# Kootenai River Instream Flow Analysis

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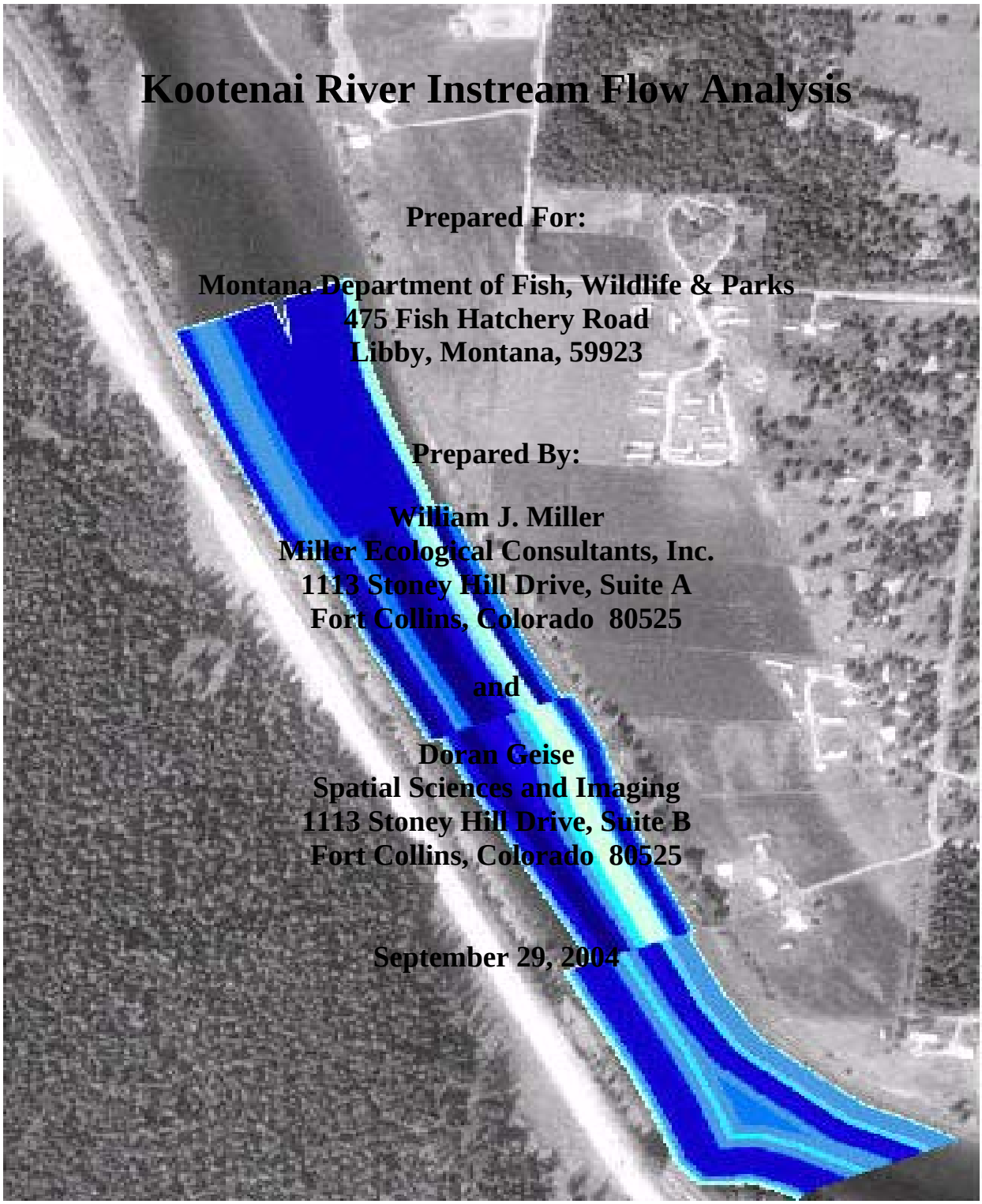

# Kootenai River Instream Flow Analysis

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**September 29, 2004**

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# EXECUTIVE SUMMARY

A modified Instream Flow Incremental Methodology (IFIM) approach was used on the mainstem Kootenai River from Libby Dam downstream to Bonners Ferry, Idaho. The objective of this study was to quantify changes in habitat for the target fish species, bull trout (*Salvelinus confluentus*) and rainbow trout (*Oncorhynchus mykiss*), as a function of discharge in the river.

This study used physical data and habitat use information from previous studies in the 1990s. The present study adapted the one-dimensional physical data into a georeferenced data set for each study site. 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 the quantity of suitable habitat is greater at lower discharges than higher discharges and that the more stable flow regime from 1993 through 2002 provided more stable habitat conditions when compared to the highly variable flow regime from 1983 through 1992.

The daily and weekly variability under 1983-1992 conditions forces subadult bull trout to use less productive habitat during the night by repetitively wetting and drying stream channel margin area. Subadult bull trout exhibit a distinct difference between daytime and nighttime habitat use (Muhlfeld 2002). These fish utilize deeper main channel habitats during the day and move to shallow channel margin areas at night. The productivity of lower trophic levels is low within the consistently watered and dewatered marginal areas and thus these areas provide little foraging value to subadult bull trout that utilize those areas as flows increase.

The more stable flow regime (for weekly or daily timesteps) from 1993-2002 should be more productive than flow regimes with high weekly or daily variability. The highly variable flows likely stress subadult bull trout and rainbow trout due to the additional movement required to find suitable habitat or through the utilization of less suitable habitat when more suitable habitat is not available.

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 two sections of the river. The habitat time series can be used to compare habitat changes over time.

If a more detailed description of habitat use is required for species such as white sturgeon, it is recommended that new sites using two-dimensional models in critical habitat areas be developed. Based on the habitat characteristics shown in this study, three study sites, one in each section, each approximately 1 mile long could be used to represent the habitat conditions in the Kootenai River.

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# INTRODUCTION

Montana Department of Fish, Wildlife and Parks initiated instream flow studies on the Kootenai River in the early 1990s. Those studies collected both physical habitat data and habitat utilization data. A detailed description of data collection techniques is provided in Hoffman et al. (2002). The present study uses that physical data in a hydraulic and GIS simulation framework to determine changes in habitat availability for fish in the Kootenai River as a function of alterations 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 a tool for decision makers to critically evaluate tradeoffs in river management scenarios.

The basis for this GIS approach comes from the Instream Flow Incremental Methodology (IFIM) and is patterned after Bovee (1982), and 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 Kootenai River. This approach is conceptually similar to the study recently completed on the Flathead River (Miller et al. 2003). Components needed for this methodology include habitat use information for the species of interest, physical geometry and hydraulics information of georeferenced physical data collected at each study site. Physical data included channel cross sections, depth, velocity, and water surface elevations, which provide the physical framework for habitat analysis.

These physical data were placed into a traditional one-dimensional hydraulic simulation where the field data is used to construct the model data sets. Models were calibrated to measured flows and hydraulic parameters simulated for the flows of interest. All output is georeferenced at each study site and the hydraulic simulations for each study site are input into the habitat component.

## Study Area

The study area includes the Kootenai River from Libby Dam downstream to Bonners Ferry, Idaho. The river was divided into two sections. Section 1 begins at Libby Dam and extends downstream to Kootenai Falls. Section 2 begins at Kootenai Falls and extends downstream to Bonners Ferry, Idaho. A third section extends from Bonners Ferry, Idaho downstream to Porthill, Idaho but no hydraulic data sets were available for analysis of this section (Figure 1). A study site was selected in each reach to represent the physical characteristics of the reach. Each study site had multiple cross sections and most represented multiple habitat types (Table 1).

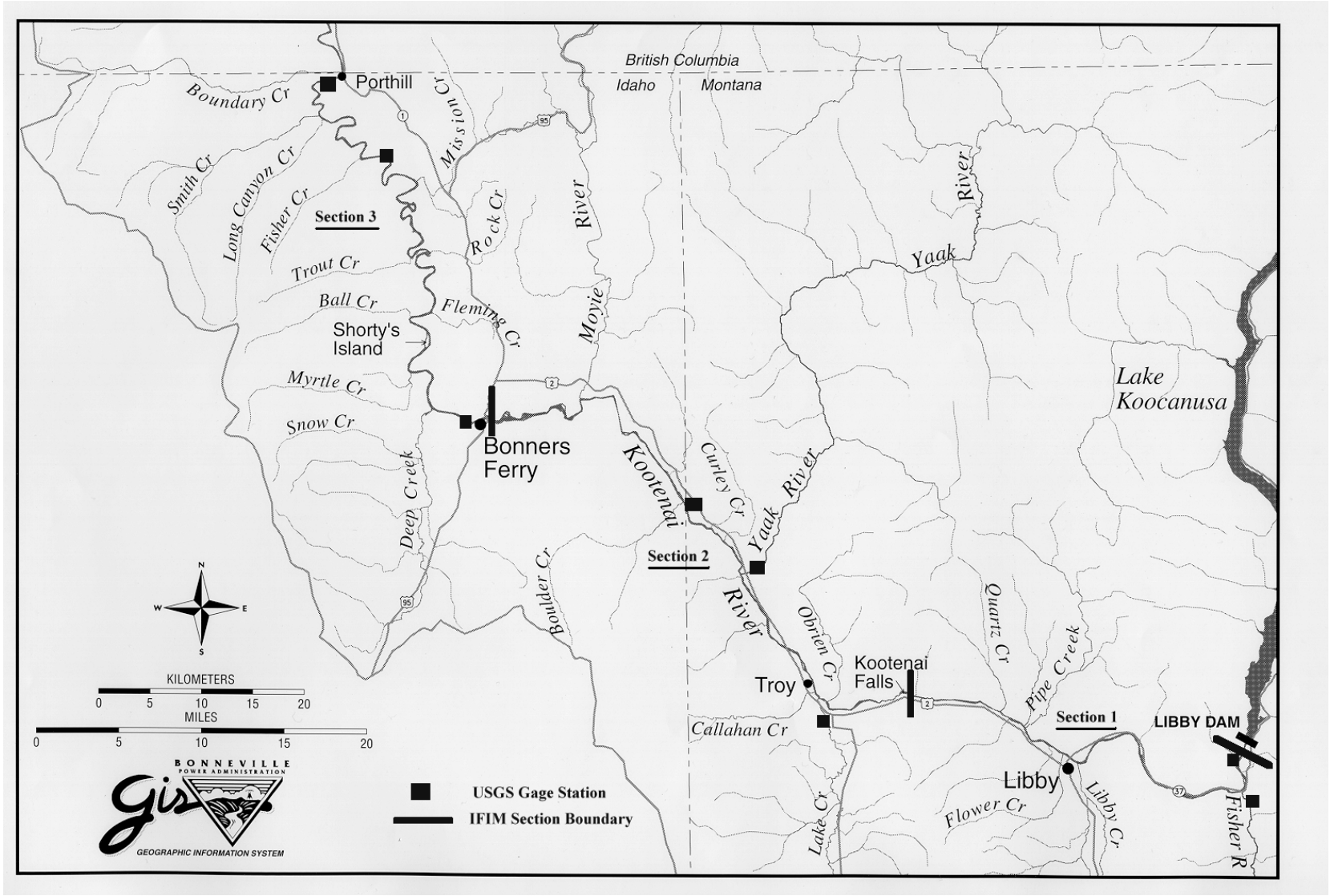



Figure **1**. Study Area for Kootenai River Instream Flow Study. (Source: Hoffman et al. 2002)

Table 1. Kootenai River IFIM study sites names and habitat types by Section.

| Section | Site Name | Habitat types |
|---|---|---|
| **Section 1** | | |
| | Pool 14 | Pool, Glide |
| | Pool 24, Side channel 24 | Pool, side channel |
| | Pool 27, Side channel 27 | Pool, side channel |
| | Pool 28 | Pool, Glide |
| | Run 45 | Run, Glide, Pool |
| | Pool 51 | Pool, Glide, Riffle |
| | Rapid 73 | Rapid, Run |
| **Section 2** | | |
| | Glide 17 | Glide, Pool |
| | Riffle 31 | Riffle, Run, Glide |
| | Run 40 | Run, Side channel |
| | Glide 71 | Glide, Pool |
| | Pool 85 | Pool, |
| | Run 98 | Run, Pool, Glide |

## Objectives

The three objectives for this study were:

1. Use existing Kootenai data sets to construct one-dimensional hydraulic models, convert the hydraulic output to GIS format and develop comprehensive, spatial and tabular attribute database (IFIM models) to characterize physical processes in the Kootenai River affected by flow from Libby Dam.

2. Use IFIM models to compare the results of alternative dam operation strategies on aquatic resources. At 13 sites within two river sections, calibrate IFIM submodels to describe hydraulic conditions under various flow rates. Simulate changes in physical habitat conditions at flows of interest.

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

# METHODS

This project used a modified application of IFIM in two sections of the Kootenai River. Target species include bull trout (*Salvelinus confluentus*)and rainbow trout (*Oncorhynchus mykiss*). To accomplish these goals, Miller Ecological Consultants, Inc. (MEC) and Spatial Sciences and Imaging (SSI)used a combination of hydraulic simulation and GIS mapping on the Kootenai River from Libby dam to near Bonners Ferry, Idaho. 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). The data collected in the 1990s was input in PHABSIM hydraulic models to simulate a range of discharges. The resulting hydraulic simulation data was incorporated into a GIS framework which produced a two-dimensional surface of depth and velocity based on channel cross section and stationing suitable for calculation of habitat area. 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 collection of cross sectional data for depth, velocity and bed profile for multiple cross sections at each study site. A Global Positioning System (GPS) was used to locate cross section endpoints at each study site. The cross section data and aerial photography were used to construct a detailed topographical map (or grid) of the channel. Multiple data sets of water-surface elevations and point velocity measurements were used to calibrate a one-dimensional hydraulic model to simulate depth and velocity at each site. The grid of resulting flow depths and velocities was then compared to habitat suitability criteria for species of interest to determine location and quality of resulting habitat.

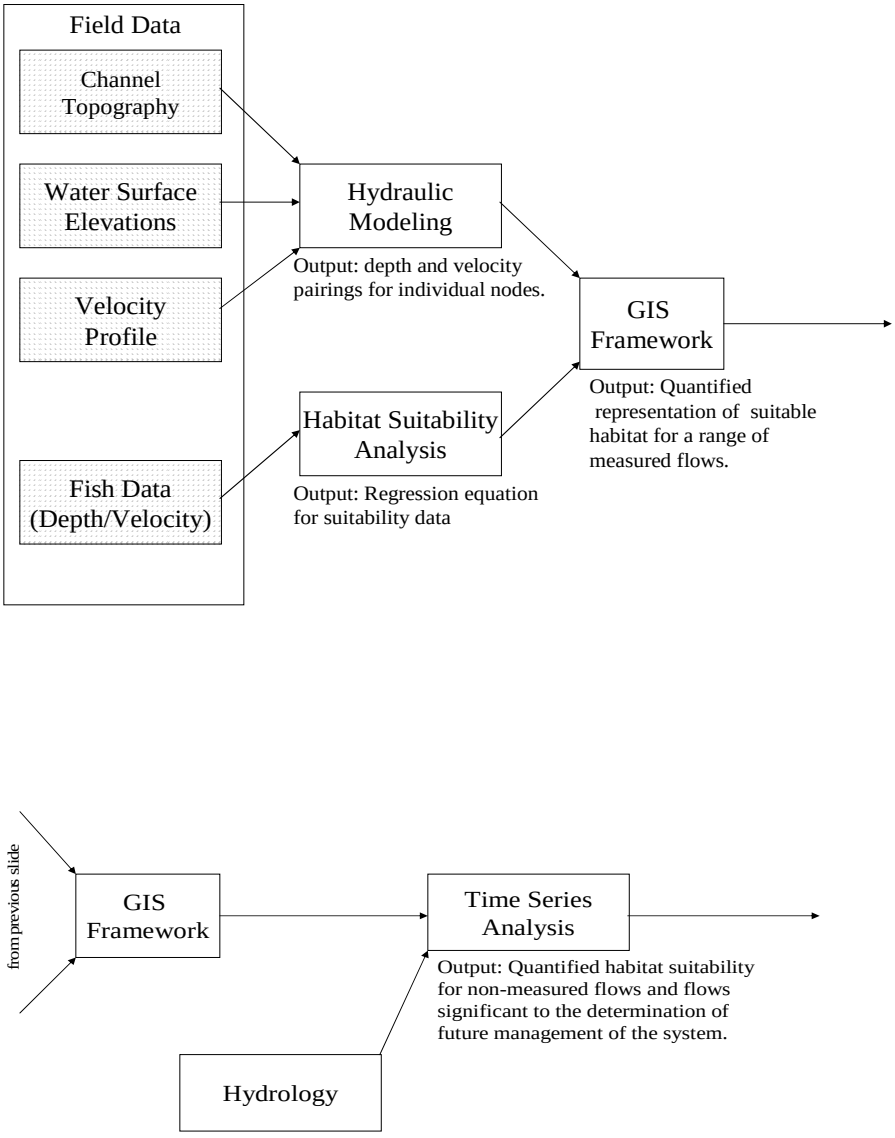



Figure **2**. Flow chart of data analysis for Kootenai River hydraulics and aquatic habitat.

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. Montana Fish, Wildlife and Parks (MFWP) requested that a geographic information system (GIS) be developed to provide these functions for the project.

Habitat suitability was developed concurrently with the physical data (Hoffman et al. 2002). In addition, data from BPA Project 9401000 (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 Kootenai River. 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.

## 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 fit that criterion. Bull trout curves were adapted to this study from Flathead River data (Muhlfeld 2002). Rainbow trout curves were developed from data collected by Hoffman et al. (2002).

Calculation of habitat suitability criteria for a GIS habitat 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 MEC (Miller Ecological Consultants, Inc. 2001) to provide bivariate 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 replicated the 3-D surface.

Site-specific rainbow trout curves were developed from data collected in the Kootenai River (Hoffman et al. 2002). Bivariate suitability equations were calculated using paired depth and velocity data. An initial analysis showed no difference between Section 1 and Section 2 data sets. Therefore, the data for both sections was pooled to generate a single river wide suitability curve for juvenile and adult rainbow trout.

The result of this analysis was a 4th order exponential (with 2nd order interaction term) polynomial equation for both juvenile and adult rainbow trout (Table 2). The equations for calculating habitat suitability are given in Table 3.

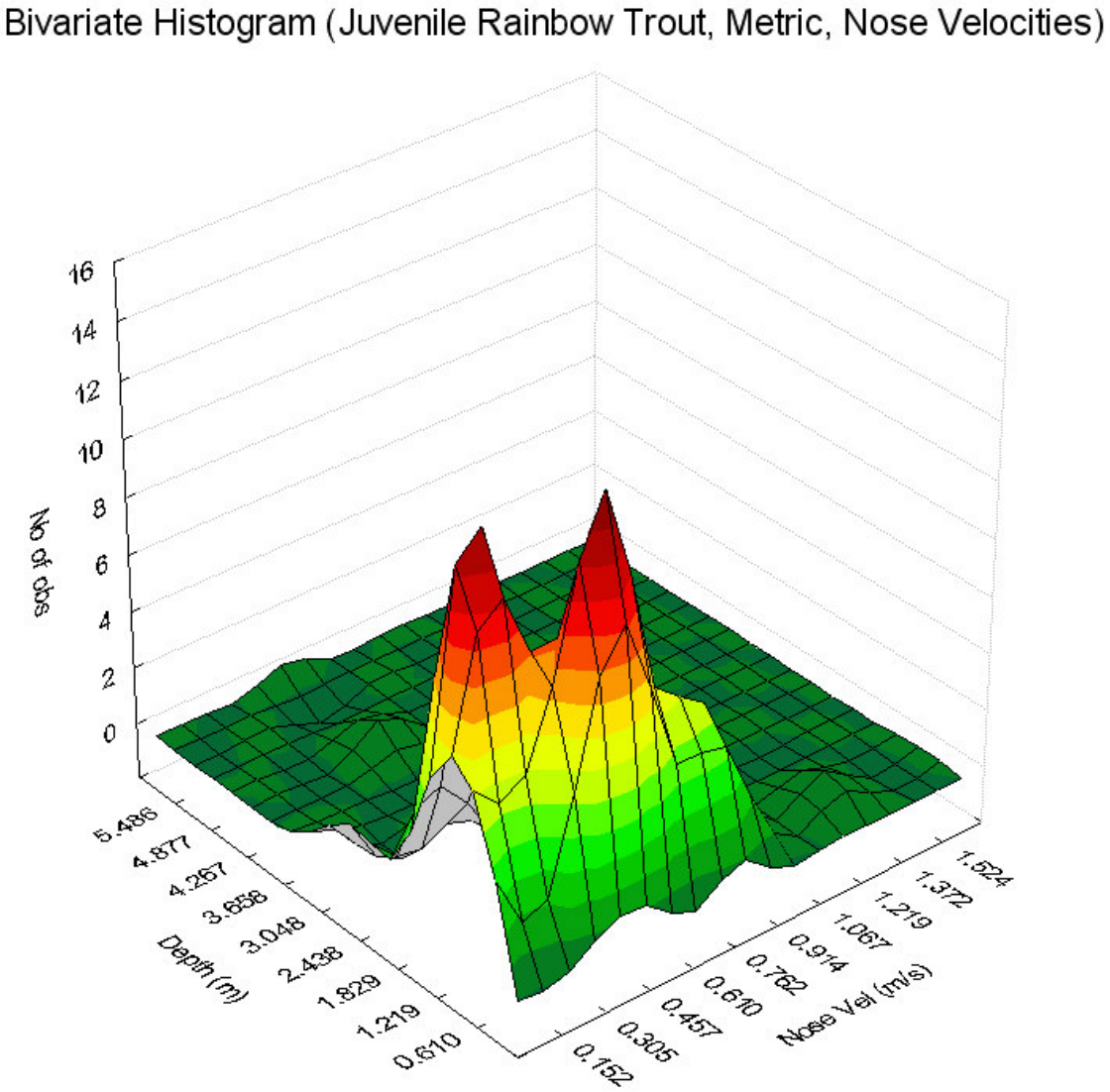



Figure 3. Juvenile rainbow trout bivariate habitat use data plot.

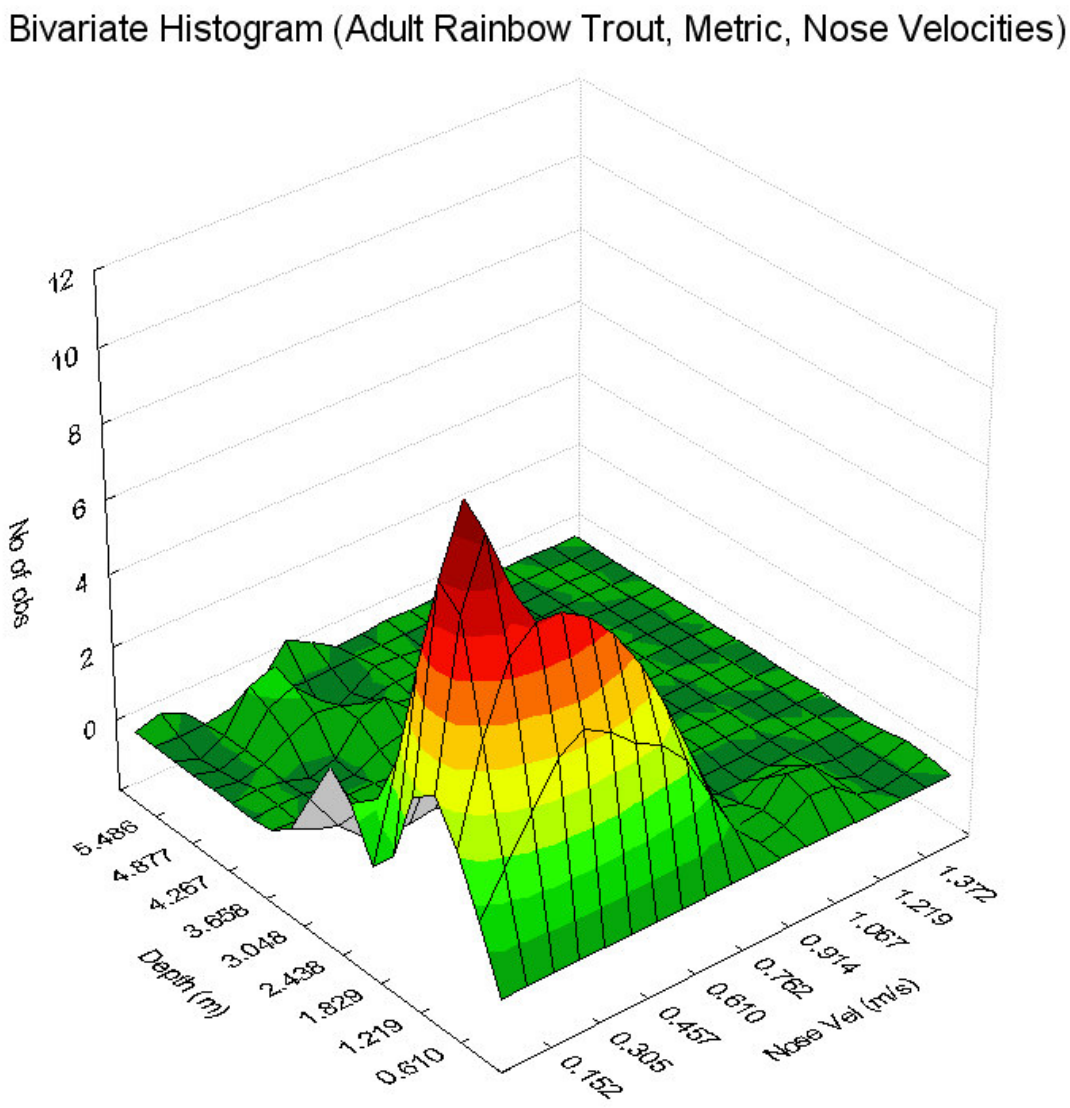



Figure 4. Adult rainbow trout bivariate habitat use data plot.

Table 2. Regression coefficients for multivariate polynomial equations.

| | Juv, Rainbow Trout, Nose Velocities | Adlt, Rainbow Trout, Nose Velocities |
|---|---|---|
| **Depth bin** | 0.98 | 1.53 |
| **Velocity bin** | 0.53 | 0.23 |
| **Max count** | 14 | 11 |
| **Regr. Value** | 11.12620579 | 9.905794381 |
| **New Eq.** | 1.000 | 1.000 |
| **$B_0$** | 12.63476 | 12.30234 |
| **$B_1$** | -29.6548 | -24.8884 |
| **$B_2$** | -5.41803 | -27.9461 |
| **$B_3$** | -1.06847 | 1.133346 |
| **$B_4$** | 22.0465 | 19.23285 |
| **$B_5$** | 5.831679 | 85.20864 |
| **$B_6$** | -6.87596 | -6.61756 |
| **$B_7$** | -9.21166 | -118.411 |
| **$B_8$** | 0.789673 | 0.865971 |
| **$B_9$** | 5.973737 | 60.06973 |
| **$B_{10}$** | 4.729324 | 1.707159 |

Table 3. Multi-variate exponential polynomial equations for rainbow trout juvenile and adult.

**Rainbow Trout, Juvenile, Nose Velocity, Metric**

$$Z=(1/11.12620579)*(\exp(-((12.63476)+(-29.6548*Dep)+(-5.41803*Vel)+(-1.06847*Dep*Vel)+(22.0465*Dep^2)+(5.831679*Vel^2)+(-6.87596*Dep^3)+(-9.21166*Vel^3)+(0.789673*Dep^4)+(5.973737*Vel^4)+(4.729324*Dep^2*Vel^2))$$

**Rainbow Trout, Adult, Nose Velocity, Metric**

$$Z=(1/9.905794381)*(\exp(-((12.30234)+(-24.8884*Dep)+(-27.9461*Vel)+(1.133346*Dep*Vel)+(19.23285*Dep^2)+(85.20864*Vel^2)+(-6.61756*Dep^3)+(-118.411*Vel^3)+(0.865971*Dep^4)+(60.06973*Vel^4)+(1.707159*Dep^2*Vel^2))$$

## GIS Model

The basis for this GIS approach comes from IFIM 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 the adaptation of one dimensional cross section based data into a surface analysis tool. In addition, a time series analysis of habitat was completed based on flow scenarios in the Kootenai River.

Physical data were input into a windows PHABSIM one-dimensional hydraulic simulation where the field data is used to construct the model data sets. The windows based PHABSIM version 1.10 software (USGS Mid-continent Ecological Science Center 2001) was used to conduct the hydraulic modeling calibrations. Models are calibrated for measured flows and hydraulics simulated for the flows of interest. The cross section data had each endpoint georeferenced. The georeferencing for the endpoint was extended along each cross section based on the stationing simulated in PHABSIM. Upstream and downstream cross section boundaries and water edge were placed on aerial photography. All output is geo-referenced for each study site and the hydraulic simulations for each study site are passed to the GIS based weighted usable area model.

## 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 georeferenced hydraulic data sets are imported into Arcview and combined with habitat suitability data for the analysis. The habitat suitability equations are combined with the georeferenced 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 analysis.

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. The Arcview instream habitat model relies on inputs from both the PHABSIM 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 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.

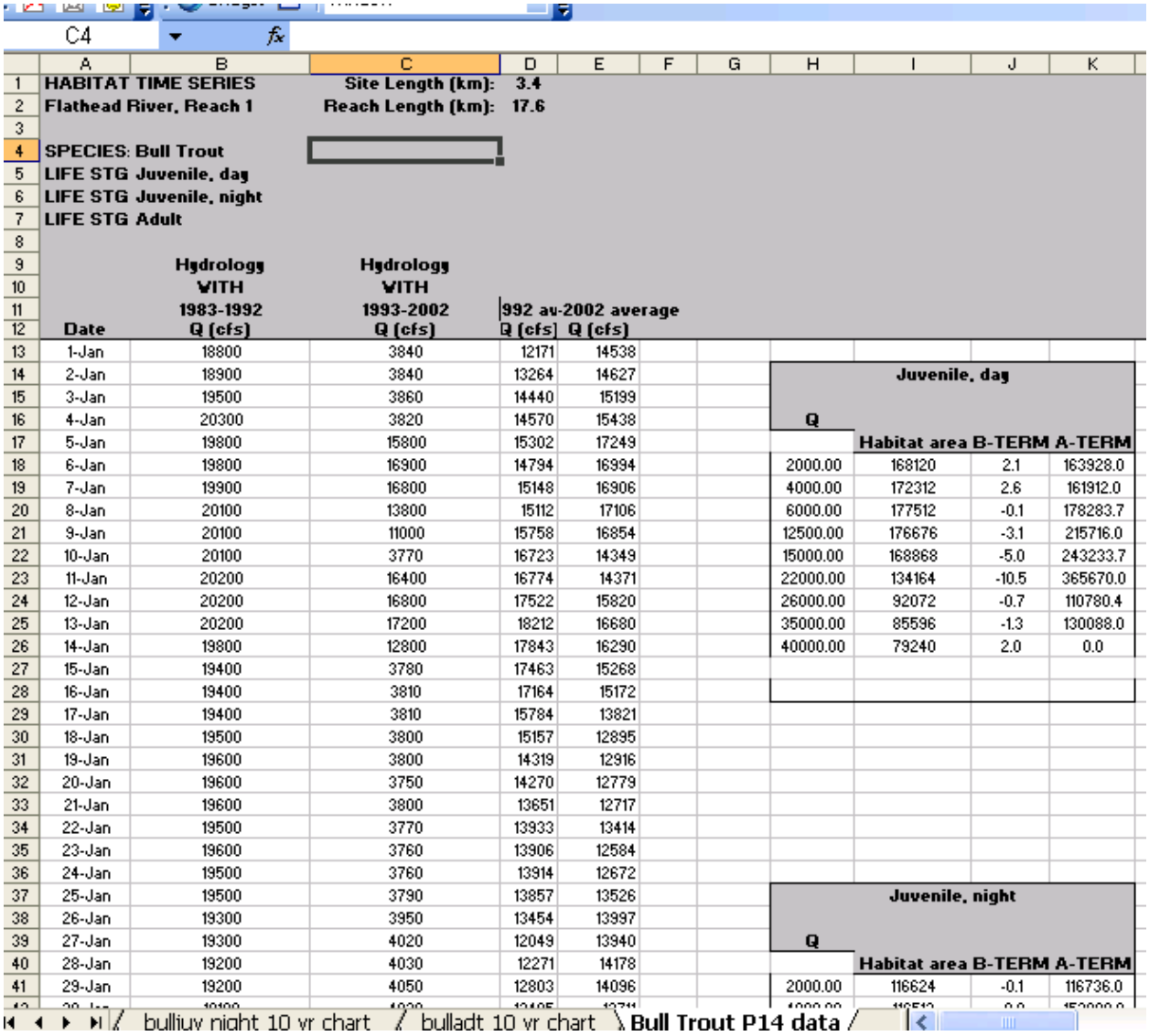
MEC conducted time series evaluations on two different flow regimes. For each flow regime assessed, we conducted both hydrology and habitat time series analysis to calculate both flow- and habitat statistics. These values allowed a direct comparison of the changes that occur in both flow and habitat 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. Column C contains the hydrology for the alternative.

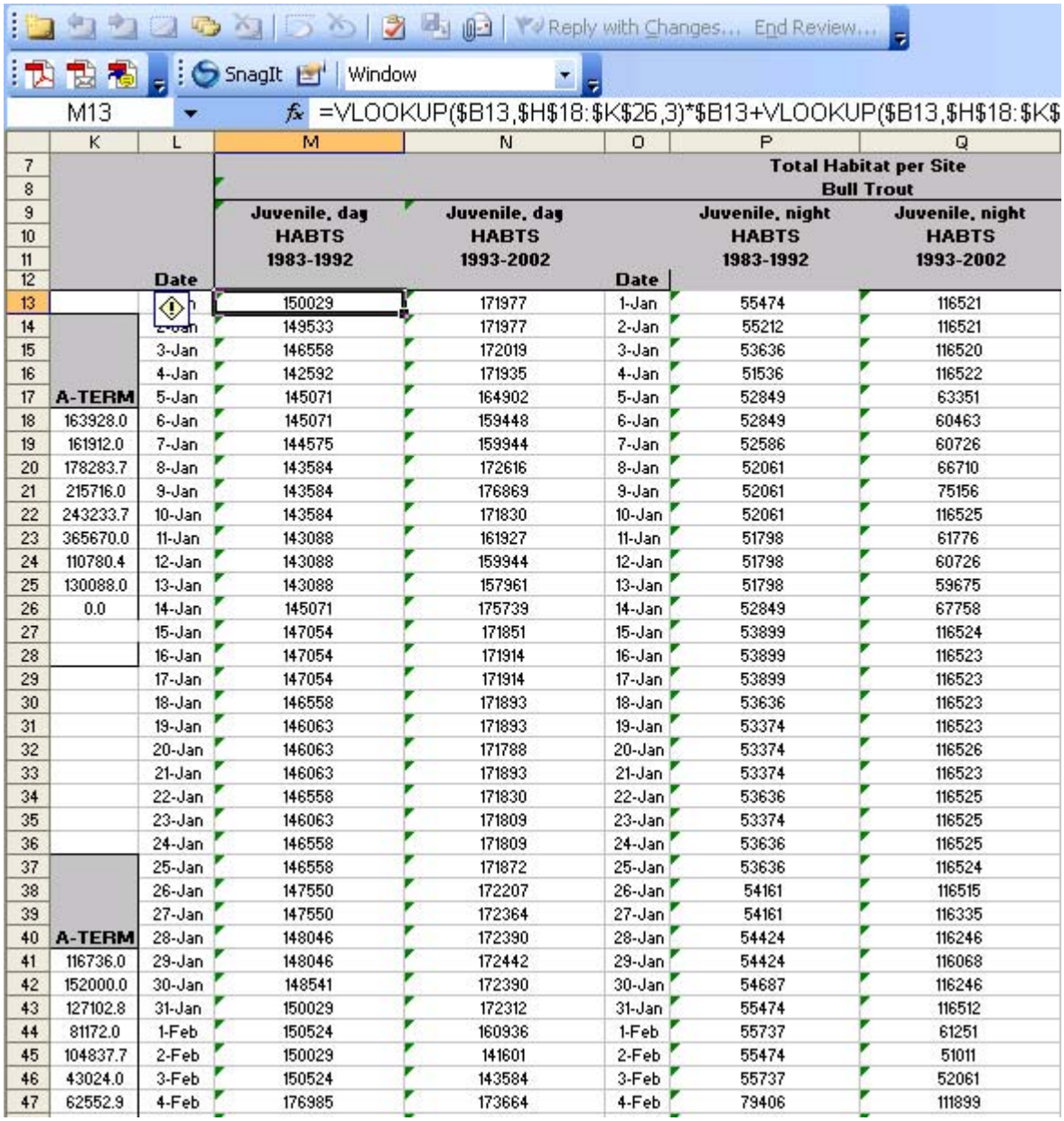
To the right of the hydrology columns are a look-up table with regression coefficients and functions for the weighted usable area for juvenile and adults of the species. The headers denote discharge (Q), habitat, and the A and B terms for the functions. The cells contain the formulas that calculate the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



| | A | B | C | D | E | H | I | J | K |
|---|---|---|---|---|---|---|---|---|---|
| 1 | HABITAT TIME SERIES | | Site Length (km): | 3.4 | | | | | |
| 2 | Flathead River, Reach 1 | | Reach Length (km): | 17.6 | | | | | |
| 3 | | | | | | | | | |
| 4 | SPECIES: Bull Trout | | | | | | | | |
| 5 | LIFE STG Juvenile, day | | | | | | | | |
| 6 | LIFE STG Juvenile, night | | | | | | | | |
| 7 | LIFE STG Adult | | | | | | | | |
| 8 | | | | | | | | | |
| 9 | | Hydrology WITH | Hydrology WITH | | | | | | |
| 10 | | 1983-1992 | 1993-2002 | 992 av-2002 average | | | | | |
| 11 | Date | Q (cfs) | Q (cfs) | Q (cfs) | Q (cfs) | | | | |
| 12 | 1-Jan | 18800 | 3840 | 12171 | 14538 | | | | |
| 13 | 2-Jan | 18900 | 3840 | 13264 | 14627 | | Juvenile, day | | |
| 14 | 3-Jan | 19500 | 3860 | 14440 | 15199 | Q | | | |
| 15 | 4-Jan | 20300 | 3820 | 14570 | 15438 | | Habitat area | B-TERM | A-TERM |
| 16 | 5-Jan | 19800 | 15800 | 15302 | 17249 | 2000.00 | 168120 | 2.1 | 163928.0 |
| 17 | 6-Jan | 19800 | 16900 | 14794 | 16994 | 4000.00 | 172312 | 2.6 | 161912.0 |
| 18 | 7-Jan | 19900 | 16800 | 15148 | 16906 | 6000.00 | 177512 | -0.1 | 178283.7 |
| 19 | 8-Jan | 20100 | 13800 | 15112 | 17106 | 12500.00 | 176676 | -3.1 | 215716.0 |
| 20 | 9-Jan | 20100 | 11000 | 15758 | 16854 | 15000.00 | 168868 | -5.0 | 243233.7 |
| 21 | 10-Jan | 20100 | 3770 | 16723 | 14349 | 22000.00 | 134164 | -10.5 | 365670.0 |
| 22 | 11-Jan | 20200 | 16400 | 16774 | 14371 | 26000.00 | 92072 | -0.7 | 110780.4 |
| 23 | 12-Jan | 20200 | 16800 | 17522 | 15820 | 35000.00 | 85596 | -1.3 | 130088.0 |
| 24 | 13-Jan | 20200 | 17200 | 18212 | 16680 | 40000.00 | 79240 | 2.0 | 0.0 |
| 25 | 14-Jan | 19800 | 12800 | 17843 | 16290 | | | | |
| 26 | 15-Jan | 19400 | 3780 | 17463 | 15268 | | | | |
| 27 | 16-Jan | 19400 | 3810 | 17164 | 15172 | | | | |
| 28 | 17-Jan | 19400 | 3810 | 15784 | 13821 | | | | |
| 29 | 18-Jan | 19500 | 3800 | 15157 | 12895 | | | | |
| 30 | 19-Jan | 19600 | 3800 | 14319 | 12916 | | | | |
| 31 | 20-Jan | 19600 | 3750 | 14270 | 12779 | | | | |
| 32 | 21-Jan | 19600 | 3800 | 13651 | 12717 | | | | |
| 33 | 22-Jan | 19500 | 3770 | 13933 | 13414 | | | | |
| 34 | 23-Jan | 19600 | 3760 | 13906 | 12584 | | | | |
| 35 | 24-Jan | 19500 | 3760 | 13914 | 12672 | | | | |
| 36 | 25-Jan | 19500 | 3790 | 13857 | 13526 | | Juvenile, night | | |
| 37 | 26-Jan | 19300 | 3950 | 13454 | 13997 | Q | | | |
| 38 | 27-Jan | 19300 | 4020 | 12049 | 13940 | | Habitat area | B-TERM | A-TERM |
| 39 | 28-Jan | 19200 | 4030 | 12271 | 14178 | 2000.00 | 116624 | -0.1 | 116736.0 |
| 40 | 29-Jan | 19200 | 4050 | 12803 | 14096 | | | | |

bulliuv night 10 yr chart | bulladt 10 yr chart | Bull Trout P14 data

Figure 5. Spreadsheet template for habitat time series.



M13 =VLOOKUP($B13,$H$18:$K$26,3)*$B13+VLOOKUP($B13,$H$18:$K$

| | K | L | M | N | O | P | Q |
|---|---|---|---|---|---|---|---|
| 7 | | | | | | Total Habitat per Site | |
| 8 | | | | | | Bull Trout | |
| 9 | | | Juvenile, day | Juvenile, day | | Juvenile, night | Juvenile, night |
| 10 | | | HABTS | HABTS | | HABTS | HABTS |
| 11 | | | 1983-1992 | 1993-2002 | | 1983-1992 | 1993-2002 |
| 12 | | Date | | | Date | | |
| 13 | | | 150029 | 171977 | 1-Jan | 55474 | 116521 |
| 14 | | | 149533 | 171977 | 2-Jan | 55212 | 116521 |
| 15 | | 3-Jan | 146558 | 172019 | 3-Jan | 53636 | 116520 |
| 16 | | 4-Jan | 142592 | 171935 | 4-Jan | 51536 | 116522 |
| 17 | A-TERM | 5-Jan | 145071 | 164902 | 5-Jan | 52849 | 63351 |
| 18 | 163928.0 | 6-Jan | 145071 | 159448 | 6-Jan | 52849 | 60463 |
| 19 | 161912.0 | 7-Jan | 144575 | 159944 | 7-Jan | 52586 | 60726 |
| 20 | 178283.7 | 8-Jan | 143584 | 172616 | 8-Jan | 52061 | 66710 |
| 21 | 215716.0 | 9-Jan | 143584 | 176869 | 9-Jan | 52061 | 75156 |
| 22 | 243233.7 | 10-Jan | 143584 | 171830 | 10-Jan | 52061 | 116525 |
| 23 | 365670.0 | 11-Jan | 143088 | 161927 | 11-Jan | 51798 | 61776 |
| 24 | 110780.4 | 12-Jan | 143088 | 159944 | 12-Jan | 51798 | 60726 |
| 25 | 130088.0 | 13-Jan | 143088 | 157961 | 13-Jan | 51798 | 59675 |
| 26 | 0.0 | 14-Jan | 145071 | 175739 | 14-Jan | 52849 | 67758 |
| 27 | | 15-Jan | 147054 | 171851 | 15-Jan | 53899 | 116524 |
| 28 | | 16-Jan | 147054 | 171914 | 16-Jan | 53899 | 116523 |
| 29 | | 17-Jan | 147054 | 171914 | 17-Jan | 53899 | 116523 |
| 30 | | 18-Jan | 146558 | 171893 | 18-Jan | 53636 | 116523 |
| 31 | | 19-Jan | 146063 | 171893 | 19-Jan | 53374 | 116523 |
| 32 | | 20-Jan | 146063 | 171788 | 20-Jan | 53374 | 116526 |
| 33 | | 21-Jan | 146063 | 171893 | 21-Jan | 53374 | 116523 |
| 34 | | 22-Jan | 146558 | 171830 | 22-Jan | 53636 | 116525 |
| 35 | | 23-Jan | 146063 | 171809 | 23-Jan | 53374 | 116525 |
| 36 | | 24-Jan | 146558 | 171809 | 24-Jan | 53636 | 116525 |
| 37 | | 25-Jan | 146558 | 171872 | 25-Jan | 53636 | 116524 |
| 38 | | 26-Jan | 147550 | 172207 | 26-Jan | 54161 | 116515 |
| 39 | | 27-Jan | 147550 | 172364 | 27-Jan | 54161 | 116335 |
| 40 | A-TERM | 28-Jan | 148046 | 172390 | 28-Jan | 54424 | 116246 |
| 41 | 116736.0 | 29-Jan | 148046 | 172442 | 29-Jan | 54424 | 116068 |
| 42 | 152000.0 | 30-Jan | 148541 | 172390 | 30-Jan | 54687 | 116246 |
| 43 | 127102.8 | 31-Jan | 150029 | 172312 | 31-Jan | 55474 | 116512 |
| 44 | 81172.0 | 1-Feb | 150524 | 160936 | 1-Feb | 55737 | 61251 |
| 45 | 104837.7 | 2-Feb | 150029 | 141601 | 2-Feb | 55474 | 51011 |
| 46 | 43024.0 | 3-Feb | 150524 | 143584 | 3-Feb | 55737 | 52061 |
| 47 | 62552.9 | 4-Feb | 176985 | 173664 | 4-Feb | 79406 | 111899 |

Figure **6.** 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 M and higher to calculate the total habitat for the site.

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 georeferenced 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.

# RESULTS

## Model Calibration

The hydraulic models were calibrated to water surface elevations as recommened in Waddle (2001) 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. Water velocities were measured at mid-flow for all three study sites.

Habitat suitability data were applied for rainbow trout and bull trout to all sites in Section 1 and Section 2. Model hydraulics show that both depths and velocities vary as expected for each of the sites and reaches (See distribution CD).

Hydrology time series was obtained for post-dam 1983-1992 and post-dam 1993-2002 conditions to compare before and after the flow release recommendations. The main differences in the hydrology are shown in the summer snow melt runoff period and the late fall period. The 1983-1992 data had very little natural hydrograph shape. The 1993-2002 period has a more natural snow melt runoff shape and less variability (Figure 7). Comparing the ten year data sets shows that prior to the change in release timing and volume, most years did not have a summer peak flow (Figure 8).

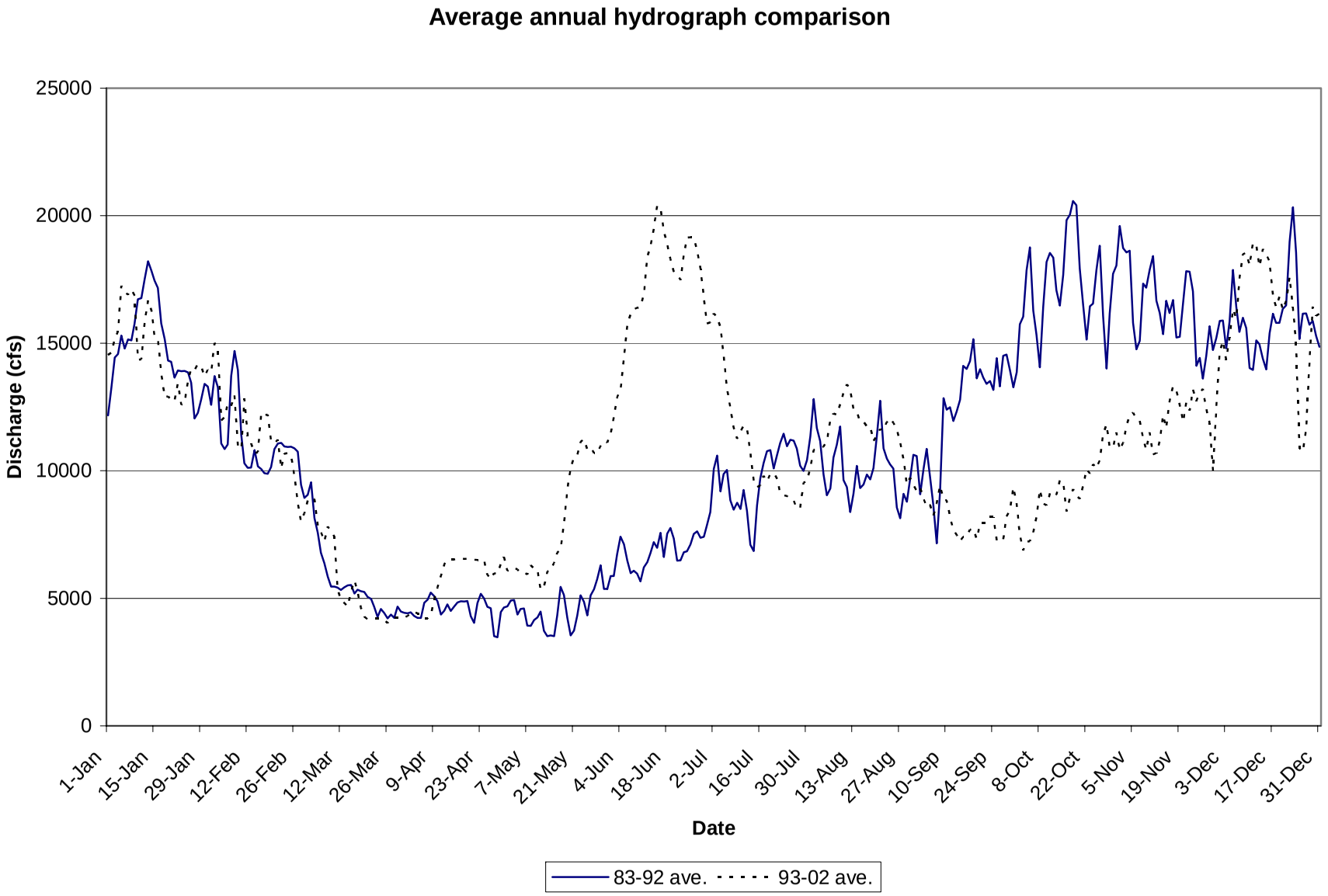



Figure 7. Average annual hydrograph comparing 1983-1992 data to 1993-2002 data.

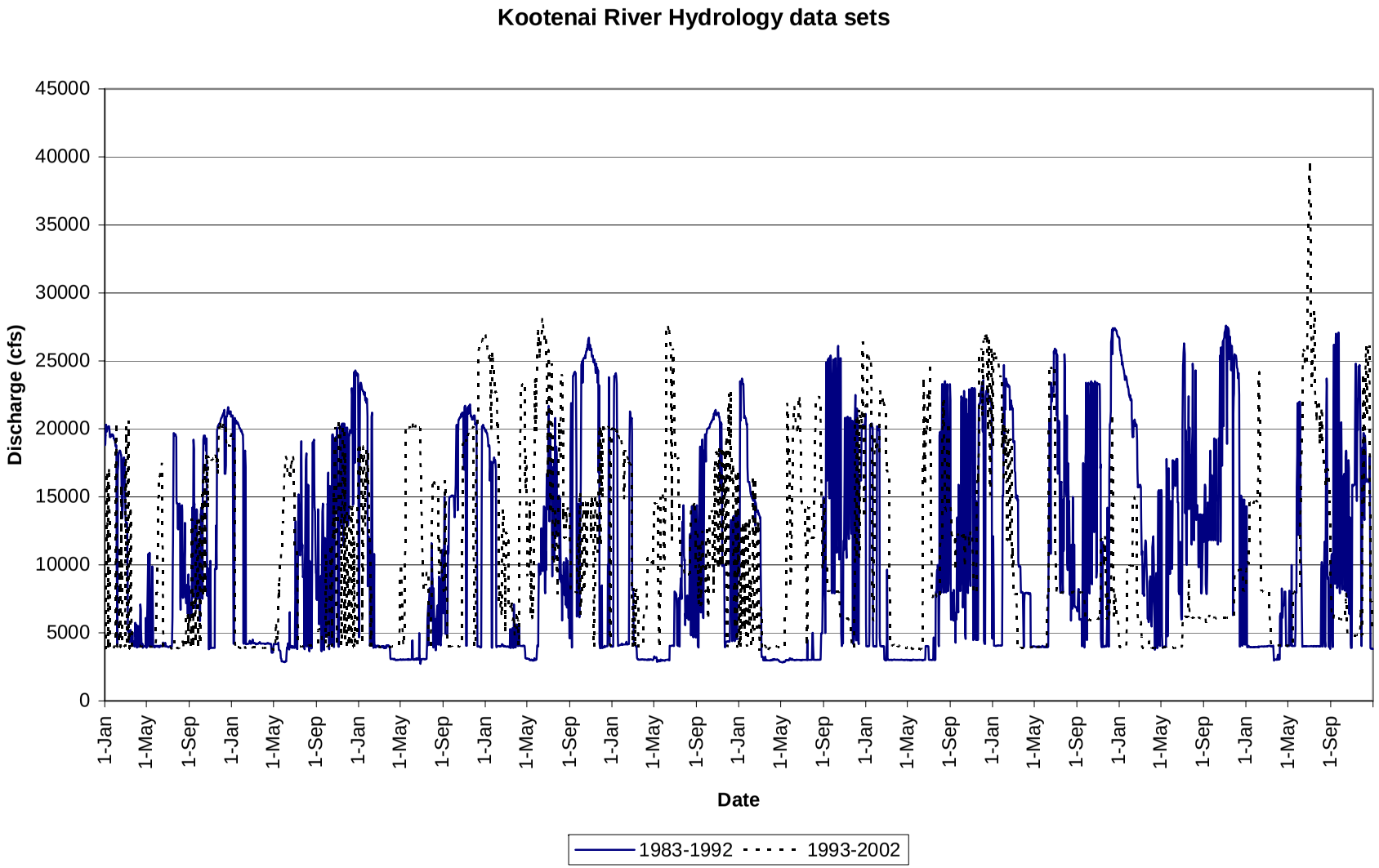



Figure 8. Ten year hydrograph comparing 1983-1992 data to 1993-2002 data.

## Habitat Simulations Section 1

**Pool 14 Site**

The Pool 14 site contained pool and glide habitat. Bull trout adult habitat is shown for a flow of approximately 4,000 cfs to illustrate the habitat quantification using GIS. The dark blue colors are the higher habitat values, while the lighter colors are lower habitat value (Figure 9).

Habitat area versus discharge functions were similar for both juvenile and adult rainbow trout (Figure 10). The highest habitat area occurred at the lowest flows. This is likely due to the use of lower velocities and depths. Most likely velocity becomes limiting before depth.

Habitat area versus discharge for bull trout adult and juvenile day life stages are similar (Figure 11). Both of these lifestages use deeper water than the bull trout juvenile night life stage. The juvenile night life stage has the highest habitat availability at the lower flows, similar to rainbow trout. As with rainbow trout this is likely due to velocity exceeding the preferred range incombination with increasing depth.

The habitat time series shows a highly variable habitat under the 1983-1992 flow regime. The 1993-2002 flow regime shows more stable habitat during most of the year. This trend is shown for all species and life stages (Figures 12 through 16).

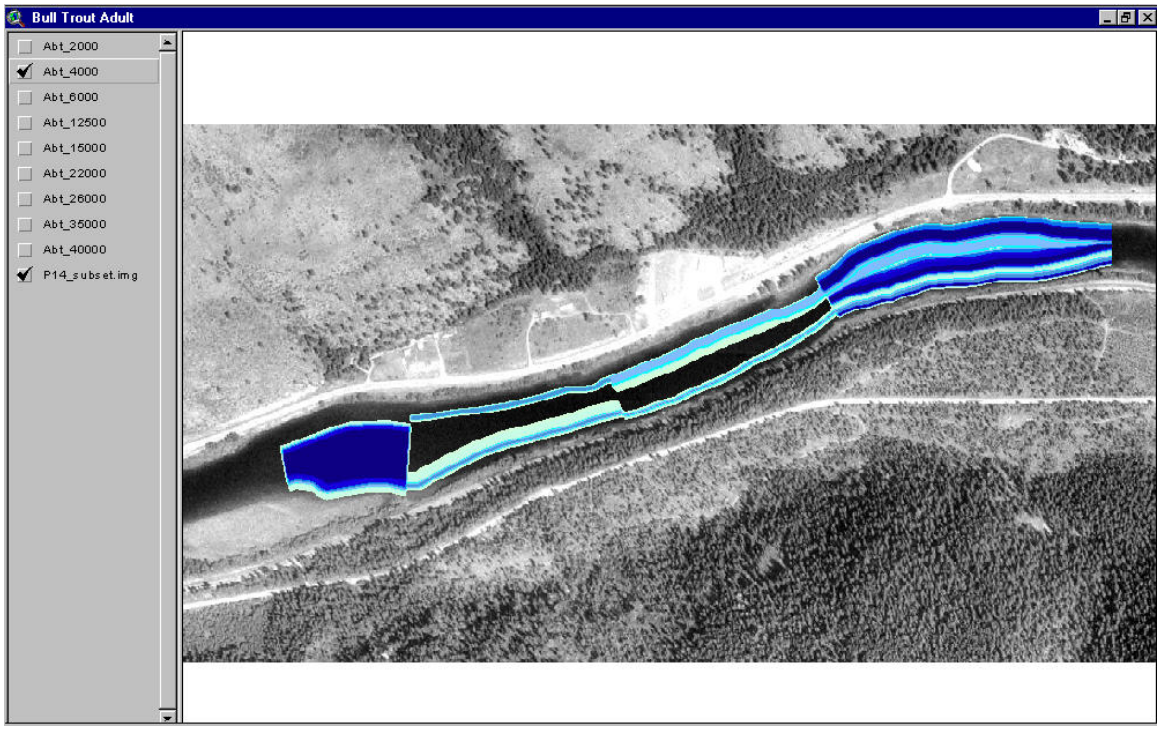



Figure 9. GIS based site map for Pool 14.

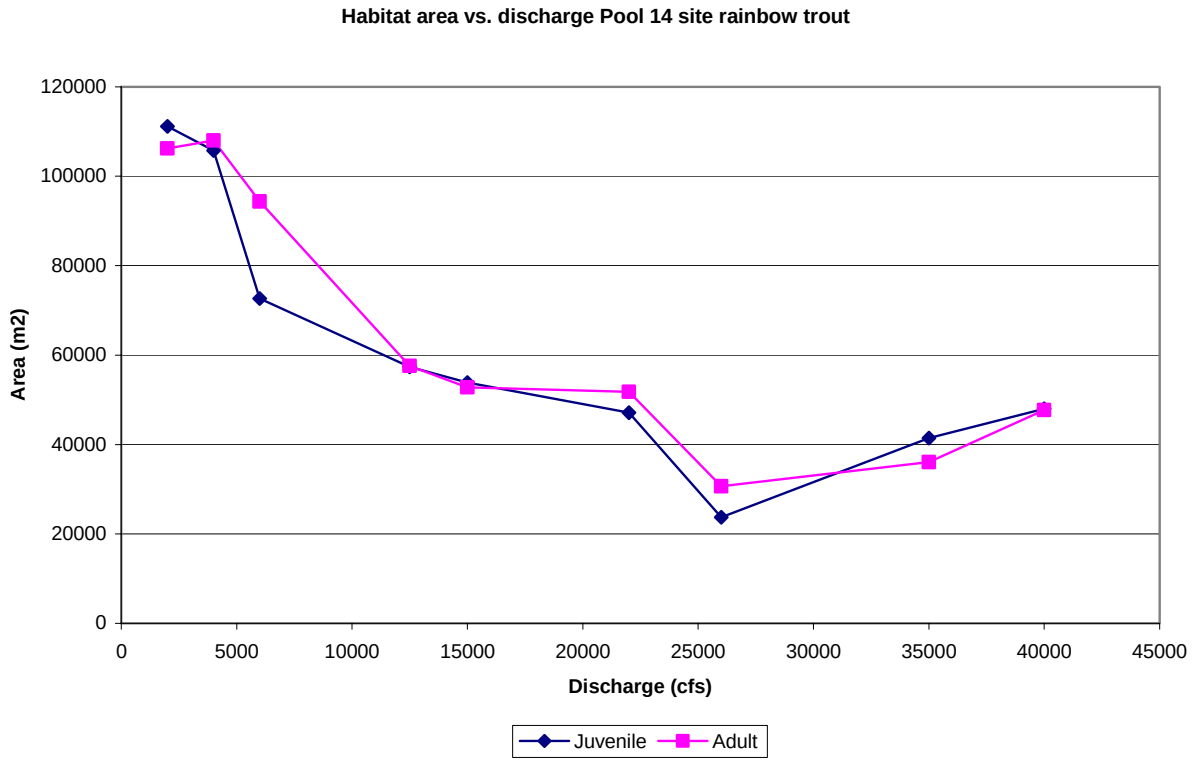



Figure 10. Habitat area vs. discharge for Pool 14 site, rainbow trout.

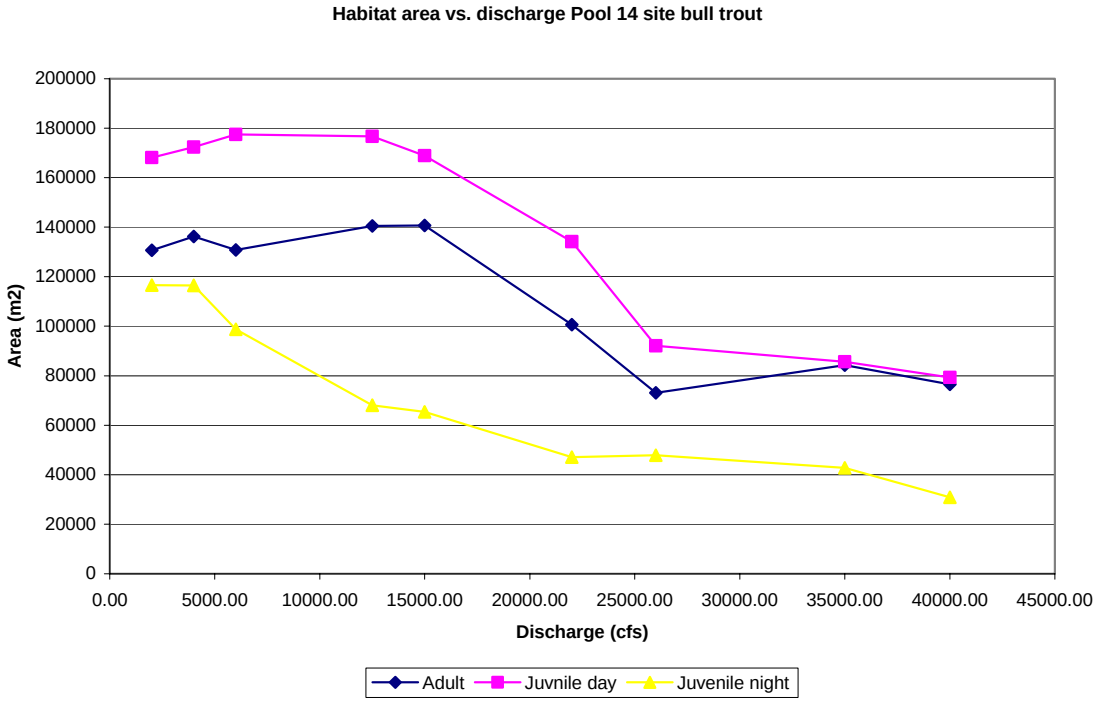



Figure 11. Habitat area vs. discharge for Pool 14 site, bull trout.

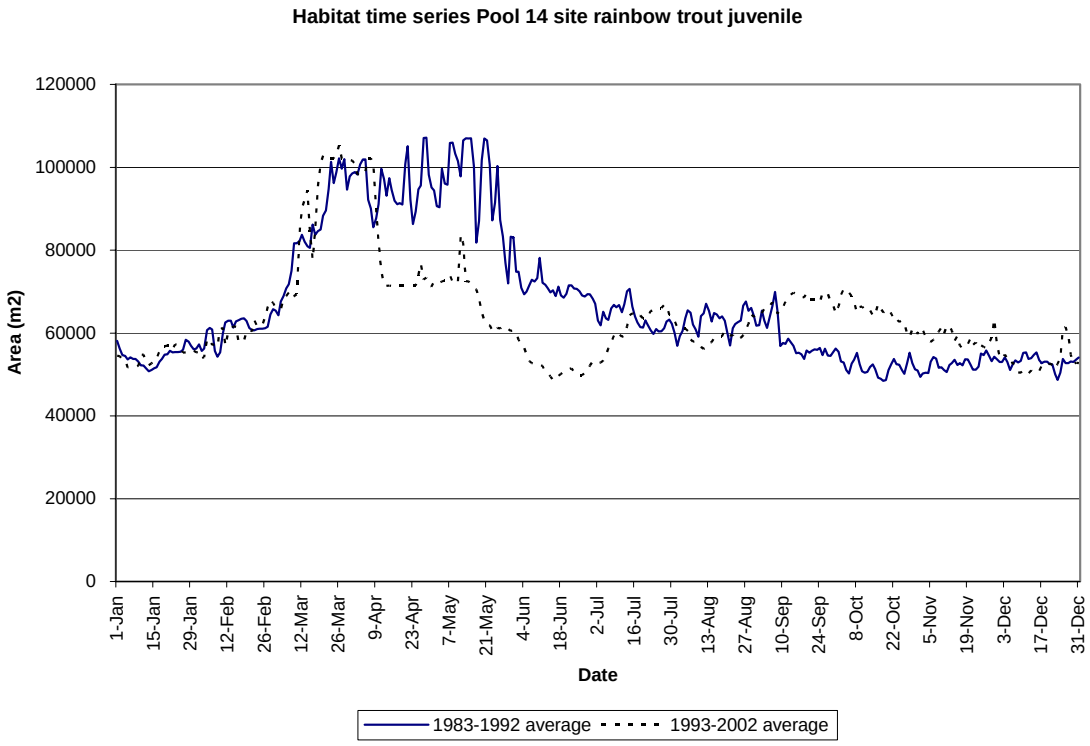



Figure 12. Annual habitat time series, rainbow trout juvenile, Pool 14 site.

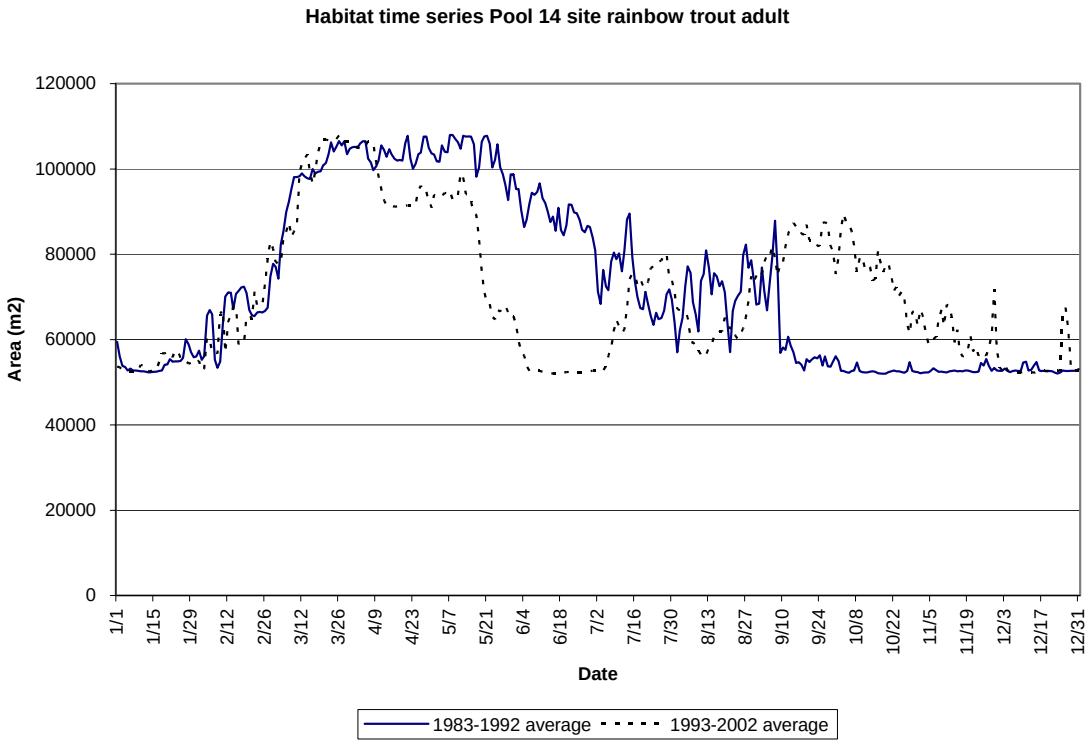



Figure 13. Annual habitat time series, rainbow trout adult, Pool 14 site.

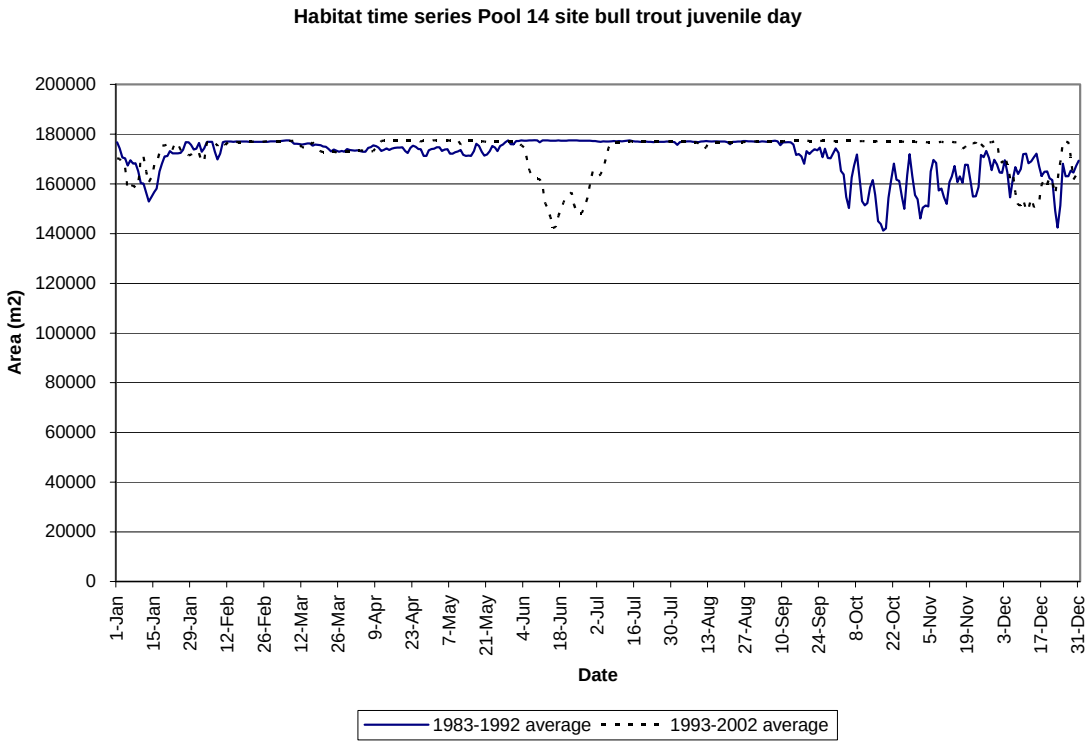



Figure 14. Annual habitat time series, bull trout juvenile day, Pool 14 site.

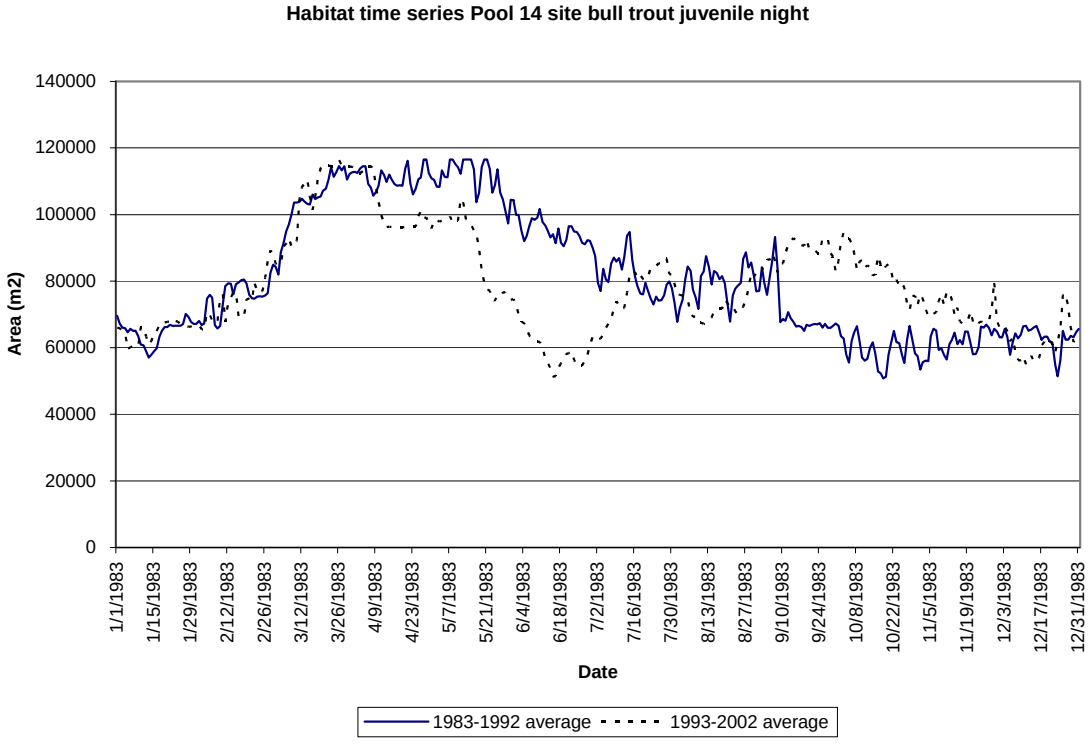



Figure 15. Annual habitat time series, bull trout juvenile night, Pool 14 site.

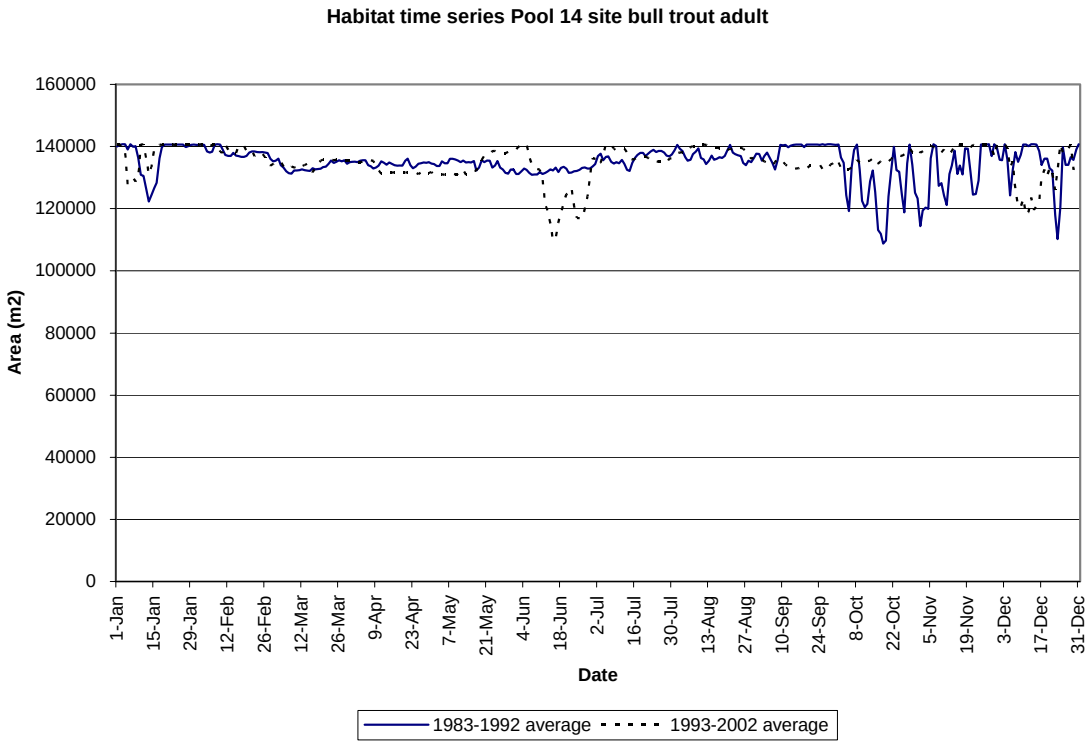



Figure 16. Annual habitat time series, bull trout adult, Pool 14 site.

**Pool 24 and side channel 24 Site**

The Pool 24 site contained pool and sidechannel habitat. Bull trout adult habitat is shown for a flow of approximately 4,000 cfs to illustrate the habitat quantification using GIS. The dark blue colors are the higher habitat values, while the lighter colors are lower habitat value (Figure 17). The side channel does not become flow through until higher discharges.

Habitat area versus discharge functions were similar for both juvenile and adult rainbow trout (Figure 18). The highest habitat area occurred between 5,000 and 15,000 cfs. This is likely due to the increased habitat in the side channel up to the point where velocity becomes too high in the majority of the channel.

Habitat area versus discharge for bull trout adult and juvenile day life stages are similar (Figure 19). Both of these lifestages use deeper water than the bull trout juvenile night life stage. The juvenile night life stage has the highest habitat availability at the lower flows, similar to rainbow trout. As with rainbow trout this is likely due to velocity exceeding the preferred range incombination with increasing depth.

The habitat time series shows a highly variable habitat under the 1983-1992 flow regime, especially during late summer and fall. The 1993-2002 flow regime shows more stable habitat during most of the year. This trend is shown for all species and life stages (Figures 20 through 24).

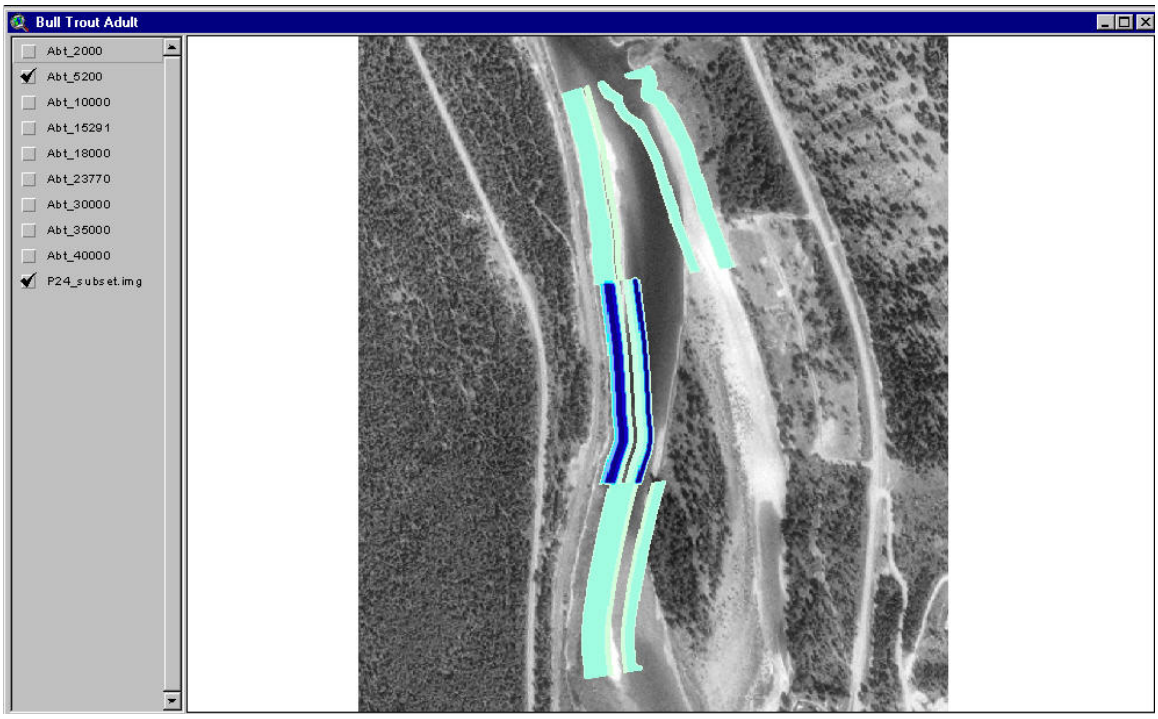


Figure 17. GIS based site map for Pool 24.

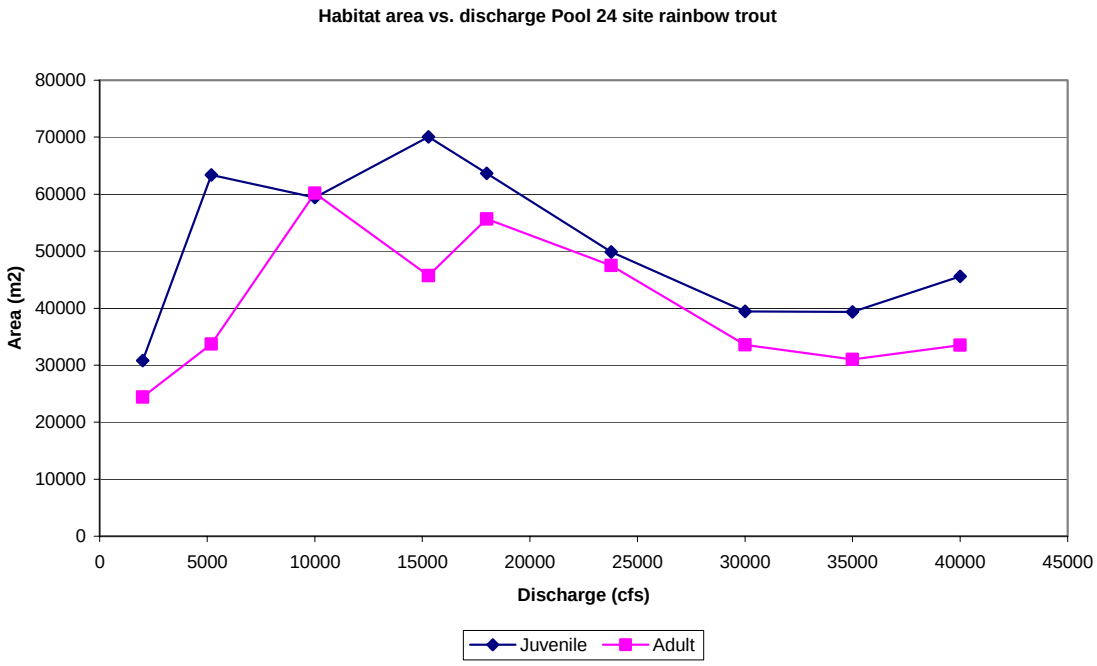



Figure 18. Habitat area vs. discharge for Pool 24 site, rainbow trout.

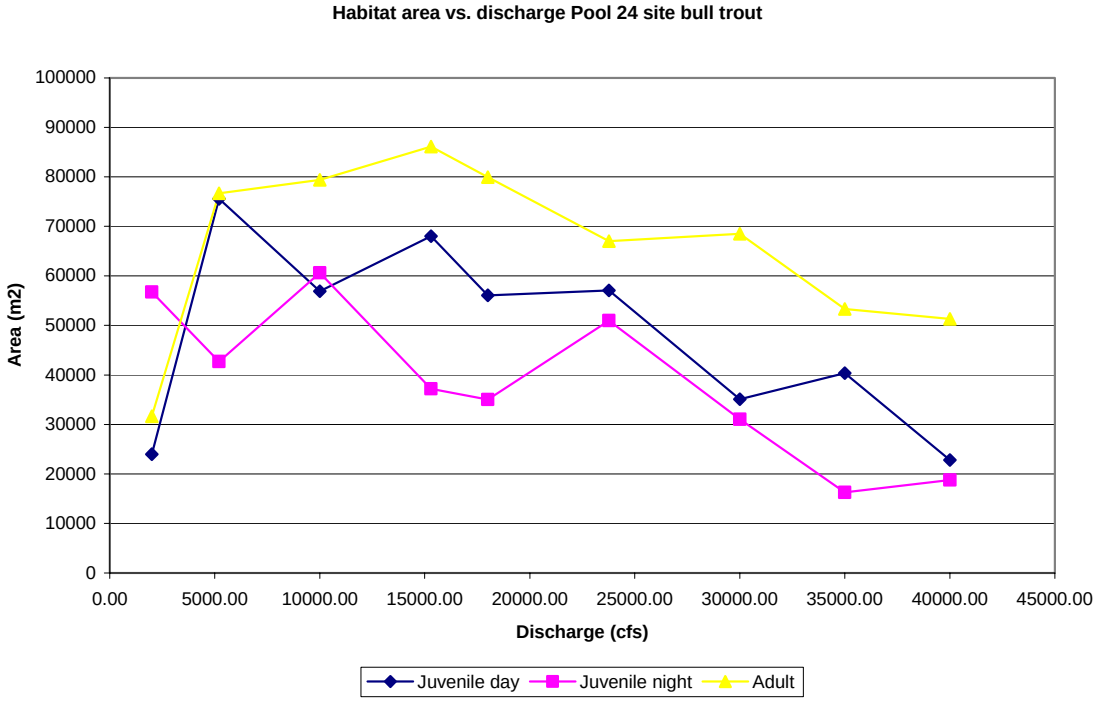



Figure 19. Habitat area vs. discharge for Pool 24 site, bull trout.

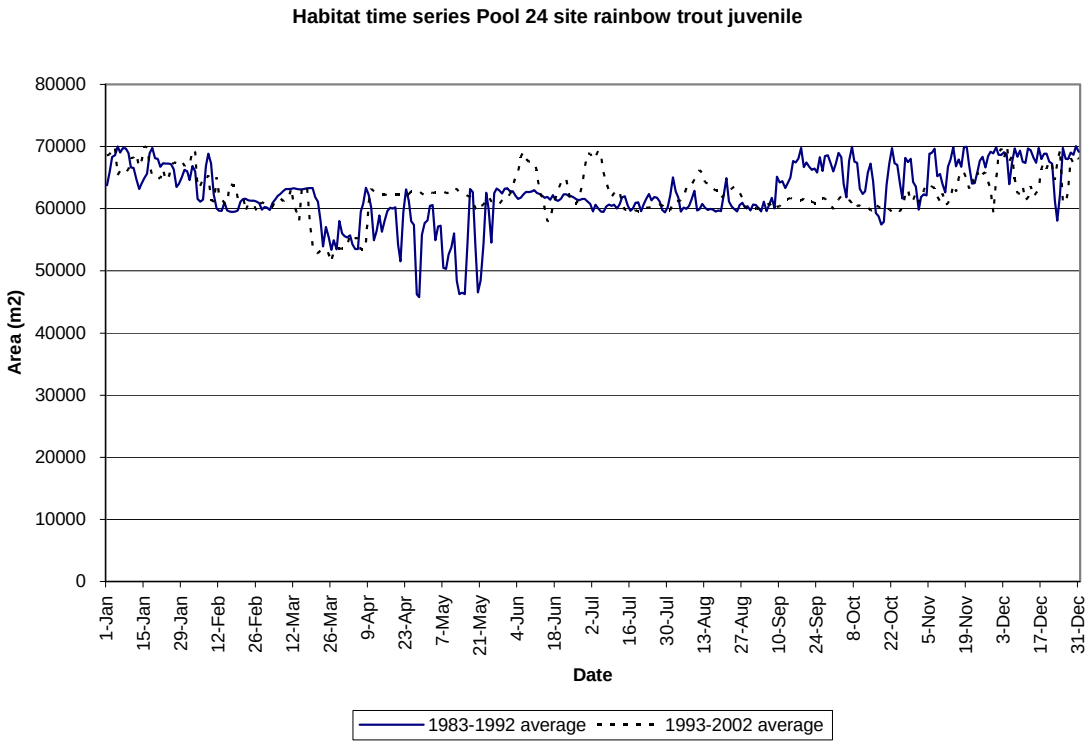



Figure 20. Annual habitat time series, rainbow trout juvenile, Pool 24 site.

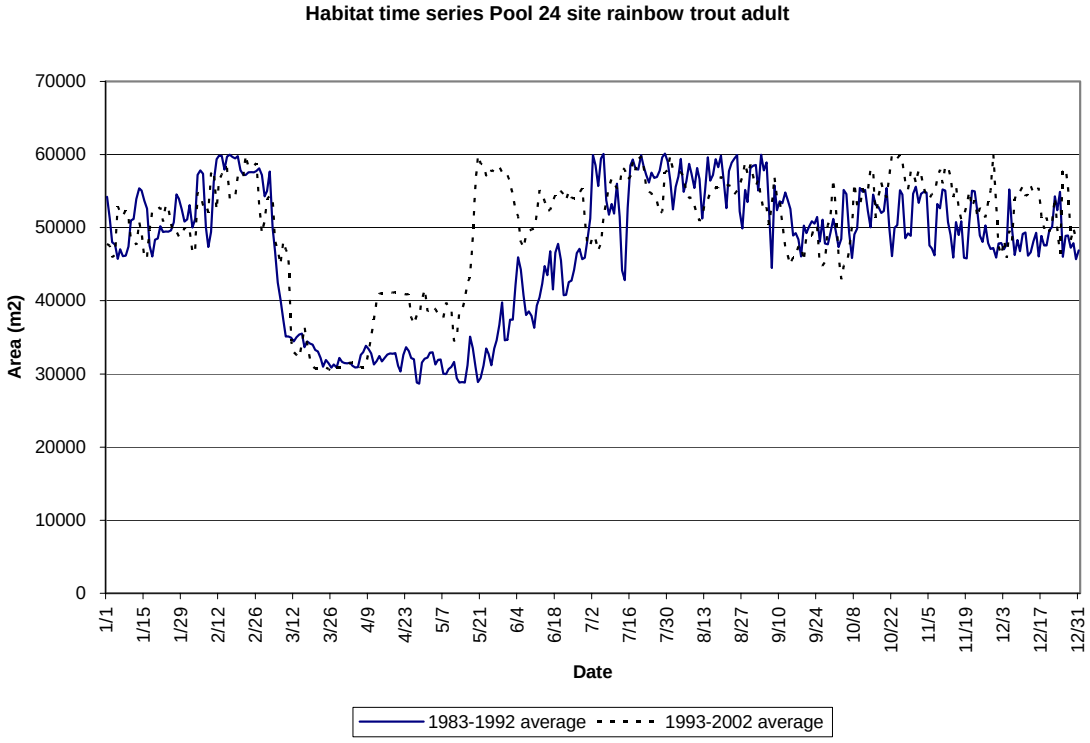



Figure 21. Annual habitat time series, rainbow trout adult, Pool 24 site.

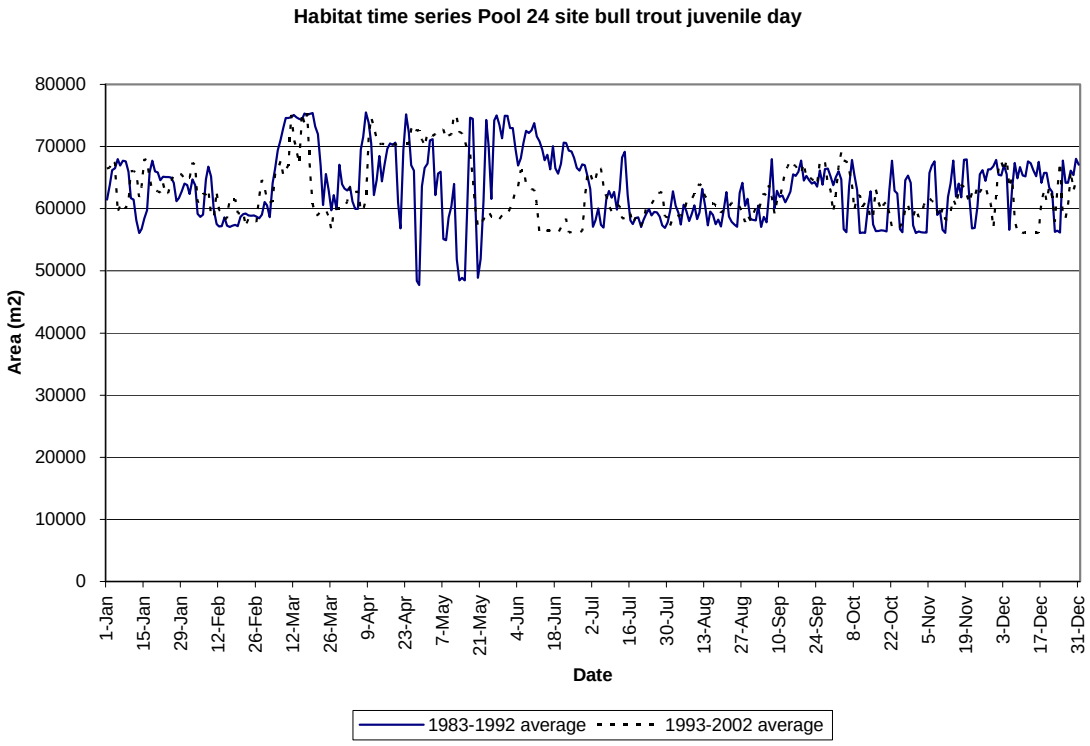



Figure 22. Annual habitat time series, bull trout juvenile day, Pool 24 site.

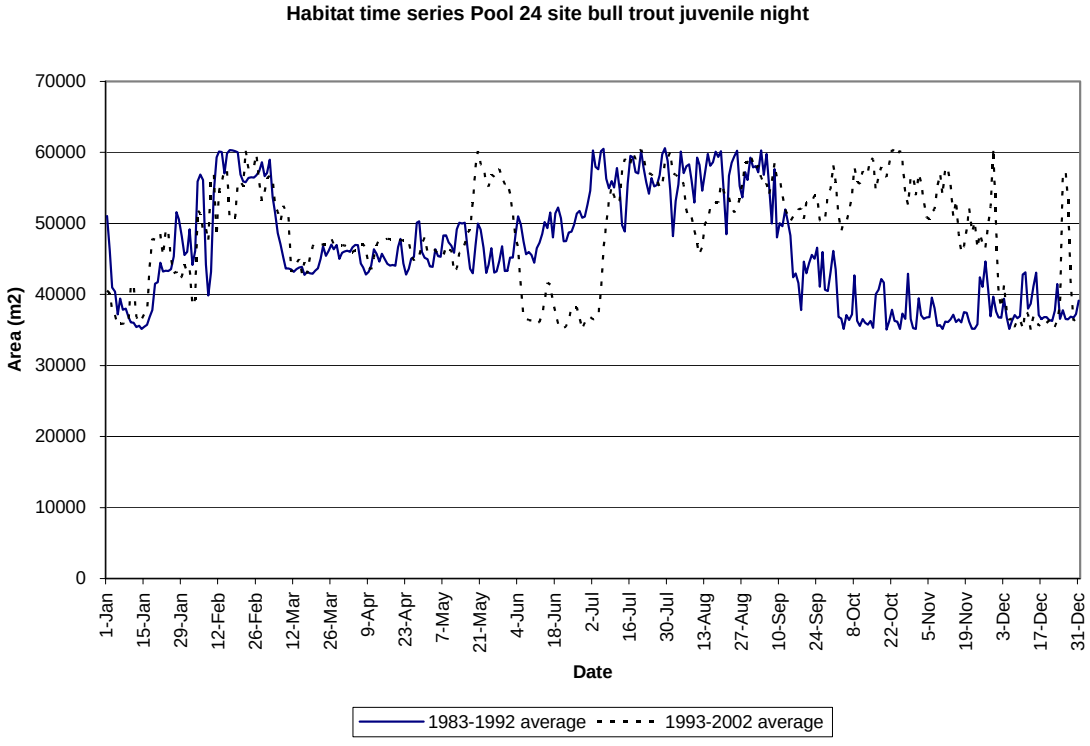



Figure 23. Annual habitat time series, bull trout juvenile night, Pool 24 site.

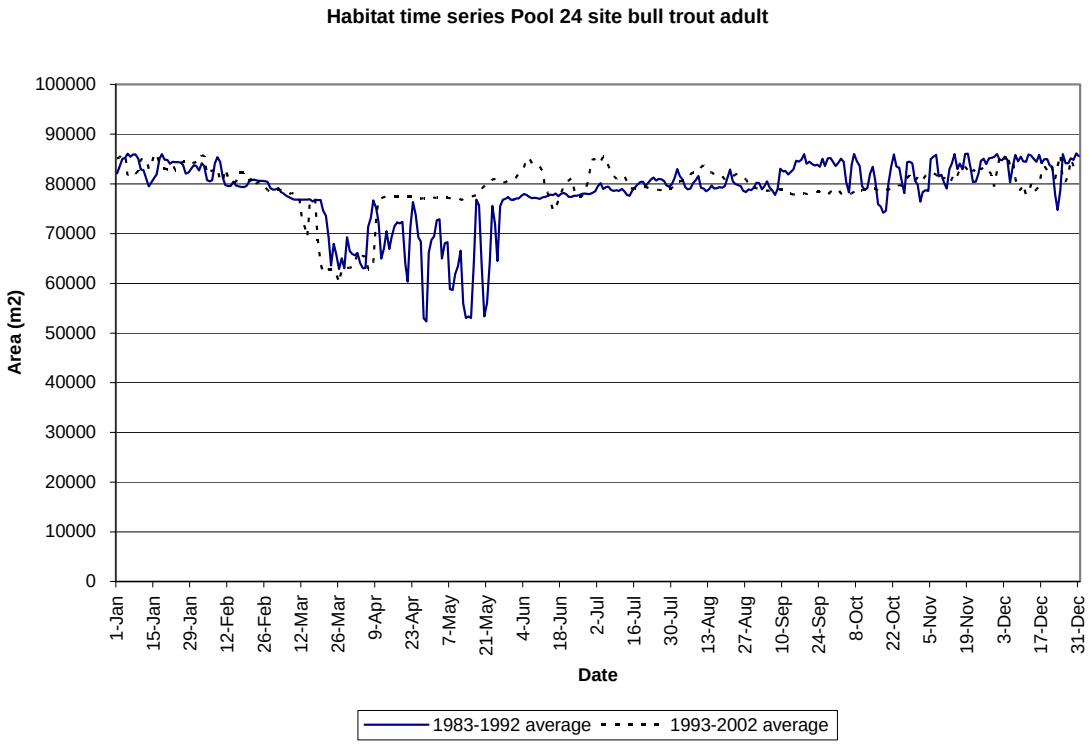



Figure 24. Annual habitat time series, bull trout adult, Pool 24 site.

**Pool 27 and side channel 27 site**

The Pool 27 site contained pool and side channel habitat. Bull trout adult habitat is shown for a flow of approximately 4,000 cfs to illustrate the habitat quantification using GIS. The dark blue colors are the higher habitat values, while the lighter colors are lower habitat value (Figure 25). The main channel habitat shows much higher habitat quality at the 4,000 cfs flow than the side channel.

Habitat area versus discharge functions were similar for both juvenile and adult rainbow trout (Figure 26). Useable habitat area is high at both the lower and upper flows. The high amount of habitat at high flows is the result of the side channel becoming better habitat at those flows.

Habitat area versus discharge for bull trout adult and juvenile day life stages are similar (Figure 27). Both of these lifestages use deeper water than the bull trout juvenile night life stage. The juvenile night life stage has the highest habitat availability at both the lower and upper flows, similar to rainbow trout.

As was shown in previous sites, the habitat time series shows a highly variable habitat under the 1983-1992 flow regime. The 1993-2002 flow regime shows more stable habitat during most of the year. This trend is shown for all species and life stages (Figures 28 through 32).

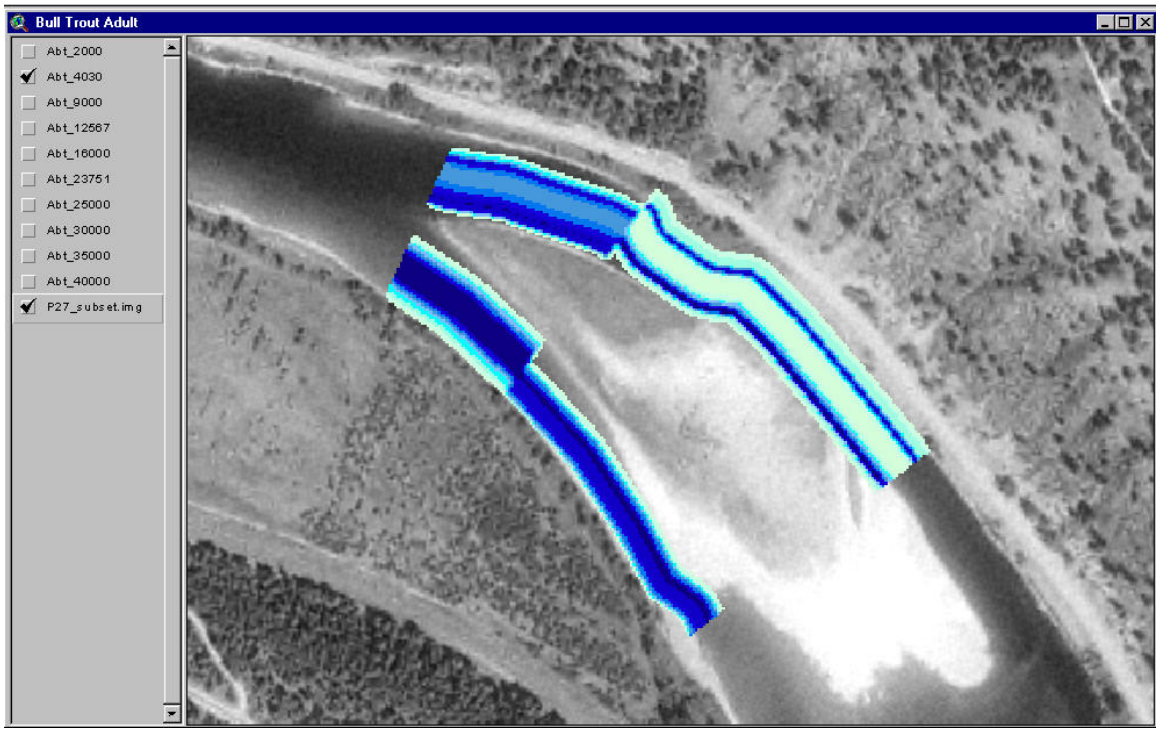



Figure 25. GIS based site map for Pool 27.

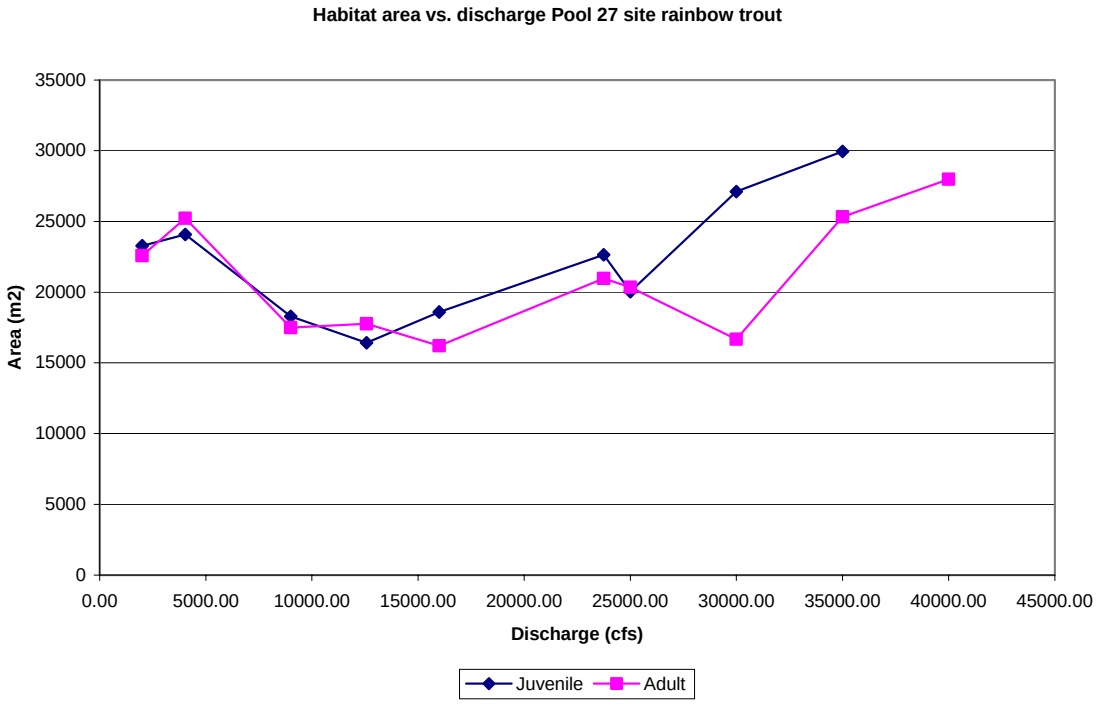



Figure 26. Habitat area vs. discharge for Pool 27 site, rainbow trout.

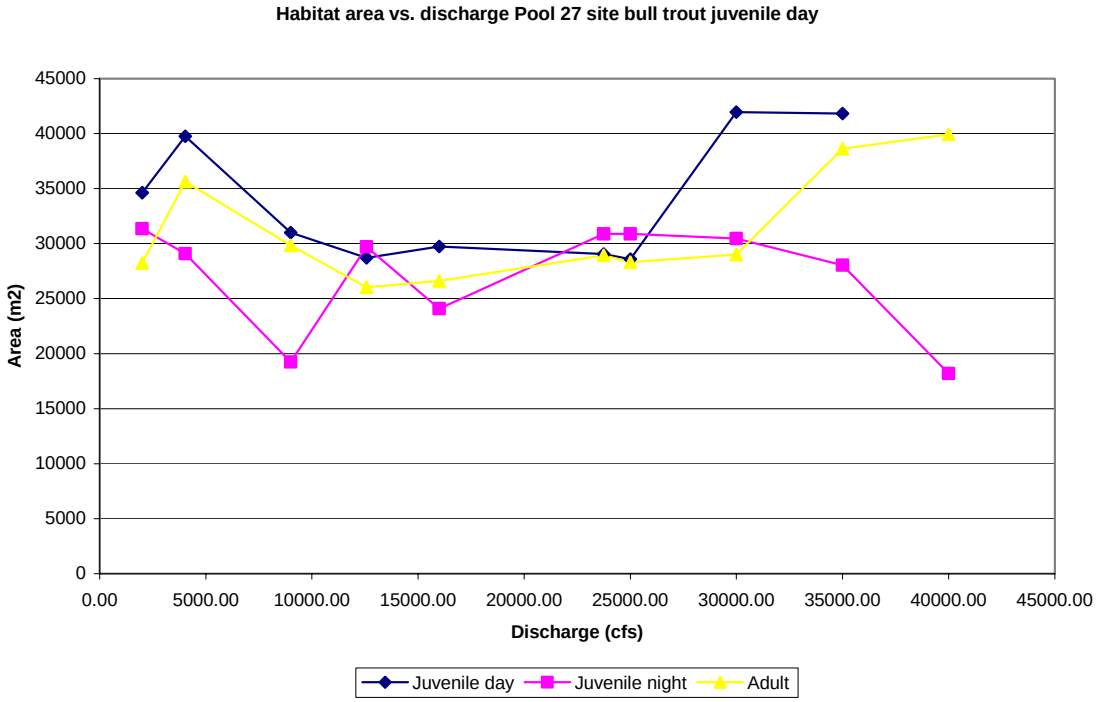



Figure 27. Habitat area vs. discharge for Pool 27 site, bull trout.

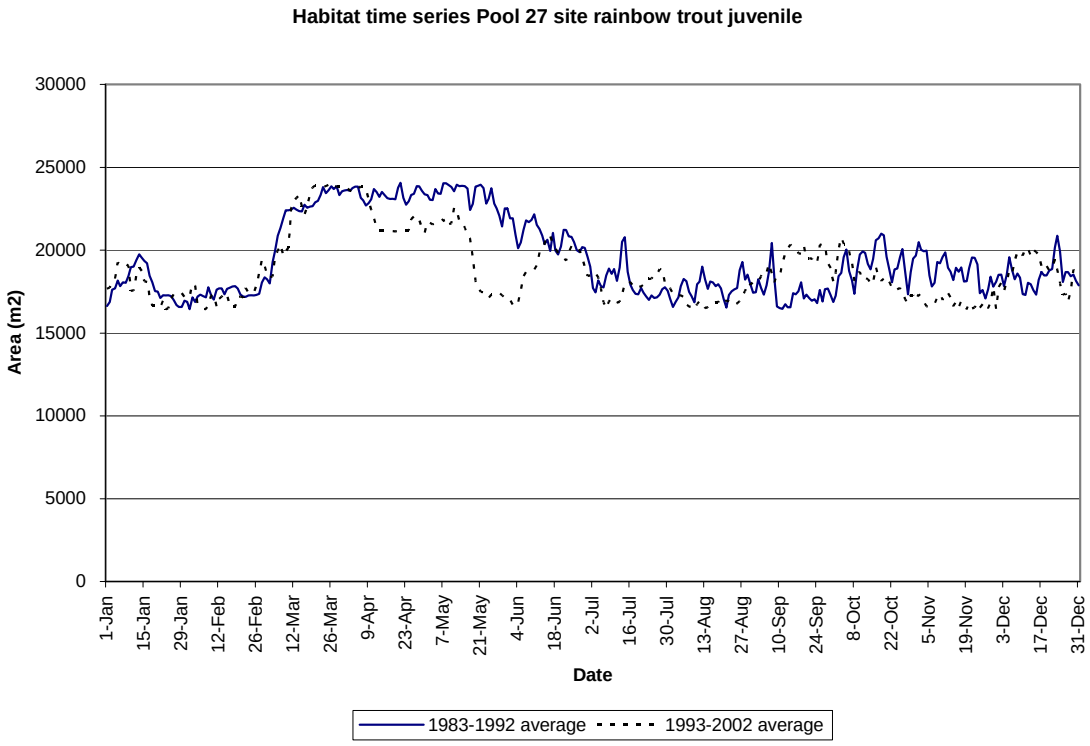



Figure 28. Annual habitat time series, rainbow trout juvenile, Pool 27 site.

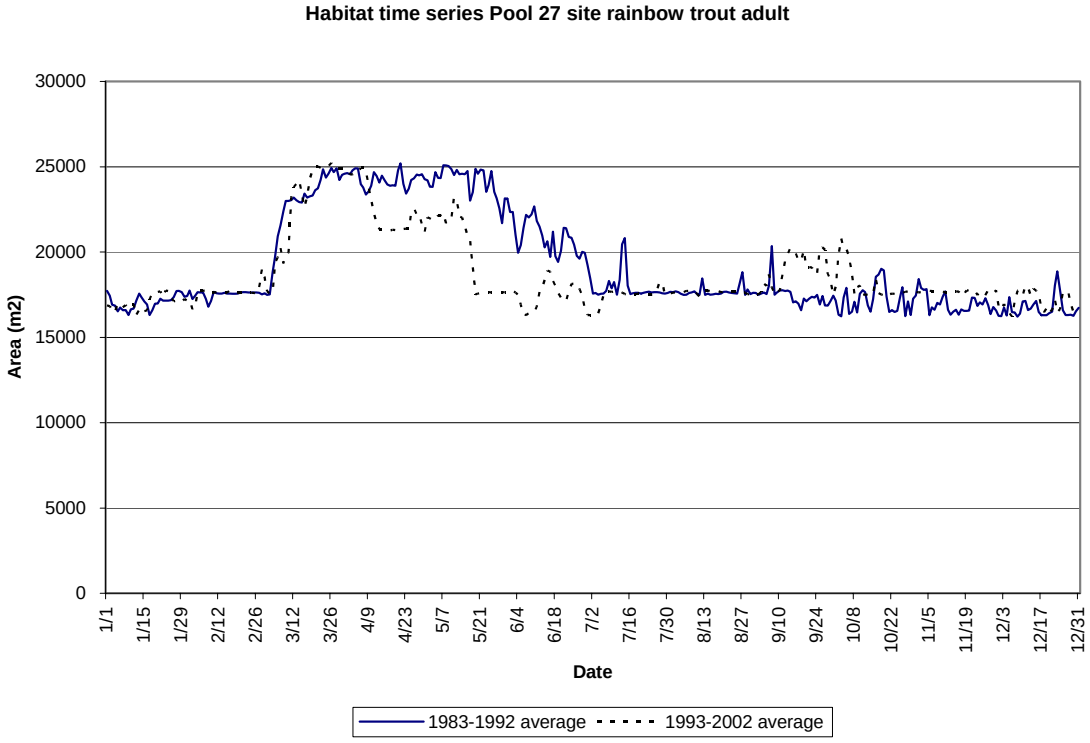



Figure 29. Annual habitat time series, rainbow trout adult, Pool 27 site.

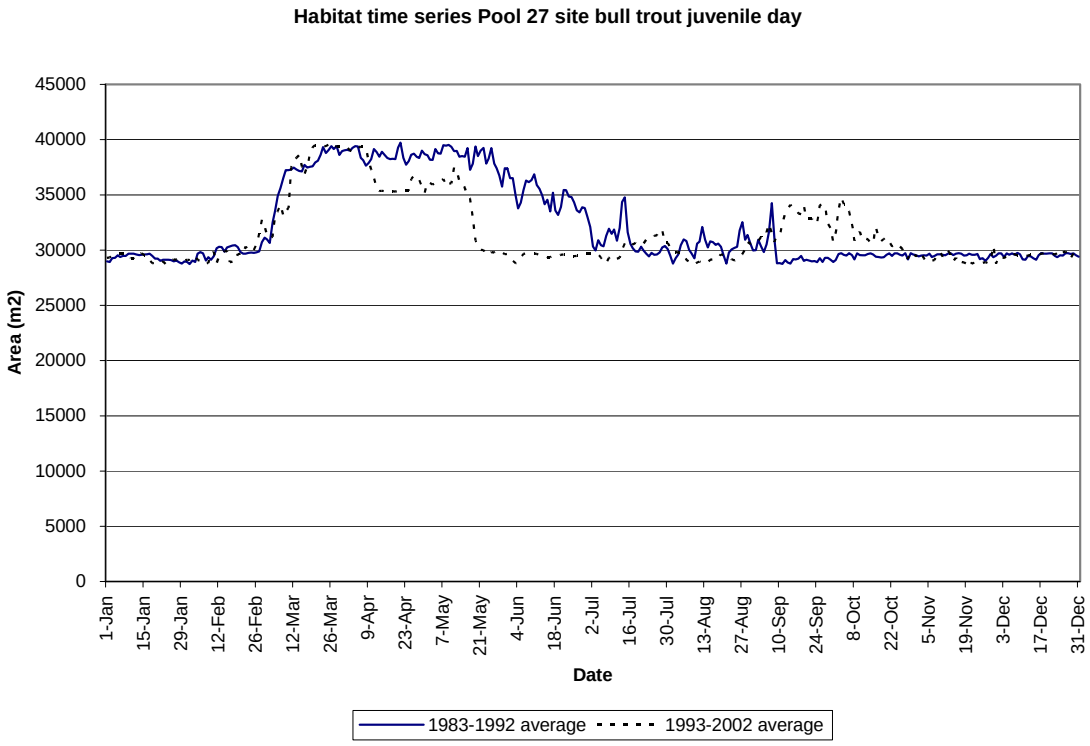



Figure 30. Annual habitat time series, bull trout juvenile day, Pool 27 site.

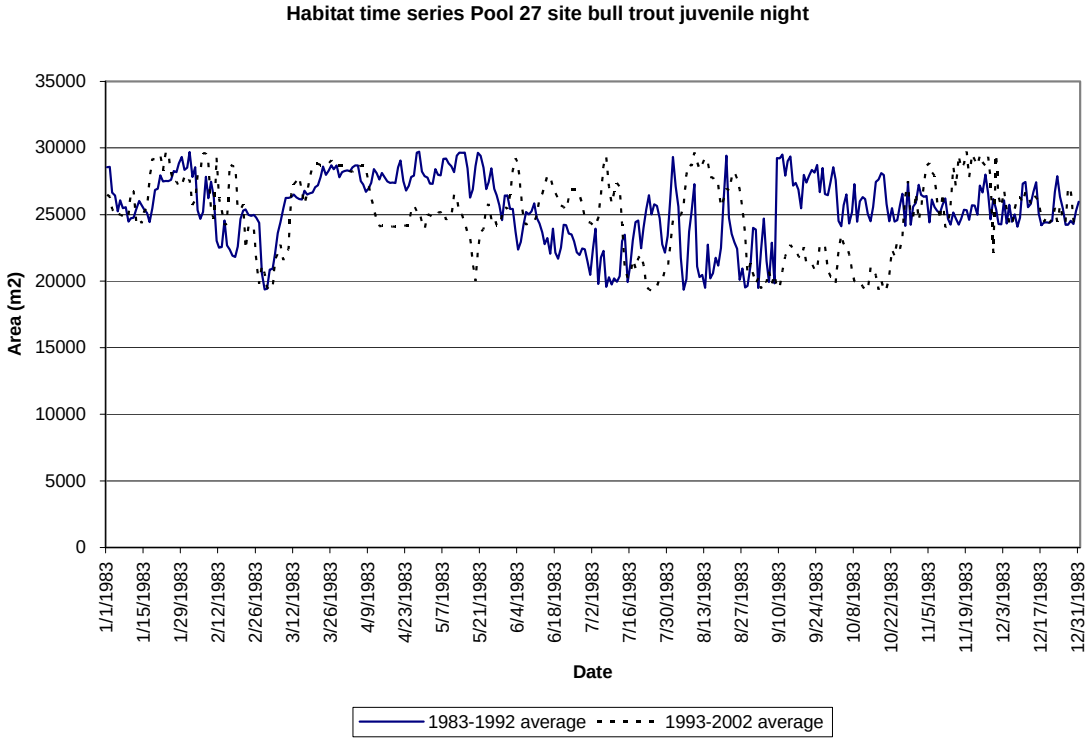



Figure 31. Annual habitat time series, bull trout juvenile night, Pool 27 site.

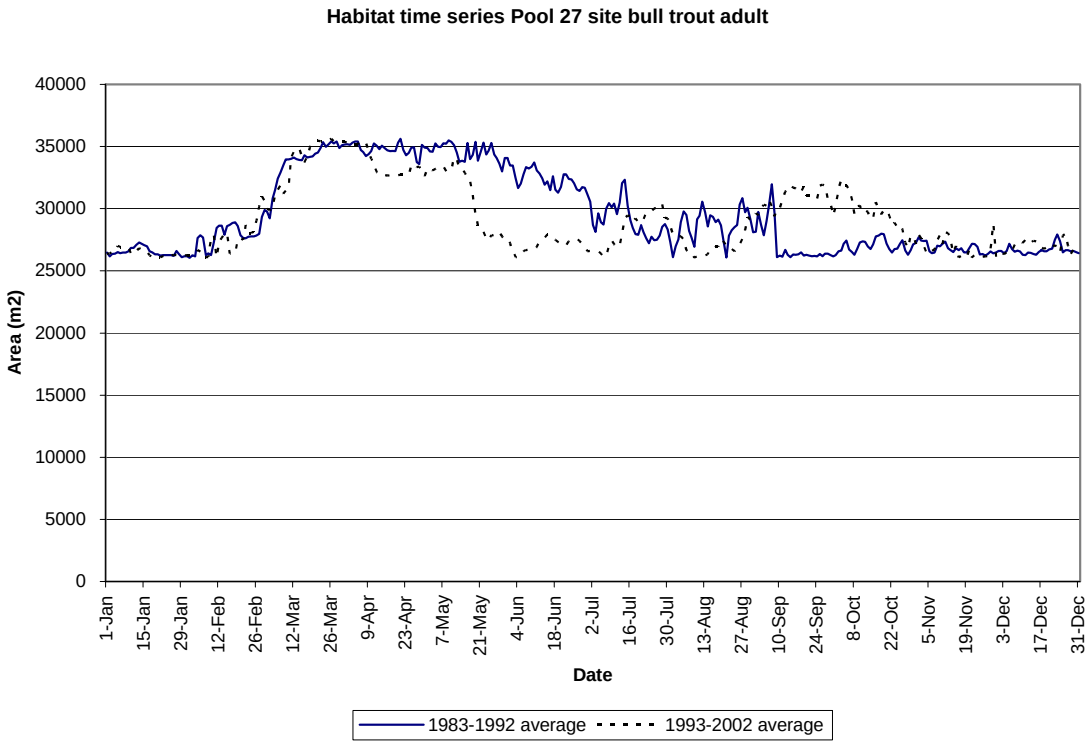



Figure 32. Annual habitat time series, bull trout adult, Pool 27 site.

**Pool 28 Site**

The Pool 28 site contained pool and glide habitat. Bull trout adult habitat is shown for a flow of approximately 4,000 cfs to illustrate the habitat quantification using GIS. The dark blue colors are the higher habitat values, while the lighter colors are lower habitat value (Figure 33).

Habitat area versus discharge functions were similar for both juvenile and adult rainbow trout (Figure 34). The highest habitat area occurred at flow between 5,000 and 10,000 cfs. The large percentage of glide habitat has depths and velocities in the most preferred at this range of flows.

Habitat area versus discharge for all bull trout life stages are similar (Figure 35) but the adult and juvenile day life stages have more habitat available. The juvenile night life stage has the highest habitat availability at the lower flows, similar to rainbow trout. As with rainbow trout this is likely due to velocity exceeding the preferred range incombination with increasing depth.

The habitat time series for all life stages is similar to the previously discussed sites. Habitat is highly variable habitat under the 1983-1992 flow regime. The 1993-2002 flow regime shows more stable habitat during most of the year. This trend is shown for all species and life stages (Figures 36 through 40).

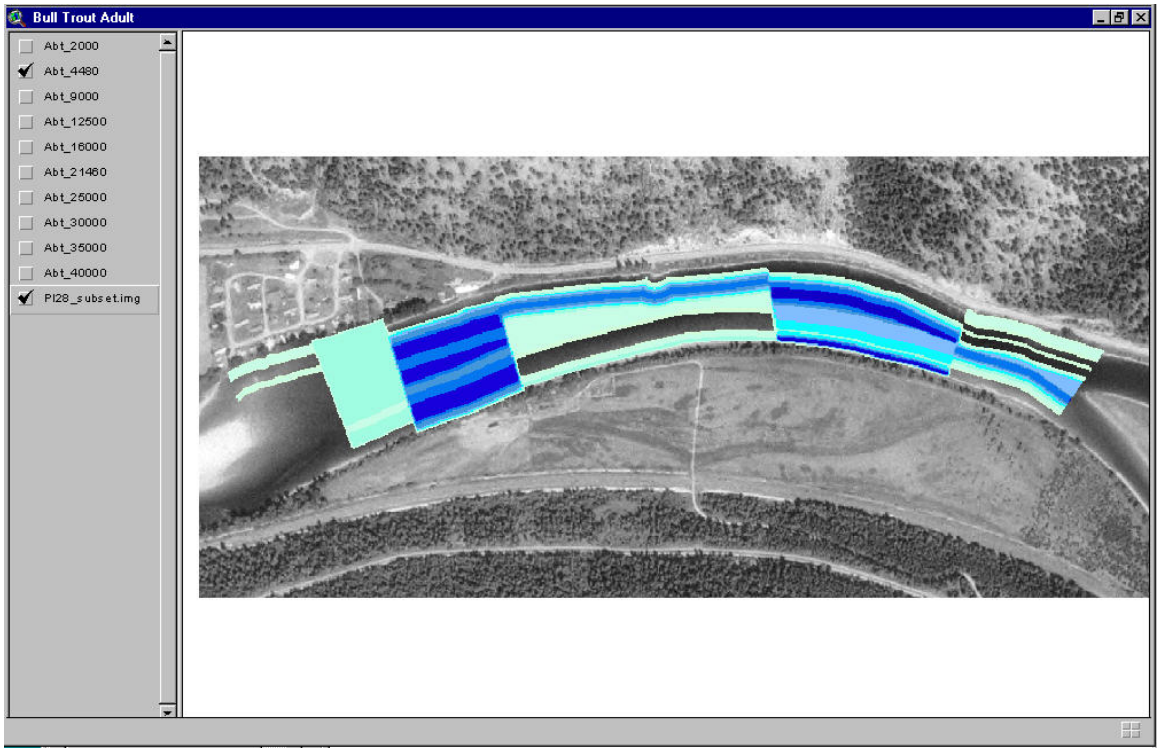



Figure 33. GIS based site map for Pool 28.

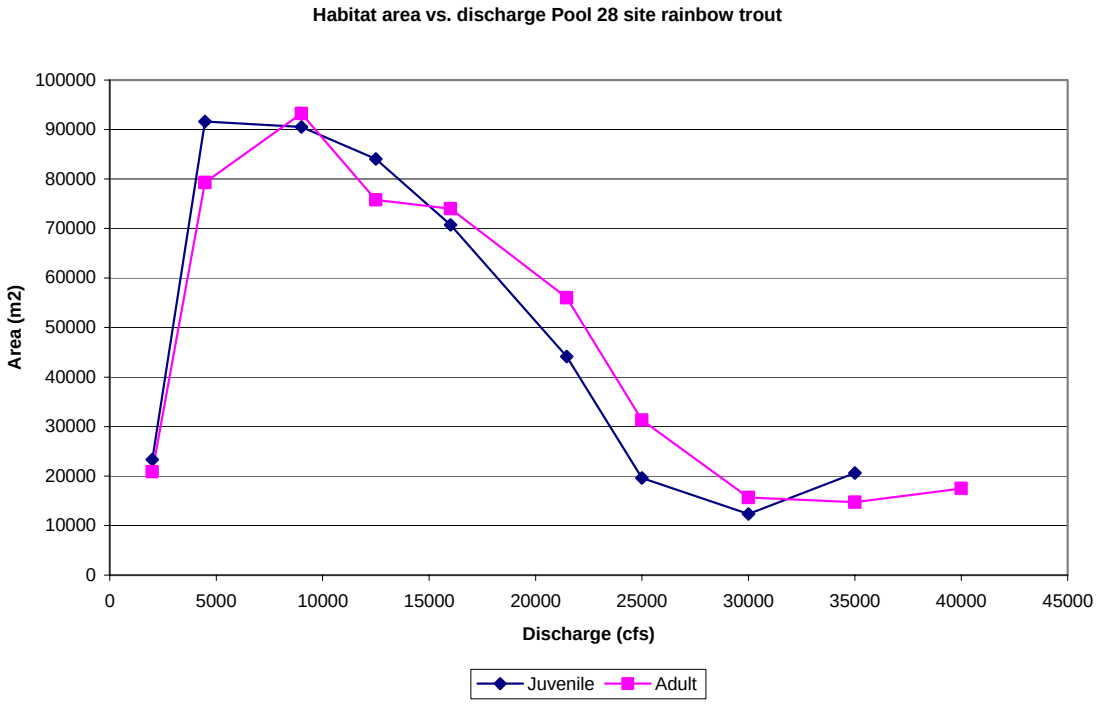



Figure 34. Habitat area vs. discharge for Pool 28 site, rainbow trout.

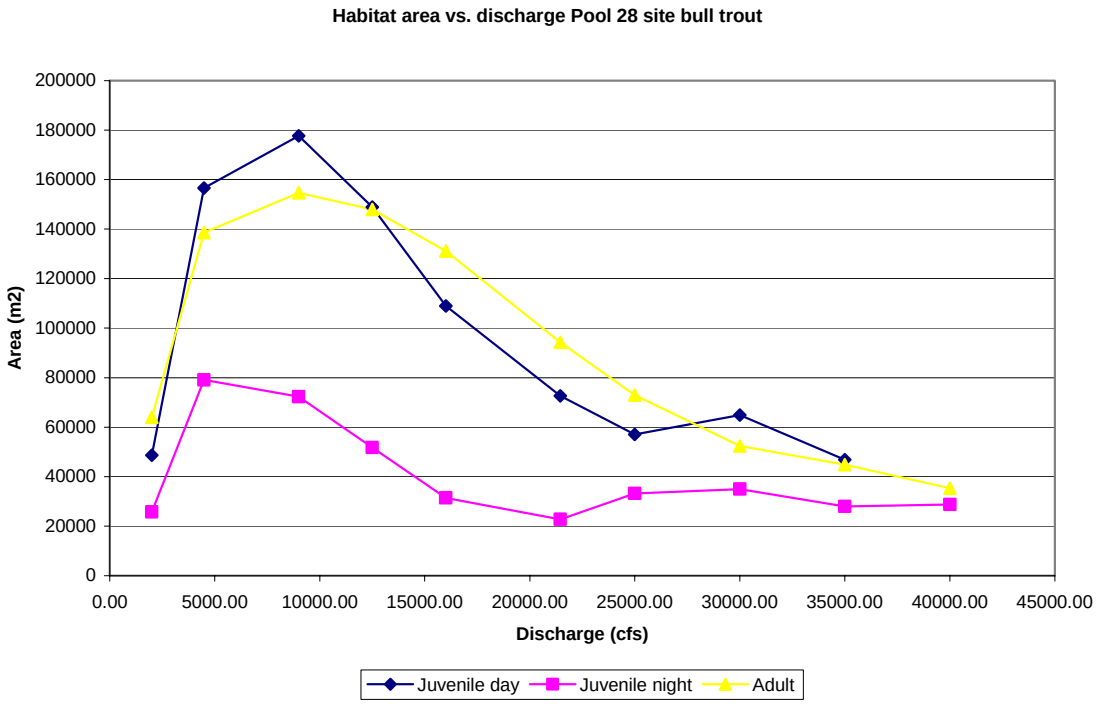



Figure 35. Habitat area vs. discharge for Pool 28 site, bull trout.

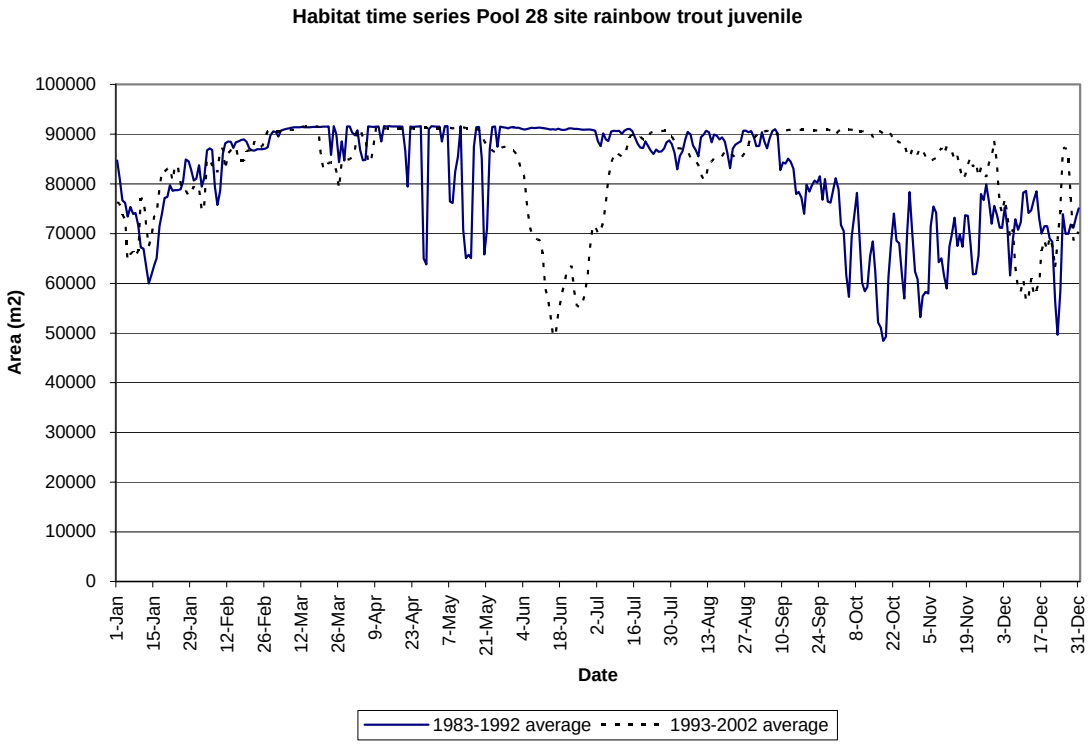



Figure 36. Annual habitat time series, rainbow trout juvenile, Pool 28 site.

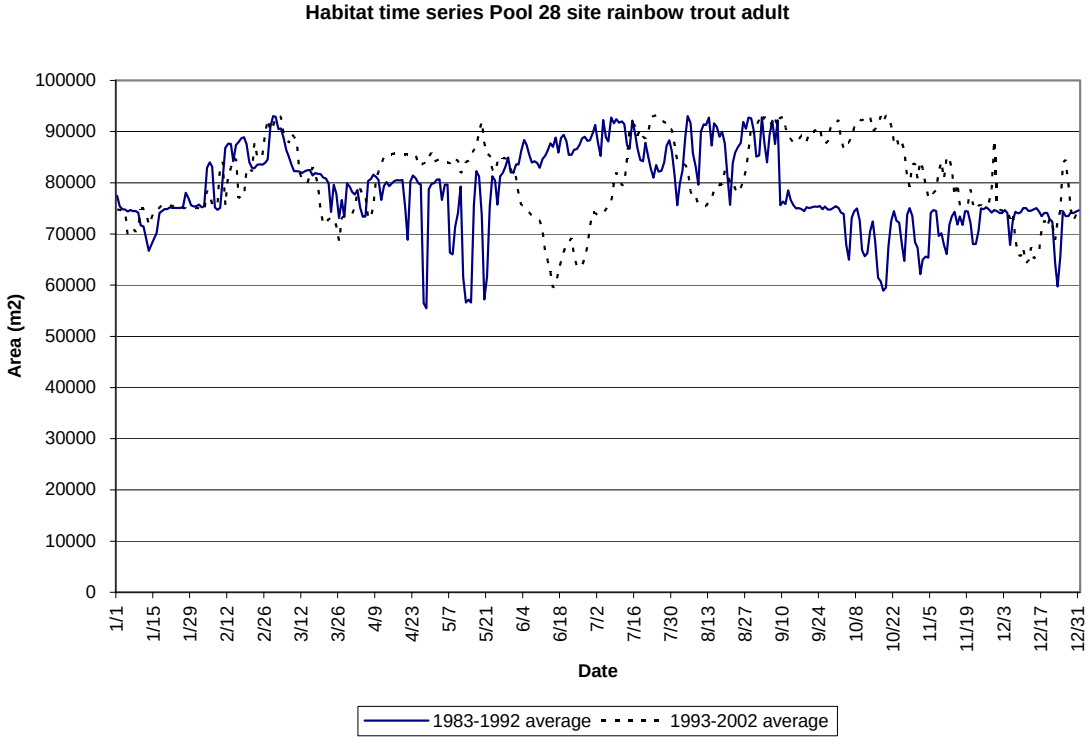



Figure 37. Annual habitat time series, rainbow trout adult, Pool 28 site.

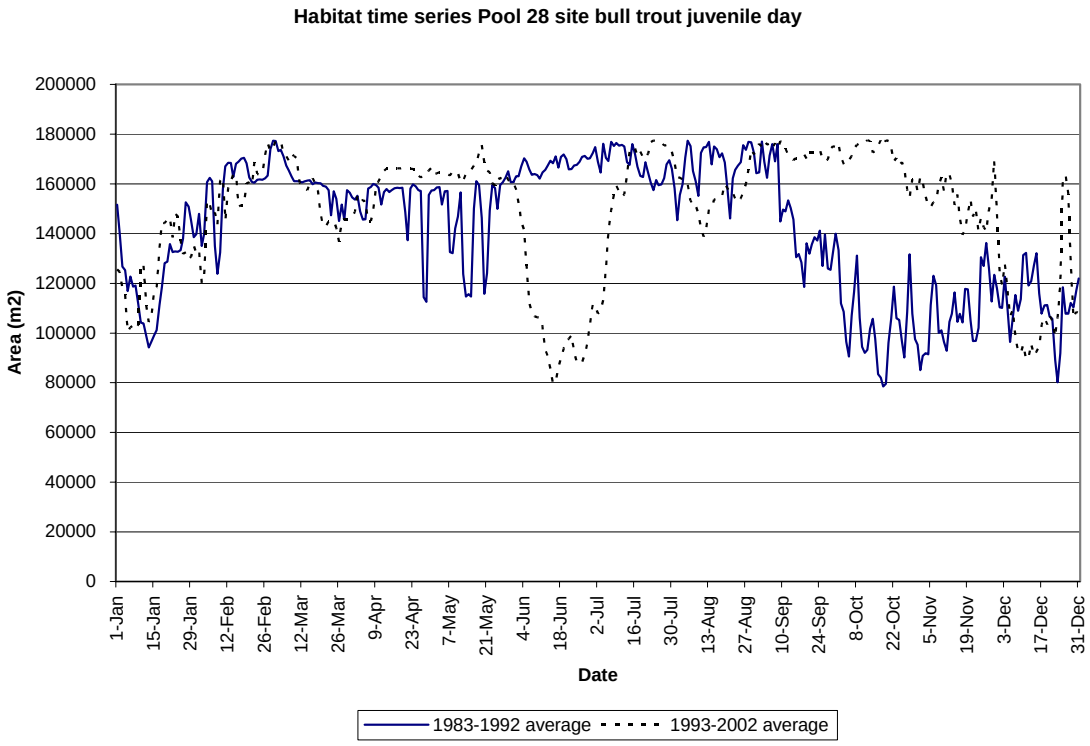



Figure 38. Annual habitat time series, bull trout juvenile day, Pool 28 site.

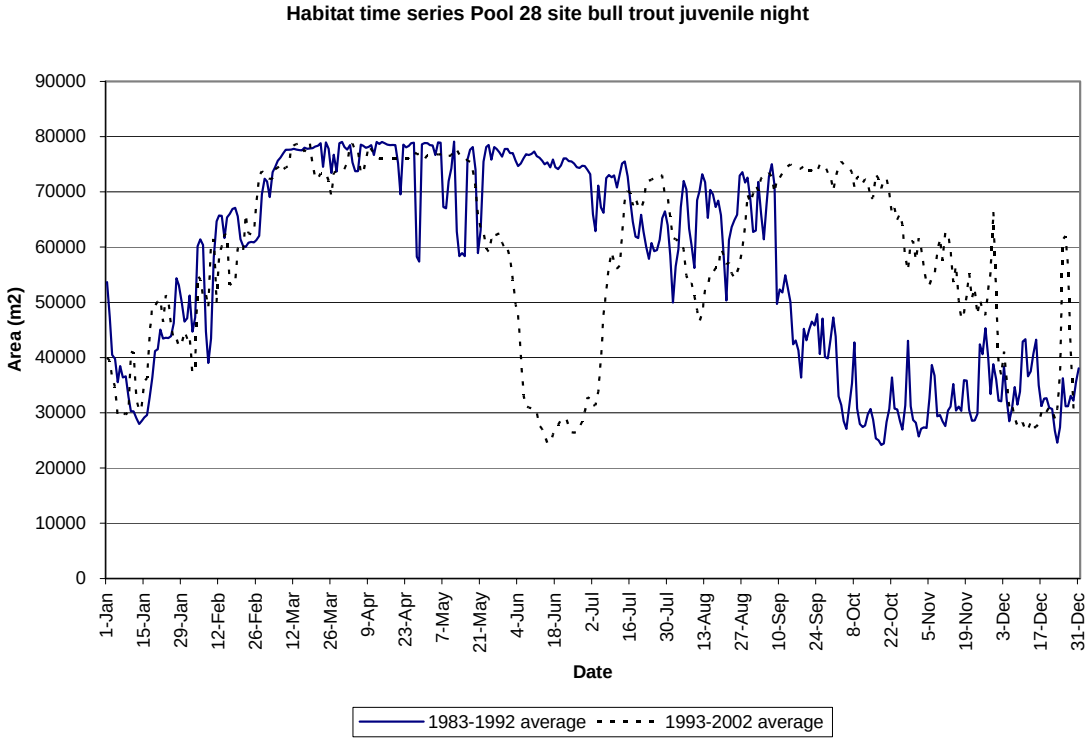



Figure 39. Annual habitat time series, bull trout juvenile night, Pool 28 site.

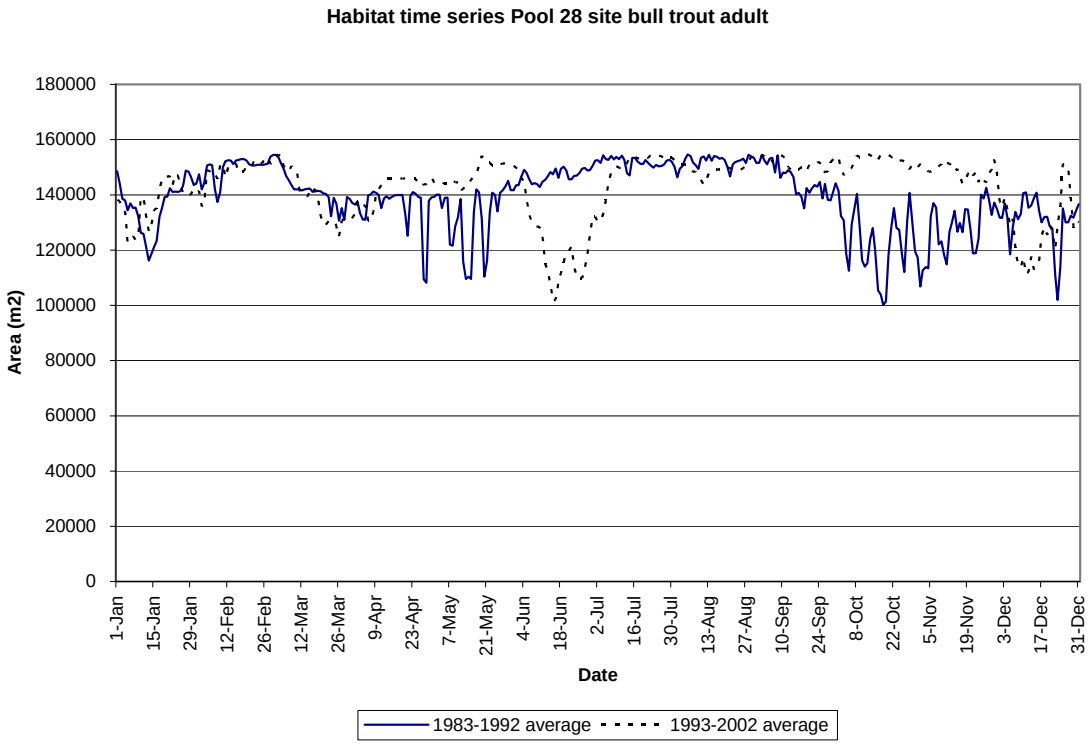



Figure 40. Annual habitat time series, bull trout adult, Pool 28 site.

**Run 45 Site**

The Run 45 site contained run, glide and pool habitat. Bull trout adult habitat is shown for a flow of approximately 4,000 cfs to illustrate the habitat quantification using GIS. The dark blue colors are the higher habitat values, while the lighter colors are lower habitat value (Figure 41). The highest amount of habitat for all species occurs at this flow.

Habitat area versus discharge functions were similar for both juvenile and adult rainbow trout (Figure 42). The highest habitat area occurred at the lowest flows and drops sharply as flows increase. This is likely due to the use of lower velocities and depths. Most likely velocity becomes limiting before depth.

Similar to Pool 28 site, habitat area versus discharge for all bull trout life stages shows a similar response to flow. The adult and juvenile day life stages are similar (Figure 43). The juvenile night life stage has the highest habitat availability at the lower flows and drops more quickly than the other life stages.

The habitat time series shows a highly variable habitat under the 1983-1992 flow regime. The 1993-2002 flow regime shows more stable habitat during most of the year. This trend is shown for all species and life stages (Figures 44 through 48).

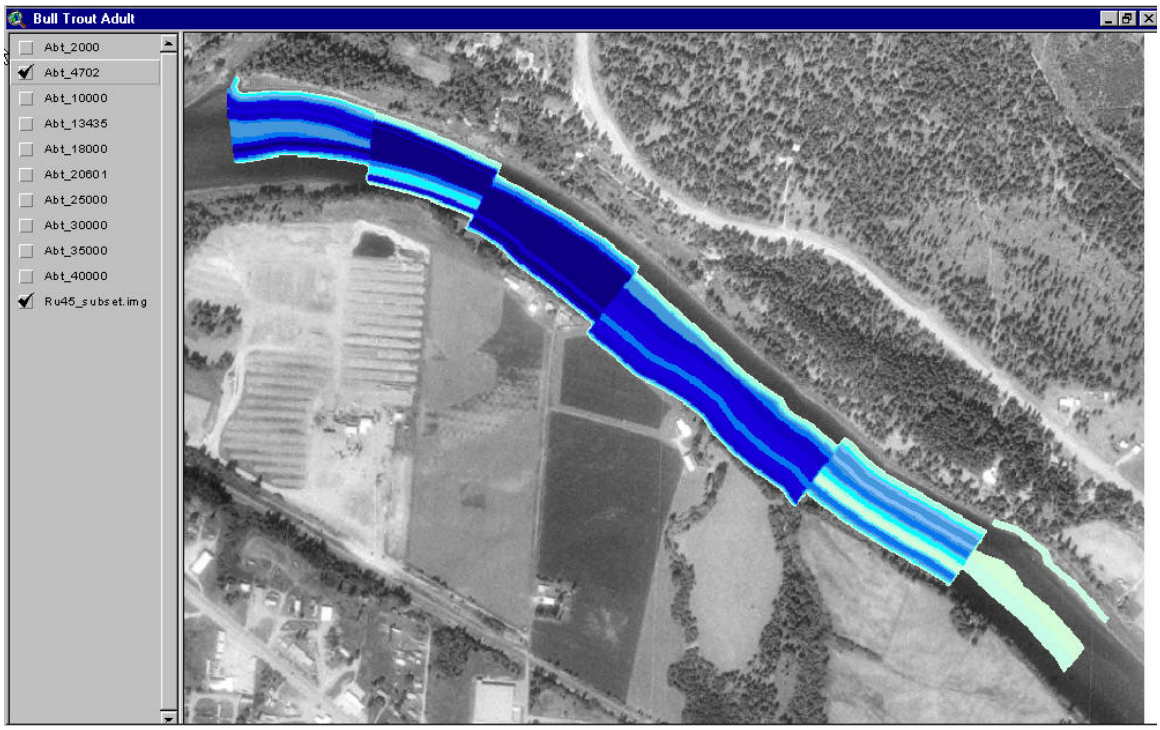



Figure 41. GIS based site map for Run 45.

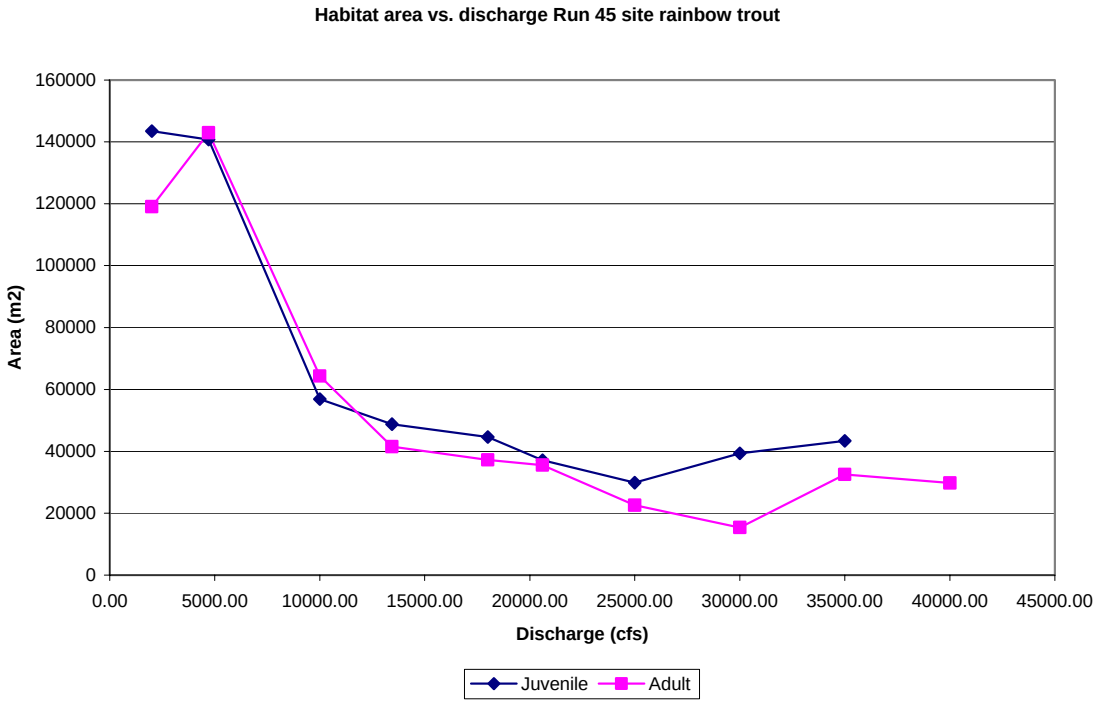



Figure 42. Habitat area vs. discharge for Run 45 site, rainbow trout.

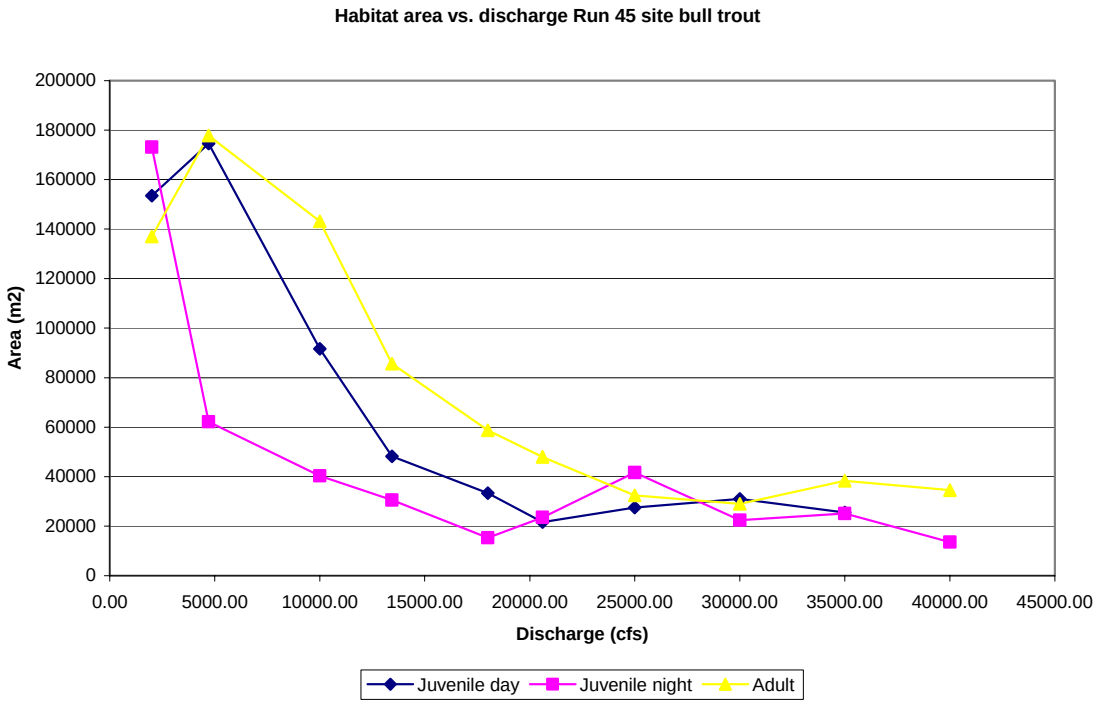



Figure 43. Habitat area vs. discharge for Run 45 site, bull trout.

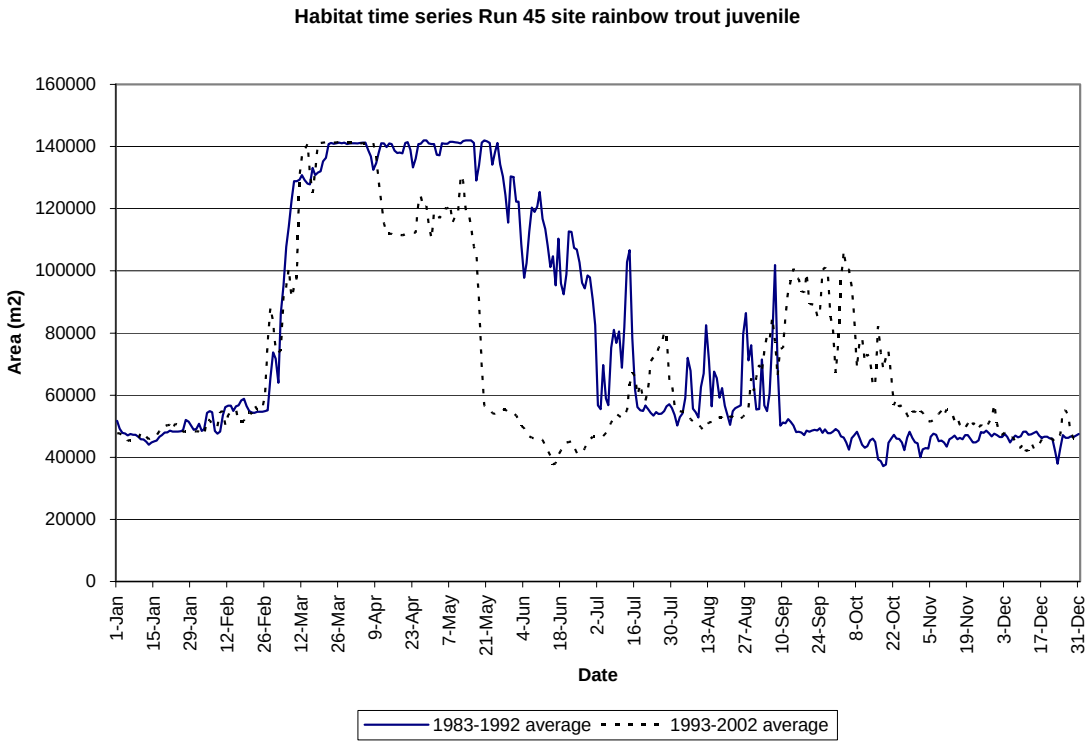



Figure 44. Annual habitat time series, rainbow trout juvenile, Run 45 site.

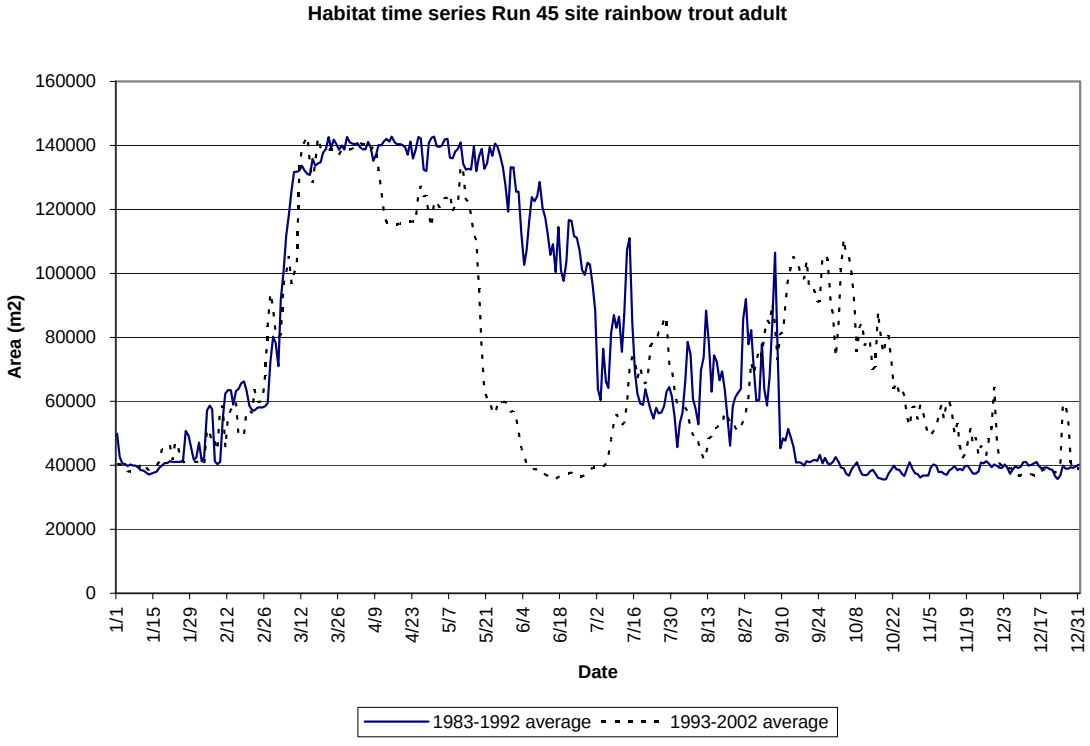



Figure 45. Annual habitat time series, rainbow trout adult, Run 45 site.

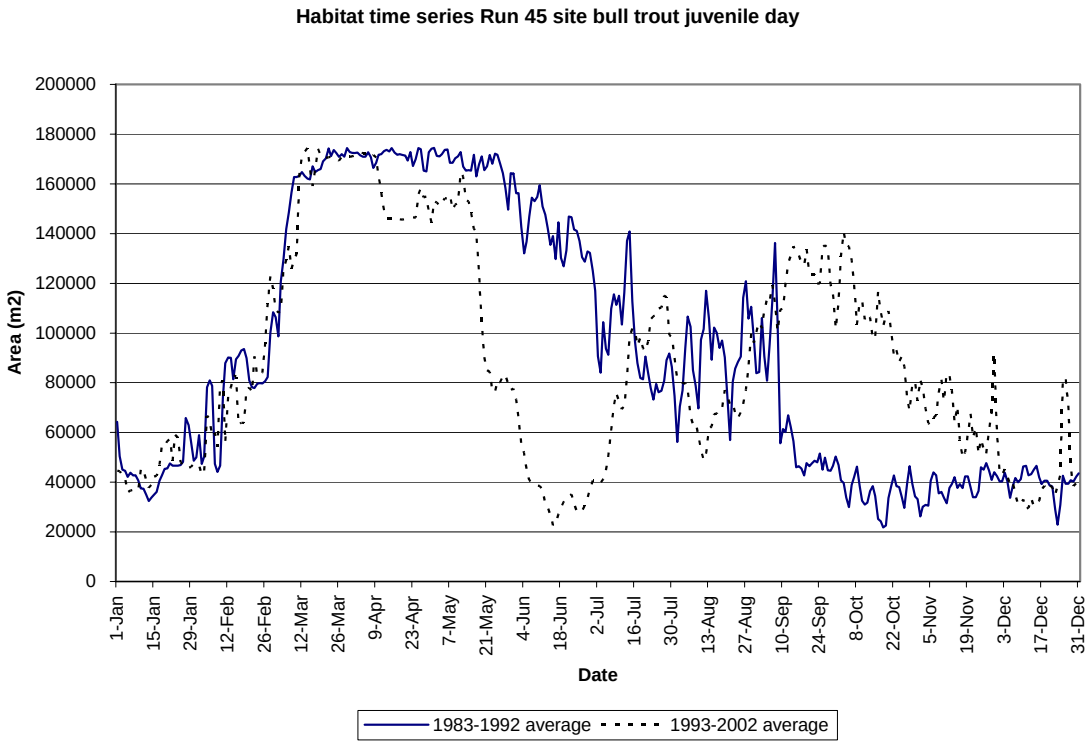



Figure 46. Annual habitat time series, bull trout juvenile day, Run 45 site.

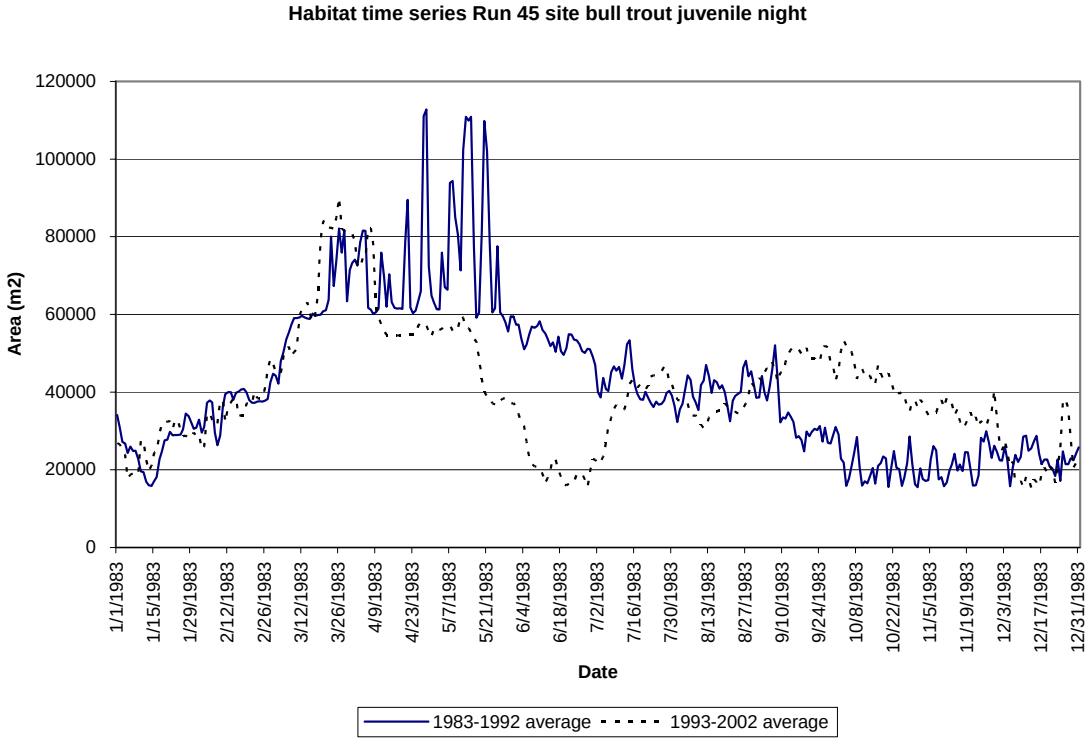



Figure 47. Annual habitat time series, bull trout juvenile night, Run 45 site.

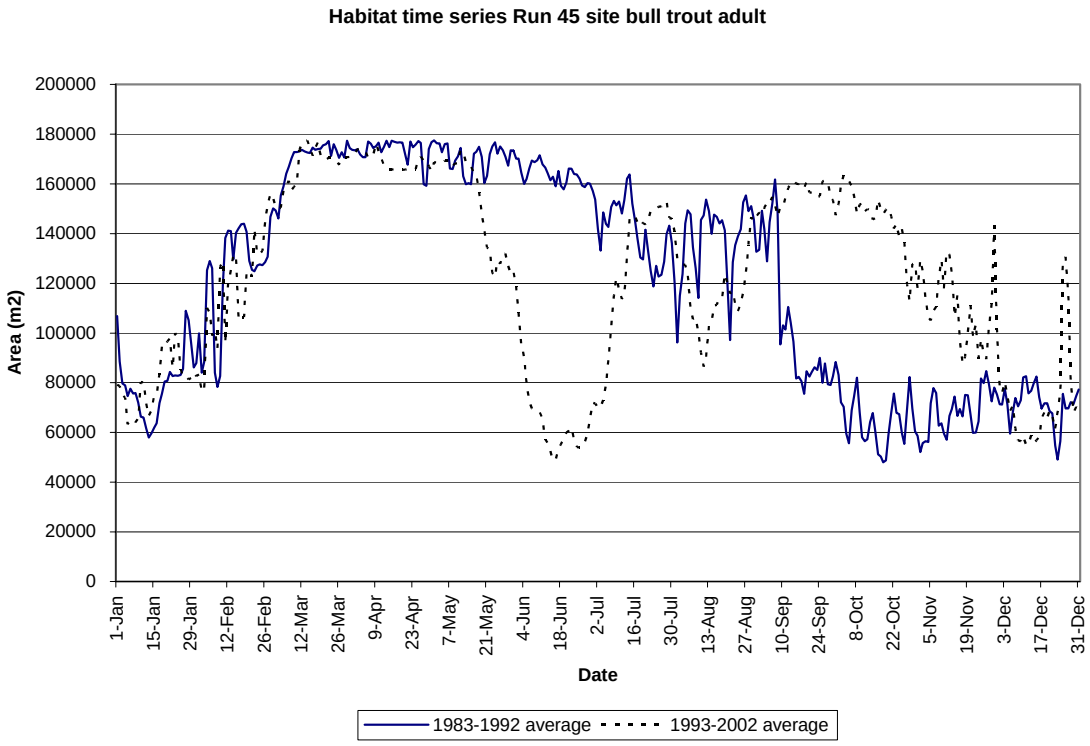



Figure 48. Annual habitat time series, bull trout adult, Run 45 site.

**Pool 51 Site**

The Pool 51 site contained pool, glide and riffle habitat. Bull trout adult habitat is shown for a flow of approximately 4,000 cfs to illustrate the habitat quantification using GIS. The dark blue colors are the higher habitat values, while the lighter colors are lower habitat value (Figure 49).

Habitat area versus discharge functions were similar for both juvenile and adult rainbow trout (Figure 50). The highest habitat area occurred at approximately 4,000 cfs. The habitat area decreases quickly as flows increase over 5,000 cfs.

Habitat area versus discharge for bull trout adult and juvenile day life stages are similar with the highest amount of habitat found between 5,000 and 10,000 cfs(Figure 51). Both of these lifestages use deeper water than the bull trout juvenile night life stage. The juvenile night life stage has the highest habitat availability at the lowest flows, similar to rainbow trout. As with rainbow trout this is likely due to velocity exceeding the preferred range in combination with increasing depth.

The habitat time series shows a response similar to Run 45 site with highly variable habitat under the 1983-1992 flow regime. The 1993-2002 flow regime shows more stable habitat during most of the year. This trend is shown for all species and life stages (Figures 52 through 56).

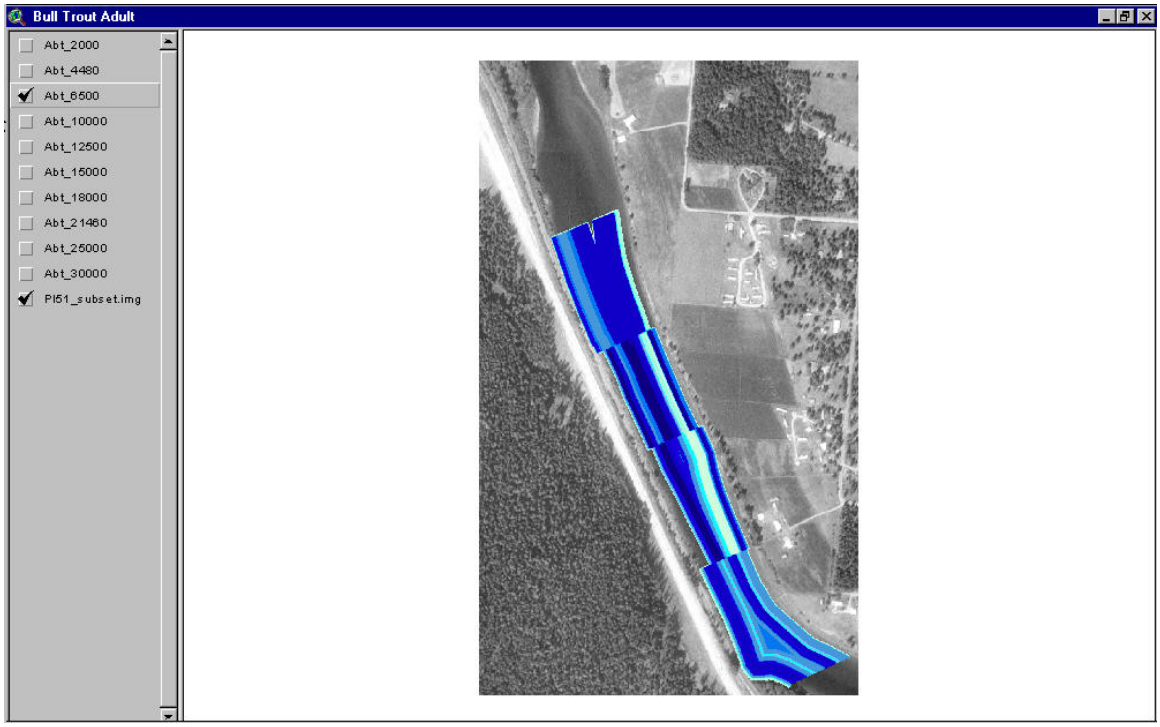



Figure 49. GIS based site map for Pool 51.

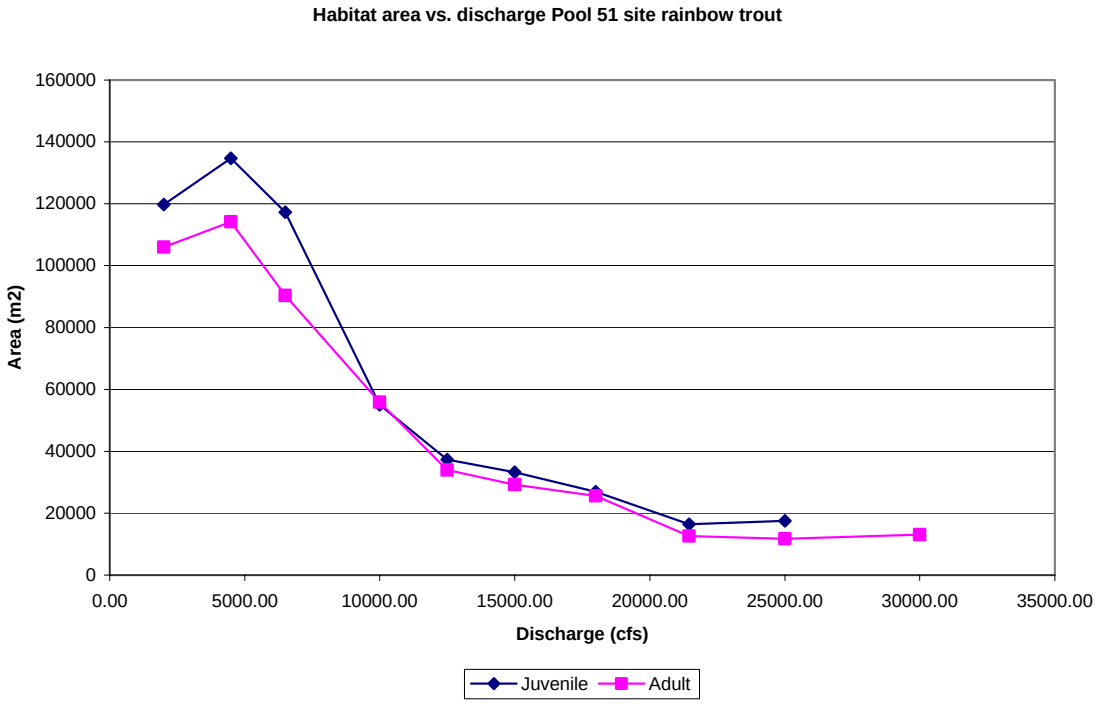



Figure 50. Habitat area vs. discharge for Pool 51 site, rainbow trout.

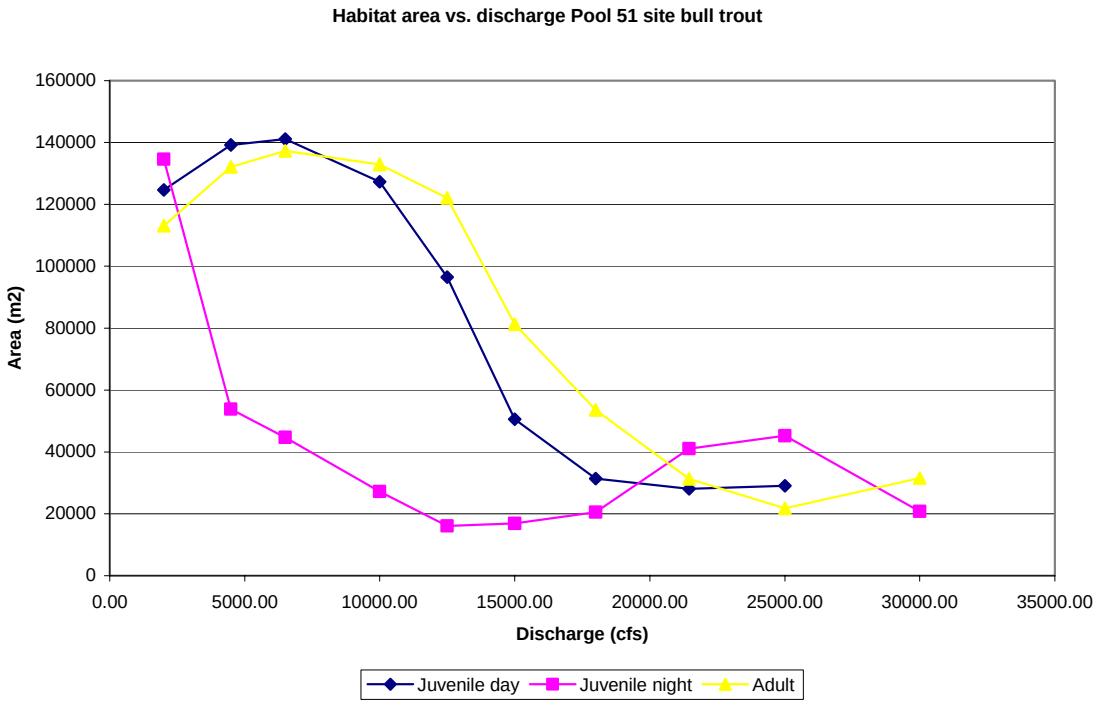



Figure 51. Habitat area vs. discharge for Pool 51 site, bull trout.

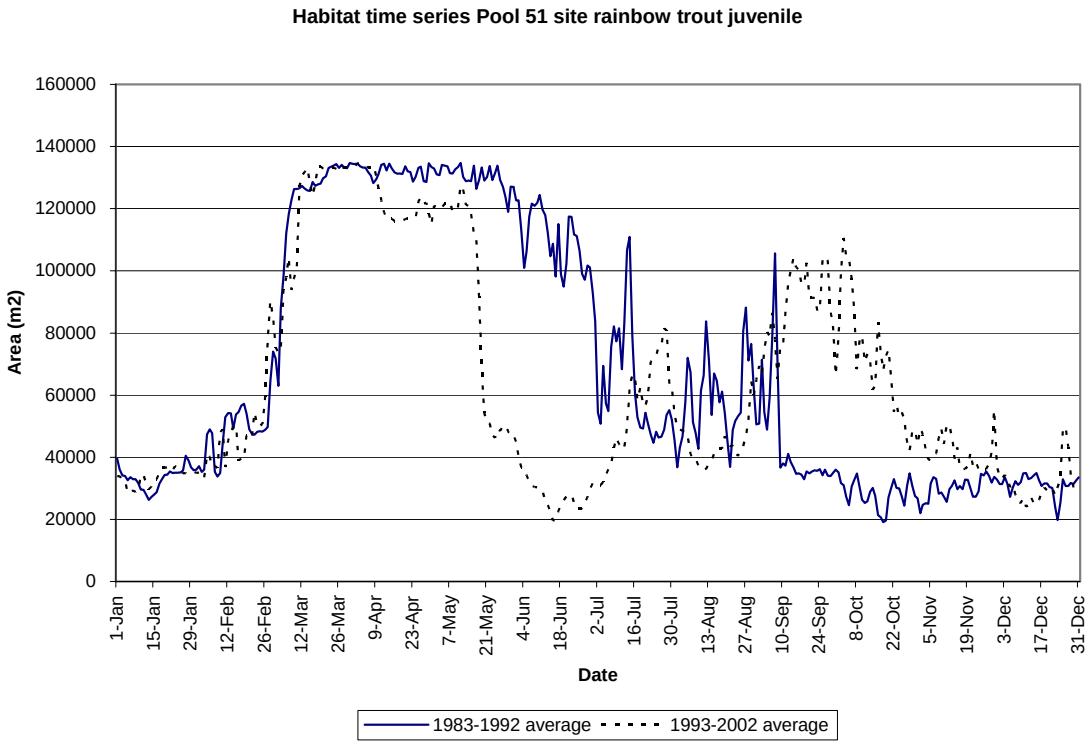



Figure 52. Annual habitat time series, rainbow trout juvenile, Pool 51 site.

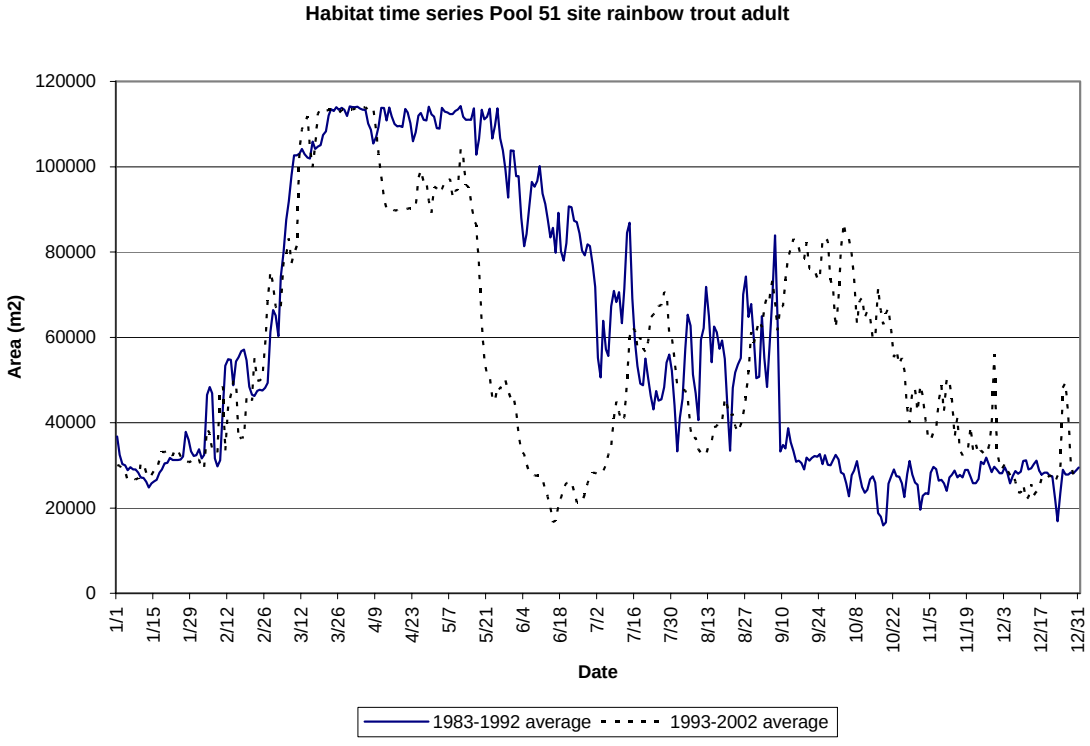



Figure 53. Annual habitat time series, rainbow trout adult, Pool 51 site.

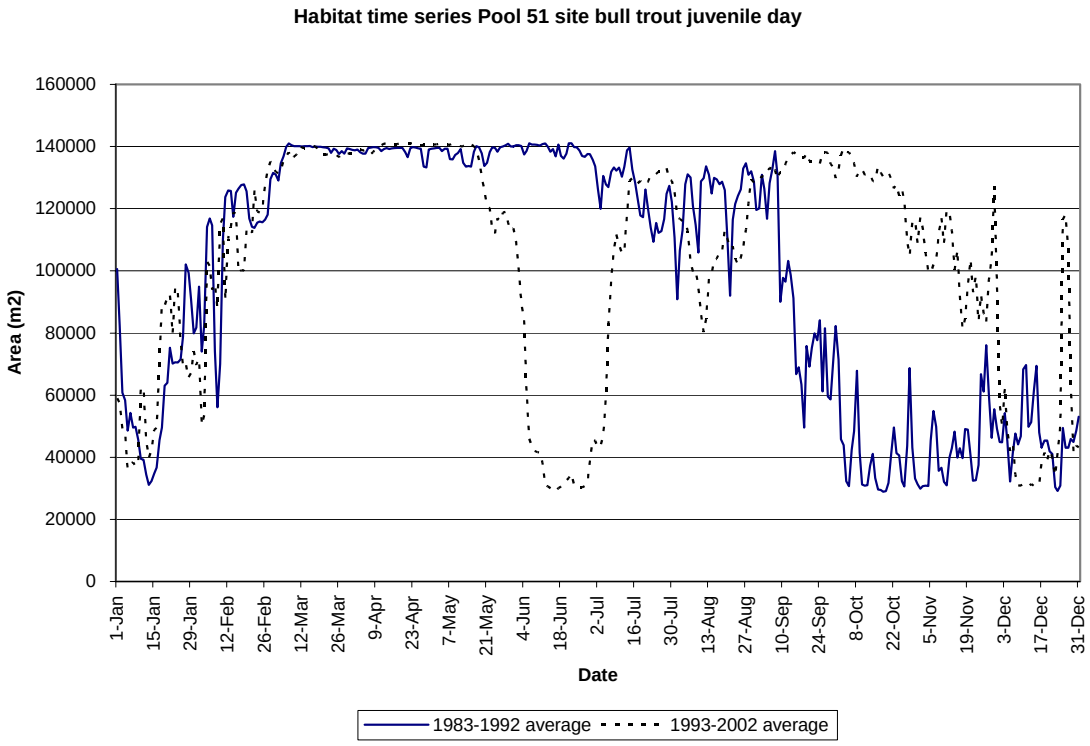



Figure 54. Annual habitat time series, bull trout juvenile day, Pool 51 site.

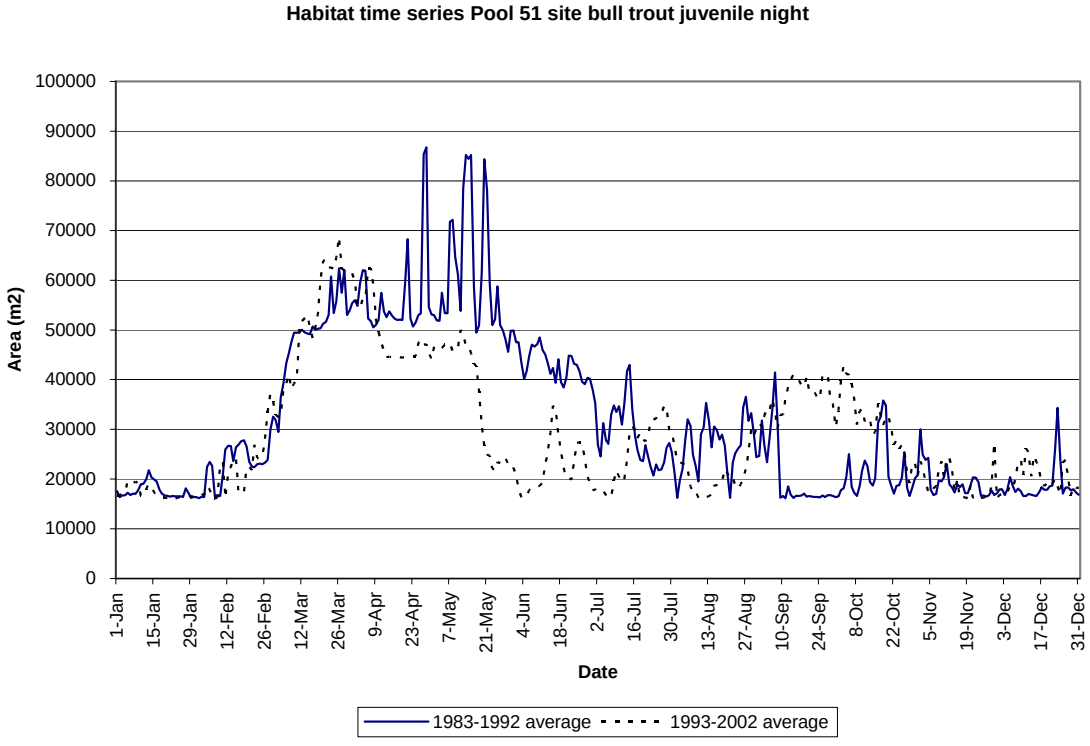



Figure 55. Annual habitat time series, bull trout juvenile night, Pool 51 site.

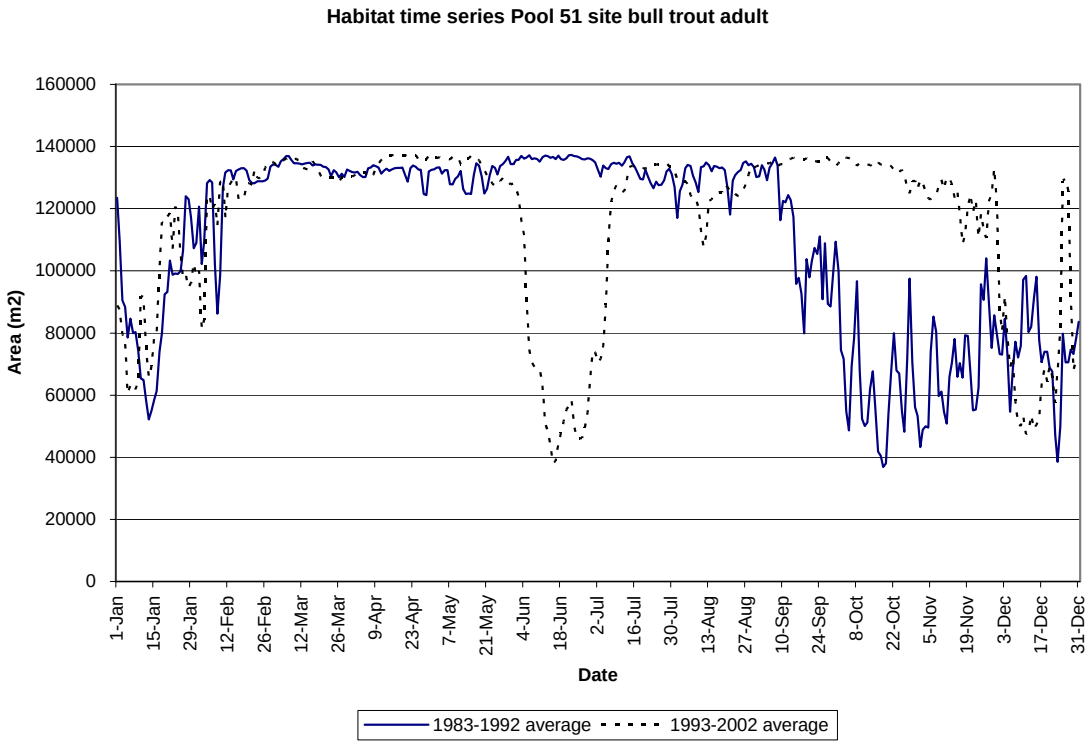



Figure 56. Annual habitat time series, bull trout adult, Pool 51 site.

**Rapid 73 Site**

The Rapid 73 site contained rapid and run habitat. Bull trout adult habitat is shown for a flow of approximately 4,000 cfs to illustrate the habitat quantification using GIS. The dark blue colors are the higher habitat values, while the lighter colors are lower habitat value (Figure 57).

Habitat area versus discharge functions were similar for both juvenile and adult rainbow trout (Figure 58). The highest habitat area occurred at approximately 4,000 cfs. Habitat availability declines rapidly as flows increase from 4,000 cfs.

Habitat area versus discharge for bull trout adult and juvenile day life stages are similar (Figure 59). The peak of habitat availability is nearly the same as for rainbow trout. Bull trout juvenile day habitat declines rapid as flows increase. As with rainbow trout this is likely due to velocity exceeding the preferred range in combination with increasing depth.

The habitat time series shows a highly variable habitat under the 1983-1992 flow regime. The 1993-2002 flow regime shows more stable habitat during most of the year. This trend is shown for all species and life stages (Figures 60 through 64).

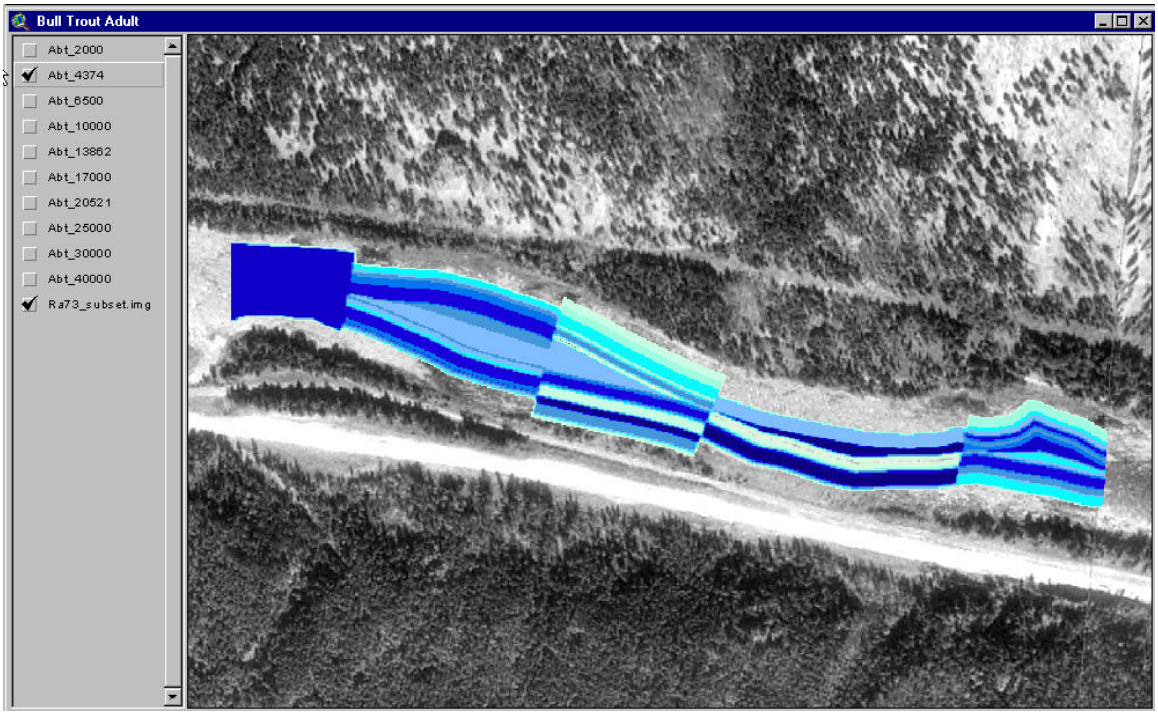



Figure 57. GIS based site map for Rapid 73.

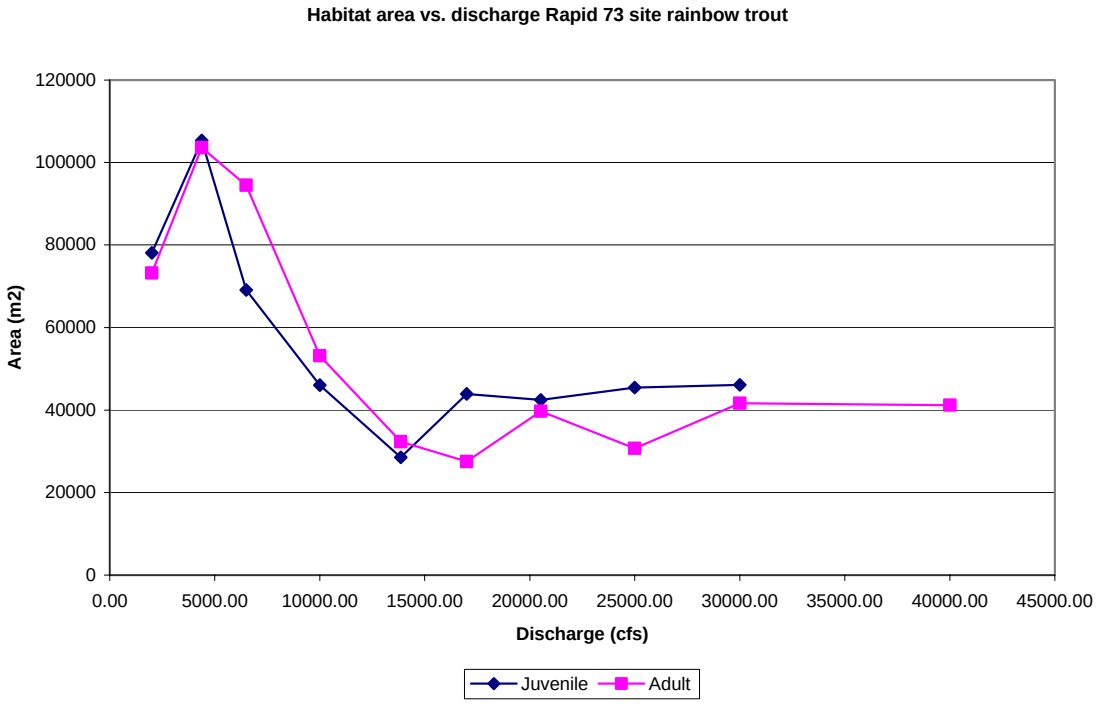



Figure 58. Habitat area vs. discharge for Rapid 73 site, rainbow trout.

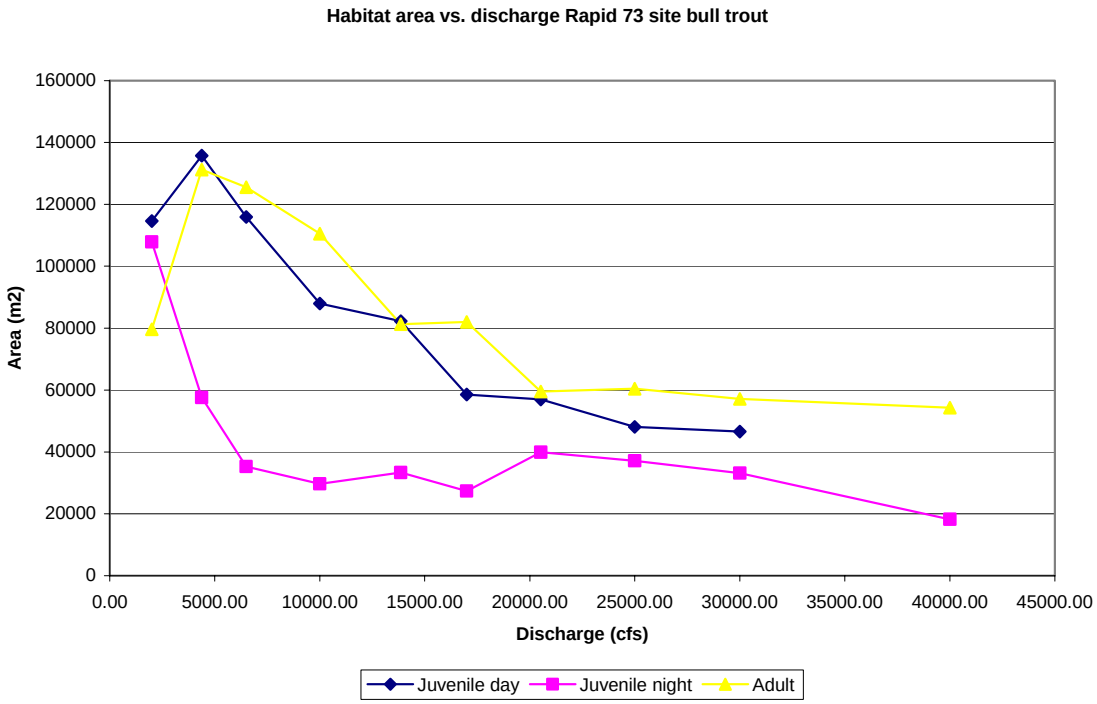



Figure 59. Habitat area vs. discharge for Rapid 73 site, bull trout.

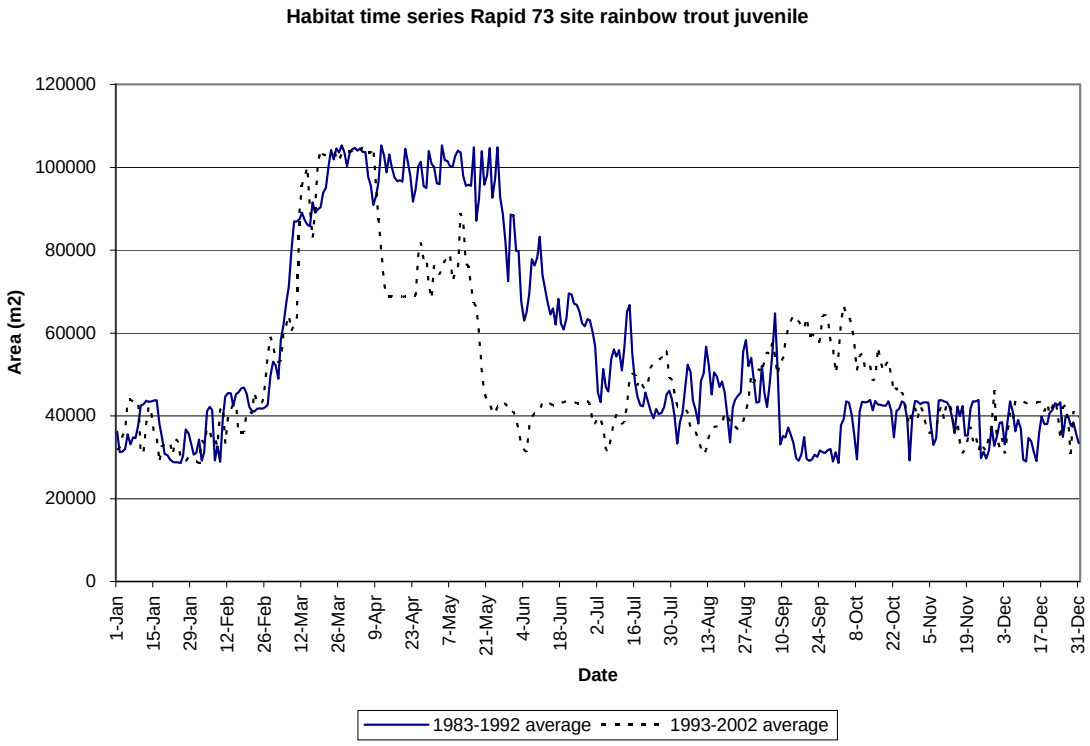



Figure 60. Annual habitat time series, rainbow trout juvenile, Rapid 73 site.

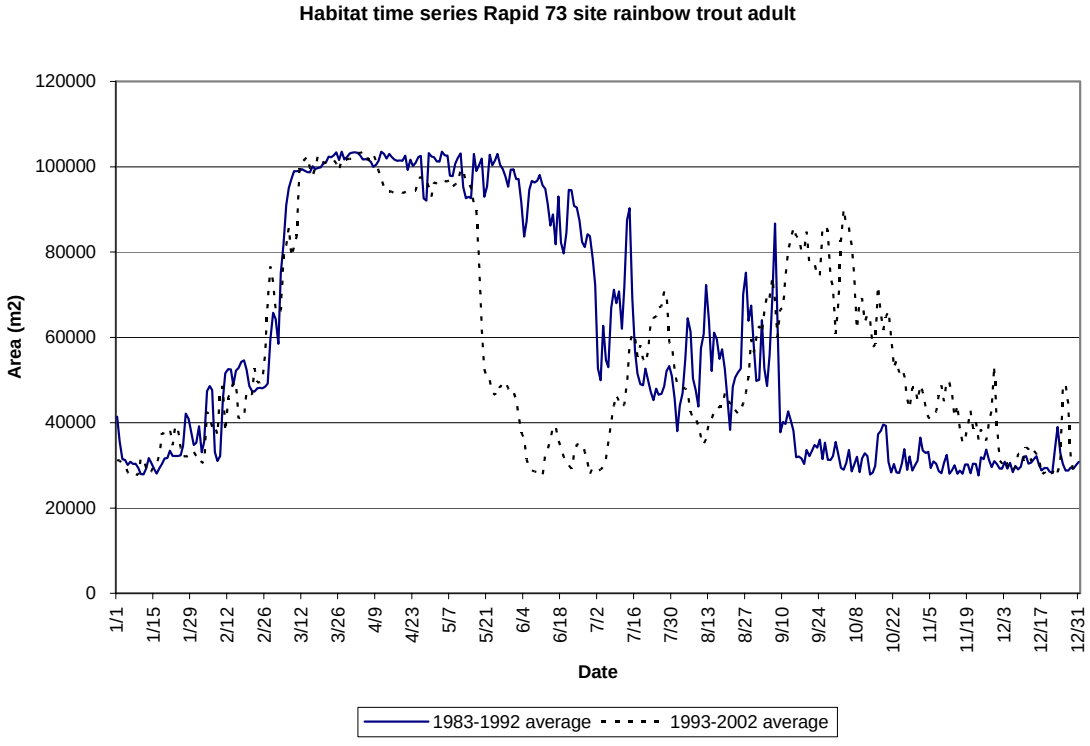



Figure 61. Annual habitat time series, rainbow trout adult, Rapid 73 site.

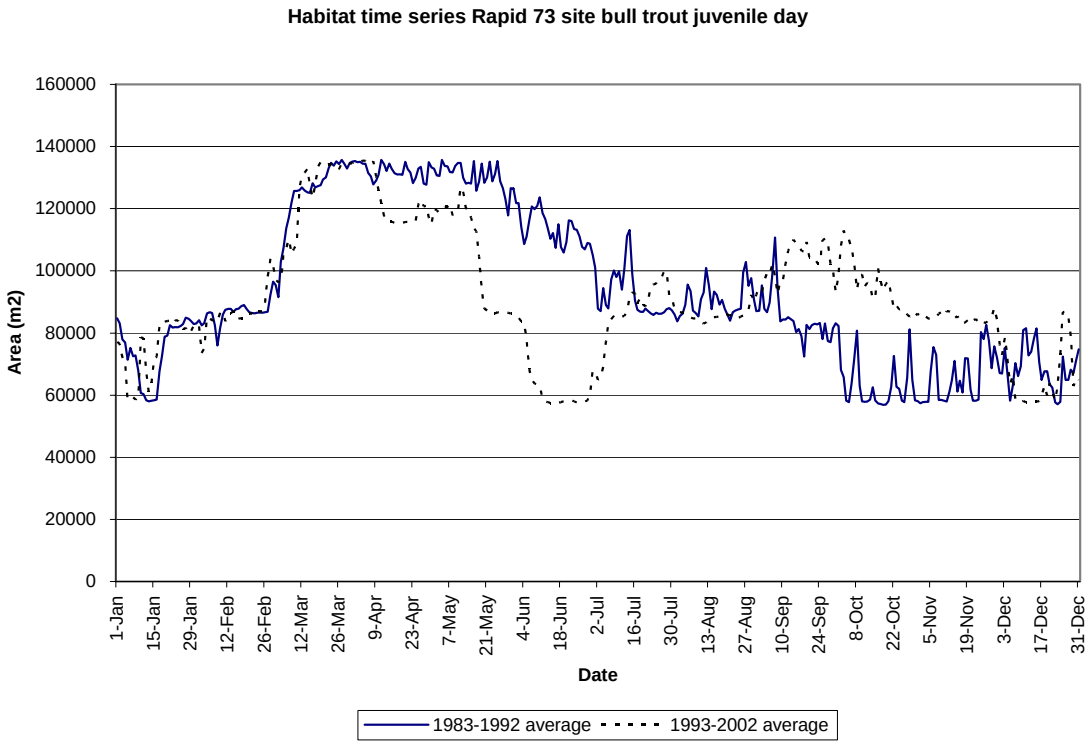



Figure 62. Annual habitat time series, bull trout juvenile day, Rapid 73 site.

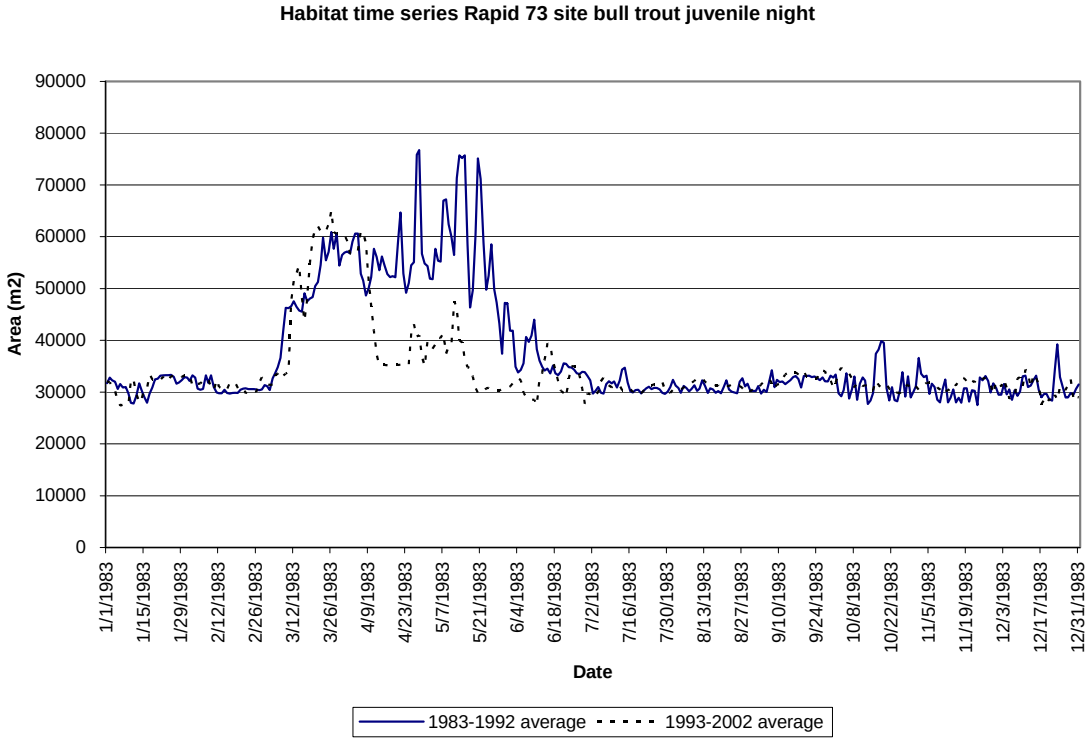



Figure 63. Annual habitat time series, bull trout juvenile night, Rapid 73 site.

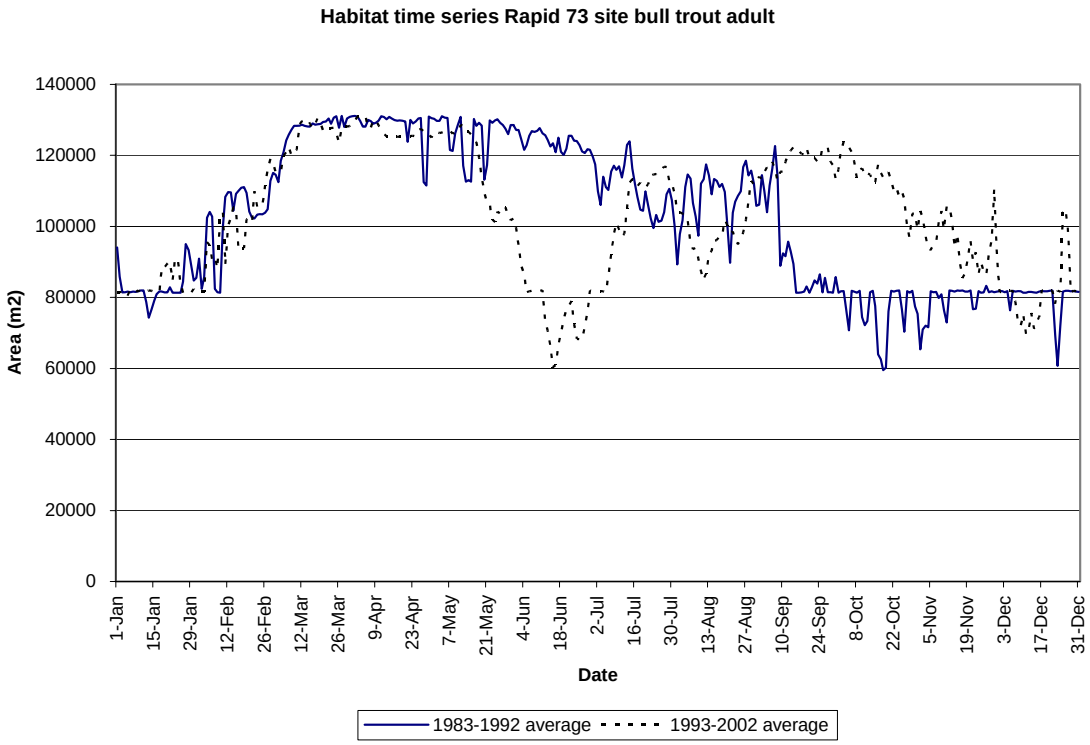



Figure 64. Annual habitat time series, bull trout adult, Rapid 73 site.

## Habitat Simulations Section 2

**Glide 17 Site**

The Glide 17 site contained pool and glide habitat. Bull trout adult habitat is shown for a flow of approximately 4,000 cfs to illustrate the habitat quantification using GIS. The dark blue colors are the higher habitat values, while the lighter colors are lower habitat value (Figure 65).

Habitat area versus discharge functions were nearly identical for both juvenile and adult rainbow trout (Figure 66). The highest habitat area occurred at the lowest flows.

Habitat area versus discharge for bull trout adult and juvenile day life stages are somewhat similar (Figure 67). The highest habitat availability occurred at approximately 10,000 cfs. The juvenile night life stage has the highest habitat availability at the lower flows, similar to rainbow trout.

The habitat time series is very similar to the more downstream sites in Section 1. The habitat time series shows a highly variable habitat under the 1983-1992 flow regime. The 1993-2002 flow regime shows more stable habitat during most of the year. This trend is shown for all species and life stages (Figures 68 through 72).

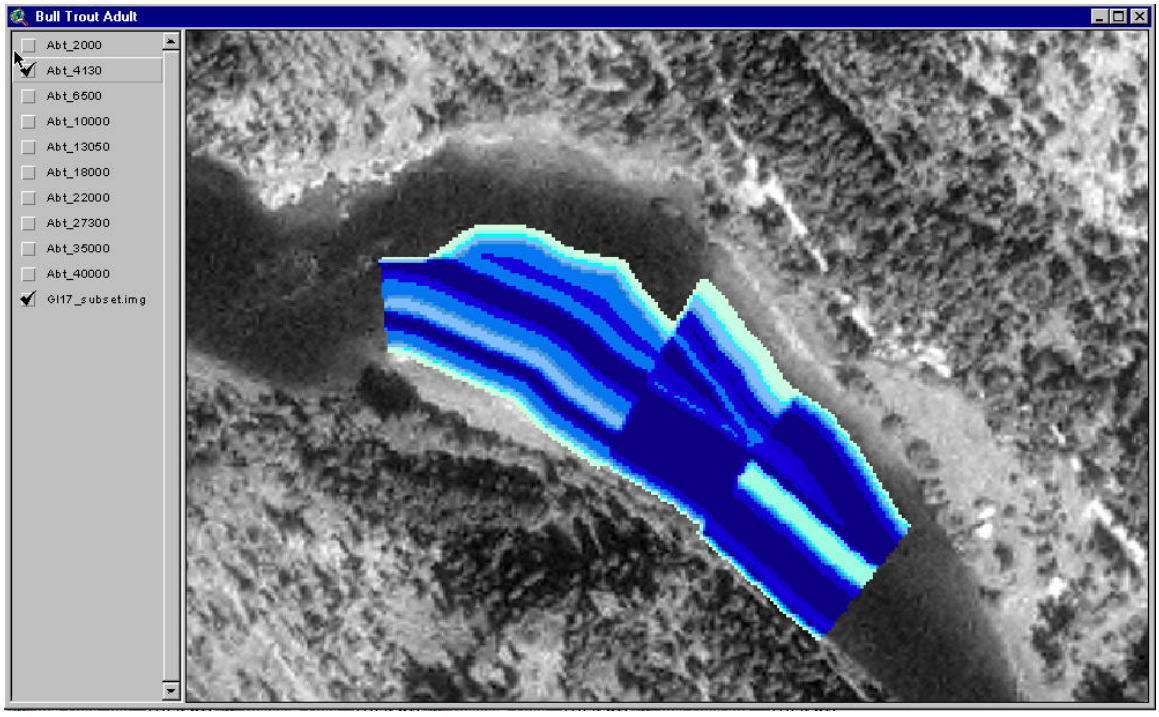



Figure 65. GIS based site map for Glide 17.

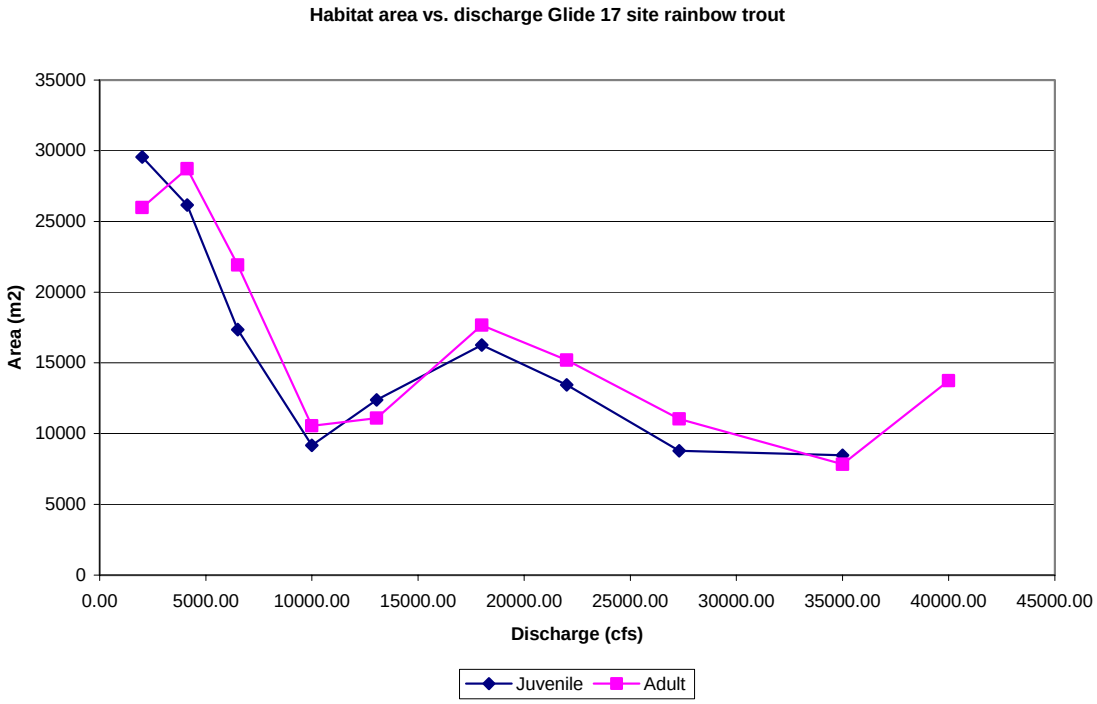



Figure 66. Habitat area vs. discharge for Glide 17 site, rainbow trout.

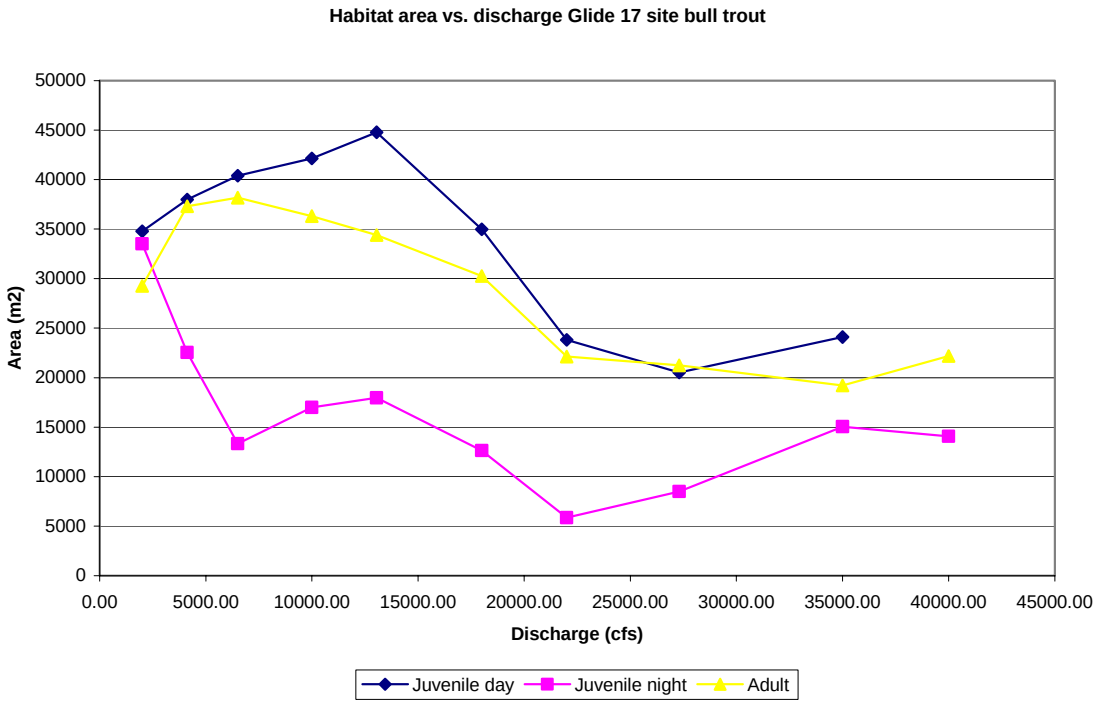



Figure 67. Habitat area vs. discharge for Glide 17 site, bull trout.

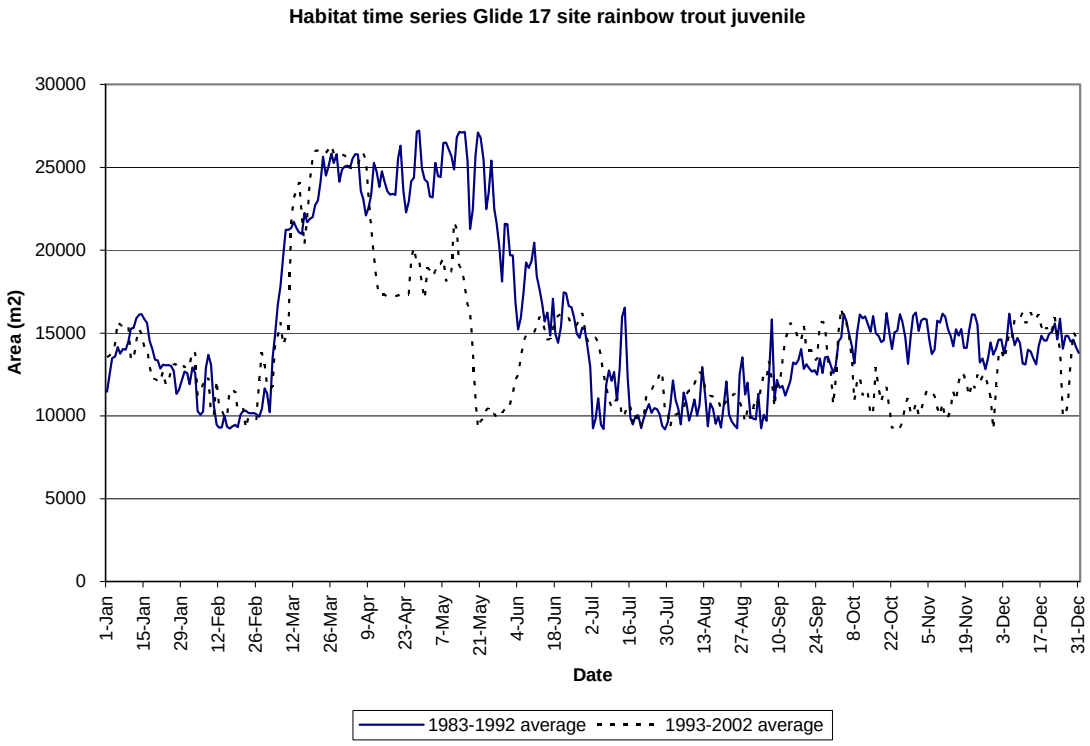



Figure 68. Annual habitat time series, rainbow trout juvenile, Glide 17 site.

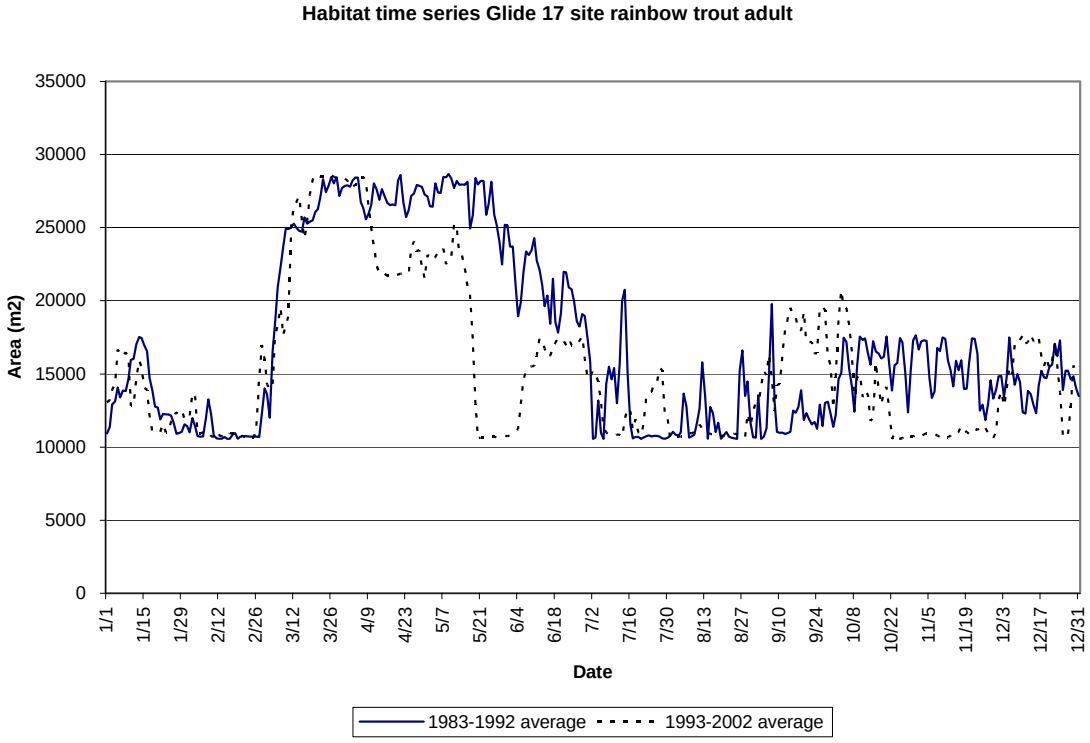



Figure 69. Annual habitat time series, rainbow trout adult, Glide 17 site.

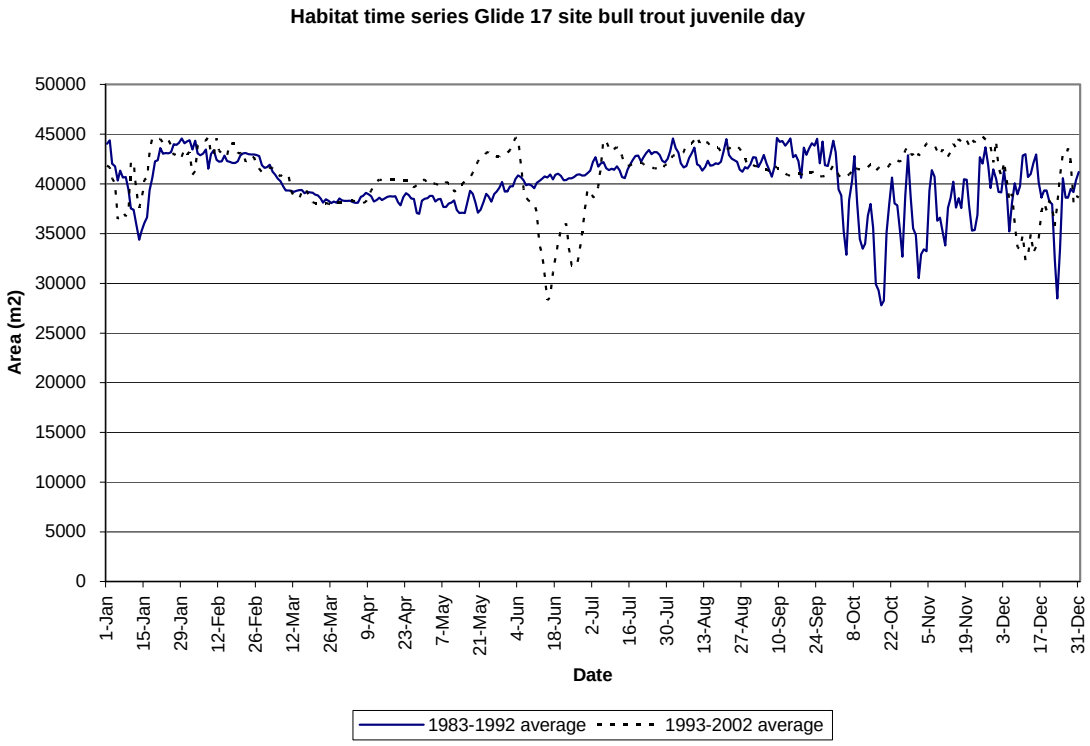



Figure 70. Annual habitat time series, bull trout juvenile day, Glide 17 site.

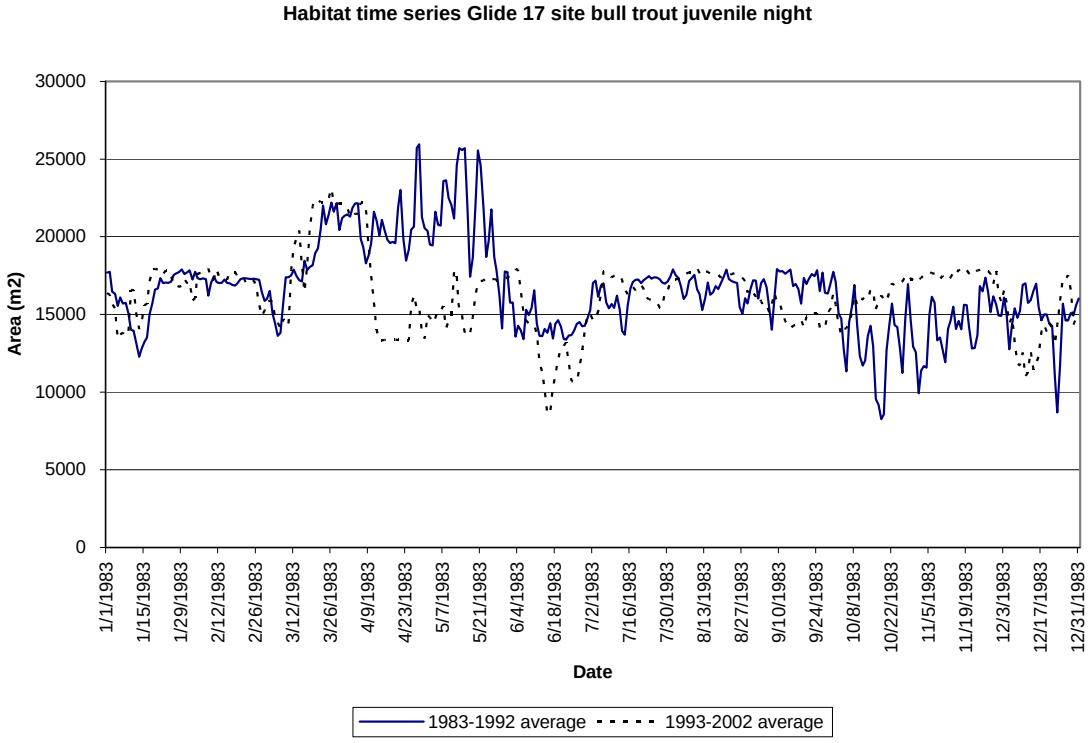



Figure 71. Annual habitat time series, bull trout juvenile night, Glide 17 site.

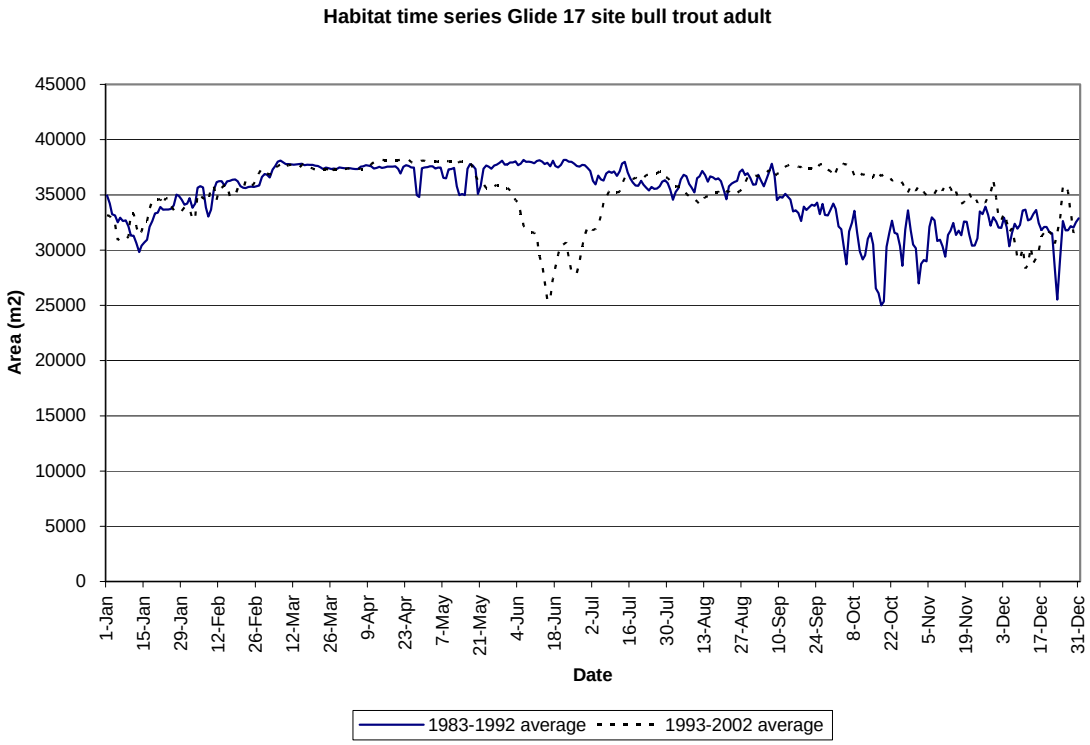



Figure 72. Annual habitat time series, bull trout adult, Glide 17 site.

**Riffle 31 Site**

The Riffle 31 site contained riffle, run and glide habitat. Bull trout adult habitat is shown for a flow of approximately 4,000 cfs to illustrate the habitat quantification using GIS. The dark blue colors are the higher habitat values, while the lighter colors are lower habitat value (Figure 73).

Habitat area versus discharge functions were similar for both rainbow trout and bull trout (Figure 74 and Figure 75). Both species have the lowest amount of available habitat at flows greater than 15,000 cfs. Most likely velocity becomes limiting before depth at this site.

The habitat time series shows a highly variable habitat under the 1983-1992 flow regime. The 1993-2002 flow regime shows more stable habitat during most of the year. This trend is shown for all species and life stages (Figures 76 through 80).

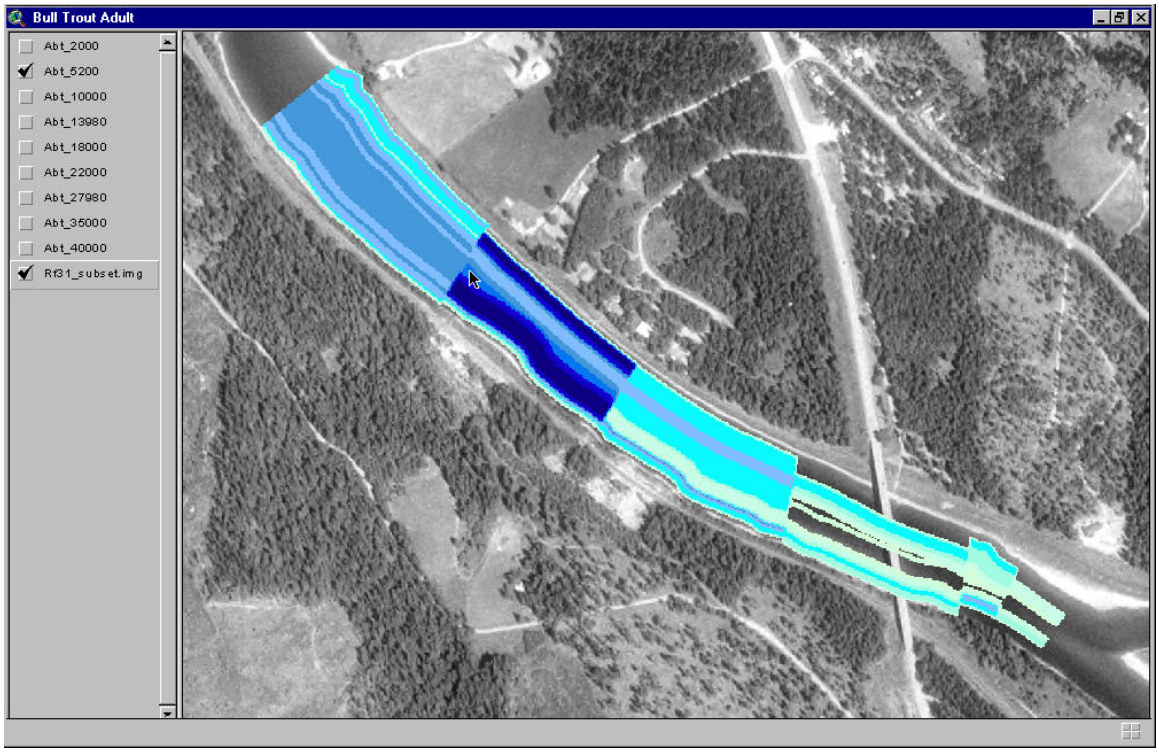



Figure 73. GIS based site map for Riffle 31.

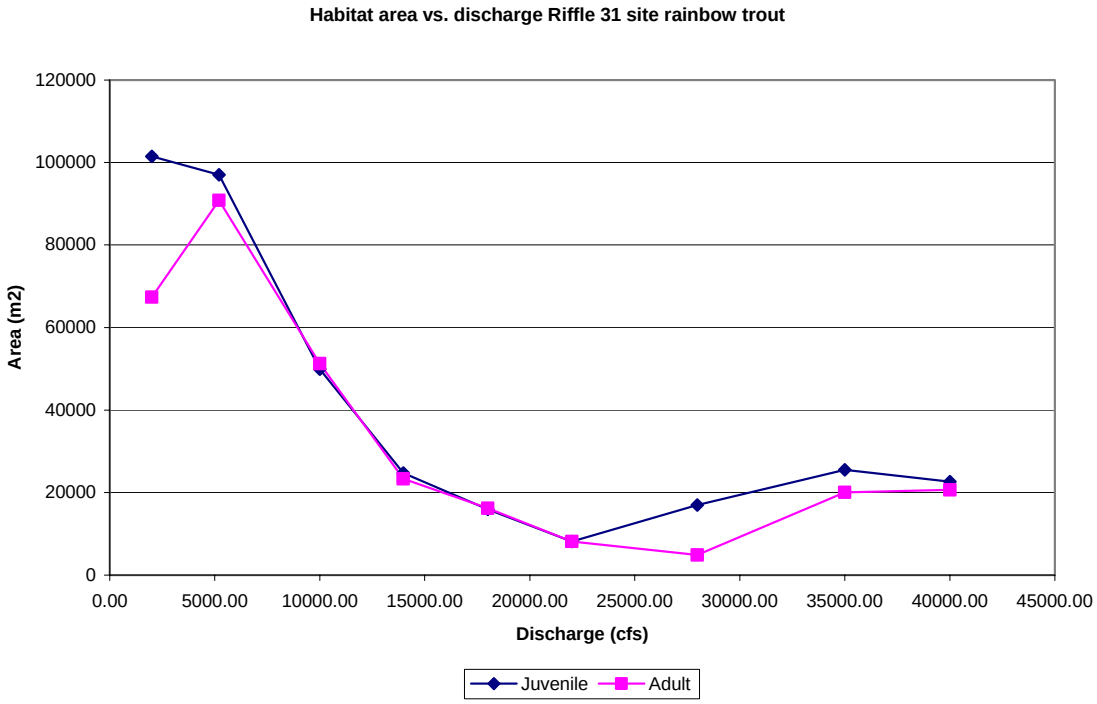



Figure 74. Habitat area vs. discharge for Riffle 31 site, rainbow trout.

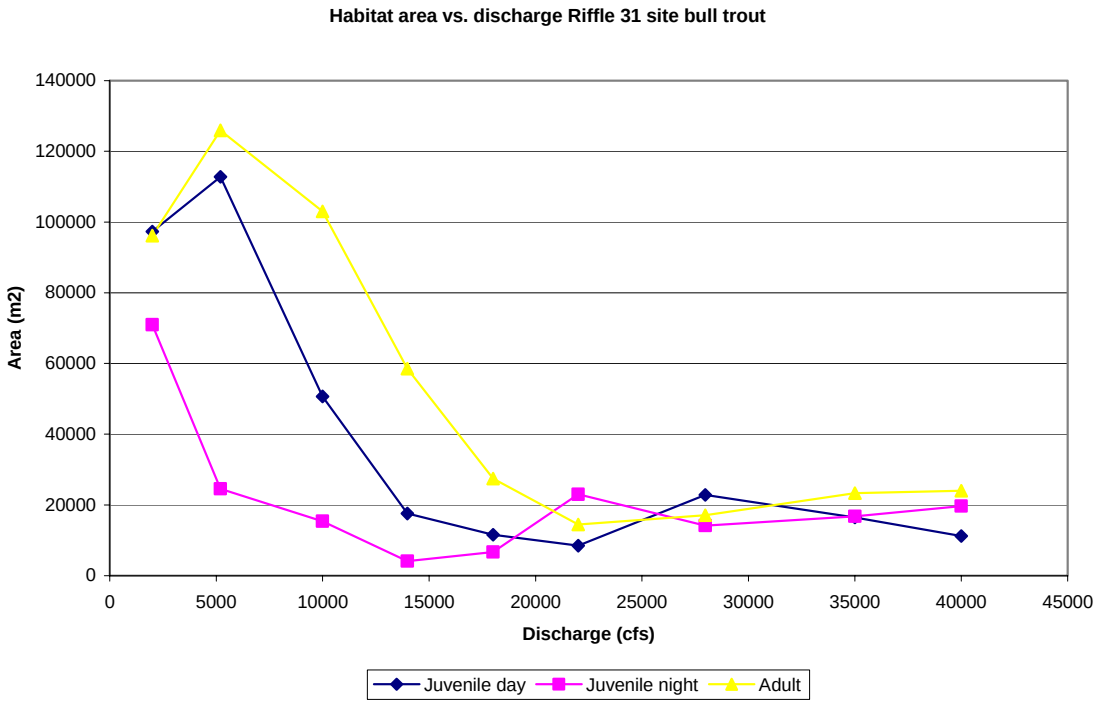



Figure 75. Habitat area vs. discharge for Riffle 31 site, bull trout.

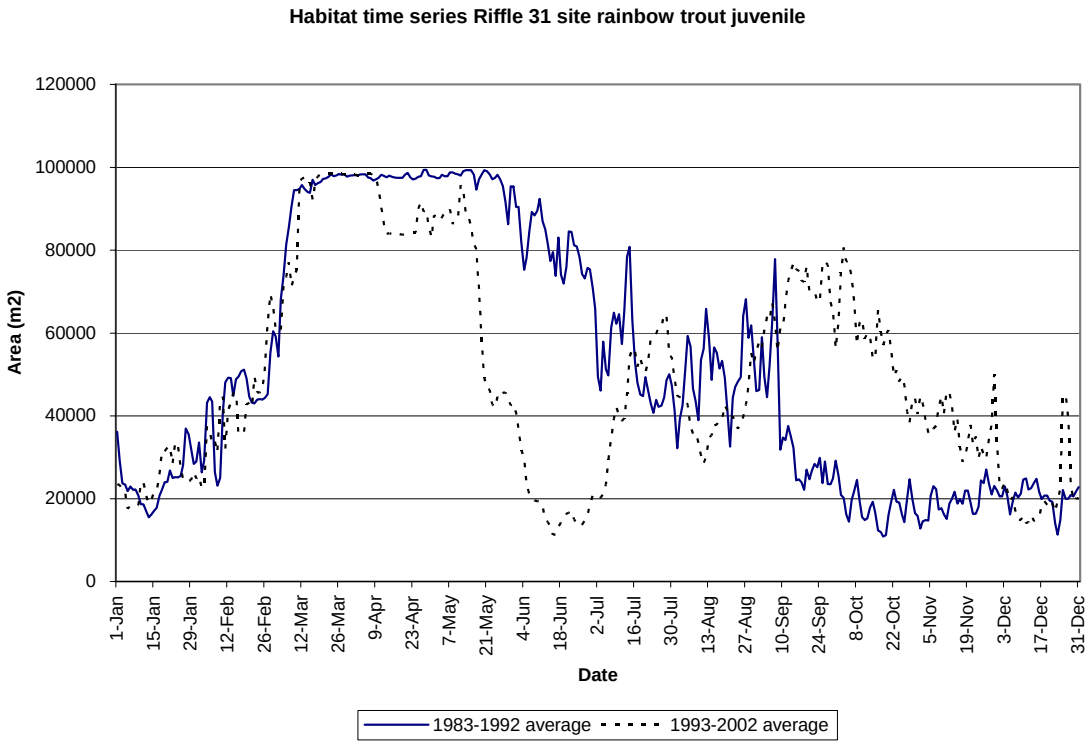



Figure 76. Annual habitat time series, rainbow trout juvenile, Riffle 31 site.

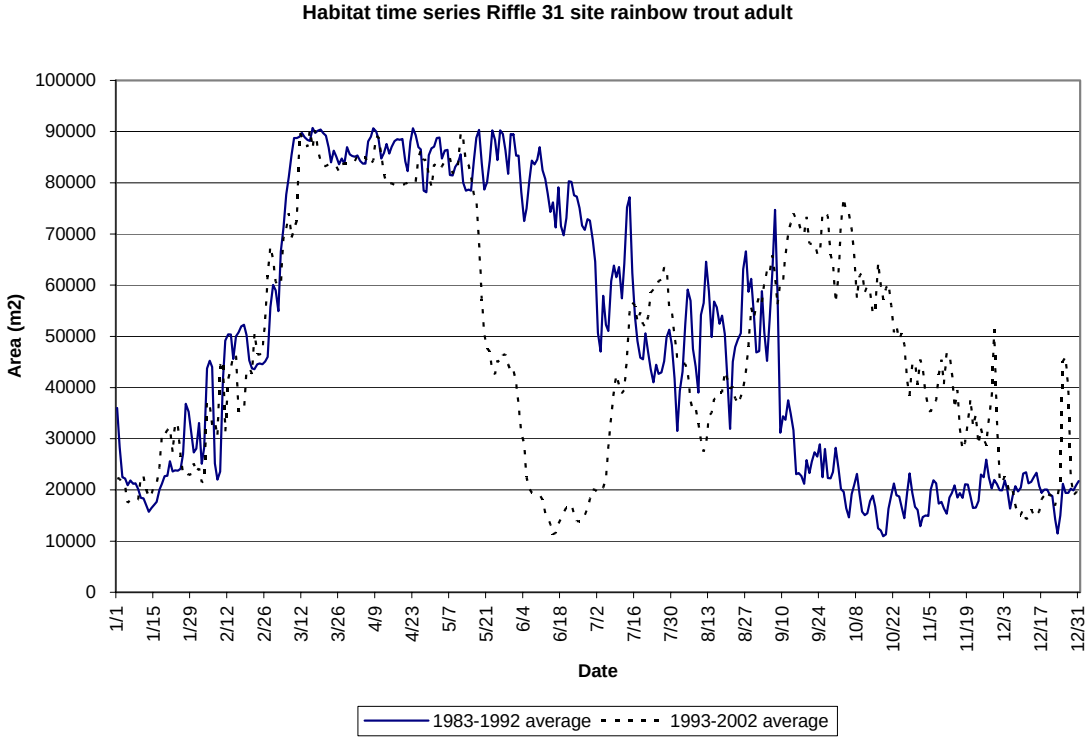



Figure 77. Annual habitat time series, rainbow trout adult, Riffle 31 site.

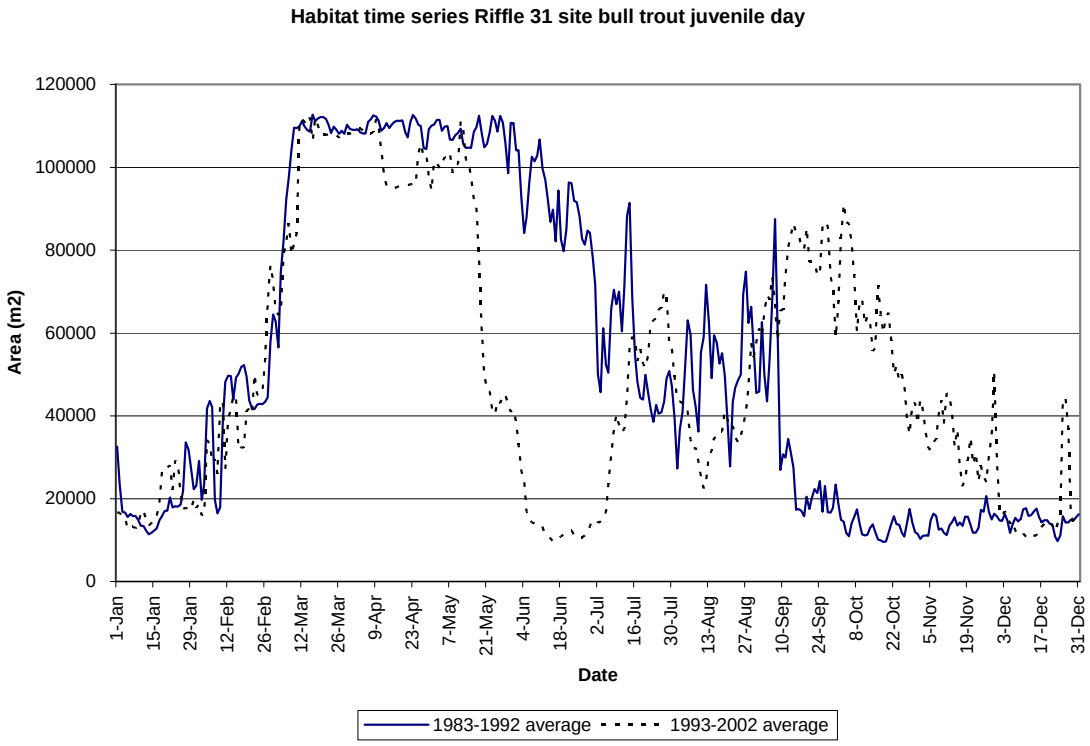



Figure 78. Annual habitat time series, bull trout juvenile day, Riffle 31 site.

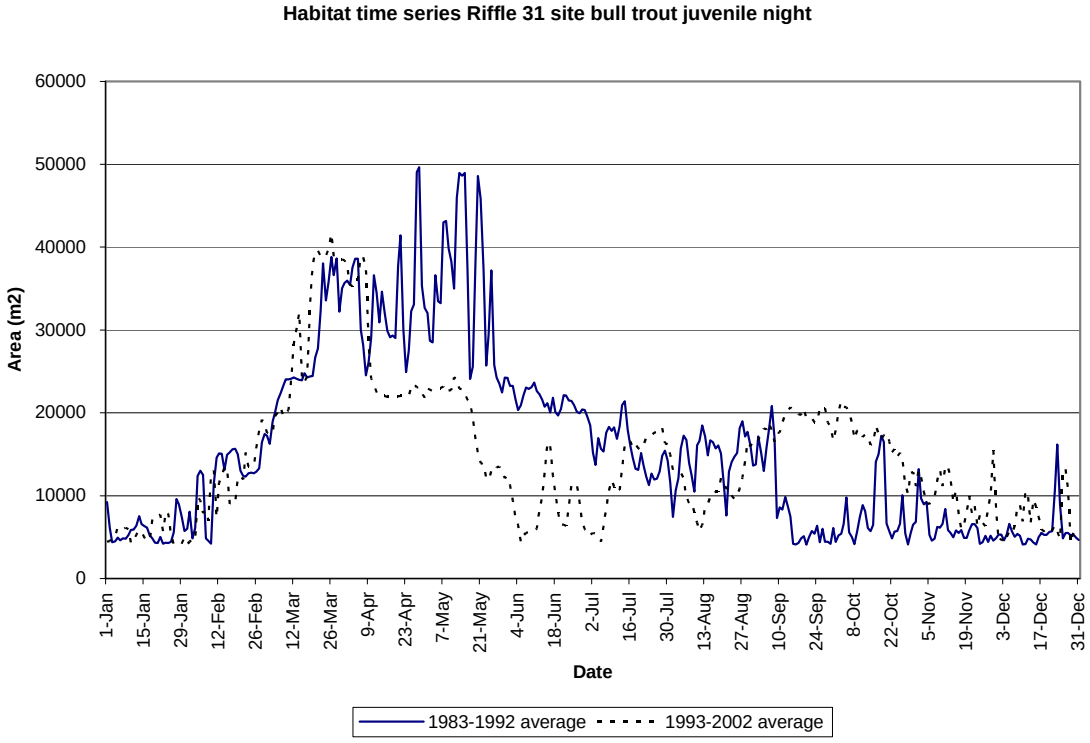



Figure 79. Annual habitat time series, bull trout juvenile night, Riffle 31 site.

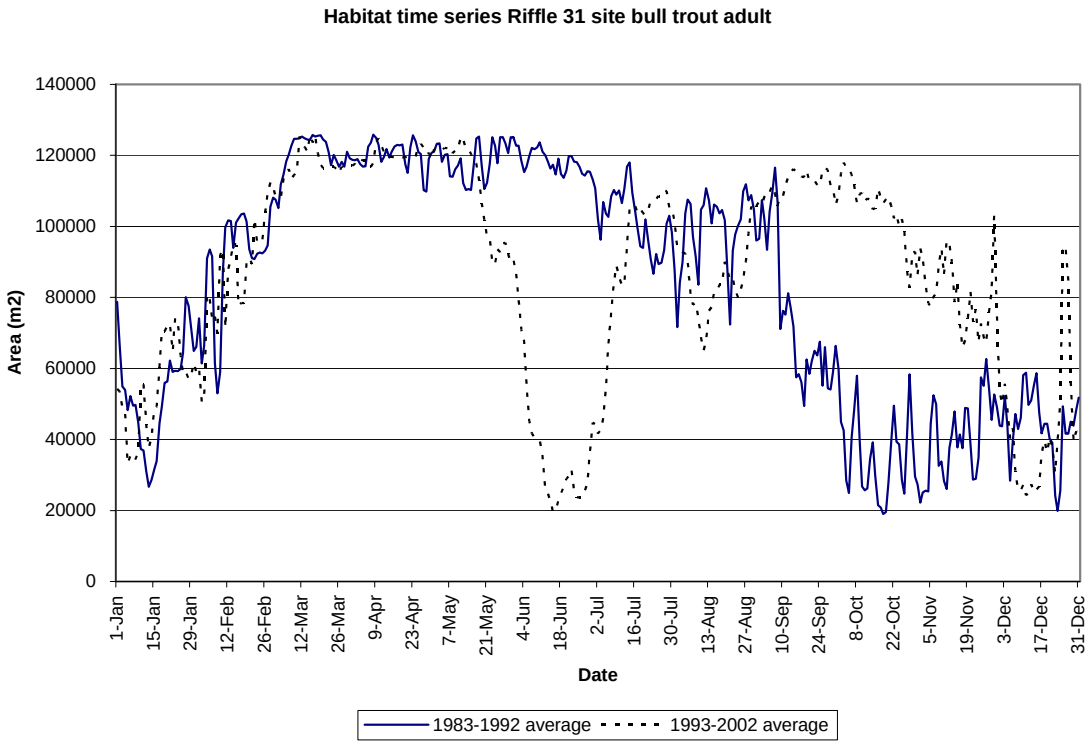



Figure 80. Annual habitat time series, bull trout adult, Riffle 31 site.

**Run 40 Site**

The Run 40 site contained run and side channel habitat. Bull trout adult habitat is shown for a flow of approximately 4,000 cfs to illustrate the habitat quantification using GIS. The dark blue colors are the higher habitat values, while the lighter colors are lower habitat value (Figure 81).

Habitat area versus discharge functions were similar for both juvenile and adult rainbow trout (Figure 82). The highest habitat area occurred at the low and high flows. This pattern is similar to the habitat response function at other side channel sites.

Habitat area versus discharge for bull trout juvenile night and juvenile day life stages are similar (Figure 83). Both of these life stages have the highest habitat at the lower flow range.

The habitat time series shows a highly variable habitat under the 1983-1992 flow regime, especially in the fall. The 1993-2002 flow regime shows more stable habitat during most of the year. This trend is shown for all species and life stages (Figures 84 through 88).

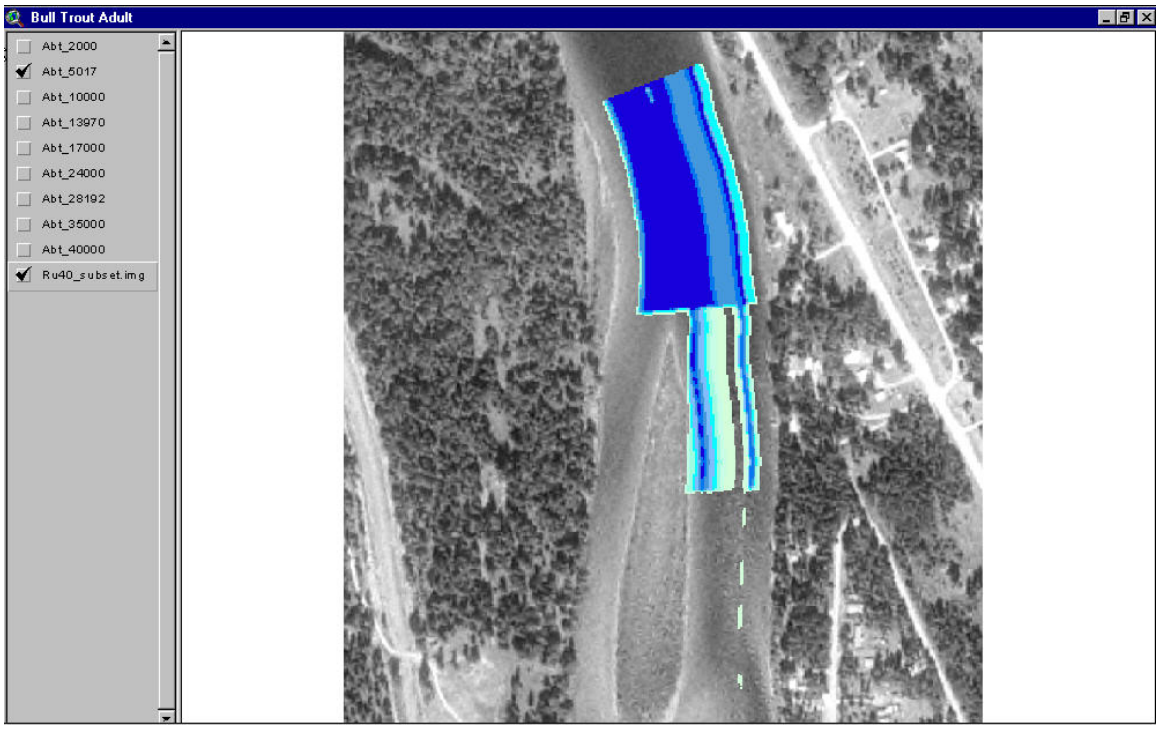



Figure 81. GIS based site map for Run 40.

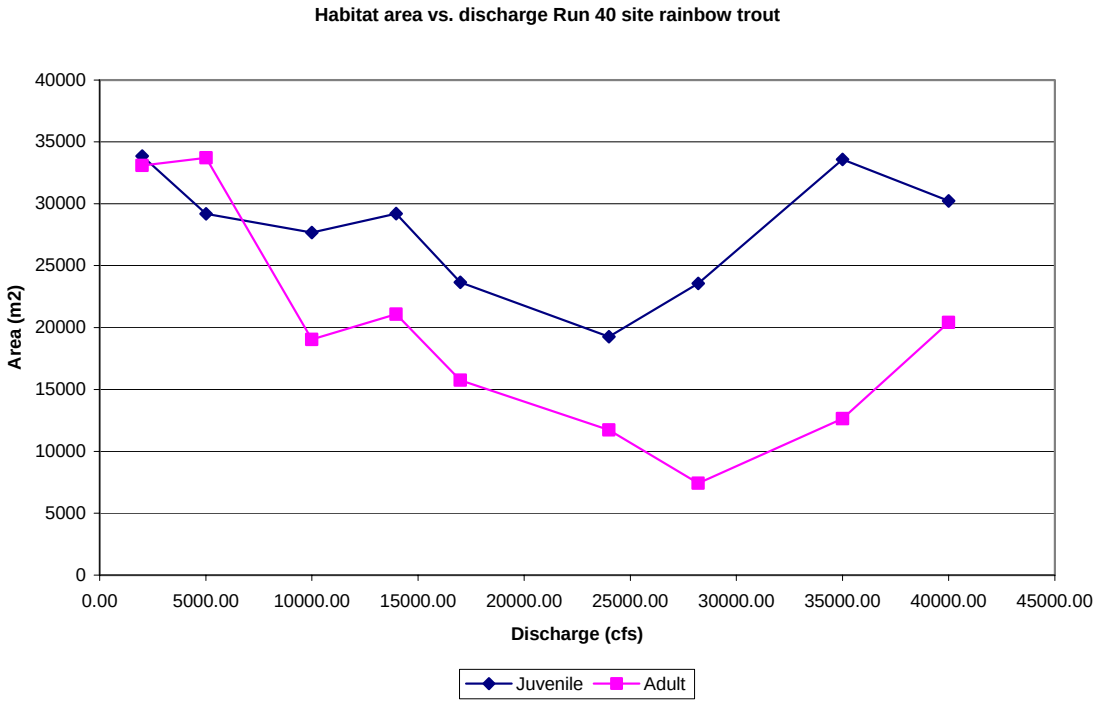



Figure 82. Habitat area vs. discharge for Run 40 site, rainbow trout.

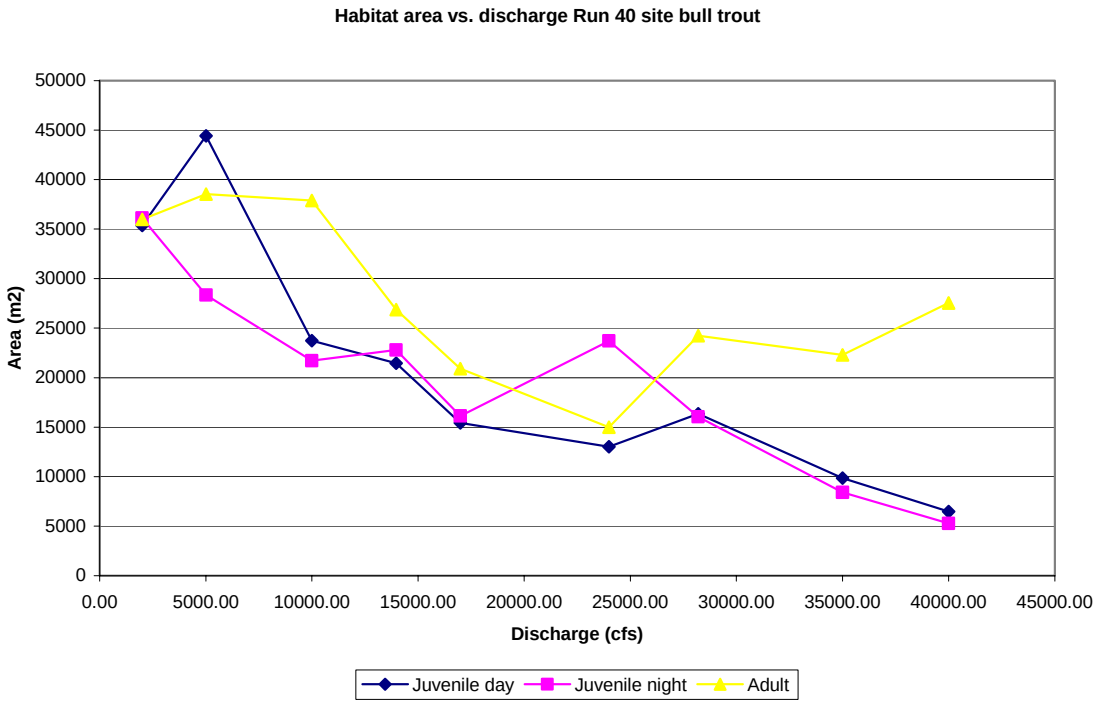



Figure 83. Habitat area vs. discharge for Run 40 site, bull trout.

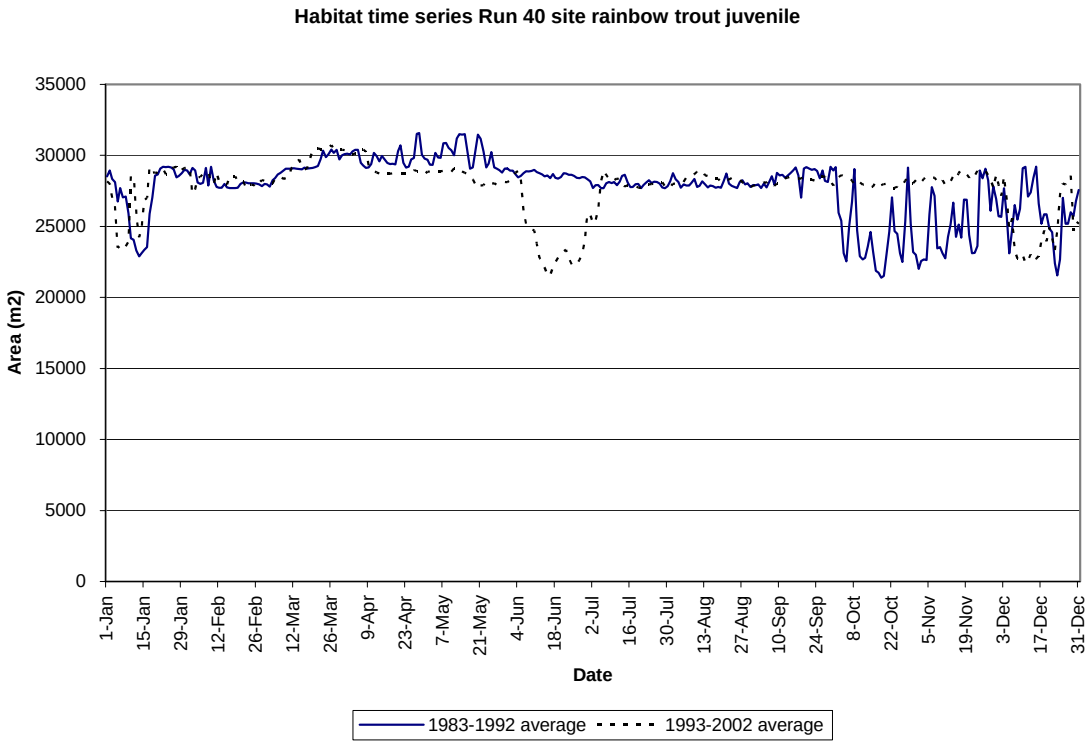



Figure 84. Annual habitat time series, rainbow trout juvenile, Run 40 site.

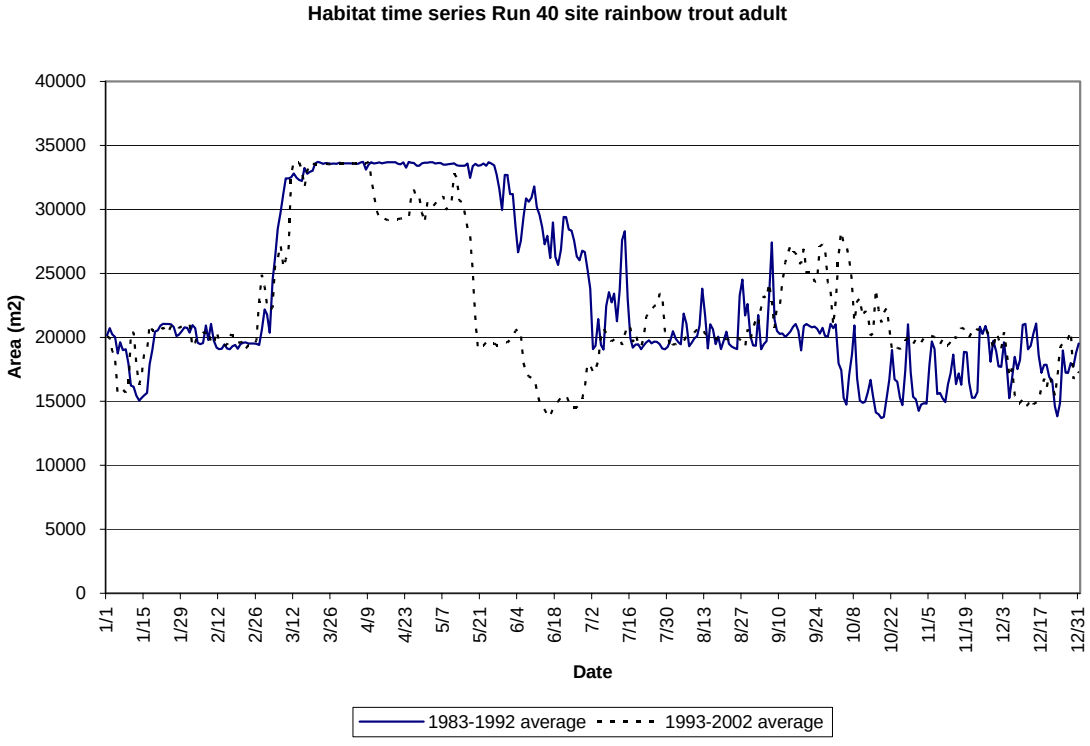



Figure 85. Annual habitat time series, rainbow trout adult, Run 40 site.

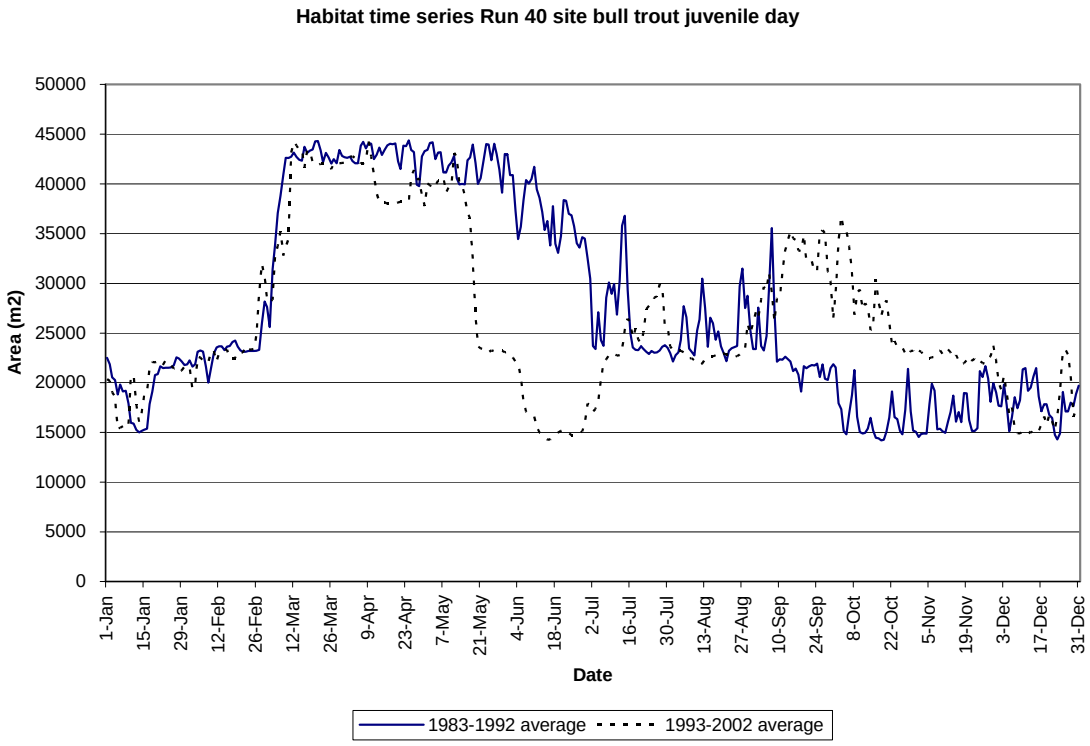



Figure 86. Annual habitat time series, bull trout juvenile day, Run 40 site.

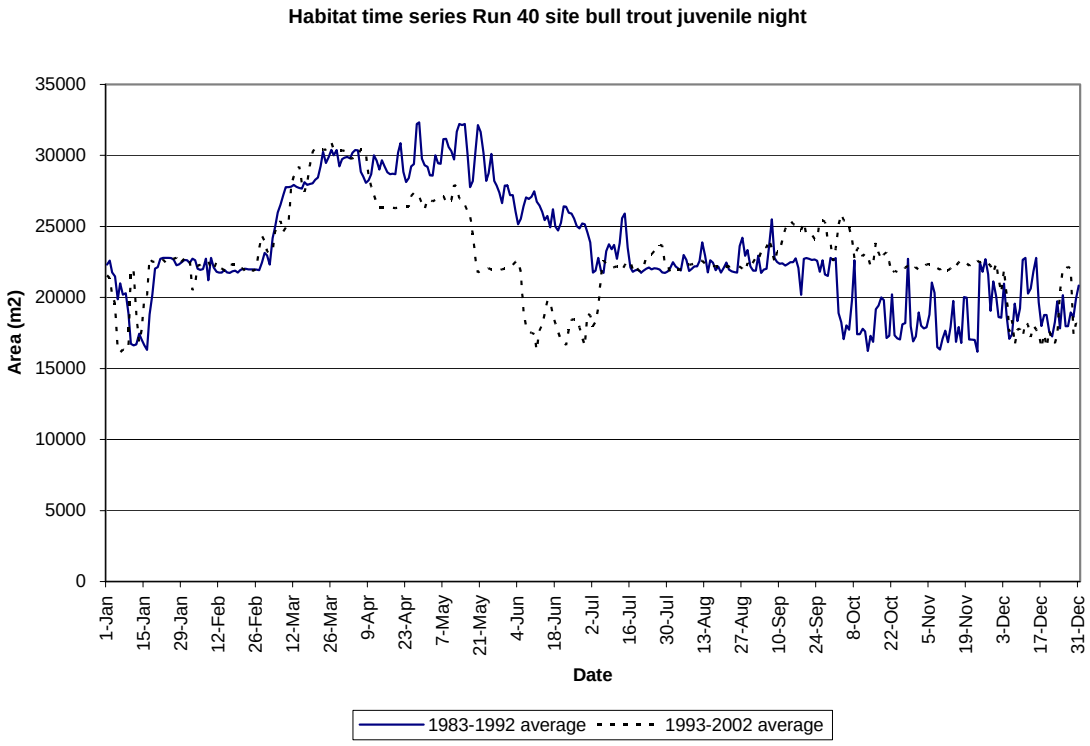



Figure 87. Annual habitat time series, bull trout juvenile night, Run 40 site.

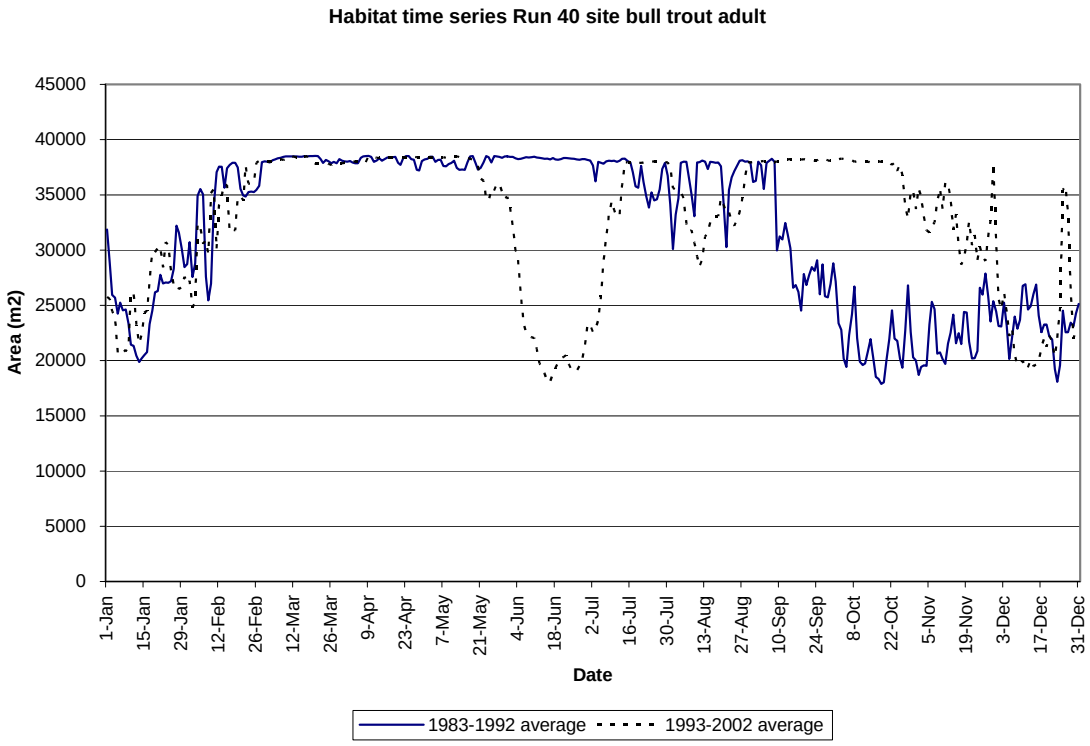



Figure 88. Annual habitat time series, bull trout adult, Run 40 site.

**Glide 71 Site**

The Glide 71 site contained glide and pool habitat. Bull trout adult habitat is shown for a flow of approximately 4,000 cfs to illustrate the habitat quantification using GIS. The dark blue colors are the higher habitat values, while the lighter colors are lower habitat value (Figure 89).

Habitat area versus discharge functions were nearly identical for both juvenile and adult rainbow trout (Figure 90). The highest habitat area occurred at the lowest flows.

Habitat area versus discharge for bull trout shows adult habitat highest at approximately 10,000 cfs and juvenile day life stages are similar (Figure 91). All life stages have decreased habitat as flows increase.

The habitat time series shows response to flow similar to the previous sites in this sections. Habitat is highly variable under the 1983-1992 flow regime. The 1993-2002 flow regime shows more stable habitat during most of the year. This trend is shown for all species and life stages (Figures 92 through 96).

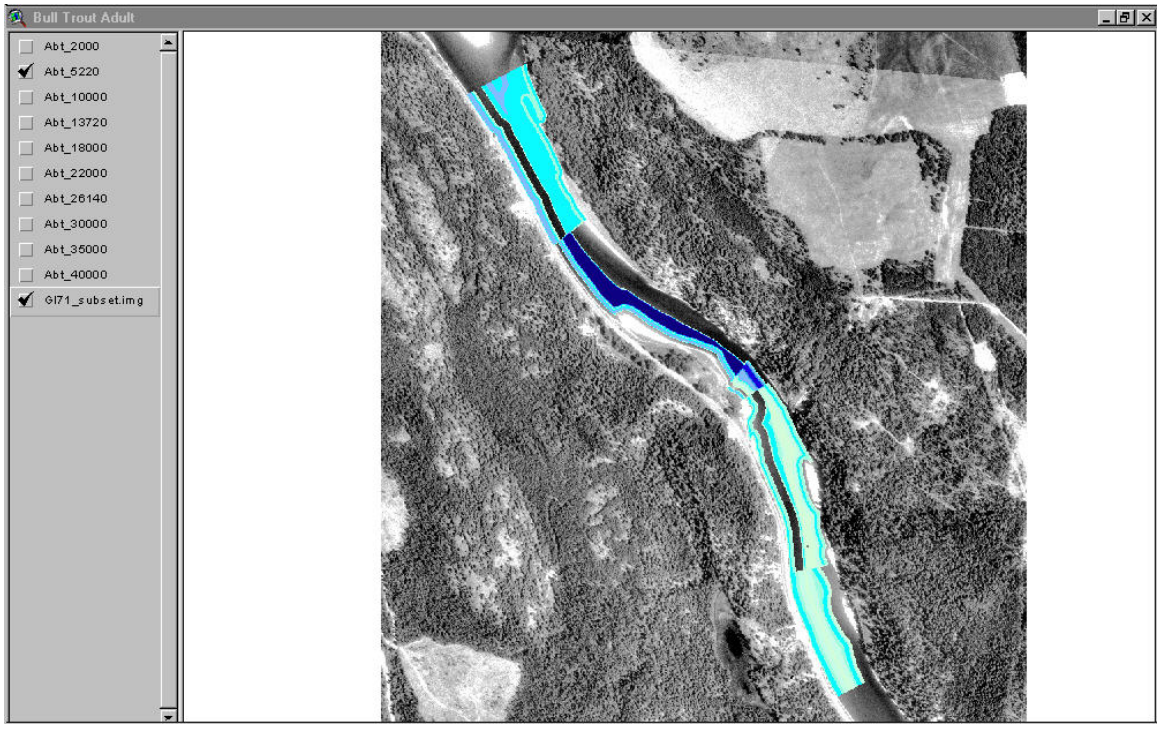



Figure 89. GIS based site map for Glide 71.

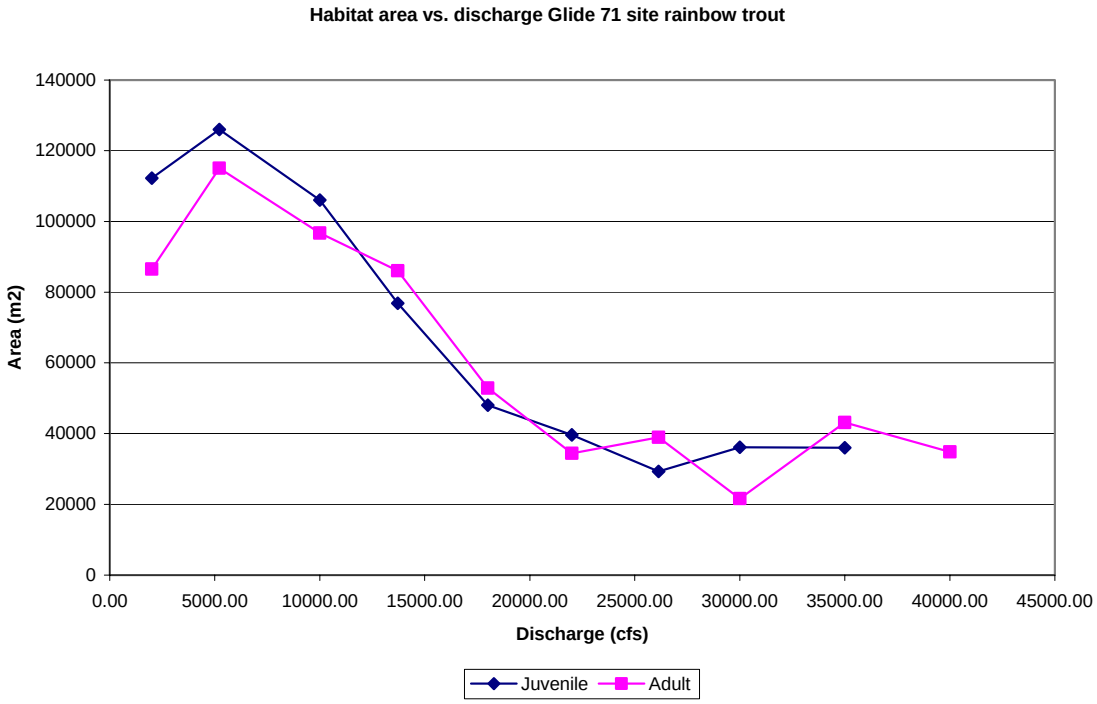



Figure 90. Habitat area vs. discharge for Glide 71 site, rainbow trout.

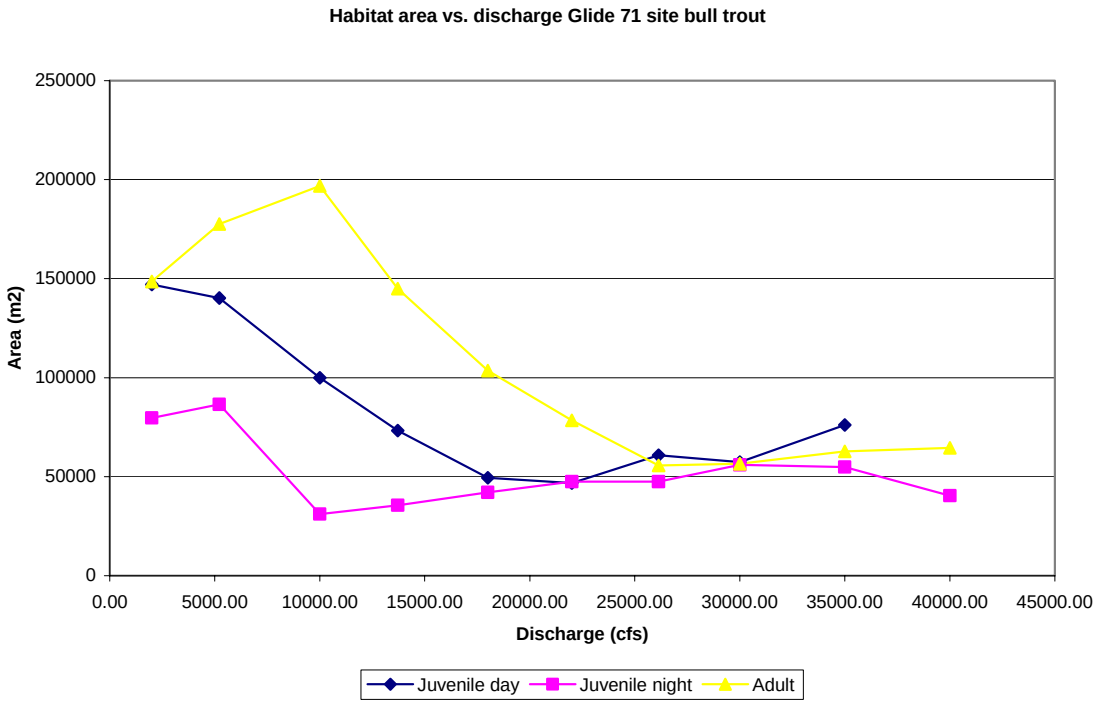



Figure 91. Habitat area vs. discharge for Glide 71 site, bull trout.

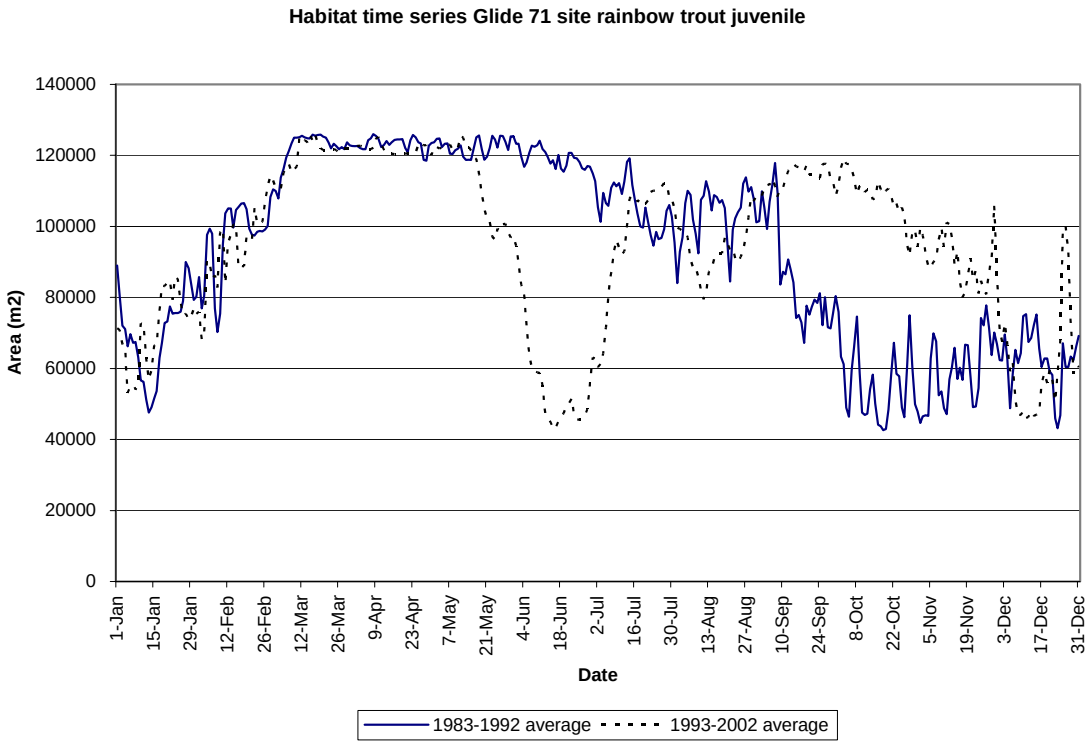



Figure 92. Annual habitat time series, rainbow trout juvenile, Glide 71 site.

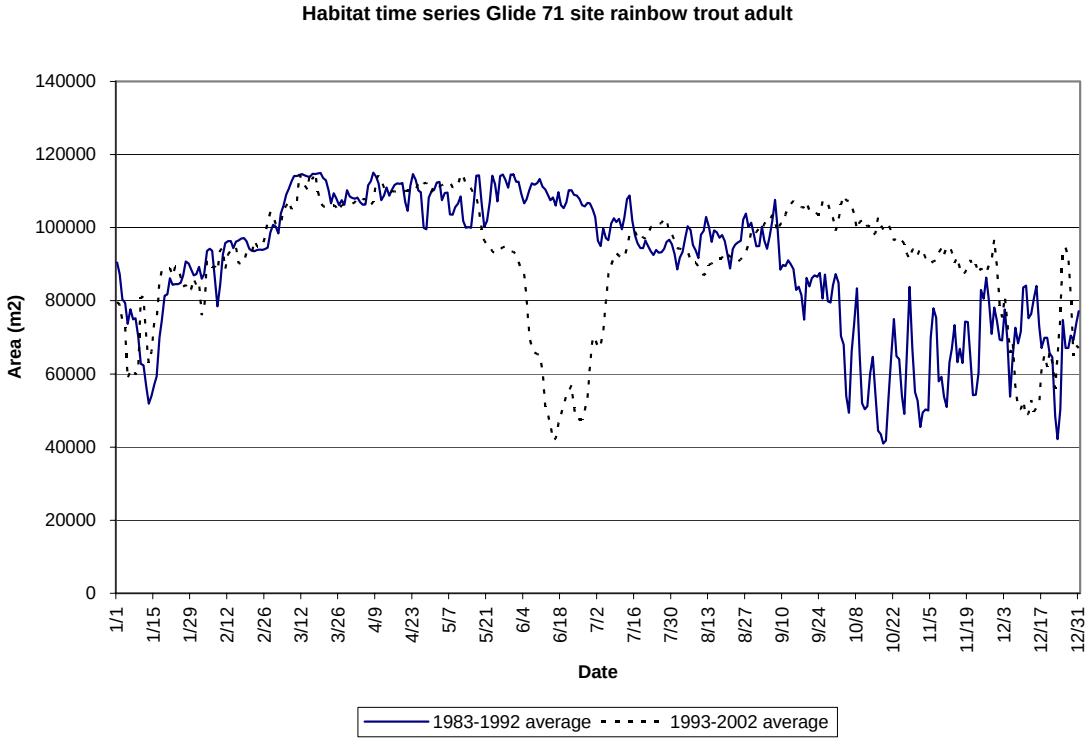



Figure 93. Annual habitat time series, rainbow trout adult, Glide 71 site.

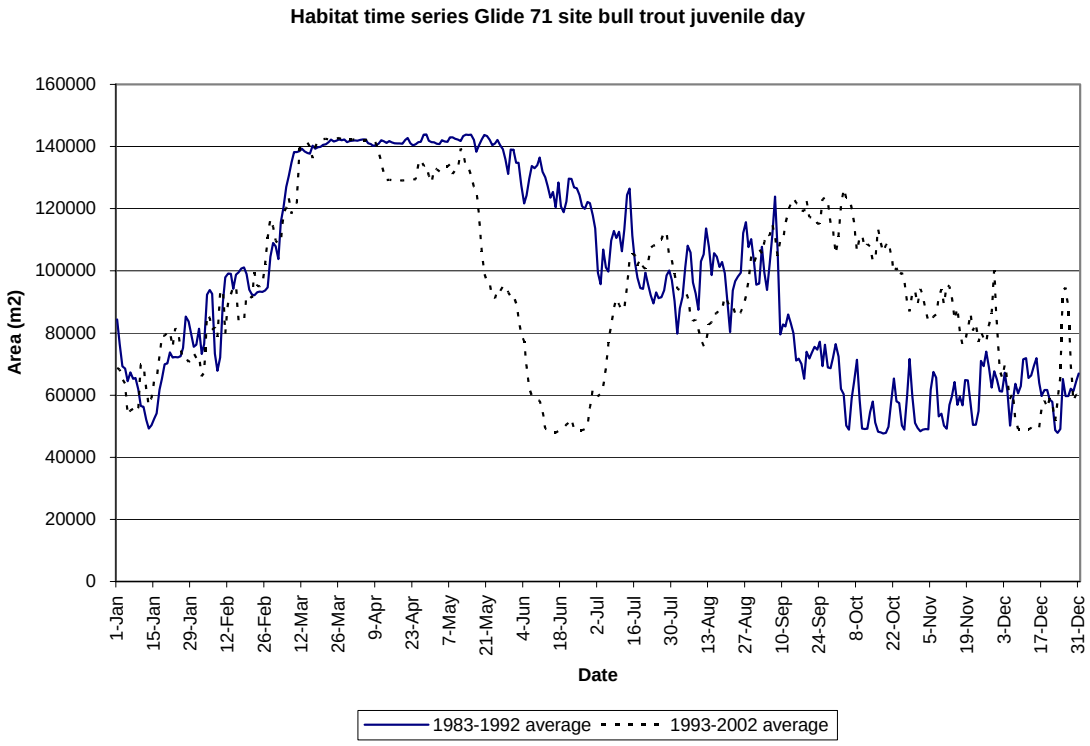



Figure 94. Annual habitat time series, bull trout juvenile day, Glide 71 site.

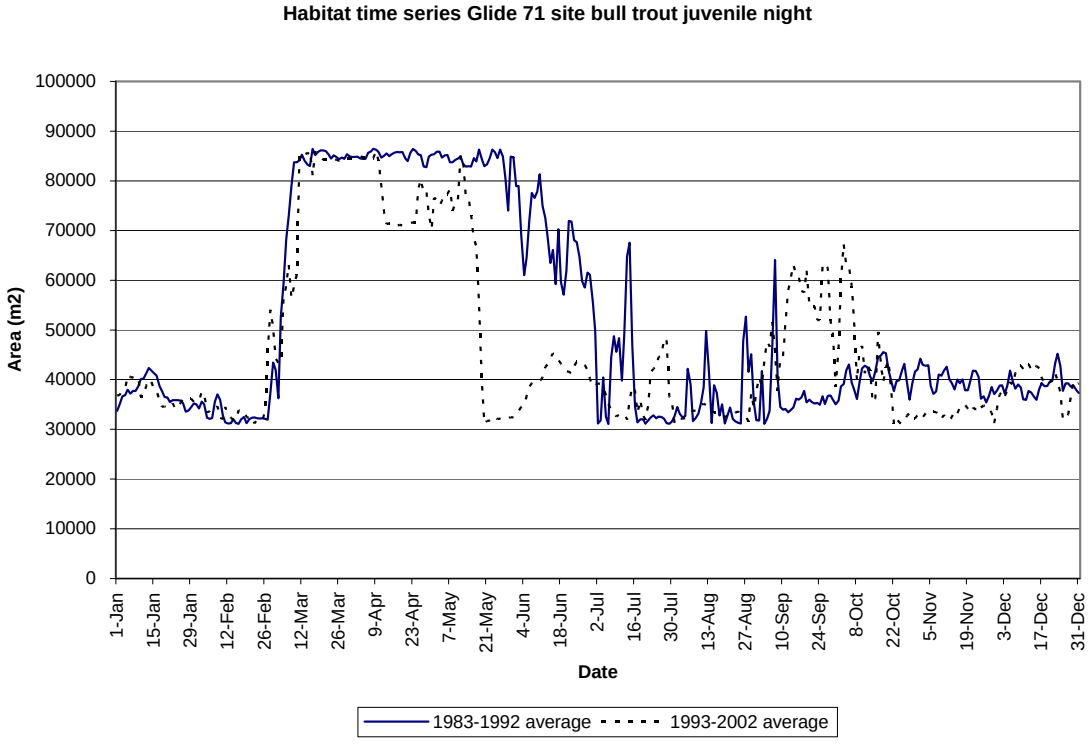



Figure 95. Annual habitat time series, bull trout juvenile night, Glide 71 site.

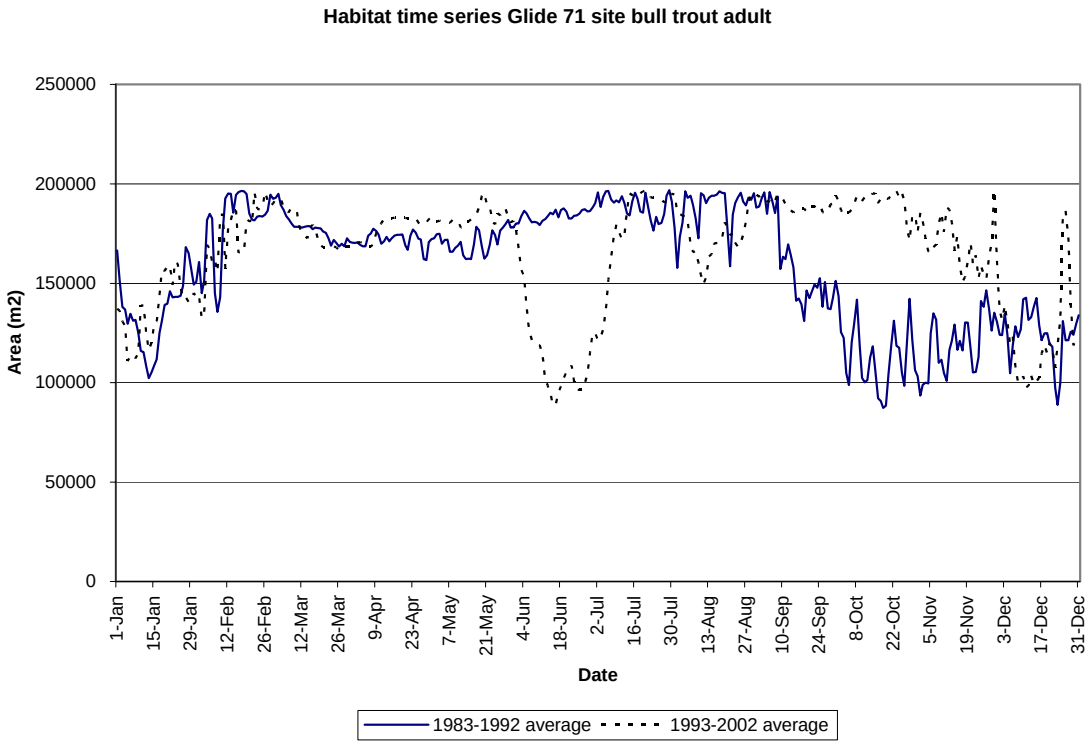



Figure 96. Annual habitat time series, bull trout adult, Glide 71 site.

**Pool 85 Site**

The Pool 85 site contained pool habitat for the entire site. Bull trout adult habitat is shown for a flow of approximately 4,000 cfs to illustrate the habitat quantification using GIS. The dark blue colors are the higher habitat values, while the lighter colors are lower habitat value (Figure 97).

Habitat area versus discharge functions were similar for both juvenile and adult rainbow trout (Figure 98). The highest habitat area occurred at approximately 5,000 cfs.

Habitat area versus discharge for bull trout adult and juvenile day life stages are similar (Figure 99). The juvenile night life stage has the highest habitat availability at the lower flows, similar to rainbow trout. As with rainbow trout this is likely due to velocity exceeding the preferred range in combination with increasing depth.

The habitat time series shows more variability than previous sites under the 1983-1992 flow regime. The 1993-2002 flow regime shows more stable habitat during most of the year. This trend is shown for all species and life stages (Figures 100 through 104).

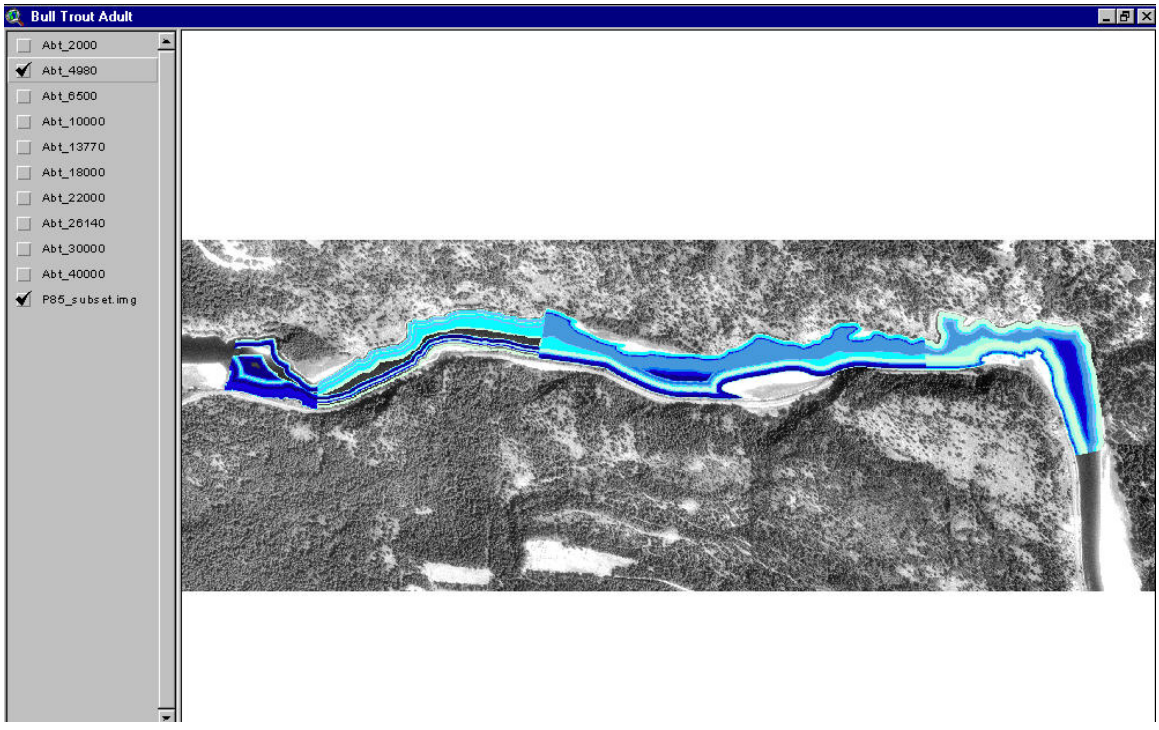



Figure 97. GIS based site map for Pool 85.

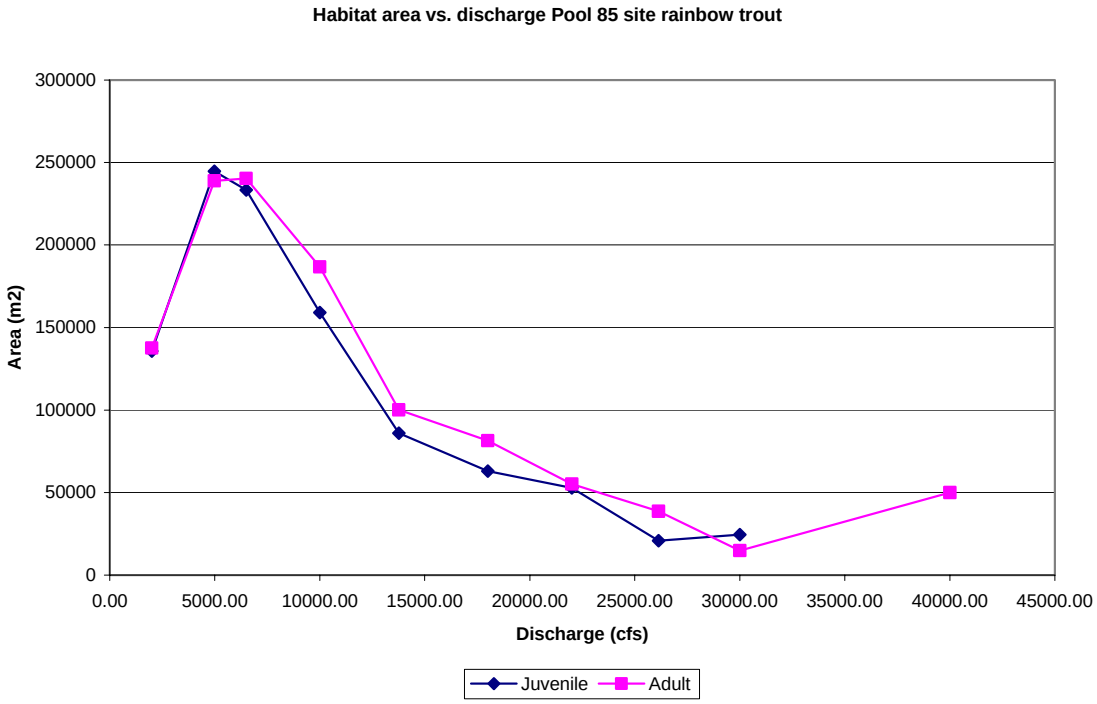



Figure 98. Habitat area vs. discharge for Pool 85 site, rainbow trout.

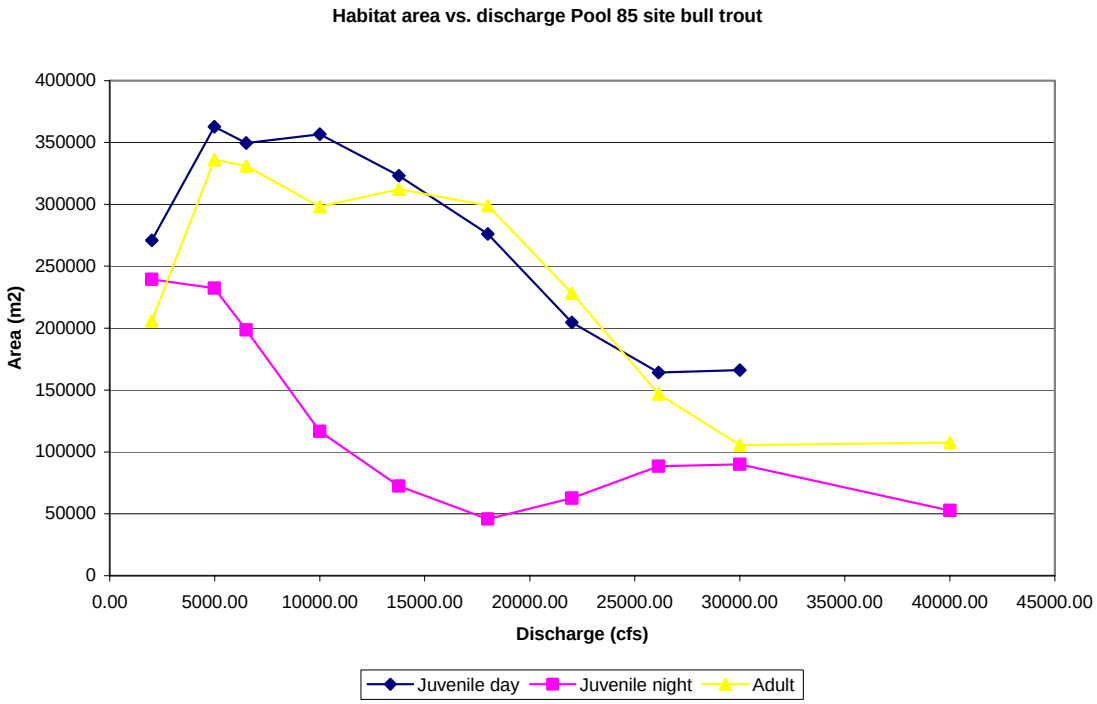



Figure 99. Habitat area vs. discharge for Pool 85 site, bull trout.

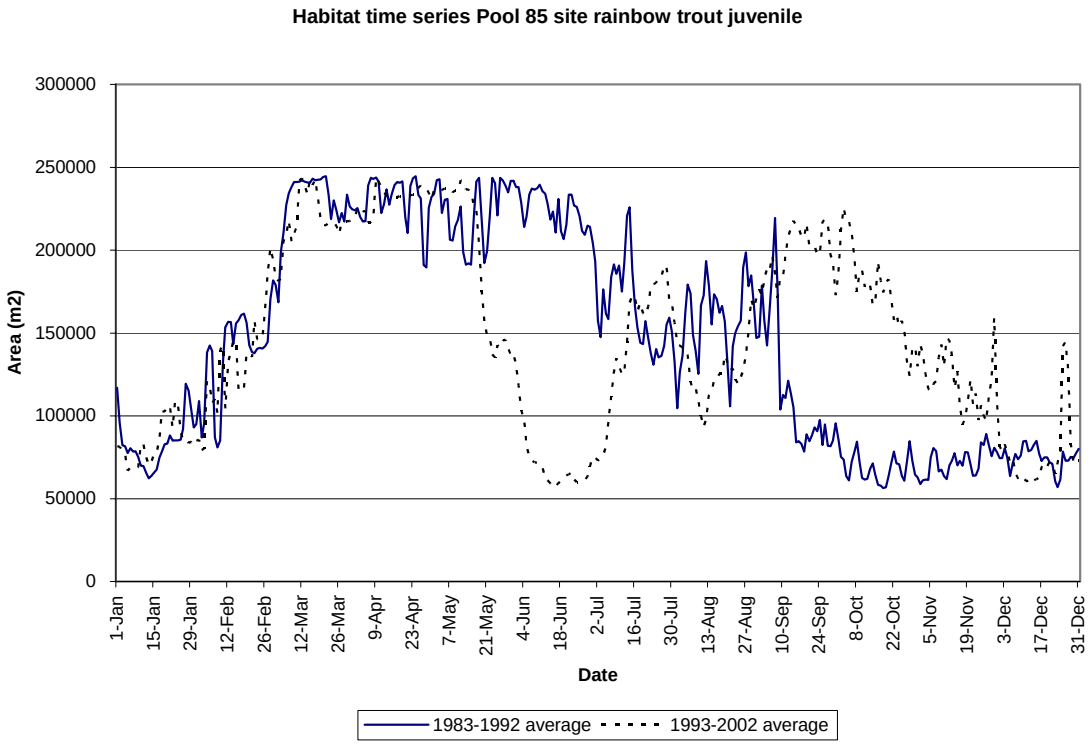



Figure 100. Annual habitat time series, rainbow trout juvenile, Pool 85 site.

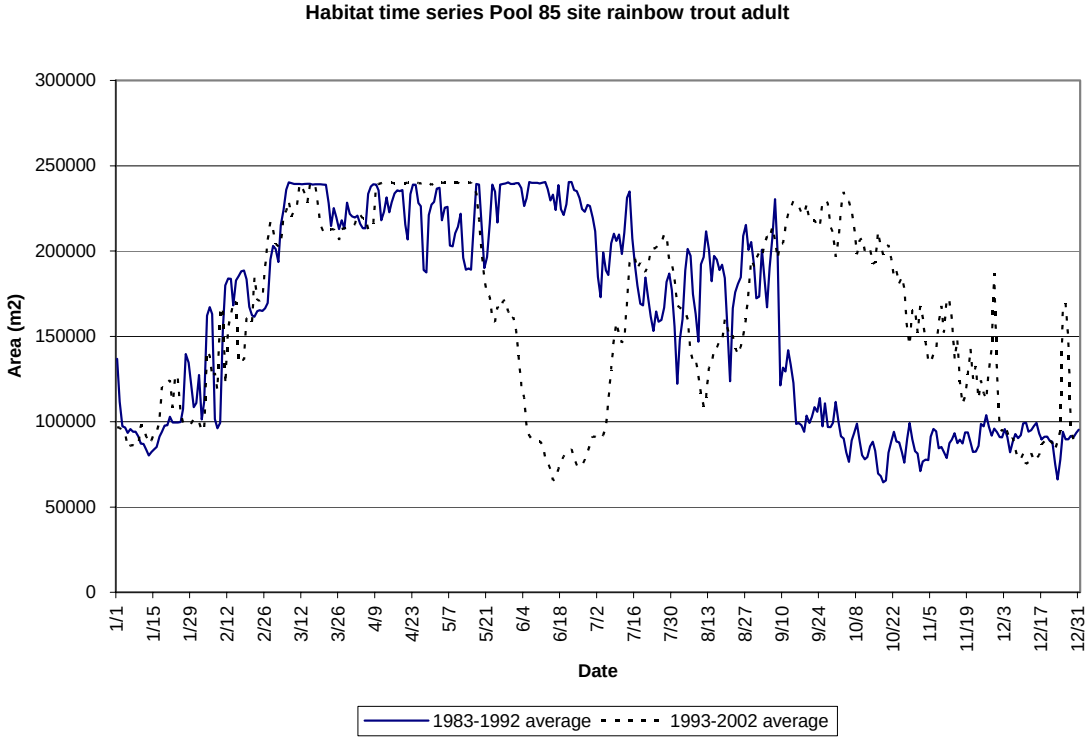



Figure 101. Annual habitat time series, rainbow trout adult, Pool 85 site.

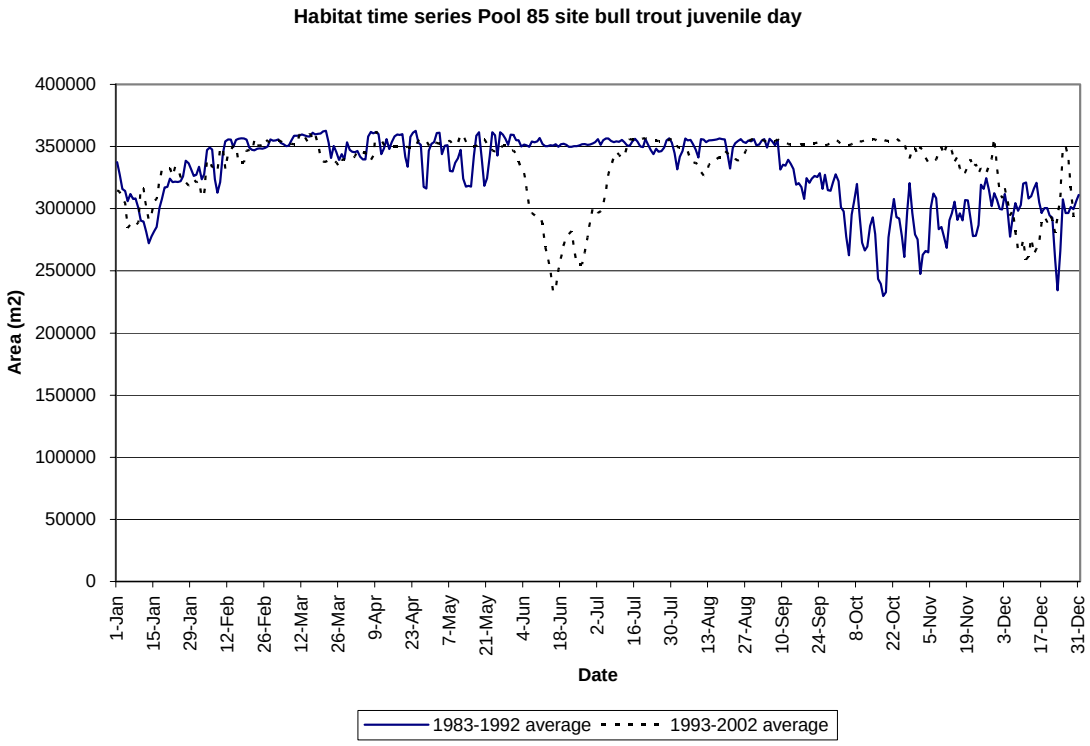



Figure 102. Annual habitat time series, bull trout juvenile day, Pool 85 site.

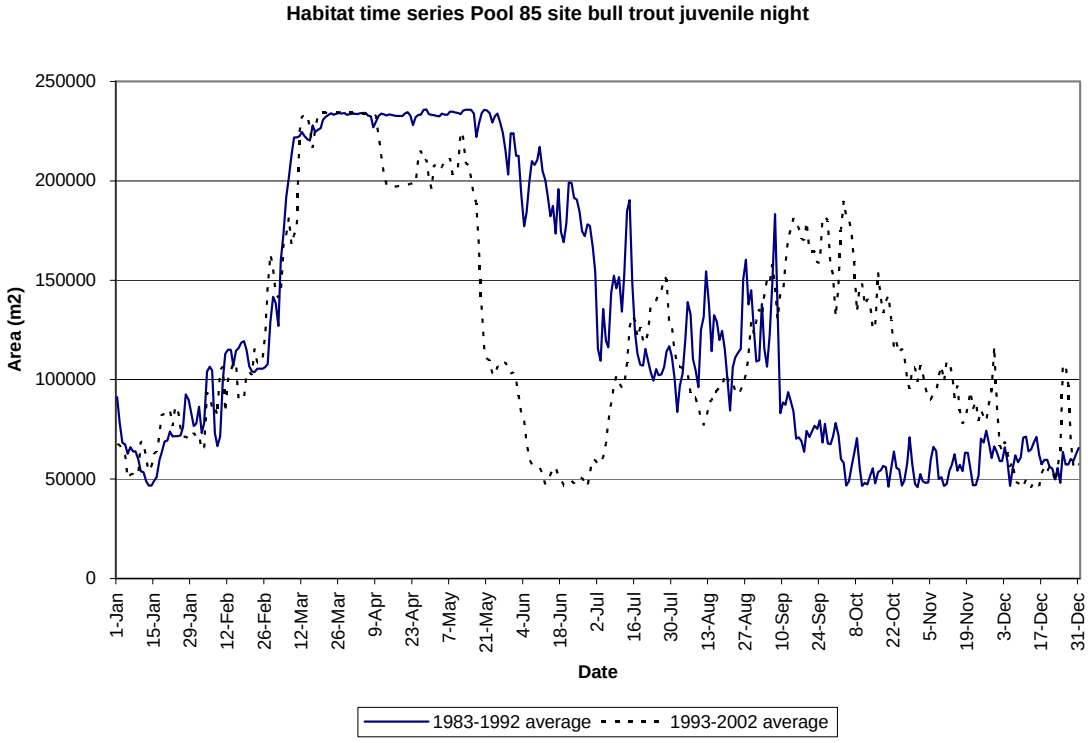



Figure 103. Annual habitat time series, bull trout juvenile night, Pool 85 site.

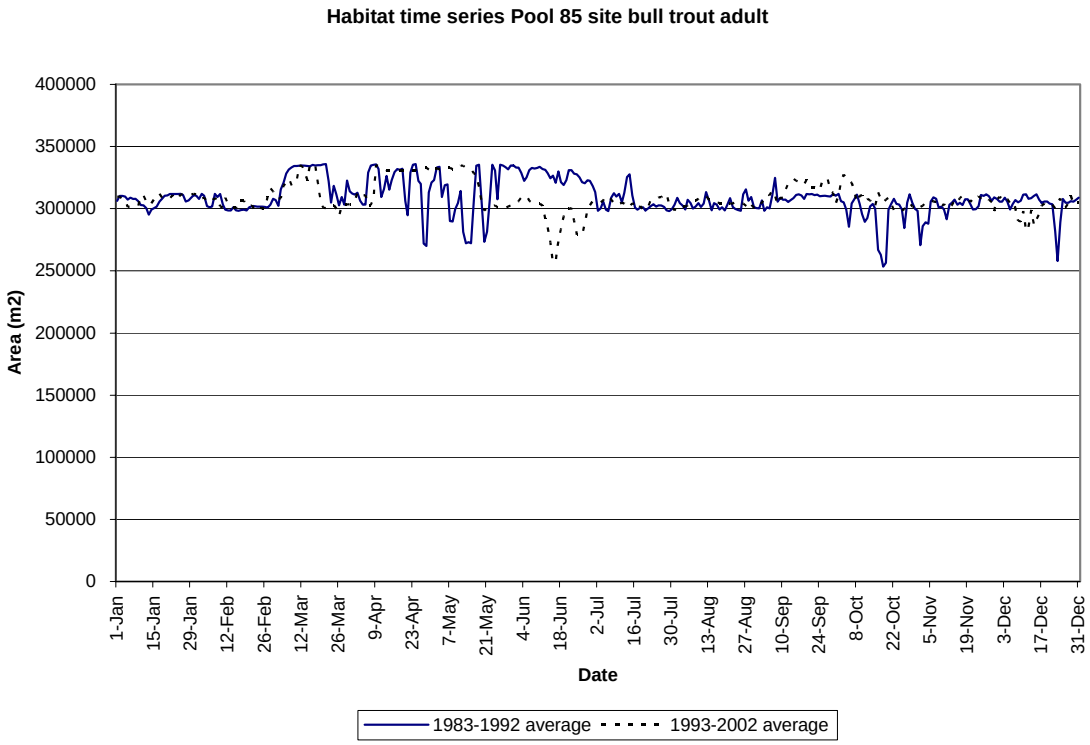



Figure 104. Annual habitat time series, bull trout adult, Pool 85 site.

**Run 98 Site**

The Run 98 site contained run, pool and glide habitat. Bull trout adult habitat is shown for a flow of approximately 4,000 cfs to illustrate the habitat quantification using GIS. The dark blue colors are the higher habitat values, while the lighter colors are lower habitat value (Figure 105).

Habitat area versus discharge functions were similar for both juvenile and adult rainbow trout (Figure 106). The highest habitat area occurred at approximately 5,000 cfs.

Habitat area versus discharge for bull trout adult and juvenile day life stages are similar (Figure 107). Both of these lifestages use deeper water than the bull trout juvenile night life stage. The juvenile night life stage has the highest habitat availability at the lower flows, similar to rainbow trout.

The habitat time series shows a highly variable habitat in summer under the 1983-1992 flow regime. The 1993-2002 flow regime shows more variability in summer than the previous sites. This trend is shown for all species and life stages (Figures 108 through 112).

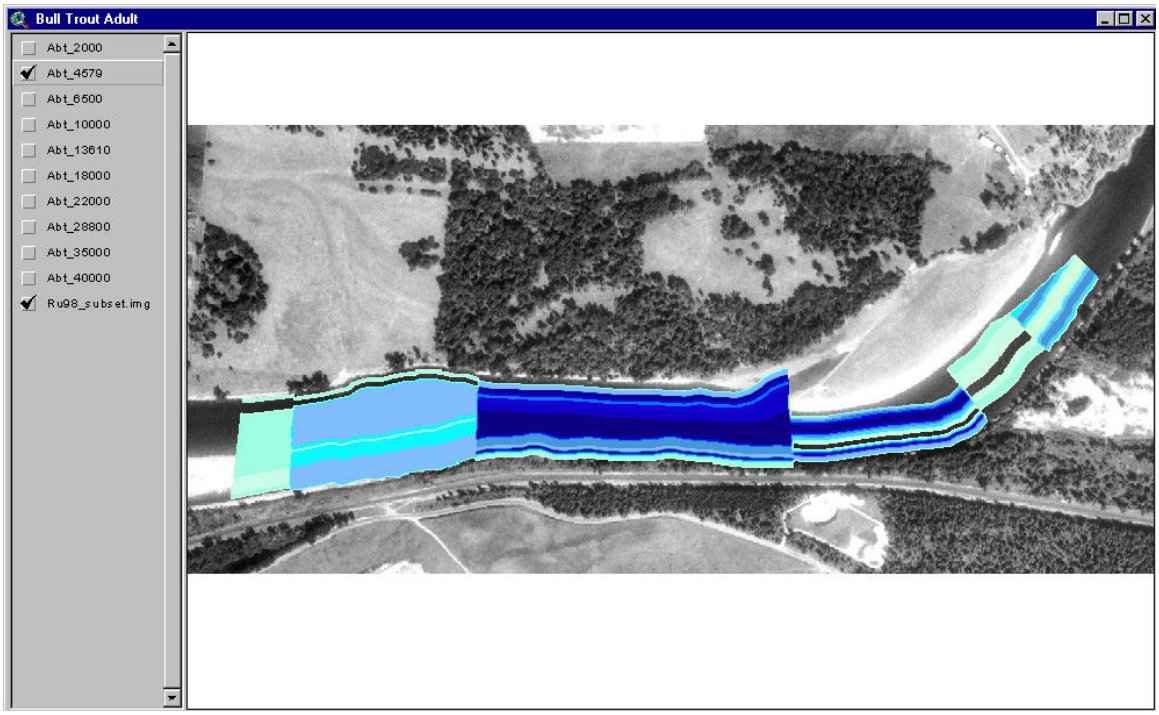



Figure 105. GIS based site map for Run 98.

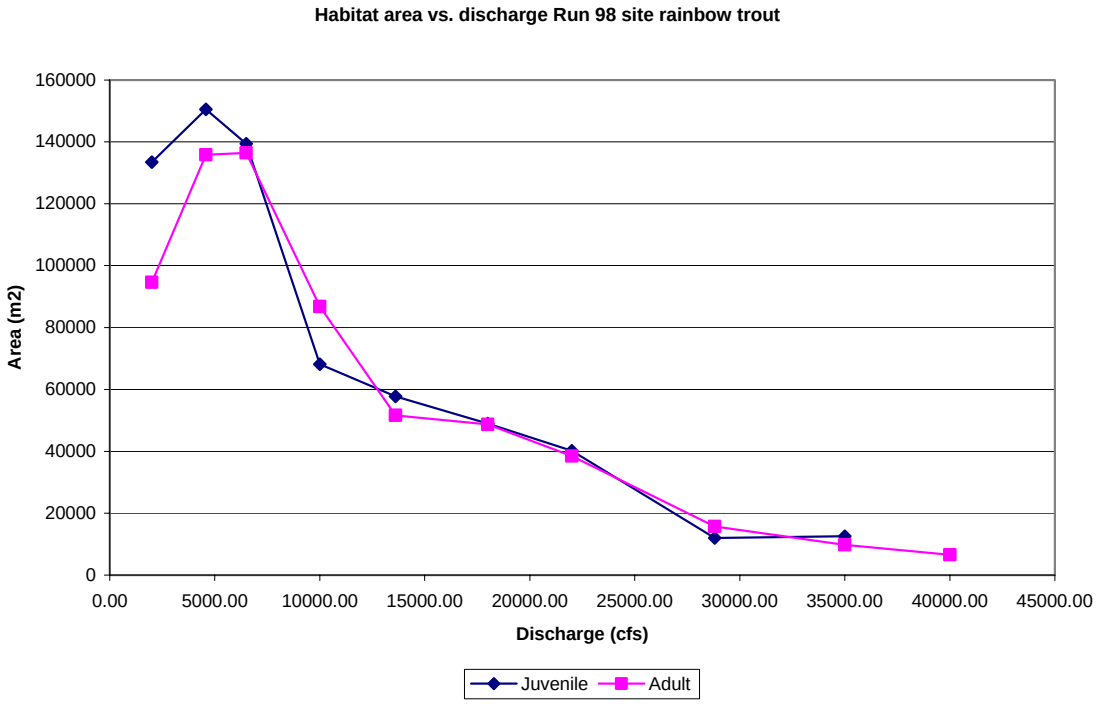



Figure 106. Habitat area vs. discharge for Run 98 site, rainbow trout.

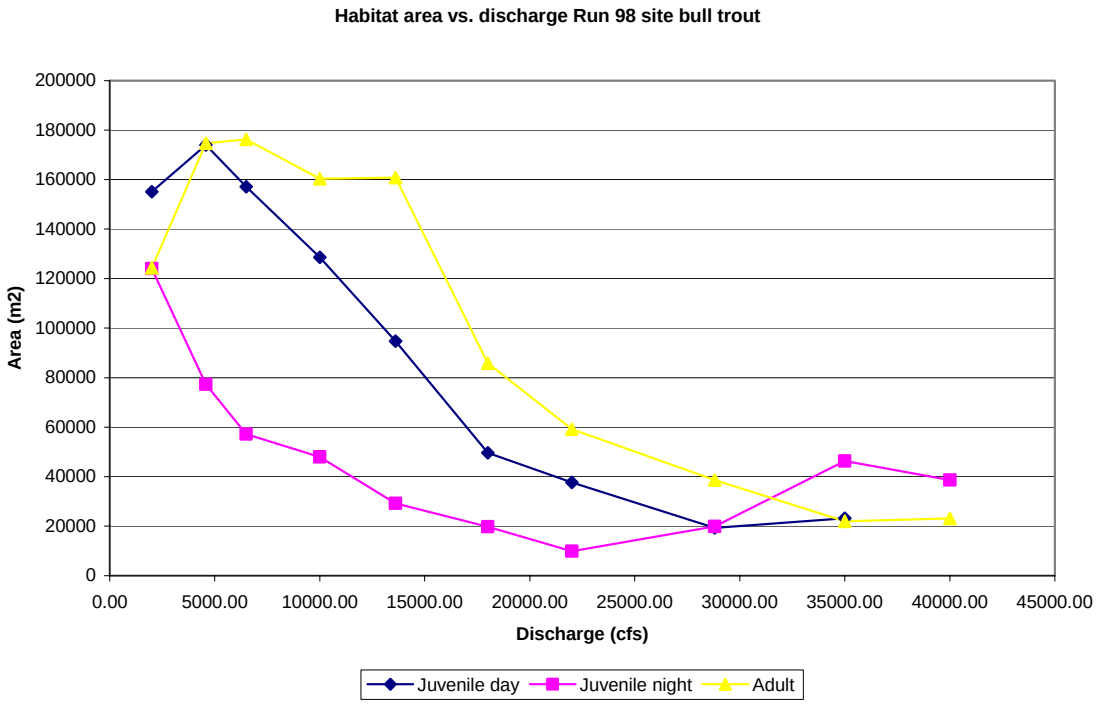



Figure 107. Habitat area vs. discharge for Run 98 site, bull trout.

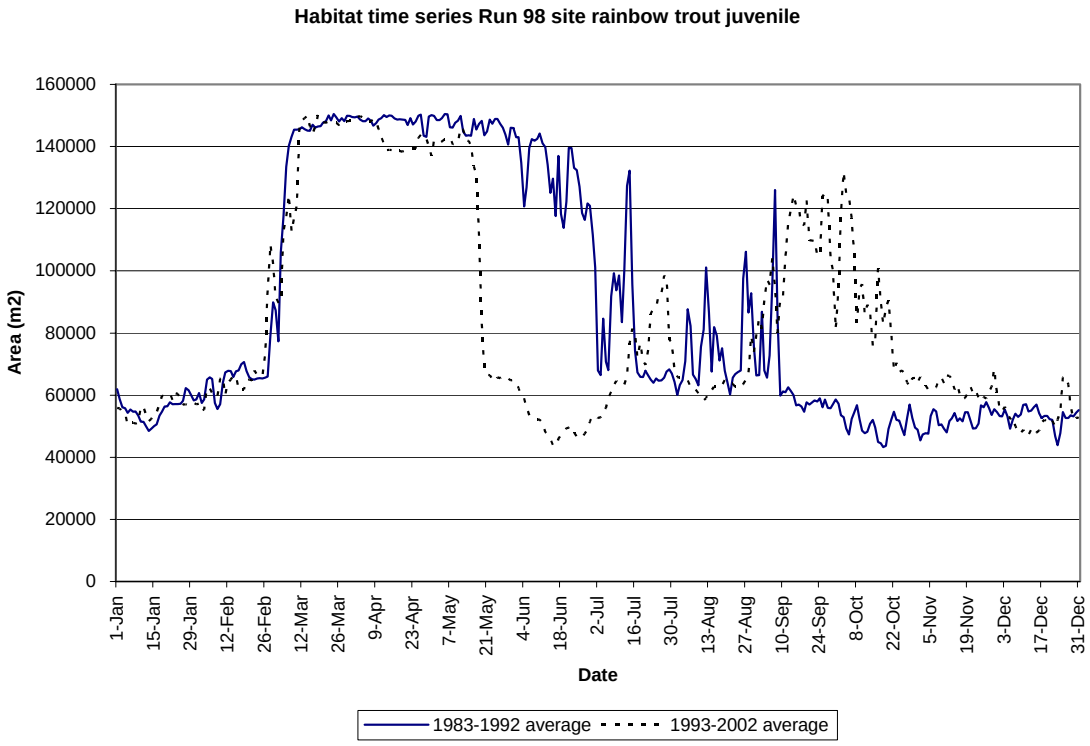



Figure 108. Annual habitat time series, rainbow trout juvenile, Run 98 site.

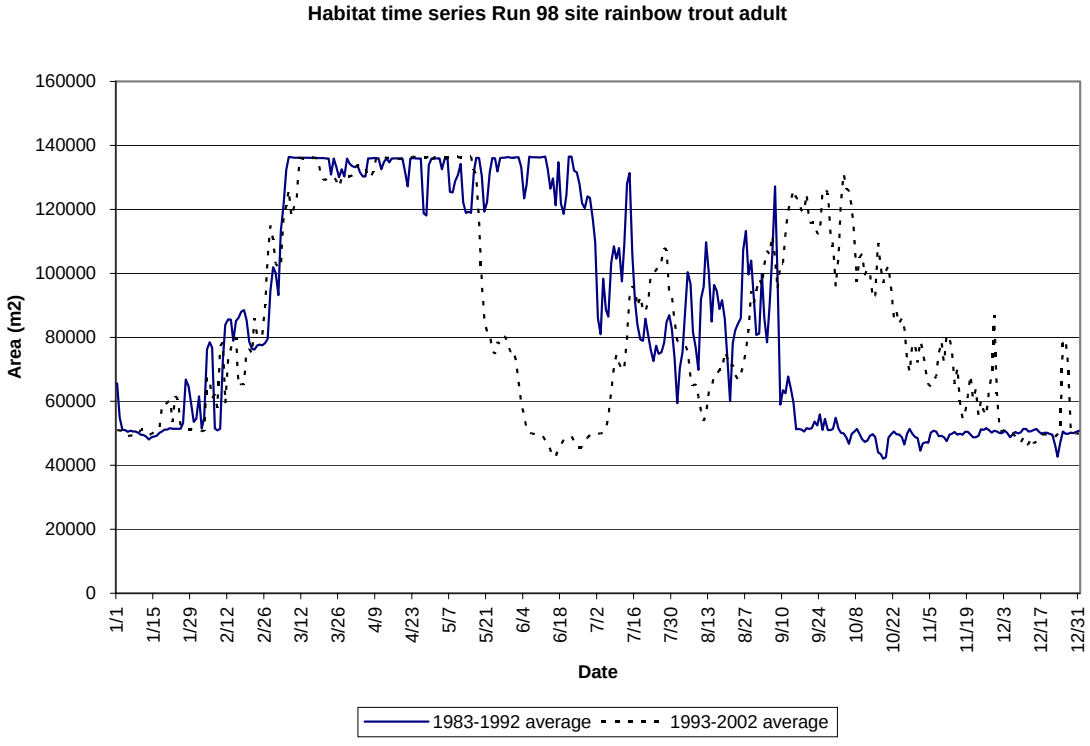



Figure 109. Annual habitat time series, rainbow trout adult, Run 98 site.

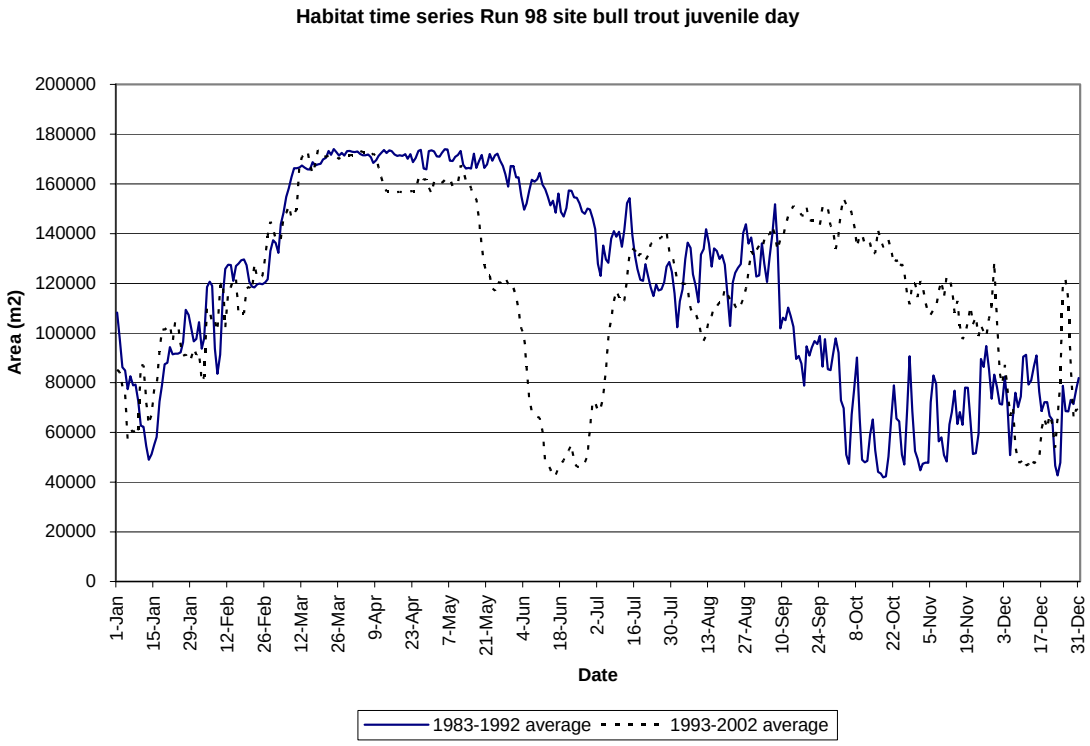



Figure 110. Annual habitat time series, bull trout juvenile day, Run 98 site.

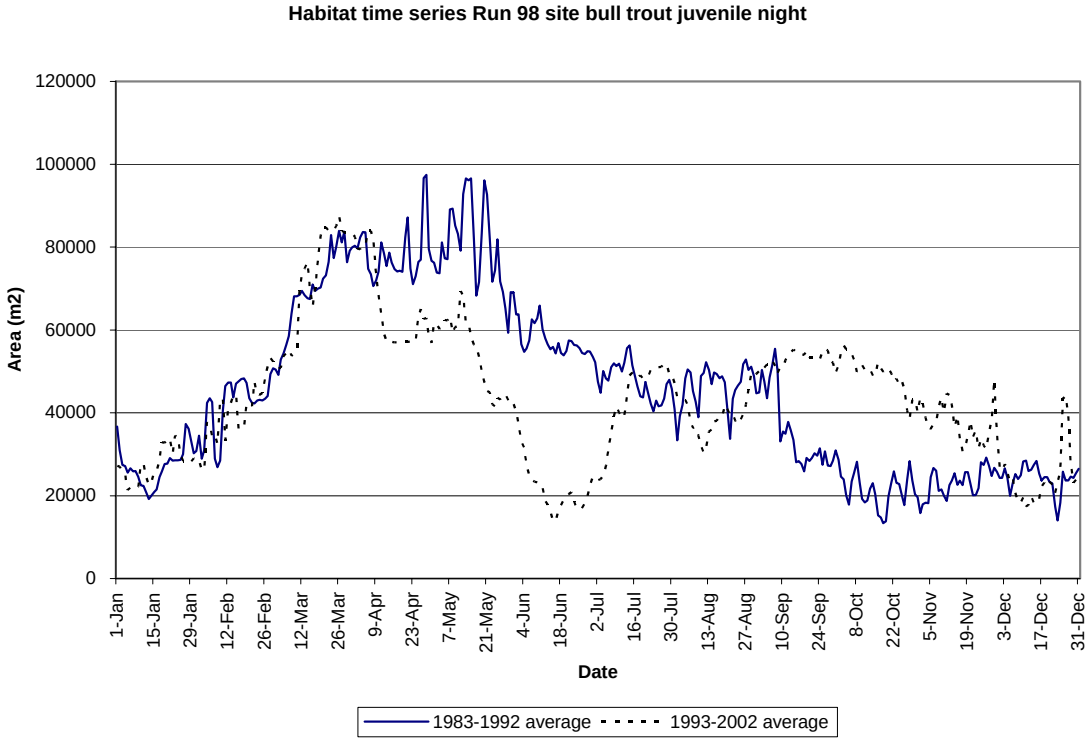



Figure 111. Annual habitat time series, bull trout juvenile night, Run 98 site.

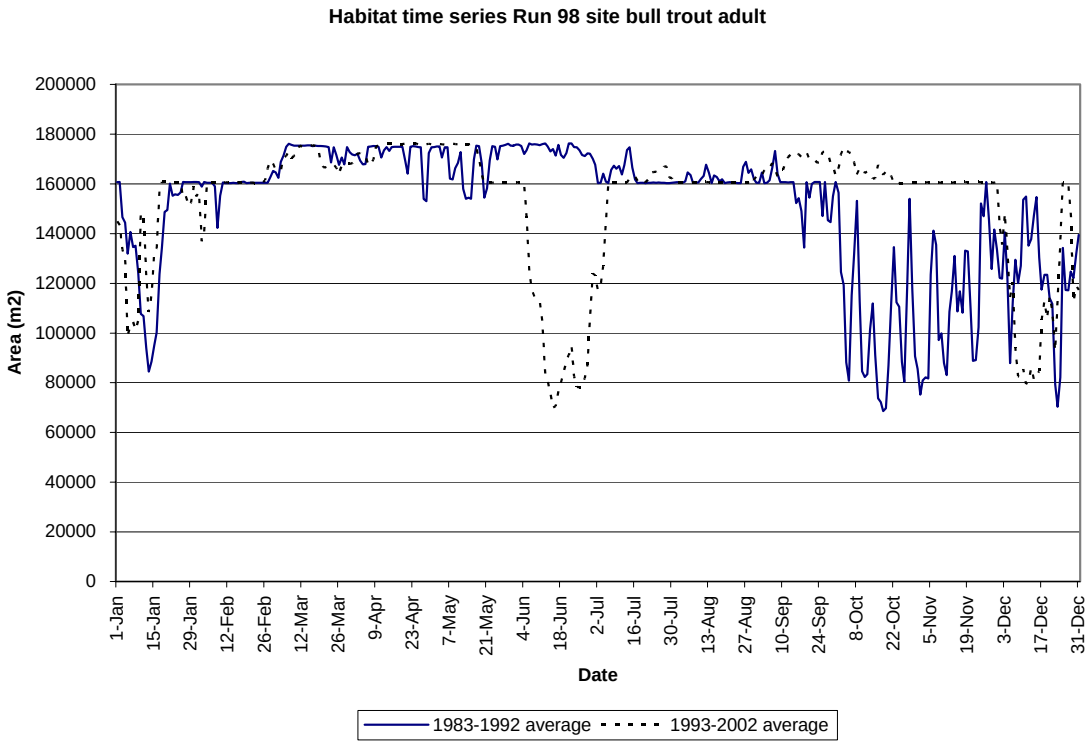



Figure 112. Annual habitat time series, bull trout adult, Run 98 site.

# DISCUSSION

Habitat for both sections was simulated using the combination of one-dimensional hydraulic model and GIS weighted useable area model to generate weighted useable area in $m^2$ for each site. Species with several life stages have similar patterns of weighted useable area discharge functions in Section 1. Rainbow trout for juvenile and adult show a similar relationship with the highest weighted useable area at the lower flow conditions at most sites. 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. 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 .

Habitat areas for both bull trout and rainbow trout for Section 2 shows similar response of weighted useable area to discharge with the higher values at the lower discharges. There is only a small difference between Section 1 sites and Section 2 sites in the response shape of the curves showing that there may be a similarity between those two sections. A second possibility for the shape of the response curve is the inablility of the one dimensional model to simulate hydraulic conditions a refined scale such as would be developed with a two dimensional model.

## Habitat Time Series

Habitat time series analysis used ten-year and annual hydrology. 1983-1992 conditions shows that the habitat was highly varied on a weekly and daily time scale. 1993-2002 conditions show that the response of habitat to flow ismore stable than the previous ten year period. The more stable flow regime may provide more or less habitat area but the stability likely increases the productivity of the benthos in the river. This increased productivity should provide better conditions for the higher trophic levels that rely on the benthos as a food source.

# CONCLUSIONS

The habitat simulations for the Kootenai River show that, under the current hydrology, there is much more stable habitat on a weekly and daily basis than during the 1983-1992 period 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. The current flow regime more closely resembles a snow melt hydrograph than the early hydrology. This likely benefits the species that evolved in this system.

The similarity in habitat response functions at many of the study sites is likely due to several factors. First, the cross section based methodology of a one-dimensional hydraulic model does not provide the detail of small scale changes in hydraulics that a two dimensional model can. The result is a coarser scale change in hydraulic conditions, which results in a less refined habitat function. Second, many of sites all contain the similar habitat types. Since the discharge in both Sections is strongly controlled by releases from Libby Dam, one would expect the channel characteristics to be similar in both sections. The similarity in the habitat response curves indicates the homogeneity of the channel types. And finally, the transition between major habitat types can not be adequately represented with cross section models at the scale that some fish use the habitat.

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 variability of habitat within the Kootenai River at a coarse scale. If a more detailed description of habitat use is required for species such as white sturgeon, it is recommended that new sites using two-dimensional models in critical habitat area be developed. Based on the habitat characteristics shown in this study, three study sites, one in each section, each approximately 1 mile long could be used to represent the habitat conditions in the Kootenai 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 Jim Dunnigan and Brian Marotz and their staff that provided the data sets and developed the habitat suitability information.

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# APPENDIX A – HABITAT TIME SERIES GRAPHS

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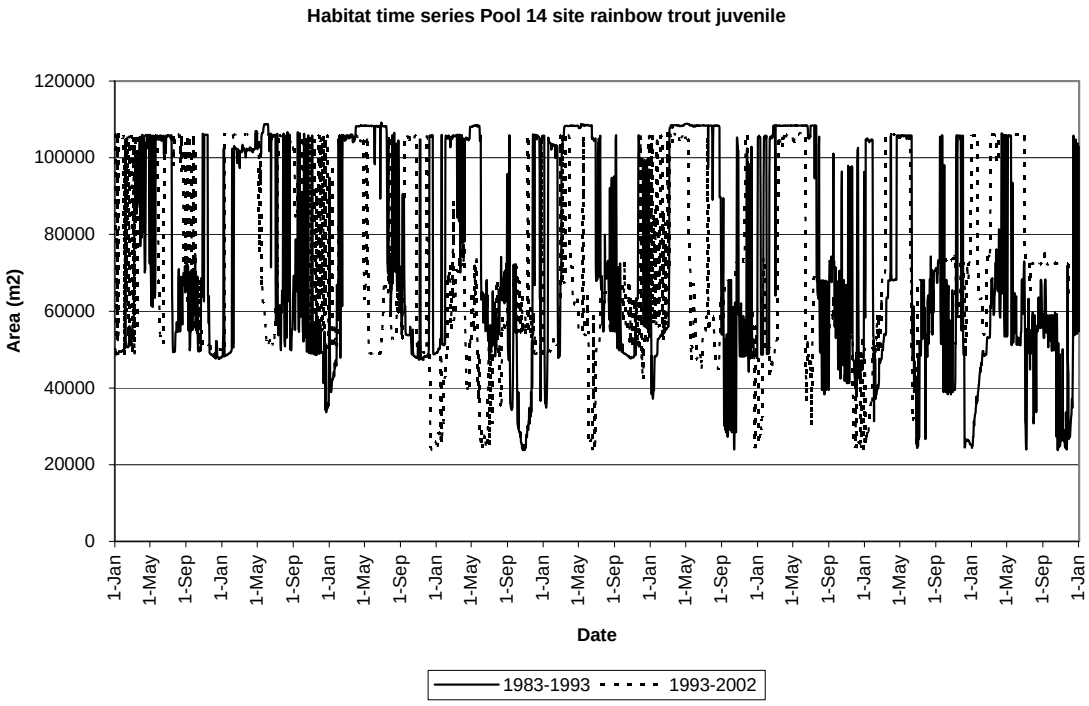


**Figure 1. Juvenile rainbow trout habitat time series using average daily flow for 2, 10 year time periods at Pool 14 site.**

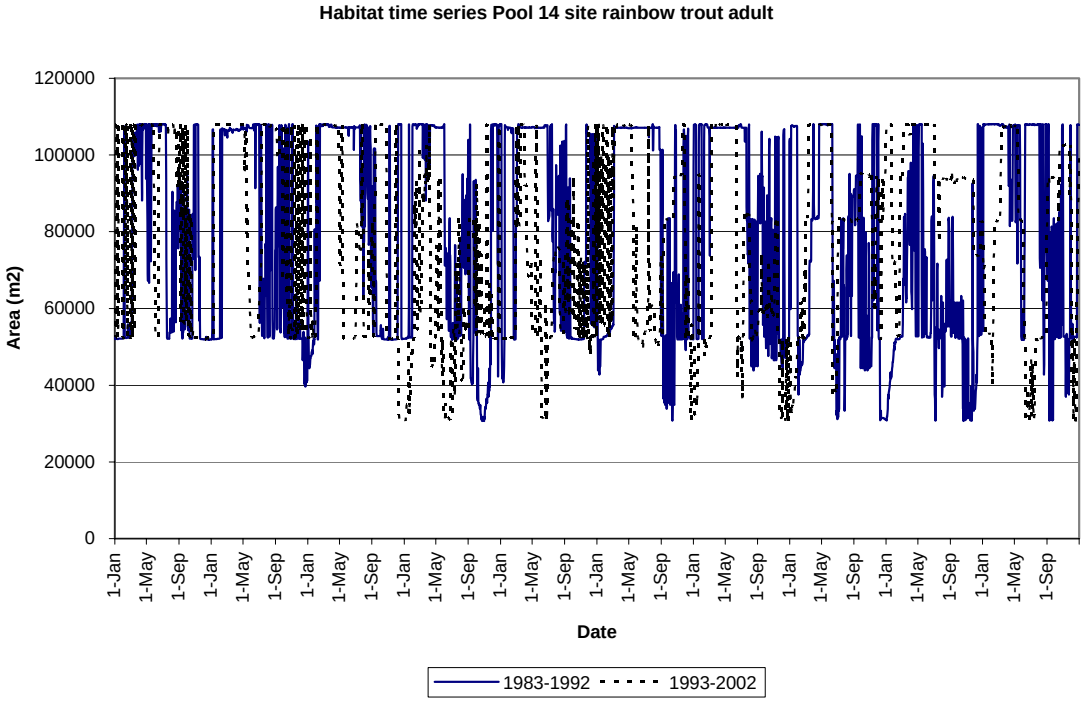


**Figure 2. Adult rainbow trout habitat time series using average daily flow for 2, 10 year time periods at Pool 14 site.**

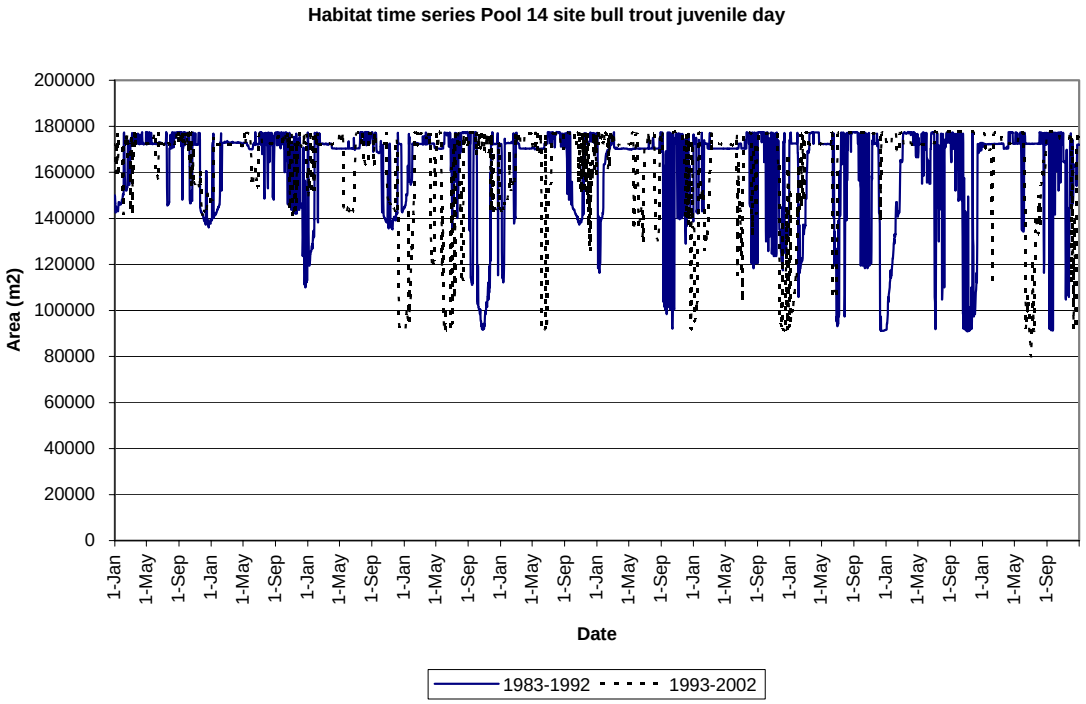


**Figure 3. Juvenile bull trout (day) habitat time series using average daily flow for 2, 10 year time periods at Pool 14 site.**

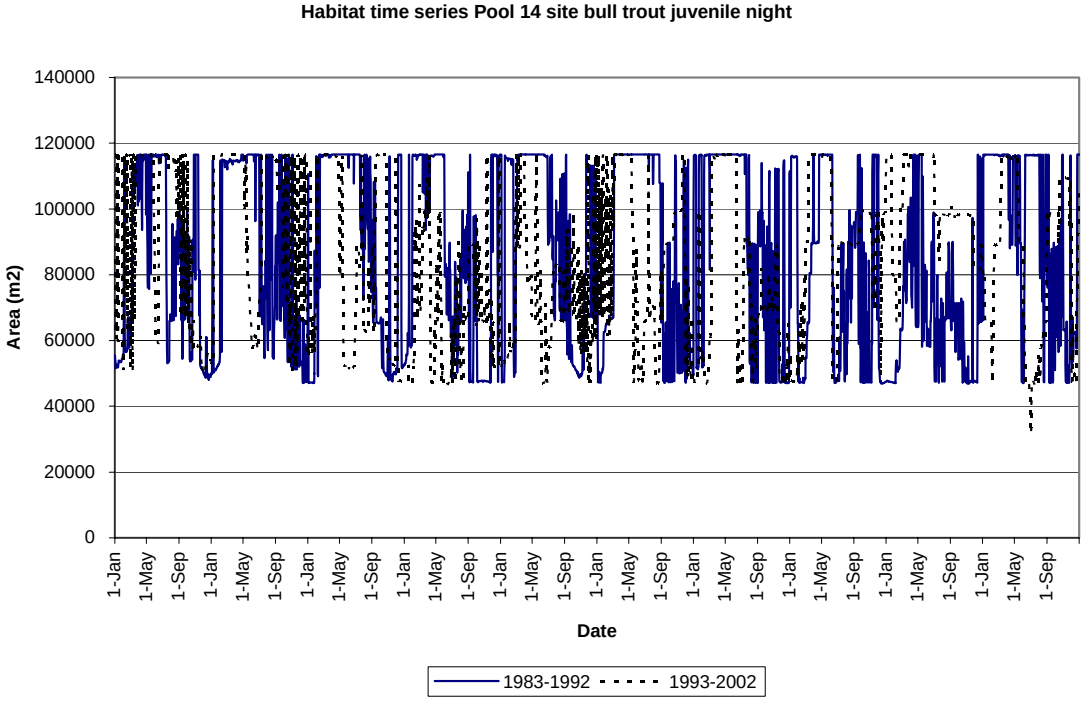


**Figure 4. Juvenile bull trout (night) habitat time series using average daily flow for 2, 10 year time periods at Pool 14 site.**

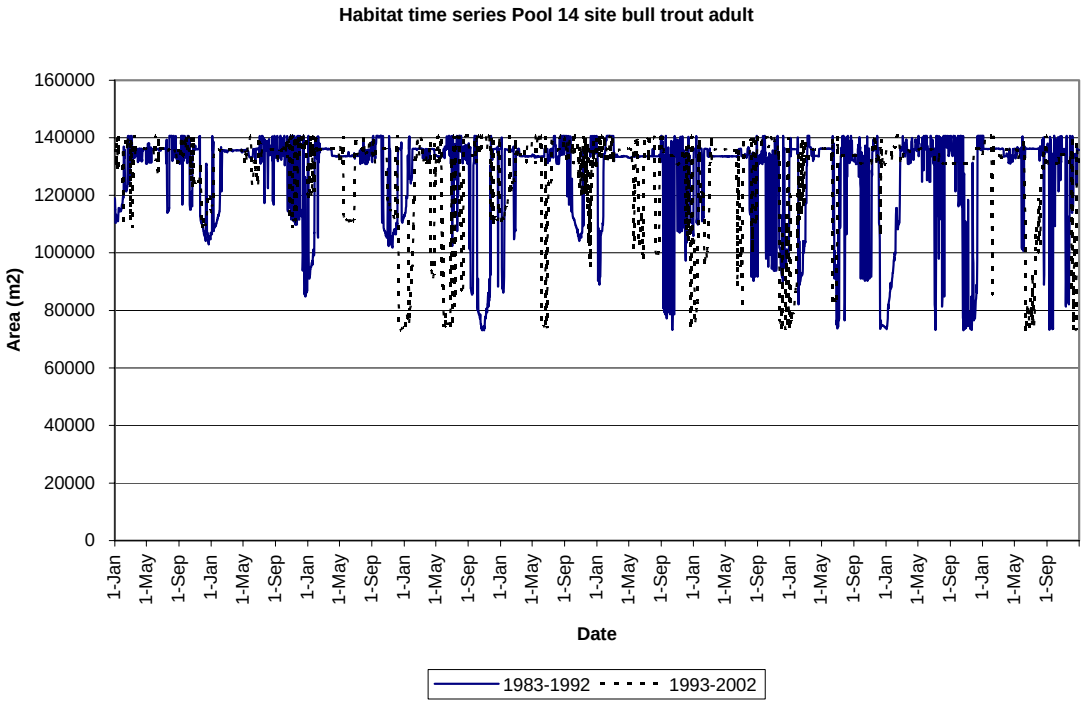


**Figure 5. Adult bull trout habitat time series using average daily flow for 2, 10 year time periods at Pool 14 site.**

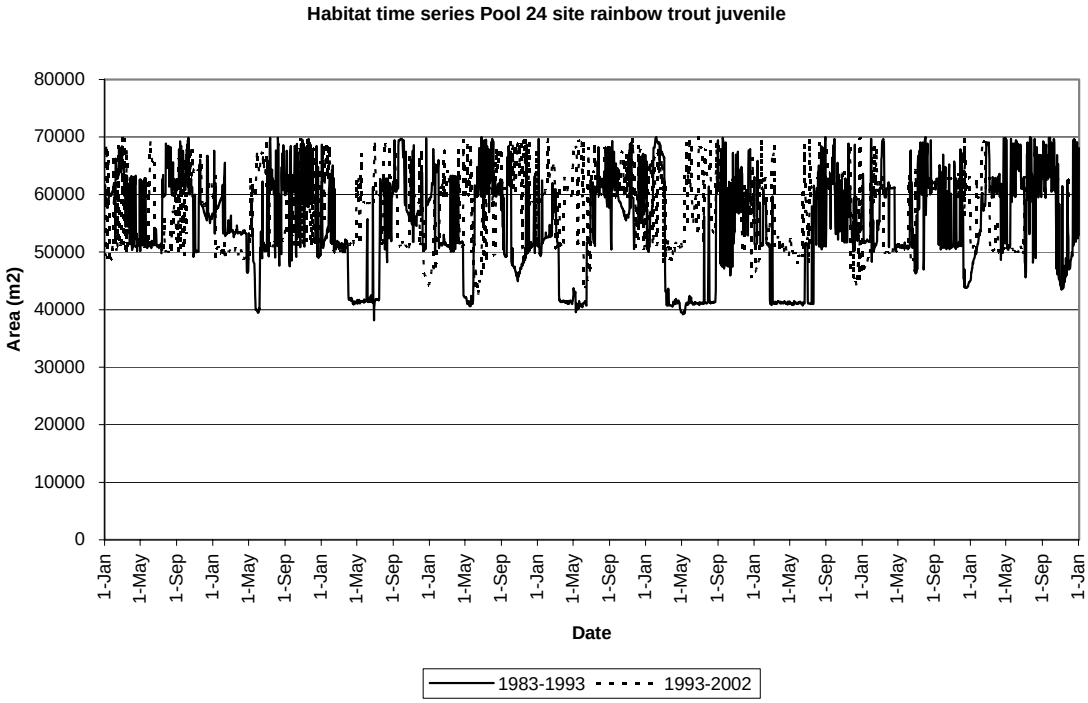


**Figure 6. Juvenile rainbow trout habitat time series using average daily flow for 2, 10 year time periods at Pool 24 site.**

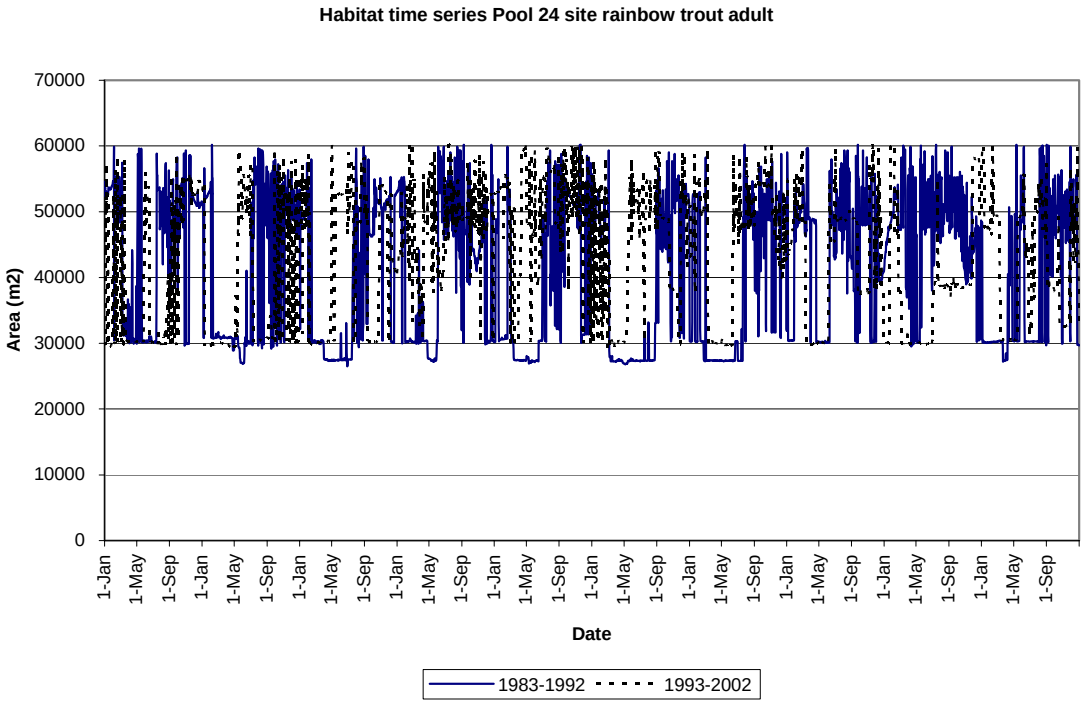


**Figure 7. Adult rainbow trout habitat time series using average daily flow for 2, 10 year time periods at Pool 24 site.**

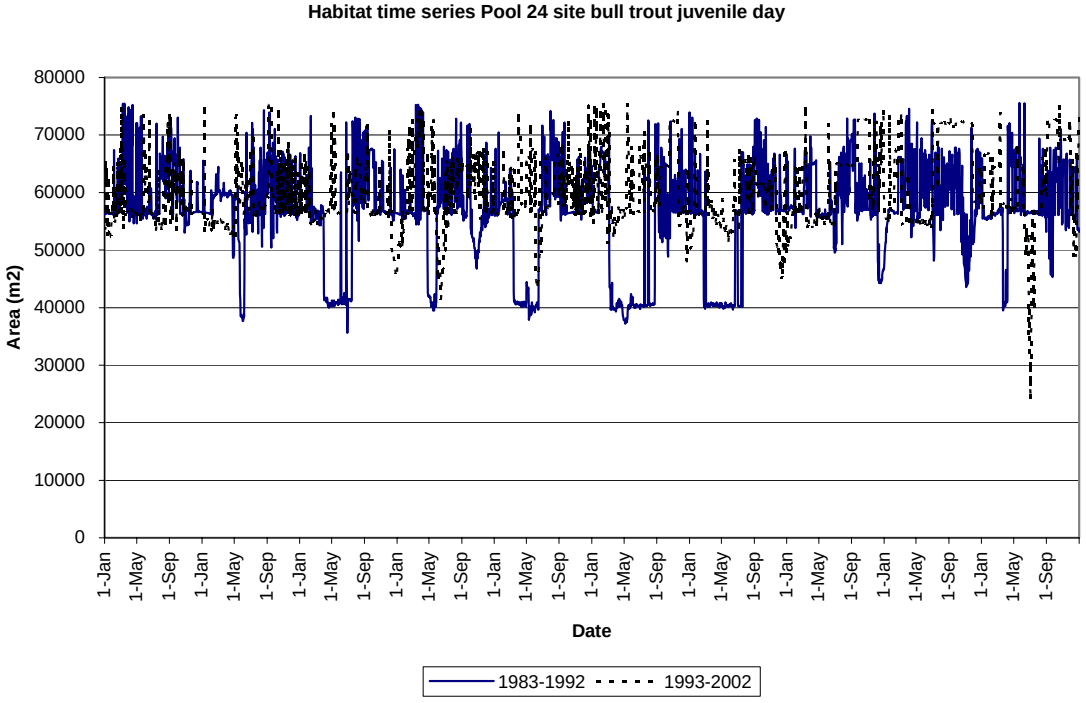


**Figure 8. Juvenile bull trout (day) habitat time series using average daily flow for 2, 10 year time periods at Pool 24 site.**

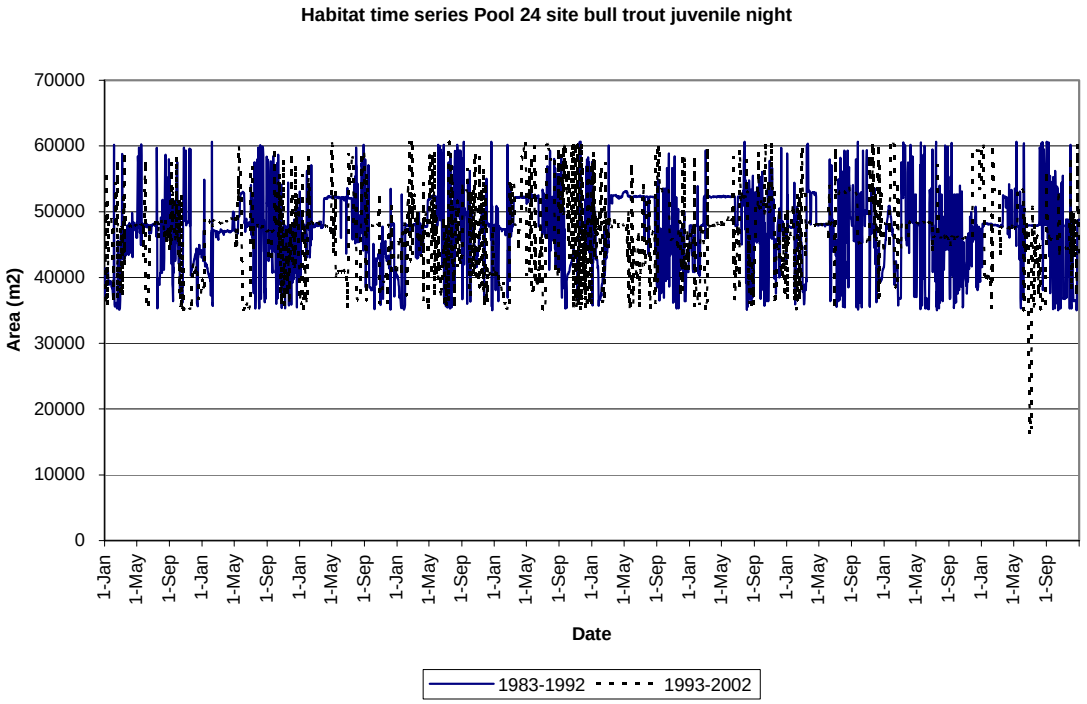


**Figure 9. Juvenile bull trout (night) habitat time series using average daily flow for 2, 10 year time periods at Pool 24 site.**

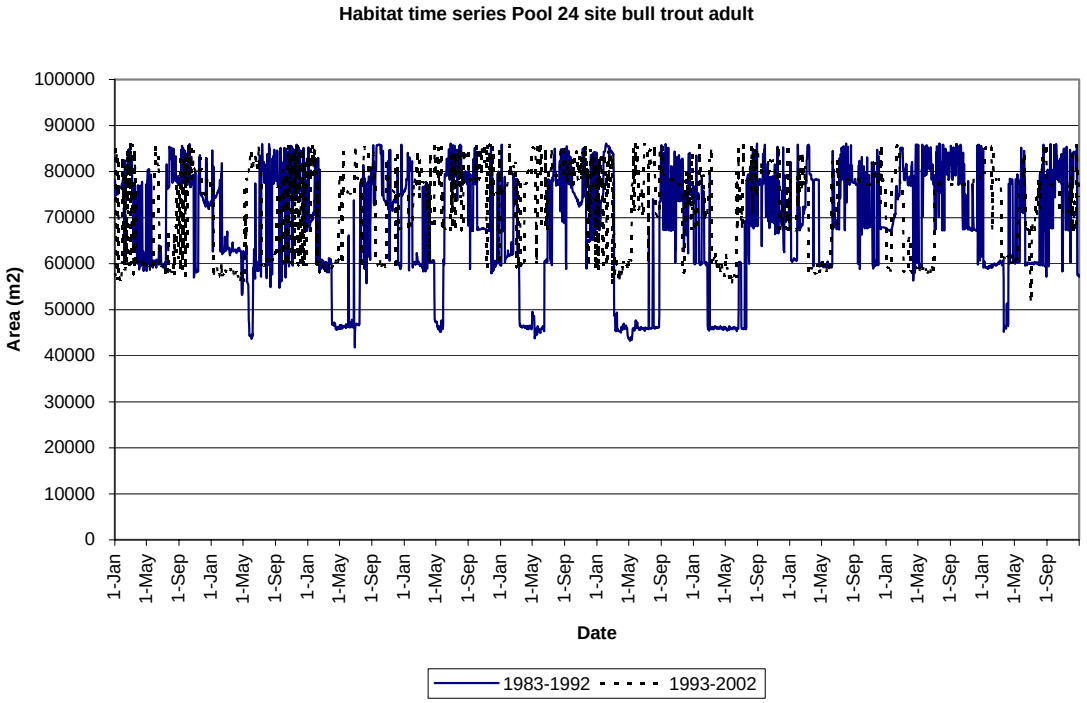


**Figure 10. Adult bull trout habitat time series using average daily flow for 2, 10 year time periods at Pool 24 site.**

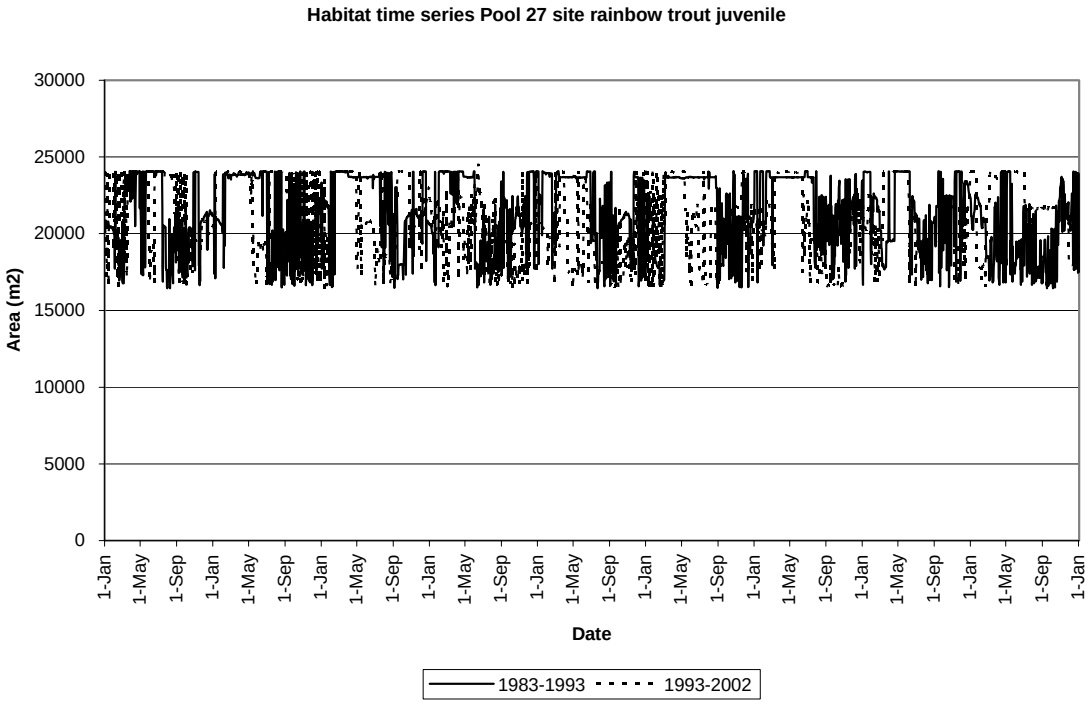


**Figure 11. Juvenile rainbow trout habitat time series using average daily flow for 2, 10 year time periods at Pool 27 site.**

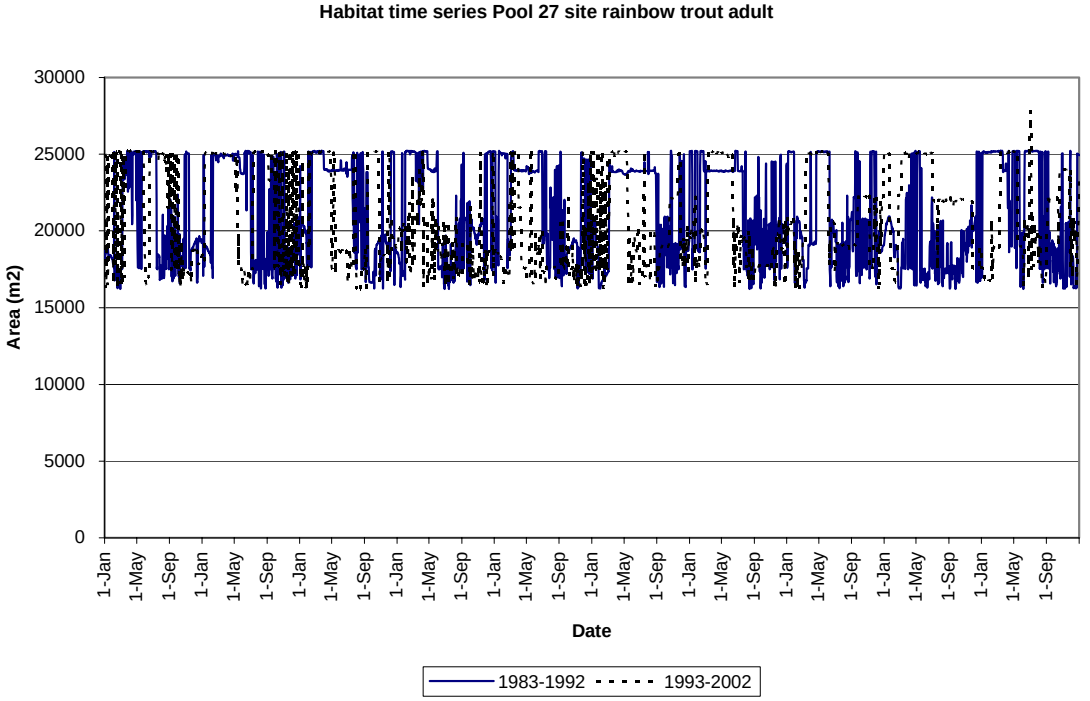


**Figure 12. Adult rainbow trout habitat time series using average daily flow for 2, 10 year time periods at Pool 27 site.**

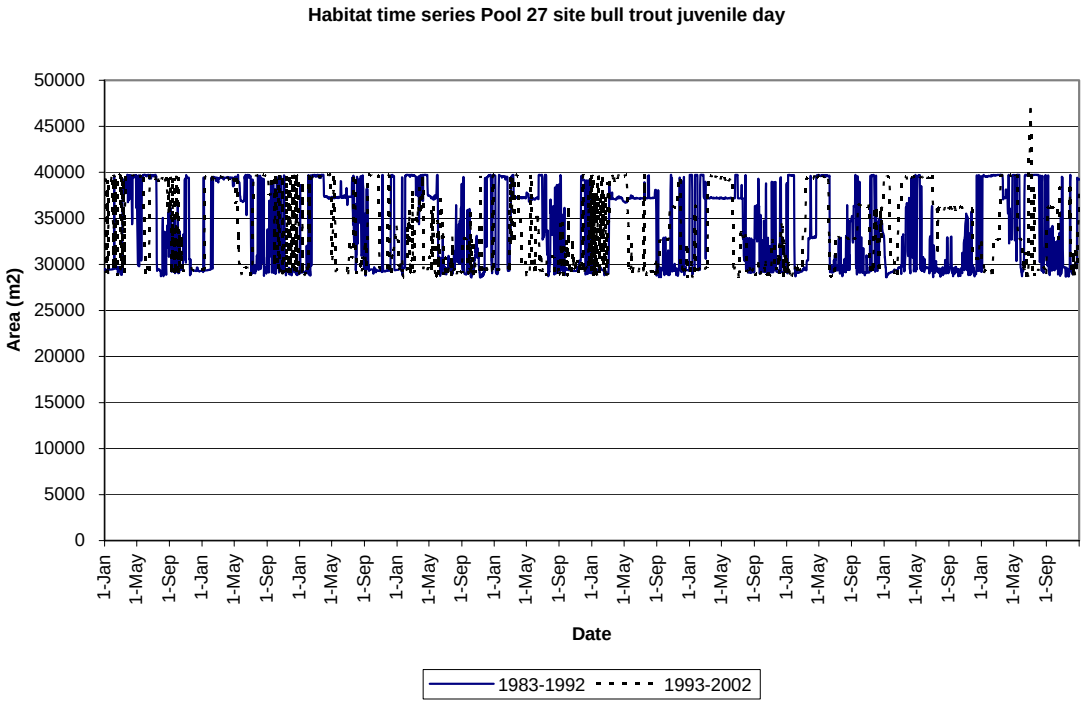


**Figure 13. Juvenile bull trout (day) habitat time series using average daily flow for 2, 10 year time periods at Pool 27 site.**

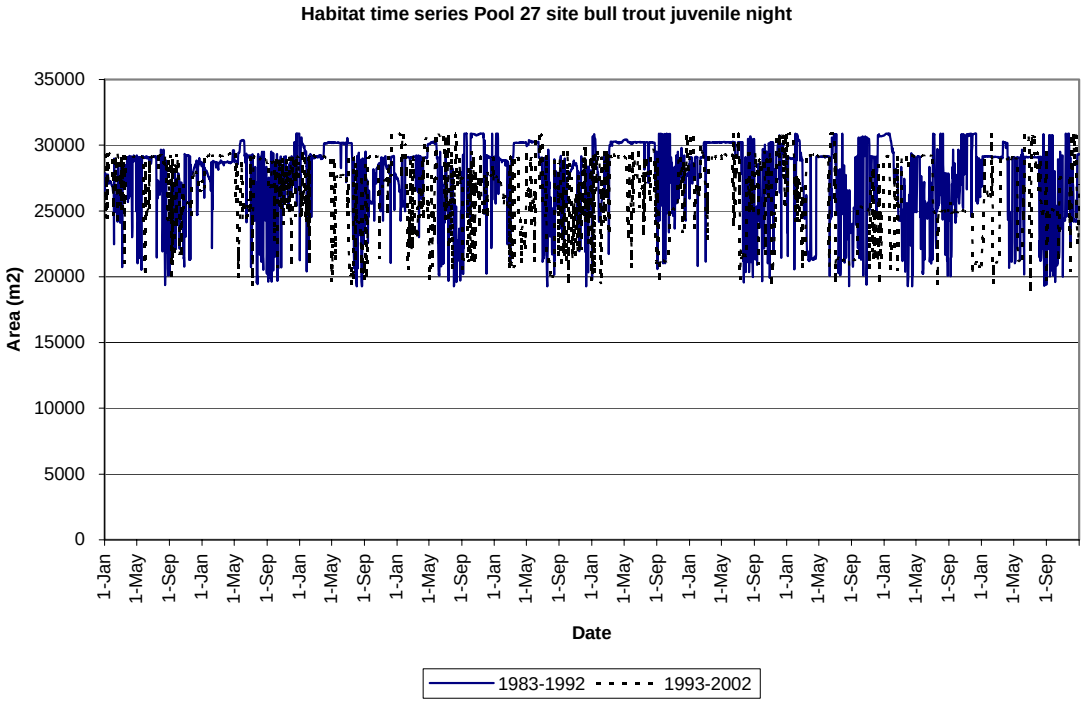


**Figure 14. Juvenile bull trout (night) habitat time series using average daily flow for 2, 10 year time periods at Pool 27 site.**

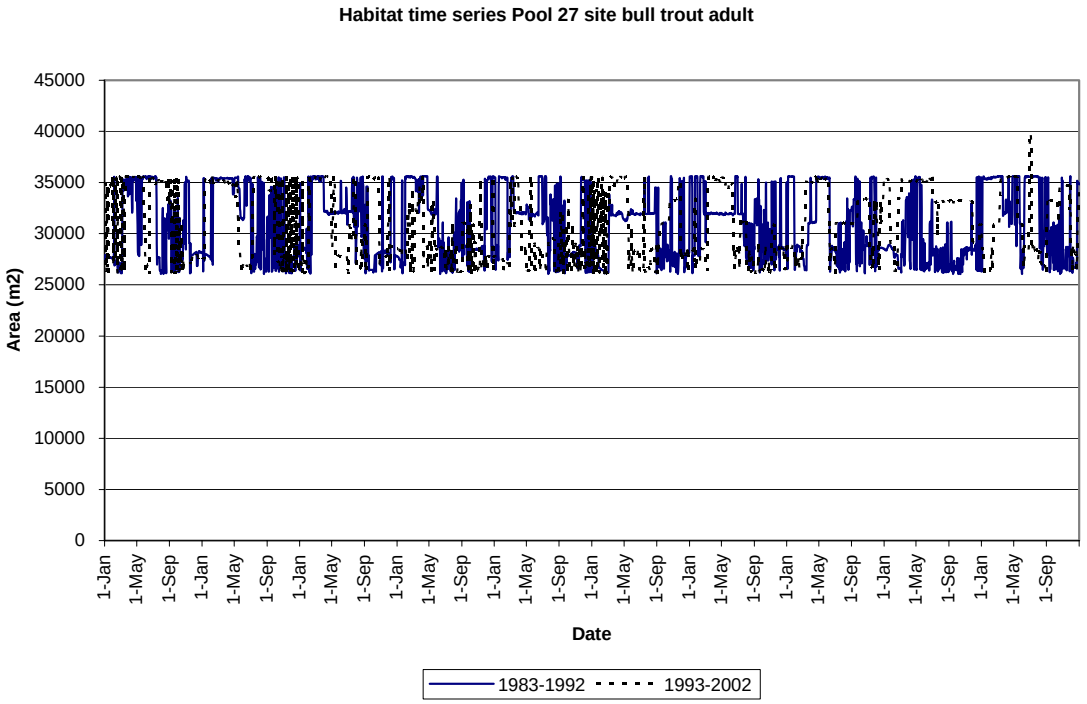


**Figure 15. Adult bull trout habitat time series using average daily flow for 2, 10 year time periods at Pool 27 site.**

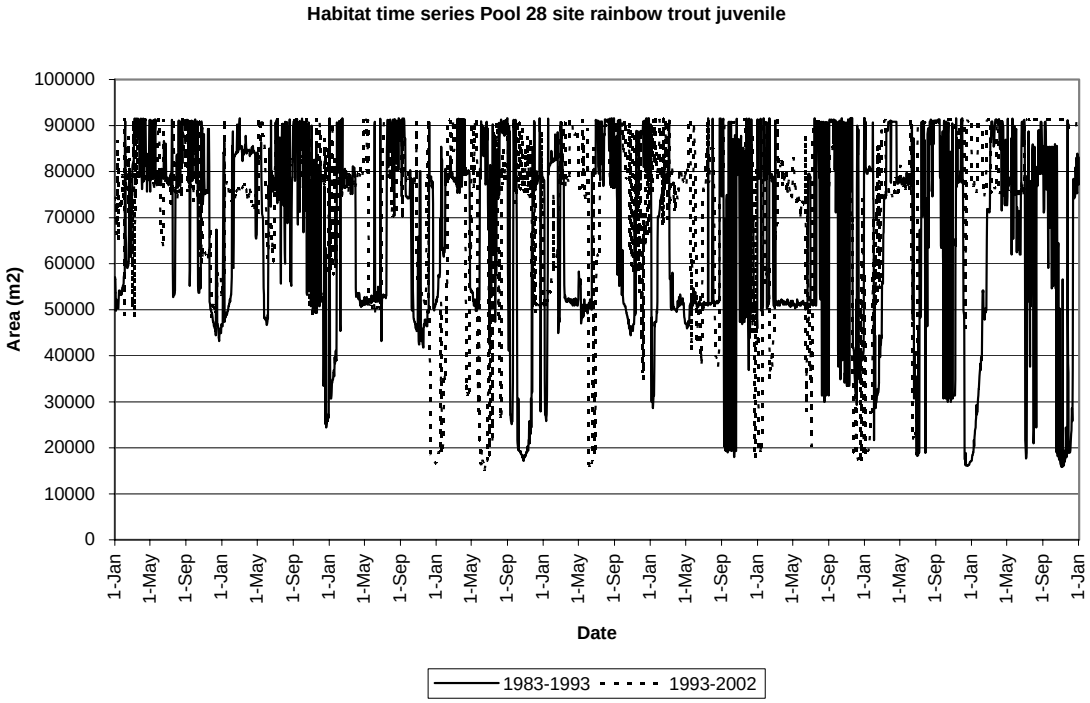


**Figure 16. Juvenile rainbow trout habitat time series using average daily flow for 2, 10 year time periods at Pool 28 site.**

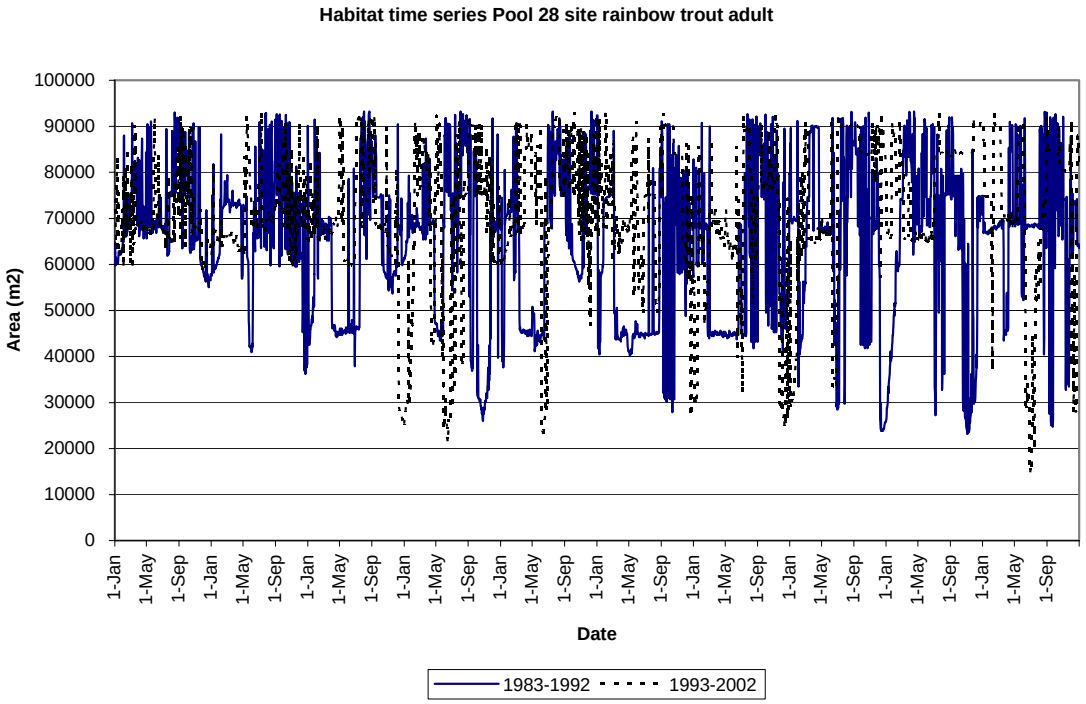


**Figure 17. Adult rainbow trout habitat time series using average daily flow for 2, 10 year time periods at Pool 28 site.**

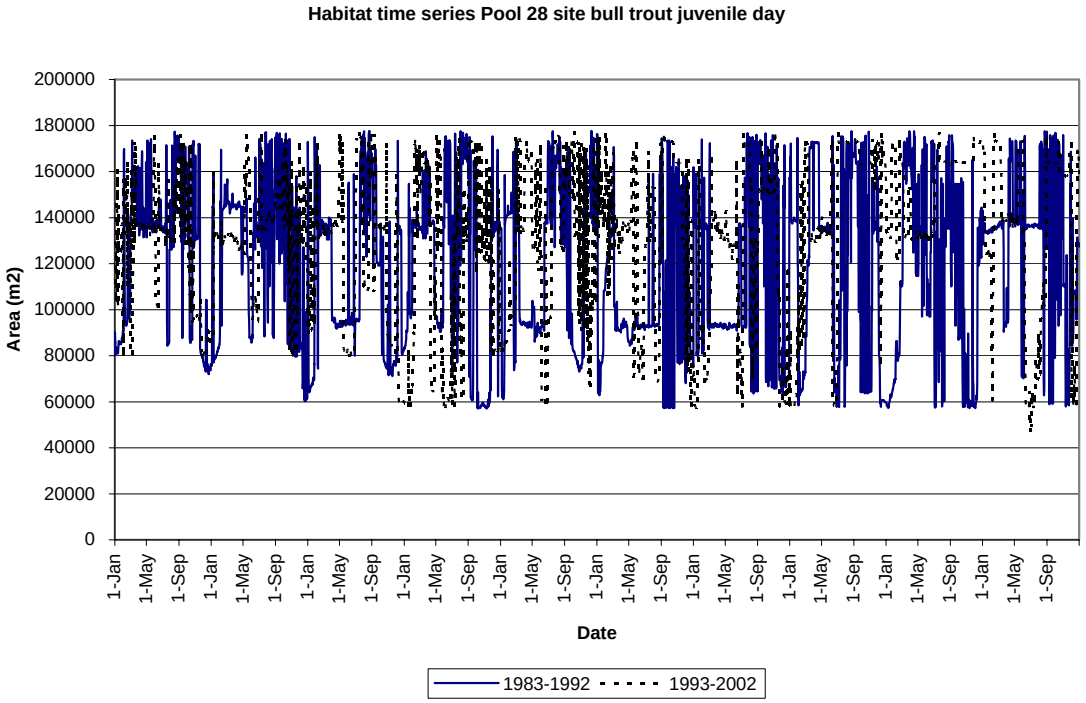


**Figure 18. Juvenile bull trout (day) habitat time series using average daily flow for 2, 10 year time periods at Pool 28 site.**

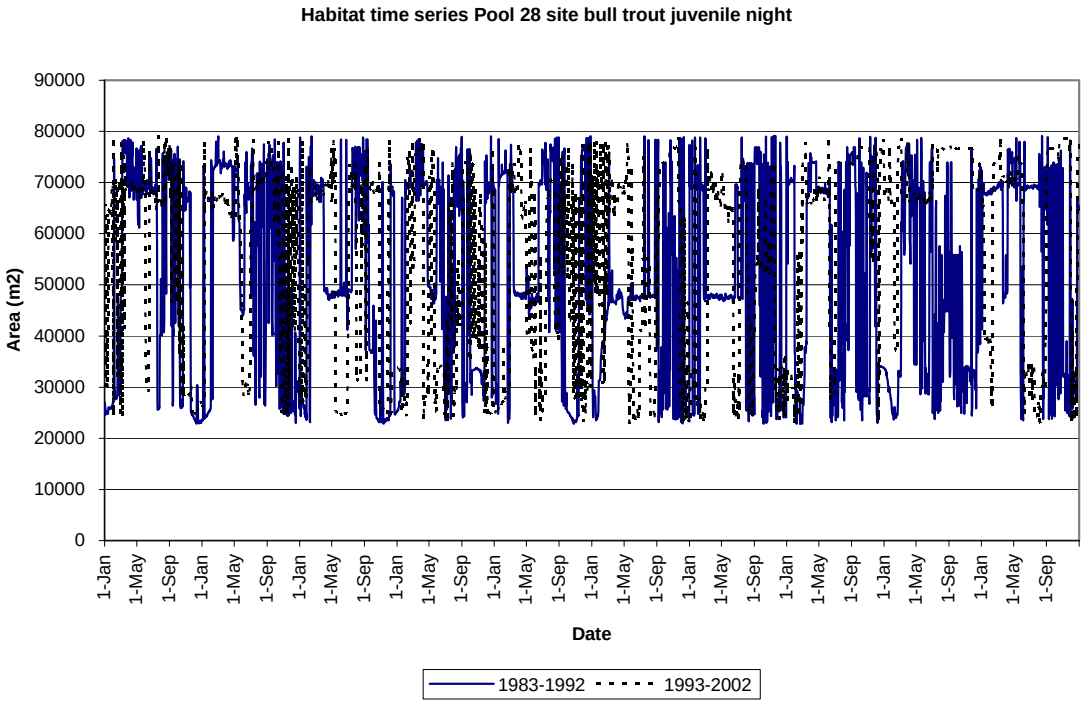


**Figure 19. Juvenile bull trout (night) habitat time series using average daily flow for 2, 10 year time periods at Pool 28 site.**

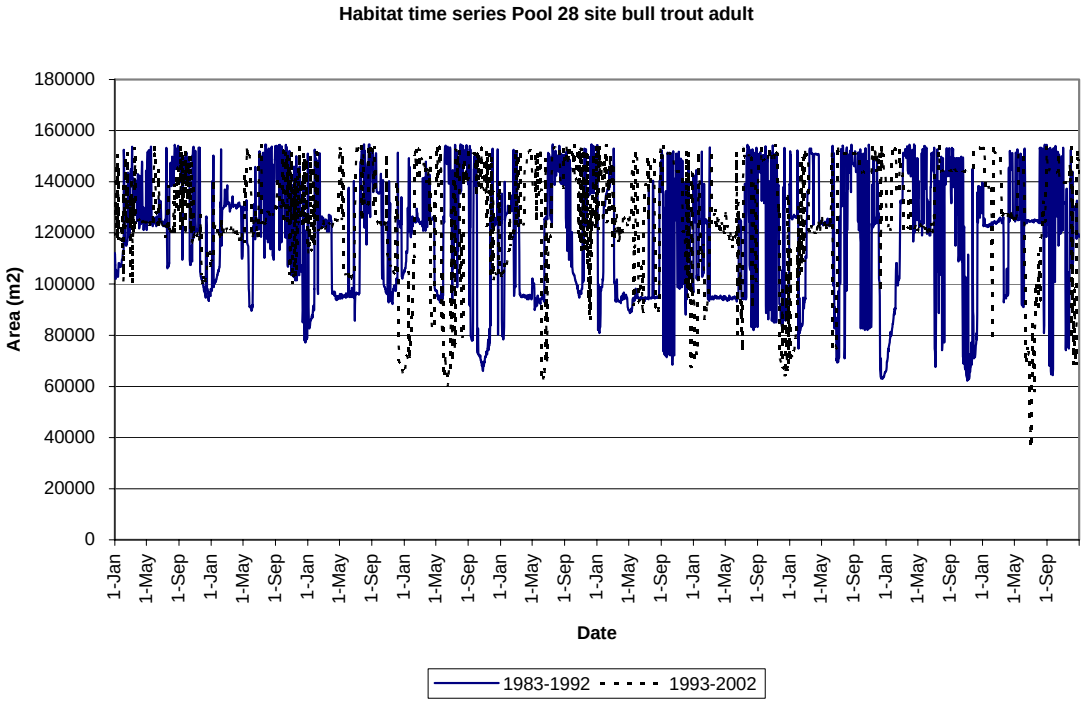


**Figure 20. Adult bull trout habitat time series using average daily flow for 2, 10 year time periods at Pool 28 site.**

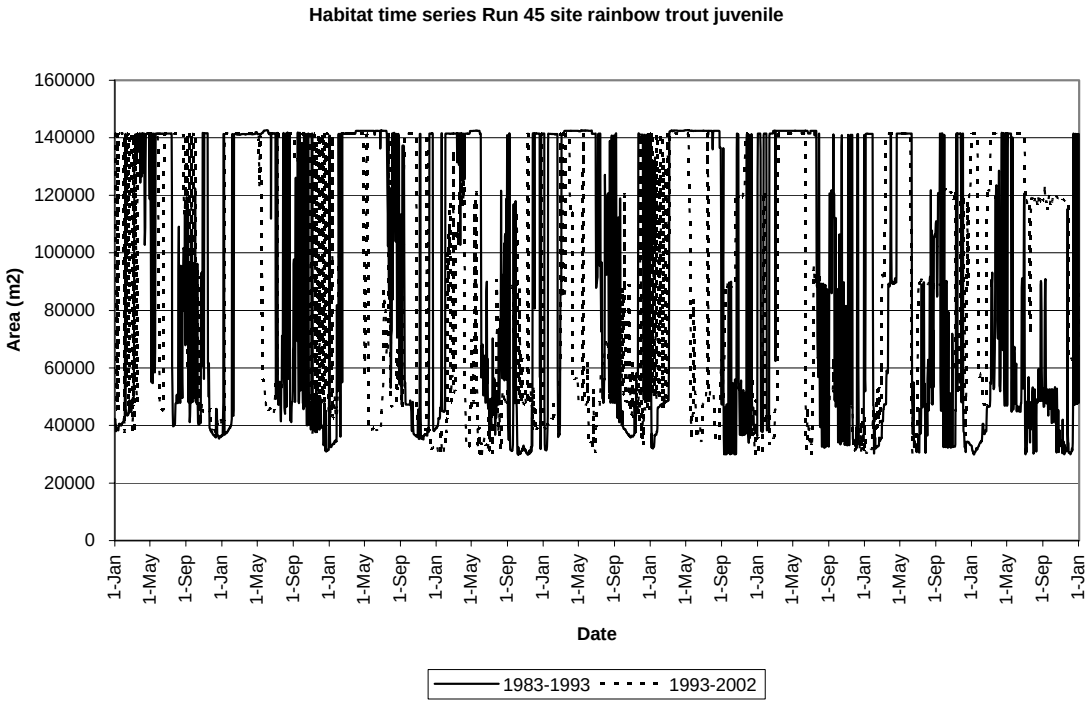


**Figure 21. Juvenile rainbow trout habitat time series using average daily flow for 2, 10 year time periods at Run 45 site.**

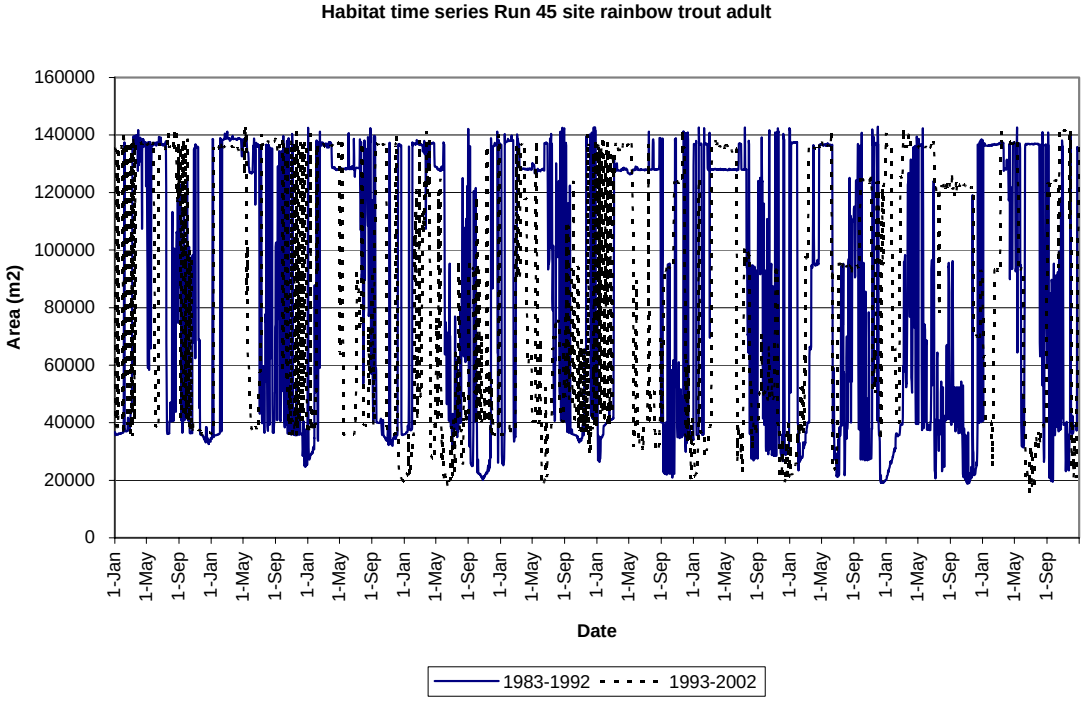


**Figure 22. Adult rainbow trout habitat time series using average daily flow for 2, 10 year time periods at Run 45 site.**

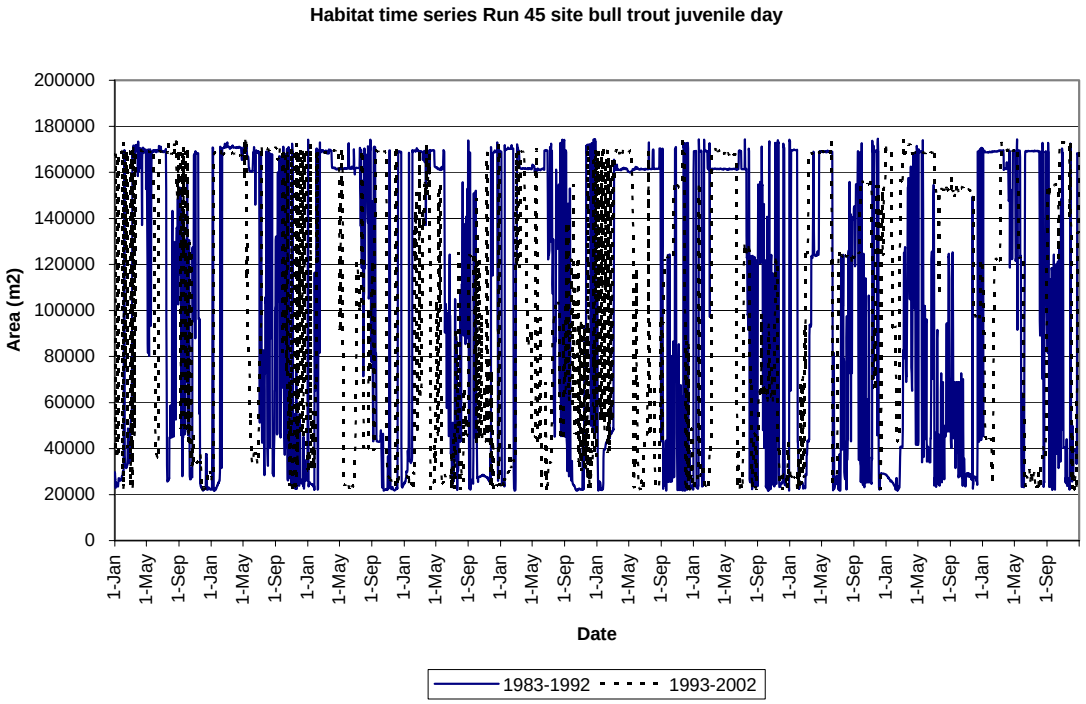


**Figure 23. Juvenile bull trout (day) habitat time series using average daily flow for 2, 10 year time periods at Run 45 site.**

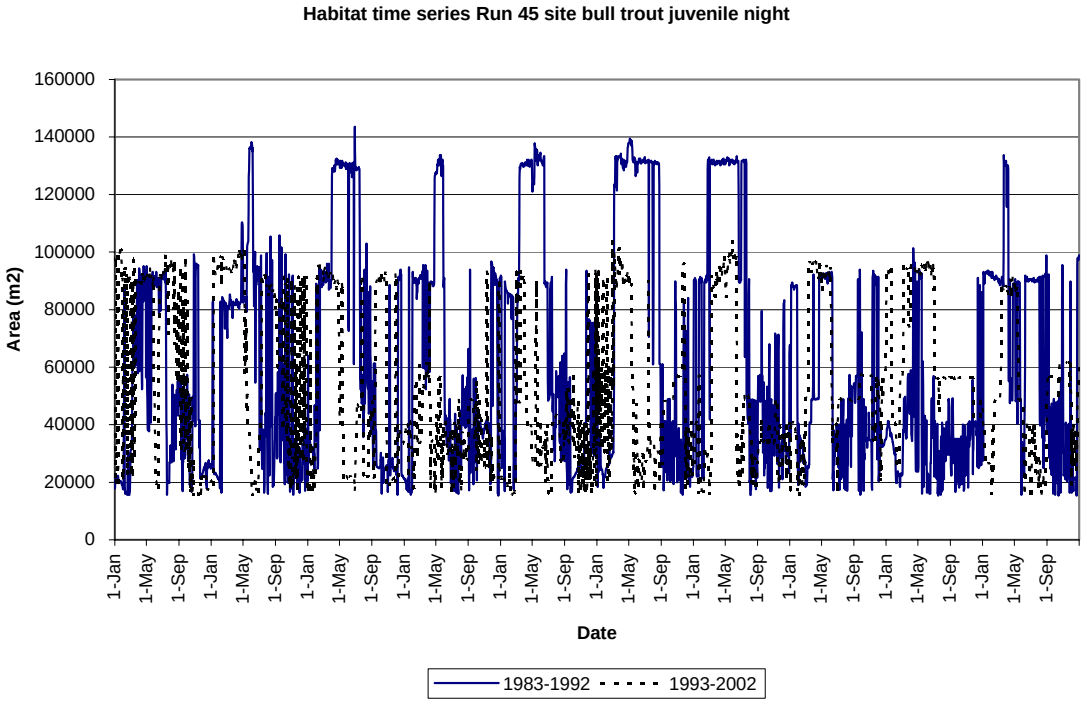


**Figure 24. Juvenile bull trout (night) habitat time series using average daily flow for 2, 10 year time periods at Run 45 site.**

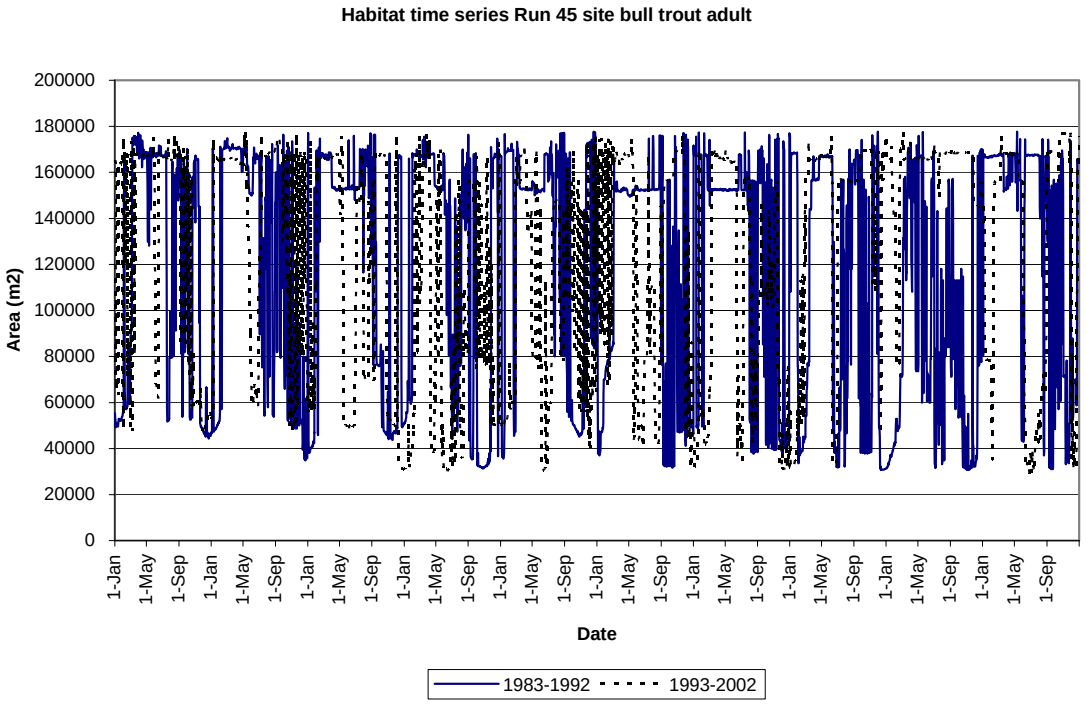


**Figure 25. Adult bull trout habitat time series using average daily flow for 2, 10 year time periods at Run 45 site.**

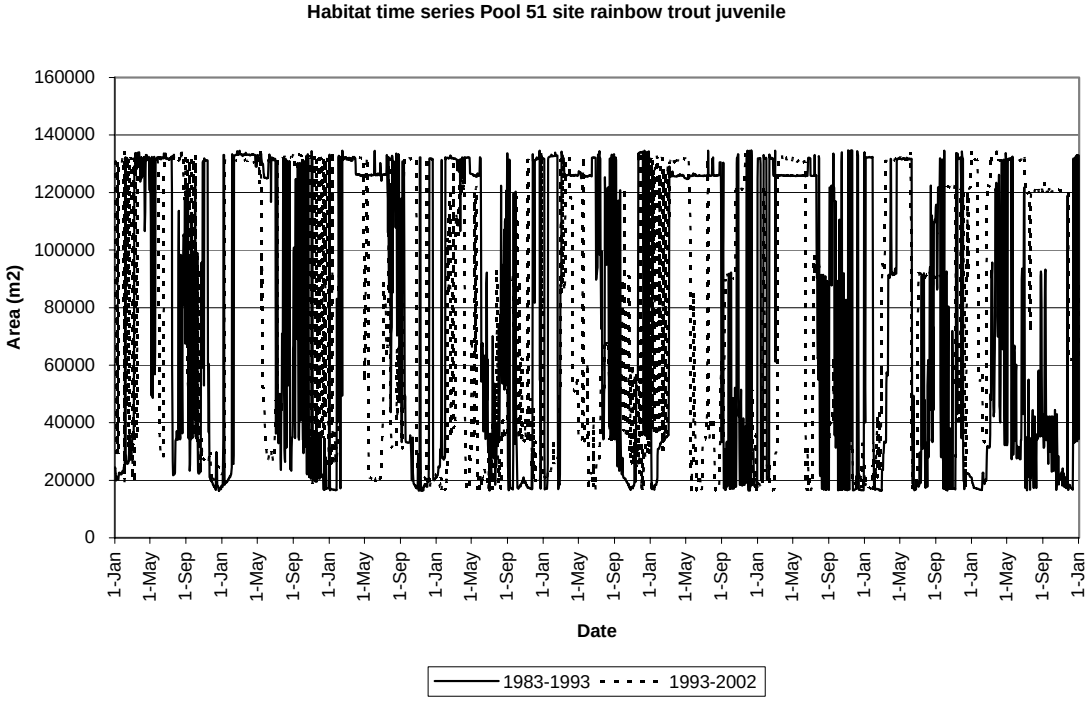


**Figure 26. Juvenile rainbow trout habitat time series using average daily flow for 2, 10 year time periods at Pool 51 site.**

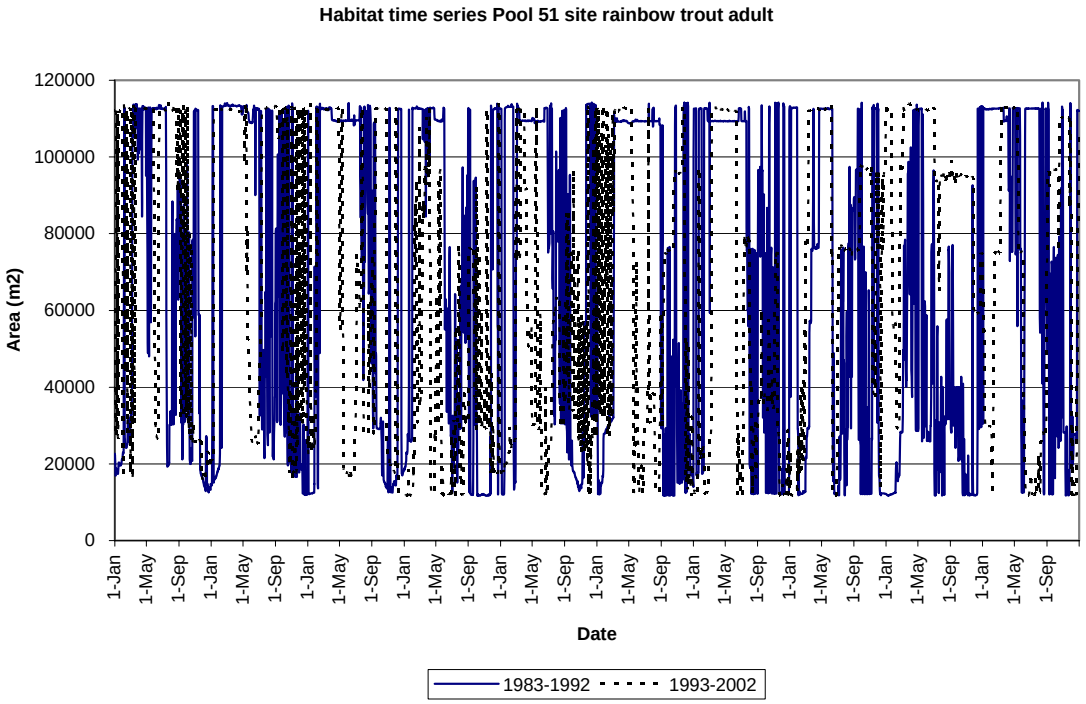


**Figure 27. Adult rainbow trout habitat time series using average daily flow for 2, 10 year time periods at Pool 51 site.**

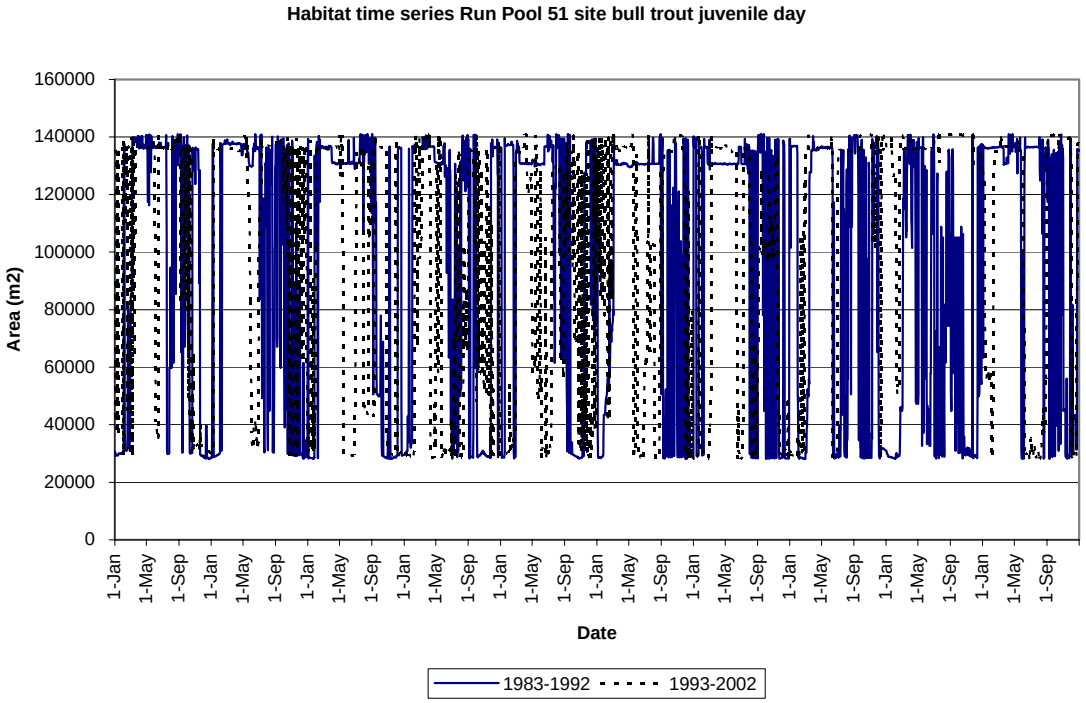


**Figure 28. Juvenile bull trout (day) habitat time series using average daily flow for 2, 10 year time periods at Pool 51 site.**

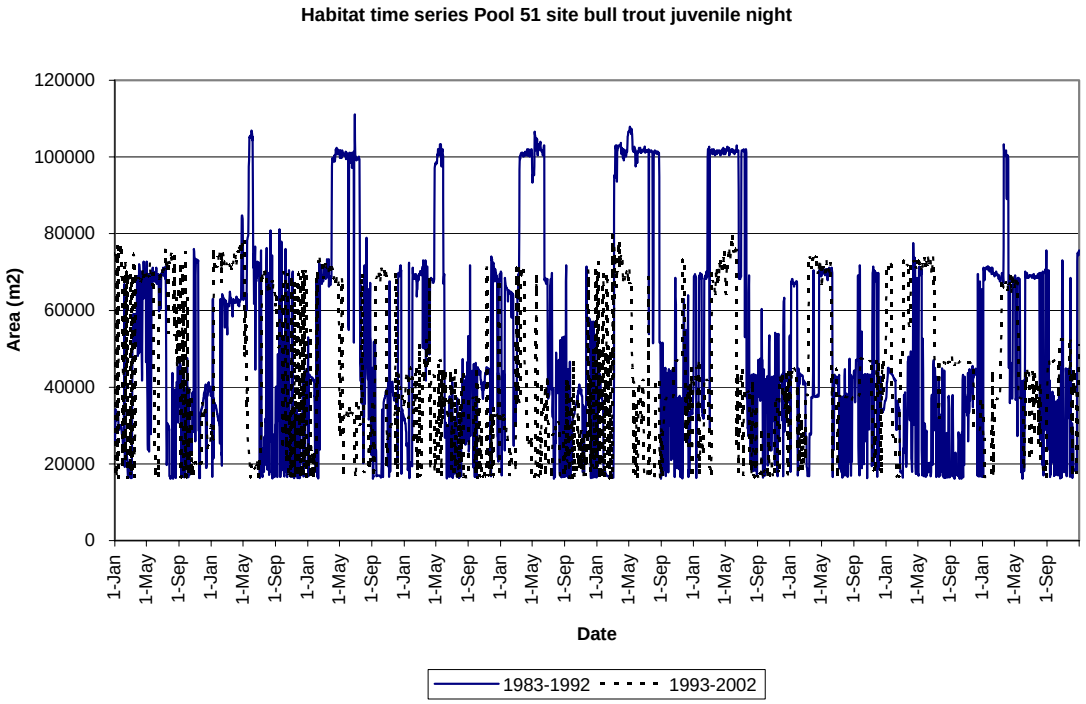


**Figure 29. Juvenile bull trout (night) habitat time series using average daily flow for 2, 10 year time periods at Pool 51 site.**

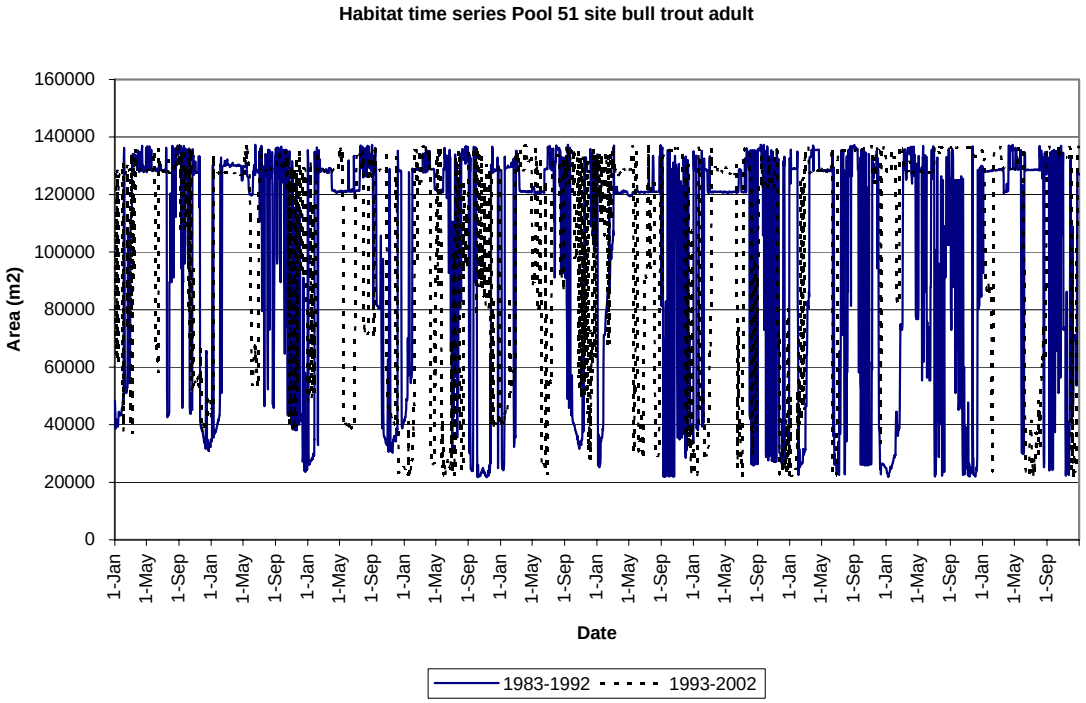


**Figure 30. Adult bull trout habitat time series using average daily flow for 2, 10 year time periods at Pool 51 site.**

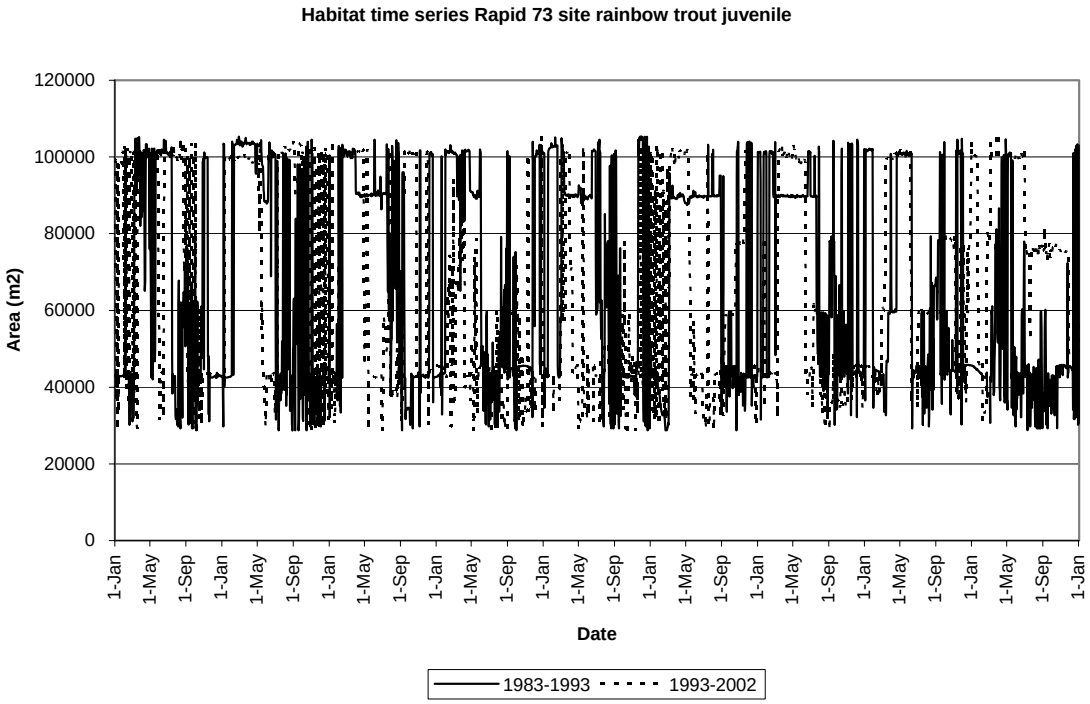


**Figure 31. Juvenile rainbow trout habitat time series using average daily flow for 2, 10 year time periods at Rapid 73 site.**

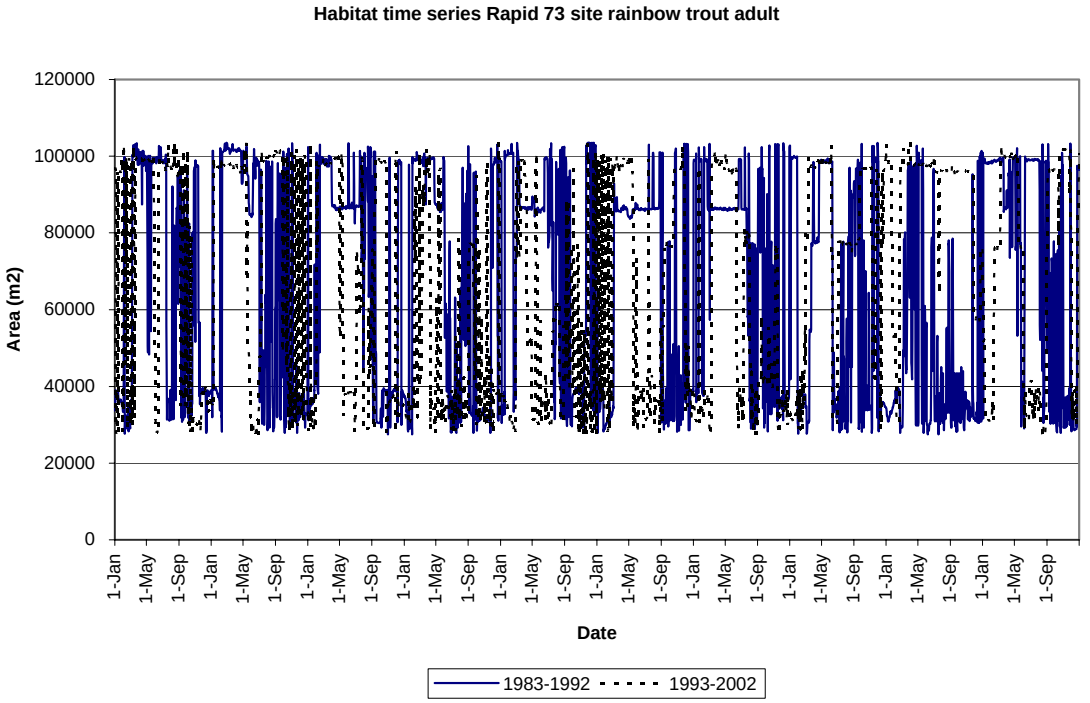


**Figure 32. Adult rainbow trout habitat time series using average daily flow for 2, 10 year time periods at Rapid 73 site.**

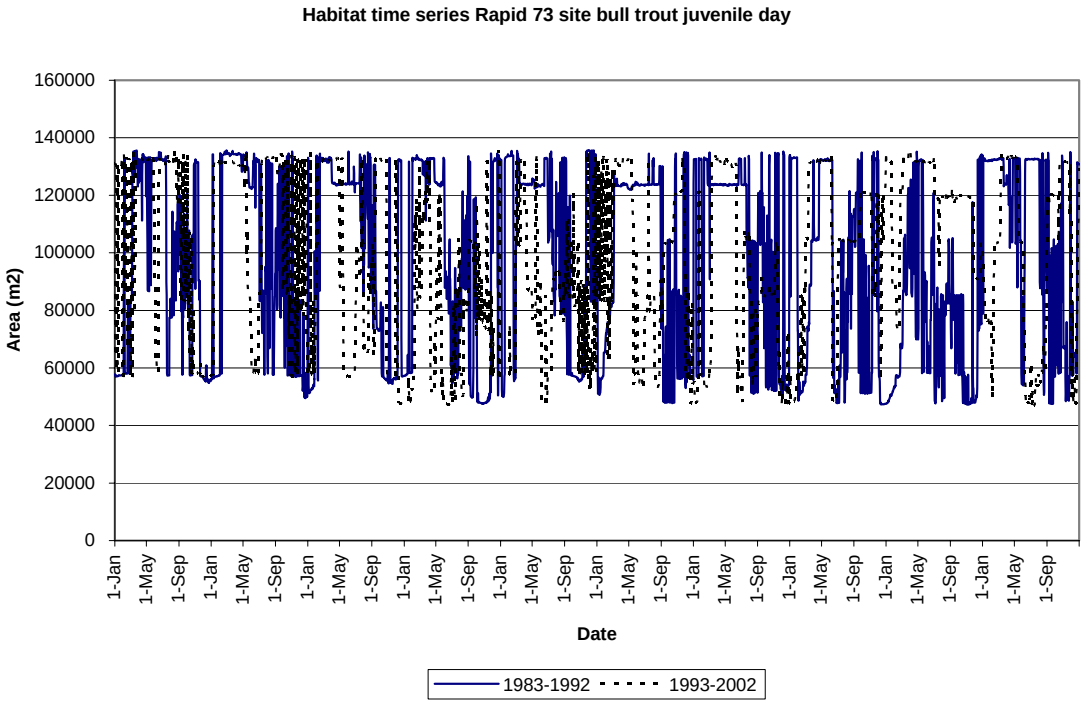


**Figure 33. Juvenile bull trout (day) habitat time series using average daily flow for 2, 10 year time periods at Rapid 73 site.**

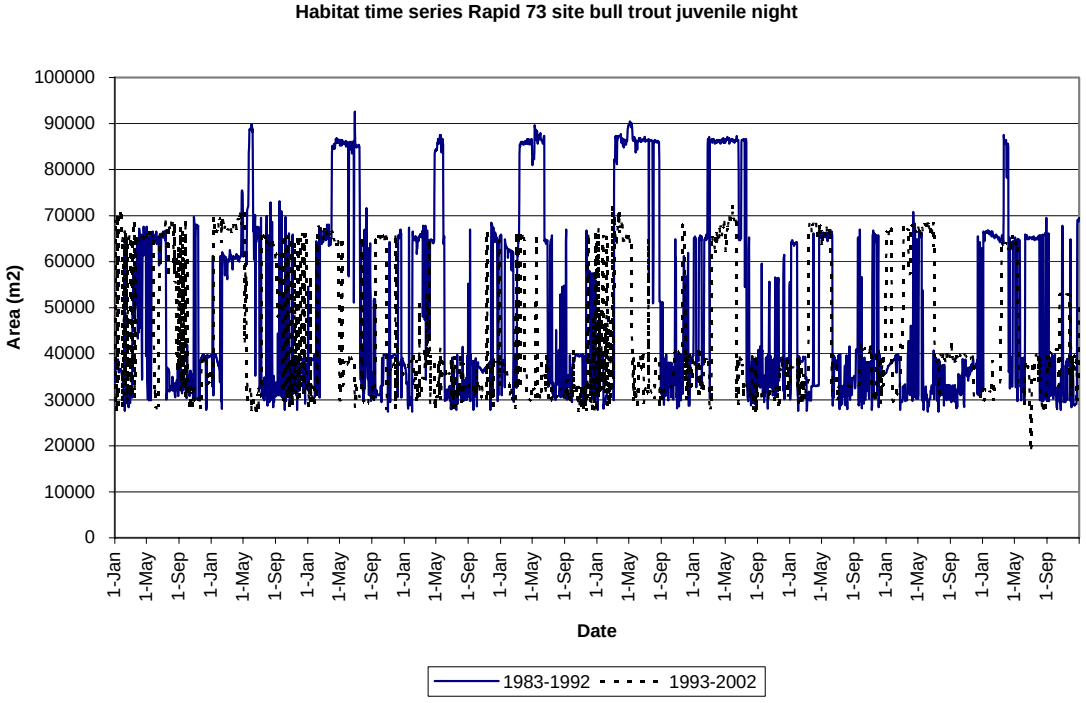


**Figure 34. Juvenile bull trout (night) habitat time series using average daily flow for 2, 10 year time periods at Rapid 73 site.**

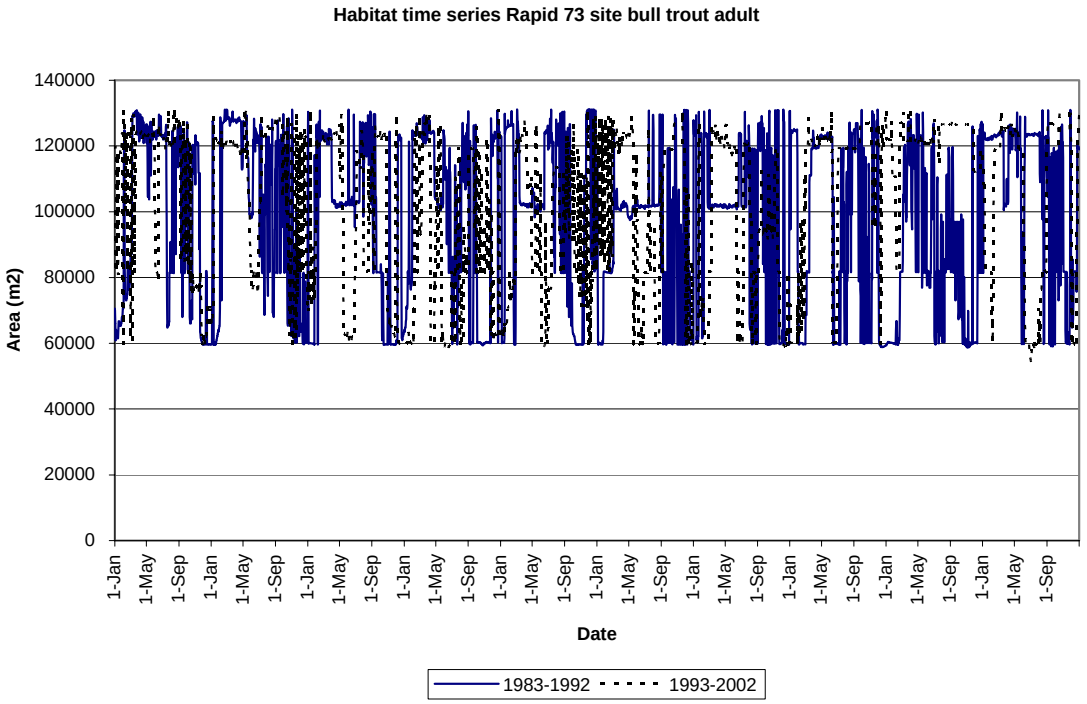


**Figure 35. Adult bull trout habitat time series using average daily flow for 2, 10 year time periods at Rapid 73 site.**

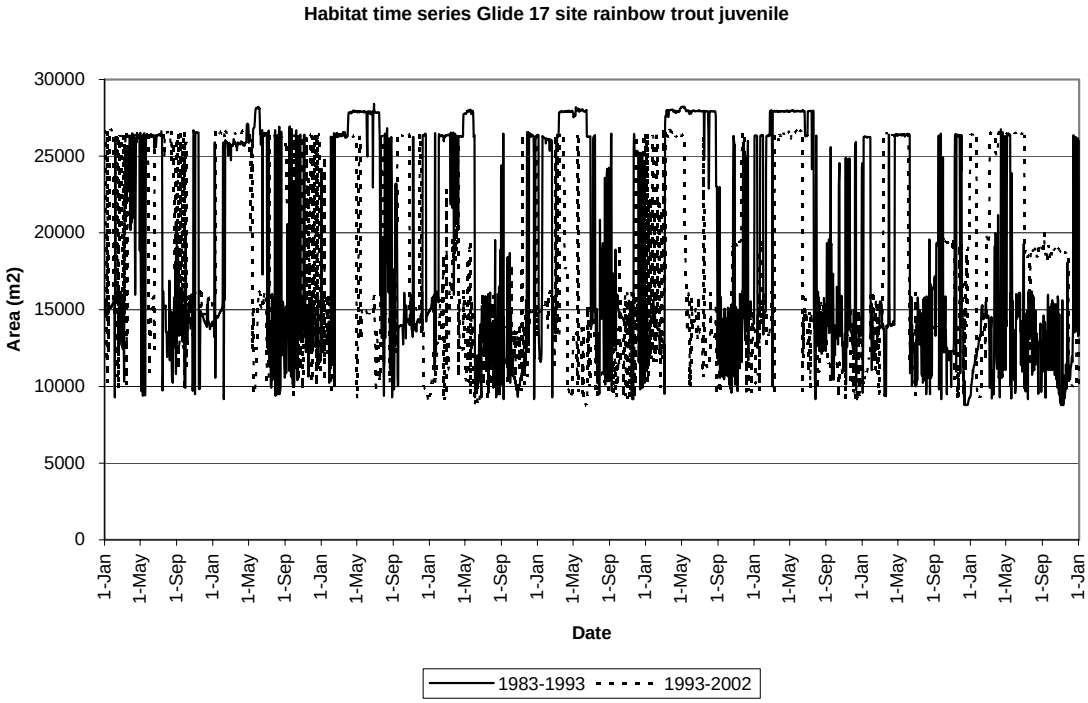


**Figure 36. Juvenile rainbow trout habitat time series using average daily flow for 2, 10 year time periods at Glide 17 site.**

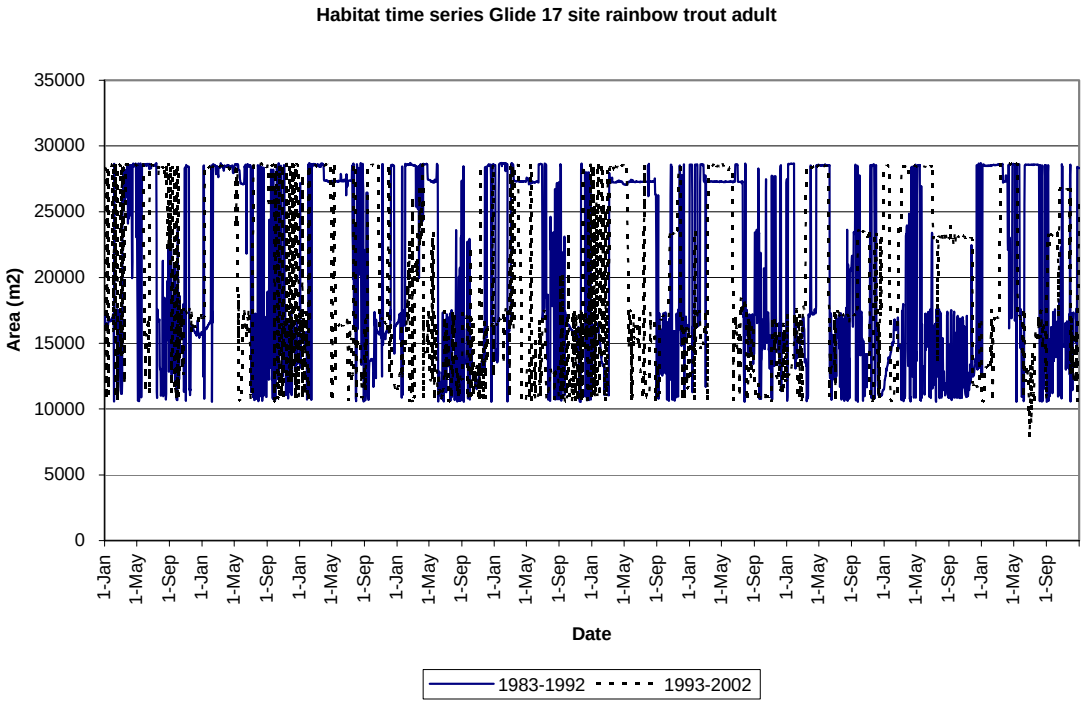


**Figure 37. Adult rainbow trout habitat time series using average daily flow for 2, 10 year time periods at Glide 17 site.**

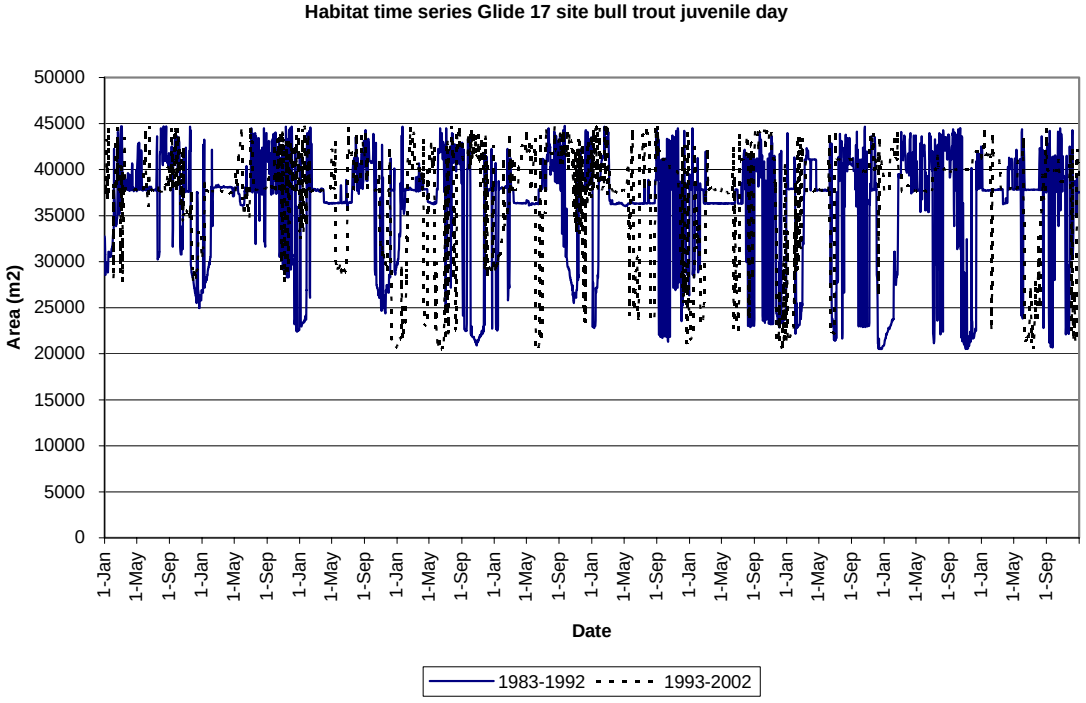


**Figure 38. Juvenile bull trout (day) habitat time series using average daily flow for 2, 10 year time periods at Glide 17 site.**

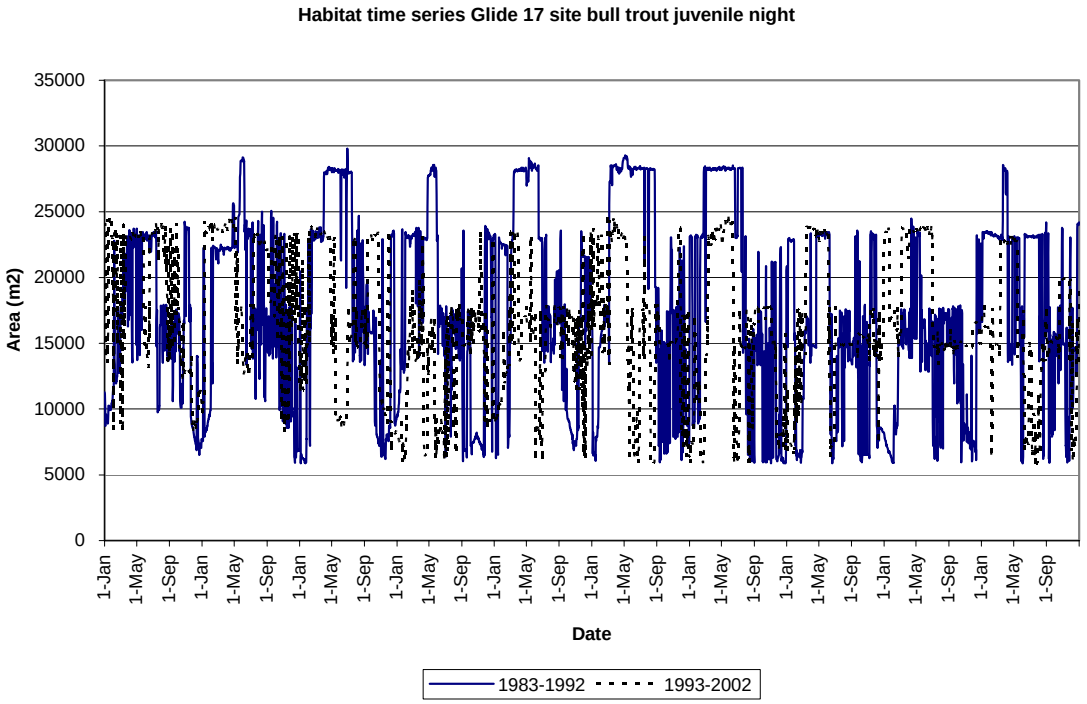


**Figure 39. Juvenile bull trout (night) habitat time series using average daily flow for 2, 10 year time periods at Glide 17 site.**

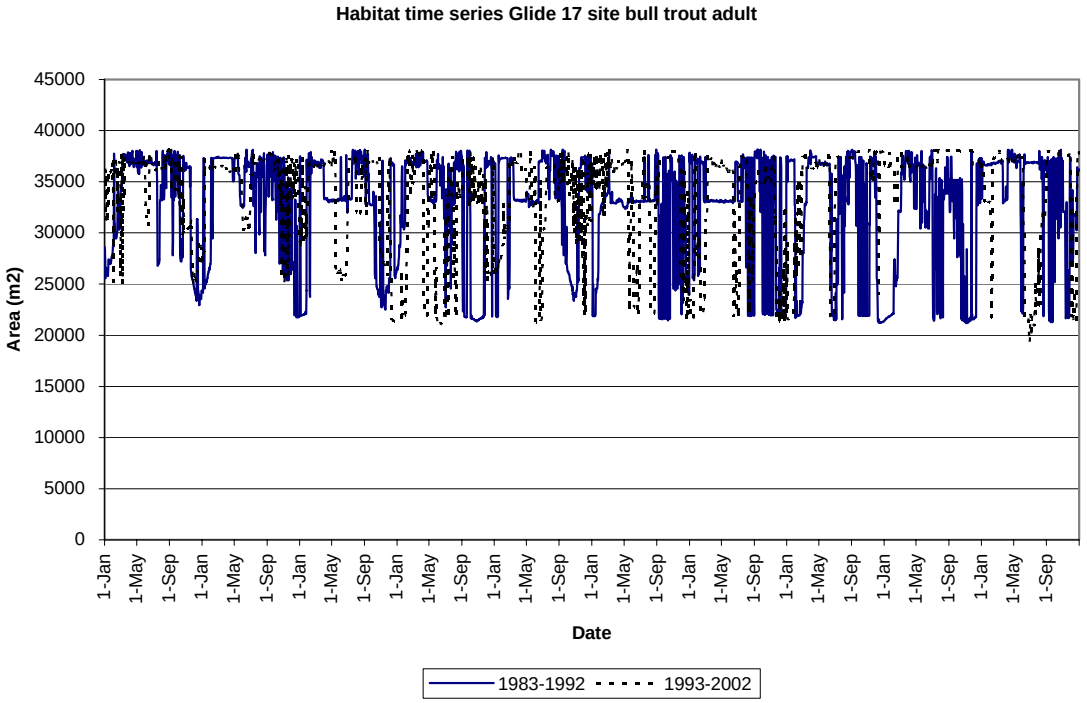


**Figure 40. Adult bull trout habitat time series using average daily flow for 2, 10 year time periods at Glide 17 site.**

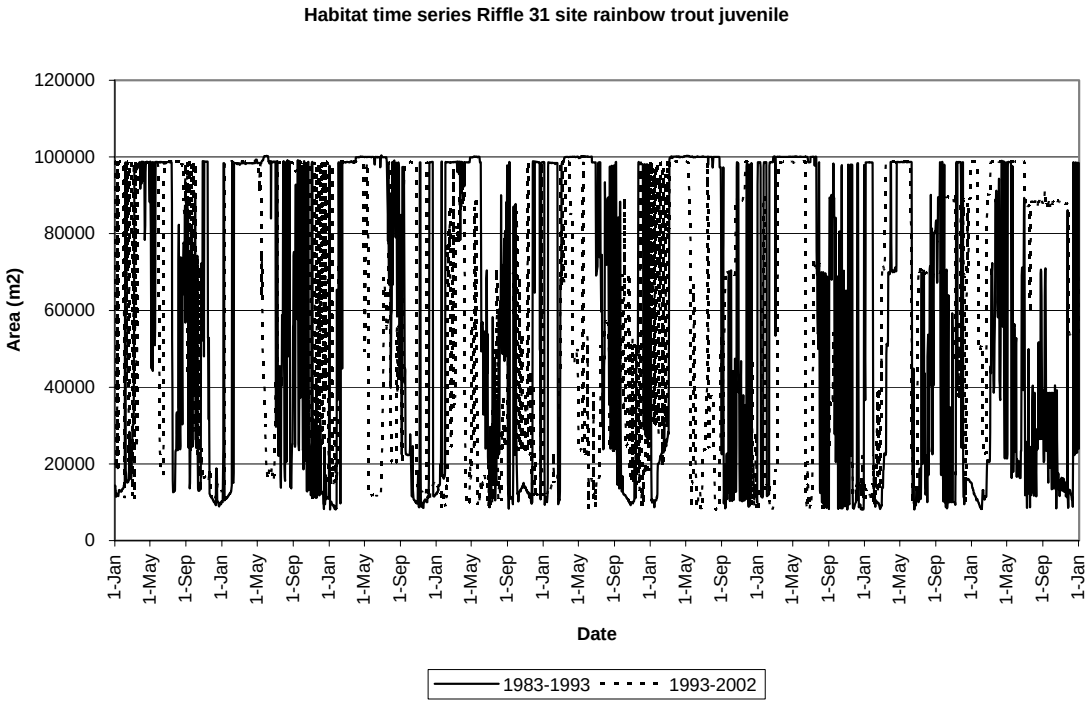


**Figure 41. Juvenile rainbow trout habitat time series using average daily flow for 2, 10 year time periods at Riffle 31 site.**

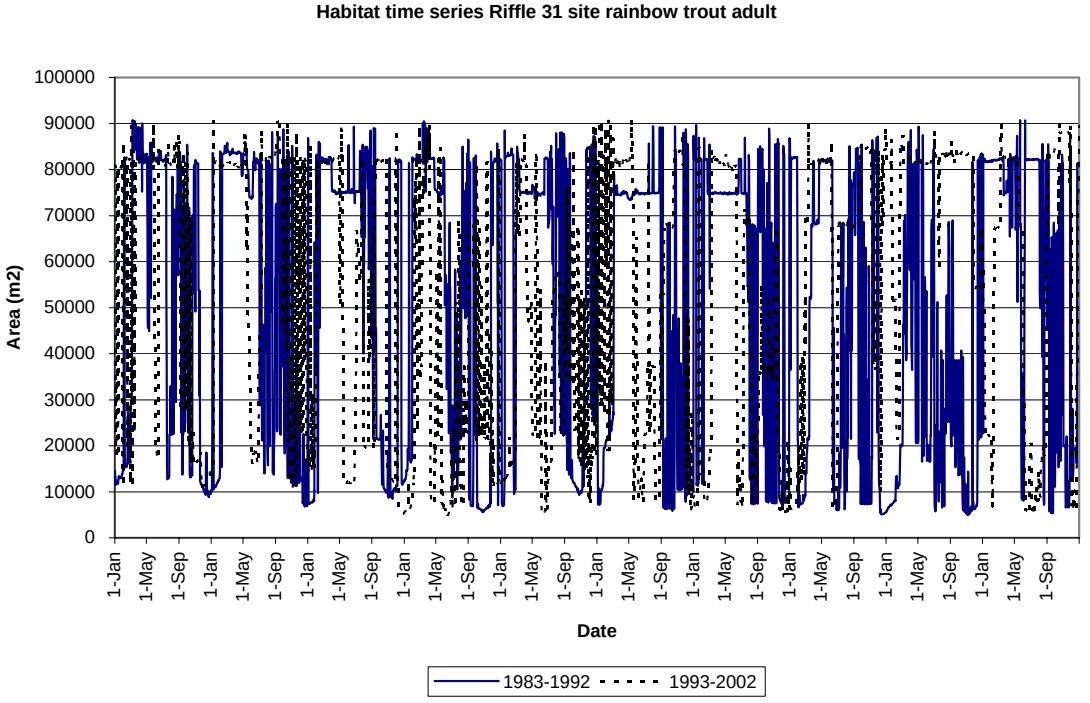


**Figure 42. Adult rainbow trout habitat time series using average daily flow for 2, 10 year time periods at Riffle 31 site.**

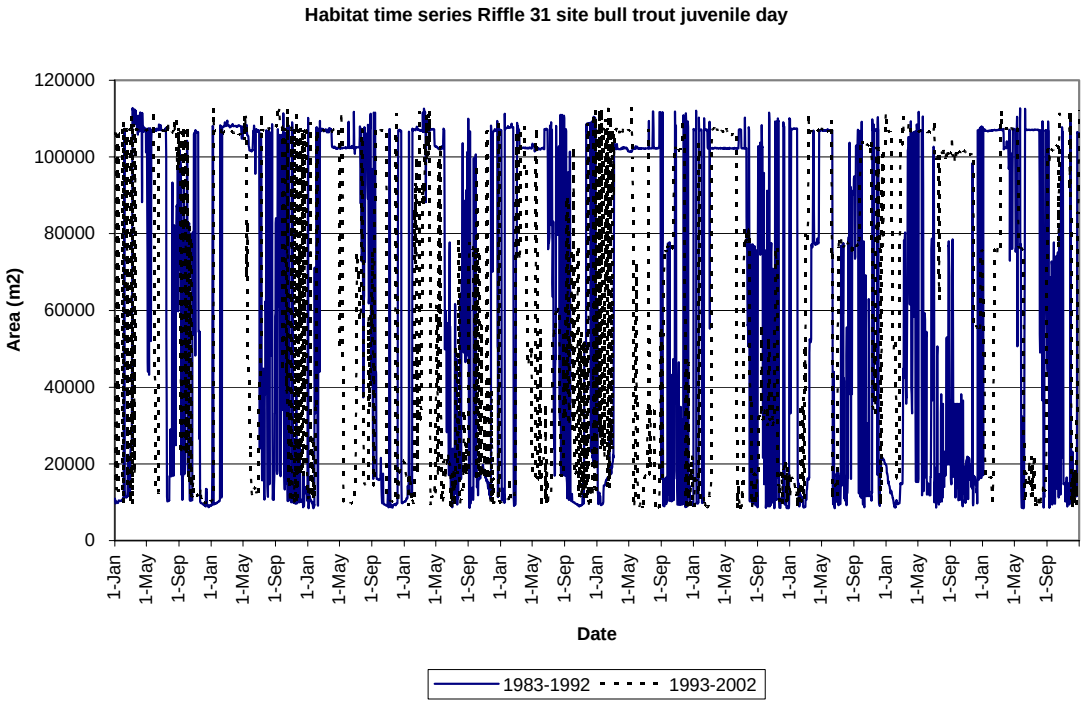


**Figure 43. Juvenile bull trout (day) habitat time series using average daily flow for 2, 10 year time periods at Riffle 31 site.**

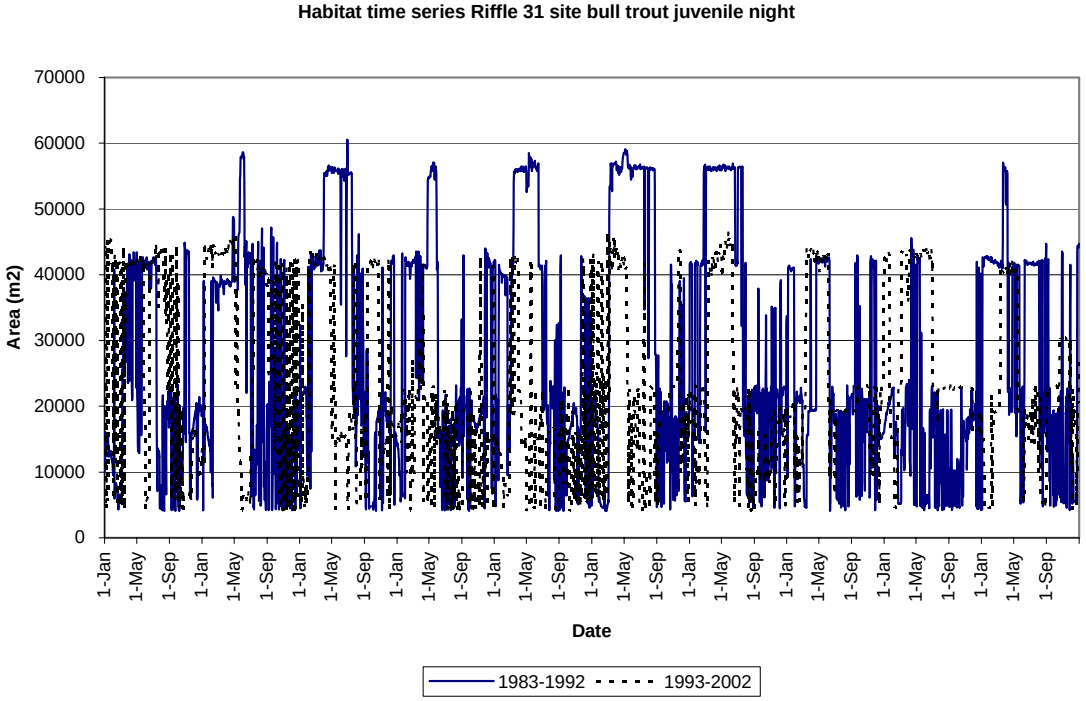


**Figure 44. Juvenile bull trout (night) habitat time series using average daily flow for 2, 10 year time periods at Riffle 31 site.**

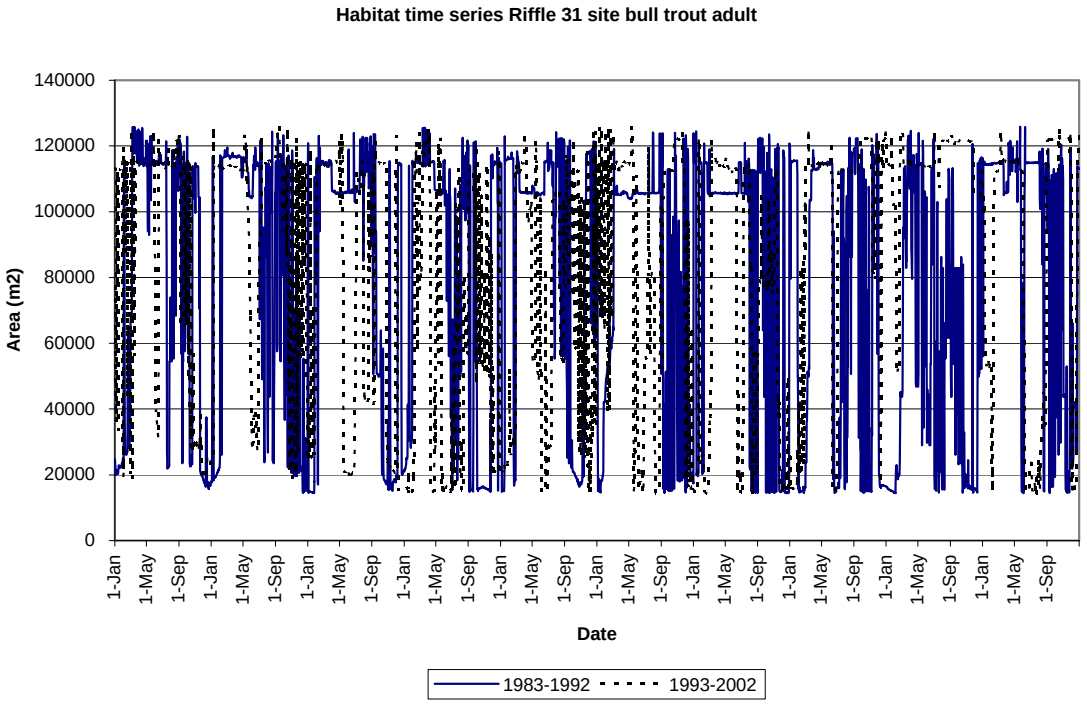


**Figure 45. Adult bull trout habitat time series using average daily flow for 2, 10 year time periods at Riffle 31 site.**

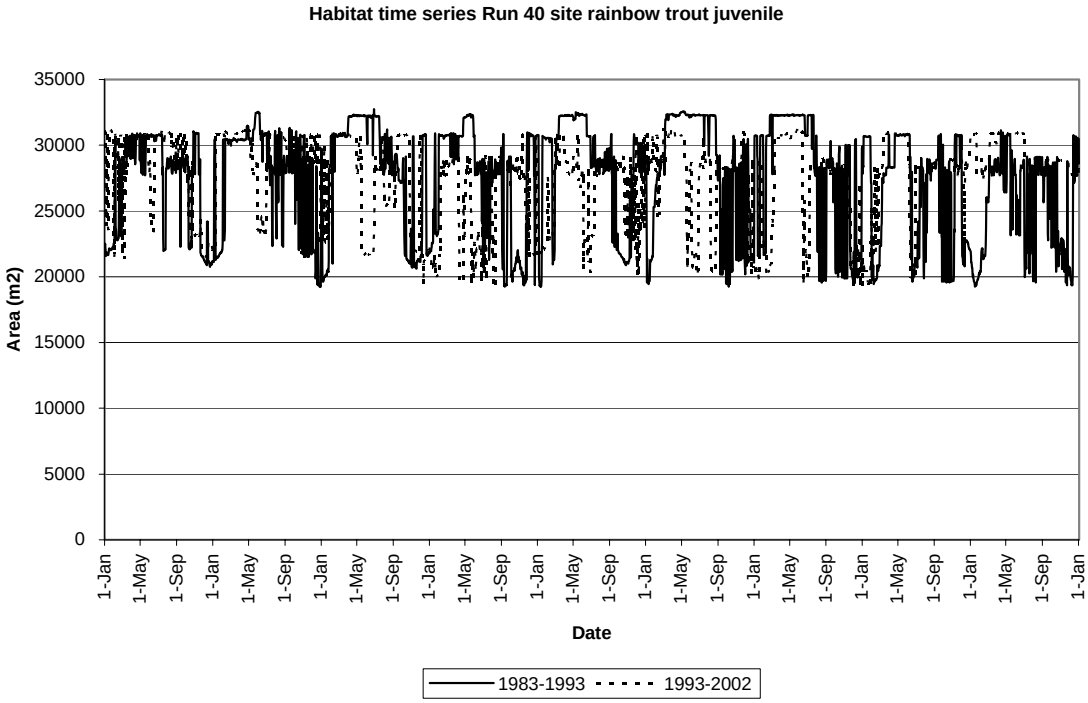


**Figure 46. Juvenile rainbow trout habitat time series using average daily flow for 2, 10 year time periods at Run 40 site.**

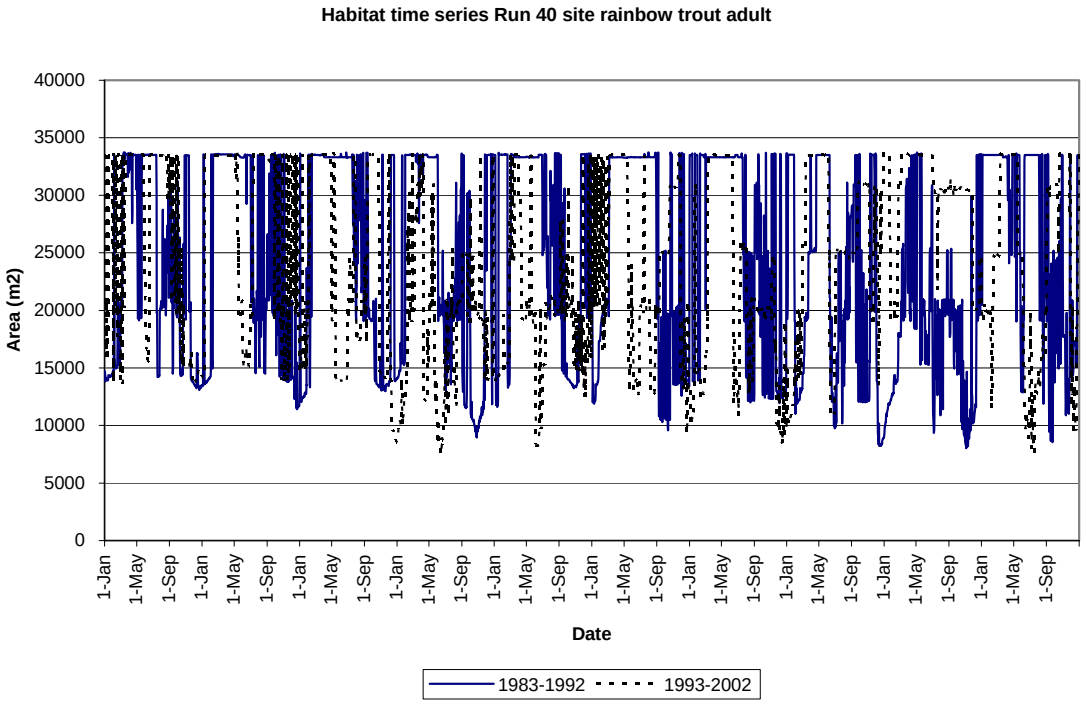


**Figure 47. Adult rainbow trout habitat time series using average daily flow for 2, 10 year time periods at Run 40 site.**

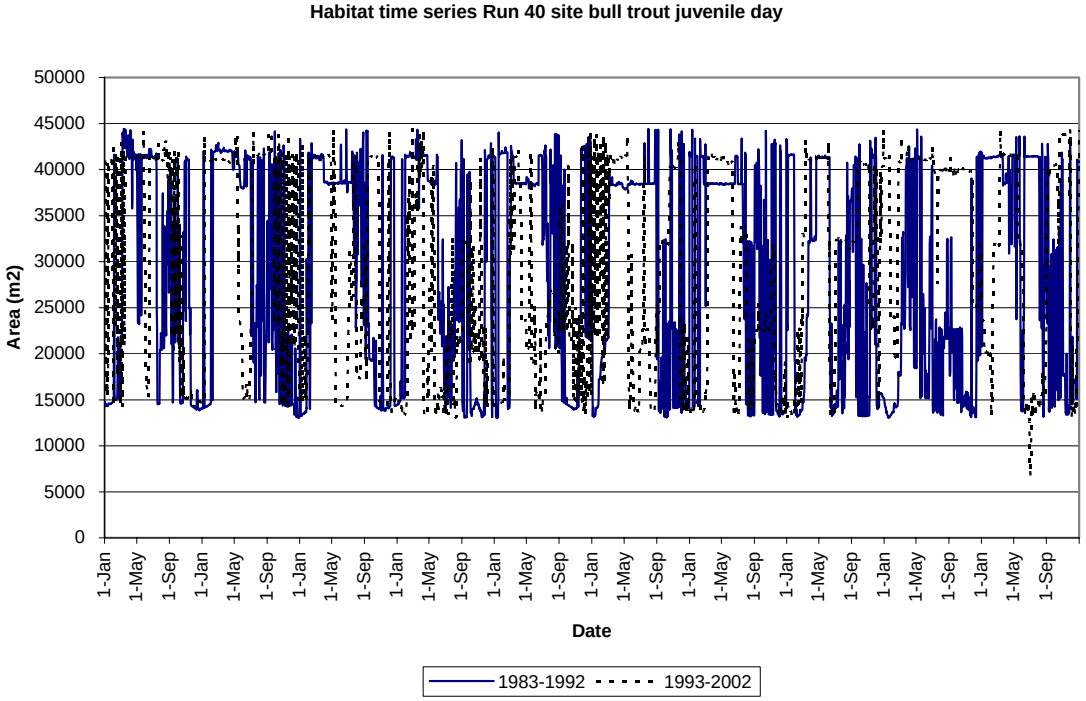


**Figure 48. Juvenile bull trout (day) habitat time series using average daily flow for 2, 10 year time periods at Run 40 site.**

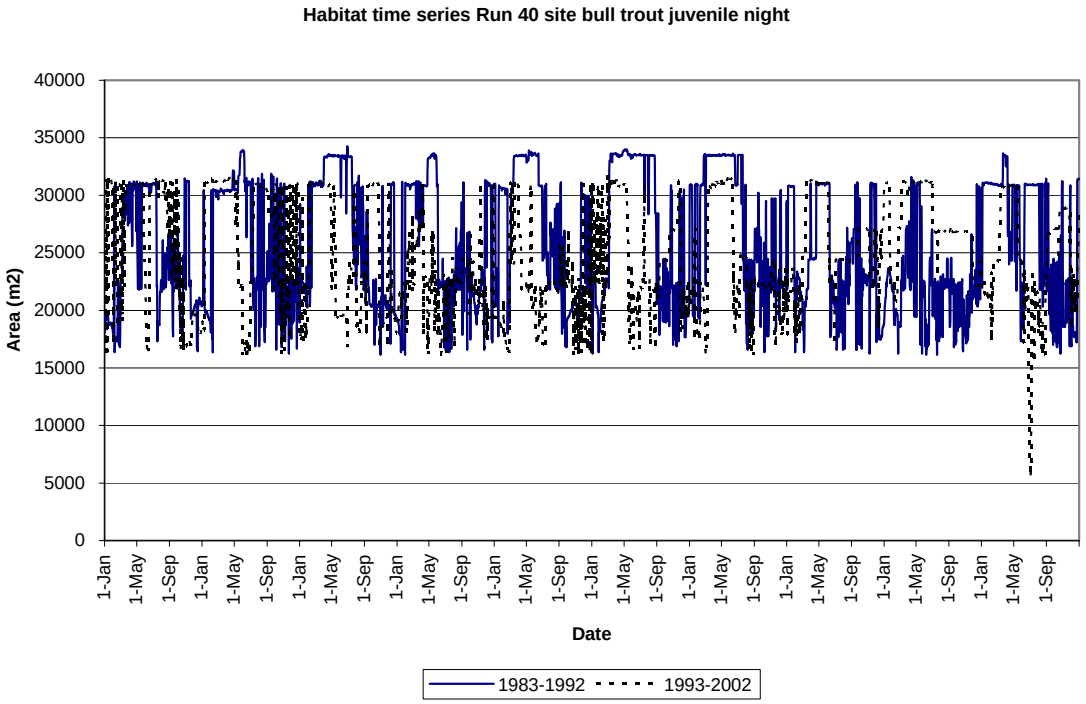


**Figure 49. Juvenile bull trout (night) habitat time series using average daily flow for 2, 10 year time periods at Run 40 site.**

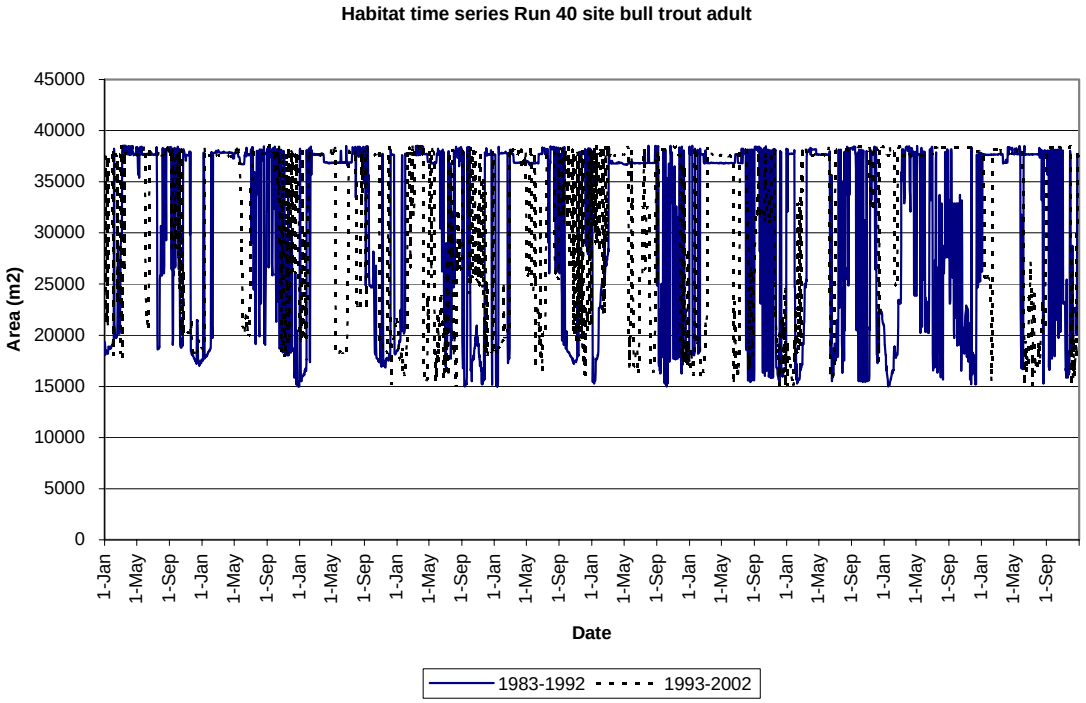


**Figure 50. Adult bull trout habitat time series using average daily flow for 2, 10 year time periods at Run 40 site.**

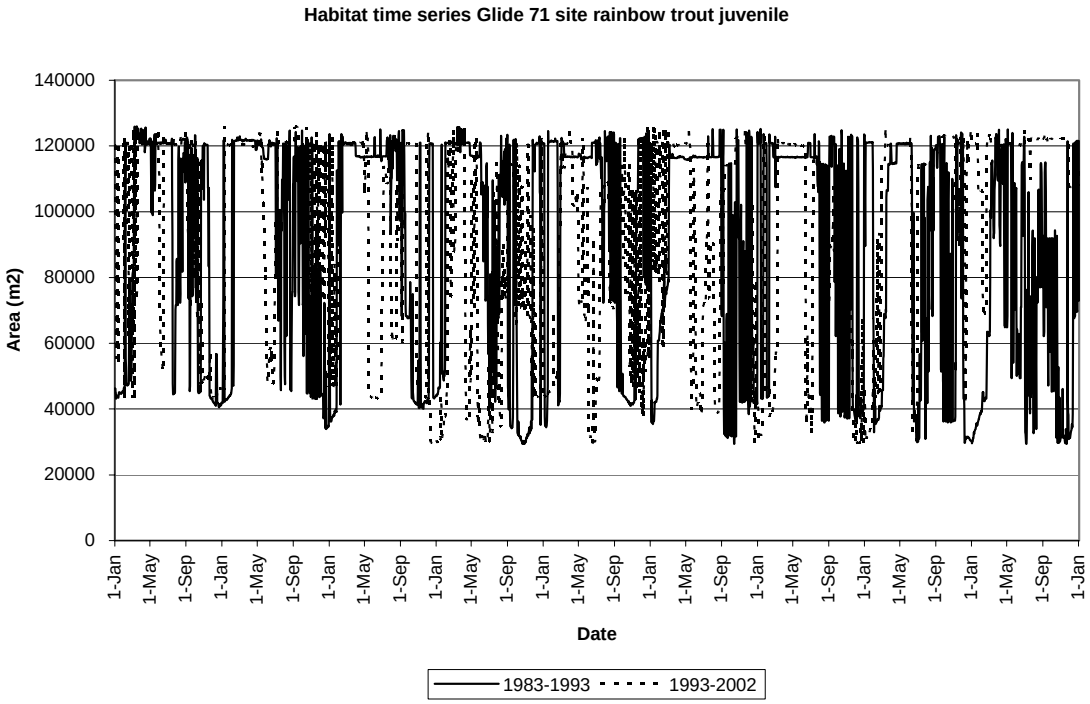


**Figure 51. Juvenile rainbow trout habitat time series using average daily flow for 2, 10 year time periods at Glide 71 site.**

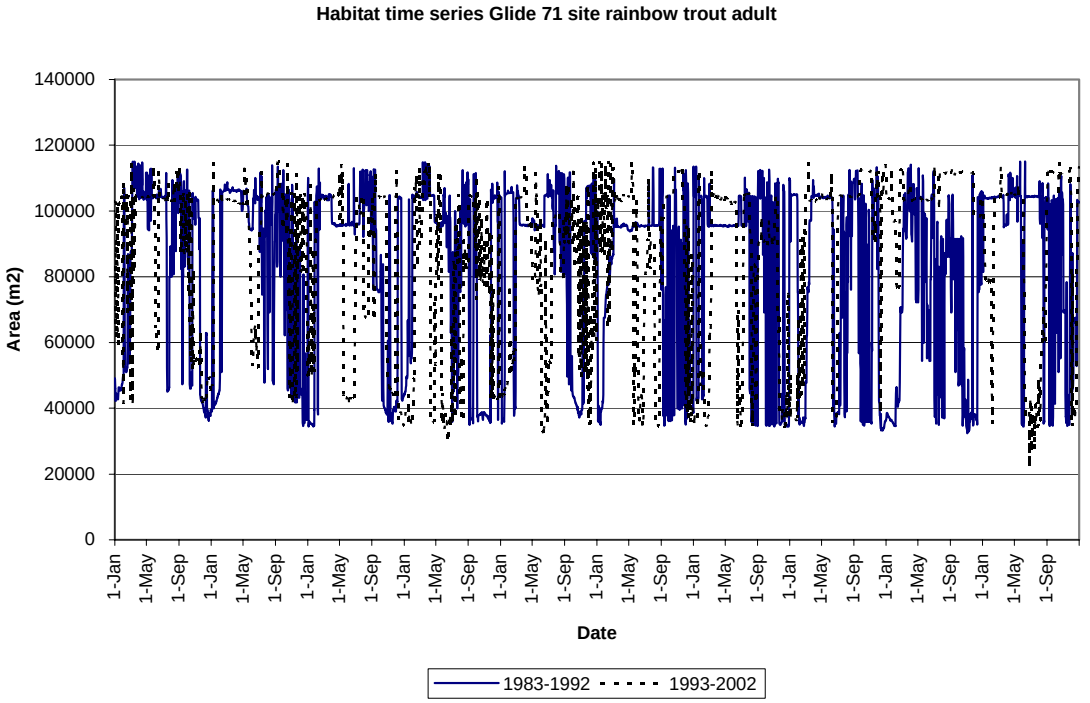


**Figure 52. Adult rainbow trout habitat time series using average daily flow for 2, 10 year time periods at Glide 71 site.**

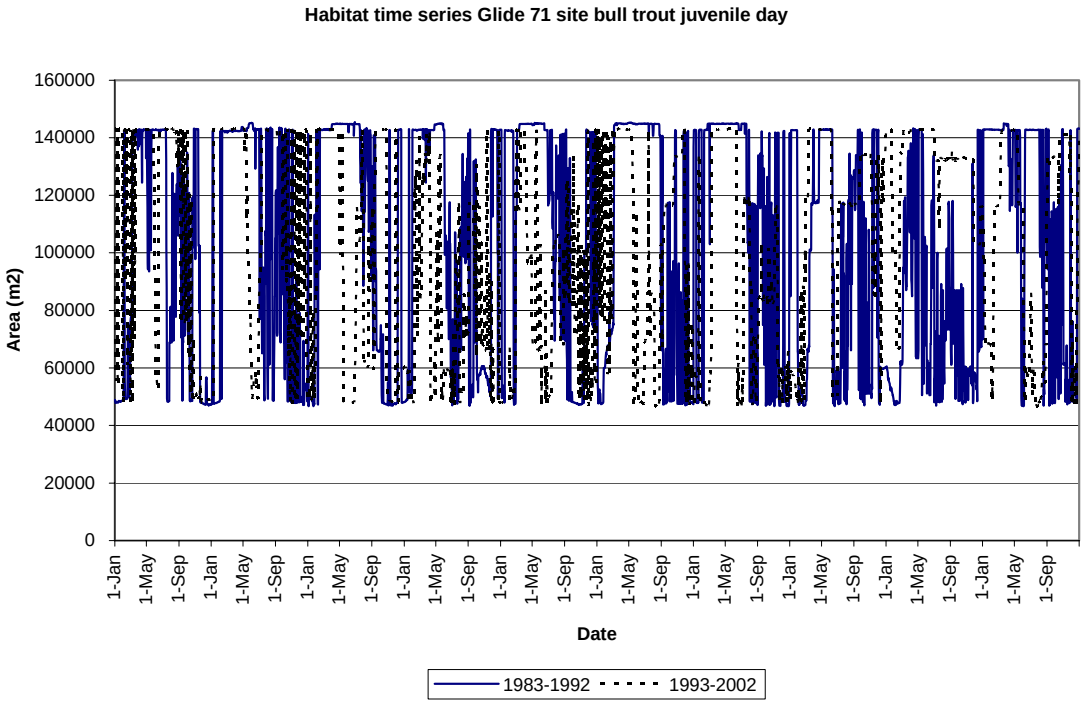


**Figure 53. Juvenile bull trout (day) habitat time series using average daily flow for 2, 10 year time periods at Glide 71 site.**

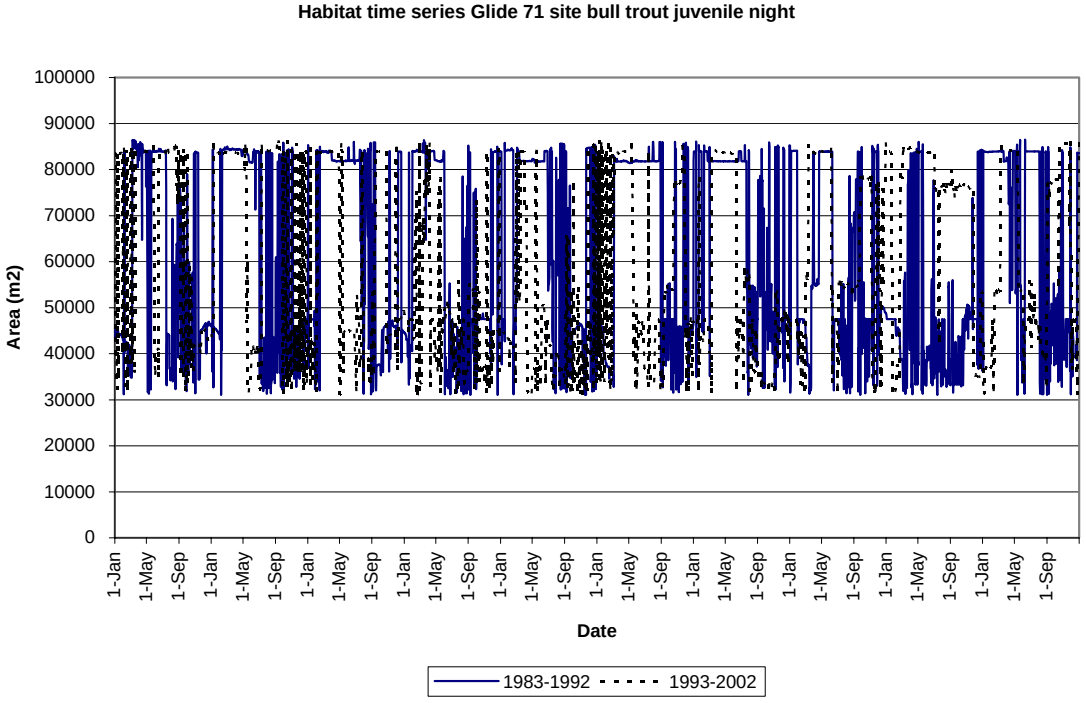


**Figure 54. Juvenile bull trout (night) habitat time series using average daily flow for 2, 10 year time periods at Glide 71 site.**

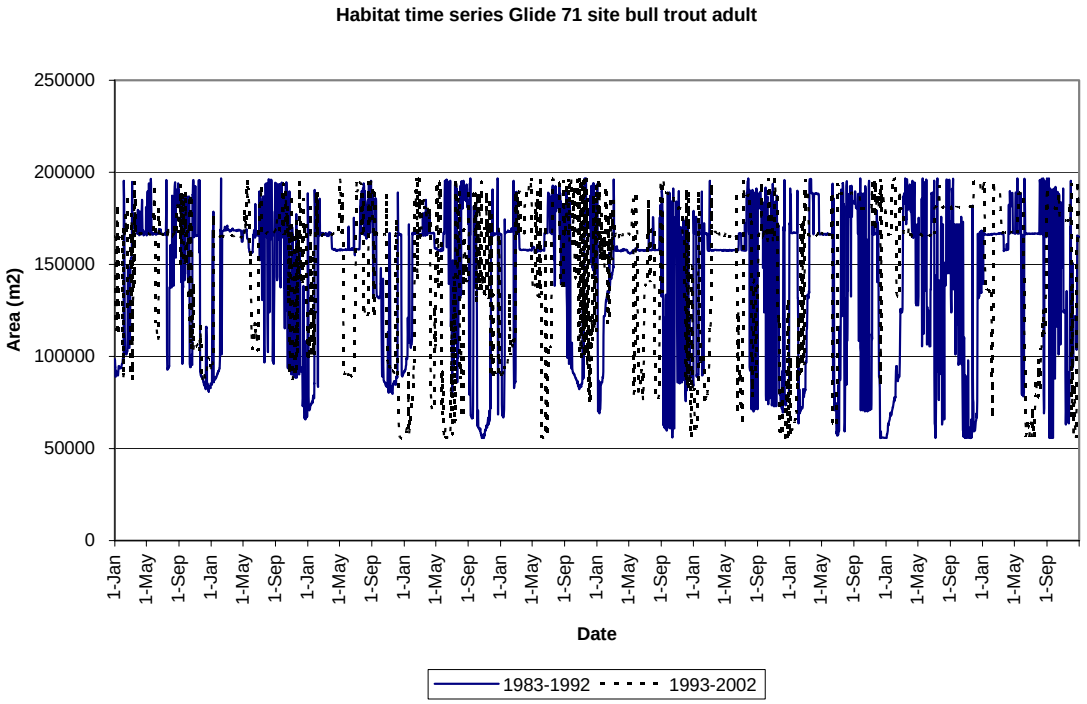


**Figure 55. Adult bull trout habitat time series using average daily flow for 2, 10 year time periods at Glide 71 site.**

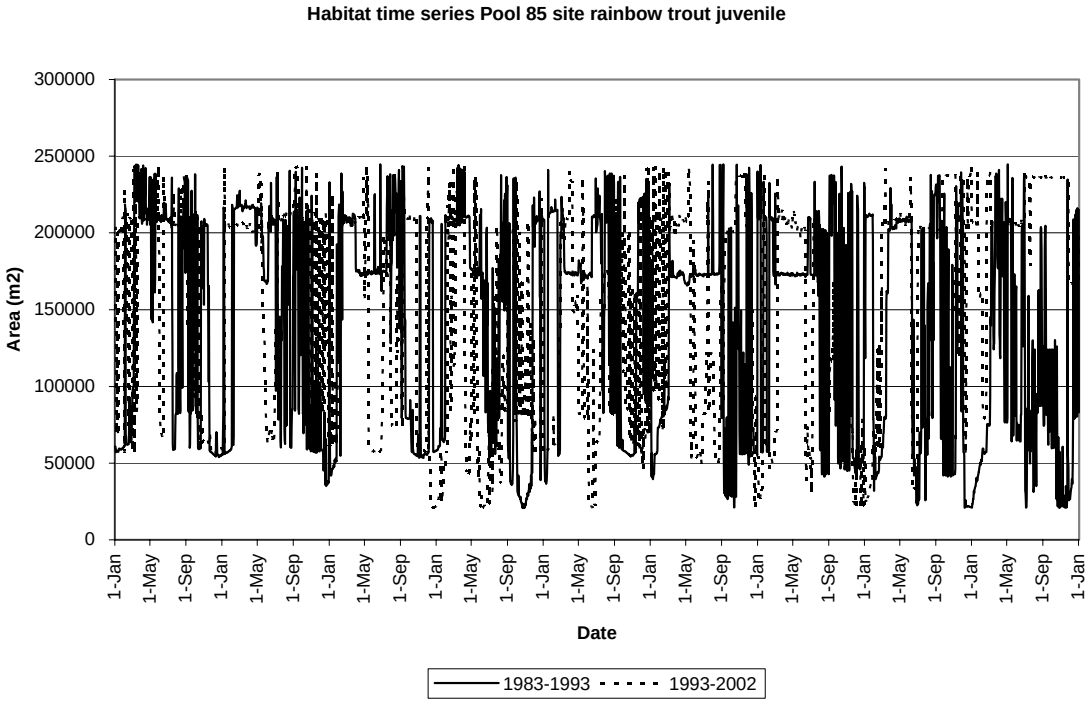


**Figure 56. Juvenile rainbow trout habitat time series using average daily flow for 2, 10 year time periods at Pool 85 site.**

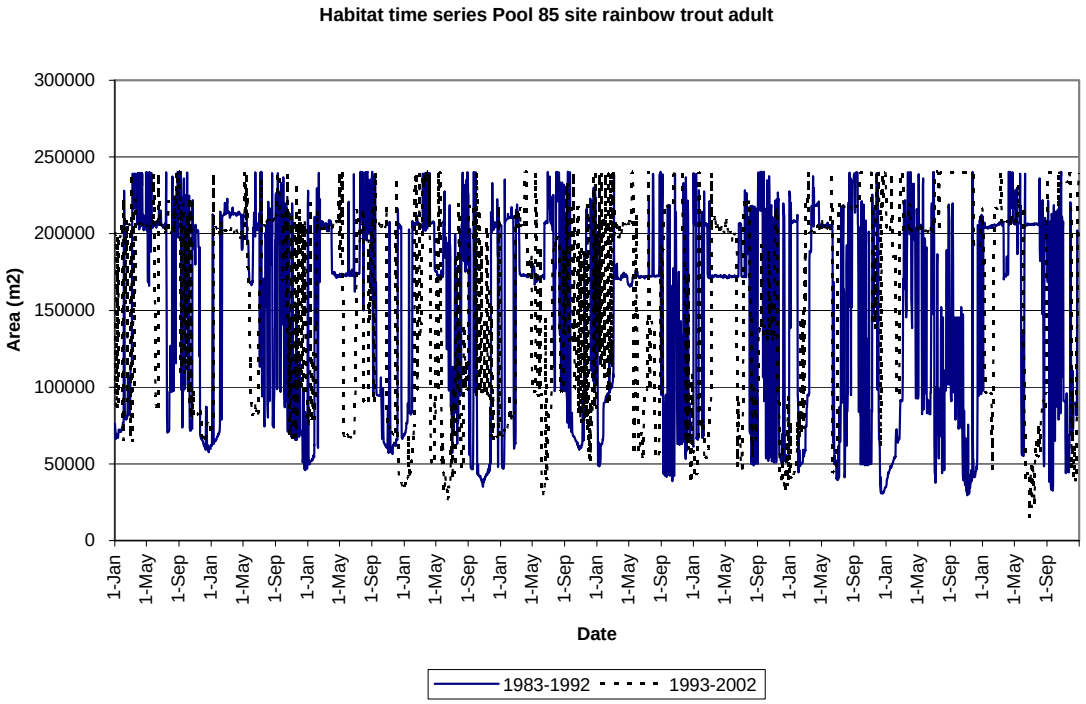


**Figure 57. Adult rainbow trout habitat time series using average daily flow for 2, 10 year time periods at Pool 85 site.**

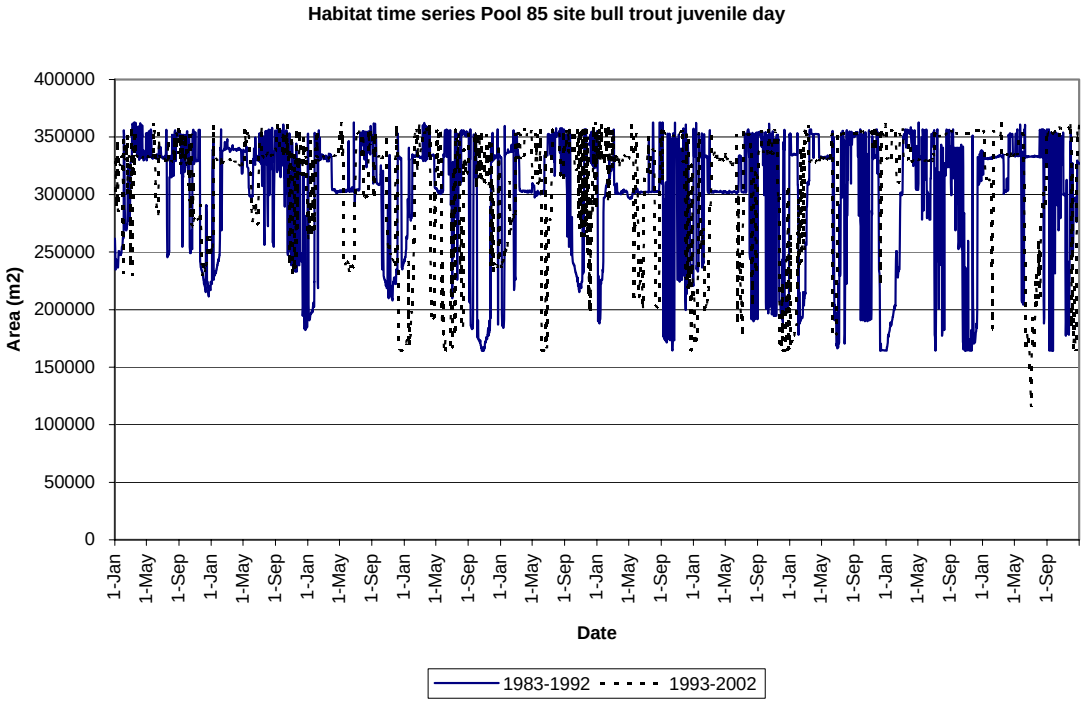


**Figure 58. Juvenile bull trout (day) habitat time series using average daily flow for 2, 10 year time periods at Pool 85 site.**

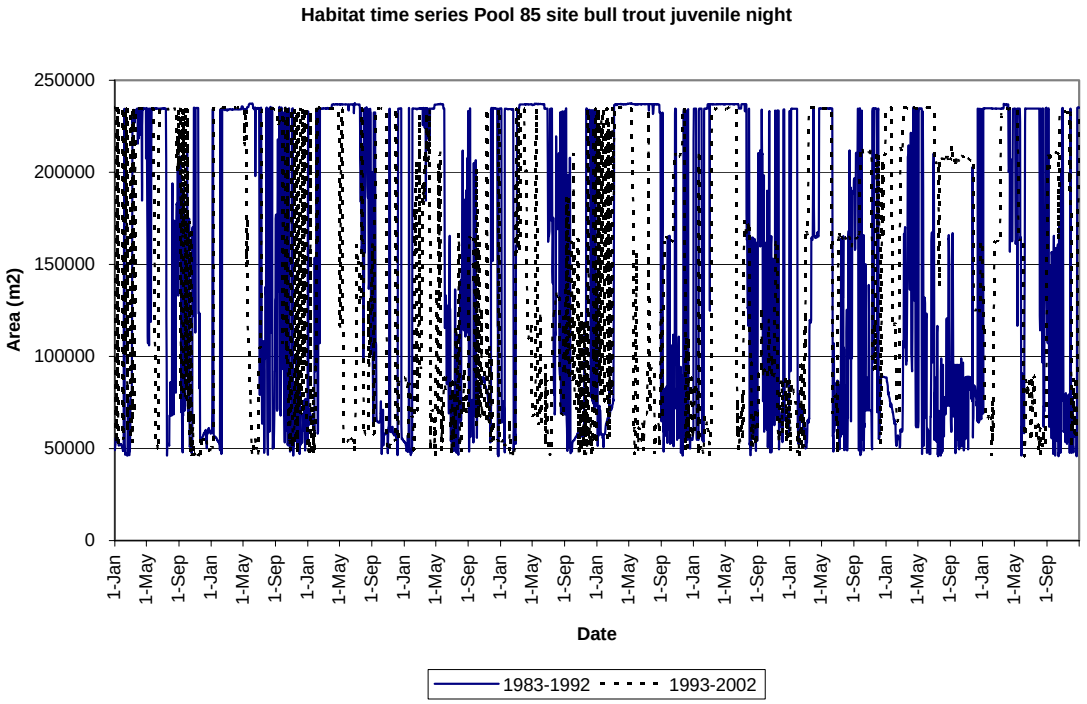


**Figure 59. Juvenile bull trout (night) habitat time series using average daily flow for 2, 10 year time periods at Pool 85 site.**

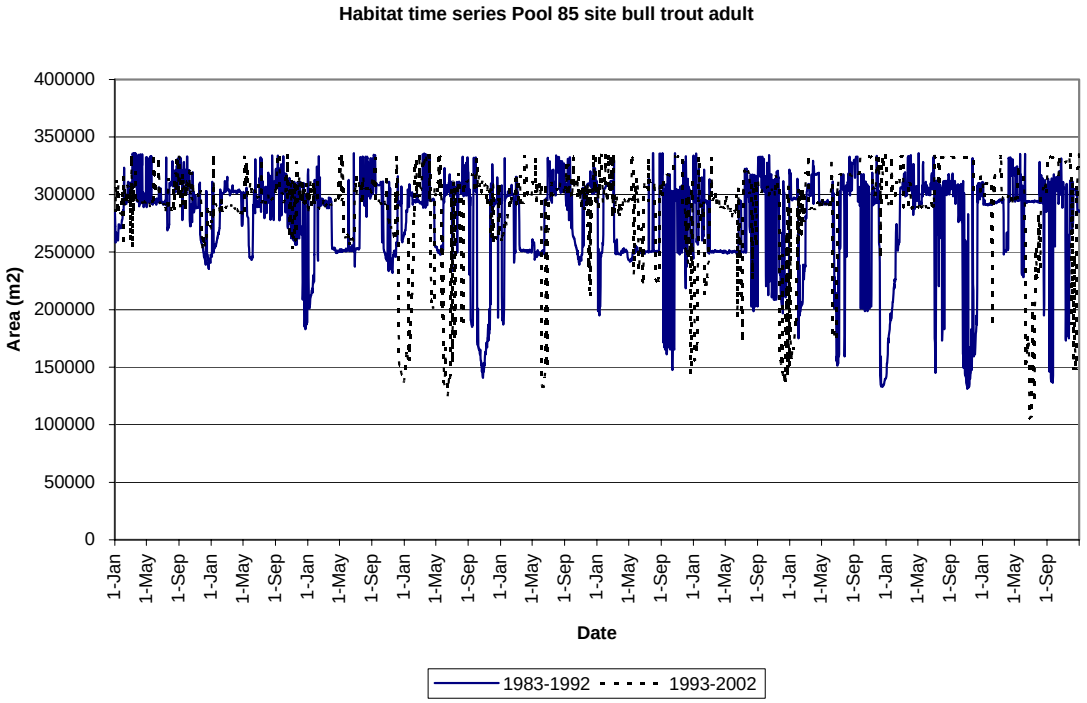


**Figure 60. Adult bull trout habitat time series using average daily flow for 2, 10 year time periods at Pool 85 site.**

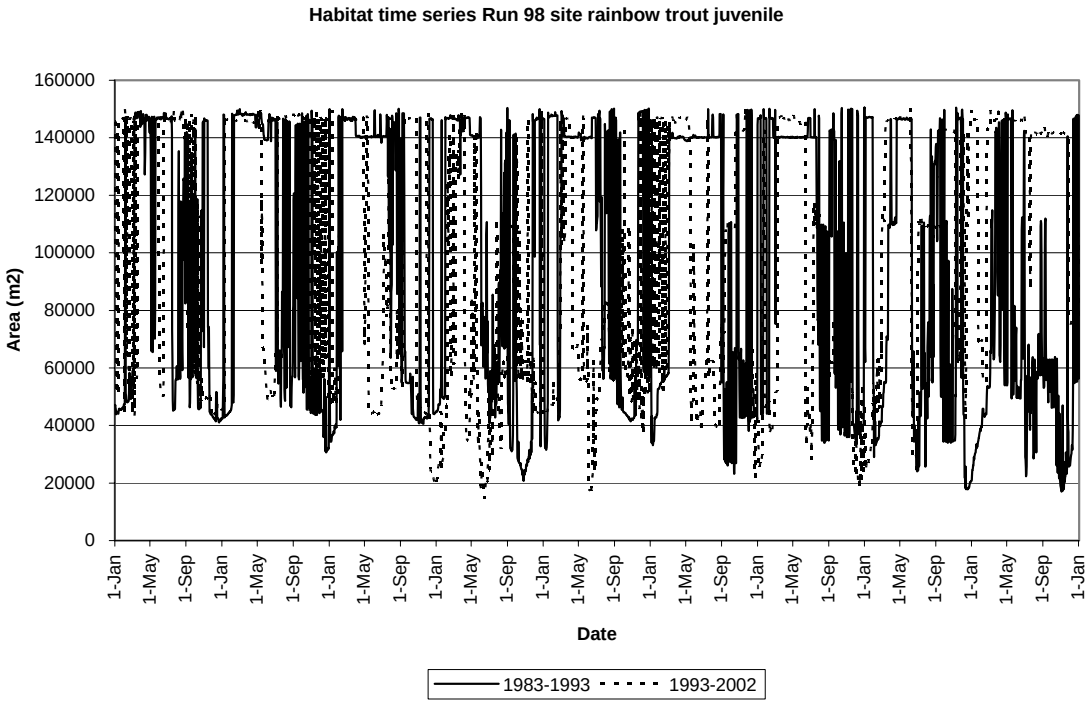


**Figure 61. Juvenile rainbow trout habitat time series using average daily flow for 2, 10 year time periods at Run 98 site.**

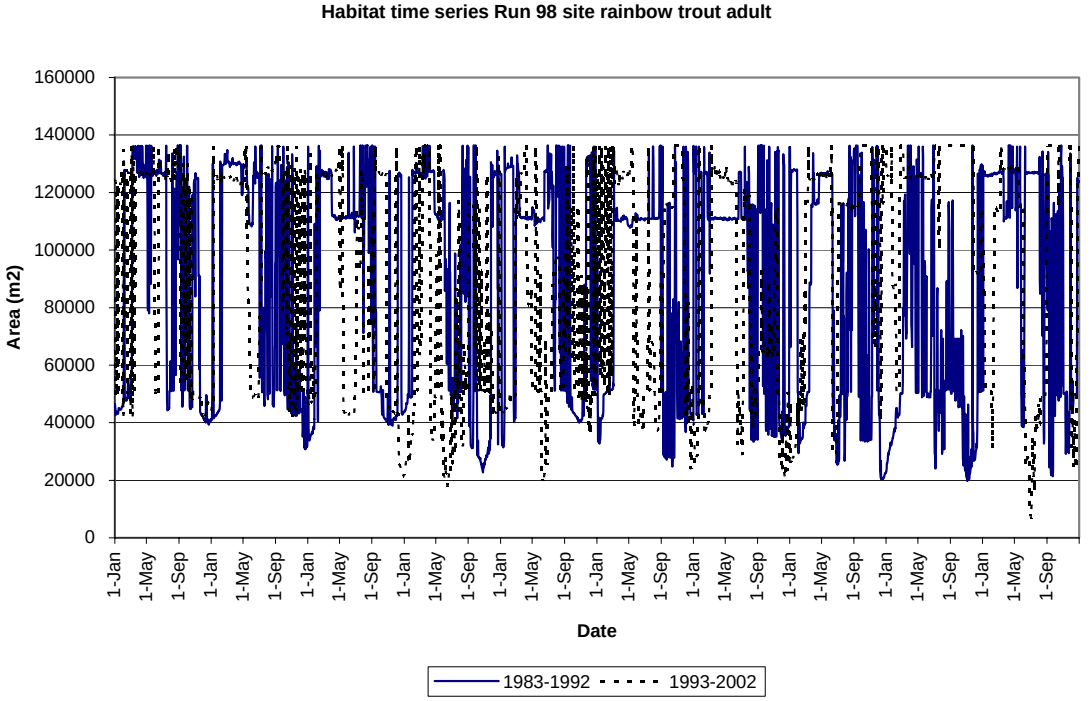


**Figure 62. Adult rainbow trout habitat time series using average daily flow for 2, 10 year time periods at Run 98 site.**

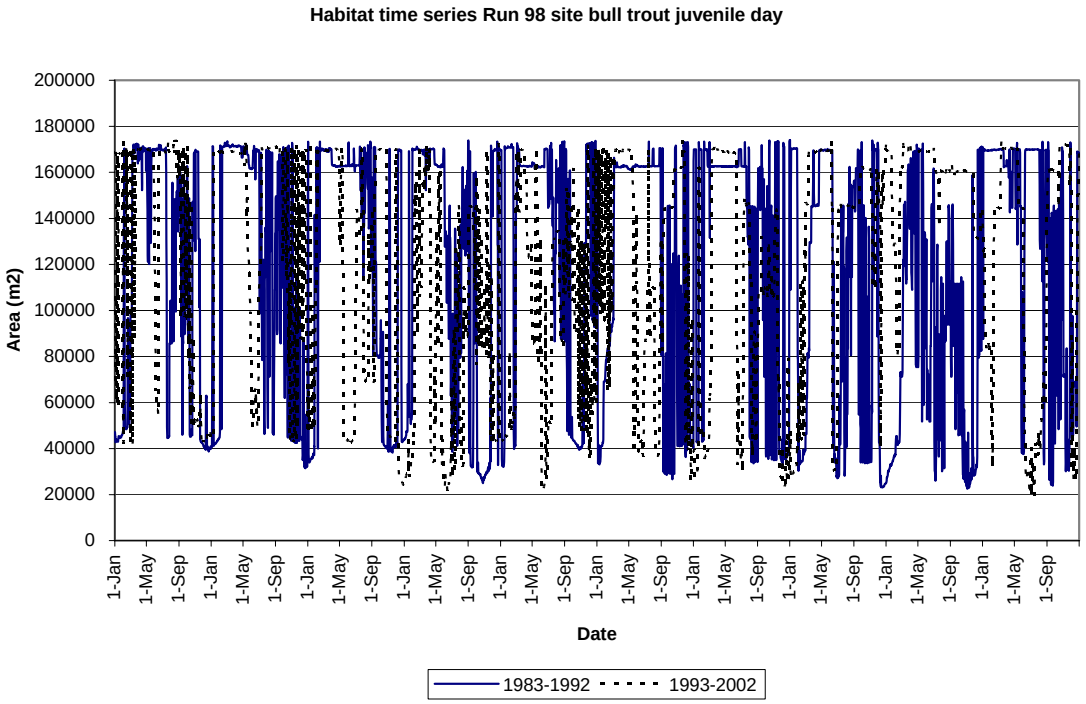


**Figure 63. Juvenile bull trout (day) habitat time series using average daily flow for 2, 10 year time periods at Run 98 site.**

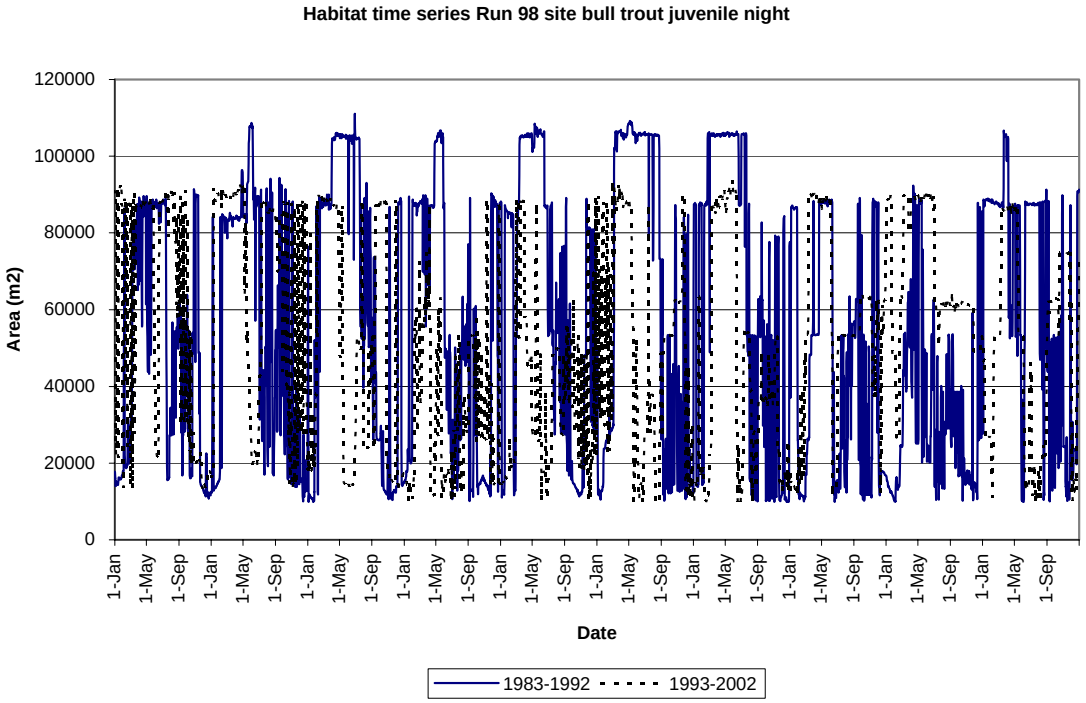


**Figure 64. Juvenile bull trout (night) habitat time series using average daily flow for 2, 10 year time periods at Run 98 site.**

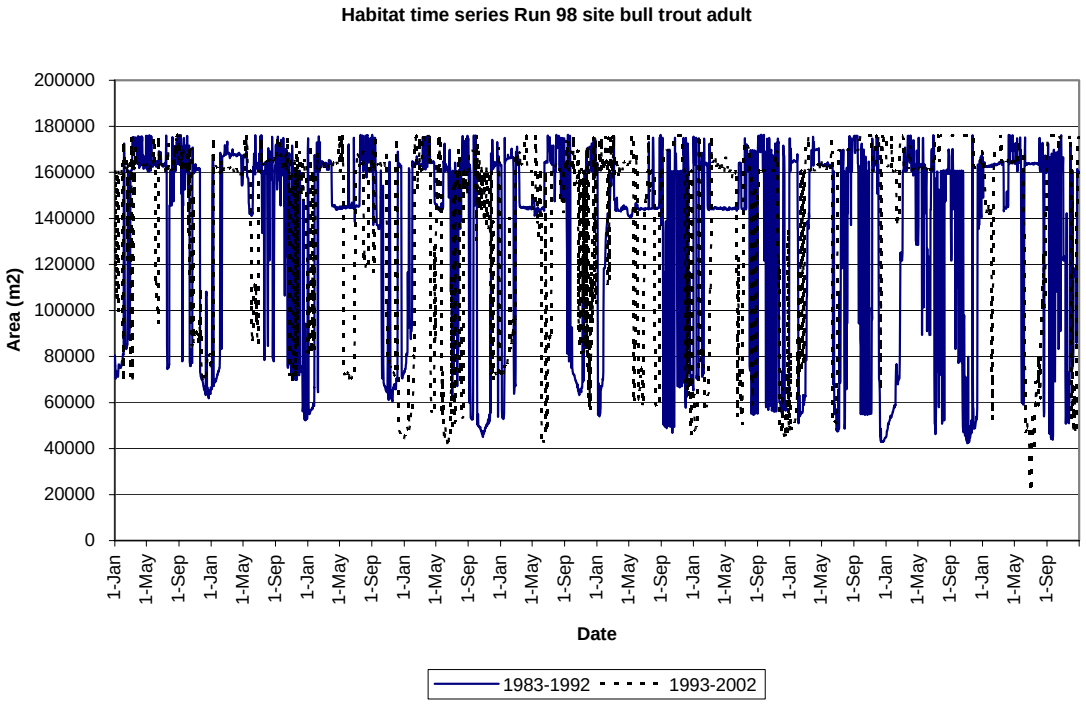


**Figure 65. Adult bull trout habitat time series using average daily flow for 2, 10 year time periods at Run 98 site.**