Riverine Fish Flow Investigations

Federal Aid Project F-289

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Federal Aid in Fish and Wildlife Restoration

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State: Colorado

Project No. 7400 ENDG 0700 Name: Aquatic Nongame Research

Study No. SE-3-22 Title: Riverine Fish Flow Investigations

Period Covered: July 1, 1997 - June 30, 2002

Study Objective: To determine relationships between flow and habitat availability for warm-water riverine fish communities of Colorado.

INTRODUCTION

Habitat loss is one of the single greatest causes of decline in populations of native fishes in North America (Williams et al. 1989). While there clearly must be some minimum flow needed to maintain a healthy, functioning river community, methods to establish minimum flows on warm water river sections have proved controversial. Most instream flow studies implemented in Colorado have focused on protecting minimum stream flow for cold water (headwater) habitats using either the R2Cross method (Nehring 1979) or Instream Flow Incremental Methodology (IFIM) (Bovee 1982), which determines habitat availability based on a single target species. IFIM estimates the amount of usable habitat for fish as a function of discharge by combining habitat suitability curves with the hydraulic model. The habitat component of the model has received much criticism because of assumptions implicit with using suitability curves and assumptions of positive relationships between habitat availability and fish abundance. Validation of these assumptions have been obstacles for successfully using IFIM to model minimum flow impacts on large warm water rivers of the west slope (Rose and Hahn 1989).

Warm water fish assemblages appear to require a more intensive approach to instream flow modeling compared to cold water fish communities. Warm water river reaches tend to be lower gradient and have higher channel complexity and sediment loads. Warm water fish populations tend to have higher species diversity. Also habitat suitability curves derived from microhabitat observations do not adequately describe habitat use for many warm water species. A broad community-level perspective, as opposed to an indicator species approach, may be required to protect all habitats of a functioning warm water stream ecosystem.

Instream flow techniques require integration of two processes that combine detailed knowledge of habitat requirements (by species and life stage), and the availability of necessary habitats. Both the collection and analysis of these data bases have been very labor intensive. Recent advances in surveying techniques (e.g. G.P.S.) and computer capabilities (G.I.S.) allow for collection and processing of much larger databases. Also, two-dimensional (2-D) flow models may have potential for application in instream flow studies (Leclerc *et al.*, 1995; Bovee, 1996). In theory, 2-D models offer a significant improvement over one-dimensional (1-D) modeling by increasing spatial resolution, allowing for highly accurate quantification of physical habitat availability. A spatially explicit flow model may eliminate the need for microhabitat suitability curves used by IFIM, and also improve biological resolution of the method. Presently, however 2-D modeling is not widely used for fishery applications and is still an unknown commodity as far as its practicality for instream flow assessment.

The goal of this project is to develop and validate a methodology for determining instream flow requirements for warm water fish communities in Colorado. The approach is to determine relationships between habitat availability and flow using a 2-D flow model to simulate meso-habitat diversity and abundance over a range of low flows on several sections of three different rivers. Also fish population and species' life history data will be collected within each of the study sites to provide habitat use and preference data to determine relationships between base flows and habitat availability for native fish species of warm water riverine fish communities.

Results of this study will be compared to instream flow recommendations made on the Yampa and Colorado Rivers to determine strengths and merits of assumptions used in other methods. These other studies include Modde et al. (1995) that used native hydrology (Yampa River), Modde et al. (1999) that used the inflection point method (Yampa River) and Osmundson et al. (1995) that used a videography approach to determine availability of preferred habitats in the Colorado River.

Study Objectives:

1) Model fish habitat availability on warm water sections of three rivers (Yampa, Colorado and Dolores) using the established methods (1-D models) and evaluate the practically of using 2-D flow models to quantify fish habitat.

2) Determine community structure, density and biomass for fish assemblages for river reaches listed above.

3) Test for relationships between habitat availability and fish abundance.

4) Develop and validate methodologies that use 1-D and 2-D flow models for the Division of Wildlife to use for minimum instream flow recommendations for warm water river sections.

STUDY AREA

The study area includes warm water reaches of the Yampa River between River Mile 59 and 135, from Cross Mountain to the town of Craig, Colorado (Figure 1.). The Duffy Tunnel station is located at River Mile 109.5, in the lower part of Little Yampa Canyon. Typically one side of the river is adjacent to a canyon wall which can contribute large boulders to the river in some sections. In Little Yampa Canyon pool and run habitat with cover provided by large boulders is fairly common. The Duffy Tunnel station has a generally flat slope. The Sevens station is located at River Mile 62.5. The river in this reach is typically in a valley flood plain adjacent to grazing pastures or hay fields. Large boulders are generally lacking in this reach, the gradient is flat and the substrate is dominated by sand.

Hydrographs that summarize the 82-year period of record for the Maybell gauge and flow were given in the 1998 progress report (Anderson 1998). The mean monthly flow for September 1998 (188 cfs) was less than the average of the mean monthly flows for the period of record for September (250 cfs). The August (495 cfs) and October (373 cfs) mean monthly flows for 1998 were higher than the average of the mean monthly flows for the period of record for August (391 cfs) and October (354 cfs). The minimum flow during the study period occurred on September 12, at 115 cfs (Figure 2), and was close to the median minimum flow (129 cfs). Flow was less than 150 cfs for a total of five days in 1998 and was under 200 cfs for 23 days.

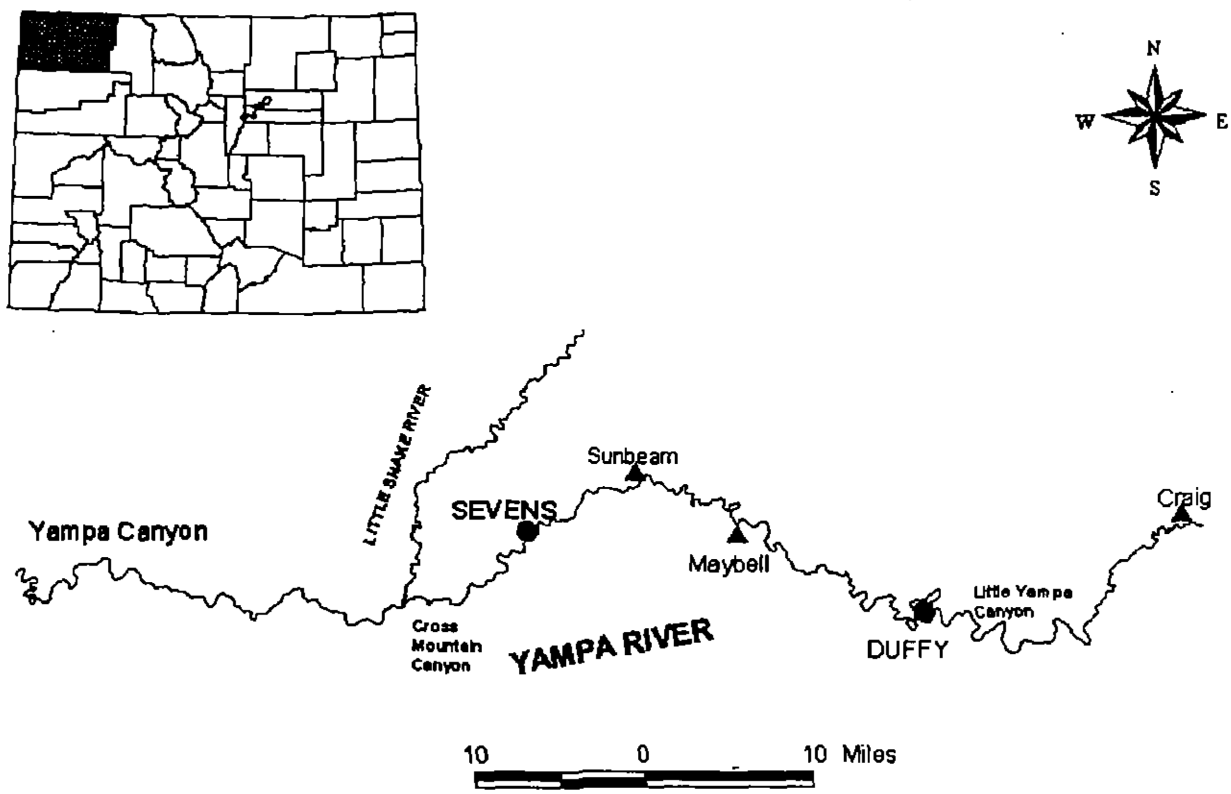

Figure 1. Location of the Sevens and Duffy habitat sampling stations, Yampa River.

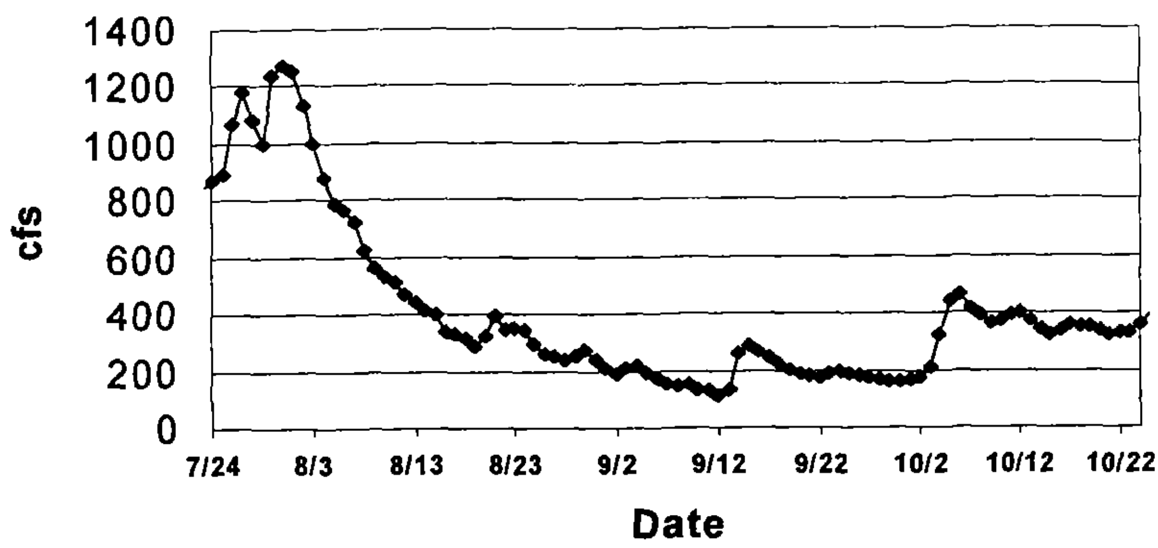

Figure 2. Mean daily flows from the Maybell gauge during the sampling period, July to October 1998.

MATERIALS AND METHODS

FISH SAMPLES

Fish were electroshocked and netted from an Achilles raft using a Smith-Root Electro-fisher powered by a 5000-watt generator with the anode mounted on a forward boom. The boat was maneuvered by either oars or by a battery operated 40 pound trolling motor. Two netters caught as many fish as possible while the shocker was in operation. All fish were measured to the nearest millimeter. Only fish over 150mm were marked and, therefore, used for mark and recapture population estimates. The Darroch multiple mark method (Everhart and Youngs 1981) was used to estimate abundance with ninety-five percent confidence intervals.

The surveyed study site (SS site) at Duffy was from RM 110.0 to 109.25 (Figure A3.1). The SS site at Sevens was from RM 62.2 to 61.5 (Figure A3.2). In the SS site a block net was set up to distinguish between fish occupying the deep (>3ft) part from those in the shallow end of the run. Multiple electrofishing passes were made both in upstream and downstream directions within the surveyed study sites. A net was set up to hold fish during multiple passes. All fish caught were marked with either single or double holes in the tail. Different marks were used to indicate whether a fish was taken from the deep part of the run versus the shallow part of the run.

In order to determine how representative the study sites were to a larger river reach, longer sections of the river were sampled with electrofishing. At Duffy, the representative reach station (RR station) was 5.2 mile long and was from RM 110.0 to

RM 105.0. The SS site was located at the upper portion of the representative reach. At Sevens the RR station was 4.0 miles in length and was from RM 64.0 to 60.0. The SS site was at the lower section of this reach. The electrofishing raft moved downstream while in operation. The same mark was used for all fish outside the SS site but was changed between days. Duffy RR was electrofished on September 15, 16, 22, 24 and 30. Sevens was sampled on September 17, 18, 23, 29, and October 1.

INVERTEBRATE SAMPLES

Aquatic invertebrates were collected at the two study sites using a surber sampler. Six samples were taken in July, August, September and October along an established transect line. Depth, velocity and the distance from the reference pin were measured for each sample. Sample densities were tested for difference based on depths with depths of 0.1 to 0.2 ft considered shallow, 0.4 to 0.6 ft were medium, and 0.8 to 1.0 ft were deep. Most specimens were identified to species and a Shannon Weaver Diversity index was calculated for each sample. Miller Ecological Inc. made identification.

At Duffy, the collections were made on July 23, August 20, September 3, and October 8. Samples at Cross Mountain were on the same date except during July when the sample was taken on July 30. Flows on those dates are given in Figure 2.

HABITAT MAPPING

During July and August of 1998, a Pentax PTSIII total station was used to obtain XYZ data points (<3cm total error) for two reaches on the Yampa River (Figure 3). The first reach is located approximately 15 miles upstream of Juniper Hot Springs near the Duffy Tunnel diversion. This site is approximately 1.3 km long and is represented by 3777 data points. The second site is located adjacent to the Sevens Ranch approximately five miles upstream of Cross Mountain Canyon. This site is approximately 1.2 km long and is represented by 1900 data points. Both sites have an average width of about 100 meters and have slopes of .08% and .03% respectively.

A Trimble GeoExplorer GPS was used to tie the XYZ data points into a meaningful geospatial reference system. At each of the two sites, at least two ground control points (GCP's) were determined using a 15 minute averaging routine and then were differentially corrected to give centimeter accuracy for each GCP. At each site, one GCP was selected to be the reference position and other GCP's were used for determining azimuth and as a rough check on total station coordinates.

Data points were gathered during the low flow periods by walking, wading, or floating the channel with a collapsible rod and prism. Instead of shooting bed profiles along transect lines, data points were taken at intervals dependent on the topography or breaks in slope. Where channel topography was highly variable, more points were captured compared to areas with relatively flat surfaces.

A relative measure of channel substrate was recorded for each XYZ data point. Substrate was determined visually on dry land and on shallow riffles, by feel where water was shallow enough to wade yet too deep to visually estimate, and by tapping with the rod where the water was too deep to wade. Channel substrate, feature, and habitat type were communicated by radio to the total station operator where it was recorded with the total station coordinates using a HP48GX, with TDS48 software.

Water-surface elevation and velocity were recorded at random points within each reach for use in calibrating the two-dimensional model. Velocities were measured at 0.6 ft depth, to represent average column velocity, using a Marsh-McBirney current meter. A staff stage was installed at both sites and a stage-discharge relationship was determined by taking flow readings several times throughout the summer.

Topographic data collected over the summer were input into the ArcInfo software package to create a Triangular Irregular Network (TIN) surface model of the channel. By mapping the topographic points on the TIN it was possible to determine where additional survey points were needed in order to accurately represent channel topography. Aerial photographs were taken of the sites at a scale of 1 inch equals 600 feet on September 15, at which time the flow was 287 cfs on the Maybell gauge. The aerial photos were qualitatively used to determine how representative the study reach compared to reaches up and down stream. Additionally, images of the site were rectified using ground control points and the Imagine software package. These images were then registered in the Surface-Water Modeling Software (SMS) and were used for reference in creating the finite element mesh.

HYDRAULIC SIMULATION

Hydraulic simulation and 2-D flow modeling was contracted with the Earth Resources Department of Colorado State University (CSU). Greg Stewart, a graduate student at CSU, collected, input the data for hydraulic modeling and performed the analysis. Many attempts were made to run the 2-D model during the first year of this contract but unfortunately, at the time of this writing, RMA2 analysis has only been partially completed and no two-dimensional modeling results are available.

HEC-RAS is a 1-D hydraulic flow model created by the Hydrologic Engineering Center of the U.S. Army Corps of Engineers (Brunner, 1998), and is based on solution of the one-dimensional energy equation (1).

$$Y_2 + Z_2 + \frac{a_2 V_2^2}{2g} = Y_1 + Z_1 + \frac{a_1 V_1^2}{2g} + h_e \qquad (1)$$

where: Y_1, Y_2 = depth of water at cross sections
Z_1, Z_2 = elevation at cross sections
V_1, V_2 = average velocities (total discharge/total flow area)
a_1, a_2 = velocity weighting coefficients
g = gravitational acceleration
h_e = energy head loss

$$h_e = L\bar{S}_f + C\left|\frac{\alpha_2 V_2^2}{2g} - \frac{\alpha_1 V_1^2}{2g}\right| \quad (2)$$

where: L = discharge weighted reach length
S_f = representative friction slope between two cross sections
C = expansion or contraction loss coeffiecient

The steady flow component is capable of modeling subcritical, supercritical, and mixed flow regime water surface profiles (Brunner, 1998). HEC-RAS has a graphical user interface (GUI) and requires station and elevation coordinates for each cross section. Energy loss due to friction is accounted for with cross-section average values for Manning n. Contraction and expansion of the channel is accounted for with the inclusion of the distance between right, left and thalweg points at adjacent cross sections. Simulation output can be expressed in tabular or graphical format and generally consists of depth, average cross-sectional velocity, and permutations of depth and velocity.

The HEC-RAS hydraulic model was used to determine wetted surface area and depths as a function of flow. Water surface profiles were computed from one cross section to the next by solving the energy equation with an iterative procedure called the Standard Step Method. HEC-RAS determines water surface elevation and an average velocity for each cross-section in an analysis. Thirty-one cross sections at approximately 150 ft intervals were inserted into the digitized Duffy channel and 29 cross sections at approximately 130 ft intervals were inserted into the digitized Sevens channel.

Water surface elevations were input into ARCView and endpoints of each cross section and a triangulated irregular network (TIN) of water surface elevation was created. Using a procedure called Cut and Fill, a TIN of the bed surface was subtracted from the TIN of water surface creating a polygon representation of wetted area. In order to determine the surface area for a given depth, the TIN's were converted to raster data (GRID) and the grid of bed surface was subtracted from the grid of water surface elevation. The resulting grid was turned into polygons and with integer values of average depth for the interval. The average zero depth value included areas above the water surface to 0.5 ft and "dry" area was removed. Wetted areas per depth categories were calculated in ARCView with the "calcacre" avenue script.

HEC-RAS outputs a single average velocity for each cross section. Cross sectional average velocities do not allow plotting the distribution and area of habitat types based on combinations of both depth and velocity. Therefore depth was the only habitat attribute available to compare differences in habitat between the two study areas in this report.

RMA2 is a two-dimensional depth averaged finite element hydrodynamic model created for the Corps of Engineers in 1973. RMA2 computes water surface elevations and horizontal velocity components for subcritical, free-surface flow in two-dimensional flow fields using a finite element solution of the Reynolds form of the Navier Stokes equations for turbulent flows. The forms of the depth-integrated equations of fluid mass and momentum conservation in two directions are shown below.

(3)

$$h\frac{\partial u}{\partial t}+hu\frac{\partial u}{\partial x}+hv\frac{\partial u}{\partial y}-\frac{h}{\rho}\left(E_{xx}\frac{\partial^2 u}{\partial x^2}+E_{xy}\frac{\partial^2 u}{\partial y^2}\right)+gh\left(\frac{\partial a}{\partial x}+\frac{\partial h}{\partial x}\right)+\frac{gun^2}{\left(1.486h^{\frac{1}{6}}\right)^2}+\left(u^2+v^2\right)^{\frac{1}{2}}=0$$

(4)

$$h\frac{\partial v}{\partial t}+hu\frac{\partial v}{\partial x}+hv\frac{\partial v}{\partial y}-\frac{h}{\rho}\left(E_{yx}\frac{\partial^2 v}{\partial x^2}+E_{yy}\frac{\partial^2 v}{\partial y^2}\right)+gh\left(\frac{\partial a}{\partial y}+\frac{\partial h}{\partial y}\right)+\frac{gvn^2}{\left(1.486h^{\frac{1}{6}}\right)^2}+\left(u^2+v^2\right)^{\frac{1}{2}}=0$$

(5)

$$\frac{\partial h}{\partial t}+h\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}\right)+u\frac{\partial h}{\partial x}+v\frac{\partial h}{\partial y}=0$$

where: h = depth
u,v = velocities in cartesian directions
x,y,t = cartesian coordinates and time
∂ = density of fluid
E = eddy viscosity coefficient
for xx = normal direction on x axis surface
for yy = normal direction on y axis surface
for xy and yx = shear direction on each surface
g = acceleration due to gravity
a = elevation at bottom
n = Mannings roughness coefficient

Equations 3, 4, and 5 are solved by the finite element method using the Galerkin Method of weighted residuals. Elements may be two-dimensional quadrilaterals or triangles and each may have curved sides. Integration in space is performed by Gaussian integration and derivatives in time are replaced by a non-linear finite difference approximation. Solutions are fully implicit and the set of simultaneous equations is solved by Newton-Raphson non-linear iteration. RMA2 permits wetting and drying within the grid either through elemental elimination or gradual wetting and drying through the consideration of marsh porosity (King 1997).

Surface-Water Modeling System (SMS) is a commonly used interface for RMA2. SMS is a pre- and post-processor for RMA2 which allows for the creation of the finite element mesh and associated boundary conditions with a GUI.

HABITAT AVAILABILITY

On September 15, 1999, at a flow of 287 cfs, aerial photographs were taken at a scale of 1"=600'. The aerial photography included the survey site and the representative reach section described for the fish sampling. Aerial photos were qualitatively used to compare habitat availability in the surveyed study sites to longer sections of the river. The images of the sites were rectified using ground control points and the Imagine software package. These images were then registered in the Surface Modeling Software (SMS) and were used for reference in creating the finite element mesh.

RESULTS

FISH SAMPLES

Species Composition

Percentages of fish captured by electrofishing, included fish less than 15 cm (YOY, and smaller species; speckled dace *Rhinichthys osculus*, mottled sculpin *Cottus bairdi*, sand shiners *Notropis stramineus*, fathead minnows *Pimephales promelas*, brook stickleback *Culaea inconstans*, redside shiner *Richardsonius balteatus* and green sunfish *Lepomis cyanellus*). This information is given in Appendix 1 Table A1.1.

White sucker *Catostomus commersoni* hybrids were common at both stations and for certain reporting purposes were grouped with those that appeared to be pure white suckers. The white-cross grouping, referred to as WSWX, represents both apparent pure white and white sucker hybrids. White sucker hybrids comprised at least 50% of the WSWX group at both Sevens and Duffy (Table A1.2).

For fish over 15 cm, flannelmouth sucker *Catostomus latipinnis* was the most common species in the Representative Reach (RR) at the Sevens station. Flannelmouth sucker comprised 43% of the total fish caught but was 37% based on density estimates (Table 1). In the shorter surveyed site (SS) the most common species were flannelmouth sucker and WSWX at 28% each (Table 1). The SS site had more WSWX than the RR station (17%), but less bluehead sucker *Catostomus discobolus* (14%) than the RR station (27%)(Table 1). Roundtail chub *Gila robusta* and other species had higher percentages in the SS site. There appeared to be a higher composition of "pool" associated species in the SS site and a lower representation of run (flannelmouth sucker) and riffle (bluehead sucker) species in the SS site than in the longer RR station.

At Duffy Tunnel, WSWX comprised 67% of the fish caught over 15 cm (Table 2). WSWX composition was 59% in the RR station based on density estimates, compared to 63% in the SS sites. Smallmouth bass *Micropterus dolomieu* composition was somewhat higher at the SS site 13% than in the longer RR station where it was 11% (Table 2). Flannelmouth sucker was lower in the SS site (3.9%) than the RR station (7.4%), while bluehead suckers were very similar between the two locations (4.6 % vs. 5.0%). Roundtail chub composition was a little less in the SS site (2.5%) than in the long RR (3.8%). Species composition was more similar between the SS site and the RR at Duffy Tunnel than at the Sevens station.

Table 1. Sevens species composition (fish over 150 mm) for total catch and estimated numbers in the Representative Reach (RR) and the Surveyed Site (SS), September 1998.

SEVENS	REPRESENTATIVE REACH		REPRESENTATIVE REACH		SURVEYED SITE	
Species	N	%	EST.	%	EST.	%
Total fish	2219		6117		862	
Flannelmouth Sucker	964	43.4%	2257	36.9%	241	28.0%
Bluehead Sucker	484	21.8%	1650	27.0%	121	14.0%
White Sucker* (WSWX)	377	17.0%	1016	16.6%	244	28.3%
Roundtail Chub	135	6.1%	409	6.7%	81	9.4%
Channel Catfish	133	6.0%	403	6.6%	75	8.7%
Carp	69	3.1%	209	3.4%	57	6.6%
Northern Pike	31	1.4%	94	1.5%	18	2.1%
Smallmouth Bass	23	1.0%	70	1.1%	21	2.4%
Crappie	7	0.3%	n.e.		n.e.	
Colorado Pikeminnow*	3	0.1%	9	0.1%	3	0.3%
Native species	1586	71.5%	4325.203	70.7%	445.9903	51.7%
Nonnative species	640	28.8%	1791.797	29.3%	416.0097	48.3%

The percent of native fish in the catch at Sevens was 71% (Table 1) and 14% at Duffy (Table 2). The biggest difference between the two areas was flannelmouth suckers, which were 43% of the catch at Sevens but 6% at Duffy. Bluehead sucker and roundtail chub were 22% and 6%, respectively at Sevens compared to 4% and 3%, respectively at Duffy. Together smallmouth bass and northern pike *Esox lucius* comprised 2% of the fish catch at Sevens compared to 12% at Duffy. Channel catfish *Ictalurus punctatus* composition was higher at Sevens, while Colorado pikeminnow *Ptychocheilus lucius* were more abundant at Duffy.

Results of electrofishing surveys by the Colorado River Recovery Program (ISMP) indicate the percent composition of native fish decreases in an upstream direction from Lily Park to Duffy Tunnel (Figure A1.1). ISMP collections 10 miles downstream of Sevens at Lily Park (RM 52) had native fish at 91% of the total catch. Flannelmouth sucker was 68% of the catch at Lily Park. Flannelmouth sucker composition decreased in an upstream direction and was 43% at Sevens (RM 62), 18% at Maybell (RM 76), 8% at Juniper (RM 99) and just 4% at Morgan Gulch (RM 104) and Duffy Tunnel (RM 110). White sucker and white sucker hybrids increased in an upstream direction and the ISMP collections near Juniper (RM 99) had native fish at 18% (Figure A1.2). Nonnative predators (smallmouth bass and northern pike) and Colorado pikeminnow tended to increase in an upstream direction (Figure A1.3).

Table 2. Duffy Tunnel species composition (fish over 150 mm) for total catch and estimated numbers in the Representative Reach and Surveyed Site, September 1998.

DUFFY	REPRESENTATIVE REACH		REPRESENTATIVE REACH		SURVEYED SITE	
Species	N	%	EST.	%	EST.	%
Total fish	1388		3574		948	
Flannelmouth Sucker	81	5.8%	258	7.2%	56	3.9%
Bluehead Sucker	56	4.0%	178	5.0%	23	4.6%
White Sucker* (WSWX)	930	67.0%	2121	59.3%	602	63.1%
Roundtail Chub	43	3.1%	137	3.8%	23	2.5%
Channel Catfish	44	3.2%	140	3.9%	13	1.4%
Carp	42	3.0%	134	3.7%	16	1.8%
Northern Pike	46	3.3%	147	4.1%	63	6.7%
Smallmouth Bass	124	8.9%	395	11.1%	122	13.0%
Crappie	1	0.1%	n.e.		n.e.	
Colorado Pikeminnow*	20	1.4%	64	1.8%	30	3.2%
Green Sunfish	1	0.1%	n.e.		n.e.	
Native species	200	14.4%	637	17.8%	132	13.9%
Nonnative species	1188	85.6%	2937	0.8	816	86.0%

Density and Biomass Estimation

The total fish density estimated at Sevens RR was 950/km (Table 3) and the total fish estimate for Duffy RR was 411/km (Table 4). The total fish density estimate was significantly higher at Sevens RR compared to Duffy RR (Table 5) and indicates a larger population of flannelmouth sucker, bluehead sucker, roundtail chub, and channel catfish at Sevens. However, total fish density estimates were not significantly different between Sevens SS and Duffy SS. Sevens SS had significantly more catfish and flannelmouth sucker and significantly fewer WSWX than Duffy SS.

Table 3. Density estimate, 95% C.I. (% of est.), and biomass estimate for the Representative Reach (RR) and Surveyed Site (SS) at Sevens, Yampa River, September 1998.

SEVENS	REPRESENTATIVE REACH			SURVEYED STUDY SITE		
	No./km	95%C.I	KG/HA	No./km	95%C.I	KG/HA
Total fish	950	8%	148	893	19%	134
Flannelmouth S.	351	11%	61	250	20%	37
Bluehead S.	256	21%	20	125	104%	9
*White S.	158	20%	23	253	57%	26
Roundtail Chub	64	36%	7	84	80%	8
Channel Catfish	63	25%	20	78	49%	19
Carp	32	62%	16	59	120%	30
Northern Pike	15	128%	1	19	NR	1
Smallmouth Bass	11	185%	1	22	159%	2
C. pikeminnow	1	NR	1	3	NR	1

Electrofishing results indicate that the SS sections (habitat mapping areas) at both areas had somewhat different fish population characteristics than in the longer reaches (RR). The total fish density at Sevens RR and SS was not significantly different; however, flannelmouth sucker was significantly different at the two sites with fewer in the SS (Table 5). At Duffy the total fish estimate in the RR was significantly different than the SS estimate due to more WSWX in the SS section. (Table 5).

Table 4. Density estimate, 95% C.I. (% of est.), and biomass estimate for the Representative Reach and Surveyed Site at Duffy, Yampa River, September 1998.

DUFFY	REPRESENTATIVE REACH			SURVEYED STUDY SITE		
	No./km	95% C.I.	Kg/ha	No./km	95% C.I	Kg/ha
Total fish	411	10%	87	786	17%	141
White Sucker	244	11%	50	499	17%	98
Smallmouth Bass	45	61%	3	101	131%	7
Flannelmouth S.	30	39%	6	46	49%	8
Bluehead Sucker	21	64%	2	19	164%	2
Channel Catfish	16	77%	6	11		4
Northern Pike	17	132%	2	52	123%	5
Roundtail Chub	16	45%	3	19	196%	3
Carp	15	132%	11	14		8
Colo. Pikeminnow	7	81%	3	25		7

Table 5. Significant difference (S.D.) for alpha 0.05 for density estimates between the two study sites, Sevens and Duffy for the SS and RR sections.

Species	Rep. Reach (RR)	Survey Site (SS)	Sevens	Duffy
	SEVENS vs. DUFFY	SEVENS vs. DUFFY	SS vs. RR	SS vs. RR
Total fish	S.D.	n.d.	n.d.	S.D.
Bluehead sucker	S.D.	n.d.	n.d.	n.d.
Channel catfish	S.D.	S.D.	n.d.	n.d.
Carp	n.d.	n.d.	n.d.	n.d.
Colorado pikeminnow	S.D.	n.d.	n.d.	S.D.
Flannelmouth sucker	S.D.	S.D.	S.D.	n.d.
Northern pike	n.d.	n.d.	n.d.	n.d.
Roundtail chub	S.D.	n.d.	n.d.	n.d.
Smallmouth bass	n.d.	n.d.	n.d.	n.d.
WSWX	S.D.	S.D.	n.d.	S.D.

Size and length frequency

Mean lengths given for each species in Table 6 are for fish over 150 mm, as was done with composition and density data. Most (7 of 11) species had significantly (alpha = 0.5) larger average lengths at Duffy RR than at Sevens RR (Table 6 and Table 7). Bluehead sucker mean length was also larger at Duffy, but significance was with a one tail test (Table 7). Two species without significant differences in mean lengths were pikeminnow and smallmouth bass; both species were rare at Sevens. Flannelmouth sucker was the only species with a smaller (significant) mean length at Sevens (Table 6).

Mean length of flannelmouth sucker (FM) (488 mm) was larger than White-flannelmouth crosses (WF) (460 mm) at Sevens RR, but this was reversed at Duffy RR where FM (459 mm) mean length was smaller than WF (475 mm) (Table 6). The smaller sized flannelmouth sucker at Duffy may suggest a competitive disadvantage for adult FM at Duffy. Only 1.5 and 1.1% of FM were between 150 and 300 mm at Seven and Duffy respectively, indicating that juveniles were rare at both sites.

White sucker (WS) mean length was 359 mm at Sevens RR and 411 mm at Duffy RR. At the Sevens 24% of white sucker were between 150 and 300 mm compared to 12% at Duffy (Tables A1.1 and A1.2). A higher proportion of white sucker between 150 and 300 mm at the Sevens could be due to less predatory pressure at that location. White-bluehead (WB) crosses had similar mean length to white sucker at Duffy, but were somewhat smaller at Sevens.

Mean lengths of bluehead sucker differed by only 15 mm between the two sites (Table 6). The percent of bluehead sucker between 150 and 300 mm was 18% at the Sevens and 19% at Duffy indicating similar size structure for this species for the two sites. Mean size of roundtail chub was 380 mm at Sevens and 442 mm at Duffy. The percent of roundtail chub between 150 and 300 mm was 5.8% at the Sevens, but the smallest chub collected at Duffy was 371 mm. The lack of roundtail chub under 370 mm could indicate this species has reduced survival for smaller sized fish at Duffy.

Table 6. Sample size and mean length (mm) of fish over 150 mm from the RR and the SS portions of Sevens and Duffy, September 1998.

	MEAN LENGTH IN MM				SAMPLE SIZE (n)			
	Sevens	**Sevens**	**Duffy**	**Duffy**	**Sevens**	**Sevens**	**Duffy**	**Duffy**
Species	**RR**	**SS**	**RR**	**SS**	**RR**	**SS**	**RR**	**SS**
BH	342	336	357	379	*547*	*43*	*63*	*8*
CC	497	444	529	525	*153*	*28*	*49*	*4*
CP	572	578	670	629	*77*	*21*	*44*	*5*
CPM	628	622	608	577	*3*	*1*	*24*	*9*
FM	488	445	459	480	*1169*	*186*	*93*	*19*
NP	383	310	433	398	*33*	*6*	*49*	*22*
RTC	380	356	442	434	*156*	*31*	*54*	*8*
SMB	295	320	278	270	*24*	*8*	*135*	*39*
WB	329	330	413	416	*11*	*2*	*95*	*14*
WF	460	420	475	481	*142*	*16*	*438*	*92*
WS	359	307	411	397	*293*	*71*	*552*	*214*

As with the RR sections, mean lengths for most species were larger (6 of 11) at Duffy SS than at Sevens SS (Table 7). At Duffy the SS had similar mean lengths for all taxa to the RR except for the most common species, white suckers (Table 7). In contrast there was a strong tendency for smaller fish at the Sevens in the SS than the RR. Mean length was significantly smaller for 6 of 11 taxa in the Sevens SS (Table 7).

Table 7. Tests of mean lengths of fish between the four study areas: Duffy RR, Duffy SS, Sevens RR and Sevens SS. Alpha equal 0.05.

	RR	SS	DUFFY	SEVENS
	DUFFY Vs. Sevens	DUFFY Vs. Sevens	RR Vs. SS	RR Vs. SS
Species				
BH	S.D.*	S.D.**	n.d.	n.d.
CC	S.D.**	n.d.	n.d.	S.D.**
CP	S.D.**	n.d.	n.d.	n.d.
CPM	n.d.	-	n.d.	n.d.
FM	S.D.**	n.d.	n.d.	S.D.**
NP	S.D.**	S.D.**	n.d.	S.D.**
RTC	S.D.**	S.D.**	n.d.	S.D.*
SMB	n.d.	S.D.**	n.d.	n.d.
WB	S.D.**	n.d.	n.d.	n.d.
WF	S.D.**	S.D.**	n.d.	S.D.**
WS	S.D.**	S.D.**	S.D.*	S.D.**

SD* significant for 2 tail test (95%)
SD** significant for 1 tail test (95%)

INVERTEBRATES

Enumeration of samples collected by date and station is given in Appendix 2. Density was higher at Duffy than at Cross Mountain ranch on all dates. Diversity was higher at Duffy except during October (Table 8). The greatest density was in September at Cross Mountain, and in October at Duffy (Table 8). October samples 1, 2, 3 and 4 at Cross Mountain and 1 and 2 at Duffy were from areas recently re-watered following an increase in flow (Figure 2). The flow on September 3 was 209 cfs. Minimum flow was 113 cfs on September 11 and flow increased to 394 cfs by October 8, when the final sample was taken. The reduced density of these samples was apparently related to the fact that shallow areas were recently dry.

Table 8. Shannon Weaver Diversity, total number of species, number of ephemeroptera, plecoptera and trichoptera taxa (E.P.T.), mean density and density of shallow, middle and deep samples for the Yampa River, September 1998.

DATE	S.W. INDEX	TOTAL SPECIES	E.P.T.	MEAN DENSITY	Shallow n=2	Middle n=2	Deep n=2
Cross Mtn. Ranch							
30 Jul. 1998	3.44	26	18	39.3	15	152	69
20 Aug. 1998	3.46	28	17	43.8	122	84	57
3 Sept. 1998	3.54	38	24	197.0	419	442	321
8 Oct. 1998	3.64	27	17	48.7	25*	63*	199
Duffy Tunnel							
23 Jul. 1998	3.93	33	21	82.2	184	215	91
20 Aug. 1998	3.69	39	21	316.2	429	935	532
3 Sept. 1998	3.63	41	23	314.0	412	975	495
8 Oct. 1998	3.56	35	22	345.8	56*	907	1112

*indicates sample collected in area of riffle dewatered prior to collection.

September is typically the month with the lowest base flow and the least amount of available riffle habitat. Since invertebrate community characteristics were similar at Duffy and Cross Mountain in September, the stations were combined for describing community structure. Mayflies and caddisflies comprised 83 to 92% of the total number of specimens in September (Table 9). Mayfly density and number of taxa decreased with increasing depths. The highest caddisfly and total invertebrate density was at the middle depth (0.4 to 0.6 ft). Density was 60% of the middle depth at both the shallow (0.1 to 0.2 ft) and the deep samples (0.8 to 1.0 ft) (Table 9). The differences in density between depths did not appeared to be due to velocity, since velocities were fairly similar between the middle and deep sites (Table A2.1).

Table 9. Invertebrate density, count, and diversity of shallow, middle and deep samples in the Yampa River, September 1998.

	DUFFY TUNNEL			CROSS MOUNTAIN			COMBINED		
	SHALLOW	MEDIUM	DEEP	SHALLOW	MEDIUM	DEEP	SHALLOW	MEDIUM	DEEP
	Number of specimens per depth group								
TOTAL DENSITY	412	975	495	419	442	321	831	1417	816
Mayflies	175	193	47	160	84	51	335	277	98
Caddisflies	172	550	394	230	339	259	402	889	653
Stoneflies	7	14	6	4	7	1	11	21	7
Diptera	28	189	32	17	7	7	45	196	39
Beatles	9	19	8	5	3	2	14	22	10
Bugs	0	0	0	0	1	0	0	1	0
Leptodoptera	0	3	1	0	1	1	0	4	2
Odonata	0	0	0	2	0	0	2	0	0
Snail	11	5	6	1	0	0	12	5	6
Oligochaeta	10	2	1	0	0	0	10	2	1
	Number of taxa per depth group								
TOTAL COUNT	28	35	26	30	25	25	38	39	35
Mayflies	10	10	5	12	10	9	13	12	11
Caddisflies	5	8	8	8	8	9	8	9	10
Stoneflies	2	2	2	1	1	1	2	2	2
Diptera	6	7	7	5	3	3	7	8	7
OTHERS	5	8	4	4	3	3	8	8	5
	Percentage								
Mayflies	42.5%	19.8%	9.5%	38.2%	19.0%	15.9%	40%	20%	12%
Caddisflies	41.7%	56.4%	79.6%	54.9%	76.7%	80.7%	48%	63%	80%
Stoneflies	1.7%	1.4%	1.2%	1.0%	1.6%	0.3%	1%	1%	1%
Diptera	6.8%	19.4%	6.5%	4.1%	1.6%	2.2%	5%	14%	5%
OTHERS	7.3%	3.0%	3.2%	1.9%	1.1%	0.9%	5%	2%	2%
S.W. DIVERSITY	3.47	4.50	2.92	3.73	3.13	3.06	3.77	3.60	3.19
DENSITY (#/FT)	206	489	248	210	221	161	208	355	204

HABITAT COMPOSITION

Preliminary analysis of habitat composition were based on habitat typing made subjectively during field surveying, not on results of hydraulic modeling that quantified surface area of habitat type possessing combinations of depth and velocity attributes. The quantification of habitat types is still in process and will be presented in next years' progress report.

The results from subjective habitat typing indicated that riffles and runs were more common at Duffy than at Sevens (Table 10), but these results are of little value in quantitatively describing the two study sites. Mean wetted perimeter was fairly similar between the two sites indicating a similar channel size. The only wetted perimeter that was significantly different (alpha = 0.05) was at 200 cfs (Table 10). The percent of the channel that was wetted tended to be higher at Duffy than Sevens at flows of 200 and 600 cfs (51 vs. 44% and 64 vs. 57 % respectively) but were fairly similar at 50 cfs (37 vs. 34 %, respectively).

Table 10. Percent habitat types and mean wetted perimeter at bankfull flow (channel) and mean wetted perimeter at 50, 200 and 600 cfs and (95% C. I.). Sample size at Duffy is 32 and at Sevens is 29.

HABITAT FEATURE	SEVENS	DUFFY
Riffles (%)	16%	21%
Runs (%)	64%	68%
Pools (%)	2%	1%
Backwater (%)	18%	9%
Mean wetted perimeter, bankfull (9000 cfs)	402.5 ft (29.5)	394.3 ft (40.3)
Mean wetted perimeter (50 cfs)	138.6 ft (13.3)	146.6 ft (20.9)
Mean wetted perimeter (200 cfs)	175.2 ft (13.5)	202.9 ft (17.4)
Mean wetted perimeter (600 cfs)	230.3 ft (16.2)	250.7 ft (17.6)

The slope of both study areas was very flat. The energy grade line (water surface slope) at Sevens 0.04% and it was 0.14% at Duffy. The flat nature of the river meant that much of the river was comprised of run habitats. The substrate composition had a higher percent of sands and fines at Sevens. At Sevens the substrate was 34% silt and sand, 28% pea gravel, 27% gravel and 5% large gravel. At Duffy the substrate was 13% silt and sand, 10% pea gravel, 32% gravel and 27% large gravel. Cobble and boulders comprised 6% of the substrate at Sevens and 16% at Duffy.

At a flow of 200 cfs, Duffy had higher percentages of very shallow (less than 0.5 ft) and very deep (over 5.5 ft) habitats than Sevens (Figure 3). Sevens had a higher composition of habitat between 1 and 4 feet of depth. The depth frequency distributions were different for the two sites indicating that Duffy has a higher depth and habitat diversity. However, without velocity data, shallow riffles could not be distinguished from shallow runs. At flows of 50, 100 and 150 cfs it was felt that most of the area over 3.5 feet deep would have very slow velocities and could be considered pool habitat.

At a flow of 50 cfs, 98.4% of the surface area was less than 3.5 feet deep at Sevens compared to 91.7% at Duffy (Figure A3.3). At flows of 50, 100, and 150 cfs the amount of area less than 2.5 feet in depth was fairly similar for the two sites and about 87% of the total. However, Duffy had more area less than 0.5 feet while Sevens had more area with depths between 0.5 and 2.5 feet (Figures A3.4 and A3.5).

At 200 cfs Sevens had double the percent of surface area at intermediate (2.5 to 3.5 ft) depths with about 12% of the area (Figure 3, and Figure A3.6). At flows of 50, 100 and 150 cfs the percent of area in the depth range of 2.5 to 3.5 feet was about 10% at Sevens compared to 5% at Duffy.

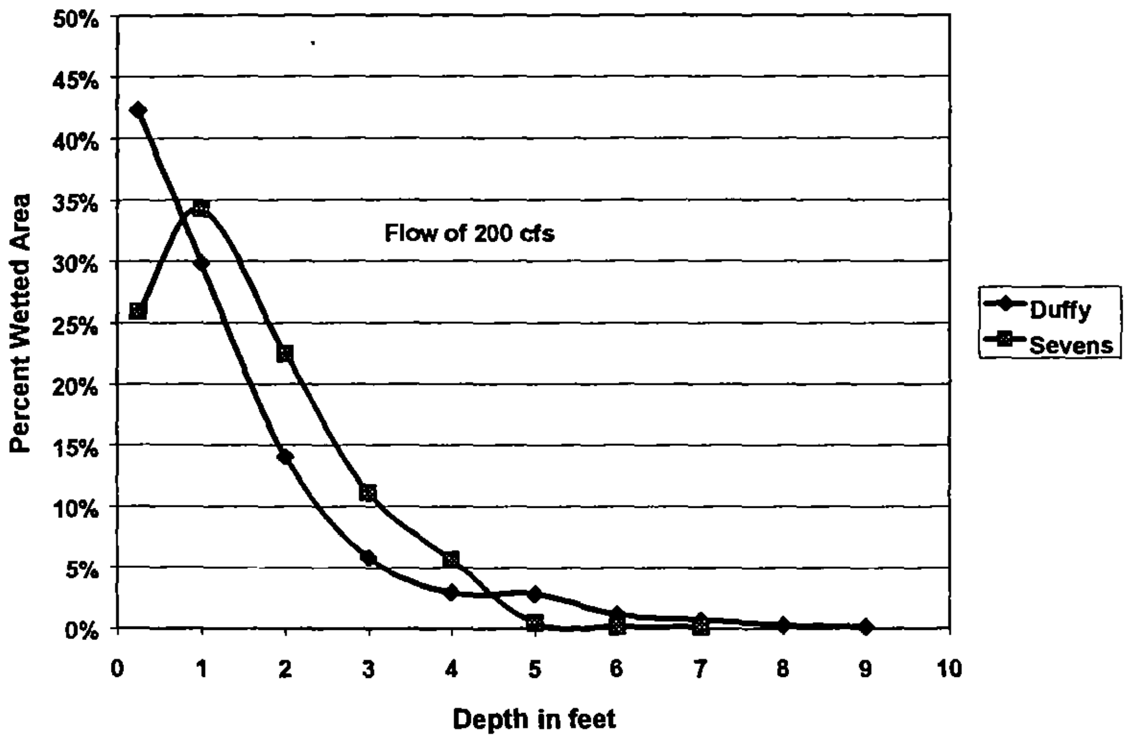

Figure 3. Percent of wetted area for depths at a flow of 200 cfs for the Duffy and Sevens study sites.

In the depth range between 3.5 to 5.5 ft Sevens and Duffy had similar areas (6%) at 200 cfs (Figure 3 and Figure A3.7). However at flows less than 200 cfs, area dropped quickly to just below 2% at Sevens but remained at 6% for Duffy (Figure A3.7). Sevens had very little area with depths over 5.5 ft (0.1%) at flows of 50, 100 and 150 cfs while Duffy had about 2% at depths over 5.5 feet between 50 and 200 cfs (Figure A3.8). This data indicated that even at very low flows, the Duffy station still maintains deep pool habitat, while deep pools are lost at the Sevens station.

DISCUSSION

FISH SAMPLES

Significant differences were identified in the fish community between Duffy and Sevens for species composition, density and size structure. Native species composition was higher, density was generally higher and mean size was generally lower for fish at Sevens compared to 50 miles upstream at Duffy. Results of recent sampling (1994 to 1998) by the interagency standardized monitoring program (ISMP) were similar to this study, finding native species composition highest at Lily Park and the lowest 50 miles upstream at Morgan Gulch (Bill Elmblad, CDOW unpublished data 1995 - 1998). However collections made in the 1970s and 1980s tend to indicate a larger native fish population in the upstream reaches (Maybell, Juniper and Craig). Holden and Stalnaker (1975) characterized flannelmouth and bluehead sucker abundant at all four locations they sampled in the Yampa River, which include Juniper and Craig. Surveys by Miller (1982), Carlson (1979), and Wick (1981 and 1986) report flannelmouth sucker composition between 25 and 75% at Lily Park, 45 and 55% at Maybell, and between 34 and 64% near Juniper and Craig. The current percent composition of flannelmouth sucker (6%) appears much less for Maybell and upstream than found earlier. It appears highly unlikely that the reduced flannelmouth population upstream of Maybell is related to recent alterations in physical habitat.

Present composition of bluehead sucker appears fairly similar to that reported by Miller (1982), Carlson (1979), and Wick (1981 and 1986) for the Lily Park and Maybell. However, these authors report bluehead composition between 7 and 39% for Juniper, generally higher than found in 1998 at Duffy (4%) and with ISMP sampling at Juniper (6%) (Elmblad pers. comm.). Bluehead sucker are generally found to be associated with riffle habitat and any changes in their composition over this time period were not attributed to presumed changes in habitat or to flow alterations.

Composition of roundtail chub reported by Miller (1982), Carlson (1979), and Wick (1981 and 1986) averaged 9% for Lily Park, 8% at Maybell and 11% at Juniper. Composition of roundtail chub in this study (6% at Sevens and 3% at Duffy) appears to be a less than earlier reported downstream of Maybell and considerably less upstream of Juniper. Adult roundtail chub are strongly associated with deep pool habitat, and pool habitat availability likely has not changed significantly over the last twenty years.

It appears more likely that any recent changes in flannelmouth, bluehead sucker and roundtail chub abundance upstream of Maybell are more likely a consequence of recent introduction of small mouth bass instead of habitat alteration. Smallmouth bass were first collected in the river in 1992 when Elkhead reservoir was drained (Nesler 1995). Nesler (1995) believed that smallmouth bass were unlikely to become established in the Yampa River due to lack of suitable habitat. Several hundred smallmouth bass YOY were collected at Duffy and bass reproduction has probably been successful in most of Little Yampa Canyon. Smallmouth bass appeared to be strongly associated with deep pools with cover provided by large boulders. This habitat was common at Duffy but rare at Sevens.

Prewitt (1977) found white sucker and their hybrids (white x flannelmouth and white x bluehead) comprised a small proportion of suckers collected (1%) at Lily Park, but were 19% of the suckers at Maybell and 76% at Craig in samples taken in 1975 and 1976. Current white sucker composition at Sevens and Duffy appear to be similar to Prewitt (1977). In this study white sucker and white hybrids were 21% at Sevens and 87% at Duffy of the total sucker catch. Prewitt (1977) reported white hybrids were about 50% of the WSWX group at Maybell and 23% at Craig. In this study white hybrids were over 50% of the sucker catch in both areas.

Both early and recent surveys report white sucker were rare in the Lily Park area and an increasing trend for white sucker in the upstream reaches. Since there appears to be a consistent longitudinal trend for white sucker, it could be that elevation or temperature is a regulating factor in the increased abundance at upstream sections.

The highest native fish composition in the Yampa River is in the Lily Park area. This is due to white sucker being very rare and flannelmouth sucker abundant. The distance between Lily Park and the Sevens is less than ten river miles and Lily Park is only about 160 feet lower in elevation. A study site at Lily Park could add information about white sucker distribution in upstream reaches. An effort will be made to electrofish this area in September 1999 and to quantify habitat availability if time permits.

Several differences in density and biomass were noted between the representative reaches, but differences between the two surveyed sites were less dramatic. Both study sites had similar total fish density and biomass estimates, but there were differences between individual species. Flannelmouth sucker and catfish were more common at Sevens, while white sucker and white sucker hybrids were abundant at Duffy.

The surveyed site included a single riffle-run sequence in both Sevens and Duffy. It was determined that the riffle-run sequences selected for habitat analysis did not have a fish community representative of the longer reach. The Sevens representative reach had five riffle-run sequences of various lengths. At Duffy there were six riffle-run sequences. The 1998 fish sampling effort focused on sampling one riffle-run sequence. In the 1999 field season, fish in different riffle-run sequences will be uniquely marked. This will allow for a more detailed examination of the relationship between habitat and fish distribution and abundance

INVERTEBRATES

The intent of the invertebrate samples was to examine for a relationship between wetted riffle area and invertebrate abundance. One result was that shallow portions of the riffle sampled in September 3 dried for a period of about 10 days and then reinundated about 20 days prior to sampling on October 8. This indicates that recolonization of reinundated portions of these riffles would require more time than observed. However since mean density was similar at Duffy for September and October a reduction in flows during that period did not appear to impact total density.

River reaches with higher riffle/run ratios may have higher potential for invertebrate production and therefore may be associated with higher fish biomass. Total riffle habitat is to be determined at the two study sites based on surveys made in 1998. Results of these collections suggest a relationship between invertebrate community dynamics and depths and velocities in riffles. If so, invertebrate productivity may be a function of quantity and quality of available riffle habitat. The riffles at Sevens and Duffy are scheduled for sampling depending on budgeting in September 1999. These and the 1998 samples will be evaluated for assigning suitable indices for invertebrates based on water depth.

HABITAT COMPOSITION

The bulk of the hydraulic modeling and habitat quantification is still in process, therefore, no analysis could be completed for comparing habitat availability to fish population characteristics. The main deterrent to successful model runs is apparently related to the low energy grade line or slope of the water surface and the steep banks of the Yampa River. This meant that the elevation of the channel bed had to be very precise and a lot of mesh refinement was required. The model is expected to perform better in higher gradient rivers such as the Colorado River in the 15-mile reach.

SUMMARY AND CONCLUSIONS

- Large differences were found in species composition between the two surveyed sites (Sevens and Duffy).

- Non-significant differences in fish density and biomass were found for the two surveyed sites (Sevens and Duffy).

- Significant difference in density and biomass were found between the two representative reach areas.

- The surveyed sites were not representative of the longer river reaches at both sites. The riffle-run sequence selected for habitat analysis contained a larger and deeper run than was typical of the river reach.

- Traditional surveying equipment used in 1998, total station and prism, was time consumptive and not practical for long river reaches.

- Differences were identified between Seven and Duffy for gradient, substrate and percent wetted perimeter at flows of 200 and 600 cfs. Mean channel widths were similar for the two sites.

- The 1-D flow model (HEC RAS) identified differences between the Sevens and Duffy surveyed sites with higher depth diversity and a higher amount of deep areas in Duffy compared to Sevens.

- The 1-D flow model (HEC RAS) did not provide a velocity attribute needed to define habitat types for habitat mapping and diversity analysis.

- The Yampa River study areas were also very low gradient and precision in the channel profile is very important in order for the model to successfully run.

RECOMMENDATIONS AND ADJUSTMENTS TO STUDY DESIGN

1. An RTK GPS system was purchased with the intent of decreasing the time needed to survey portions of the river channel. The new system will use a GPS to give a position and an echo sounder to give a depth for that position. This system will be tested in the 1999 field season in the 15-mile reach of the Colorado River. If successful and efficient the study area of the Colorado River should be mapped in July 1999. This system will also be used to survey portions of the representative reaches of the Duffy and Sevens sites in July 1999.

2. I am considering adding a third study site to the Yampa River in the Lily Park area. This site has the highest proportion of native fish in the Yampa River. The addition of this site will depend on funding and time constraints and will be tentatively added to the 2000 field season.

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REFERENCES

Anderson, R. M. 1998. Riverine fish-flow investigations. Colorado Division of Wildlife. Federal Aid Project F-288. Job Progress Report. Fort Collins, Colorado. 44pp.

Bovee, K. 1996. 'Perspectives on two-dimensional river habitat models: the PHABSIM experience'. *Proceedings - 2nd International Symposium on Habitat Hydraulics*. B150-B152.

Bovee, K. D. 1982. A guide to stream habitat analysis using the instream flow incremental methodology. Instream flow information paper 12. FWS/OBS-82/86. United States Department of the Interior, Cooperative Instream Flow Service Group, Fort Collins, Colorado.

Brunner, G. W. 1998. HEC-RAS River analysis system, user manual version 2.2. U.S. Army corps of engineers, Hydrologic Engineering Center. Davis California. pp 230.

Carlson, C.A., C.G. Prewitt, D. E. Snyder, E. J. Wick, E. L. Ames, and W.D. Fronk. 1979. Fishes and macroinvertebrates of the White and Yampa Rivers, Colorado. Colorado Bureau of Land Management Biological Series 1.

Everhart, W. H. and W. D. Youngs. 1981. Principles of fishery science. Cornell University press.

Holden, P. B. and C. B. Stalnaker. 1975. Distribution of fishes in the Dolores and Yampa River systems of the upper Colorado basin. Southwest. Natur. 19(4): 403-412.

King, I. 1997. The users guide to RMA2 WES Version 4.3. The U.S. Army Corps of Engineers – Waterways experiment laboratory. pp 240.

Leclerc, M., A. Boudreault, J.A. Bechara, and G. Corfa. 1995. Two-dimensional hydrodynamic modeling: a neglected tool in the instream flow incremental methodology, *Trans. Am. Fisheries Soc.*, 124 (5), 645-662.

Miller, W.H., D.L. Archer, H.M. Tyus and R.M. McNatt. 1982. Yampa River fishes study. Final Report for Memorandum of Understanding 14-16-0006-81-931(IA), U.S. National Park Service. U.S. Fish and Wildlife Service, Salt Lake City, Utah.

Modde, T., W. J. Miller, R.M. Anderson, and D. Irving. 1999. Determination of habitat availability and habitat use, and flow needs of endangered fishes in the Yampa River between August and September. Colorado River Recovery Program Report for Project #CAP-9. Denver, Colorado. 128 pp.

Modde, T. and G. Smith. Flow recommendations for endangered fishes in the Yampa River. Final Report submitted to the Recovery Implementation Program for the Recovery of Endangered Fishes in the Upper Colorado River Basin. U.S. Fish and Wildlife Service, Denver, Colorado. 44 pp.

Nehring, R. B. 1979. Evaluation of instream flow methods and determination of water quantity needs for stream in the state of Colorado. Colo. Div. Wild. Job Compl. Report. U. S. Fish and Wildl. Service Contract No. 14-16-0006-78-909. 144pp.

Nesler, T. 1995. Interaction between endangered fishes and introduced gamefishes in the Yampa River, Colorado 1987 - 1991. Colo. River Rec. Imp. Program Project No 91-29. Fed. Aid Proj. SE-3. Colo. Div. of Wildlife, Fort Collins, Colorado. 184pp.

Osmundson, D.B., P. Nelson, K. Fenton, and D.W. Ryden. 1995. Relationships between flow and rare fish habitat in the '15-mile reach' of the upper Colorado River. U. S. Fish and Wildlife Service Final Report. Grand Junction, Colorado.

Prewitt, C. G. 1977. Catostomid fishes of the White and Yampa Rivers Colorado. M. S. Thesis, Colorado State Univ., Fort Collins, Colorado. 122 pp.

Rose, K. L., and D. R. Hahn. 1989. A summary of historic habitat modeling on the Yampa River using the physical habitat simulation system. U.S. Fish and Wildlife Service, Grand Junction, Colorado. 18 pp.

Wick, E. J., T.A. Lytle, and C.M. Haynes. 1981. Colorado squawfish and humpback chub population and habitat monitoring, 1979-1980. Progress Report SE-3-3. Endangered Wildlife Investigations. Colorado Division of Wildlife, Denver, Colorado.

Wick, E.J., J.A. Hawkins and C.A. Carlson. 1986. Colorado squawfish population and habitat monitoring. 1985. Final Report, SE 3-8. Endangered Wildlife Investigations, Colorado Division of Wildlife, Denver, Colorado.

Williams, J.E., J.E. Johnson, D.A. Hendrickson, S. Contreras-Balderas, J.D. Williams, M. Navarro-Mendoz, D.E. McAllister, and J.E. Deacon. 1989. Fishes of North America endangered, threatened, or of special concern: 1989, Fisheries (Bethesda) 14(6): 2-20.

APPENDIX 1.

Fish Data

Table A1.1. Lengths (cm) of fish measured (n) during electrofishing at Sevens representative reach (RR) station, September, 1998. Only fish over 15 cm were used *in population estimation*, total fish includes counts of stunned but not measured fish (all less than 12 cm).

Species	BH	FM	WS	WF	WB	CS	RTC	CP	CC	SMB	NP	CRPY	MS	SD	SS	RDS	FH
Total*	549	1183	352	142	11	3	199	78	153	37	33	17	51	337	161	8	4
No. > 15 cm	547	1169	293	142	11	3	156	77	153	24	33	7	0	0	0	0	0
Sample (n)	549	1179	315	142	11	3	178	78	153	31	33	17	11	79	22	4	3
Length (CM)																	
4		1											2	19	3	1	
5		3					5						5	32	1		3
6		1	4				13			1			1	6	13		
7		2	5							1			0	6	5		
8		2	6							2		1	1	3		2	
9			1				1						1	11		1	
10							2			1		1	1	1			
11			1				1					2		1			
12	1		2					1				2					
13			2									4					
14	1	1	1							2							
15		1	5														
16			5							1							
17			2				1					2					
18	1		3				1					2					
19			2									2					
20	2		2		1												
21		2	6		1					1		1					
22	1	4	7														
23	2	2	8		1					1							
24	3	1	6		1					3							
25	3	2	10							3	1						
26	6	1	8							2							
27	8	1	3	1				1									
28	22		2	1													
29	18	1	1	4			2										
30	31	3	1		1		5		1	2	1						
31	26	1	3	1			3		3		4						
32	39	6	2				2		4	3							
33	33	1	4	1			6		2	2	4						
34	51	2	6				9		2		3						
35	66	3	4				7		1		2						
36	60	5	5		1		12		2		5						
37	68	9	9				16		1	4	3						
38	39	8	15	2			11	1	2	1	4						
39	32	9	24	5			12	2	3								
40	23	19	37	4	1		21	1	5	1							
41	9	18	28	6	1		18		4								
42	2	41	31	5	2		11	1	6								
43		54	24	3			9	1	5								
44		107	12	10			6	1	3		1						
45	1	147	9	9	1		3		3								
46	1	145	5	9				1	8		1						
47		155		10					5								
48		160	3	21			1	1	7								
49		89	1	13					7								
50		73		11				2	6								
51		37		10					8								
52		23		6					6								
53		10						1	6								
54		10		3		1		2	3								
55		9		5				3	6								
56		5		1				5	6		1						

Species	BH	FM	WS	WF	WB	CS	RTC	CP	CC	SMB	NP	CRPY	MS	SD	SS	RDS	FH
57		5		1				6	7								
58								2	3								
59								10	2								
60								8	5								
61								10	2		2						
62						1		6	2								
63								3	8								
64								2	1								
65								1	2								
66									1								
67								3									
68								3	3								
69									1								
70									1								
71																	
72																	
73						1					1						

Table A1.2. Lengths (cm) of fish measured (n) during electrofishing at the Duffy Tunnel representative reach (RR) station, September 1998. Only fish over 15 cm were used in population estimation, total fish includes counts of stunned fish (all less than 12 cm).

Species	BH	FM	WS	WF	WB	RTC	CS	CP	CC	SMB	NP	MS	SD	SS	RARE*
TOTAL	63	93	700	438	95	54	24	44	49	859	49	309	221	593	7
No.>15	63	93	552	438	95	54	24	44	49	135	49	0	0	0	0
Sample (n)	63	94	686	438	95	55	24	50	49	504	49	82	96	117	7
Length (cm)															
4			6									1	1		
5			23							10		27	30	6	1BSB
6			44					1		75		17	29	62	1RDS,2FH
7			29			1		3		148		2	5	48	
8		1	13					2		82		10	18	1	
9			2							36		16	11		1GS
10			1							11		6	2		
11			3							2		2			1MW
12			1									1			
13			5							1					
14			7							4					
15			3							2					
16			9							2					
17			3							2					
18			3							2					1BCY
19			1							1					
20			3							3					
21		1	10							10					
22	1		8		1					13					
23	2		6		2					11					
24			3							3					
25	2		4							5					
26	1		3							7					
27	2		6							8	1				
28			2							3	1				
29	3		2							4	2				
30	1		0		2					7	3				
31	4		1							4	3				
32			2							10	2				
33	1		1							6	5				
34	3		2	1						7	3				
35	2		6	1						2	2				
36	3		5		1				1	3	1				
37	2		1		2				1	5	1				
38	4	1	6		2	1			2	1					
39	13		8	1	3				1	2					
40	6		41	3	7	1			1	4	1				
41	2		41	5	16	1				1					
42	4		56	7	12	8				0					
43	7	2	52	21	17	5		1	2	3					
44		3	61	13	15	8			1	2					
45		1	55	33	7	10			3	2					
46		6	55	49	1	11	1		1						
47		9	34	70	3	3									
48		14	27	45		4			2		2				

Species	BH	FM	WS	WF	WB	RTC	CS	CP	CC	SMB	NP	MS	SD	SS	RARE*
49		12	10	50	3	2					3				
50		10	6	52	1		1		1						
51		15	4	26					3						
52		4	6	30			2		2		3				
53		3	1	13					5		1				
54		2	4	8					1		2				
55		4		8			1		1		1				
56		3	1	1			1	1			2				
57		2							1		1				
58		1					2	1	3		2				
59							1	1	4		2				
60				1			2	2	1						
61							1	1	2		3				
62							4	1	3						
63							2	4	2						
64							1	2			1				
65							1	1							
66								1	3						
67							1	6							
68									2		1				
69								5							
70								3							
71								1							
72								3							
73															
74							1	1							
75								5							
76								4							
77							1								
82							1								

*Rare: Brook stickleback, redside shiner, green sunfish, fathead minnow, mountain whitefish, black crappie.

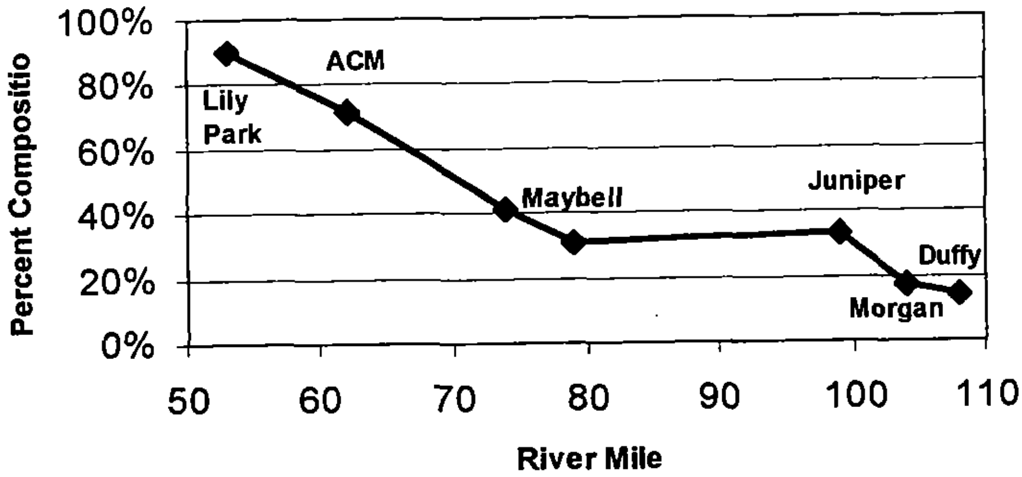

Figure A1.1. Percent composition of native fish at seven sampling sites on the Yampa river. Sevens and Duffy are from this study and the other sites are from unpublished ISMP data.

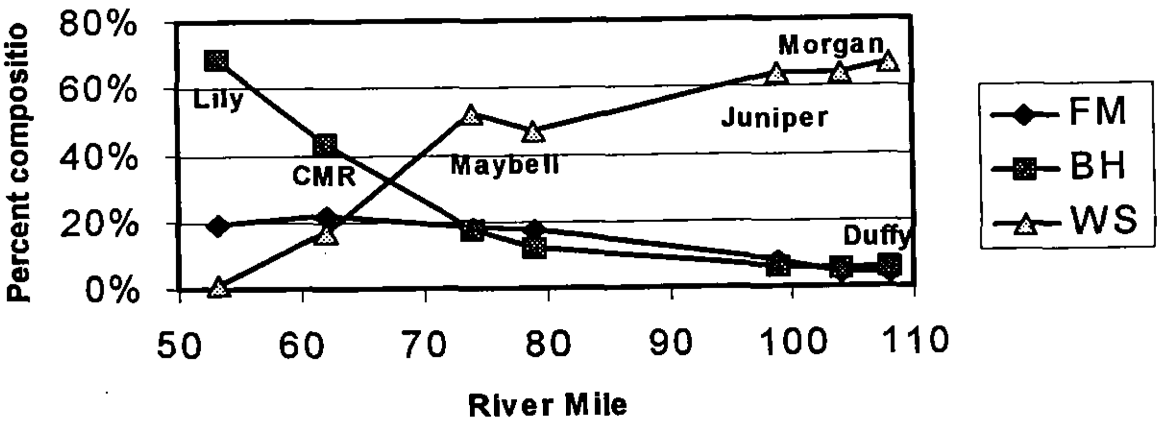

Figure A1.2. Percent composition of flannelmouth, bluehead and WSWX (white sucker and crosses) at seven sites on the Yampa River. Sevens and Duffy are from this study and the other sites from unpublished ISMP data.

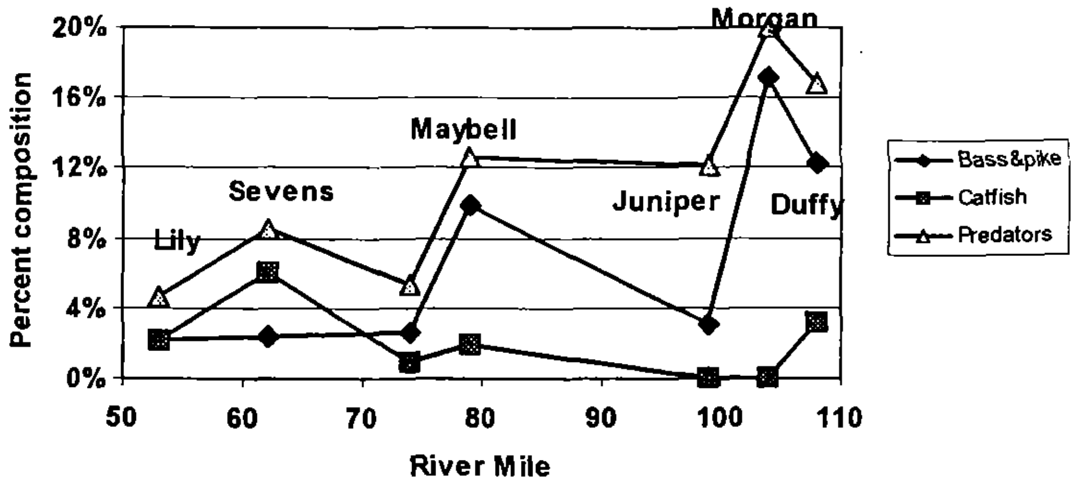

Figure A1.3 Percent composition of predator species (CC, CPM, NP & SMB) at seven sites on the Yampa River. Sevens and Duffy are from this study and the other sites from unpublished ISMP data.

APPENDIX 2.

Invertebrate Data

Table A2.1. Date, position, depth and velocity of surber samples collected on the Yampa River, 1998.

	DUFFY TUNNEL STATION				SEVENS STATION			
	23-Jul	20-Aug	3-Sep	8-Oct	31-Jul	20-Aug	3-Sep	8-Oct
Station	Distance from reference pin in feet							
1	17	30.7	40	30.7*	13.7	53.1	81	72.2*
2	20.5	31.9	45	31.3*	18.3	54.1	82.8	72.9*
3	32	43.3	53.6	42.8	30.4	55.4	87.8	76.9*
4	36.1	50.2	59.2	52.7	39.9	56.9	92.6	80.5*
5	44	55.4	73	56.3	43.5	57.4	96.5	87.1
6	47.2	67.4	77.9	66.1	45.7	59.3	100	88.6
	Depth of sampler in feet							
1	0.1	0.1	0.1	0.1*	0.1	0.1	0.1	0.1*
2	0.2	0.2	0.2	0.2*	0.2	0.2	0.2	0.2*
3	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4*
4	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6*
5	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
6	0.9	1	1	1	1	1	1	1
	Velocity at mouth of sampler net in feet/second							
1	0.5	nr	0.1	0.4	0.8	nr	0.3	0.7
2	1.1	nr	0.9	0.6	1.2	nr	0.5	0.9
3	2.7	nr	1.4	2.4	1.5	nr	1.4	1.6
4	2.8	nr	3.1	2.5	1.7	nr	1.9	2.2
5	3.0	nr	3.1	3.0	2.1	nr	1.8	2.4
6	3.4	nr	2.8	2.6	2.8	nr	2.1	2.6

*Indicated that this section of the riffle was dewatered since prior collection.

Table A2.2. **Mean number of invertebrates collected from six surber samples at the Sevens Ranch in July, August, September and October 1998.**

SEVENS RANCH	30 Jul. 1998	20 Aug. 1998	3 Sept. 1998	8 Oct. 1998
Species	Mean	Mean	Mean	Mean
Acentrella insignificans	0.3		3.0	1.0
Camelobaetidius warreni	12.0	0.3	6.7	
Centroptilum bifurcatum	0.5		0.2	
Baetis sp.	2.7	0.8	7.3	0.5
Ephemera simulans		0.2		
Ephoron album	1.5	2.0	3.2	
Ephemerella sp.			1.2	1.2
Heptagenia sp.	1.7	1.3	4.0	0.8
Rhithrogena sp.	0.3	0.2	11.3	7.3
Choroterpes albiannulata	4.0	13.5	0.5	0.2
Paraleptophlebia sp.				0.2
Traverella albertana	0.5	0.3	2.2	
Ameletus sp.		0.3	3.2	5.0
Tricorythodes corpulentus	2.7	5.0	3.0	
Tricorythodes minutus	7.2	6.8	3.5	1.7
Brachycercus sp.	0.3			
Isogenoides sp.	0.2		2.0	0.2
Brachycentrus occidentalis		0.2	1.2	0.3
Culoptila cantha			3.2	0.5
Protoptila erotica		0.2	39.7	5.0
Helicopsyche borealis		0.3	1.0	
Cheumatopsyche sp.	0.8	1.7	42.7	9.2
Hydropsyche cockerelli	0.3	0.2	2.8	0.2
Hydropsyche occidentalis	0.2		1.5	2.0
Hydropsyche oslari	0.3	0.2	43.0	8.3
Mayatrichia sp.	0.3			
Oecetis sp.			2.8	
Nectopsyche stigmatica			0.2	
Petrophila sp.			0.3	
Orthocladiinae	0.2	0.8	0.8	0.7
Tanypodinae		0.7	0.5	
Tanytarsini		3.8	2.2	
Chironomini		2.0	1.2	0.7
Simulium sp.		0.3	0.2	
Hemerodromia sp.				0.2
Hexatoma sp.			0.2	0.2
Rhabdomastix sp.				0.2
Atherix pachypus			0.2	
Psychodidae sp.	0.5			
Helichus striatus		0.2		
Zaitzevia parvula	0.2		0.2	
Dubiraphia sp.	0.2	0.2	0.2	

	30 Jul. 1998	20 Aug. 1998	3 Sept. 1998	8 Oct. 1998
Microcylloepus sp.			1.3	0.8
Dytiscidae		0.2		0.3
Ochthebius lineatus				1.0
Ophiogomphus severus	0.3	1.7	0.3	
Corixidae	1.2	0.3	0.2	
Ambrysus mormon	0.2			
Rhagovelia sp.	0.8			
Ancylidae				0.7
Physa sp.			0.2	
Pisidium sp.		0.2		
Oligochaeta				0.5
Totals	78.7	87.7	394.0	97.3

Table A2.3. Mean number of invertebrates collected from six surber samples at Duffy surveyed site in July, August, September and October 1998.

Duffy Tunnel	23 Jul. 1998	20 Aug. 1998	3 Sept. 1998	8 Oct. 1998
	Mean	Mean	Mean	Mean
Acentrella insignificans	1.5		0.7	0.3
Plauditus virilis			0.3	
Camelobaetidius warreni	0.3	4.0	2.5	
Acerpenna pygmaea		0.3	0.2	
Baetis sp.	13.5	13.2	22.0	15.5
Ephemerella sp.			5.7	55.8
Serratella sp.	8.3	0.2		
Heptagenia sp.	0.7	0.2	2.7	3.0
Rhithrogena sp.	0.5	3.0	26.8	59.0
Choroterpes albiannulata	0.8	5.8	1.7	
Paraleptophlebia sp.				9.5
Traverella albertana		0.2		
Ameletus sp.			0.2	0.3
Tricorythodes corpulentus	1.7	10.8	2.3	
Tricorythodes minutus	4.7	20.0	4.2	4.0
Capnia sp.				0.5
Claassenia sabulosa	0.2	1.0	1.3	0.7
Isogenoides sp.	0.3	1.7	3.2	0.8
Isoperla sp.				1.8
Brachycentrus occidentalis			0.2	0.2
Culoptila cantha	1.2	11.3	8.0	0.5
Protoptila erotica		8.8	29.2	47.0
Helicopsyche borealis				0.3
Cheumatopsyche sp.	0.5	57.5	68.2	46.5
Hydropsyche cockerelli	5.2	3.5	8.5	1.7
Hydropsyche occidentalis	1.0	3.0	0.7	2.8
Hydropsyche oslari	2.2	63.2	70.0	36.8

	23 Jul. 1998	20 Aug. 1998	3 Sept. 1998	8 Oct. 1998
Hydroptila sp.			0.8	0.2
Agraylea multipunctata	6.2	40.8		
Mayatrichia sp.	4.2	0.7		
Neotrichia sp.	0.5	0.3		
Lepidostoma sp.	0.5			
Oecetis sp.			0.5	0.3
Psychomyia flavida	0.2			
Petrophila sp.		0.2	0.7	
Orthocladiinae	11.2	1.5	5.3	12.0
Tanypodinae	0.2	3.8	4.0	0.5
Tanytarsini	0.3	0.7	0.5	0.7
Chironomini	3.2	34.7	3.0	0.8
Simulium sp.	10.7	15.0	27.0	10.2
Hemerodromia sp.	0.3	1.0	0.8	0.2
Hexatoma sp.	0.5	0.7	0.3	0.2
Rhabdomastix sp.		0.3	0.2	
Ephydridae			0.3	
Atherix pachypus		0.2		
Optioservus sp.	0.2	0.2	1.8	
Heterlimnius corpulentus			0.2	
Zaitzevia parvula		0.3	0.2	1.2
Microcylloepus sp.	0.7	3.2	3.8	0.8
Paracymus sp.		0.2		
Ochthebius lineatus		0.3		0.8
Corixidae	0.2			
Rhagovelia sp.	0.3			
Decapoda		0.2	0.3	
Ancylidae		3.0	3.5	7.7
Physa sp.			0.2	1.2
Oligochaeta	0.5	1.3	2.2	22.0
Totals	164.3	632.3	628.0	691.7

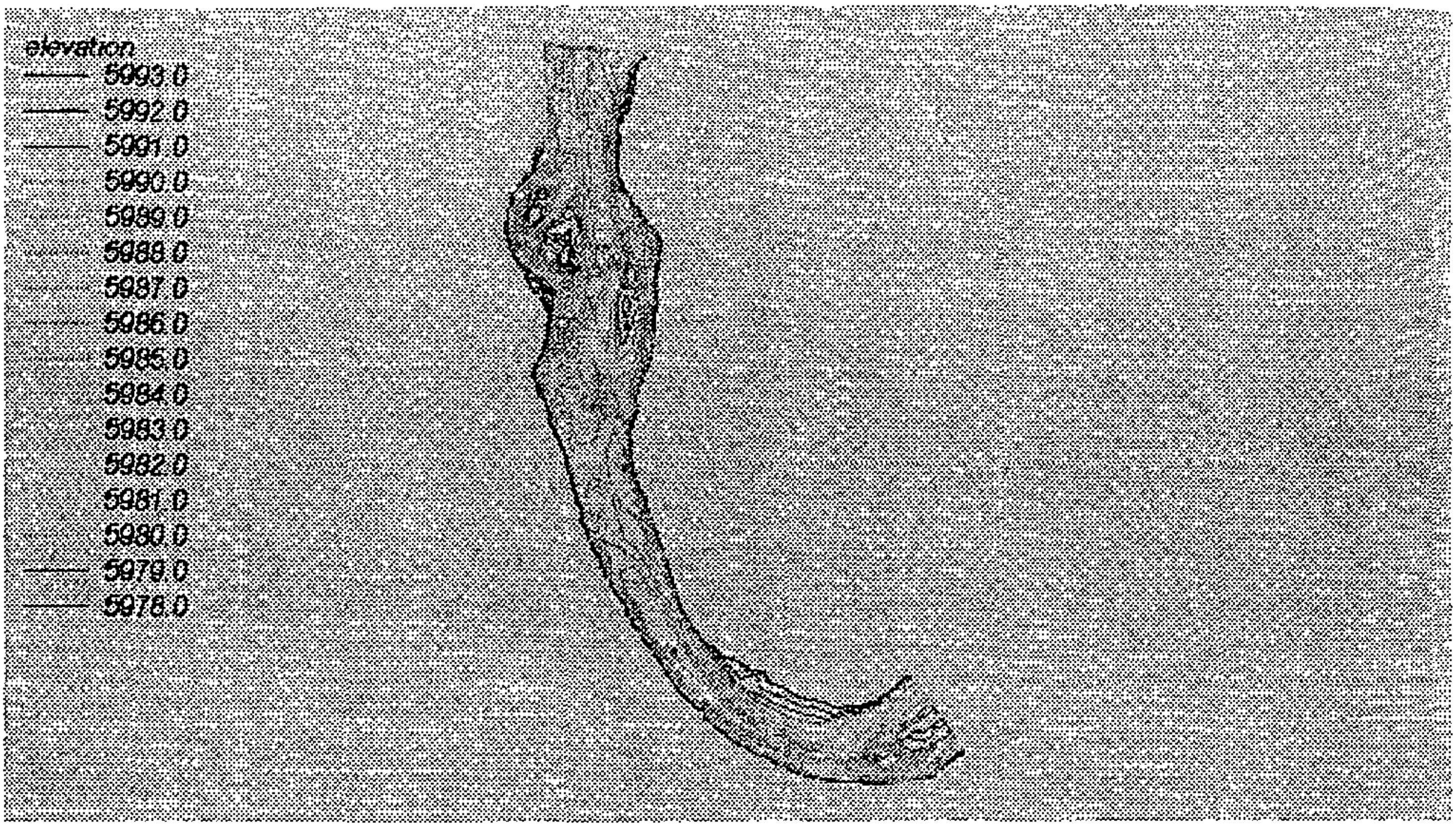

Figure A3.1 Elevations at the Duffy surveyed sites.

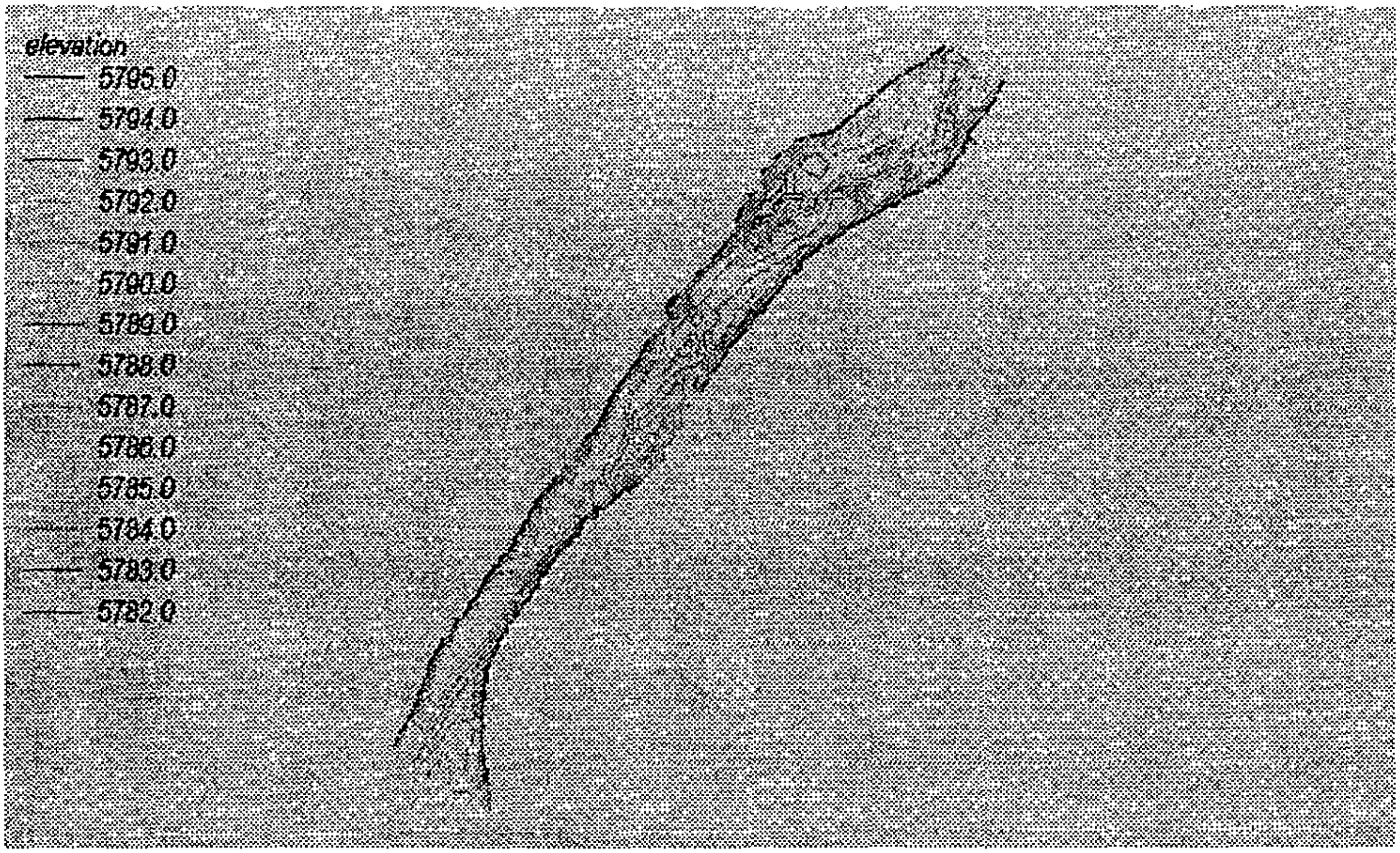

Figure A3.2. Elevations at the Sevens surveyed site.

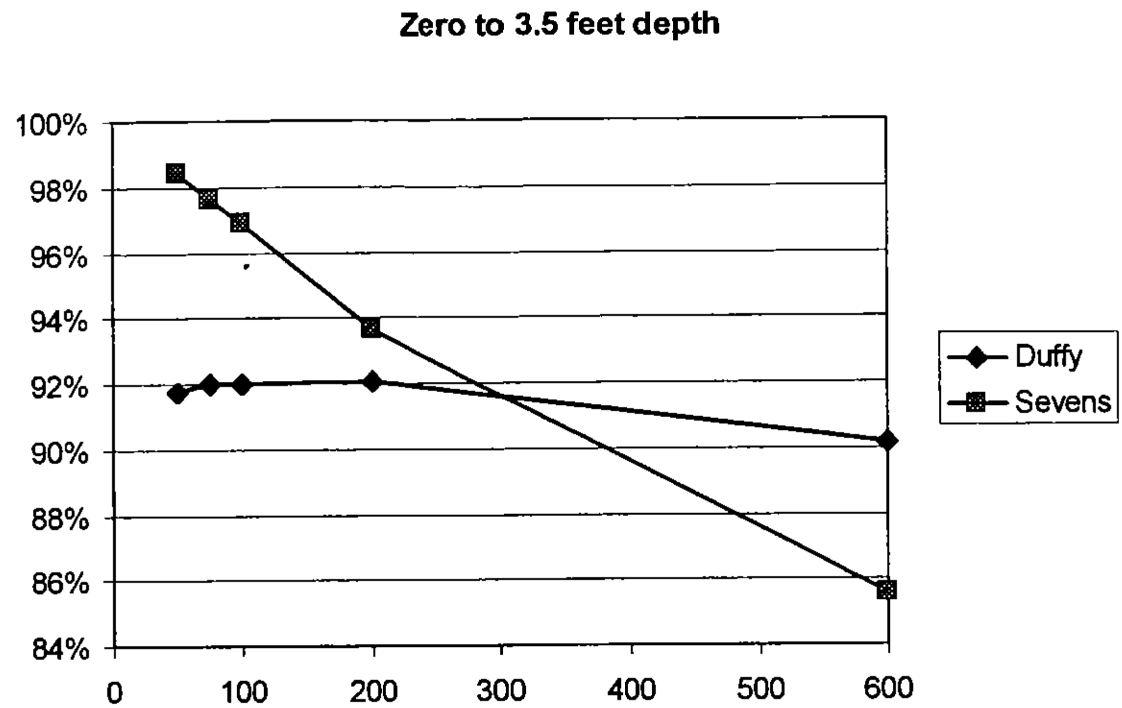

Figure A3.3. Percent surface area with depths less than 3.5 feet at the Duffy and Sevens study sites at flows of 50, 100, 150, 200 and 600 cfs.

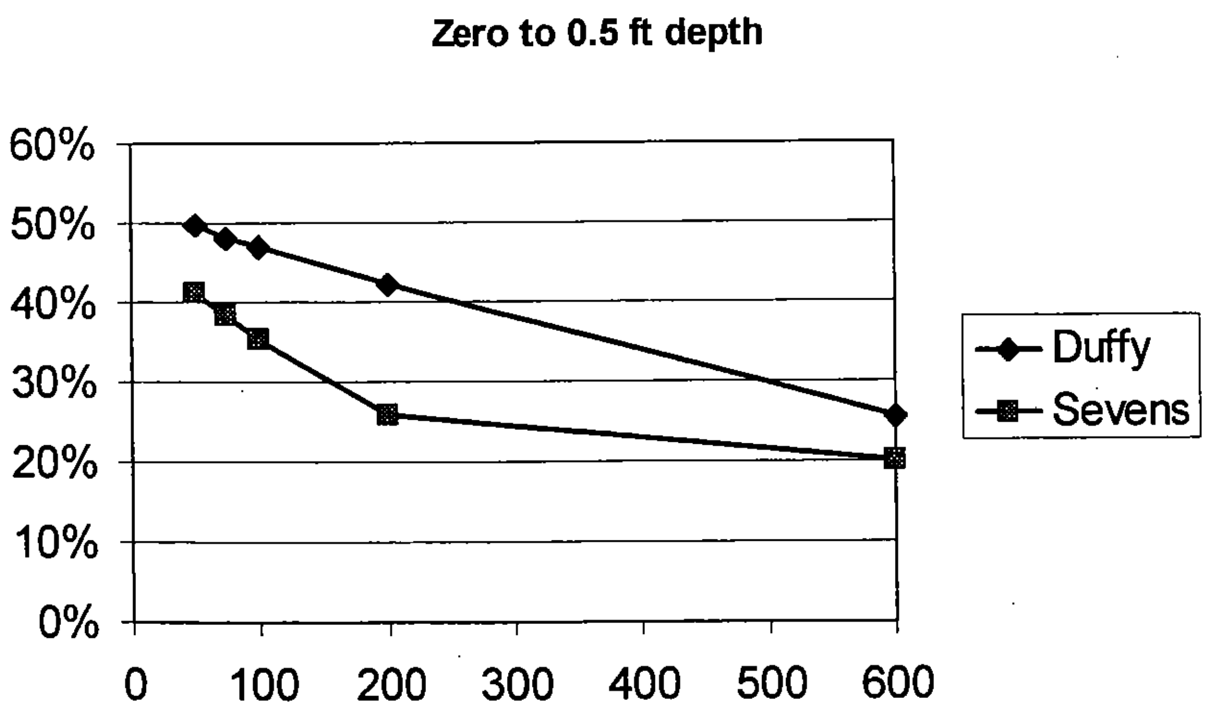

Figure A3.4. Percent of surface area with depths less than 0.5 feet at Duffy and Sevens study sites at flows of 50, 100, 150, 200 and 600 cfs.

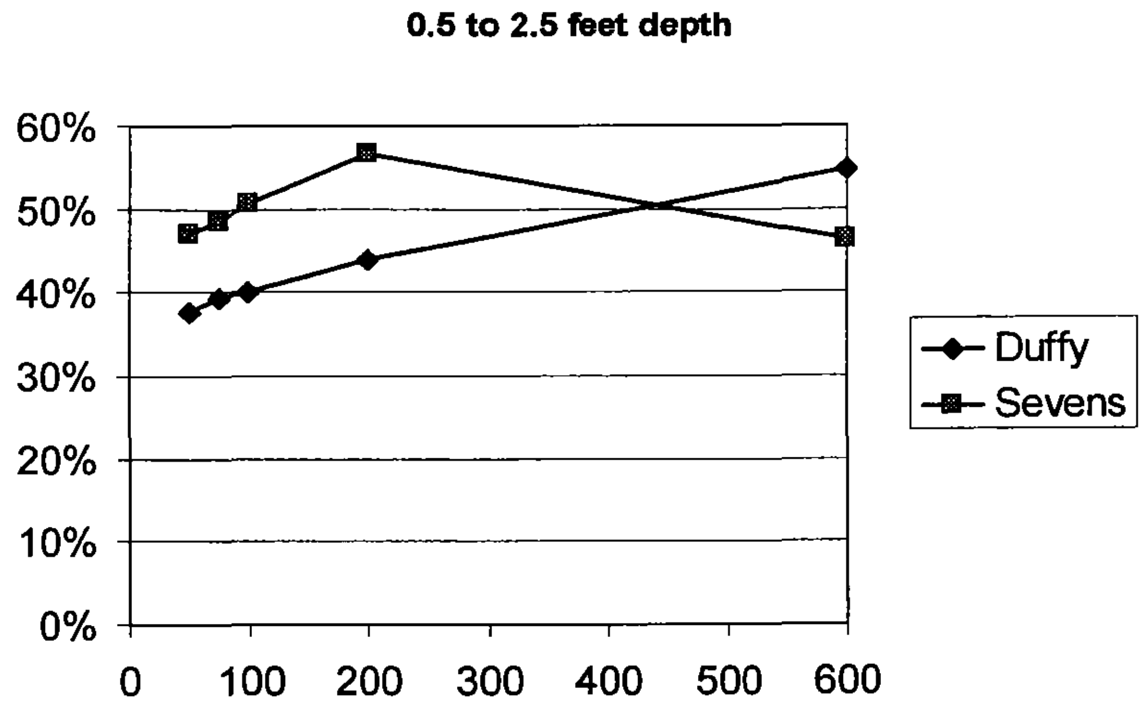

Figure A3.5. Percent of surface area at depths between 0.5 and 2.5 feet at Duffy and Sevens study sites at flows of 50, 100, 150, 200 and 600 cfs.

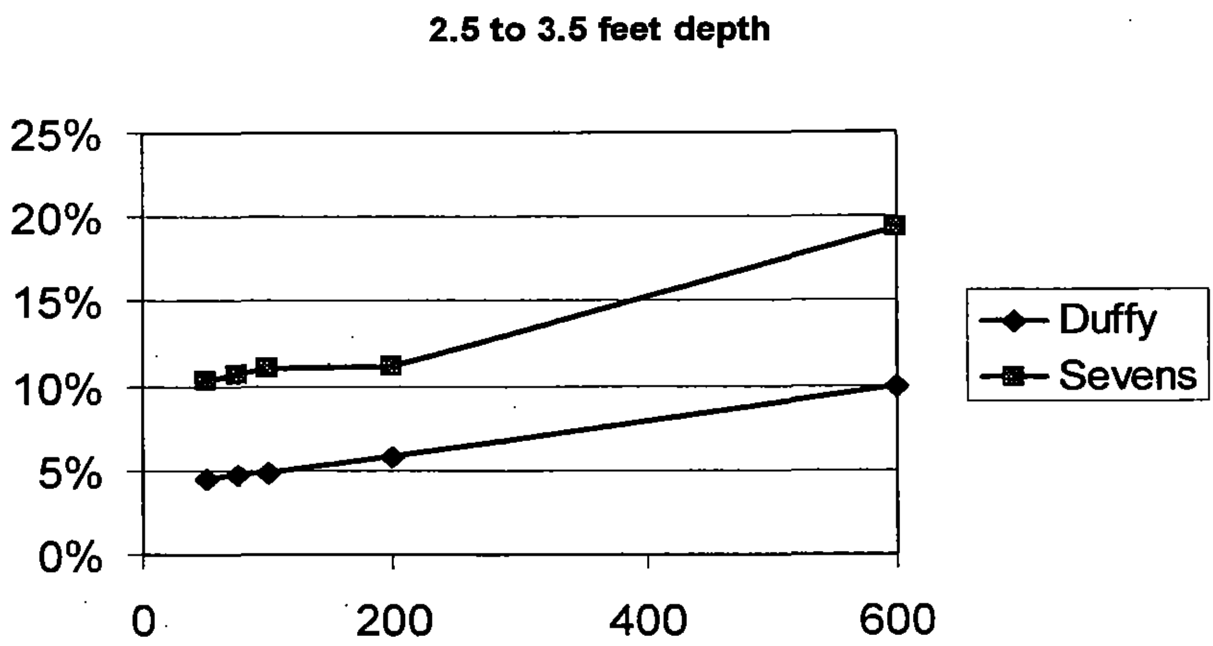

Figure A3.6. Percent of surface area at depths between 2.5 and 3.5 feet at Duffy and Sevens study sites at flows of 50, 100, 150, 200 and 600 cfs.

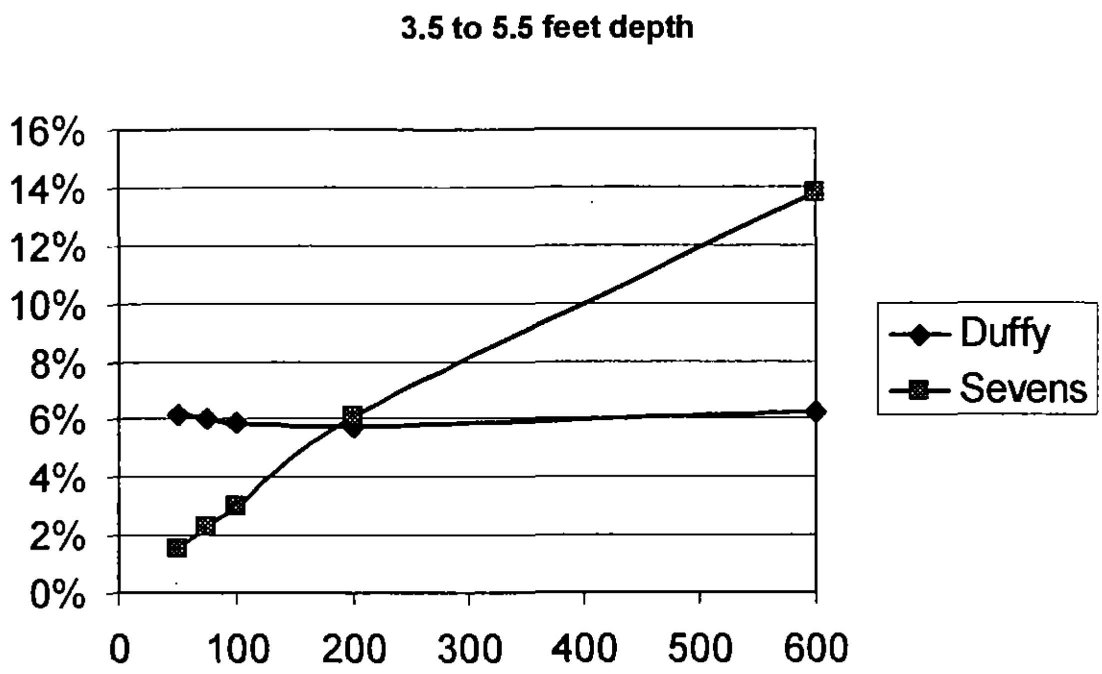

Figure A3.7. **Percent of surface area at depths between 3.5 and 5.5 feet at Duffy and Sevens study sites at flows of 50, 100, 150, 200 and 600 cfs.**

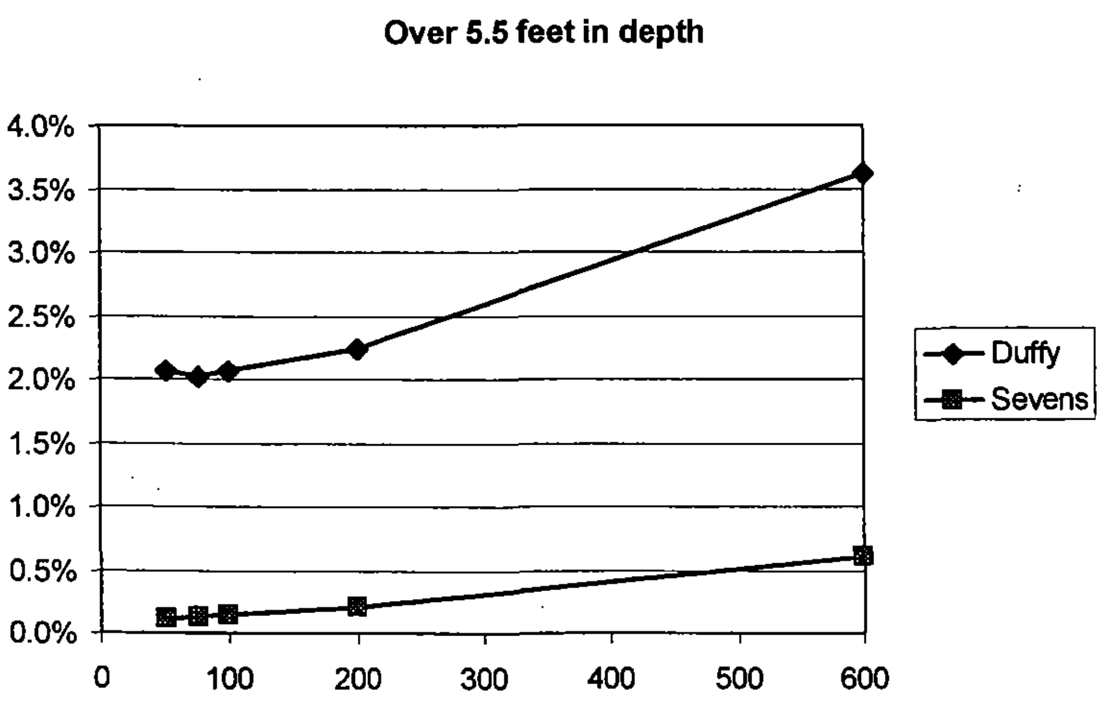

Figure A3.8. **Percent of surface area at depths over 5.5 feet at Duffy and Sevens study sites at flows of 50, 100, 150, 200 and 600 cfs.**