Final Report

Evaluation of River Health

Roaring Fork River near Aspen, Colorado

Contract # 114-2010

Submitted to:

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Executive Summary

The objective of this study was to determine current baseline river health conditions in the Roaring Fork River from the Salvation Ditch diversion downstream to the confluence with Castle Creek. This study included both physical and biological evaluations. The physical components of the study include year-round hydrology, stream channel characteristics (including the near stream riparian zone), stream stability, and instream habitat. The biological components of the study include benthic macroinvertebrates and fish populations.

The study approach was a multi-phased analysis that included: 1) hydrologic analysis of existing and natural stream flows, 2) stream channel characteristics including cross-sectional and longitudinal profiles, 3) geomorphic assessment of stream stability, 4) instream habitat evaluation using two-dimensional modeling methods, 5) benthic macroinvertebrate sampling, and 6) fish population sampling.

The study area is the Roaring Fork River between the Salvation Ditch diversion and the confluence of Castle Creek, a distance of approximately 3.2 miles. The urban environment of the city of Aspen surrounds the majority of the river within this reach.

The Roaring Fork River study reach has two distinct hydrologic subreaches: 1) from the Salvation Ditch downstream to Hunter Creek, and 2) from Hunter Creek downstream to Castle Creek. A continuous time series of daily flows from the period 1977 to 2009 was developed using USGS gaging stations 09073400 (Roaring Fork River near Aspen, CO) and 09074000 (Hunter Creek near Aspen, CO) and the Salvation Ditch diversion records.

Stream stability and geomorphic characteristics were included in the study. During the initial data collection in September 2010, man-made structures were identified in the study reach that appeared to impact the natural functions of the river channel. Several man-made structures and channel modifications have been constructed in the river in an effort to improve fish habitat and to create recreational features. In addition, structures were place to protect underground utilities at the stream crossings. However, these structures may now be creating detrimental impacts to both channel stability and fish habitat. The original study was expanded to include a geomorphic assessment of the stability of the river to evaluate if these structures are a benefit or a detriment to the river channel.

This study used the two-dimensional hydraulic model River2D for hydraulic analysis. The information presented in this report includes an analytical model that combines two-dimensional hydraulics, a GIS habitat model, and hydrologic data into a habitat time series. This approach follows the concepts of the Instream Flow Incremental Methodology (IFIM) (Bovee 1982, Bovee et al. 1998). IFIM is an analysis framework that combines stream hydraulics, habitat use criteria, and hydrology data to predict fish habitat as a function of stream flow. Stream hydraulics were measured in the field and modeled with the two-dimensional hydraulic simulations. Existing habitat suitability data from the Colorado Division of Wildlife were used for the target fish species. These habitat criteria were combined with the hydraulic simulations in a GIS habitat

model to calculate habitat versus discharge relationships. The habitat versus discharge relationships were combined with hydrology data to calculate habitat over time.

The benthic macroinvertebrate community was sampled for two reasons: 1) macroinvertebrates are a major food source for many fish species. Estimates of density and biomass can indicate the availability of food for fish. 2) certain macroinvertebrate metrics are indicators of water quality and stream conditions.

The fish community was sampled via electrofishing. Two backpack electrofishers with three anodes were used to collect fish. The total length of stream sampled was 690 feet and was within the reach modeled for instream habitat.

The hydrograph of the Roaring Fork downstream of Salvation Ditch is very similar to the hydrograph for the Roaring Fork River upstream of the Salvation Ditch. This suggests that, on a large scale, diversions to the Salvation Ditch do not affect the general shape of the hydrograph of the Roaring Fork River. However, at a finer scale, it is apparent that diversions to the Salvation Ditch can significantly decrease the amount of water in the Roaring Fork, particularly in late summer. Flows in the Roaring Fork have been in the single digits in several years and all water was completely diverted for many days in 1977, 1978, and 1980.

The reach of the Roaring Fork River through the City of Aspen is significantly encroached upon as a result of urban development. Very little of the river's floodplain remains along the river corridor and upstream diversions, and man-made perturbations within the watershed have changed not only the hydrology of the system, but also a whole host of other functions and processes including the sediment transport characteristics of the river. As indicated in the watershed report (Clarke et al. 2008), the natural in-stream and riparian habitat quality in this reach of the river is considered severely degraded as a result of these perturbations.

Contributing to the degraded in-stream habitat is the presence of boulder grade control structures placed to protect exposed utility crossings and to provide flow to man-made split flow channels. These structures create significant vertical drops that are an impediment to fish passage as well as inducing localized upstream aggradation that reduces the flow depth, increases the channel width through bank erosion, and buries spawning substrates within the aggraded reach.

The boulder structures appear to create a significant impediment to fish passage during low flows, but may develop a large scour hole and depositional zone downstream that may provide some beneficial habitat. However, the structures also creates a significant flattening of the channel gradient for a short distance upstream, which in turn also induces localized aggradation which reduces the quality of in-stream habitat and spawning substrate at that location. Both the structures and upstream aggradation can also induce or contribute to bank erosion at the ends of the structures as well as immediately upstream of the structure. Bank erosion at the ends of the structures can result in flanking or significant damage to the structures.

The structures at three of the locations were constructed to protect exposed sewer pipeline crossings. Since it is imperative that these crossing be protected, it would be beneficial to river function to modify the protecting structures such that they still provide maximum protection to the pipelines as well as provide fish passage at all flows. A number of agencies provide design guidance for grade control features that also allow for fish passage. For example, one method of grade control consists of a series of rock weirs placed such that flow is allowed to pass over and around the overall structure while maintain unobstructed fish passage as well as grade control.

At this time, we would recommend that the Healthy Rivers and Streams Program, in cooperation with the City of Aspen and Pitkin County reconstruct the boulder structures using a series of weirs. We would also recommend the complete removal of the structure at Jenny Adair Park as it appears to serve no other purpose than an aesthetic one. If the split flow channel at this location is, in fact, used by the Aspen Center for Environmental Studies and serves a useful purpose, we would recommend that the boulder grade control structure used to divert flows into the split flow channel still be removed, but that the diversion point be located much further upstream. This can be accomplished by extending the upper end of the split flow channel further upstream to a point where flow can be successfully diverted without requiring a diversion structure while maintaining adequate flow depths and widths as well as fish passage at all flow levels. We also recommend the removal of the pipelines crossing the river downstream of Mill Street. The pipelines create an impediment to the natural flow lines and could trap floating debris at higher flows. These pipelines appear to be abandoned and if so, should be removed.

The kayak park upstream of the Aspen Art Museum also impacts natural river channel function. We recommend the complete removal of the course and reclamation of the area occupied by the course to a functional floodplain. Based on our knowledge of the course, it appears that the course is used infrequently and only when there is sufficient flow, such as during spring runoff. Thus, the course is only viable for a short period during the entire year and will likely require ongoing maintenance to keep the course pools clear of sediment and organic debris. The fine sediment and slow velocities at low flows are excellent habitat for tubifex worms that can host whirling disease. Removal of the course would remove this habitat from the river. The kayak channel could be reclaimed by removing the excavated material from the intervening island and refilling the kayak channel with little to no effect on in-stream habitat on the main channel of the river. By refilling the kayak channel, the floodplain area occupied by the island that was covered with the material previously excavated from the kayak channel would also be restored. Reshaping of the left bank of the river and replanting riparian vegetation on the reclaimed island/floodplain area would also contribute to habitat diversity in this reach.

We suggest that Pitkin County, through its Healthy Rivers and Streams Board, initiate discussions with the appropriate city, county, and private entities regarding the above recommendations to restore stream channel function. These initial discussions could assist these groups to: 1) prioritize the recommended channel restorations in this report; 2) begin the process for channel restorations; and 3) develop a long term strategy for maintaining river health and function.

Instream habitat for each species is a function of both quantity and quality. Both of these characteristics vary with discharge. Habitat versus discharge relationships for rainbow trout show the greatest amount of habitat between 98 and 200 cfs. Juvenile habitat is more abundant than other life stages at all discharges and peaks at 150 cfs. Adult habitat peaks at 200 cfs and fry habitat is most abundant at 98 cfs. Spawning habitat is essentially non-existent except at the lowest flows.

Habitat versus discharge relationships for brown trout show the greatest amount of habitat between 98 and 150 cfs. Brown trout fry and spawning habitat use a common suitability with rainbow trout and therefore the relationship is the same as the rainbow trout function. Juvenile habitat is more abundant than other life stages at all discharges and peaks at 150 cfs. Adult habitat peaks at 98 cfs and fry habitat is most abundant at 98 cfs as well. Overall, juvenile habitat for rainbow trout and brown trout is similar for a given flow. In contrast, more habitat is available for adult rainbow trout than for adult brown trout.

Differences in habitat quality are also apparent. For example, while adult brown trout habitat peaks at 98 cfs, the highest habitat quality occurs at 200 cfs. For rainbow trout, the highest habitat quality occurs at 150 cfs for adults and 98 cfs for juveniles. For brown trout, the highest habitat quality occurs at 200 cfs for adults and 90 cfs for juveniles. Trout fry habitat quality peaks at 98 cfs. High-quality spawning habitat is not present at this site.

Chironomid midges (subfamily Orthocladinae) dominated the macroinvertebrate community, comprising 40% of the sample (all three replicates combined). 32% of the sample consisted of the caddisfly *Brachycentrus americanus*. In all, 29 different taxa were collected. Of these, 7 taxa were from the Ephemeroptera, Plecoptera, and Trichoptera (EPT) orders. The EPT values at the study site are lower than EPT values from upstream and downstream sites in the Roaring Fork and sites in nearby Castle and Maroon creeks. The EPT index at a Roaring Fork site upstream of the Northstar Open Space was 12 – 15 (Miller 2010). EPT indexes for Castle and Maroon creeks ranged from 15-21 and 20-23, respectively (Miller and Swaim 2011). At a downstream site in the Roaring Fork near Basalt sampled by MEC (Ptacek et al. 2003) the EPT index ranged from 22-29. Compared to these other local sites, an EPT index of 7 at the Roaring Fork downstream of Mill Street is low and indicates some type of degradation.

The existing flow regime in the Roaring Fork River includes most of the components for proper ecological function. There are high peak flows that exceed bank full conditions on a regular basis (one in two years). However, these flows are reduced by some degree due to the transbasin diversion in the headwaters of both the Roaring Fork River and Hunter Creek. The current peak flows provide the conditions to create and maintain habitat, particularly in wet hydrologic conditions for the existing river channel. In addition, these flows provide the conditions to maintain near stream riparian conditions. The ascending and descending limbs of the peak runoff have a natural shape determined by each year's snowpack and are not abruptly truncated by diversions.

The late summer base flows appear to be most effected by upstream diversions. The Colorado Water Conservation Board (CWCB) holds an instream flow for 32 cfs in the study area, which is junior to other upstream water rights. The late summer flows are lower than 32 cfs in many years. In several years the low flows are between 15-20 cfs. Flows in this range have less wetted area available for macroinvertebrate production than flows greater than 30 cfs. There is approximately 20% less wetted habitat at 17 cfs than at 30 cfs. If minimum flows were maintained at the specified level (i.e. 32 cfs), invertebrate food base would likely increase with the wetted area. The current EPT macroinvertebrate community at the study site is less robust than either upstream or downstream of the study area. The cause of this decline in the macroinvertebrates is unknown. Although there is a difference in the species present in the study site, the density and biomass for the study site is similar to other locations with higher EPT values. Additional sampling at multiple locations could potentially identify the cause of the reduction in EPT species if it is caused by a point discharge. The location of the source of impact may not be discernable, if the cause is the general watershed characteristics within the city.

Instream fish habitat also substantially changes between 17.5 and 30 cfs or greater discharge. Instream habitat for adult and juvenile rainbow and brown trout increases by more than 30% when flow increases from 17 to 30 cfs. Maintaining higher summer base flows may result in higher fish populations in the study area. The current fish populations, especially brown trout are good for the size of river. The fish condition factor for both trout species is good as well, indicating that the food resources are adequate to support the current populations.

The data collected in this study indicate that the Roaring Fork River in the study area has a macroinvertebrate community that indicates slight degradation of water quality compared with locations upstream and downstream of the study area. The trout in the study area have good body condition indicating that the food base is adequate to support the current populations. The brown trout population has all size classes present indicating that natural reproduction is occurring and the fish survive and recruit to older age classes. Rainbow trout do not have this same age class distribution but it is likely due to factors such as whirling disease rather than flow. Rainbow trout are stocked by Colorado Parks and Wildlife and do survive and grow in the study area.

To maintain the current stream habitat conditions, peak flows greater than 350 cfs should occur every other year and peak flows greater than 1000 cfs should occur approximately 1 in 10 years. The ascending and descending limbs of the hydrograph should be maintained in the current shape without a sharp increase or decrease. Habitat conditions at base flows would be improved by maintaining stream flows at 30 cfs or greater. Additional hydraulic and habitat simulations would be needed to refine the low flow recommendation.

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INTRODUCTION

The Pitkin County Healthy Rivers and Streams Program was established in 2008 and has several objectives, one of which is to maintain and improve water quality and quantity within the Roaring Fork watershed. The program also aims to ensure ecological health and wildlife and riparian habitat by securing, creating, and augmenting minimum stream flows. The program proposed an evaluation of river health in the Roaring Fork River upstream of Castle Creek near Aspen, Colorado. The Roaring Fork River from the Castle Creek confluence upstream to the Salvation Ditch diversion was the reach selected for an initial evaluation. This section of the river was subject to extremely low flows during the drought of 2002 and there is concern that future droughts and other water management activities may cause a lower level of stream health in this reach.

Objectives

The objective of this study was to determine current baseline river health conditions in the study area. This study included both physical and biological evaluations. The physical components of the study include year-round hydrology, stream channel characteristics (including the near stream riparian zone), stream stability, and instream habitat. The biological components of the study include information on benthic macroinvertebrate and fish populations.

The study approach was a multi-phased analysis that included: 1) hydrologic analysis of existing and natural stream flows, 2) stream channel characteristics including cross-sectional and longitudinal profiles, 3) geomorphic assessment of stream stability, 4) instream habitat evaluation using two-dimensional modeling methods, 5) benthic macroinvertebrate sampling, and 6) fish population sampling.

Study Area

The study area is the Roaring Fork River between the Salvation Ditch diversion and the confluence of Castle Creek, a distance of approximately 3.2 miles. The urban environment of the city of Aspen surrounds the majority of the river within this reach (Figure 1). Site reconnaissance for instream habitat modeling and fish and invertebrate sampling took place on August 10, 2010. We determined from the site visit that the river at the Mill Street bridge was representative of the 3.2-mile reach. The study site is 1090 feet long (0.20 miles or 330 meters) (Figure 2). The downstream end of the site occurs at the Rio Grande Trail pedestrian bridge at Jenny Adair Park and the upstream end of the site is just west of the Aspen Art Museum. Photos of the site can be found in Appendix D.

Figure 1. Study reach and hydrologic study reaches of the Roaring Fork River between the Salvation Ditch diversion and the confluence with Castle Creek.

Figure 2. Map of the River2D study site on the Roaring Fork River.

METHODS

Hydrology

The Roaring Fork River study reach extends 3.2 miles, from the Salvation Ditch diversion upstream of the City of Aspen to the confluence with Castle Creek. A major tributary, Hunter Creek, joins the Roaring Fork River in Aspen just downstream of the Aspen wastewater treatment plant. The Roaring Fork River study reach has two distinct hydrologic subreaches: 1) from the Salvation Ditch downstream to Hunter Creek, and 2) from Hunter Creek downstream to Castle Creek (Figure 1). Daily discharge data are available from USGS gaging stations located on the Roaring Fork River upstream of Salvation Ditch and on Hunter Creek about 1.5 miles above its confluence with the Roaring Fork River. In addition, daily records of Salvation Ditch diversions are available from Colorado's Decision Support Systems (CDSS)'s HydroBase, developed by the Colorado Water Conservation Board and the Colorado Division of Water Resources.

A continuous time series of daily flows from the period 1977 to 2009 was developed using USGS gaging stations 09073400 (Roaring Fork River near Aspen, CO) and 09074000 (Hunter Creek near Aspen, CO) and the Salvation Ditch diversion records. Both USGS stations are currently active and have continuous daily flow data for this time period. Flow diversions at Salvation Ditch were subtracted from the flows at USGS gage 09073400 to develop the daily time series for Roaring Fork River flows above Hunter Creek (Reach 1). Daily flows for Hunter Creek were area-adjusted for drainage basin area using USGS regional regression relationships (Capesius and Stephens 2009) and added to the Roaring Fork time series to reconstruct the flow series downstream of the Hunter Creek confluence (Reach 2). Data were missing for the years 2001 and 2002 for the Salvation Ditch diversions. To fill this data gap, daily diversions from 1977-2009 were averaged for each day for the period from May 1st to October 31st. These averages were used as estimates of diversion rates from May 1st to October 31st for 2001 and 2002. From the reconstructed daily flows, "dry", "median", and "wet" years were identified and used for hydraulic modeling and habitat assessment with River2D. Other meaningful hydrologic statistics, such as 7-day and 30-day low flow recurrence intervals, were also extracted from the reconstructed time series.

Stream Stability

During the initial data collection in September 2010, man-made structures were identified in the study reach that appeared to impact the natural functions of the river channel (see Figure 3 for an example). Several man-made structures and channel modifications have been constructed in the river in an effort to improve fish habitat and to create recreational features. In addition, structures were place to protect underground utilities at the stream crossings. However, these structures may now be creating detrimental impacts to both channel stability and fish habitat. The original study was expanded to include a geomorphic assessment of the stability of the river to evaluate if these structures are a benefit or a detriment to the river channel.

A brief review of available literature, maps, and pertinent data was conducted. 2008 orthophotographs and 1-foot contour maps were obtained from the City of Aspen/Pitkin County GIS department. Historical aerial imagery and USGS topographic maps from Google Earth Pro were also examined.

A site reconnaissance documented and assessed the existing geomorphic characteristics and in-channel conditions along the study reach. The reconnaissance was conducted by walking accessible portions of the river or making observations from bridges where access was limited. The assessment focused on the portion of the Roaring Fork River from just below the Rio Grande Trail pedestrian bridge (near the confluence with Castle Creek) to just upstream of the Salvation Ditch diversion. Specific in-channel conditions that were documented included significant bank erosion and lateral retreat, major scour and deposition, areas of aggradation and/or degradation, backwatering, and any other geomorphic characteristics indicative of ongoing or potential channel instability. Other features that were documented included mechanically-placed boulders within the channel, revetments (bank protection), man-made in-channel structures, and artificial encroachments. Locations of all significant geomorphic features were recorded with a handheld sub-meter GIS-based GPS unit.

Figure 3. Example of large boulders placed in the Roaring Fork River at the Rio Grande Trail pedestrian bridge at Jenny Adair Park. Note the elevation change is approximately 2-3 feet.

Instream Habitat

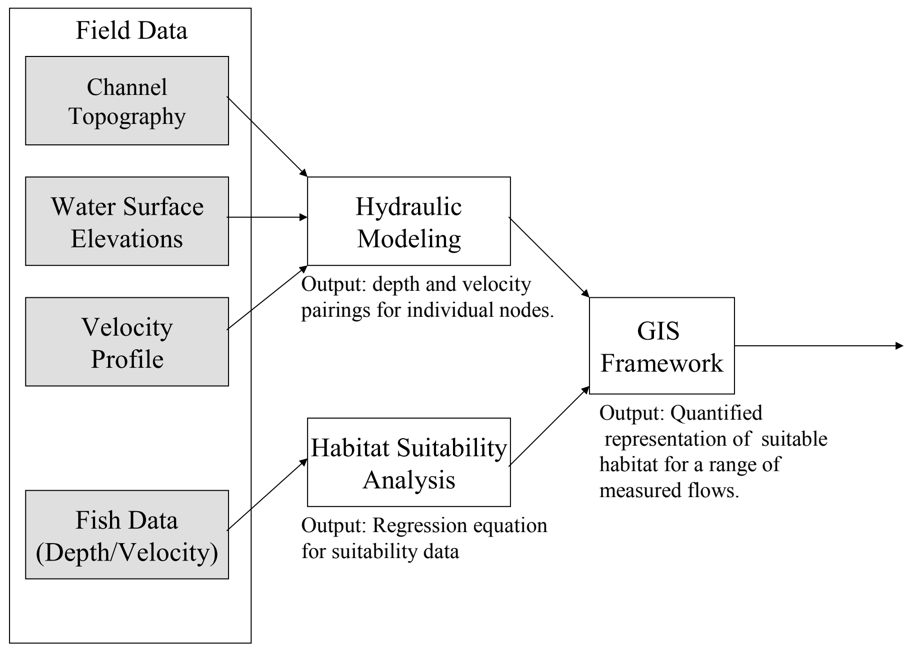
Two-Dimensional Hydraulic and Habitat Modeling – General Approach

The state-of-the-art model used for instream flow studies is the two-dimensional hydraulic model River2D. The information presented in this report includes an analytical model that combines two-dimensional hydraulics, a GIS habitat model, and hydrologic data into a habitat time series. This approach follows the concepts of the Instream Flow Incremental Methodology (IFIM) (Bovee 1982, Bovee et al. 1998). IFIM is an analysis framework that combines stream hydraulics, habitat use criteria, and hydrology data to predict fish habitat as a function of stream flow. Stream hydraulics were measured in the field and modeled with the two-dimensional hydraulic simulations. Existing habitat suitability data from the Colorado Division of Wildlife were used for the target fish species (CDOW unpublished data). These habitat criteria were combined with the hydraulic simulations in a GIS habitat model to calculate habitat versus discharge relationships. The habitat versus discharge relationships were input to a computer spreadsheet and combined with hydrology data to calculate habitat over time. Generally, the time series analysis is the primary output from IFIM, which indicates the changes in habitat for a duration of time (Figure 4).

The IFIM assumes that physical habitat is a function of stream flow level in the streams being studied (Bovee 1982). Part of the scoping process for application of IFIM involves determining the factors that may be limiting to fish populations. The factors evaluated include channel geometry, water temperature, water quality, food sources (such as benthic macroinvertebrates), and management factors affecting fish populations.

Topographic Data Collection

Two-dimensional hydraulic modeling began with construction of a digital terrain map of the study area. Data points were obtained to construct a detailed topography map (or grid) of the channel and adjacent floodplains and terraces. A survey-grade GPS unit was used to collect data points. Within the river channel, data points were closely spaced to define channel geometry in both plan form and cross section. Other channel geometry points, such as toe of bank, top of bank, and even beyond the typical high-water mark, were collected so that various flow regimes can be modeled. Each point's coordinates were in the UTM coordinate system, zone 13N, and elevation recorded in meters. Substrate composition was visually estimated for all in-channel locations. The following categories were used to denote substrate type: Aquatic vegetation, Silt, Sand, Small gravel (0.25 – 1.0 inch), Large gravel (>1.0 – 3.0 inches), Cobble (>3.0 – 10.0 inches), Boulder (>10.0 inches), and Bedrock. Substrate was categorized by dominant and subdominant size class. Vegetation type was also recorded for those points outside of the river channel and reference photos were taken.



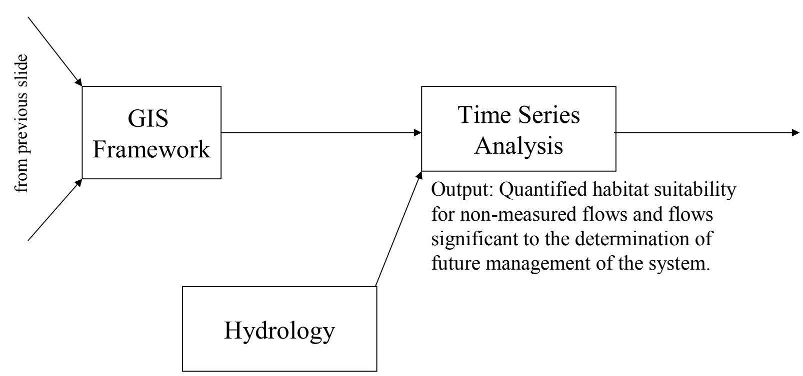


Figure 4. Flow chart of data analysis for the Roaring Fork River instream habitat modeling.

Hydraulic Data Collection

Two-dimensional hydraulic modeling requires channel geometry data, multiple water-surface elevation data sets, and multiple velocity data sets. The specific hydraulic data that were collected at the site included stream bed elevations, mean column velocity at selected locations (multiple collections at each habitat type), water-surface elevations, and visual estimates of dominant and subdominant substrate size. A survey-grade GPS was used to collect stream bed elevations as described above and water-surface elevations. Velocities were measured with a Marsh-McBirney Flo-Mate portable velocity meter attached to a top-set wading rod with the GPS unit attached to the rod.

To calibrate the hydraulic model, repeat measurements of water-surface elevations, depths, and velocities were taken from three different discharge levels. Each time water-surface elevations were surveyed, discharge was measured either with the velocity meter or it was estimated from USGS gage data. These stage-discharge measurements provided the necessary data for model calibration and for extending the range of hydraulic simulations.

Two-Dimensional Hydraulic Modeling

Two-dimensional hydraulic modeling was accomplished using River2D hydrodynamic modeling software (Steffler and Blackburn 2002). The model was developed to simulate two-dimensional velocity vectors in river systems and can simulate element (i.e., grid cell) wetting and drying as flows are increased or decreased. Data inputs included site topography, substrate, and flow impediments (e.g. riffles, eddies, islands); a stage-discharge relationship at the downstream end of the site; and calibration and validation data throughout the site. Model calibration and validation data consist of depth, velocity, and water-surface elevation measurements taken at known discharges. This model operates on an irregular triangulated grid developed from the digital terrain model for each site. The grid system represents the stream geometry as a mesh. For the Roaring Fork River mesh size was 0.5 meters. This mesh was combined with the hydraulic data to simulate water depths and velocities for a range of flow conditions.

Habitat Suitability Curves

Species habitat suitability criteria were required for the habitat analysis. 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.

Development of habitat suitability curves requires precise information on water depths, velocities, substrates, and cover types utilized by each life stage of the target species. Calculation of habitat suitability criteria for a two-dimensional hydraulic model can include use of a bivariate analysis of depth-velocity paired data to calculate fish preference for depth and velocity in the stream reach. Data from CDOW were used to develop habitat suitability criteria for adult and juvenile brown trout and rainbow trout, as well as trout fry. Trout spawning habitat suitability was developed from Raleigh et al. (1984, 1986).

A bivariate statistical analysis was used to develop habitat suitability criteria for brown and rainbow trout adult and juvenile life stages (Miller Ecological Consultants, Inc. 2001). This analysis first plotted bivariate histograms, then converted those to a three-dimensional surface, and finally computed a polynomial expression that replicates the three-dimensional surface to predict suitability values. A multivariate exponential polynomial equation was developed to fit the three-dimensional surface. The peak of the surface shape represents optimal depth and velocity for the life stage of interest (Figure 5).

Habitat Modeling

The habitat modeling for this analysis followed the concepts of IFIM and the computer simulation steps of the Physical Habitat Simulation System (PHABSIM). IFIM requires hydraulic data and simulations, habitat use data expressed as habitat suitability criteria, and hydrology data for a range of stream discharge conditions. The hydraulic analysis and simulations were described above.

Habitat suitability modeling for each species and life stage of interest was accomplished in an ArcView GIS analysis (Miller Ecological Consultants, Inc. and Spatial Sciences & Imaging

2003). The ArcView instream habitat model relies on inputs from both the two-dimensional 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 provided by the two-dimensional hydraulic modeling were developed for each discharge and overlain with data layers for substrate and cover within the study site. Specific habitat criteria developed from the suitability analyses described above were then used to conduct GIS queries. In this way, the amount of area within the study site that matches a particular species' habitat preference was determined for a specified discharge. Multiple layers of usable habitat were generated, corresponding to each species, life stage, and flow of interest. The analysis was output as a two-dimensional map for a visual presentation of the results. Summation of total habitat for each species and simulated flow resulted in a habitat-flow relationship by species and life stage that became input for the habitat-time series analysis. The usable habitat area for each species of interest was the result of combining the hydraulic simulations for each flow with the habitat suitability function for each species and life stage. The general sequence of habitat modeling was as follows.

The two-dimensional hydraulic simulations use a mesh to depict the stream channel. This mesh is configured to best represent each simulated flow. The result is multiple model meshes to represent the range of flow conditions. Unlike a one-dimensional hydraulic simulation that uses multiple cross sections that remain fixed for the full range of simulation flows, each of the two-dimensional meshes can have a different number of nodes and therefore a different surface area. The hydraulic simulation data sets contain the horizontal and vertical reference locations for each node in the model mesh. In addition, the node locations have depth, velocity and substrate data for each flow. These georeferenced data sets were combined with the habitat suitability functions in ArcView. The result of the GIS analysis is a georeferenced map of usable habitat for each species and life stage. The GIS model created a summation file for the usable habitat for each flow. The habitat–discharge relationship for the flows simulated at each site was developed for each species and life stage.

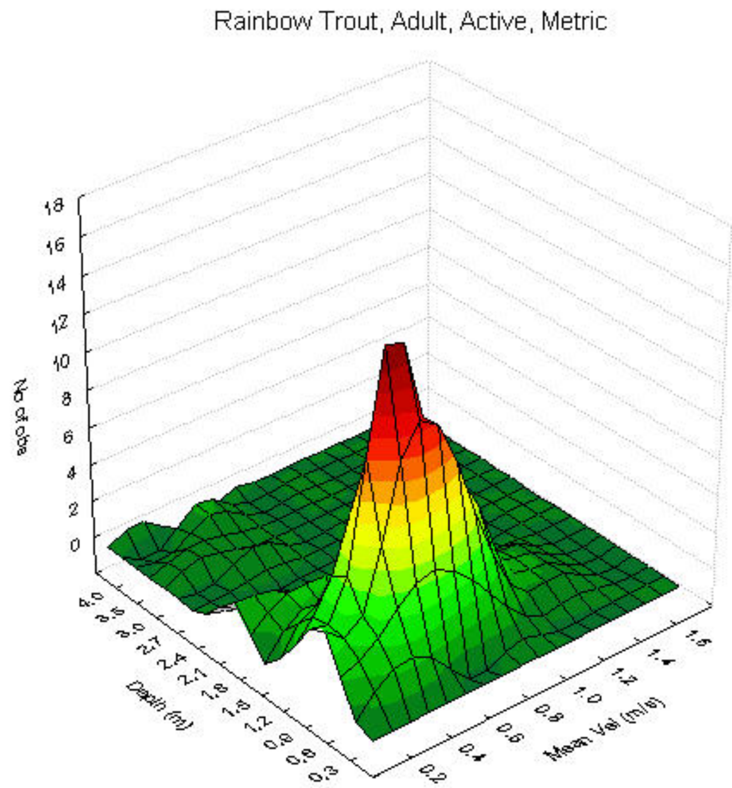


Figure 5. Example of a three-dimensional surface used to generate a habitat suitability equation for adult rainbow trout.

The habitat–discharge relationships are a set of theoretical functions based on channel shape and hydraulics. The actual habitat realized by the species is a function of the discharge at the site over time. The combination of the habitat–discharge function and hydrology data is the habitat time series.

Habitat Time Series

The actual habitat experienced by the fish in any river depends on the flow regime of the river. The relative abundance of habitat conditions over a period of time is an integral part of the comparison of flow regimes. Generally, the habitat time series is the comparative analysis used for the decision point in IFIM. Habitat time series produces the data needed to compare a range of flow conditions over time and to compare different flow scenarios. The habitat-discharge relationships for each study site were used as input data for the habitat time series. This analysis allowed a comparison between the existing flow regime by hydrologic year type.

MEC conducted time series evaluations on several three different flow regimes (wet, average, and dry conditions). For each flow regime assessed, we conducted both hydrology and habitat time series analyses 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.

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 Results section.

Macroinvertebrates

The benthic macroinvertebrate community was sampled for two reasons: 1) macroinvertebrates are a major food source for many fish species. Estimates of density and biomass can indicate the availability of food for fish. 2) certain macroinvertebrate metrics are indicators of water quality and stream health. Benthic macroinvertebrates are particularly valuable in biomonitoring for several reasons (Rosenberg and Resh 1993). The first reason is that benthic macroinvertebrates are abundant and can therefore be affected by environmental perturbations in many types of aquatic systems and habitats within those systems. Second, macroinvertebrate samples typically contain a large number of taxa and so there is a wide array of responses to environmental perturbations. Third, benthic macroinvertebrates are essentially sedentary and it is therefore possible to evaluate how pollution or other disturbances are spatially distributed. Finally, benthic macroinvertebrates have fairly long life cycles (annual) and this allows for analyses of the effects of perturbation over time.

Benthic macroinvertebrate samples were collected with a modified Hess sampler. Three replicate samples were collected within the site. Selection of specific sampling locations was based on similarity of habitat characteristics. An effort was made to take all samples in areas of similar-sized substrate and similar depth in order to avoid bias that may be associated with these variables. Substrate within the sampler was thoroughly agitated and individual rocks were scrubbed by hand to dislodge all benthic organisms. All macroinvertebrates were rinsed into sample jars and preserved in a 70% ethanol solution. Each sample jar contained labels (with date, location and sample ID number) on the inside and outside of the jar. Samples were transported to the lab where they were sorted, enumerated, and identified to the lowest practical taxonomic level (Merritt and Cummins 1996; Ward et al. 2002) and then dried and weighed for biomass estimates. Identification to the "lowest practical taxonomic level" means that all specimens are identified down to the level that is permitted by the available morphological characteristics. Early life stages of many species sometimes lack certain anatomical characteristics that allow the specimen to be identified to the genus or species level. In these cases the "lowest practical taxonomic level" may mean only the family level; however, if the available characteristics are consistent with a species that has been previously confirmed during this study then the individual may be included as a member of that taxon. As a means of quality assurance, qualified personnel inspected each sample after sorting to ensure that less than 5% of total sorted invertebrates remained in the sample. Any samples with more than 5% were resorted and individual specimens removed to the appropriate container for identification.

A macroinvertebrate species list was developed for the site. Data were used in various indices recommended by the Environmental Protection Agency's Rapid Bioassessment Protocols (Barbour et al. 1999) and the White River National Forest to provide information regarding macroinvertebrate community structure, function, and general aquatic conditions. The following paragraphs provide descriptions of each index (metric) that was used in this study.

Shannon-Weaver diversity (diversity) and evenness (evenness) values were used to detect changes in macroinvertebrate community structure. In pristine waters, diversity values typically range from near 3.0 to 4.0. In polluted waters this value is generally less than 1.0. The overall evenness value ranges between 0.0 and 1.0, with values lower than 0.3 indicative of organic pollution (Ward et al. 2002). Diversity and evenness are similar measurements because they both rely heavily on the numerical distribution of taxa (although taxa richness also influences diversity). Both indices are designed to detect unbalance in communities (where a few species are represented by a large number of individuals). These situations are usually the result of pollution/disturbance-induced changes to the aquatic community. Diversity and evenness were used in this study as a surrogate for water quality monitoring. They are not necessarily sensitive indicators of sediment related problems; however, some sediment-induced changes related to microhabitat availability might influence these values.

The Ephemeroptera, Plecoptera, Trichoptera (EPT) index was employed to assist in the analysis of data. The EPT index is reported as the total number of distinguishable taxa in the orders Ephemeroptera, Plecoptera, and Trichoptera found at each site. It is a direct measure of taxa richness among species that are generally considered to be sensitive to disturbances (Barbour et al. 1999). Most macroinvertebrate species have specific habitat requirements. The value produced by this metric will indicate locations with preferred habitat as well as areas of disturbance or habitat modification. This value may vary spatially if a change in location results in a change in physical habitat features. Results provided by this metric will naturally vary among river systems, but are valuable when comparing samples taken from the same stream reach. The EPT index was used in analysis of this data to monitor the distribution of disturbance-sensitive species.

Taxa richness was also reported for the site. This measurement is simply reported as the total number of identifiable taxa collected from the site. It is similar to the EPT index, except that it includes all aquatic macroinvertebrate species (including those that are thought to be tolerant to disturbance). Taxa richness is useful when describing differences in habitat complexity or aquatic conditions between rivers or site locations. Taxa richness values also provide an indication of habitat preference and complexity. As with the EPT index, increasing richness correlates with increasing health of the macroinvertebrate community.

The Hilsenhoff Biotic Index (HBI) is often used in macroinvertebrate studies as a means of detecting organic enrichment. Organic pollution includes such factors as sewage runoff, feedlot or grazing area runoff, and other types of contaminants that deplete dissolved oxygen from the water. Because the HBI requires modification for use in many areas, the number indicating a certain water quality rating will vary among regions. Comparison of the values produced within a given system should, however, provide information regarding differences in sites based on nutrient enrichment. Values for the HBI range from 0 to 10 and increase as water quality decreases (Barbour et al. 1999).

The Colorado Water Quality Control Division developed the Multi-Metric Index (MMI), a bioassessment tool composed of separate metrics that respond to stressors affecting aquatic communities (Colorado Water Quality Control Commission (CWQCC) 2010a). The MMI is used to determine if a water body supports aquatic life uses as described in Water Quality Control Commission Regulation No. 31: Basic Standards and Methodologies for Surface Water (CWQCC 2010b). The MMI is designed to detect environmental stressors that result in the alteration of the aquatic community, but it does not identify specific stressors. The metrics used in the MMI depend on the biotype of the area. For this study the biotype was Biotype 2: Mountains. The metrics selected for the Biotype 2 MMI represent categories of community characteristics such as richness, composition, functional feeding group, mode of locomotion, and pollution tolerance. More specifically, the metrics used to calculate the MMI for Biotype 2 are total taxa (taxa richness), percent Ephemeroptera, number of predator and shredder taxa, Beck's Biotic Index, and number of clinger taxa. Each individual metric is calculated and scored according to a formula developed by CWQCC, the metric scores are summed together, and this number is divided by the number of metrics (5 for Biotype 2). Scores range from 0 to 100. For Biotype 2, the attainment threshold is 50. This means that water bodies with an MMI score of at least 50 support aquatic life uses as defined by CWQCC.

A measure of macroinvertebrate standing crop at the site was determined using density and biomass. Macroinvertebrate density was reported as the mean number of macroinvertebrates per square meter. Biomass was reported as the mean dry weight of macroinvertebrates per square meter. Biomass values were obtained by drying macroinvertebrates from each sample in an oven at

100° C for 24 hours or until all water content had evaporated (no decrease in weight could be detected). Biomass values offer production-related information in terms of quantitative weight of macroinvertebrates produced at each site. Density and biomass provide a means of measuring and comparing standing crop and provide an indication of productivity for the macroinvertebrate portion of the food web at each sampling location.

An analysis of macroinvertebrate functional feeding groups was also conducted. This metric provides a measurement of macroinvertebrate community function as opposed to other metrics that measure community structure. Aquatic macroinvertebrates were categorized according to feeding strategy to determine the relative proportion of various groups. Taxa were placed into functional feeding groups based on acquisition of nutritional resources (Merritt and Cummins 1996; Ward et al. 2002). The proportion of certain functional feeding groups in the macroinvertebrate community can provide insight to various types of stress in river systems (Ward et al. 2002). River ecosystems that provide a variety of feeding opportunities usually maintain good representation of each corresponding functional feeding group. Numerous variables (including habitat quality) may affect the proportions of certain functional feeding groups. A measure of functional feeding groups is often recommended as part of benthic macroinvertebrate analysis and evaluation (Ward et al. 2002). Typically the Collector-Gatherer group is dominant in western streams, but other groups should be well represented.

Other indices that were calculated (such as percent dominant taxon and number of Diptera taxa) are fairly self-explanatory and will not be described further. Many of these indices were calculated because they are part of the White River National Forest protocol and therefore it will be possible to compare the site on the Roaring Fork River with other sites within the national forest.

Fish

The fish community was sampled via electrofishing. Two backpack electrofishers with three anodes were used to collect fish. The total length of stream sampled was 690 feet and was within the same reach modeled for instream habitat (Figure 2). Two passes for fish removal were made at the site and a population estimate could be calculated. All captured fish were identified, weighed, measured, checked for external parasites, and returned to the stream. Fish population estimates were made using the Colorado Division of Wildlife "Jakeomatic" software program.

RESULTS

Hydrology

The Roaring Fork River upstream of the Salvation Ditch diversion has flows that are typical of a western U.S. snowmelt river. Peak flows occur from mid-June to early-July and the lowest flows occur in the winter months (Figure 6). The highest peak flows occurred in 1995 and 1985. The lowest peak flows occurred in 2002 and 2004.

From 1977 to 2009, the Salvation Ditch has diverted flows from 0.96 to 41 cfs (Figure 7). The average amount of flow diverted during this period was 22 cfs (median flow was 20 cfs). Subtracting these flows from the Roaring Fork River upstream of the ditch gives the flows for Reach 1 (Figure 8). The hydrograph of Reach 1 is very similar to the hydrograph for the Roaring Fork River upstream of the Salvation Ditch. This suggests that, on a large scale, diversions to the Salvation Ditch do not affect the general shape of the hydrograph of the Roaring Fork River. However, at a finer scale, it is apparent that diversions to the Salvation Ditch can significantly decrease the amount of water in the Roaring Fork through Reach 1, particularly in late summer. As Table 1 shows, flows that were in the single digits occurred in several years and all water was completely diverted for many days in 1977, 1978, and 1980.

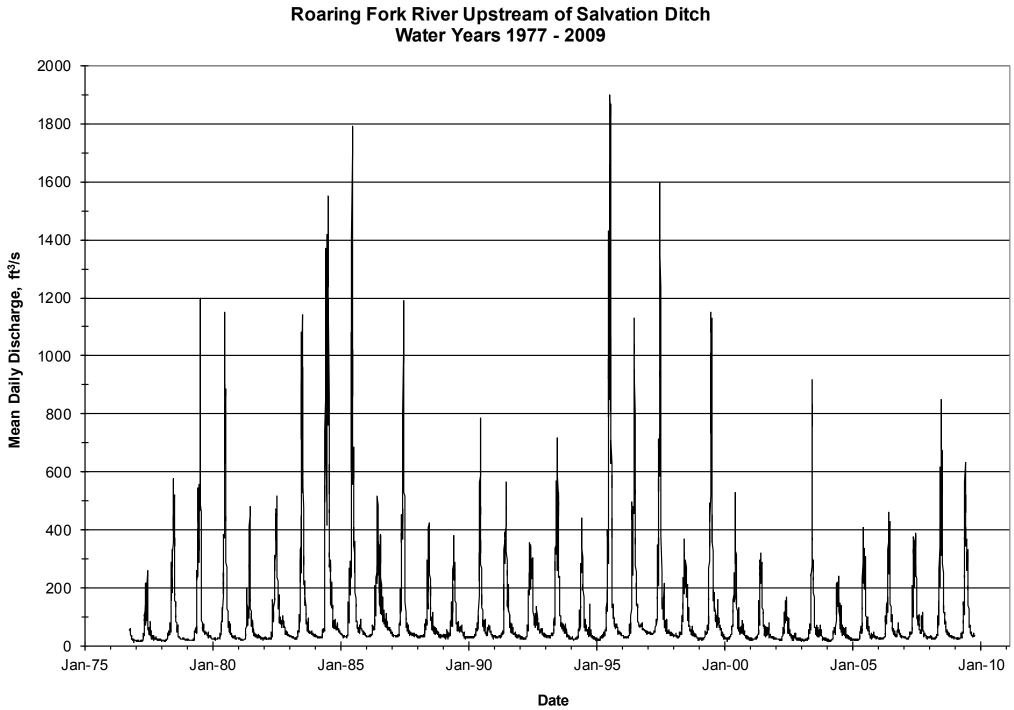


Figure 6. Average daily discharge for the Roaring Fork River upstream of the Salvation Ditch diversion, water years 1977-2009.

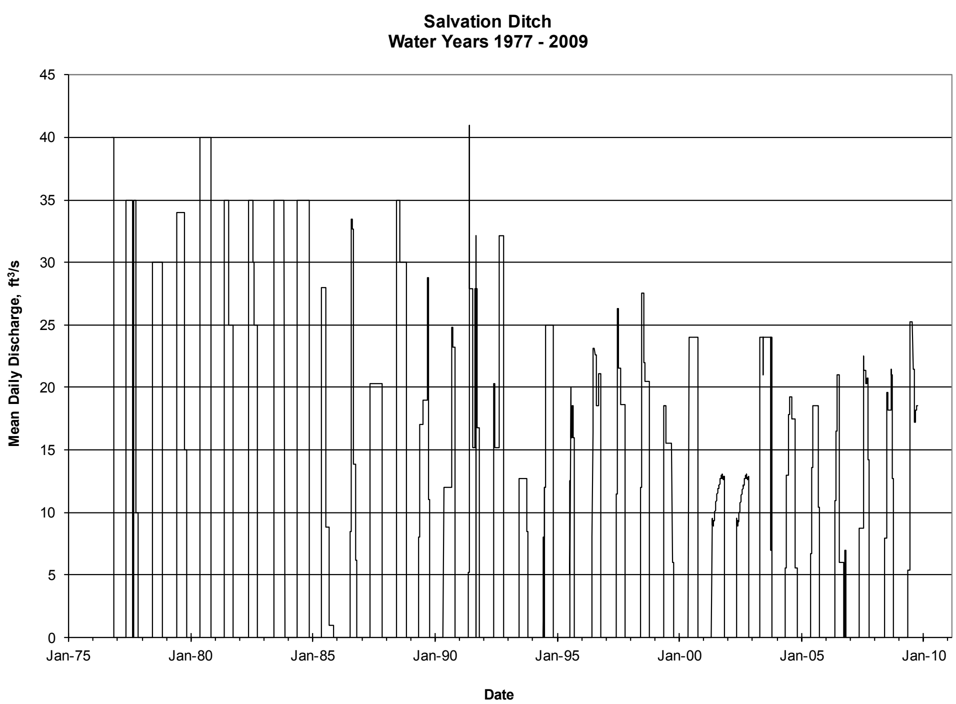


Figure 7. Average daily discharge for the Salvation Ditch, water years 1977-2009. Data for 2001 and 2002 are estimates calculated from the other years.

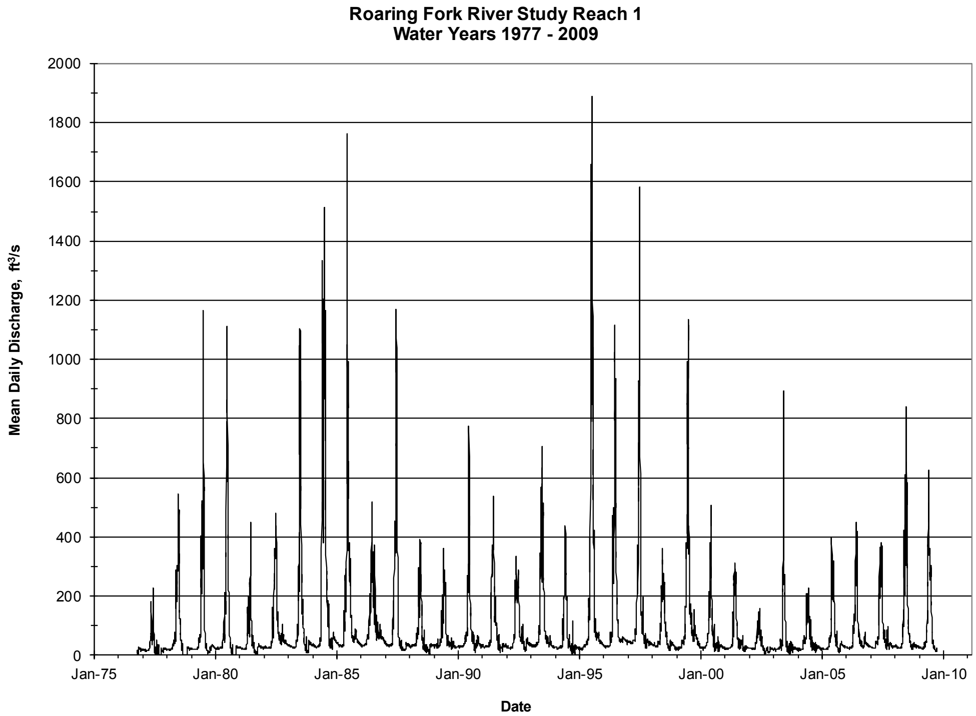


Figure 8. Average daily discharge for Reach 1 (Roaring Fork River from Salvation Ditch to Hunter Creek), water years 1977-2009.

Table 1. Comparison of flows in the Roaring Fork River upstream and downstream of the Salvation Ditch diversion.

Year	Period of diversions	Discharge of Roaring Fork upstream of Salvation Ditch (cfs)	Discharge diverted to Salvation Ditch (cfs)	Discharge of Reach 1 (cfs)	Days of Zero Flow in Reach 1
1977	5-1 to 10-31	20-260	10-35	0-225	50
1978	6-1 to 10-31	21-576	30	0-546	61
1979	6-1 to 10-31	30-1200	15-34	4-1166	0
1980	5-15 to 10-31	25-1150	40	0-1110	52
1981	5-20 to 9-29	28-482	25-35	3-447	0
1982	5-20 to 9-28	62-516	25-35	37-481	0
1983	6-1 to 10-31	43-1140	35	8-1105	0
1984	5-15 to 10-31	53-1550	35	18-1515	0
1985	5-15 to 10-31	44-1790	1-28	43-1762	0
1986	7-10 to 10-15	64-382	6-33	50-373	0
1987	5-1 to 10-30	35-1190	20	15-1170	0
1988	6-1 to 10-30	32-425	30-35	2-390	0
1989	5-2 to 10-15	34-378	8-29	19-361	0
1990	5-6 to 10-18	34-786	12-25	9-774	0
1991	5-20 to 10-31	30-565	5-41	10-537	0
1992	5-20 to 10-14	43-354	15-32	11-334	0
1993	6-4 to 10-13	41-717	9-13	29-704	0
1994	7-3 to 10-30	29-142	12-25	4-117	0
1995	7-6 to 9-13	67-1900	5-20	51-1888	0
1996	6-3 to 10-7	62-1130	8-23	42-1114	0
1997	6-2 to 10-9	42-1600	12-26	23-1584	0
1998	6-1 to 10-3	36-367	8-28	16-359	0
1999	5-20 to 10-14	62-1150	6-19	47-1135	0
2000	5-20 to 10-9	36-529	24	12-505	0
2003	4-21 to 10-14	29-916	24	5-892	0
2004	5-11 to 10-31	25-240	6-19	8-227	0
2005	5-16 to 9-29	24-406	7-19	10-399	0
2006	5-18 to 10-31	30-459	5-21	24-448	0
2007	5-18 to 10-12	32-389	9-23	20-380	0
2008	5-30 to 10-1	33-849	8-21	19-841	0
2009	5-18 to 9-30	32-632	5-25	14-627	0

Hunter Creek has a flow regime similar to the Roaring Fork River, with peak flows occurring in June and low flows occurring in the winter months (Figure 9). While smaller than the Roaring Fork River, Hunter Creek contributes a considerable amount of water to the river, especially during peak runoff. During the runoff season, flows from Hunter Creek can match those of the Roaring Fork River. Mostly typically though, flows from Hunter Creek are between 30-50% of flow from the river. During the non-runoff season, flows from Hunter Creek are typically between 25-50% of flow from the river. This input is especially critical in late summer when flow in the Roaring Fork River continues to decrease and the Salvation Ditch is still diverting water. If mean discharge from each day of the year from 1977-2009 is averaged for each day, then Hunter Creek contributes anywhere from 6 cfs to 250 cfs to the Roaring Fork River (Figure 10). Therefore, flows in Reach 2 (Figure 11) do not drop to the levels seen in Reach 1.

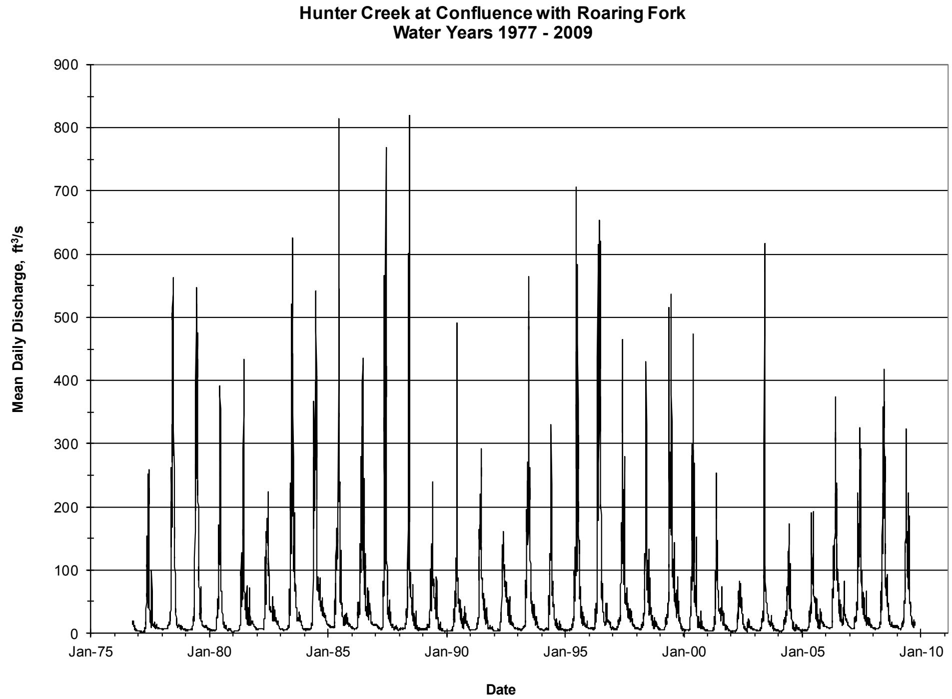


Figure 9. Average daily discharge for Hunter Creek at its confluence with the Roaring Fork River, water years 1977-2009.

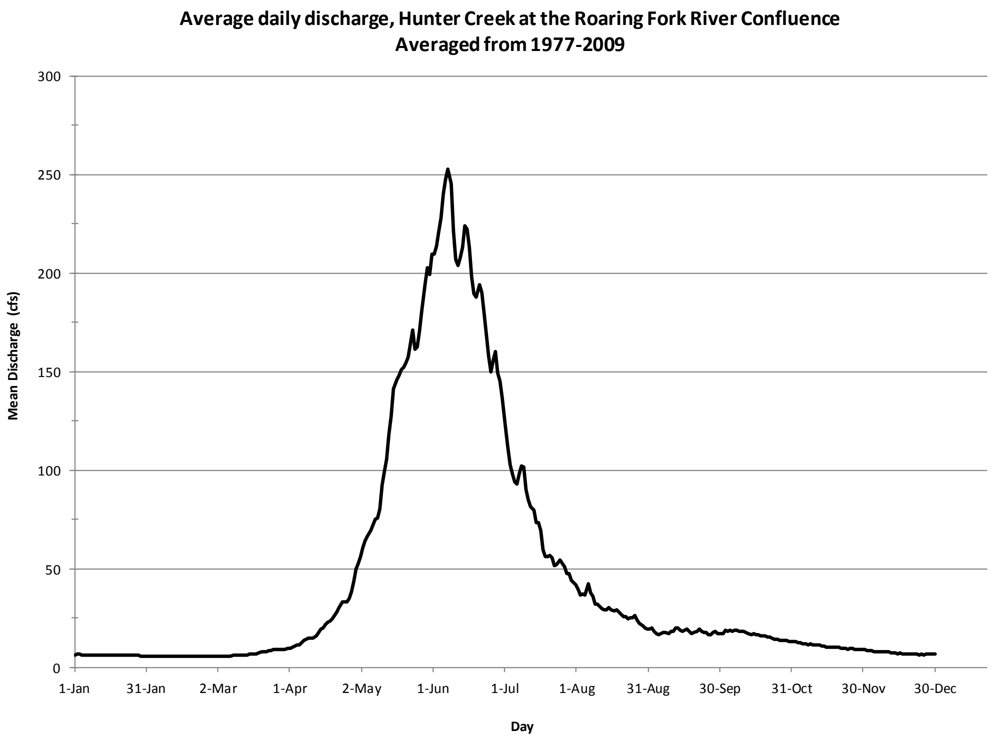


Figure 10. Daily discharge from Hunter Creek averaged from 1977-2009.

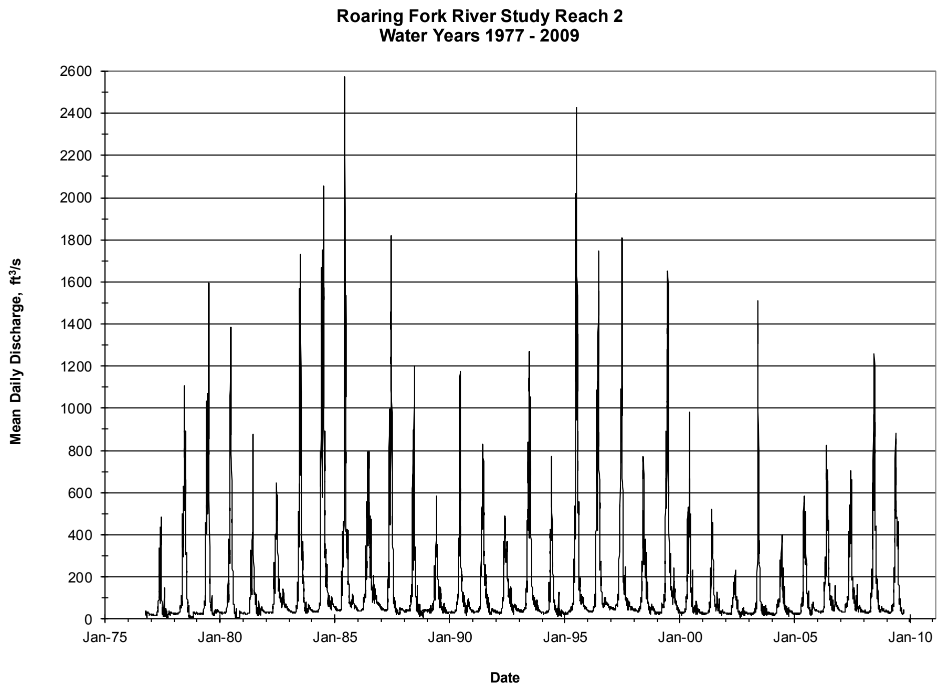


Figure 11. Average daily discharge for Reach 2 (Roaring Fork River from Hunter Creek to Castle Creek, water years 1977-2009.

Three year types were selected for the analysis of daily habitat: dry (90% of the time these flows are exceeded), median (50% of the time exceeded), and wet (10% of the time exceeded). These year types show the range of conditions that can occur. During wet years on the Roaring Fork River upstream of Salvation Ditch peak flows reach 1100 cfs (Figure 12). In median years flow peaks around 350 cfs and in dry years flow peaks at approximately 230 cfs. During the late summer months discharge in wet years is approximately 80 cfs, in median years it is approximately 45 cfs, and in dry years it is approximately 30 cfs.

Peak flows on the Roaring Fork River downstream of Salvation Ditch to Hunter Creek (Reach 1) are similar to those upstream of Salvation Ditch for all three year types (Figure 13). During the late summer months discharge in wet years is approximately 50 cfs, in median years it is approximately 30 cfs, and in dry years it is approximately 20 cfs (Figure 14).

During wet years on Hunter Creek peak flows reach 600 cfs (Figure 15). In median years flow peaks around 200 cfs and in dry years flow peaks around 100 cfs. During the late summer months discharge in wet years is approximately 35 cfs, in median years it is approximately 15 cfs, and in dry years it is approximately 8 cfs.

During wet years on the Roaring Fork River from Hunter Creek to Castle Creek (Reach 2) peak flows reach 1550 cfs (Figure 16). In median years flow peaks around 550 cfs and in dry years flow peaks around 300 cfs. During the late summer months discharge in wet years is approximately 80 cfs, in median years it is approximately 45 cfs, and in dry years it is approximately 30 cfs. Overall, the late summer averages for all three year types suggest that flow inputs from Hunter Creek are approximately equal to the amounts diverted by the Salvation Ditch.

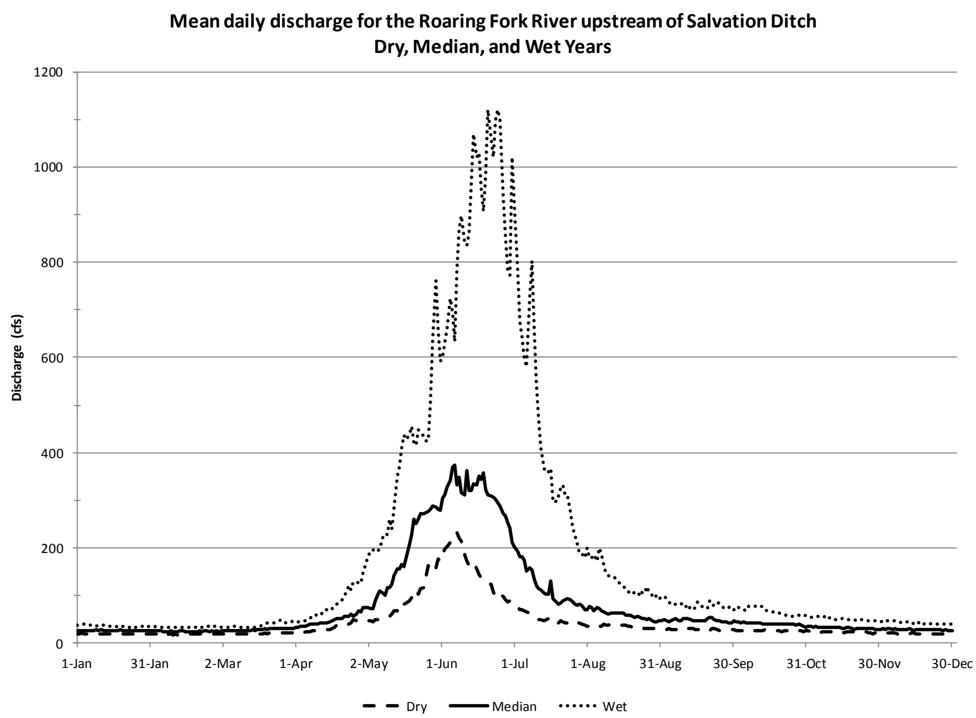


Figure 12. Average daily discharge for the Roaring Fork River upstream of Salvation Ditch in dry, median, and wet years.

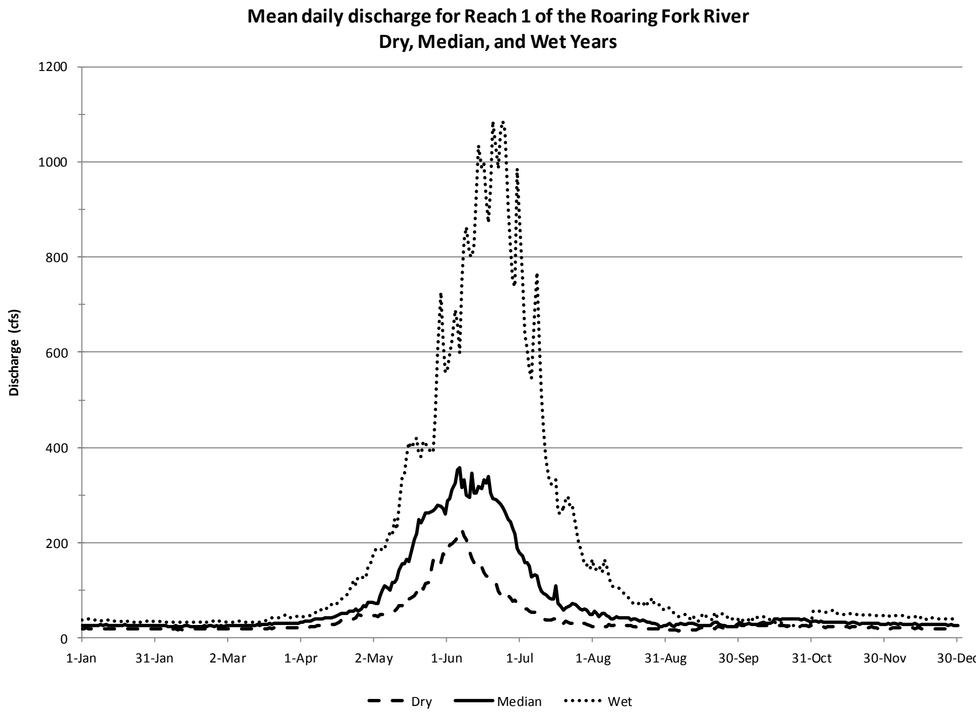


Figure 13. Average daily discharge for the Roaring Fork River from Salvation Ditch to Hunter Creek (Reach 1) in dry, median, and wet years.

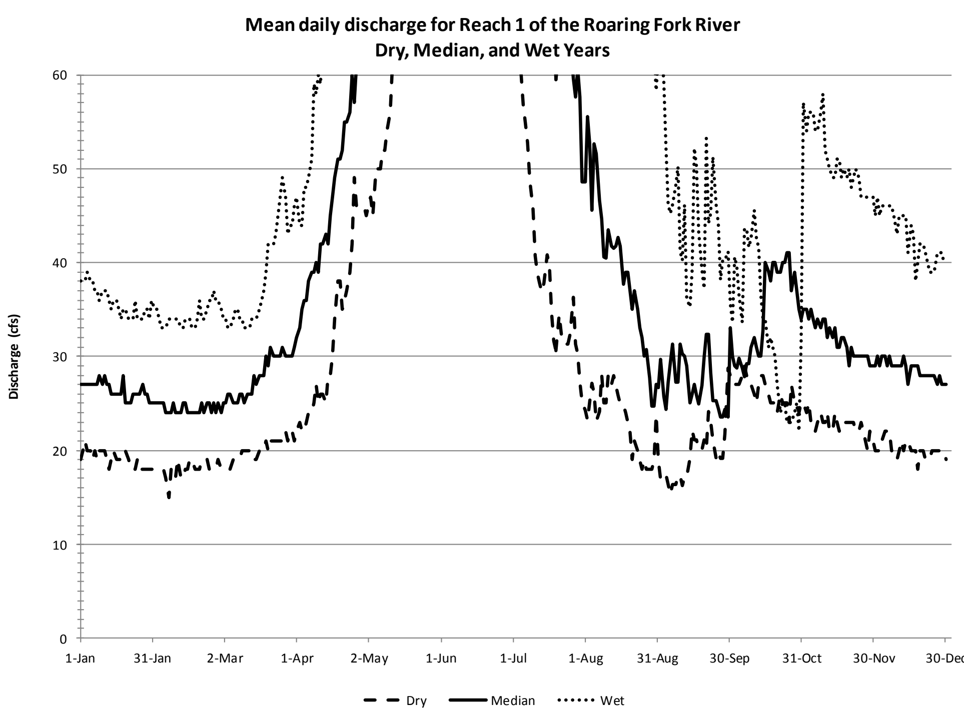


Figure 14. Average daily low flow discharge for the Roaring Fork River from Salvation Ditch to Hunter Creek (Reach 1) in dry, median, and wet years.

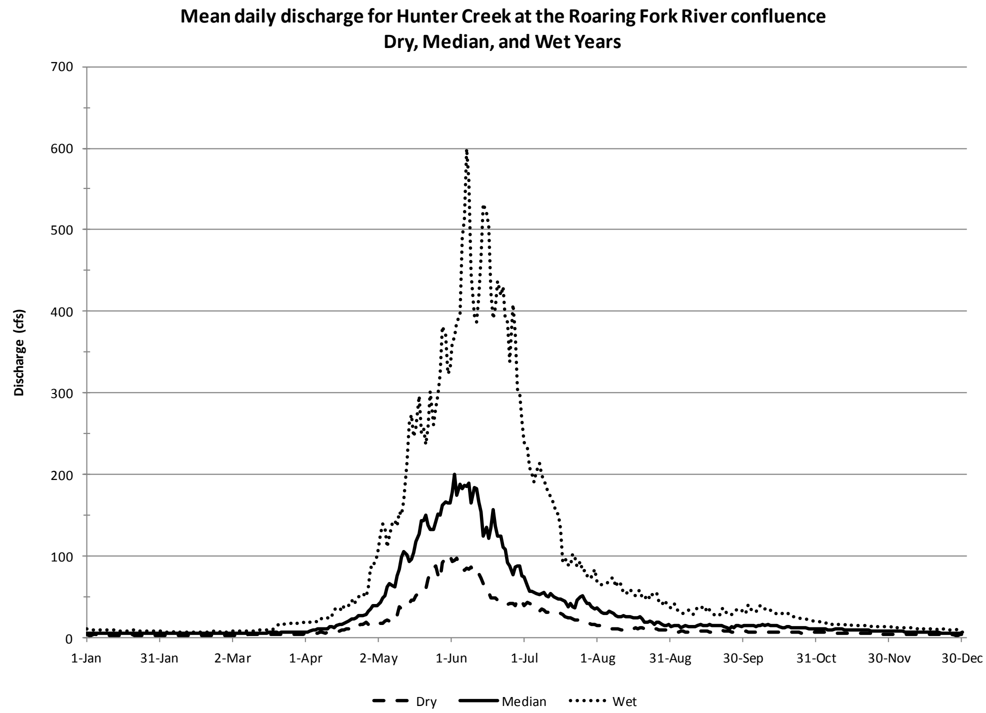


Figure 15. Average daily discharge for Hunter Creek in dry, median, and wet years.

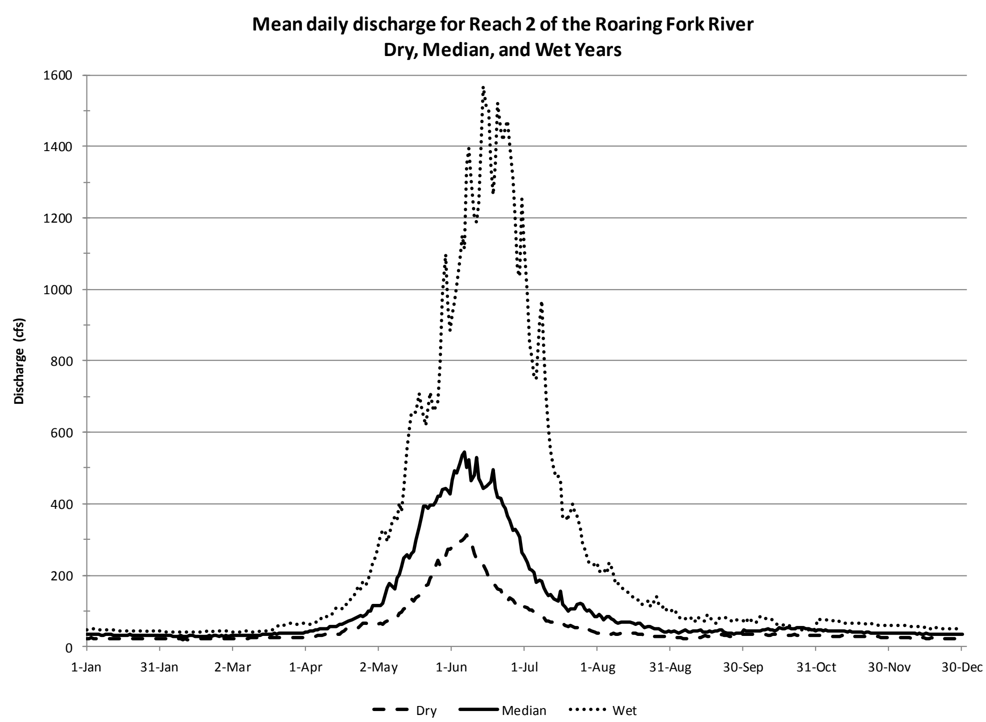


Figure 16. Average daily discharge for the Roaring Fork River from Hunter Creek to Castle Creek (Reach 2) in dry, median, and wet years.

Stream Stability

The site visit to assess current geomorphic conditions in the river occurred on November 16, 2010. The assessed reach contained several man-made structures that are problematic with regard to degraded fish habitat, obstructed low-flow fish passage, and sediment transport (Figure 17). A summary of the findings is provided below. The complete geomorphic assessment, with aerial photos and photos of man-made structures, can be found in Appendix E.
The largest diversion structure is the Salvation Ditch diversion. The vertical drop created by the diversion is 5-6 feet high and is an impediment to fish passage. Two cobble/boulder diversion structures are also present, but they do not cross the entire channel and do not impede fish passage.

Three grade control structures were documented. These structures consist of a series of boulders placed side by side across the entire width of the channel. They were constructed to protect utility lines that cross the channel upstream. The vertical drop created was approximately 2 feet at all three structures and these could be impediments to fish passage at low flows. The structures flatten channel slope upstream and reduce the energy of the slope. As a result, water velocities are reduced and fine sediments begin to fill in the stream. As sedimentation continues, substrate that could be used for spawning fish fills in and can possibly create very shallow conditions at low flows. The grade control structures may also cause erosion by forcing flow to the sides of the channel.

Three man-made channels were also documented. These primarily impact the river by diverting flow from the main channel. The most problematic of the three is the kayak course at the John Denver Sanctuary, which contains seven pools and eight boulder drop structures. At high or moderate flows, fish may migrate or get diverted into the course. Then, once flows recede, fish can become trapped in the pools, which was observed during the site visit.

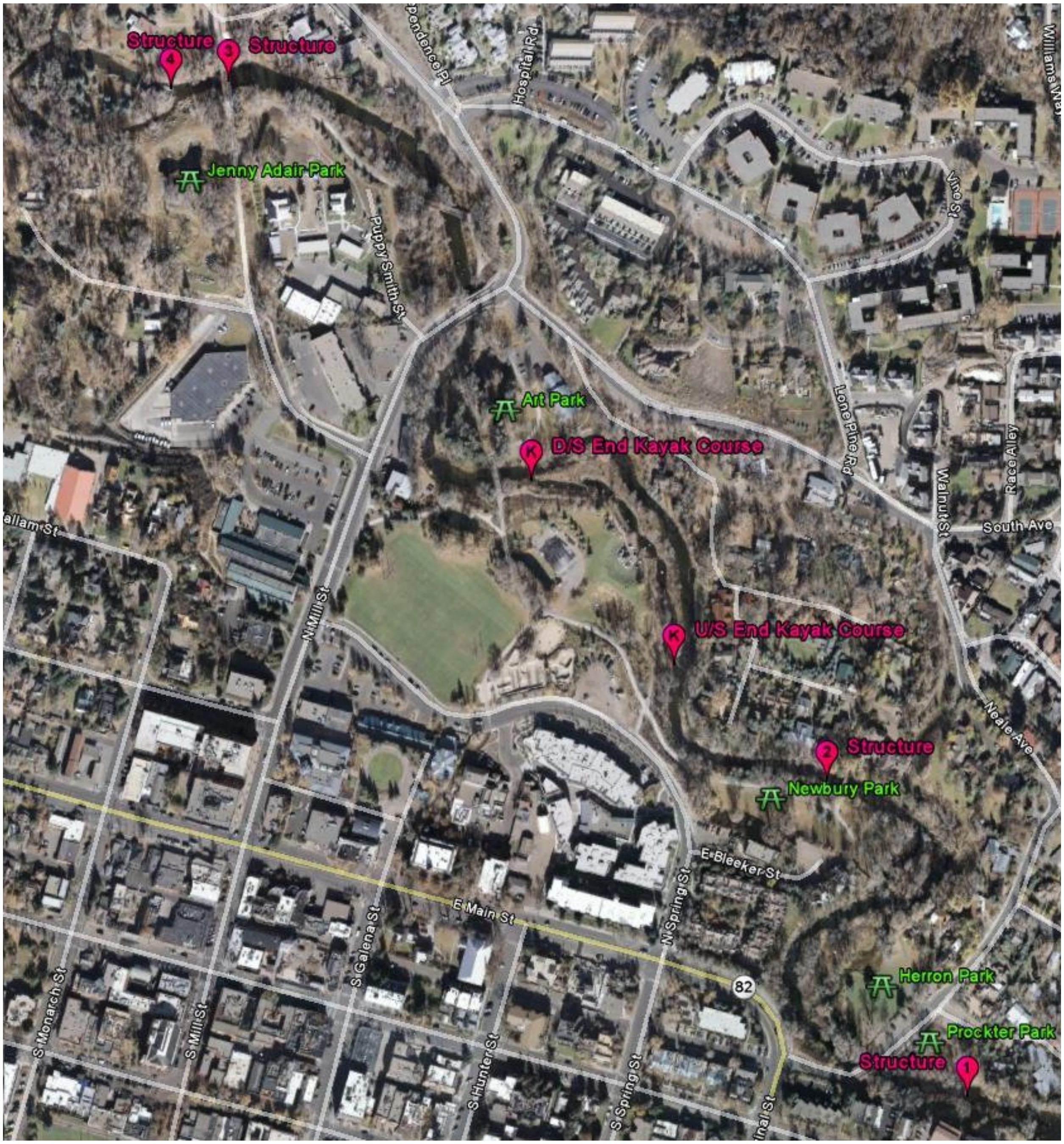


Figure 17. Aerial view (2008) of the reach of the Roaring Fork River in which a more detailed geomorphic assessment was conducted. Man-made in-channel features are shown in red. The complete reach that was assessed extended upstream to the Salvation Ditch diversion.

Several boulder revetments (forms of bank protection) were observed. The longest section extended from the Oklahoma Flats Trail pedestrian bridge downstream to the John Denver

Sanctuary (590 feet). Two exposed pipelines were documented and are discussed further in the instream habitat section. The river from the Hunter Creek confluence to the Castle Creek confluence is generally stable. Man-made structures do not appear to exist in this section. Overall, the reach of the Roaring Fork River through the City of Aspen is significantly encroached upon as a result of urban development. Very little of the river's floodplain remains along the river corridor. Upstream diversions and man-made perturbations within the watershed have changed not only the hydrology of the system, but also a whole host of other functions and processes including the sediment transport characteristics of the river.

Instream Habitat

Topographic and Hydraulic Data

High-flow measurements were collected on June 13, 2011. Discharge was 450 cfs and was estimated from USGS gage 09073400 above the Salvation Ditch diversion. Only water-surface elevation data were collected. Flow was too high to safely wade into the river to collect depth and velocity data.

Mid-flow measurements were collected on May 23, 2011. Discharge was 98 cfs and was measured with the Marsh-McBirney velocity meter. Water-surface elevation, depth, and velocity data were collected.

Low-flow measurements were collected on September 28, 2010. Discharge was 17.5 cfs and was measured with the Marsh-McBirney velocity meter. Water-surface elevation, depth, and velocity data were collected. Topographic data collection occurred on September 27-29, 2010. A sufficient number of points were surveyed to enable construction of a digital terrain model (Figure 18).

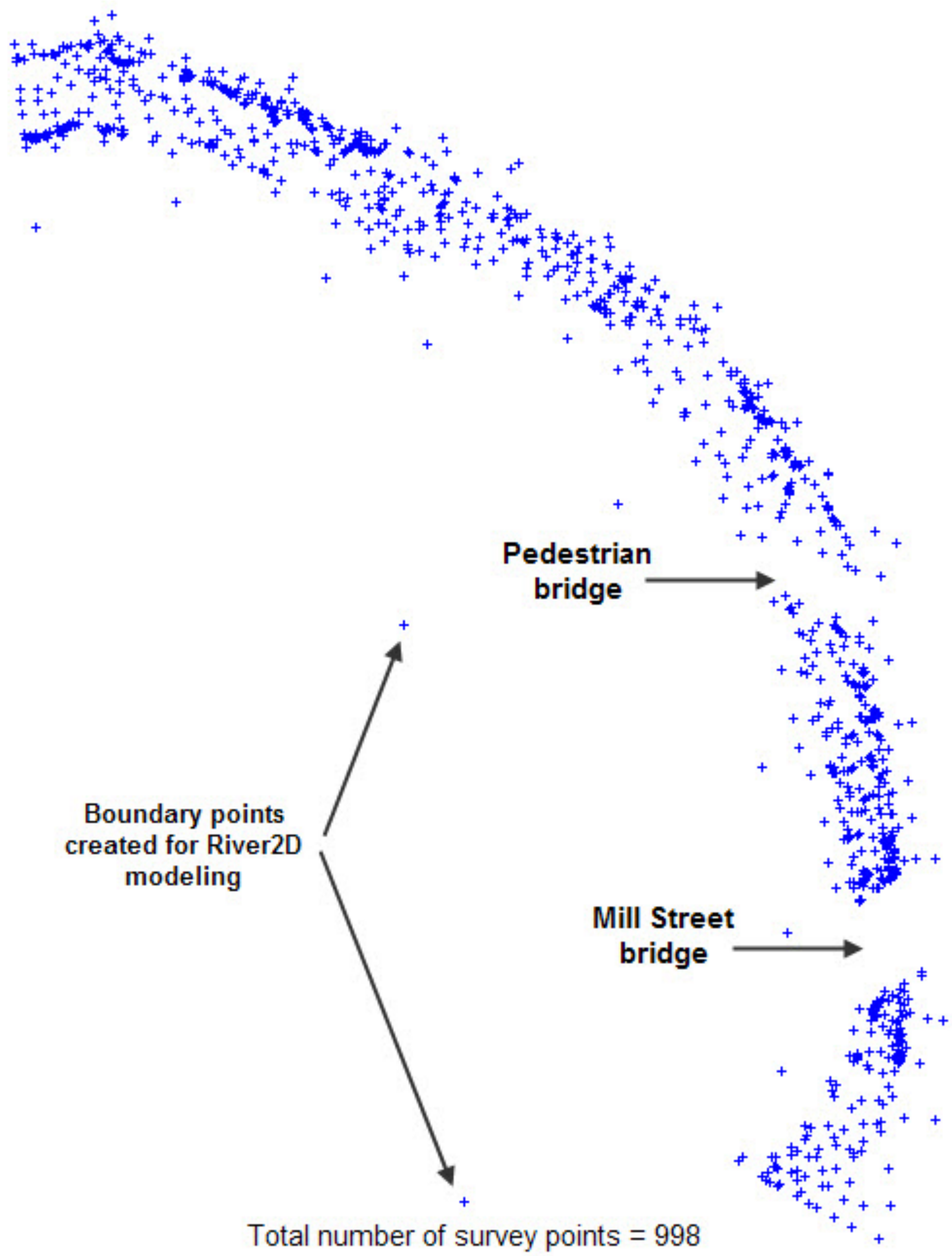


Figure 18. Topography survey locations on the Roaring Fork River.

River2D Hydraulic Model Calibration

River2D hydraulic models were calibrated from the low, mid, and high flows. For each of the three flows, several models were run with varying bed roughnesses and transmissivities. The measured water-surface elevation, depth, and velocity data were compared to simulated data at the same flow to determine model calibrations. Models were considered calibrated when the simulated water-surface elevations, depths, and velocities generally matched the observed values (Figure 19). The calibrated models were then used for model simulations for a range of discharges. Simulated discharges (cfs) were the following: 25, 30, 45, 60, 75, 90, 150, 200, 250, 300, 350, 600, 800, 1000, and 1500.

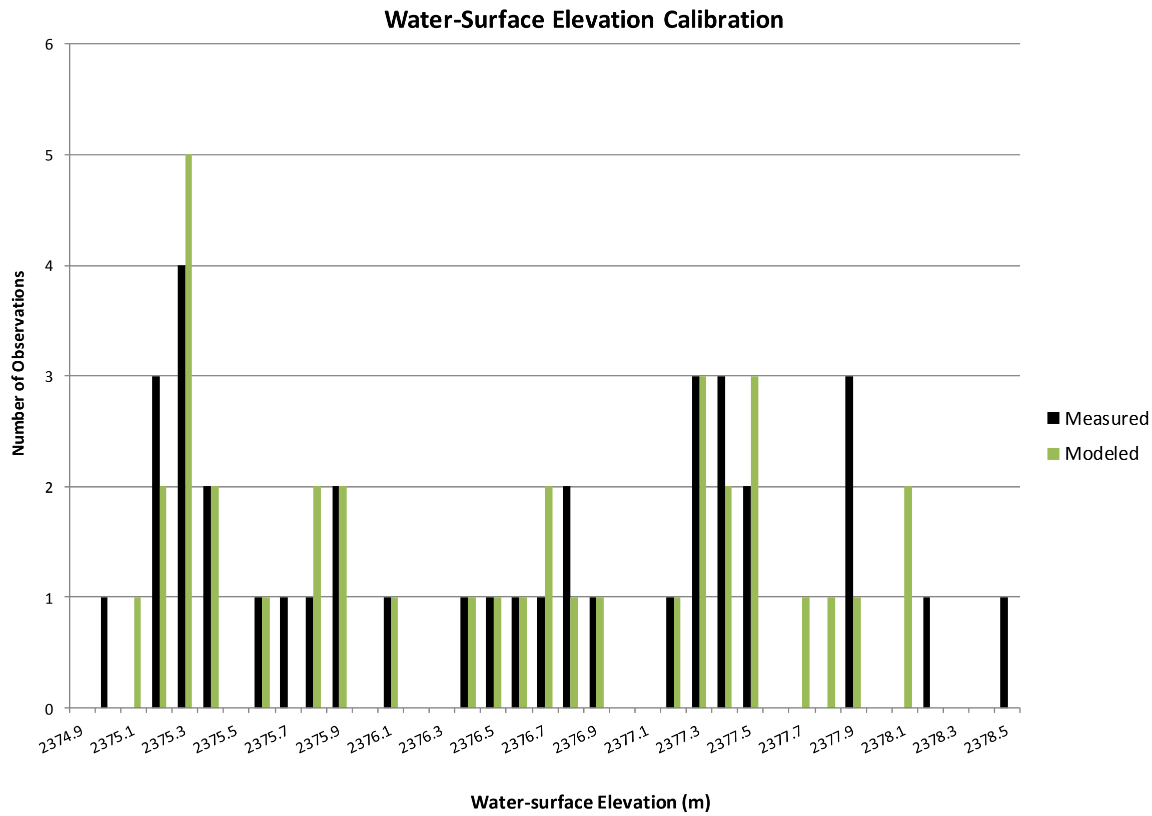


Figure 19. Example of measured versus modeled water-surface elevations at high flow.

Habitat Suitability Criteria

The species modeled at each site were determined in consultation with CDOW biologists. The habitat suitability criteria for brown and rainbow trout were derived from CDOW data collected in the South Platte and Cache La Poudre rivers. These data were collected by direct observation by life stage. The data for adult and juvenile trout were transformed to habitat suitability criteria using a bivariate analysis to develop a multivariate exponential equation. The data for trout fry were a univariate function derived from CDOW data. Data for spawning were developed from existing spawning habitat criteria and modified for use in the GIS model. These suitability functions were used to transform the hydraulic model output into habitat values for the study site using GIS.

Normalized suitability equations used to determine the habitat suitability for each point in the hydraulic files (Note: units for depth are meters, units for velocity are meters per second):

Brown Trout-Juvenile

$Z = (1/31.64259495) * (\exp(-((3.905144) + (-69.092 * Dep) + (41.6398 * Vel) + (-5.22811 * Dep * Vel) + (188.0895 * Dep^2) + (-205.393 * Vel^2) + (-227.543 * Dep^3) + (423.2293 * Vel^3) + (131.2333 * Dep^4) + (-378.955 * Vel^4) + (-27.5451 * Dep^5) + (124.5627 * Vel^5))$

Where:

Dep = Depth

Vel = Velocity

Brown Trout-Adult

$Z = (1/8.984860564) * (\exp(-((33.61703) + (-148.355 * Dep) + (-89.8087 * Vel) + (-77.5644 * Dep * Vel) + (384.7402 * Dep^2) + (273.4011 * Vel^2) + (-366.375 * Dep^3) + (-225.051 * Vel^3) + (136.2446 * Dep^4) + (77.94253 * Vel^4))$

Rainbow Trout-Juvenile

$Z = (1/21.10178982) * (\exp(-((4.340354) + (-61.9731 * Dep) + (19.46745 * Vel) + (-7.67705 * Dep * Vel) + (155.9402 * Dep^2) + (-85.5221 * Vel^2) + (-164.439 * Dep^3) + (185.1374 * Vel^3) + (77.34849 * Dep^4) + (-173.877 * Vel^4) + (-11.8636 * Dep^5) + (61.66031 * Vel^5))$

Rainbow Trout-Adult

$Z = (1/11.08667378) * (\exp(-((0.087184) + (11.36193 * Dep) + (56.9357 * Vel) + (3.539872 * Dep * Vel) + (-51.7545 * Dep^2) + (-309.223 * Vel^2) + (55.63995 * Dep^3) + (626.7088 * Vel^3) + (-23.3391 * Dep^4) + (-559.162 * Vel^4) + (3.403427 * Dep^5) + (184.4437 * Vel^5))$

2-4 Week Trout Fry

$Z = (((-85.2 * Vel^3) + (56.454 * Vel^2) - (12.388 * Vel) + 0.9248) * ((-18153 * Dep^5) + (14008 * Dep^4) - (3451.2 * Dep^3) + (229.84 * Dep^2) + (10.575 * Dep) - 0.0063))$

Trout Spawning

$Z = (((-2.6353 * Vel^5) + (14.929 * Vel^4) - (27.642 * Vel^3) + (18.323 * Vel^2) - (2.3518 * Vel) + 0.0053) * ((0.0543 * Dep^3) - (0.6838 * Dep^2) + (1.5715 * Dep)) * ((-0.101 * CI^3) + (0.7676 * CI^2) - (0.7654 * CI) - 1.807 * CI))$

Where:

CI = Channel Index (substrate for spawning)

Hydraulic Modeling

Most of the study site consists of run habitat. The longest stretch of riffle habitat occurs from the upstream end of the site to the Mill Street bridge. Under the bridge, the channel narrows and is more like a chute and water depth is greater here. Below the bridge, several large boulders create pool habitat and this section is where water depth is greatest (Figure 20). In general, pool habitat occurs downstream of large boulders. About three-fifths of the way down the site, two exposed pipelines cross the channel (Figure 21). The pipelines trap sediment upstream and form pool habitat downstream, creating a step-pool sequence. It is not known if the pipelines are a barrier to fish passage at low flows. Water velocities are highest at the upstream end of the site and under the Mill Street bridge (Figure 22). The two pipelines also create small areas of high velocity. Substrates within the channel were equal percentages cobble and boulder (Figure 23). Photos of the river at high, mid, and low flow can be found in Appendix D.

Habitat Modeling

Habitat for each species is a function of both quantity and quality. Both of these characteristics vary with discharge. An example of the change in habitat for selected life stages and species is shown below to illustrate these relationships. Detailed habitat maps for all species and life stages are presented in Appendix A.

Habitat versus discharge relationships for rainbow trout show the greatest amount of habitat between 98 and 200 cfs (Figure 24). Juvenile habitat is more abundant than other life stages at all discharges and peaks at 150 cfs. Adult habitat peaks at 200 cfs and fry habitat is most abundant at 98 cfs. Spawning habitat is essentially non-existent except at the lowest flows. Habitat versus discharge relationships for brown trout show the greatest amount of habitat between 98 and 150 cfs (Figure 25). Brown trout fry and spawning habitat use a common suitability with rainbow trout and therefore the relationship is the same as the rainbow trout function. Juvenile habitat is more abundant than other life stages at all discharges and peaks at 150 cfs. Adult habitat peaks at 98 cfs and fry habitat is most abundant at 98 cfs as well. Spawning habitat is essentially non-existent except at the lowest flows. Overall, juvenile habitat for rainbow trout and brown trout is similar for a given flow. In contrast, more habitat is available for adult rainbow trout than for adult brown trout.

Differences in habitat quality are also apparent. For example, while adult brown trout habitat peaks at 98 cfs, the most high-quality habitat occurs at 200 cfs (Figure 26, Figure 27). Higher quality is denoted by more areas with suitability values in the range of 0.5 to 1.0. For rainbow trout, the highest habitat quality occurs at 150 cfs for adults and 98 cfs for juveniles. For brown trout, the highest habitat quality occurs at 200 cfs for adults and 90 cfs for juveniles. Trout fry habitat quality peaks at 98 cfs. High-quality spawning habitat is not present at this site.

Habitat quality is also evident in a comparison of flows with approximately the same usable area. The total amount of adult brown trout is similar between 30 cfs and 300 cfs (Figure 25), however, the quality of the habitat at those two flows is different. There is less high quality habitat (>0.5) at 30 cfs (Figure 28) and more high quality habitat at 300 cfs (Figure 29). Juvenile brown trout habitat also has a difference in habitat quality for the same amount of total habitat. High quality juvenile brown trout habitat is much more abundant at 60 cfs (Figure 30) than at 300 cfs (Figure 31). The higher quality habitat at 300 cfs is near the shore, which is likely due to the more preferred velocity at the higher discharge.

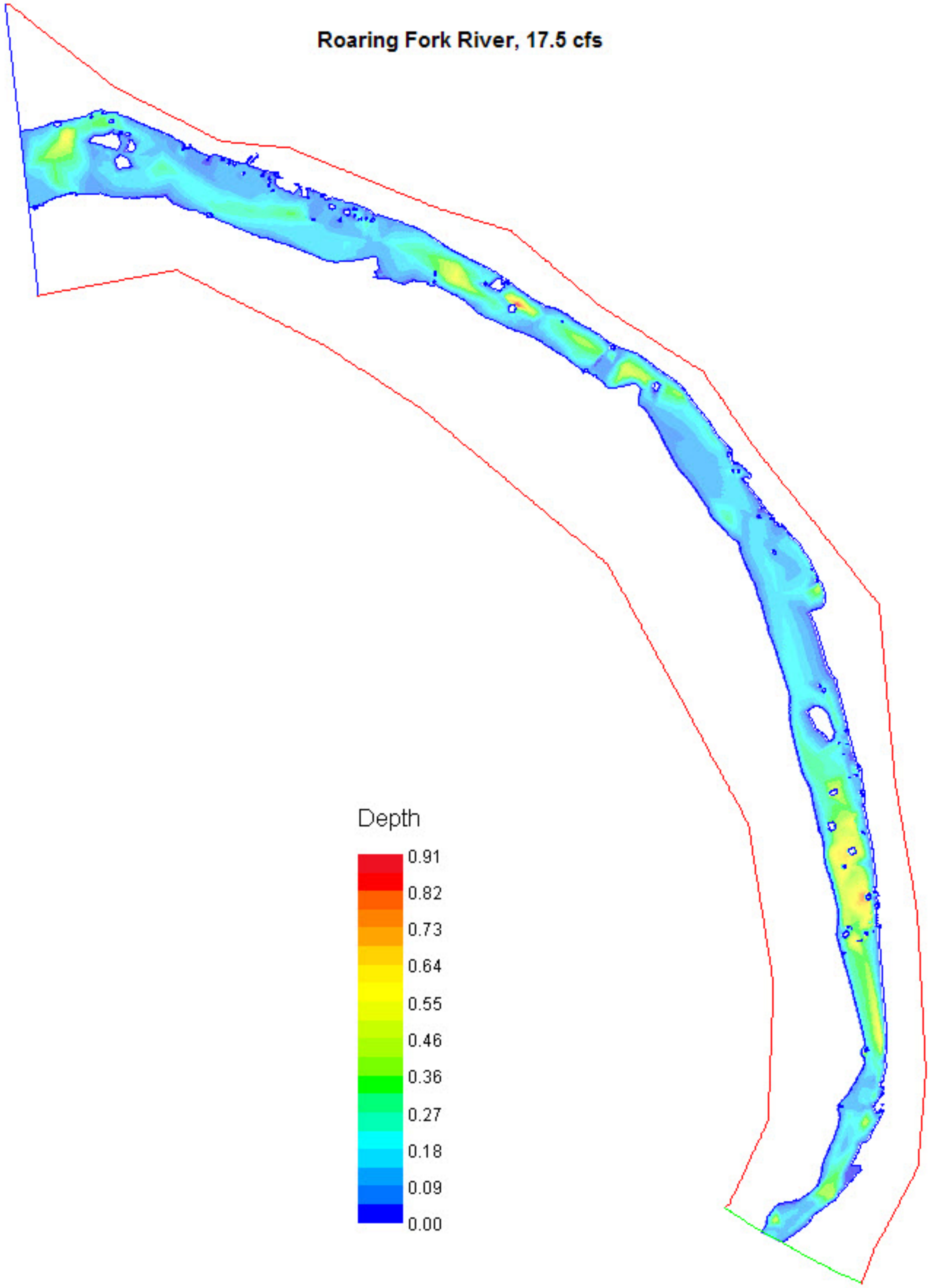


Figure 20. Simulated water depth at 17.5 cfs (low flow). Depths are in meters. Flow moves from bottom to top.

Figure 21. Exposed pipelines at low flow (17.5 cfs).

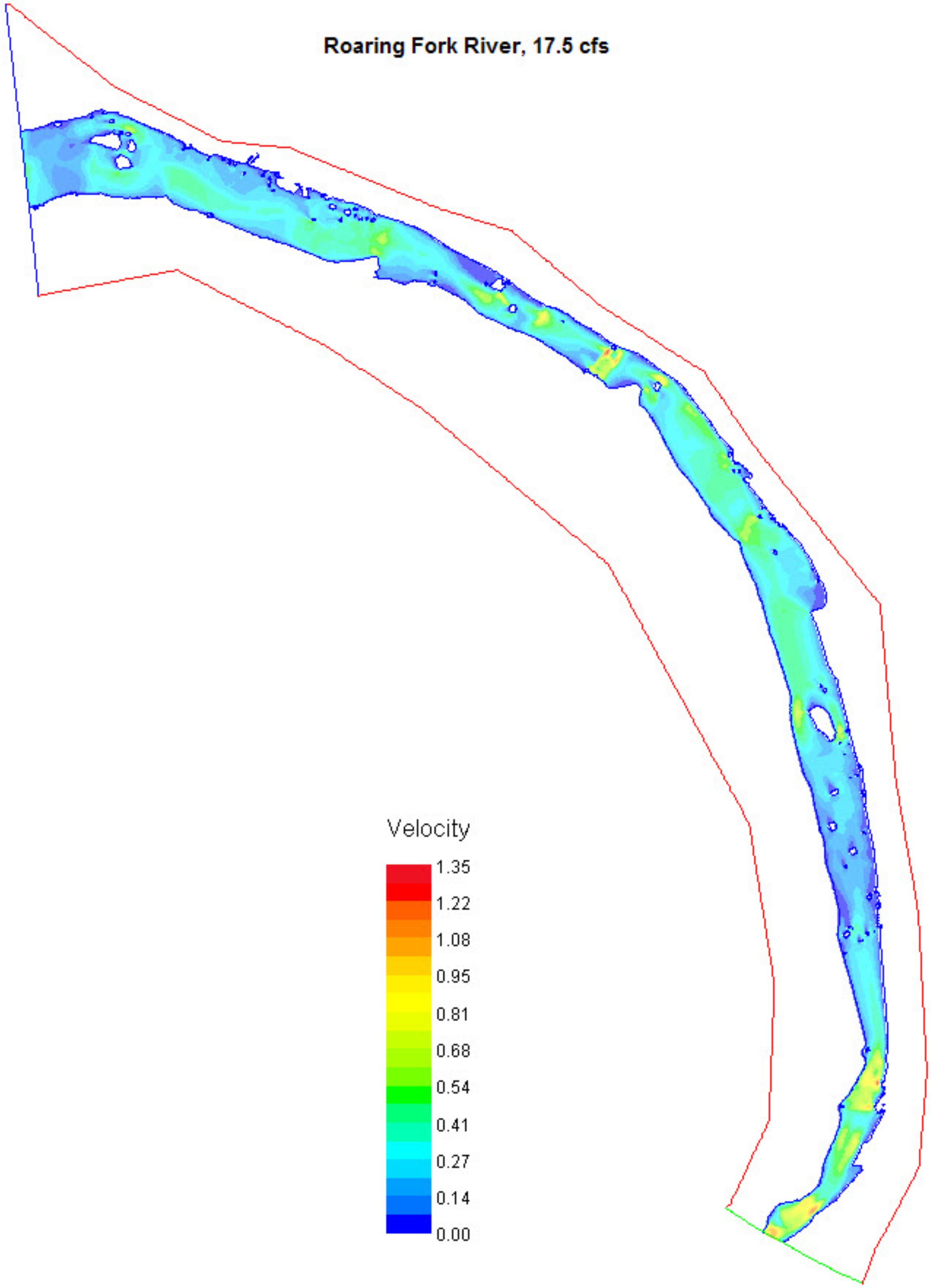


Figure 22. Simulated water velocity at 17.5 cfs (low flow). Velocities are in meters/second. Flow moves from bottom to top.

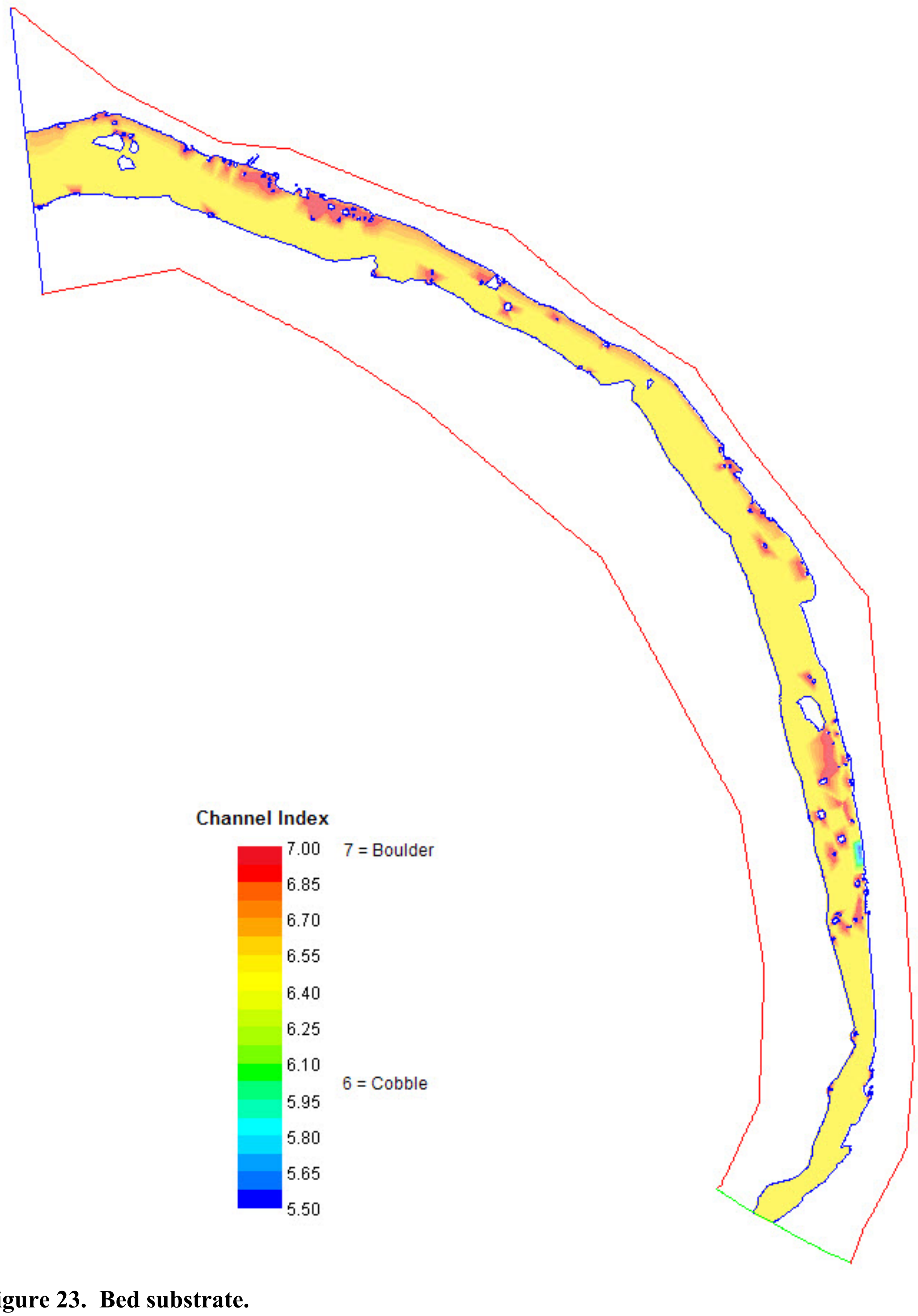


Figure 23. Bed substrate.

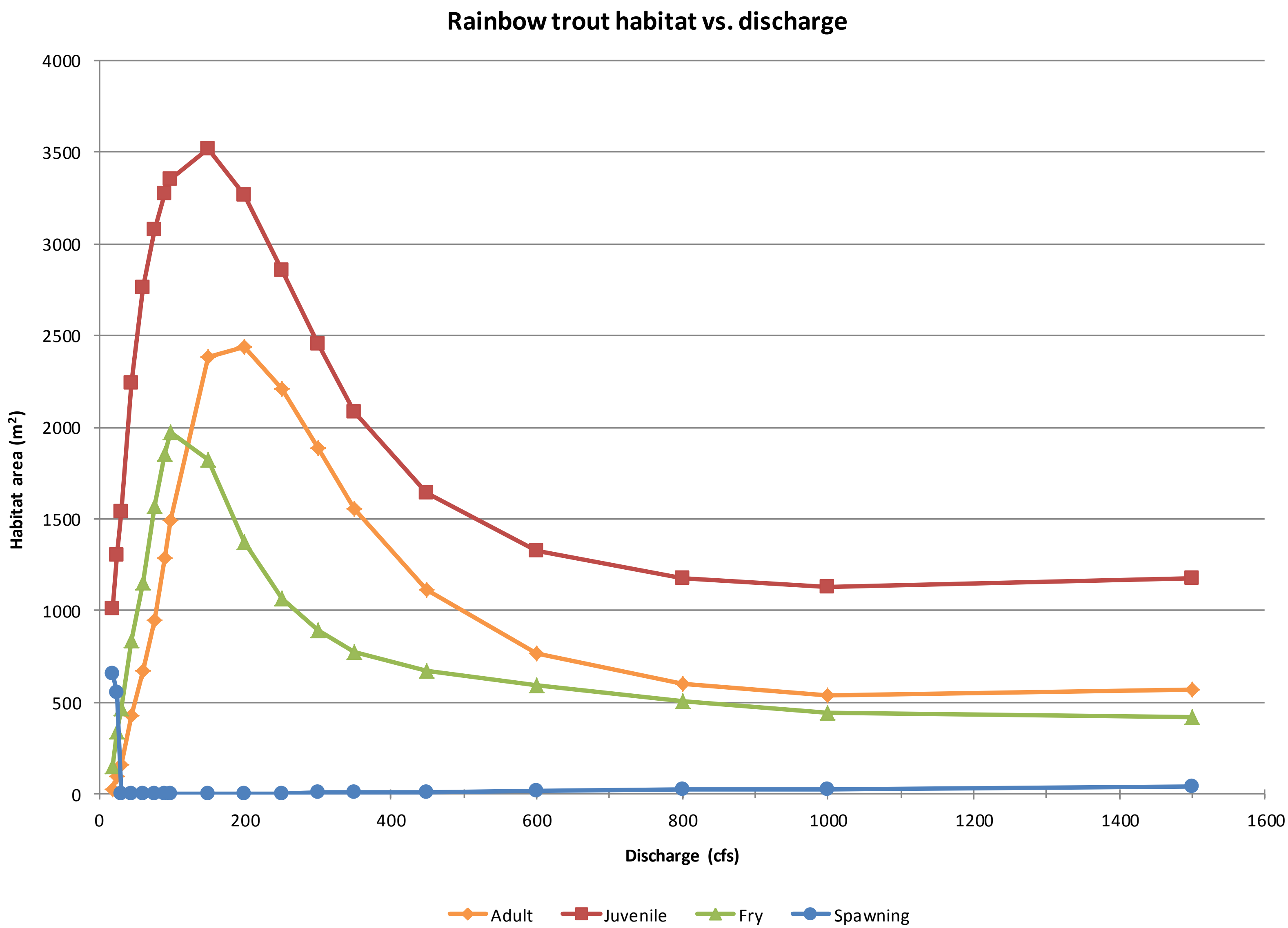


Figure 24. Rainbow trout habitat versus discharge.

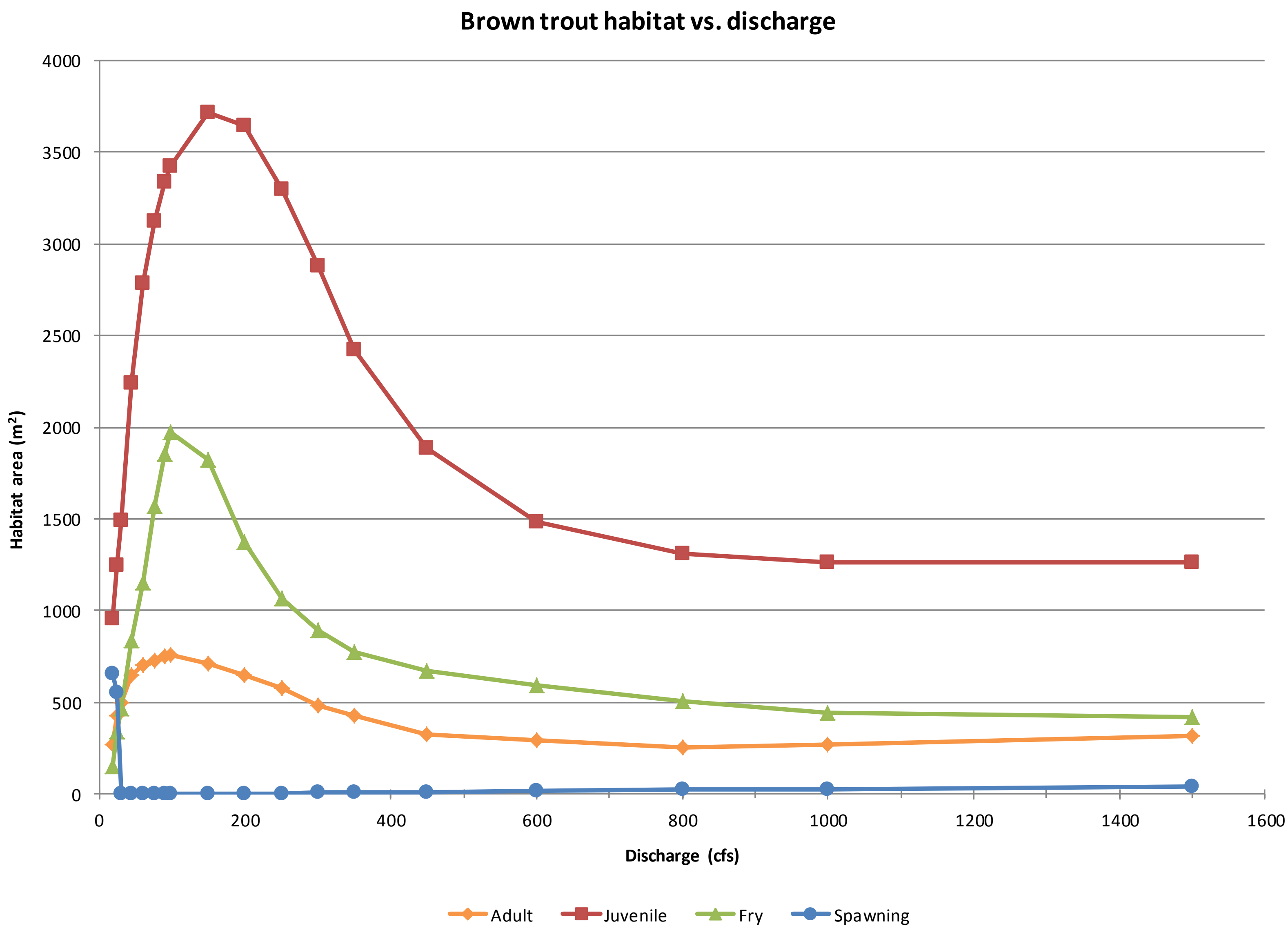


Figure 25. Brown trout habitat versus discharge.

Habitat Time Series

The daily variability in habitat location and quantity depends on the daily flows. Some examples of these variations are shown in the time series plots of habitat below. Habitat time series graphs for all species and life stages are presented in Appendix B. The hydrology used for the time series analyses was taken from USGS gage stations and was discussed previously (see Figure 13). The data for dry, median, and wet year types were used to display the annual change in habitat for a range of hydrologic conditions. Flows in 2010-2011 during our data collection were above median peak flows but would not be considered wet year conditions. Our late-summer flow measurement of 17.5 cfs was below that of an average dry year (20 cfs).

Figure 32 and Figure 33 display habitat time series for adult rainbow trout and adult brown trout. The graphs are incomplete from mid-May to mid-June because direct measurements of fish preferences at peak flows have not been made and estimates of habitat area during these high flows could be inaccurate. While adult rainbow trout have more habitat than adult brown trout during the runoff season, less habitat is available to adult rainbow trout in the late-summer and winter months. Habitat time series for the juvenile life stage is similar for the two species. Amount of habitat for the fry life stage is similar for the two species, although this life stage occurs at different times of the year. More spawning habitat is available for brown trout than for rainbow trout.

For both species, wet years have the largest amount of habitat except during the runoff season and early fall. The decrease in habitat in October in wet years is likely due to continued diversions into Salvation Ditch, whereas in median or dry years these diversions have likely stopped or decreased considerably. By November diversions into Salvation Ditch have stopped and this is represented by the jump in wet-year habitat.

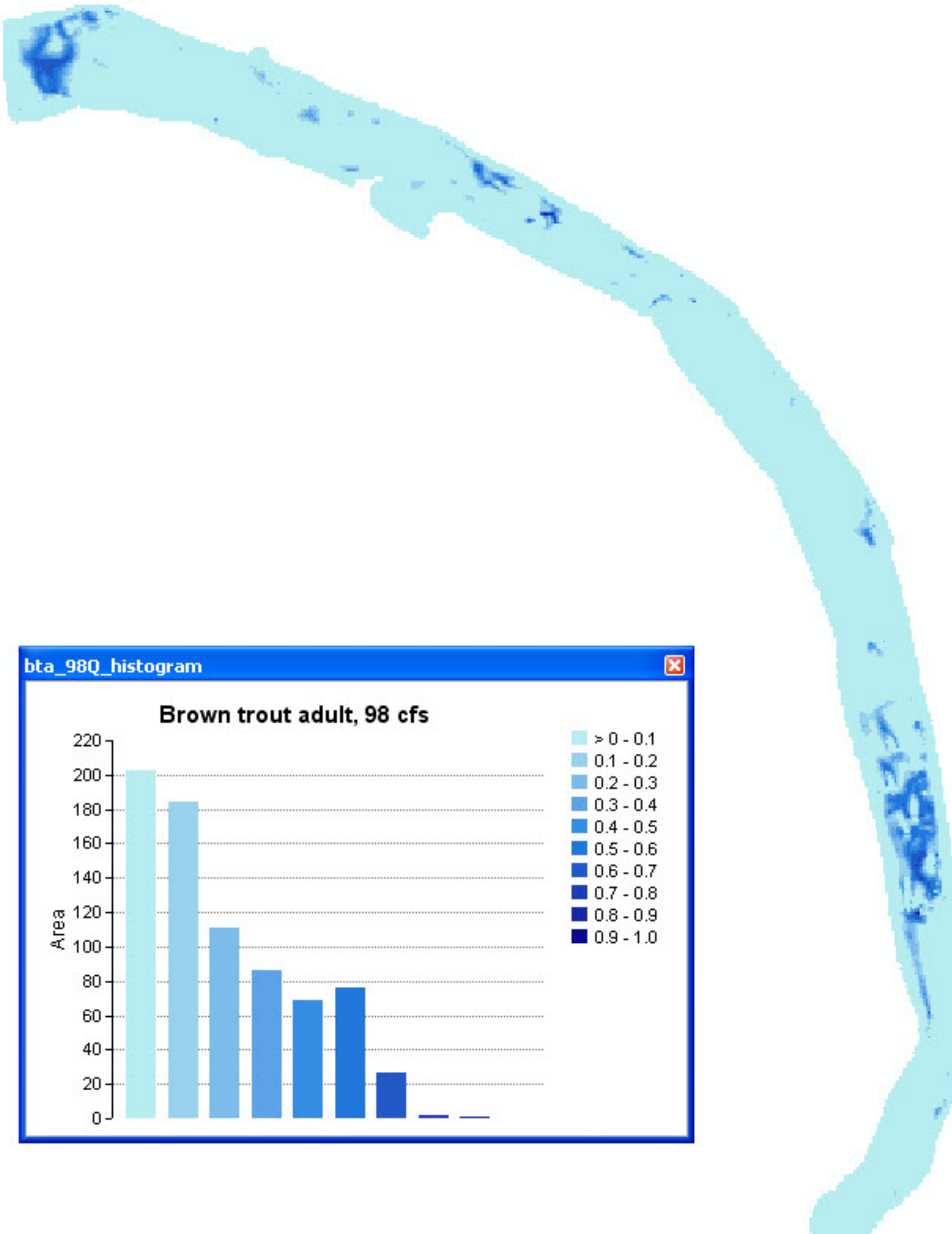


Figure 26. Adult brown trout habitat map, 98 cfs.

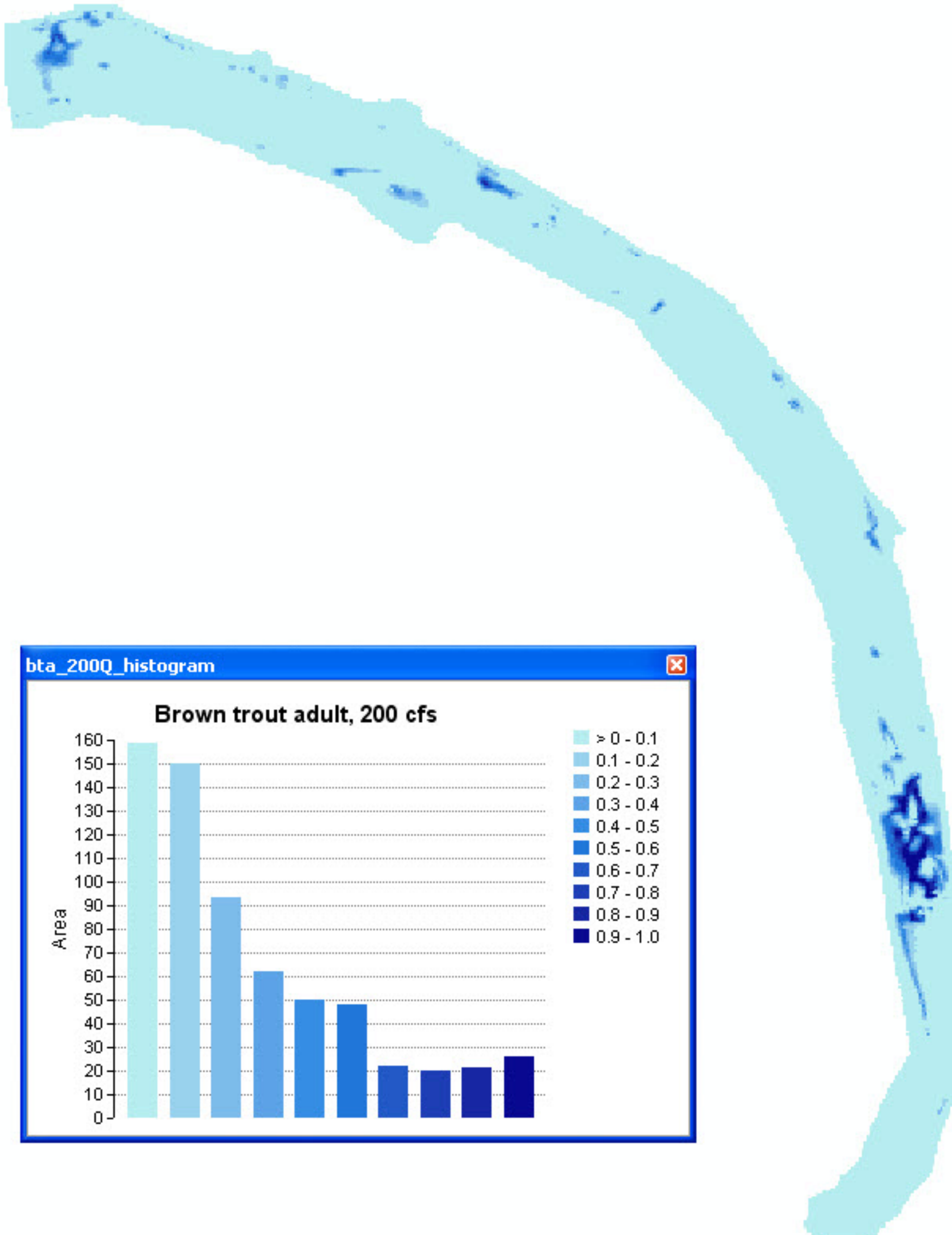


Figure 27. Adult brown trout habitat map, 200 cfs.

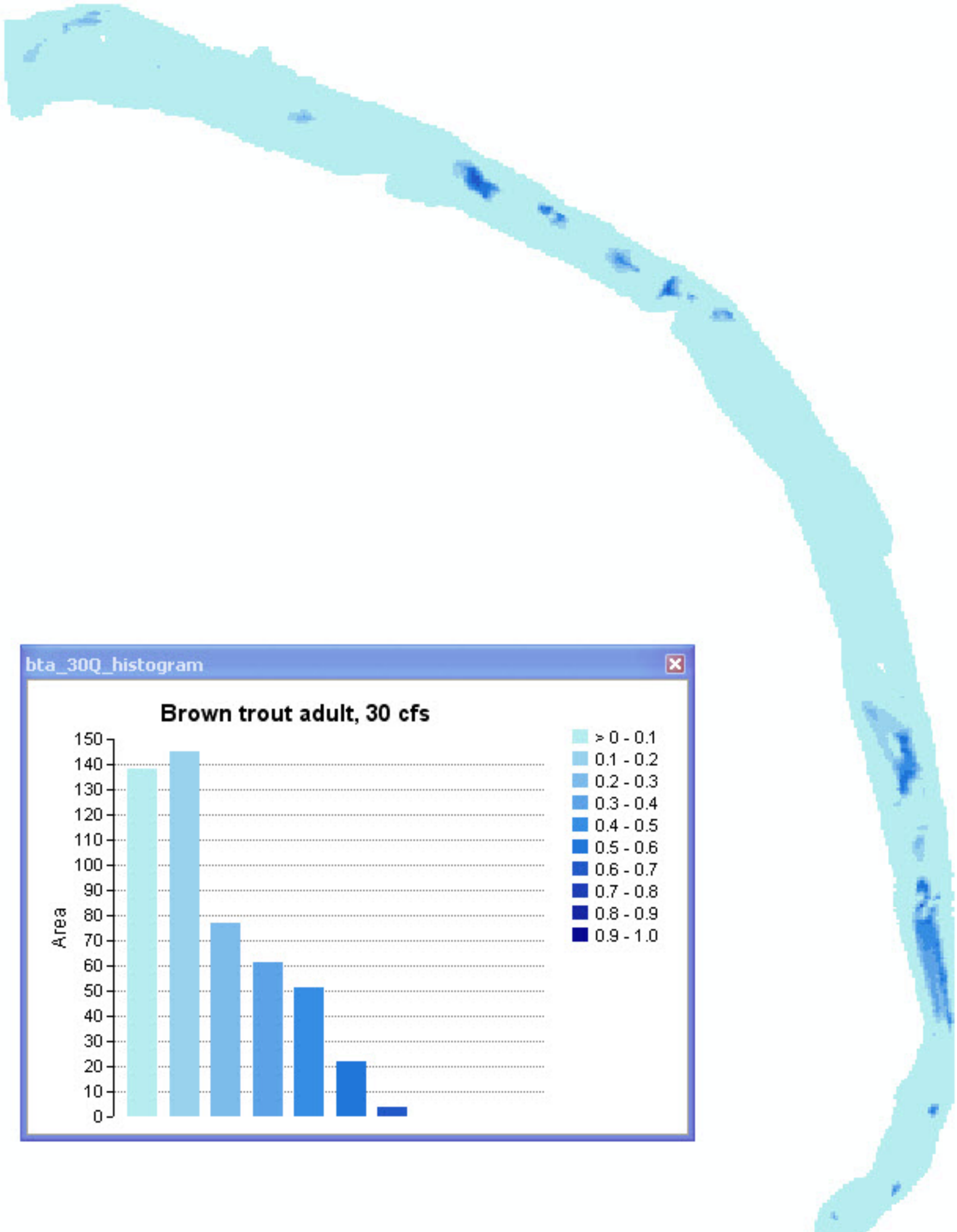


Figure 28. Adult brown trout habitat map, 30 cfs.

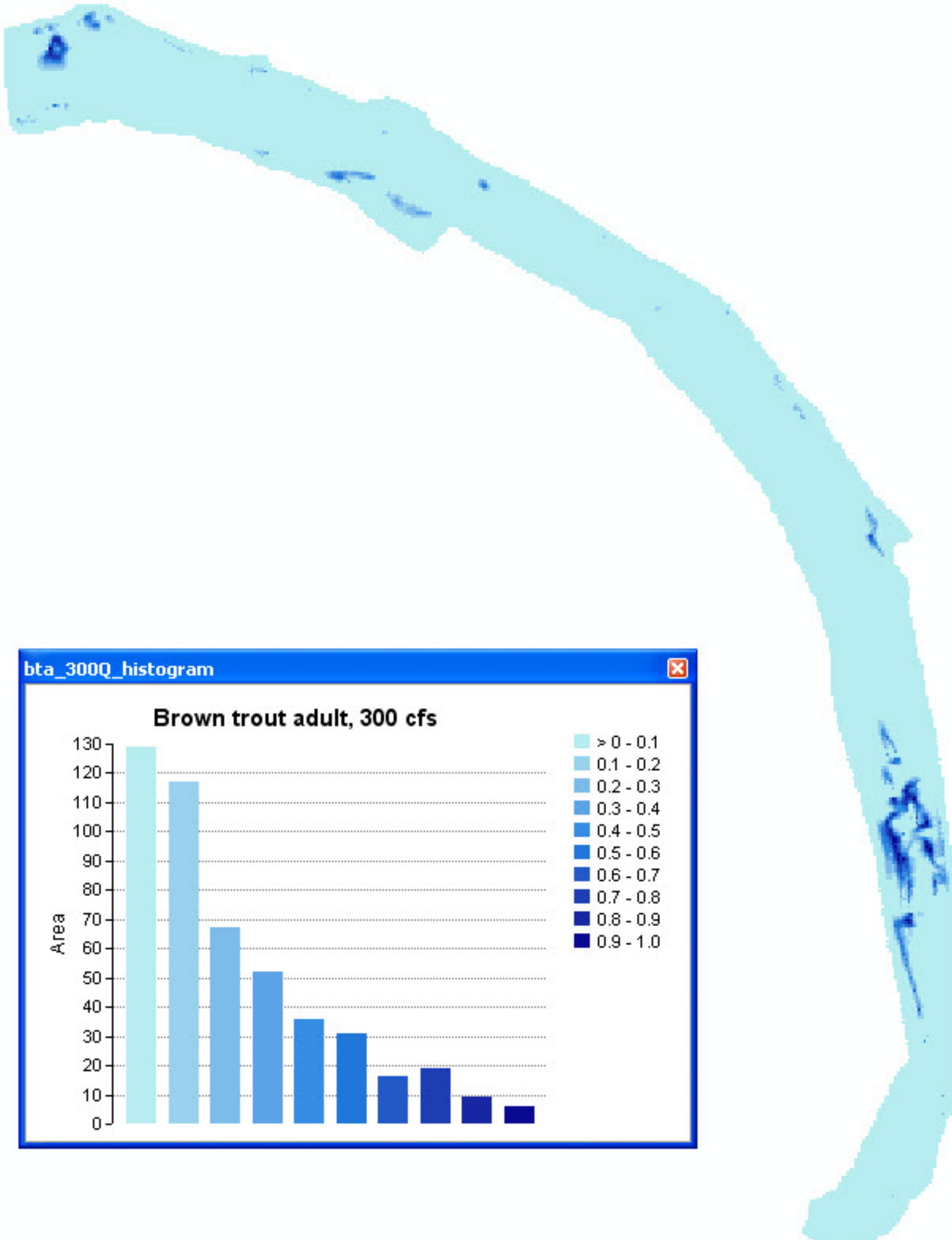


Figure 29. Adult brown trout habitat map, 300 cfs.

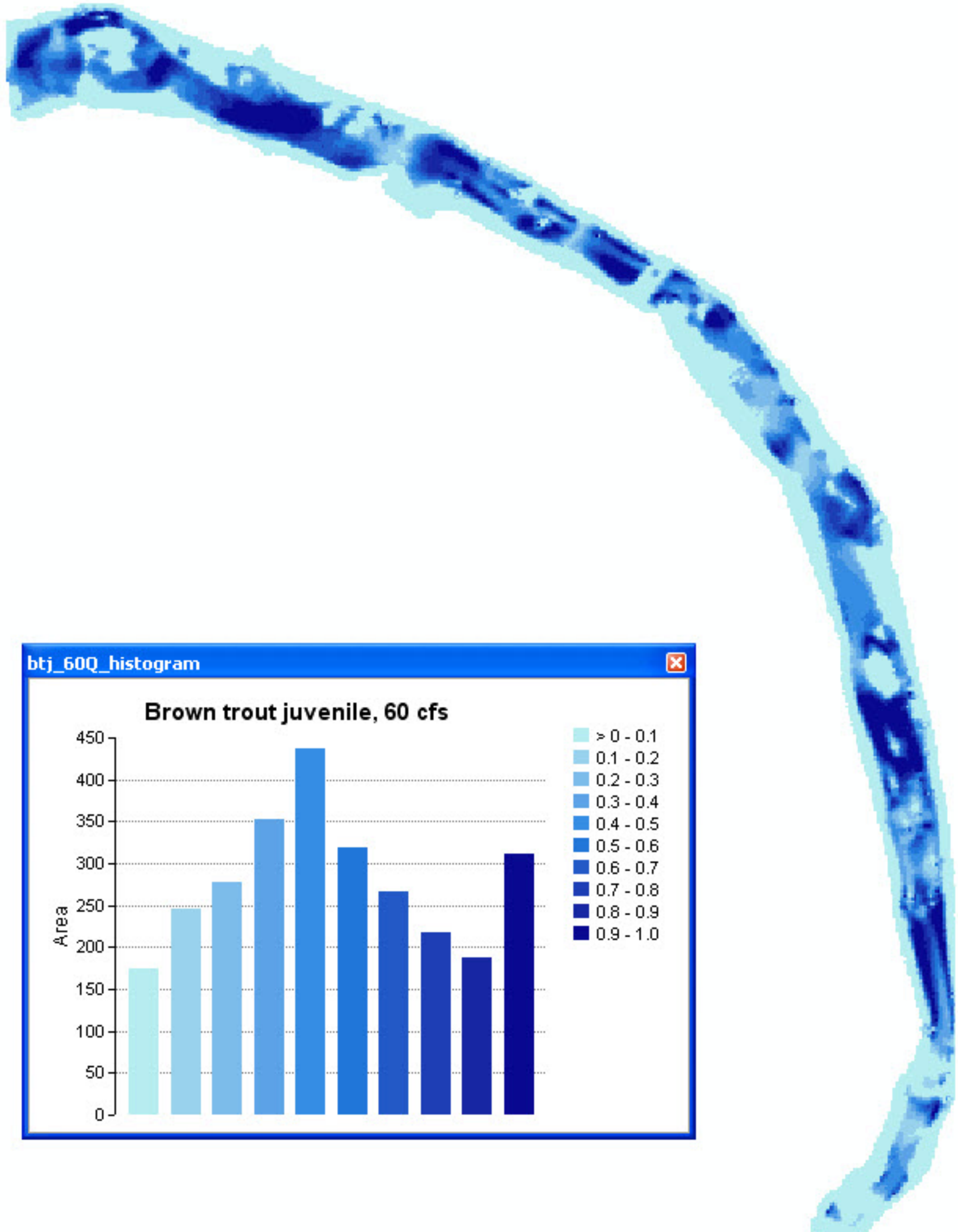


Figure 30. Juvenile brown trout habitat map, 60 cfs.

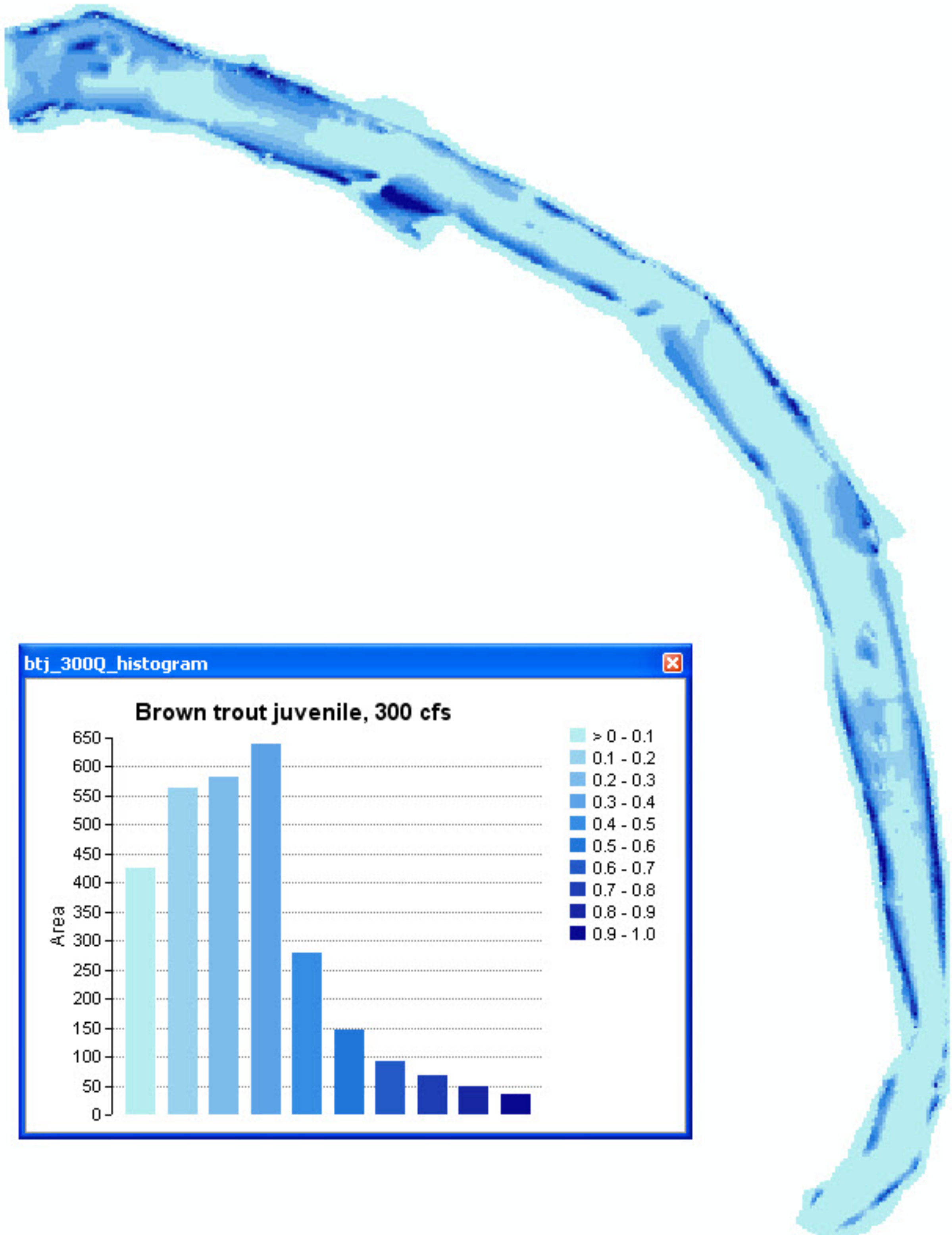


Figure 31. Juvenile brown trout habitat map, 300 cfs.

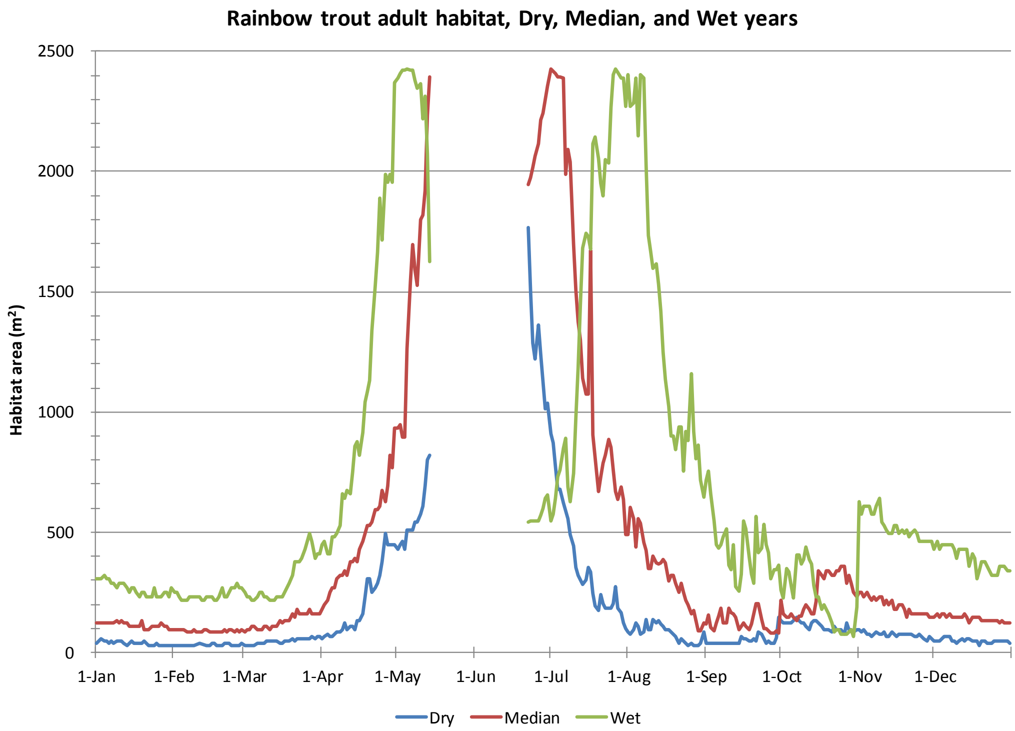


Figure 32. Adult rainbow trout habitat in dry, median, and wet years.

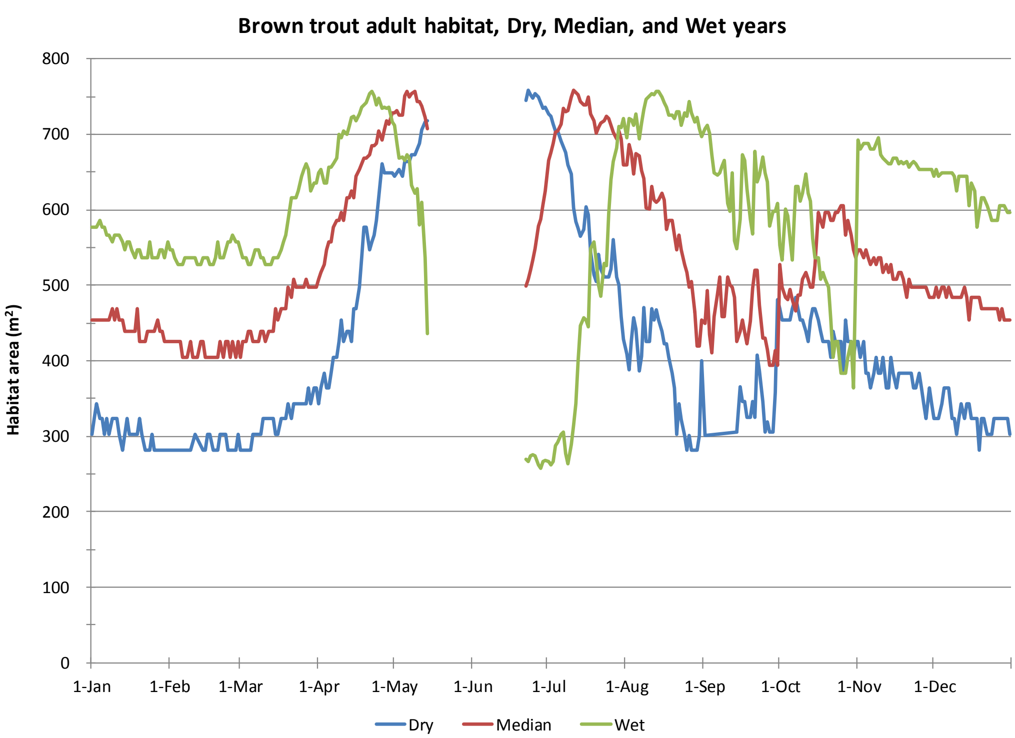


Figure 33. Adult brown trout habitat in dry, median, and wet years.

Macroinvertebrates

Macroinvertebrate samples were collected on September 28, 2010. Samples were taken from within the same reach that was sampled for fish and modeled for instream habitat (Figure 2). A complete species list is provided in Appendix C.

Chironomid midges (subfamily Orthocladinae) dominated the macroinvertebrate community, comprising 40% of the sample (all three replicates combined). 32% of the sample consisted of the caddisfly *Brachycentrus americanus*. In all, 29 different taxa were collected (Table 2). Of these, 7 taxa were from the Ephemeroptera, Plecoptera, and Trichoptera (EPT) orders. The EPT values at the study site are lower than EPT values from upstream and downstream sites in the Roaring Fork and sites in nearby Castle and Maroon creeks. The EPT index at a Roaring Fork site upstream of the Northstar Open Space was 12 – 15 (Miller 2010). EPT indexes for Castle and Maroon creeks ranged from 15-21 and 20-23, respectively (Miller and Swaim 2011). At a downstream site in the Roaring Fork near Basalt sampled by MEC (Ptacek et al. 2003) the EPT index ranged from 22-29. Compared to these other local sites, an EPT index of 7 at the Roaring Fork downstream of Mill Street is low and indicates some type of degradation. Diversity and evenness scores indicate that the site does not show evidence of organic pollution. An HBI value of 3.57 is on the low end of the range and suggests that the site does not experience organic enrichment. The overall MMI was greater than 50, indicating that the site supports aquatic life uses. However, if each replicate is considered individually, the MMI score is less than 50 for all three replicates.

Density and biomass for the current study site were 6,074 macroinvertebrates per square meter and 0.952 grams per square meter, respectively. This is similar to the values in the upper Roaring Fork and Castle and Maroon creeks. Density and biomass were lower than previous study conducted by MEC near Basalt. In that study, density ranged from 16,000-26,000 macroinvertebrates per square meter. Biomass ranged from 2.541-7.948 grams per square meter.

The lower EPT values may be the result of local inputs from the city. There are several irrigation returns and surface water drains that flow to the river within the city and could be affecting the EPT values.

Table 2. Metrics and comparative values for macroinvertebrate samples collected from the Roaring Fork River in September 2010.

Metric	Roaring Fork River Rep 1	Rep 2	Rep 3	Average	Total
Total Macroinvertebrate Density (#/m^2)	5965	4826	7430	6074	
Biomass (g/m^2)	2.031	0.386	0.437	0.952	
Taxa Richness	21	24	20	22	29
S-W Diversity	2.59	2.65	2.48	2.57	
S-W Evenness	0.589	0.521	0.624	0.578	
# EPT Taxa	7	5	6	6	7
# Ephem. Taxa	3	2	3	3	3
# Plec. Taxa	2	1	1	1	2
# Trich. Taxa	2	2	2	2	2
% EPT	34.3	34.7	38.3	35.8	
% Ephem.	2.7	2.2	3.1	2.7	
# Intolerant Taxa (TV = 0 or 1)	5	3	5	4	5
% Tolerant Organisms (TV = 10)	0	0	0	0	0
% Dominant Taxon	39.4	41.2	40.1	40.2	
HBI	3.58	2.94	4.38	3.63	
% Collector-Filterers	30.8	31.1	34.3	32.1	
% Collector-Gatherers	53.2	55.9	55.7	54.9	
% Predators	12.5	10.8	7.8	10.4	
% Scrapers	0.8	0.0	0.3	0.4	
% Shredders	0.0	0.0	0.0	0.0	
# Clinger Taxa	8	7	6	7	10
# Shredder Taxa	0	0	0	0	0
# Predator Taxa	7	10	4	7	11
% Clingers	40.5	41.0	43.7	41.7	
# Diptera Taxa	9	12	7	9	12
# Chironomidae Taxa	4	4	4	4	4
% Diptera	63.2	58.8	54.5	58.8	
% Chironomidae	51.9	49.6	46.5	49.3	
% Tribe Tanytarsini	0	0	0	0	
Biotype 2 MMI	45	46	34	42	58

Fish

The fish community was sampled by MEC and CDOW on September 21, 2010. Brown trout (*Salmo trutta*) was the most frequently captured species, followed by sculpin (*Cottus* sp.) and rainbow trout (*Oncorhynchus mykiss*) (Table 3). Sculpin were either mottled sculpin or Paiute sculpin; identification by CDOW is pending. A total of 194 brown trout, 13 rainbow trout, and 127 sculpins were captured during the sampling. Many more fish were captured in the first pass of the site than the second pass, which allowed for population estimates to be calculated that had fairly narrow confidence limits. However, sculpin are hard to capture effectively with electrofishing and so the estimates given for that species in Table 3 are likely not representative of the true population.

Brown trout were a range of sizes, from young-of-year to adult (Figure 34). Young-of-year rainbow trout were not captured. On average, rainbow trout were larger, weighed more, and had a higher condition factor than brown trout. One brown trout had a gill injury and gill lice, but no other fish captured had external parasites.

There are approximately 1500 brown trout and 100 rainbow trout per mile of river in the study area (Table 3). The average condition factor for both species is greater than 1.0 which indicates that the fish have adequate food resources. The rainbow trout had a slightly better condition than brown trout. Both rainbow and brown trout had multiple year classes present in the sample. Brown trout had at least 5 year classes present (Figure 34).

Table 3. Species counts, population estimates, and averages for length, weight, and condition factor, Roaring Fork River, September 2010.

	Brown trout	Rainbow trout	Sculpin
Count	194	13	127
Avg. Total Length (mm)	216	285	78
Avg. Weight (g)	137.8	251.1	5.5
Avg. Condition	1.02	1.32	0.95
Population Estimate*	200 ± 7	13 ± 2	139 ± 13
Fish / mile	1534 ± 57	101 ± 15	1062 ± 101
Lbs. / acre	98 ± 4	12 ± 2	3 ± 0

*All confidence intervals are 95%

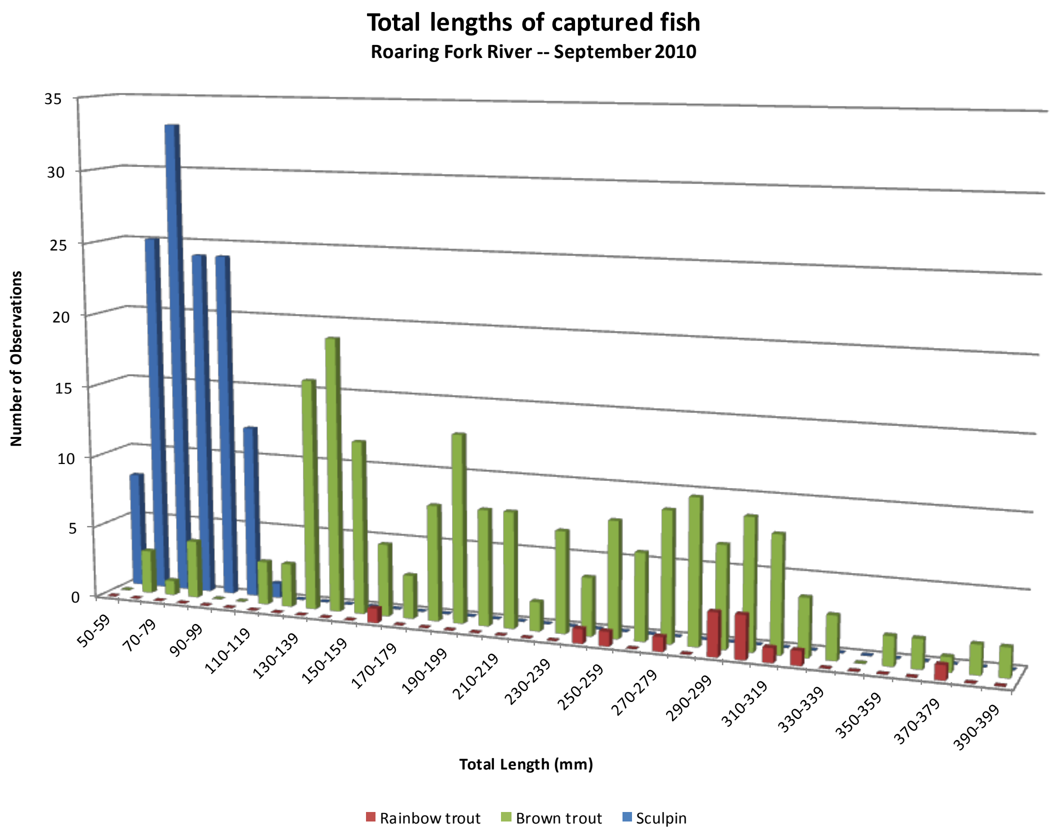


Figure 34. Species length frequencies, Roaring Fork River, September 2010.

DISCUSSION AND CONCLUSIONS

Ecological Flows and Stream Health

Recently, research has focused on comprehensive ecologically-based management of riverine systems to provide function for both instream aquatic biota as well as near-stream riparian areas (Bunn and Arthington 2002, Chapin et al. 2002, Lytle and Merritt 2004, Lytle and Poff 2004, Richter et al. 2003). Natural flow regimes, with both floods and droughts, occurred for many years prior to any river regulation. The biota in these ecosystems have adapted to that flow regime. That adaptation is the response to changes in the physical environment with floods as well as the biological adaptation to withstand floods or prolonged droughts in those systems (Lytle and Poff 2004). Lytle and Merritt (2004) in their study of riparian forests concluded that a natural flow regime was the best prescription for maintaining near-stream cottonwood riparian areas.

In addition to instream flows, research has focused on river conservation and restoration (Trush et al. 2000). The study of river ecosystems includes all of the riverine components listed by the Instream Flow Council in the context of a functioning system that provides the components necessary for restoring and maintaining a diverse ecosystem similar to natural conditions. The dynamic character of river systems has been stated as one of the important features in maintaining ecological integrity (Poff et al. 1997). The natural variability within riverine systems needs to be considered as part of restoration and flow manipulation efforts. Any specified instream flow management should include a strategy for incorporating this natural variability and also the potential uncertainty involved with that in restoration of river systems (Wissmar and Bisson 2003).

Physical components of riverine systems that affect the biota both in the riparian and instream areas include hydrology, geomorphology, and water quality. Hydrology within riverine systems, especially in systems with snowmelt-driven hydrographs, usually have spring or early summer peak flows with base flows occurring in fall through winter. The magnitude and duration of the peak flows are variable and dependent on annual snowpack and also rainfall events that occur after snowpack has subsided. These flows affect the stream morphology. Specific flow magnitude and duration are required to move sediment, initiate channel migration, create and maintain habitat, and incorporate organic material in the form of woody debris into the system.

Research has shown that the geomorphic changes occur with peak flows of various return intervals. Hill et al. (1991) discussed the need for large flow events for channel migration and valley form influences. These events are generally large events that occur approximately 1 in 25 years or greater. More frequent flooding occurs on nearly an annual basis. These flows occur at a bankfull or slightly higher than bankfull level and are shown to rework channel features without a lot of channel migration. In general, these flows occur every 1.5 to 2 years in most stream systems. Research has shown that flows that occur during the annual peaks do most of the in-channel reworking of bars and instream habitat to create habitat for the base flow period of the year.

The ecological flows should have a recurrence interval for overbank flooding that is approximately 1.5 to 2 years between flow events to maintain connectivity with the riparian areas and maintain longevity of riparian forests. In addition the specified bankfull flows, to maintain instream channel habitat and create new habitats, should occur at a frequency that is generally found in the natural system and is suitable for present channel conditions. Habitat-flow relationships for base flow conditions and other seasons of the year can be determined from stream cross-sectional data for riffles, which is an indicator of benthic invertebrates' productivity.

Biological Components of Riverine Systems

Biological components of riverine systems include instream biota such as primary and secondary producers (e.g. algae, periphyton, and benthic invertebrates) and consumers (e.g. invertebrates and fish). Aquatic biota have evolved to survive within the range of flows that occur under natural conditions. For example, benthic invertebrates with annual life cycles are in life stages that avoid high flow's impacts. These include adult free-flying life stages and egg life stages.

Fish species also have evolved to minimize impacts from detrimental flows. Timing of spawning, hatching, and emergence for native salmonids is timed to maximize long-term survival under natural flow regimes. The natural flow regimes create habitat that can be used by juvenile and adult fish to avoid detrimental effects of high flows and refuge habitat during low flows.

Riparian corridors also include terrestrial species of plants and animals that depend on instream flows. High flows during runoff inundate riparian areas which promote new vegetation growth, maintain existing vegetation, and carry organic material into the stream channel.

The channel geometry and plan form of the channel and the biota within the channel are all affected by the volume and timing of annual discharges. Physical features of the stream channel change as a result of peak flows and the biota respond to those physical changes.

Aquatic biota responses to peak flows are also apparent in the various biota that inhabit the stream. Benthic macroinvertebrates in snowmelt runoff systems have generally evolved to avoid the detrimental effects of high flows. These include being in locations or in life stages that avoid those high flow impacts. Many of the macroinvertebrates in western stream systems have evolved so that adults emerge and lay eggs prior to runoff. Therefore the most dominant life stages that exist in peak flow are the egg or early instars. The small size of these life stages allows them to avoid many of the detrimental effects of peak flows.

Overall stream productivity, on average, in natural systems is determined by the base flow conditions that provide for primary and secondary productivity and feeding as well as refuge habitats. Peak flows temper those populations and can influence the year class strength of salmonids if very high discharges occur when the young fish are susceptible to peak flows. In general the peak flow time period is the lowest amount of optimal habitat for fish species but that peak flow provides the work in the channel that shapes, creates, and maintains habitat for the majority of the year for those species.

Environmental Condition in the Roaring Fork River

The existing flow regime in the Roaring Fork River includes most of the components for stream health. There are high peak flows that exceed bank full conditions on a regular basis (one in two years). However, these flows are reduced by some degree due to the transbasin diversion in the headwaters of both the Roaring Fork River and Hunter Creek. The current flows provide the conditions to create and maintain habitat, particularly in wet hydrologic conditions. In addition, these flows provide the conditions to maintain near stream riparian conditions. The ascending and descending limbs of the peak runoff have a natural shape determined by each year's snowpack.

The late summer base flows appear to be most effected by upstream diversions. The Colorado Water Conservation Board (CWCB) holds an instream flow for 32 cfs in the study area, which is junior to other upstream water rights. The late summer flows are lower than 32 cfs in many years (Table 1). In several years the low flows are between 15-20 cfs. Flows in this range have less wetted area available for macroinvertebrate production than flows greater than 30 cfs. There is approximately 20% less wetted habitat at 17 cfs than at 30 cfs. If minimum flows were maintained at the specified level, invertebrate food base would likely increase with the wetted area. The current EPT macroinvertebrate community at the study site is less robust than either upstream or downstream of the study area. The cause of this decline in the macroinvertebrates is unknown. Although there is a difference in the species present in the study site, the density and biomass for the study site is similar to other locations with higher EPT values. Additional sampling at multiple locations could potentially identify the cause of the reduction in EPT species if it is caused by a point discharge. The location of the source of impact may not be discernible if the cause is the general watershed characteristics within the city.

Instream fish habitat also substantially changes between 17.5 and 30 cfs or greater discharge. Instream habitat for adult and juvenile rainbow and brown trout increases by more than 30% when flow increases from 17 to 30 cfs. This increase may result in higher fish populations in the study area. The current fish populations, especially brown trout are good for the size of river. The fish condition factor for both trout species is good as well, indicating that the food resources are adequate to support the current populations.

The data collected in this study indicate that the Roaring Fork River in the study area has a macroinvertebrate community that indicates slight degradation of water quality compared with locations upstream and downstream of the study area. The trout in the study area have good body condition indicating that the food base is adequate to support the current populations. The brown trout population has all size classes present indicating that natural reproduction is occurring and the fish survive and recruit to older age classes. Rainbow trout do not have this same age class distribution but it is likely due to factors such as whirling disease rather than flow. Rainbow trout are stocked by Colorado Parks and Wildlife and do survive and grow in the study area.

To maintain the current stream habitat conditions, peak flows greater than 350 cfs should occur every other year and peak flows greater than 1000 cfs should occur approximately 1 in 10 years. The ascending and descending limbs of the hydrograph should be maintained in the current shape without a sharp increase or decrease. Habitat conditions at base flows would be improved by maintaining stream flows at 30 cfs or greater.

Stream Stability

The reach of the Roaring Fork River through the City of Aspen is significantly encroached upon as a result of urban development. Very little of the river's floodplain remains along the river corridor and upstream diversions, and man-made perturbations within the watershed have changed not only the hydrology of the system, but also a whole host of other functions and processes including the sediment transport characteristics of the river. As indicated in the watershed report (Clarke et al. 2008), the in-stream and riparian habitat quality in this reach of the river is considered severely degraded as a result of these perturbations.

Contributing to the degraded in-stream habitat is the presence of boulder grade control structures emplaced to protect exposed utility crossings and to provide flow to man-made split flow channels. These structures create significant vertical drops that are an impediment to fish passage as well as inducing localized upstream aggradation that reduces the flow depth, increases the channel width through bank erosion, and buries spawning substrates within the aggraded reach.

The boulder structure creates a significant impediment to fish passage during low flows, but may develop a large scour hole and depositional zone downstream that may provide some beneficial habitat. However, the structure also creates a significant flattening of the channel gradient for a short distance upstream, which in turn also induces localized aggradation which reduces the quality of in-stream habitat and spawning substrate at that location. Both the structure and upstream aggradation can also induce or contribute to bank erosion at the ends of the structure as well as immediately upstream of the structure. Bank erosion at the ends of the structure can result in flanking or significant damage to the structures.

The structures at three of the locations were constructed to protect exposed sewer pipeline crossings. Since it is imperative that these crossing be protected, it would be beneficial to river function to modify the protecting structures such that they still provide maximum protection to the pipelines as well as provide fish passage at all flows. A number of agencies provide design guidance for grade control features that also allow for fish passage. For example, one method of grade control consists of a series of rock weirs placed such that flow is allowed to pass over and around the overall structure while maintain unobstructed fish passage as well as grade control.

At this time, we would recommend that the Healthy Rivers and Streams Program, in cooperation with the City of Aspen and Pitkin County reconstruct the boulder structures using a series of weirs. See Appendix E for examples.

We would also recommend the complete removal of the structure at Jenny Adair Park as it appears to serve no other purpose than an aesthetic one. If the split flow channel at this location is, in fact, used by the Aspen Center for Environmental Studies and serves a useful purpose, we would recommend that the boulder grade control structure used to divert flows into the split flow channel still be removed, but that the diversion point be located much further upstream. This can be accomplished by extending the upper end of the split flow channel further upstream to a point where flow can be successfully diverted without requiring a diversion structure while maintaining adequate flow depths and widths as well as fish passage at all flow levels.

The kayak park upstream of the Aspen Art Museum impact natural river channel function. We recommend the complete removal of the course and reclamation of the area occupied by the course to a functional floodplain. Based on our knowledge of the course, it appears that the course is used infrequently and only when there is sufficient flow, such as during spring runoff. Thus, the course is only viable for a short period during the entire year and will likely require ongoing maintenance to keep the course pools clear of sediment and organic debris. These pools with fine sediment provide habitat for tubifex worms, which are one of the hosts for whirling disease. Removal of the course would remove the habitat for the whirling disease host. The kayak channel could be reclaimed by removing the excavated material from the intervening island and refilling the kayak channel with little to no effect on in-stream habitat on the main channel of the river. By refilling the kayak channel, the floodplain area occupied by the island that was covered with the material previously excavated from the kayak channel would also be restored. Reshaping of the left bank of the river and replanting riparian vegetation on the reclaimed island/floodplain area would also contribute to habitat diversity in this reach.

Although these recommendations would likely require a significant budget as well as appropriate permitting to accomplish, the upfront costs should be offset and mitigated by the long-term advantages of restoring in-stream and floodplain habitat at the locations described above.

We suggest that Pitkin County, through its Healthy Rivers and Streams Board, initiate discussions with the appropriate city, county, and private entities regarding the above recommendations to restore stream channel function. These initial discussions could assist these groups to: 1) prioritize the recommended channel restorations in this report; 2) begin the process for channel restorations; and 3) develop a long term strategy for maintaining river health and function.

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APPENDIX A: INSTREAM HABITAT MAPS

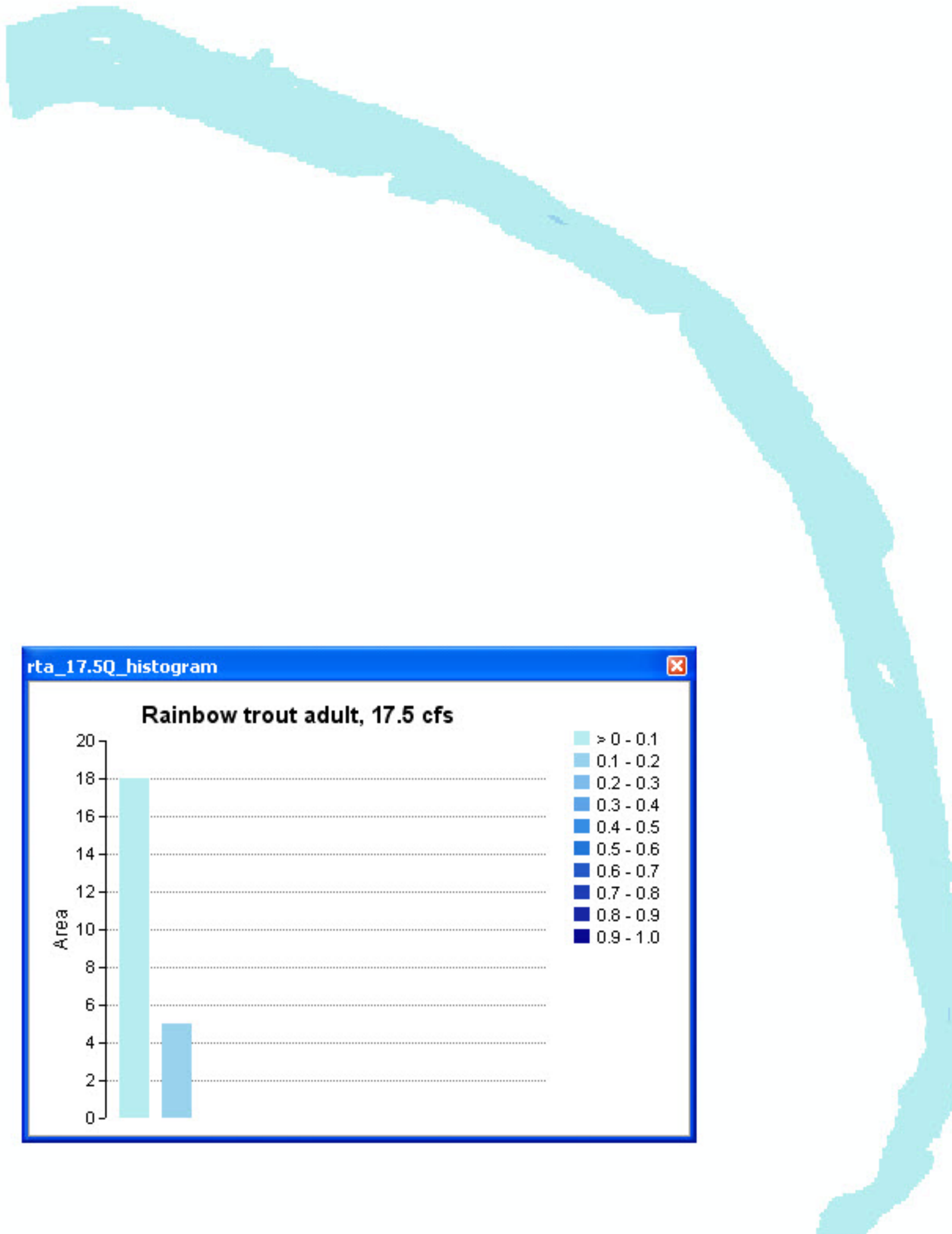

Figure A-1. Adult rainbow trout habitat map, 17.5 cfs.

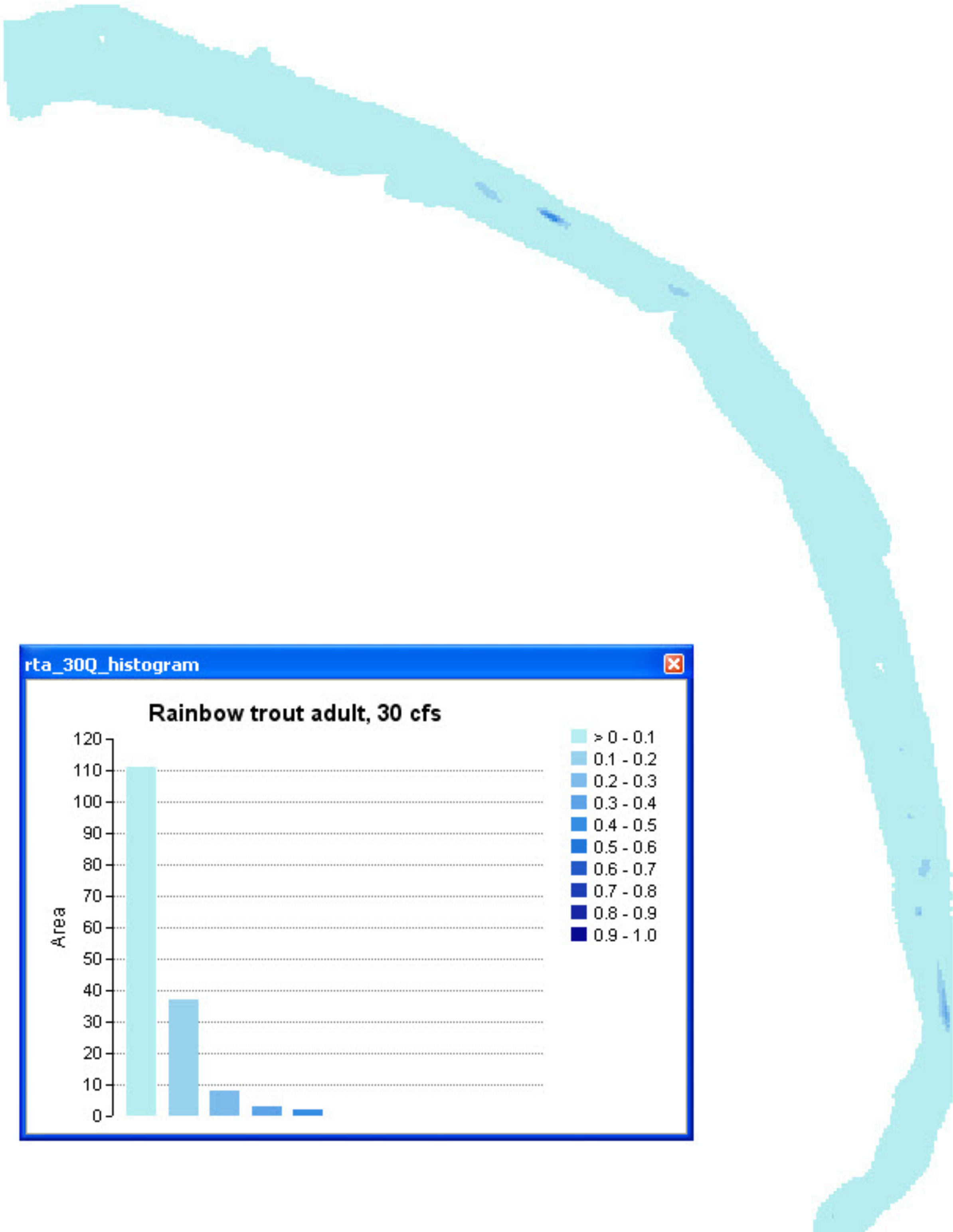

Figure A-2. Adult rainbow trout habitat map, 30 cfs.

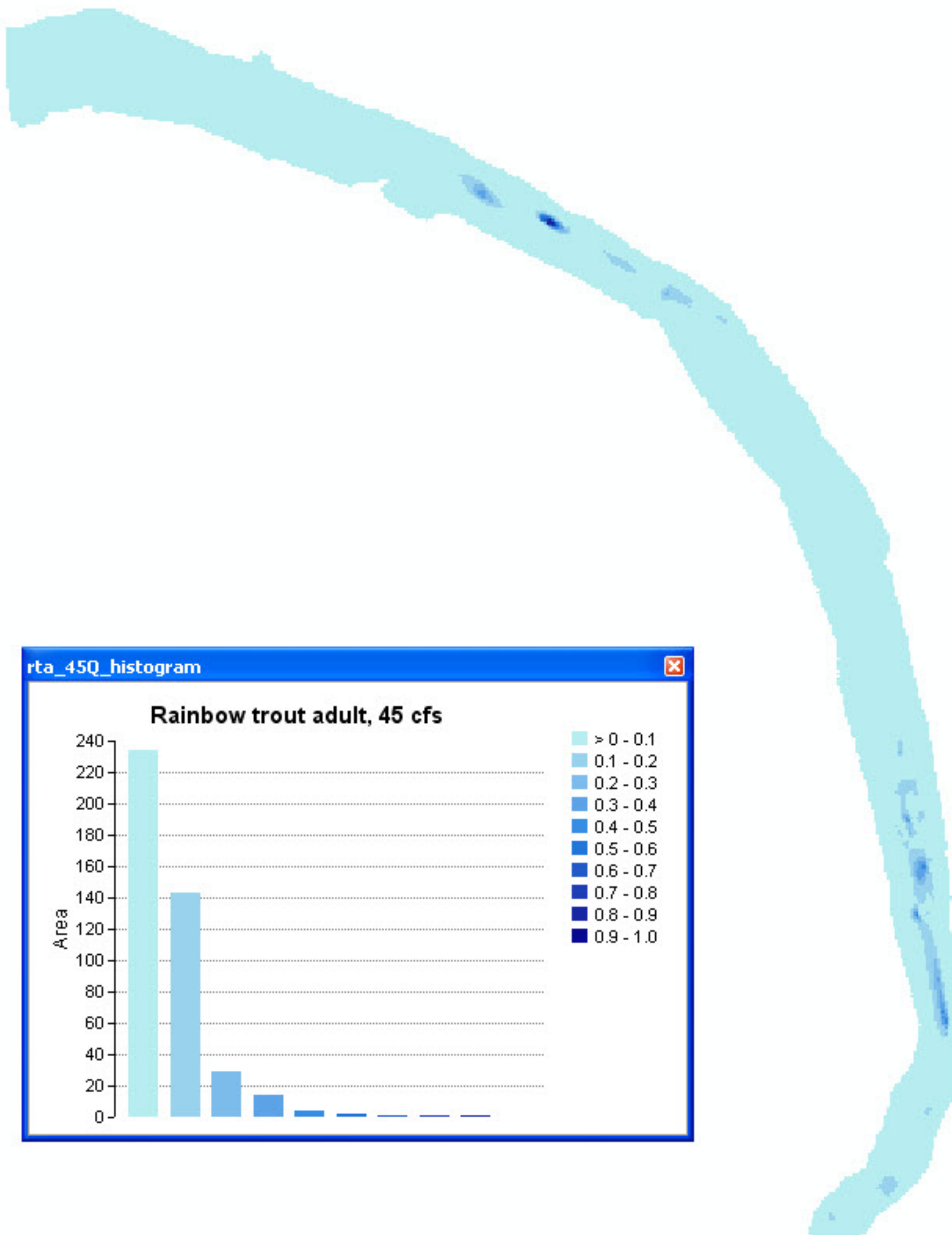

Figure A-3. Adult rainbow trout habitat map, 45 cfs.

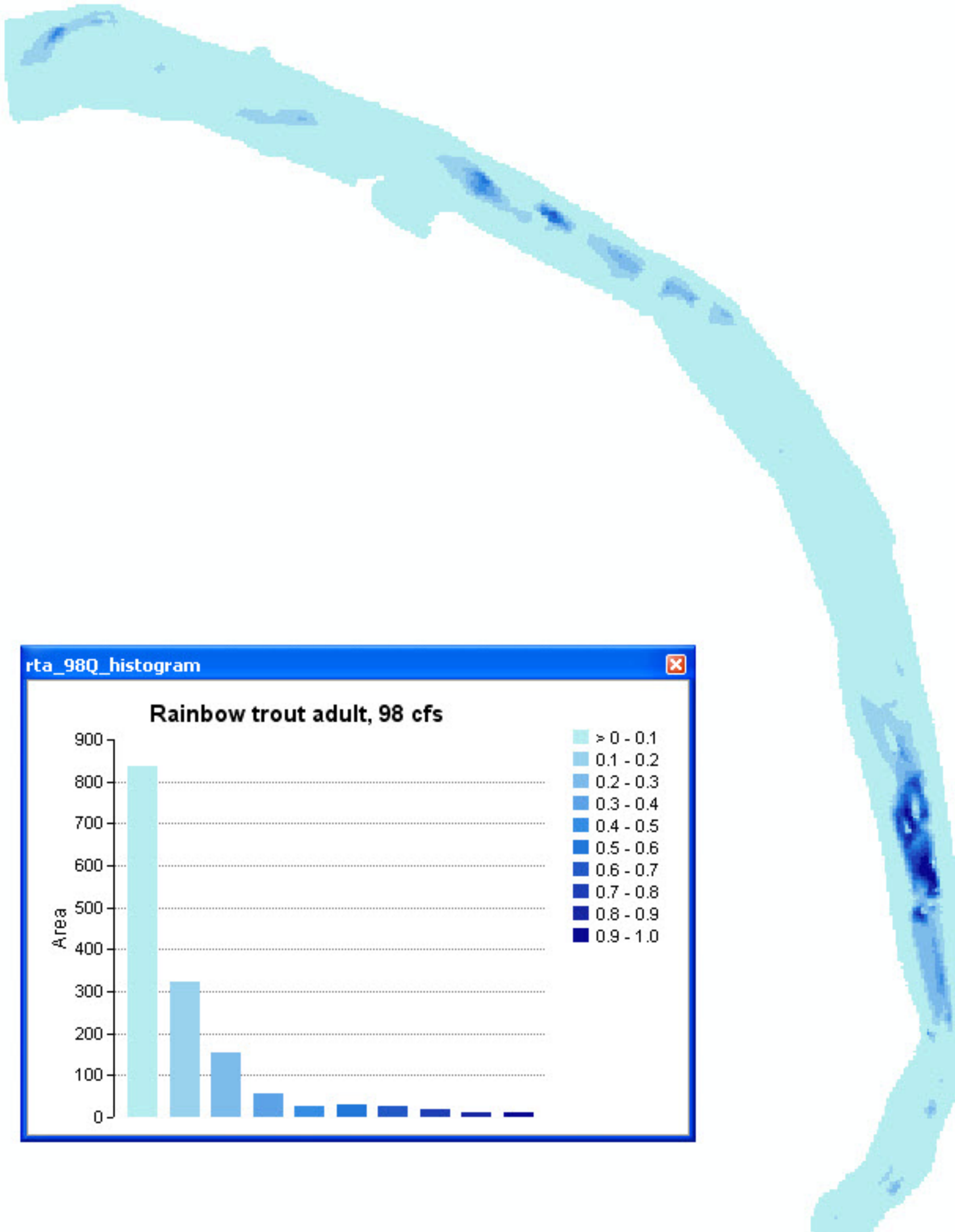

Figure A-4. Adult rainbow trout habitat map, 98 cfs.

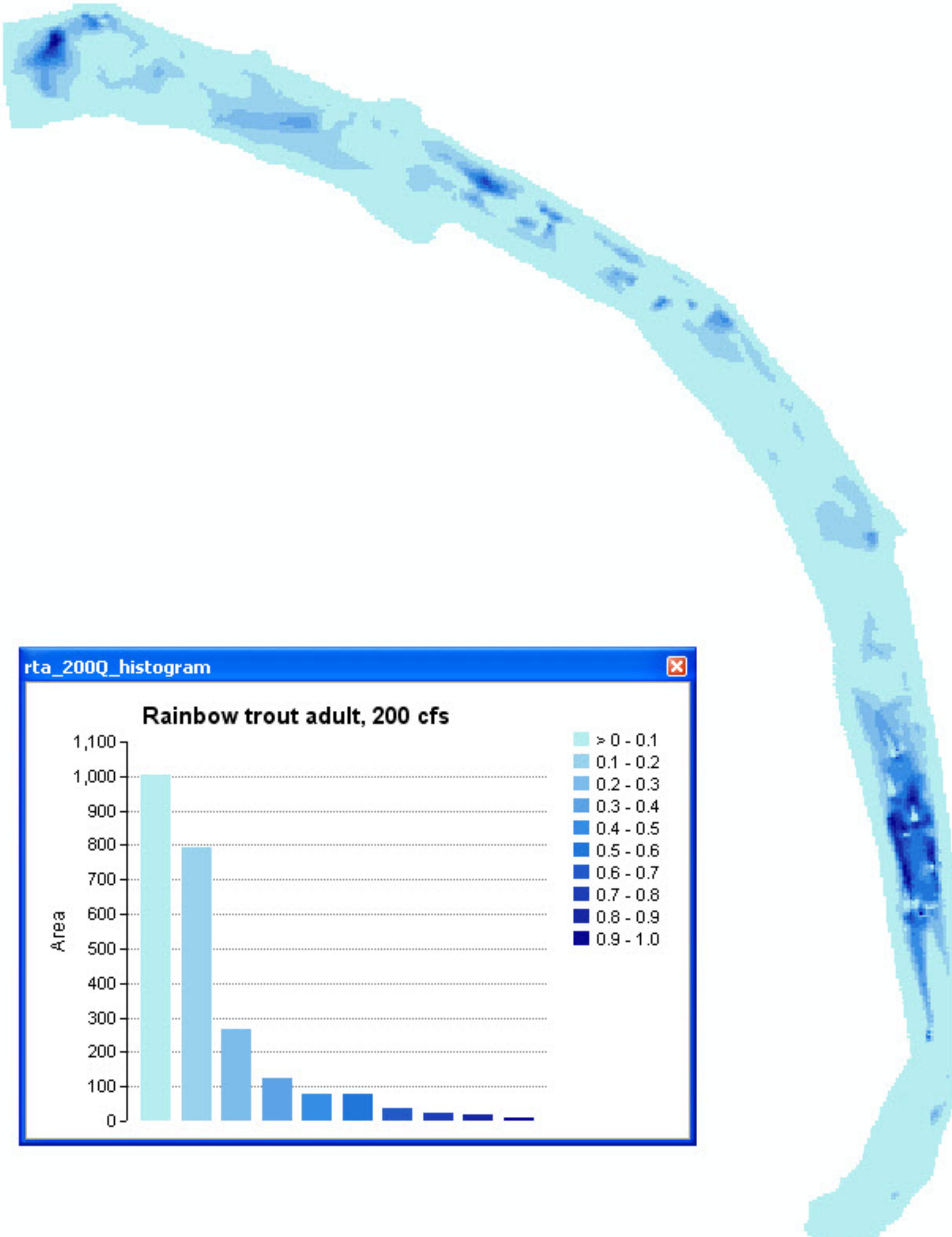

Figure A-5. Adult rainbow trout habitat map, 200 cfs. This map represents the peak total habitat available for this species and life stage.

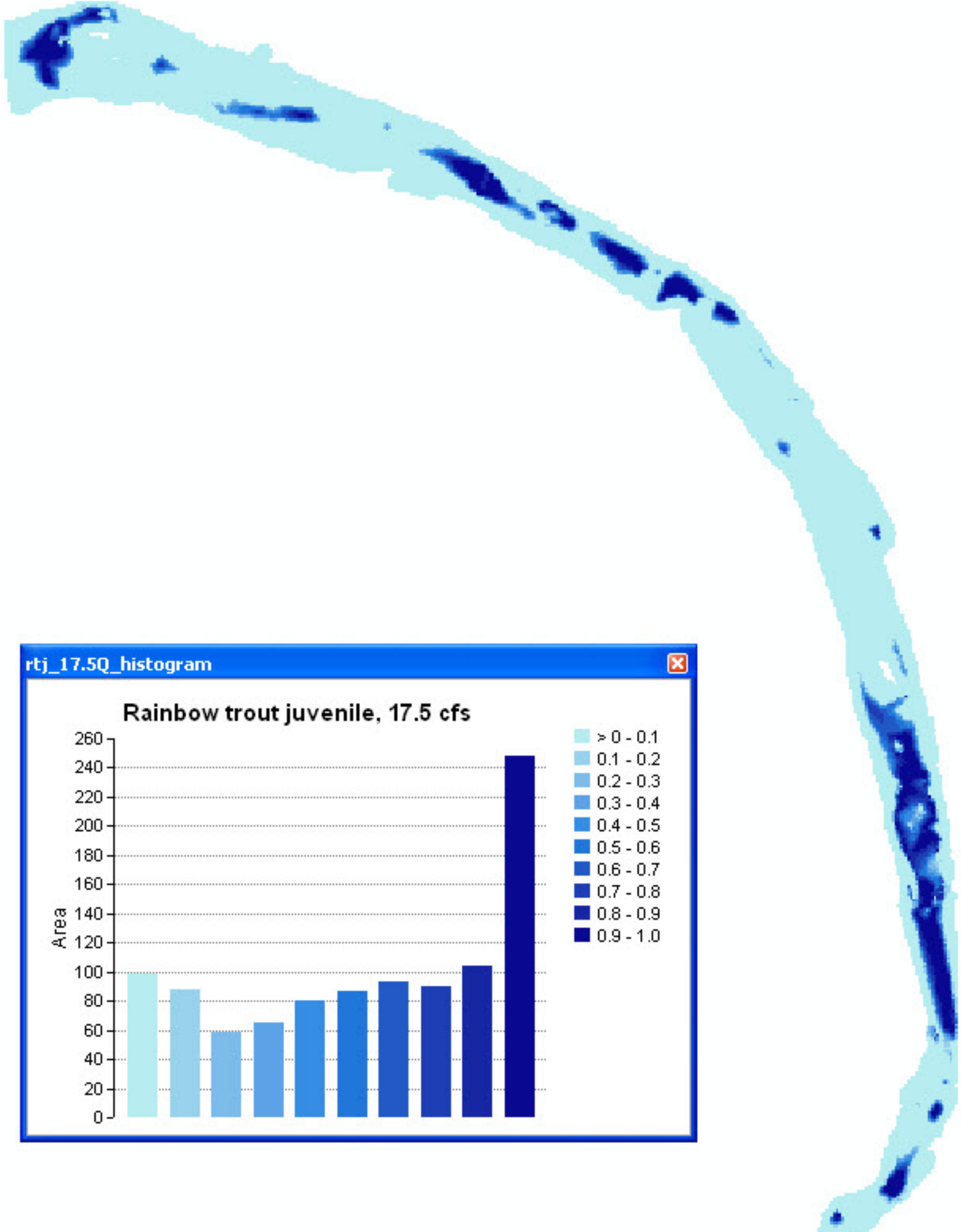

Figure A-6. Juvenile rainbow trout habitat map, 17.5 cfs.

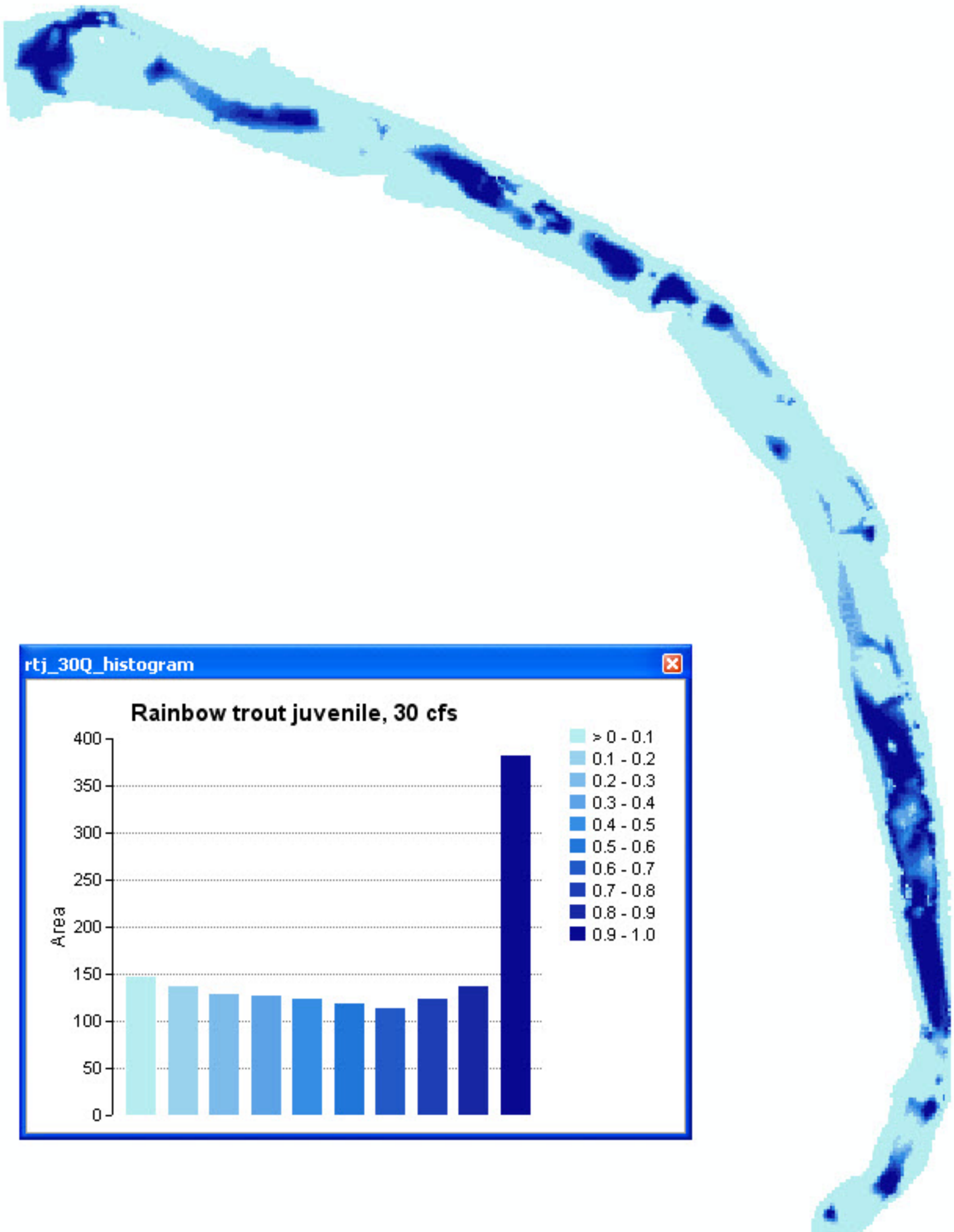

Figure A-7. Juvenile rainbow trout habitat map, 30 cfs.

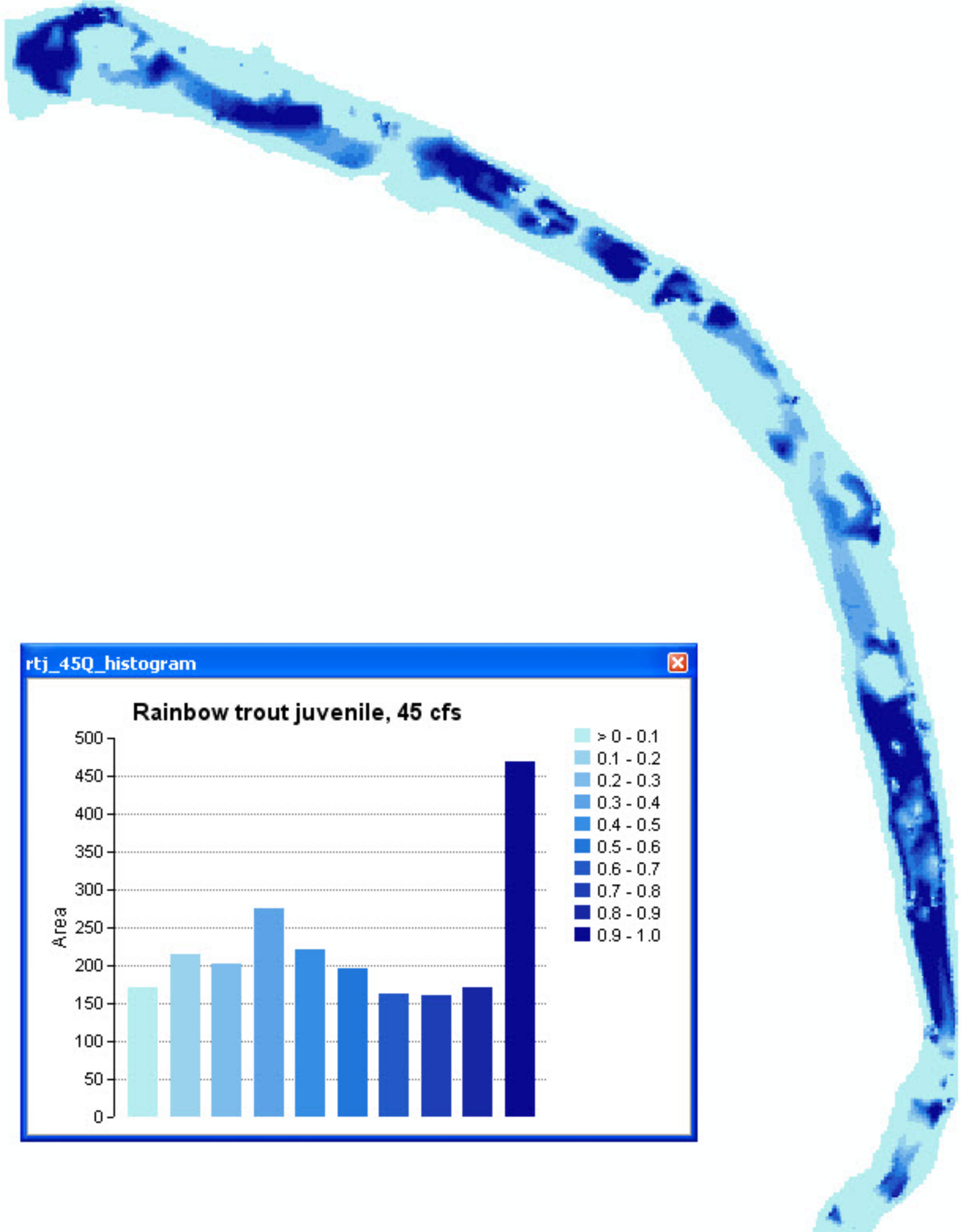

Figure A-8. Juvenile rainbow trout habitat map, 45 cfs.

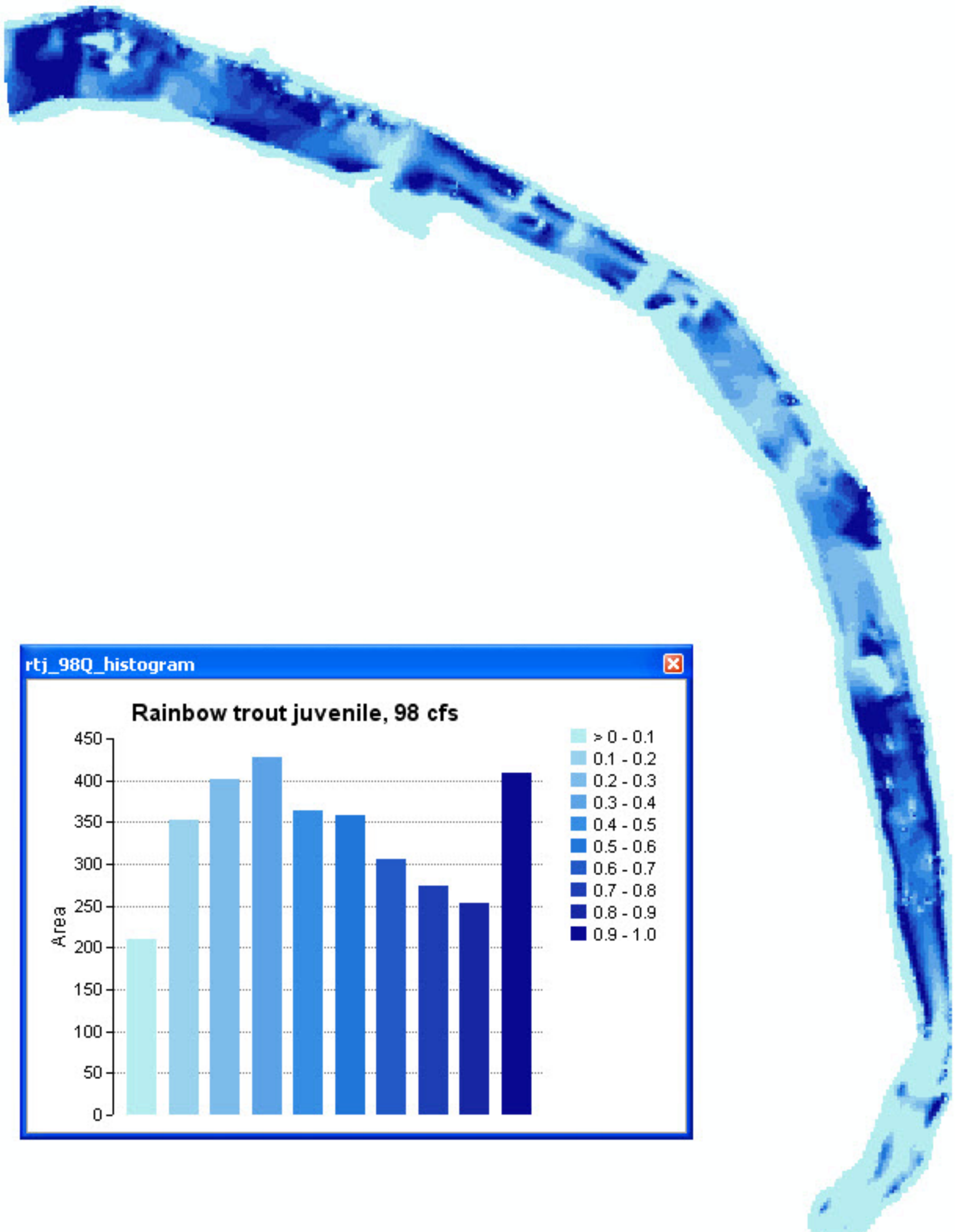

Figure A-9. Juvenile rainbow trout habitat map, 98 cfs. This map represents the largest amount of high-quality habitat for the species and life stage.

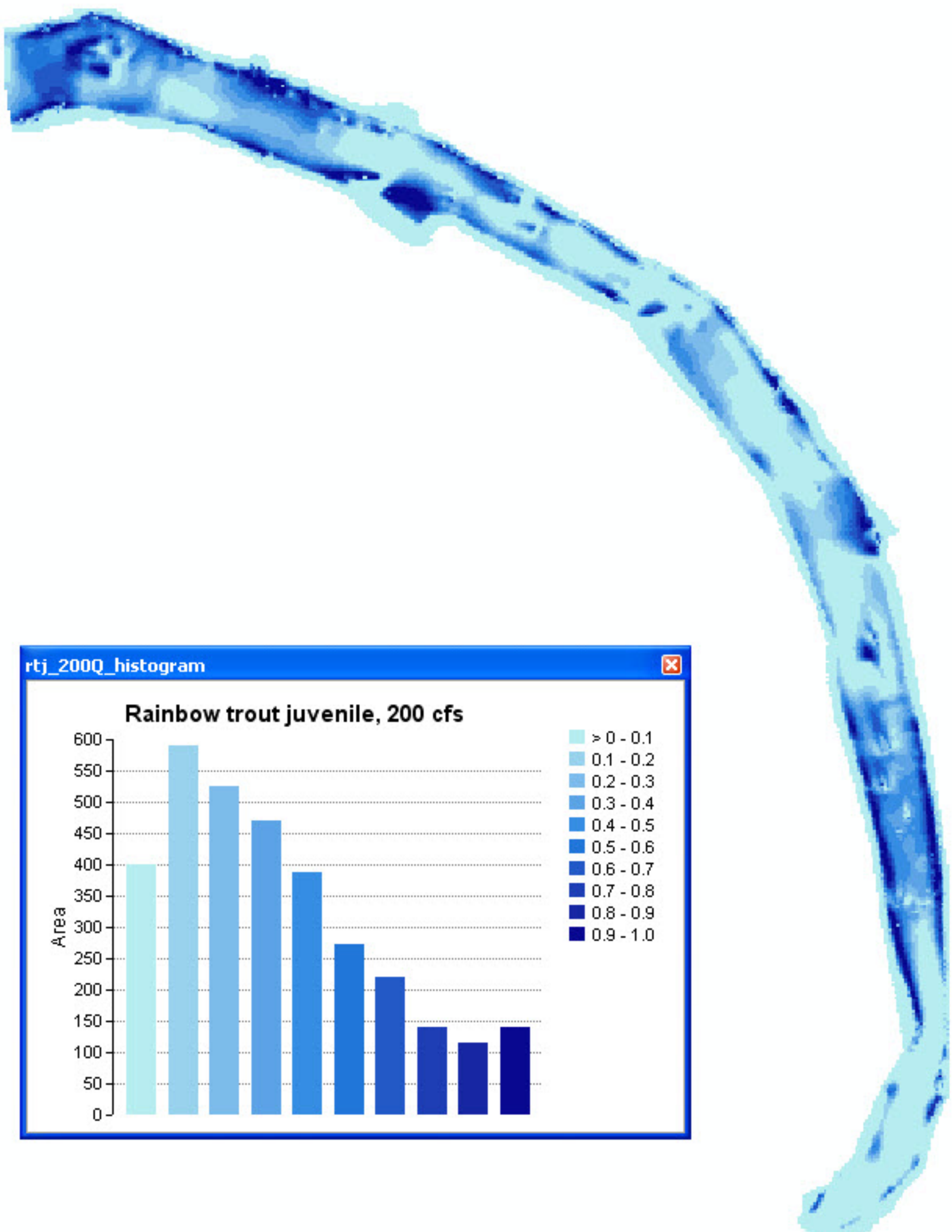

Figure A-10. Juvenile rainbow trout habitat map, 200 cfs.

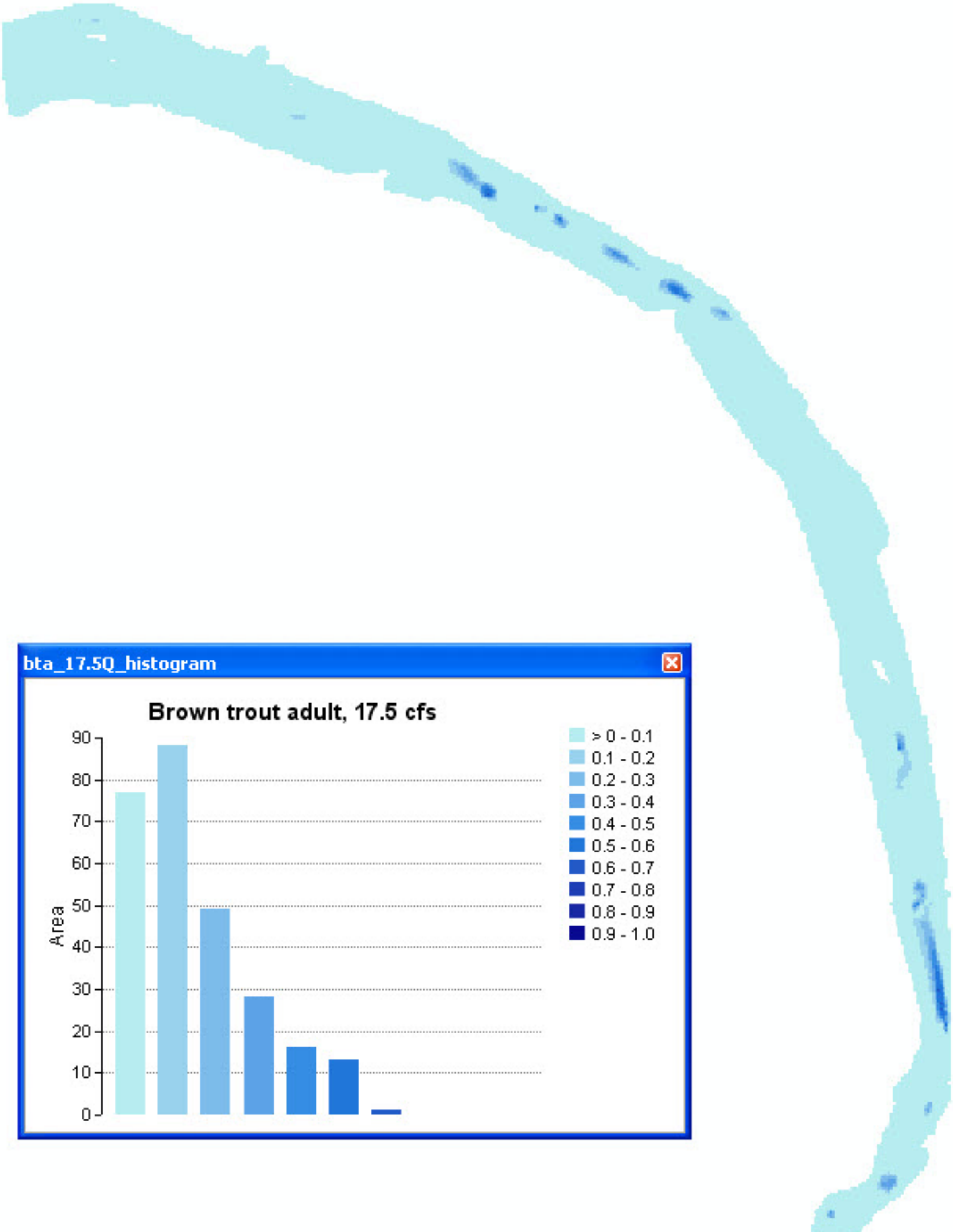

Figure A-11. Adult brown trout habitat map, 17.5 cfs.

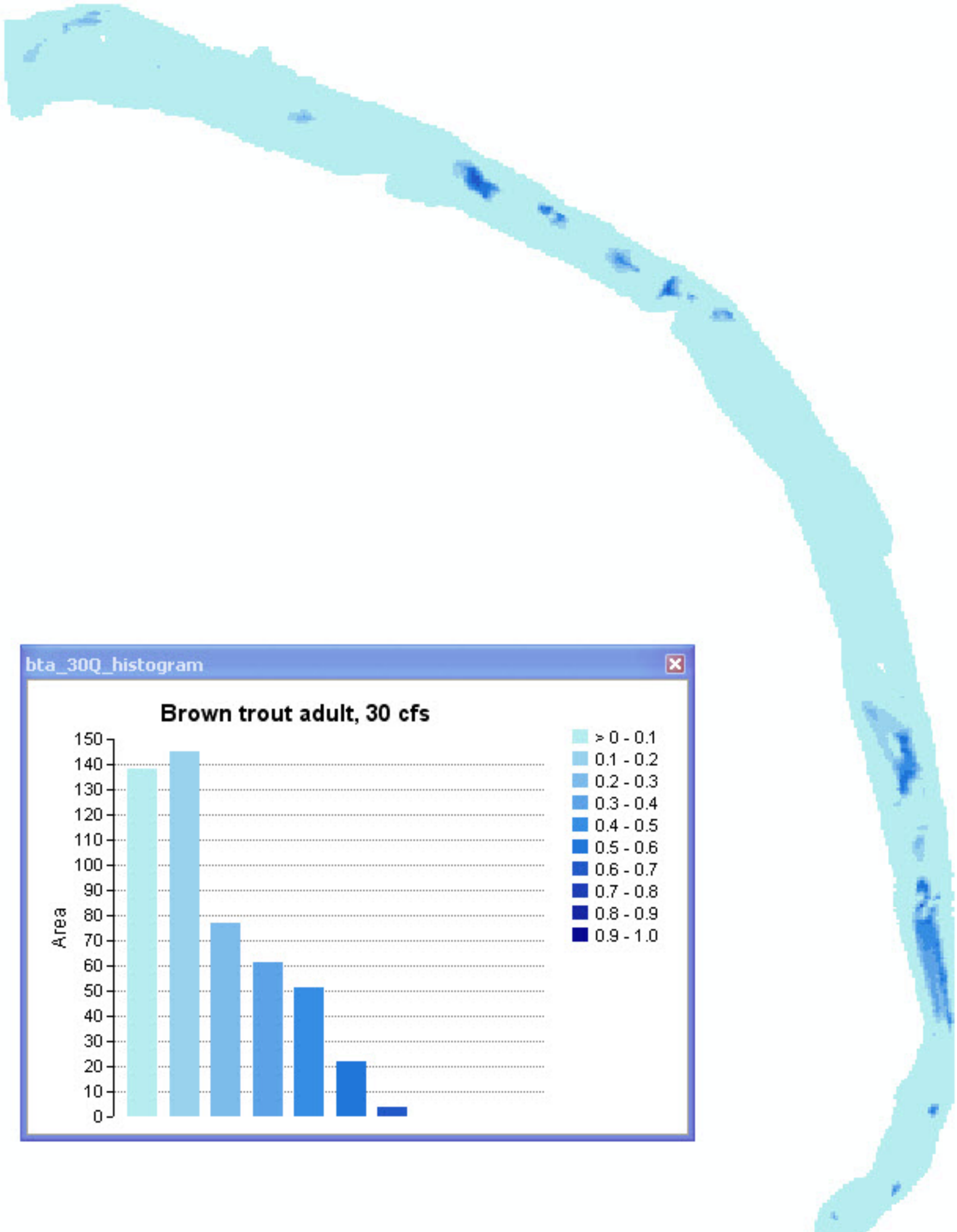

Figure A-12. Adult brown trout habitat map, 30 cfs.

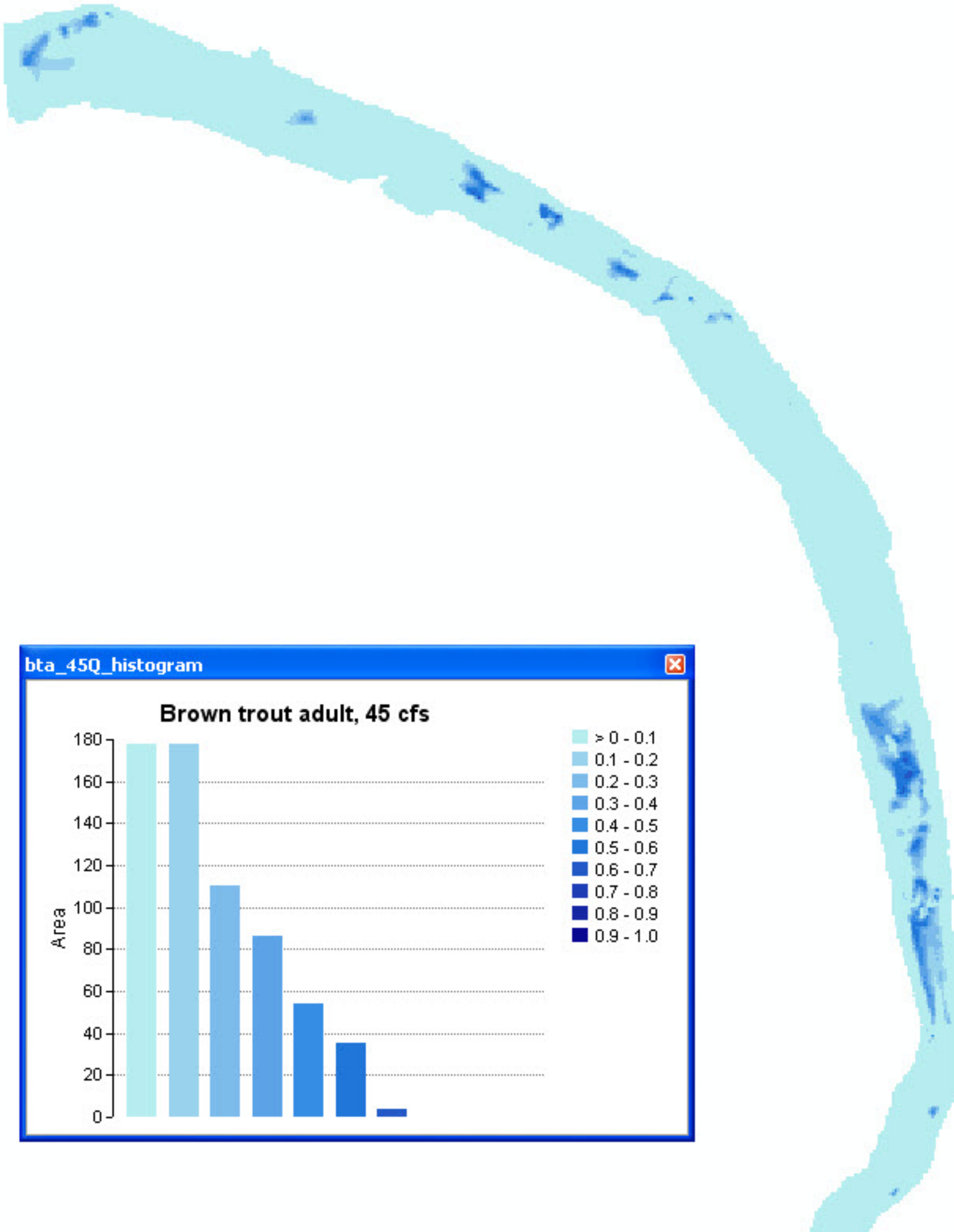

Figure A-13. Adult brown trout habitat map, 45 cfs.

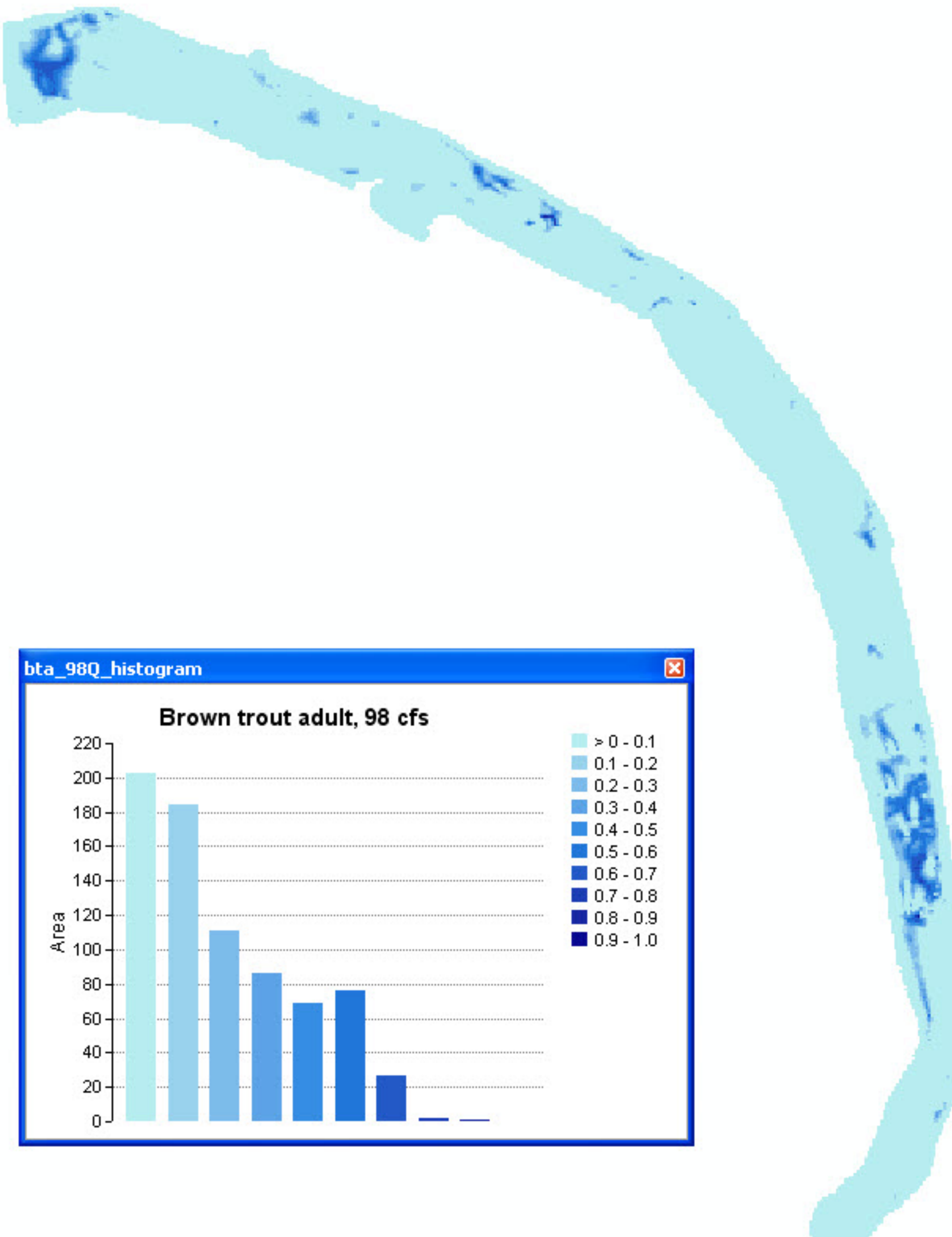

Figure A-14. Adult brown trout habitat map, 98 cfs. This map represents the peak total habitat available for this species and life stage.

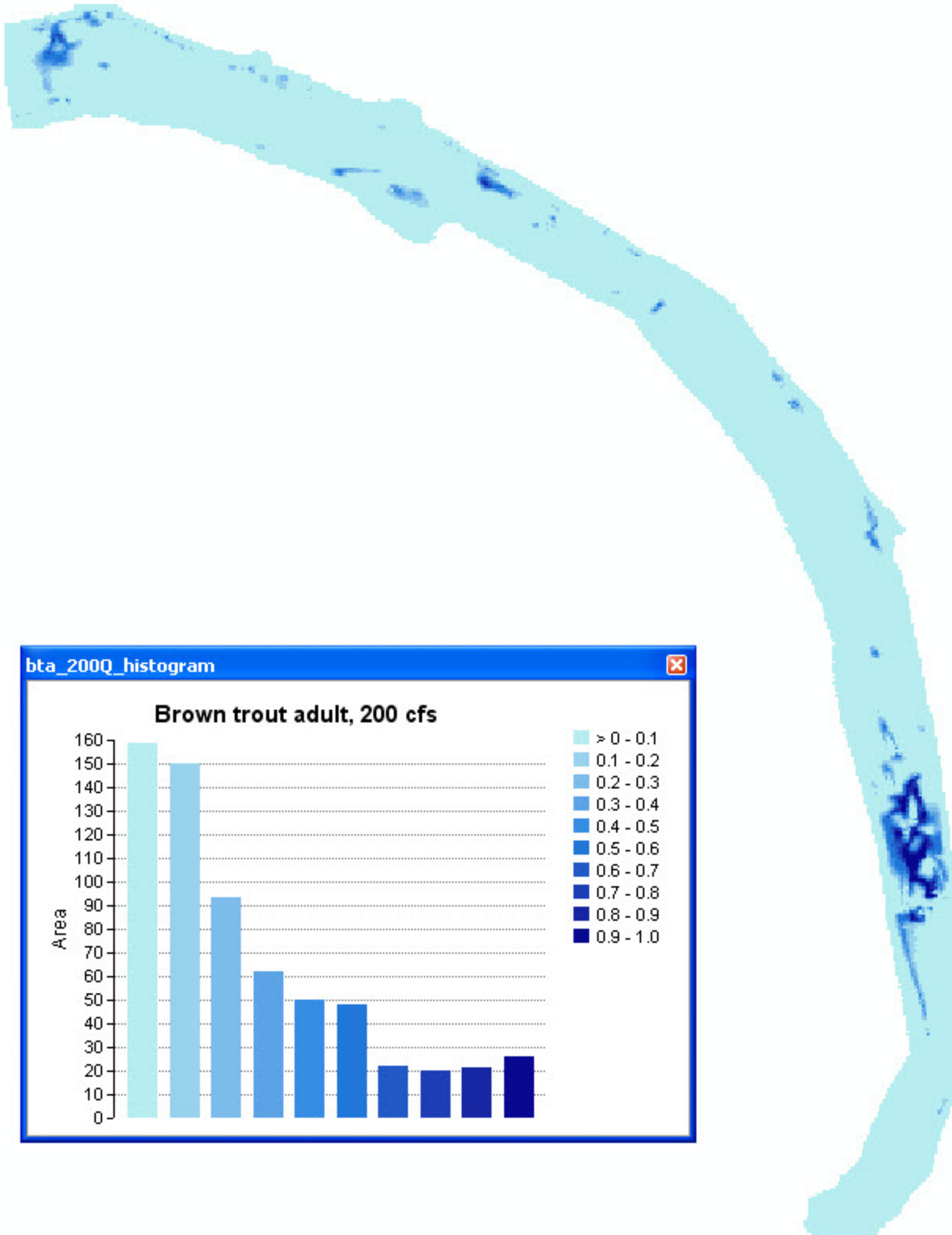

Figure A-15. Adult brown trout habitat map, 200 cfs. This map represents the largest amount of high-quality habitat for the species and life stage.

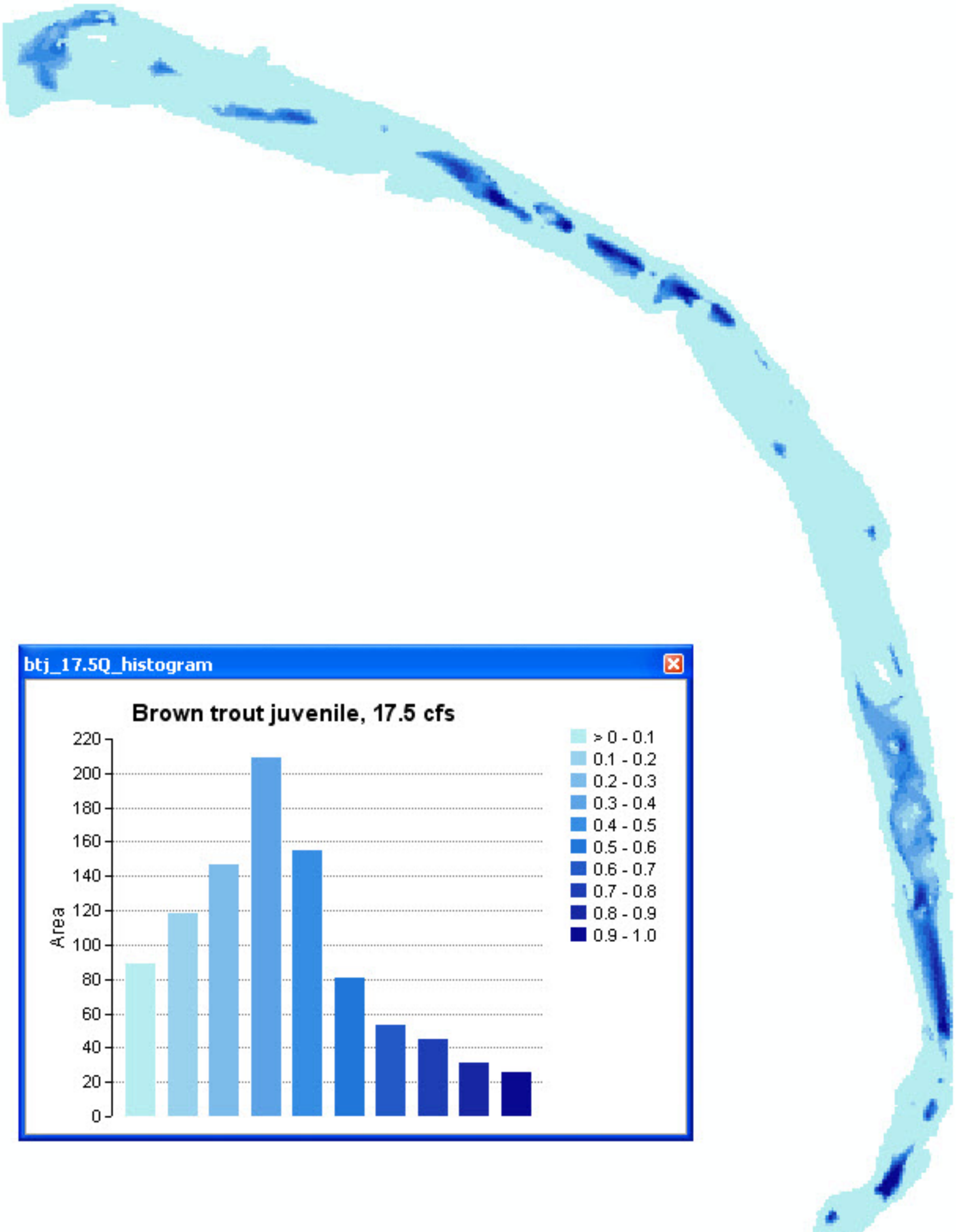

Figure A-16. Juvenile brown trout habitat map, 17.5 cfs.

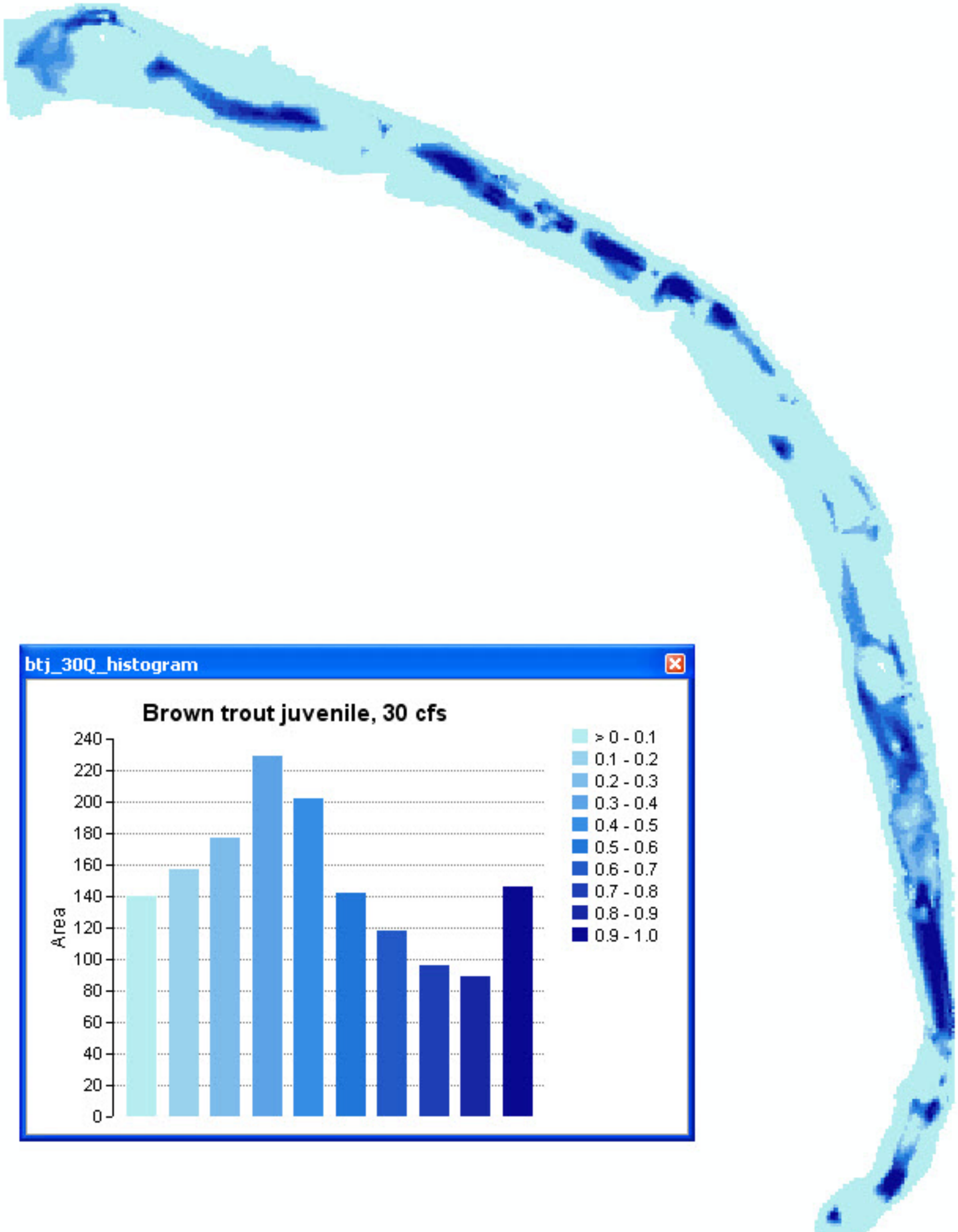

Figure A-17. Juvenile brown trout habitat map, 30 cfs.

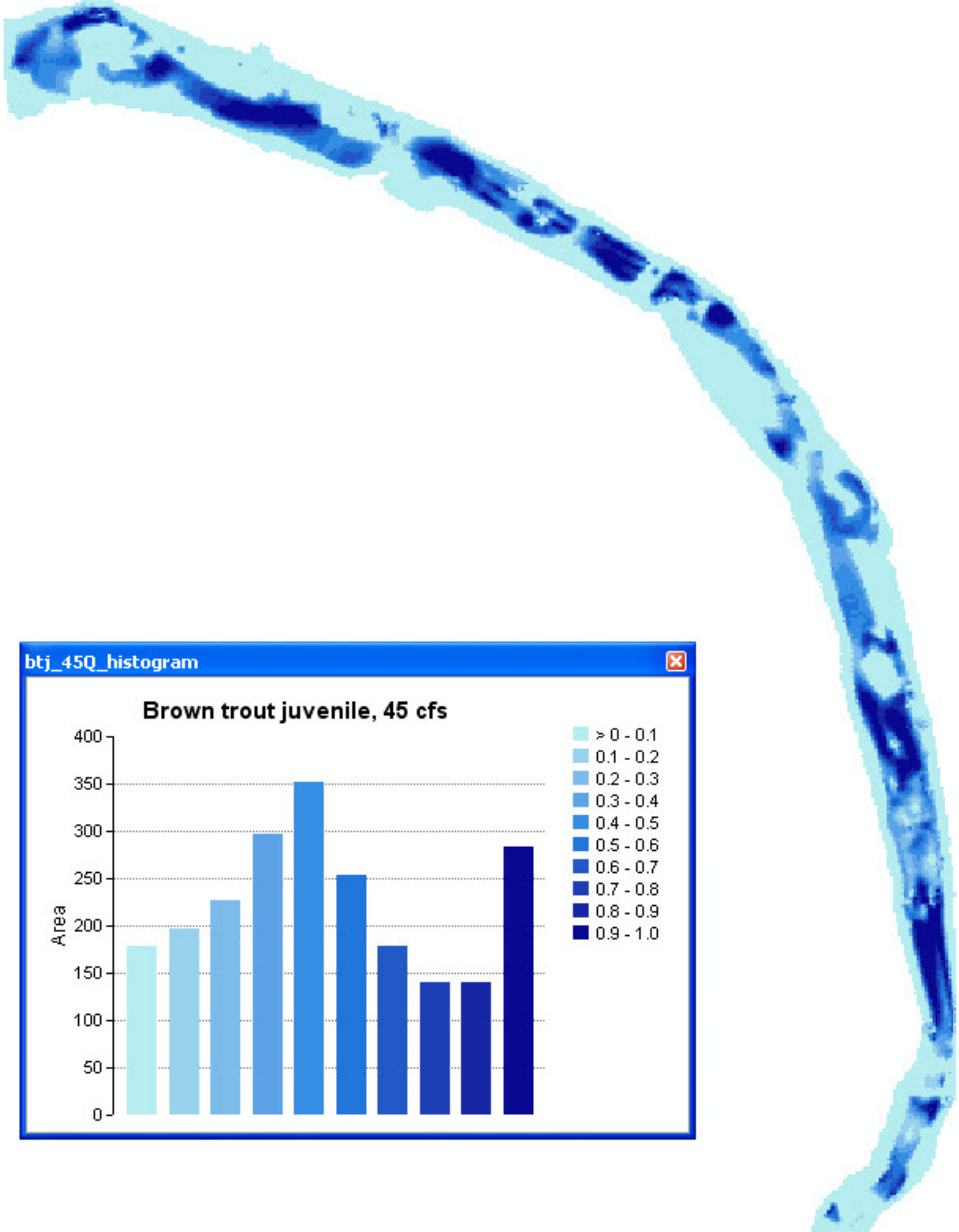

Figure A-18. Juvenile brown trout habitat map, 45 cfs.

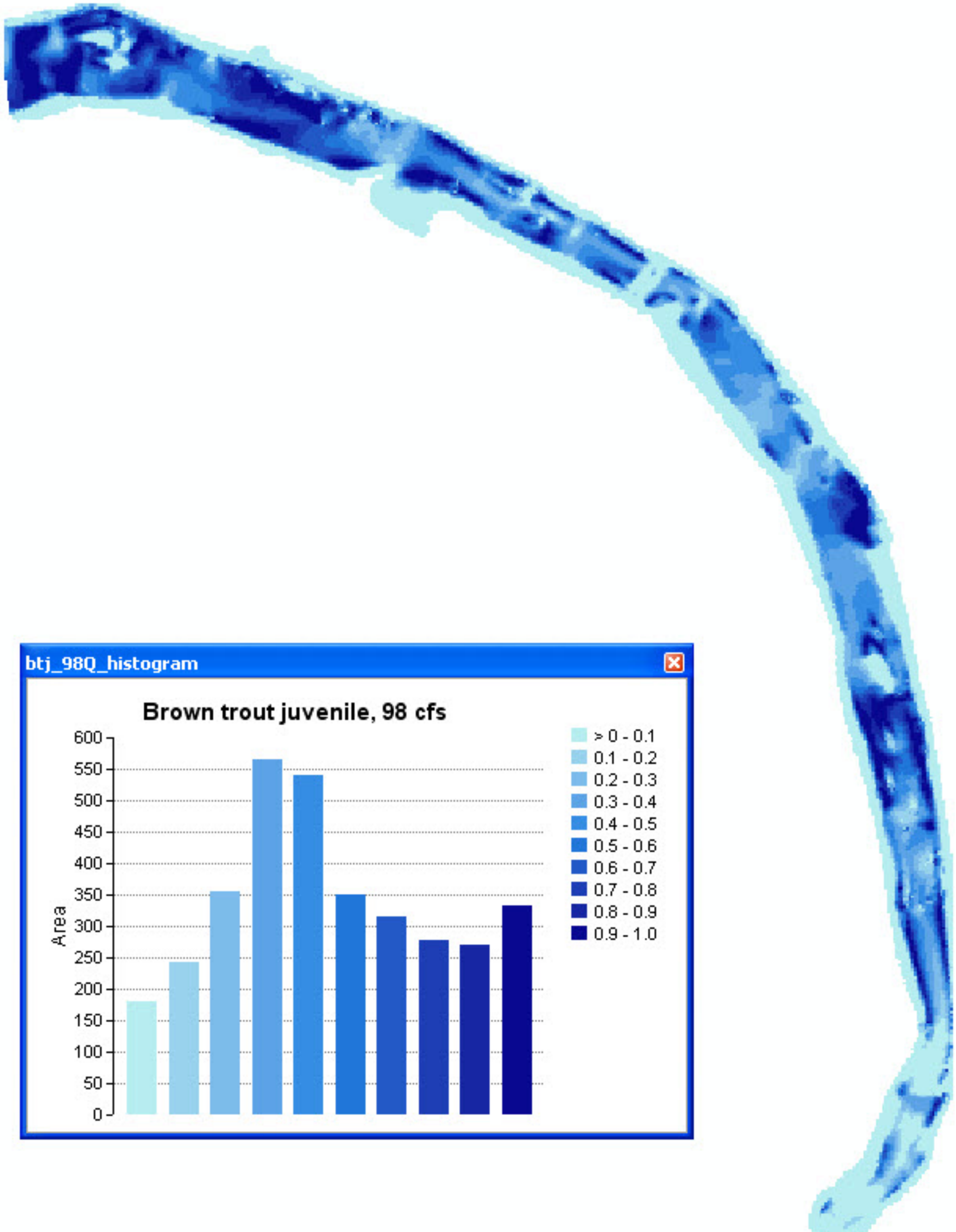

Figure A-19. Juvenile brown trout habitat map, 98 cfs. This map is comparable to the largest amount of high-quality habitat for the species and life stage.

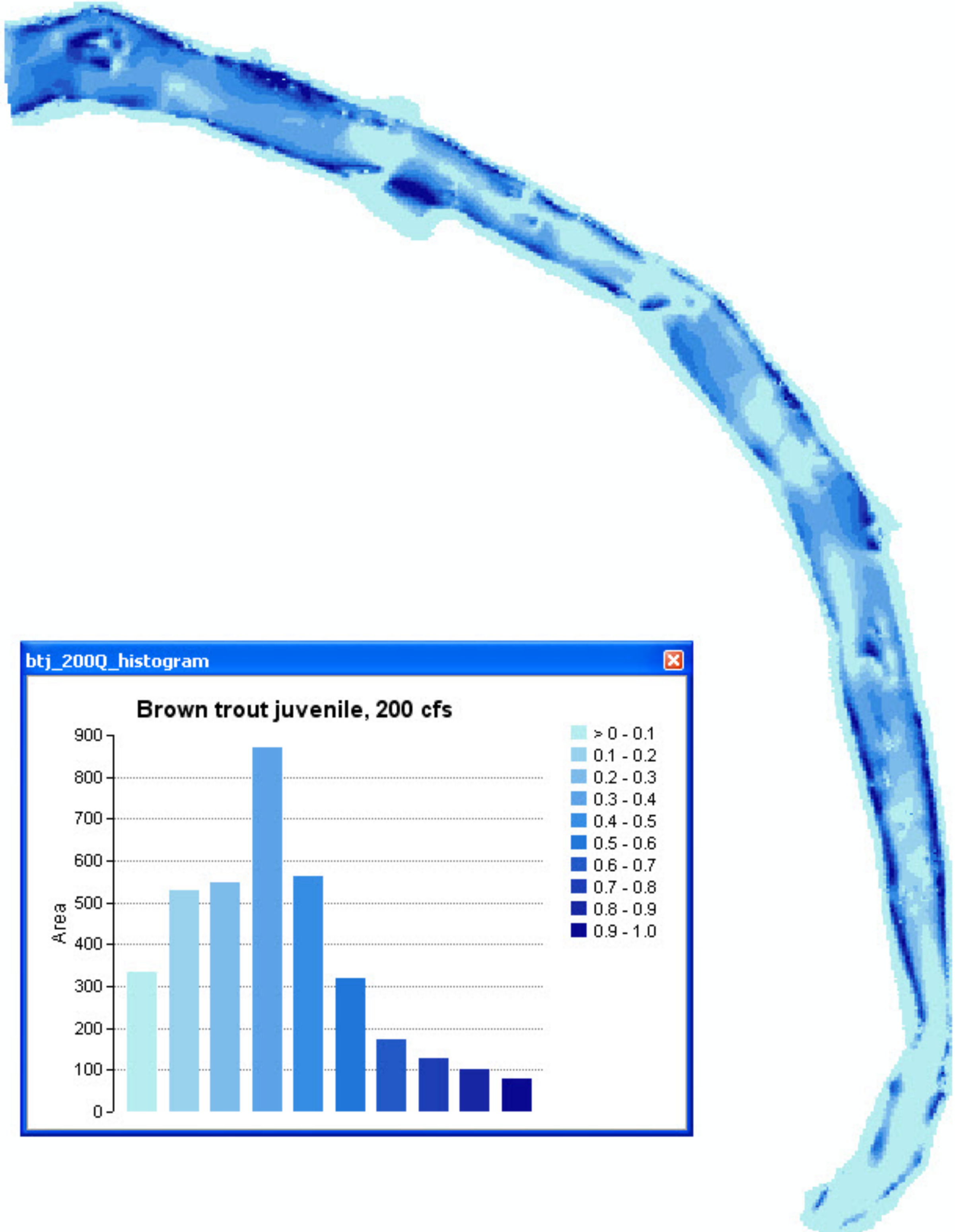

Figure A-20. Juvenile brown trout habitat map, 200 cfs. This map is comparable to the peak total habitat available for this species and life stage.

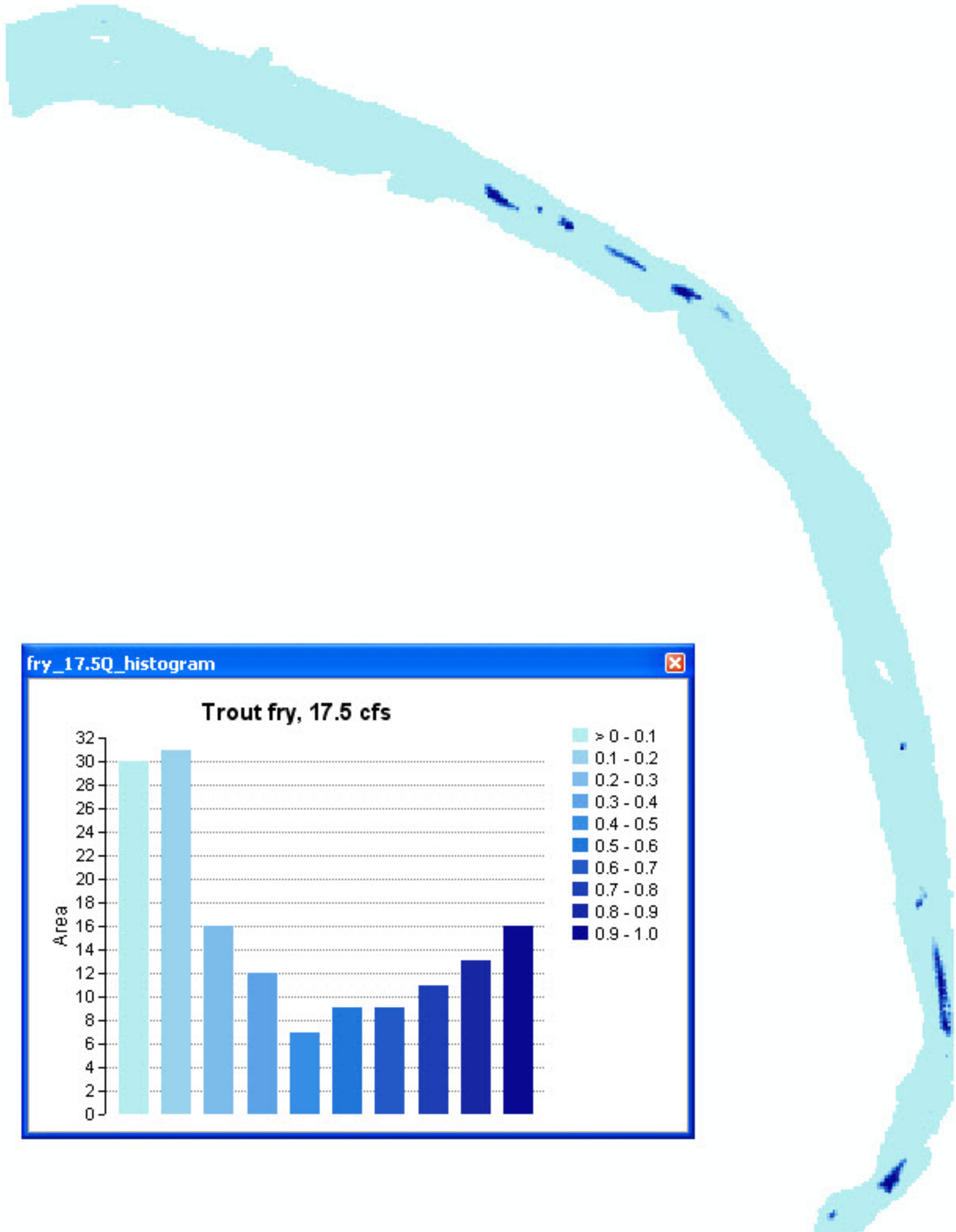

Figure A-21. Trout fry habitat map, 17.5 cfs.

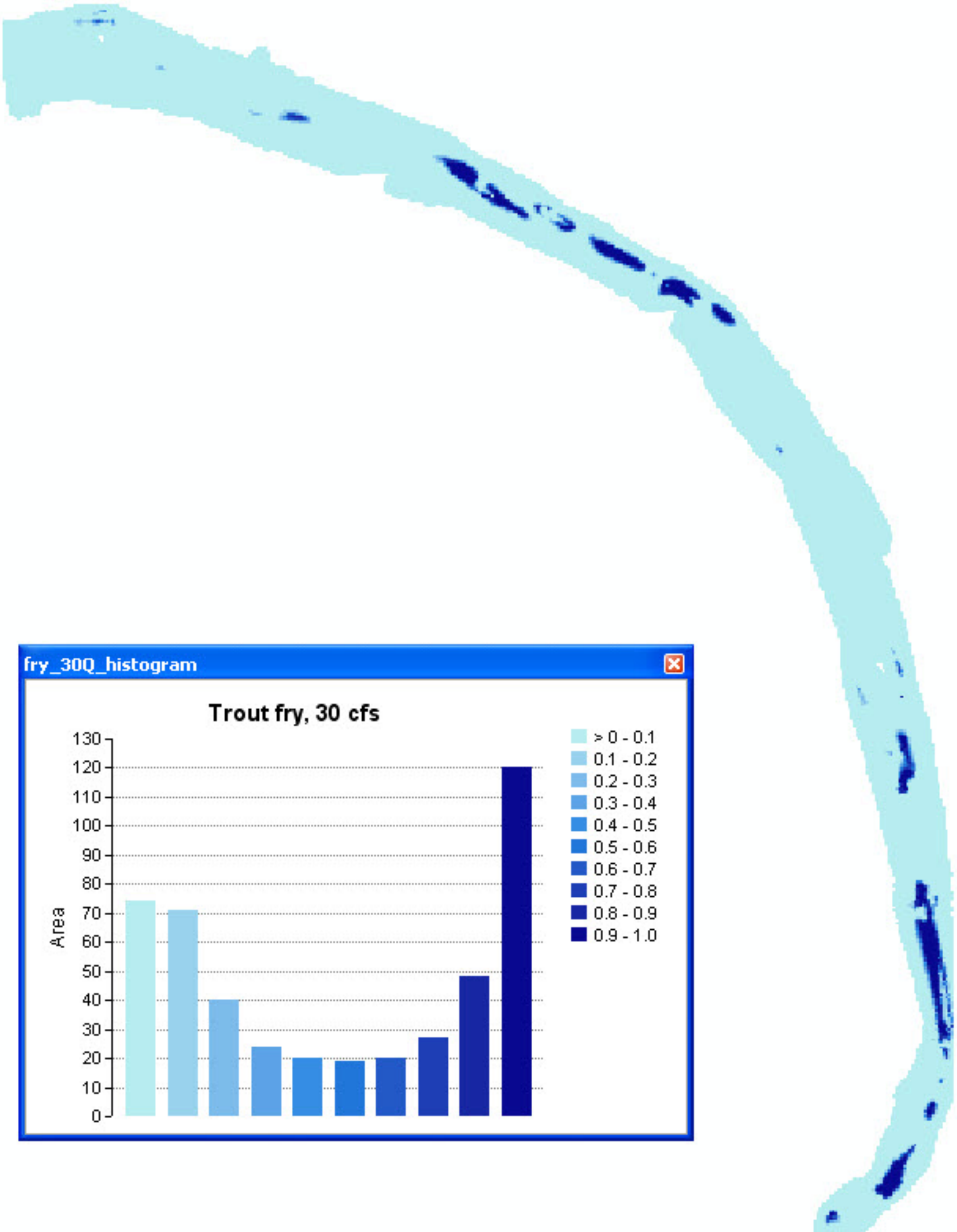

Figure A-22. Trout fry habitat map, 30 cfs.

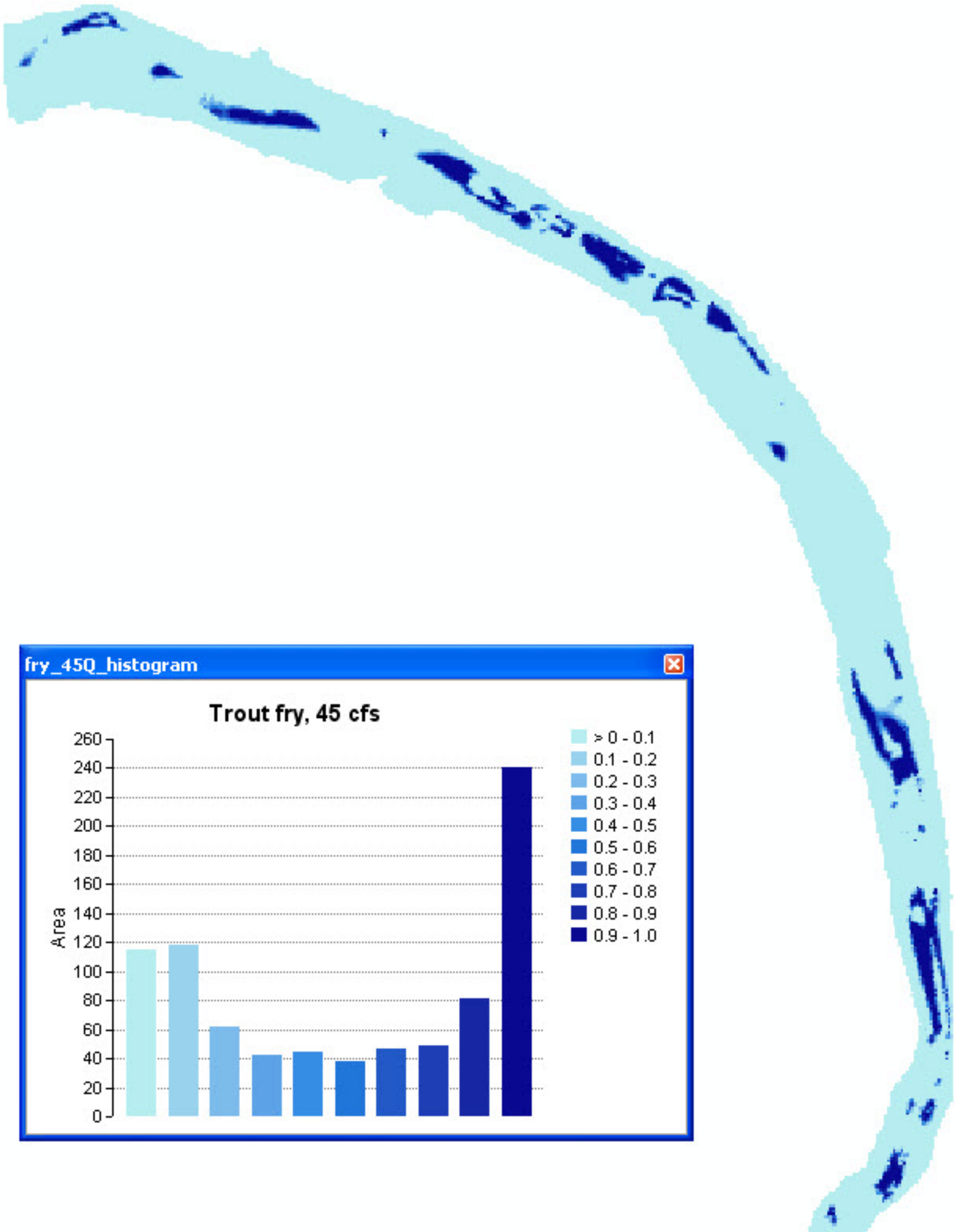

Figure A-23. Trout fry habitat map, 45 cfs.

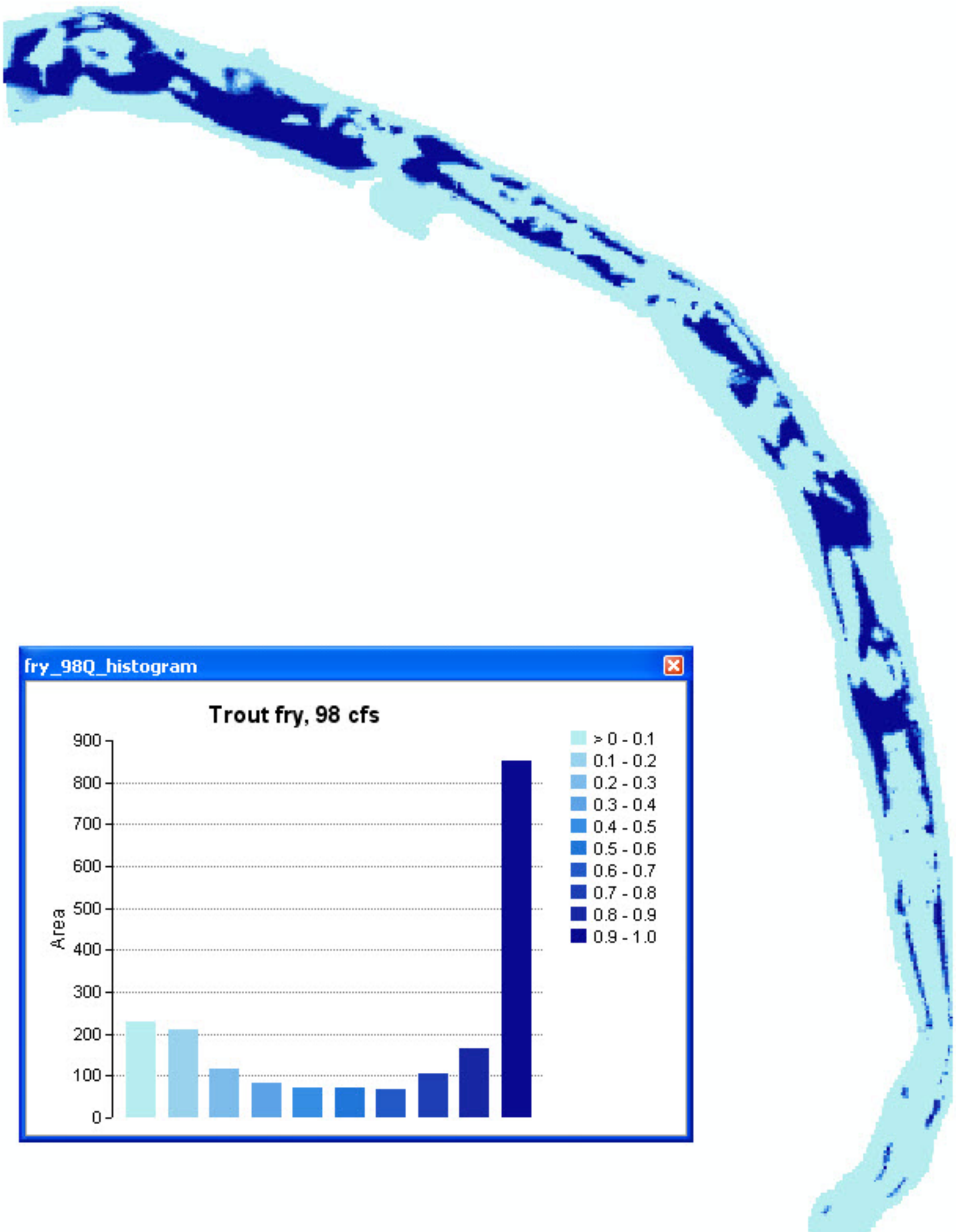

Figure A-24. Trout fry habitat map, 98 cfs. This map represents both peak total habitat available and the largest amount of high-quality habitat for the trout fry life stage.

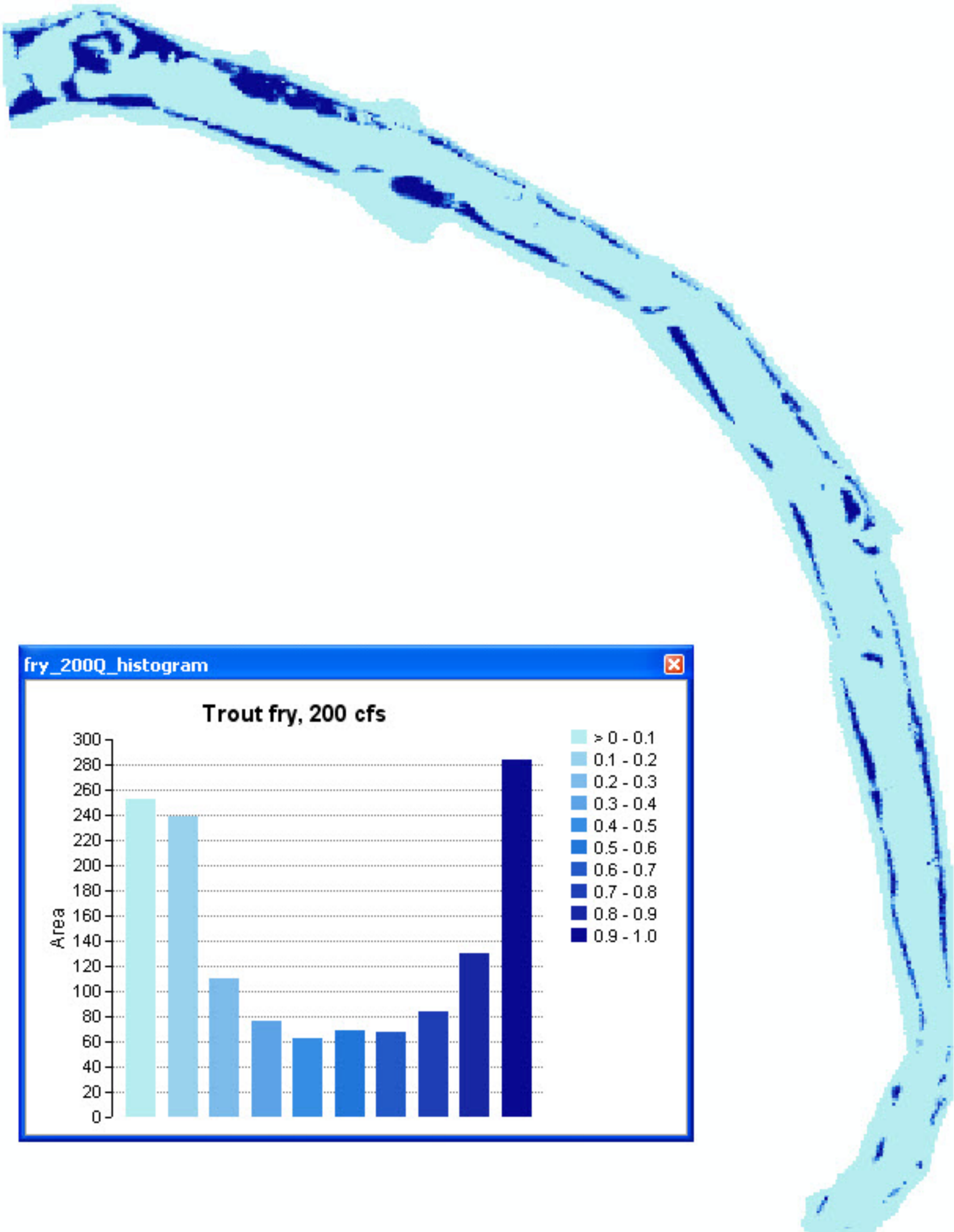

Figure A-25. Trout fry habitat map, 200 cfs.

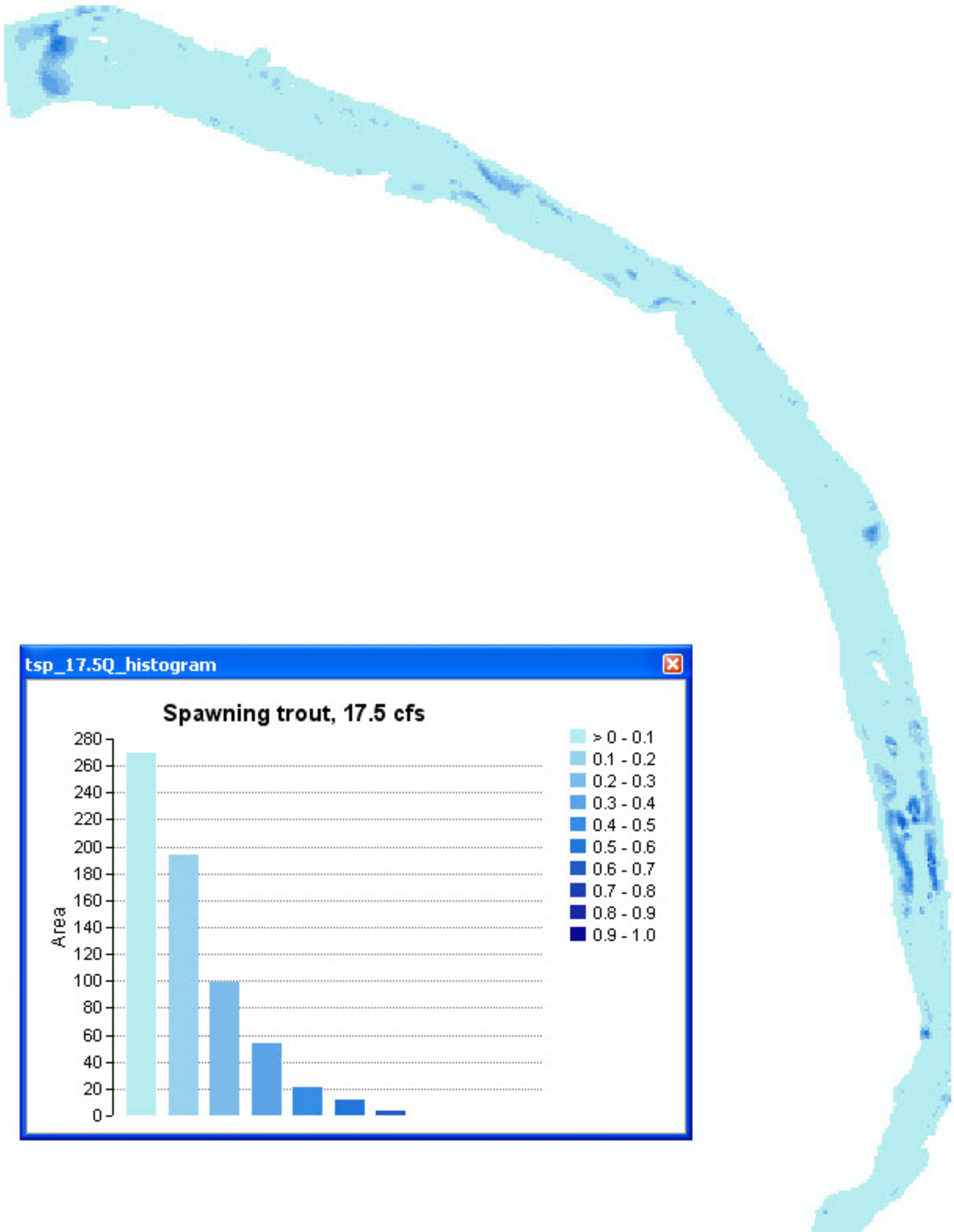

Figure A-26. Spawning trout habitat map, 17.5 cfs. This map represents the peak total habitat available for this life stage.

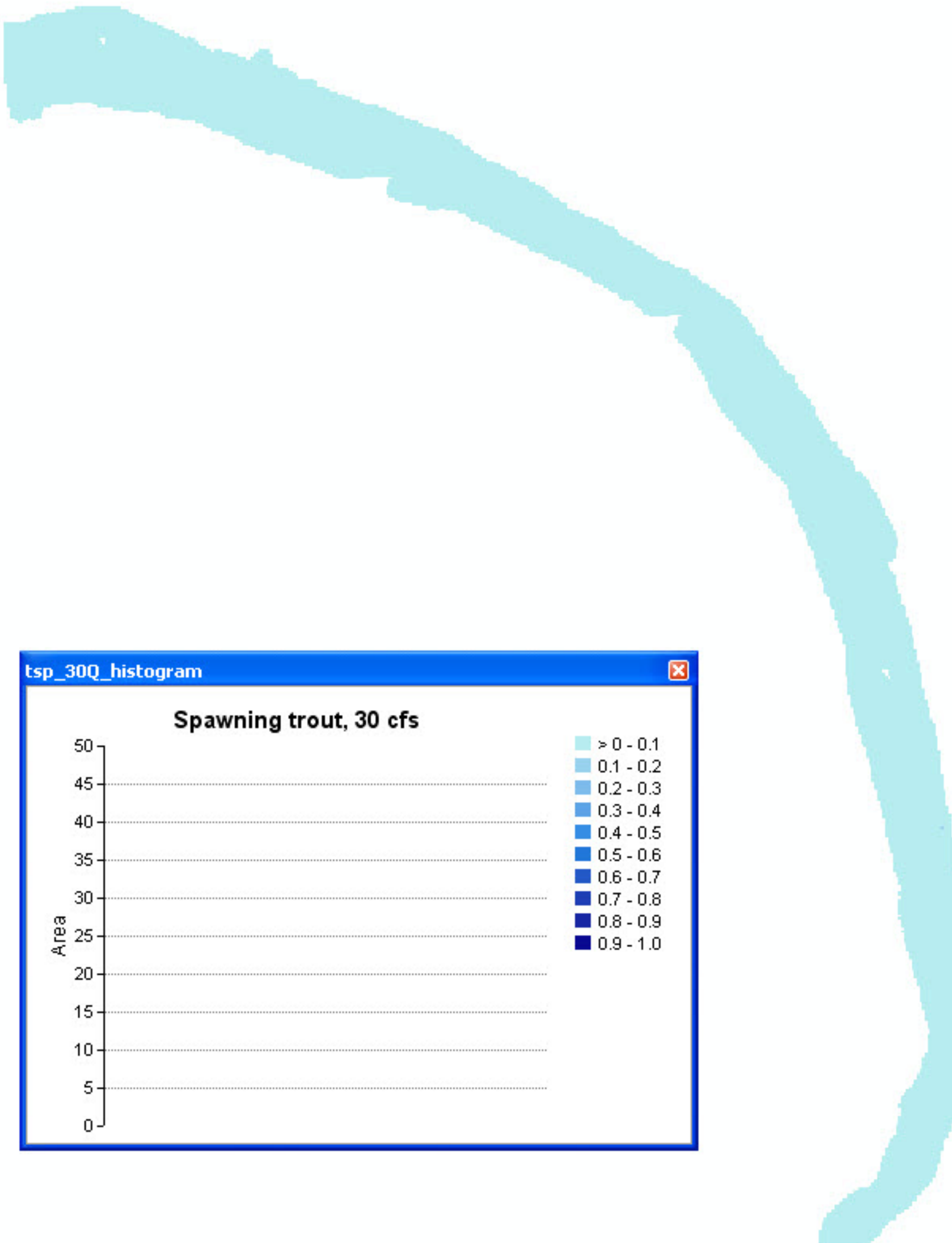

Figure A-27. Spawning trout habitat map, 30 cfs. This is the same habitat map for spawning trout for 45, 98, and 200 cfs.

APPENDIX B: HABITAT TIME SERIES GRAPHS

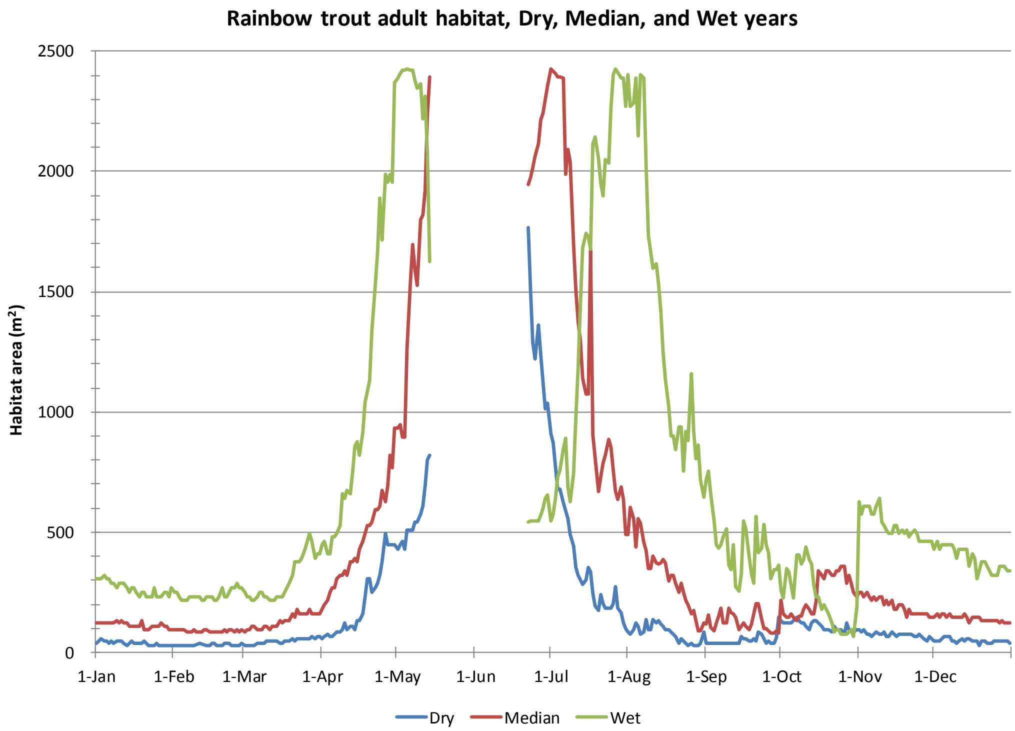

Figure B-1. Adult rainbow trout habitat time series, dry, median, and wet years.

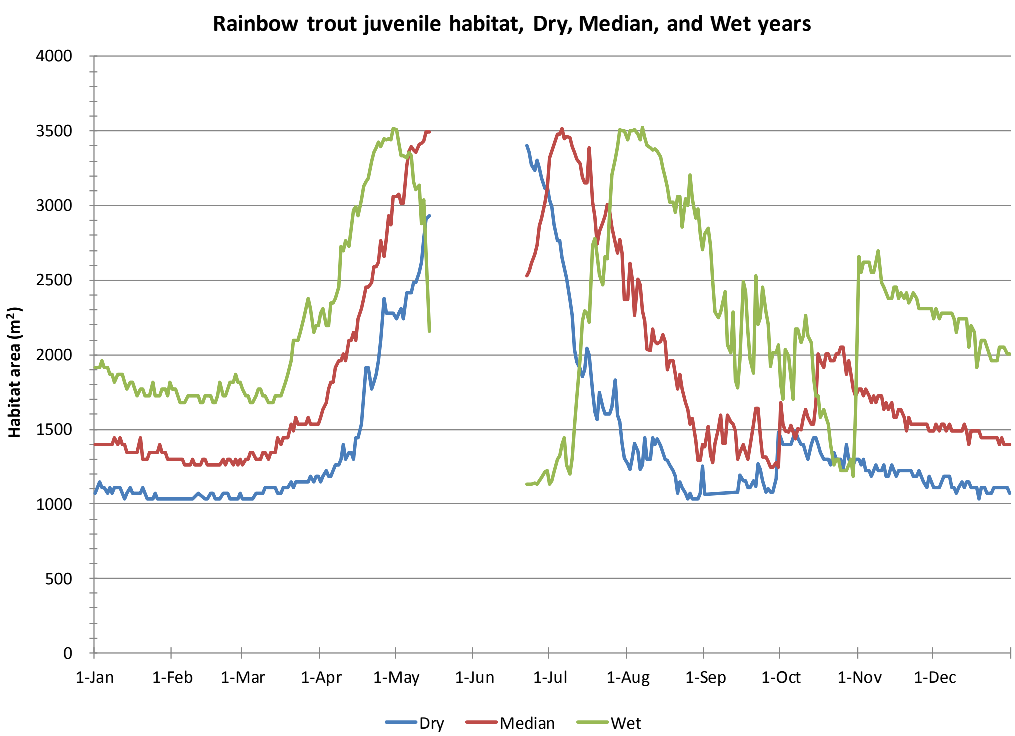

Figure B-2. Juvenile rainbow trout habitat time series, dry, median, and wet years.

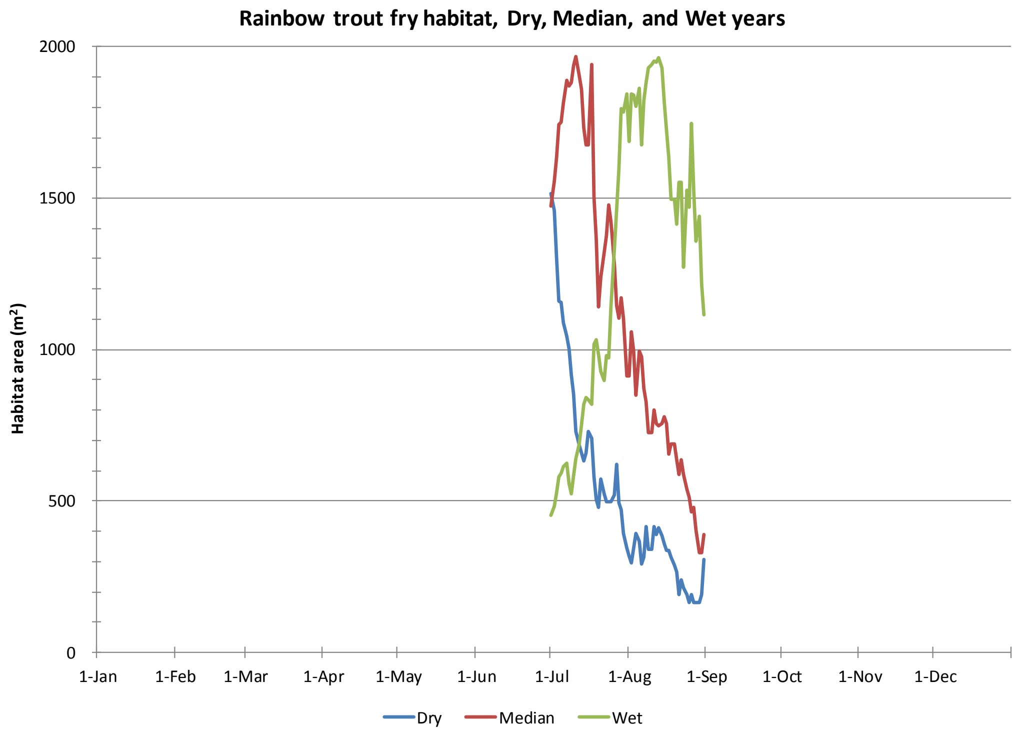

Figure B-3. Rainbow trout fry habitat time series, dry, median, and wet years.

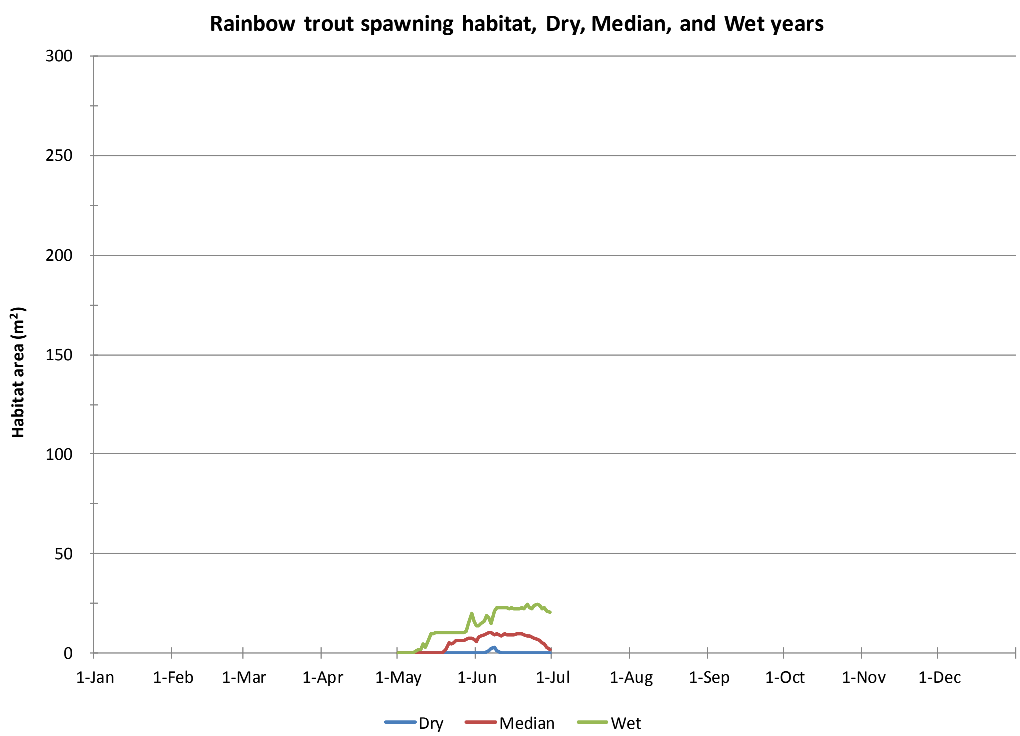

Figure B-4. Rainbow trout spawning habitat time series, dry, median, and wet years.

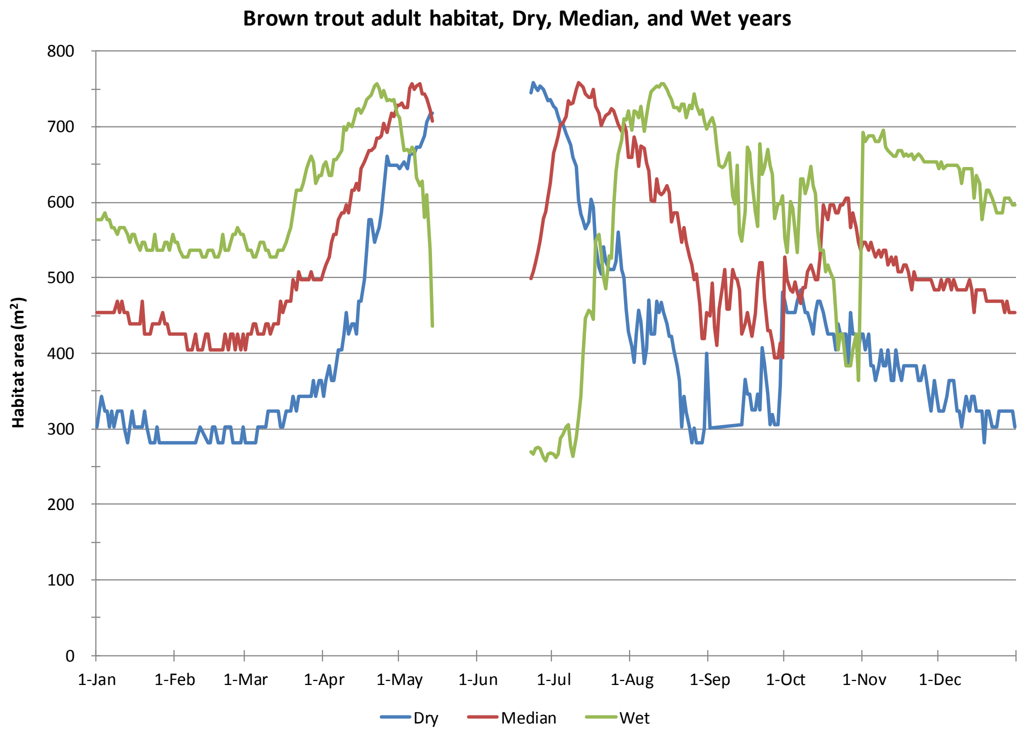

Figure B-5. Adult brown trout habitat time series, dry, median, and wet years.

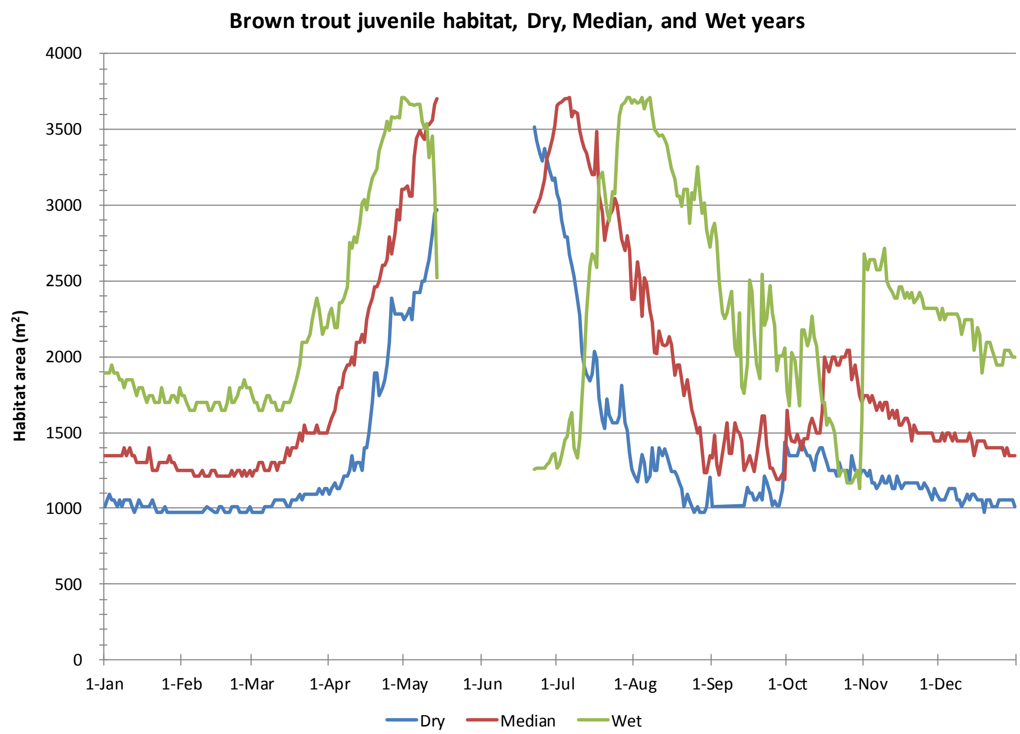

Figure B-6. Juvenile brown trout habitat time series, dry, median, and wet years.

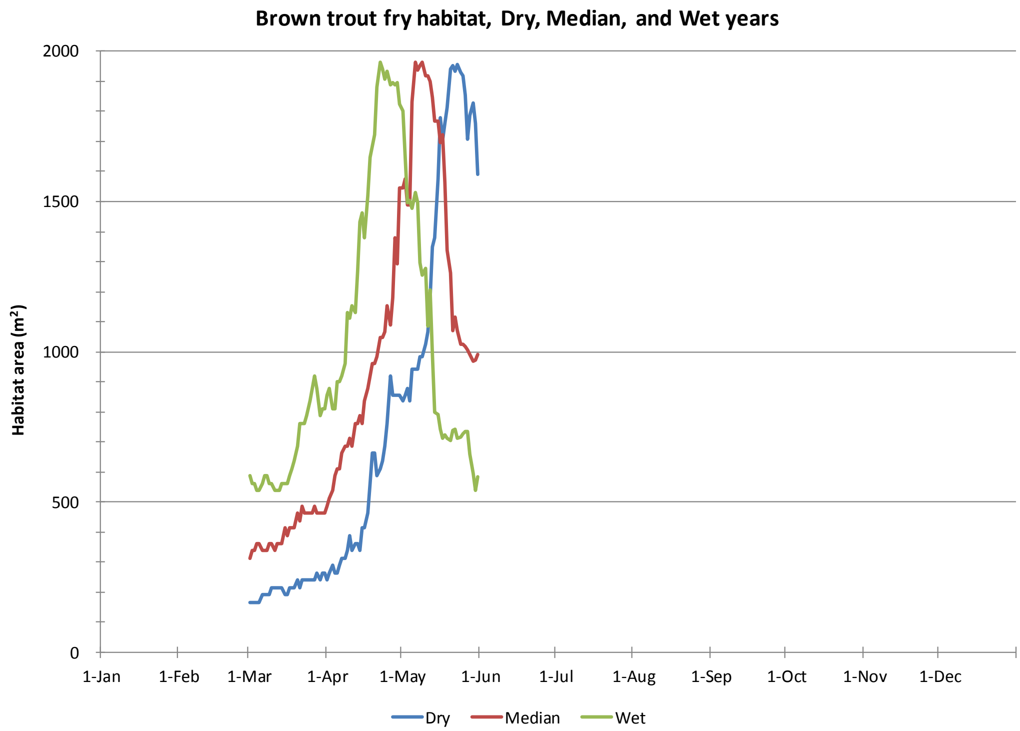

Figure B-7. Brown trout fry habitat time series, dry, median, and wet years.

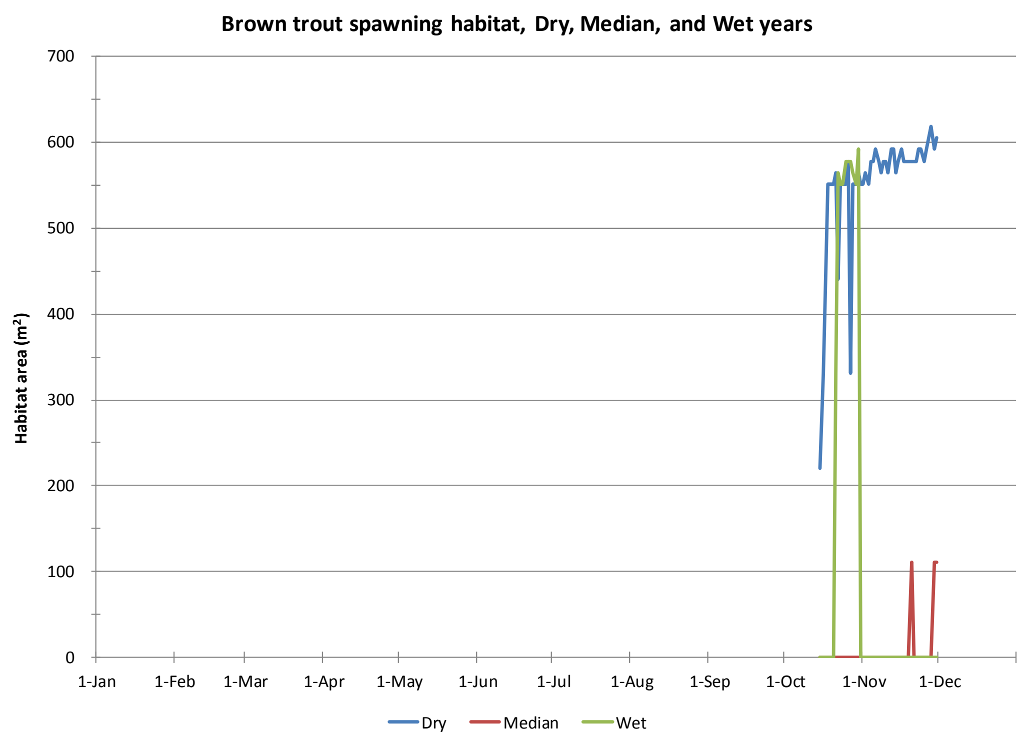

Figure B-8. Brown trout spawning habitat time series, dry, median, and wet years.

APPENDIX C: MACROINVERTEBRATE DATA

Table C-1. Macroinvertebrate species list, September 2010.

Roaring Fork 9/28/2010										
						Combined Results Sample				
		Taxa	FFG	Behavior	TV	Rep 1	Rep 2	Rep 3	Total
EPHEMEROPTERA									
	Baetidae	Baetis bicaudatus	cg	sw	5	3	3	12	18
		Baetis tricaudatus	cg	sw	5	7	6	6	19
	Ephemerellidae	Drunella grandis	sc	cn	0	4		2	6
PLECOPTERA									
	Chloroperlidae	Sweltsa sp.	pr	cn	1	3	6	6	15
	Perlidae	Claassenia sabulosa	pr	cn	3	1			1
TRICHOPTERA									
	Brachycentridae	Brachycentrus americanus	cf	cn	1	153	127	216	496
	Hydropsychidae	Arctopsyche sp.	cf	cn	1	5	2	3	10
COLEOPTERA									
	Elmidae	Heterlimnius (Larvae)	cg	cn	4	4	15	14	33
		Narpus sp. (Larvae)	cg	cn	4		1		1
		Optioservus sp. (Larvae)	cg	cn	4	1			1
DIPTERA									
Chironomidae	Chironominae		cg	bu	6	6	8	4	18
	Orthocladinae		cg	sp	5	202	171	256	629
	Diamesinae		cg	sp	6	42	18	32	92
	Tanypodinae		pr	sp	7	16	9	5	30
OTHER DIPTERA	PUPAE					14	9	12	35
	Ceratopogonidae	Palpomyia sp.	pr	bu	6	1	1		2
	Empididae	Clinocera sp.	pr	cn	6		1		1
		Chelifera sp.	pr	sp	6	5	5	1	11
	Muscidae	Limnophora sp.	pr	bu	6		2		2
	Psychodidae	Pericoma/Telmatoscopus	pr	bu	4		1		1
	Tipulidae	Antocha sp.	pr	cn	3	37	18	38	93
		Hexatoma sp.	pr	bu	2	1	1		2
Other Organisms									
	Hydracarina	Lebertia sp.	cg		8		3	7	10
		Sperchon sp.	cg		8	3	3	11	17
		Torrenticola sp.	cg		8		1	4	5
	Haplotaxida	Naididae	cg		5	4	3	8	15
	Nematoda		pr		5		1		1
	Physidae	Physa sp.	cg		8			1	1
	Tricladida	Planariidae	cg		1	1		1	2
Totals						513	415	639	1567

APPENDIX D: SITE PHOTOS

Figure D-1. Downstream end of the site looking upstream, 17.5 cfs (low flow), September 28, 2010.

Figure D-2. Downstream end of the site looking upstream, 98 cfs (mid flow), May 23, 2011.

Figure D-3. Downstream end of the site looking upstream, 450 cfs (high flow), June 13, 2011.

Figure D-4. Downstream view from the pedestrian bridge, 17.5 cfs (low flow), September 28, 2010.

Figure D-5. Downstream view from the pedestrian bridge, 98 cfs (mid flow), May 23, 2011.

Figure D-6. Downstream view from the pedestrian bridge, 450 cfs (high flow), June 13, 2011.

Figure D-7. Upstream view from the pedestrian bridge looking toward the Mill Street bridge, 17.5 cfs (low flow), September 28, 2010.

Figure D-8. Upstream view from the pedestrian bridge looking toward the Mill Street bridge, 98 cfs (mid flow), May 23, 2011.

Figure D-9. Upstream view from the pedestrian bridge looking toward the Mill Street bridge, 450 cfs (high flow), June 13, 2011.

Figure D-10. View from the Mill Street bridge looking upstream toward the upper end of the site, 17.5 cfs (low flow), September 28, 2010.

Figure D-11. View from the Mill Street bridge looking upstream toward the upper end of the site, 98 cfs (mid flow), May 23, 2011.

Figure D-12. View from the Mill Street bridge looking upstream toward the upper end of the site, 450 cfs (high flow), June 13, 2011.

APPENDIX E – GEOMORPHOLOGY REPORT

Geomorphic Assessment of the Stability of the Roaring Fork River Through the City of Aspen, Pitkin County, Colorado

OBJECTIVE

Through a sub-agreement with Miller Ecological Consultants Inc. (MEC), Pitkin County (County) requested that Ayres Associates Inc. (Ayres) conduct a geomorphic assessment of the stability of the river channel, in-channel structures, and man-made channel modifications along the Roaring Fork River within the City of Aspen, Pitkin County, Colorado. Initially there were concerns regarding a number of man-made boulder drop structures and channel modifications currently present within the river, which may have been installed in part to improve fish habitat. At one location, a kayak park was also constructed along the channel. However, these structures and channel modifications appeared to be creating detrimental impacts to both channel stability and fish habitat. Therefore, as defined in the Scope of Work (SOW) provided to the County, Ayres performed a number of tasks to document the current conditions within the river, assess the geomorphic impacts of these man-made features, and provide recommendations for rehabilitating the in-channel geomorphologic characteristics of the river in support of improving fish habitat within the project reach. This assessment is conducted in support of the Healthy Rivers and Streams Program (http://www.aspenpitkin.com/Departments/Attorney-Pitkin-County/Healthy-Rivers-and-Streams/).

BACKGROUND

The reach of the Roaring Fork River that was examined as part of this assessment extends from the confluence of Castle Creek upstream to the Salvation Canal diversion structure, a distance of approximately 3.2 river miles (**Figure 1**). However, the focus of this assessment was on the a portion of the reach starting from just below the Rio Grande Trail pedestrian bridge at Jenny Adair Park to just upstream of the Neale Avenue crossing (Florence and Fred Gilden Bridge) and Prockter Park (**Figure 2**). Within this subreach, there are a series of man-made structures, also shown in Figure 2, that are problematic with regard to degraded fish habitat, obstructed low flow fish passage, and sediment transport.

As indicated in the SOW, the first task was to conduct a brief review of available literature, maps, and data pertinent to the project reach and geomorphic conditions therein. This included obtaining and reviewing existing 2008 orthophotography and 1-ft contour mapping covering the project reach. This data was made available by the City of Aspen/Pitkin County GIS department (http://www.aspenpitkin.com/Departments/GIS-Mapping/). In addition, we also examined historical aerial imagery and USGS topographic maps that were available using Google Earth Pro (http://www.google.com/earth/businesses/).

Figure 3 shows the longitudinal profile of the overall project reach of the river as obtained from the 1-ft contour mapping provided by the County. **Figure 4** shows the subreach of interest as described above. **Table 1** shows the overall channel slope for segments of the river through town. As can be seen in Figures 3 and 4 and Table 1, river channel slopes are greatest between the Aspen Club and Neale Avenue, but decrease significantly below Neale Avenue. These slope changes can be tied directly to the geology of the valley floor in this area. Based on the geologic mapping of the valley (Bryant 1971), the relatively flat portion of the profile just upstream of the Aspen Club corresponds with a highly meandering segment of the river in a short but fairly wide, unconfined, alluvial section of the valley. An analysis of the contour mapping for the Aspen area also reveals that the valley floor in the area of the Aspen Club is highly constricted (see Figure 1), which may have contributed to the flat, meandering section of the river immediately upstream. Upstream, the Salvation Canal diversion structure and Stillwater Drive are situated on coarse-grained glacial moraine deposits. The steeper segments of the river downstream of the Aspen Club are situated on glacial outwash deposits. Thus, relict coarse-grained glacial material is the primary sediment found in the banks and bed of the river. Immediately downstream of the Aspen Club to about Neale Avenue, the river flows over and is slowly downcutting through older glacial outwash deposits. Below Neale Avenue, the river flows over younger glacial outwash deposits. In places along the lower portion of the reach, the river is bound by and flows between relict glaciofluvial terraces.

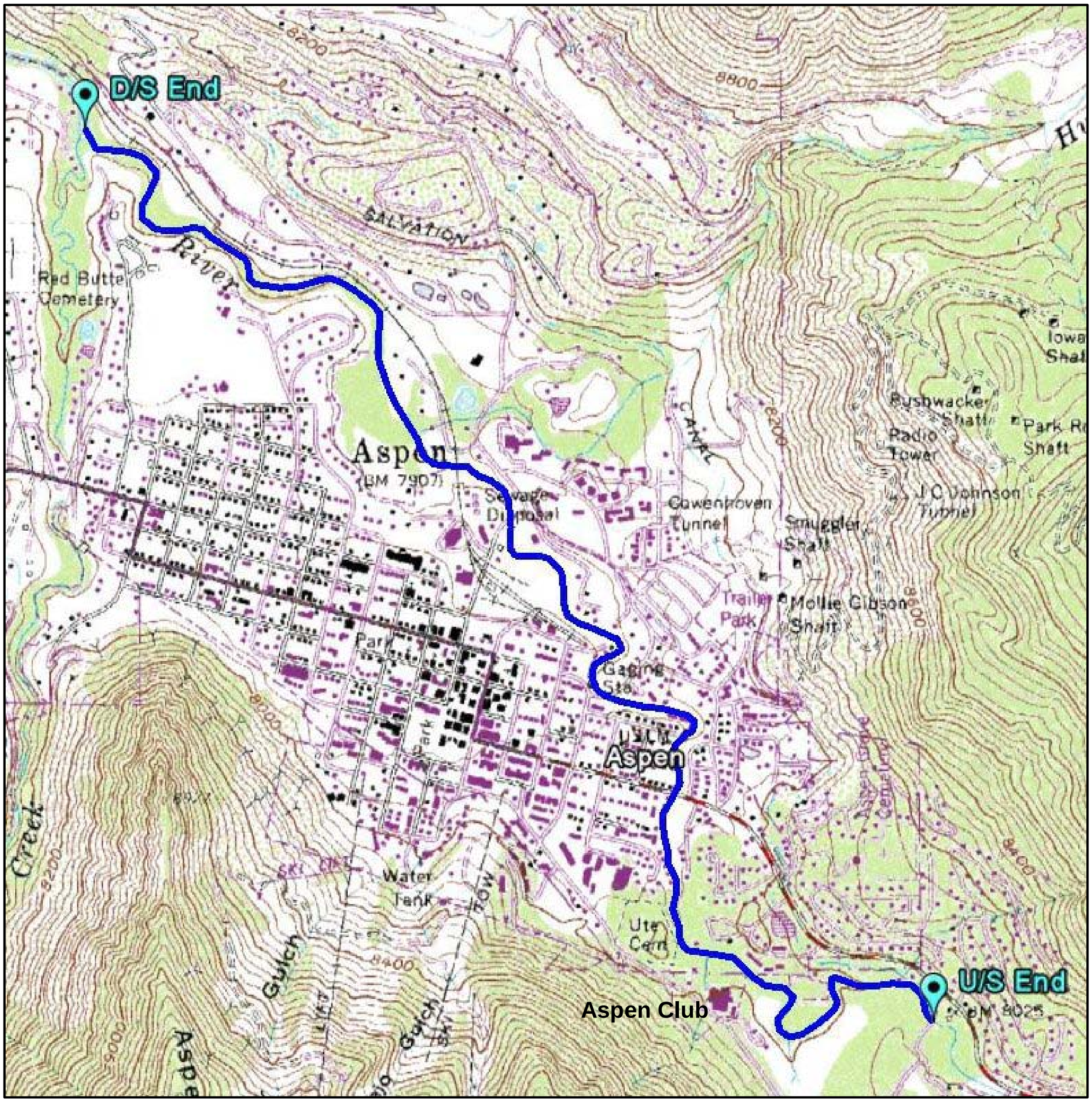

Figure 1. Location map of the project reach of the Roaring Fork River through Aspen, Colorado. Flow is from lower right (SE) to upper left (NW).

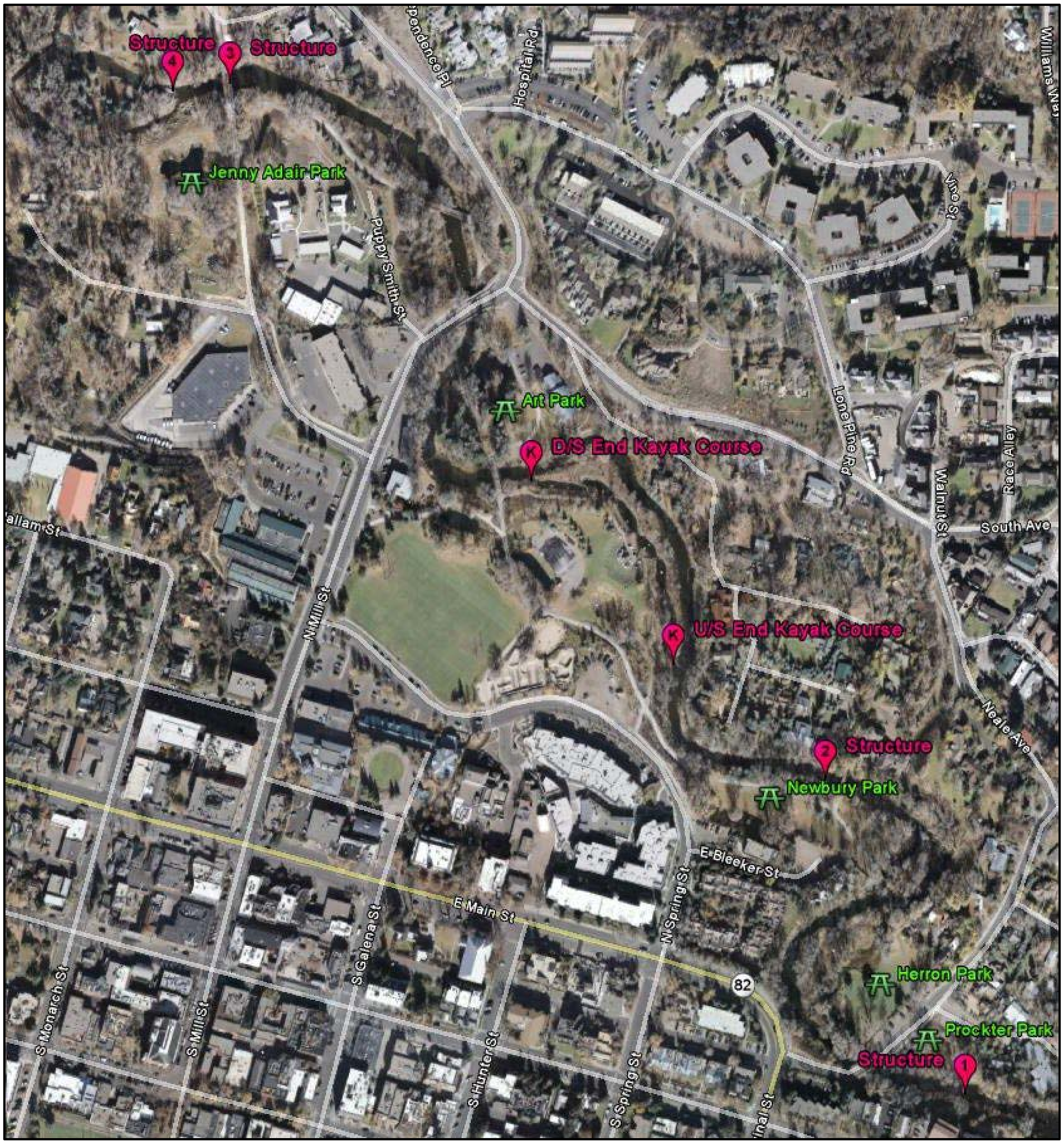

Figure 2. Aerial view (2008) of the subreach of the Roaring Fork River in which a more detailed geomorphic assessment was conducted. Man-made in-channel features are shown in red.

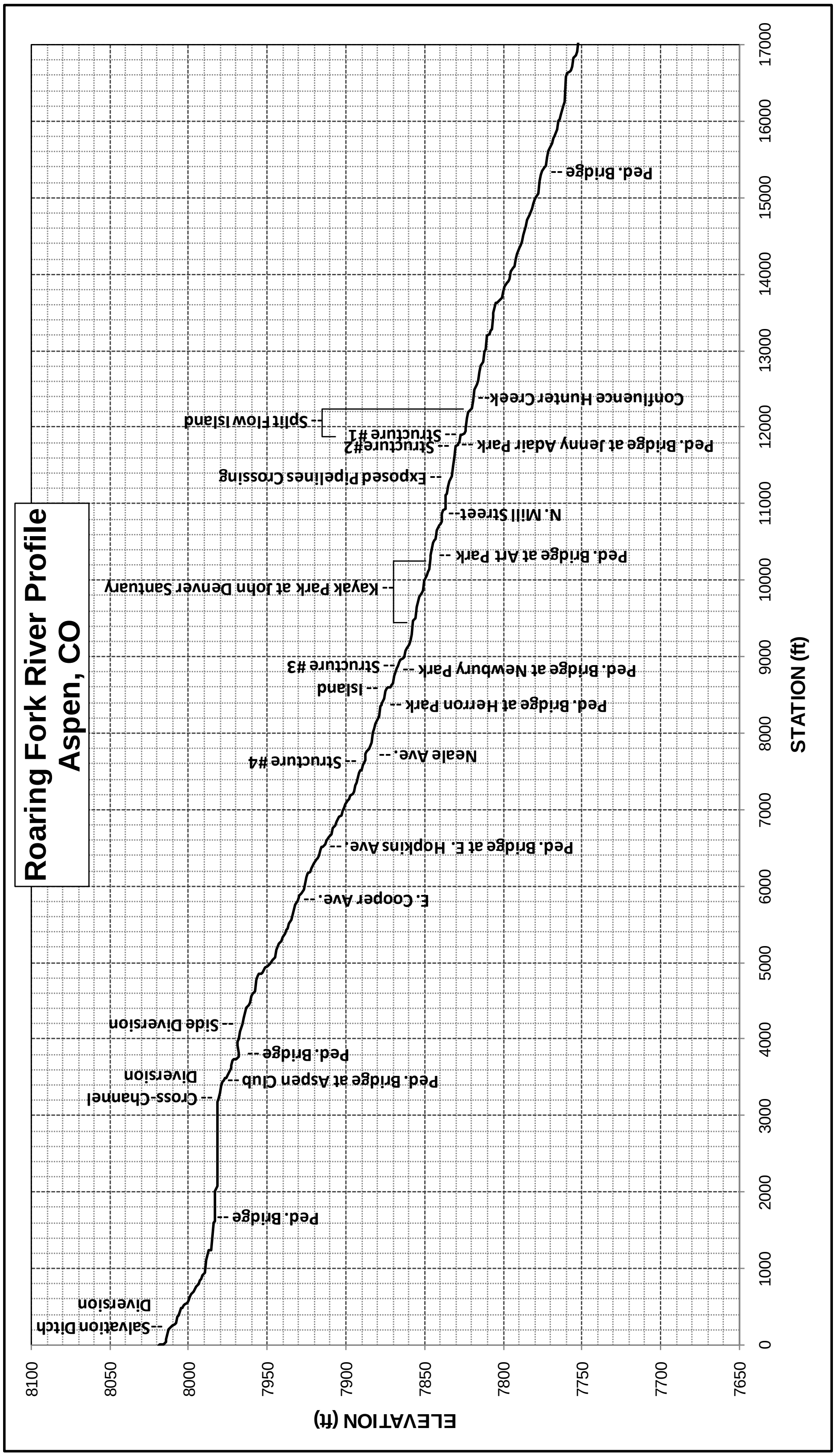

Figure 3. Longitudinal profile of the overall project reach of the Roaring Fork River through Aspen, CO.

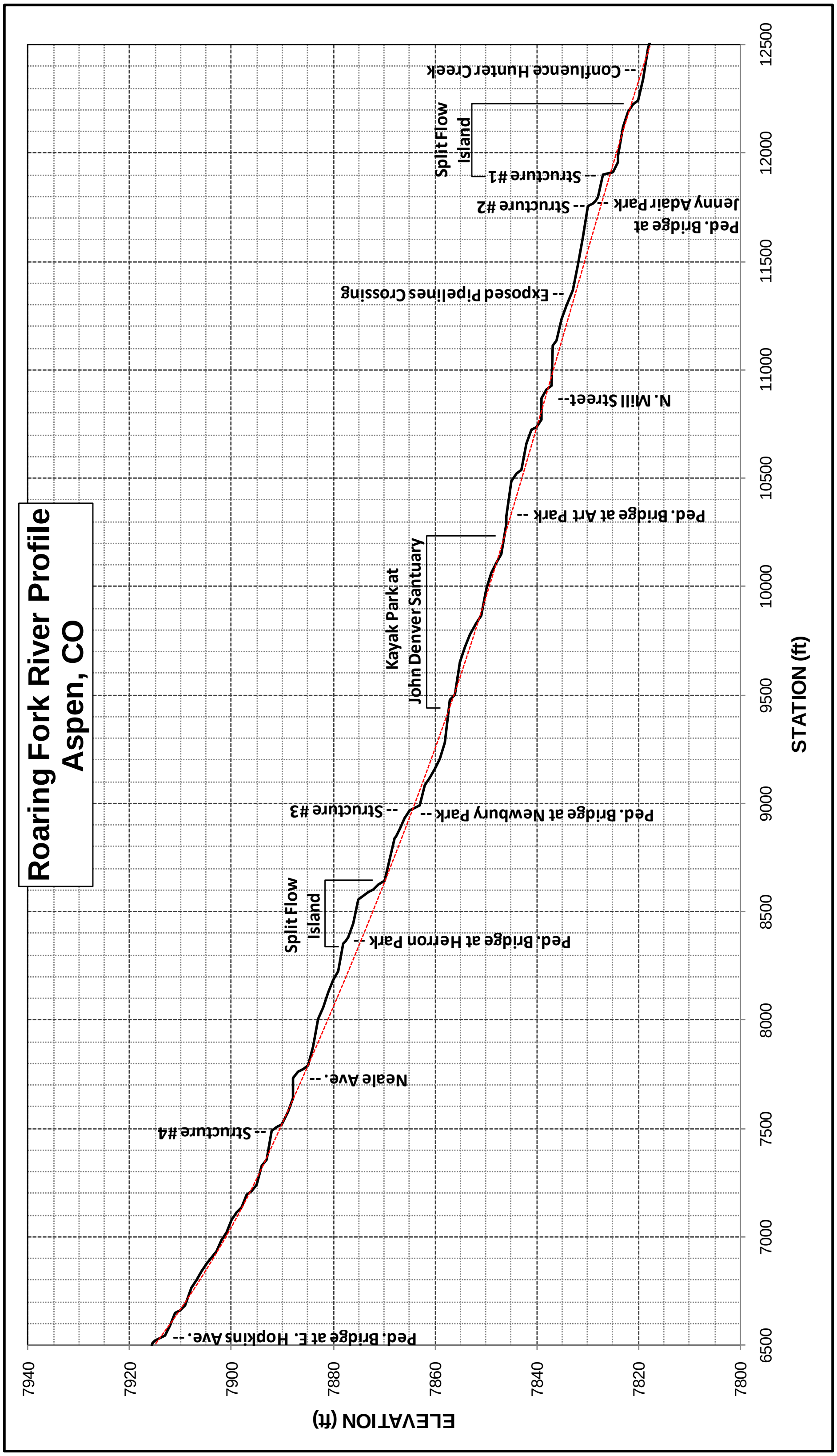

Figure 4. Longitudinal profile of the subreach of interest of the Roaring Fork River through Aspen, CO. The red line is a best fit line used to highlight significant channel profile changes.

Table 1. Slope Data for Segments of the Roaring Fork River in Aspen, CO.		
Reach	Slope (ft/ft)	Slope (ft/mile)
Aspen Club to E. Cooper Ave.	0.020261	107.0
E. Cooper Ave. to Neale Ave.	0.022344	118.0
Neale Ave. to N. Mill St.	0.015610	82.4
N. Mill St. to Hunter Creek Confluence	0.013609	71.9
Hunter Creek Confluence to Castle Creek Confluence	0.013643	66.8

Background information and other material relevant to the project reach is available from the Roaring Fork Conservancy website (http://www.roaringfork.org/). The principal document reviewed was the "State of the Roaring Fork Watershed" report (Clarke et al. 2008). As stated in the Executive Summary of the report, it "illustrates the current status of the Roaring Fork Watershed in terms of water quality and quantity and its water dependent eco-systems." Detailed information for the Upper Roaring Fork Sub-Watershed, which includes the project reach, is provided in Chapter 4 of the document (http://www.roaringfork.org/pub/collaborative/4.1_URF.pdf).

As indicated in the watershed report (Clarke et al. 2008), the in-stream and riparian habitat quality in this reach of the river is considered severely degraded. The poor quality of the habitat is attributed primarily to altered hydrologic conditions associated with in-basin and trans-mountain diversions, degraded water quality, channelization, in-stream and floodplain modifications and encroachments, and bankline armoring.

The altered river hydrology and decreased flows, channel modifications, and the Salvation Canal diversion structure in the channel at the upstream end of the city have contributed to the reduction of incoming sediment to the subreach within the City limits. The river channel in this subreach has been severely encroached upon by urban development and there is little remaining floodplain along the river. The resulting confinement, and in some places constriction, of the river channel as well as significant armoring of the banks within the City combined with the obstruction of incoming sediment from upstream have contributed to a reduction in the subreach sediment supply. However, it should be noted that, although limited, sediment is still supplied to the reach through winter road sanding operations, localized scour of the channel bed, small tributary contributions, and infrequent bank erosion. Nonetheless, the decreased sediment supply has resulted in the channel in this subreach becoming slightly entrenched with localized armoring of the channel bed.

SITE RECONNAISSANCE AND ASSESSMENT

A site visit to assess the current conditions of the river was conducted by the Ayres Project Geomorphologist, Mr. William Spitz, PG, on Tuesday, November 16, 2010. Mr. Spitz was accompanied by Dr. William Miller of MEC. The site reconnaissance was conducted by walking accessible portions of the project reach or making observations from bridges where access was limited. River conditions and geomorphic characteristics were documented through the use of field notes and photographs.

Beginning at the upstream end of the reach at the Stillwater Drive bridge, observations were made of the channel upstream and downstream of the bridge. The reach above the bridge consists of a gently meandering channel inset within a wide floodplain that covers much of the valley floor. Examination of the aerial imagery for this reach indicates that the river has been impacted by limited mining of the valley floor and artificial straightening of the channel for about

0.4 miles upstream of the Stillwater Drive bridge. Although natural and man-made cutoffs of meander bends are present along the river further upstream, the river generally appears to be freely meandering in the upper part of the valley.

Immediately downstream of the Stillwater Drive bridge, the channel is heavily confined by armored banks. The Salvation Canal diversion dam, which creates a significant grade drop in the river, is located about 180 feet downstream of the bridge. **Figure 5** shows the confined channel with armored banks and the Salvation Canal diversion structure. Downstream of the structure, the river returns to its relatively unconfined and freely meandering form until about the Aspen Club location. Two cobble/boulder diversion structures are present in the river in the area of the Aspen Club (**Figure 6**). One is a right bank cross-channel diversion structure present just to the east of the Aspen Club and one is a side-channel diversion structure located on the left bank just downstream of the club. Except for the Salvation Canal diversion structure, which is approximately 5-6 feet high, it appears that none of these structures is an impediment to fish passage during low flow.

Figure 5. View looking downstream from the Stillwater Drive bridge toward the Salvation Canal diversion structure.

From the Aspen Club downstream to the Neale Avenue bridge, the river steepens, is much less sinuous, and becomes confined by urban development that encroaches on the river. This segment of the river contains a number of typical boulder riffles and pools (**Figure 7**) with a long, narrow split flow island just upstream of the E. Cooper Avenue bridge. None of these features poses an impediment to fish passage at low flow. In fact, the boulder clusters, which do not obstruct fish passage, do produce localized upstream backwatering and scour on the downstream side of the boulders, which is optimal habitat for fish.

Figure 6. Aerial view of the river in the area of the Aspen Club showing the location of existing diversion structures and pedestrian bridges.

Figure 7. Aerial View of typical boulder riffles and pools just upstream of E. Cooper Avenue.

The first man-made cross-channel structure in the project reach occurs approximately 220 feet upstream of the Neale Avenue bridge (**Figure 8**). This structure, hereafter known as Structure #1, appears to be a grade control structure constructed of a series of boulders placed side by side across the channel (**Figure 9**). The vertical drop on the structure, which is evident in Figure 4, is about 1.5 to 2 feet. The structure is coincident with and downstream of a diagonal sewer pipeline crossing in the river. The pipeline, which was not evident at the time of the site visit, is about 15 feet from the grade control structure at its closest point (on the right bank) and about 65 feet at its furthest point (on the left bank). Although not observed at the time of the site visit, based on the 2008 aerial photos, a pool has developed just upstream the grade control structure and appears to be filling with finer grained sediment. Flattening of the channel slope upstream of the structure is also evident in Figure 4. It also appears that the right bank just upstream of the structure has been protected with revetment. A revetment is a form of bank protection, either as a slope paving or a retaining wall, constructed from a variety of materials including quarried stone, boulders, or other erosion resistant materials. In most cases, the bank revetment along the study reach of the Roaring Fork River consists of dumped or stacked quarry stone or boulders.

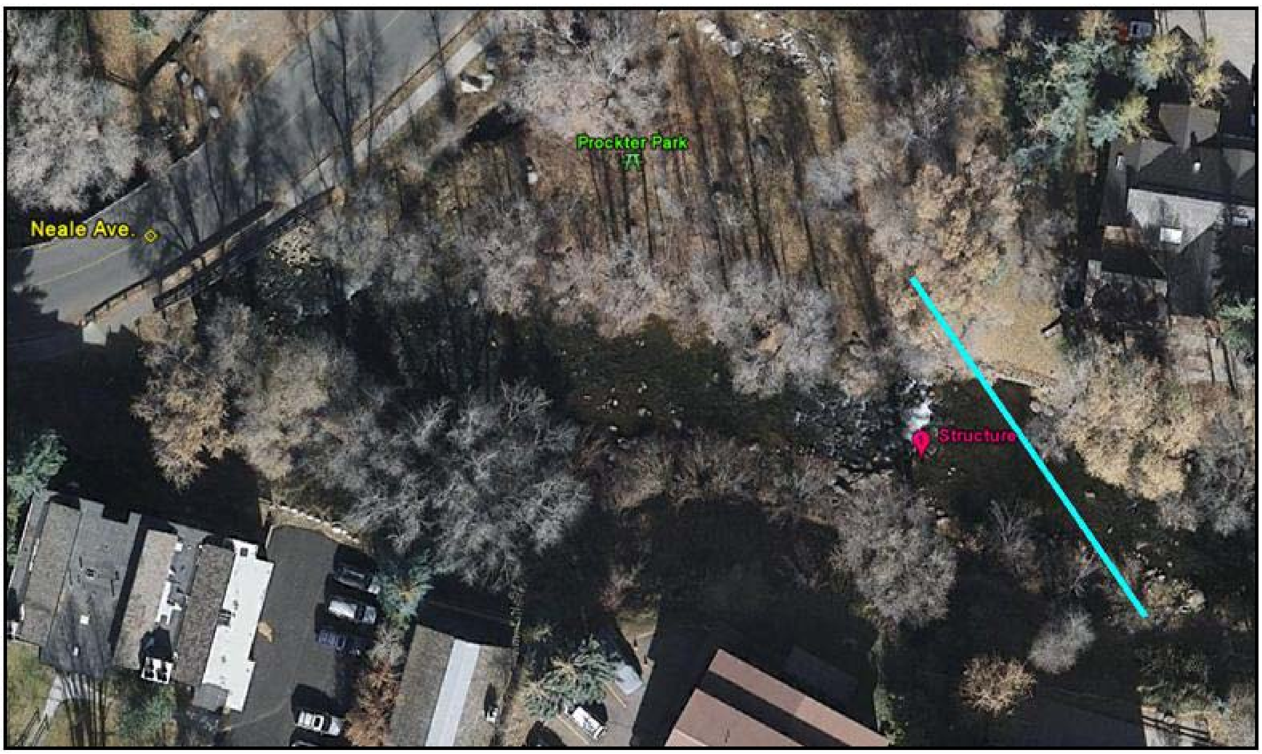

Figure 8. Aerial view of the location of boulder Structure #1 and a sewer pipeline crossing (light blue line) just upstream of the Neale Avenue bridge.

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Although Figure 8 would suggest that fish passage may be possible on the right side of Structure #1, the apparent 1.5 to 2-foot drop may be too much during lower flows for fish to overcome. In addition, the fine sedimentation in the pool upstream of the structure may ultimately fill the pool and create very shallow conditions immediately upstream of the structure. These shallow conditions may not be conducive for fish passage during low flows and may also induce bank erosion by forcing flow to the sides of the channel.

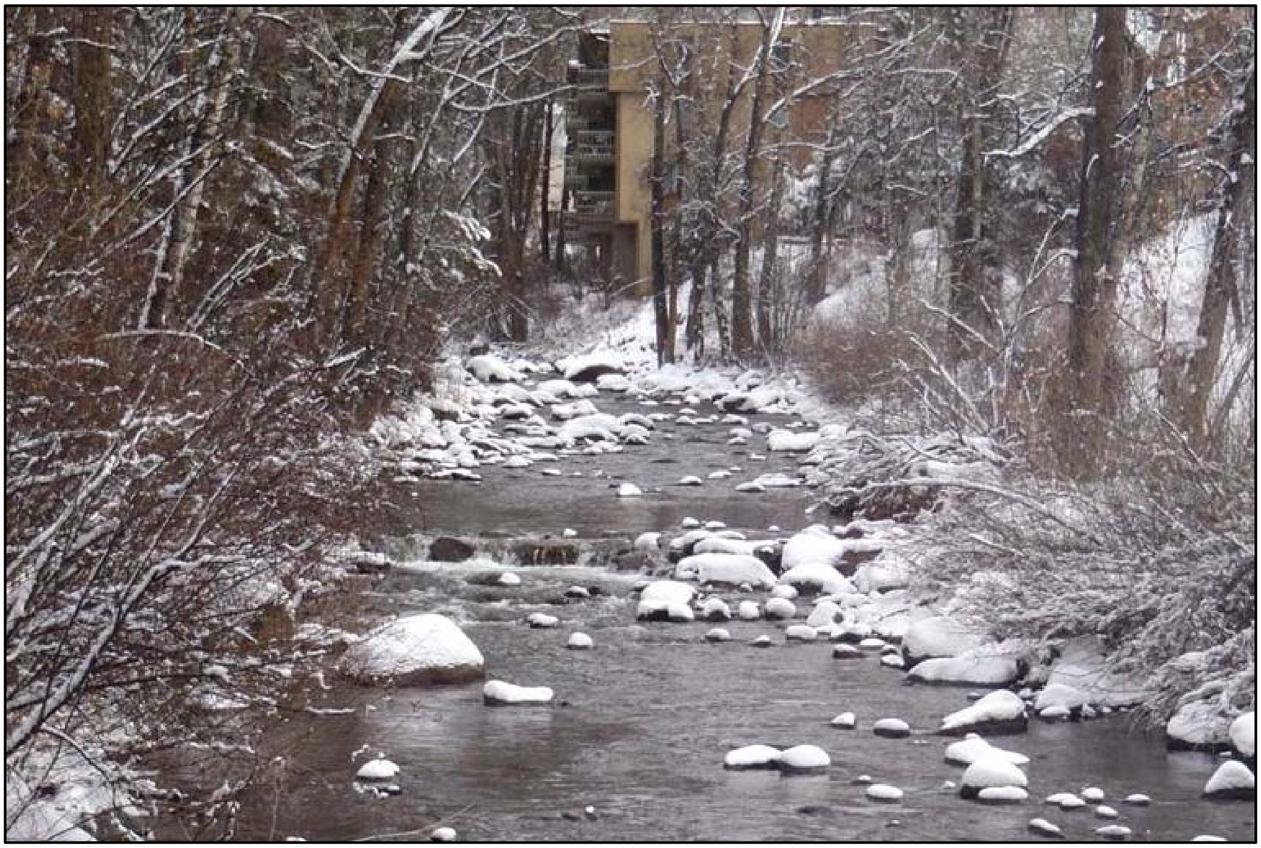

Figure 9. View looking upstream from Neale Avenue bridge toward the cross-channel boulder Structure #1.

The next segment, known as the Herron Park segment, extends from the Neale Avenue bridge to the pedestrian bridges about 600 feet downstream (**Figure 10**). This reach is represented by a large radius left hand bend. The inside of the bend is cut by a man-made channel that intersects a wetland pond at about the center of the bend. The man-made channel continues downstream and intersects the river just upstream of the pedestrian bridge. The left or outer bank of the bend is revetted over most of its length within this segment.

Although not evident during the site visit, a sewer pipeline crosses the river just upstream of the pedestrian bridge (see Figure 10). Just downstream of the pedestrian bridge at this location is the site of an avulsion or cutoff of the channel across the inside of a right hand bend. Although not evident at the time of the site visit, any grade control placed in the river to protect the sewer line crossing at this site may have contributed to or induced the cutoff of the channel and the formation of the island there. In addition, the upstream cutoff channel at Herron Park may also have contributed to the cutoff downstream of the pedestrian bridge by forcing flow toward the left side of the main channel where the Herron Park cutoff channel rejoins the river at the pedestrian bridge.

The river then makes a sharp turn toward the west below the Herron park pedestrian bridge and the island just downstream. The right bank at this location is a high steep bank composed of glacial outwash material, with the toe of the bank armored by boulders eroded from the bank. The river slope is fairly steep through this segment as seen in Figure 4.

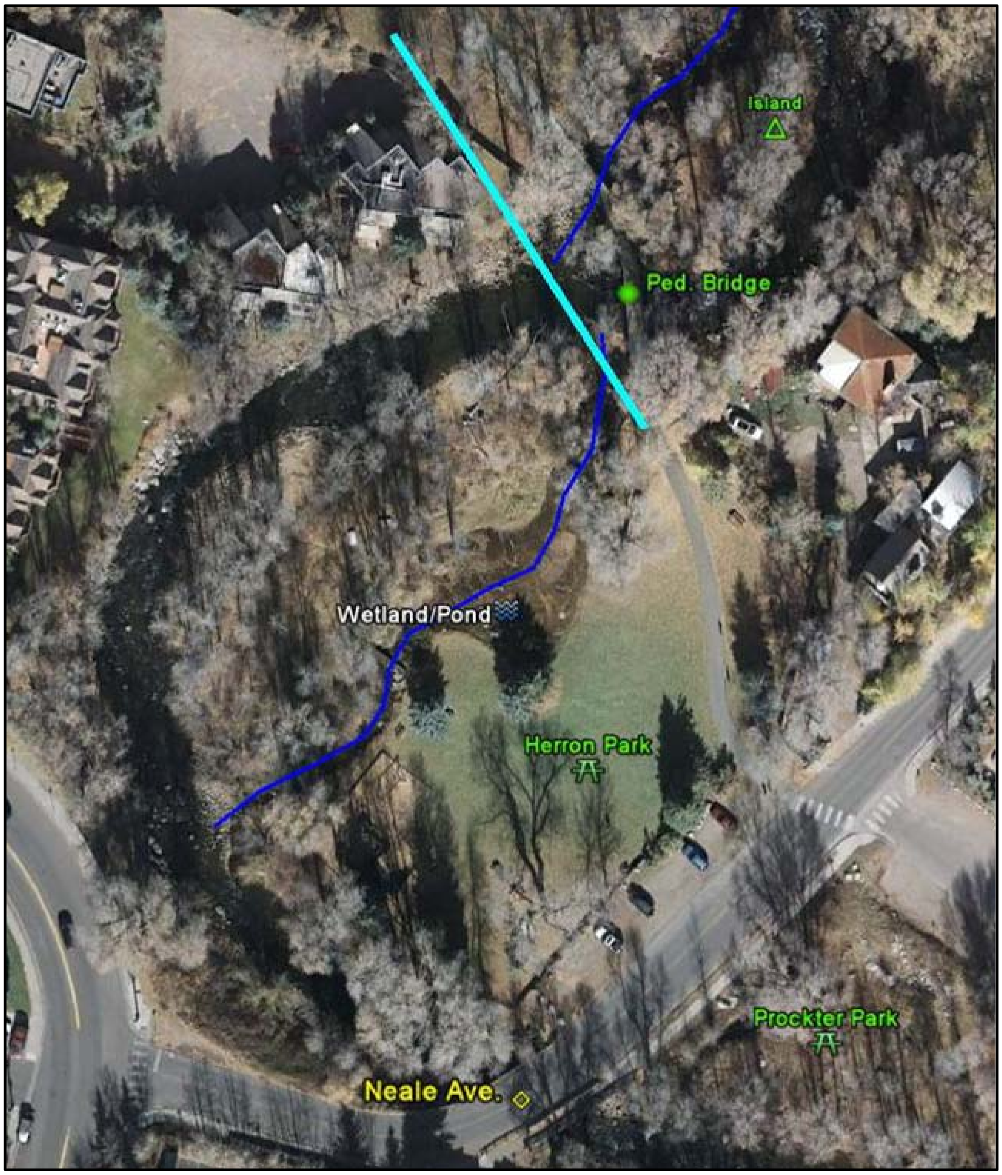

Figure 10. Aerial view of the Herron Park segment of the project reach showing the pedestrian bridges at the downstream end of the segment, the sewer pipeline crossing (light blue line) just upstream, and the man-made split flow channel (dark blue line) and wetland pond at the park.

The next man-made structures in the river are two old concrete bridge abutments on the banks of the channel about 140 feet upstream of the Oklahoma Flats Trail pedestrian bridge over the river at Newbury Park (**Figure 11**). These abutments do not obstruct flow or create any significant problems in terms of channel processes, but do create a slight constriction in the channel width. About 35 feet downstream of the pedestrian bridge is the another cross-channel boulder grade control structure, Structure #2, which also creates an impediment to fish passage at low flows. As shown in Figure 11, the structure was placed to protect an exposed sewer line crossing located about 20 feet upstream. Figure 11 shows the relationship of the structure to the channel and the sewer line crossing. **Figures 12** and **13** show the alignment of Structure #2, which has a drop of approximately 1.5 to 2 feet over the crest. The drop at Structure #2 is also evident in Figure 4.

Figure 11. Aerial view of Structure #2 relative to the sewer line crossing (light blue line) just downstream of the Oklahoma Flats Trail pedestrian bridge at Newbury Park.

Figure 12. View looking toward the right bank showing Structure #2 just downstream of the Oklahoma Flats Trail pedestrian bridge at Newbury Park.

Fiogure 13. View looking downstream from the Oklahoma Flats Trail pedestrian bridge. Note Structure #2 and boulder revetment along the right bank downstream.

Although the flows seen in Figure 12 appear to be sufficient to allow for fish passage, summer low flows may be significantly less and may not be sufficient to allow for fish passage. In addition, Structure #2 is creating sufficient backwater upstream to cause finer grained sedimentation in the channel for some distance upstream of the pedestrian bridge (**Figure 14**) due to the reduction in the energy slope created by the structure. This sediment appears to be finer than the substrate sizes necessary for spawning and appears to be partially burying or infilling the spawning substrate at this location. Small scour holes have developed off the downstream face of the structure.

The lower portions of both banks of the river are revetted with large boulders over much of the reach from the Oklahoma Flats Trail pedestrian bridge to the upstream end of the kayak park at the John Denver Sanctuary, a distance of about 590 feet. The kayak course located at the John Denver Sanctuary is situated on the inside of a large radius right hand bend which makes a sharp turn to the west near the Aspen art museum in Art Park (**Figure 15**). The kayak course, which diverts water from the main channel, covers a length of approximately 675 feet, whereas the river length over the same reach is approximately 815 feet. The grade drop for both the kayak course and the river in this reach is about 10-11 feet. Boulders placed in the river at the upstream end of the kayak course are strategically located in and across the channel to assist in the diversion of flow into the course (**Figure 16**). There are 7 pools and 8 boulder drop structures or sluiceways within the kayak channel. **Figure 17** shows one of the drop structures and upstream pools relative to the main channel of the river and the intervening island.

Figure 14. View looking upstream at aggradation induced by Structure #2 upstream of the Oklahoma Flats Trail bridge.

Figure 15. Aerial view of the kayak course reach of the river at the John Denver Sanctuary.

Figure 16. View looking downstream toward the right bank showing the boulder flow split and diversion into the kayak course channel.

Figure 17. View toward the right bank showing a typical boulder drop structure and upstream pool in the kayak course channel and the main channel of the river in the background. Note the high island between the river and the kayak channel. A remnant of the low floodplain is in the background. Note the house on pilings.

There are a number of potential problems associated with the kayak course that impact river function. First, the course diverts flow from the main channel for its use. Since the width of the main channel through this reach has been maintained, the flow diversion into the kayak course results in shallower flows in the main channel during low to moderate flows. Second, the reduced flows in the main channel can also result in fine grained sediment deposition, which may limit the availability of spawning substrate. Also, during higher spring flows, a significant amount of sediment eroded from the unprotected banks of the kayak course as well as sediment transported in from the main channel is deposited in the pools of the course. Deposition of fine sediment within the pools as well as the trapping and deposition of organic materials may limit the viability of the course if not regularly removed. Finally, there are boulder drop structures at both ends of the course with the downstream structure having a drop of about 3.5-4 feet and the upstream structure having a 1-1.5 foot drop. These upper and lower structures create an obstruction to fish passage during low flows. During the moderate to high flows, fish may migrate or be diverted into the kayak channel and can become trapped in the pools once flows recede (this was readily evident during our site visit). The sediment and organic material deposition in the pools, the limited habitat, and potential summer heating of the water in the pools can be detrimental to any fish stranded in the kayak channel during the summer months.

The river then passes under an old railroad bridge on the Rio Grande Trail just downstream of the end of the kayak course. From there, the river makes a sharp left hand bend, turning back to the north (**Figure 18**). The left or outer bank in this bend is revetted with large boulders, whereas the right bank and low floodplain of Art Park is defined by man-made wetlands/ponds. The river then passes under the N. Mill Street bridge and then under a Rio Grande Trail pedestrian bridge about 200 feet further downstream. Both banks of the river are revetted between the N. Mill Street bridge and the pedestrian bridge. An unexposed sewer line (light blue line in Figure 18) passes under the river about half way between these bridges. Fish passage through this reach is unobstructed.

Two exposed pipelines cross the river about 215 feet downstream of the Rio Grande Trail pedestrian bridge located just below the N. Mill Street bridge (**Figure 19**). The two exposed pipes are not included in the City's utility mapping database and are, therefore, assumed to be abandoned. These pipes appear to extend across the entire width of the river and produce less than 1 foot of drop each. It is not known if these pipelines create an impediment to fish passage at low flows.

Further downstream in the area of Jenny Adair Park (**Figure 20**), two additional structures were noted, Structures #3 and #4. Structure #3 is located on the upstream side of the Rio Grande Trail pedestrian bridge at Jenny Adair Park and Structure #4 is located about 115 feet downstream of the bridge. As seen in Figure 4, the vertical drop in the profile at both structures is well defined and the apparent backwater flattening of the channel slope upstream of the structures is also well defined

Structure #3 is a man-made boulder drop structure (**Figure 21**) that is associated with a previously exposed sewer line crossing about 15 feet upstream of the structure crest. The structure consists of structural boulders placed across the channel along the upstream face of the pedestrian bridge to protect the sewer line crossing located just upstream. The boulder structure creates about a 2-3 foot vertical drop in the channel gradient immediately below the pedestrian bridge and significant flattening of the upstream channel gradient. Plunging flow over the drop structure has created a significant scour hole along the downstream face of the structure directly under the bridge. Sediment from the scour hole has been deposited immediately downstream of the bridge.

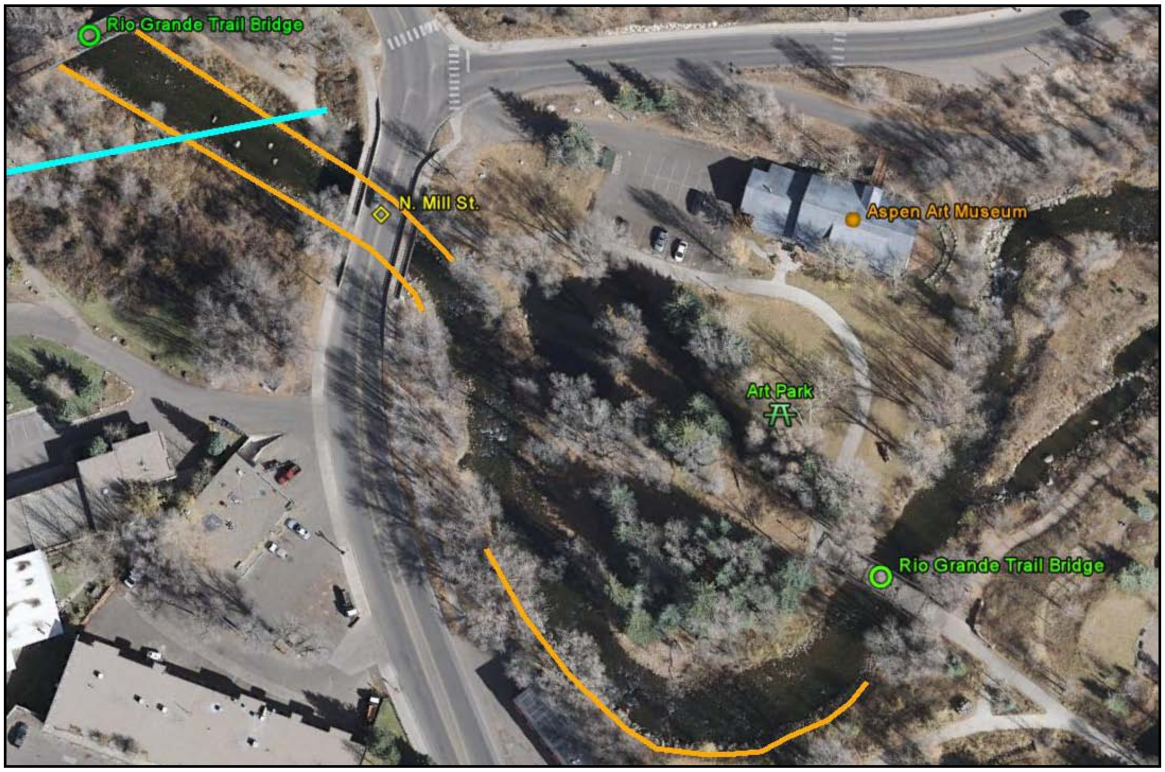

Figure 18. Aerial View of the river segment from the kayak course to the pedestrian bridge downstream of N. Mill Street. Note buried pipeline crossing (light blue) and revetment (orange).

Figure 19. Aerial view of two exposed pipelines in the river downstream of the Rio Grande Trail pedestrian bridge located just below the N. Mill Street bridge.

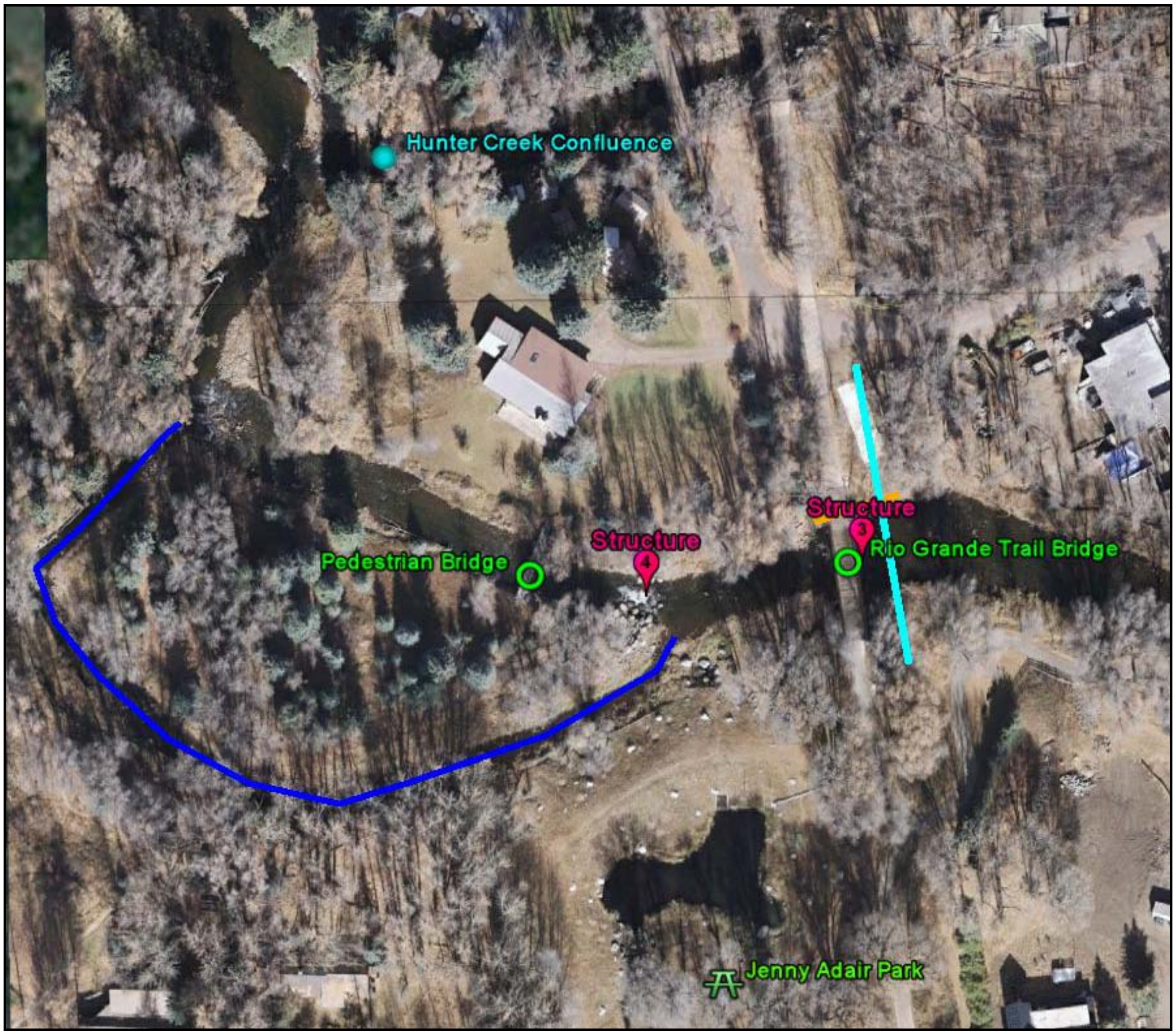

Figure 20. Aerial view of the river segment covering the area around Jenny Adair Park and the Hunter Creek confluence. Note the sewer line crossing (light blue line) and the man-made flow split (dark blue line) associated with Structures #3 and #4, respectively.

Structure #3 has also induced upstream aggradation, which has fully buried the previously exposed sewer line. Since this structure is located in a high radius bend and as is expected with regard to flow and sediment transport processes in a bend, the bulk of the upstream aggradation has occurred along the left (inner) bank portion of the channel (i.e. point bar) while some slow erosion is occurring along the right (outer) bank upstream of the structure. As seen in Figure 20, typical meander bend processes and the impacts of the structure have created a wider, shallower channel section immediately upstream of the structure. This structure is an impediment to fish passage during low flows and the fine-grained sedimentation that the structure induces for a short distance upstream creates a shallower channel and partially buries available spawning substrate at that location.

Figure 21. View of boulder Structure #3 on the upstream side of the Rio Grande Trail bridge at Jenny Adair Park.

Structure #4 is associated with a man-made split flow channel and island immediately to the south of the structure (see Figure 20). **Figure 22** shows the relationship of the boulder drop structure and the upstream end of the man-made flow split, the resultant island, and the upstream riffle and sedimentation induced by the features. The vertical drop over Structure #4, which is evident in the profile shown in Figure 4, is about 3-4 feet.

It appears that Structure #4 was constructed in conjunction with construction of the man-made split flow channel to the south. The structure appears to be used to divert flows from the main channel of the river into the split flow channel. Both the structure and the split flow channel appear to be associated with the nearby Aspen Center for Environmental Studies. These features are also detrimental to fish passage during low flows. The drop over the boulder structure is too precipitous during low flows to allow fish passage. In addition, an examination of the contour mapping of the area reveals that the upstream end of the split flow channel has a very flat slope, which likely results in either a dry channel or flows too shallow to allow for fish passage during periods of low flow.

Structure #4 also creates a significant flattening of the upstream channel gradient, as indicated by the upstream riffling and sedimentation seen in Figure 22. This riffled and aggraded segment of the river may be sufficiently shallow during low flows to preclude or limit fish passage.

The remainder of the river from the confluences of Hunter Creek to Castle Creek is generally stable and well confined between high terraces stable. No know man-made features that may be detrimental to fish habitat or impediments to fish passage exist within this remaining segment of the river.

Figure 22. View looking downstream from the pedestrian bridge at Jenny Adair Park showing the boulder drop Structure #4 in the river channel on the right and the narrower, shallow, man-made split flow channel on the left.

CONCLUSIONS AND RECOMMENDATIONS

The reach of the Roaring Fork River through the City of Aspen is significantly encroached upon as a result of urban development. Very little of the river's floodplain remains along the river corridor and upstream diversions, and man-made perturbations within the watershed have changed not only the hydrology of the system, but also a whole host of other functions and processes including the sediment transport characteristics of the river. As indicated in the watershed report (Clarke et al. 2008), the in-stream and riparian habitat quality in this reach of the river is considered severely degraded as a result of these perturbations.

Contributing to the degraded in-stream habitat is the presence of boulder grade control structures emplaced to protect exposed utility crossings and to provide flow to man-made split flow channels. These structures create significant vertical drops that are an impediment to fish passage as well as inducing localized upstream aggradation that reduces the flow depth, increases the channel width through bank erosion, and buries spawning substrates within the aggraded reach. For example, **Figure 23** shows the plan and profile view a typical steep, unobstructed, boulder/cobble bed channel like the Roaring Fork River. In this view, it can be seen that water "piles up" on the upstream side of a large boulder and then accelerates as it goes around the boulder. As flow passes around the boulder, flow acceleration and eddying may create a scour hole on the downstream side of the boulder. Minor amounts of localized sediment deposition may occur just downstream of the boulder, both a result of the scour and as a result of the boulder creating a shadow zone. The individual boulder, its scour hole, and the minor sediment deposition downstream all create diverse habitat for fish.

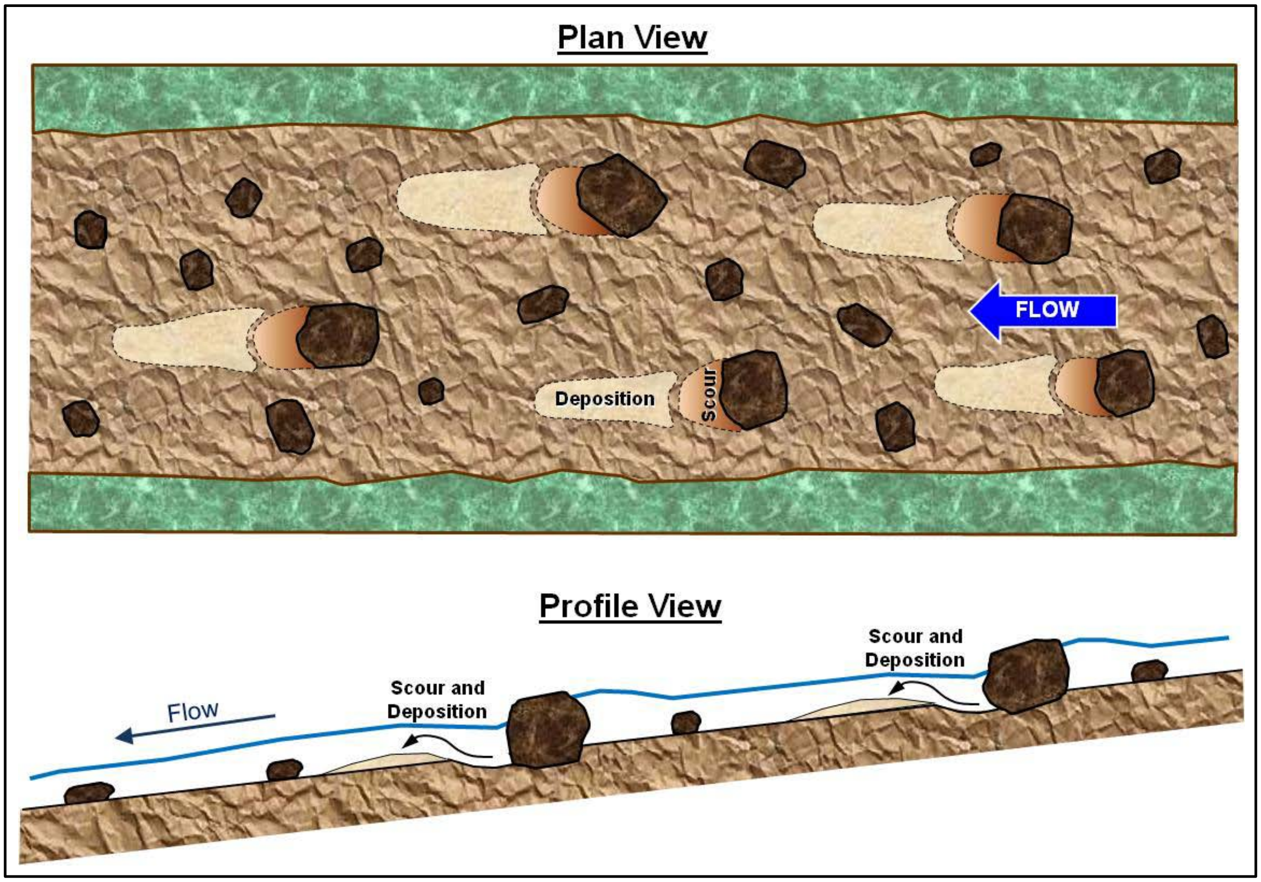

Figure 23. Typical flow, scour, and deposition patterns on a steep, boulder/cobble bed stream.

In comparison, **Figure 24** shows the plan and profile view of a typical boulder grade control structure that has been constructed on the river in at least 4 locations. As previously discussed, the boulder structure creates a significant impediment to fish passage during low flows, but may develop a large scour hole and depositional zone downstream that may provide some beneficial habitat. However, the structure also creates a significant flattening of the channel gradient for a short distance upstream, which in turn also induces localized aggradation which reduces the quality of in-stream habitat and spawning substrate at that location. Both the structure and upstream aggradation can also induce or contribute to bank erosion at the ends of the structure as well as immediately upstream of the structure. Bank erosion at the ends of the structure can result in flanking or significant damage to the structures.

The structures at three of the locations were constructed to protect exposed sewer pipleline crossings. Since it is imperative that these crossing be protected, it would be beneficial to river function to modify the protecting structures such that they still provide maximum protection to the pipelines as well as provide fish passage at all flows. A number of agencies (e.g. Forest Service 2008, Caltrans 2007) provide design guidance for grade control features that also allow for fish passage. For example, one method of grade control consists of a series of rock weirs placed such that flow is allowed to pass over and around the overall structure while maintain unobstructed fish passage as well as grade control. **Figure 25** provides a conceptual plan and profile view of a typical grade control structure using rock weirs.

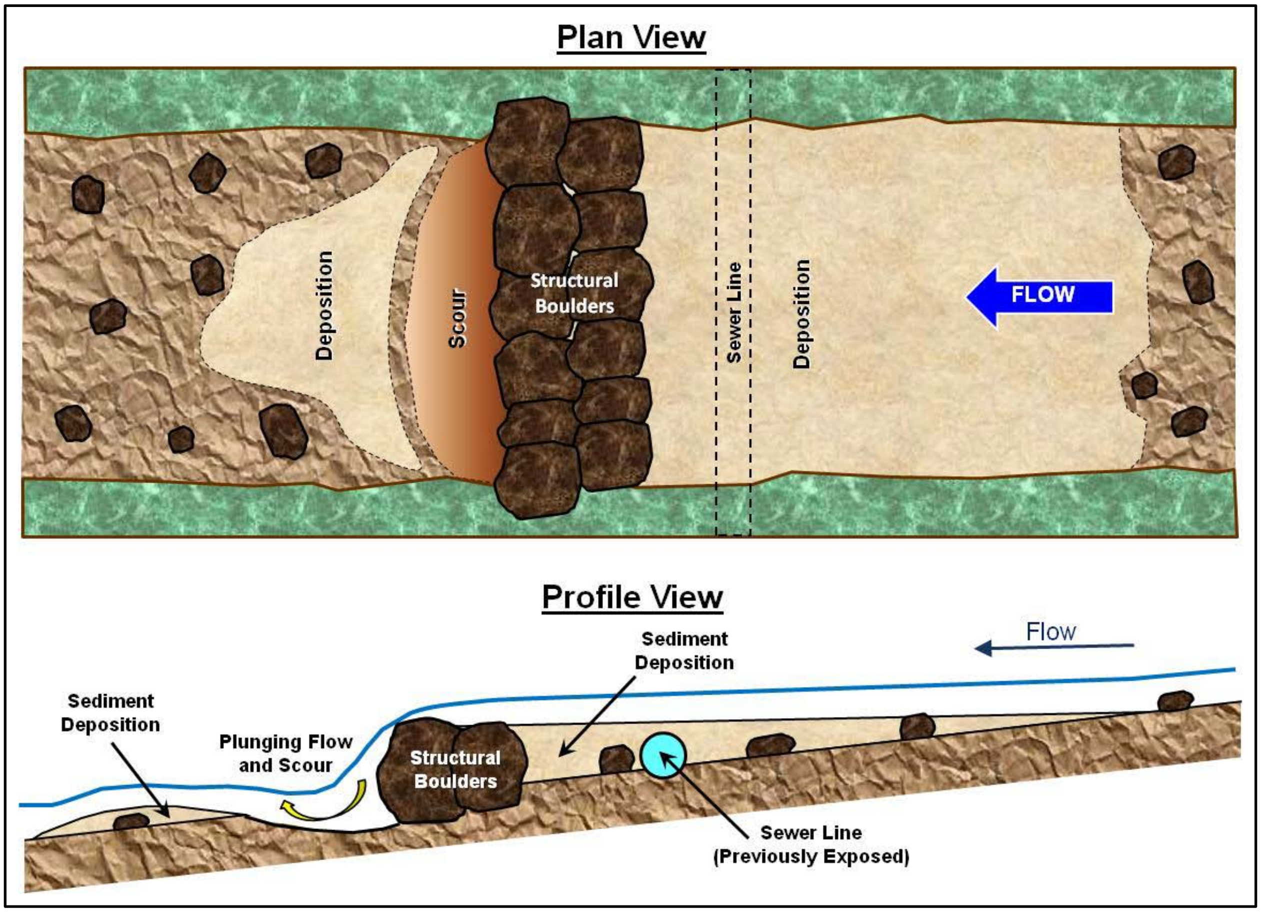

Figure 24. Modified flow, scour, and sedimentation patterns created by a boulder grade control structure on a cobble and boulder bed stream.

At this time, we would recommend that the Healthy Rivers and Streams Program, in cooperation with the City of Aspen and Pitkin County reconstruct Structures #1-3 using a series of weirs similar to that described in Figure 25.

We would also recommend the complete removal of Structure #4 at Jenny Adair Park as it appears to serve no other purpose than an aesthetic one. If the split flow channel at this location is, in fact, used by the Aspen Center for Environmental Studies and serves a useful purpose, we would recommend that the boulder grade control structure used to divert flows into the split flow channel still be removed, but that the diversion point be located much further upstream. This can be accomplished by extending the upper end of the split flow channel further upstream to a point where flow can be successfully diverted without requiring a diversion structure while maintaining adequate flow depths and widths as well as fish passage at all flow levels.

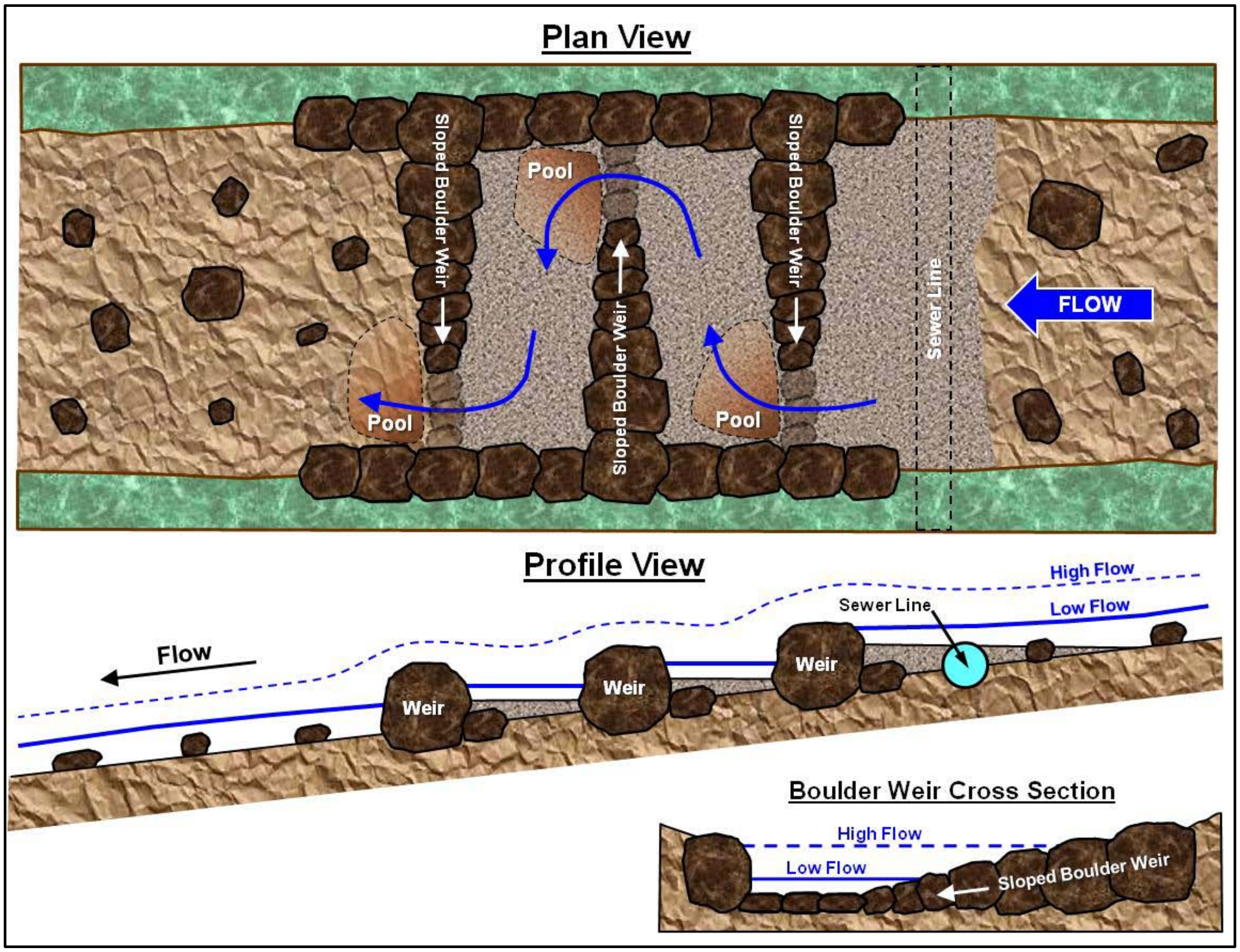

Figure 25. Plan, centerline profile, and cross section views of a typical grade control structure that consists of a series of boulder weirs.

With regard to the kayak park at the John Denver Sanctuary, we would recommend the complete removal of the course and reclamation of the area occupied by the course to a functional floodplain. Based on our knowledge of the course, it appears that the course is used infrequently and only when there is sufficient flow, such as during spring runoff. Thus, the course is only viable for a short period during the entire year and will likely require ongoing maintenance to keep the course pools clear of sediment and organic debris. The kayak channel could be reclaimed by removing the excavated material from the intervening island and refilling the kayak channel with little to no effect on in-stream habitat on the main channel of the river. By refilling the kayak channel, the floodplain area occupied by the island that was covered with the material previously excavated from the kayak channel would also be restored. Reshaping of the left bank of the river and replanting riparian vegetation on the reclaimed island/floodplain area would also contribute to habitat diversity in this reach.

Although these recommendations would likely require a significant budget as well as appropriate permitting to accomplish, the upfront costs should be offset and mitigated by the long-term advantages of restoring in-stream and floodplain habitat at the locations described above.

We suggest that Pitkin County, through its Healthy Rivers and Streams Board, initiate discussions with the appropriate city, county, and private entities regarding the above recommendations to restore stream channel function. These initial discussions could assist these groups to: 1) prioritize the recommended channel restorations in this report; 2) begin the process for channel restorations; and 3) develop a long term strategy for maintaining river health and function.

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