Flathead River Instream Flow Investigation Project

Final Report
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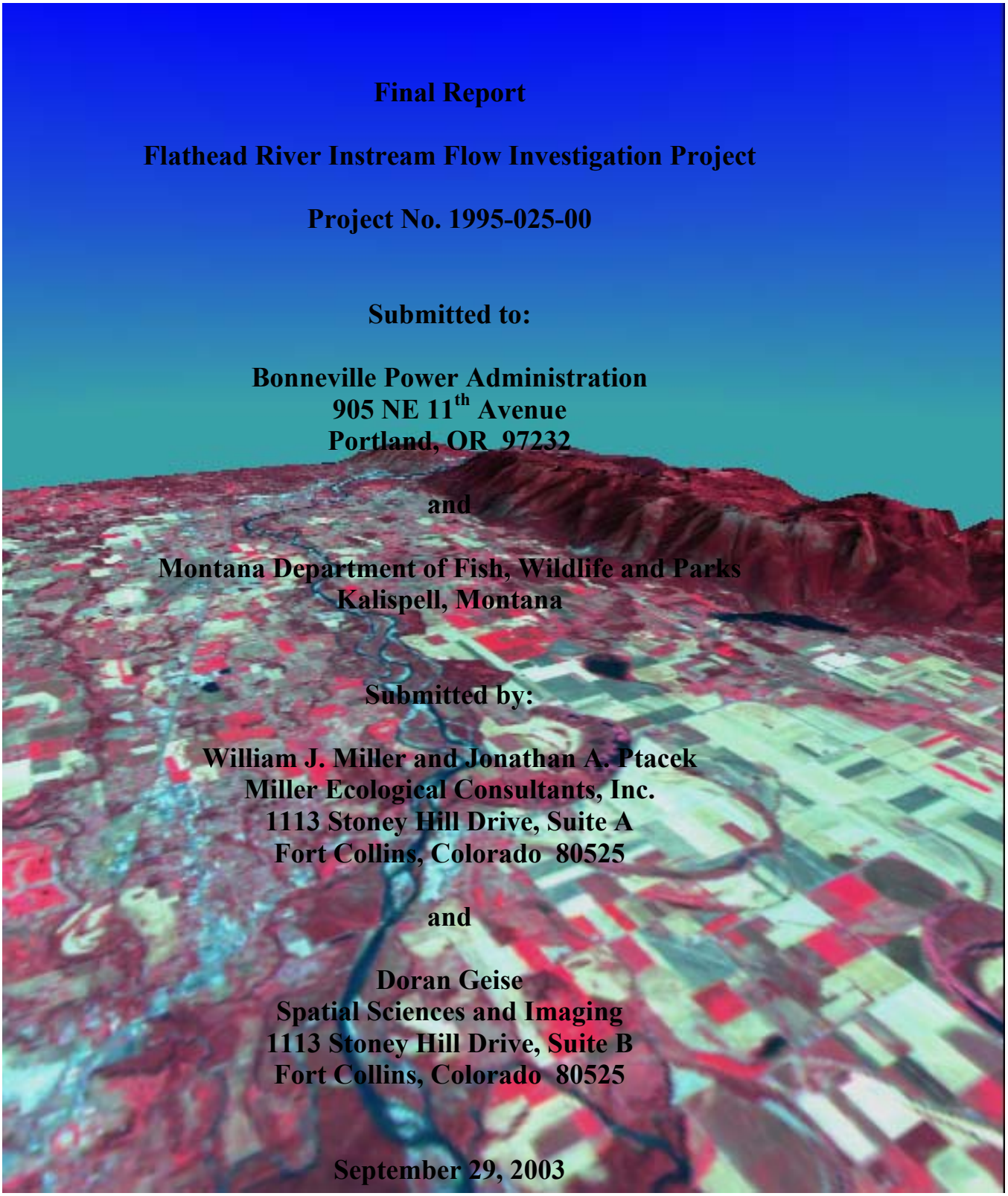

Final Report

Flathead River Instream Flow Investigation Project

Project No. 1995-025-00

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EXECUTIVE SUMMARY

A modified Instream Flow Incremental Methodology (IFIM) approach was used on the mainstem Flathead River from the South Fork Flathead River downstream to Flathead Lake. The objective of this study was to quantify changes in habitat for the target fish species, bull trout (*Salvelinus confluentus*) and west slope cutthroat trout (*Oncorhynchus clarki lewisi*), as a function of discharge in the river.

This approach used a combination of georeferenced field data for each study site combined with a two-dimensional hydraulic simulation of river hydraulic characteristics. The hydraulic simulations were combined with habitat suitability criteria in a GIS analysis format to determine habitat area as a function of discharge.

Results of the analysis showed that habitat area is more available at lower discharges than higher discharges and that in comparison of the pre-dam hydrology with post-dam hydrology, the stable pre-dam baseflows provided more stable habitat than the highly variable flow regime during both summer and winter baseflow post-dam periods.

The variability week to week and day to day under post-dam conditions waters and dewaters stream margins. This forces sub-adult fish, in particular bull trout, to use less productive habitat during the night. There is a distinct difference between daytime and nighttime habitat use for bull trout sub-adults. The marginal areas that are constantly wet and then dried provide little in productivity for lower trophic levels and consequently become unproductive for higher trophic levels, especially bull trout sub-adults that use those areas as flows increase.

A stable flow regime would be more productive than flow regimes with high variability week to week. The highly variable flows likely put stress on a bull trout subadult and west slope cutthroat trout, due to the additional movement required to find suitable habitat.

The GIS approach presented here provides both a visual characterization of habitat as well as Arcview project data in the distribution cassette disk that can be used for additional analysis of flow regimes and spatial variability of habitat within the three reaches of the river. The habitat time series can be used to compare habitat changes over time.

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INTRODUCTION

Bonneville Power Administration (BPA) requested studies on the Flathead River from the South Fork Flathead River downstream to Flathead Lake to determine changes in habitat availability for fish in the Flathead River as a function of changes in river flow. The goal of this study was to provide the physical framework for assessing changes in physical habitat in the river as a function of flow for the species of interest and provide the tool for decision makers to assess tradeoffs in river management scenarios.

The basis for this GIS approach comes from the Instream Flow Incremental Methodology and is patterned after Bovee (1982), Bovee et al. (1998). We used the components of physical hydraulic simulations, habitat suitability data, and the GIS analysis tool to develop habitat versus discharge functions for the Flathead River. Components needed for this methodology include habitat use information for the species of interest, physical geometry and hydraulics information of geo-referenced physical data collected at each study site. Data included bed topography, bathymetry, depth, velocity, substrate cover, and water surface elevations. These data provide the physical framework for habitat analysis.

These physical data are then placed into a two-dimensional hydraulic simulation where the field data is used to construct the model data sets. Models are calibrated for measured flows and hydraulics simulated for the flows of interest. All output is geo-referenced for each study site and the hydraulic simulations for each study site are passed to the habitat component.

Study Area

The study area includes the Flathead River from the South Fork confluence downstream to the river mouth on Flathead Lake, Montana. The river was divided into three reaches. The first reach begins at the South Fork confluence and extends downstream 17.6 km in mostly homogeneous habitat with some island complexes. The second reach was the braided reach and depositional area from the end of Segment 1 downstream to the end of the braided section. The third reach extends from the lower end of the braided section to the mouth of Flathead Lake and is characterized by low gradient and seasonal backwater effects from the lake impounded by Kerr Dam (Figure 1). A study site was selected in each reach to represent the physical characteristics of the reach. Each study site was more than 3 km in length (Table 1).

Table 1. Flathead River IFIM study Reach lengths and site lengths.

Reach	Total Length (km)	Site Length (km)
1	17.6	3.4
2	19.2	3.9
3	31.6	3.7

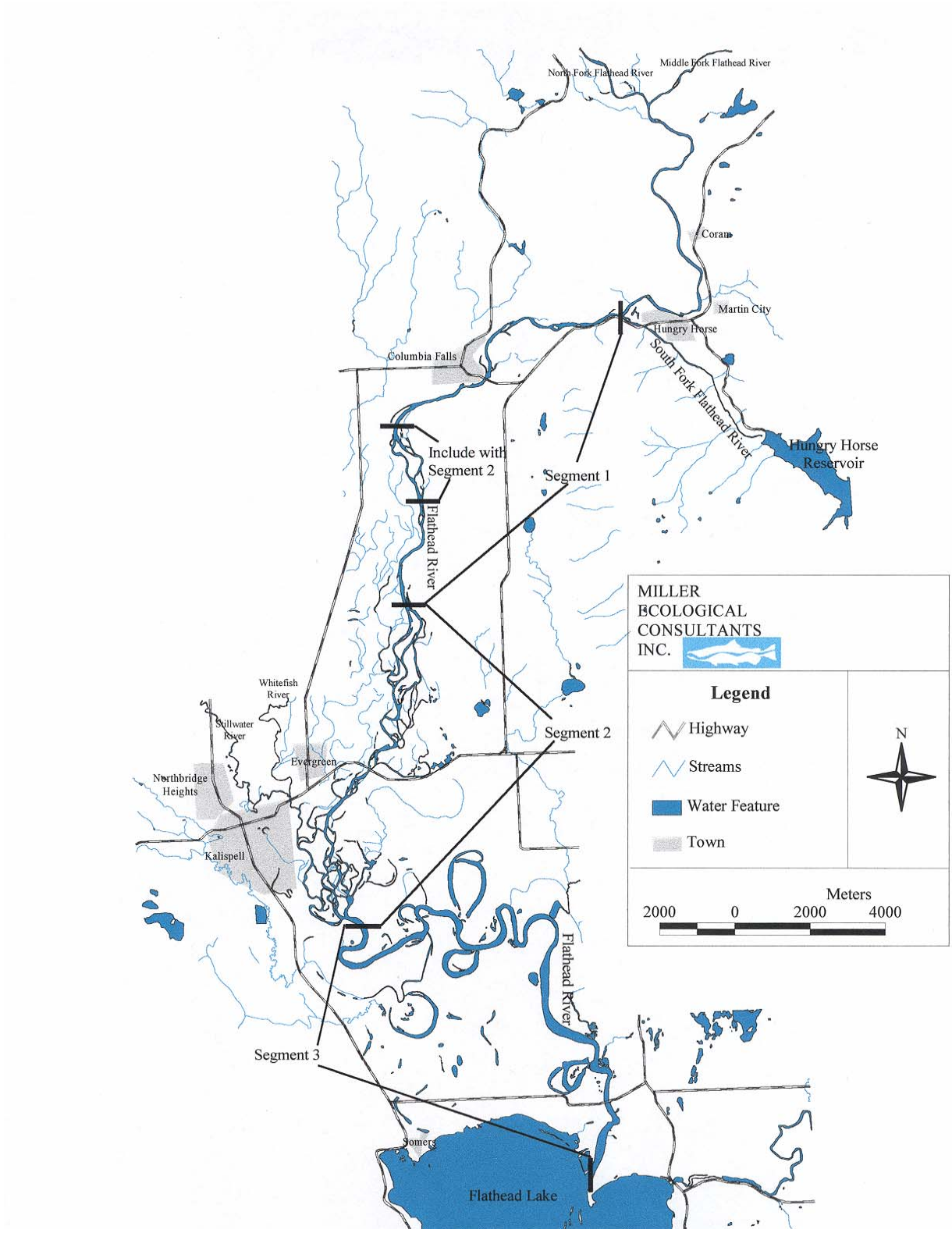

Figure 1. Study Area for Flathead River Instream Flow Study.

Objectives

There are three objectives for this study:

1. Develop comprehensive, spatial and tabular attribute database (IFIM models) to characterize physical processes in the Flathead River affected by flow from Hungry Horse Dam.

2. Use IFIM models to compare the results of alternative dam operation strategies on aquatic resources. Within each of three reaches, calibrate IFIM submodels to describe hydraulic conditions under various flow volumes. Simulate changes in physical habitat conditions at flows of interest.

3. Document results in reports, maps, and calibrated models in user manuals.

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METHODS

This project used a modified application of IFIM in three reaches of the Flathead River. The entire river segment downstream of Hungry Horse Dam was mapped using GIS technology and onstream ground truthing. Microhabitat use by fish life stages was provided by another BPA project (9401000) and overlaid on the framework provided by this project. Target species include bull trout (*Salvelinus confluentus*)and west slope cutthroat trout (*Oncorhynchus clarki lewisi*). To accomplish these goals, MEC used a combination of hydraulic simulation and GIS mapping on the Flathead River from the South Fork confluence to the mouth of Flathead Lake as the base map for the overall analysis. The technical approach is presented in the following sections.

General Approach

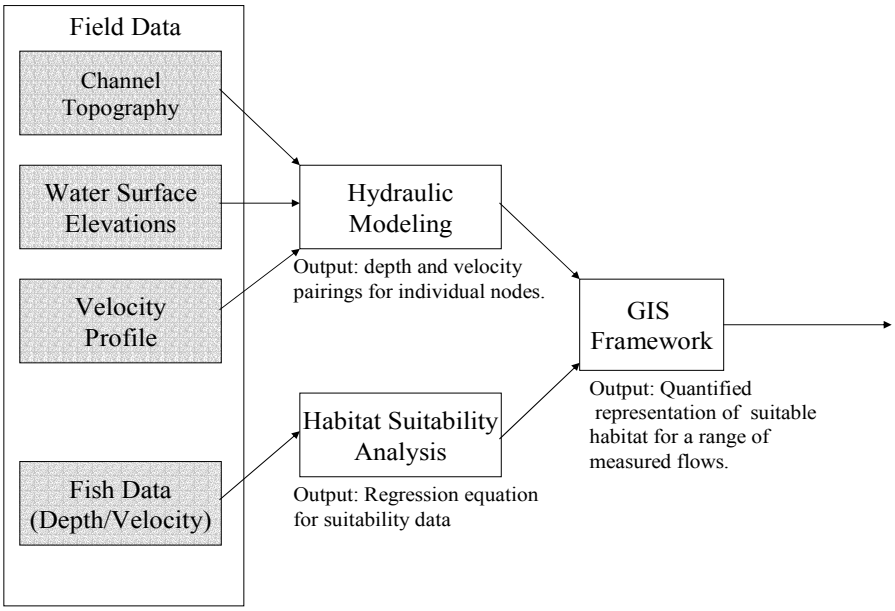
The approach for assessing instream flow needs for fish utilized hydraulic analysis and habitat modeling in a modified incremental method to evaluate changes in quantity, quality, and distribution of habitat with changes in flow (Figure 2). By collecting the hydraulic data in a manner suitable to two-dimensional modeling of habitat, spatial distribution of habitat was displayed with a Geographic Information System (GIS), and tabulations of habitat quantity and quality were related to flow levels in the river.

Hydraulic modeling begins with construction of a digital terrain map for the study area. A survey-grade Global Positioning System (GPS) was used to field map each study site, and data points were used to construct a detailed topography map (or grid) of the channel. Multiple data sets of water-surface elevations and point velocity measurements were used to calibrate a two-dimensional hydraulic model to simulate depth and direction of flow through each site (Table 2). The grid of resulting flow depths and velocities is then compared to habitat preference criteria for species of interest to determine location and quality of resulting habitat.

Table 2. Hydraulic measurements recorded on the Flathead River above Flathead Lake, Montana.

Date	Discharge (m^3/s)		Measurement
	Reaches 1-2	Reach 3	
2-9 August 1999	246.56	257.10	Bed topography, water surface elevations, velocity profiles, substrate mapping
20 June 2000	594.65	624.88	Water surface elevations
3-7 January 2001	105.17	108.15	Water surface elevations

Note: Reported discharge for Reaches 1 and 2 are from USGS gaging station 12363000 (Flathead River at Columbia Falls, MT). Discharge for Reach 3 is the combined flow reported from USGS gaging stations 12363000, 12366000 (Whitefish River near Kalispell, MT), and 12365000 (Stillwater River near Whitefish, MT).



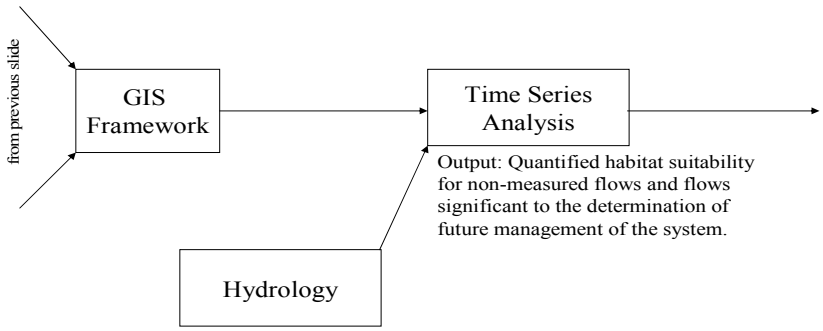


Figure 2. Flow chart of data analysis for Flathead River hydraulics and aquatic habitat.

Habitat modeling thus requires information on fish utilization of certain depths and velocities of flow, in addition to utilization of certain substrate, cover, and other channel conditions. The habitat suitability functions are then used as a filter against the grid of depth and velocity values predicted by the hydraulic model to estimate suitability of habitat in each grid cell at the site. The area of grid cells with suitable habitat are then summed to obtain total usable area for a given streamflow level. BPA requested that a geographic information system (GIS) be developed to provide these functions for the project.

Hydraulic data was measured in a manner compatible with both standard and modified IFIM techniques. River gradient and flow was measured using standard surveying techniques. Channel morphology was measured using a boat mounted GPS hydroacoustic system to develop detailed river topography maps and digital terrain maps that could be incorporated in GIS. These maps were developed for two mile subreaches of each of the three main reaches. A total of six miles of digital terrain mapping was conducted on the river. The digital terrain maps were linked to above water surveys to the high water mark at each of the two mile reaches to establish ground topography for higher flow regimes for the modeling effort. Substrate and cover data was collected using visual or tactile methods to determine sediment at cross-sections established for the IFIM modeling. Habitat suitability was developed concurrently in BPA Project 9401000. The data from that project (Muhlfeld 2002) was used as input to the habitat model for the IFIM analysis.

River hydrology for determining flow scenarios and flow operations was calculated using existing hydrology from USGS records for the Flathead River and Hungry Horse Dam. A flow time series was constructed using approximately ten years of daily flow data and incorporating that into a spreadsheet for flow comparison alternatives. Flow comparisons were made for both flow scenarios. The specific methods for the project are listed below.

River Channel Change Analysis and Land Use/Land Cover Mapping

The main objectives of this portion of the project were: 1) Identify areas of the Flathead River channel that are dynamically changing and, 2) Map land use and land cover along the river. A detailed description of the land use/land cover mapping is provided in Appendix A.

This task involved processing the river channel and land use/land cover data to produce deliverable products. The old and new river channel GIS layers were overlain to produce a layer that identifies all of the areas where the river course has shifted between the two time periods. This simple change layer highlights the most dynamic reaches of the river. A second analysis utilized historical resource photography to determine what land use/land cover was present before changes occurred at a given site. This analysis produced a complex ("from and to") change map. From this information, BPA can determine which land uses are most likely to be affected by river dynamics.

Topographic Mapping

Each study site was surveyed with a survey-grade GPS for the purpose of constructing a digital terrain model for the site. The GPS provided latitude, longitude, and elevation of each point to an accuracy of about 0.1 foot for both horizontal and vertical resolution. Horizontal stations and elevations were georeferenced to known points of origin in the vicinity of each study site. A sufficient number of points were surveyed on the ground to enable construction of a digital terrain model for the study reach. In the vicinity of the channel, points were spaced to define channel geometry both in plan form and cross section. Channel geometry points were collected up to the typical high-water marks to establish ground topography for modeling high flow regimes. Substrate and cover were recorded for each site, along with field notes describing general stream and habitat conditions at the study site and reference photos for the area.

Hydraulic Data Collection

Two-dimensional hydraulic modeling requires channel geometry data, multiple water-surface elevation data sets, and multiple velocity data sets. Thus, the specific hydraulic data collected at each site includes stream bed elevations, mean column velocity at selected locations (multiple collections at each habitat type), visual estimates of dominant and subdominant substrate size and percent embeddedness, and percent cover. All hydraulic data were georeferenced for inclusion in the digital terrain model of the site and the associated GIS data base. The following procedures were used to obtain the necessary data.

Stream Bed Elevations The survey-grade GPS was used to collect stream bed elevations as described above. Above-water points also were surveyed using standard techniques and georeferenced for linkage to GIS.

Water Velocities At a selected number of locations within each study site, water velocity was measured for use in hydraulic model calibration. Multiple measurements were taken in each specific site for use in model calibration.

Substrate Composition Substrate composition was visually estimated at each site for all habitats. Substrate was denoted for the following categories:

- Aquatic vegetation
- Silt
- Sand
- Small gravel (0.25 - 1.0 inch)
- Large Gravel (>1.0 - 3.0 inch)
- Cobble (>3.0 - 10.0 inch)
- Boulder (>10.0 inch)
- Bedrock

The substrate was categorized by dominant and subdominant size class. The substrate classification system was modified to provide the information required for the habitat

suitability criteria. This method of substrate categorization can be adapted to most of the usual substrate codes in the existing habitat suitability criteria.

Cover was visually estimated by percentage. The following cover types were used:

Velocity Refuge: any instream object that provides a velocity refuge for the species of interest. This could include objects such as boulders, root wads, large woody debris or other such objects.

Visual Isolation: any object that provides visual isolation for the species of interest such as overhanging vegetation, undercut banks, or other such items.

Combination Cover: any cover that provides both velocity refuge and visual isolation. This could be any combination of the cover items listed above or a single cover object such as a downfall that provides both velocity refuge and visual isolation.

No Cover: absence of cover will also be noted.

The full set of data was recorded at one flow (Table 2). Repeat measurements of water-surface elevations were taken at low and high flows. During these measurements water-surface elevations were surveyed at each study site. These stage-discharge measurements provided the data necessary for model calibration and for extending the range of hydraulic simulations.

Two-Dimensional Hydraulic Modeling

Two-dimensional hydraulic modeling was accomplished in the Surface-water Modeling System (SMS) using the Corps of Engineers RMA2 model. This model was developed specifically to look at two-dimensional velocity vectors in river systems, and is capable of handling element (i.e., grid cell) wetting and drying as flows are increased or decreased. This model operates on a grid developed from the digital terrain model for each study site, and output can be linked to GIS models for analysis and display of habitat availability (Appendix B).

The 2-D model uses the georeferenced field data collected from each study site. Data inputs include maps of site topography, substrate, and flow impediments; a stage-discharge relationship at the downstream end of the site; and calibration and validation data throughout the reach. Model calibration and validation data consist of depth and velocity measurements taken at know flow rates and locations in the study site, usually at points upstream of impediments, along one or more cross sections, and scattered throughout the reach. The GPS survey data is used to develop a grid system to represent the stream geometry (Figure 3). This mesh is combined with the hydraulic data to simulate water depths and velocities for a range of flow conditions (Figures 4 and 5).

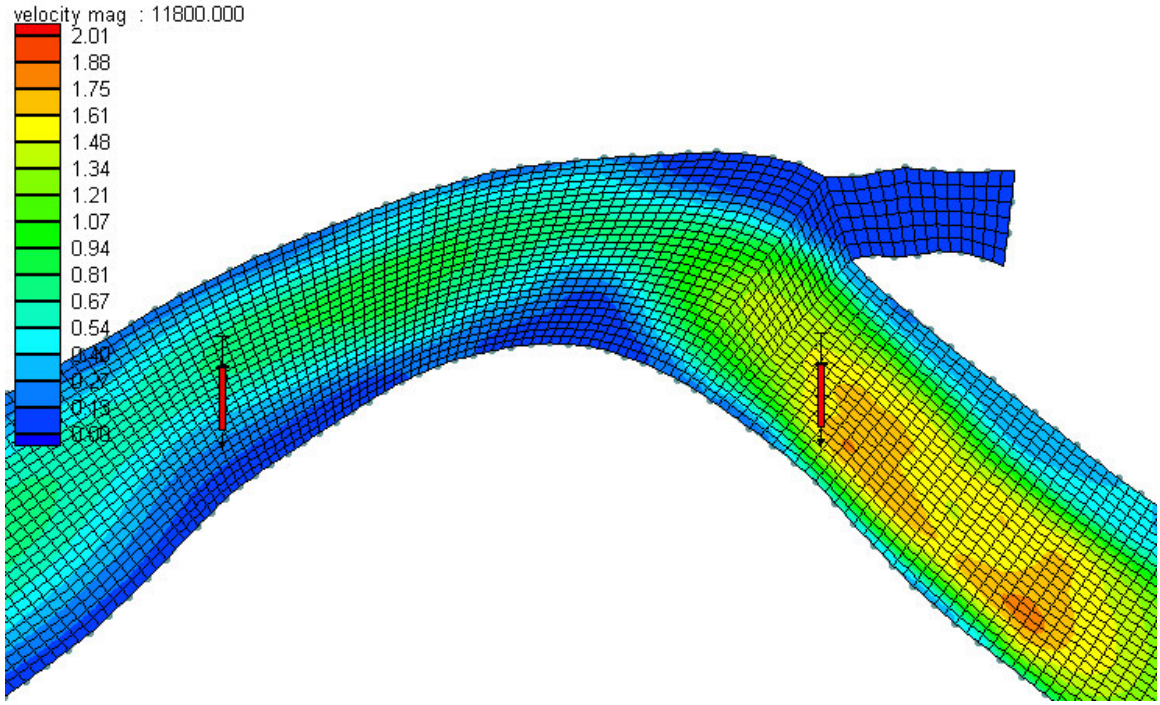


Figure 3. Example of grid network developed from topography data.

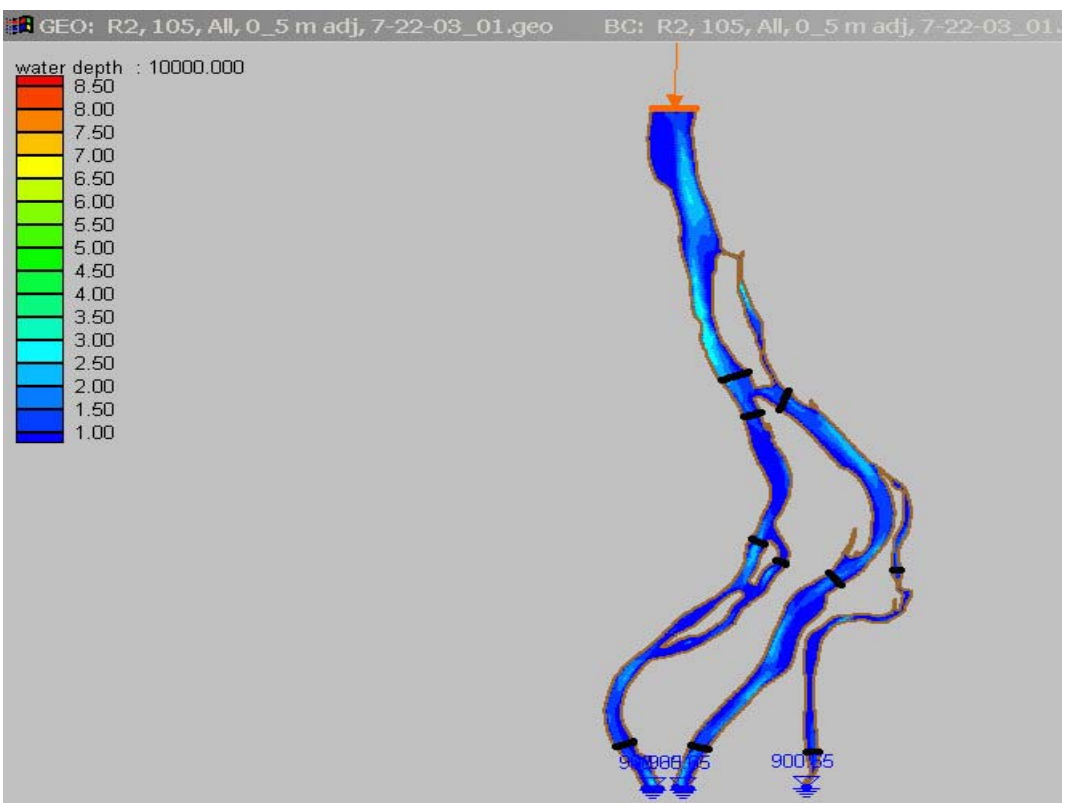


Figure 4. Example of depth contours for Flathead River, Site 2 105 cms.

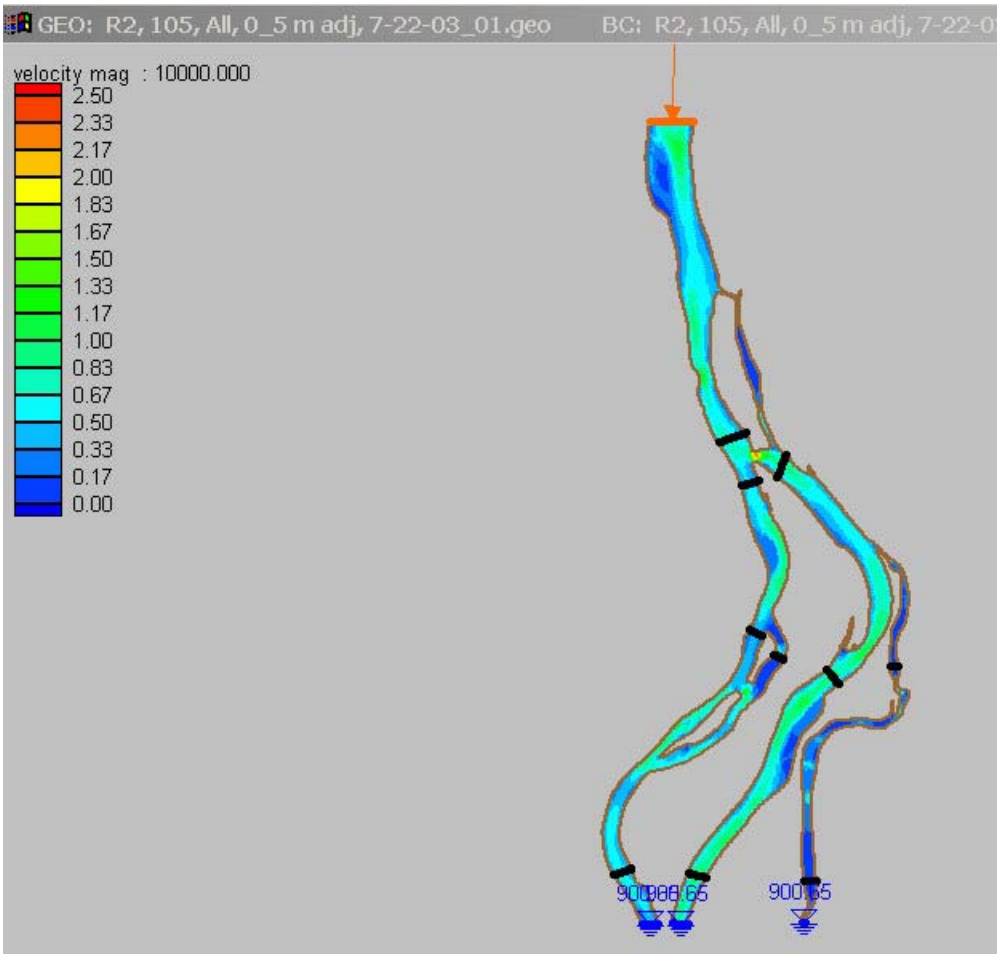


Figure 5. Example of velocity contours Flathead River Site 2, 105 cms.

Habitat Suitability Curves

Species habitat-suitability criteria are required for the habitat analysis. The recommended approach is to develop site-specific criteria for each species and life stage of interest. Habitat suitability criteria that accurately reflect the habitat requirements of the species of interest are essential to conducting meaningful and defensible instream flow analyses. The curves used in this study will fit that criterion. Site specific curves were developed for the study by Muhlfeld (2002).

Calculation of habitat suitability criteria for a two-dimensional hydraulic model requires use of a bivariate analysis of depth-velocity paired data to calculate fish preference for depth and velocity in the stream reach.

An analysis approach was developed by Miller Ecological (2001, Appendix C) for this suitability criteria. A bivariate statistical analysis was used to develop habitat suitability criteria for each species with sufficient data. This analysis first plotted bivariate histograms, then converted those

to a 3-dimensional surface and finally computed a polynomial expression to compute suitability values that replicate the 3-D surface.

GIS Model

The basis for this GIS approach comes from the Instream Flow Incremental Methodology and is patterned after Bovee (1982), Bovee et al. (1998). We used the components of physical hydraulic simulations, habitat suitability data, and the GIS analysis tool to develop habitat use information. The original concept for this approach was presented in Miller Ecological Consultants, Inc. and SAIC (2000). The current application of the GIS approach included a time series analysis of habitat based on flow scenarios in the Flathead.

Components needed for this methodology include habitat use information for the species of interest, physical geometry and hydraulics information of geo-referenced physical data collected at each study site. Data included bed topography, bathymetry, depth, velocity, substrate cover, and water surface elevations. These data provide the physical framework for habitat analysis.

These physical data are then placed into a two-dimensional hydraulic simulation where the field data is used to construct the model data sets. Models are calibrated for measured flows and hydraulics simulated for the flows of interest. All output is geo-referenced for each study site and the hydraulic simulations for each study site are passed to the habitat component.

GIS Based Weighted Usable Area Model

After pre processing data for habitat suitability and hydraulic simulations, these components are used for simulation of usable habitat. The geo-referenced hydraulic data sets are imported into Arcview and combined with habitat suitability data for the analysis. The habitat suitability equations are combined with the geo-referenced output from the hydraulic data sets and habitat suitabilities are calculated based on the depth and velocity at each point within the site. Habitat maps are created and tabular data sets produced that are used in the habitat time series. A detailed description of the analytical steps is provided in the software manual (Appendix B).

The combination of hydraulics and habitat are repeated at each study site for all flows of interest and for all species and life stages. The habitat areas for each flow for each species are extracted from the GIS output and either copied or typed into the time series spreadsheet to conduct the habitat time series.

Habitat versus Discharge Modeling

Habitat suitability modeling for each species of interest is accomplished in an Arcview GIS analysis (Appendix B). The Arcview instream habitat model relies on inputs from both the 2-D hydraulic modeling and the habitat suitability criteria described above. These inputs are

provided in the form of data layers within the GIS and parameters for spatial queries. Data layers corresponding to flow depths and velocities are provided by the 2-D hydraulic modeling. Specific habitat criteria developed from the suitability analyses described above are then used to conduct GIS queries. In this way, the amount of area within the study site that matches a particular species' habitat use can be determined for a specified flow rate. Multiple layers of usable habitat were generated, corresponding to each species, life stage, and flow of interest. The analysis can be output as a 2D map and linked to a GIS base map or plotted as hard copy for visual presentation of the results. Summation of total habitat for each species and simulated flow results in a habitat-flow relationship by species that becomes input for the habitat-time series analysis.

Habitat Time Series

The actual habitat experienced by the fish in any river depends on the flow regime of the river. The development of habitat conditions over a period of time is an integral part of the comparison of flow regimes. Habitat time series is the decision point in IFIM (Bovee 1982). Habitat time series analysis requires the following data: total usable habitat for each species and life stage at each flow of interest, preferably over a range from normal high to low flow; hydrology data for current conditions, usually weekly or daily flow for a range of water years; and hydrology for the proposed operation for the same dates as the current conditions.

MEC conducted time series evaluations on several different flow regimes. For each flow regime assessed, we conducted both hydrology and habitat time series analysis to calculate both flow- and habitat statistics. These values allowed a direct comparison of the changes that occur in both flow and habitat under a range of conditions. These tabular data can be displayed for each flow scenario to represent the spatial habitat distributions.

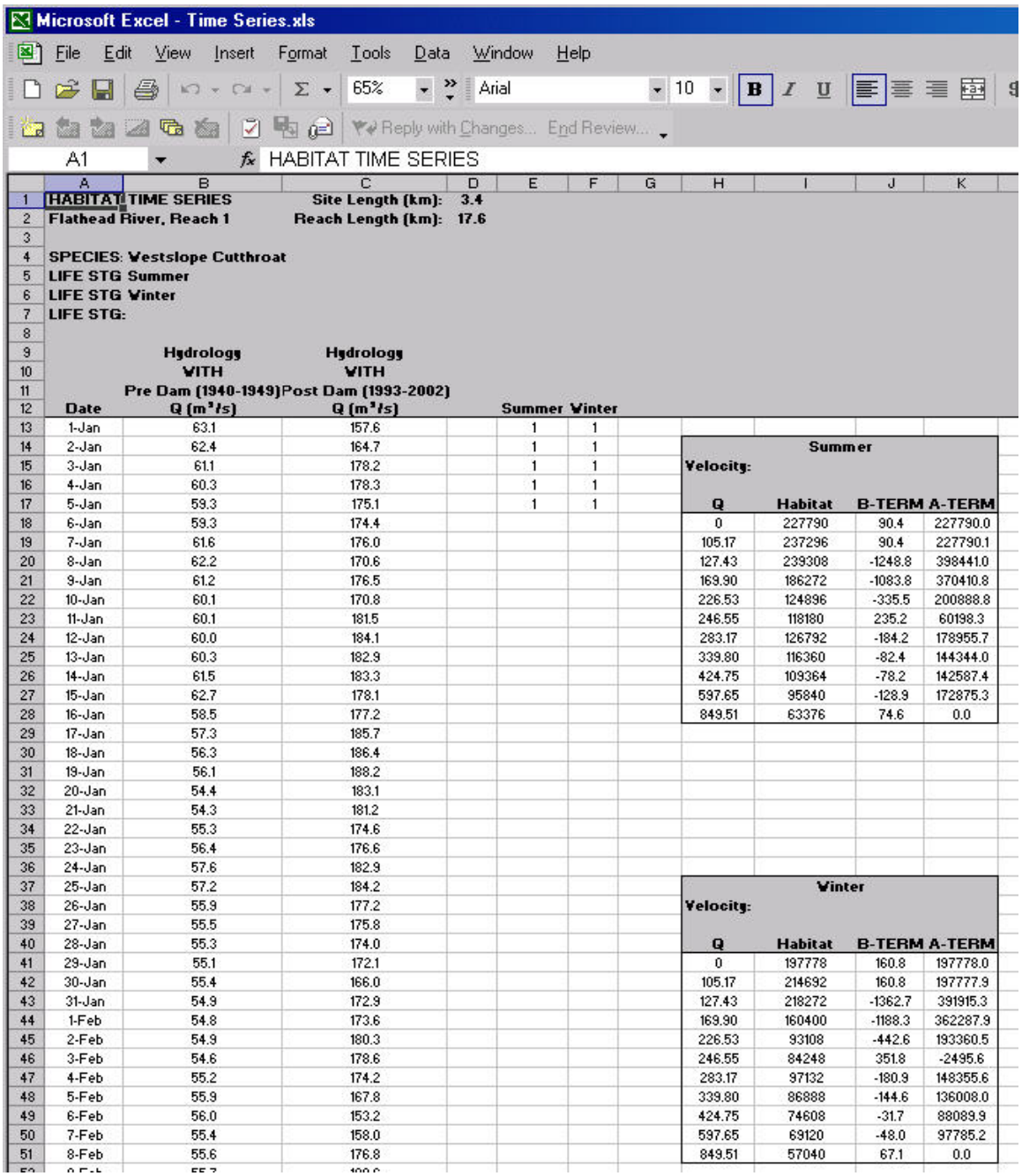
Habitat time series uses a spreadsheet format with data arranged in columns and rows that combines the hydrology over time with the habitat use as a function of discharge. These values are converted to area of habitat for the study site and then area of habitat for the reach. Comparisons of change in habitat over time for each flow of interest are possible with this spreadsheet setup. The steps to use the spreadsheet for analysis are as follows:

The habitat time series spreadsheet is arranged with data in column format. Cell A1 contains the title. Cell A2 contains the name of the river. Cells A4 through A6 are titles for species and life stage. The species names and life stages are typed into Cells B4, B5, and B6 (Figure 6).

The hydrology data is placed in columns A, B and C. Rows 10 through 12 of those columns contain header information. Column A contains the Date, and Columns B and C contain the hydrology data. Column B contains the baseline hydrology titled "Pre-dam". Column C contains the hydrology for the "Post-dam" alternative.

To the right of the hydrology columns are a look-up table with regression coefficients and functions for the weighted usable area for juvenile and adults of the species. The headers denote discharge (Q), habitat, and the A and B terms for the functions. The cells contain the formulas

that calculate the A and B terms. The discharge and habitat values are generated in the GIS Base habitat model and copied or typed into the cells. The data for the blocks should start in cells of the time series spreadsheet contained in the distribution CD. The habitat for the site for each flow is analyzed by date and flow regime. The rows must be identical for the correct analysis. The habitat calculations are based on a Vlookup formula contained in cells R12, S12 and higher (Figure 7).



Microsoft Excel - Time Series.xls

File Edit View Insert Format Tools Data Window Help

A1 HABITAT TIME SERIES

1	HABITAT TIME SERIES		Site Length (km):	3.4	
2	Flathead River, Reach 1		Reach Length (km):	17.6	
3					
4	SPECIES: Westslope Cutthroat				
5	LIFE STG Summer				
6	LIFE STG Winter				
7	LIFE STG:				
8					
9		Hydrology	Hydrology		
10		WITH	WITH		
11		Pre Dam (1940-1949)	Post Dam (1993-2002)		
12	Date	Q (m³/s)	Q (m³/s)	Summer	Winter
13	1-Jan	63.1	157.6	1	1
14	2-Jan	62.4	164.7	1	1
15	3-Jan	61.1	178.2	1	1
16	4-Jan	60.3	178.3	1	1
17	5-Jan	59.3	175.1	1	1
18	6-Jan	59.3	174.4		
19	7-Jan	61.6	176.0		
20	8-Jan	62.2	170.6		
21	9-Jan	61.2	176.5		
22	10-Jan	60.1	170.8		
23	11-Jan	60.1	181.5		
24	12-Jan	60.0	184.1		
25	13-Jan	60.3	182.9		
26	14-Jan	61.5	183.3		
27	15-Jan	62.7	178.1		
28	16-Jan	58.5	177.2		
29	17-Jan	57.3	185.7		
30	18-Jan	56.3	186.4		
31	19-Jan	56.1	188.2		
32	20-Jan	54.4	183.1		
33	21-Jan	54.3	181.2		
34	22-Jan	55.3	174.6		
35	23-Jan	56.4	176.6		
36	24-Jan	57.6	182.9		
37	25-Jan	57.2	184.2		
38	26-Jan	55.9	177.2		
39	27-Jan	55.5	175.8		
40	28-Jan	55.3	174.0		
41	29-Jan	55.1	172.1		
42	30-Jan	55.4	166.0		
43	31-Jan	54.9	172.9		
44	1-Feb	54.8	173.6		
45	2-Feb	54.9	180.3		
46	3-Feb	54.6	178.6		
47	4-Feb	55.2	174.2		
48	5-Feb	55.9	167.8		
49	6-Feb	56.0	153.2		
50	7-Feb	55.4	158.0		
51	8-Feb	55.6	176.8		

Summer			
Velocity:			
Q	Habitat	B-TERM	A-TERM
0	227790	90.4	227790.0
105.17	237296	90.4	227790.1
127.43	239308	-1248.8	398441.0
169.90	186272	-1083.8	370410.8
226.53	124896	-335.5	200888.8
246.55	118180	235.2	60198.3
283.17	126792	-184.2	178955.7
339.80	116360	-82.4	144344.0
424.75	109364	-78.2	142587.4
597.65	95840	-128.9	172875.3
849.51	63376	74.6	0.0

Winter			
Velocity:			
Q	Habitat	B-TERM	A-TERM
0	197778	160.8	197778.0
105.17	214692	160.8	197777.9
127.43	218272	-1362.7	391915.3
169.90	160400	-1188.3	362287.9
226.53	93108	-442.6	193360.5
246.55	84248	351.8	-2495.6
283.17	97132	-180.9	148355.6
339.80	86888	-144.6	136008.0
424.75	74608	-31.7	88089.9
597.65	69120	-48.0	97785.2
849.51	57040	67.1	0.0

Figure 6. Spreadsheet template for habitat time series.

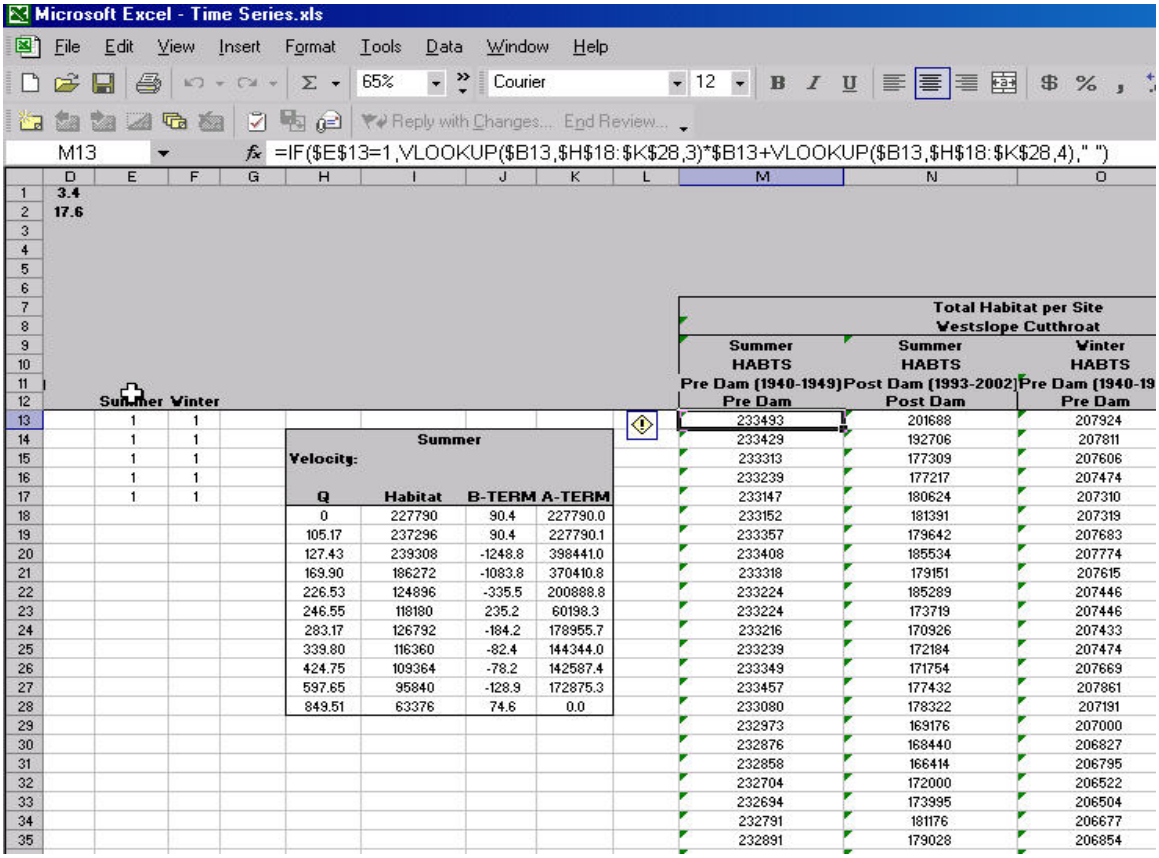


Figure 7. Example of Vlookup function for time series analysis.

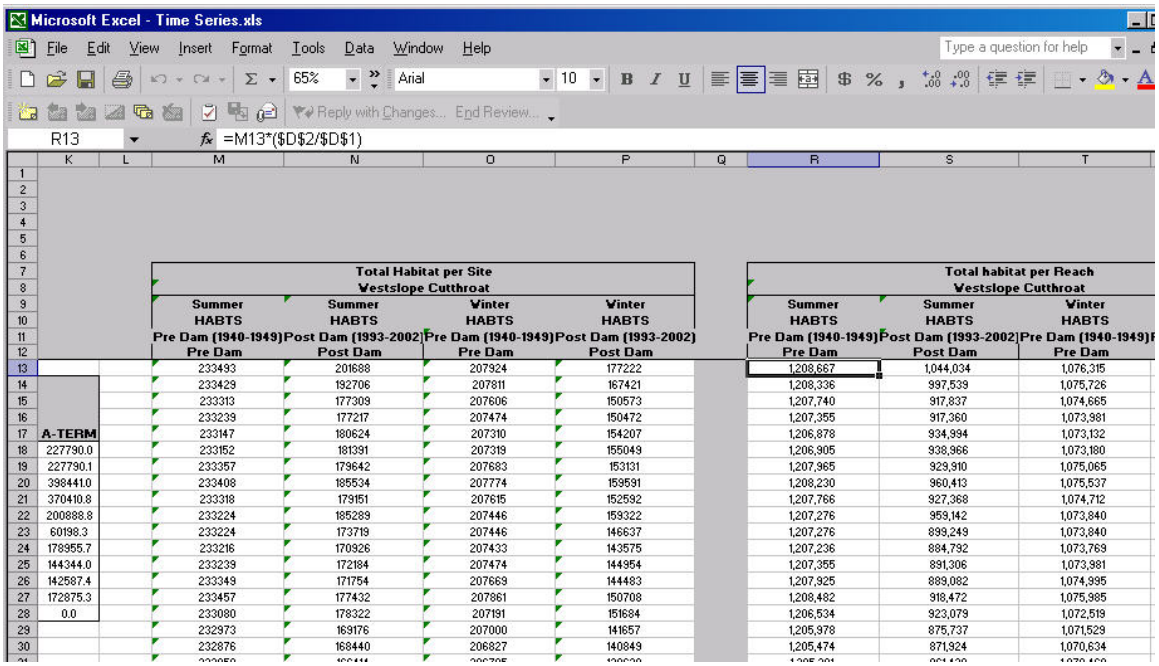
Calculation of habitat for the site is completed for each life stage. The spreadsheet is set up to calculate habitat for each species and life stage of interest. The analysis requires that the formula be copied into the appropriate number of rows that correspond to every row containing hydrology in Columns B and C.

There are corresponding formulas in columns R, S, T and U to calculate the total habitat for the reach. The amount of habitat for the site is multiplied by the reach distance to compute total habitat for the reach (Figure 8). Again, the number of rows corresponds to the number of hydrology data points.

This spreadsheet can also be used to graphically display the data to compare habitat over time. This identifies the information visually to give the capability of displaying where changes occur in habitat over time with the proposed flow regimes. Those results are presented in the next section.

The GIS based model calculated habitat from geo referenced hydraulic data and habitat suitability indices. The resulting values calculate habitat time series using the included spreadsheet. The habitat time series relies on formulas in specific cells to calculate habitat

values over time. The user is cautioned to keep the data in the same cells as those in the example sheet. An experienced spreadsheet user can customize the example sheet for any number of species and dates for hydrology. In our experience it is best to limit each spreadsheet to no more than four hydrology data sets and four life stages.



	K	M	N	O	P	R	S	T
7		Total Habitat per Site				Total habitat per Reach		
8		Westslope Cutthroat				Westslope Cutthroat		
9		Summer	Summer	Winter	Winter	Summer	Summer	Winter
10		HABTS	HABTS	HABTS	HABTS	HABTS	HABTS	HABTS
11		Pre Dam (1940-1949)	Post Dam (1993-2002)	Pre Dam (1940-1949)	Post Dam (1993-2002)	Pre Dam (1940-1949)	Post Dam (1993-2002)	Pre Dam (1940-1949)
12		Pre Dam	Post Dam	Pre Dam	Post Dam	Pre Dam	Post Dam	Pre Dam
13		233493	201688	207924	177222	1,208,667	1,044,034	1,076,315
14		233429	192706	207811	167421	1,208,336	997,539	1,075,726
15		233313	177309	207606	150573	1,207,740	917,837	1,074,665
16		233239	177217	207474	150472	1,207,355	917,360	1,073,981
17	A-TERM	233147	180624	207310	154207	1,206,878	934,994	1,073,132
18	227790.0	233152	181391	207319	155049	1,206,905	938,966	1,073,180
19	227790.1	233357	179642	207683	153131	1,207,965	929,910	1,075,065
20	398441.0	233408	185534	207774	159591	1,208,230	960,413	1,075,537
21	370410.8	233318	179151	207615	152592	1,207,766	927,368	1,074,712
22	200888.8	233224	185289	207446	159322	1,207,276	959,142	1,073,840
23	60198.3	233224	173719	207446	146637	1,207,276	899,249	1,073,840
24	178955.7	233216	170926	207433	143575	1,207,236	884,792	1,073,769
25	144344.0	233239	172184	207474	144954	1,207,355	891,306	1,073,981
26	142587.4	233349	171754	207669	144483	1,207,925	889,082	1,074,995
27	172875.3	233457	177432	207861	150708	1,208,482	918,472	1,075,985
28	0.0	233080	178322	207191	151684	1,206,534	923,079	1,072,519
29		232973	169176	207000	141657	1,205,978	875,737	1,071,529
30		232876	168440	206827	140849	1,205,474	871,924	1,070,634

Figure 8. Habitat time series example for the site and reach.

RESULTS

The results presented here provide the details of the instream flow analysis for the Flathead River reaches 1, 2 and 3. A more comprehensive data set is included in the distribution compact disk (CD) with the Arcview projects files that contain all simulations for all species and life stages at each site. Those data present the visual results of the analysis as well as provide grid files for additional analysis in GIS as needed by BPA and Montana Fish, Wildlife and Parks.

Model Calibration

The hydraulic models were calibrated to both water surface and water velocity to insure an accurate representation of the measured flows for each study site. Water surface elevations, from the simulations, accurately represent measured flows for low, mid and high flow ranges (Figure 9). Water velocities were measured at mid-flow for all three study sites. A comparison of measured water velocity to predicted shows that the predicted velocities, in general, match measured water velocities with a slight underprediction (Figure 10).

Habitat suitability data were applied for west slope cutthroat trout for reach 1 and 2, summer and winter curves, and west slope cutthroat trout year round for reach 3 (Muhlfeld 2002). In addition, bull trout sub-adult criteria for day and bull trout sub-adult criteria for night were applied to sites 1, 2 and 3. Bull trout adult data were applied to reaches 1, 2 and 3. The only diel comparison was made for sub-adult bull trout in reaches 1 and 2.

Model hydraulics show that both depths and velocities vary as expected for each of the sites and reaches (See distribution CD). There is a significant difference between the wetted channel width for the 105 cms and the 169 cms values in riffle areas. Fluctuations in riffles between these two flows can reach approximately 40 meters (Figure 11).

Hydrology time series was generated for pre-dam and post-dam conditions to compare the unregulated and regulated system. The main differences in the hydrology are shown in the winter baseflow period where post-dam flows are highly variable and in the reduction of peak flows during certain conditions, especially during peak snowmelt runoffs. Historically, pre-dam conditions had summer peak flows during snowmelt of over 2,000 cms and very stable but lower baseflows. Current post-dam conditions show that the baseflow period can vary by as much 200cms or more and that peak flows are generally less than 1,500 cms (Figure 12). There is a similar representation of high hydrology for reach 3. The difference between hydrology in reach 3 and reaches 1 and 2 is the additional inflow from the White Fish and Stillwater rivers that enter the Flathead at the upstream end of reach 3 (Figure 13). Average annual hydrology were developed from the 1940-49 pre-dam data and the 1993-2002 post-dam hydrology. These annual hydrographs allow the comparison of baseflow and peak flow conditions to show the differences between those two seasonal characateristics (Figures 14 and 15). The baseflow period is much more variable in the post-dam hydrology and peak flows truncated when compared with the pre-dam hydrology showing very stable baseflows and higher peak flows.

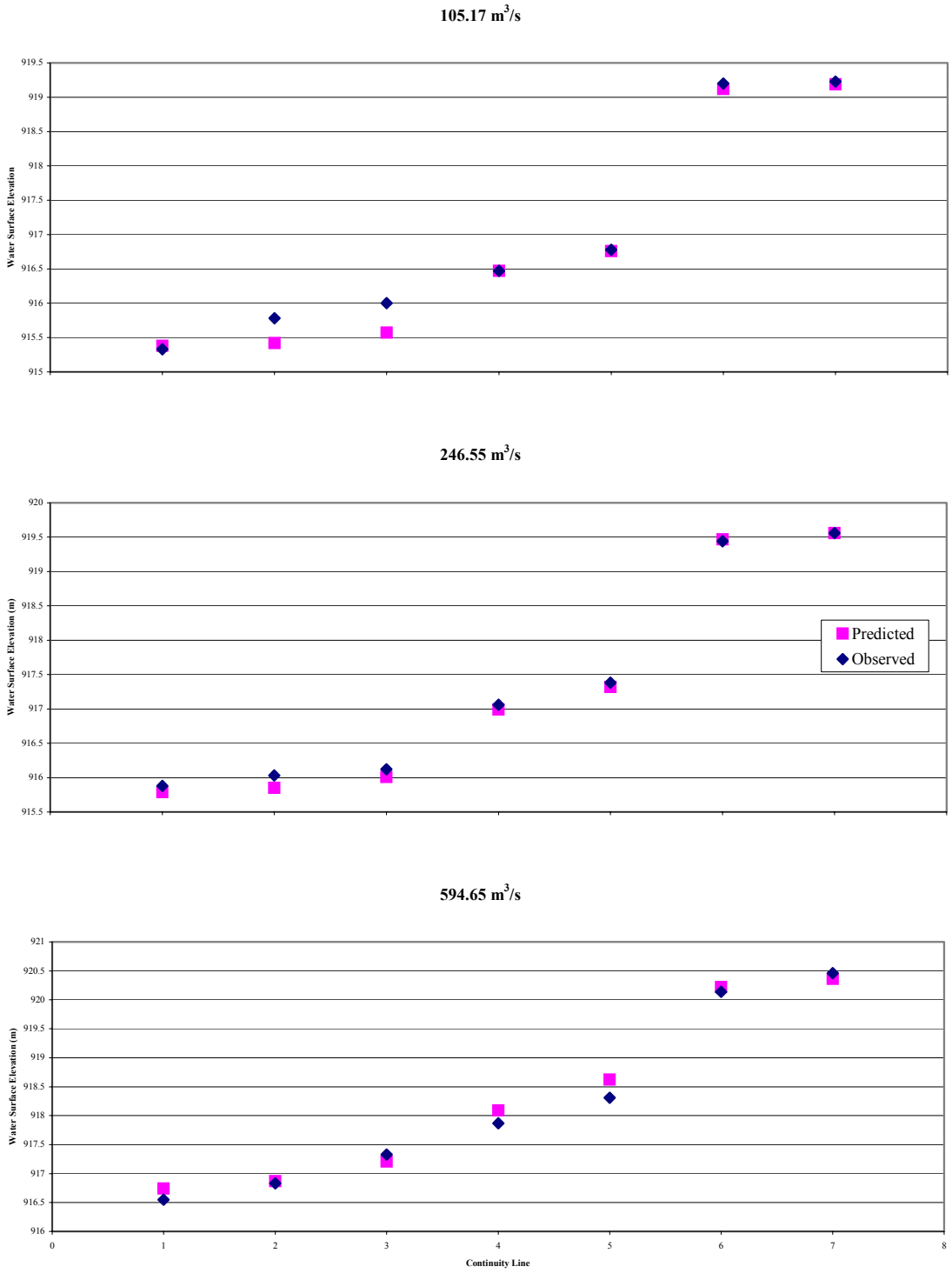


Figure 9. Observed versus predicted water surface elevations for three flows at Reach 1.

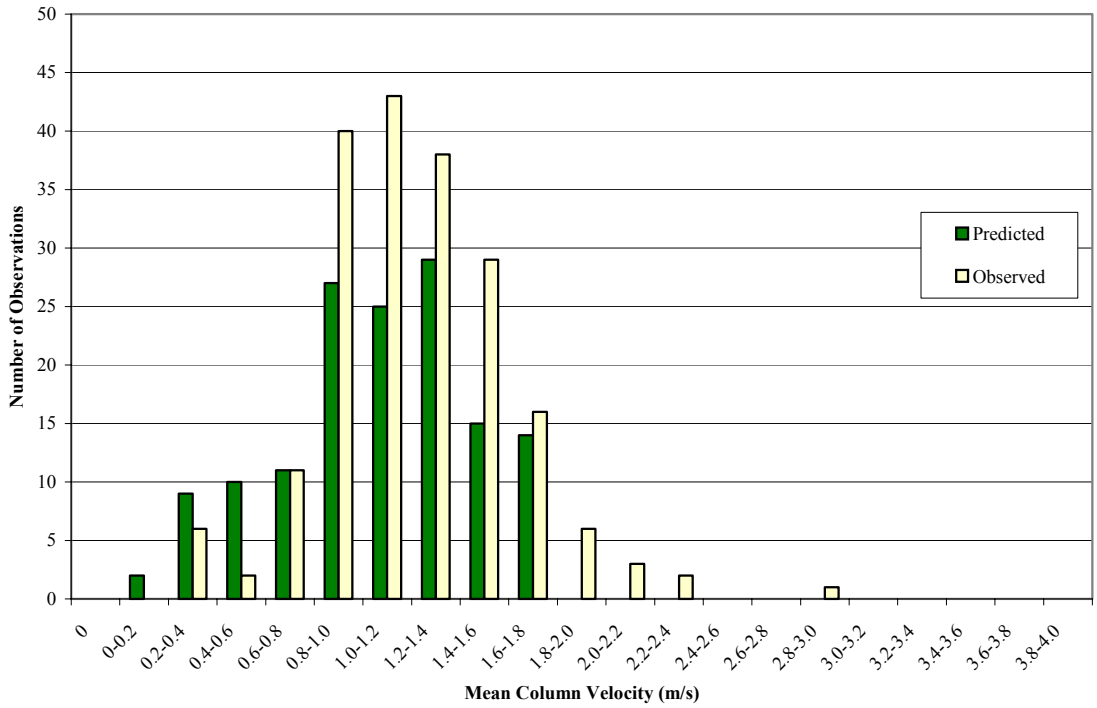


Figure 10. Histogram of observed and predicted water velocities for 246.55 cms at Reach 1.

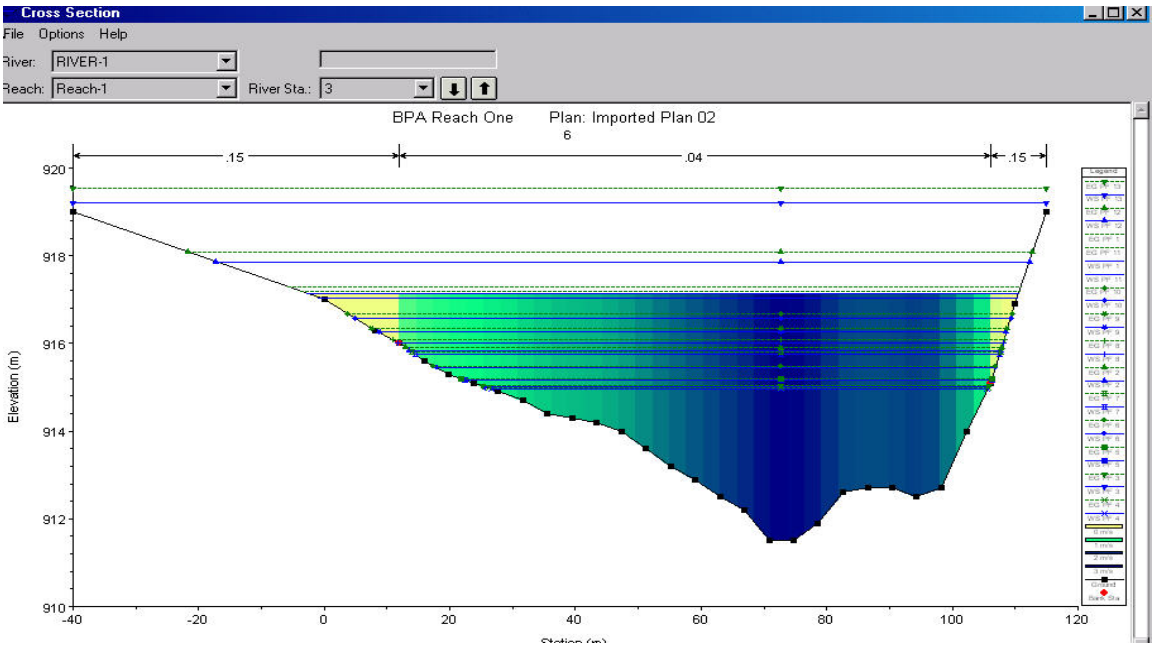


Figure 11. Water surface elevations at a range of discharges for Site 1, Flathead River.

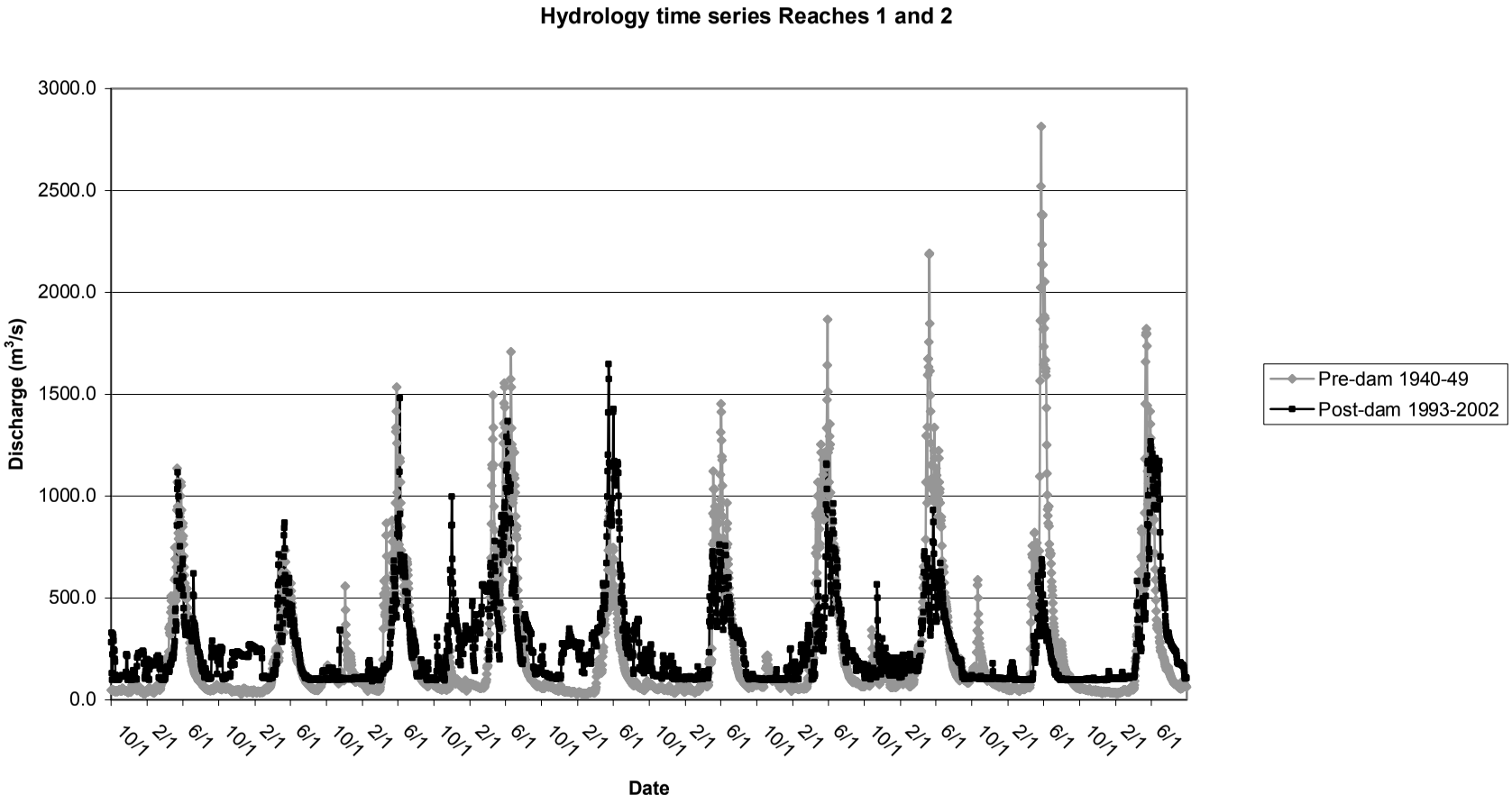


Figure 12. Hydrology time series Reaches 1 and 2.

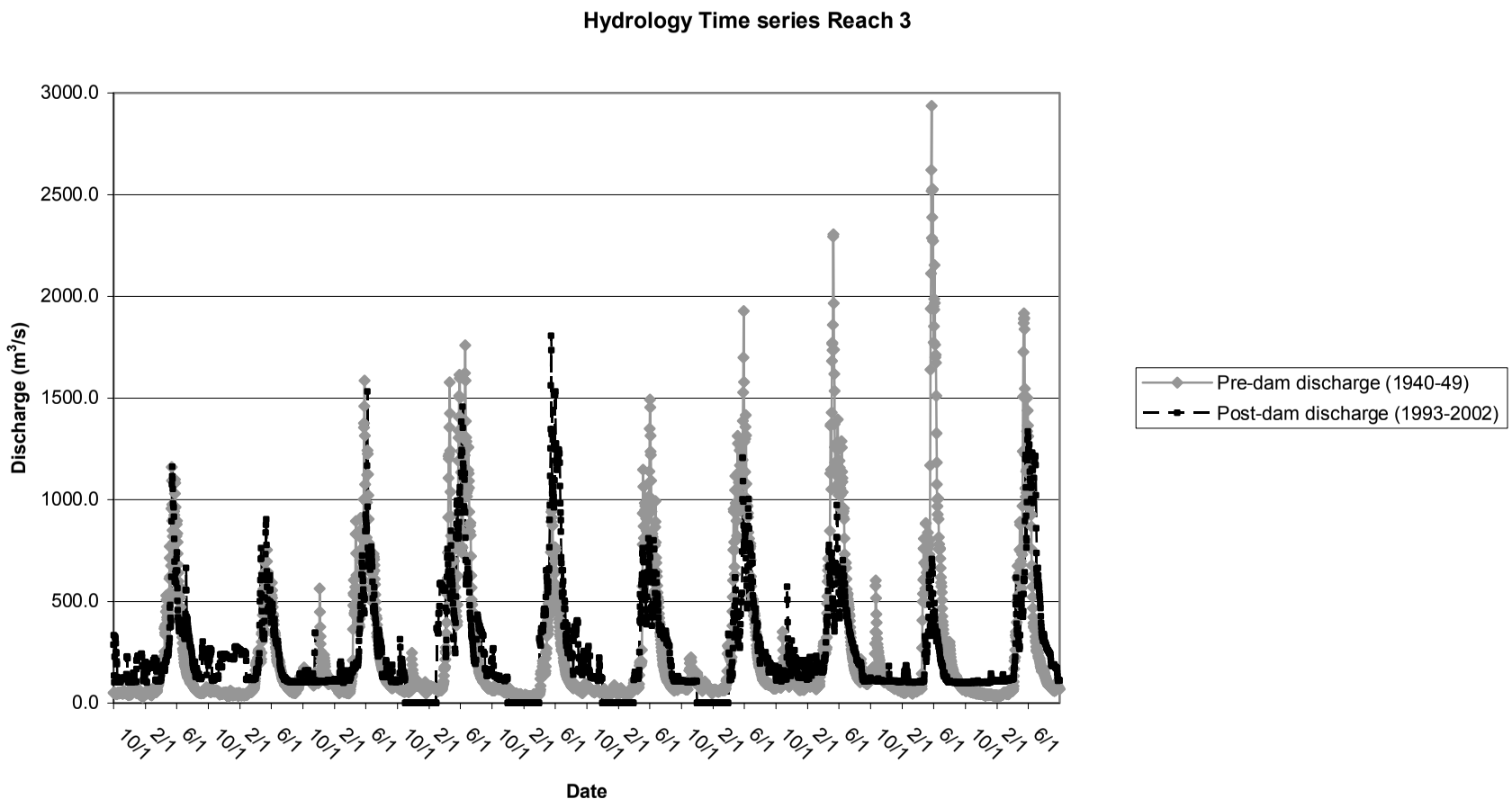


Figure 13. Hydrology time series Reach 3.

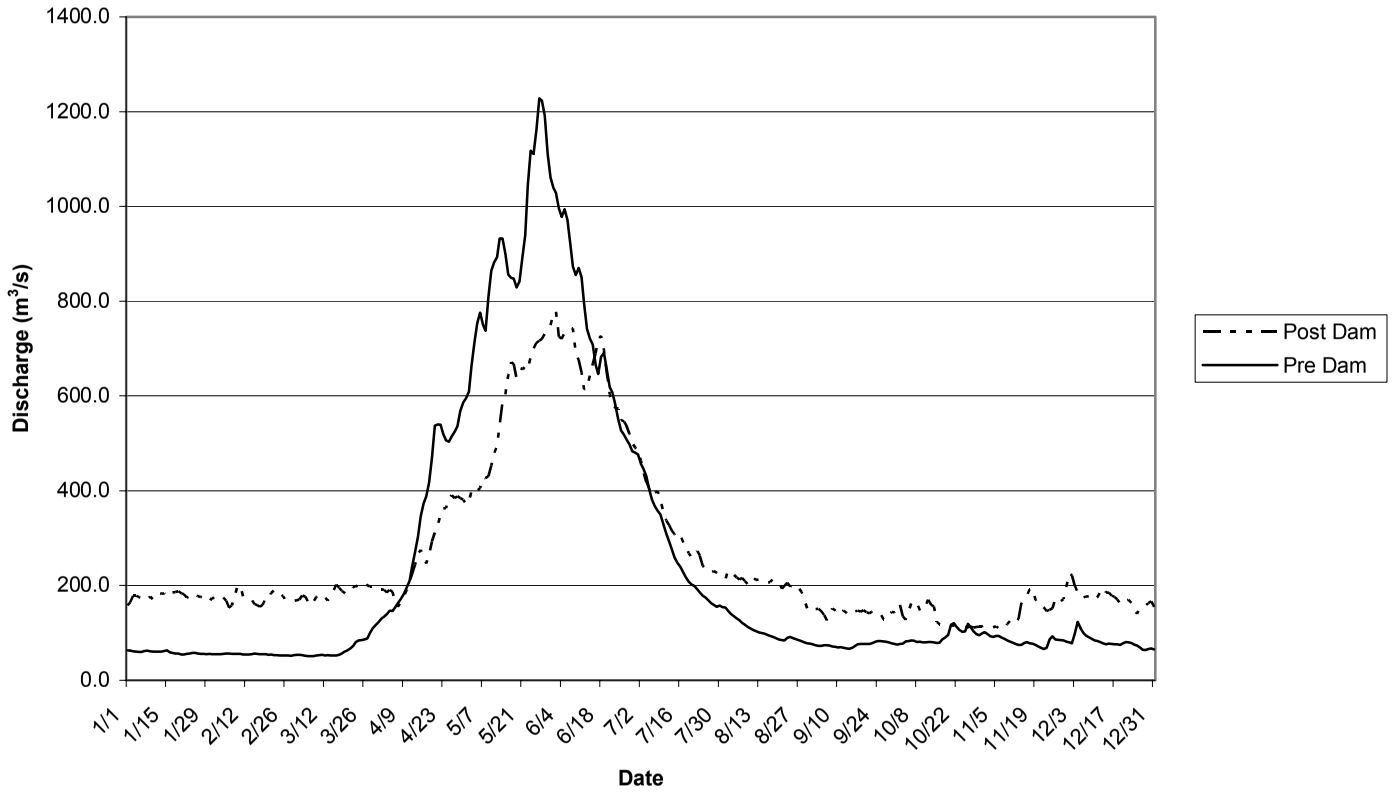


Figure 14. Average Discharge Reaches 1 and 2.

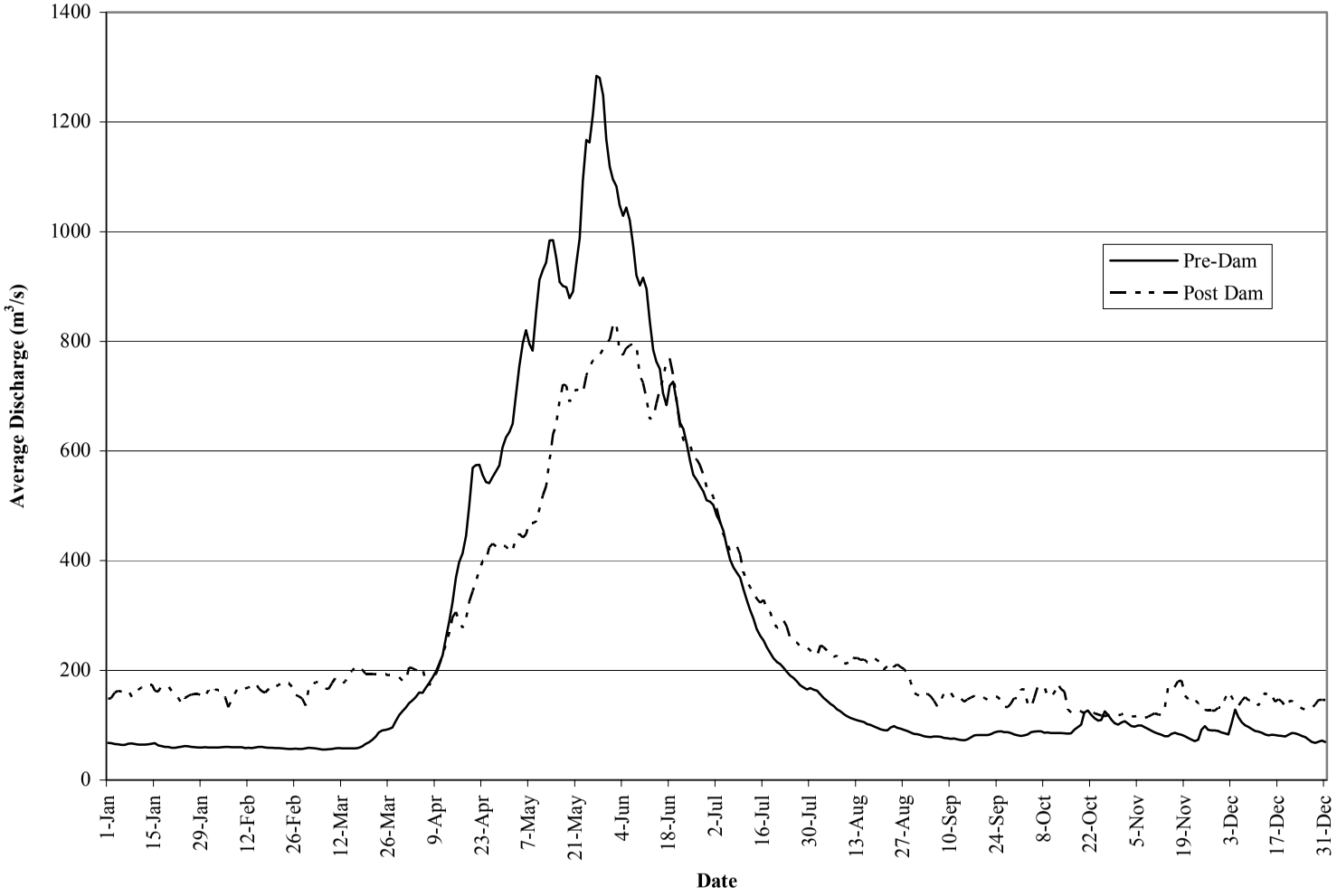


Figure 15. Average discharge Reach 3.

Habitat Simulations

Habitat for all three reaches was simulated using the combination of two-dimensional hydraulic model and GIS weighted useable area model to generate weighted useable area in m^2 per kilometer for each of the three reaches. Species with several life stages have similar patterns of weighted useable area discharge functions in reach 1. Bull trout habitat versus discharge shows a similar relationship with the highest weighted useable area occurring at the lower flows and value of weighted useable area being reduced at higher flows for both day and night usage and for adults (Figure 16). West slope cutthroat trout for fall and winter criteria and summer show a similar relationship with the highest weighted useable area at the lower flow conditions (Figure 17). Both of these species show that the useable habitat area is more widely distributed through the channel at the lower flow conditions than they are at the high flow conditions. This is likely a result of the increased velocities that occur as flows increase with most of the habitat occurring along the lower velocity margins of the river and around the islands rather than in the main channel (Figures 18 through 21).

The reduction in suitable near shore habitat is particularly important for bull trout subadults. Muhlfeld (2003) reports a distinct difference in diel habitat use by subadult bull trout. The shallow habitat near the river shorelines is used at night by subadult bull trout. The quality of this habitat is higher when the river is stable for longer periods (several weeks) and benthic productivity can increase.

Habitat areas for both bull trout and west slope cutthroat trout for reach 2 shows similar response of weighted useable area to discharge with the higher values at the lower discharges. There is a difference between reach 1 and reach 2 in the response shape of the curves showing that there is a difference between those two reaches for hydraulic conditions. The curve that is most different in reach 2 from those in reach 1 is sub-adult night bull trout (Figure 22) and the fall and winter west slope cutthroat trout curves (Figure 23).

Reach 3 is hydraulically controlled by the water surface elevation of Flathead Lake and therefore there is very little change with discharge to the amount or the shape of the weighted useable area criteria curve for bull trout. In general, it appears to be a scaling factor of where that habitat is located based on depth of the water and current velocity. In general, there is very little difference between the amount of habitat for each life stage at high or low flow as those response curves are very flat. There is a difference in absolute value for weighted useable area between the different life stages of sub-adult night, sub-adult day and adult bull trout (Figure 24).

West slope cutthroat trout, in contrast, has a distinct relationship between discharge and weighted useable area in reach 3 (Figure 25). As with the upper two reaches, the habitat is greatest at the lower flow range and then declines in the upper flow ranges. There is a substantial decline in reach 3 response which may be due to depth differences as well as velocity differences.

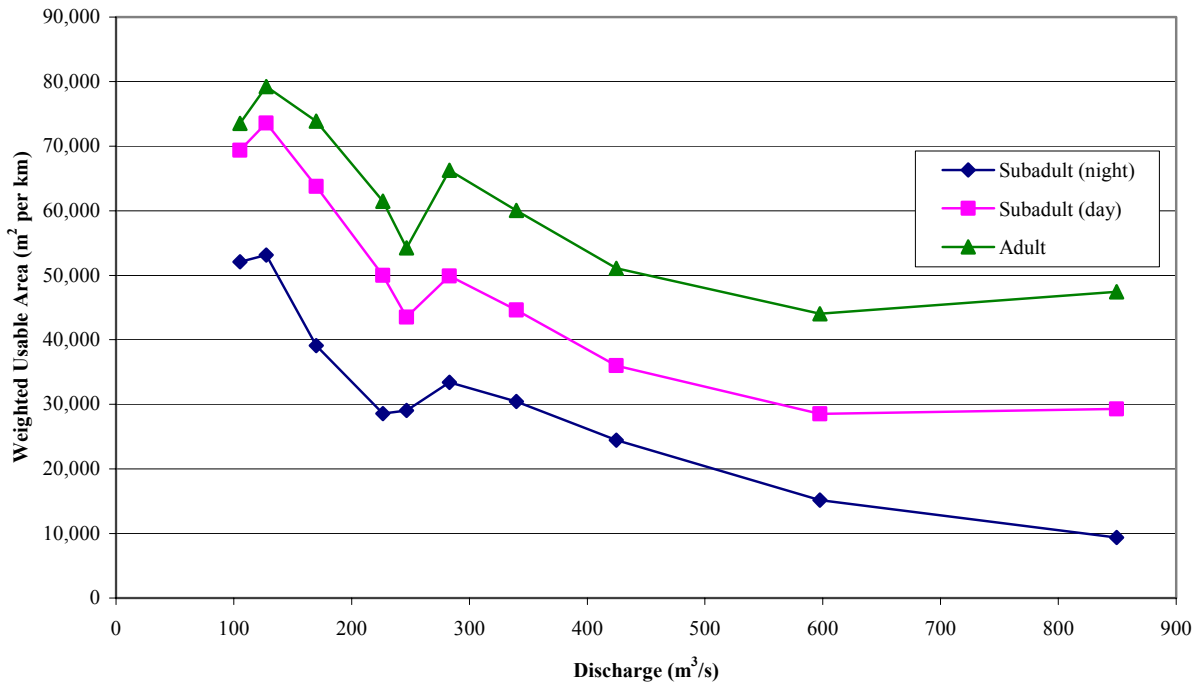


Figure 16. Reach 1 Bull trout habitat versus discharge.

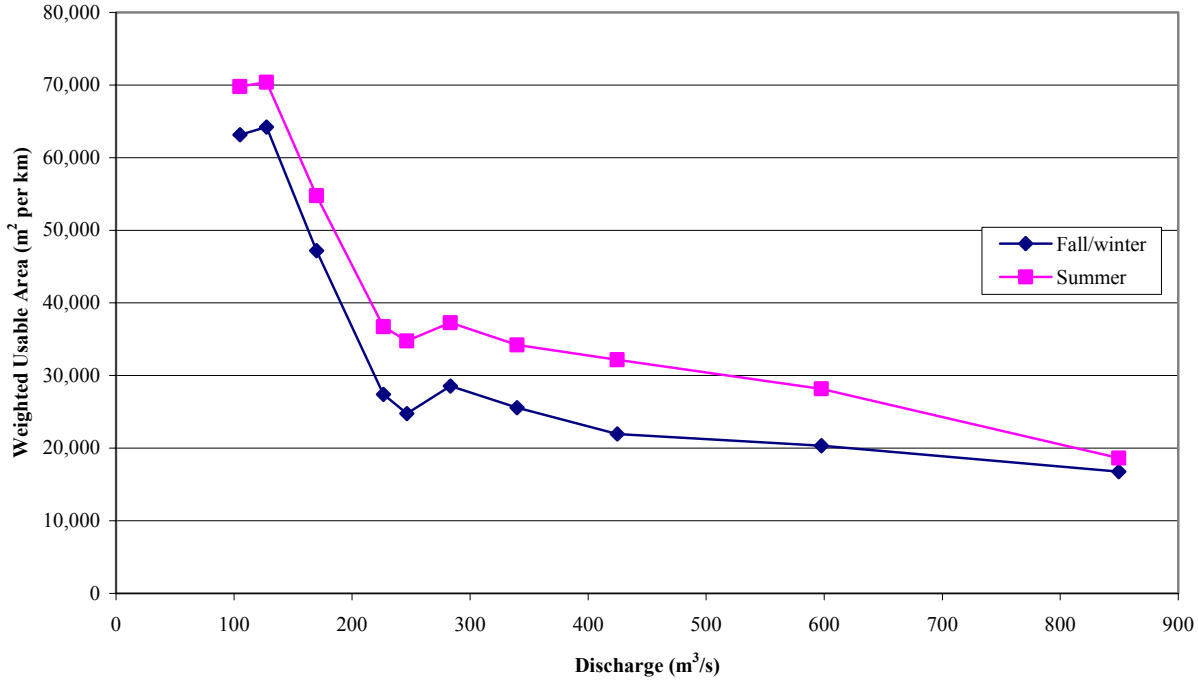


Figure 17. Reach 1 West slope cutthroat trout habitat versus discharge.

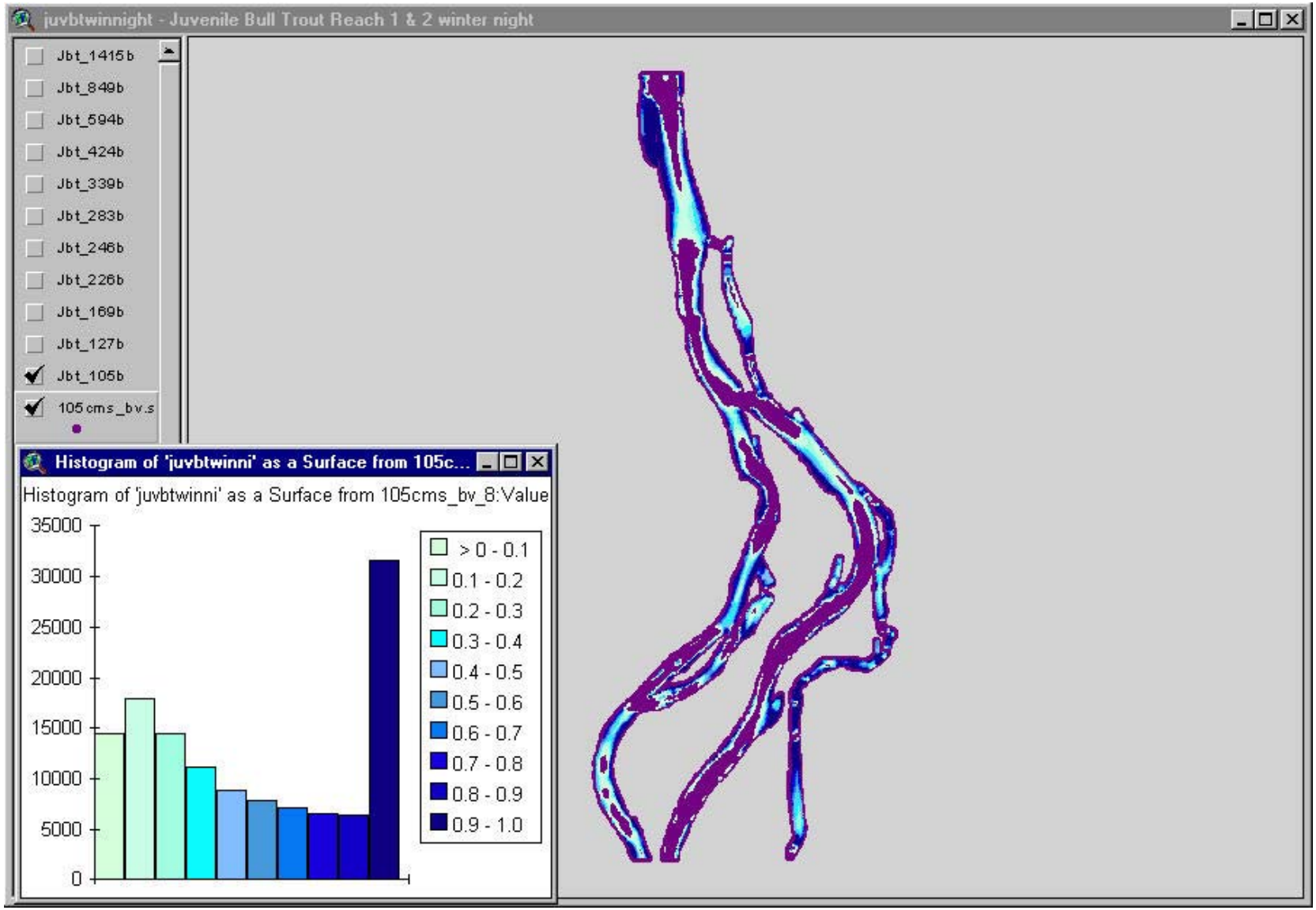


Figure 18. Bull trout sub-adult night habitat area, 105 cms, Reach 2.

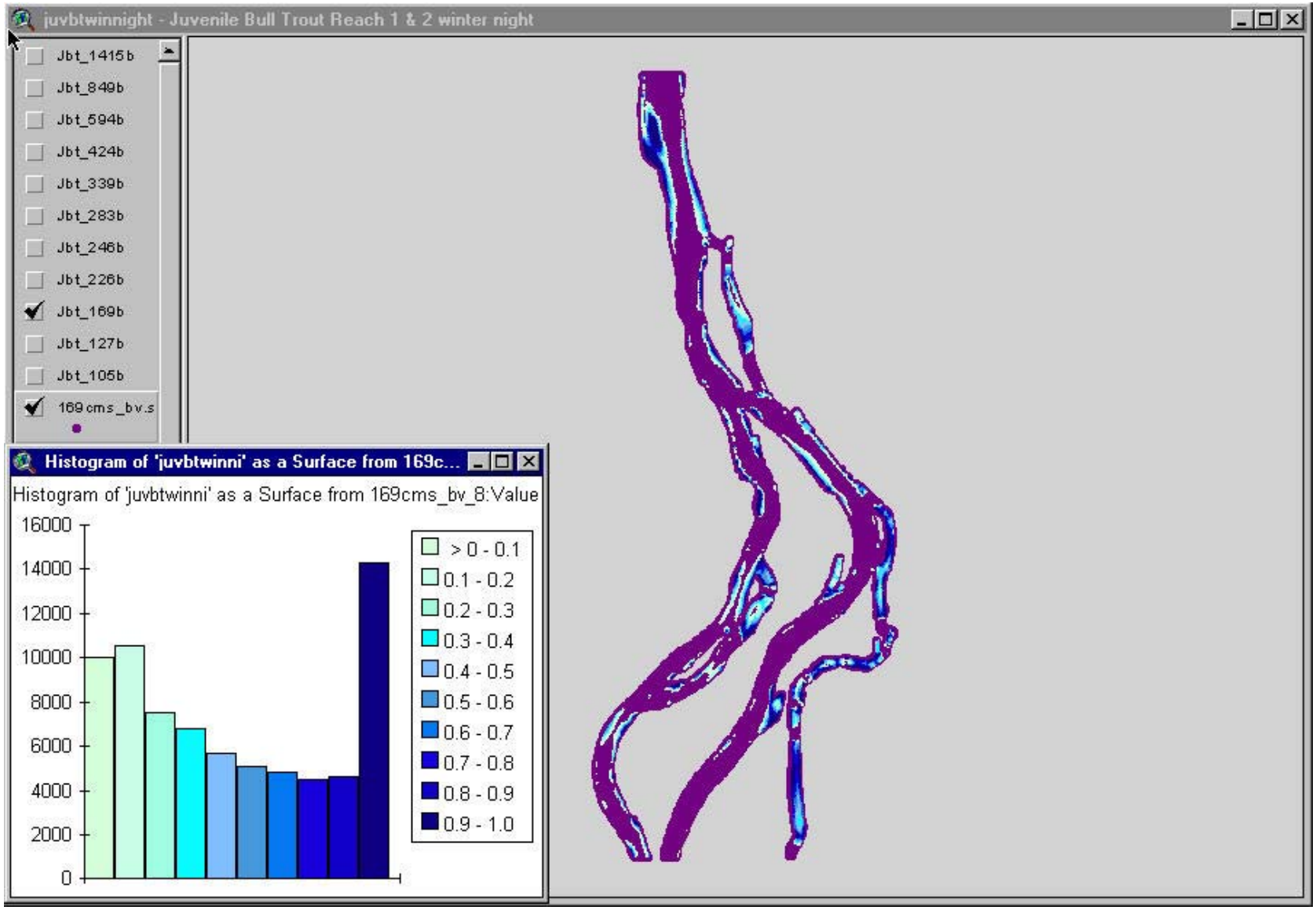


Figure 19. Bull trout sub-adult night habitat area, 169 cms, Reach 2.

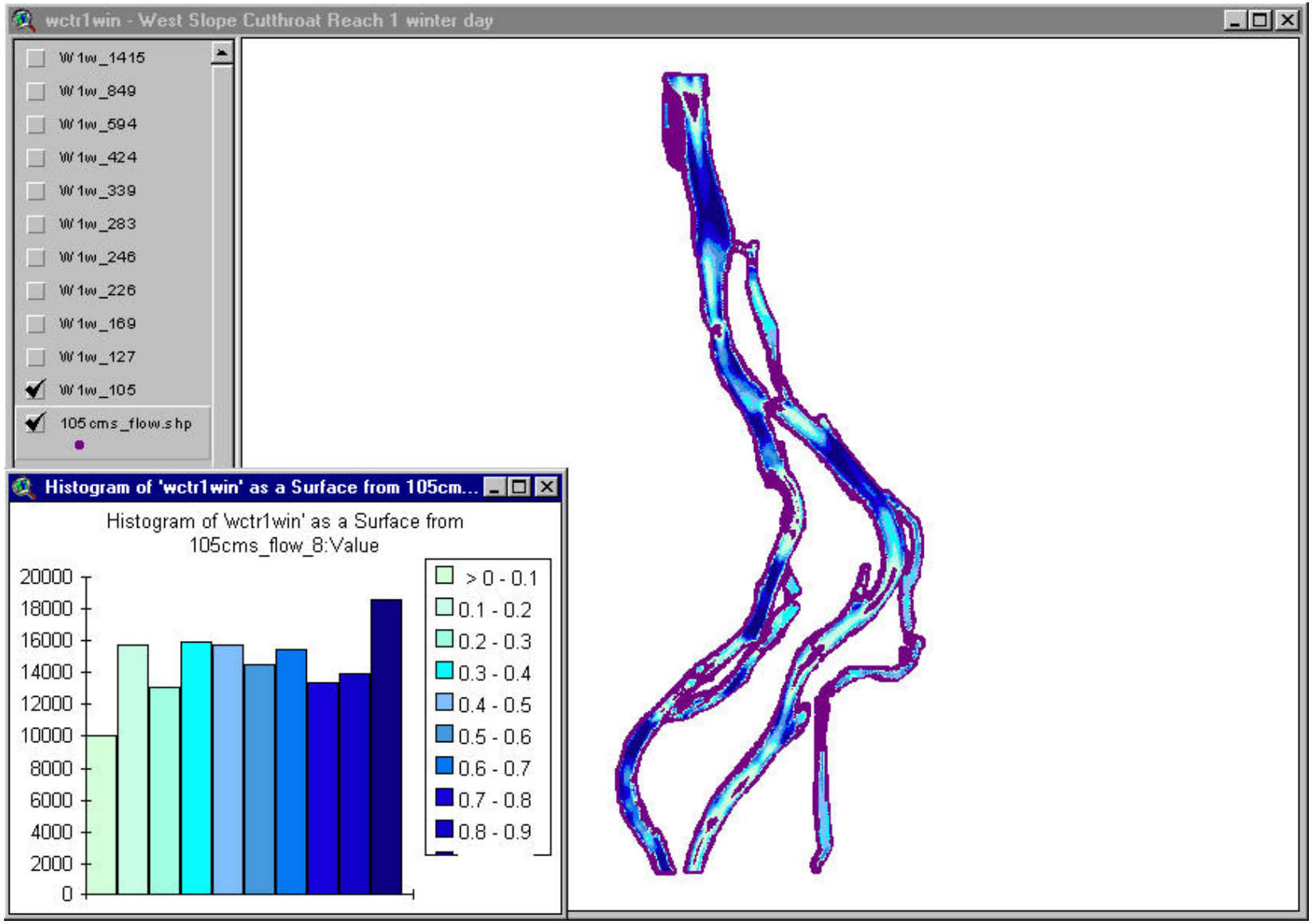


Figure 20. West slope cutthroat trout habitat area, 105 cms, Reach 2.

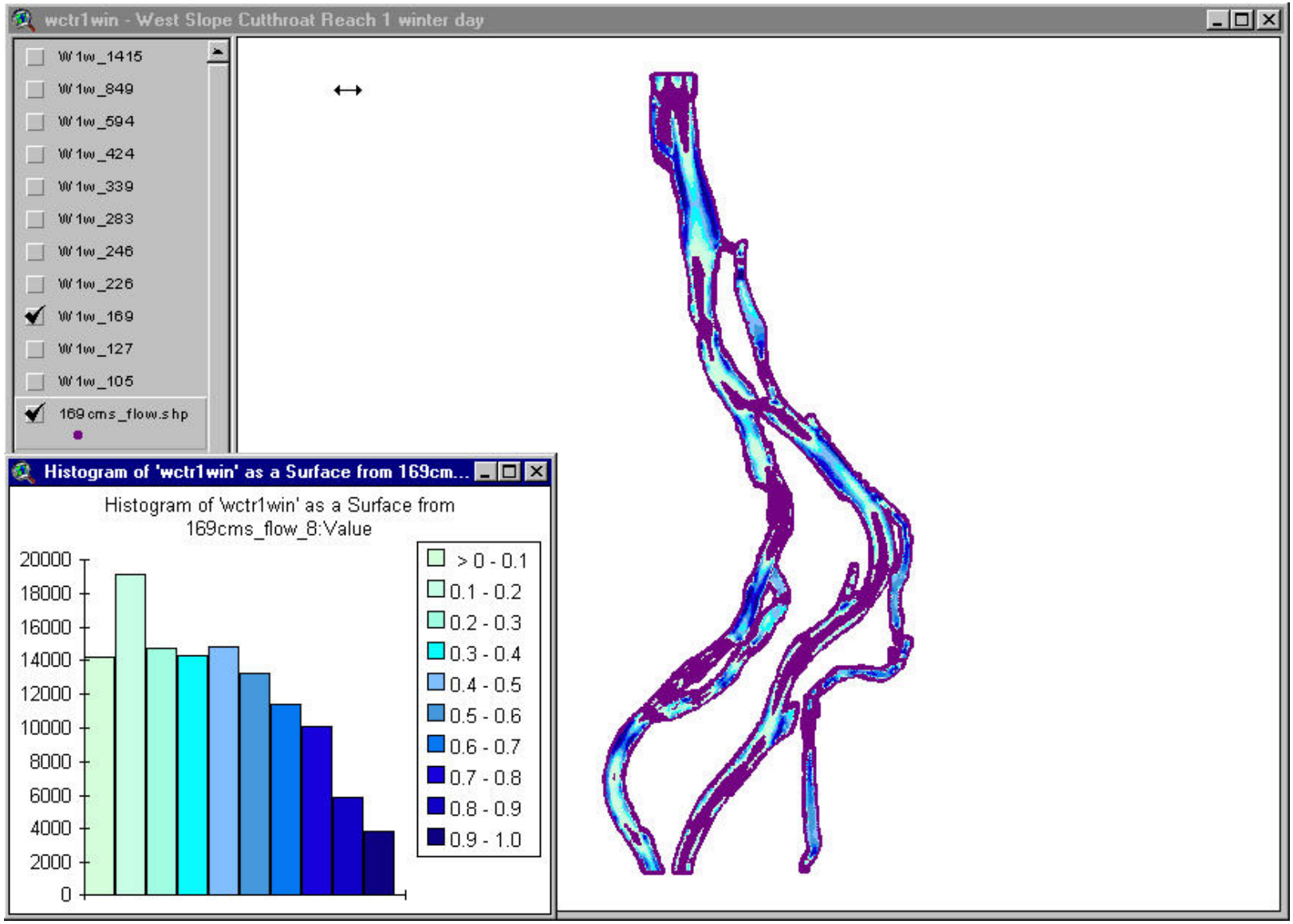


Figure 21. West slope cutthroat trout habitat area, 169 cms, Reach 2.

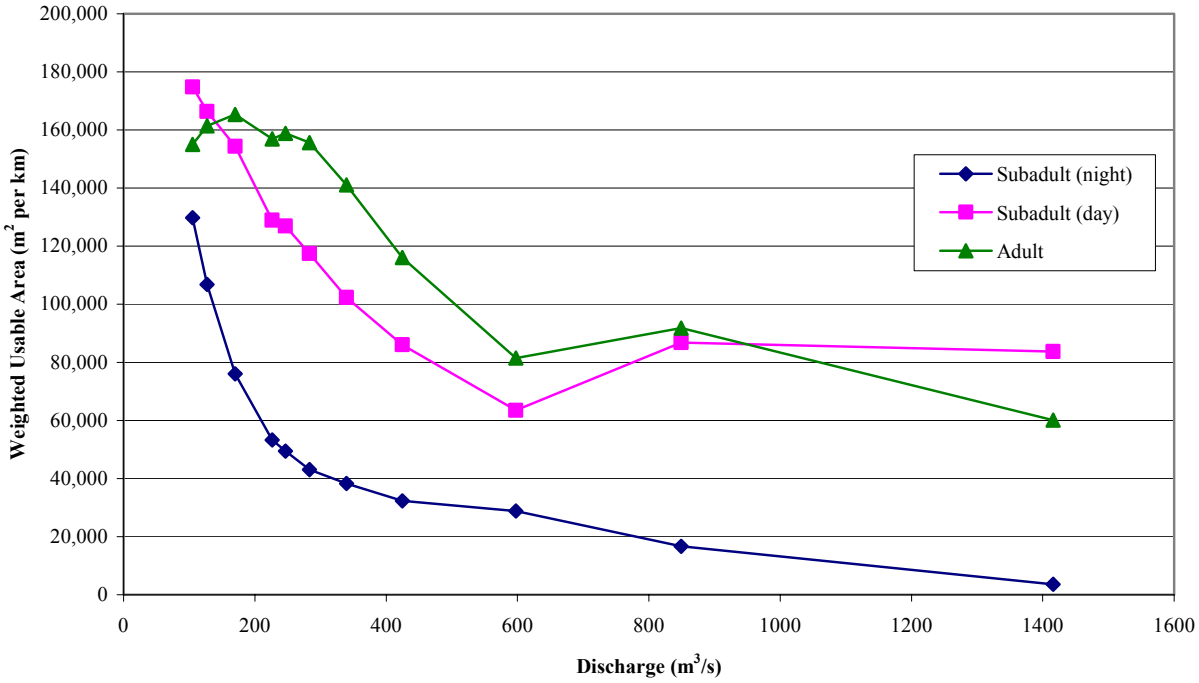


Figure 22. Reach 2 Bull Trout Habitat versus discharge.

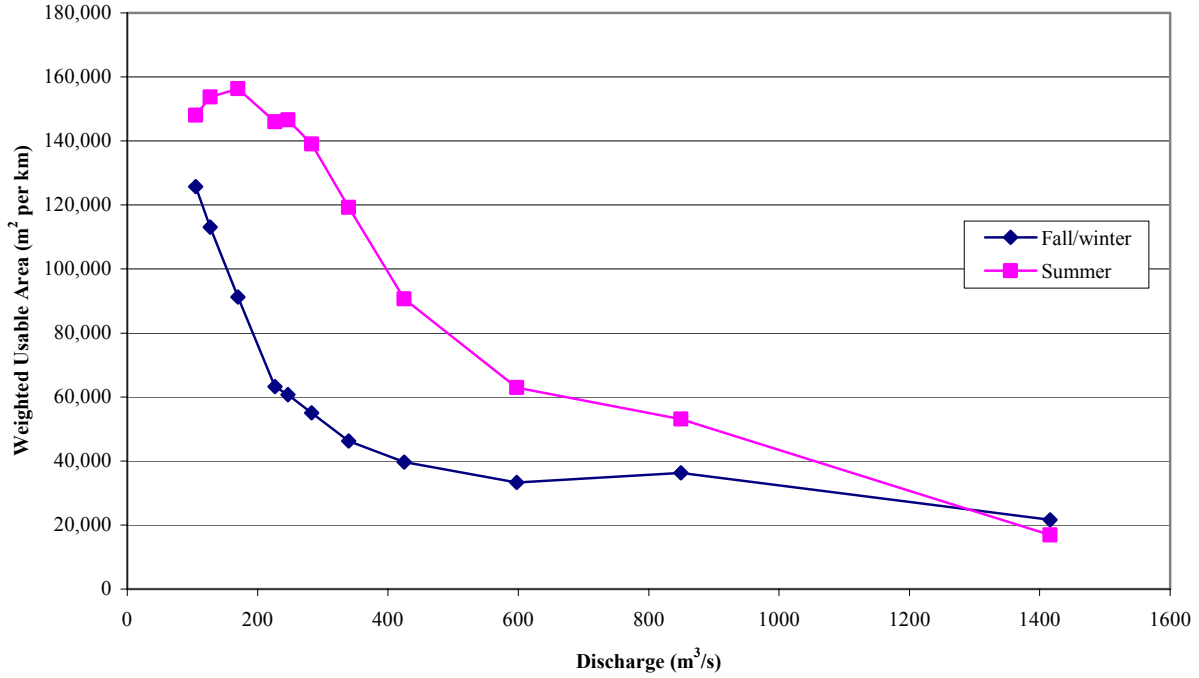


Figure 23. Reach 2 Westslope cutthroat trout habitat versus discharge.

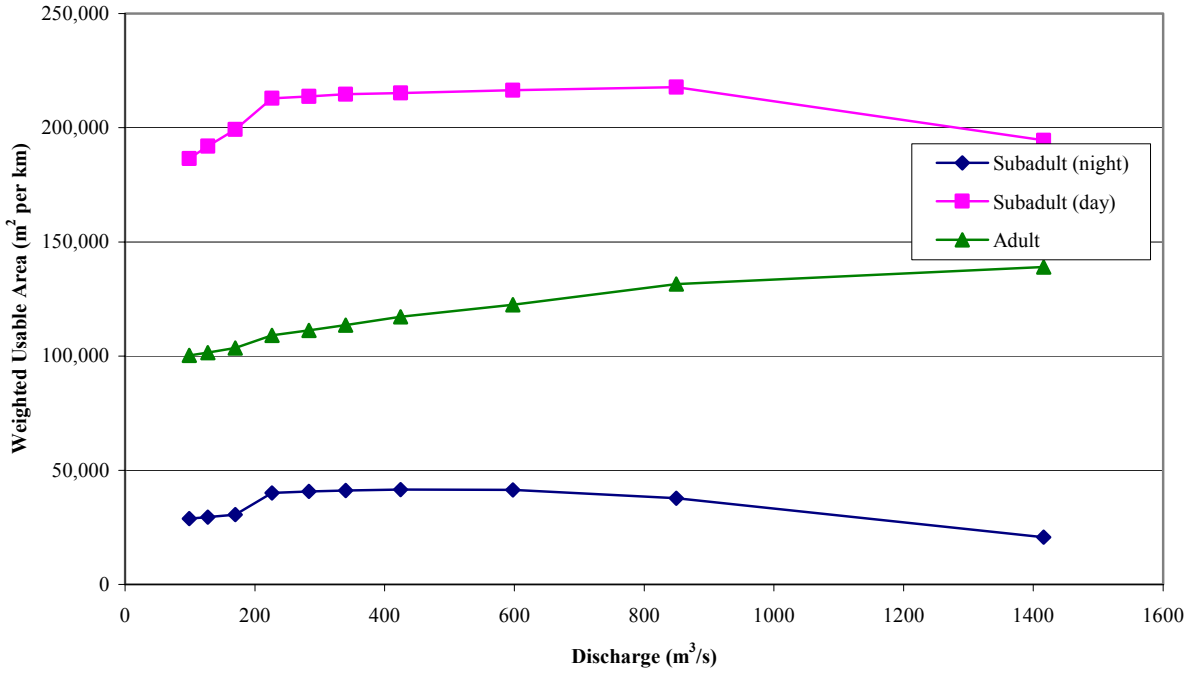


Figure 24. Reach 3 Bull trout habitat versus discharge.

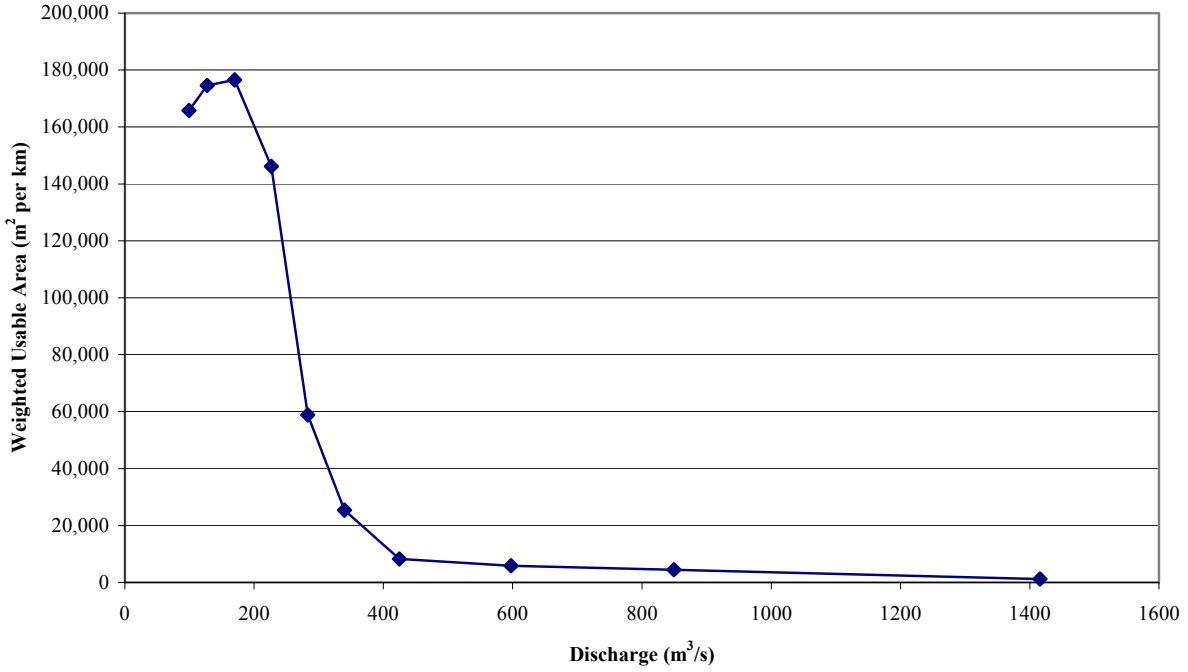


Figure 25. Reach 3 West slope cutthroat habitat versus discharge.

Habitat Time Series

Habitat time series analysis used ten-year and annual hydrology. The hydrology for west slope cutthroat trout was divided into summer and winter seasons. The response of habitat to flow is similar to the flow regime change between the pre-dam and post-dam conditions. Pre-dam conditions for summer shows that the habitat increased sharply after runoff and was stable in the summer baseflow period. Post-dam conditions show that the response of habitat to flow is slower and also is much more variable in the summer baseflow period (Figure 26). Winter baseflows for west slope cutthroat trout show that the winter pre-dam period was very stable with a relatively high amount of habitat area and that current conditions have much more variable habitats over time (Figure 27). The ten-year time series also show that the variability and magnitude of habitat response continues over time from what was calculated in the annual hydrograph series (Figures 28 and 29). The baseflow period is much more variable than during the post-dam conditions, than the pre-dam conditions, and habitat values for pre-dam can be higher at times than the post-dam period.

Bull trout sub-adults show a very similar response to flow for day and night. Although the nighttime suitability criteria for bull trout sub-adults shows that the total amount of habitat in pre-dam conditions was higher during the winter baseflows than currently exist. Also there is more stability during the pre-dam conditions during summer and winter baseflows than exist for both bull trout sub-adult nighttime and daytime criteria (Figures 30 and 31). Bull trout adult habitat in reach 1 shows a similar stability during the pre-dam, baseflow conditions and much more variability during the post-dam baseflow conditions (Figures 32 and 33).

Habitat characteristics for reach 2 are similar to those shown for reach 1 with west slope cutthroat trout having more variability in baseflow conditions post-dam than pre-dam. The curve habitat area during runoff in summer periods show that there is very little difference between the reach 2 conditions pre- and post-dam. There is a distinct difference for winter west slope cutthroat trout habitat showing both less habitat and more variability in the habitat on a daily basis in the post-dam condition than was shown in the pre-dam condition (Figures 34 and 35). The analysis of the ten-year time series again shows west slope cutthroat trout to be more variable post-dam than pre-dam with more stability and higher habitat availability in the pre-dam conditions (Figures 36 and 37). Bull trout sub-adults in reach 2 show the habitat in pre-dam conditions for nighttime was more abundant and more stable during baseflows than the post-dam period, which has more daily variability in habitat. This is shown both in the annual times series in Figures 38 and 39, and also in the ten-year time series in Figures 41 through 43.

Reach 3 habitat conditions show that the post-dam conditions for west slope cutthroat trout have better habitat than were shown in the pre-dam conditions (Figures 44 and 45). Bull trout habitat for reach 3 shows that there is slightly more quanitity of habitat in the post-dam hydrology than pre-dam hydrology for sub-adults and adults but there is more variability during baseflow conditions of that habitat (Figures 46 through 53).

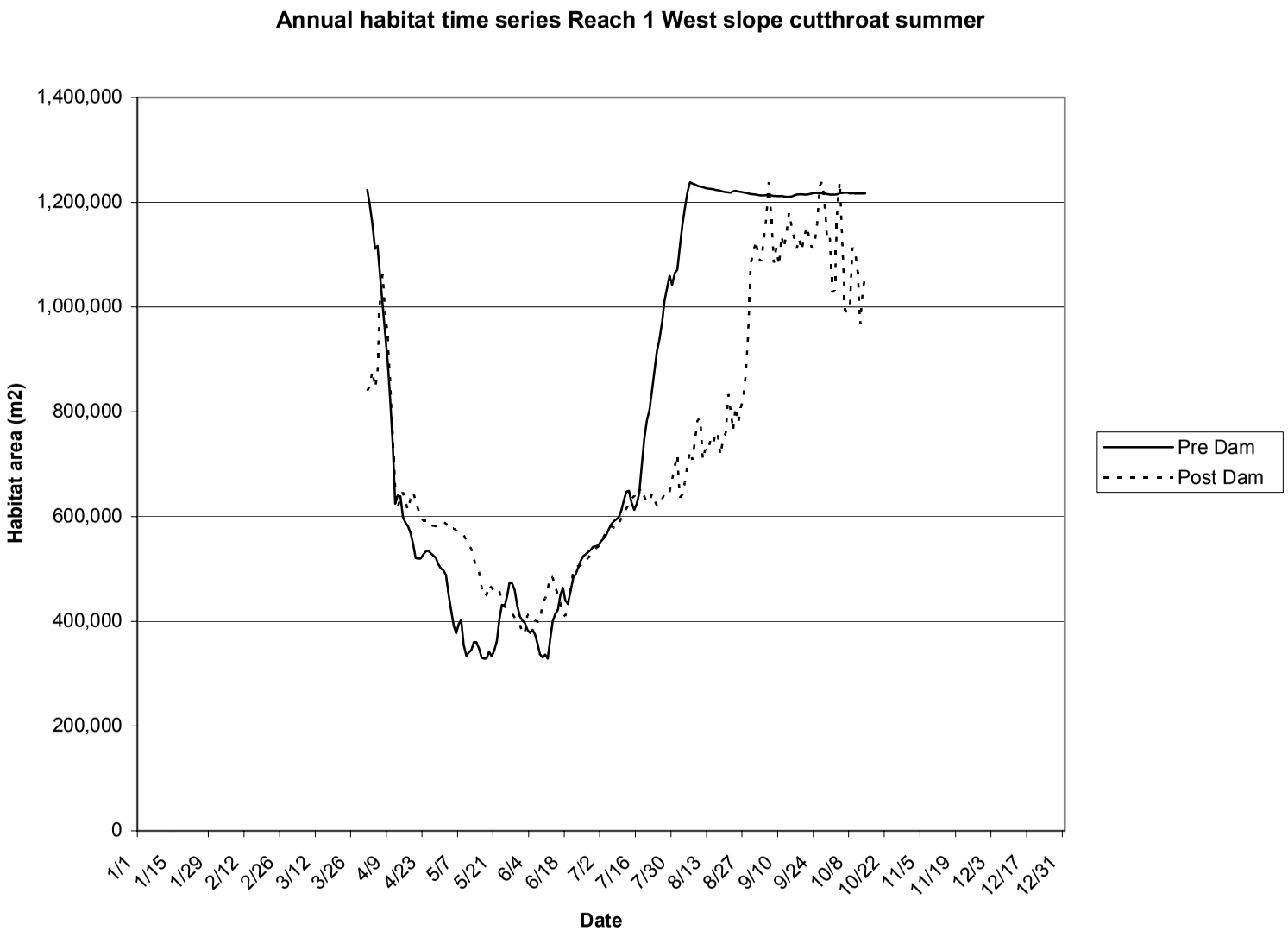


Figure 26. Annual habitat time series Reach 1 West slope cutthroat summer.

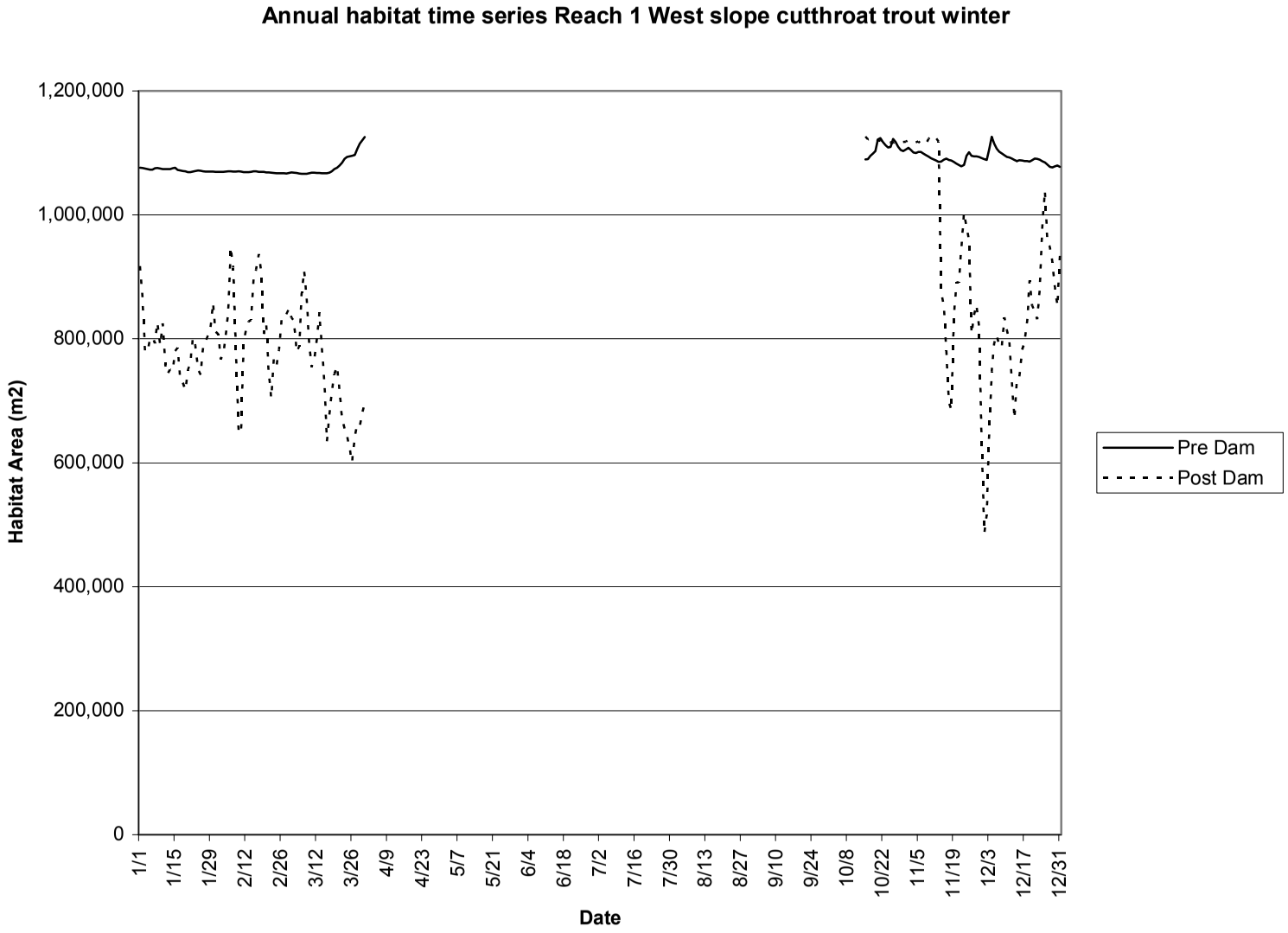


Figure 27. Annual habitat time series Reach 1 West slope cutthroat trout winter.

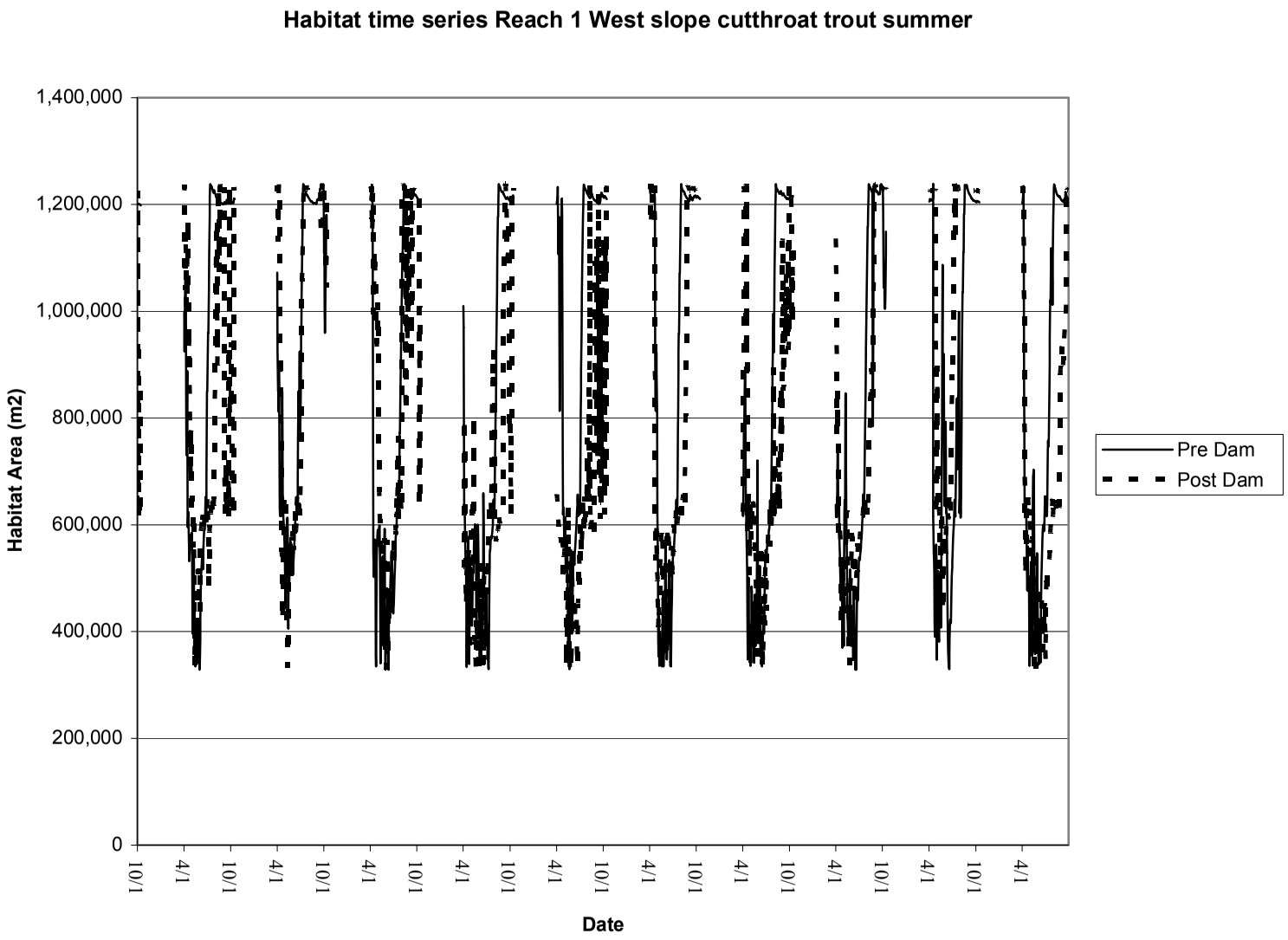


Figure 28. Habitat time series Reach 1 West slope cutthroat trout summer.

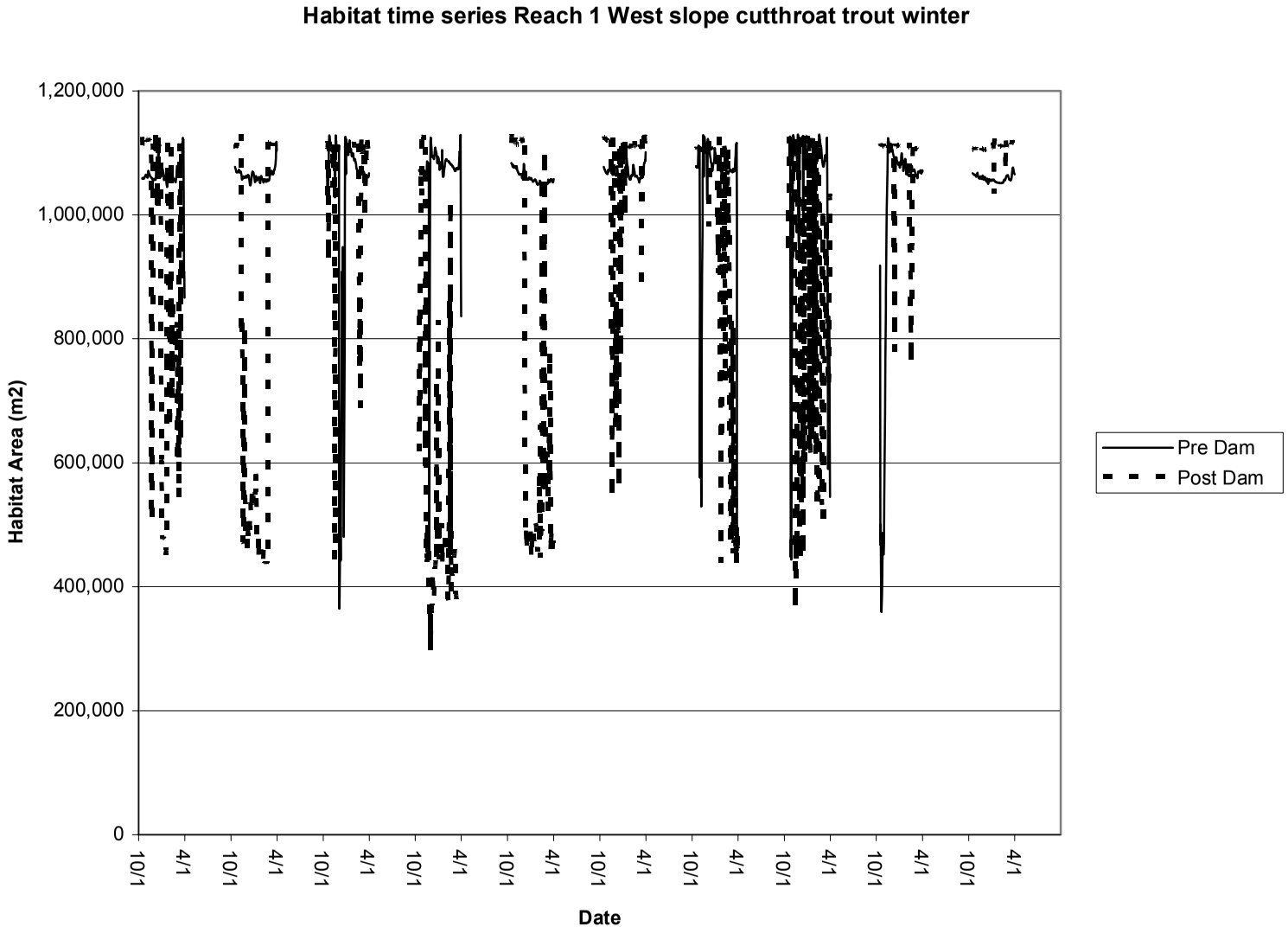


Figure 29. Habitat time series Reach 1 West slope cutthroat trout winter.

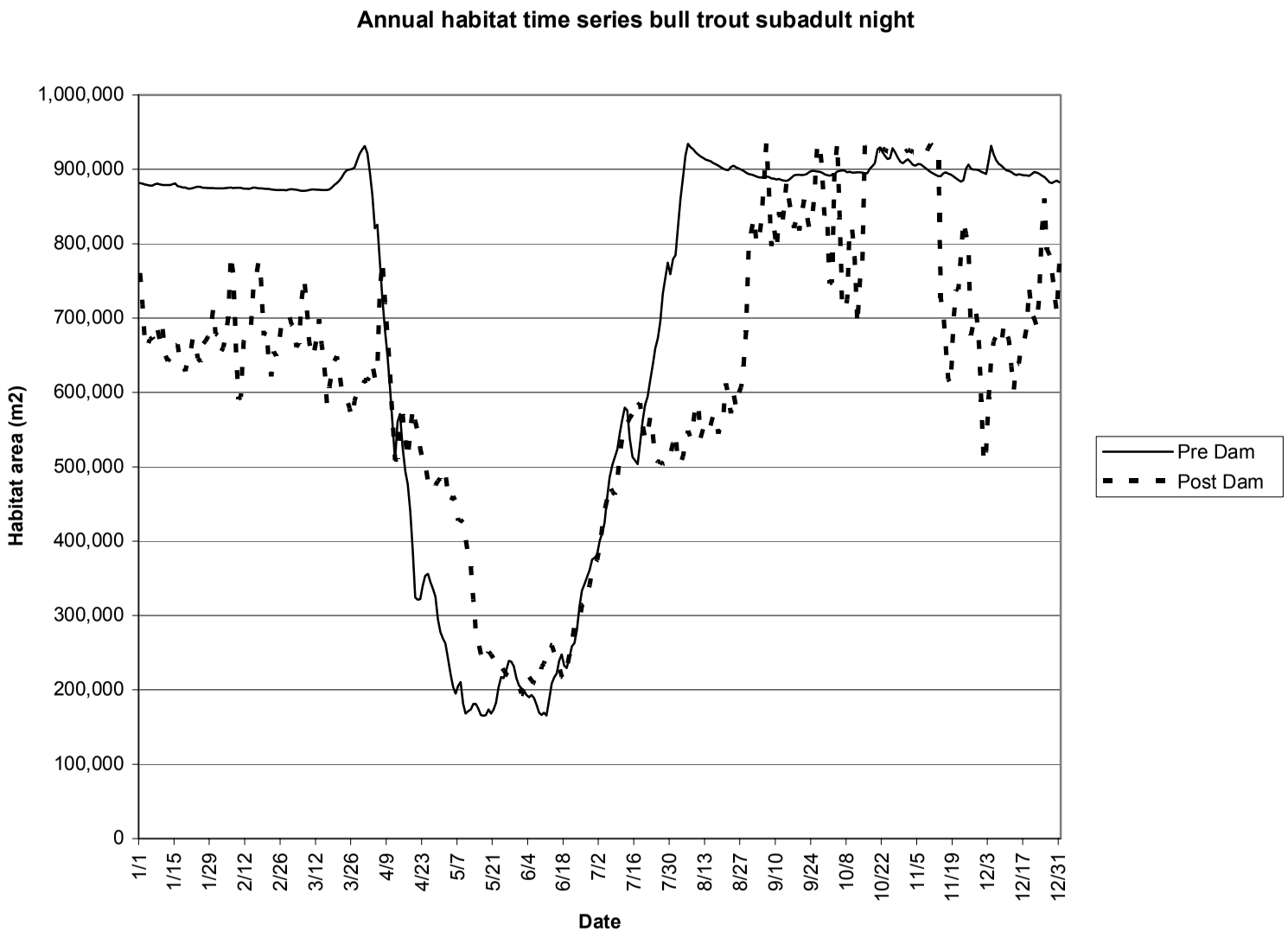


Figure 30. Annual habitat time series bull trout subadult night.

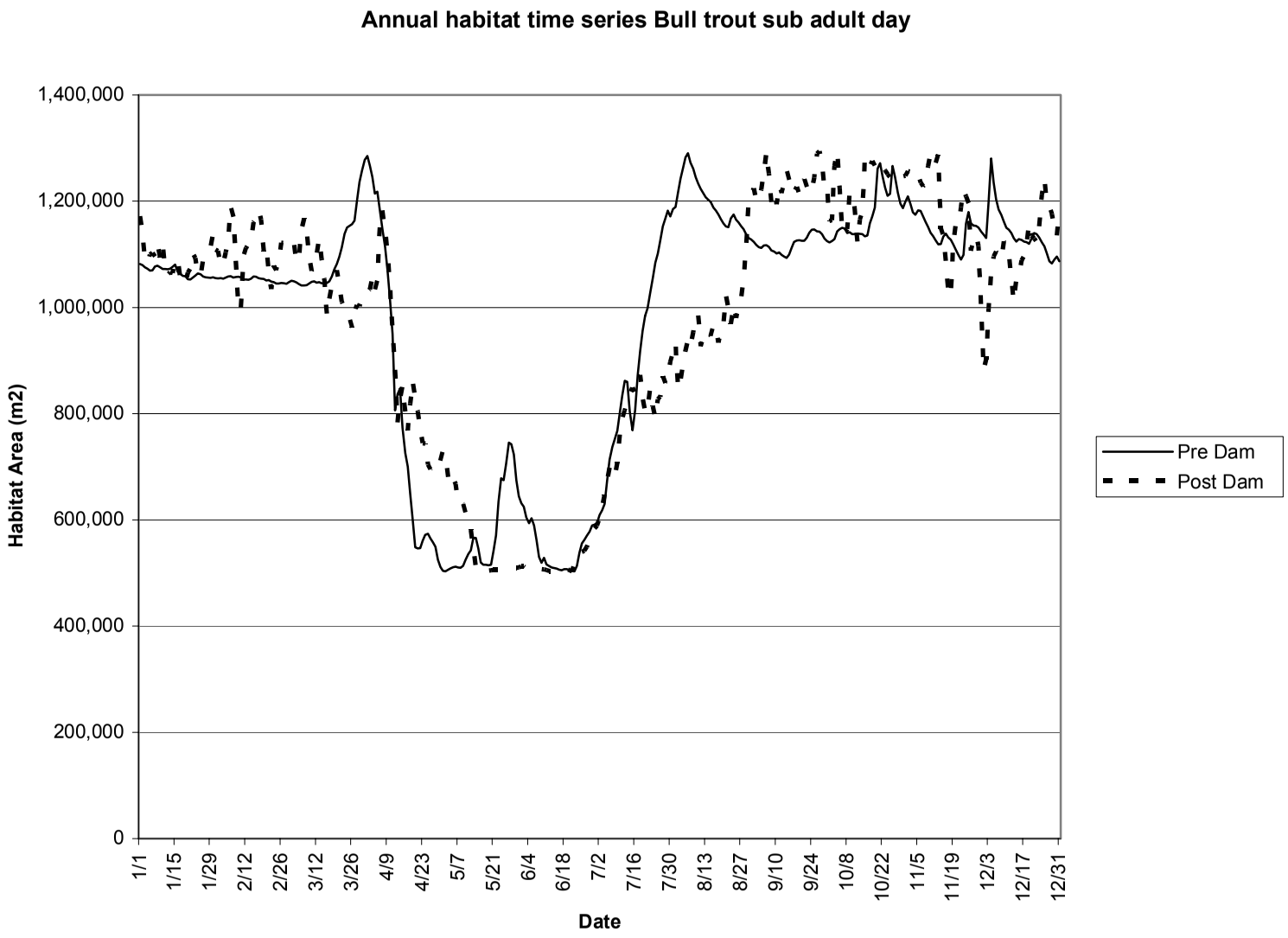


Figure 31. Annual habitat time series Bullt rout subadult day.

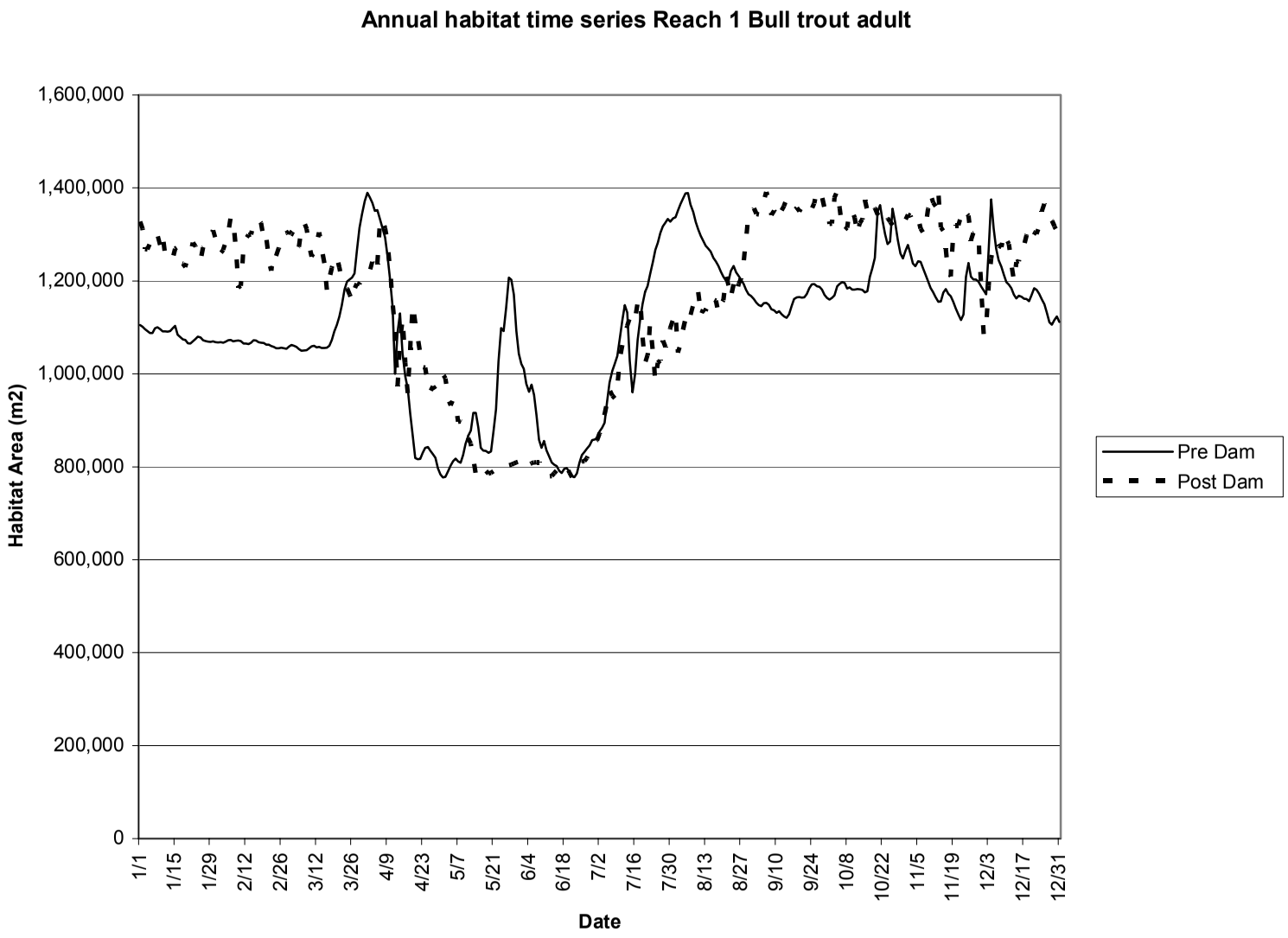


Figure 32. Annual habitat time series Reach 1 Bull trout adult.

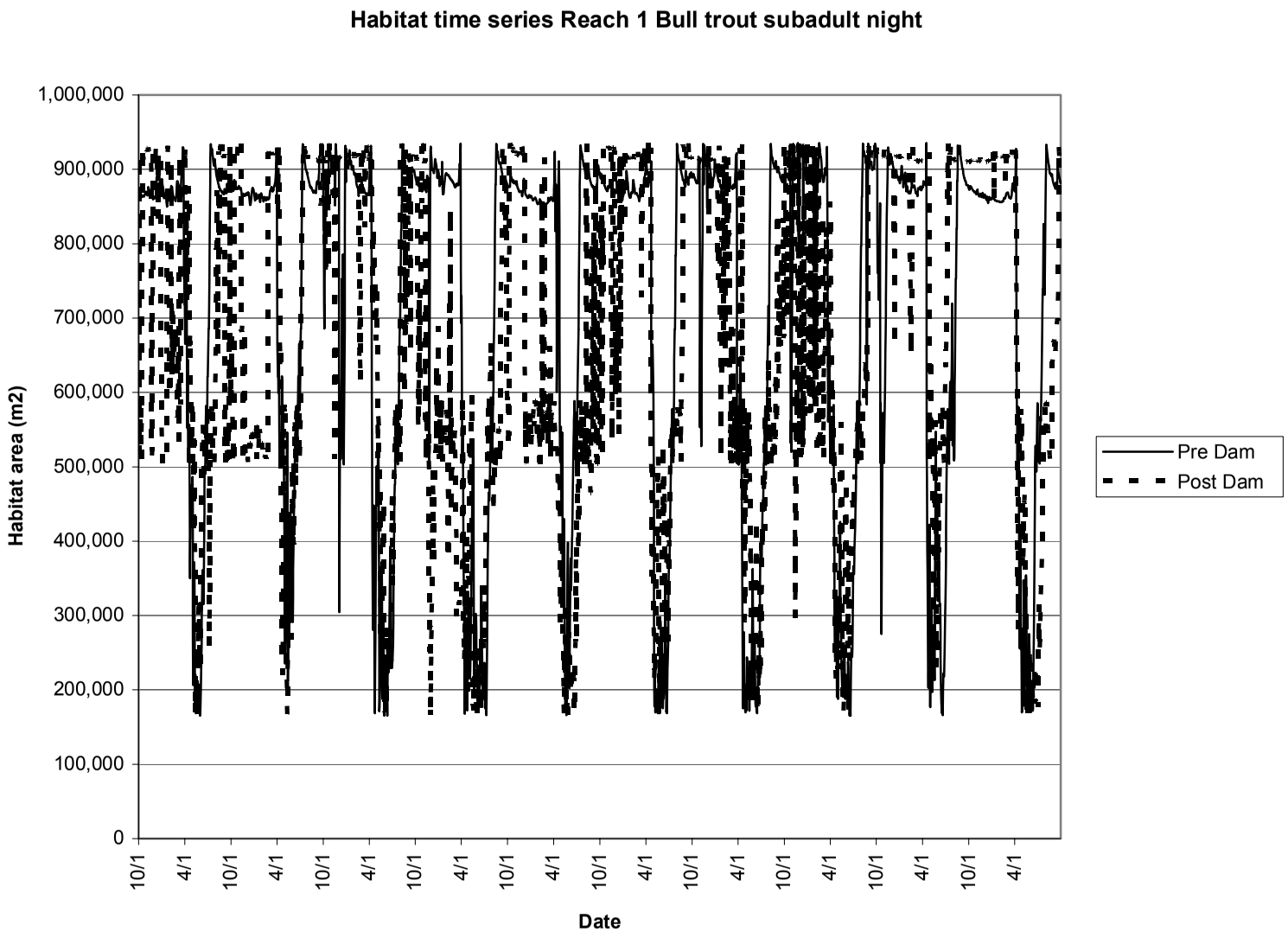


Figure 33. Habitat time series Reach 1 Bull trout subadult night.

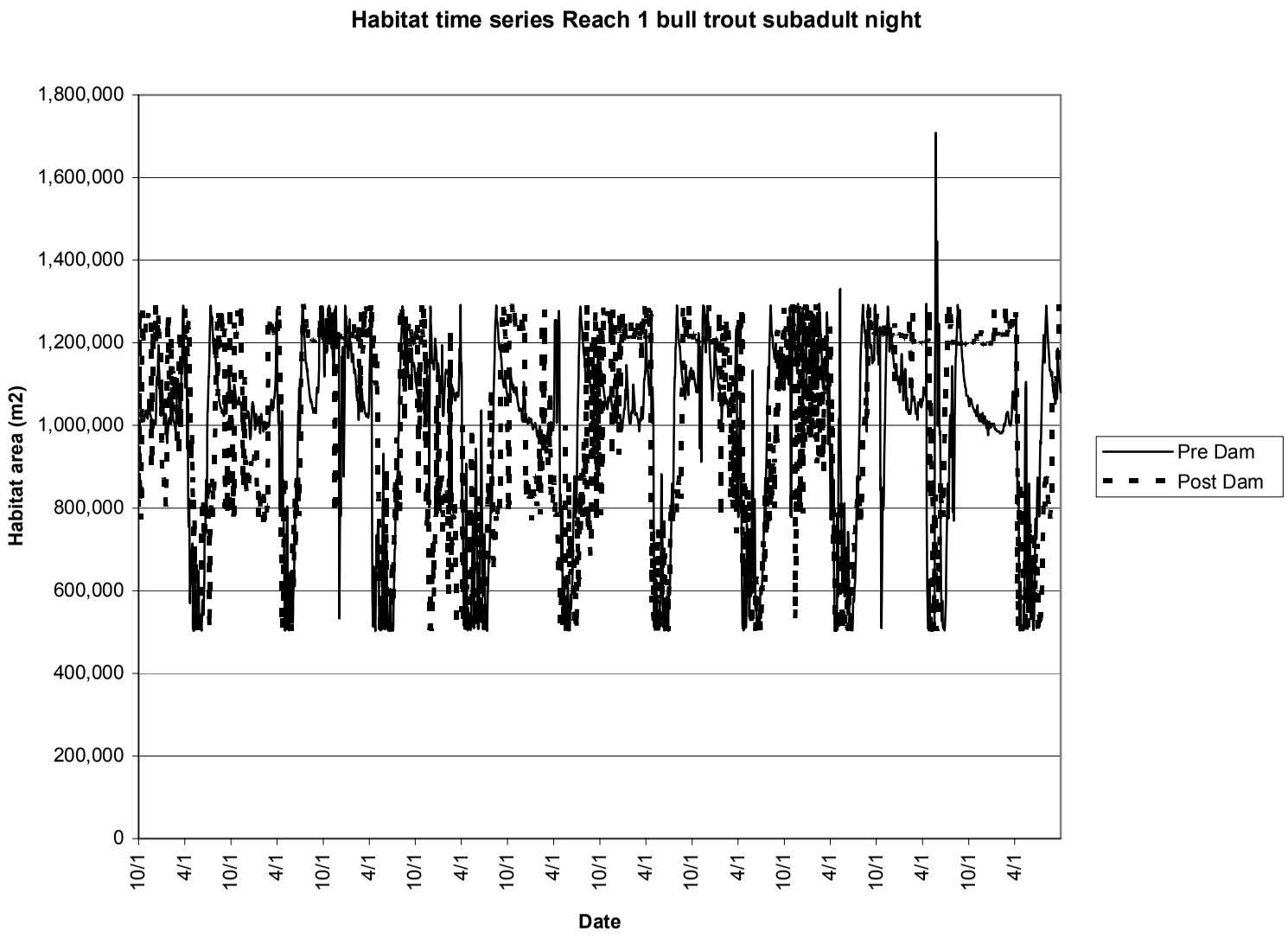


Figure 34. Habitat time series Reach 1 Bull trout subadult night.

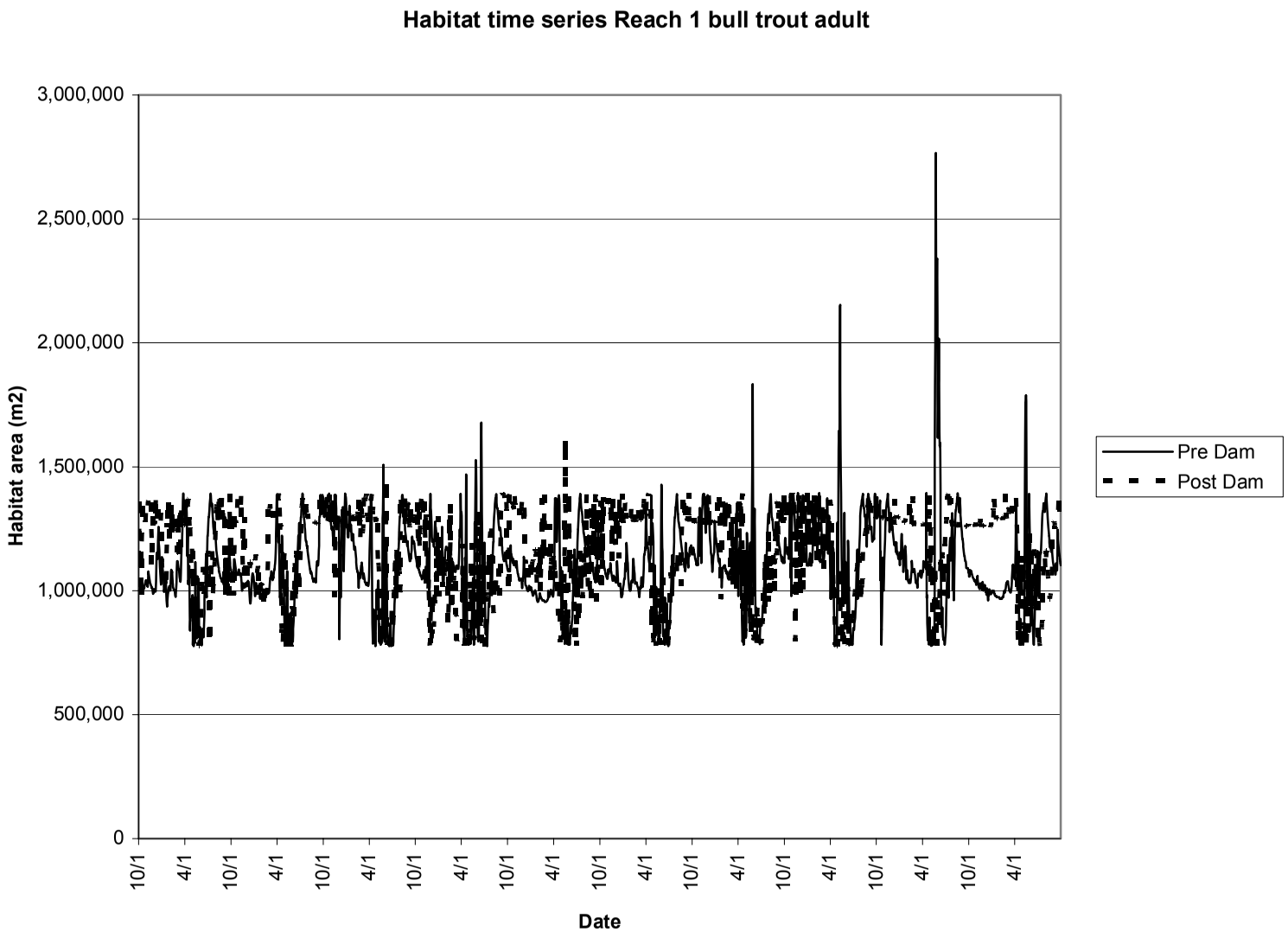


Figure 35. Habitat time series Reach 1 Bull trout adult.

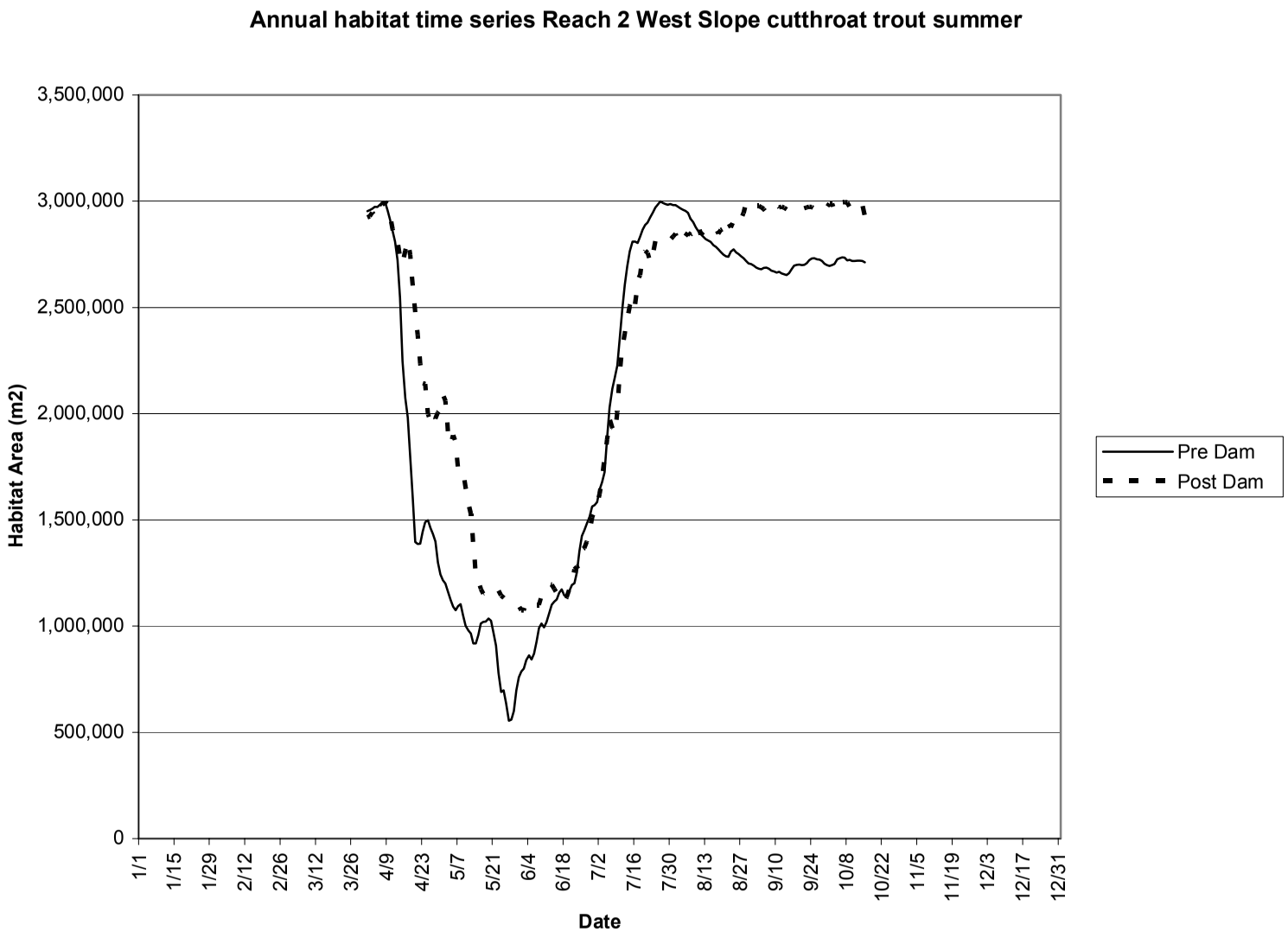


Figure 36. Annual habitat time series Reach 2 West Slope cutthroat trout summer.

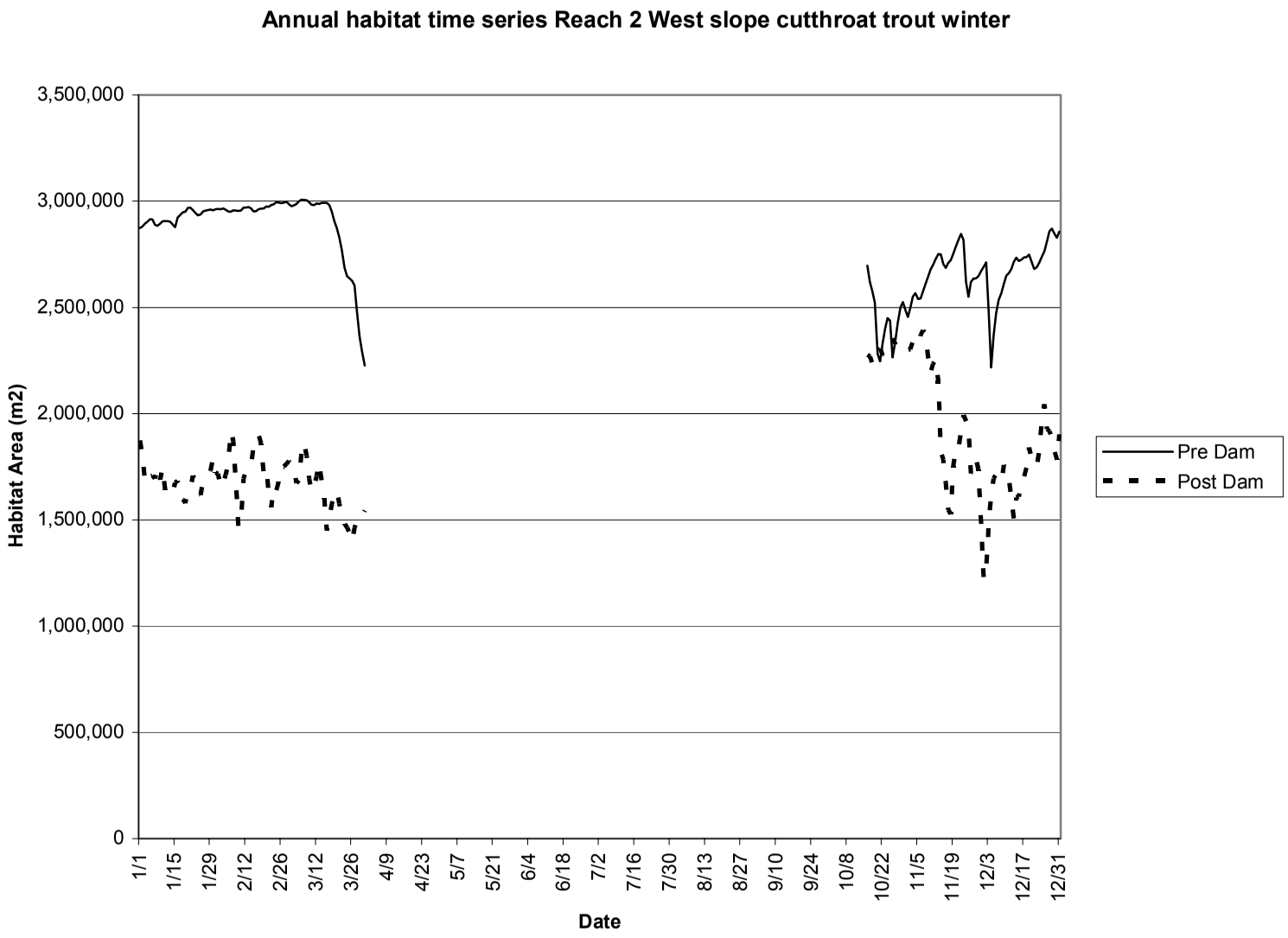


Figure 37. Annual habitat time series Reach 2 West Slope cutthroat trout winter.

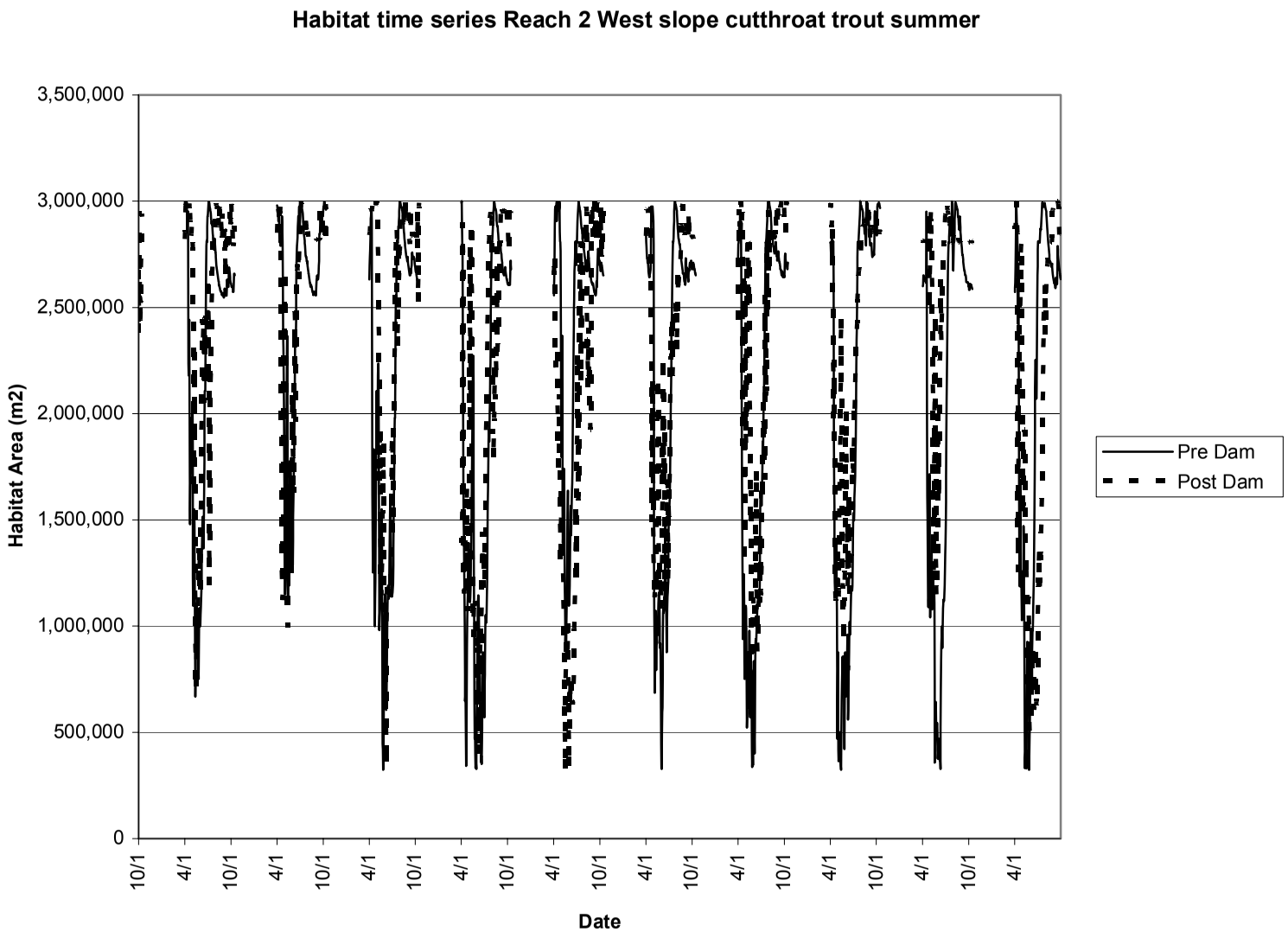


Figure 38. Habitat time series Reach 2 West Slope cutthroat trout summer.

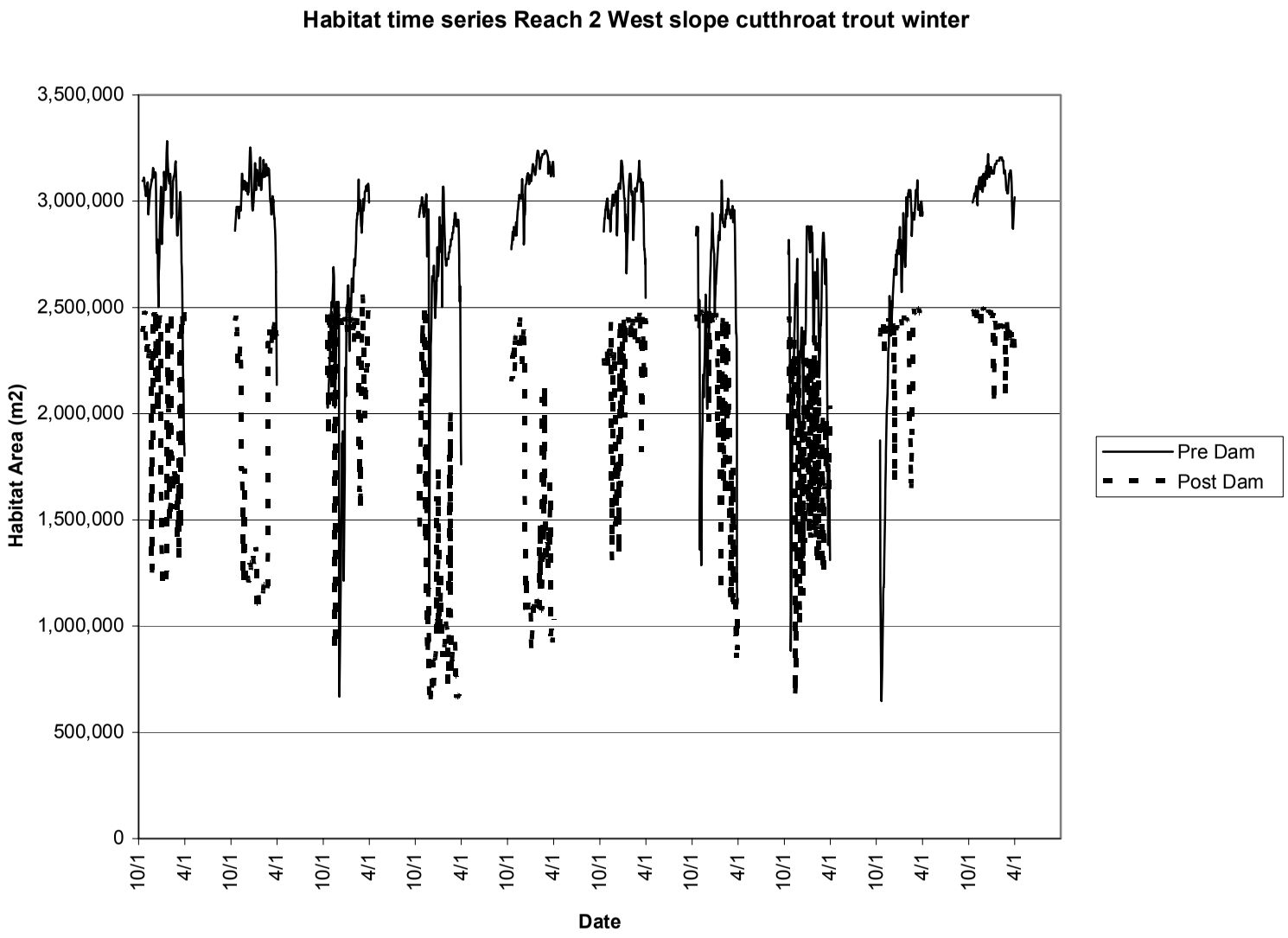


Figure 39. Habitat time series Reach 2 West Slope cutthroat trout winter.

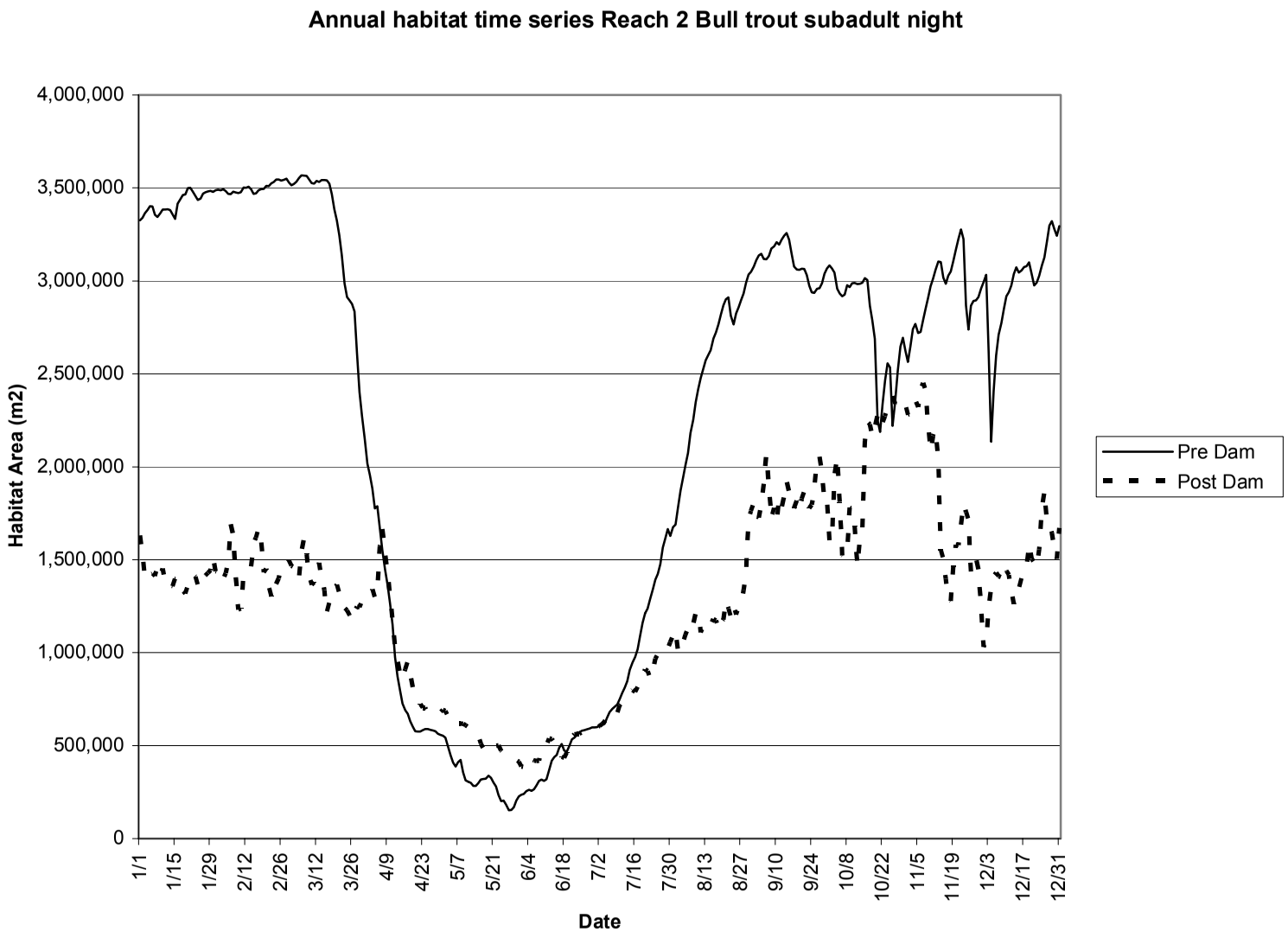


Figure 40. Annual habitat time series Reach 2 Bull trout subadult night.

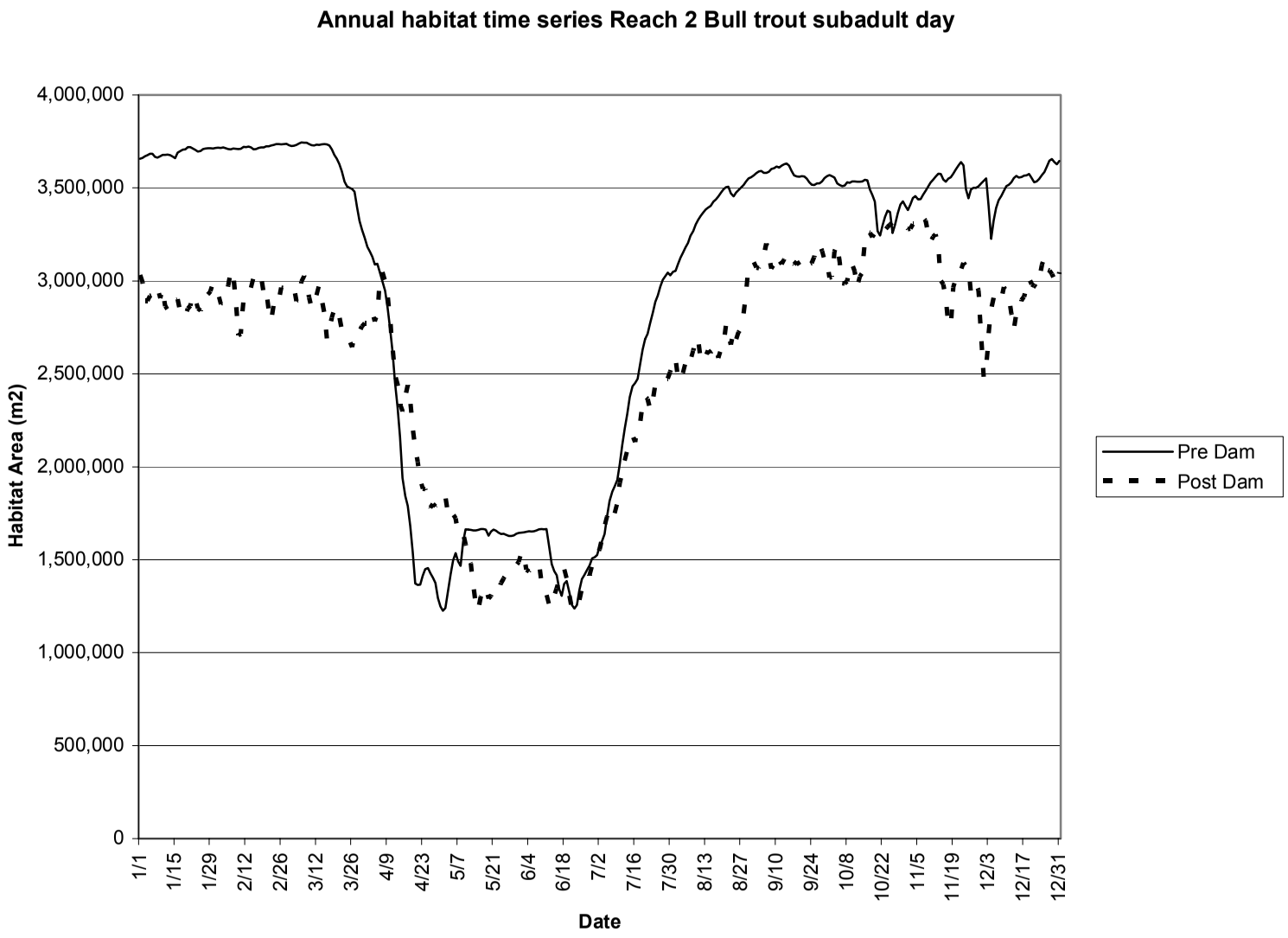


Figure 41. Annual habitat time series Reach 2 Bull trout subadult day.

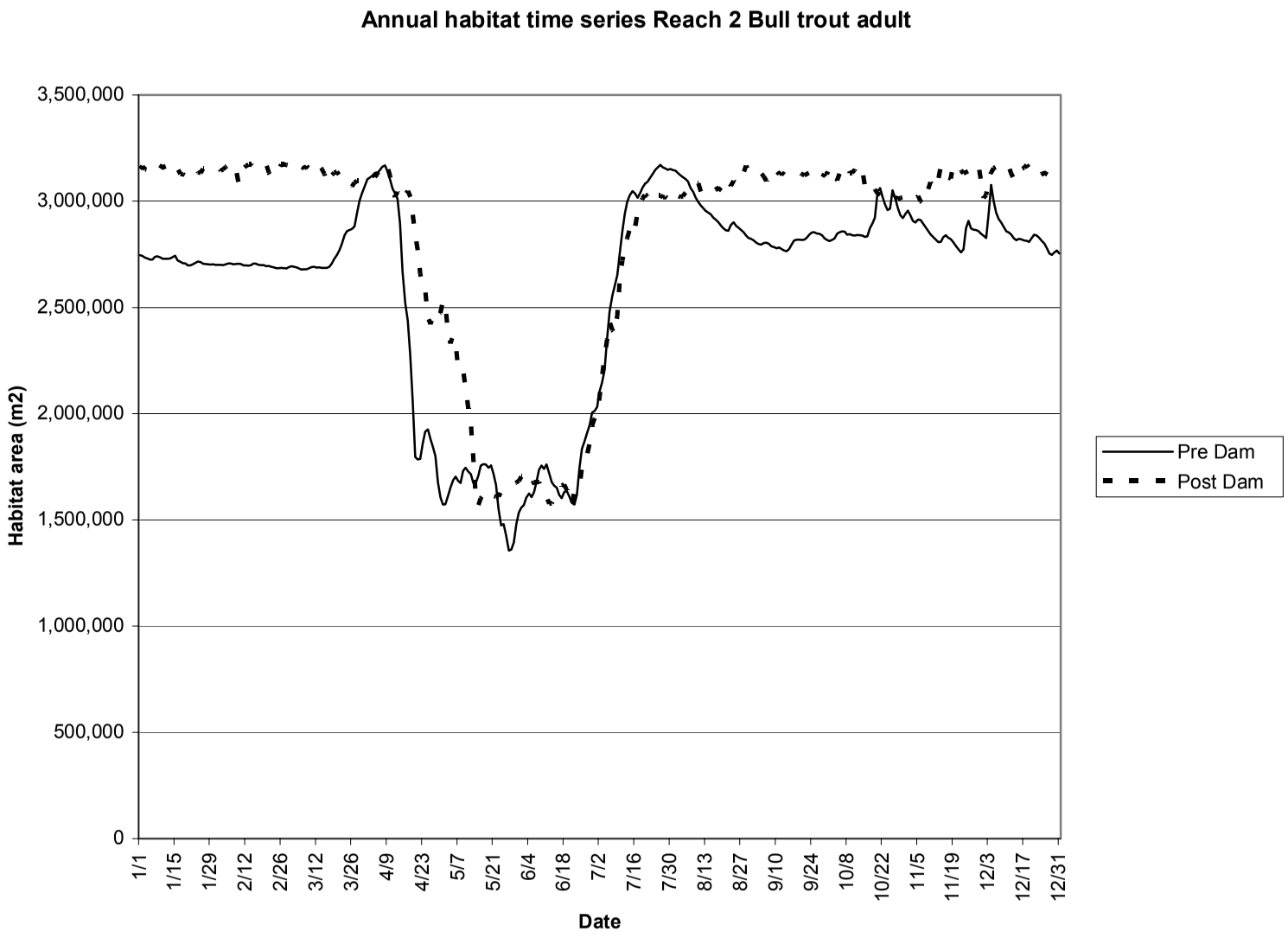


Figure 42. Annual habitat time series Reach 2 Bull trout adult.

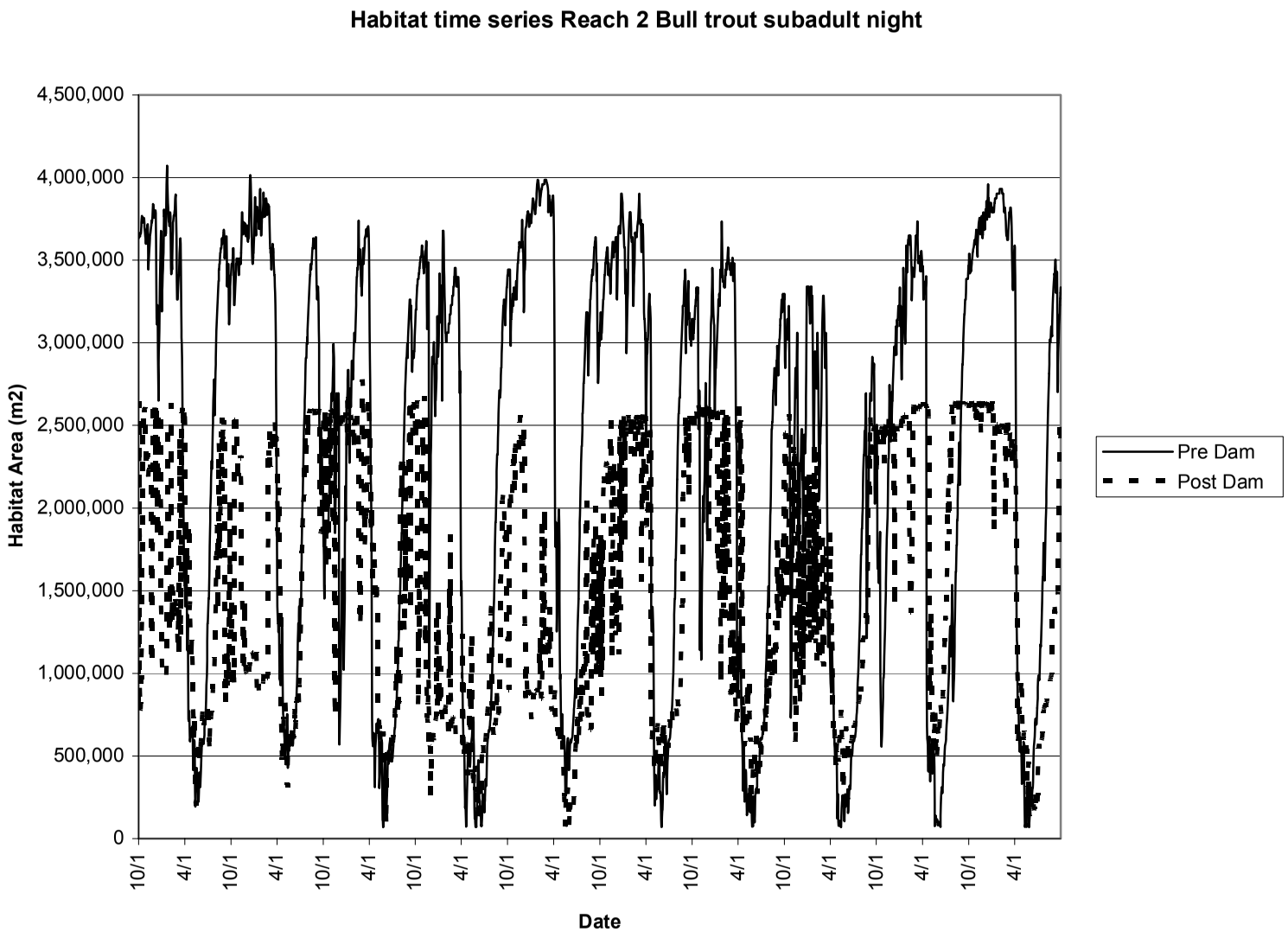


Figure 43. Habitat time series Reach 2 Bull trout subadult night.

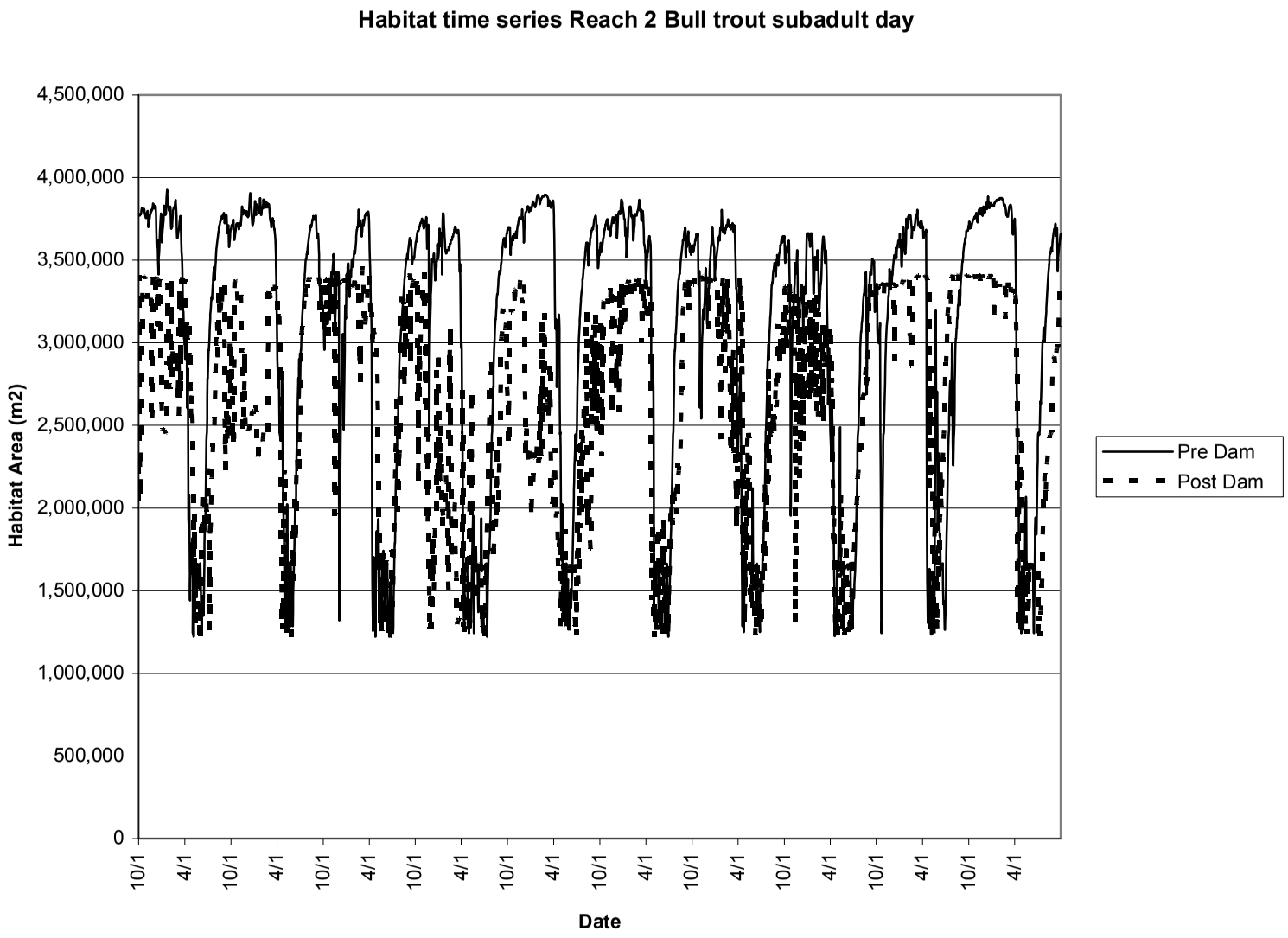


Figure 44. Habitat time series Reach 2 Bull trout subadult day.

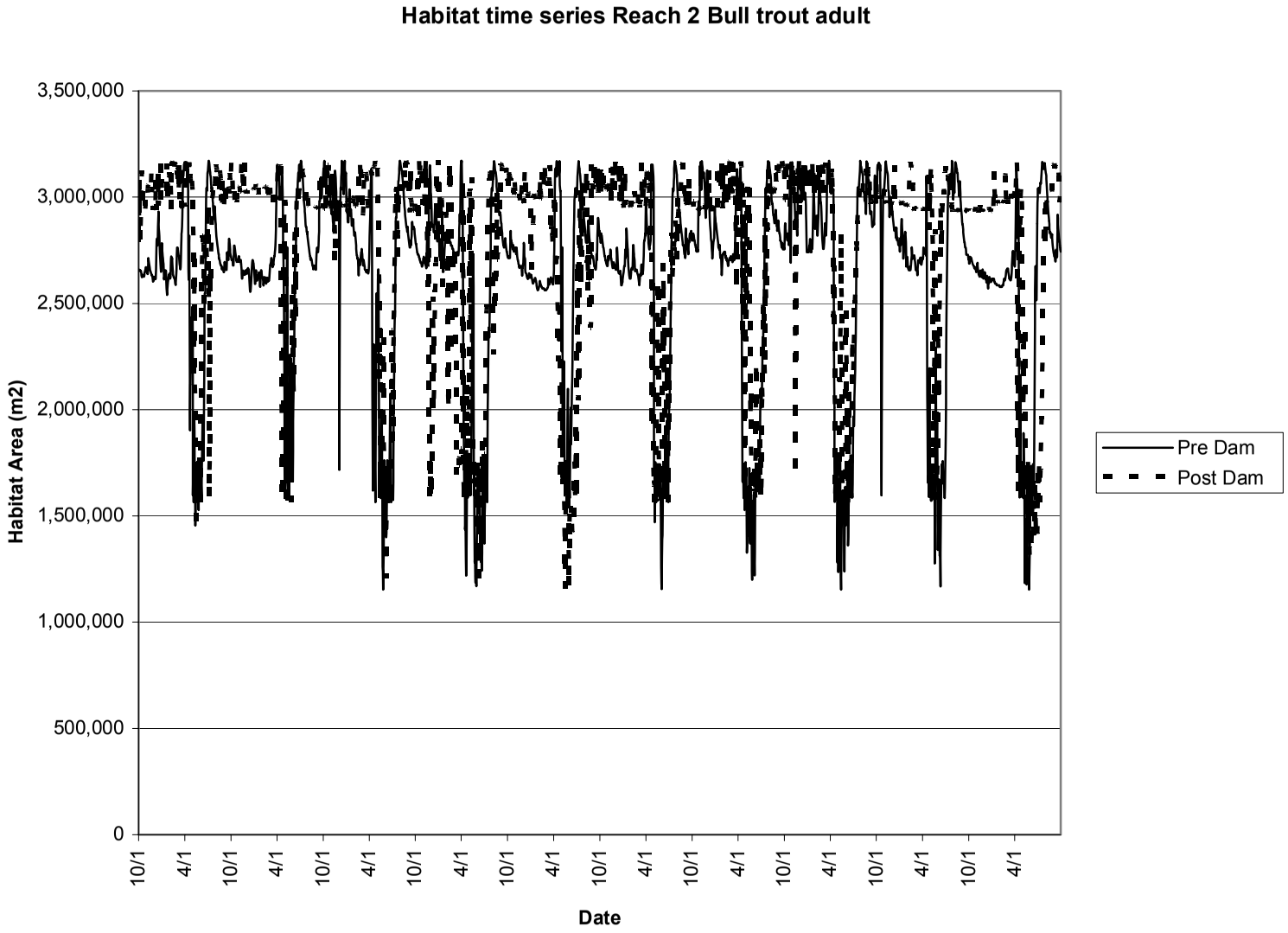


Figure 45. Habitat time series Reach 2 Bull trout adult.

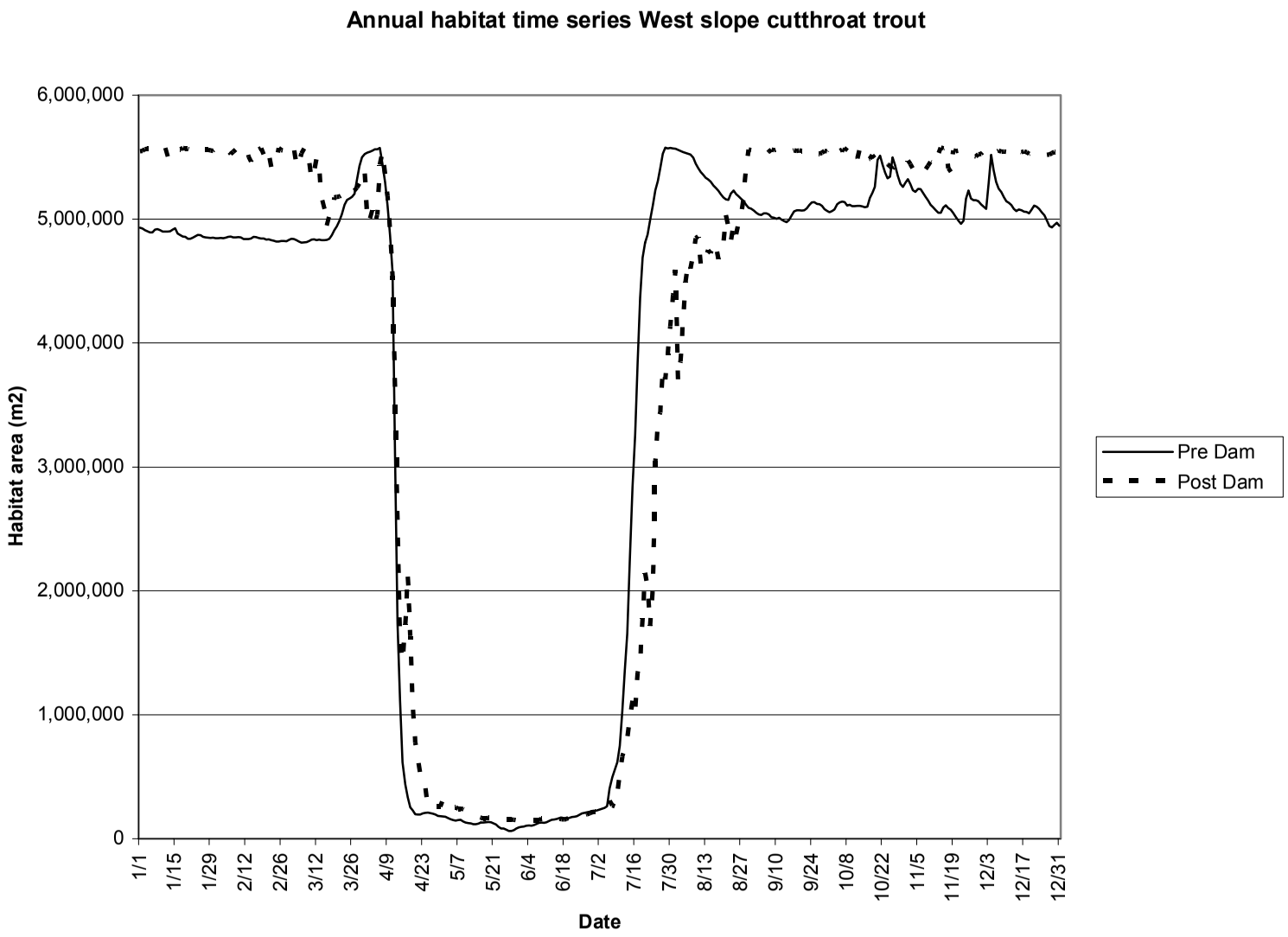


Figure 46. Annual habitat time series West Slope cutthroat trout.

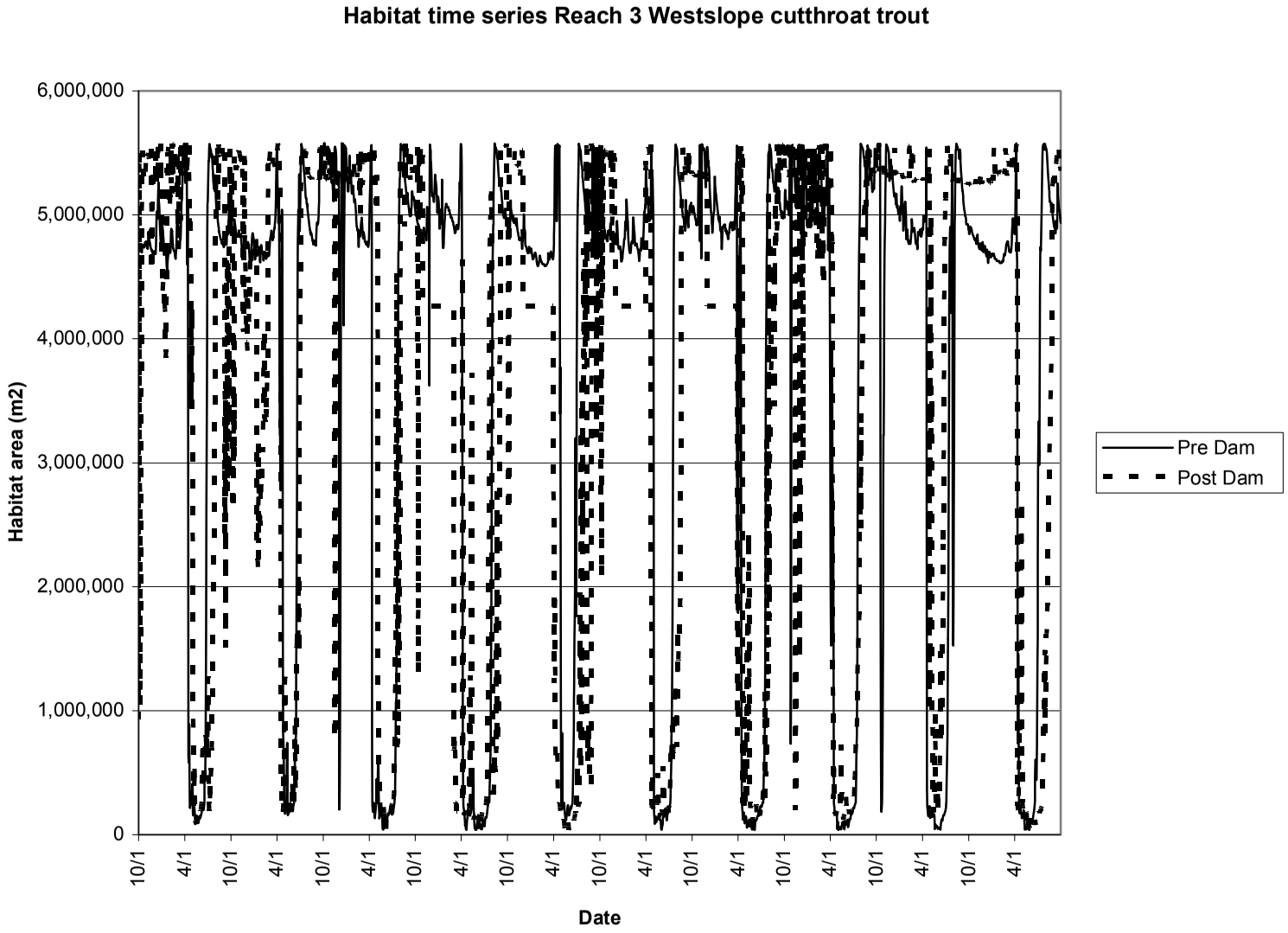


Figure 47. Habitat time series Reach 3 West Slope cutthroat trout.

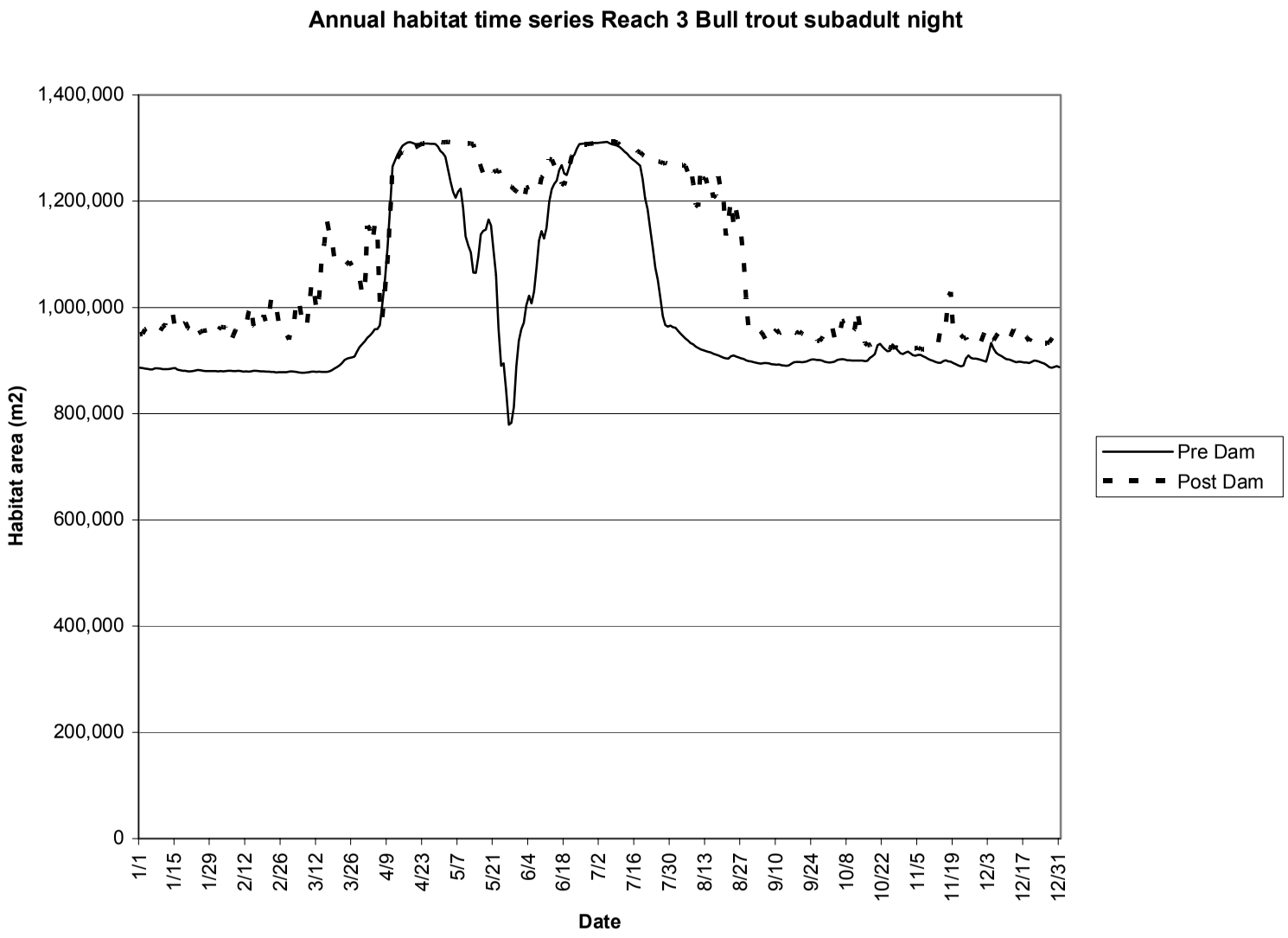


Figure 48. Annual habitat time series Reach 3 Bull trout subadult night.

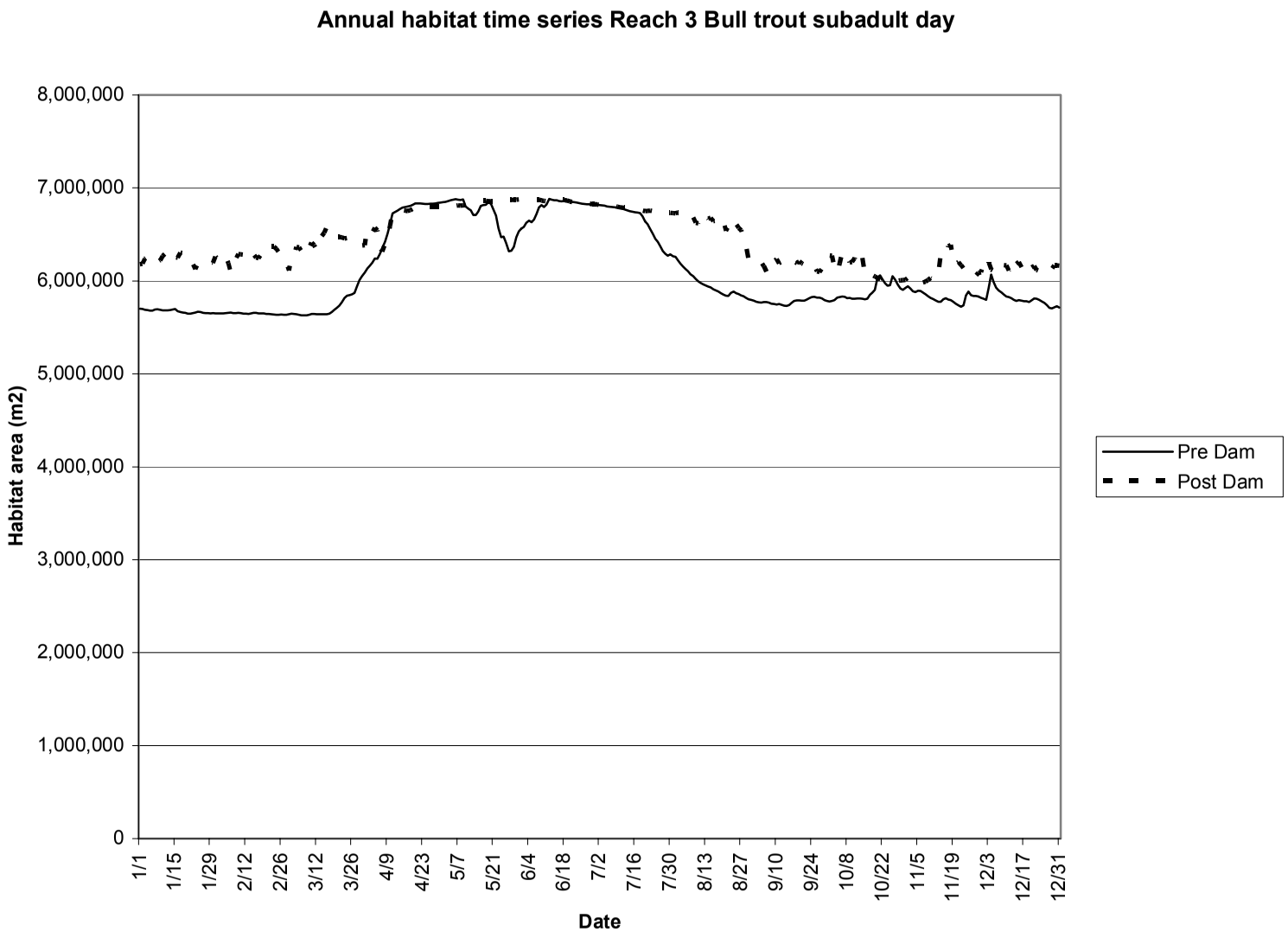


Figure 49. Annual habitat time series Reach 3 Bull trout subadult day.

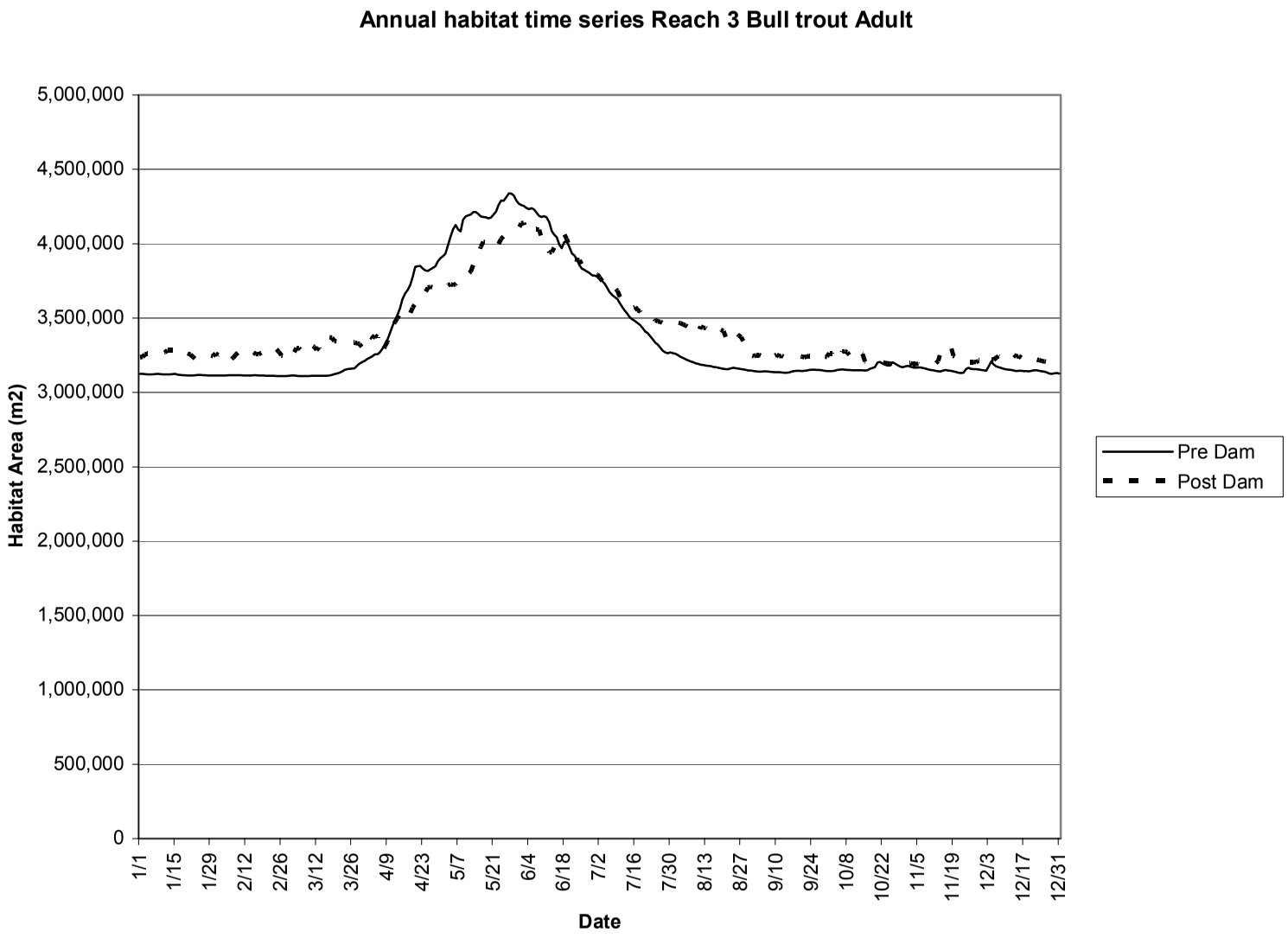


Figure 50. Annual habitat time series Reach 3 Bull trout adult.

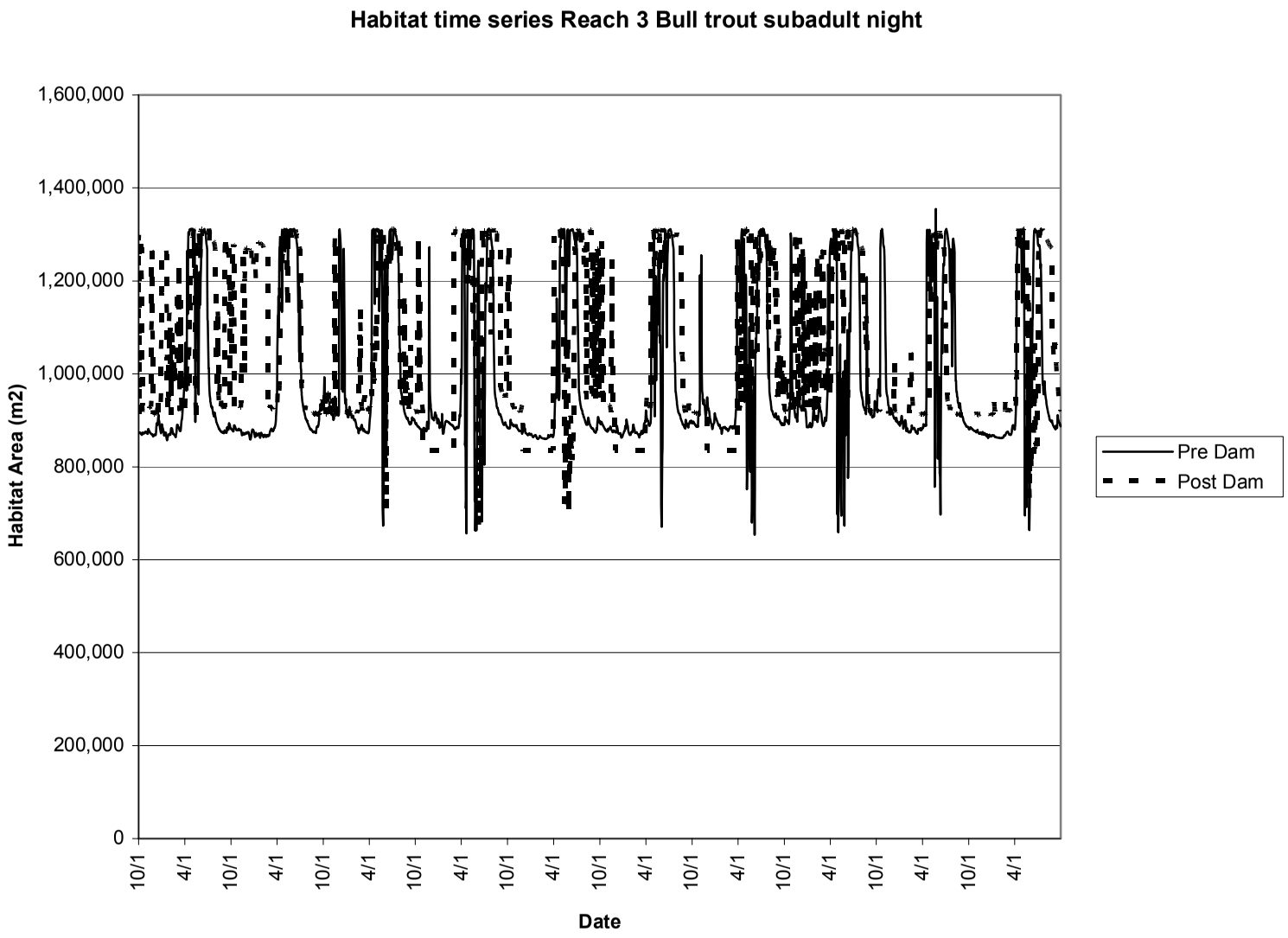


Figure 51. Habitat time series Reach 3 Bull trout subadult night.

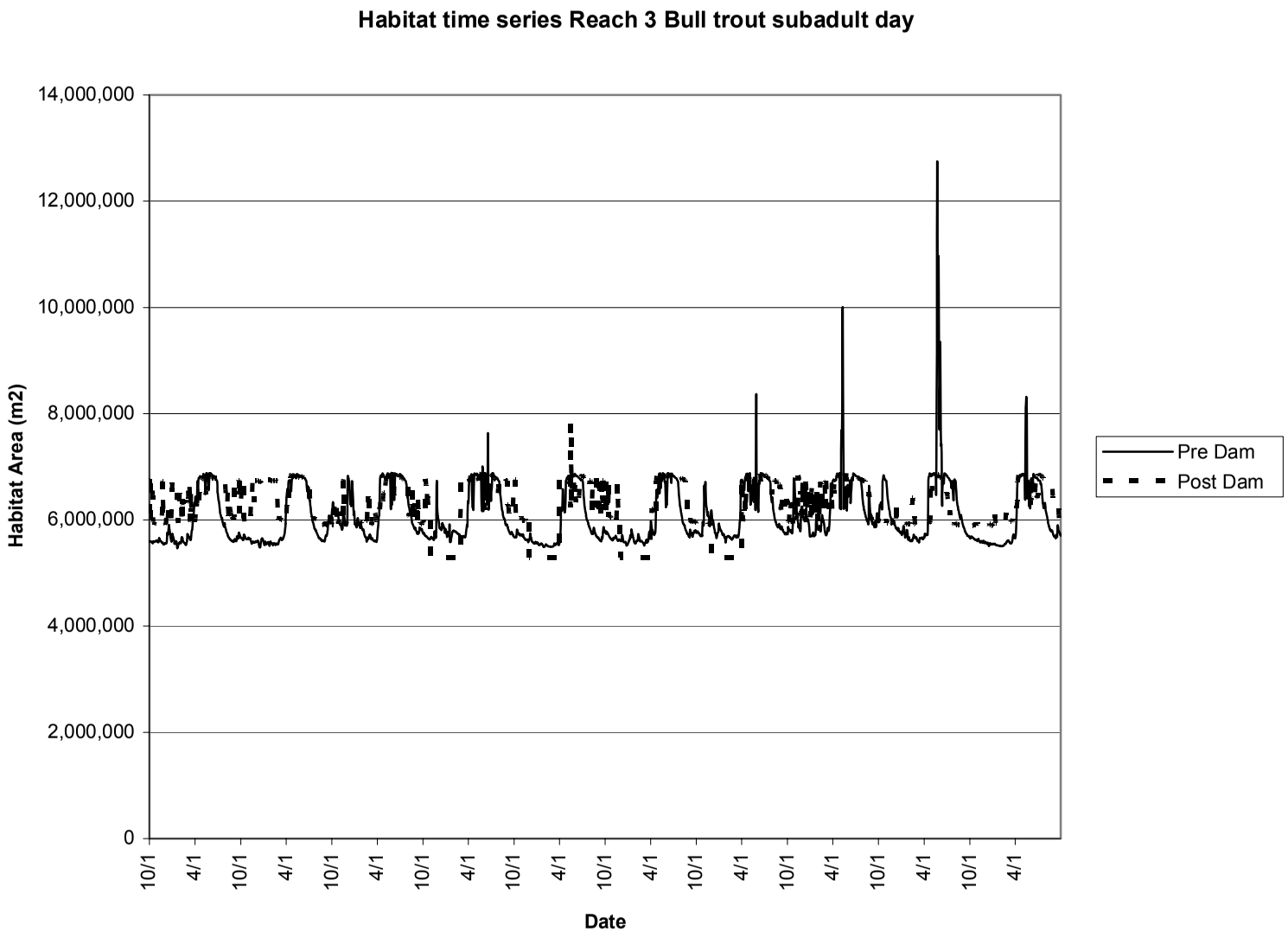


Figure 52. Habitat time series Reach 3 Bull trout subadult day.

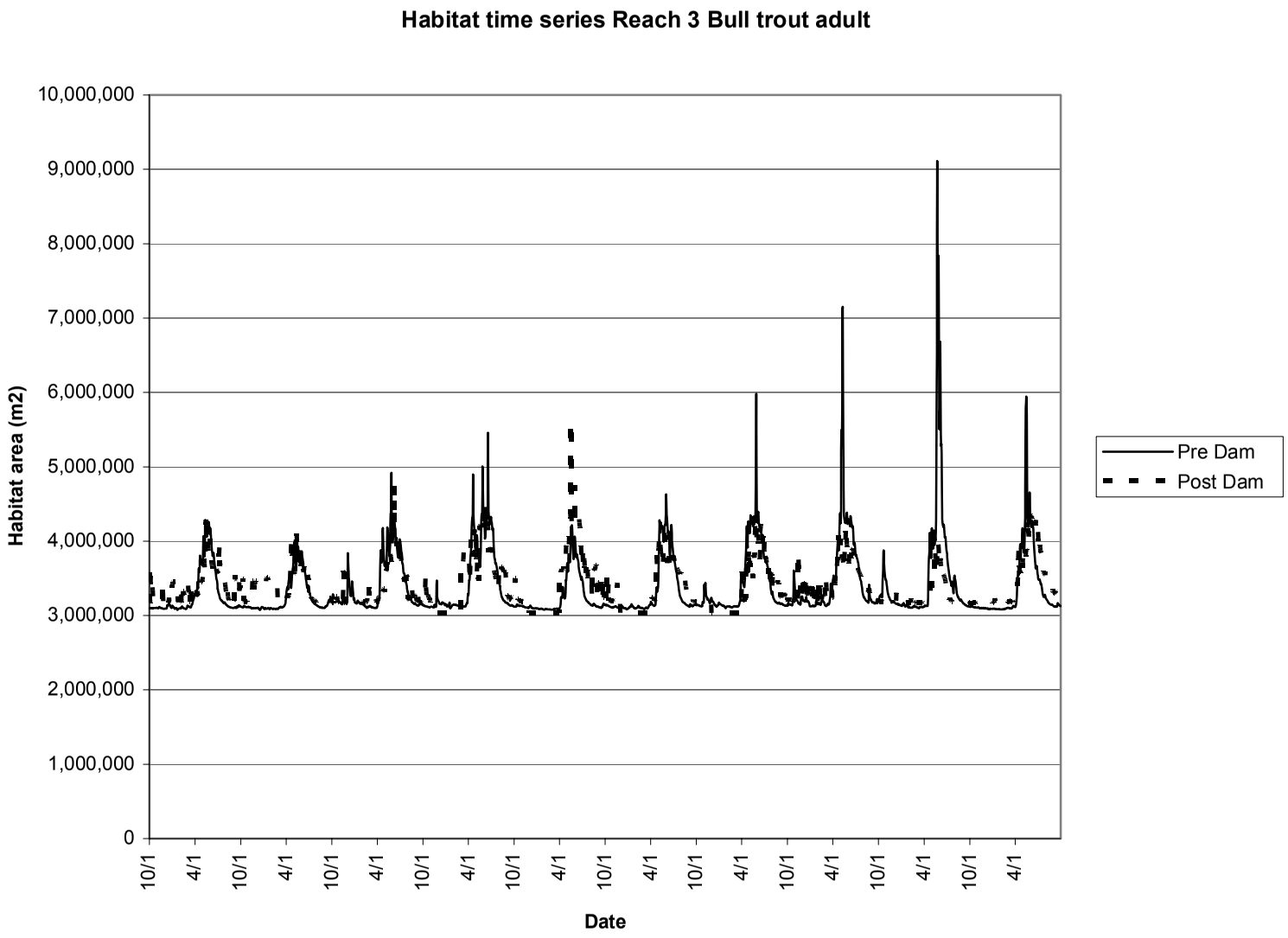


Figure 53. Habitat time series Reach 3 Bull trout adult.

CONCLUSIONS

The habitat simulations for the Flathead River show that, under the current hydrology, there is much more variability in habitat on a weekly and daily basis during the baseflow period through pre-dam. There are times when flows change from 105 cms to 169 cms in winter baseflows and extensive areas of channel margins are wet and then dried. The habitat suitability criteria show that bull trout move into those shoreline areas at night most likely to feed (Muhlfeld et al. 2003). Areas that are recently inundated have not had time to recolonize with benthic invertebrates. Dewatering of shoreline areas likely impacts bull trout sub-adults in foraging behavior as well as the benthic productivity of those areas. Benthic invertebrates provide food for higher trophic levels, such as west slope cutthroat trout. Fluctuations during summer periods from 10,000 to 20,000 cfs also have impacts to channel margins. Similar impacts to invertebrates can occur, which may require movement to find suitable foraging habitat by sub-adult and juvenile life stages of bull trout and west slope cutthroat trout.

The flow regimes with more stable baseflows, whether those flows are at 3,500 or 6,000 cfs, will likely be more productive for the system than flow regimes with high variability week to week and day to day in the operation of the reservoir. Summer flows with increased flow magnitudes late summer may be just as disruptive as the smaller fluctuations that occur in the winter period. Fluctuations in the summer with the higher discharges may be more disruptive to younger life stages, which have less ability to move about the channel and are required to move more often to find better habitat. An illustration of that was shown in the overlay maps with the 105cms and 169cms values that show that the habitat areas change substantially when flows change.

The results of this study can be used by Montana Fish, Wildlife and Parks for incorporation into flow recommendations for the Flathead River. The data presented here can incorporate operational constraints for both the thermal regime and spatial variability of habitat within the Flathead River.

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ACKNOWLEDGEMENTS

We thank those individuals and organizations that helped support this project. In particular, personnel from Montana Fish, Wildlife & Parks including Clint Muhlfeld and Brian Marotz and their staff that developed the habitat suitability information. Thanks also to Bonneville Power Administration for technical and administrative support on this project.

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APPENDIX A – LAND USE/LAND COVER ANALYSIS

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FLATHEAD RIVER INSTREAM FLOW INVESTIGATION

LAND COVER CLASSIFICATION AND CHANGE DETECTION ANALYSIS

DRAFT FINAL REPORT

September 10, 2003

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Revised August 2003

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1.0. Introduction

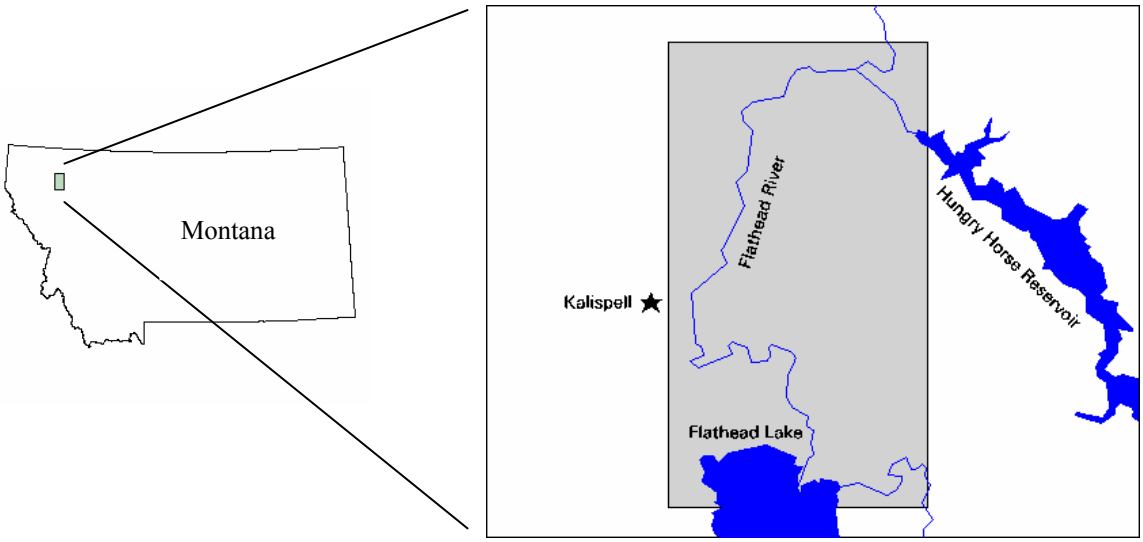
This report describes the land cover classification and change detection analysis work completed for Bonneville Power Administration (BPA) in conjunction with Montana Fish Wildlife and Parks (MFW&P) as part of the Flathead River Instream Flow Investigation Project.

The land cover classification was derived from a spatially enhanced, multispectral IRS-1C image acquired in 1998. Historic river channels were delineated from data acquired at three different time periods spanning 20 years to help identify and monitor changes in the river channel. Changes occurring between 1990 and 1998 were mapped in greater detail identifying the type (from – to) of land use / land cover change.

2.0. Project Area

The Flathead River stretches approximately 42 miles through the Flathead Valley in northwest Montana. The valley consists of fertile agriculture land and timber and is bound by the Swan Mountain Range to the East. The study area encompasses the Flathead River from the confluence of the South Fork of the Flathead River, near Columbia Falls, south to the Flathead Lake inlet. It was determined at the project initiation meeting that land cover would be mapped within one-half mile of the furthest outlying river channel.

Figure 1. Flathead River Study Area



3.0. Classification Scheme

It was determined during the project initiation meeting between MFW&P and SSI that the following land cover classes would be mapped for the study area. Classes mapped at a larger scale were facilitated through the collection of data during two days of fieldwork. Channel characteristics such as erosive banks and stabilized banks, were captured in vector format because of their linear nature. The vectors were coded by height as shown below in Table 1. See Appendix A for class definitions.

Table 1. Final Land Cover classification scheme

Class	Format	Mapping Scale	Source
Domestic	raster	1:24,000	IRS-1C Imagery
Agriculture	raster	1:24,000	IRS-1C Imagery
Grasslands	raster	1:24,000	IRS-1C Imagery
Forest	raster	1:24,000	IRS-1C Imagery
Willow	raster	1:12,000	IRS-1C Imagery
Bare, rocky lands	raster	1:24,000	IRS-1C Imagery
Water	raster	1:24,000	IRS-1C Imagery
Steep, highly erosive banks	vector	1:12,000	Field work
<= 5 feet			
6-10 feet			
> 10 feet			
Stabilized banks	vector	1:12,000	Field work
Automobiles			
Rock Rip Rap			
Cobbles			

4.0. Data Used

4.1. IRS Satellite Imagery

Imagery from the Indian Remote Sensing Satellite (IRS-1C) was acquired to produce the 1998 land cover classification. Since the IRS satellite has multiple sensors on board, it was possible to obtain both a 20-meter mutlispectral image (LISS III channel) and a 5-meter panchromatic (PAN channel) image that were acquired at the same time. The two images were then merged together to create a single image that combined the spectral resolution from the LISS III product with the higher spatial resolution of the PAN product. This spatially enhanced multispectral image allowed SSI to map the land cover and changes at a larger scale.

Table 2. IRS bands used for classification.

Band	Wavelength (µm)	Wavelength (nominal)
2	0.52-0.59	Green
3	0.62-0.68	Red
4	0.77-0.86	Near-infrared
PAN	0.5-0.75	Panchromatic

Table 3. IRS imagery specifications.

Scene	Date	Scene ID	Size	Notes
249/034	9/6/98	99103037-01	70x70 km	1C - Panchromatic
249/034	9/6/98	99103037-01	141x141 km	1C- LISS –3 4band multi spectral

4.2. USDA Forest Service Resource Photography

Aerial photography was acquired from the USDA Forest Service at a scale of 1:15,840. These natural color photographs were flown during 1997 and 1998. The aerial photographs provided ground reference information for the land cover classification and also served as a basemap for classifying channel characteristics during fieldwork. Twenty-five 10x10 photographs were required for full coverage of the study area. A diagram showing the coverage can be found in Appendix B.

4.3. Digital Orthophoto Quarter Quads

Digital Orthophoto Quarter Quads (DOQQs) were acquired and used as the data source for interpreting the 1990 river channel and detailing the change that occurred

between 1990 and 1998. These panchromatic aerial photos are scanned at 1-meter spatial resolution and orthogonally rectified to remove any displacement caused by relief or camera distortions. The aerial photos were flown during the month of July 1990 and 1991. A list of the DOQQs that cover the study area can be found in Appendix C.

4.4. Digital Raster Graphics

Digital Raster Graphics (DRGs) were used as the data source for interpreting the earliest river channel. A DRG is a standard USGS 7.5 minute topographic map scanned at a resolution of 2.8 meters and output to a georeferenced TIF file. The majority of the DRGs used for the study area were originally produced during the 1950s and photo updated in 1978. A list of the DRGs used can be found in Appendix D.

5.0. Flow Levels

Mapping the extent of the river from aerial photographs and satellite imagery involved interpreting the boundary between water and land within the river channel. Since the Hungry Horse Dam impacts the flow of the Flathead River, the dynamic flow levels of the river influence the channel boundaries. Daily flow levels were obtained from the USGS gauging station located at Columbia Falls, which lies on the upper portion of the study area. The following chart shows the daily flows for the dates of data acquisition.

Table 4. Daily Flow Levels for Flathead River at Columbia Falls

Data Source	Acquisition Date	Flow (CFS)
USGS DRGs	1978	< 27,000 *
DOQQs	7/1/90	27,000
IRS-1C	9/6/98	3,570
Resource Photography	7/28/97	8,020
	7/16/98	12,600
Field Work	8/2/99	8,810
	8/3/99	9,990

Note: The USGS DRGs cannot be linked to a specific date, therefore no daily flow measurement was available. It is estimated that the flow level is less than that of the highest flow of 27,000 cfs.

6.0. Methodology

6.1. Rectification

Rectification of the satellite imagery is required so that it will geographically register with a specified map coordinate system and other GIS data layers. The output land cover data will have the same geometric characteristics as the rectified satellite imagery, so rectification of the imagery is an important step. The process involves collecting ground control points from a data source with a known map coordinate system and selecting corresponding points on the satellite imagery. Over twenty points are usually collected to rectify an entire satellite scene. The geometric relationship among the points is used to calculate the root mean square (RMS) error, which is a measure of the accuracy of the rectification. A RMS error of about one half of a pixel (0.5) is considered excellent and an error of less than 1.0 is usually acceptable.

DOQQs were used to collect ground control points for rectification. No irregularities were encountered during the rectification process and a RMS error of less than 0.5 was attained for both of the satellite scenes.

6.3. Ground Truth Data - Collection

Fieldwork was required to collect data that was not discernable on the satellite imagery and also to provide additional ground truth for areas adjacent to the river channel for the 1998 classification. A piloted boat was provided by MFW&P for two days to allow two image analysts from SSI to map channel features and adjacent land uses and land cover. Natural color aerial photography printed at 1:15,840 scale was used as a basemap for mapping features such as eroded banks, stabilized banks and willows. These data were then digitized to create a digital, georeferenced data set that could be used to enhance the land cover classification derived from the IRS image. Table 5 shows the data created from the fieldwork completed in July 1999.

Table 5. Data Collected During Field Work

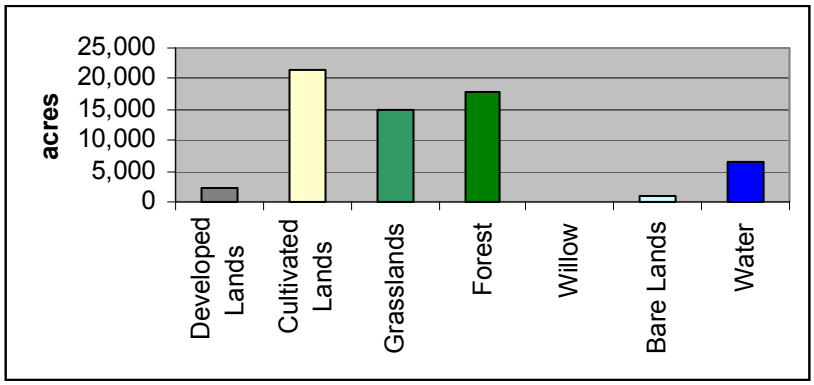
Feature	Class
Erosive Bank	<= 5 feet
	6-10 feet
	> 10 feet
Stabilized Bank	Automobiles
	Rock Rip Rap
	Cobbles
Willows	Willows

6.4. Classification

The enhanced IRS data was processed using an ISODATA clustering routine, which groups the image into spectral clusters. The number of spectral clusters output by the ISODATA routine is specified by the image analyst, and depends on the spectral variability of the data. For the initial clustering process, 125 clusters were specified for the study area. Once the 125 clusters were analyzed, those clusters that represented true classes were kept and those that were considered confusion clusters were run through the routine again to further refine the clustering. Once all of the clusters were assigned to a designated class, manual editing of the classification took place to correct any misclassifications of spectrally similar features. Table 5 shows the acreage for each land cover category in the study area.

Table 5. Land cover acreage counts, 1998 classification.

Land Cover Category	Total Acreage
Developed Lands	2,194
Cultivated Lands	21,357
Grasslands	14,774
Forest	17,818
Willow	123
Bare Lands	1,085
Water	6,584
Total Area Classified	63,935



6.5. Urban and Rural Developed Areas Classification

The urban and rural developed lands were classified separately from the rural areas to help improve the accuracy of the classification. Urban structures such as concrete and rooftops are often spectrally similar to dry, bare soil and exposed rock. To avoid confusion between these cover types, urban areas were manually delineated on the IRS data and extracted from the imagery. An unsupervised classification was then performed on these areas. One hundred spectral clusters were specified for the urban classification regions. Clusters that represented urban areas were saved and coded appropriately. Clusters that did not represent urban areas were coded as class zero, so that categories from the rural classification would inhabit these areas when the urban and rural classifications were combined.

6.7. Raster Generalization

The land cover classification was generalized to remove "salt and pepper" from the land cover data. In most original classification products, very small pixel clumps, which fall along category boundaries, are erroneously classified. In this project, the single pixels and small clumps were dropped out using a "clump and sieve" routine and filled in by using a majority filter algorithm. Clumps less than four pixels in size were eliminated and replaced with the surrounding majority class.

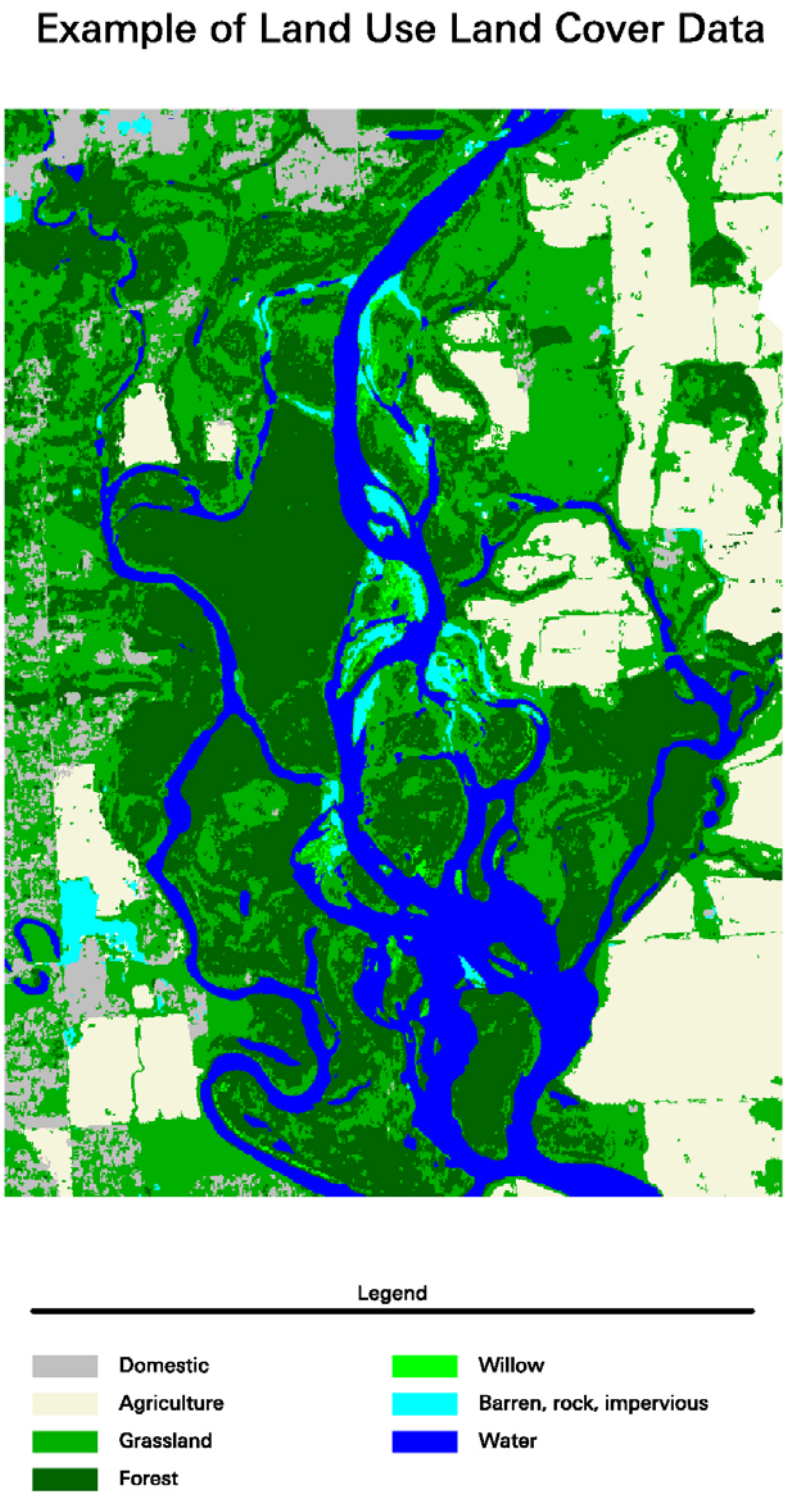


Figure 2. Example of 1998 land cover classification.

6.8. Simple Change Detection

Simple change was defined as a change from water to another land cover class or any land cover class to water. Simple change in the river channel was identified for three time periods: 1978-1990, 1990-1998 and 1978-1998. The river channels were digitized from the DRGs to create the 1978 channel, the DOQQs to create the 1990 channel and extracted from the IRS-1C classification to create the 1998 channel. An overlay technique was used to compare the river channels and identify areas of change and the general type of change. Table 6 shows amount of change identified.

Table 6. Results of the Simple Change Detection Analysis

	Simple Change	Acres
1978-1990	from land surface to water	1,359
	from water to land surface	697
1978-1998	from land surface to water	1,048
	from water to land surface	1,122
1990-1998	from land surface to water	470
	from water to land surface	1,205

The simple change analysis was extended to include the time span between 1937-38 and 1978, 1990 and 1998. Black and white aerial photos were acquired from federal archives of the Agricultural Stabilization and Conservation Service.

Twenty-seven photos from three dates of acquisition were available to make up the composite image for the Flathead River. The dates are 8/16/1937, 8/29/1937 and 5/21/1938. The recorded flow of the river for each date were 2,910 cfs, 2,200 cfs and 26,100 cfs respectively. The four photos from the high flow date of 5/21/1938 covered an east-west strip approximately midway between the upper and lower ends of the study area.

The photos were scanned, rectified to the project coordinate system and mosaiced into one seamless image. Within the mosaicing process steps were taken to minimize the area used from the high flow date photos.

The river channel was digitized and converted to a raster image file for processing. The results of each date comparison are shown in Table 7 below:

Table 7. Results of the Simple Change Detection Analysis 1937 – 1978, 1990, 1998

	Simple Change	Acres
1937-1978	from land surface to water	1,460
	from water to land surface	628
1937-1990	from land surface to water	2,495
	from water to land surface	606
1937-1998	from land surface to water	2,106
	from water to land surface	948

As opposed to the more recent river change detection, conducting this simple change analysis revealed a very high magnitude of change in the Flathead River since 1937. Multiple areas exist where the shift in the main channel is 300 to 400 feet and in some cases is over 1,000 feet in the upper reaches of the river study area. Changes are equally dramatic in the braided area east and south-east of Kalispell. In the lower reaches of the river affected by Flathead Lake changes are less pronounced but still visible in multiple areas. See Figures 3 and 4 for examples of this change.

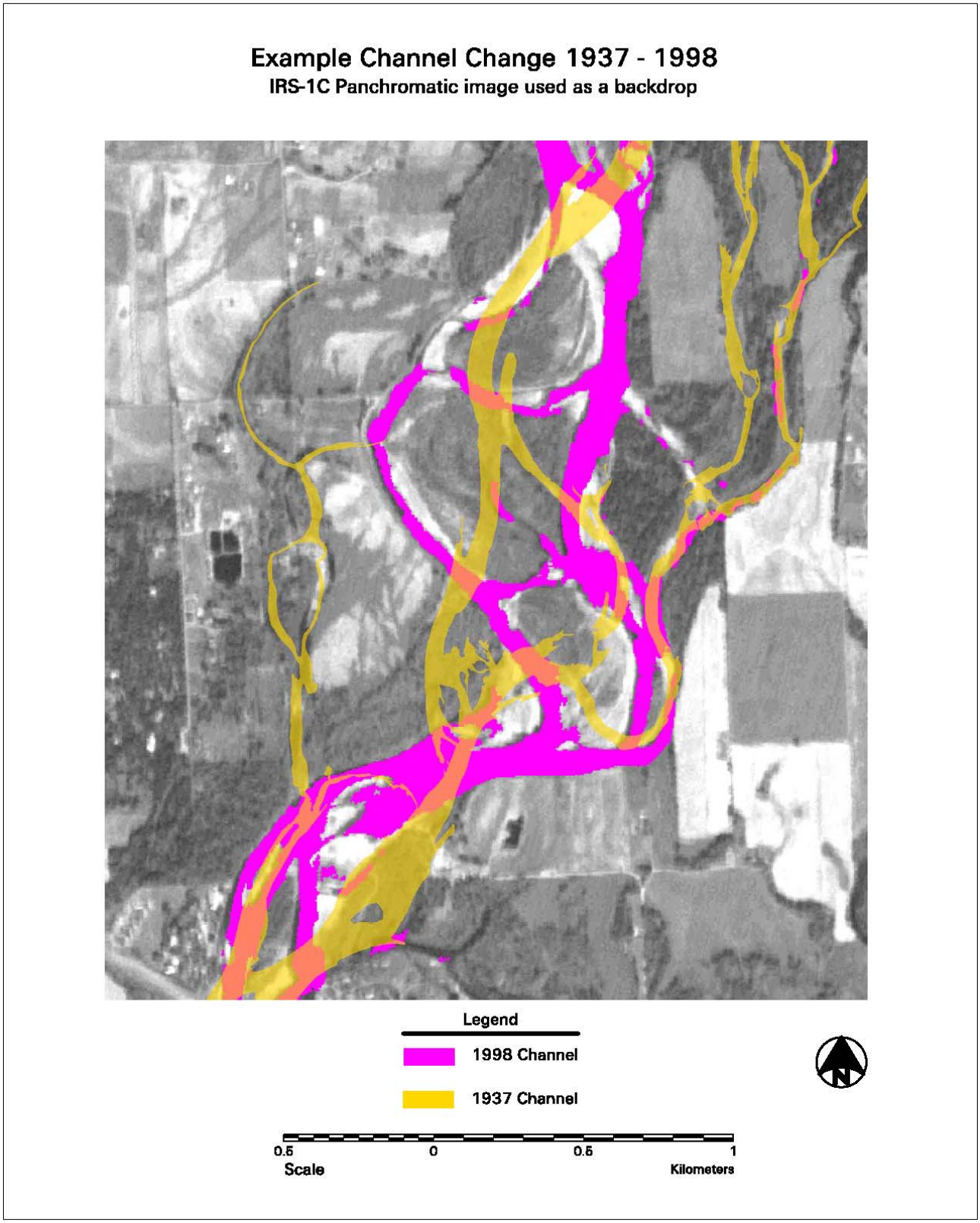


Figure 3. Example of 1937 – 1998 change

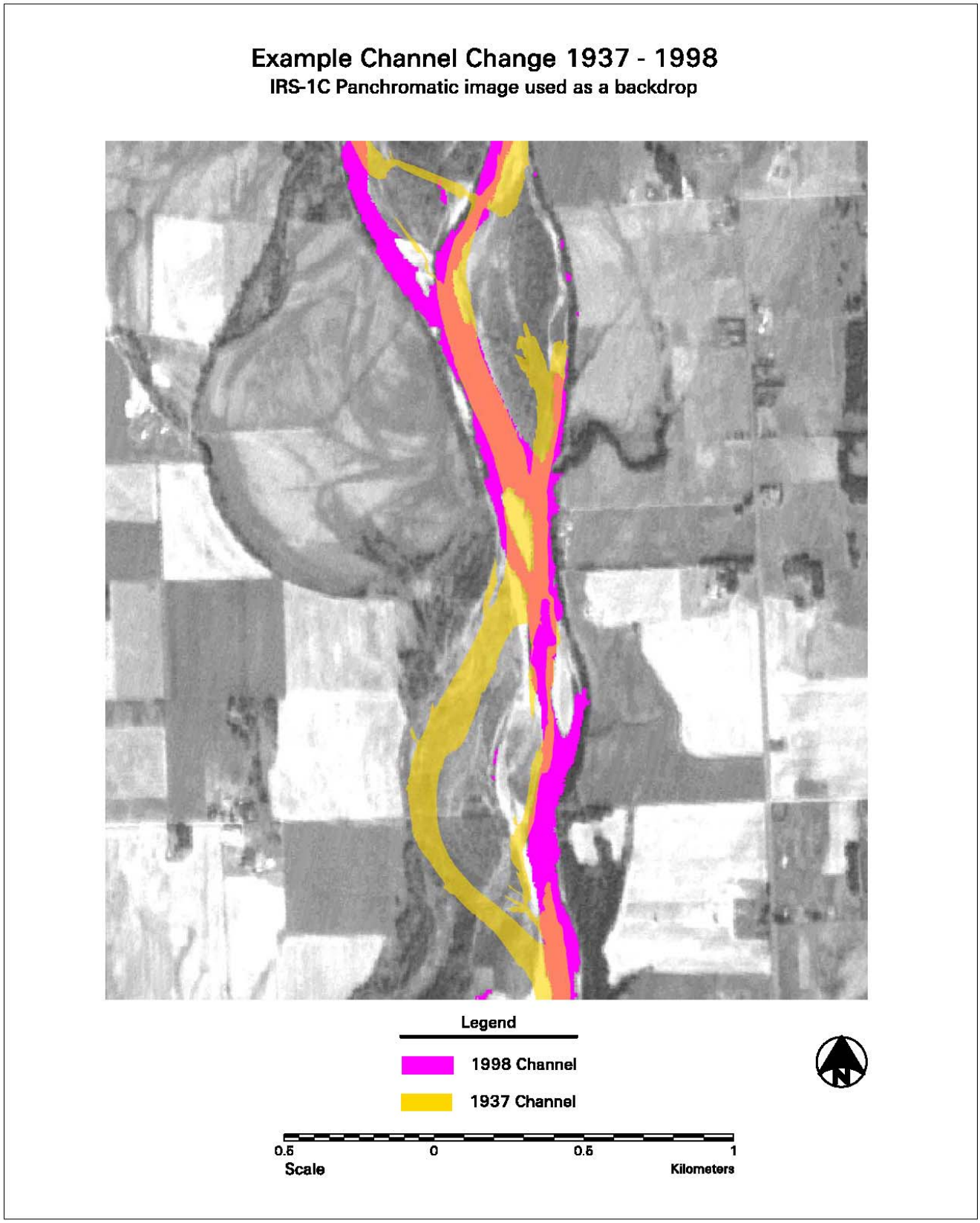


Figure 4. Example of 1937 - 1998 change

6.9. Detailed Change Analysis

Areas identified as change during the 1990-1998 time period were processed at a larger scale and in greater detail to produce the Detailed Change Analysis layer. The DOQQs, aerial photographs, ground truth data and the 1998 IRS land cover classification were used to create this layer which identifies the "from and to" classes of change.

A spatial model was developed to further classify the type of change identified in the results of the simple change analysis. Areas that had changed from water in 1990 to a class other than water in 1998 were coded using the values of the1998 land cover classification as the "to" class. Since there was not any land cover established for the 1990 data beyond the water class, areas that had changed "from" a land cover class other than water had to be manually interpreted from the 1990 DOQQ data. The results produced a detailed "from and to" change analysis layer mapped at approximately 1:12,000 scale. Table 6 shows the "from and to" classes and amounts identified for each class.

Table 6. Results of the Detail Change Detection Analysis

Change Type	Acres
agriculture to water	341
grassland to water	939
forest to water	1,115
barren to water	867
water to grass	10,937
water to forest	7,388
water to barren	10,420
water to willow	1,365

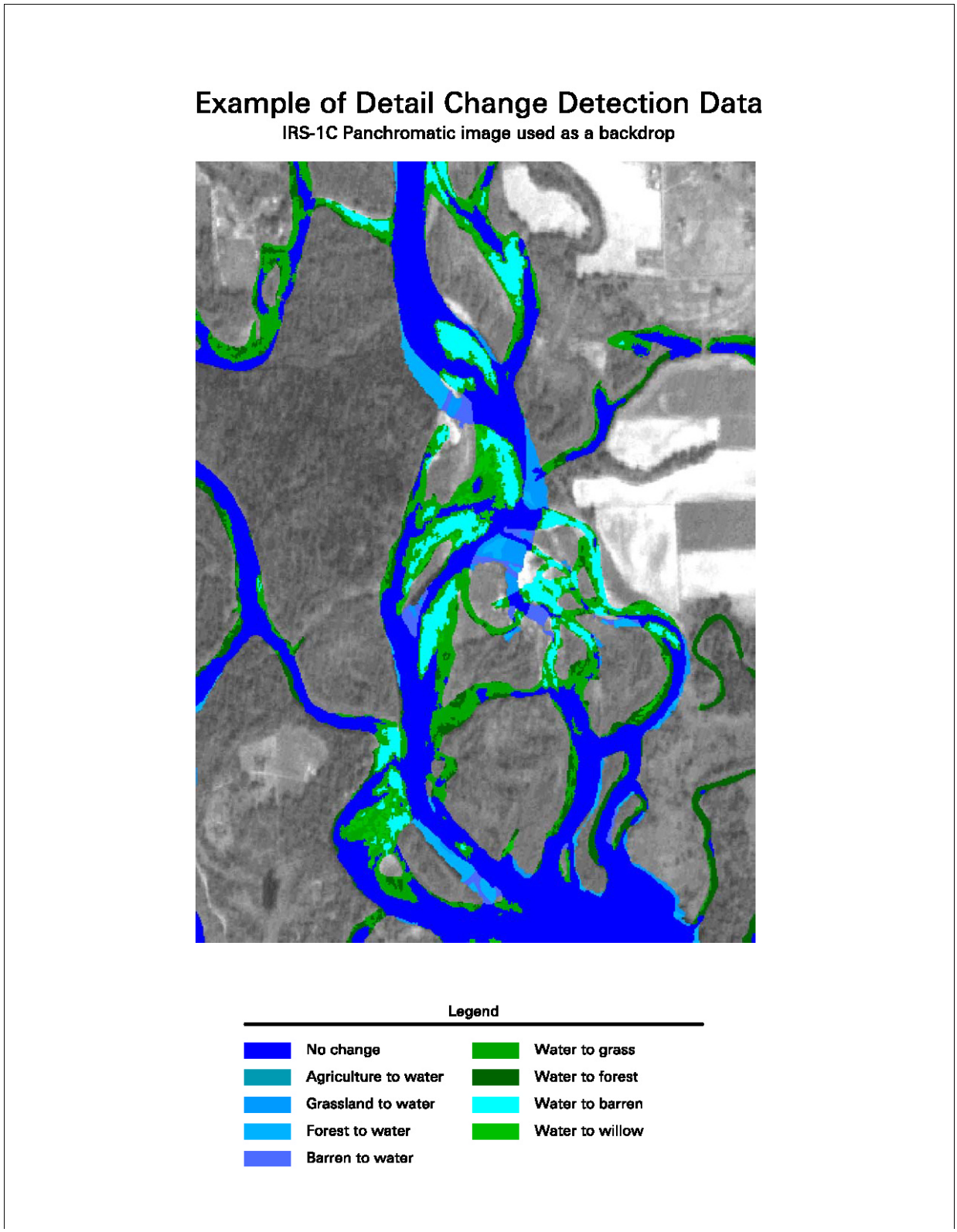


Figure 5. Example of detailed change detection analysis.

6.9. Classification Accuracy Assessment

After completion of the 1998 IRS classification, accuracy assessment was performed. This task was accomplished by analyzing 100 randomly selected assessment points within the classification. At least 10 accuracy assessment sites for each class were obtained. The number of accuracy assessment sites assigned to each information class was roughly proportional to the abundance of that category in the classification.

Accuracy assessment sites were coded based on the land cover type present in the aerial photography, where coverage was available, and the IRS image in other areas. All of the accuracy assessment sites were compared with the classification to determine an overall accuracy for a classification unit. In addition, accuracy figures were calculated for each class. Appendix F shows the accuracy assessment tables.

6.10. Weighted Useable Area Habitat Analysis

Together, MEC and SSI developed an automated GIS-based software script to analyze weighted useable area for fish habitat and produce graphic and tabular output quantifying the results. These software routines run on ESRI's ArcView 3.x platform with Spatial Analyst. The software script is called WUAM for Weighted Useable Area Modeling. The software produces the weighted useable area through the following process:

1. Builds point shapefile from tabular .csv file produced by MEC hydraulic modeling containing x. y, elevation, depth and velocity.
2. Applies operator selected fish species/life stage equation and minimum/maximum valid values for depth and velocity to produce habitat value at each point in the shapefile.
3. Creates continuous surface by extrapolating between points using an Inverse Distance Weighting algorithm. This distance and the grid cell size are selected by the operator.
4. Calculates total habitat within the 0 – 1.0 range in .1 increments. Creates bar chart showing the distribution of the habitat per increment.
5. Creates a permanent ESRI GRID file of the habitat.

This process is discussed in more detail in Appendix – WUAM User Manual.

7.0. Results Analysis

7.1. Land Cover Classification

The land cover classification derived from the enhanced IRS-1C imagery proved to be an accurate representation of the river channel and the adjacent lands providing an overall classification accuracy of 91%.

Due to spectral similarities between Agriculture lands and Grasslands, many of the Agriculture lands were delineated manually. Grasslands were recoded to agriculture if the land use pattern indicated agricultural practices were being applied. Since these classes were very similar in the spectral response, it was not unexpected to see some Grassland and Agriculture confusion in the accuracy assessment table.

Water and Forest classes did extremely well in the accuracy table. Deep, clear water and coniferous forests are spectrally similar and are often confused with each other. Some confusion of this nature had to be edited out, but the amount was minimal. Some Forest may be confused with water where coniferous trees are growing next to the river. In this case it was sometimes challenging to separate the boundary between trees and water using the IRS imagery.

The Barren class showed slight confusion with several of the other classes. This confusion seems to represent the natural intermixing of the Barren class with Willow, Agriculture and Grassland. The willows were found mainly on rocky substrates within the channel and intermixed with the Barren class, which represented the rocks. Confusion with the Agriculture class and Grassland class appeared to be a result of the spectral reflectance of the soil being stronger than the spectral reflectance of the sparse vegetation.

7.2. Change Detection Analysis

The Simple Change data created accurate representations of the dynamic river channel over the span of twenty years. Differences in water levels may have contributed to false change identification. The 1990 data had a flow level that was 7.5 times the flow during the acquisition of the 1998 IRS imagery. Although certain types of change may have been influenced by the difference in water levels, true changes in the channel's extent were detected.

The Detail Change went a step further to identify exactly what types of changes had occurred during the 1990-1998 time period. This process required manual interpretation of the historic land cover present in the 1990 DOQQ data where change was identified. A portion of the areas identified in the Simple Change layer were not identified further if there was not substantial evidence in the data that true change had

occurred. Some of these uncharacterized areas were influenced by tree canopies and shadows that extended into the river channel due to the off-nadir look angle inherent in the DOQQ data.

The types of detailed changes identified can be divided into two broader categories for comparison purposes, change "from Water" in 1990 and change "to Water" in 1998. Approximately 30,000 acres of land cover fell into "from Water" while only 3,300 acres were classified as "to Water." The large amount of land cover identified as "from Water" is due to the increased flow of water in the 1990 data. Those areas classified as "to Water" are more indicative of true change representing a loss of landmass due to erosion.

8.0. Deliverables

The following products were delivered for the Flathead River:

- 1937 river channel in Shapefile format
- 1978 river channel in Shapefile format
- 1990 river channel in Shapefile format
- 1998 river channel in Shapefile format
- 1978 – 1990 simple channel change in Shapefile format
- 1978 – 1998 simple channel change in Shapefile format
- 1990 – 1998 simple channel change in Shapefile format
- 1998 land cover classification in Shapefile format
- 1990 – 1998 "From and to" change analysis file in Shapefile format
- 1999 channel characteristics derived from fieldwork in Shapefile format
- Metadata for the above Shapefiles
- IRS satellite imagery
- 1937 historical air photo mosaic
- DOQQs
- DRGs
- Preliminary report
- Final report

9.0. Hardware and Software

Two Pentium PCs were used for image processing. Both systems were equipped with dual Pentium Pro 200 processors, 128 megabytes of RAM and 11 gigabyte hard drives. The system used for vector processing was a Pentium Pro 200 with 132 megabytes of RAM and six gigabytes of disk space. All systems were running Windows NT, version 4.0.

ERDAS Imagine software, version 8.3.1 was used for image processing and ARC/INFO version 7.2.1 was used for vector manipulation. Both software packages were developed for the NT operating system. Microsoft Word was used for word processing and Excel was utilized for mathematical operations.

10.0. Conclusion and Recommendations

This portion of the Flathead River Instream Flow Investigation Project has provided many insights into the dynamic characteristics of this river system while providing a solid baseline for future studies and data development. The next step is to transform this two-dimensional data set into three dimensions. Three reaches of the Flathead River, each representing unique channel characteristics, have been identified. Detailed channel topography has been generated for each of these reaches and will be used for three-dimensional visualization. A spatial model will also be developed to identify species habitat suitability based on river characteristics such as habitat, depth and velocity.

Recommended next steps for this contract include:

1) Map and quantify area of habitat types in the 1937 river channel. Compare to area of habitat mapped by MEC in 1998.

2) Summarize the habitat from each species/life stage through all flows to identify best habitat locations through the range of flows.

3) Assess high value habitats in 2 above for risk of modification due to dam operations looking at flow velocities and substrate. Develop mitigation plans based on results.

4) Build a comprehensive GIS plan, framework, and processes to collect, analyze and map ongoing management and investigations into this reach of the Flathead River.

SSI feels fortunate to be a part of the Flathead Instream Flow Investigation Project and would like to thank everyone that has assisted our staff throughout this portion of the project.

11.0. References

ERDAS. 1995. *Field Guide.* Third Edition. Atlanta, Georgia.

Lillisand, T.M. and R.W. Kiefer. 1994. *Remote Sensing and Image Interpretation.* Third Edition, John Wiley & Sons.

Lunetta, R.S. and C.D. Elvidge. 1998. *Remote Sensing Change Detection – Evironmental Monitoring Methods and Applications.* Ann Arbor Press.

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APPENDIX B – GIS WEIGHTED USABLE AREA MODEL

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GIS-based Weighted Useable Area Model Software User Manual

Bonneville Power Administration
Flathead River Instream Flow Investigation

Miller Ecological Consultants, Inc.

SPATIAL SCIENCES & IMAGING

Draft

September, 2003

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This user manual will describe the steps MEC and SSI took to complete habitat modeling for the Flathead River Instream Flow project. The procedures were created by MEC and SSI to aid personnel in processing the data for the project and to provide Montana Fish, Wildlife and Parks the results of this analysis. These procedures and software routines have been developed from standard IFIM procedures with field survey and GIS data. While this procedure is not specific to this data or project, the equations or data used may need to be modified to accommodate other fish species, life cycles or other project requirements.

This report will discuss raster and vector GIS data processing. The GIS work uses ArcView and ESRI Spatial Analyst processes, modules and terms. The vector processing terms "coverage", "theme" and "shapefile" are used interchangeably.

Note on filename conventions: Several different file formats are used in this procedure. You will use ArcView shapefiles and grid (raster) files, ASCII and comma delimited text files, and Microsoft Excel files. They will all be referred to by their root coverage name.

Approved systems required for processing

Software:
1. ArcView 3.2a
2. Spatial Analyst extension

Hardware:
1. PC Workstations: 256 Mbytes RAM and at least 250 Mbytes swap space. Enough available disk space for your project.
2. Networked printer.
3. Tape Backup System

Notes/Terms:

*****This manual was written with the assumption that the reader or user is proficient with ESRI's ArcView, Spatial Analyst, Microsoft Windows environments, and GIS concepts and PC hardware. For more detailed information on specific processes or software use please refer to the software manuals or manufacturers online help systems.**

All references to software and function are copyright of the respective manufacturer.

Use of this manual and the GIS based Weighted Useable Area Modeling software constitutes acceptance of the GIS WUAM End User License Agreement.

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GIS-based Weighted Useable Area Modeling Software License Agreement

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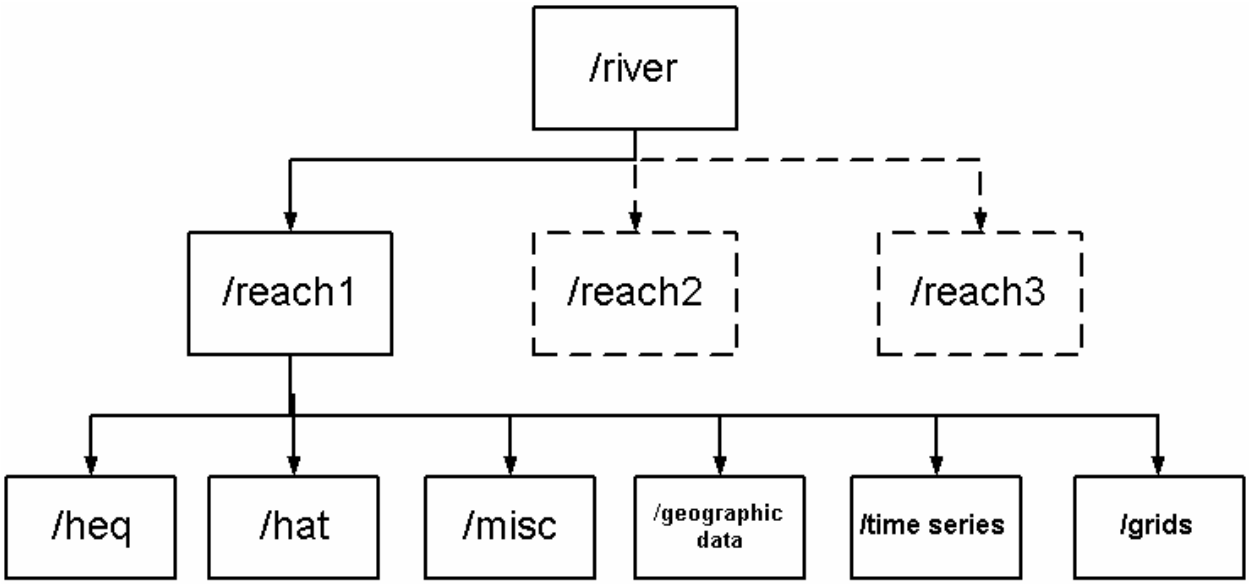
CHAPTER 1. DIRECTORY STRUCTURE

1. Make the proper directories for this project. Your root project directory should have the following directories within it:



2. Directory definitions and Contents:

~/river:	Contains nested project directories for the river being modeled. This may be the river name, i.e. /flathead.
~/reach1 – reach (n)	Contains all the reach specific directories and files including equations, geographic data and miscellaneous files used to model the reach
~/heq	Contains all species/lifecycle equations
~/hat	Contains all modeling results in .csv format
~/misc	Contains program icons, legends and other misc. files
~/geographic data	Contains all geographic data files including shapefiles and comma delimited files.
~/time series	Contains the time series data created from the modeling. Data is in .xls format.
~/grids	Contains all grids created for the reach. Note: the path to the grid directory must not contain any subdirectory names longer then eight characters.

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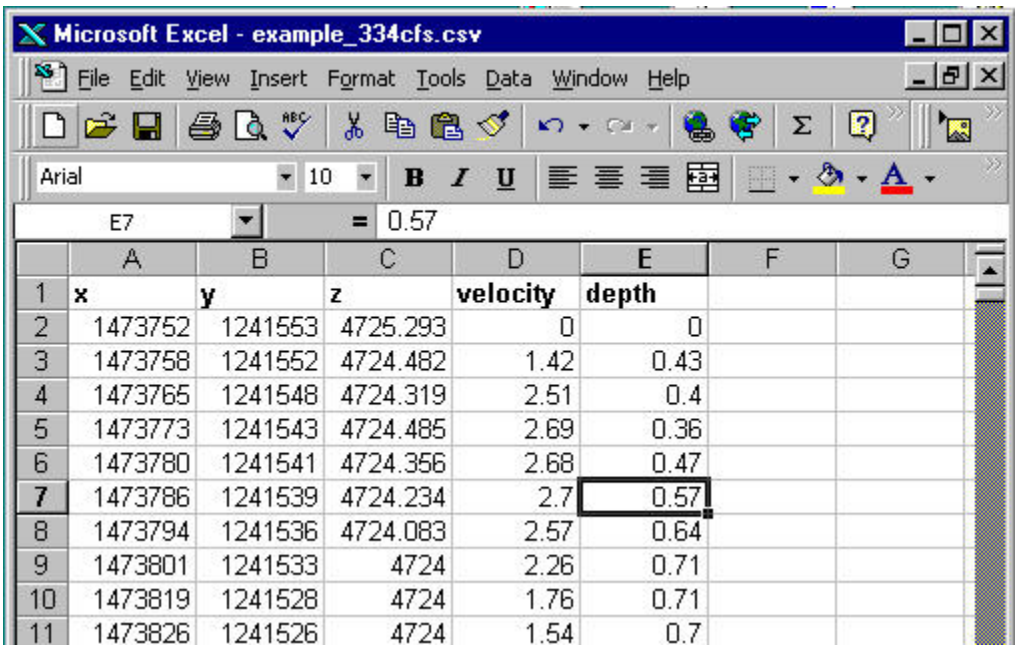
CHAPTER 2. DATA PRE-PROCESSING

Processing Hydraulic Flow Data

1. Load the hydraulic data on to your computer hard disk. This should be an MS Excel spreadsheet (if it represents just one flow) or a workbook (if it contains multiple flows). Typically, the name of the file refers to the flow it represents so a file representing a hydraulic flow of 805 cfs would be named 805cfs.xls. See below.



	A	B	C	D	E	F	G
1	x	y	z	velocity	depth		
2	1473752	1241553	4725.293	0	0		
3	1473758	1241552	4724.482	1.42	0.43		
4	1473765	1241548	4724.319	2.51	0.4		
5	1473773	1241543	4724.485	2.69	0.36		
6	1473780	1241541	4724.356	2.68	0.47		
7	1473786	1241539	4724.234	2.7	0.57		
8	1473794	1241536	4724.083	2.57	0.64		
9	1473801	1241533	4724	2.26	0.71		
10	1473819	1241528	4724	1.76	0.71		
11	1473826	1241526	4724	1.54	0.7		

2. Once the data has been loaded QC the data.

   Quality Control: Verify that the .xls spreadsheet has data columns and names for x, y, z, velocity and depth, in that order in the first row of the table. If there is any other data above these delete it.

3. Save this .xls file as a comma delimited .csv file of the same name. Use the |File|Save As| option in Excel. If the file is a workbook, save each tabbed spreadsheet as a separate .csv file. Save the files to the \geographic data subdirectory.

Creating Shapefiles

1. To create shapefiles click the Create shapefiles button This will pop up a dialog box that will allow you to navigate to the \geographic data subdirectory. See below.

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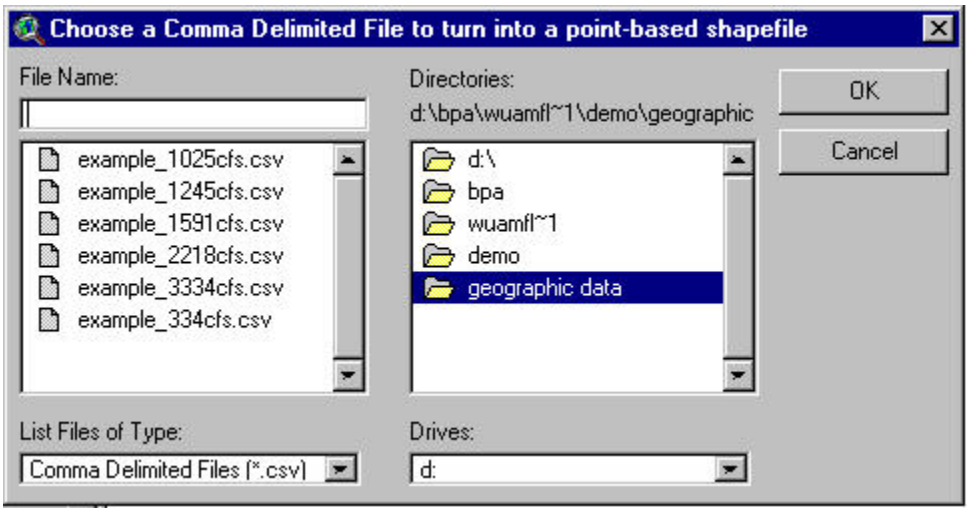

2. You can select one or more .csv files for processing. Each file selected will be generated as a shapefile with the same filename prefix. The shapefiles will also be loaded into the active view document in ArcView.

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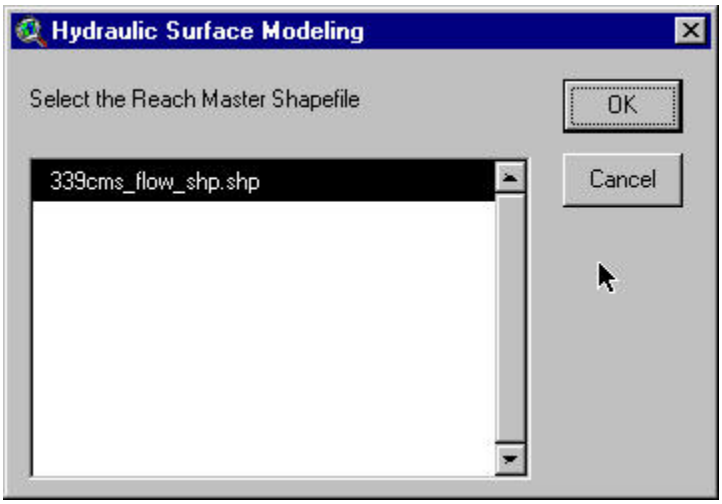
CHAPTER 3. GIS BASED WEIGHTED USEABLE AREA MODELING

Conducting the Weighted Useable Area Modeling

1. Make sure that you have at least one fish species/life stage equation (name.heq) and species/life stage min/max value statement (name.hmm) in the \heq directory. You will also need at least one flow shapefile in the \geographic data directory. We will be using the 339 cfs shapefile in this example.

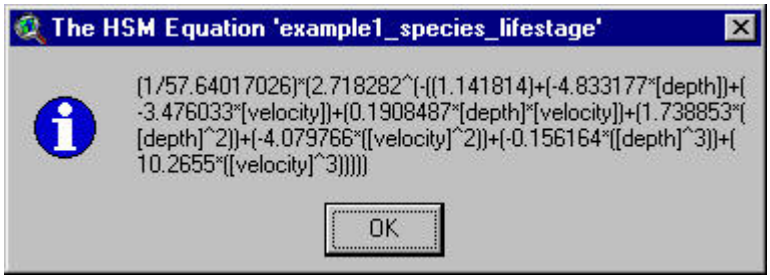
2. Bring the 339 cfs shapefile up in the View document. Click on the HSM Equations and Surface Modeling button . This will start up a series of input dialog boxes to set up the modeling.

3. The first dialog box allows you to select the flow that you want to model.



Select the flow and click OK.

4. The program will then search the \heq directory to find all species/life stage equations. If it finds an equation that has not been run for that flow shapefile it will list the equation as in the box below:



If it does not find a new equation it will move on to step 6.

5. Click OK. The program will then query the shapefile .dbf file and select only those values for processing that are within the minimum and maximum ranges of depth and velocity for the species/life

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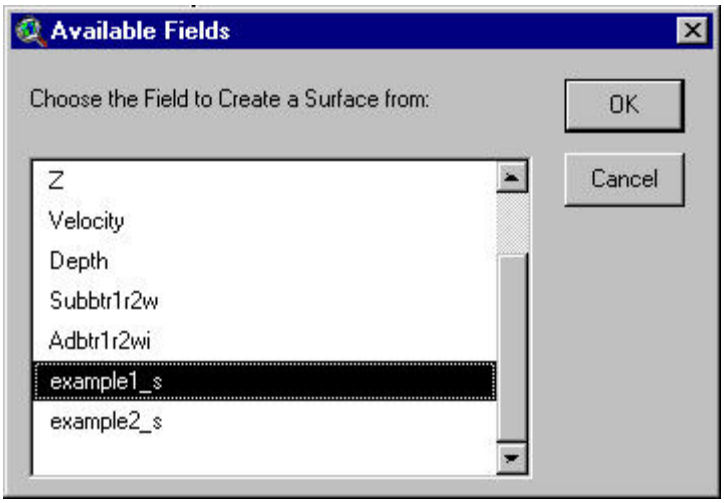
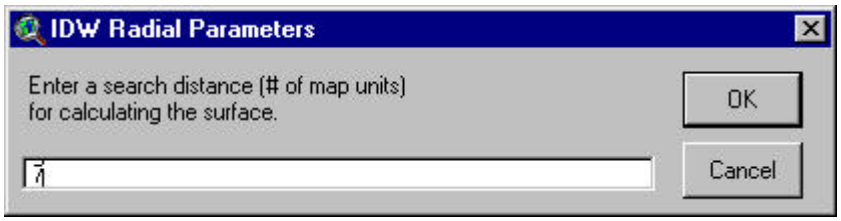
stage using the name.hmm file. It will then process the Depth and Velocity data to produce a new fish species/life stage field in the shapefile .dbf.

6. After it completes step 5 the program will ask which species/life stage that you want to further process for a surface and create the output files. In this case we want to use the example1 field in the list. See below:

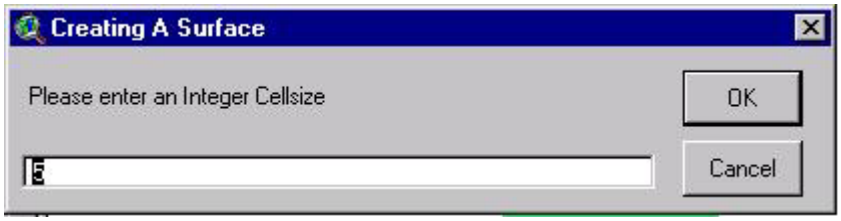


Click OK.

7. The program will request a search distance from each point to calculate a surface using an Inverse Distance Weighting (IDW) algorithm. Typically, this distance should be 2.5 to 3 times the average distance between points in the depth and velocity point shapefile created earlier. Enter the value and click OK.



8. The program will then start interpolating a continuous surface using the species/life stage suitability values from each point in the shapefile. A new dialog box will pop up to allow you to modify the output grid cell size that the program will use in creating the surface. See below:



The default value is 5. The units of measurement are equal to the units used in the shapefile. Usually

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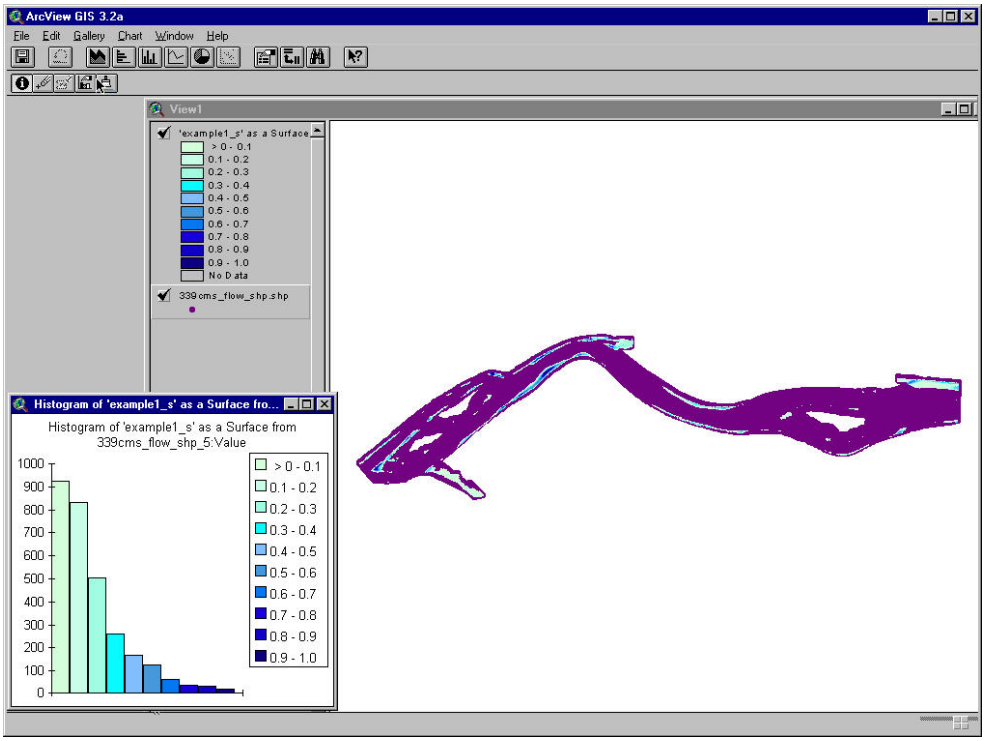
this will be either feet, as in this example or meters. Considerations in modifying this value are the units you are working in, the density of data points in the shapefile and the complexity of the river system. You may want to experiment with the cell size to see what creates the most acceptable results. Click OK. Processing of the surface finishes.

CHAPTER 4. HABITAT AREA MODELING RESULTS

1. After processing of the surface the program creates three files from the analysis: a continuous surface, a summary habitat suitability histogram chart and a summary habitat suitability table in .csv format, which is saved in the \hat subdirectory. The window below indicates that the analysis is complete:

Click OK.

2. A legend is automatically created for the surface. The legend has ten categories of 0.10 increments of habitat suitability. These same categories are reflected in the summary .csv. See the results view below:



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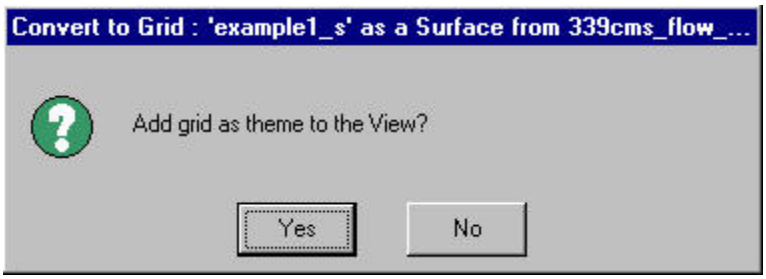
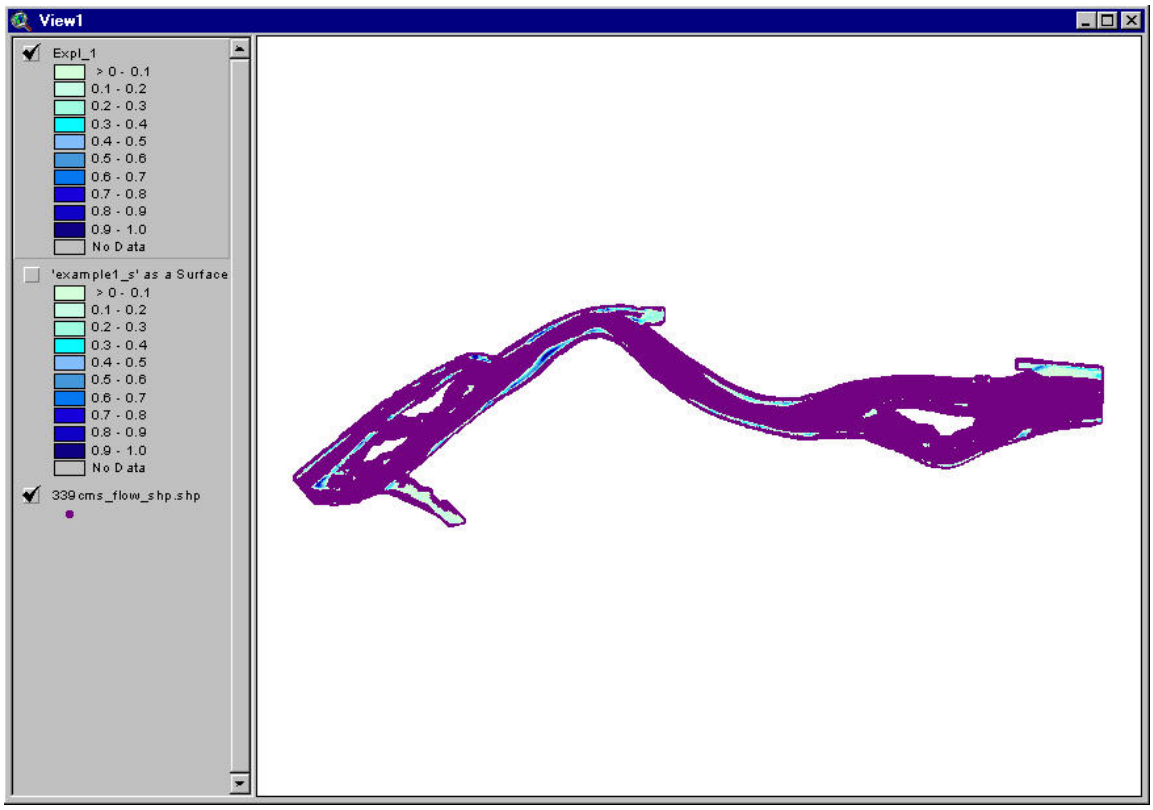
3. The surface that is created by the software is a temporary file. To save it to a permanent file format click the Convert to GRID button.

4. This will make a ESRI GRID file and replicate the suitability categories of the original file. The program will ask if you want to add the GRID file as a theme to the current view. Click Yes.



5. The graphic below shows the results.



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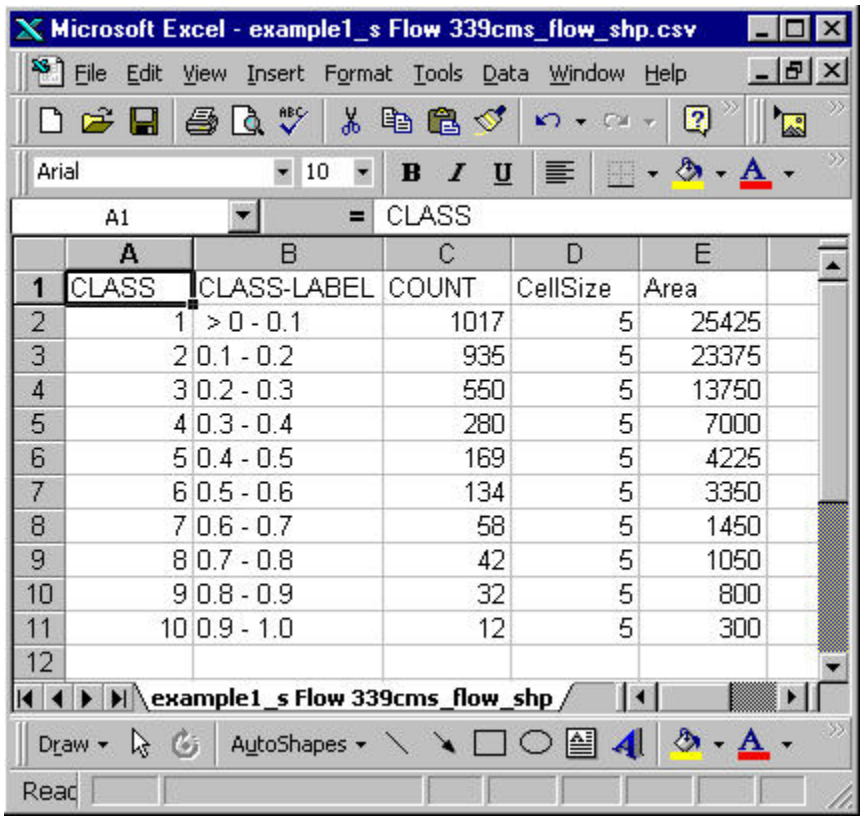
6. The summary .csv looks like this:



CLASS	CLASS-LABEL	COUNT	CellSize	Area
1	> 0 - 0.1	1017	5	25425
2	0.1 - 0.2	935	5	23375
3	0.2 - 0.3	550	5	13750
4	0.3 - 0.4	280	5	7000
5	0.4 - 0.5	169	5	4225
6	0.5 - 0.6	134	5	3350
7	0.6 - 0.7	58	5	1450
8	0.7 - 0.8	42	5	1050
9	0.8 - 0.9	32	5	800
10	0.9 - 1.0	12	5	300

Definitions:

Class Label – the class category of habitat suitability
Count – the number of pixels or raster cells represented in the class category
CellSize – the number 5 means the pixels are 5' by 5' or 25 sq. ft. in area
Area – total area of the class category in sq. ft.

The area calculations listed in the example above are used in the habitat time series analysis. The values in column E are summed to provide the total habitat for the site for each flow modeled. The total habitat and discharge are either typed or copied into the appropriate location in the habitat time series spreadsheet. The details of the habitat time series are presented in the Instream Flow Project Report.

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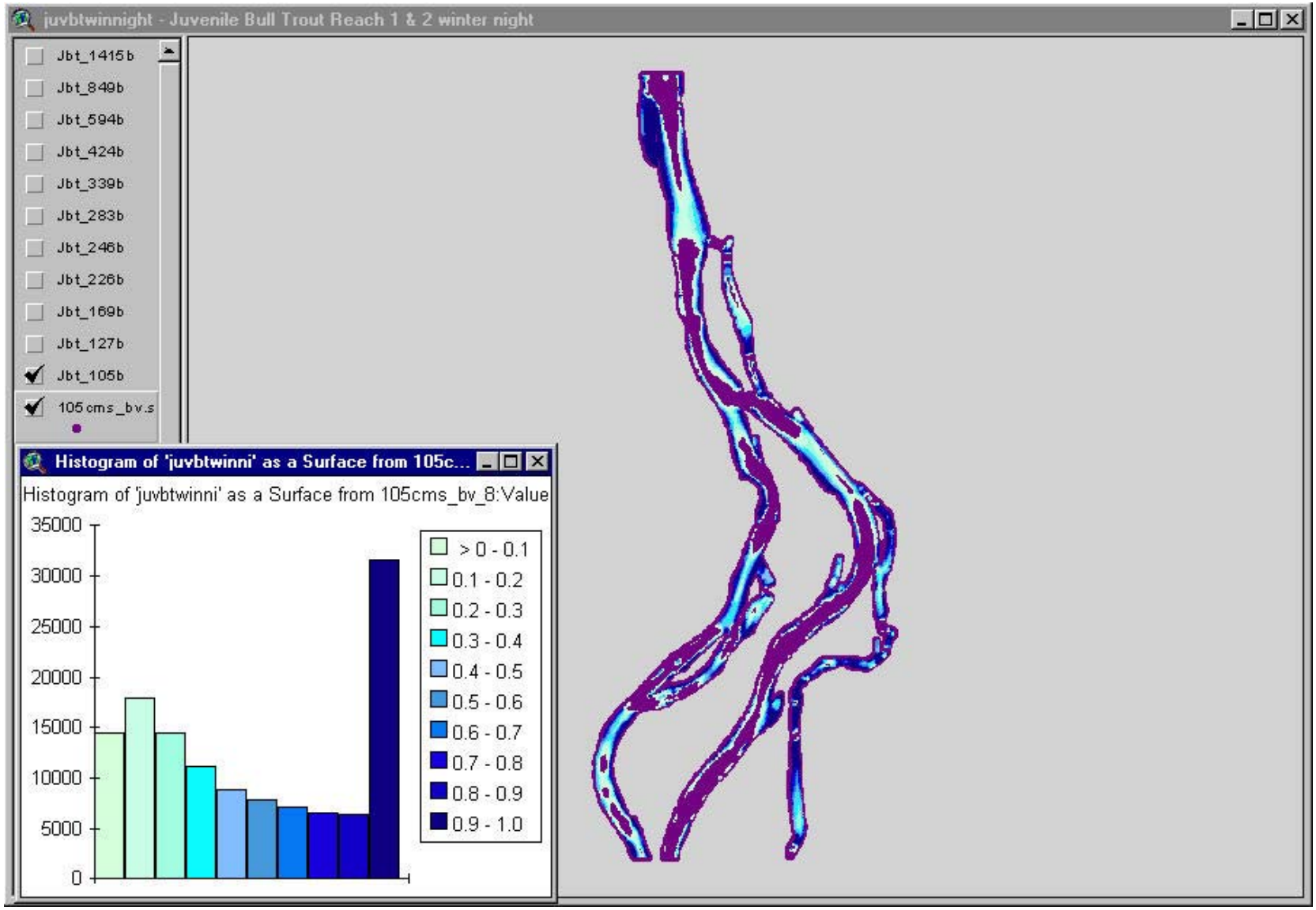
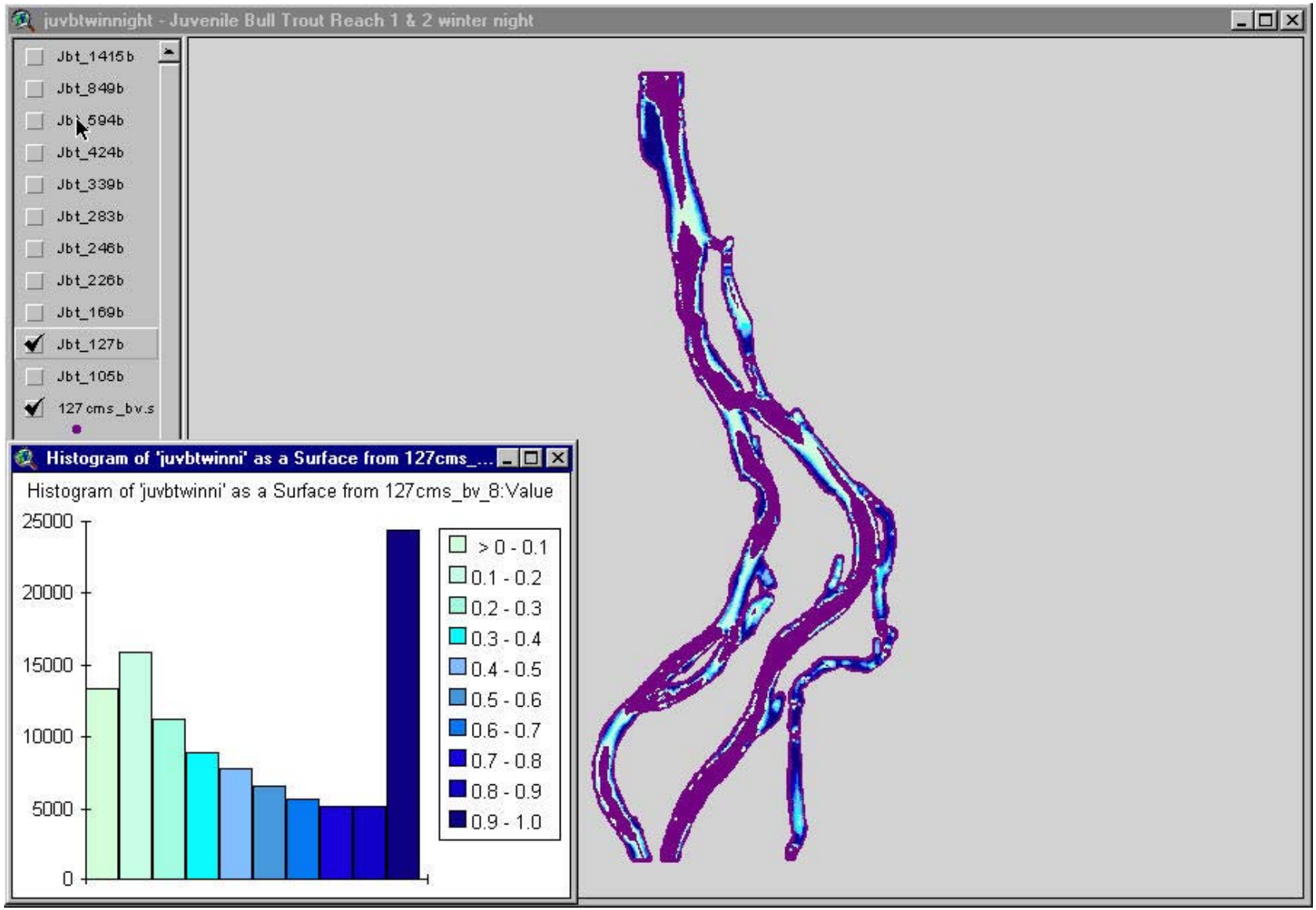
Appendix

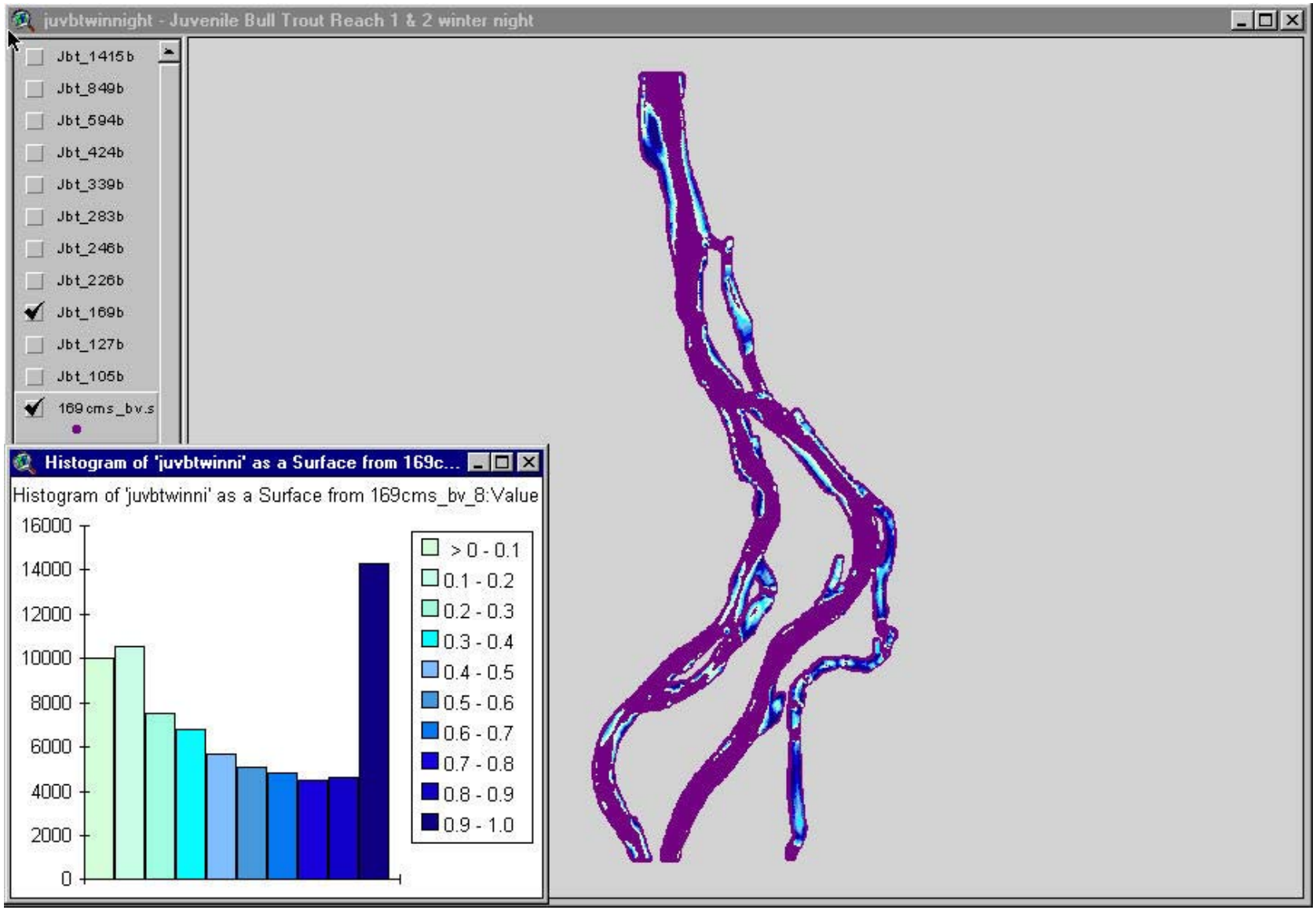
Example GIS output from Weighted Useable Area Model, Site 2 – Juvenile Bull Trout



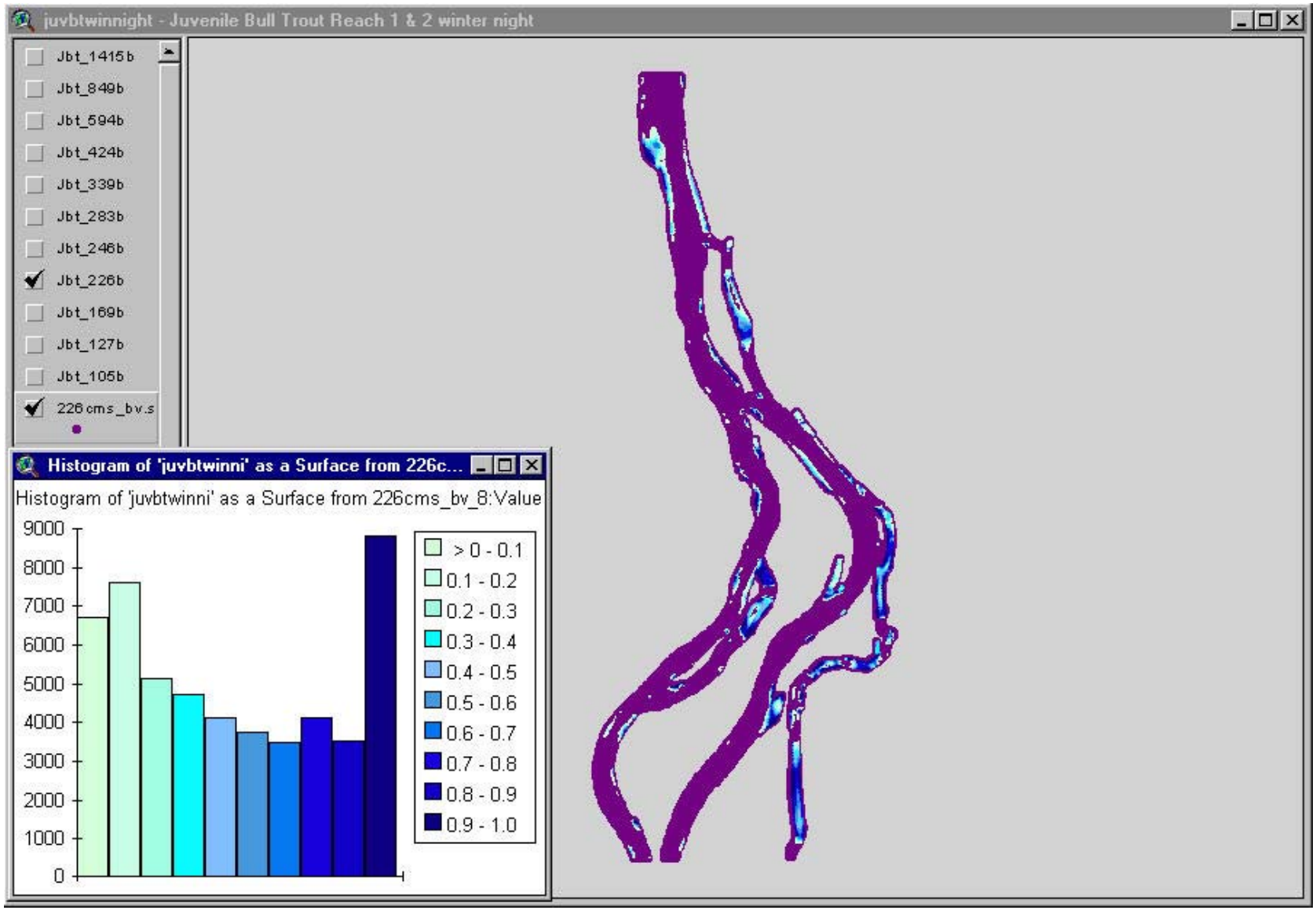
Juvenile Bull Trout – 105 cms



Juvenile Bull Trout – 127 cms



Juvenile Bull Trout – 169 cms



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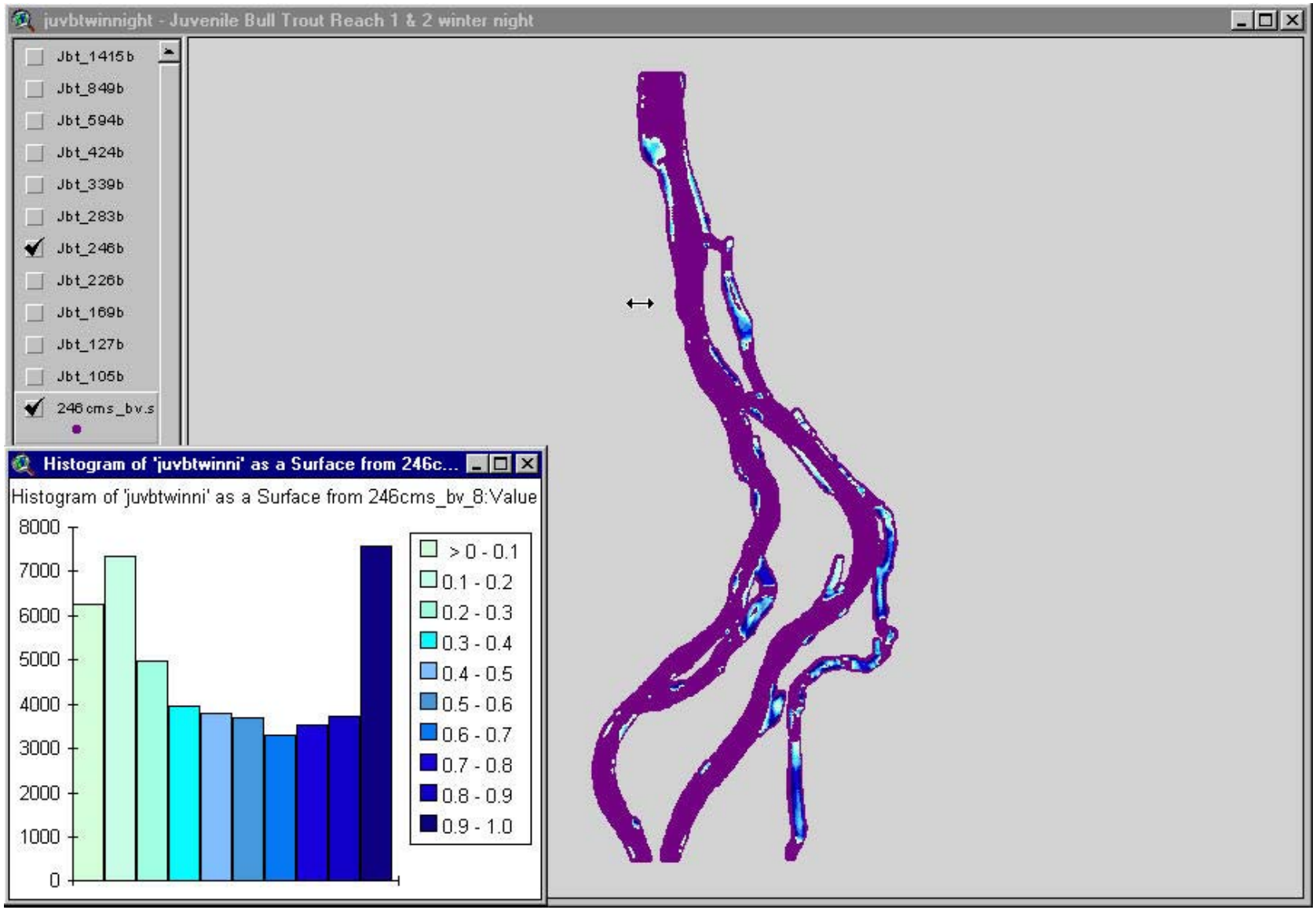

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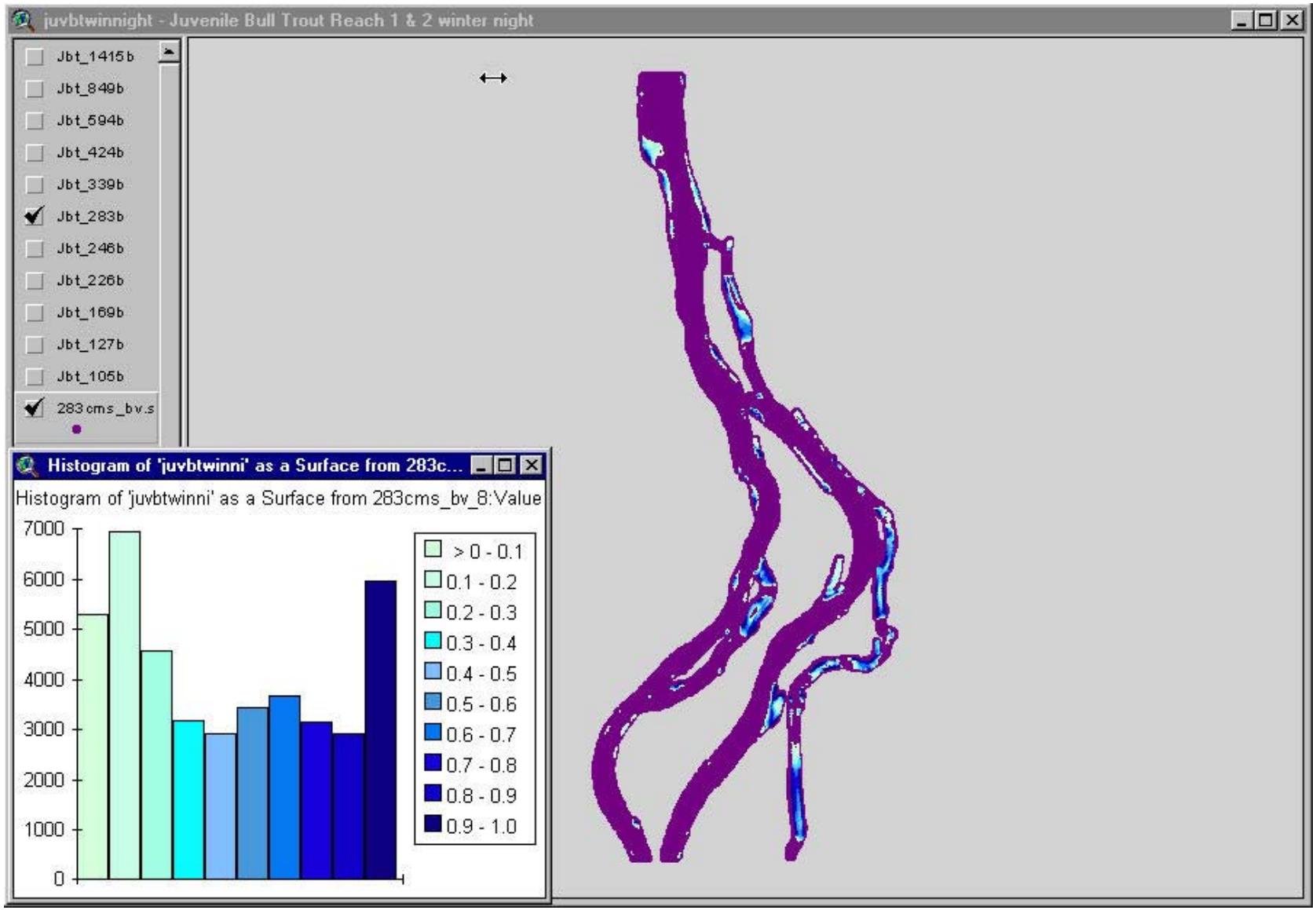

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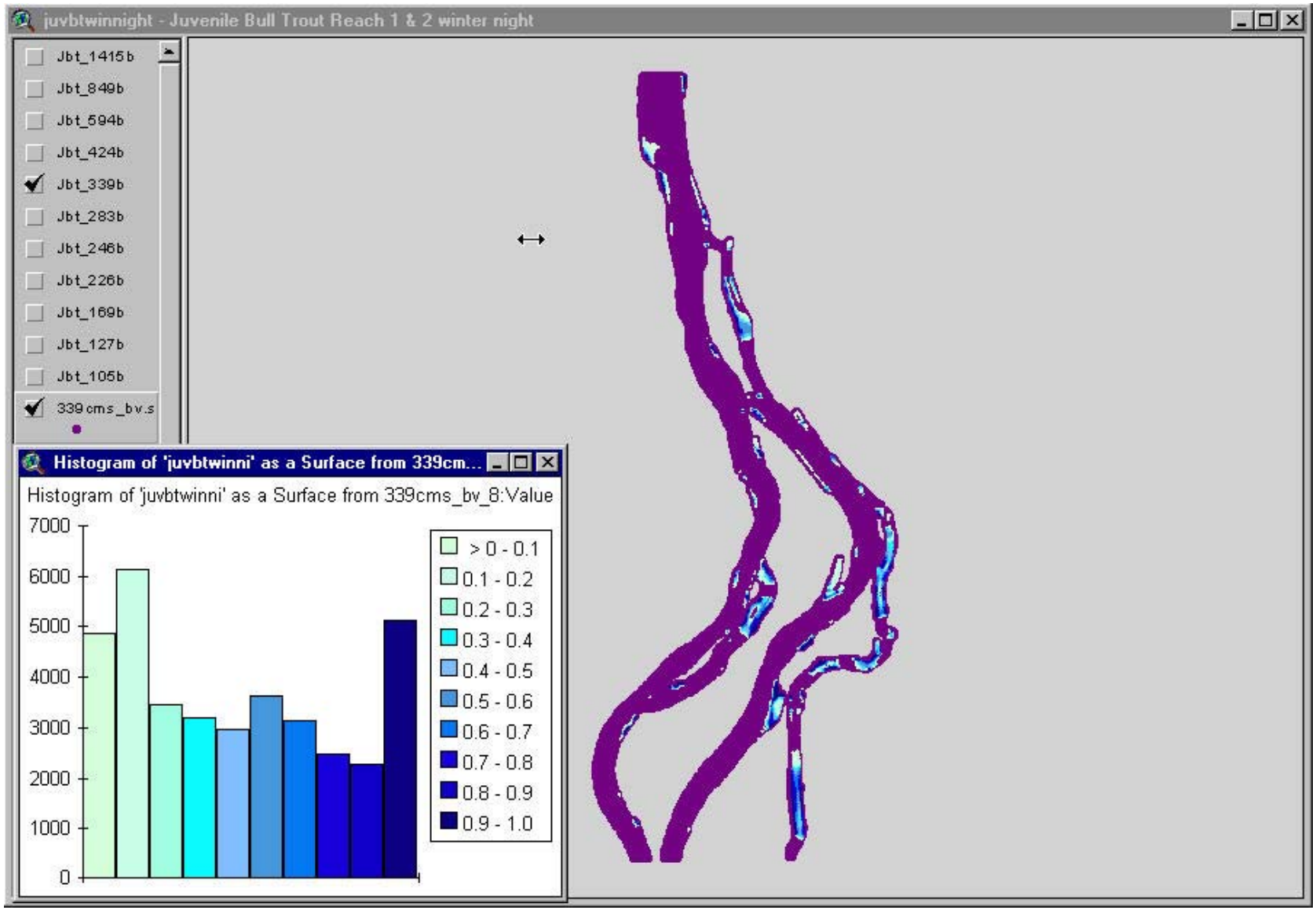
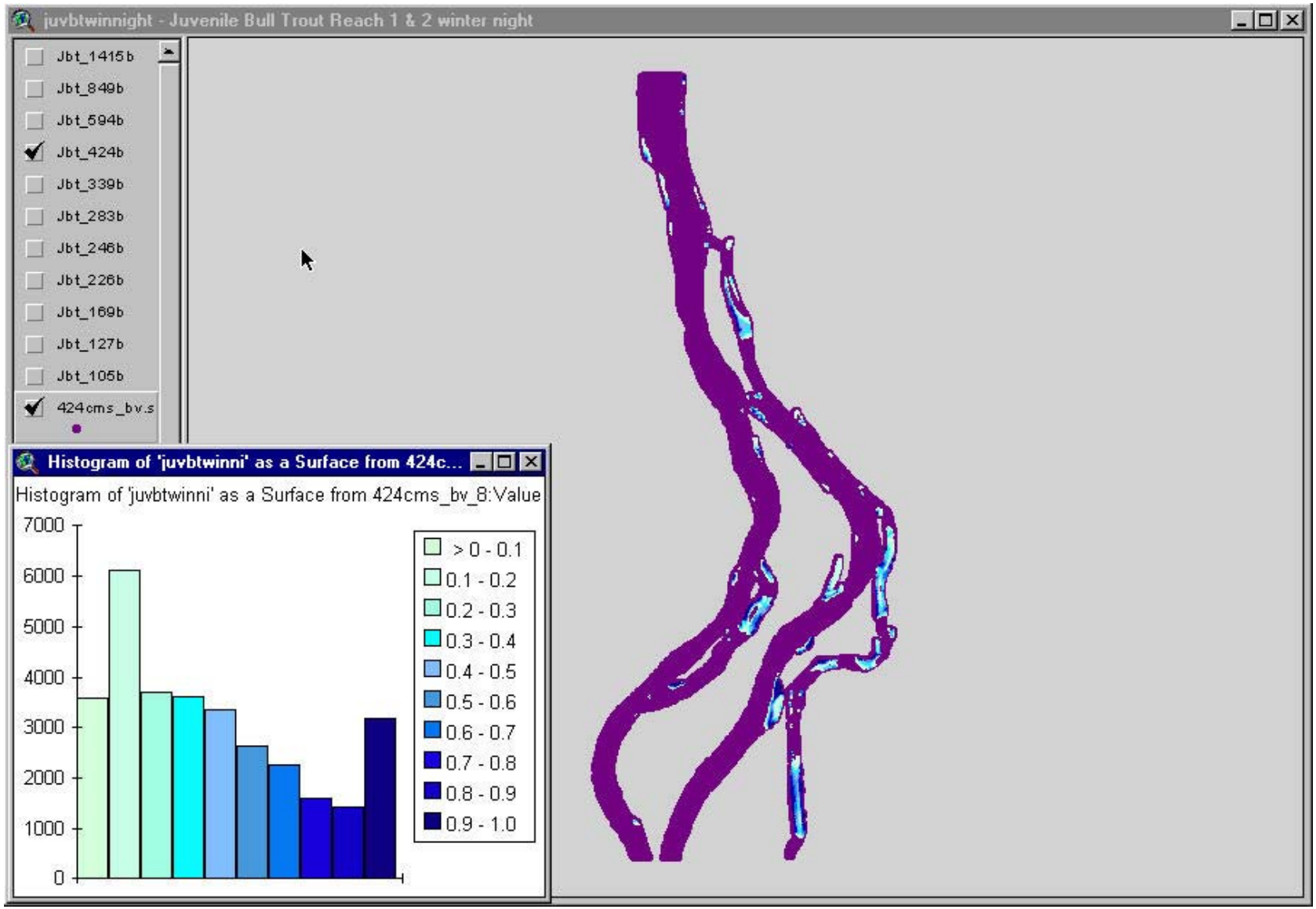
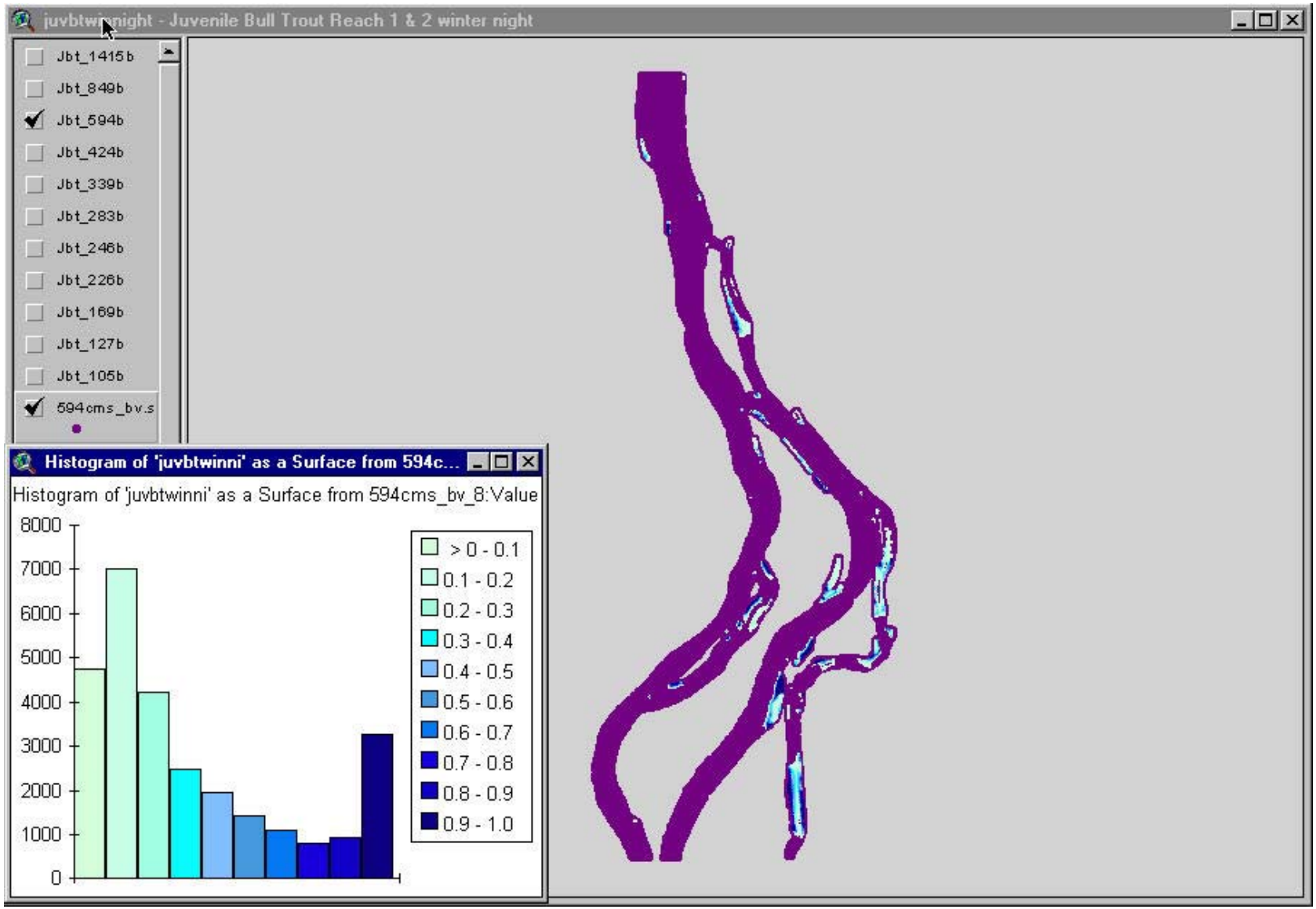


Juvenile Bull Trout – 339 cms



Juvenile Bull Trout – 424 cms



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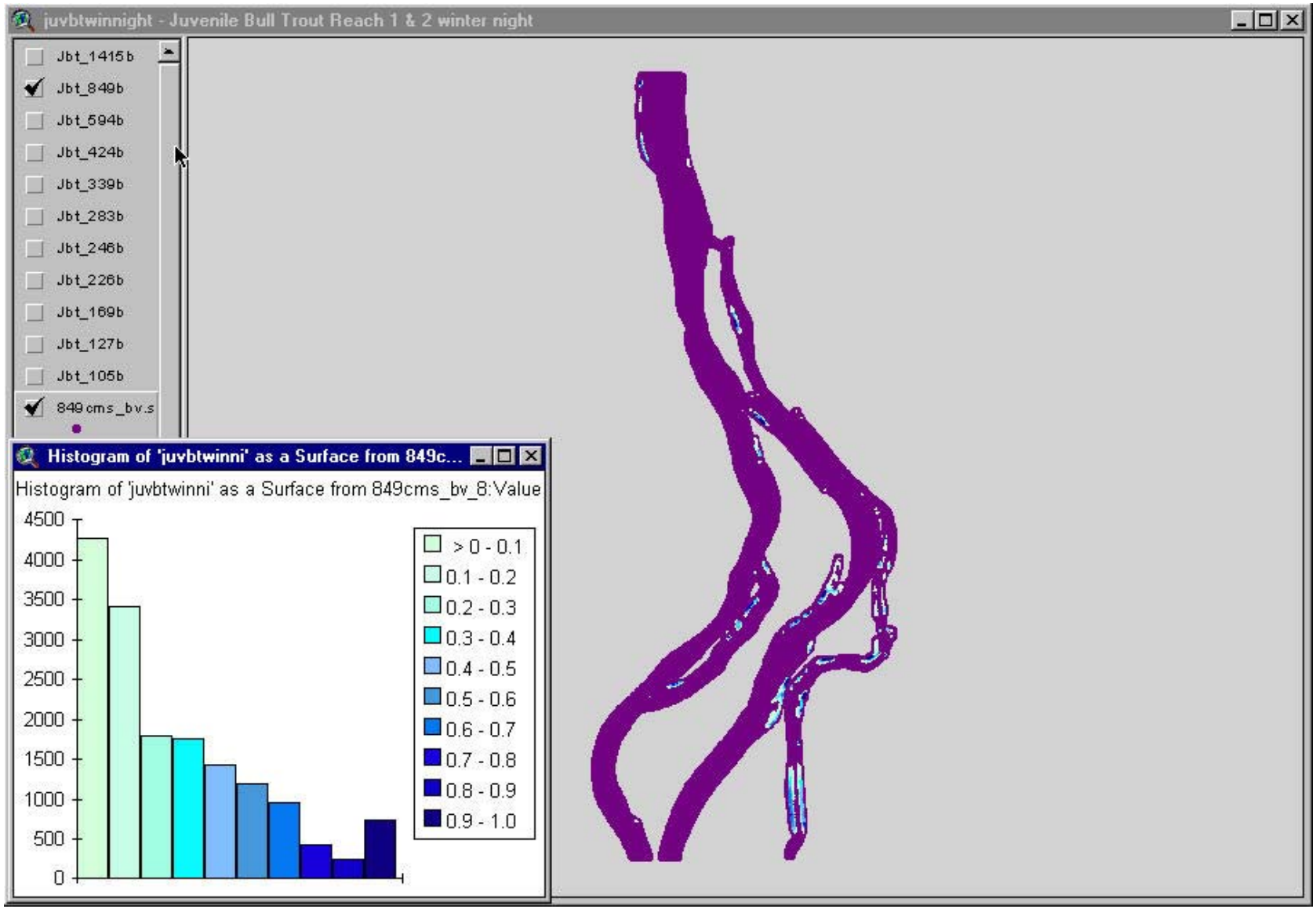
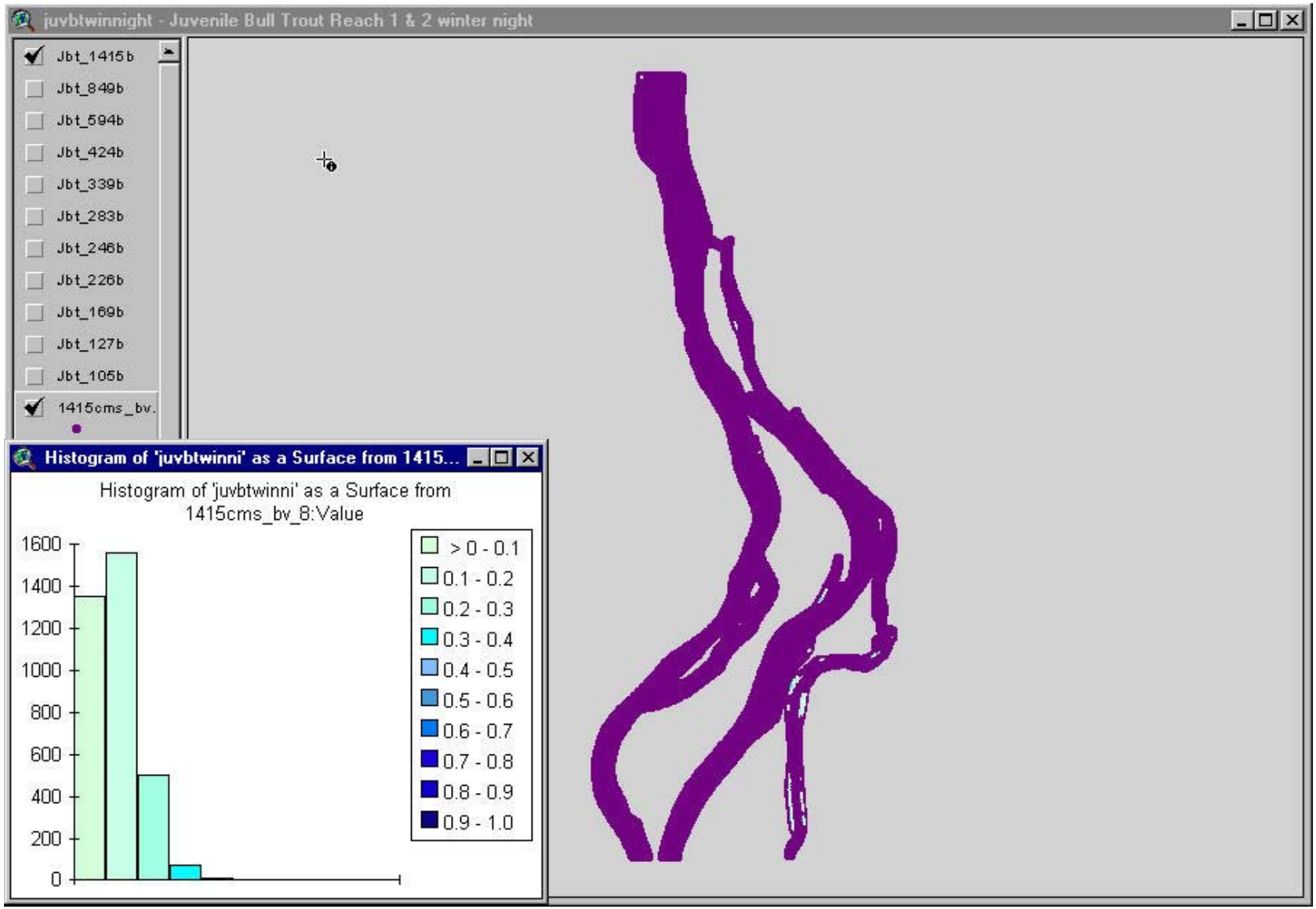


Juvenile Bull Trout – 849 cms



Juvenile Bull Trout – 1415 cms

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APPENDIX C – BIVARIATE SUITABILITY METHODOLOGY

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TECHNICAL REPORT

CALCULATION OF BIVARIATE HABITAT SUITABILITY FUNCTIONS IN THE STATISTICA SOFTWARE ENVIRONMENT

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May 24, 2001

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INTRODUCTION

This is a procedural manual that outlines the calculation of bivariate habitat suitability functions in the STATISTICA software environment. These procedures produce a 3-dimensional frequency distribution of habitat utilization (3D Bivariate Histogram). The bivariate histogram frequency data is reduced to an exponential polynomial function describing depth and velocity in habitat selection by fish. This information is then used in assigning habitat suitability for use in modeling instream habitat.

The steps outlined here start with raw data describing habitat utilization by fish - paired depth and velocity observations. This raw data is used to produce a 3D Bivariate Histogram showing patterns of habitat utilization over the range of values collected for total water column depth and average water column velocity. The three-dimensional surface is then used in a nonlinear regression model. An exponential polynomial equation is fit to the three-dimensional surface, by regressing the depth and velocity (independent) variables onto the frequency histogram surface (dependent variable). This equation is of the form:

$$Z = \exp (b_0 + b_1D + b_2V + b_3DV + b_4D^2 + b_45V^2\ldots)$$

where:

Z = number of fish observed
D = water column depth
V = average water column velocity
$b_0, b_1, b_2, \ldots$ = equation coefficients

and is fitted to the surface using a least squares regression technique. All of this is performed in the STATISTICA software environment. Example data is provided, along with examples of each required step in the process. This process follows techniques described by Prewitt (1982) and Bovee (1986).

PAIRED DEPTH – VELOCITY DATA

This procedure assumes the investigator has a complete data set of paired depth-velocity observations. STATISTICA allows the importation of many common formats (e.g. MS Excel spreadsheet data). The format of the new data set should be thoroughly checked, after it is brought into STATISTICA. Assure that the observations are aligned properly in the variables and cases (columns and rows), and that the correct decimal places are displayed. Be careful to place labels in the variable headers, since STATISTICA assigns a numeric value to text data that appears anywhere in a spreadsheet (See Edit –>Variables –>Current Specs…to assign variable field names, decimal places, etc.). The data must be free of missing data points (gaps) or unpaired depth-velocity observations. The data should be meticulously examined and quality controlled before starting any statistical analysis. The investigator should visually inspect a simple linear plot of each variable, determining which (if any) outlying or questionable data points should be removed. The researcher should become familiar with each data set, and know the range of values, mean, standard deviation, and distribution characteristics before progressing to any regression analysis.

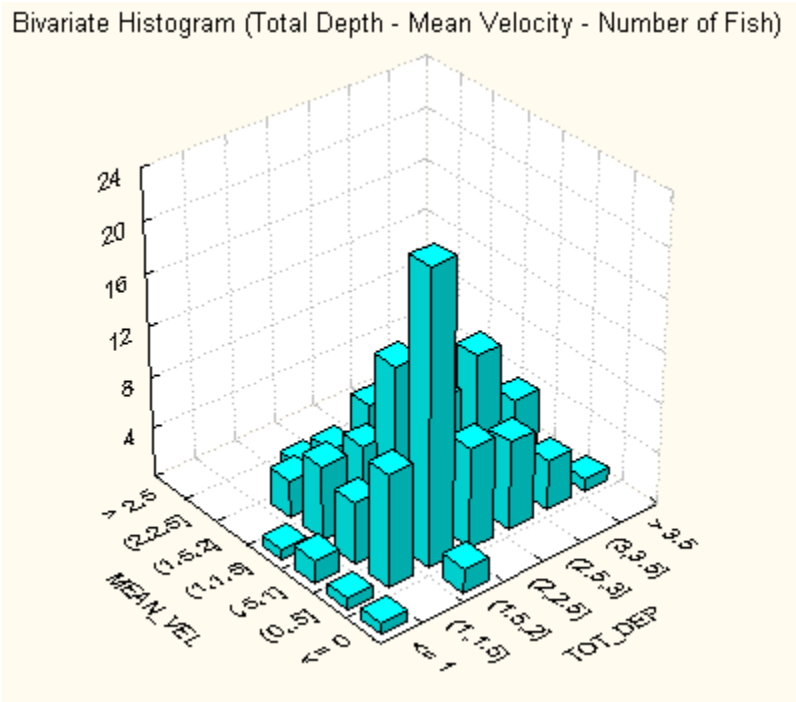
Record the boundary values from the depth and velocity observations (D_{min}, D_{max}, V_{min}, V_{max}). These boundaries set the range over which the habitat suitability functions can be applied, since the functions are fit within these bounds and are not representative outside the scope of the input data. It is recommended that all data be plotted and visually inspected again after the depth-velocity matrix is complete.

CREATING THE 3D BIVARIATE HISTOGRAM

The goal of data processing is to reduce raw frequency data down to an easily interpreted graphical display. This represents the behavioral response of a species with respect to environmental parameters (Bovee, 1986). The 3D Bivariate Histogram takes observations of water depth and velocity in habitat utilization by fish, and displays the frequency of use for each combination of these variables. The graphical display of these behavioral observations serves as the basis for the regression analysis.

From the STATISTICA Basic Statistics module open/import the desired data file. From the Graphs pull-down menu select Stats 3D Sequential Graphs->Bivariate Histograms… This brings up the 3D Bivariate Histograms dialog box. Click on Variables to bring up the Select Variables Bivariate Histogram dialog box. Select the variables you wish to display (e.g. Tot_Dep in category 1, and Mean_Vel in category 2), then click OK which returns you back to the 3D Bivariate Histograms dialog box. Click OK in the 3D Bivariate Histograms dialog box to create a 3D Bivariate Histogram of the selected variables. STATISTICA creates a 3D Bivariate Histogram of the selected variables (see Figure 1).

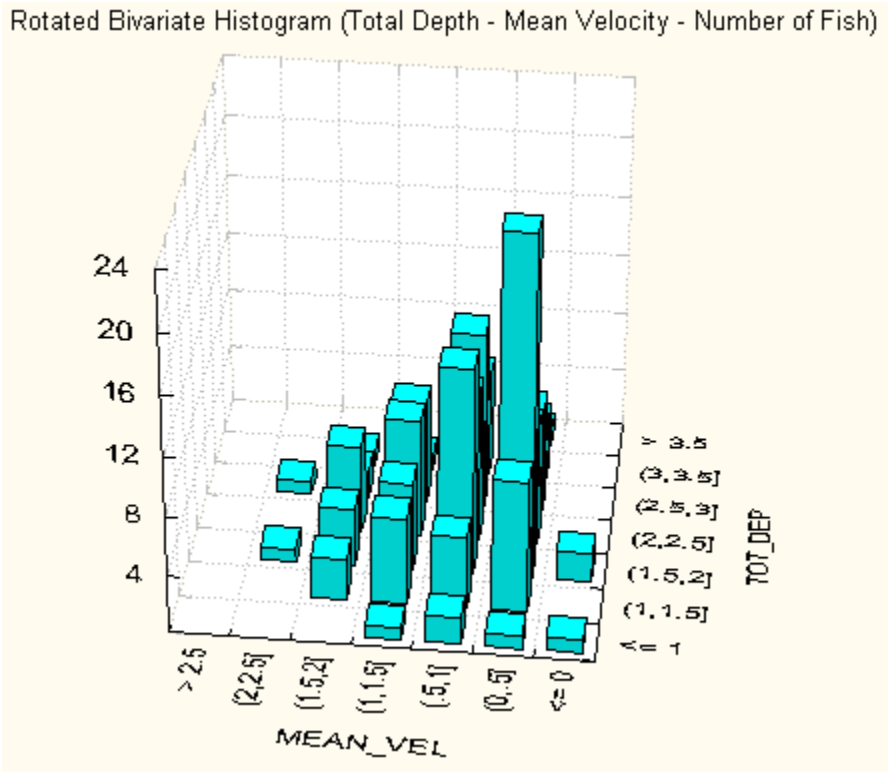
Figure 1. 3D Bivariate Histogram of Depth-Velocity-Fish Frequency.



Depending upon the data set, it may be necessary or desirable to specify the boundaries used to calculate the depth/velocity matrix used to create the histogram. Boundaries are analogous to the step size used while integrating. Boundaries set the range of values used to sort parameters into bins while creating the histogram. Allowing STATISTICA to auto-calculate these boundaries is a good first step. Then go back and specify boundaries and compare the histograms. The desired output is a contour smooth enough to allow adequate surface fitting, while maintaining a detailed and well defined gradation away from data peaks. Experimentation with different boundary settings is highly encouraged.

This is an excellent opportunity to perform a final quality control on the data. Check the graph for outliers (questionable data points) and for trends and characteristics of the two variables. STATISTICA allows rotation of the histogram (Right mouse click anywhere on the graph, select Rotate Graph/Perspective). Figure 2 shows the same plot rotated to afford a different view of the 3D Bivariate Histogram. Print the 3D Bivariate Histogram for later comparisons by using the File pull-down menu, or Right mouse click anywhere on the graph. This graph should be printed from at least two perspectives to obtain a full view of the surface of the histogram.

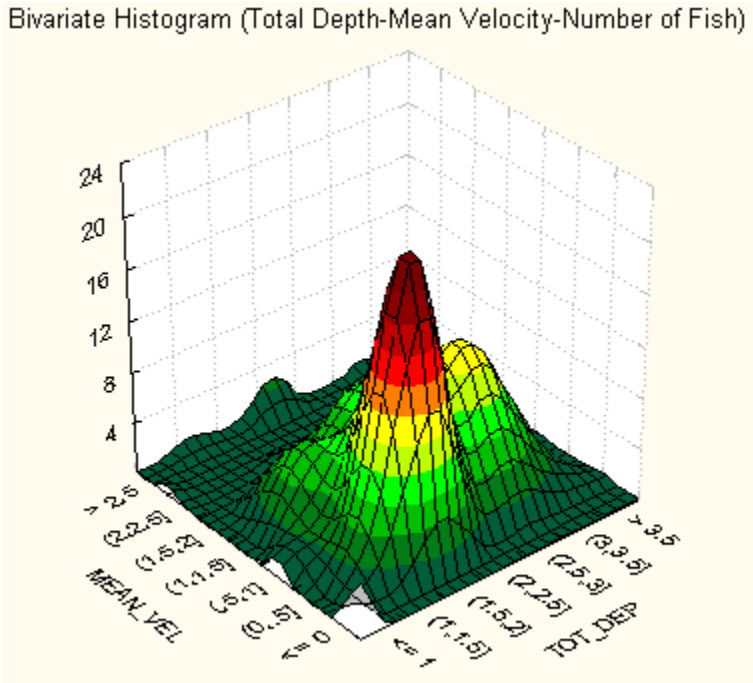
Figure 2. Rotated 3D Bivariate Histogram of Depth-Velocity-Fish Frequency.



STATISTICA will produce a surface plot of the 3D Bivariate Histogram. Right-mouse-click anywhere on the graph, select Change General Layout, then under Graph Type: select Surface Plot. This changes the existing 3D Bivariate Histogram to a surface plot, which should also be printed from several perspectives. Figure 3 shows the 3D Surface Plot of the 3D Bivariate

Histogram data. The surface plot representation makes a useful point of comparison as the curve fitting results in Nonlinear Regression are displayed similarly.

Figure 3. 3D Surface Plot of the Bivariate Histogram Data.



CREATING THE 3D SURFACE DATA MATRIX

The Nonlinear Estimation process uses a matrix containing the observations of depth and velocity (independent variables), and frequency (dependent variable) from the 3D Bivariate Histogram. The Nonlinear Estimation process will analyze each depth bin against each velocity bin, and use the corresponding frequency (Z) value to calculate regression coefficients for the exponential polynomial. Therefore each permutation of depth and velocity bins, along with the corresponding frequency (Z) value, must be set up in the 3D Surface Data Matrix.

Create a new data file for the 3D Surface Data Matrix using the File pull-down menu: File->Open other->New data. STATISTICA prompts you to name this new file (e.g. DVZTbl), then click Save. This brings up the new blank data file that must now be sized to accommodate the Graph Data from the 3D Bivariate Histogram. The number of cells in the histogram determines the size of the new data file. In the example provided the histogram contains 7 ranges for values of both Tot_Dep and for Mean_Vel (i.e. both data sets are grouped into 7 bins – Note that a square matrix is not necessary). This requires a 3 X 49 sized 3D Surface Data Matrix – one column each for the depth, velocity and frequency values; and 49 rows for each of the possible combinations of depth-velocity bins (7 X 7). The file can be resized using the Edit pull-down menu: Edit->Variables/Cases->Add/Delete (or use Right-mouse-click anywhere on the file, and select Modify Variables/Cases->Add/Delete).

To fill the 3D Surface Data Matrix return to the histogram and use the Layouts pull-down menu and select Edit Data (or Right-mouse-click anywhere on the 3D Bivariate Histogram and select Edit Graph Data). This opens the Graph Data file displaying the frequency (Z) values within each bin (cell) of the histogram (see Figure 4). The bins along the y-axis of the histogram (e.g. Mean_Vel bins) are displayed in the Graph Data as the variables (columns). The bins along the x-axis of the histogram (e.g. Tot_Dep bins) are displayed in the Graph Data as the cases (rows). Use the Z values shown to fill in the Z data column in the 3D Surface Data Matrix (e.g. DVZTbl). The first 21 rows of a sample DVZ Table are shown in Figure 5.

Figure 4. Graph Data Matrix from the 3D Bivariate Histogram.

	Var1	Var2	Var3	Var4	Var5	Var6	Var7
Case 1	1.00	1.00	2.00	1.00	0.00	0.00	0.00
Case 2	0.00	9.00	5.00	6.00	3.00	0.00	0.00
Case 3	2.00	23.00	14.00	6.00	4.00	1.00	0.00
Case 4	0.00	8.00	10.00	8.00	6.00	0.00	0.00
Case 5	0.00	7.00	12.00	7.00	2.00	1.00	0.00
Case 6	0.00	4.00	7.00	1.00	1.00	0.00	0.00
Case 7	0.00	1.00	0.00	0.00	0.00	0.00	0.00

Figure 5. Sample portion of the 3D Surface Data Matrix - DVZTbl.

	1 TOTDEPTH	2 MEANVEL	3 Z
1	1.000	0.000	1.000
2	1.000	.250	1.000
3	1.000	.750	2.000
4	1.000	1.250	1.000
5	1.000	1.750	0.000
6	1.000	2.250	0.000
7	1.000	2.750	0.000
8	1.250	0.000	0.000
9	1.250	.250	9.000
10	1.250	.750	5.000
11	1.250	1.250	6.000
12	1.250	1.750	3.000
13	1.250	2.250	0.000
14	1.250	2.750	0.000
15	1.750	0.000	2.000
16	1.750	.250	23.000
17	1.750	.750	14.000
18	1.750	1.250	6.000
19	1.750	1.750	4.000
20	1.750	2.250	1.000
21	1.750	2.750	0.000

The TOTDEPTH and MEANVEL values in the 3D Surface Data Matrix must be assigned using the ranges for each of the histogram cells. The midpoint value for each range will usually suffice. Again, knowing the distribution of the input data will highlight instances where a

different assignment strategy is necessary (e.g. averages within each bin). Be careful to assign appropriate values at the extremes of each parameter. If the lowest Tot_Dep range includes data from 0 – 1 feet, yet no fish were observed shallower than 0.8 feet, then 0.75 or 1.0 would be a better value assigned to TOTDEPTH than 0.5 feet. Again, be careful not to create bins outside the range of the original observations. Note the 3D Surface Data matrix variables are renamed to avoid confusion with the original raw data (Tot_Dep -> TOTDEPTH and Mean_Vel -> MEANVEL). Save this file once the full matrix is complete.

NONLINEAR USER-SPECIFIED ESTIMATION

The 3D Surface Data Matrix (DVZTbl) contains the independent variables (TOTDEPTH and MEANVEL) and the dependent variable (Z) that are used in fitting a nonlinear regression model. The investigator must specify this model in the Nonlinear Estimation module. An exponential polynomial equation is fit to the three-dimensional surface, by regressing the independent (depth and velocity) variables onto the dependent variable (histogram frequency surface). This equation is of the form:

$$Z = \exp (b_0 + b_1D + b_2V + b_3DV + b_4D^2 + b_45V^2\ldots)$$

where:

Z = number of fish observed
D = water column depth
V = average water column velocity
$b_0, b_1, b_2, \ldots$ = equation coefficients

and is fitted to the surface using a least squares regression technique (Prewitt, 1982; Bovee, 1986). The results are displayed in several ways, which are analyzed to test the fit of the equation (Hanson, 1988). Once a final equation is chosen, the data are normalized to provide a maximum output value of 1.

Specifying the Input and Model

To begin the regression of depth and velocity on the Z surface click on the STATISTICA Module Switcher->Nonlinear Estimation and click the Switch To button. The Nonlinear Estimation Panel will open. Click cancel on the Nonlinear Estimation Dialog Box. From the pull-down menus select File->Open Data, which brings up the Open Data File Dialog Box. Select the previously saved 3D Surface Data Matrix (e.g. DVZTbl) and click Open. This opens the data file created in the previous section within the Nonlinear Estimation Panel. From the pull-down menus select Analysis->User-specified regression, which opens the User-Specified Regression Function dialog box. Click on the Function To Be Estimated and Loss Function button, which opens the Estimated Function and Loss Function Dialog Box. In the Estimated Function box you must specify the function to be used in the regression.

The function specified to describe the frequency distribution surface contains terms for each variable (depth and velocity), and one or more terms describing the interactions among the

variables. The complexity of the 3D Bivariate Histogram surface (number of complete peaks) determines the polynomial order necessary to describe the surface. A first order exponential polynomial depicts an exponential decay. A second order function describes a bell shaped curve (Bovee, 1986). The order of the terms used, and which interaction terms to include must be decided by the researcher. The recommended first equation is:

Z = exp (- (b0 + b1*v1 + b2*v2 + b3*v1*v2 + b4*v1^2 + b5*v2^2))

where:

Z = number of fish observed
v1 = water column depth
v2 = average water column velocity
b0, b1, b2 … = equation coefficients.

The recommended Loss Function is the program default:

L = (OBS – PRED)**2

where:

L = loss
OBS = observed values
PRED = predicted values.

Note that STATISTICA syntax rules require TOTDEPTH and MEANVEL be entered as v1 and v2; and that multiplication and powers be specified with the * and ^ operators. (See the STATISTICA manual sections for General Syntax Conventions: Regression Equations/Loss Function for the proper syntax, if another loss function is desired.) Next, click OK to return to the User-Specified Regression Function dialog box. There should be no missing data, so just click OK.

Running the Regression and Evaluating the Model Fit

The Regression Model dialog box opens and displays the model, number of parameters (equation coefficients), loss function, dependent and independent variables, missing data strategy, and number of valid cases (rows in the data matrix). The recommended Estimation Method is the default Quasi-Newton (Hanson, 1988; Bovee, 1986). This is a reliable and fast estimation subroutine, and works well with most datasets. Make sure these inputs are correct, then click OK.

STATISTICA begins the regression calculations and displays its progress in the Parameter Estimation dialog box. The number of iterations performed, loss and coefficient values are shown, and if successful, the message Parameter Estimation Process Converged appears in the bottom of the box. If the estimation does not initially converge try several more attempts (continue). If the parameter estimation process will not converge, try specifying different orders of the depth and velocity terms and different (usually less) interaction terms. If the estimation process still does not converge, repeat these adjustments using a different Estimation Method. Click OK when the Parameter Estimation Process is complete.

The Results dialog box is opened. From here the investigator can review many different displays of the resulting fit of the equation. The Parameter Estimates, Fitted 3D Function and Observed Values, and Distribution of Residuals are a recommended minimum for reviewing the results (see Figures 6 through 9). It is quite helpful to print the Fitted 3D Function and Observed Values graph, and Parameter Estimates (showing R and %Variance Explained (R^2) values) for later comparisons. Observe the Coefficient of Determination (R), and values assigned to the Equation Coefficients (parameters). The Coefficient of Determination evaluates how well the values predicted by the model matched the actual values. The Equation Coefficients offer insight to the relative importance of each term in the equation. If an Equation Coefficient approaches 0, then consider omitting that term in the next running of the model. The Normal Probability Plot of Residuals, and Predicted vs. Observed Values plot are also useful for comparisons between different model runs (see Figures 10 and 11). Click OK to complete this regression and return to the User-Specified Regression Function dialog box.

Note that some functions are too complex, and cannot be printed within the Results dialog box. These functions can be copied into the 3D XYZ Graphs. Select Graphs -> 3D XYZ Graphs -> Surface Plots… In the 3D Surface Plots dialog box assign the variables in the proper order, and select Custom Function and enter the fitted equation and coefficients. (These variables must be entered as x,y,z in the Custom Function.)

Figure 6. Parameter Estimates (coefficients) for the regression equation.

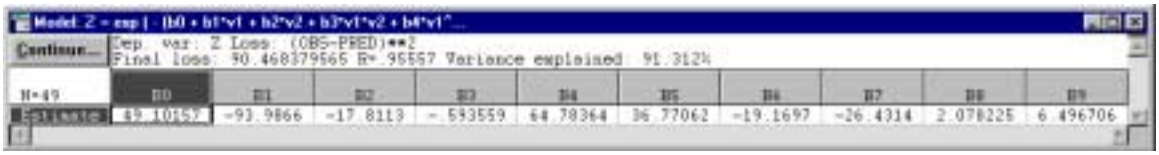
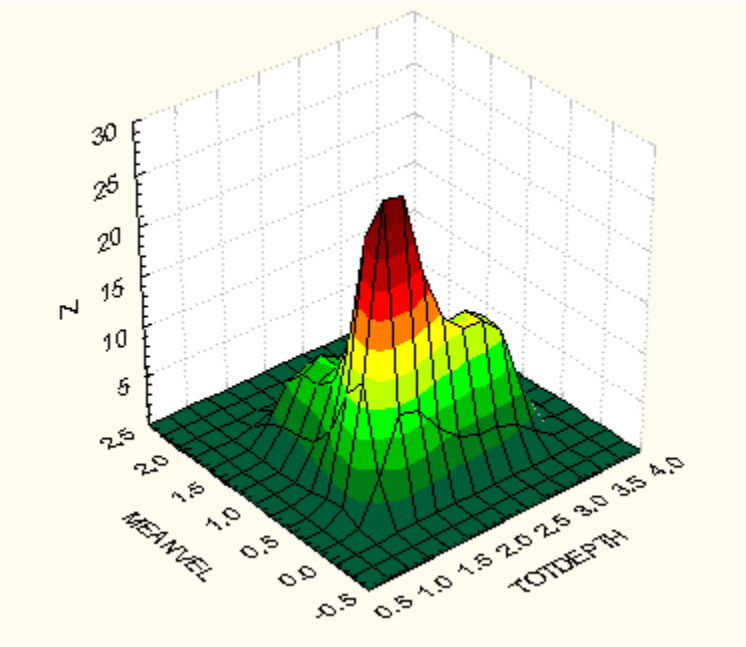


Figure 7. Graph of the Fitted 3D Function and Observed Values.



Use the same commands to rotate the Graph of the Fitted 3D Function and Observed Values as in the 3D Bivariate Histogram section. This allows the researcher to view all aspects of the goodness-of-fit accomplished in the estimation process (see Figure 8).

Figure 8. Rotated Graph of the Fitted 3D Function and Observed Values.

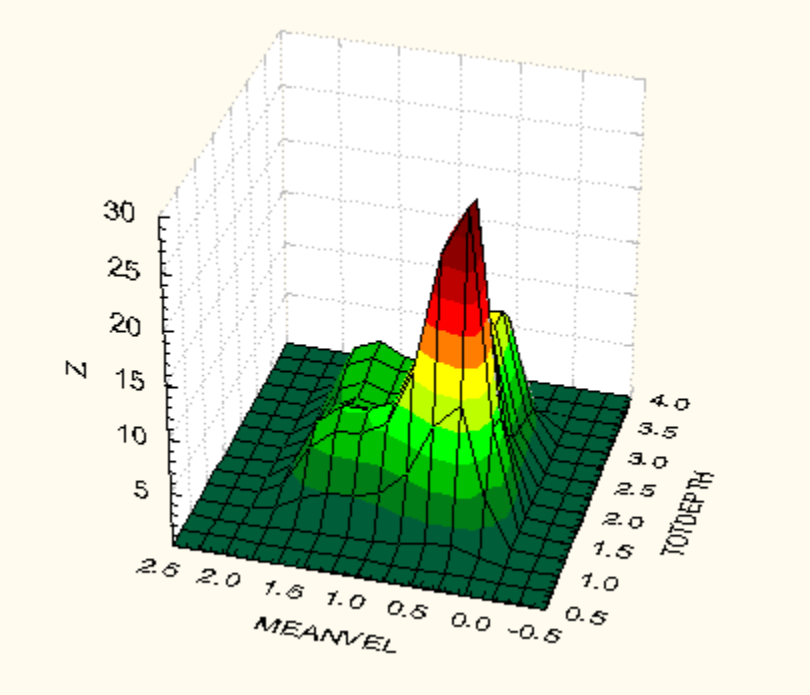


Figure 9. Frequency Distribution of the Residual Values.

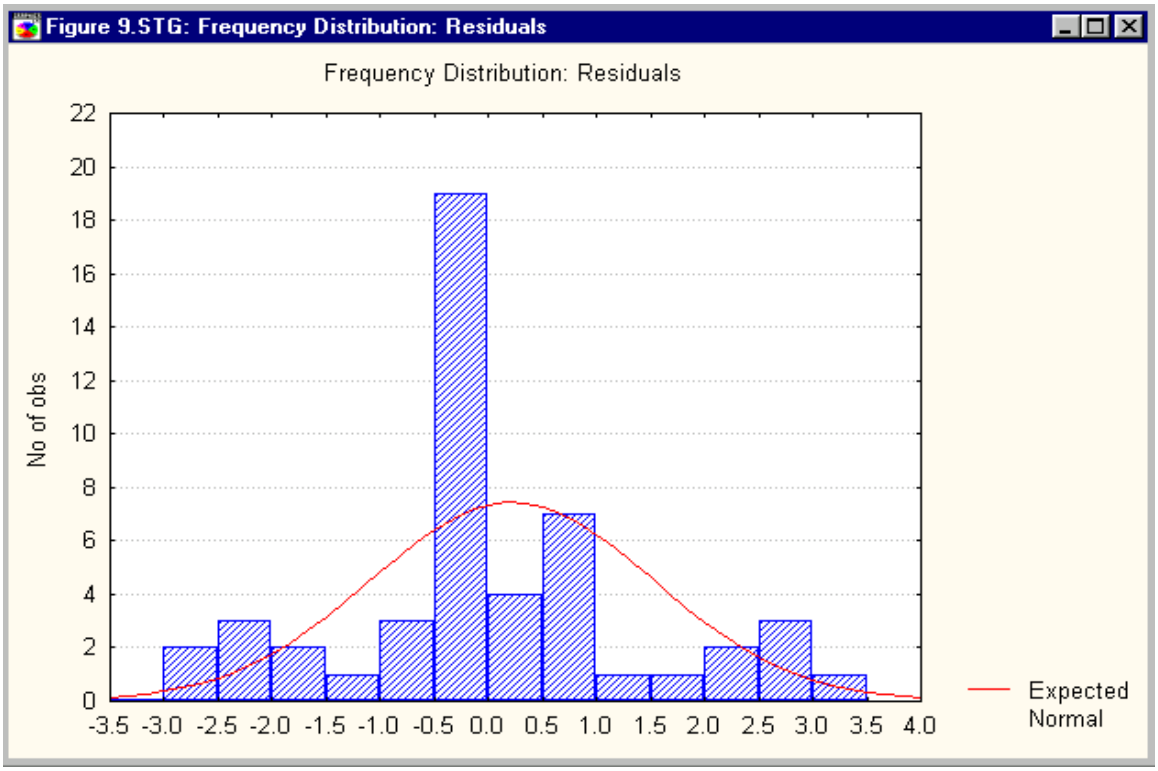


Figure 10. Normal Probability of the Residual Values.

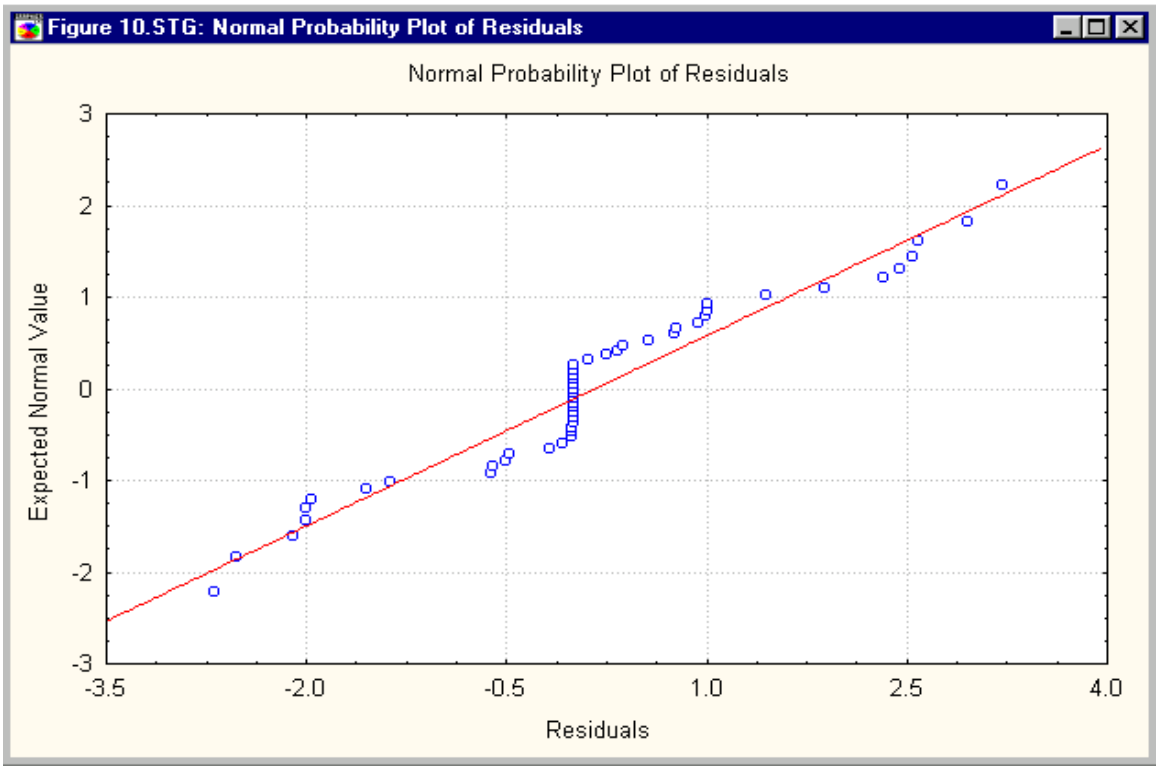
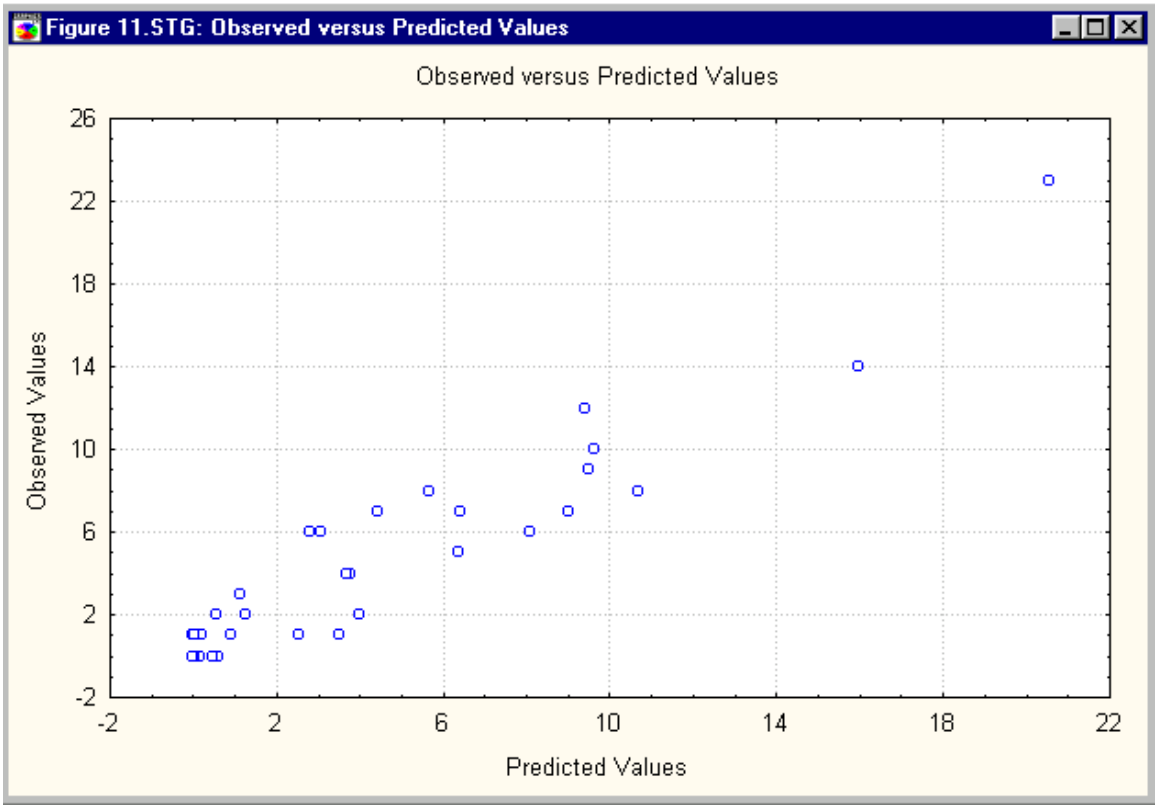


Figure 11. Plot of Observed versus Predicted Values.



Finding the best fit to the 3D Surface Matrix is an iterative process, and generally requires multiple fine-tuning attempts. It is important to experiment with the order of the fitted polynomial in trying to match any particular data set. The first example above used second order terms in both depth and velocity and a first order interaction term. Multiple equation fitting attempts on the sample data set direct one towards a final model yielding the largest coefficient of determination (R) with the fewest terms. This model contained depth and velocity terms expressed to the fourth order, and a first order interaction term. This took seven iterations of running different model equations, and yielded an increase in the R^2 value from 0.64 to 0.91. The investigator should attempt to reach an R^2 value exceeding 0.9.

The investigator is encouraged to work with many different equations and settle on the one providing the best fit to the characteristics of the data set under consideration. Note that Bovee (1986) cautions against the use of terms beyond second order. Hanson (1988) finds the best results using higher order terms, with the largest Coefficient of Determination. Hanson cautions that when using models with higher order terms to evaluate the results only within the bounds of the original data. This is an important constraint on the use of the modeling. The original data set determines the range of application of the modeling results. This process does not yield valid results outside the boundaries set by D_{min} - D_{max}, V_{min} - V_{max}. Results of the modeling should be interpreted and utilized only within these boundaries.

After printing and/or saving the results of the first model, return to the User-Specified Regression Function dialog box. Enter in the next equation used to fit the 3D Surface Data

Matrix, and repeat the process. Print and/or save the results for comparing between different iterations. The above steps are repeated until the final testing and comparisons are done, and the model providing the best fit to the data is chosen.

Normalizing the Habitat Suitability Index

The final regression equation must be normalized to provide a maximum habitat suitability index of 1. Take the maximum value (N) from the final model and enter it into the fitted equation as a normalizing term in front of the exponential polynomial expression. This forces the maximum value equal to 1, and all other values between 0 and 1. This new equation takes the form:

$$SI = (1/N) \exp (b_0 + b_1D + b_2V + b_3DV + b_4D^2 + b_45V^2\ldots)$$

where:

SI = Habitat Suitability Index
N = normalizing term
D = water column depth
V = average water column velocity
b_0, b_1, b_2, … = equation coefficients

This is the input equation for the habitat suitability modeling.

These steps are repeated for each species and life stage to develop a series of equations for habitat suitability. These equations with the data sets will be passed to Miller Ecological Consultants, Inc. for use in the Flathead River instream flow study.

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Hanson, D. F. 1988. Investigations into the use of bivariate habitat suitability functions in application of the PHABSIM model. In: Bovee, K. D. and J. R. Zuboy, ed., Proceedings of a Workshop on the Development and Evaluation of Habitat Suitability Criteria, 1988, Fish and Wildlife Service, U.S. Department of the Interior, Biological Report 88(11), 407pp.

Prewitt, C. G. 1982. The Effect of Depth-Velocity Correlations on Aquatic Physical Habitat Usability Estimates. Ph.D. Dissertation submitted to Department of Fishery and Wildlife Biology, Colorado State University. 83pp.

APPENDIX

A. Step by Step Sequence

1. Import data and make necessary formatting adjustments.

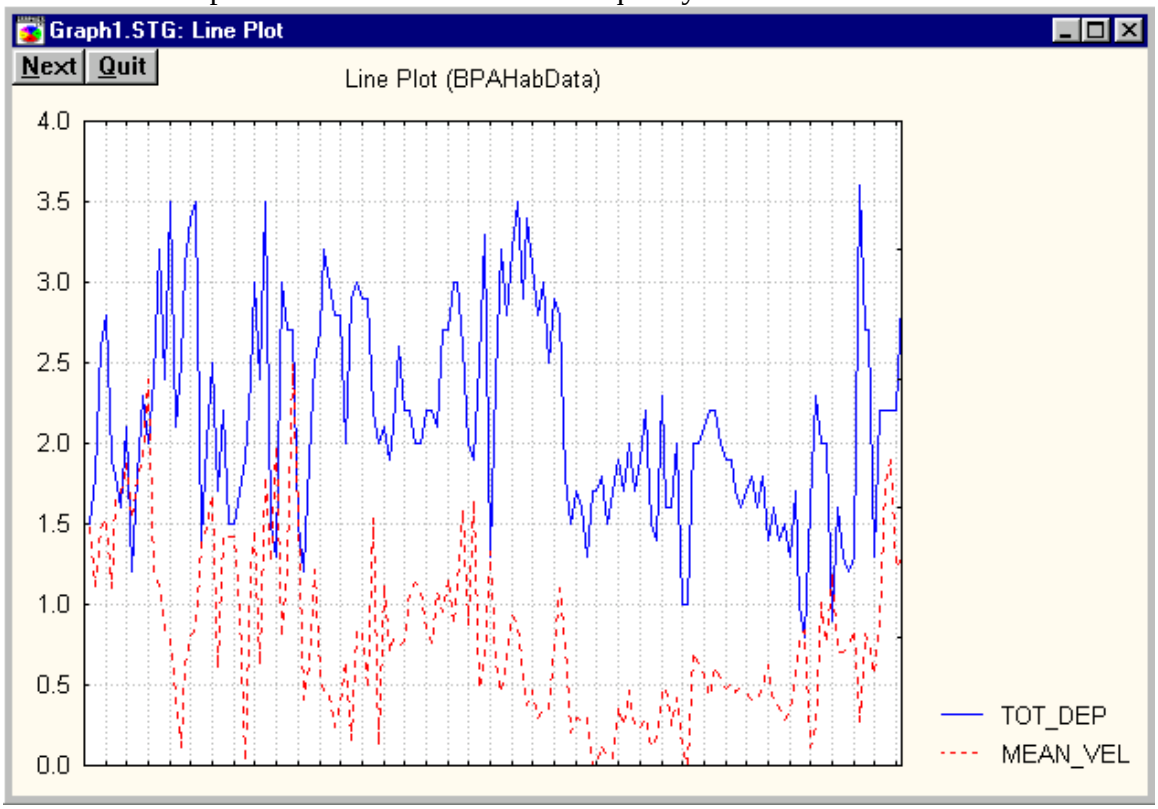
Data: BPA Habitat data test set.STA 20v * 160c

	1 VAR1	2 VAR2	3 VAR3	4 VAR4	5 VAR5	6 VAR6	7 VAR7	8 VAR8	9 VAR9	10 VAR10	11 VAR11	12 VAR12
1	SAN JUAN		OBS #	SPECIES	LS	TIME	TEMP	HAB TYPE	TOT DEP	FISH DEP	MEAN VEL	FISH VEL
2	34912		1	RB	ADULT	910	9	GLIDE	2.	1.	1.	1.
3	SPILLWAY		2	RB	ADULT	914	9	GLIDE	2.	1	1.	1.
4	NORTH BA		3	RB	ADULT	915	9	GLIDE	3.	2.	1.	2.
5	CATCH &		4	RB	ADULT	916	9	GLIDE	3.	2.	2.	2.
6			5	RB	ADULT	917	9	GLIDE	2.	1.	1.	1.
7			6	RB	ADULT	919	9	GLIDE	2.	1	2.	2.
8			7	RB	ADULT	925	9	GLIDE	2.	1	2.	2.
9			8	RB	ADULT	926	9	GLIDE	2.	1.	2.	2.
10			9	RB	ADULT	931	9	GLIDE	1.	1.	2.	2.
11			10	RB	ADULT	933	9	GLIDE	2.	1.	2.	2.
12			11	RB	ADULT	934	9	GLIDE	2.	1.	2.	1.
13			12	RB	ADULT	936	9	GLIDE	2	1.	2.	2.
14			13	RB	ADULT	950	9	POOL	2.	1.	1.	1.
15			14	RB	ADULT	952	9	POOL	3.	2.	1.	1.

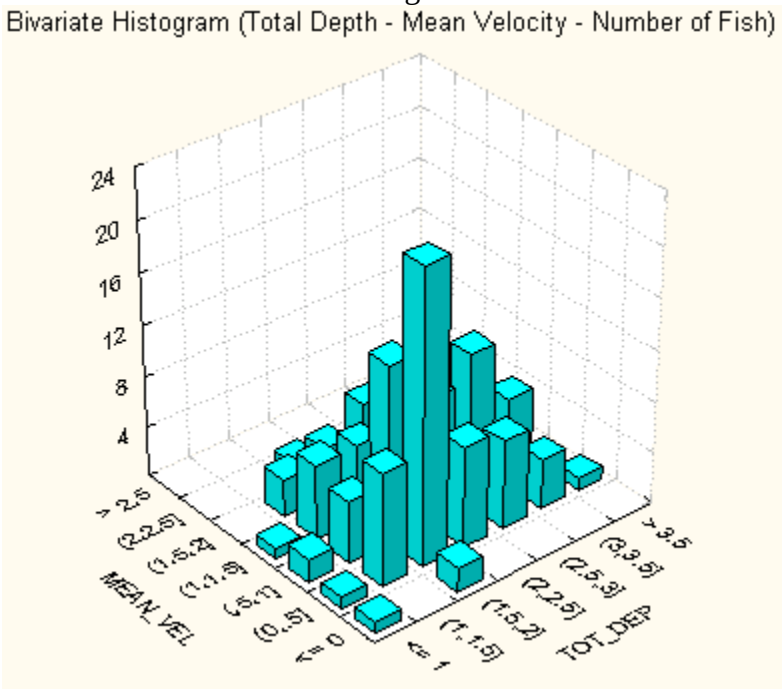
Data: BPAHAB~1.STA 18v * 159c

	1 VAR1	2 VAR2	3 OBS_NO_	4 SPECIES	5 LS	6 TIME	7 TEMP	8 HAB_TYPE	9 TOT_DEP	10 FISH_DEP	11 MEAN_VEL	12 FISH_VEL
1	SAN JUAN		1	RB	ADULT	910	9.000	GLIDE	1.500	.600	1.480	1.200
2	34192		2	RB	ADULT	914	9.000	GLIDE	1.800	1.000	1.110	1.080
3	SPILLWAY		3	RB	ADULT	915	9.000	GLIDE	2.600	1.600	1.480	1.780
4	NORTH BA		4	RB	ADULT	916	9.000	GLIDE	2.800	1.800	1.540	2.060
5	CATCH &		5	RB	ADULT	917	9.000	GLIDE	1.900	.500	1.100	.930
6			6	RB	ADULT	919	9.000	GLIDE	1.800	1.000	1.670	1.940
7			7	RB	ADULT	925	9.000	GLIDE	1.600	1.000	1.690	2.110
8			8	RB	ADULT	926	9.000	GLIDE	2.100	1.400	1.880	2.250
9			9	RB	ADULT	931	9.000	GLIDE	1.200	.600	1.530	1.720
10			10	RB	ADULT	933	9.000	GLIDE	1.800	.900	1.780	1.890
11			11	RB	ADULT	934	9.000	GLIDE	2.300	1.200	1.920	1.120
12			12	RB	ADULT	936	9.000	GLIDE	2.000	.800	2.400	2.430
13			13	RB	ADULT	950	9.000	POOL	2.400	1.400	1.190	1.170
14			14	RB	ADULT	952	9.000	POOL	3.200	1.500	1.120	1.050
15			15	RB	ADULT	953	9.000	POOL	2.400	.600	.840	.830

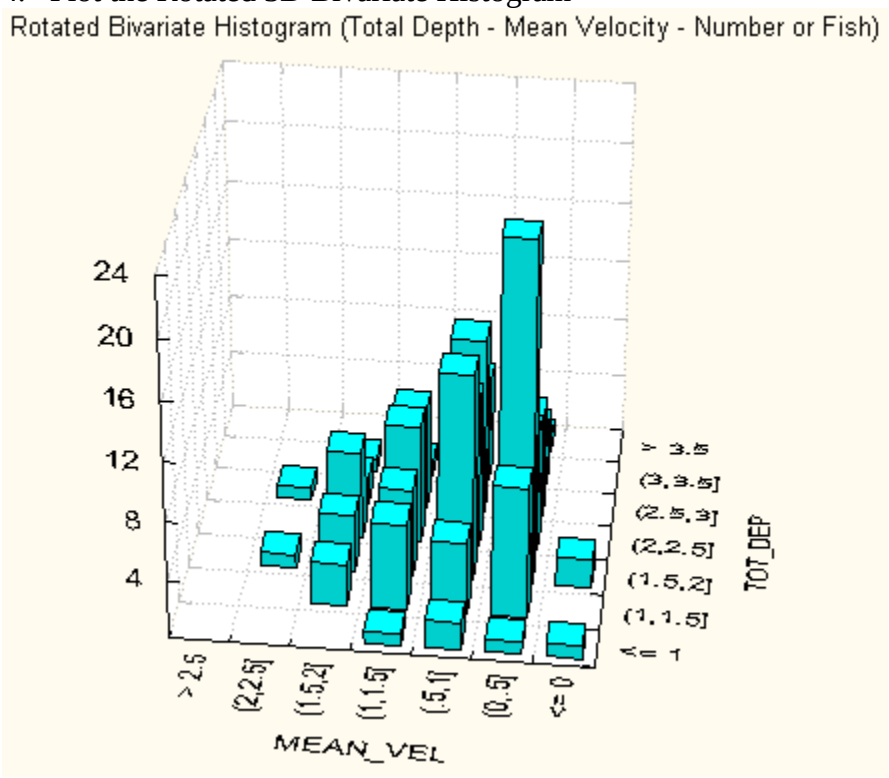
2. Produce simple Line Plots of variables and quality-control the data.



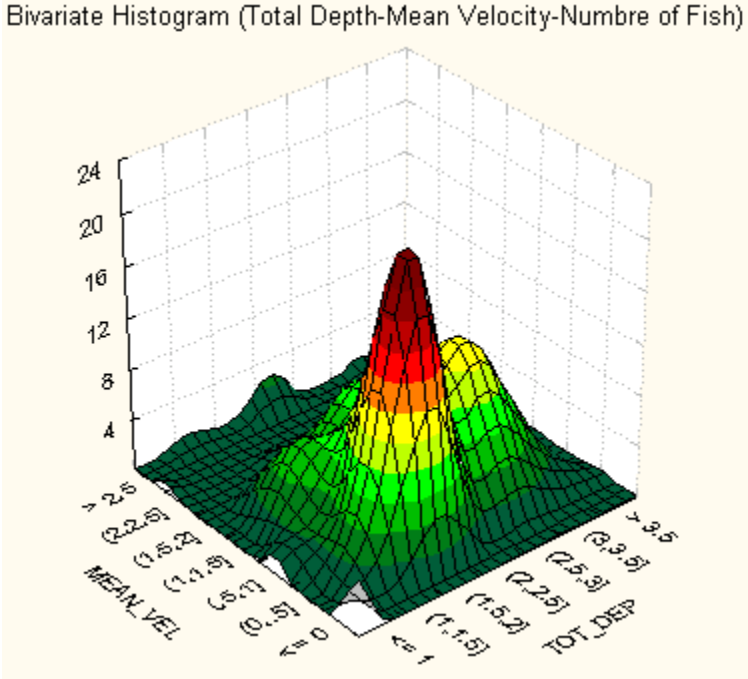
3. Produce 3D Bivariate Histogram



4. Plot the Rotated 3D Bivariate Histogram



5. Produce the 3D Surface and Rotated 3D Surface Plots of the 3D Bivariate Histogram



6. Edit the 3D Bivariate Histogram graph data matrix.

Graph Data for Graph11: Bivariate Histogram

Bivariate Histogram (BPAHabData2.sta 18v*159c)

	Box Plot						
	Var1	Var2	Var3	Var4	Var5	Var6	Var7
Case 1	1.00	1.00	2.00	1.00	0.00	0.00	0.00
Case 2	0.00	9.00	5.00	6.00	3.00	0.00	0.00
Case 3	2.00	23.00	14.00	6.00	4.00	1.00	0.00
Case 4	0.00	8.00	10.00	8.00	6.00	0.00	0.00
Case 5	0.00	7.00	12.00	7.00	2.00	1.00	0.00
Case 6	0.00	4.00	7.00	1.00	1.00	0.00	0.00
Case 7	0.00	1.00	0.00	0.00	0.00	0.00	0.00
Case 8							

7. Create the 3D Surface Data Matrix – DVZTbl.

Data: DVZTBL.STA 3v * 4...

NUM VAL	1 TOTDEPTH	2 MEANVEL	3 Z
1	1.000	0.000	1.000
2	1.000	.250	1.000
3	1.000	.750	2.000
4	1.000	1.250	1.000
5	1.000	1.750	0.000
6	1.000	2.250	0.000
7	1.000	2.750	0.000
8	1.250	0.000	0.000
9	1.250	.250	9.000
10	1.250	.750	5.000
11	1.250	1.250	6.000
12	1.250	1.750	3.000
13	1.250	2.250	0.000
14	1.250	2.750	0.000

8. Specify the Input, Nonlinear Estimation Model, and the Loss Function.
   Z = exp (- (b0 + b1*v1 + b2*v2 + b3*v1*v2 + b4*v1^2 + b5*v2^2))

where:

Z = Z from DVZTbl = number of fish observed
v1 = TOTDEPTH from DVZTbl = water column depth
v2 = MEANVEL from DVZTbl = average water column velocity
b0, b1, b2 … = equation coefficients.

L = (OBS – PRED)**2

where:

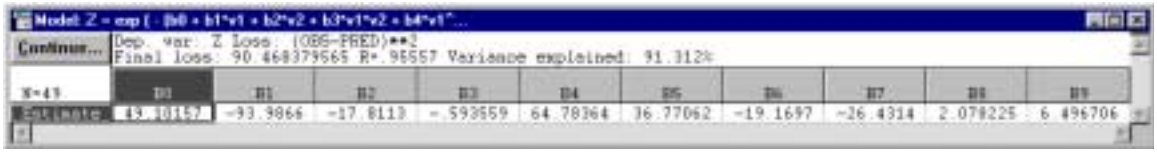
L = loss
OBS = observed values
PRED = predicted values.

9. Assign/check Model settings and Run the Regression Model.
   Model equation/parameters (equation coefficients)/loss function/variables
   Missing data/valid cases/estimation method

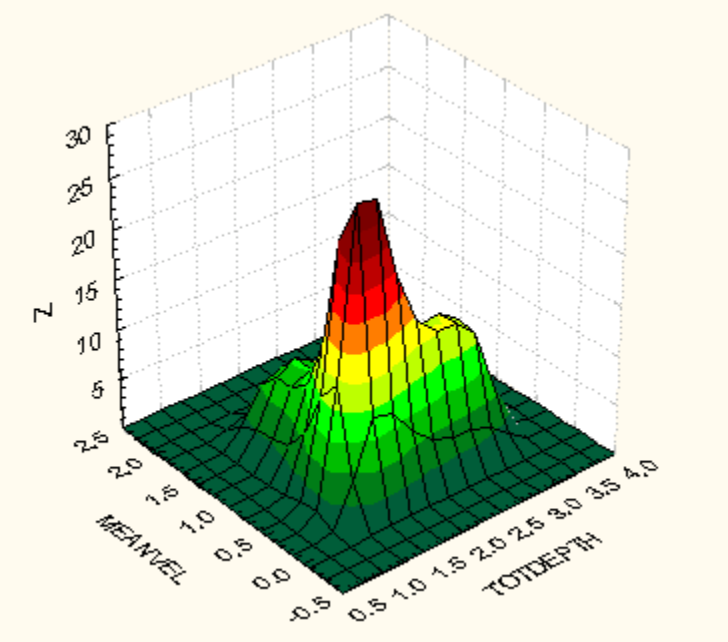
   Convergence of the Parameter Estimation Process

10. Evaluating the Model Fit

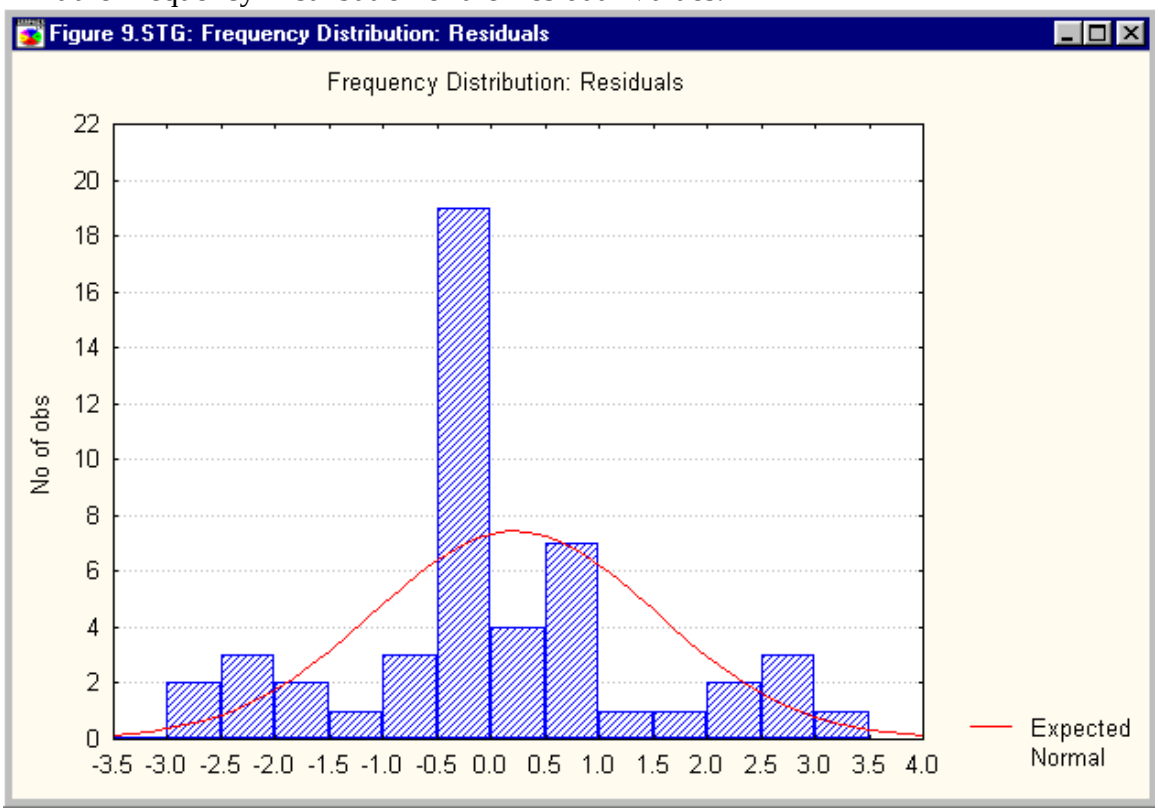
Print the Parameter Estimates, Loss, and Variance results.



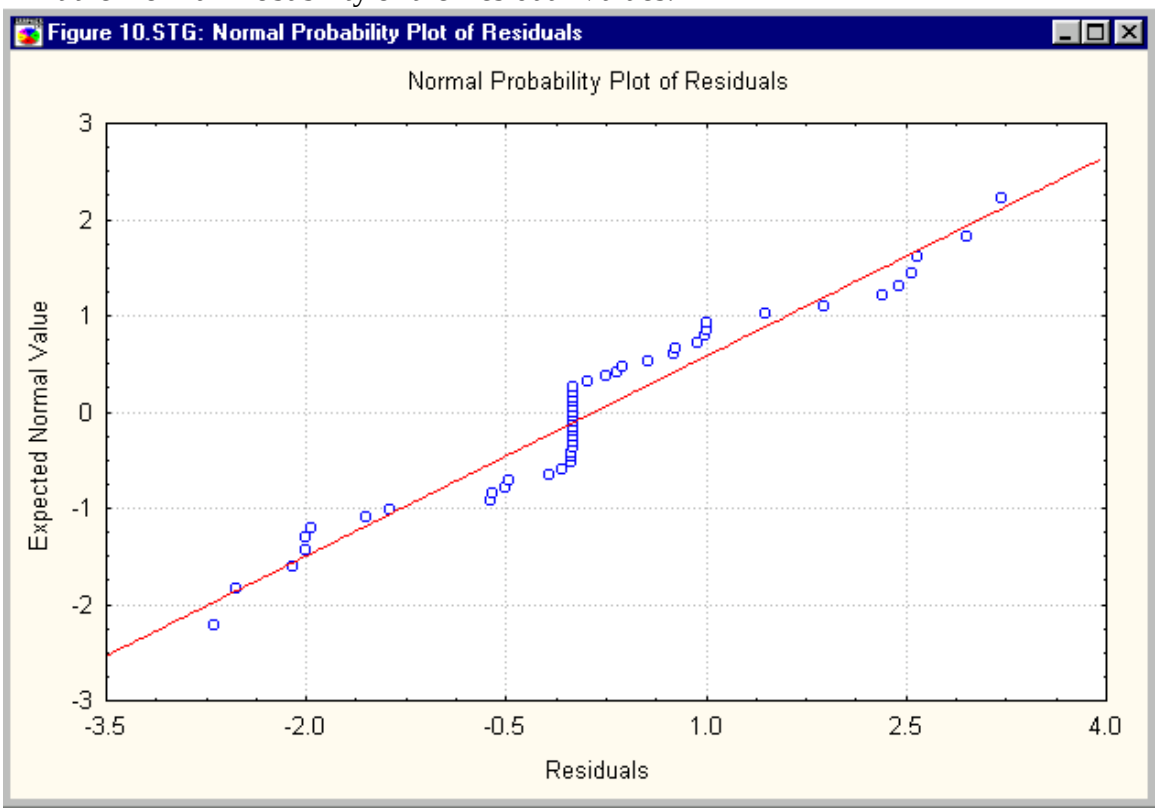
Print the Fitted 3D Function and Rotated 3D Function graphs.



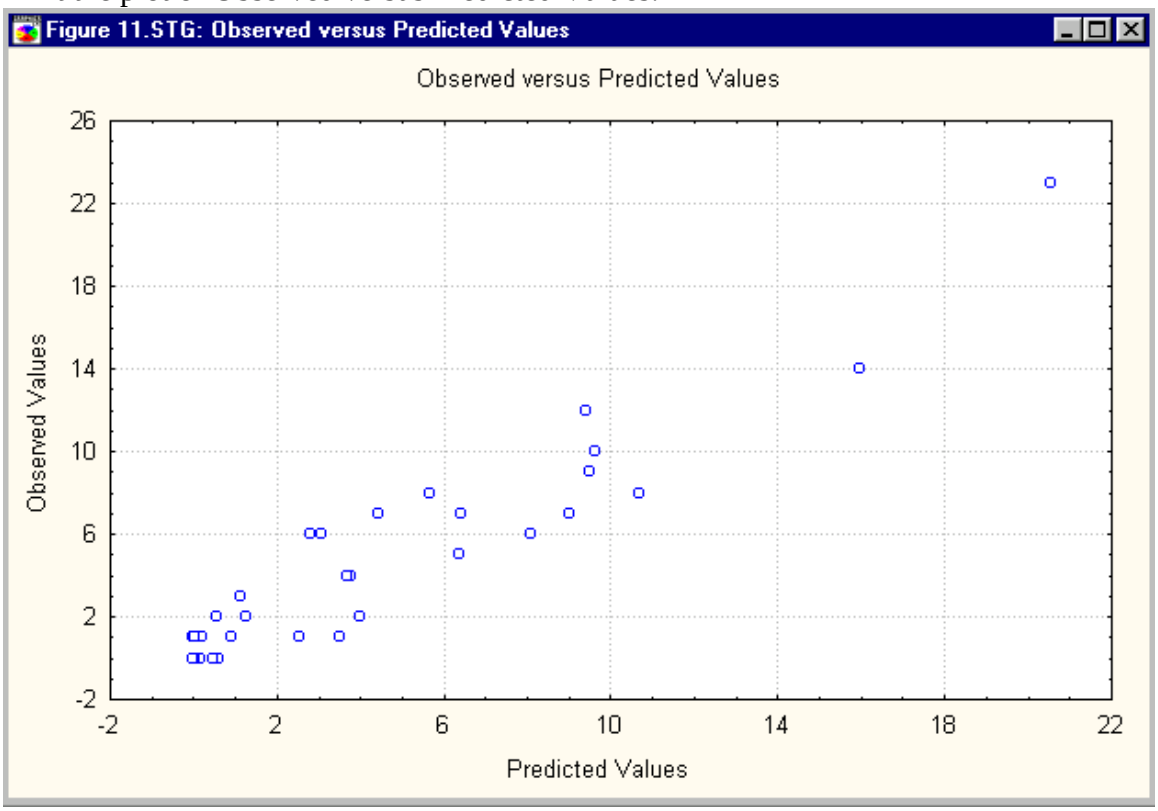
Print the Frequency Distribution of the Residual Values.



Print the Normal Probability of the Residual Values.



Print the plot of Observed versus Predicted Values.



11. Test models to find the best fit to the data. Formulate the final regression equation based on iterations of the model testing.

12. Normalize the final equation to produce the Habitat Suitability Index.

$$SI = (1/N) \exp (b_0 + b_1D + b_2V + b_3DV + b_4D^2 + b_45V^2 \ldots)$$

where:

SI = Habitat Suitability Index
N = normalizing term
D = water column depth
V = average water column velocity
b_0, b_1, b_2, … = equation coefficients

13. Repeat these steps for each species and life stage to develop a series of equations for habitat suitability.

B. Quality Control Measures

Quality control of the calculation of bivariate habitat suitability functions using the above process requires, at a minimum, that Montana Fish, Wildlife and Parks return to Miller Ecological Consultants, Inc. copies of the following for each species and life stage analyzed:

1. Boundary values for the input Depth-Velocity observations: D_{min}, D_{max}, V_{min}, V_{max}.
2. 3D Bivariate Histogram and Rotated 3D Bivariate Histogram plots.
3. 3D Surface and Rotated 3D Surface plots of the 3D Bivariate Histogram.
4. 3D Surface Data Matrix (DVZ table).
5. Description of the Model Inputs used in fitting an equation to the DVZ table.
6. Evaluation of the Model Fit for the final equation including:
   - Model equation
   - Parameter estimates and R value
   - Graph of the Fitted 3D Function
   - Rotated graph of the Fitted 3D Function
   - Plot of the Frequency Distribution of Residual Values
   - Normal Probability Plot of the Residuals
   - Plot of Observed versus Predicted Values
   - Habitat Suitability Index (SI)
   - Normalizing term used to set maximum habitat suitability index = 1.0

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