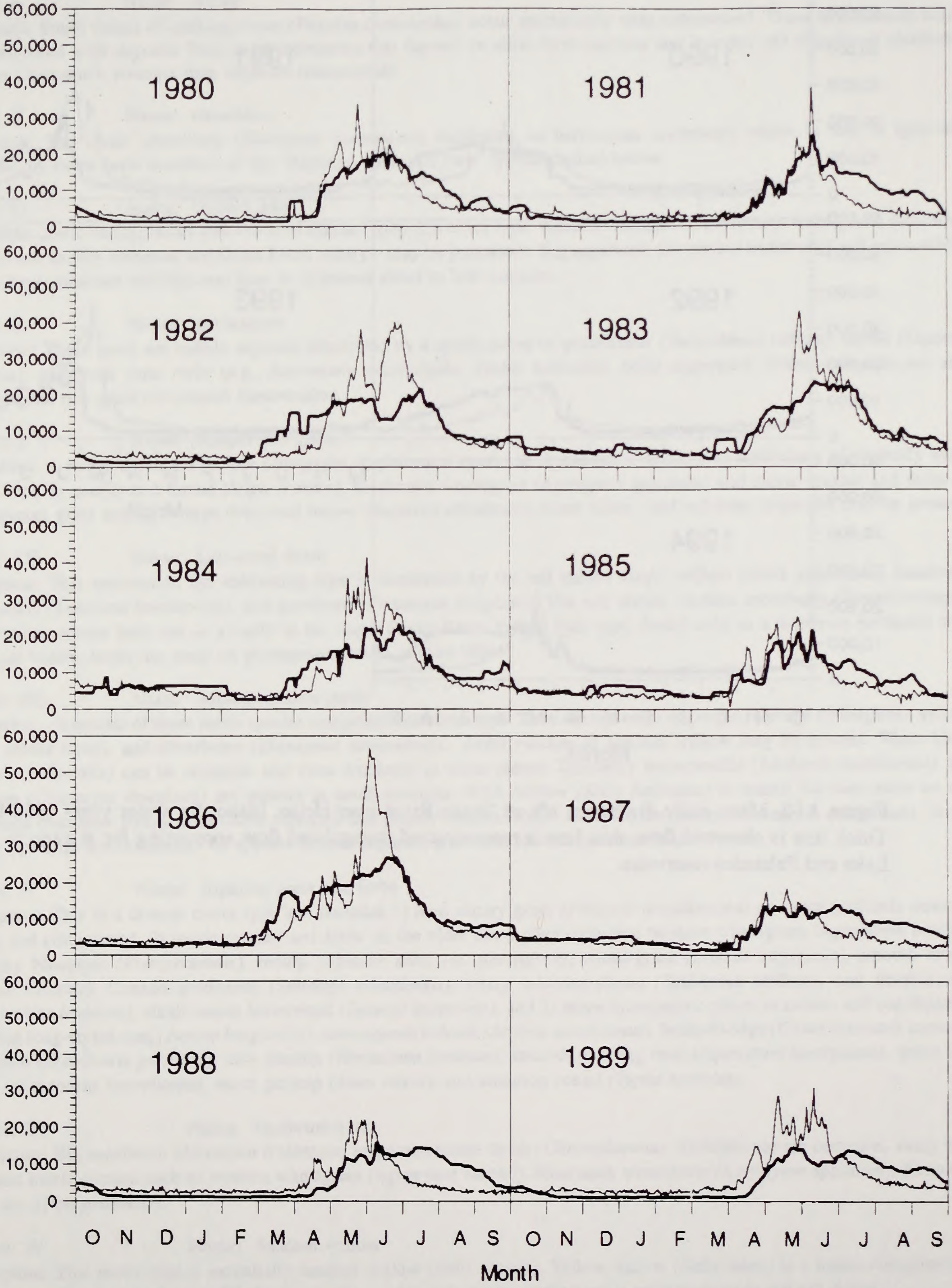


Figure A9. Mean daily discharge, cfs, at Snake River near Heise, Idaho, for water years 1980 to 1989. Thick line is observed flow, thin line is reconstructed unregulated flow accounting for storage in Jackson Lake and Palisades reservoirs.

Appendix A. Annual hydrographs showing observed and reconstructed natural flows for South Fork Snake River — continued.

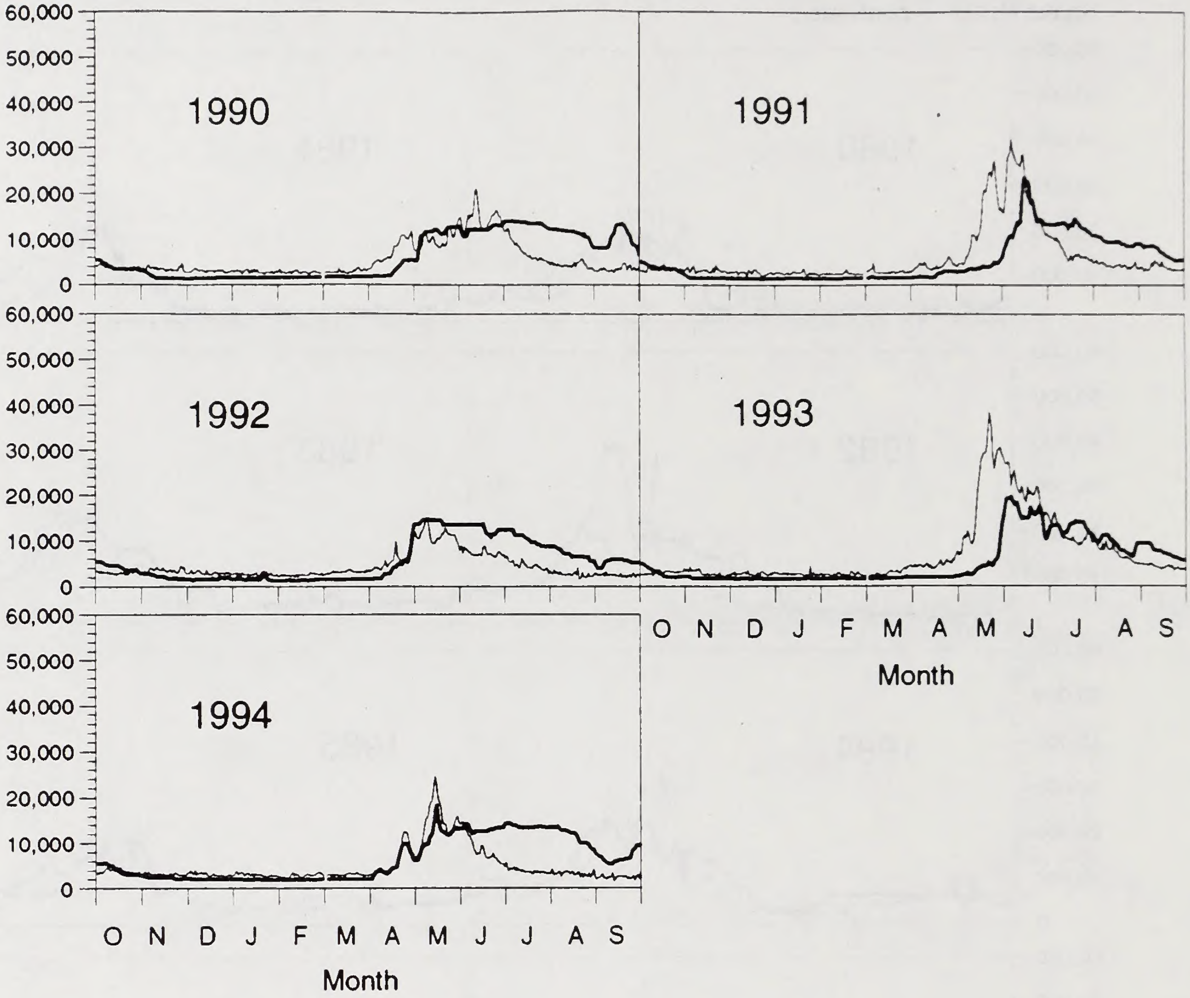


Figure A10. Mean daily discharge, cfs, at Snake River near Heise, Idaho, for water years 1990 to 1994. Thick line is observed flow, thin line is reconstructed unregulated flow accounting for storage in Jackson Lake and Palisades reservoirs.

## Appendix B. Map unit descriptions for flood plain maps (Plate 11 to 17).

Symbol: A Name: Aspen
Description: Small stands of quaking aspen *(Populus tremuloides)* occur sporadically with cottonwood. These small stands seem to be associated with deposits from small tributaries that fan-out on main river deposits and in some old abandoned channels. They are often much younger than adjacent cottonwoods.

Symbol: E Name: silverberry
Description: The shrub silverberry *(Elaeagnus commutata)* dominates an herbaceous understory which in turn is typically dominated by more-xeric members of the "Riparian grass and forb" type described below.

Symbol: G Name: Upland grass
Description: Xeric bunchgrasses and scattered shrubs typify this cover type. Western wheatgrass, bluebunch wheatgrass, Kentucky bluegrass are usually common and Great Basin wildrye may be prominent. Big sagebrush *(Artemisia tridentata)* and green rabbit brush *(Chrysothamnus viscidiflorus)* may be scattered about in low amounts.

Symbol: H Name: goldenaster
Description: These areas are cobbly deposits dominated by a sparse cover of goldenaster *(Heterotheca villosa)*, lupine *(Lupinus argenteus)*, numerous xeric forbs (e.g., *Antennaria microphylla, Arabis holboellii, Gilia aggregata, Sedum lanceolatum*) and usually Indian rice grass *(Oryzopsis hymenoides)*.

Symbol: J Name: Juniper and grass
Description: A rocky mountain juniper *(Juniperus scopulorum)* savannah dominates a herbaceous understory of typically xeric grasses such as needle and thread *(Stipa comata)*, bluebunch wheatgrass *(Agropyron spicatum)* and mesic grasses and forbs of the "Riparian grass and forb" type described below. Scattered silverberry, water birch, and red-osier dogwood may be present.

Symbol: LS Name: Late-seral shrub
Description: This uncommon but interesting type is dominated by the tall shrubs Geyer willow *(Salix geyeriana)*, bearberry honeysuckle *(Lonicera involucrata)*, and hawthorn *(Crataegus douglasii)*. The low shrub, western snowberry *(Symphoricarpos occidentalis)*, occurs here too — a rarity in the upper Snake River Valley. This type, found only in a relatively-protected area in Conant Valley, looks the same on photographs taken around 1908.

Symbol: MS Name: Mixed riparian shrub
Description: A mosaic of three shrub species comprises this cover type. They are red-osier dogwood *(Cornus stolonifera)*, yellow willow *(Salix lutea)*, and silverberry *(Elaeagnus commutata)*. Small patches of sandbar willow may be present. Water birch *(Betula occidentalis)* can be common and even dominate in some places. Bearberry honeysuckle *(Lonicera involucrata)* and hawthorn *(Crataegus douglasii)* are present in small amounts. Bebb willow *(Salix bebbiana)* is scarce but can occur on old abandoned channels. Woods rose *(Rosa woodsii)* and prickly current *(Ribes lacustre)* are the most common mid-shrubs. Small canopy openings are dominated by species in the "Riparian grass and forbs" type described below.

Symbol: R Name: Riparian grass and forbs
Description: This is a diverse cover type and includes 1) reed canary grass *(Phalaris arundinacea)* on young islands amongst willow and cottonwood, 2) mesic grasses and forbs on the older flood plain including western wheatgrass *(Agropyron smithii)*, Kentucky bluegrass *(Poa pratensis)*, redtop *(Agrostis alba* var. *stolonifera)*, terrell-grass *(Elymus virginicus)*, smooth brome *(Bromus inermis)*, Canada goldenrod *(Solidago canadensis)*, starry solomon-plume *(Smilacina stellata)*, and licorice root *(Glycyrrhiza lepidota)*, alkali-marsh butterweed *(Senecio indecorus)*, and 3) more-hydrophytic plants in swales and old channels including long-styled rush *(Juncus longistylis)*, three-square bulrush *(Scripus americanus)*, beaked sedge *(Carex rostrata)*, common spike-rush *(Eleocharis palustris)*, cow parsnip *(Heracleum lanatum)*, smooth scouring rush *(Equisetum laevigatum)*, green bog orchid *(Habenaria hyperborea)*, water parsnip (*Sium suave*), and common cattail *(Typha latifolia)*.

Symbol: S Name: sagebrush/grass
Description: Big sagebrush *(Artemisia tridentata)* and green rabbit brush *(Chrysothamnus viscidiflorus)* are common, along with xeric and mesic grasses such as western wheatgrass *(Agropyron smithii)*, bluebunch wheatgrass *(Agropyron spicatum)*, Kentucky bluegrass. *(Poa pratensis)*.

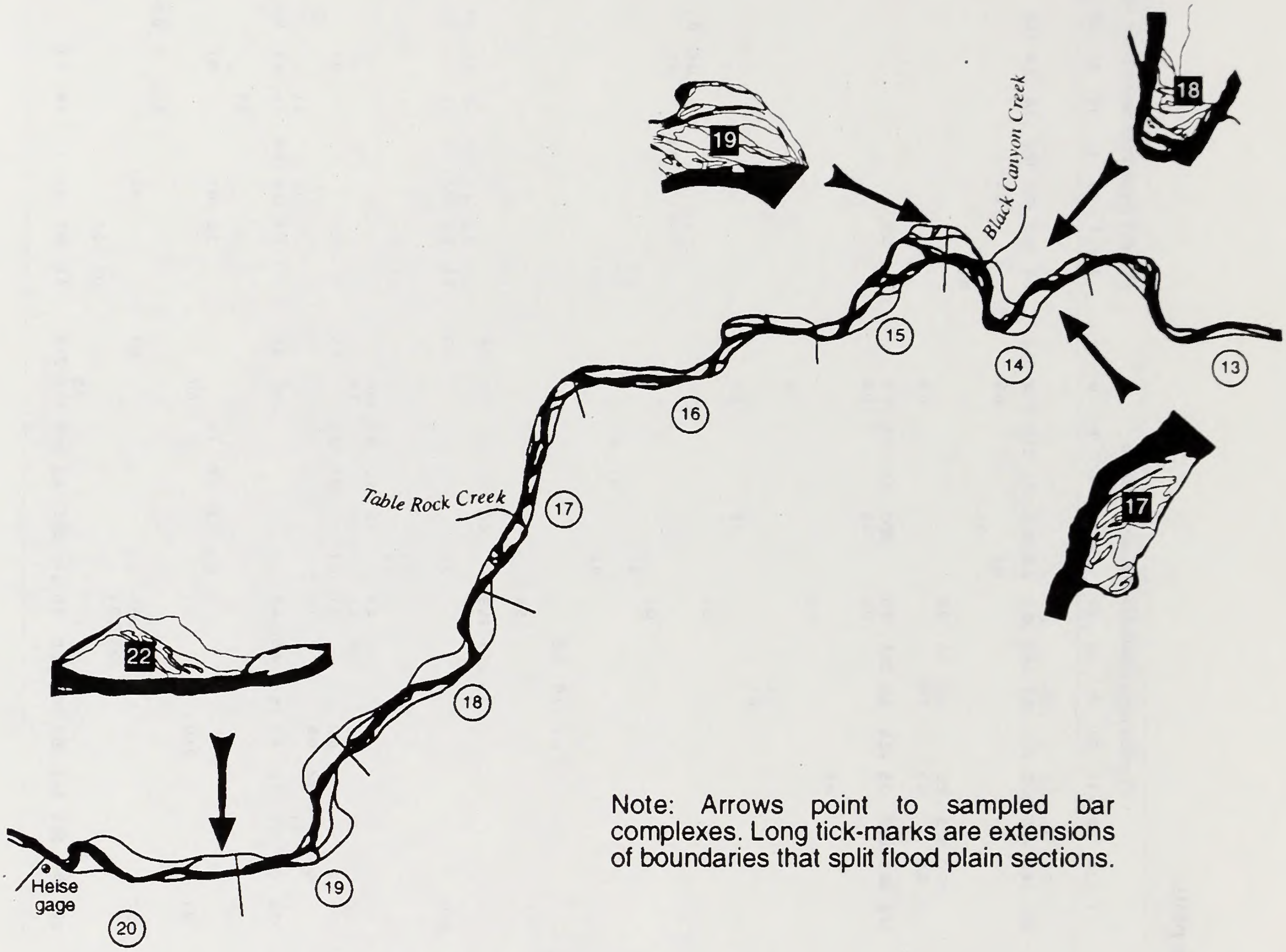
Symbol: W Name: Sandbar willow
Description: This cover type is essentially sandbar willow *(Salix exigua)*. Yellow willow *(Salix lutea)* is a minor component in some places. Reed canary grass *(Phalaris arundinacea)* may form the understory if willow cover is not too dense.

Table C1. Percent canopy cover for species on sample plots.

| | *Populus angustifolia/Comus stolonifera* | | | | | | | | | *Populus angustifolia/Elaeagnus commutata* | | | | | | | | | | | | | | *Populus angustifolia/Heterotheca villosa* | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Plot number: | 13 | 18 | 24 | 25 | 31 | 7 | 8 | 12 | 28 | 11 | 14 | 16 | 17 | 20 | 23 | 30 | 21 | 2 | 4 | 5 | 6 | 9 | 27 | 1 | 3 | 10 | 15 | 19 | 22 | 29 | 26 |
| Species name | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Juniperus scopulorum | 0.5 | | | | | | | | | | 0.5 | 0.5 | 0.5 | | 0.5 | | | | | | | | | | | | | | | | |
| Populus angustifolia | 86.3 | 1.3 | 66.3 | 69.5 | 74.3 | 63.5 | 88.0 | 74.8 | 59.3 | 45.0 | 74.8 | 27.5 | 59.5 | 21.0 | 62.8 | 64.0 | 62.0 | 6.3 | 50.0 | 48.0 | 21.0 | 40.3 | 55.3 | 15.5 | 20.3 | 40.3 | 12.8 | 17.0 | 15.8 | 13.0 | 3.8 |
| Amelanchier alnifolia | | | | | | 0.5 | 2.5 | 0.5 | | | | | | | | | | 0.5 | | | | 0.5 | | | | 0.5 | | | | | |
| Berberis repens | | | | | | | | | | | | | | | | | | | 0.1 | | | | | | | | | | | | |
| Chrysothamnus visciditlorus | | | | | | | | | | | | | | | | | | | | | | | | 0.5 | | | | | | | |
| Clematis ligusticifolia | 2.5 | 0.5 | | | | | | | | | 15.0 | 37.5 | 2.5 | | 2.5 | 0.5 | 0.5 | | | | | | | | | | | | | | |
| Cornus stolonifara | 17.5 | 112.5 | 30.0 | 17.5 | 77.5 | 15.0 | 37.5 | 15.5 | 17.5 | | 0.5 | | 0.5 | | 1.0 | | | | | | | 0.5 | | | | | | | | | |
| Crataegus douglasii | | | | | 3.0 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Elaeagnus commutata | 17.5 | 15.5 | 1.0 | | | 15.0 | 5.0 | 15.0 | 0.5 | 87.5 | 38.0 | 85.0 | 0.5 | 42.5 | 5.0 | 30.5 | 18.0 | | 38.0 | 1.0 | 3.5 | 2.5 | | | 3.0 | | | | | | |
| Lonicera involucrata | | | | 0.5 | | | | | 0.5 | | | | | | | | 0.5 | | 0.5 | | | 0.5 | | | | | | | | | |
| Prunus virginiana | | | | | | 0.5 | | | | | | | | | | | | | | | | | | | | | | | | | |
| Rhus trilobata | 2.5 | | | | | | | | | | | | 0.5 | | | | | | | | | | | | | | | | | | |
| Ribes lacustra | | | | | | | 0.5 | | 0.5 | | | | | | | | 0.5 | | | | | | | | | | | | | | |
| Rosa woodsii | 3.0 | 3.0 | | | | 0.5 | 0.5 | 2.5 | | | | | | | | | | | | | | 0.5 | | | | | | | | | |
| Salix exigua | | | 2.5 | | | | | | | | | | | | 0.5 | | | | | | | | | | | | | | | | |
| Salix lutaa | | 5.0 | 0.5 | 2.5 | 15.0 | | | | 2.5 | | | | | | 0.5 | | | | | | | | | | | | | | | | |
| Symphoricarpos albus | | | | | | 2.5 | 0.5 | 0.5 | | | | | | | | | | | 0.5 | | | 0.5 | | | | | | | | | |
| Achillea millefolium | | | | | | | | | | | | | | | | | 0.5 | | | | | | | | | | | | | | |
| Arabis holboellii | | | | | | | | | | | | | | | | | | | | | | | | | 1.0 | | | | 0.6 | 0.1 | |
| Antennaria microphylla | | | | | | | | | | | | | | | | | | | | | | | | | | | 0.1 | | 0.1 | | |
| Arnica longifolia | | | | | | | | | | | | | | | | | 0.1 | | | | | | | | | | | | | | |
| Artemisia dracunculus | | | | | | | | | | | | | | | | | | 0.1 | | | | | | 0.0 | | | | | | | |
| Artemisia ludoviciana | | | | | | | | | | | | | | | | | | | | 0.1 | 0.5 | | | 0.1 | | | | | | | |
| Astragalus tenellus | | | | | | | | | | | | | | | | | | 0.2 | | | | | | 1.1 | | | | | | | |
| Cirsium arvensis | | | | | | | | | 6.7 | | | | | | | | | | | | | | | | | | | | | | |
| Equisetum laevigatum | 0.7 | 2.5 | 0.1 | 0.7 | 0.5 | | | 0.2 | 0.1 | | | | | 0.1 | 2.0 | 0.2 | | | | | | | | | | | | | | | |
| Erigeron glabellus | | | | | | | | 0.1 | | | | | | | | | | | | | | | | | | | | | | | |
| Galium triflorum | 0.5 | | 0.2 | | 11.0 | 0.5 | 6.7 | 3.0 | | | | | | | | | 6.6 | | | | | | | | | | | | | | |
| Gilia aggregata | | | | | | | | | | | | | | | | | | | | | | | | 1.0 | | 0.1 | | | | | |
| Glycyrrhiza lepidota | | | 11.5 | 4.2 | | | 3.0 | 13.7 | 28.5 | | | | | | 7.5 | 23.1 | 25.6 | | 6.0 | | | 8.1 | 12.5 | | | | | | | | |
| Hetarotheca villosa | | | | | | | | | | | | | | | | | | | | | | | | 1.5 | 7.5 | 4.1 | 24.0 | 7.0 | 7.6 | 7.5 | 0.5 |
| Lupinus argantaus | | | | | | | | | | 26.0 | | | | | | | | 3.1 | | | | | 3.0 | 7.5 | 3.5 | 0.7 | 0.2 | 3.5 | | 0.7 | |
| Osmorhiza chilensis | | | | | | 1.5 | 0.5 | | | | | | | | | | | | | | | | | | | | | | | | |
| Penstemon angustifolius | | | | | | | | | | | | | | | | | | 0.1 | | | | | | | | | | | | | |
| Sedum lanceolatum | | | | | | | | | | | | | | | | | | 1.2 | | | | | | 0.1 | 0.1 | | | | | | |
| Smilacina stellata | 3.5 | | | | | 6.6 | 6.5 | 40.5 | 11.5 | | | | | | | | 4.1 | | 1.0 | 5.0 | 6.5 | 19.0 | | | | | | | | | |
| Solidago canadensis | | | 1.0 | 7.1 | | 11.0 | 7.7 | 7.6 | 3.0 | 3.0 | | | | 9.0 | 11.0 | 3.6 | 8.0 | | 0.5 | | | 3.5 | | | | | | | 0.5 | | |
| Solidago occidentalis | 0.1 | | | | | 3.5 | | | | | 0.1 | | | 0.5 | 0.1 | | 0.1 | 0.1 | | 0.1 | 3.8 | | 7.5 | | 0.1 | | | | 0.1 | | |
| Taraxacum officanalis | | | 3.6 | | | 0.5 | 0.6 | 0.5 | | | 0.1 | | 0.2 | 0.6 | | | 1.0 | | | | | | | | | | | | | | |
| Tragopogon dubius | | | | | | | | | | | | 0.1 | | | | | | | | | | | | | | 0.5 | | 0.1 | | | |
| Trifolium dubium | 0.5 | | 0.1 | 28.5 | | 0.5 | | 0.1 | | 23.0 | 0.1 | 3.5 | 1.2 | 4.2 | 6.5 | 4.6 | 4.0 | | | | | 26.0 | 9.6 | | 0.1 | 12.0 | 0.9 | 7.5 | 4.1 | 0.2 | 0.1 |
| Trifolium sp. | | | | 0.5 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| anuual mustard | | | | | | | | | | | | | | | | | | | | | | | | | | | | 0.1 | | | |
| Agropyron smithii | | | | | | | | | | | | | | | | | | 0.5 | 3.6 | 7.0 | 1.5 | | | | 3.6 | 0.1 | | | 0.1 | | 0.1 |
| Agrostis alba | 20.0 | 2.5 | 66.5 | 25.6 | 20.1 | | 0.2 | 3.5 | 1.0 | 0.1 | | | | 21.0 | | | | | | | | 0.1 | | | | | | | | | |
| Bromus anomalus | | | | | | 0.1 | | | | | | | | | | | | | | | | | | | | | | | | | |
| Bromus tectorum | | | | | | | | | | | | | | | | | | | | | | | | | | | | 0.6 | | 0.2 | |
| Dactylis glomerata | | | | | | | | | | 3.0 | | | | | | | 38.0 | | | | | | 0.1 | | | 0.1 | | | | | |
| Elymus virginicus | | | | | | 0.6 | 0.1 | | | | | | | | | 0.1 | 0.1 | | | | | | | | | | | | | | |
| Oryzopsis hymenoidas | | | | | | | | | | | | | | | | | | | | | | | | 0.1 | 0.1 | | | | | | 6.2 |
| Phleum pratensis | | | | | | | | 8.1 | | | | | | | | | | | | | | 3.2 | | | | | | | | | |
| Poa pratensis | 49.5 | 0.5 | | 47.5 | 9.0 | 37.0 | 15.0 | 30.0 | 33.0 | 23.5 | 85.0 | 33.5 | 56.5 | 16.5 | 30.6 | 85.0 | 9.0 | 21.0 | 33.5 | 6.5 | 46.5 | 13.5 | 31.0 | 1.0 | 10.7 | 0.6 | | 3.6 | 1.1 | | |
| unidant. grass | | | 0.1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

Appendix C. Vegetation sample plot data.

Plate 1



Note: Arrows point to sampled bar complexes. Long tick-marks are extensions of boundaries that split flood plain sections.

# Sampling design for cottonwood and flood plain aging

Scale

1 inch = 9000 feet

1:108000

1 inch

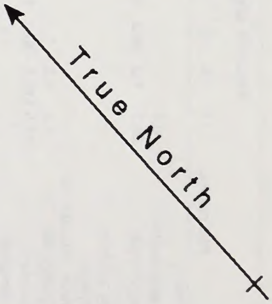


Plate 1

Randomly-chosen flood plain sections: ⑦ ④ ⑲ ⑮ ⑰ ⑳ ⑨ ⑪ ⑭ ③

(N = 20, n = 10) (selection order)

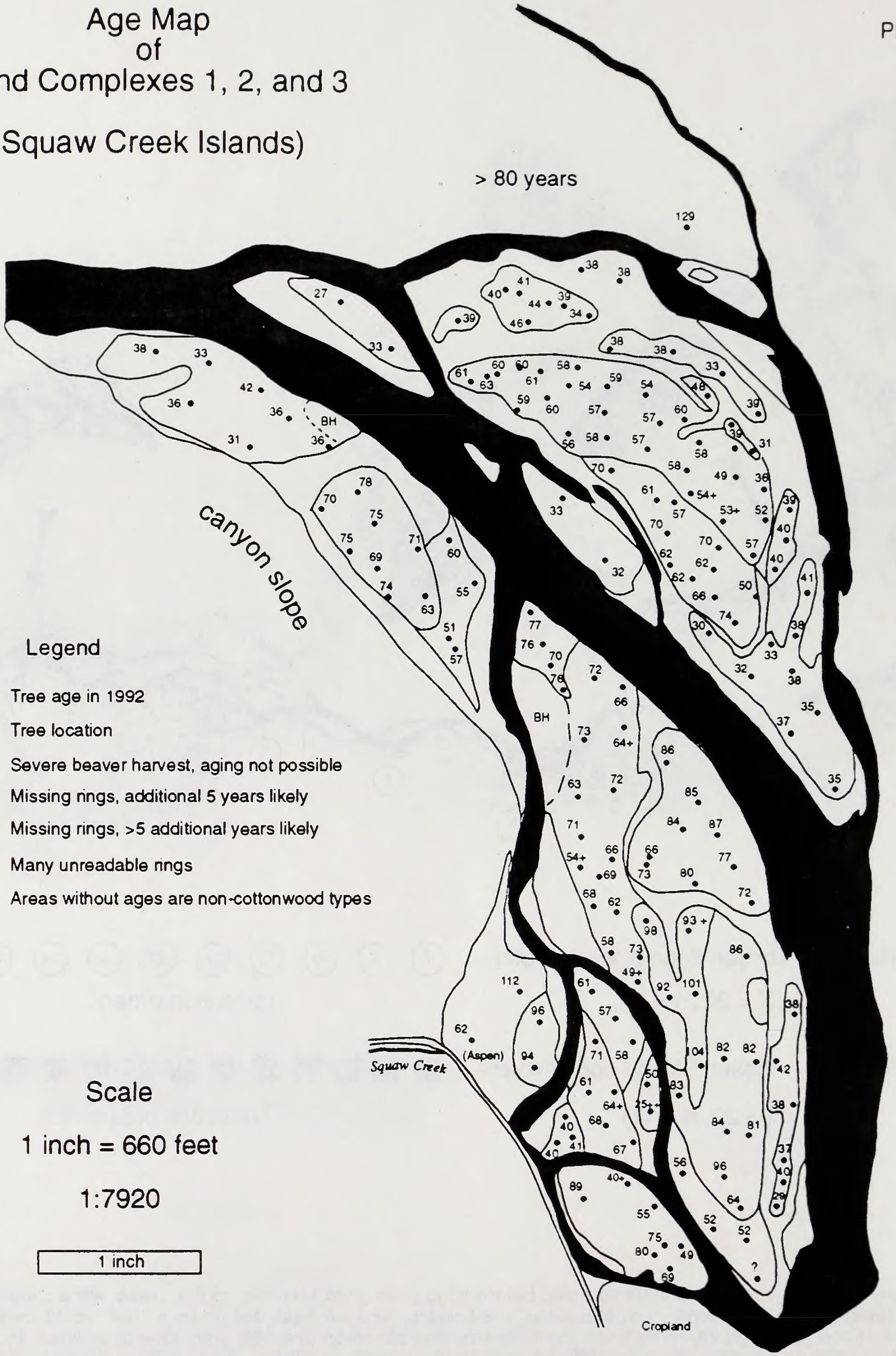
"Randomly-chosen" island-complexes: 18 16 9 2 15 10 17 3 19 1 7 12 22

(N = 22, n = 11) (selection order)

Nearly all island-complexes were sampled before flood plain units. Island-complex areas were chosen based on an apparent broad range in age classes < 80 years, and no past disturbance that would confound tree-age-to-flood-plain-age interpretations. Sample size was based on available time. Due to logistics and time, area 7 had limited sampling, while area 9 was sampled along with ⑦. Hence, the sample is not truly random. A few other areas from the original list of island complexes were not sampled due to excessive ages. The first 10 selected flood plain units were sampled. The flood plain sample size was based on estimated variances and available time. The total number of aged trees to define island complexes and flood plain sections is 1285.

# Age Map of Island Complexes 1, 2, and 3

## (Squaw Creek Islands)



## Legend

| | |
|---|---|
| 75 | Tree age in 1992 |
| ● | Tree location |
| BH | Severe beaver harvest, aging not possible |
| + | Missing rings, additional 5 years likely |
| ++ | Missing rings, >5 additional years likely |
| ? | Many unreadable rings |
| | Areas without ages are non-cottonwood types |

## Scale

1 inch = 660 feet

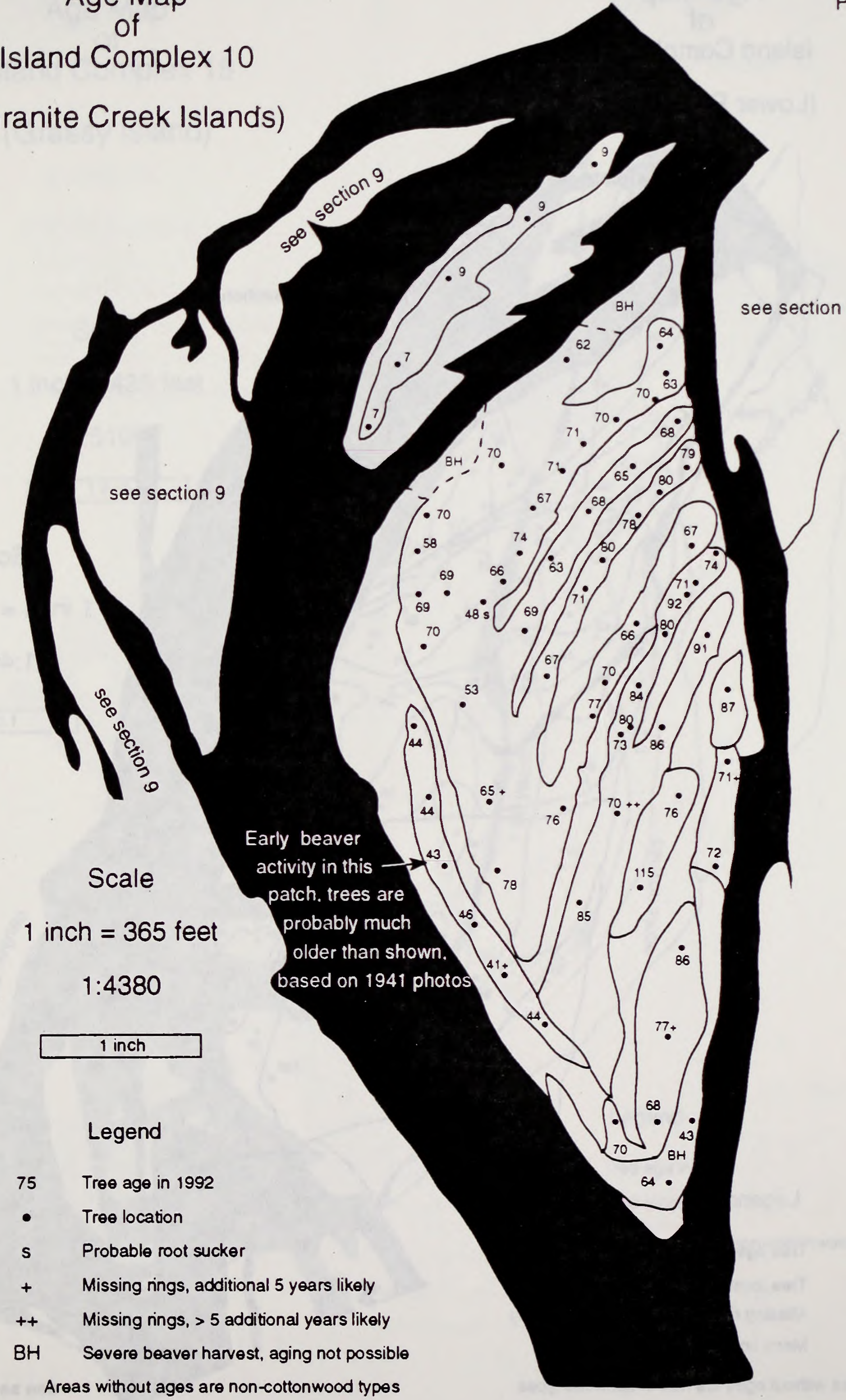
1:7920

1 inch

Plate 3

# Age Map of Island Complex 10

## (Granite Creek Islands)



Early beaver activity in this patch, trees are probably much older than shown, based on 1941 photos

Scale

1 inch = 365 feet

1:4380

1 inch

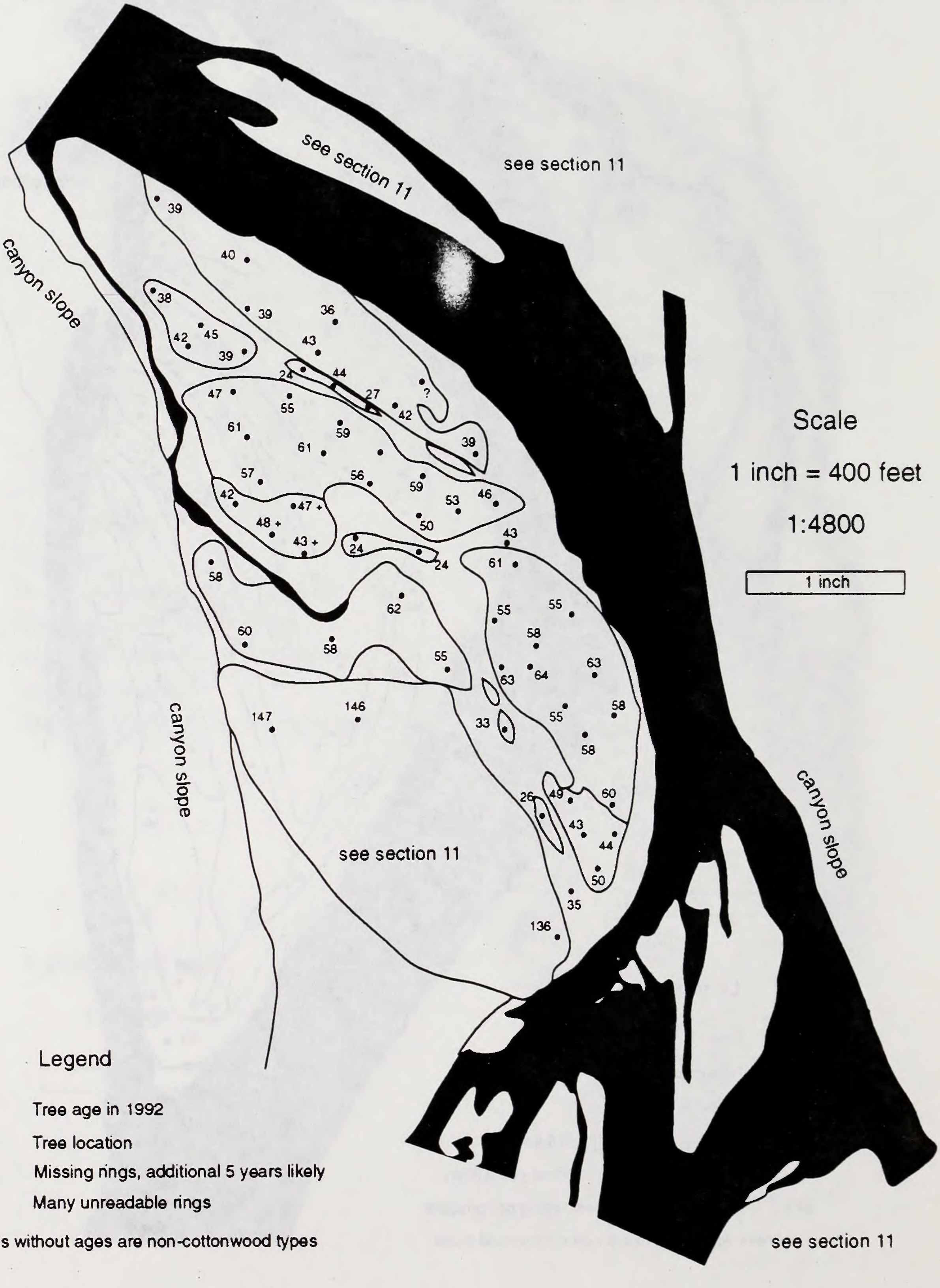
## Legend

| | |
|---|---|
| 75 | Tree age in 1992 |
| ● | Tree location |
| s | Probable root sucker |
| + | Missing rings, additional 5 years likely |
| ++ | Missing rings, > 5 additional years likely |
| BH | Severe beaver harvest, aging not possible |

Areas without ages are non-cottonwood types

# Age Map
# of
# Island Complex 12

## (Lower Pine Creek)



Scale

1 inch = 400 feet

1:4800

1 inch

Legend

| | |
|---|---|
| 75 | Tree age in 1992 |
| ● | Tree location |
| + | Missing rings, additional 5 years likely |
| ? | Many unreadable rings |

Areas without ages are non-cottonwood types

# Age Map of Island Complex 15

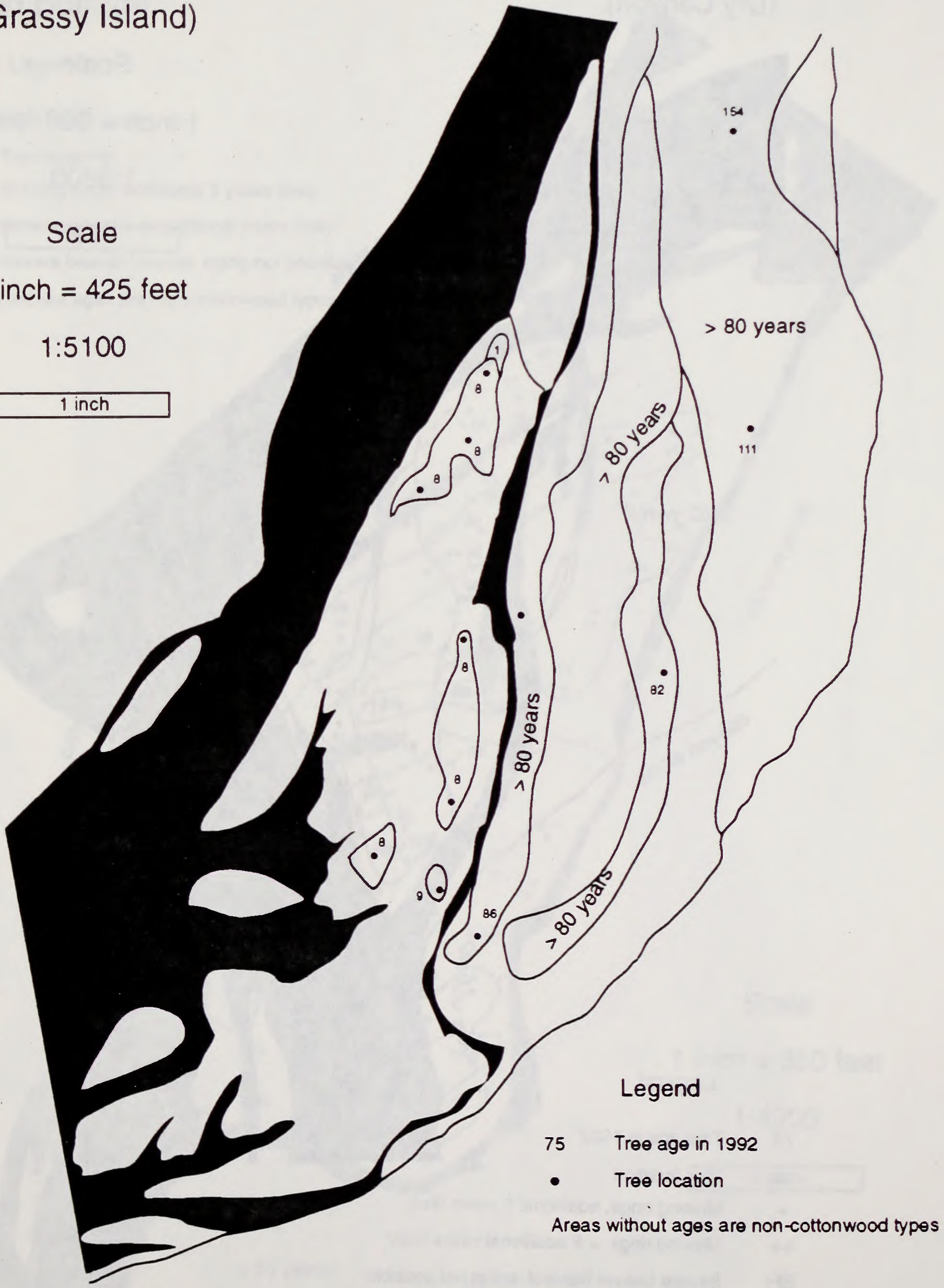
## (Grassy Island)

Scale

1 inch = 425 feet

1:5100

1 inch



# Age Map
# of
# Island Complex 16

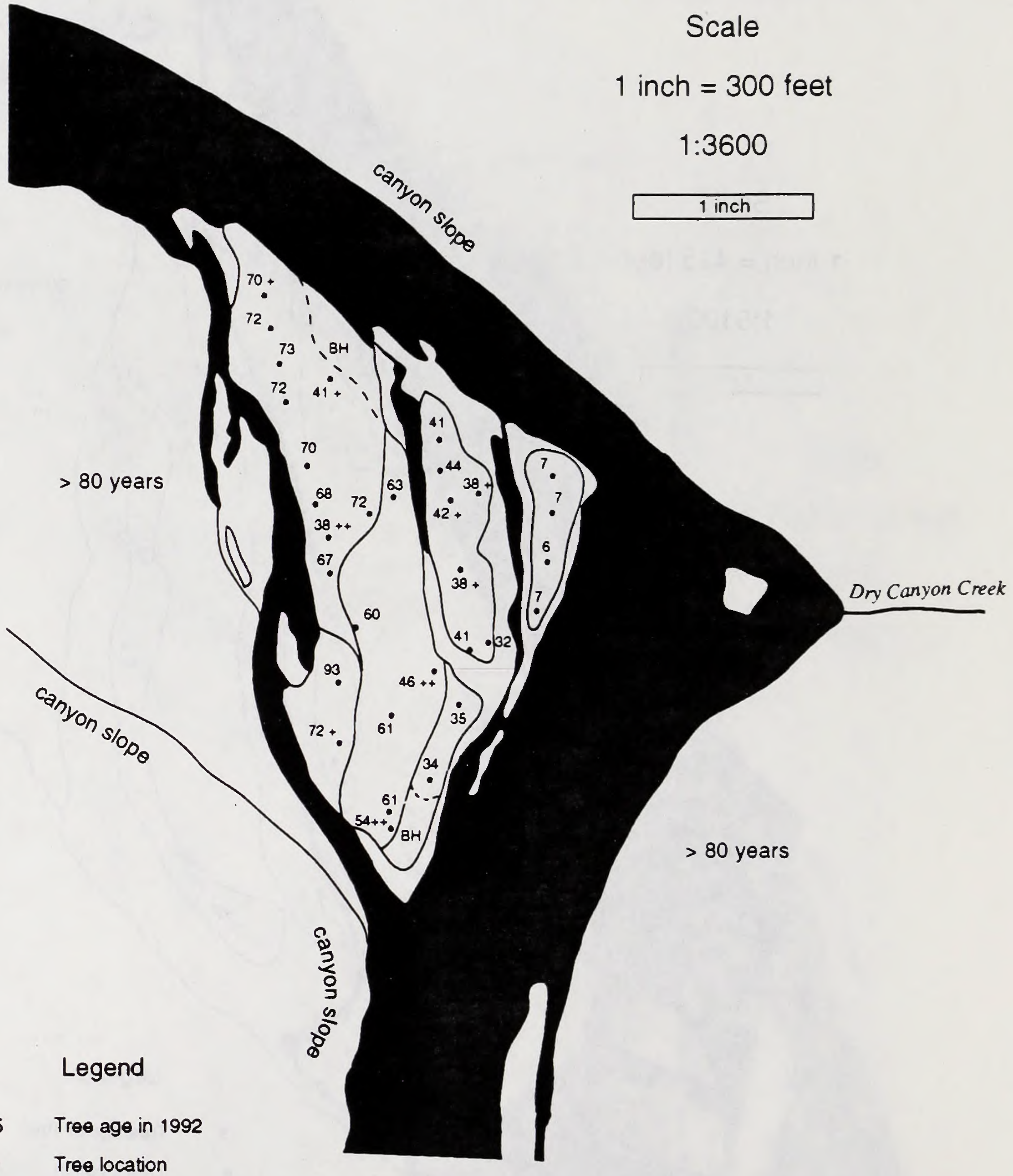
## (Dry Canyon)

Scale

1 inch = 300 feet

1:3600

1 inch



## Legend

| | |
|---|---|
| 75 | Tree age in 1992 |
| ● | Tree location |
| + | Missing rings, additional 5 years likely |
| ++ | Missing rings, > 5 additional years likely |
| BH | Severe beaver harvest, aging not possible |

Areas without ages are non-cottonwood types

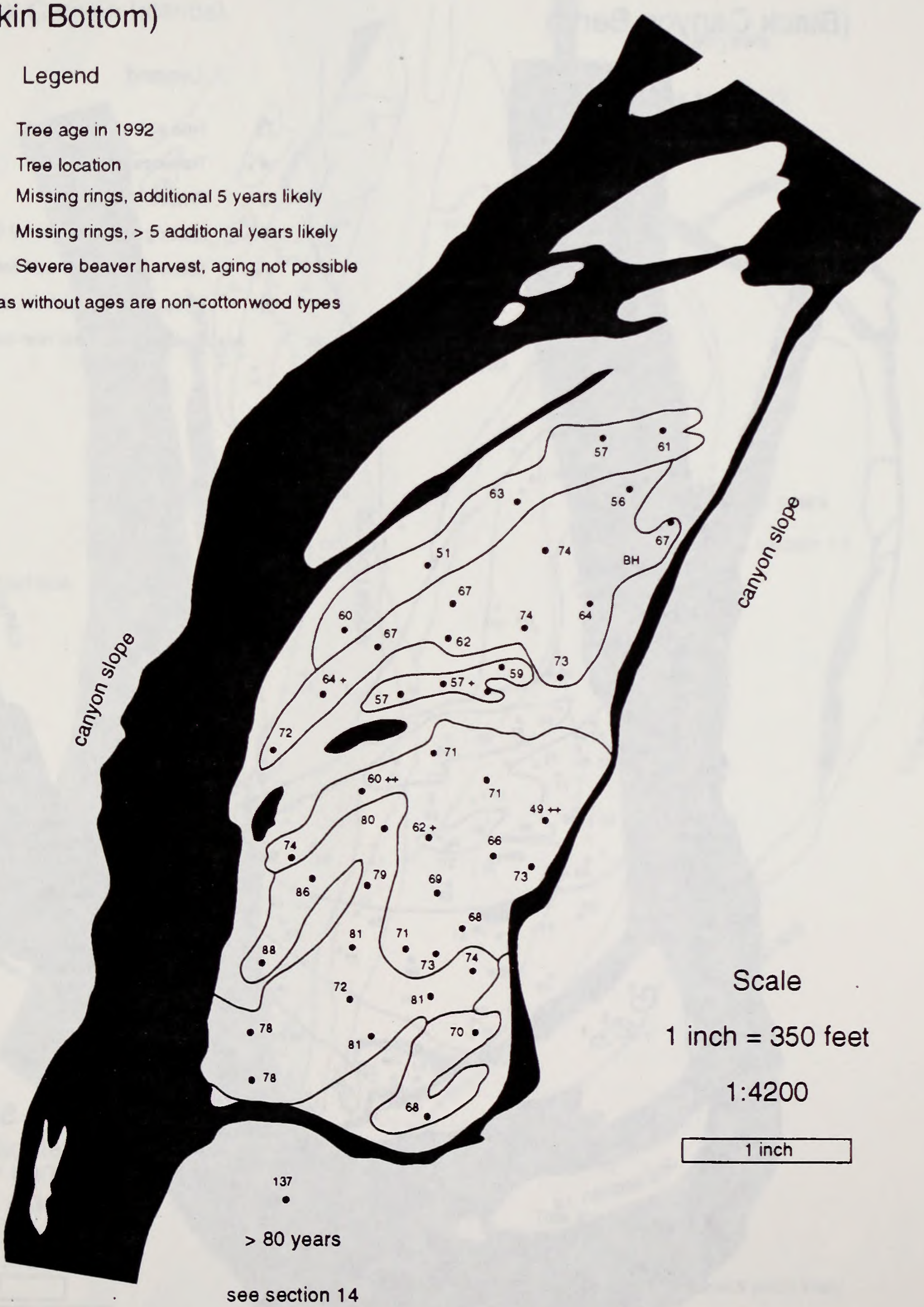
# Age Map of Island Complex 17

## (Lufkin Bottom)

### Legend

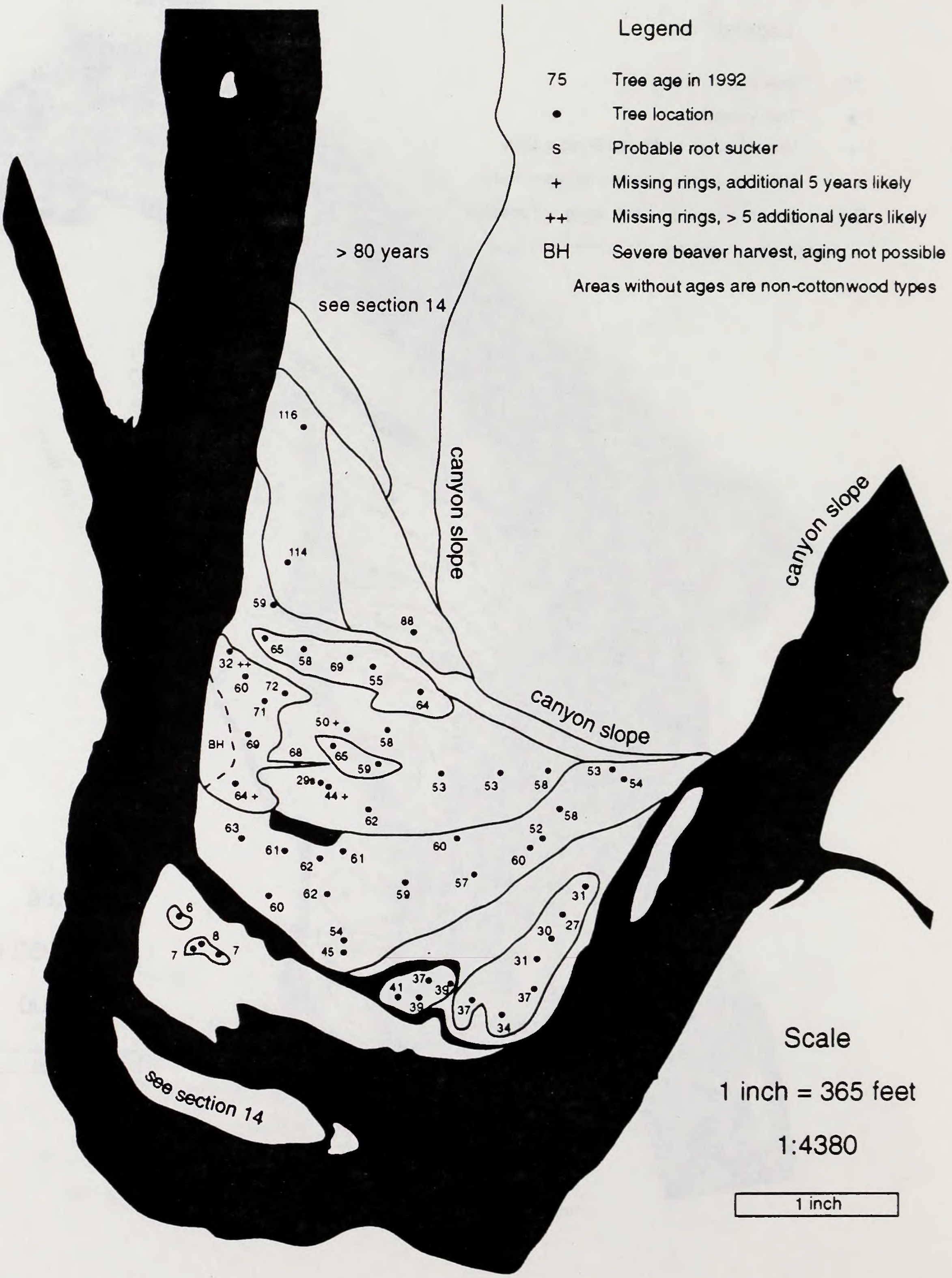
| | |
|---|---|
| 75 | Tree age in 1992 |
| ● | Tree location |
| + | Missing rings, additional 5 years likely |
| ++ | Missing rings, > 5 additional years likely |
| BH | Severe beaver harvest, aging not possible |

Areas without ages are non-cottonwood types



# Age Map
# of
# Island Complex 18

# (Black Canyon Bend)



Legend

| | |
|---|---|
| 75 | Tree age in 1992 |
| ● | Tree location |
| s | Probable root sucker |
| + | Missing rings, additional 5 years likely |
| ++ | Missing rings, > 5 additional years likely |
| BH | Severe beaver harvest, aging not possible |

Areas without ages are non-cottonwood types

Scale

1 inch = 365 feet

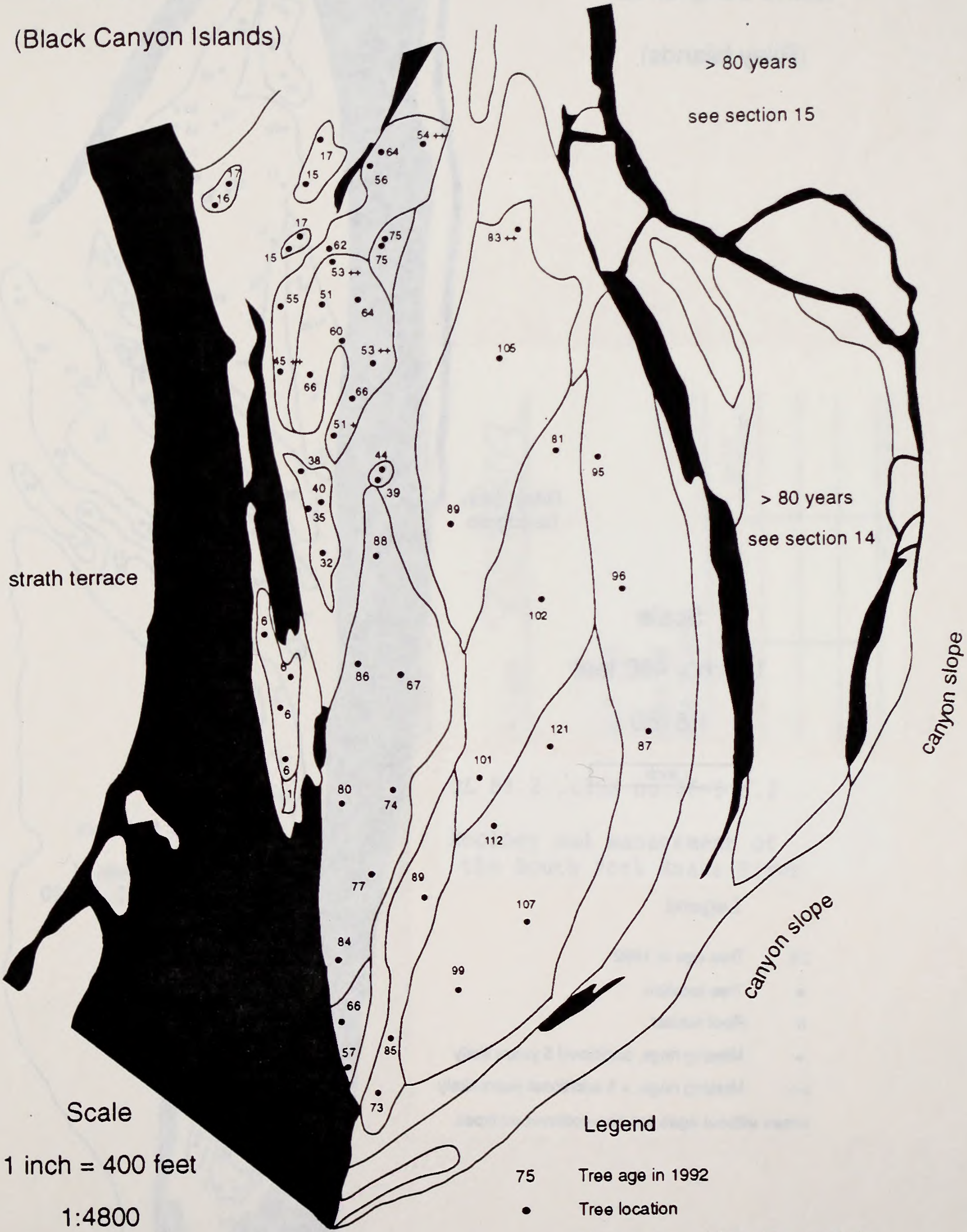
1:4380

1 inch

Plate 9

# Age Map of Island Complex 19

## (Black Canyon Islands)



Scale

1 inch = 400 feet

1:4800

1 inch

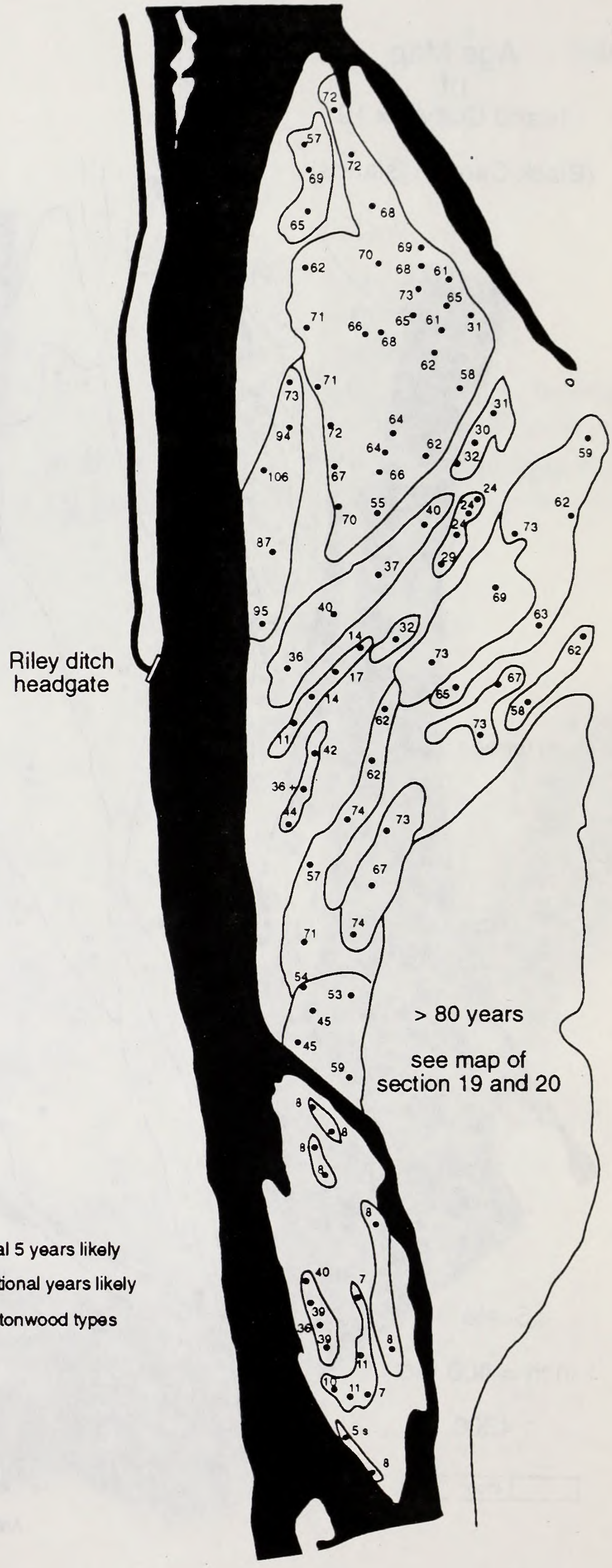
Legend

| | |
|---|---|
| 75 | Tree age in 1992 |
| ● | Tree location |
| + | Missing rings, additional 5 years likely |
| ++ | Missing rings, > 5 additional years likely |

Areas without ages are non-cottonwood types

# Age Map
# of
# Island Complex 22

## (Riley Islands)



## Scale

1 inch = 480 feet

1:5760

1 inch

## Legend

| | |
|---|---|
| 75 | Tree age in 1992 |
| ● | Tree location |
| s | Root sucker |
| + | Missing rings, additional 5 years likely |
| ++ | Missing rings, > 5 additional years likely |

Areas without ages are non-cottonwood types

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