THE RELATIONSHIP BETWEEN FLOW AND BACKWATER FISH HABITAT OF THE COLORADO RIVER IN GRAND CANYON

A comparison between 5,000 and 15,000 cfs in 1991;
and between 4,800 and 28,000 cfs in 1985.

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INTRODUCTION

Dramatic changes have taken place in Glen and Grand Canyons since Glen Canyon Dam was completed in 1963. Impoundment of the Colorado River and flow regulation have changed the magnitude and timing of river flows, the amount of sediment carried by the river, and the temperature of the water. This in turn has substantially changed the downstream riverine environment.

On May 25, 1978, the U.S. Fish and Wildlife Service (FWS) concluded that construction and operation of Glen Canyon Dam had jeopardized the continued existence of the endangered humpback chub by reducing water temperature and changing the aquatic ecosystem. They also concluded that dam operations were limiting the potential for recovering humpback chub, Colorado squawfish, bonytail chub, and razorback sucker. Because little information was available on habitat needs of these fishes, the FWS was unable to recommend any changes in dam operations which would aid recovery of the fish. Additional study was therefore requested.

The purpose of this study was to assess the size and number of backwaters at different flow levels in order that a recommendation might be made on a flow level that would optimize conditions for native fishes.

Colorado River backwaters are important nursery and resting area for both native and introduced fishes (Holden 1977, Valdez and Wick 1981, Valdez 1982, Archer et al. 1985, and Valdez et al. 1986). Since the construction of Glen Canyon Dam, backwaters are the only portion of the mainstem offering warm water for successful rearing, higher productivity, lower current, refugia from predatory fishes, and other characteristics needed for optimum growth (Grabowski and Heibert, 1989).

BACKGROUND

Perhaps the most unique group of native fishes of the Colorado River Basin, the large-bodied "big river" fishes, which are highly adapted for life in the variable, sometimes harsh environment of the larger rivers (Minckley, 1973, 1991). Eight native fish species inhabited the pre-dam Colorado River and its tributaries. Of these, only endangered humpback chub and three other native species (bluehead sucker, flannelmouth sucker, and speckled dace) can still be found in the River below Glen Canyon Dam.

Backwaters, protected areas away from the influence of main channel currents, and bounded by land on three sides (unless it is an isolated backwater), with one opening to the river, serve as rearing habitat for native fish. Backwaters are typically associated with alluvial, fine-grained sediment deposits formed by recirculation zones (eddies) downstream from abutments of talus or bedrock or by debris fans at tributary mouths (Schmidt and Graf 1988). As water level drops, the surrounding topography is exposed, and the primary eddy return current channel becomes a backwater. Studies by the U.S. Geological Survey (USGS), which have been confirmed by aerial photography, suggest that antecedent flows prior to decreases in water levels may be a controlling factor in backwater formation. Under steady flows, sand in an eddy return channel is deposited with greater topographic relief, resulting in deeper, larger backwaters when flows drop. After the backwater is formed, its longevity is also influenced by river flow patterns. Backwaters disappear faster during periods of fluctuating water levels than under steady flows (GCES Final Report, 1988).

Larval native fishes are relatively immobile, very susceptible to predation and stranding, and require quiet, warm water for optimum growth and survival. As flows fluctuate, the depth, temperature, and velocity of backwaters change, forcing fish to move into the mainstem river (GCES Final Report, 1988). This increases the risk of predation and requires an additional expenditure of energy. Maddux et al. (1987) observed that juvenile chub used backwaters during spring, summer, and fall when backwater temperatures exceed those of the mainstem river. Mainstem Colorado River flows were steady throughout most of the study period (April 1984 - June 1986) and the effects of fluctuations on backwater use could only be measured for a few days in fall, 1985. During this time, juvenile chub moved in and out of backwaters with fluctuations in flow and little stranding was observed (Maddux et al. 1987).

Fluctuations may disrupt reproduction of zooplankton in backwaters, thereby potentially limiting food availability for chub (Angradi et al. 1992, Grabowski and Hiebert, 1989, GCES Final Report, 1988, and Holden et al. 1986). In addition, fluctuations can erode backwaters and decrease warm-water habitat availability for juvenile chub. There is no information on the long-term effects of daily displacement from warm backwaters to the cold mainstem on juvenile chub growth and survivorship.

The majority of larval humpback chub in the Grand Canyon begin their life in the Little Colorado River, but rearing of many individuals may occur in backwaters of the mainstem river. High, mainstem flows during spring and early summer back up the Little Colorado River at its confluence with the Colorado River, and provide favorable warm-water habitat for larval humpback chub growth.

Maddux et al. (1987) found that native fish were more abundant that non-native fish in the backwaters in the upper part of the Colorado River in Grand Canyon. Native fishes represented 89.7% of the catch from between river mile (RM) 1-61.4 (Paria River to Little Colorado River-or LCR) and 63.5% from between RM 61.4-87.8 (LCR to Bright Angel Creek). Maddux et al. (1987) also found that humpback chub catch per unit effort decreased from RM 87-225, but increased from 14.1 fish/100m^2 to 44.0 fish/100m^2 from RM 61.4-87.8. Speckled dace showed a similar pattern.

Even though the importance of backwaters as habitat for native fish has been recognized, no specific backwater criteria has been developed. Several characteristics of backwaters are thought to be important, but are beyond the scope of this report. All of the following characteristics ultimately affect productivity of the backwater, which is important in habitat assessment.

Two important factors in assessing backwaters are size and connectedness, due to their influence on water quality. Size is important because larger backwaters may provide more diverse habitat than small backwaters. Larger backwaters may not warm as quickly as smaller backwaters, resulting in fewer water quality problems (i.e. low dissolved oxygen), however, once warmed, they tend to stay warmer longer. Connectedness describes how a backwater is connected to the river and therefore how well flushed the backwater is with the river water. Previous studies had identified daily flushing as important in maintaining good water quality for fish populations and invertebrate production (Angradi et al. 1992, Holden et al. 1986 and Kennedy, 1979). Backwaters that are connected to the river also tend to be deeper than closed (isolated) backwaters, and the connection to the river provides passage for fish between the river and backwater. Circulation of water going in and out of the backwater also plays an important role in productivity and habitat suitability.

The relationship between flushing of backwaters and productivity on the Colorado River in Grand Canyon is not known, but backwaters on the lower Colorado (below Lake Mead) need to be flushed, preferably with a slow current, to maximize aquatic productivity. Too much flushing results in a riverine environment, too little results in stagnation and water quality problems. This finding was noted for the lower Colorado River backwaters by Kennedy (1979) and Arizona Coop Fish Unit (1976a, b), and for Mississippi River backwaters by Vanderford (1980), Holland et al. (1983) and Gutreuter (1980), and others.

Substrate is important in productivity and habitat use. Substrate could be classified to major categories of clays, silts, sands, gravels, cobbles, and boulders according to criteria and terminology of the American Geophysics Union (Lane 1947). In addition, backwater characteristics important in the Little Colorado River such as travertine, calcium carbonate (unconsolidated floc), and detritus substrate categories could be established.

Features of aquatic habitats potentially used as cover by fishes, which might also be helpful in assessing backwaters include turbidity, turbulence, depth >0.5m, shore ledges, undercut banks, overhanging vegetation, dense instream vegetation, large boulders, and undercut travertine (Arizona Game and Fish--AGF 1992).

Increased water temperature in backwaters could significantly affect food resources of the fish species in Grand Canyon. Blinn et al. (1989) observed significant changes in epiphytic diatom communities when water temperature was increased from 12°C to 18°C, but no change was observed between 18°C and 21°C, suggesting a temperature threshold between 12°C and 18°C for diatom flora below Glen Canyon Dam. One proposed method of warming the waters of the Colorado River in Grand Canyon is through the use of multiple level intake structures in Glen Canyon Dam. Another possible way to provide warm habitat for rearing fish and possibly spawning of native fish is to increase backwater areas by operating the dam in ways that would enhance the creation and stability of backwaters.

Mainchannel temperatures, which are lethal to chub ova (Hamman 1982), may limit the distribution of humpback chub. Mainchannel abundance of humpback chub appears to be dependent upon the success of reproduction within the Little Colorado River. In the mainstem juvenile fish have been found in backwaters, which may play an important role in juvenile growth. Minckley 1979, and Holden et al. 1986) found that backwaters along the Lower Colorado River were typically were 2° to 4°C warmer at the surface than the mainstem in summer. Maddux et al. (1987) and Gilbreath 1989 found that backwater temperatures on the Colorado River in Grand Canyon were strongly related to flow regime, i.e. the degree of exchange with cold, mainchannel waters, particularly during summer months. Mean water temperature where humpback chub juveniles were captured on the Colorado River in Grand Canyon was 15.2° C, which is warmer than that for other native fishes except speckled dace (Maddux et al. 1987).

One of the attributes of backwaters that makes them important as habitat is their productivity. Under steady flow conditions, backwaters may develop phytoplankton, zooplankton, aquatic macroinvertebrates and insect communities which may provide food for fishes (Grabowski and Heibert 1989 and GCES Final Report, 1988). Kennedy (1979) indicated that vegetation, particularly submergent vegetation, was an important factor in maintaining invertebrate density and diversity in backwaters on the lower Colorado River. Backwaters on the lower Colorado, including those which were flushed on a daily basis by water level changes near dams, were consistently higher in phytoplankton populations, as indicated by chlorophyll a, than in the adjacent mainstream. The increased phytoplankton community would provide a food base for zooplankton and macroinvertebrate communities to develop within the backwater. Connected backwater samples were much richer in macroinvertebrates in the Colorado River in Grand Canyon, and were dominated by chironimids and oligochaetes (Angradi et al. 1992).

Water quality (i.e. differences in pH, DO_2, conductivity, etc.)is different in backwaters than the mainstem. These factors contribute to the productivity, and the suitability of the backwater as a fish habitat. Backwaters were less variable in pH than was the channel, ranging from 6.6 to 7.8 in studies done on the lower Colorado River (Holden et al. 1986). Backwaters were more saline (100 to 500 conductivity units higher) than the mainstream, and were high in dissolved oxygen, remaining near or above 100% of saturation near the surface, and rarely falling below 50% near bottom (Holden et al. 1986).

METHODS

All backwaters large enough to measure (approximately 100m square in area) on the Colorado River between Glen Canyon Dam and RM 276 were measured. However, only RM 50-72 are used in this analysis. This section was selected due to its importance in the endangered fish studies, and because backwaters in this area are utilized by native fish (Maddux et al. 1987).

Video images were used to determine area, location, type, and orientation of the backwaters were recorded. Location was by river mile left or right, using "The Colorado River in Grand

Canyon" (Stevens, 1990) as the mileage reference. Orientation was recorded, noting if the backwater was a flood channel or return channel. A backwater was defined as a return channel if it was formed on the upstream end of a reattachment bar. A flood channel was defined as a backwater formed on the downstream end of the alluvial deposit.(Schmidt and Graf 1988, Figure 1). The type of backwater, whether connected to the mainstem or isolated was noted. Area was calculated by digitizing the area using Map and Image Processing Software (MIPS).

Aerial videography was obtained by using an Ikigami video camera attached to a helicopter with a Tyler mount and connected to a monitor viewed by a flight scientist. A 2000 foot flight level above the river was maintained. Videography from 7/27/91 and 5/21/91 were used in the analysis. The river flow on 7/27/91 was recorded to be 5000 cfs according to Glen Canyon Dam releases, and releases for 5/21/91 recorded to be 15000 cfs. The video images were analyzed on a Relax 386 microcomputer system which included an Everex Vision 16 video capture board, and Electrohome color monitor. 3/4" video tapes were used. Analysis was performed with MIPS software.

Video images were viewed on the color monitor and captured at appropriate intervals. Scale was calculated by registering the video to USGS topographic maps. Ground truth measurements were later performed to verify scale and deviated no more than 10% of real values.

The outlines of backwaters were traced using a cursor controlled by a mouse and creating short line segments on the image in a manner similar to those digitized by photographic/GIS analysis. The area was calculated by MIPS software. The area was saved into a file, and later exported into dBASE for further analysis. Data from 1985 was also entered into the dBASE file, although there were no area or orientation data associated with this. The 1985 Anderson et al. data were acquired by viewing oblique video footage of the Colorado River in Grand Canyon, with presence of backwaters noted to the nearest half mile. Due to the nature of this video footage, some backwaters may have been overlooked, so the actual number of backwaters may be slightly higher. For further information on the specific methods used for this analysis see Anderson et al. (1986)

Three analyses were made with the data: 1)The total number of backwaters were determined from 1985 data at constant 4800 cfs and were compared with constant 28000 cfs. 2)Total area of backwaters at the constant 5000 and 15000 cfs flow regimes in 1991 was calculated. 3)Total number of backwaters for RM 50-72 at constant 4800 cfs and 5000 cfs were compared between 1985 and 1991. 4)Total number and area of backwaters for RM 50-72 at constant 8000 cfs flow regime in 1993 was calculated.

RESULTS AND DISCUSSION

The area of backwater for 1991 at 5000 cfs and 15000 cfs for the entire river corridor are summarized in figures 2 and 3. Both the total number and total area of backwaters decreased with an increase in flow. In 1991 backwater numbers decrease from 36 at 5000 cfs to 9 at 15000 cfs. The total area of backwaters at 5000 cfs was 32,301 square meters, and decreased to 5708 square meters at 15000 cfs, (18% of the backwaters at 5000 cfs). The total number of connected backwaters at 5000 cfs was 34, with 2 isolated backwaters. This shows that both the total area and number of backwaters decreases with an increase in discharge. At 15000 cfs there were 8 connected backwaters, and one isolated backwater. There were 32 return channels at 5000 cfs, and at 15000 cfs there were 8 return channels.

There was a four-fold increase in the number of backwaters at 4800 cfs (130) as compared with the backwaters present at 28000 cfs (20) in 1985 (Anderson et al 1985). Figure 5 shows that the number of backwaters decreases with an increase in flow. When availability of backwaters was examined at 28,000 cfs, from RM 61.5-77 contained only 4 connected backwaters (2.1% of all backwaters). At 4800 cfs there were 78 connected backwaters (15.7%), a twenty fold increase (Anderson et al. 1985).

A backwater is usually formed by the return current channel of an eddy, which explains why the total of backwaters with the designation return channel far exceeds those denoted as flood channel formed backwaters. A coordinated research project should be conducted on backwaters with the involvement of both sediment researchers and biologists. The morphology of backwater formation and longevity, and how backwater formation relates to different flow regimes needs to be investigated.

Although the 1985 flow of 4800 cfs and the 1991 5000 cfs flow were not exactly the same, major changes have occurred. Also, it should be recognized that the 1985 4800 cfs flow was following a period of high flows, which caused changes in alluvial deposits (Schmidt and Graf 1988). The 1991 5000 cfs and 15000 cfs flows followed a period of research flows. The relationship between flow and backwaters is not known, but may play a vital role in backwater formation and longevity.

A similar analysis of backwaters using October 23, 1990 and October 12, 1992 aerial video at 8000 cfs constant flow was performed from RM 52-72. Since the aerial video footage was incomplete, RM 51 and 52 could not be used in the analysis. In 1990 there were 20 backwaters, totaling 15,392 square meters, and in 1992 there were 8 backwaters, totaling 1721 square meters. Glen Canyon Dam release records showed a difference of 517 cfs from the low of October 1990 to the high of October 1992. This is the greatest difference that could have occurred between the two dates. This fluctuation may have accounted for a small difference in the number of backwaters, because on the 1992 video it was noted that many of the backwaters seen in 1990 were slightly visible beneath the surface of the water. A small difference in flow may have covered them enough that they could not be used in the analysis. However, most of the difference is probably due to infilling of the backwaters, and may reflect the impact of interim flows on backwaters, since the October 1992 8000 cfs flow followed 15 months of interim flows.

Overall results of backwaters at 5,000 cfs, 8,000 cfs and 15,000 cfs from RM 52-72 are shown in Figure 5. This shows that backwater area is negatively correlated with stage across a discharge range of 5000 to 15000 cfs.

A comparison of backwaters with the 11 geomorphic reaches as defined by Schmidt and Graf (1988) was performed. The reaches are based on the types of bedrock exposed at river level. Because channel characteristics of the Colorado River vary with the types of bedrock that are exposed (Schmidt and Graf 1988), these reaches may reflect backwater size and abundance. The analysis showed that the most numerous numbers of backwaters occurred in the widest reaches, which are reaches 4, 5, and 10. This occurred in the 1985 4800 cfs flow, and the 1991 5000 cfs flow. The 1991 data at 15000 cfs flow and the 1992 8000 cfs flow showed the highest number of backwaters remaining in reaches 4 and 10. The results of all years by geographic reach are summarized in Figures 3, 6, and 7 (AGF Mcguinn-Robbins, 1993, unpublished data).

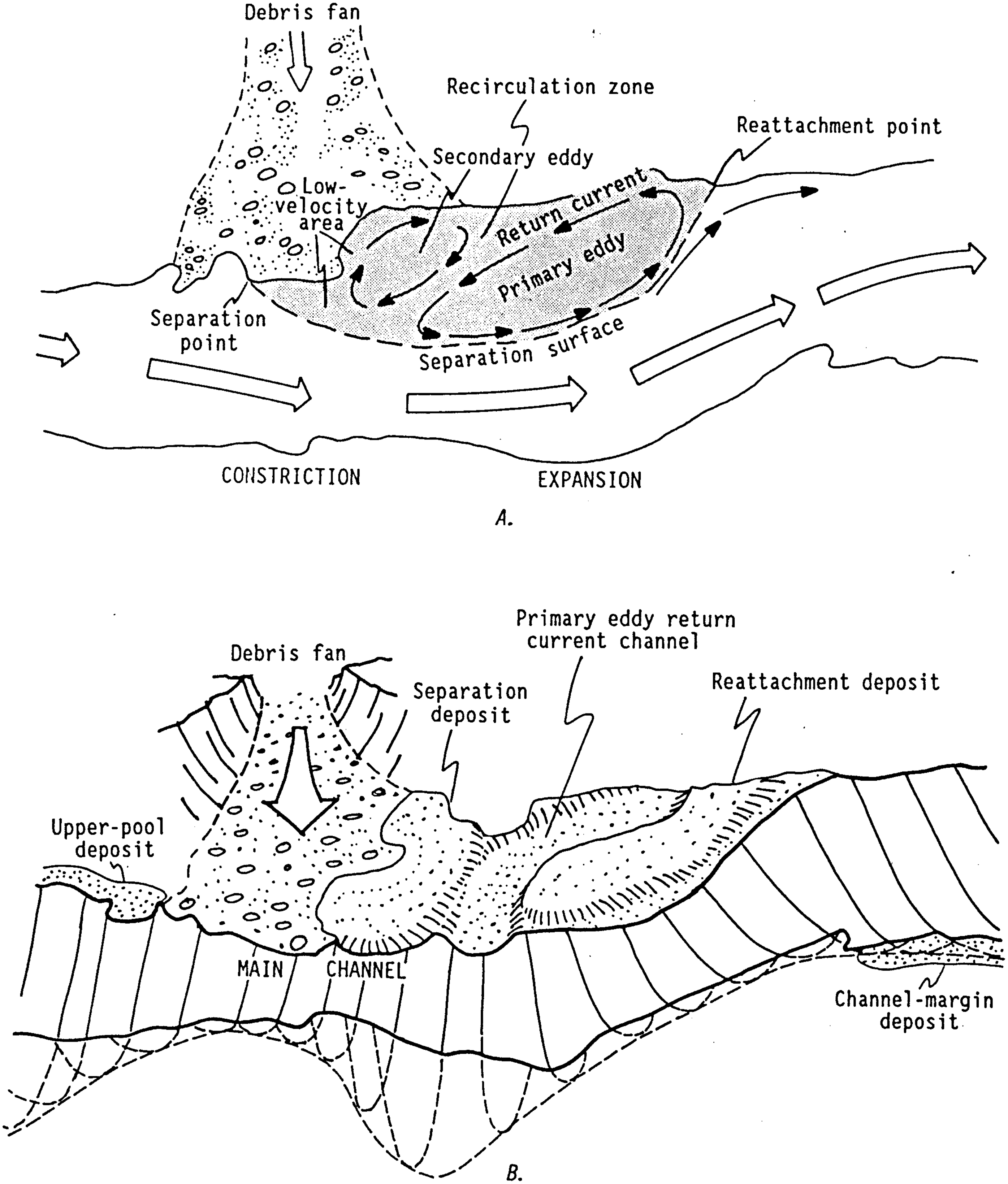
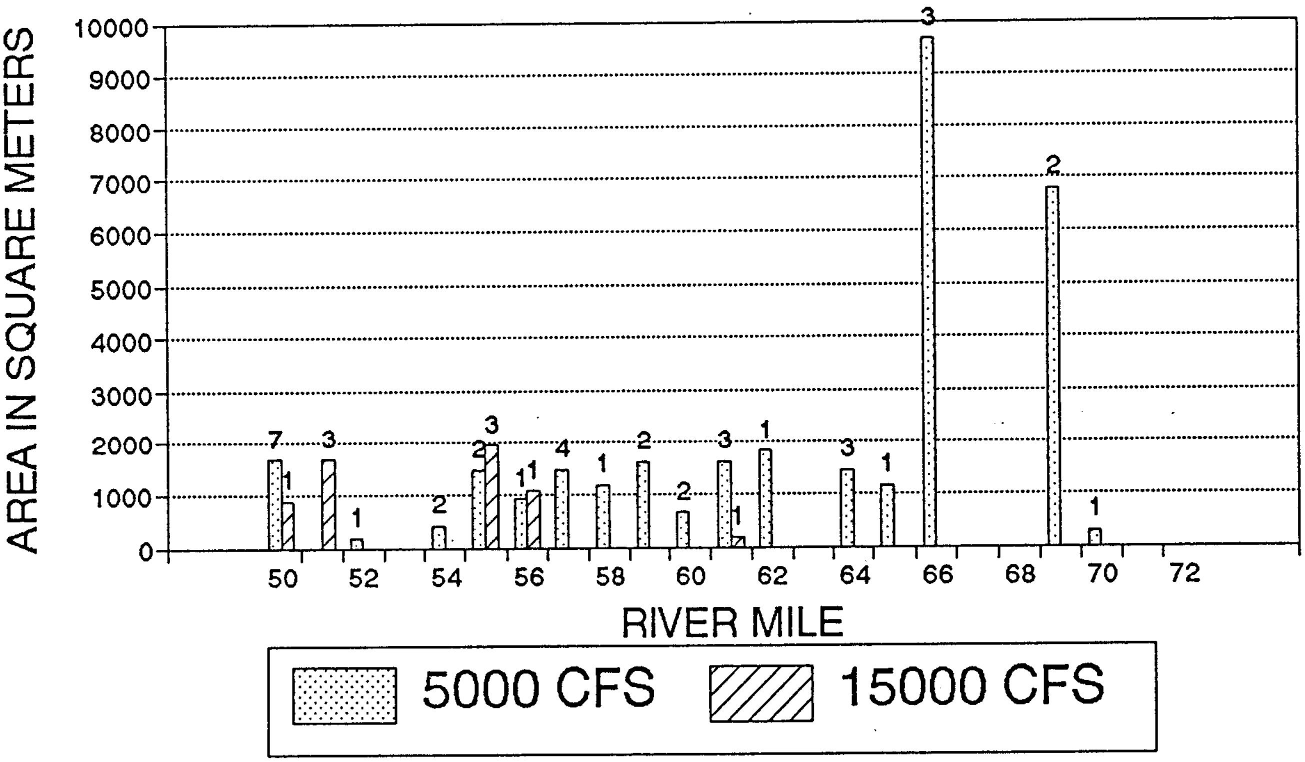


Figure 1.--Flow patterns and configuration of bed deposits in a typical recirculation zone. A, Flow patterns. B, Configuration of bed deposits. (Schmidt and Graf, 1988)

BACKWATER COMPARISON
1991



N=NUMBER OF BACKWATERS

FIGURE 2

1991 GCES BACKWATER DATA									
REACH		NO. OF BACKWATERS				TOTAL AREA (M^2)			
		5000 cfs		15000 cfs		5000 cfs		15000 cfs	
#	MILES	CB	IB	CB	IB	CB	IB	CB	IB
0	-15.5 - 0	1	0	3	2	324.8	---	17277.9	1140.7
1	0 - 11.3	0	0	0	0	---	---	---	---
2	11.3 - 22.6	2	0	2	0	2326.5	---	504.2	---
3	22.6 - 35.9	9	0	1	0	3859.1	---	129.3	---
4	35.9 - 61.5	40	0	15	1	18616.0	---	7302.5	238.6
5	61.5 - 77.4	10	2	1	0	14454.1	7193.0	503.2	---
6	77.4 - 117.8	3	0	0	0	2430.7	---	---	---
7	117.8 - 125.5	6	1	0	0	1595.8	424.0	---	---
8	125.6 - 139.9	0	0	1	0	---	---	259.6	---
9	140 - 159.9	1	0	0	0	215.5	---	---	---
10	160 - 213.8	24	2	19	0	6655.7	973.3	6344.0	---
11	213.9 - 235	0	0	1	0	---	---	189.5	---
12	235 - 278	3	10	0	0	2174.1	10612.9	---	---
	Sub-total	99	15	43	3	52652.3	19203.2	32510.2	1379.3
					x	531.8	1280.2	756.1	459.8
					sd	776.3	1302.4	2540.8	284.6
TOTALS		114		46		71855.5		33889.5	
					x	630.3		736.7	
					sd	893.0		2456.5	

CB = connected backwater
IB = isolated backwater
x = mean
sd = standard deviation
Note: Total Area was rounded up to the nearest tenth.

Figure 3

TOTAL BACKWATERS
1985 RM 50-72

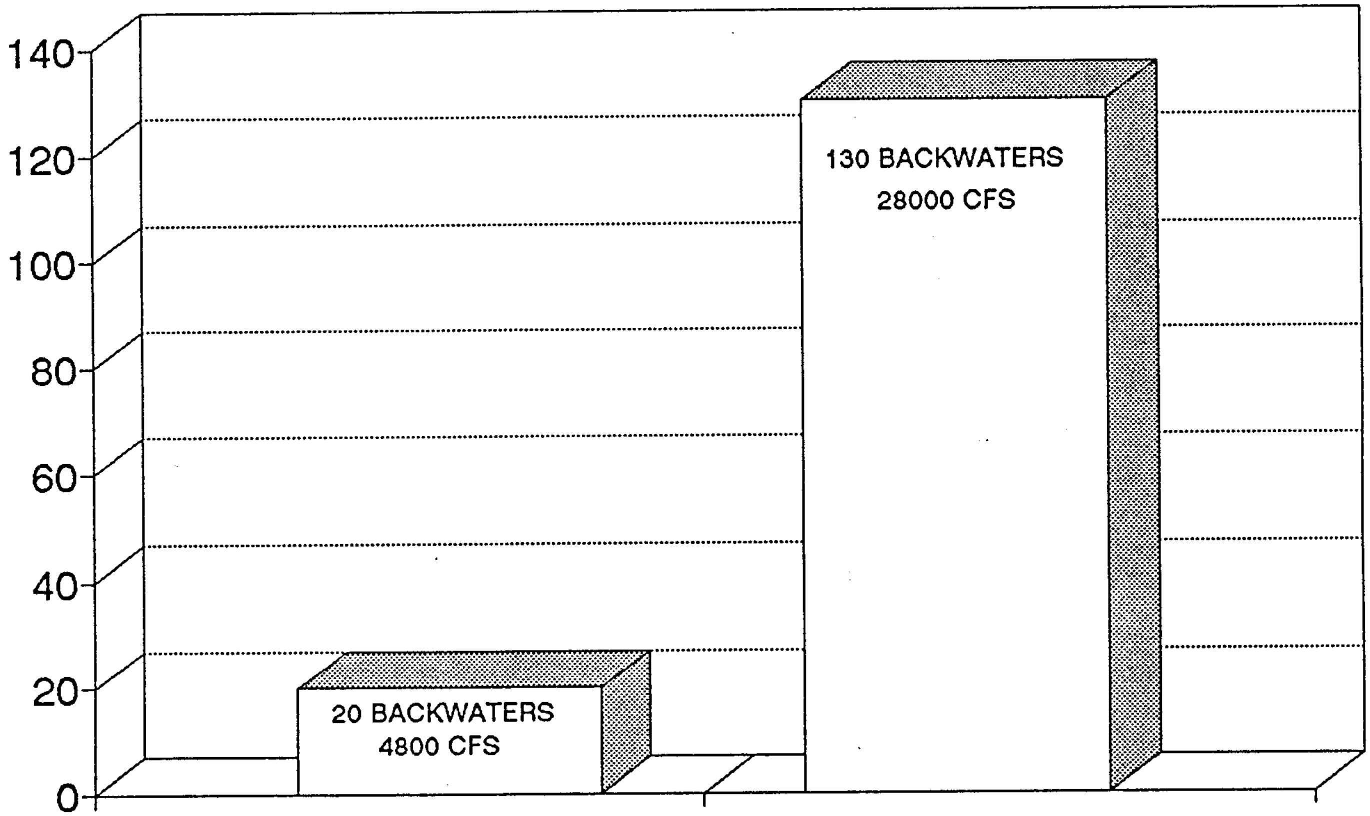


FIGURE 4

NUMBER AND AREA OF BACKWATERS

RM 52-72

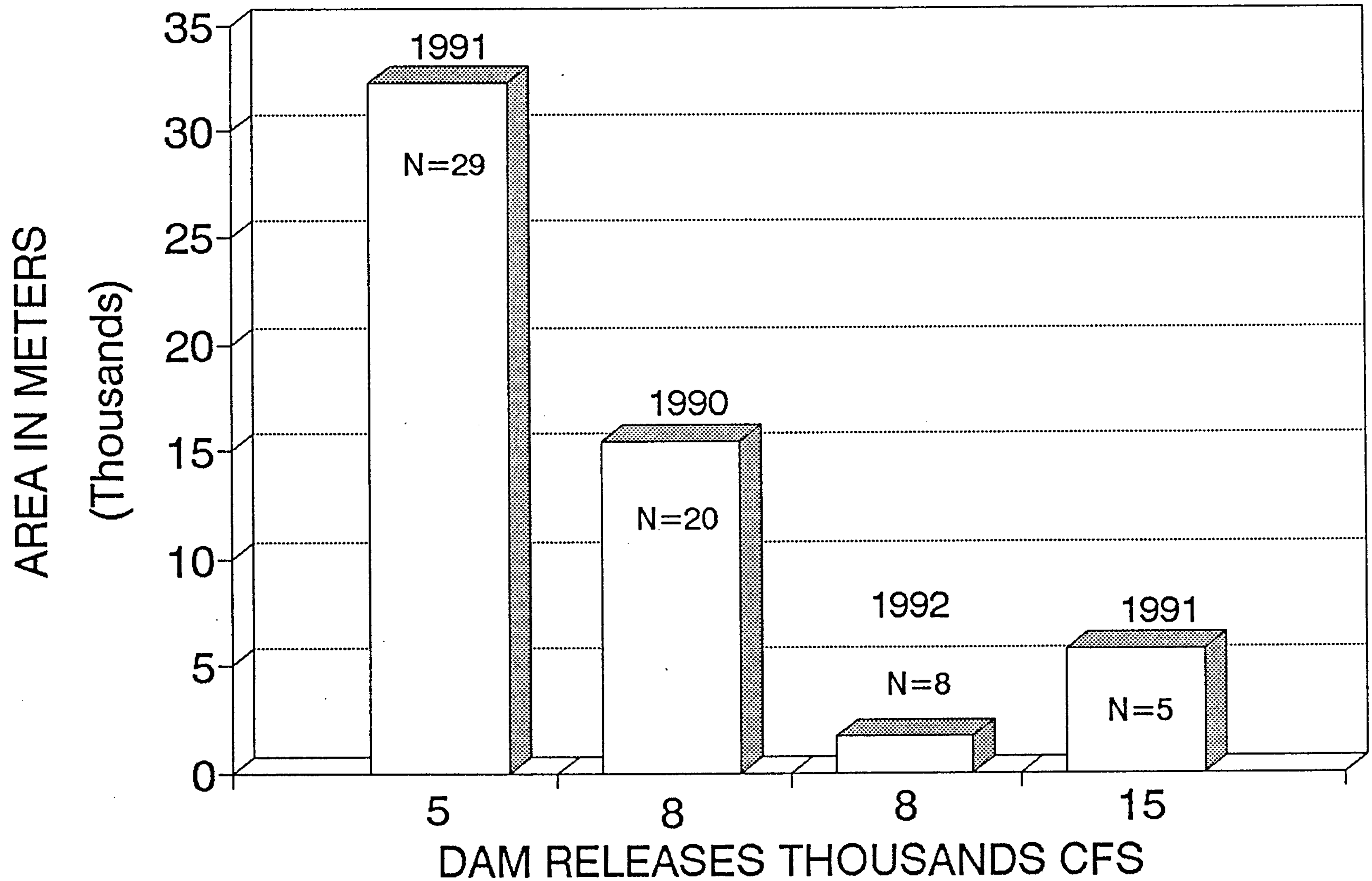


FIGURE 5

N=NUMBER OF BACKWATERS

1985 GCES BACKWATER DATA										
REACH		NO. OF BACKWATERS 4800 cfs		NO. OF BACKWATERS 28000 cfs		TOTAL AREA (M^2) 4800 cfs		TOTAL AREA (M^2) 28000 cfs		
#	MILES	CB	IB	CB	IB	CB	IB	CB	IB	
0	-15.5 - 0	16	5	1	0					
1	0 - 11.3	4	0	1	0					
2	11.3 - 22.6	10	0	1	0					
3	22.6 - 35.9	13	0	1	0					
4	35.9 - 61.5	72	23	21	3					
5	61.5 - 77.4	62	17	3	0					
6	77.4 - 117.8	52	4	4	0					
7	117.8 - 125.5	9	2	3	0					
8	125.6 - 139.9	12	1	5	0					
9	140 - 159.9	5	1	12	0					
10	160 - 213.8	191	21	114	0					
11	213.9 - 235	45	3	19	0					
12	235 - 278	0	0	0	0					
	Sub-total	491	77	185	3					
TOTALS		568		188		n/a		n/a		

CB = connected backwater
IB = isolated backwater
Note: Total Area for backwaters was not measured during 1985.

Figure 6

1992 GCES BACKWATER DATA (10/11-12/92)					
REACH		NO. OF BACKWATERS 8000 cfs		TOTAL AREA (M^2) 8000 cfs	
#	MILES	CB	IB	CB	IB
0	-15.5 - 0	5	0		
1	0 - 11.3	2	2		
2	11.3 - 22.6	2	0		
3	22.6 - 35.9	1	0		
4	35.9 - 61.5	15	1		
5	61.5 - 77.4	4	0		
6	77.4 - 117.8	3	0		
7	117.8 - 125.5	0	0		
8	125.6 - 139.9	2	0		
9	140 - 159.9	0	0		
10	160 - 213.8	21	4		
11	213.9 - 235	3	0		
12	235-278	5	0		
TOTALS		63	7		

CB = connected backwater
IB = isolated backwater

Figure 7

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