SOME CONCEPTS RELATIVE TO PALLID STURGEON (*SCAPHIRHYNCHUS ALBUS*) SPAWNING AND PLANS TO FACILITATE SUCCESSFUL SPAWNING

Missouri River Technical Committee
of the
Siouxland Chamber of Commerce

Some Concepts Relative to Pallid Sturgeon (*Scaphirhynchus albus)* Spawning and Plans to Facilitate Successful Spawning

by
Donald G. Jorgensen
Hydrologist, Civil Engineer, 33599 479 Ave., Jefferson, South Dakota 57038

Cover photo: Lisbon Bottoms Chute, courtesy of HDR Company
Above photo: Pallid sturgeon, courtesy U.S. Army Corps of Engineers

Partial funding for this investigation by:

Missouri Levee and Drainage Districts Association
Missouri River Technical Group
MARC 2000
MO-ARK

Conclusions in this report are not necessarily the positions of the funding organizations

Jan. 18, 2005

EXECUTIVE SUMMARY

SOME CONCEPTS RELATIVE TO PALLID STURGEON (*Scaphirhynchus albus*) SPAWNING AND PLANS TO FACILITATE SUCCESSFUL SPAWNING

By Donald Jorgensen[1]

Presently (2005) an effort to both design and evaluate plans to facilitate successful spawning of the pallid sturgeon is in progress. The spring-rise concept has been proposed as the starting point. Design of a spring rise for the lower Missouri River by altering flow from Gavins Point Dam is complicated by the scarcity of information about successful pallid sturgeon spawning that results in recruitment to the population. New information about the species or about surrogate species is available and should be useful.

The applicability of the spring-rise concept to the highly altered Missouri River Basin is questionable. The lower Missouri River below the Platte River to the mouth as well as the included tributaries already has spring rises. Unfortunately, there is no compelling evidence that these spring rises are resulting in any significant successful spawning.

Information based on study of the shortnose sturgeon shows that a spring rise is not needed for spawning, and that spawning is possible if minimum photoperiod and minimum temperature are met, and if the bottom-water velocity is within the correct range. This information may be applicable to pallid sturgeon.

Historic information indicates that the shovelnose sturgeon and the pallid sturgeon spawn in tributary streams of the Missouri, Mississippi, and Ohio rivers. However, these observations should not be interpreted to mean that some spawning is not occurring in the Missouri River, or that spawning cannot be accomplished in the river. Because the tributaries are typical spawning areas for sturgeon, the question of the importance or lack of importance of a spring rise in the mainstem of the Missouri River for sturgeon spawning arises.

1 PE, Consulting Engineer and Hydrologist: 33599 479 Ave., Jefferson, South Dakota 57038

The proposed spring rise requires large discharges (flood pulse) from Gavins Point Dam and other upstream dams. Flood pulses exacerbate streambed and bank erosion. Streambed degradation (erosion), over the long term, incises the river, thus reducing sand bar areas, and starts a long chain of other negative environmental and economic impacts. Some of these impacts are loss of connectivity of the river with chutes and backwaters, dewatering of alluvial lakes and wetlands, sedimentation in the reservoirs, as well as increasing pumping lifts for water supplies and increasing potential for flooding.

Three plans for the purpose of enhancing pallid sturgeon spawning leading to recruitment by utilizing a spring rise were examined. All three plans suffer from the lack of supporting science and the lack of design criteria. All three plans would impair the congressionally authorized purposes for management of the Missouri River.

A plan of Missouri River field testing in conjunction with laboratory testing to determine the important items needed to enhance successful spawning of pallid sturgeon has the best potential to succeed. This approach will result in a plan based on science and should produce the relevant information in a more timely manner than a trial and error change of annual flow approach, which may never succeed.

CONTENTS

SOME CONCEPTS RELATIVE TO PALLID STURGEON (*Scaphirhynchus albus*) SPAWNING AND PLANS TO FACILITATE SUCCESSFUL SPAWNING

By Donald G. Jorgensen

INTRODUCTION

Background: The USFWS (U.S. Fish and Wildlife Service, 2003) proposed a bi-modal spring rise for the Lower Missouri River in their amendment to the biological opinion for the Missouri River. (Lower Missouri River is defined herein as below Gavins Point Dam to the confluence of the Mississippi and Missouri Rivers near St. Louis, Missouri. (See figure 1.) A spring rise was also suggested by the National Research Council in 2002. The USACE (U.S. Army Corps of Engineers) is presently evaluating different plans for the purpose of incorporation into the Master Water Control Manual. The plan that is selected, as part of the USACE's current process of evaluating different plans, may or may not be the plan implemented in 2006. (See figure 2.) The selected plan would be in effect in 2006 and beyond until, based on the best science available and the adaptive management process under a Missouri River recovery program, another plan is selected. To support this process, the USGS Columbia Environmental Research Center and others, are conducting investigations to better understand the factors that trigger spawning and ultimately the recruitment of pallid sturgeon. (Mcallister, 2004).

In general, it is reported in the biological opinion and other documents that the mainstem of the Missouri River has been altered, and it is assumed largely a priori that 'restoration' of the river is not possible without flow modification from Gavins Point Dam (USFWS, 2000a, p. 2). The biological opinion assumes without evaluation that the changes made on the mainstem of the Missouri River are predominantly responsible for the declining pallid sturgeon population. The effects of changes on the tributaries, which dominate the hydrology, are only cursorily examined. Information, presented by Hedman and Jorgensen (1990) indicates that the tributary streams contribute well over 90 percent of the increase in flow in the Lower Missouri River. The USFWS (2000a, p. 241) also states that a spring rise for the Lower Missouri River will "trigger spawning activity in pallid sturgeon and other native fishes". However, this also is largely an assumption. The USACE (2001, p. 22) states: "Corps and USFWS biologists agree there are no data to support definition of a spawning cue that would successfully result in spawning on the Lower River." Another assumption is that before development of the river, flow and temperature were coupled to cue the native fishes, such as the pallid sturgeon, to spawn. However, very little science or information has been presented that supports this view with respect to the Missouri River.

Figure 1. Lower Missouri River.

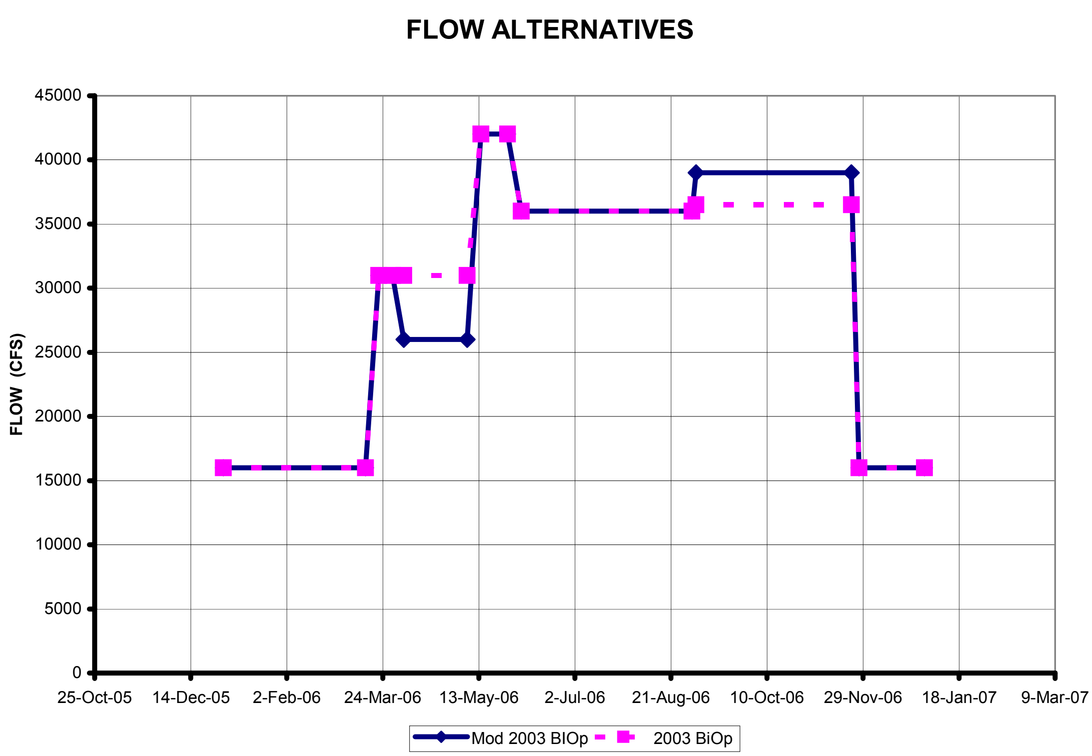


Figure 2 Fall back plan for Gavins Point flow releases as per the 2003 amended biological opinion and including the summer-flow exemption. Plan assumes 'normal flow' conditions and is termed '2003 BiOp'. A modification of '2003 BiOp' termed Mod 2003 BiOp is also shown.

The USFWS and the USACE have not provided adequate details on the objectives and supporting science related to a spring rise. Because of the paucity of information presented, it is very difficult to 'design' a flow plan. Additionally, existing information often contradicts the validity of the flow modifications that are being considered.

A major purpose of this document is to collate and evaluate the information and science that relates to the veracity of a spring rise in the Missouri River, especially as it relates to pallid sturgeon spawning in the Lower Missouri River. Lastly, the USACE has asked for suggestions on plans that will lead to spawning and recruitment of pallid sturgeon. Mike Olson (2004), USFWS, suggests that alternatives that would result in more improvement to the pallid sturgeon than from the fallback plan presented in the amendment to the biological opinion is needed. Plans to facilitate successful spawning of the pallid sturgeon will be evaluated.

Acknowledgements: The need for the study was a product of a series of meetings in the summer and fall of 2004 among the USACE, USFWS, MRBA (Missouri River Basin Association), MRNRC (Missouri River Natural Resources Committee), and stakeholders. The meetings were for the purpose of designing or otherwise evaluating proposed spring-rise plans. This compilation of information and analyses has benefited from reviews by many. Reviews have been generously provided by Roy Mcallister (USACE), Steve Frentz (USFWS), and three were provided by MRNRC. Additional reviews have been by William Beacom and others of the Missouri River Technical Committee of the Siouxland Chamber of Commerce. Partial funding has been provided by the Missouri River Technical Group, MO-ARK, MARC 2000, and the Missouri Levee and Drainage Association. The views expressed in this article are those of the writer and are not necessarily those of the reviewers or the sponsors.

A COLLATION OF INFORMATION

This document presents a collation of information that is believed relevant to spawning of pallid sturgeon in the Lower Missouri River, especially as it may relate to a spring rise. Because information is lacking about many aspects of pallid sturgeon spawning, information relating to the shortnose sturgeon, *Acipenser brevirostrum*, and the shovelnose sturgeon, *Scaphirhynchus platorynchus,* is also included as these species are likely suitable surrogates in relation to many but certainly not all aspects of the life of the pallid sturgeon. Thus, not all information on surrogates may be applicable to the pallid sturgeon. Nevertheless, sturgeons typically share many characteristics and much can be learned by studying the surrogate species.

Spring Rise - Flood Pulse Concept. The "spring rise" is an extension of the "flood-pulse" concept and has been proposed as a management tool for the Missouri River. The flood-pulse concept for big rivers was formalized by Junk and others (1989). However, its universal applicability is in question, especially for strongly altered streams, such as the Lower Missouri River and its tributaries, and especially to the restoration of a specific species, such as, the pallid sturgeon. Junk and others (1989) state in their "benchmark" paper:

> In temperate regions, light and / or temperature variations may modify the effects of the pulse, and anthropogenic influences on the flood pulse or floodplain frequently limit production.

Tyus and Saunders (1996) cautioned that universal application of the flood-pulse concept does not constitute a panacea for ecological restoration, especially in greatly altered systems. There is no doubt that the Missouri River mainstem and the Missouri River tributaries have been greatly altered. The tributaries provide the dominance of water and sediment. It should also be noted that the mouths of tributaries and the tributaries themselves typically provide the spawning grounds, nursery areas, and the forage areas for many of the native Missouri River fishes (USFWS, 2000a, p. 159). For example, Harrow and Schlesinger (1980) state:

> It was documented that at various times of the seasons, increases in larval fish density occurred between successive transects. In view of the normal attrition that occurs in larval fish, this numerical increase is clear evidence of local inputs which are at times capable of reversing the expected density decline. As might be expected, the Platte River is a major contributor. The Platte is capable of adding fish in sufficient numbers so as to change the basic species assemblage pattern on the Missouri.

It seems possible, if not likely, that changes in the tributaries along with factors, such as the unprecedented land use changes that have occurred, hormonal disruption, construction of more than 20,000 dams on the tributaries, and the introduction and stocking of competing non-native fish species in the tributaries, in the mainstem, and in the reservoirs, may be largely responsible for the decline of the pallid sturgeon in the Lower Missouri River. USGS (U.S. Geological Survey, 2003, p. 10) states: " Numerous factors may play a role in limiting spawning activity and reproductive success for sturgeon. These may include hydrology, temperature, impediments to migration, lack of substrate, inadequate numbers of reproductive adults, hybridization with closely related sympatric species, predation, and contaminants".

The Missouri River reache below Plattsmouth, Nebraska, to the Mississippi River typically has one or more rises during spring and summer each year. This is because many of the tributary streams are largely unregulated, and they have significant rises due to melting snow or rain events. For the last 6 years (1998-2004), there has been a significant effort to find pallid sturgeon larvae in this reach and in the reach of the Mississippi River below the confluence of the Missouri and Mississippi rivers. Two pallid sturgeon larvae were collected in 1998 and one in 1999 at Lisbon Bottoms, Missouri, by USFWS personnel (Louise Mauldin, USFWS, 2004). On July 7, 1978, *Scaphirhynchus* spp larvae at RM 411 were collected (Harrow and Schlesinger, 1980, p. 57). The locations of the spawning grounds from which these larvae originated are not known. A pallid sturgeon larva was collected by Kerry Reeves, University of Missouri doctorate student, in the reach of RM 157-214.0 (Gallat, 2004). It has been speculated by Ress (2000, p. 1) that sturgeon larvae in the lower reaches of Lower Missouri River may originate from the tributary Platte River in Nebraska. In 1998 and 1999, Cory Reade (2000), a University of Nebraska graduate student, netted sturgeon protolarvae (*Scaphirhynchus* spp) from the Platte River near Louisville, Nebraska. In addition, a small number of sturgeon larvae have been collected by Columbia, Missouri, based USFWS personnel in the lower reaches of the Missouri River. These samples presently await identification as to species. Personnel of the Missouri Department of Conservation, Open Rivers and Wetland Field Station, have also collected sturgeon larvae in the Middle Mississippi River (MMR) below the Missouri River mouth (Herzog and others, 2005). Again, these candidate specimens have also not been identified because of the lack of funds for analysis. In addition, this group reports that successful reproduction of shovelnose sturgeon and pallid sturgeon is occurring in the MMR; however, they also suggest that successful recruitment to age 1 may be a limiting factor for long-term viability in the MMR. Even if all the unidentified larvae are pallid sturgeon, the number, unfortunately, would still not be large. However, the closely related shovelnose sturgeon, which in general shares the same habitat, and which has been shown not to necessarily require a spring rise to spawn, is believed to at least some degree to have successful spawning that results in recruitment. Information from Moos (1978) suggests spawning of shovelnose sturgeon near Vermillion, South Dakota, on the Missouri River without a spring rise. It should be remembered that sturgeon, including pallid and shovelnose sturgeons, can multiple spawn during the summer, and thus spawning is not dictated by a spring rise. The information above suggests that spring rises, or the lack of spring rises, is not the primary reason why the pallid sturgeon are not successfully recruiting. Further, at this time there is no convincing information to suggest that pallid sturgeon are successfully spawning (spawning that results in recruitment to the adult pallid sturgeon population) to any significant degree in the lower reaches of the Lower Missouri River, even though these reaches experience numerous rises and have approximately 20 acres per mile of shallow-water habitat (USACE, 2003b; Jorgensen and others, 2004).

Spring Rise, Erosion, Streambed Degradation and Sandbars: Flood pulses exacerbate erosion and streambed degradation below dams, such as Gavins Point Dam. Note: The Northwest Division of the USACE relates that the annual volume of water moved is the factor that controls the volume of material eroded. Further, they state that redistribution of that volume of water does not result in more or less erosion or degradation. The Northwest Division's position above is in essence stating that erosion or sediment transport has a linear relation with volume of flow. This is inconsistent with the established tenets of hydraulics and alluvial geomorphology. For example, Simon and Senturk (1992, p. 44) state:

$$Q_s \sim (\tau_o V)\, w\, C_F / D_{50}\,.$$

Where Q_s is the sediment discharge, τ_o is shear on the streambed, C_F is the concentration of fine streambed material, w is the width, D_{50} is the median grain size of the bed material, and V is the velocity. From fluid mechanics and hydraulics, we note that streambed shear (τ_o) is a function of the water velocity squared. Thus, clearly, erosion or streambed degradation is an exponential function of velocity not a linear function.

Jorgensen (2003c, p. 1) analyzed the extensive data collected by the USACE (1996) and USGS (Sando and Neitzert, 1999) below Gavins Point Dam. Jorgensen concluded that streambed degradation would be exacerbated by flood pulses. Streambed degradation below Gavins Point Dam, Fort Randall Dam, and other dams has resulted in stream entrenchment and sandbar area reduction.

Spring Rise and Reservoir Sedimentation: Sedimentation of material eroded by a spring rise is deposited in the next lower reservoir except below Gavins Point Dam. Jorgensen (2003c) analyzing USGS and USACE data concluded that the proposed spring rises would increase sedimentation in most of Missouri River reservoirs.

Other Characteristics of a Spring Rise for the Lower Missouri River: Streambed degradation lowers water levels in the stream which reduces connectivity to the river's backwaters and chutes. Streambed degradation results in decreasing ground-water levels in adjacent alluvial plains. Lowering of ground-water levels tends to dry up wetlands in the alluvial plain because these wetlands are supported directly or indirectly by ground water levels. Lower ground-water levels in the alluvial plain would result in increased pumping lifts for water supplies because the quantity of ground water stored in the adjacent aquifers is being reduced.

Spring rises, especially during April and May, would retard interior drainage during the crop planting season.

Spring rises, as for all flood pulses, would increase the probability of flooding, especially in the lower reaches of the Lower Missouri River.

A spring rise of the magnitude proposed in the biological opinion would not inundate most of the sandbar islands below Gavins Point, and thus would not effectively "clean" the sandbar islands (USACE, 2003; Jorgensen, 2003a).

Spring Rise, A Cue To Spawn Missouri River Native Fishes: It is reported in the Biological Opinion (USFWS, 2000) that a spring rise is needed to cue spawning of the native fishes of the Missouri River. Not all native fish in the Missouri River require a spring rise for triggering spawning. For example, examination of figure 3 shows that neither the sauger nor the shovelnose sturgeon, both of which are native fish, spawned in response to a spring rise.

Spawning characteristics of Missouri River fishes, which were identified by Galat and Clark (2002), were tabulated by Jorgensen (2003a). Based on the spawning information collected, Jorgensen surmised that there is little substantive information to indicate that a spring rise is essential to spawning of most of these fishes, because nearly all were capable of either and / or spawning in tributaries, lakes, backwater, or reservoirs. Similarly, Brown and Coon (1994, p. 731) relate: "Our study demonstrates the Missouri River fishes use the lower reaches of tributaries as backwater habitat for early life stages."

Biologic Characteristics of a Spring Rise; A spring rise is generally believed to have beneficial characteristics including reshaping sand bars, recreating channel habitats, and carrying nutrients. Some fish species are more dependent on one exogenous spawning factor than others. It is generally believed that these factors all work together, and depriving one factor may result in no spawning, or spawning that will not result in recruitment to the species (Krentz, 2004).

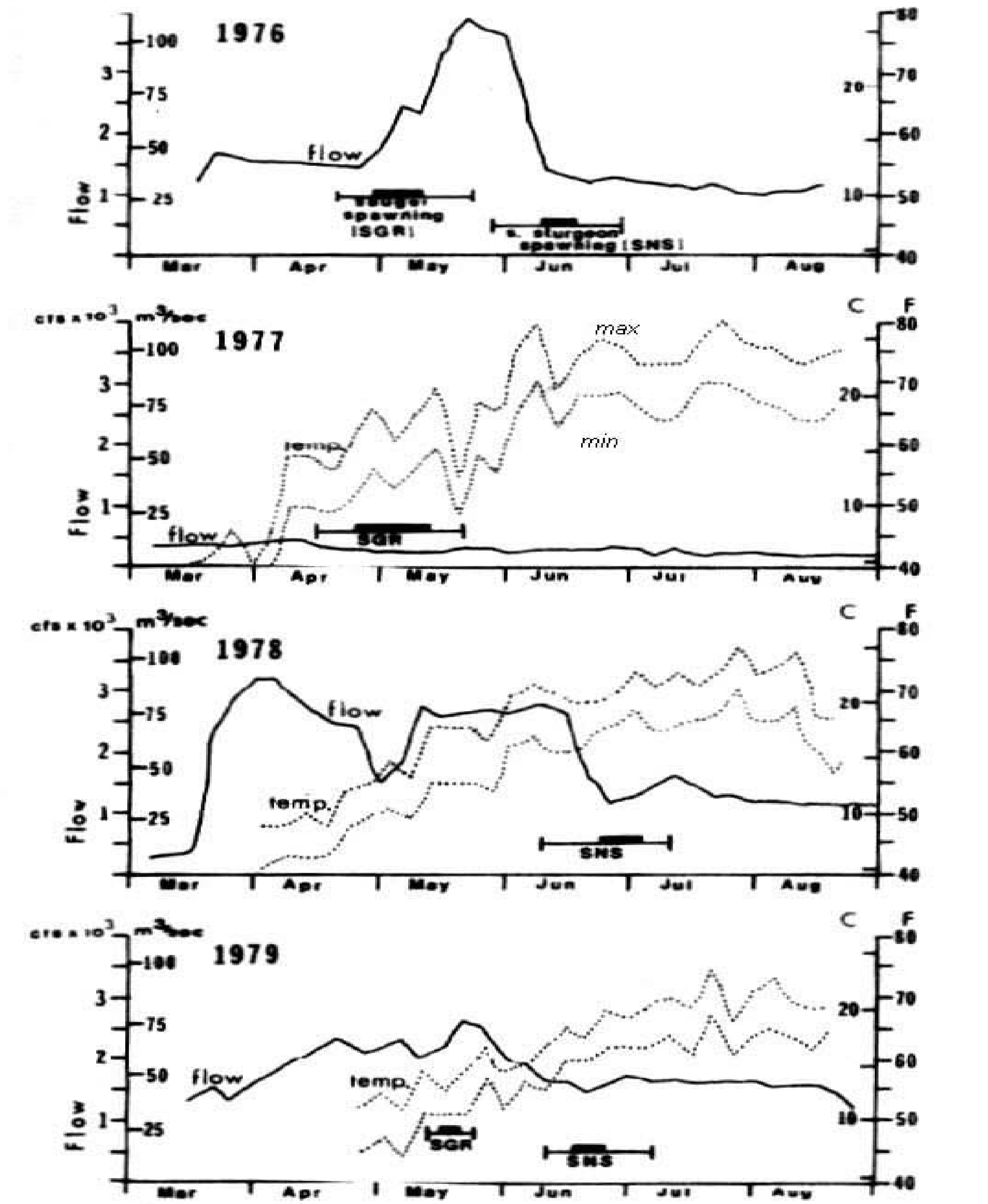
Spring Rise and Pre-Spawning Migration: Pre-spawning migration of sturgeon is not believed to be directly tied to a spring rise (Kynard, 2004a.). For example, in Iowa, it has been observed that the migration of sturgeon in tributary streams has been greater in years of low flow (Iowa DNR, 2002). However, additional flow may result in additional spawning substrate being available and/or result in the correct bottom velocity being available (Krentz, 2004).

Spawning and a Declining Hydrograph: Information and observations of sturgeon spawning worldwide indicate that sturgeon typically spawn on a declining hydrograph and off peak (Kynard, 2004a). Observations of shovelnose sturgeon spawning in the Marias River (Berg, 1981, fig. 22) show that the spawning of shovelnose sturgeon is post-spring rise and on a declining hydrograph. (See figure 3.) This information suggests that spawning is on a declining hydrograph, but the precursor rise may or may not be a flood pulse and/ or a spring rise.

Coupled Water Temperature and Flow Spawning Cue: It is reported in the Biological Opinion (USFWS, 2000a) that coupled water temperature and spring rise will trigger the spawning of the pallid sturgeon and native Missouri River fishes. Water temperature and the 'natural' spring rise of the Missouri River at Sioux City, Iowa, were not found to be closely coupled (Jorgensen, 2003b, p.21). The water temperature of the Missouri River at Sioux City, Iowa, was largely a function of mean air temperature of the current day and of the two previous days at or upstream of the location. By contrast, the date of 'natural' spring rise (June rise) was largely a function of the time of snow melt in the upstream mountainous areas of the basin. The reconstructed natural hydrographs at Sioux City for the years 1929-55, show that the average date of the start of the spring rise was May 15 with a standard deviation of 13 days and ranged from April 21 through June 2. The average date when the water temperature reached 18 C for three days was May 26 with a standard deviation of 18 days, and the range was from April 13 to June 26. The average time difference between the 18 C occurrence and the start of the spring rise was minus 13 days with a standard deviation of 19 days. The range was from minus 52 days to plus 11 days.

Similarly, water temperature and the 'second' rise at Boonville were not found to be closely coupled. (Second rise was defined as the rise that included a period of 18 C water temperature for 3-days and started not later than August 15.) The dates when water temperature reached 18 C and the dates when the 'second rise' started at Boonville, Missouri, were determined for the years 1984 through 2003. (See attached hydrographs in Appendix A.) The start dates were not found to be closely coupled. The average start date when water temperature was 18 C for 3 days was May 8 with a standard deviation of 10 days. The average magnitude of the rise, increased flow of the pulse, was 155,000 cfs. The average date of the start of the second rise was April 25 with a standard deviation of 26 days. The average offset of the start of 18 C water temperatures and the start of the second rise was 11 days with a standard deviation of 25 days. The range was from minus 30 days to plus 44 days.

The limited temperature and flow data for the Marias River, a tributary of the upper Missouri River, indicates that even in the upper Missouri River the occurrence of the spring rise and a water temperature of 18 C are not closely coupled. (See Berg, 1981, fig. 22, which is fig. 3 herein.) The above information indicates that coupled spring rise and temperature does not typically occur on the Missouri River presently or historically, and even if coupled would not necessarily be a critical factor in relation to spawning.



Relation of water temperature and discharge to spawning of sauger and shovelnose sturgeon in the lower Marias River from 1976 through 1979.

Figure 3. Spawning of shovelnose sturgeon in Marias River. (From Berg 1981)

Historical Spawning of Pallid and Shovelnose Sturgeon in Tributaries: Historically, spawning of pallid and shovelnose sturgeon was observed in the tributaries of large rivers, such as the Missouri, Mississippi, and Ohio rivers (Jorgensen and others, 2003a, p. 8; USFWS, 2000, p. 159; Goode, 1894, p. 663; Iowa Fish Commission, 1892-93, p.22; Iowa DNR, 2002; Ress, 2000, p. 1; Berg, 1981, Fig. 22). For example, a report by the Iowa Fish Commission (1892-3, p. 22) relates: - "The shovelnose or white sturgeon is found in the Ohio and Mississippi valleys, extending to the upper Missouri and to the Rio Grand. In large tributaries of the Mississippi, the species is very common. The maximum length is 8 feet, but it is not an important food fish, being little esteemed. Nothing is recorded of its habits, except that it runs up the small streams in May for the purpose of spawning". Note, prior to 1905, the pallid sturgeon (white sturgeon) and the shovelnose were both listed as *Scaphirhynchus platyrhynchus*. The pallid sturgeon in the Mississippi and Missouri basins has also been called the white sturgeon, white shovelnose sturgeon and the white hackleback (Pfleiger, 1997, p.50). In general, pallid-sturgeon researchers assume that tributaries are used primarily for foraging and /or spawning (USFWS, 2000a, p. 159). Shovelnose sturgeon are reported as spawning in the Yellowstone, Tongue, Marias, and the Teton rivers, which are tributary streams in the upper Missouri River Basin. Dryer and Sandvol (1993) state that tributaries of the Missouri and Mississippi River are important feeding and nursery areas for many large-river fishes. Pallid sturgeon use tributaries, such as the Kansas, Platte, and Niobrara rivers (USFWS, 2000a, p. 159; Hofpar, 1997, p. 37). Information in this section should not be used to infer that pallid and shovelnose sturgeon have not or cannot spawn in the Missouri River mainstem, but the information is presented to point out that both species have been historically observed spawning in tributary streams of large rivers, such as the Missouri and Mississippi rivers. If most spawning is in the tributaries, the importance of a spring rise on the Lower Missouri River in reference to providing a cue for spawning would largely be moot.

Dispersal of Pallid Sturgeon Larvae: Pallid sturgeon free embryos and larvae are in a dispersion stage for about 13 days (Kynard, 2004a; Kynard and others, 2005). USGS (2003, p. 16), states that in laboratory, drifting lasts 8-13 days. Although the larvae are good swimmers, they can't control their location as it is dominantly controlled by water flow (Kynard, 2004a). Their swimming behavior in the laboratory was to swim to near surface and then to drift and settle. This repeated movement in the river would eventually move them back into the current if they are caught in an eddy (Kynard, 2004a; Kynard and others, 2002). An estimate of the distance drifted or diffused downstream of the spawning area of a free embryo and early larvae stage pallid sturgeon is the mean water velocity multiplied by drift time, e.g. 13 days (Kynard and others, 2002). However, the estimate is likely a maximum as it does not account for time the free embryo and early stage larvae could be in eddies or in slow moving water, such as a back water. Additionally, to apply this estimate for larvae in the Missouri River, one must be certain that the spawning was in the river and not in a tributary as the water velocity in the tributary may not be the same as the water velocity in the mainstem.

Movement of Adult Sturgeons: Upstream movement of adult non-spawning shortnose sturgeon is believed to occur in connection with increased flow (Kynard, 2004a).

Apparently the movement is associated with an instinct to move to a new aggregation or forage area. (Kynard, 2004a). Downstream migrations of adult shortnose sturgeon, which are not associated with pre-spawning and spawning, tend to occur intermittently (Kynard, 2004a). Migration and activities of adult shortnose sturgeon are minimal at less than 6 C water temperature and are at a maximum at about 18 C (Kynard, 2004b, p. 15: Kynard, 2004 a). Pallid and shovelnose sturgeons are reported active in the Mississippi and Missouri rivers at temperatures of 4 C or greater.

Pre-spawning pallid sturgeon may tend to stage (concentrate) in an area during the summer and fall for the next spawning event. Kynard (2004a) observed that pre-spawning shortnose sturgeon migrate upstream in summer and fall to the utmost foraging and wintering site nearest the spawning site. Kynard suggests that this behavior is likely to be related to conserving energy to prepare for a winter of not feeding. This migration was believed to be a response to a temperature cue. The next spring, the sturgeon only have a short upstream migration to the staging area for spawning.

Shortnose sturgeon were found to migrate to a staging area for spawning as the result of a temperature cue and not a water discharge cue. Kynard (2004a.), based on results from an ongoing 15-year study of shortnose sturgeon behavior in both the field and in the laboratory, relates: “Our (15-year) study of the shortnose sturgeon found that water temperature, not discharge, was correlated with the time that pre-spawning adults left the wintering area and moved upstream”.

Shallow-Water Habitat: It is reported in the Biological Opinion (USFWS, 2000) with little supporting evidence that shallow-water habitat is needed for specific life stages of the pallid sturgeon. However, to date, the specific life stage has not been identified. Shallow-water habitat has been inferred to be important to larval and young of the year sturgeon. New information suggests that young of the year are found with adult sturgeons near the bottom in relatively deep water.

Area of shallow-water habitat in the Missouri River is reduced if the discharge at Boonville, Missouri, is reduced below 40,000 cfs (Jorgensen and others, 2004, p. 13). Information presented by Jacobson and others (2004) also indicates the severe loss of shallow-water habitat in the lower reaches of the Lower Missouri River when discharges are less than 40,000 cfs.

Pallid Sturgeon Larvae and Light: Pallid sturgeon larvae movement is photopositive under laboratory conditions. (Kynard, 2004a). If this characteristic holds for the Missouri River conditions, the larvae would be at a high risk of predation by sight feeders in the Lower Missouri River because of water clarity.

Natural (not artificially induced) spawning of shortnose sturgeon occurs under laboratory conditions without a spring rise (Kynard, 2004a). Natural spawning of shortnose sturgeon in laboratory conditions is related to photoperiod and temperature (Kynard, 2004a). Kynard (2004a) states: “Spawning occurred during 15 years (1990-2004) by shortnose sturgeon when two environmental windows were open: photoperiod (day length) between 13.9 - 14.9 hours (27 April – 22 May) and temperature 6.5 - 14.7 C (April 8 – 29 May). (Note: Pallid and shovelnose sturgeon typically spawn between 15 and 22 C, with the maximum spawning activity about 18 C.) Figure 3 clearly shows that shovelnose sturgeon in the Marias River spawned when the mean temperature was about 18 C if there was adequate water in the tributary.

The photoperiod for shovelnose and pallid sturgeon spawning in the Missouri River Basin may be about 13 hours, which occurs about April 15 in Topeka, Kansas. Reports of sturgeon spawning in the central United States range from April at Topeka, Kansas, to May and June in Montana (Bramblett, 1996 ; Berg, 1981,Brown, 1971) Most observations of sturgeon spawning are in May (Helms, 1974 ; Goode, 1892) However, Moos (1988) reported spent shovelnose sturgeon in the Missouri River below Gavins Point Dam near Vermillion, South Dakota, during June. The mesolarvae pallid sturgeon collected at Lisbon Bottoms likely spawned in mid to late July possibly as one of a multiple spawning event. The protolarvae sturgeon collected by Reade (2000) from the Platte River likely spawned in mid May and mid June. It would seem that the minimum photoperiod in the Missouri River Basin is reached at a date prior to the date the water temperature reaches 18 C.

Bottom-Water Velocity: Velocity of the bottom flow at the spawning area is a critical element for successful shortnose sturgeon spawning (Kynard, 2004a.). Suitable bottom-water velocity was measured at 0.5 meter above the bottom with a velocity of 0.3 to 1 meter per second. Note the above statement does not necessarily mean that a spring rise is needed for sturgeon spawning, but only that an adequate water velocity is present at the spawning site (Kynard, 2004a).

Depth of Water at Spawning Site: Depth of water at the spawning area and type of substrate may not be a strong limiting factor. Experiments with shortnose sturgeon in the laboratory showed depth of water if above a minimum threshold was not a determining factor if the correct bottom-water velocity range was available (Kynard, 2004a).

Water Temperature and Spawning: Water temperature is an exogenous element that controls spawning (USFWS, 2000a; Jorgensen, 2003a, p.19-20). For example, USFWS (2000b) suggests a warm water release over the Fort Peck Dam spillway would act as a reproductive trigger for the pallid sturgeon. Kynard (2004a) relates that when the minimum photoperiod is reached and the water temperature is suitable for spawning, gravid shortnose sturgeon are likely to spawn. However, if bottom-water velocity is not correct spawning may not occur, and if spawning does occur, it may not be successful.

Sounds of Spawning Sturgeon: Pallid sturgeon and shovelnose sturgeon produce unique sounds during breeding season. Bioacoustic monitoring may allow the date and the location of spawning to be determined (Phillips and Johnston, 2005).

Olfactory Stimulus: Male pre-spawning shortnose sturgeon will migrate and stage due to an olfactory stimuli (Kynard, 2004a). Accordingly, males will stage with females before spawning. Males milting at an egg deposition site is also probably in response to an olfactory stimuli (Kynard, 2004a).

Spawning Substrate: Shortnose sturgeon spawn on many different substrates if the temperature and photoperiod are correct and the bottom velocity is correct. (0.3 - 1m/s specified range at a depth of 0.5 meter above the bottom (Kynard, 2004a). Kynard (2004a) reported that if conditions of photoperiod, temperature and light were correct that shortnose sturgeon will spawn on many types of substrate. Kynard reports that shortnose sturgeon spawning has occurred over wooden boards when photoperiod and water temperature were correct.

Spawning substrates in the Upper Missouri River are reported to be hard substrate, such as gravel or cobble. However, in the Lower Missouri River, it is not known if successful spawning can be on substrates in addition to gravel and cobble. It is thought that the substrate must be stable until hatching.

Sturgeon and Habitat: It has been speculated that sturgeon will proliferate best in turbid water. Sturgeons are known for poor eyesight and can feed in water with little light, such as in deep turbid water, which was characteristic of the predevelopment Missouri River. It is also believed that turbid water protects sturgeon larvae and juveniles from predation from sight feeders. However, a non-turbid segment of the Missouri River in the upper Basin has a healthy and robust shovelnose sturgeon population (Gardner, 2005).

A laboratory test of juvenile pallid and juvenile shovelnose sturgeons indicated a preference of deep- over medium- and shallow-depth habitat, dark over light habitat, and fast- over slow-water velocities (Allen and others, 2005). Shovelnose sturgeon under laboratory conditions selected sand and sand with cover over gravel / pebble substrate (Irwin, 2005). Population assessments in the Middle Mississippi River and other locations indicated larger concentrations of pallid sturgeons in deep water, especially near breaks in the bottom slope.

A MODIFICATION OF THE 2003 AMENDMENT TO THE BIOLOGICAL OPINION PLAN

This plan, which is a modification of the plan presented in the USFWS 2003 amendment to the biological opinion plus the summer low flow exemption, is shown in figure 2 as the modification of the 2003BiOp. One of the important principles to consider in designing a spring rise is that any management scheme should strive not to eliminate or to be extremely harmful to any of the congressional purposes. The spring rise as presented in the 2003 amendment to the biological opinion has several onerous characteristics that are unnecessarily harmful to congressionally authorized purposes. The first mode of the spring rise, largely in late March and early April, would tend to retard interior drainage during the crop planting season. The second mode of the spring rise, which is largely in June, occurs at a time when flows in the lower reaches of the Lower Missouri River are typically high, and increases the potential for flooding. The proposed flow between the two modes was less than the release needed for full service level of navigation at Sioux City. In reference to navigation, spring is the most important time as it is the time when most barges are moved. Although barges can physically be moved to Sioux City on the upper reaches of the Lower Missouri River at minimum service levels, the barges cannot be fully loaded. This condition sharply reduces the amount of cargo that can be moved, which in turn sharply reduces profit. Thus, the minimum service level that the amendment to the biological opinion recommends constitutes an unreasonable detriment to a congressional purpose. The substitution of full navigation service level for the period between the first and second modes removes this hindrance. This small change also will reduce, to some degree, the amount of water that must be released after August for normal flow. The changes are shown as the 'Modified 2003 BiOp' curve. Nevertheless, this derivative plan as well as its predecessor, is not based on well defined design criteria, nor is the background science well defined or established, and the effects of the plan are needlessly harmful. This plan is not recommended.

A NEW SPRING-RISE PLAN

The data on the numerous spring rises on the lower reaches of the Lower Missouri River (Plattsmouth, Nebraska, to the confluence at St. Louis) as well as on the tributaries in this same reach, many of which experience spring rises, is strong evidence that the spring rise is not the critical element in dictating the population of the pallid sturgeon because there is little data to show significant successful pallid sturgeon recruitment.

The Corps has asked for information and input for a spring rise alternative as well as for other alternatives. Accordingly, some guides for designing a flow alternative from Gavins Point Dam are presented.

No science or information has been presented by either the USACE or by the USFWS to justify the first mode of the proposed bimodal spring rise. Accordingly, the first mode is dropped from further consideration.

No justification was given by either the USFWS or by the USACE to use minimum navigation flow, between the first and second mode of the proposed spring rise presented in the amendment to the biological opinion, and, thus, minimum navigation flow was not included in the hydrograph developed herein.

For spawning of pallid sturgeon, there are three dominant items to be considered (Kynard, 2004a).

1) Minimum photoperiod has to be exceeded.

2) Mean water temperature greater than 15 C, preferably at 18 C is needed.

If the two elements above are met, a third important element for *successful* pallid sturgeon spawning is needed.

3) Specifically, the correct bottom-water velocity over a stable substrate is essential.

The alternative developed herein would be for years of normal flow when neither extra flood control measures are dominant nor when drought control plans are dominant. Further development of the plan would be needed for these and other conditions.

The flow segments are:

A) Winter flow that meets the needs of congressionally authorized purposes as well as the Clean Water Act and the ESA will be maintained during the winter until the start of the navigation season about mid March. (See figure 4.)

B) Releases would be increased in mid March to full service navigation level at Sioux City, Iowa. This would tend to encourage terns and plovers to nest higher on the sandbars. The full service releases would ensure adequate depth of channel for economic loading of navigation barges during the spring when the majority of barge traffic occurs.

Flow for this period, of course, could be greater than 31,000 cfs if preventive flood control releases are needed. C) The spring rise could be initiated by increasing discharges after the average water temperature at Sioux City exceeds 18 C for three consecutive days (excluding abnormally warm periods in March and April). The date at which the average water temperature exceeds 18 C for three days at Sioux City is the last week of May.

The increase in discharge would be a minimum of 10 % above prior discharge. For example, if prior flow was 31,000 cfs, the spring rise would be at 34,000 cfs for a minimum 10 %. The maximum release should not be of such a magnitude to increase the potential of flooding. The increased discharges would tend to increase the water velocity and would tend to remove fine sand, silt, and mud from potential spawning substrate (and unfortunately exacerbate streambed degradation). Also, this alternative would provide a test to try to determine the proper bottom velocity at spawning sites. It should be noted at this time spawning sites have not been identified in the upper reach of the Lower Missouri River. It also should be noted that only four pallid sturgeons have been caught or observed in the reach from Gavins Point Dam to the Platte River since 1998. Thus, designing a spring rise for 2006 by modification of flow from Gavins Point Dam is likely premature. It should also be noted that it is probable that there are different bottom-water velocities at different potential spawning sites.

It is also likely that there are different bottom-water velocities within a single potential spawning site. If so, it might not be necessary to change flow for any plan because the preferred bottom-water velocity is likely to exist at least over part of the substrate.

D) Releases could be maintained at the same discharge rate as step C for two weeks to create stability at the spawning sites during the approximately 1-week hatching period.

E) Flow could then be gradationally reduced to September 1, thus providing a declining hydrograph. The level at September 1 would be the same level as immediately prior to the start of the spring rise. Note: Flow at Sioux City should not be less than 26,000 cfs as that is the minimum navigation service level at Sioux City. Further, during drought years, releases should always be of such a magnitude above minimum service level so that flow at Boonville, Missouri, is not less than 40,000 cfs. The latter will tend to maximize shallow-water habitat from Kansas City to St. Louis, Missouri. Full service navigation flow at Kansas City is 41,000 cfs, which is coincidentally near the flow at which maximum shallow water habitat will occur.

F) Increased releases could start in September to evacuate water for flood protection to the end of navigation season if needed, or the navigation season could be extended. Most of these releases would occur at water temperature exceeding 6 C, and thus migration of adult sturgeon could occur. Further, the increased fall flows, if needed, might tend to "clean" candidate spawning areas for next year and would tend to clean sandbar islands in part without disrupting nesting and rearing of terns and plovers. However, the immediate effect of a flood pulse is to wash away the material at the shore line resulting in a steep or vertical bank being formed. This condition is especially harmful to the small self feeding piping plover. It should be noted that any flood pulse increases the potential for downstream flooding and exacerbates streambed degradation.

G) Decrease releases to winter levels at the end of the navigation season. Little sedimentation would occur during the winter because these flows are characteristically low in sediment.

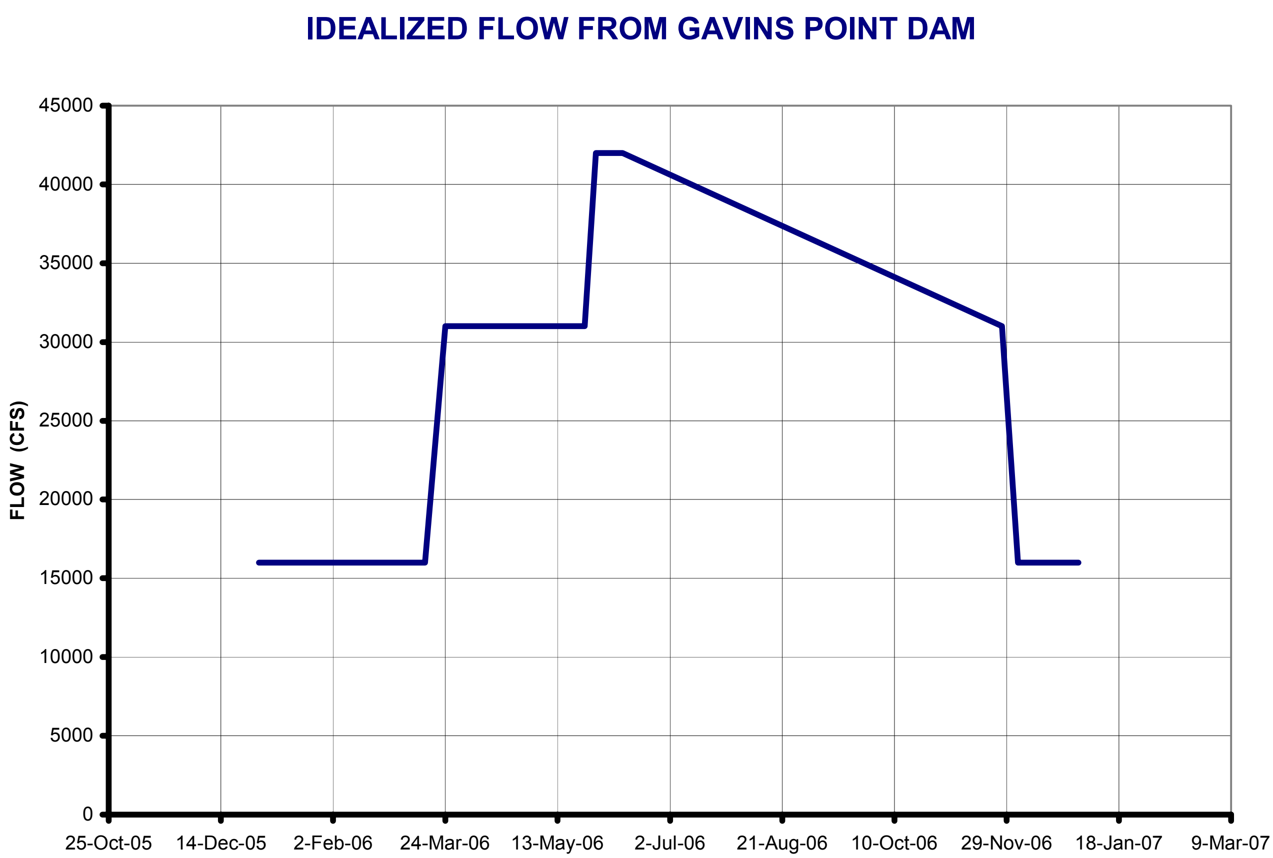


Figure 3. Alternative flow release plan from Gavins Point Dam for "normal" flow conditions.

The plan described above is not recommended because it would tend to increase the potential for flooding and would also exacerbate streambed degradation with all its negative aspects. This spring-rise plan as others lacks convincing science to support the need.

MISSOURI RIVER FIELD AND LABORATORY PLAN

A laboratory program to determine pallid-sturgeon spawning information should be started as soon as possible. Laboratory testing should produce information relating to the conditions for pallid sturgeon spawning in a timely, efficient, and definitive manner as compared to creating a spring rise on the river to change river flow on an annual manner. Additionally, laboratory testing will allow many conditions to be controlled accurately as compared to the default plan outlined in the amendment to the biological opinion. Laboratory testing will be much more economical than using trial and error method of modifying flow from Gavins Point Dam, especially in considering the very large costs of accurate and comprehensive field monitoring in the complex multivariable Missouri River environment. At this time, it is questionable if it is even pragmatically possible to monitor the results of a flow modification from Gavins Point Dam to a comparable accuracy that can easily be obtained as part of the laboratory testing plan.

A proactive program of field testing of factors affecting successful pallid sturgeon should also be initiated in chutes in the Lower Missouri River as well as in the tributaries. Initially, a chute in the lower reach of the Lower Missouri River, a chute in the relatively unchanneled river below Gavins Point Dam in the upper reach of the Lower Missouri River, and a chute in the Platte River in Nebraska should be considered. The testing in the chutes should include control of flow, bottom-water velocity, and different substrates. Results from the laboratory should become available in less time than results from field testing. Because laboratory testing will result in rapid determinations, testing in chutes could be used to verify results from the laboratory. Selection of testing sites and construction of flow-control structures should be initiated as soon as possible.

In summary, this alternative has large potential. Laboratory testing and testing in chutes, along with the proactive pallid-sturgeon research that is already in progress, offers the greatest potential for the timely recovery of the pallid sturgeon.

SUMMARY AND CONCLUSIONS

Presently (2004) an effort is in progress to both design and evaluate plans to facilitate successful spawning of the pallid sturgeon. The spring-rise concept has been proposed as the starting point. Design of a spring rise for the lower Missouri River by altering flow from Gavins Point Dam is complicated by the scarcity of information about the pallid sturgeon, especially in relation to spawning that results in recruitment to the population. Additional information as to the applicability of the spring-rise concept to the Missouri River Basin is now available. Additionally, new information is becoming available about the species or about surrogate species that should be useful. Further, a program of acquiring new information on the species has been accelerated since 2002.

The applicability of the spring-rise concept to the highly altered Missouri River Basin is problematic. Questions have arisen about the usefulness of a spring rise to cue spawning of the pallid sturgeon that would result in recruitment. The lower Missouri River below the Platte River to the mouth and the mainstem tributaries in this reach already have spring rises. Unfortunately, there is no compelling evidence that these spring rises are resulting in any significant successful spawning of pallid sturgeon. These observations and other information do not support the reportedly critical need for the spring rise for the pallid sturgeon.

Information based on study of the shortnose sturgeon show that a spring rise is not needed for spawning, but that spawning is possible if minimum photoperiod, minimum temperature, and the bottom-water velocity is within the correct range. This information may be applicable to pallid sturgeon.

Historic information indicates that the shovelnose sturgeon and pallid sturgeon have been observed spawning in tributary streams of the Missouri, Mississippi, and Ohio rivers. No observations of spawning in the mainstem of the Missouri are known. Numerous observations of shovelnose sturgeon spawning in the Missouri River tributaries have been reported. However, these observations should not be interpreted to mean that some spawning is not occurring in the Missouri River or that spawning cannot be accomplished in the river. Unsuccessful spawning may be occurring. The observations do indicate that spawning in the tributaries is typical. Because the tributaries are typical spawning areas for sturgeon, it also brings up the question of the importance or degree of applicability of a spring rise in the mainstem of the Missouri River for sturgeon spawning.

The spring rise as typically proposed requires large discharges (flood pulse) from Gavins Point Dam and upstream dams. The flood pulses will at the time of the pulse slightly increase connectivity. However, it should be noted that flood pulses exacerbate streambed and bank erosion. Streambed degradation (erosion), over the long-term, incises the river, reduces sand-bar areas and starts a long chain of other negative environmental and economic impacts. Some of these long term impacts are loss of connectivity of the river with chutes and backwaters, dewatering of alluvial lakes and wetlands, and sedimentation in the reservoirs, as well as increasing pumping lifts for water supplies and increasing potential for flooding.

Several plans to enhance pallid sturgeon spawning leading to recruitment were examined. The three spring-rise plans negatively impact many of the congressionally authorized purposes for the Missouri River.

A plan of Missouri River field testing in conjunction with laboratory testing to determine the important items needed to enhance successful spawning of pallid sturgeon has the best potential to succeed. This approach will result in a plan based on science. It is likely to produce the relevant information in a timely manner as compared to the trial and error approach of annual flow-change based on questionable assumptions, which may never succeed.

CITATIONS

Allen, Teresa C., Robert D. Davinroy, and Dawn M. Lamm, 2005. A laboratory examination of substrate, depth and light use by juvenile pallid sturgeon (*Scaphirhynchus albus*) and shovelnose (*Scaphirhynchus platorynchus*) sturgeon: *Scaphirhynchus* 2005 Conference, Jan. 11-13, U.S. Army Corps of Engineers, St. Louis Univ., and U.S. Fish and Wildlife Service, St Louis, Missouri, abs.

Berg, Rodney K., 1981. Fish populations of the Wild & Scenic Missouri River, Montana: Montana Department of Fish, Wildlife & Parks, Proj. FW-3-R.

Brown, Claudius J, 1971. Fishes of Montana: Big Sky Books, Montana State University, Bozeman, 201 p.

Brown, Danny J., and Thomas G. Coon, 1994. Abundance and assemblage structure of fish larvae in the Lower Missouri River and its tributaries: Transactions of the American Fisheries Society, v. 123, p. 718-732.

Dryer, M.P. and A. J. Sandvor, 1993. Recovery plan for the pallid sturgeon (*Scaphirhynchus albus*): U.S. Fish and Wildlife Service, Bismarck, ND.

Galat, David L., 2004. Personal communication: U.S. Geological Survey, Oct. 25.

Galat, David, L., and Sandra Clark, 2002. Fish spawning and discharge temperature coupling along the Missouri River: 6th Annual Missouri River Natural Resources Conference, April 21-24, South Sioux City, NE, abs.

Gardner, William M., 2005: Population abundance and size characteristics of shovelnose sturgeon (*Scaphirhynchus platorhynchus*) in the Upper Missouri River, Montana: *Scaphirhynchus* 2005 Conference, U.S. Army Corps of Engineers, St. Louis Univ., and U.S. Fish and Wildlife Service, Jan. 11-13, St. Louis, Missouri, abs.

Goode, George B., 1884. The fisheries and fishes industry of the United States: U.S. Commission of Fish and Fisheries, GPO, 895 p.

Harrow, Lee G., and Allen B. Schlesinger, 1980. Larval Fish Recruitment Study: Environmental Series Bulletin No. 5, Omaha Public Power District, Nebraska, 91 p.

Hedman, E. Robert, and Donald G. Jorgensen, 1990. Surface- and ground-water interaction and hydrologic budget of the Missouri River Valley Aquifer between Yankton, South Dakota, and St. Louis, Missouri: U. S. Geological Survey hydrological Investigation Atlas, 1 sheet.

Herzog, David P., Robert Habrik, Ron Brooks, Timothy W. Speir, David Ostendorf, Jason Crites, Collin Beachum, and Rob Columbo, 2005. Assesment of *Scaphirhynchus* spp spawning and rearing locations in the Middle Mississippi River: Insights from collection of larval and young-of-the year fishes: *Scaphirhynchus* 2005 Conference ,Jan 11-13,2005, St Louis Missouri, U.S. Army Corps of Engineers, St. Louis Univ., U.S. Fish and Wildlife Service, abs.

Hofpar, Robin F., 1997. Biology of shovelnose sturgeon, *Scaphirhynchus platorynchus*, in the Lower Platte River, Nebraska: Master's Thesis University of Nebraska, Lincoln, 83 p.

Iowa DNR, 2002, Shovelnose sturgeon: Iowa Department of Natural Resources, www.state.ia.us/dnr/organza/fwb/fish/iafish/ .

Iowa Fish Comm., 1892-93. 10th Biannual Report of the Fish Commission of the State of Iowa.

Irwin, Elise R., 2005. Habitat selection of juvenile shovelnose sturgeon: *Scaphirhynchus* 2005 Conference, U.S. Army Corps of Engineers, St. Louis Univ. and U.S. Fish and Wildlife Service, Jan 11 – 13, St. Louis, Missouri, abs.

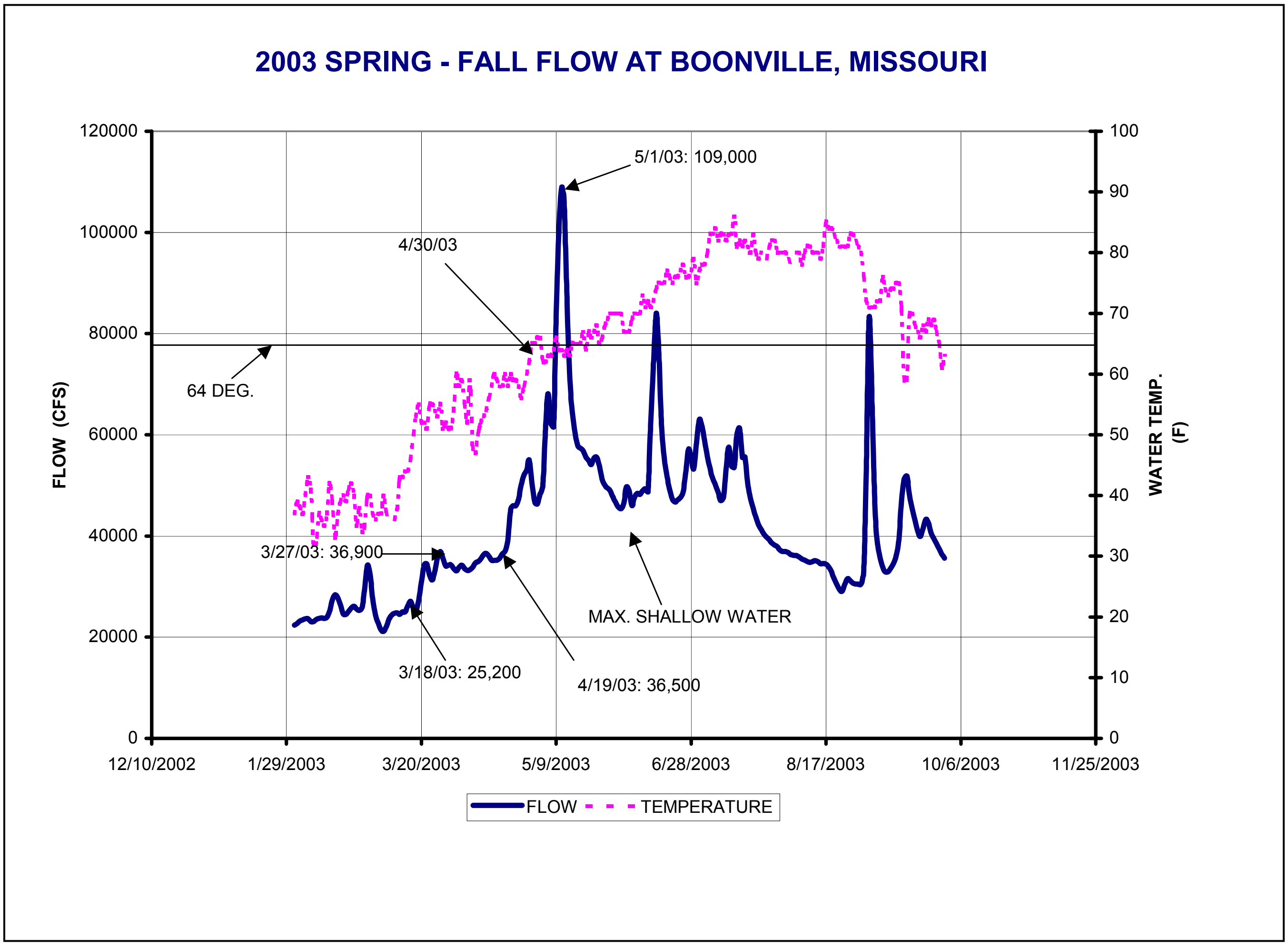
Jacobson, Robert B., Harold E. Johnson, Mark S. Laustrup, Gary J. D'Urso, and Joanna M. Reuter, 2004. Physical habitat dynamics in four side-channel chutes, Lower Missouri River: U.S. Geological Survey Open-File Report 2004-1071, 66 p.

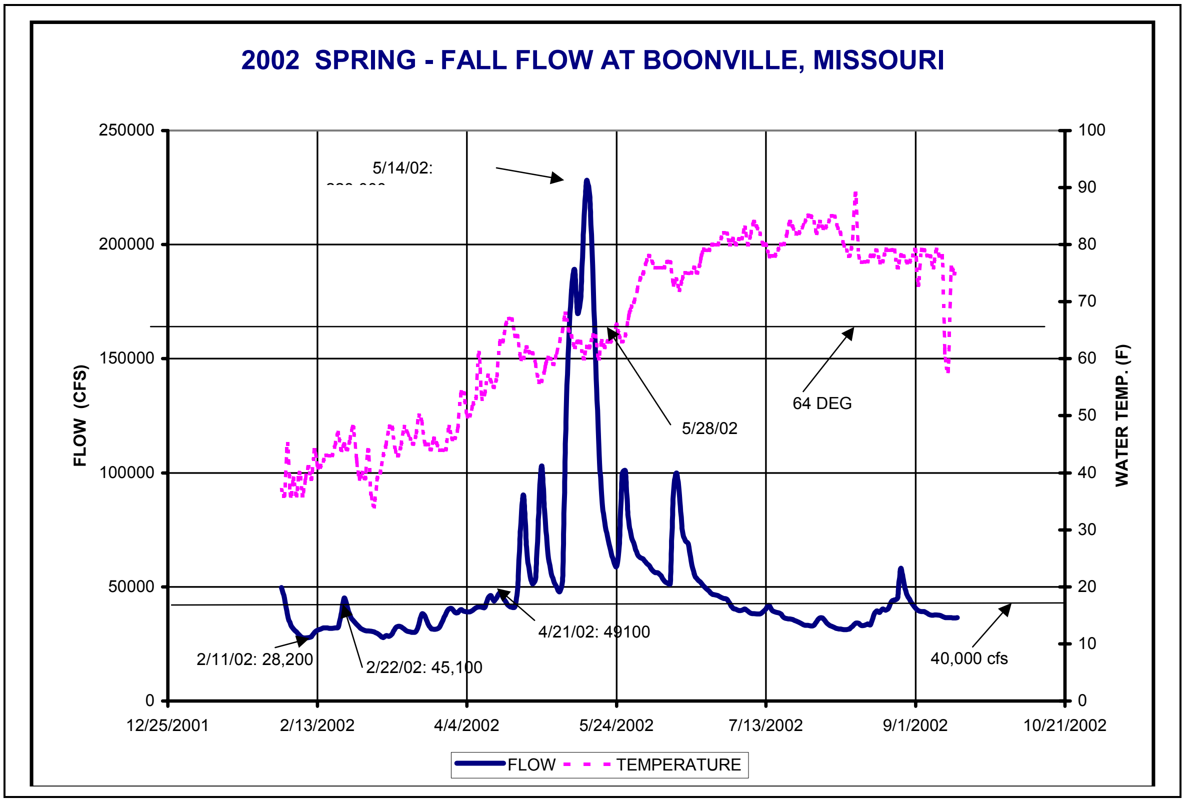
Jorgensen, Donald G., 2003a. Evaluation of a spring rise for the Missouri River: Missouri River Technical Committee of the Siouxland Chamber of Commerce, Sioux City, IA, 68 p.
Jorgensen, Donald G., 2003b. Analysis of the Missouri River natural hydrograph at Sioux City, Iowa: Missouri River Technical Committee of the Siouxland Chamber of Commerce, Sioux City, IA, 34 p.
Jorgensen, Donald G., 2003c. The Missouri River below Gavins Point—the least terns, piping plovers, sandbars, and the natural hydrograph: Missouri River Technical Committee of the Siouxland Chamber of Commerce, Sioux City, IA, 67 p.
Jorgensen, Donald G., William M. Beacom, and Donald M. Meisner, 2004. Summer low flows for the Lower Missouri River: Missouri River Technical Committee of the Siouxland Chamber of Commerce, Sioux City, IA, 14 p.
Junk, Wolfgang J., Peter Bailey, and Richard E. Sparks, 1989. The flood-pulse concept in river-floodplain systems, in D.P. Dodge (ed.) Proceedings of the International Large River Symposium: Can. Publ. Fish Aquat. Sci., p 110-127.
Krentz, Steve, 2004. Personal communication: U.S. Fish and Wildlife Service, Bismarck, ND.
Kynard Boyd, Erika Henley, and Martin Horgan, 2002. Ontogenetic behavior, migration, and social behavior of pallid sturgeon, *Scaphirhynchus albus*, and shovelnose sturgeon, *S. platorynchus*, with notes on the adaptive significance of body color: Environmental Biology of Fishes, v. 63, p. 389-403.
Kynard, Boyd, 2004 a. Personal communication October: Conte Anadromous Fish Center, Turner Falls, MA.
Kynard, Boyd, 2004 b. Pallid Sturgeon Recovery Update. *editor* Ryan Wilson: April 2004, no. 13, 25 p.
Kynard, Boyd, Erika Parker, Don Pugh, and Tim Parker, 2005. Experimental studies of pallid sturgeon dispersal and vertical swimming height during ontogeny: *Scaphirhynchus* 2005 Conference, U.S. Army Corps of Engineers, St. Louis University, and U.S. Fish and Wildlife Service, Jan 11 – 15, St. Louis Missouri, abs.
Mauldin, Louise, 2004. Personal Communication: US Fish and Wildlife Service, Columbia, Missouri.
Mcallister, Roy F., 2004. Personal communication: U.S. Army Corps of Engineers, Northwest Division, Omaha, NE.
Moos, Richard E., 1978. Movement and reproduction of shovelnose sturgeon, *Scaphirhynchus Platorynchus*, in the Missouri River South Dakota: Ph D dissertation, University of South Dakota, Vermillion, 216 p.
NRC, 2002. The Missouri River ecosystem—Exploring the prospects for recovery: National Research Council, National Academy Press, Washington, D.C., 149 p.
Olson, Mike, 2004, Oral communication at Sept. 8 MRBA Meeting of Sept 7-8: U.S. Fish and Wildlife Service.
Pfleiger, William L., 1997. The fishes of Missouri: Missouri Department of Conservation, Jefferson City, 372 p.
Phillips, Catherine N. and Carol E. Johnston, 2005. Sound Production in *Scaphirhynchus*: Potential use as a conservation tool: *Scaphirhynchus* 2005

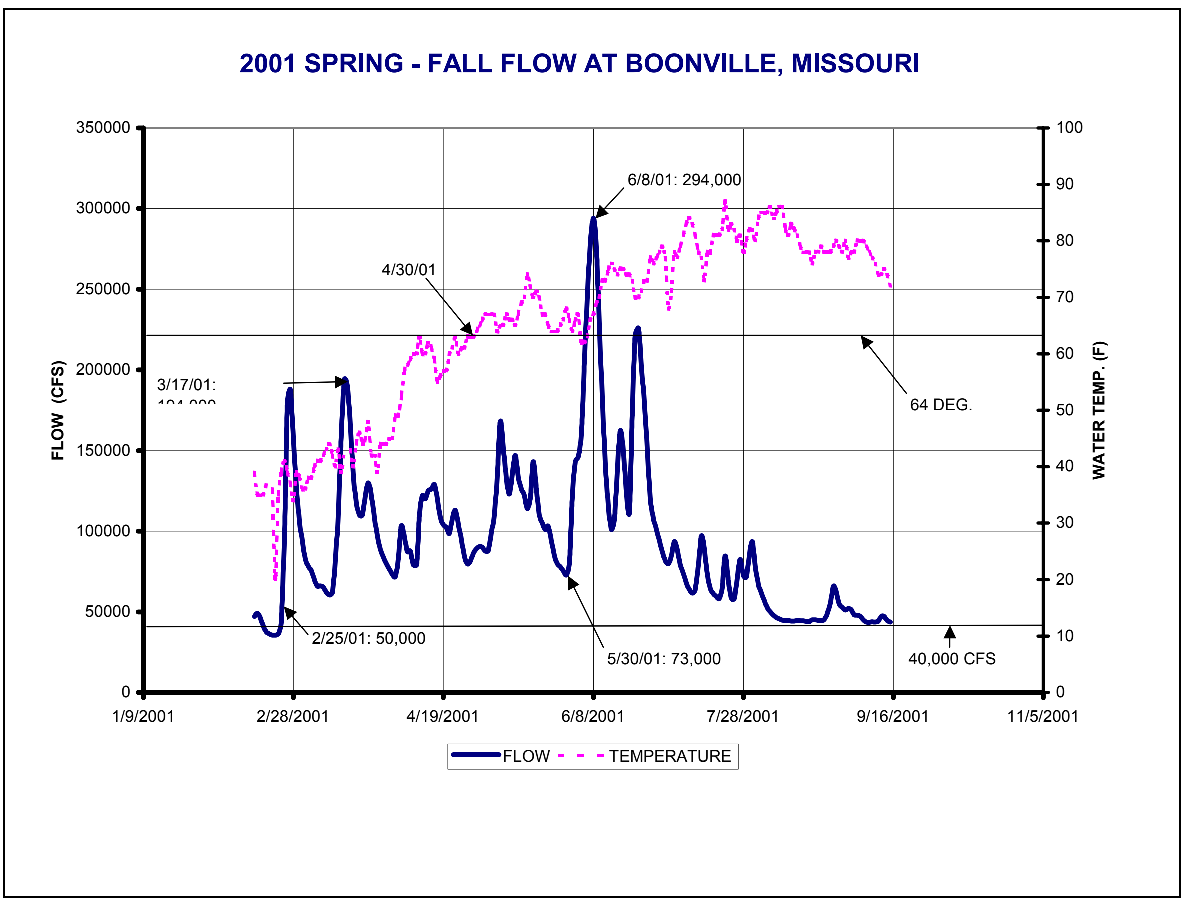
Conference, U.S. Army Corps of Engineers, St. Louis Univ., and U.S. Fish and Wildlife Service, Jan. 11 - 15, St Louis, Missouri, abs.
Reade, Corey N., 2000. Larval fish drift in the lower Platte River, Nebraska: Thesis University of Nebraska, Lincoln.
Ress, Steve, 2000. Water Current: Water Center Univ. Nebr., Lincoln, October 2000, 12 p.
Sando, Steven K., and, Kathleen M. Neitzert, 1999. Characteristics of the Missouri River channel downstream from Gavins Point Dam, South Dakota: U.S. Geological Survey Open-file report, 51 p.
Simon, Doyle, and Fault Senturk, 1992. Sediment Technology, water and sediment dynamics: Water Resources Publication, Littleton, Colorado, 897 p.
Tyus, H. M., and J. F.Saunders III, 1996. Nonnative fishes in the Colorado River Basin and a strategic plan for control: Final Report to the Colorado River Recovery Implementation Program For Endangered Species in the Upper Colorado Basin, Denver, CO: U.S. Fish and Wildlife Service.
USACE, 1996. Missouri River Gavins Point Dam degradation trends study: U.S. Army Corps of Engineers, Omaha, Nebraska, variously paged.
USACE, 2001. Summary of Revised Draft Environmental Impact Statement of the Missouri River Master Water Control Manual: U.S. Army Corps of Engineers, Northwest Division, 29 p.
USACE, 2003a. Supplemental biological assessment for the current water control plan: U.S. Army Corps of Engineers, Northwestern Division, Missouri River Basin Water Management Division, 24 p.
USACE, 2003b. Final biological assessment on the operation of the Missouri River Main Stem Reservoir System, the operation and maintenance of the Bank Stabilization and Navigation Project, and the operation of Kansas River Reservoir System: U.S. Army Corps of Engineers, Northwestern Division, Missouri River Basin, Water Management Division, Appendix A, 33 p.
USFWS, 2000a. Biological opinion of the operation of the Missouri River main stem reservoir system, operation and maintenance of the Missouri River Bank Stabilization and Navigation Project, and operation of the Kansas River Reservoir System: U.S. Fish and Wildlife Service.
USFWS, 2000b. Missouri River Pallid sturgeon—Status-endangered: U.S. Fish and Wildlife Service Fact Sheet, Nov., 1 p.
USFWS, 2003. U.S. Fish and Wildlife Service 2003 amendment to the 2000 biological opinion on the operation of the Missouri River Main Stem Reservoir System, operation and maintenance of the Missouri River Bank stabilization and Navigation Project, and operation of the Kansas River Reservoir System: U.S. Fish and Wildlife Service, 308 p.

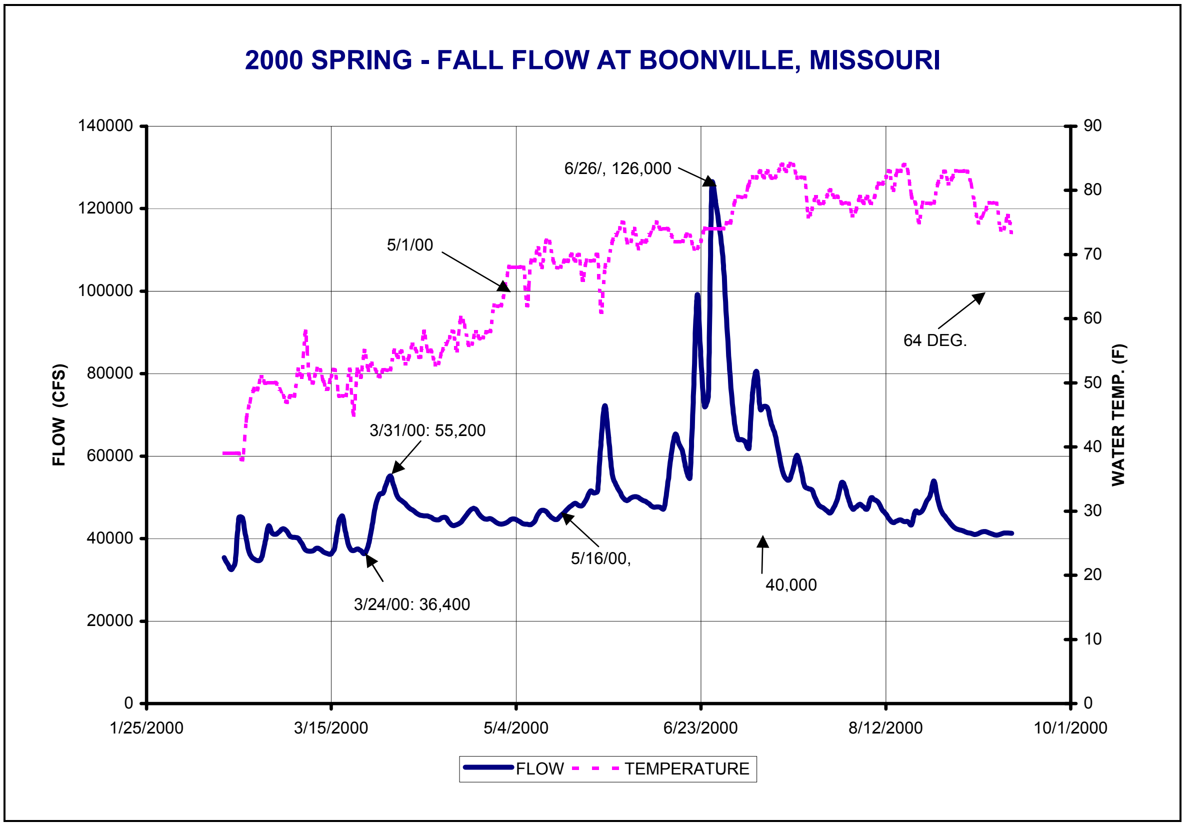
APPENDIX A. HYDROGRAPHS OF FLOW AND WATER TEMPERATURE AT BOONVILLE, MISSOURI

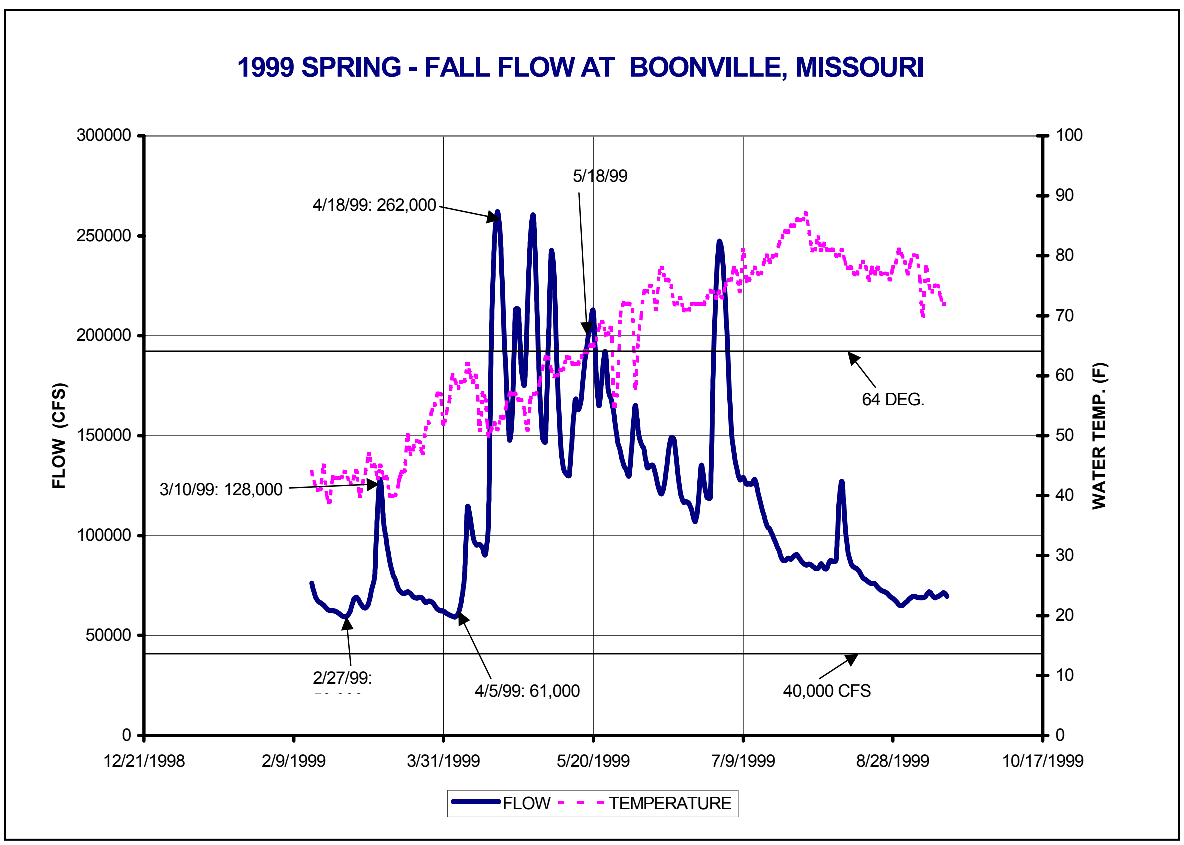
Flow data from USGS, water-temperature data from Boonville Water Treatment Plant, Boonville, Missouri.

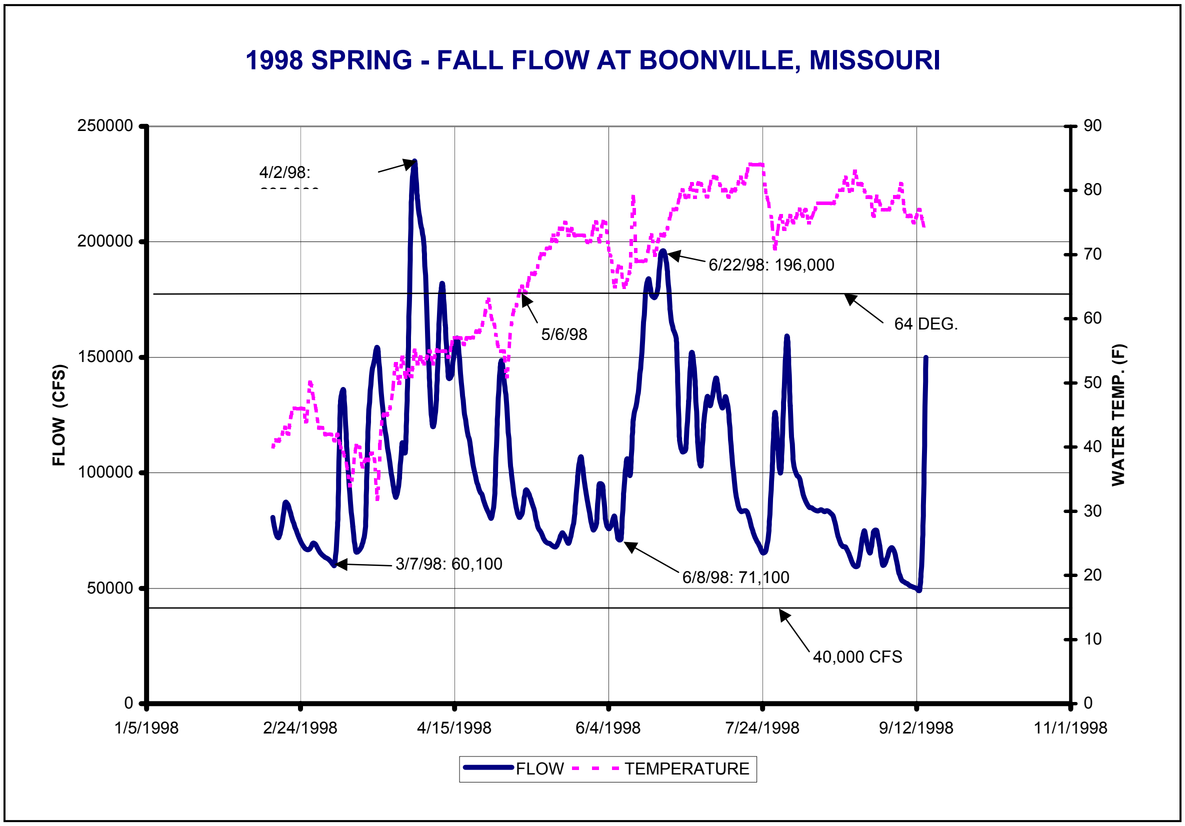


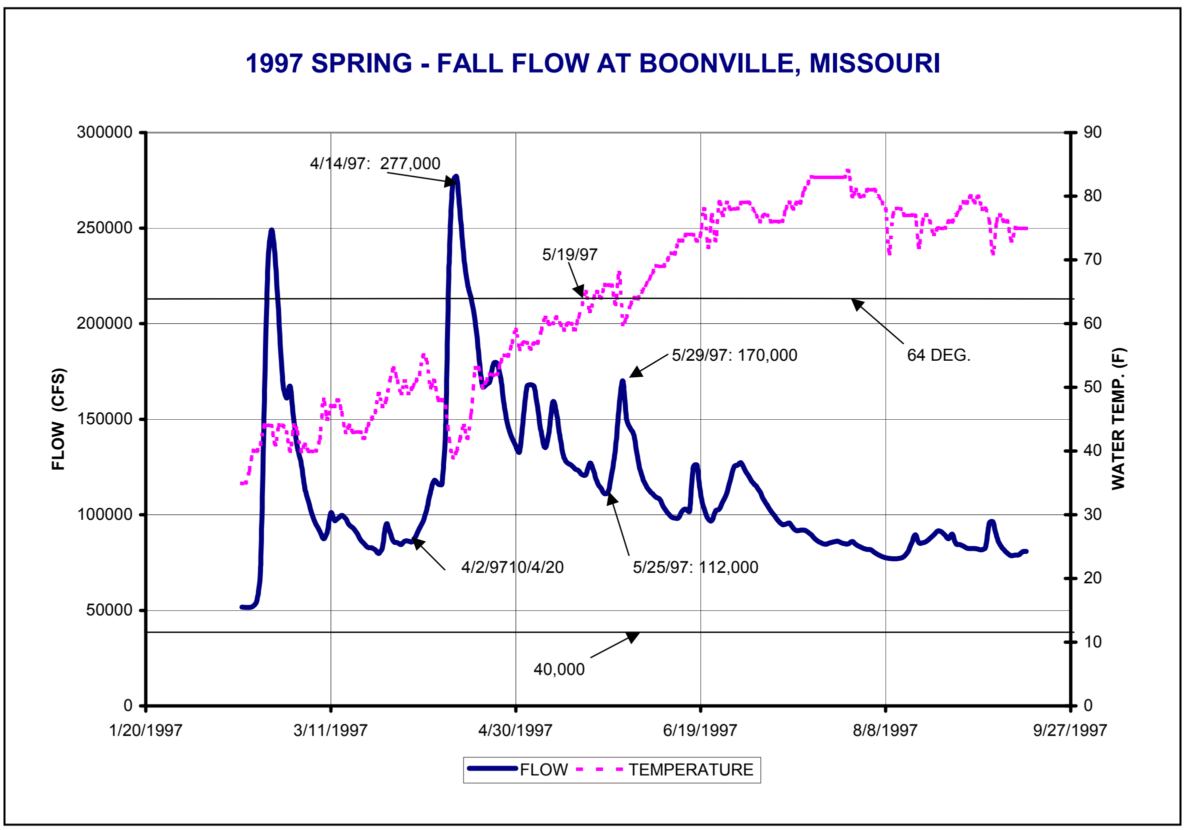

2002 SPRING - FALL FLOW AT BOONVILLE, MISSOURI
FLOW (CFS)
WATER TEMP. (F)
250000
200000
150000
100000
50000
0
100
90
80
70
60
50
40
30
20
10
0
12/25/2001
2/13/2002
4/4/2002
5/24/2002
7/13/2002
9/1/2002
10/21/2002
5/14/02:
5/28/02
64 DEG
4/21/02: 49100
2/11/02: 28,200
2/22/02: 45,100
40,000 cfs
FLOW
TEMPERATURE

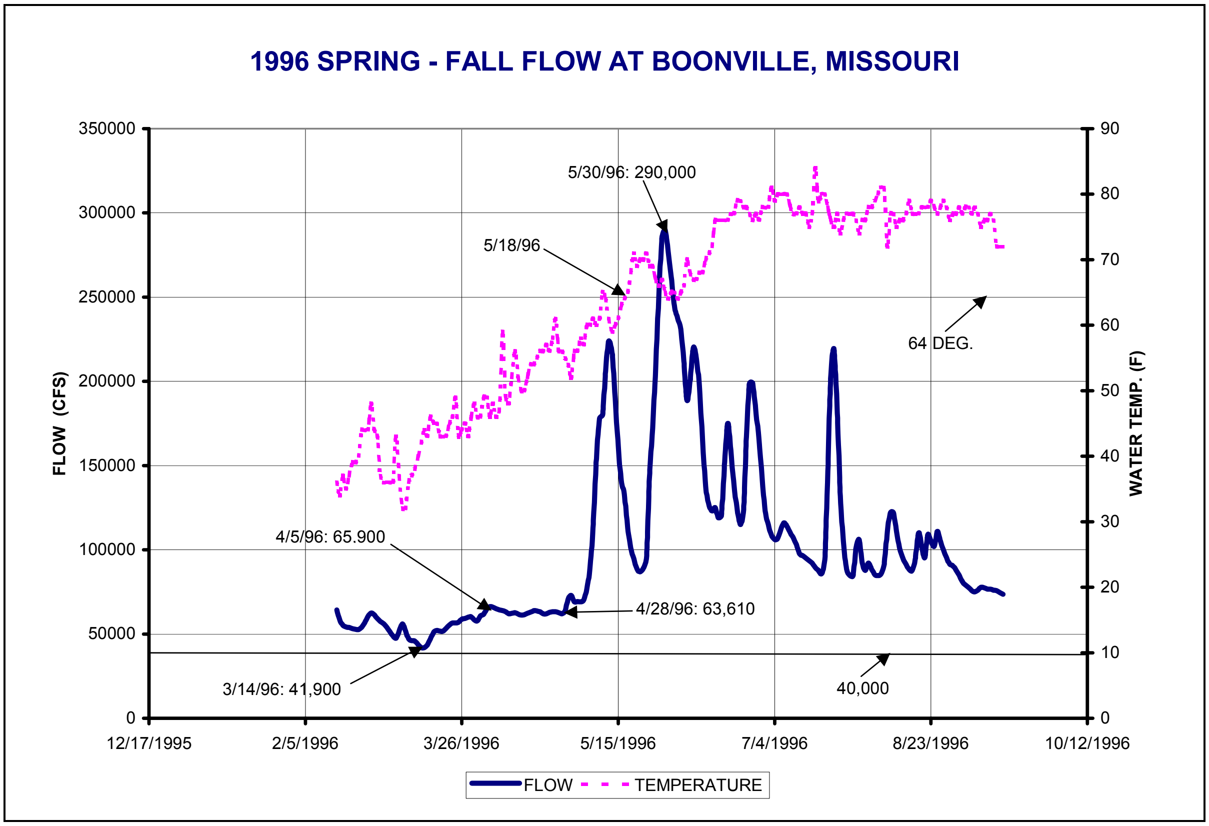

2001 SPRING - FALL FLOW AT BOONVILLE, MISSOURI
FLOW (CFS)
WATER TEMP. (F)
350000
300000
250000
200000
150000
100000
50000
0
100
90
80
70
60
50
40
30
20
10
0
1/9/2001
2/28/2001
4/19/2001
6/8/2001
7/28/2001
9/16/2001
11/5/2001
6/8/01: 294,000
4/30/01
3/17/01:
64 DEG.
2/25/01: 50,000
5/30/01: 73,000
40,000 CFS
FLOW
TEMPERATURE


2000 SPRING - FALL FLOW AT BOONVILLE, MISSOURI
FLOW (CFS)
WATER TEMP. (F)
140000
120000
100000
80000
60000
40000
20000
0
90
80
70
60
50
40
30
20
10
0
1/25/2000
3/15/2000
5/4/2000
6/23/2000
8/12/2000
10/1/2000
6/26/, 126,000
5/1/00
64 DEG.
3/31/00: 55,200
5/16/00,
40,000
3/24/00: 36,400
FLOW
TEMPERATURE

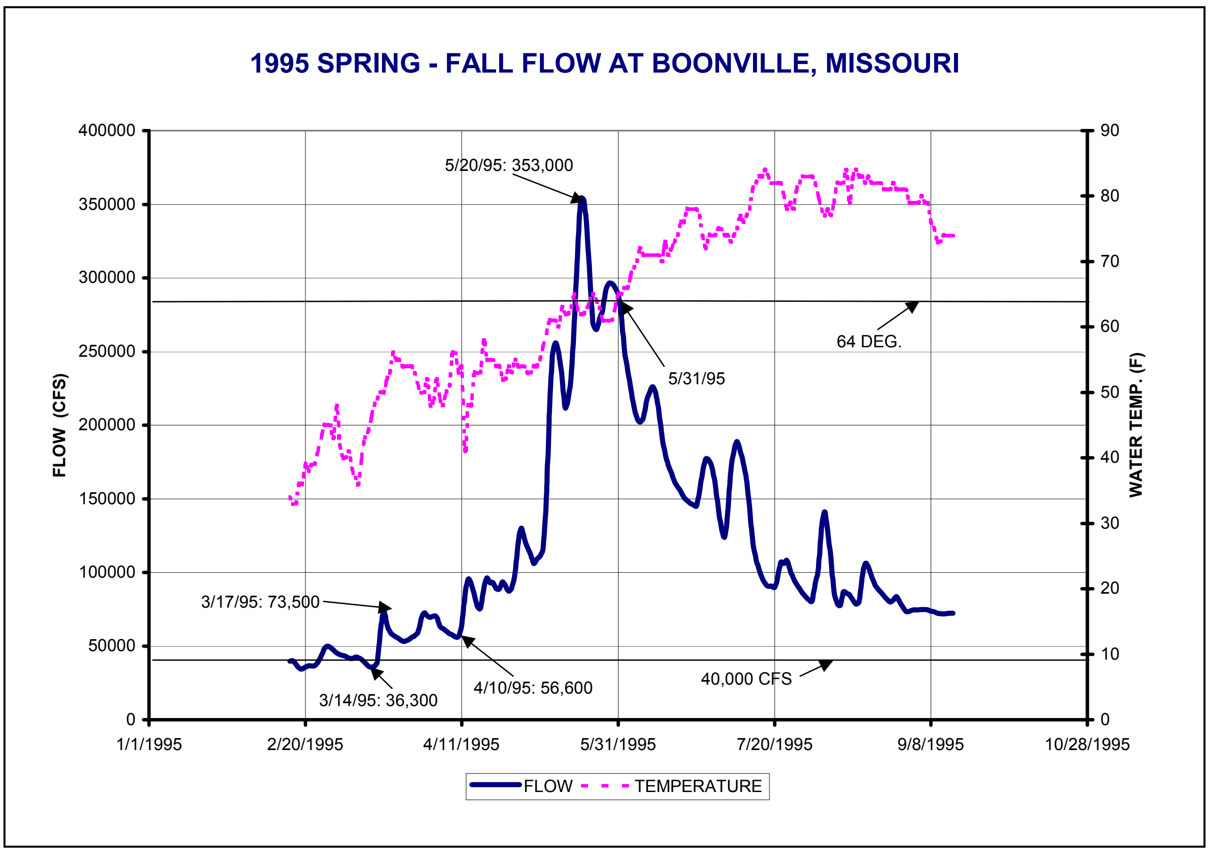

1999 SPRING - FALL FLOW AT BOONVILLE, MISSOURI
FLOW (CFS)
WATER TEMP. (F)
300000
250000
200000
150000
100000
50000
0
100
90
80
70
60
50
40
30
20
10
0
12/21/1998
2/9/1999
3/31/1999
5/20/1999
7/9/1999
8/28/1999
10/17/1999
5/18/99
4/18/99: 262,000
64 DEG.
3/10/99: 128,000
2/27/99:
4/5/99: 61,000
40,000 CFS
FLOW
TEMPERATURE


1998 SPRING - FALL FLOW AT BOONVILLE, MISSOURI
FLOW (CFS)
WATER TEMP. (F)
4/2/98:
3/7/98: 60,100
5/6/98
6/22/98: 196,000
64 DEG.
6/8/98: 71,100
40,000 CFS
1/5/1998
2/24/1998
4/15/1998
6/4/1998
7/24/1998
9/12/1998
11/1/1998
FLOW
TEMPERATURE

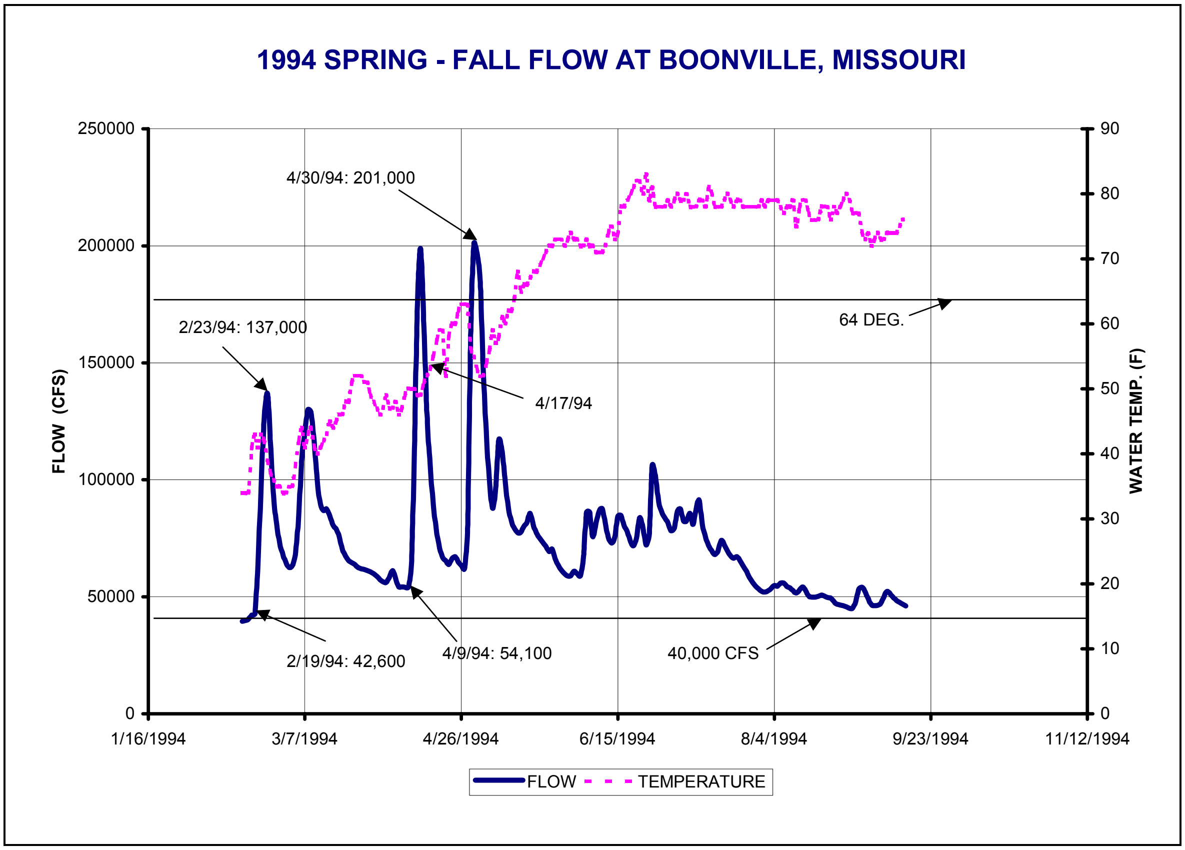

1997 SPRING - FALL FLOW AT BOONVILLE, MISSOURI
FLOW (CFS)
WATER TEMP. (F)
4/14/97: 277,000
5/19/97
5/29/97: 170,000
64 DEG.
4/2/9710/4/20
5/25/97: 112,000
40,000
1/20/1997
3/11/1997
4/30/1997
6/19/1997
8/8/1997
9/27/1997
FLOW
TEMPERATURE

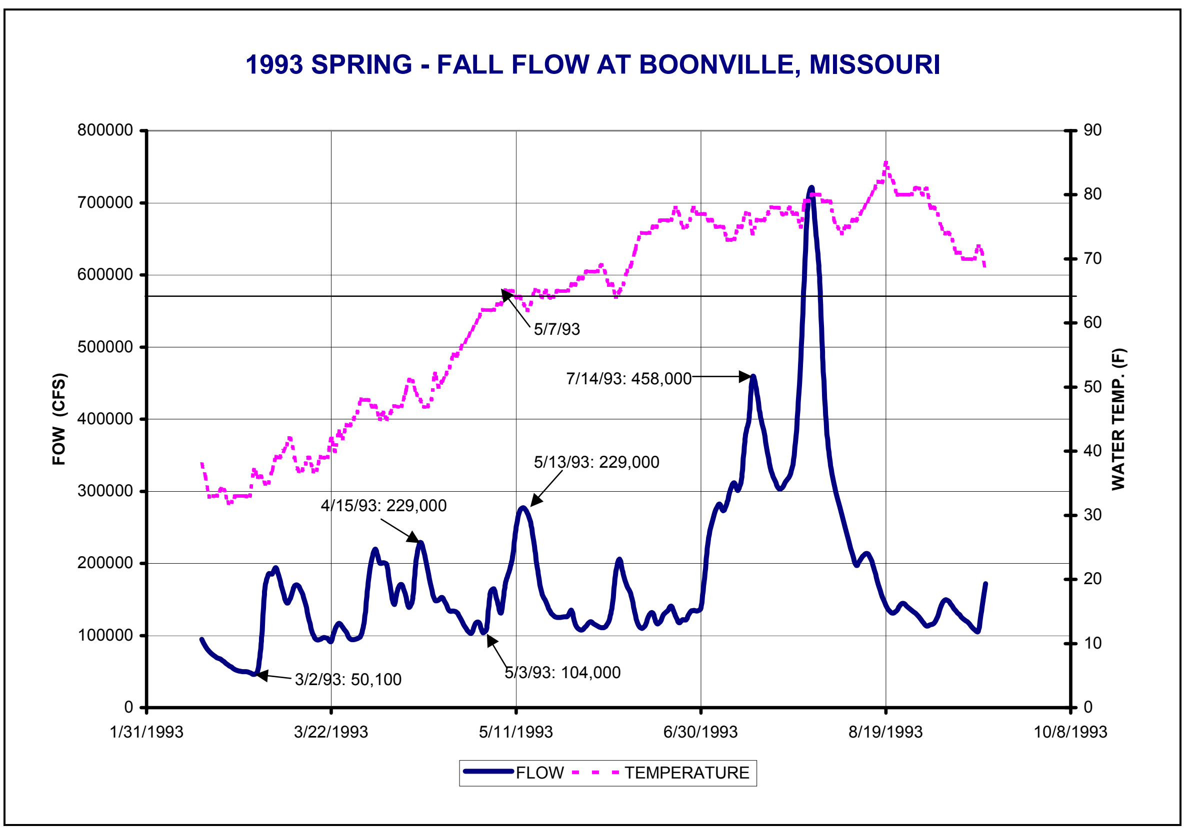


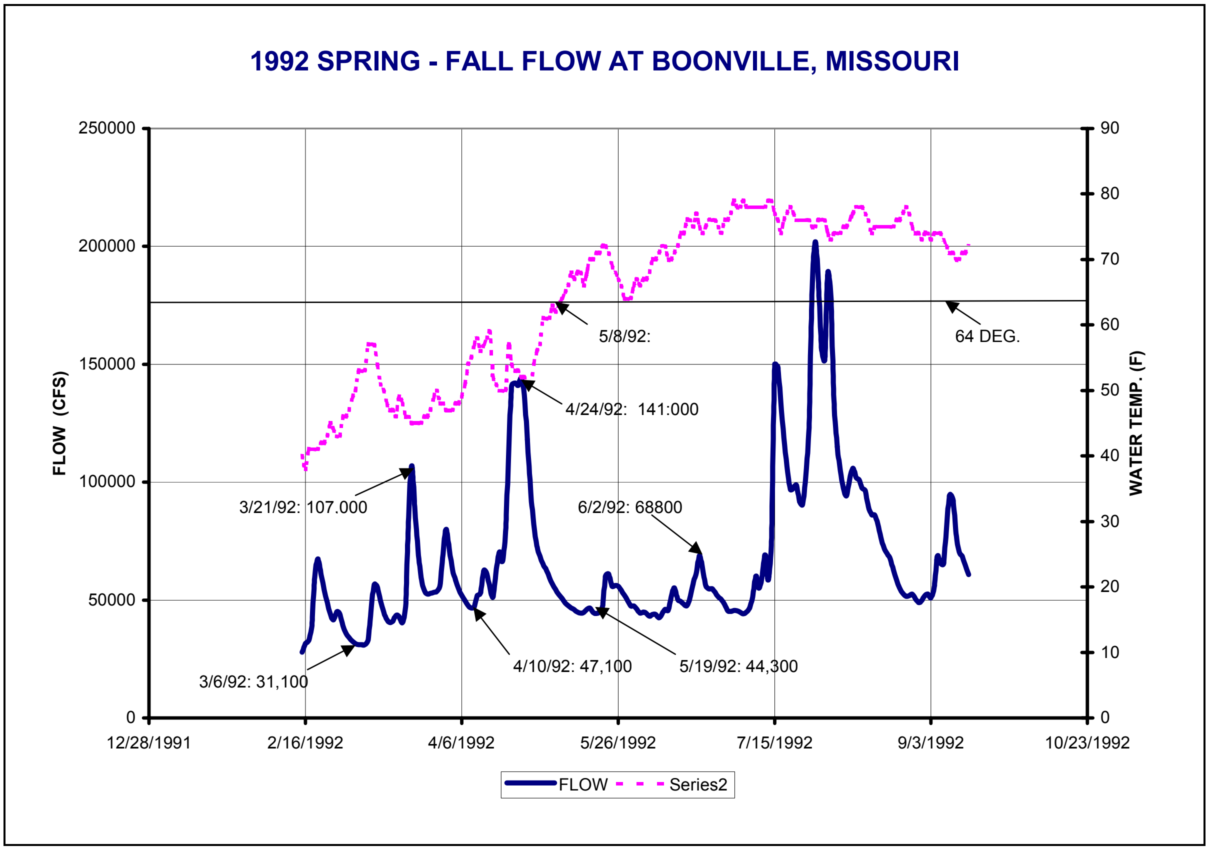
1996 SPRING - FALL FLOW AT BOONVILLE, MISSOURI
FLOW (CFS)
WATER TEMP. (F)
5/30/96: 290,000
5/18/96
64 DEG.
4/5/96: 65.900
4/28/96: 63,610
3/14/96: 41,900
40,000
12/17/1995
2/5/1996
3/26/1996
5/15/1996
7/4/1996
8/23/1996
10/12/1996
FLOW
TEMPERATURE

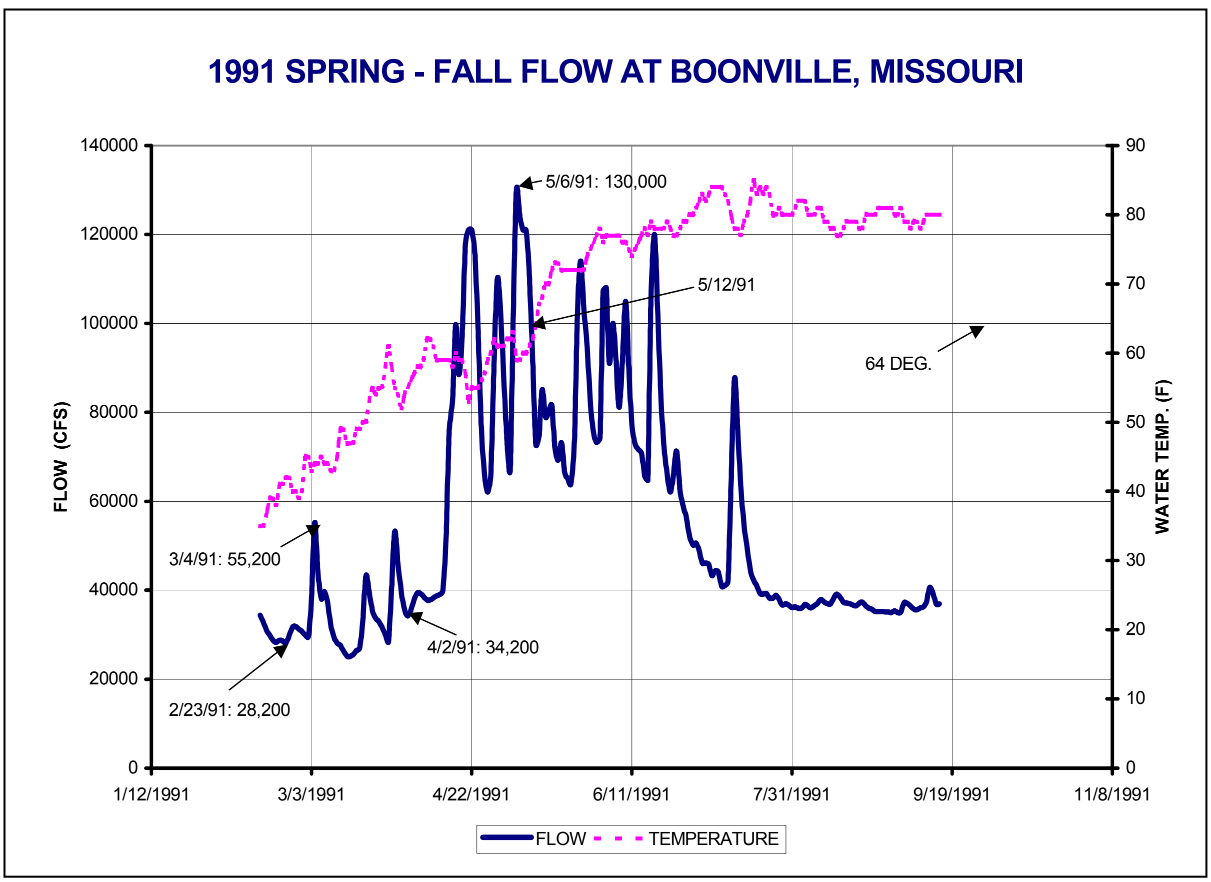


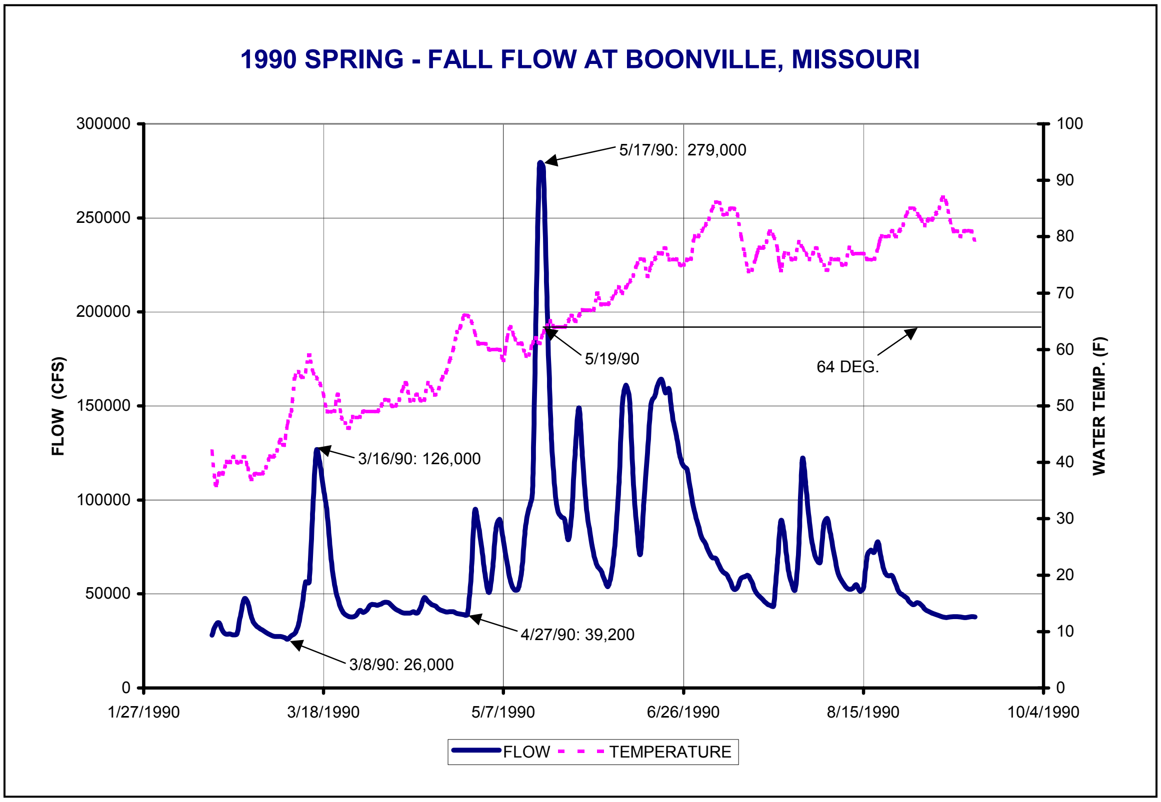
1995 SPRING - FALL FLOW AT BOONVILLE, MISSOURI
FLOW (CFS)
WATER TEMP. (F)
5/20/95: 353,000
5/31/95
64 DEG.
3/17/95: 73,500
3/14/95: 36,300
4/10/95: 56,600
40,000 CFS
1/1/1995
2/20/1995
4/11/1995
5/31/1995
7/20/1995
9/8/1995
10/28/1995
FLOW
TEMPERATURE

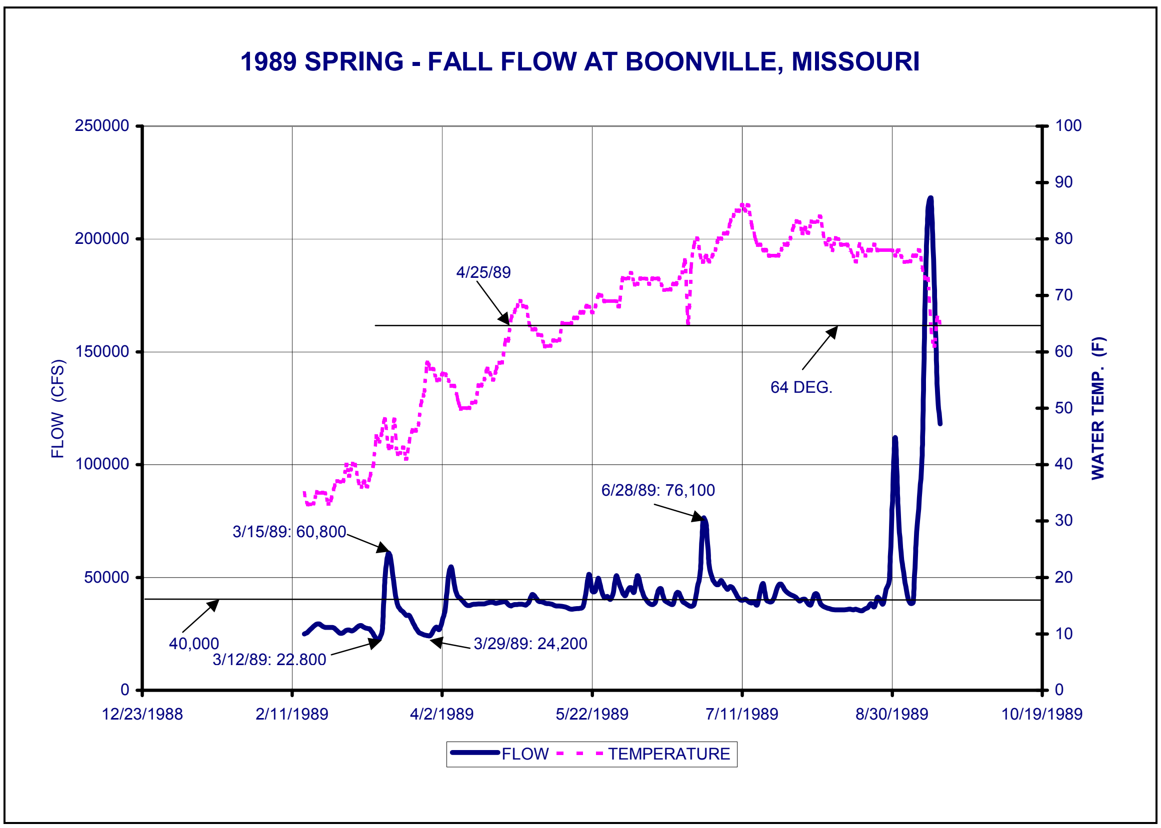

1994 SPRING - FALL FLOW AT BOONVILLE, MISSOURI
FLOW (CFS)
WATER TEMP. (F)
250000
200000
150000
100000
50000
0
90
80
70
60
50
40
30
20
10
0
1/16/1994
3/7/1994
4/26/1994
6/15/1994
8/4/1994
9/23/1994
11/12/1994
4/30/94: 201,000
2/23/94: 137,000
64 DEG.
4/17/94
2/19/94: 42,600
4/9/94: 54,100
40,000 CFS
FLOW
TEMPERATURE

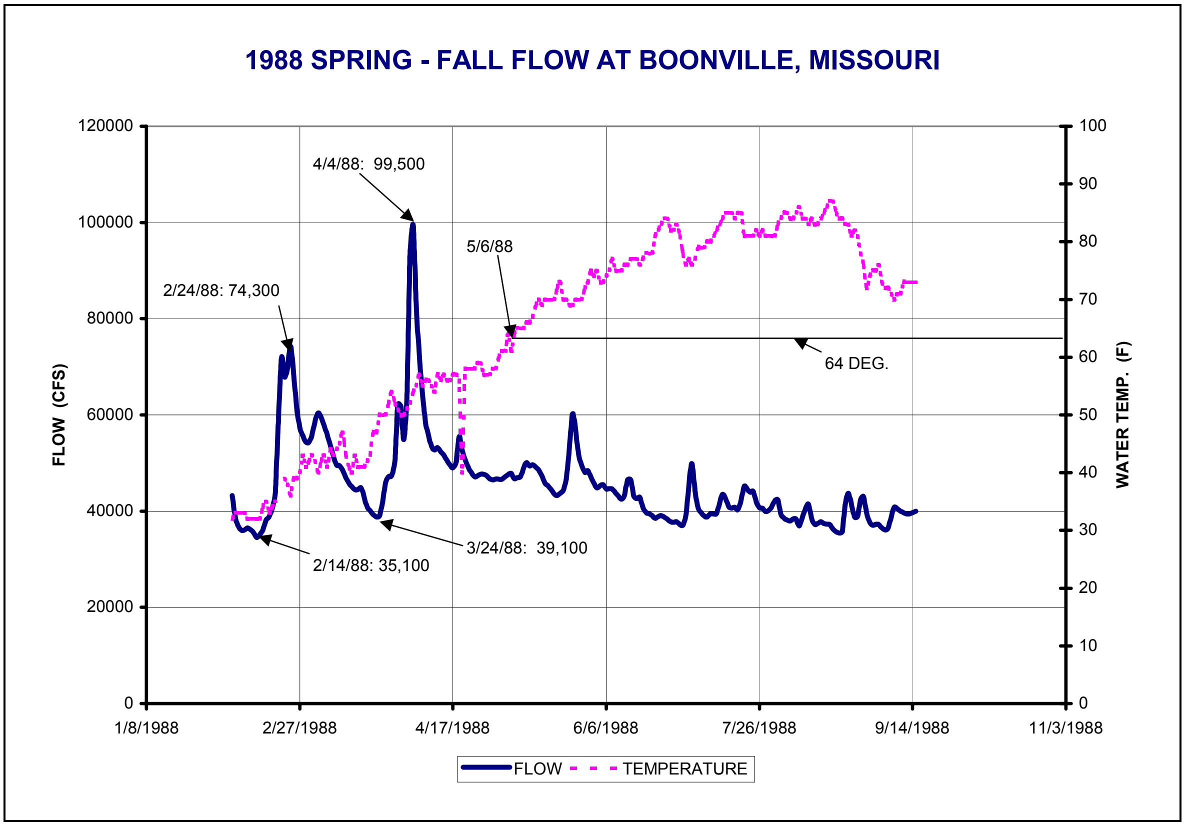

1993 SPRING - FALL FLOW AT BOONVILLE, MISSOURI
FOW (CFS)
WATER TEMP. (F)
800000
700000
600000
500000
400000
300000
200000
100000
0
90
80
70
60
50
40
30
20
10
0
1/31/1993
3/22/1993
5/11/1993
6/30/1993
8/19/1993
10/8/1993
5/7/93
7/14/93: 458,000
5/13/93: 229,000
4/15/93: 229,000
3/2/93: 50,100
5/3/93: 104,000
FLOW
TEMPERATURE

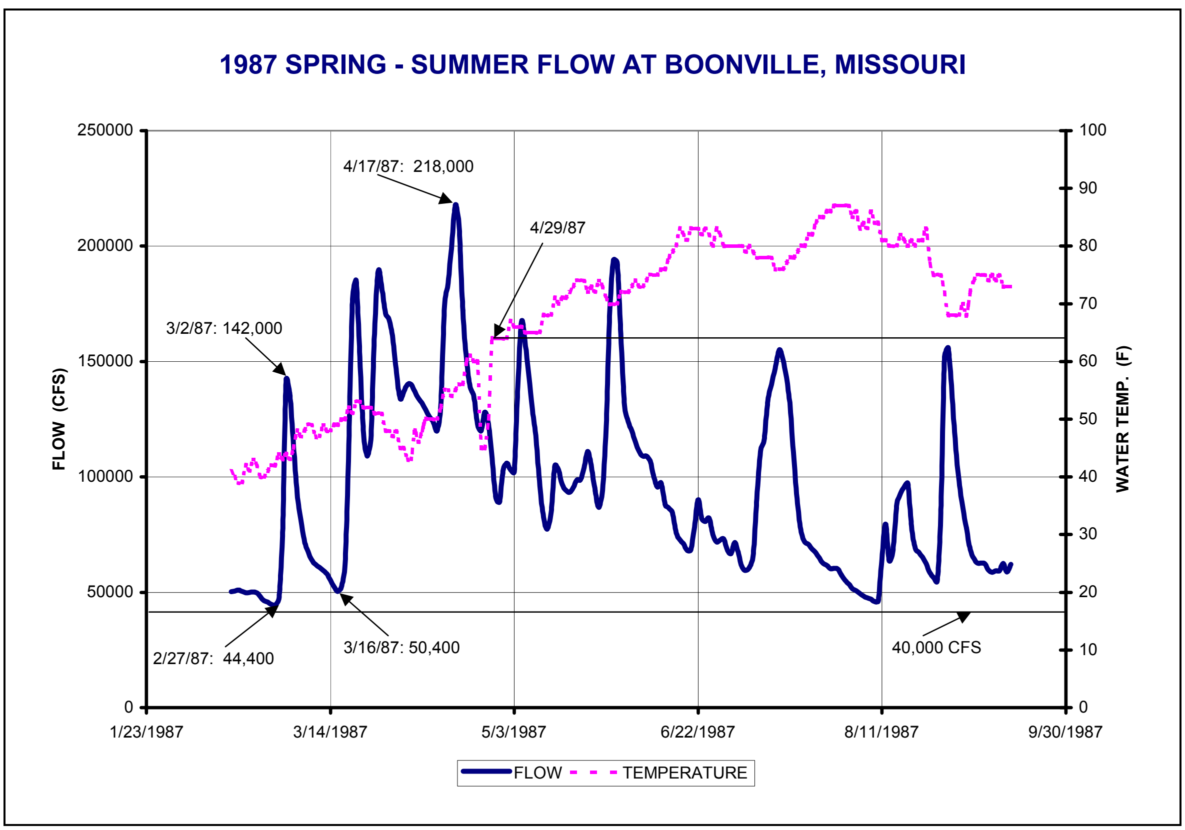

1992 SPRING - FALL FLOW AT BOONVILLE, MISSOURI
FLOW (CFS)
WATER TEMP. (F)
250000
200000
150000
100000
50000
0
90
80
70
60
50
40
30
20
10
0
12/28/1991
2/16/1992
4/6/1992
5/26/1992
7/15/1992
9/3/1992
10/23/1992
5/8/92:
64 DEG.
4/24/92: 141:000
3/21/92: 107.000
6/2/92: 68800
3/6/92: 31,100
4/10/92: 47,100
5/19/92: 44,300
FLOW
Series2

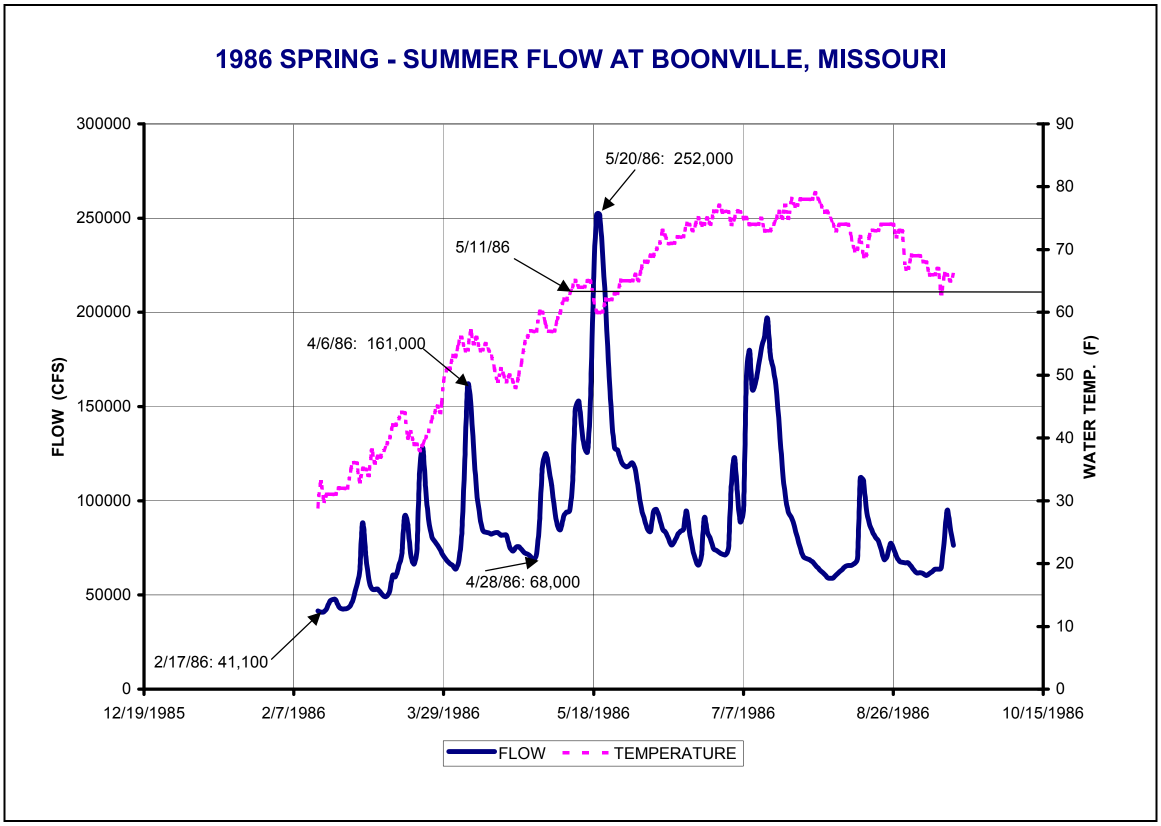

1991 SPRING - FALL FLOW AT BOONVILLE, MISSOURI
FLOW (CFS)
WATER TEMP. (F)
140000
120000
100000
80000
60000
40000
20000
0
90
80
70
60
50
40
30
20
10
0
1/12/1991
3/3/1991
4/22/1991
6/11/1991
7/31/1991
9/19/1991
11/8/1991
5/6/91: 130,000
5/12/91
64 DEG.
3/4/91: 55,200
4/2/91: 34,200
2/23/91: 28,200
FLOW
TEMPERATURE


1990 SPRING - FALL FLOW AT BOONVILLE, MISSOURI
FLOW (CFS)
WATER TEMP. (F)
300000
250000
200000
150000
100000
50000
0
100
90
80
70
60
50
40
30
20
10
0
1/27/1990
3/18/1990
5/7/1990
6/26/1990
8/15/1990
10/4/1990
5/17/90: 279,000
5/19/90
64 DEG.
3/16/90: 126,000
4/27/90: 39,200
3/8/90: 26,000
FLOW
TEMPERATURE

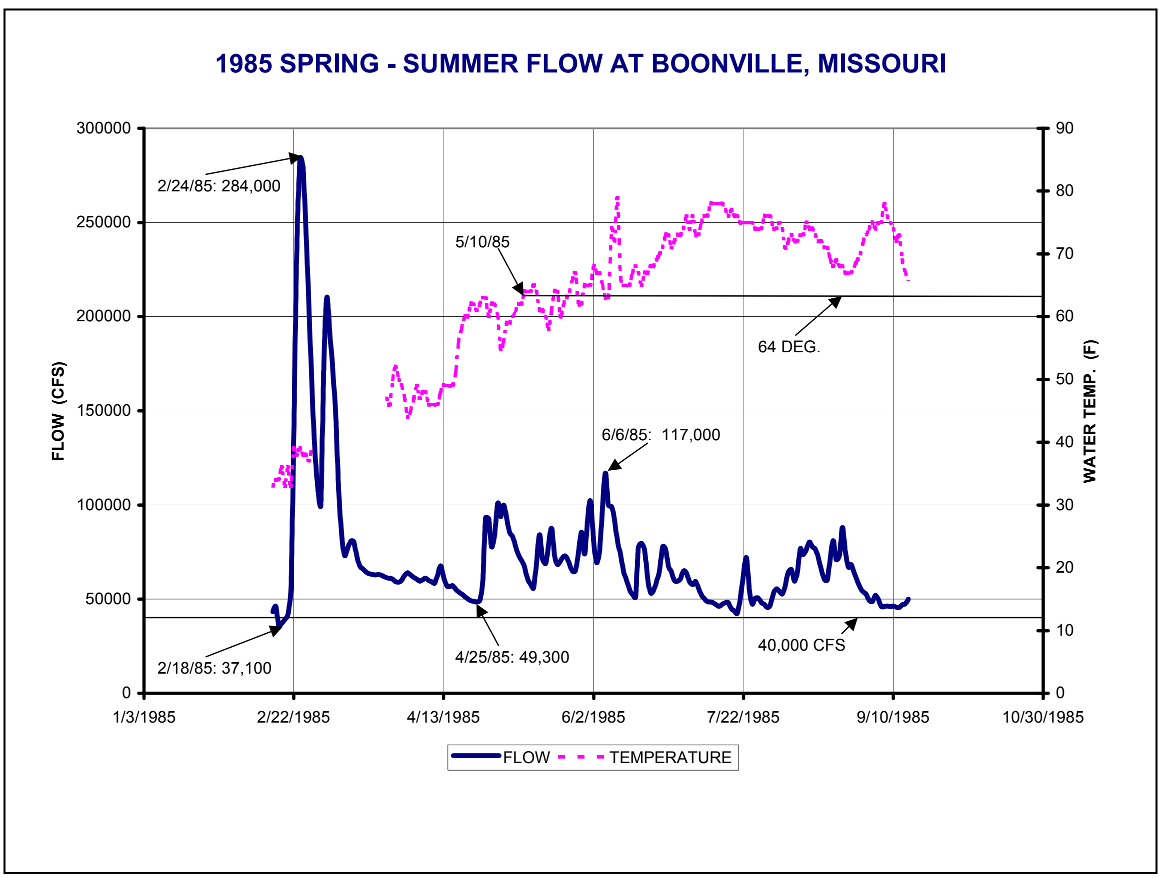

1989 SPRING - FALL FLOW AT BOONVILLE, MISSOURI
FLOW (CFS)
WATER TEMP. (F)
250000
200000
150000
100000
50000
0
100
90
80
70
60
50
40
30
20
10
0
12/23/1988
2/11/1989
4/2/1989
5/22/1989
7/11/1989
8/30/1989
10/19/1989
4/25/89
64 DEG.
6/28/89: 76,100
3/15/89: 60,800
40,000
3/12/89: 22.800
3/29/89: 24,200
FLOW
TEMPERATURE


1988 SPRING - FALL FLOW AT BOONVILLE, MISSOURI
FLOW (CFS)
WATER TEMP. (F)
120000
100000
80000
60000
40000
20000
0
100
90
80
70
60
50
40
30
20
10
0
1/8/1988
2/27/1988
4/17/1988
6/6/1988
7/26/1988
9/14/1988
11/3/1988
4/4/88: 99,500
5/6/88
2/24/88: 74,300
64 DEG.
3/24/88: 39,100
2/14/88: 35,100
FLOW
TEMPERATURE

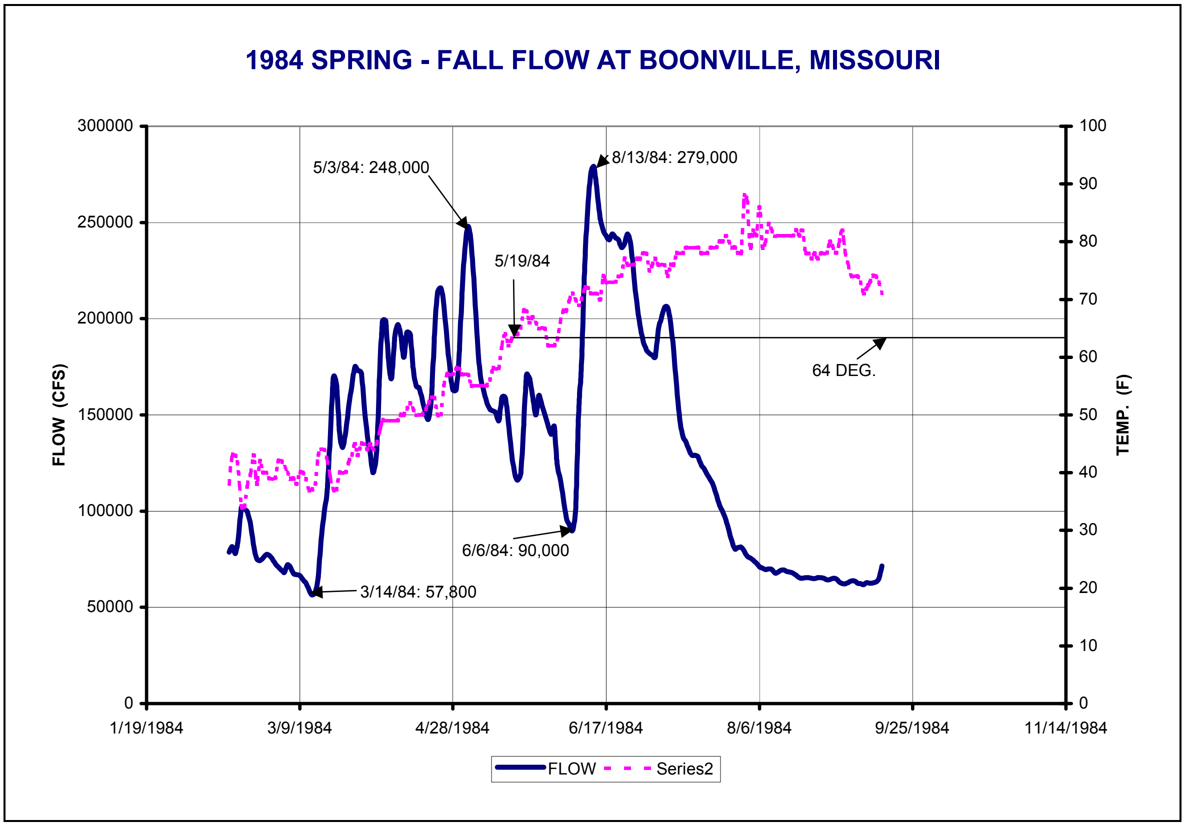

1987 SPRING - SUMMER FLOW AT BOONVILLE, MISSOURI
FLOW (CFS)
WATER TEMP. (F)
250000
200000
150000
100000
50000
0
100
90
80
70
60
50
40
30
20
10
0
1/23/1987
3/14/1987
5/3/1987
6/22/1987
8/11/1987
9/30/1987
4/17/87: 218,000
4/29/87
3/2/87: 142,000
2/27/87: 44,400
3/16/87: 50,400
40,000 CFS
FLOW
TEMPERATURE



1986 SPRING - SUMMER FLOW AT BOONVILLE, MISSOURI
FLOW (CFS)
WATER TEMP. (F)
300000
250000
200000
150000
100000
50000
0
90
80
70
60
50
40
30
20
10
0
12/19/1985
2/7/1986
3/29/1986
5/18/1986
7/7/1986
8/26/1986
10/15/1986
5/20/86: 252,000
5/11/86
4/6/86: 161,000
4/28/86: 68,000
2/17/86: 41,100
FLOW
TEMPERATURE



1985 SPRING - SUMMER FLOW AT BOONVILLE, MISSOURI
FLOW (CFS)
WATER TEMP. (F)
300000
250000
200000
150000
100000
50000
0
90
80
70
60
50
40
30
20
10
0
1/3/1985
2/22/1985
4/13/1985
6/2/1985
7/22/1985
9/10/1985
10/30/1985
2/24/85: 284,000
5/10/85
64 DEG.
6/6/85: 117,000
2/18/85: 37,100
4/25/85: 49,300
40,000 CFS
FLOW
TEMPERATURE


1984 SPRING - FALL FLOW AT BOONVILLE, MISSOURI
FLOW (CFS)
TEMP. (F)
300000
250000
200000
150000
100000
50000
0
100
90
80
70
60
50
40
30
20
10
0
1/19/1984
3/9/1984
4/28/1984
6/17/1984
8/6/1984
9/25/1984
11/14/1984
5/3/84: 248,000
8/13/84: 279,000
5/19/84
64 DEG.
6/6/84: 90,000
3/14/84: 57,800
FLOW
Series2