# Water Quality and Aquatic Resources Monitoring Program for the Ralston Afterbay Sediment Management Project

## 2001 Annual Report

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# Water Quality and Aquatic Resources Monitoring Program for the Ralston Afterbay Sediment Management Project—2001 Annual Report

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# Contents

# Tables

# Figures

**Follows Page**

# Photographs

# Water Quality and Aquatic Habitat Monitoring Program for the Ralston Afterbay Sediment Management Project—2001 Annual Report

## Executive Summary

Placer County Water Agency (PCWA) is proposing to initiate a pilot sediment management project at Ralston Afterbay Reservoir (Ralston Afterbay), a component of the American River Hydroelectric Project on the Middle Fork American River (MFAR). The primary purpose of the sediment management project is to create sediment storage capacity in Ralston Afterbay, maintain operational flexibility of Ralston Dam and Oxbow Powerhouse, and delay the complete sedimentation of Ralston Afterbay.

The sediment management project consists of 2 components. The first component consists of dredging approximately 75,000 cubic yards (yds) of sediment from the upstream end of the reservoir and placing approximately 48,000 yds of this material downstream of the Ralston Dam on Indian Bar. The sediment will be configured to allow high flows to mobilize and transport the sediment to reaches downstream of the dam. The second component, termed *sediment-pass-through* (SPT), consists of reoperating Ralston Dam during high flow events to pass greater quantities of fine sediment past the dam than passes under current operations.

A secondary objective of the project is to restore the natural migration of coarse and fine sediment that occurred in the project area before dam construction. This sediment, especially the intermediate-sized material (gravel, pebbles, and cobbles), is critically important for maintaining suitable stream habitat for fish and benthic macroinvertebrates (BMI) (insects and other aquatic organisms that live in or on the streambed). Since the construction of Ralston Dam in 1966, a portion of the total sediment load transported by high flows from the MFAR and Rubicon River above Ralston Afterbay has accumulated in the reservoir, requiring periodic dredging of the reservoir to maintain the reliability of Ralston and Oxbow Powerhouses. As documented for other rivers, the retention of sediment by dams and corresponding reductions in sediment supply to downstream reaches can lead to a reduction in habitat quality in these reaches as high flows continue to transport cobble and finer materials that are not replaced by upstream sources.

SPT operations and sediment placement on Indian Bar constitute an effective and economic approach for managing sediment at Ralston Afterbay while compensating for the long-term effects of sediment retention on aquatic habitat in potentially sensitive reaches of the MFAR downstream of the dam. The proposed sediment management activities will allow the river to mobilize sediments and carry them downstream as they did naturally before dam construction. The placement of reservoir sediment, composed largely of gravel and larger materials, is expected to have beneficial effects on aquatic habitat downstream of the dam. Analyses of the hydraulic and sediment transport characteristics of the MFAR indicate that increases in the amount of fine sediment resulting from SPT operations and sediment placement will not cause adverse effects on water quality and aquatic resources because the amount of fine sediment affected by the project is small compared to the total amount of fine sediment transported by the MFAR.

In 2001, PCWA initiated a monitoring program to ensure project compliance with established water quality objectives and monitor the effects of the project on aquatic habitat and BMI in the MFAR downstream of Ralston Dam. Potential project effects will be evaluated by collecting a minimum of 1 year of water quality data and 2–3 years of aquatic habitat and BMI data before project activities begin and a minimum of 2–3 years of water quality, aquatic habitat, and BMI data after project activities begin. Key water quality, aquatic habitat, and BMI parameters will be monitored at treatment sites below Ralston Afterbay and at control sites above the reservoir. These parameters will include turbidity, total suspended solids, substrate size composition, embeddedness, and several BMI community and population attributes. Because of the high degree of variability of natural systems and lack of baseline data, an adaptive monitoring approach will be used to regularly evaluate the monitoring program and determine whether modifications are warranted to improve its performance. Evidence for project effects will be a significant postproject change (adverse or beneficial) in water quality and aquatic habitat conditions in the treatment reaches relative to changes in the control reaches. If these changes constitute an adverse effect on water quality and aquatic habitat conditions downstream of the dam, the magnitude of these changes will be compared with established water quality and habitat thresholds to evaluate project performance and determine whether corrective actions are warranted. The need for corrective actions will also be based on the results of BMI monitoring, which will serve as a key indicator of the biological effects of observed water quality and habitat changes. In addition, these changes will be evaluated in the context of other watershed events and trends that may influence the monitoring results and conclusions.

In 2001, 4 treatment and 3 control reaches were selected for aquatic habitat and BMI based on several criteria designed to maximize the ability of the monitoring program to detect potential project effects. These criteria, based on known hydraulic and sediment characteristics of the MFAR, included the need for all sites to be sensitive to changes in sediment loads, respond similarly to such changes, and provide important aquatic habitat for trout and BMI. These criteria were best met by localized alluvial portions of the river where sediment deposition occurs in response to channel and valley constrictions associated with tributary alluvial fans, landslide debris, and bedrock outcrops. Forty-four transects were established at all major riffles to sample substrate conditions in each of the monitoring sites. Twenty of these transects were selected for BMI sampling.

Preproject monitoring of aquatic habitat and BMI began in 2001. No project operations have begun. PCWA is currently obtaining the necessary state and federal permits and approvals for the project. Substrate size composition and embeddedness were measured in October 2001 using the methods described by Bain (1999). BMI samples were collected in June, August, and October, 2001, and processed in the laboratory using standard bioassessment methods developed by the Environmental Protection Agency. Water quality monitoring was not conducted because no significant storm events occurred during the 2000–2001 winter period.

Although it is difficult to make specific assessments with 1 year of monitoring data, aquatic habitat in the MFAR generally appears to be in good condition based on the substrate and BMI data collected in 2001. Additional monitoring is necessary to characterize annual variability in aquatic habitat and BMI and define appropriate thresholds for evaluating project effects in future years. However, the results of the first year of monitoring indicate that the sediment management program has the potential to improve habitat quality in the MFAR downstream of Ralston Dam. Both the substrate and BMI data indicate that habitat quality in the reaches immediately downstream of Ralston Dam are lower than other reaches because of coarser substrate (higher proportion of boulders) and smaller quantities of finer materials (gravel, pebbles, and cobbles). These materials, which provide a number of habitat needs for trout and BMI, will be made available to these reaches in future years by placing reservoir sediments at Indian Bar. As proposed, preproject monitoring will continue in 2002 to further characterize baseline variation in water quality, substrate, and BMI parameters.

Watershed events and disturbances in 2001 that could affect sediment loads in the project area in future years include the Star Fire and associated landslides, timber sales, and prescription burns in the Rubicon River and MFAR upstream of Ralston Afterbay. Suction dredge mining, an ongoing activity in the project area, may have localized effects on streambed conditions in the monitoring reaches. These activities and disturbances will continue to be monitored to determine their potential effects on the monitoring results in future years.

# Introduction

PCWA operates a series of reservoirs and powerhouses as part of the American River Hydroelectric Project on the MFAR and Rubicon Rivers (Middle Fork Project) in the central Sierra Nevada (figure 1). The Middle Fork Project includes Ralston Afterbay, created by the construction of Ralston Dam in 1966. The dam and reservoir are located on the MFAR on the border of Placer and El Dorado Counties, California.

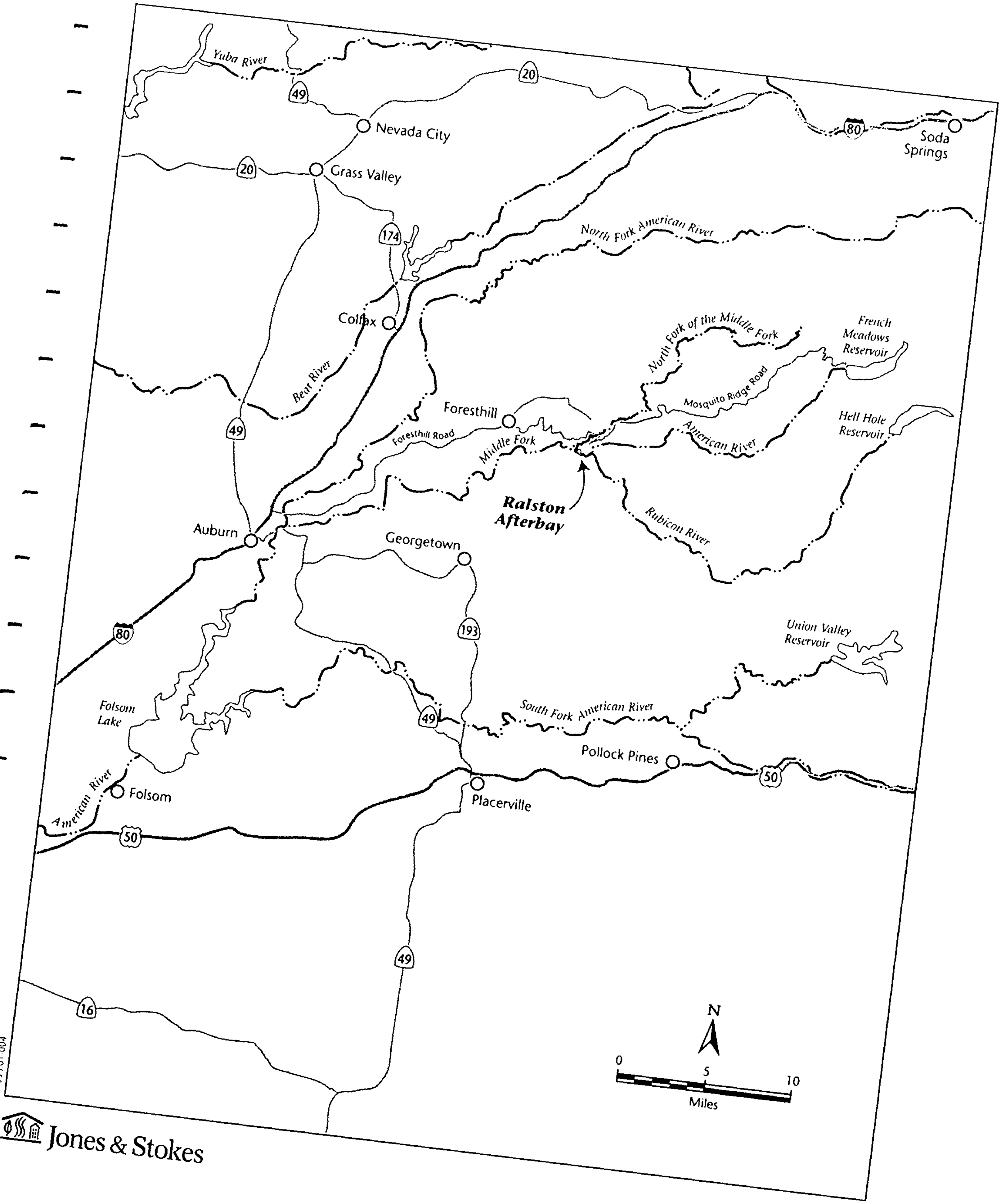
Ralston Afterbay serves 3 primary purposes. First, it protects public safety and fisheries by regulating the rate of river stage change downstream. Second, it allows the 2 largest powerhouses of the Middle Fork Project—Middle Fork and Ralston Powerhouses—to quickly respond to system electrical needs. Third, it impounds water for power generation at Oxbow Powerhouse.

PCWA is proposing to initiate sediment management at Ralston Afterbay to address continuing sedimentation of the reservoir that threatens the reliability of power generation at Ralston and Oxbow Powerhouses. PCWA issued and adopted an initial study/mitigated negative declaration for the Ralston Afterbay Sediment Management Project in August 2001. The primary purposes of the sediment management project are to create sediment storage capacity within Ralston Afterbay, maintain operational flexibility of Ralston Dam and Oxbow Powerhouse, and delay the complete sedimentation of Ralston Afterbay.

The sediment management project consists of 2 independent components. The first component consists of dredging approximately 75,000 cubic yds of sediment from the upstream end of the reservoir and placing this material downstream of the dam on a 7-acre portion of Indian Bar (photo 1). The sediment will be configured to allow high flows to mobilize and transport it to the river downstream of the dam. The second component of the project will consist of reoperating the dam during high flow events to pass greater quantities of fine sediment beyond the dam. SPT operations will be conducted whenever river flows exceed approximately 3,500 cubic feet per second (cfs).

PCWA is proposing an initial placement of 48,000 cubic yds of sediment on Indian Bar to evaluate the project at a pilot level and to address concerns regarding recreational uses at Indian Bar (Jones & Stokes 2002). This evaluation will include consideration of potential strategies for increasing the sediment volume while maintaining or enhancing recreational opportunities at Indian Bar. Other sediment placement locations (e.g., Junction Bar) may also be considered.

A secondary objective of the project is to restore the natural migration of coarse and fine sediment that occurred in the project area before dam construction. This sediment, especially the intermediate-sized material (gravel, pebble, and cobble), is critically important for maintaining suitable stream habitat for fish and BMI (Waters 1995). Following construction of dams, these materials continue to be transported from the reaches below dams but without replacement from upstream sources, resulting in loss of important habitat (Kondolf and Matthews 1993). Other effects include scouring and deepening of the channel and associated increases in substrate size (i.e., channel armoring), a process that has been occurring below Afterbay Dam since its construction (Stiehr, pers. comm.). Efforts to mitigate these effects on salmon and trout streams in California have focused primarily on augmenting the supply of spawning-size gravels (Parfitt and Buer 1980). These efforts, which include placing gravel on bars and riffles and installing artificial and natural gravel-retaining structures downstream of dams, can be costly and ineffective over the long term. A more satisfactory alternative is to attempt to maintain natural channel features below dams by managing water releases and sediment in ways that preserve, as much as possible, the predam geomorphic processes (Ligon et al. 1995).




Jones & Stokes

**Figure 1**
**Regional Location**

Photograph 1. Ralston Afterbay Dam and Reservoir

Photograph 2. Indian Bar

SPT operations and placement of sediment on Indian Bar constitute a viable and economic approach for managing sediment at Ralston Afterbay while mitigating for the long-term effects of sediment trapping on aquatic habitat downstream of the dam. The proposed sediment management activities will allow the river to mobilize sediments and carry them downstream as occurred naturally before dam construction. Preliminary analyses indicate that these activities will not cause adverse effects on aquatic resources. For reasons cited above, the reintroduction of sediment below the dam is expected to have beneficial effects on stream habitat and aquatic resources downstream of the dam. Both SPT operations and sediment disposal at Indian Bar are expected to result in relatively small, temporary increases in turbidity and suspended sediment above ambient levels during high flow events. In addition, past analyses and modeling of the hydraulic and sediment transport characteristics of the MFAR indicate that the channel is inherently stable and therefore relatively insensitive to changes in discharge and sediment supply (Harvey pers. comm.).

In 2001, PCWA initiated a monitoring program to test these predictions and ensure compliance of the project with established water quality objectives. The following report presents the monitoring plan and the results of the first year of baseline monitoring activities.

# Purpose and Objectives

The purpose of the monitoring program is to evaluate the potential effects of the Ralston Afterbay Sediment Management Project on water quality, aquatic habitat, and BMI in the MFAR downstream of Ralston Dam. The primary objectives of the monitoring program are to:

- quantitatively evaluate project compliance with the water quality objectives established by the Central Valley Regional Water Quality Control Board (RWQCB) in the Water Quality Control Plan (Basin Plan) (Regional Water Quality Control Board 1998), and
- quantitatively evaluate project effects on aquatic habitat based on changes or trends in streambed and BMI populations downstream of the reservoir (treatment area) relative to changes or trends in unaffected areas (control areas), and

PCWA will use the results of annual monitoring to evaluate project effects and implement appropriate corrective measures if the data indicate that the project is adversely affecting water quality and aquatic resources in the MFAR.

# Project Area

Ralston Afterbay is located at the confluence of the MFAR and Rubicon Rivers at an elevation of approximately 1,200 ft. Indian Bar is located immediately downstream of Ralston Dam. The project area includes the MFAR watershed from French Meadows Reservoir (5,200 ft elevation) to the confluence the NFAR (600 ft elevation), the Rubicon River watershed from Hell Hole Reservoir (4,600 ft elevation) to Ralston Afterbay, and the North Fork of the MFAR watershed from its headwaters (6,000 ft elevation) to its confluence with the MFAR (1,000 ft elevation). The North Fork of the MFAR enters immediately downstream of Ralston Dam and Oxbow Powerhouse (figure 1).

# Climate

The MFAR watershed is dominated by a Mediterranean-like climate (warm, dry summers and cool to cold, wet winters). Air temperatures vary widely during the year and there is no appreciable precipitation in the summer except for scattered thunderstorms. Average annual precipitation in the form of rain and snow ranges from 60 to 65 inches per year with the majority of it falling between November and April (El Dorado National Forest 2001a). A portion of the watershed lies in the transient rain-on-snow zone, which occurs at elevations between 3,500 and 6,000 ft. Areas experiencing rain-on-snow events are considered to have a higher sensitivity to watershed disturbance than areas with rain- or snow-dominated climates (El Ddorado National Forest 2001a and b).

# Geology

The MFAR and North Fork of the MFAR watersheds include 2 different geologic units: the Shoo Fly Complex and the Mehrten formation (California Department of Conservation 1992). The rocks of the Shoo Fly geologic unit, comprising approximately 90% of the watershed, are relatively impermeable (El Dorado National Forest 2001a, b, and c). The Mehrten formation comprises approximately 10% of the watershed.

The Rubicon River watershed includes 5 different geologic units: Paleozoic metasedimentary undifferentiated rocks, the Mehrten formation, Mesozoic granitic rocks, Cretaceous-Jurassic plutonic rocks (gabbro), and glacial moraine deposits (California Department of Conservation 1981 and 1982). Paleozoic metasedimentary undifferentiated rocks, comprising approximately 60% of the watershed, are relatively erodible, and are especially erodible when unvegetated. The Mehrten formation comprises approximately 20% of the watershed. The contact zones between the Mehrten formation and adjacent units are often locations where landslides occur (El Dorado National Forest 2001c). Mesozoic granitic rocks, Cretaceous-Jurassic plutonic rocks, and glacial moraine deposits comprise the remaining 20%.

# Soils

The MFAR and North Fork MFAR watersheds contain a diverse set of soils with 6 different soil map units described. The major soils in the watershed are the Hurlbut, Rock Outcrop, and Deadwood series associated with the Shoo Fly Complex and the Waca, Ledmount, and McCarthy series associated with the Mehrten formation. With the exception of Rock Outcrop, these soils have a moderate to very high erosion hazard, depending on the slope.

The Rubicon River watershed contains 7 different soil map units. Major soils in the watershed are the Hurlbut and Deadwood series associated with the Shoo Fly Complex; the Waca, Ledmount, and McCarthy series associated with the Mehrten formation; and the Chaix and Zeibright series associated with the granitic rocks and glacial deposits. These soils have a moderate to very high erosion hazard, depending on the slope.

# Vegetation

Vegetation within the MFAR, Rubicon River, and North Fork of the MFAR watersheds consists mostly of mixed conifers with true firs at higher elevations. Major species of mixed conifer include ponderosa pine, sugar pine, incense cedar, white fir, Douglas-fir, big leaf maple, California black oak, and interior live oak. Shrub species include deerbrush, mountain whitehorn, Sierra mountain misery, green leaf manzanita, thimble berry, and Sierra currant.

# Hydrology

The MFAR watershed upstream of Ralston Afterbay covers approximately 115 square miles. The nearest U.S. Geological Survey (USGS) flow gage, 10 miles upstream at Interbay Dam, represents flow from 90 square miles of the watershed. Flows in the MFAR are substantially attenuated by upstream reservoir storage facilities, including French Meadows Reservoir. USGS flow records indicate that the average daily flow in the MFAR is about 50 cfs, with a peak flow of 9,990 cfs recorded in 1980 (Hydrosphere Data Products 2000).

The Rubicon River watershed covers about 315 square miles and provides the majority of flow to Ralston Afterbay with an average daily flow of 332 cfs. The unregulated portion of the Rubicon River watershed extends 32 miles upstream to Hell Hole Reservoir. Flows in this reach exhibit large annual and seasonal variation. An historical peak flow of approximately 300,000 cfs occurred when Hell Hole dam failed in December 1964. The North Fork MFAR has an 89-square-mile watershed and enters immediately downstream of Ralston Dam and Oxbow Powerhouse. The North Fork MFAR is unregulated by reservoirs and contributes a substantial amount of flow to the MFAR with an average daily flow of 285 cfs, a 1% exceedance flow of 2,400 cfs, and a peak flow of 30,100 cfs recorded in 1980.

PCWA operates a flow gage on the MFAR immediately downstream of the North Fork MFAR confluence and upstream of Horseshoe Bar. The flow records for this site indicate that the average daily flow is 1,150 cfs and the 1% exceedance flow is 6,900 cfs. The January 1997 storm was considered to generate peak flows in the American River basin and its tributaries that were nearly as large as the projected 100-year flood event; however, peak flows were not recorded for the Rubicon River, North Fork MFAR, or MFAR at the Horseshoe Bar gage. PCWA estimated the peak 1997 flow passing Ralston Dam to be about 100,000 cfs. The highest recorded peak flow at the Horseshoe Bar gage, excluding the peak caused by the December 1964 Hell Hole Dam failure, was 113,000 cfs recorded in 1963.

## Geomorphology

The MFAR, Rubicon River, and North Fork MFAR are characterize primarily by steep, canyon-bound channels with a step-pool morphology. Average stream gradient ranges from <1% in the lower reaches of the MFAR to 2% in the MFAR and Rubicon River above Raslton Afterbay. Sediment transport capacity in these systems generally exceeds sediment supplied by eroded canyon walls and upper portions of the watershed. Consequently, fine sediments are easily transported through the system even during relatively small storm events. The channel bed consists largely of bedrock, boulders, and cobbles. The presence of these larger bed materials indicates that transport of larger material occurs only during large storm events (Bechtel Corporation 1997). The sediment transport and geomorphic characteristics of the MFAR watershed are further described below.

# Sediment Transport and Geomorphic Characteristics of the Middle Fork American River

For large river basins like the MFAR basin, the amount of suspended sediment carried in the river will depend on a number of hydrologic and hydraulic characteristics as well as the source of sediment. Particles larger than 1.0 millimeter (mm) typically travel as bedload sediment close to or on the bottom; particles less than 0.1 mm generally travel suspended in the water as total suspended solids (TSS); particles between 0.1 mm and 1.0 mm may travel as either bedload or TSS. Sediment sources include organic litter on the soil surface, soil erosion, landslides, and other mass wasting of debris, as well as scouring of existing channel substrate. Sediment transport will vary during a storm in relation to rainfall, runoff, and streamflow conditions. As streamflow increases during a storm, the TSS load and associated turbidity carried in the flow will rise and then typically decrease as the storm passes and streamflow starts to recede (Environmental Protection Agency 1991). Bedload sediment may be mobilized and transported only during extremely high and infrequent flows. The MFAR has sufficient gradient and hydraulic energy to transport sediment at a faster rate than the natural rate of sediment input from watershed sources (Harvey pers. comm.). Consequently, there is very little deposition of sediment in the high gradient reaches of the river.

Potential sources of sediment transport to Ralston Afterbay vary in space and time and include the Rubicon Rivers and MFAR, upstream of the reservoir. The project area that may be affected by the proposed project also includes the MFAR downstream of Ralston Dam. Additional sources of sediment to the project area include sediments residing in Ralston Afterbay, the North Fork MFAR, smaller tributaries downstream of the North Fork MFAR, and the downstream slopes of the MFAR canyon. Given the large watershed area and variability in flows and erosion rates, background variation in sediment transport is expected to be large. Bathymetric surveys of Afterbay indicate that about 1,205,000 yds of course and fine sediments currently reside in the reservoir (Bechtel Corporation 1997). The estimated annual rate of accumulation since 1966 was estimated at 56,000 yds annually (EA Engineering, Science, and Technology 1990); however, a more recent evaluation indicates that the annual rate between 1987 and 1995 was only 36,250 yds (Bechtel Corporation 1997). It was presumed that the higher rate in previous years was a result of residual contribution of sediments to MFAR from the 1964 failure of Hell Hole Dam, which released large quantities of sediment to the river (Bechtel Corporation 1997). Current estimates of annual sediment transport in the MFAR downstream of Ralston Afterbay from natural sources are about 11,000 cubic yds of bedload sediment and 18,000 cubic yds of suspended sediment annually (Ayres Associates 1997). Field observations indicate that there is no accumulation of sediment upstream of the tunnel at Horseshoe Bar, suggesting that the existing sediment load passes through the tunnel (Mussetter Engineering 2001).

The quantity of material proposed to be placed at Indian Bar is approximately 75,000 yds. It is unknown how much fine sediment will be transported downstream during SPT operations; however, only about 20% of the total amount of suspended sediment reaching Ralston Afterbay is currently estimated to be deposited in the reservoir (Ayres Associates 1997). Consequently, the amount of sediment affected by the proposed project is a relatively small amount of the total amount transported in the river. Additionally, not all of the sediment stored in Ralston Afterbay or placed at Indian Bar will be transported in any 1 year, so the potential for project-related effects will most likely be further reduced relative to the existing annual sediment transport rates in the river.

The MFAR downstream of Ralston Afterbay is characterized by a steep, canyon-bound channel that is inherently stable and therefore relatively insensitive to changes in discharge and sediment supply (Harvey pers. comm.). In general, the channel form and processes of such rivers are related to infrequent flood events (50-year or greater recurrence interval), structural controls, landslides, human-induced impacts (e.g., hydraulic and placer mining), and discharges that occurred under different climatic regimes. The MFAR exhibits significant bedrock control of channel position, geometry, and gradient. Landslides, rock falls, and tributary-derived debris flows have placed materials with a wide range of sizes in the channel. In addition, mining practices and failure of Hell Hole Dam on the Rubicon River in 1964 (Resource Consultants and Engineers 1993) have modified the terraces and high-elevation boulder bars between Ralston Dam and the North Fork American River (NFAR) confluence.

The MFAR has a step-pool morphology composed of steep, coarse-grained (predominantly bedrock and boulder) reaches interspersed with lower-gradient, alluvial reaches associated with tributary alluvial fans, landslide debris, and bedrock outcrops. These features form localized constrictions that create upstream zones of sediment deposition during flood events. The steeper reaches act as conduits that convey most of the supplied sediment to downstream reaches during floods while the lower-gradient reaches act to temporarily store sediments between flood events. These lower-gradient, alluvial reaches generally exhibit a pool-riffle morphology (alternating pools, riffles, and bars) formed by fine- to coarse-grained alluvial deposits.

# Monitoring Approach

The proposed monitoring approach is based on general principles and design of environmental impact studies (e.g., Bernstein and Zalinski 1983, Green 1979). Potential project effects are evaluated by collecting preproject and postproject water quality, aquatic habitat, and BMI data at monitoring sites located upstream and downstream of Ralston Afterbay. The downstream locations serve as treatment sites (areas potentially affected by the project) and the upstream locations serve as control sites (areas unaffected by the project). In this design, preproject (baseline) monitoring of the parameters of interest is conducted to characterize differences or relationships between the treatment and control sites before the project begins. After the baseline monitoring period, the project is initiated and monitoring will continue to determine whether the differences or relationships between the treatment and control sites significantly change relative to those measured during the baseline period. Such a change will be evidence of a project effect. This is considered an effective design for detecting environmental impacts because it offers, with proper pairing of treatment and control reaches, a means of separating the effect of a given action from other extraneous sources of variation (e.g., climatic factors).

The monitoring plan proposes acquiring a minimum of 1 year of preproject water quality data and 1–2 years of preproject aquatic habitat and BMI data, followed by a minimum of 2–3 years of postproject water quality, aquatic habitat, and BMI data. However, the number and frequency of preproject and postproject monitoring years will be subject to change, depending on the project schedule, the occurrence of SPT-triggering flows, and potential changes in the monitoring program in response to new information. The potential effects of Indian Bar sediment disposal will be monitored concurrently with SPT operations, although the schedule may permit independent evaluations of these 2 activities.

An adaptive monitoring strategy is proposed to address the uncertainties related to the complex behavior of natural river systems. Factors that increase uncertainty and affect the ability of the monitoring program to detect project effects include:

- large natural variability (both spatial and temporal) in water quality, aquatic habitat, and BMI populations and communities;
- lack of sufficient baseline data and limited time frame in which to characterize preproject variability in the monitoring parameters; and
- local variation in flows, sediment loads, and sediment transport capacity that may differentially affect the monitoring parameters in the treatment and control areas.

Detecting the effect of a given management activity on water quality and aquatic habitat requires a demonstration that the change lies outside the normal range of the variable and that the change is attributable to the management activity. Thus, sufficient preproject data are required to adequately characterize preproject conditions and provide a meaningful basis for detecting project effects. In addition, because habitat monitoring stations will be located downstream of the project area and will be influenced by other sediment sources (North Fork MFAR and smaller tributaries), establishing a link between observed changes and the project may be difficult. Accordingly, monitoring data will be analyzed regularly to evaluate the monitoring program and determine whether any modifications can be made to improve its overall effectiveness.

A primary objective in developing the monitoring approach was to maximize the ability of the monitoring program to detect project effects within time and budget constraints. Accordingly, knowledge of hydraulic, sediment transport, and channel characteristics of the MFAR watershed will be used to select monitoring sites that are most sensitive to changes in sediment loads. Concurrent monitoring of several key water quality, aquatic habitat, and BMI parameters will also provide a more comprehensive and reliable indicator of overall trends in sediment and habitat conditions than 1 or 2 parameters alone. To further address uncertainty, the relative effects of the sediment management program will be evaluated in the context of other management activities or disturbances in the watershed. This task will involve continued coordination with federal, state, and local resource agencies to gather and update information on land management activities and watershed events (e.g., fires, landslides) that may significantly affect sediment loads in the MFAR, North Fork MFAR, and Rubicon Rivers.

After project activities begin, evidence for project effects will consist of significant changes (adverse or beneficial) in the relationships or differences between key water quality and aquatic habitat parameters established between treatment and control sites before project activities begin. If these changes constitute an adverse effect on water quality and aquatic habitat conditions downstream of Ralston Dam, the magnitude of these changes will be compared with established water quality and habitat thresholds to evaluate project performance and determine whether corrective actions are warranted. The need for corrective actions will also be based on the results of BMI monitoring, which will serve as a key indicator of the biological effects of observed water quality and habitat changes. In addition, these changes will continue to be evaluated in light of other watershed events and trends that may influence the monitoring results and conclusions.

A current limitation in determining an optimum sampling design and appropriate statistical model for detecting project effects is the lack of sufficient baseline data to adequately characterize natural variability in water quality, aquatic habitat, and BMI communities in the project area. Therefore, as more data become available, the monitoring program will continue to be evaluated to determine whether any changes in the sampling design or methods are warranted to improve the program's ability to achieve the objectives.

# Water Quality and Aquatic Resources Monitoring Plan

## Water Quality Monitoring

### Objectives

The water quality monitoring program is designed to monitor project compliance with the water quality objectives established by the RWQCB in the Water Quality Control Plan (Basin Plan) (Regional Water Quality Control Board 1998). The Basin Plan objectives constitute allowable changes in water quality from project-related disturbances. Therefore, the main objectives of the monitoring program include quantifying water quality differences between sampling stations located upstream and downstream of Ralston Afterbay and ensuring that project-related changes in TSS and turbidity do not exceed the applicable Basin Plan water quality objectives. The water quality monitoring program will be most useful for evaluating project-related effects from SPT operations. SPT operations have a greater likelihood of affecting fine sediment transport that travels as suspended material because coarse material settles out at the upper end of the reservoir. Placement of reservoir sediments at Indian Bar is presumed to have little effect on background concentrations of suspended sediment because excavated reservoir sediments will consist mostly of coarse material that will be transported as bedload. The effects of the project on the coarser material traveling as bedload sediment will be addressed by the habitat monitoring program.

The RWQCB Basin Plan includes numerical water quality objectives for turbidity; however, there are no numerical standards for TSS. The narrative water quality objective for suspended sediment states that the load and discharge rate shall not be altered in such a manner as to cause nuisance or adversely affect beneficial uses. The turbidity water quality objectives vary in relation to the background levels as follows:

- where natural turbidity is between 5 and 50 nephelometric turbidity units (NTUs), increases shall not exceed 20%;
- where natural turbidity is between 50 and 100 NTUs, increases shall not exceed 10 NTUs; and

- where natural turbidity is greater than 100 NTUs, increases shall not exceed 10%.

These objectives will serve as thresholds for evaluating project performance. Accordingly, the water quality monitoring results will be used to test the following null hypotheses.

- **$H_0$:** During SPT operations, increases in turbidity downstream of Ralston Dam do not exceed 20% of ambient levels when natural turbidity is between 5 and 50 NTUs.
- **$H_0$:** During SPT operations, increases in turbidity downstream of Ralston Dam do not exceed 10 NTUs of ambient levels when natural turbidity is between 50 and 100 NTUs.
- **$H_0$:** During SPT operations, increases in turbidity downstream of Ralston Dam do not exceed 10% of ambient levels when natural turbidity is greater than 100 NTUs.

Based on limited TSS data available for the MFAR, background conditions may vary considerably during storm events and all 3 ranges of the numerical turbidity objectives may apply to the proposed project. Preproject monitoring will be conducted to establish this range and determine the relationship between turbidity and TSS at stations upstream and downstream of Ralston Afterbay.

# Monitoring Parameters

Turbidity levels are generally correlated to the TSS concentrations, typically accounting for roughly 80% of the variability observed in simultaneous TSS measurements (Environmental Protection Agency 1991). The relationship between turbidity and TSS values is not typically linear and must be determined on a site-specific basis because the relationship can vary as a result of storm size, water color, organic matter, and algae growth. Collecting TSS samples that accurately represent average river conditions depends on hydraulic characteristics such as current patterns, flow velocity, and eddies. A composite sample collected over vertical and lateral intervals in the channel will typically provide a better representation of the average river TSS concentration than a single sample (Environmental Protection Agency 1985).

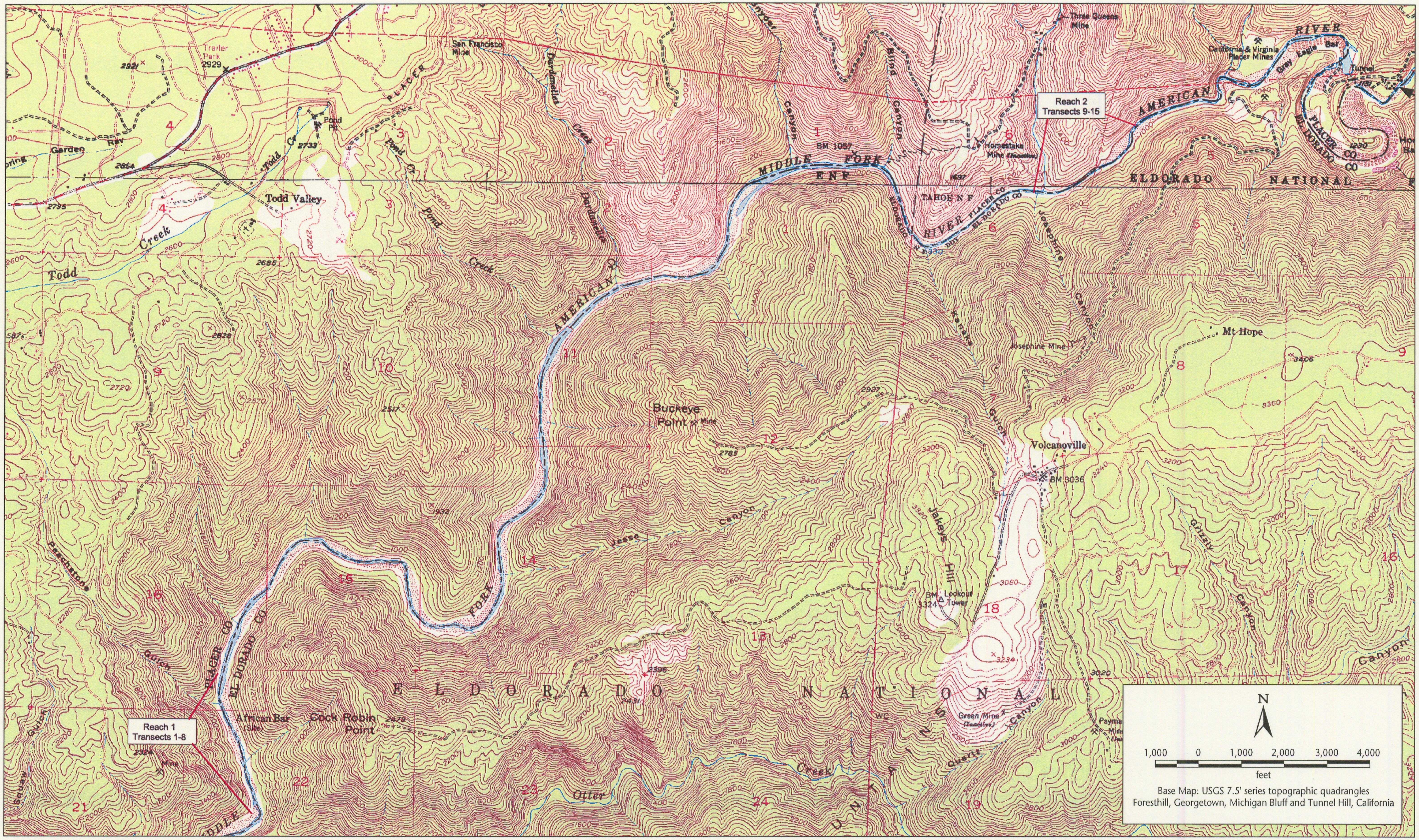
Turbidity measurements are less sensitive to the sampling location because turbidity is primarily a function of finer materials (silt and clay) that are more readily held in suspension and evenly distributed throughout the water. The time required to transport samples to a lab and conduct the analytical procedures for TSS effectively precludes its use as a real-time monitoring tool. Given the practical limitations of TSS sampling methods, need for correlation analysis with turbidity, and lack of regulatory objectives, this monitoring program will be focused on intensive automated turbidity monitoring; TSS data will be collected on a supplemental basis. The site-specific relationship between turbidity and TSS will be determined after sufficient monitoring data have been collected.

Few water quality data are available for the MFAR downstream of Ralston Dam. Simultaneous grab sample data for TSS are available from the MFAR at Foresthill and Auburn (47 miles downstream) for 25 scattered dates, collected during high flow periods between the years 1956 and 1962 (EarthInfo 1993). Other scattered grab samples are available up to 1985. Given that flow and TSS data are available for a variety of years with differing precipitation patterns, the available data may provide a reasonable estimate of the range of conditions that will be observed under current conditions and when the proposed project is implemented. The data represent sediment transport that is affected by several primary watersheds within the project area, including the Rubicon River (315 square miles), MFAR above Ralston Afterbay (94 square miles), and NMFAR (89 square miles) watersheds. Streamflow and TSS values at Foresthill and Auburn are reasonably correlated with each other (figure 2). TSS values range up to a maximum of about 120 milligrams per liter (mg/l), and values at Auburn are generally lower than at Foresthill. Table 1 presents descriptive statistics for TSS data from all MFAR sample dates. The maximum value recorded at Foresthill and Auburn of 397 mg/l and 537 mg/l, respectively, are considerably larger than the paired data in figure 2. The coefficient of variation (i.e., standard deviation/mean) is large and indicates that variability in the values is high.

**Table 1.** Summary Descriptive Statistics for TSS Data in MFAR

| Statistic | MFAR at Foresthill (mg/l) | MFAR at Auburn (mg/l) |
|---|---|---|
| Mean | 54.6 | 45.6 |
| Median | 30.0 | 12.0 |
| Standard deviation | 71.3 | 85.5 |
| Minimum | 2 | 1 |
| Maximum | 367 | 537 |
| 95% confidence interval of mean | ± 25.3 | ± 19.7 |
| Sample Size | 33 | 75 |

Real-time automated turbidity monitoring data will serve as the primary tool for evaluating water quality conditions during SPT operations. Appropriate numerical turbidity objectives for long-term evaluation of water quality conditions during SPT were estimated from the variability in existing TSS data for the MFAR. Numerical data quality objectives are generally stated in terms of a specific level of precision and confidence that is desired in the collected data. Based on the Basin Plan objectives for allowable project-related increases in turbidity and lack of existing turbidity values for the MFAR, the monitoring program may need to be able to detect differences between upstream and downstream samples as low as 5 NTUs. Consequently, turbidity monitoring is designed to produce data capable of detecting differences of 5 NTUs with a 95% confidence level. Data will be collected that are sufficient to identify differences in TSS with a precision of 30 mg/l at a 95% confidence interval. Approximately

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Jones & Stokes

Figure 2
Aquatic Habitat/Benthic Macroinvertebrate Monitoring Sites in Reaches 1 and 2

70–100 samples per year for the range of flows shown in table 1 may be needed to detect significant annual differences between upstream and downstream samples at this recommended level of precision.

# Sampling Design

Table 2 presents sampling locations and protocols for the water quality monitoring program, including collection schedule and sampling methods. Figure 1 shows the location of the water quality monitoring stations. It is hypothesized that during SPT operations, water quality conditions will not differ appreciably between upstream and downstream monitoring stations. Therefore, this monitoring program is designed to evaluate the proposed sediment management activities and ensure that adverse water quality effects do not occur. An initial 3-year monitoring period is recommended, consisting of 1 year of preproject monitoring followed by 2 years of monitoring to evaluate the water quality effects of SPT operations. The need for follow-on monitoring after year 3 will be evaluated after the initial data are collected and evaluated. Preproject monitoring data will be used to develop relationships between turbidity and TSS concentrations at stations upstream and downstream of Ralston Afterbay.

To obtain as many data values as possible during storm events and SPT operations, turbidity will be monitored on a real-time basis with automated sensors that can collect data at any desired time interval and relay the data by telemetry to the Ralston Powerhouse and PCWA's Foresthill office. Two sampling locations were selected for installation of automated turbidity monitoring probes to provide the primary compliance monitoring data. The Rubicon River, approximately 200 feet upstream from the Ralston Powerhouse (which is generally discharging about 1,000 cfs to the river), will serve as the primary upstream sample site. The Rubicon River has the largest contributing watershed and generates most of the sediment input to the reservoir (Bechtel Corporation 1997). PCWA's river-gaging station immediately upstream of Horseshoe Bar will serve as the principal downstream compliance monitoring location. The Horseshoe Bar gaging station records river stage and has a telemetry unit with radio link to Ralston Powerhouse. The gage can also be monitored from PCWA's Foresthill office.

Supplemental grab samples will be collected for both turbidity and TSS in the MFAR upstream of Ralston Afterbay at the bridge crossing, MFAR bridge crossing, and in the MFAR between Ralston Dam and the Oxbow Powerhouse tailrace. Samples for TSS will be collected manually by field personnel. Grab sample locations will serve as additional indicators of water quality conditions during the initial years of monitoring and allow site-specific correlation between turbidity and TSS values.

**Table 2.** Summary of Water Quality Monitoring Locations, Schedule, and Methods

| Monitoring Locations | Schedule of Sampling Activities | Constituents Monitored & Frequency of Activity | | |
|---|---|---|---|---|
| | | Total Suspended Solids (Grab Samples Only [1]) | Turbidity | |
| | | | Grab Samples [1] | Automated [2] |
| Rubicon River Upstream from Ralston Powerhouse | Year 1 preproject monitoring | X | | X |
| | Years 2 & 3 monitoring | X | | X |
| | After year 3 follow-on monitoring | X (as needed) | | X (as needed) |
| MFAR Upstream from reservoir at bridge | Year 1 preproject monitoring | X | X | |
| | Years 2 & 3 monitoring | X (as needed) | X (as needed) | |
| MFAR Upstream from Oxbow Powerhouse tailrace | Year 1 preproject monitoring | X | X | |
| | Years 2 & 3 monitoring | X (as needed) | X (as needed) | |
| North Fork of the MFAR at bridge | Year 1 preproject monitoring | X | X | |
| | Years 2 & 3 monitoring | X (as needed) | X (as needed) | |
| MFAR at Downstream gage house | Year 1 preproject monitoring | X | | X |
| | Years 2 & 3 monitoring | X | | X |
| | After year 3 follow-on monitoring | X (as needed) | | X (as needed) |

[1] Grab samples for turbidity and total suspended solids (TSS) will be collected at a minimum of 4-hour intervals during storm events when water level is rising and starting when streamflow is 3,000 cfs or greater. Sampling should be targeted to include sufficient storm events that provide data from as wide a range of high streamflows as possible. Sampling in successive years should be targeted at storm events that generate flow conditions similar to those sampled during the pre-project monitoring.

[2] Automated turbidity probe and telemetry system can be adjusted as needed based on available battery power. Data will be monitored during storm events and downloaded by telemetry at a minimum of 4-hour intervals. Turbidity recorders need be used only during storm events and at a frequency sufficient to generate at least 70 samples per year. Sampling should be targeted to include sufficient storm events that provide data from as wide a range of streamflows in excess of 3,000 cfs as possible. Sampling in successive years should be targeted at storm events that generate similar flow conditions similar to those sampled during the pre-project monitoring.

If the initial monitoring data indicate that turbidity and TSS data are closely correlated and turbidity measurements are effective for monitoring compliance of SPT operations, compliance monitoring for TSS will be discontinued and the real-time turbidity data will be used as the primary indicator for SPT operations compliance. The TSS data will be used primarily for long-term evaluation of SPT operations and for additional confirmation of real-time water quality conditions as indicated with the automated turbidity sensors.

SPT operations will commence when river flows exceed 3,500 cfs. Therefore, preproject monitoring of turbidity and TSS will be conducted when storms generate river flow rates that exceed 3,000 cfs. Preproject data for low flow events will not be conducted because natural variability in TSS and turbidity will be much lower and not representative of conditions during SPT operations. Both automated turbidity and grab sample data will be collected at a minimum of 4-hour intervals during storm events commencing when streamflows begin to rise and ceasing when the hydrograph has begun to recede or SPT operations are discontinued, whichever occurs first. The trigger for commencing sample collection can be water level in the reservoir or flow at the Horseshoe Bar gage. An additional automated water level recorder is recommended for the Rubicon River site to determine when streamflow starts to increase during storm events and provide time to prepare for the necessary manual sampling activities. This gage does not have to be an approved USGS-type stilling well. The system can be a simple enclosure with a pressure transducer for monitoring water level. A flow-rating curve does not need to be calculated. For monitored storm-flow events, sampling should be targeted to include data from as wide a range of streamflows as possible that exceed 3,000 cfs. Sampling in successive years should be targeted to storm events that generate flow conditions similar to those sampled during the preproject monitoring.

During SPT operations, PCWA staff will monitor the real-time upstream and downstream turbidity monitoring data to evaluate compliance of operations with Basin Plan water quality objectives. All grab sample data collected at field sites will be recorded on a field data form. TSS and turbidity samples will be collected by hand using an appropriate bottle sampling device (e.g., Van Dorn, Kemmerer). Sample bottles will be specified by the laboratory performing the analyses. Samples will be analyzed to provide the lowest practical detection limit for TSS (less than or equal to 5 mg/l) and turbidity (less than or equal to 1 NTU). Field samples will be refrigerated for sample preservation and shipped to a commercial laboratory after each sampling event. A field blank of deionized water and field duplicate samples should be collected once for every 20 samples, with a minimum of 1 replicate per storm event. Automated turbidity probes installed at the Rubicon River and Horseshoe Bar sites will have a minimum detection limit of 1% of full-scale reading. The probe should be capable of measuring a range of turbidity measurements up to 500 NTU.

# Data Analysis

Standard data control charting methods will be used to identify the rate and direction of change in real-time turbidity concentrations in the river and detect significant excursions from the Basin Plan water quality objectives. Supplemental information regarding TSS concentration conditions will be evaluated from the grab sample data. The long-term performance of SPT operations with respect to water quality objectives will be evaluated with standard statistical testing of the mean differences between preproject and postproject conditions. Linear regression analysis will also be used for year-to-year evaluations of project-related effects on water quality based on the relationship between values collected at the primary upstream and downstream sample sites. If routine patterns of turbidity and TSS in the tributary streams are constant over the duration of the monitoring program, regression analysis will allow the detection of changes between the Rubicon and the Horseshoe Bar gaging site attributable to the project without explicitly evaluating changes in the tributaries. Consequently, until the initial data collected from the tributaries prove otherwise, it is assumed that the automated turbidity data will be sufficient to establish a statistically significant relationship reflecting differences in water quality conditions between the upstream and downstream sites.

Following collection of the first year of pre-project data, results will be evaluated for statistical variability in turbidity and TSS concentrations. Descriptive and exploratory analysis of the data will be necessary to ensure that the proper statistical tools are applied to the analyses. Issues that may need to be addressed include transformation of data to approximate a normal data distribution and evaluation for autocorrelation among the data points. The estimated number of samples necessary to achieve the desired data quality objectives will be confirmed. Following the second and third years of data collection, means testing and linear regression analysis of turbidity and TSS data will be conducted to identify the differences between preproject and postproject data and the statistical significance of the differences. Adjustments to the data based on related variables such as background TSS and turbidity concentrations or streamflow may be used to improve the sensitivity of the data analyses.

The procedures for determining water quality conditions necessitating corrective actions will be defined in advance in coordination with RWQCB and California Department of Fish and Game (DFG). When the data indicate that downstream turbidity values exceed the water quality objectives, possible corrective actions may include immediately taking additional samples for both turbidity and TSS to provide additional data on the water quality conditions. If SPT operations are presumed to be causing a water quality compliance problem, other possible corrective actions may include reducing the flow through the gates, increasing flow through the spillway gates, or both. As a final action, the low level outlet gate may be closed to cease SPT until more favorable conditions occur. The procedure for ceasing and restarting SPT operations will also be defined before starting SPT.

Two issues described below merit consideration when interpreting project-related water quality monitoring data for SPT operations and to avoid taking corrective actions when they are not necessarily warranted: (a) evaluating effects of water residence time in the reservoir at varying levels of streamflow; and, (b) evaluating the direction of change in turbidity and TSS concentrations.

- **Hydraulic residence time:** Based on the volume of the reservoir, the residence time of a slug of water passing from the upper end of the reservoir to the downstream end will be short at high flows (approximately 40 minutes at 50,000 cfs) and samples collected simultaneously at upstream and downstream locations will presumably be adequately comparable to each other. When SPT operations first begin at a flow of 3,500 cfs, however, the residence time will be approximately 10 hours. TSS values typically rise and fall in correlation with streamflow. Therefore, it is likely that when upstream turbidity concentrations start to decrease as the stormflows recede, simultaneous measurement made downstream may indicate continued increasing concentrations and regulatory exceedances because of the time delay of previously high turbidity water moving downstream. In order to account for water residence time in the reservoir, data charting procedures should account for the time delay at varying flow rates to establish whether an exceedance in the thresholds is truly occurring. The transport time can be reasonably predicted with empirical calculations from bathymetric profile data of the reservoir. In addition, dye tracer tests can be conducted to more accurately characterize flow through the reservoir. The need for dye tracing will be evaluated after the first year of monitoring to determine whether such precision is necessary for the program.
- **Direction of changes in monitored constituents:** As noted above, TSS will typically rise and fall with the streamflow pattern. Following the passage of peak flows and corresponding TSS and turbidity transport during storm events, high variability in upstream and downstream TSS and turbidity may continue despite an overall decreasing trend in their values. Consequently, the absolute differences between upstream and downstream values during the receding period of a storm event may exceed the numerical water quality objectives. Compliance evaluations should account for whether the concentrations at upstream and downstream locations are rising or falling when interpreting the data with respect to this criteria. If concentrations are decreasing overall, yet downstream values are higher, it will indicate that the flush of sediment resulting from initial mobilization and transport is nearing completion. Concentrations at this point in the storm may be relatively low compared to the higher peak values occurring earlier in the storm and should not constitute a violation of the water quality objectives.

# Aquatic Habitat Monitoring

## Objectives

The primary objective of aquatic habitat monitoring is to quantitatively evaluate project effects on aquatic habitat based on changes or trends in key substrate and BMI parameters upstream and downstream of Ralston Afterbay. The results will be used to test the following null hypothesis:

- **$H_0$:** Differences in streambed conditions between the treatment and control reaches during preproject years do not change during postproject years.

Alternatively, this hypothesis may be stated as follows:

- **$H_0$:** The relationship between streambed conditions in the treatment and control reaches during preproject years does not change during postproject years.

Rejection of either hypothesis will be evidence of significant project effects (adverse or beneficial). The biological significance of these changes will be evaluated based on the general trout- and BMI-substrate relationships and observed changes in BMI population or community attributes measured in the treatment and control reaches.

Stream and laboratory studies have shown that excessive amounts of fine sediments can adversely affect aquatic habitat and the capacity of that habitat to support trout and aquatic invertebrates. Although the results vary with species, life stage, and season, significant declines in fish and aquatic invertebrates were generally associated with riffles in which 50% or more of the coarse particles (gravels and larger materials) were covered or surrounded by fine sediment (embeddedness). This level will serve as a preliminary threshold for evaluating habitat quality during the preproject monitoring period. Additional years of preproject data will be necessary to adequately characterize annual variation in substrate conditions and establish an impact threshold (i.e., change in substrate conditions) that would trigger the need for corrective actions. This impact threshold will also be based on the results of BMI monitoring and any observed relationships between the BMI parameters and substrate conditions during the preproject monitoring period.

The BMI monitoring data will indicate seasonal and annual patterns of abundance, composition, and diversity associated with the ecology and natural history of BMI communities. These patterns will be compared from year to year to detect any change or shift that would indicate a response to an environmental change. More importantly, BMI monitoring will be useful in evaluating the biological effects (beneficial or adverse) of any changes in water quality and substrate conditions observed during the monitoring program.

## Monitoring Parameters

Substrate size composition and embeddedness will be used as key monitoring parameters for assessing project effects on aquatic habitat. These parameters were selected because they are sensitive indicators of changes in sediment loads, can be rapidly measured in the field, and provide a direct or indirect measure of factors known to affect the abundance and production of fish and invertebrates in streams.

The size composition of streambed substrates is a major factor determining the quality of stream habitat for trout and aquatic invertebrates. Changes in substrate size can affect the productive capacity of trout streams by affecting the suitability of substrate for spawning, the availability of suitable cover and shelter for juvenile and adult trout, and the amount of living space for aquatic invertebrates (Waters 1995, Bjornn and Reiser 1991). Bain (1999) described a rapid field technique for quantifying stream substrate for aquatic habitat assessment. This technique provides measures of substrate coarseness and heterogeneity, both of which are important indicators of habitat quality in trout streams. Monitoring of these parameters in combination with embeddedness and BMI monitoring will be used to assess the significance of potential trends in streambed characteristics.

Embeddedness is the percentage to which coarse sediments (gravel and larger particles) are surrounded or covered by fine sediment (silt/clay and sand). This parameter provides a measure of the amount of interstitial space between coarse sediments and thus reflects the suitability of the streambed for incubation, emergence, and overwintering of trout, and the amount of living space for BMI. Excessive amounts of fine sediments and embeddedness have been shown to affect the abundance of juvenile salmonids and aquatic invertebrates in laboratory and natural streams (Hillman et al. 1987, Bustard and Narver 1975, Bjornn et al. 1977). Although the results vary depending on species, life stage, and season, a general observation was that significant declines in fish and invertebrate abundance were generally associated with embeddedness levels of 50% or more.

# Sampling Design

Because of the high degree of spatial and temporal variability in habitat conditions in natural river systems, several criteria were developed to guide selection of monitoring sites. These criteria were based on the need to minimize differences between treatment and control sites, increase sampling efficiency, and maximize the ability of the monitoring program to detect potential project effects. Foremost among these criteria is the need for all monitoring sites, especially those that serve as primary treatment and control reaches, to be equally sensitive to changes in sediment loads and respond similarly to these changes. Second, monitoring sites should have similar channel and substrate characteristics that provide important aquatic habitat for trout and aquatic invertebrates. Third, monitoring sites should be located as close as possible to Ralston Afterbay to reduce the confounding effects of other sediment sources (e.g., tributaries). Finally, as a practical consideration, all sites should be accessible and provide safe conditions for field measurements.

Based on the hydraulic and sediment transport characteristics of the river, these criteria appear to best be met by localized alluvial portions of the river where sediment deposition occurs in response to local channel and valley constrictions that include tributary alluvial fans, landslide debris, and bedrock constrictions (Mussetter Engineering 2001). Mussetter Engineering identified 5 such reaches between the Ralston Dam and the North Fork of the American River confluence (table 3).

Before selecting monitoring sites, a Jones & Stokes fisheries biologist will conduct an aerial survey of the MFAR by helicopter to examine the 5 reaches identified by Mussetter Engineering and identify other potential treatment and control reaches upstream and downstream of Ralston Afterbay. The aerial survey will include the first 5 miles of the MFAR and Rubicon River upstream of Ralston Afterbay, the MFAR from Ralston Dam to Louisiana Bar, and the lowermost 5 miles of the North Fork MFAR. The goal of this initial survey is to evaluate the suitability of potential treatment and control reaches based on the criteria presented above. Preference will be given to those reaches that are closest to the project area and are reasonably accessible by foot. All potential monitoring reaches will be delineated on 7.5-minute topographic maps. Photographs will be taken of representative portions of the potential monitoring reaches.

**Table 3**. Locations and Characteristics of Hydraulic Controls for Sediment Transport in the Middle Fork of the American River

| Location | River Mile | Comments |
|---|---|---|
| Louisiana Bar | 50.4 | Pool and riffle upstream of bedrock control; road accessible |
| Mammoth Bar | 52.4 | Pool and riffle upstream of bedrock constriction at Murderer's Gulch; road accessible |
| Cherokee Bar | 59.0 | Head of alluvial reach that extends from Greenwood Bridge to Mammoth Bar; pools and riffles; road accessible |
| Canyon Creek | 61.44 | Pool formed by alluvial fan constriction and backwater from Ruck-A-Chucky landslide; not road accessible but can be reached by track in about 20 minutes |
| Other sites: | | |
| Otter Creek | 64.65 | Pools and riffles upstream of alluvial fan-induced contractions; neither site is readily accessible but they are closer to Ralston Dam. |
| Volcano Creek | 71.4 | |

Note: River mile 50.37 is the confluence with the North Fork of the American River.

Table 4 presents the proposed locations and schedule for aquatic habitat and BMI monitoring. Two reaches will be established immediately downstream of Ralston Afterbay between the dam and the confluence of the North Fork MFAR and between the confluence of the North Form MFAR and Horseshoe Bar. These reaches will be used primarily to evaluate changes in substrate composition associated with coarse sediment input from the Indian Bar disposal site. One or more treatment reaches will be established on the MFAR downstream of Horseshoe Bar to evaluate potential changes in fine and coarse sediment associated with SPT operations and Indian Bar sediment disposal. One or more control areas will be established on the Rubicon River upstream of Ralston Afterbay, the MFAR upstream of the reservoir, and on the North Fork MFAR.

Following selection of monitoring reaches, ground surveys will be conducted to more closely examine the reaches and identify specific habitats that meet the selection criteria above. Riffles will likely be key habitats because they are considered relatively sensitive indicators of bed conditions, provide important habitat for trout and invertebrates, and allow safe conditions for collecting substrate data across the entire channel.

Up to 10 substrate sampling sites (e.g., riffles) will be established in each monitoring reach, depending on variability in substrate conditions. Monitoring sites will be selected randomly or by selecting the first site randomly and selecting all subsequent sites at regular intervals (e.g., every third riffle upstream or downstream of the first).

Aerial surveys and monitoring site selection were conducted in the first year of preproject monitoring. Substrate sampling was conducted in the first year of preproject monitoring and will be conducted in subsequent preproject and postproject years. Because substrate conditions are not expected to change significantly after winter and spring storm events, substrate sampling will be conducted once a year during the summer or fall when flows are low enough to permit sampling. Sampling will be conducted at the same time each year to minimize the effects of possible seasonal changes in fine sediments.

Preproject monitoring should begin as soon as possible and be conducted in selected years during the preproject monitoring period to characterize baseline variation in substrate conditions among and within reaches. Ideally, preproject data should include measurements of streambed conditions following flow events equal in magnitude and duration to those that will trigger SPT operations. A minimum of 2–3 years of preproject monitoring may be necessary to provide a meaningful basis for evaluating potential changes in substrate conditions during postproject years.

Monitoring of project effects should be conducted in the first year after initiation of SPT operations and in subsequent years following the occurrence of each SPT event. A minimum of 2–3 years of postproject monitoring is recommended. Because SPT operations will probably not occur every year, it may be necessary to wait several years to complete the postproject monitoring. Additional monitoring during the intervening years may be warranted to further characterize the relationship between substrate conditions in the treatment and control reaches. Monitoring of the potential effects of sediment disposal at Indian Bar will be conducted concurrently with SPT monitoring.

**Table 4.** Summary of Aquatic Habitat and BMI Monitoring Locations, Activities, and Schedules

| Monitoring Reach | Purpose | Aerial Survey and Monitoring Reach Selection | Monitoring Site Selection | Field Measurements |
|---|---|---|---|---|
| Rubicon River upstream of Ralston Powerhouse | Control for SPT operations | Conduct in first year of preproject monitoring period and in subsequent years only if warranted | Conduct in first year of preproject monitoring period and in subsequent years only if warranted | Sample in 2-3 preproject years and 2-3 postproject years following each occurrence of SPT operations. Schedule subject to change depending on project schedule, the occurrence of SPT-triggering flows, and adaptive monitoring |
| MFAR upstream of Ralston Afterbay | Control for SPT operations | | | |
| MFAR between Ralston Dam and North Fork of the MFAR | Treatment for Indian Bar sediment disposal | | | |
| MFAR between North Fork of the MFAR and Horseshoe Bar | Treatment for SPT operations and Indian Bar sediment disposal | | | |
| North Fork of the MFAR | Control for SPT operations and Indian Bar sediment disposal | | | |
| MFAR downstream of Horseshoe Bar | Treatment for SPT operations and Indian Bar sediment disposal | | | |

Field measurements of substrate composition and embeddedness will follow the methods described by Bain (1999). The location of each transect will be marked with paint and flagging above the high-water mark. Cloth or metal measuring tapes will be suspended above the wetted channel (perpendicular to the channel) between 2 metal stakes secured at the edge of the low-flow channel. Substrate composition will be measured with a 1-meter (m) metal ruler, divided into ten 10-centimeter (cm) sections painted contrasting colors. The first sampling location along each transect will be selected randomly and subsequent locations selected at regular intervals from the first. Sampling locations will be separated by at least 1 m. A maximum of 15 sampling locations will be evenly distributed across the transect, depending on channel width.

At each sampling location, the ruler will be lowered across the stream substrate (perpendicular to the current) and the dominant substrate class under each 10-cm segment will be recorded using the modified Wentworth scale (table 5).

**Table 5.** Modified Wentworth Classification of Substrate Types by Size

| Substrate Type | Particle Size Range (millimeters) | Code |
|---|---|---|
| Silt and clay | <0.059 | 0 |
| Sand | 0.06–1 | 1 |
| Gravel | 2-15 | 2 |
| Pebble | 16-63 | 3 |
| Cobble | 64–256 | 4 |
| Boulder | >256 | 5 |

Embeddedness was visually determined at each transect by examining the coarse sediments (gravel, pebble, cobble, boulder) in the deepest portion of the channel and recording the dominant level of embeddedness (table 6).

**Table 6.** Embeddedness Rating for Stream Channel Materials*

| Level of Embeddedness | Description | Code |
|---|---|---|
| Negligible | Gravel, pebble, cobble, and boulder particles have <5% of their surface covered by sediment. | 0 |
| Low | Gravel, pebble, cobble, and boulder particles have 5-25% of their surface covered by sediment. | 1 |
| Moderate | Gravel, pebble, cobble, and boulder particles have 25–35% of their surface covered by sediment. | 2 |
| High | Gravel, cobble, and boulder particles have 50–75% of their surface covered by sediment. | 3 |
| Very High | Gravel, pebble, cobble, and boulder particles have >75% of their surface covered by sediment. | 4 |

* Fine sediment includes materials less than 2 mm in diameter: sand, silt, and clay.

# Data Analysis

Substrate composition and embeddedness data will be analyzed quantitatively using statistical techniques developed for control-treatment designs (e.g., Bernstein and Zalinski 1983). As discussed earlier, the applicability of the proposed design depends on proper pairing of the treatment and control reaches and sufficient preproject data to characterize the differences or relationship between streambed conditions in these reaches. Alternatively, the data can be analyzed graphically using descriptive statistics (e.g., means, confidence intervals) and/or regression techniques to characterize trends in streambed parameters over time (e.g., Adams and Beschta 1980).

Because the sampling design may not be able to effectively discern project effects from those of other sediment sources in the MFAR watershed, it will be necessary to complement the monitoring program with additional information to assess the relative magnitude of effects related to SPT and other sources. For example, bathymetric surveys of Ralston Afterbay before and after SPT operations will provide valuable information on the preproject and postproject quantities of fine sediment in the reservoir. In the event that a large amount of sedimentation is detected downstream of Ralston Dam, bathymetric surveys will provide a measure of net changes in reservoir sediment conditions, which will help assess the extent to which SPT operations contributed to the supply of fine sediment. The data then may help in the assessment of whether any net contribution to fine sediment supply in the river is attributable to the reservoir. Other sources of information include ongoing watershed monitoring programs and assessments being conducted by the U.S. Forest Service (Forest Service), U.S. Geological Survey, and other federal and state agencies responsible for resource and land management in the MFAR, Rubicon, and North Fork MFAR watersheds.

In addition, annual reports, maps, and interviews with resource managers will be used to monitor the occurrences of major events (e.g., fires, landslides, intense land use activities) that could influence erosion and sedimentation processes in these watersheds. This information will be used to further evaluate the relative effects of these sediment sources on habitat conditions in the monitoring reaches. The interpretation of monitoring results will also include an analysis of hydrologic parameters that may differentially affect geomorphic conditions in the monitoring reaches from year to year.

# Benthic Macroinvertebrate Monitoring

## Objectives

The primary objective of BMI monitoring is to provide biological indicators of aquatic habitat health and functionality to be used in conjunction with the water quality and substrate data to evaluate potential project effects on aquatic habitat. Quantitative bioassessment based on BMI was developed by the Environmental Protection Agency as a tool for monitoring and assessing the impacts of watershed management activities on water quality, fish, and stream productivity. Quantitative bioassessment has become the legal standard in most states for mitigation and restoration projects. Justifications for the use of BMI as indicators of water and habitat quality have been described by Hutchinson (1993), Resh and Jackson (1993), Rosenburg and Resh (1993), and others. Additional advantages of BMI-based biological assessment include long storage life for preserved samples and the establishment of BMI voucher collections. Voucher collections may be evaluated by other investigators and serve as a source of information for taxonomists and resource managers.

# Monitoring Parameters

The following parameters will be used to monitor the overall health and functionality of aquatic habitat in the treatment and control reaches during preproject and postproject periods.

## Invertebrate Density

Invertebrate density is the number of individual invertebrates per square meter. This is a measure of overall habitat utilization by BMI, as well as a measure of forage available to fish. Typically, BMI density remains fairly stable. Sudden BMI density fluctuations are indicative of impacts on habitats and water quality. Disturbed systems also may exhibit high BMI densities attributed mainly to opportunistic species. Some opportunistic species include Philippine clam, some crawdad species, chironomid midges (e.g., Chironomus), culicids, and some worms.

## Taxa Richness

Taxa richness is the total number of individual taxa and is used as a means of determining the overall health of an aquatic habitat (Plafkin et al. 1989). In general, the higher the water quality, habitat suitability, and variety, the higher the taxa richness. Similarly, sudden drops in taxa richness will indicate a negative impact within the system.

## BMI Productivity

BMI productivity is defined as the grams of living invertebrates per square meter within the study area. This measurement yields the biomass per unit area that the habitat is able to support. Diverse, highly functional habitats typically produce higher biomass than is produced by impaired systems. Alternately, disturbed systems that are overrun by opportunistic species may have abnormally high biomass.

## Ephemeroptera, Plecoptera, Trichoptera Ratios

By measuring the abundance of invertebrate families most sensitive to changes in water quality and habitat suitability, the relative habitat health can be examined. The Ephemeroptera, Plecoptera, Trichoptera (EPT) index examines nymphal Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies), which as a group are generally considered to be pollution sensitive. The abundance index of these families increases with increasing water quality (Plafkin et al. 1989).

## Jaccard Coefficient of Community Similarity

Jaccard Coefficient of Community Similarity and Community Loss indices (Barbour et.al. 1999) will be used to determine similarities between the treatment and control reaches and between preproject and postproject years.

$$\text{Jaccard Coefficient of Community Similarity} = \frac{\text{\# of taxa common to both samples}}{\text{\# of taxa in both samples}}$$

The Jaccard Coefficient of Community Similarity estimates the degree of similarity between samples, based on presence or absence of taxa. The coefficient values range from 0 to 1.0. The higher the coefficient, the greater the similarity between the samples.

## Community Loss Index

The Community Loss index estimates the loss of taxa between comparison samples and reference samples.

$$\text{Community Loss} = \frac{[\text{\# of taxa in reference sample}] - [\text{\# of taxa common to both samples}]}{\text{\# of taxa in comparative sample}}$$

The index identifies the differences in sample composition. The higher the index value, the greater the dissimilarity between the comparison sample and the reference sample.

BMI populations will be sampled in the same monitoring reaches and the same years as aquatic habitat monitoring (table 4). Samples will be collected in the late spring (June), midsummer (August), and fall (October). Sampling 3 times per year is a standard protocol to adequately characterize seasonal changes and assess potential seasonal impacts on species and life stage composition of BMI communities. Littoral sampling from Ralston Afterbay will not be necessary because the water in the reservoir fluctuates sufficiently during normal yearly maintenance practices to limit colonization of the littoral zone by BMI.

A standard kick seine will be used to sample BMI at 3 locations along selected transects. These locations were selected to provide samples from a representative range of velocities along each transect. A kick is accomplished by placing the kick net in a stationary position and disturbing 0.33 square meter of substrate immediately upstream of the net. Large cobble and boulders will be dislodged and cleaned by hand to remove attached organisms. Sand, gravel, and pebble substrates will be disturbed by hand and with the toe or heel of a boot and the current will carry dislodged organisms into the net. Sample material from each kick will be combined into a single composite sample, which represents one square meter of substrate area. The material will be placed in an airtight container and preserved immediately in 95% ethanol. All samples will be labeled with the collection number, station, date, and collector. The samples will then be transported to the Jones & Stokes laboratory for analysis. After 24 hours, the ethanol in each sample will be replaced with fresh 95% ethanol.

In the laboratory, chain of custody forms will be used to track the samples. The contents of each sample will be placed into a 300 µm sieve, gently rinsed, and then placed in a Pyrex pan with 30% ethanol. The sample contents will then be examined for BMI by a technician using illuminated magnifying glasses. All BMI will be removed from debris with forceps and placed in containers filled with 70% ethanol. Once a sample presumably has all BMI removed, a second technician will then review the sample to ensure that all BMI are removed. After 2 technicians have searched the sample and found no more BMI, all debris will be discarded. If the second technician finds 4 or more BMI remaining in the sample, the original sorter will repeat the search of the entire sample.

Invertebrate biomass will be estimated using volumetric displacement. BMI specimens from all samples will be dried at room temperature for 15 minutes on size 613 qualitative filter paper and then placed in a 25 ml graduated cylinder with 15 ml of 15°C deionized water. The volumetric displacement will then be determined and recorded.

Specimens collected from each sample will be identified by taxonomists to the lowest justifiable taxon using an Olympus SZ-ST40 zoom stereo scope and the appropriate taxonomic references (Arnett 1968; Edmunds et al. 1976; McAlpine et al. 1981; Merritt and Cummins 1984; Pennak 1978; Usinger 1956; Wiggins 1977) in order to establish diversity, EPT ratios, opportunistic taxa ratios, taxa richness, and abundance, and to develop community indexes.

## Data Analysis

All data analyses will be conducted following the protocols for quantitative bioassessment established by EPA and the scientific community (Plafkin et al. 1989; Resh and Rosenberg 1984; Merritt and Cummins 1984; Hutchinson 1993; Resh and Jackson 1993; Rosenburg and Resh 1993).

# Data Management and Reporting

Successful implementation of the water quality and aquatic resource monitoring program requires proper data reduction and analysis procedures, routine quality control checks during sampling and data processing, and annual reporting of results for permit compliance, impact assessment, and performance evaluation. The chain of custody for data handling, storage, and processing will be clearly established. It is best to have a single person responsible for the monitoring program to ensure that all field and laboratory techniques, data entry, quality control and assurance methods, and analytical methods are coordinated and follow established protocols.

Standard field and laboratory data forms will be prepared for each monitoring component. All completed field and laboratory data forms will be kept in a central location or logbook. Duplicates will be made and stored in a separate location. The lead technician will proof all data forms at the end of each day of field or laboratory work. All data will be entered into Microsoft Excel spreadsheets (or equivalent) and maintained in a central database. The original spreadsheets will be checked for errors by comparing all entries in the electronic spreadsheets with the raw field and laboratory entries. The central database will be write-protected and maintained on a main computer server. Working copies of the spreadsheets will be used for data reduction, analysis, and reporting.

The results of the preproject and project operation monitoring will be presented in annual reports prepared at the end of each annual monitoring period. The reports will summarize the methods and results of the current and previous years' monitoring activities. Data and statistical analyses will be presented in summary graphs and tables. The reports will present and update conclusions regarding permit compliance, impact assessment, and monitoring performance and will include recommendations for modifications of sampling design and other program elements, if warranted.

# 2001 Monitoring Activities

## Monitoring Site Selection

On May 9, 2001, a Jones & Stokes fisheries biologist conducted an aerial survey of the MFAR (by helicopter) to examine the potential monitoring reaches identified by Mussetter Engineering (table 3) and identify other potential treatment and control monitoring locations downstream and upstream of Ralston Afterbay. The survey included the MFAR from its confluence with the NFAR to Ralston Afterbay and approximately 5 miles of the MFAR, North Fork MFAR, and Rubicon Rivers above the reservoir.

Four treatment and 3 control reaches were selected for aquatic habitat monitoring (figures 2 and 3). The Otter Creek and Volcano Creek reaches (photos 3 and 4) were selected as primary treatment reaches (Reaches 1 and 2) for evaluating project effects because of their proximity to Ralston Afterbay and the absence of significant local sediment sources. The Cherokee Bar reach (photo 5) was initially considered as a monitoring location but it was later concluded that the delivery of sediment to this reach may be strongly influenced by Landslide Rapid. Landslide Rapid, formed in 1940 by a massive slope failure associated with construction of a proposed sediment detention dam, is a significant control on sediment delivery to downstream reaches (Resource Consultants and Engineers 1993). Evidence for this conclusion is the large pool and extensive deposition of fine sediments upstream of the rapid (Canyon Creek reach, photo 6). The Canyon Creek reach was not considered an acceptable monitoring location because of the poor quality of existing habitat. The Louisiana Bar and Mammoth Bar reaches were also rejected because they were considered too far

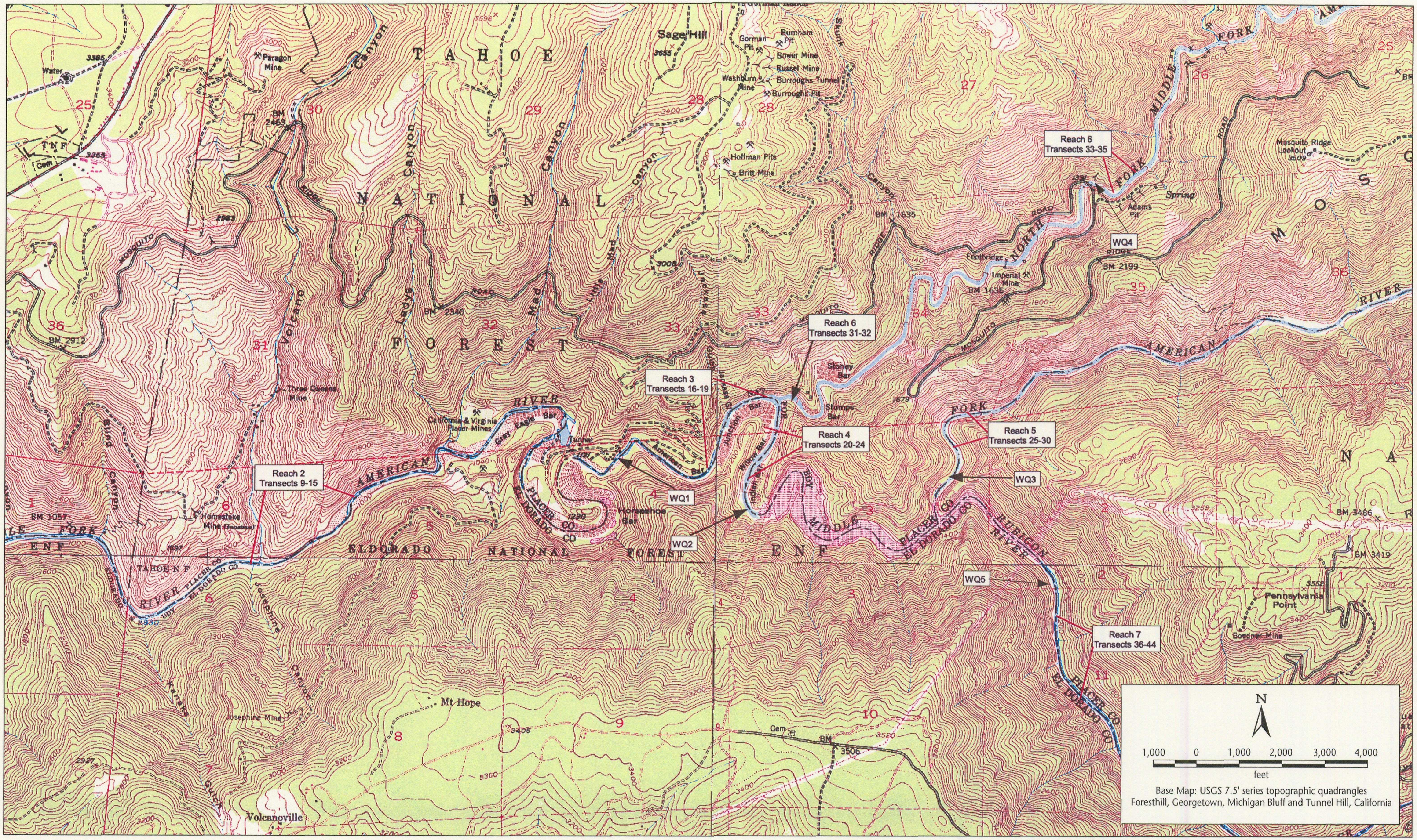


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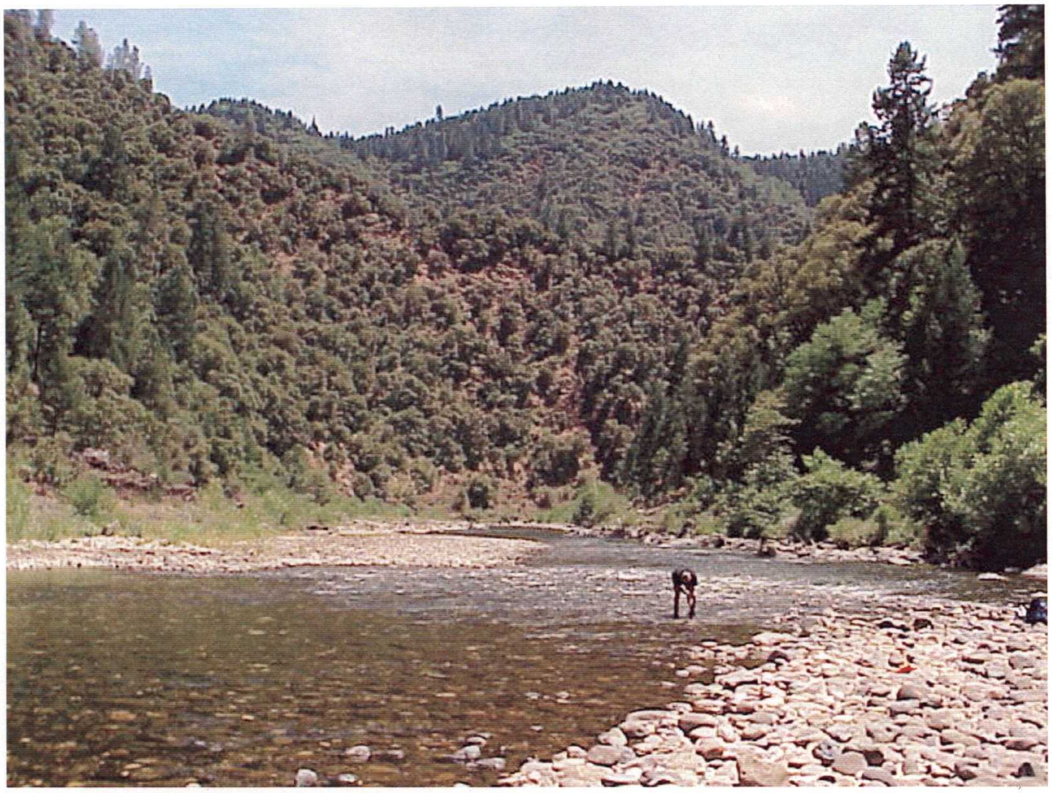
Figure 3
Aquatic Habitat/Benthic Macroinvertebrate Monitoring Sites in Reaches 2 through 7



Photograph 3. Middle Fork American River above Otter Creek (Reach 1)

Photograph 4. Middle Fork American River above Volcano Creek (Reach 2)

Photograph 5. Middle Fork American River at Cherokee Bar

Photograph 6. Middle Fork American River above Canyon Creek

downstream and subject to relatively large inputs of sediment from local sources (e.g., slope failures) (Resource Consultants and Engineers 1993).

Monitoring reaches were also established between Horseshoe Bar and the North Fork MFAR (Reach 3) and between the North Fork MFAR and Ralston Dam (Reach 4) (photos 7 and 8). Although these reaches are relatively steep and coarse-grained, they were considered important reaches for monitoring the downstream dispersal of coarse sediments from the Indian Bar disposal site. Aerial surveys revealed that the North Fork MFAR, MFAR above Ralston Afterbay, and Rubicon River are steep, bedrock-controlled streams that generally lack the distinct alluvial reaches of the MFAR downstream of Ralston Afterbay. The only significant depositional area occurs on the Rubicon River immediately upstream of Ralston Powerhouse (upstream of the reservoir inundation zone) (Reach 7, photo 9). This reach will serve as a primary control area for evaluating project effects because of its general similarity to the treatment reaches downstream of Ralston Dam. Although the MFAR above the reservoir (Reach 5) and the North Fork MFAR (Reach 6) were not considered adequate control reaches, they were included to monitor any significant changes or trends in watershed conditions that may occur during the course of the monitoring program (photos 10 and 11).

Ground surveys were conducted on May 12, 13, and 17, 2001, to establish reach boundaries and select specific monitoring sites. Upstream and downstream reach boundaries were established at known valley and channel constrictions (e.g., mouths of Otter and Volcano Creeks) or where distinct transitions in channel and streambed characteristics were apparent (e.g., pool-riffle to step-pool channels). In reaches lacking distinct transitions or pool-riffle morphology (Reaches 4–6), reach boundaries were determined on the basis of accessibility and other practical considerations (e.g., avoidance of local disturbances such as suction dredge mining).

Substrate sampling areas were established at the heads of all major riffles in the selected treatment and control reaches. These areas generally marked the transition from pools (or runs) to riffles. In reaches where distinct riffles were absent and hydraulic conditions were controlled by large boulders and bedrock (step-pool channels, Reaches 4–6), sampling locations were established in areas immediately upstream of major steps. No stratification of sampling areas by substrate type or size was necessary because substrate conditions were relatively uniform throughout the selected areas. Instead, sampling areas were stratified on the basis of current velocity to control for any current-related effects on streambed conditions and ensure that the transects included areas with relatively fast currents where BMI are most effectively sampled. Accordingly, each sampling area was divided into 2 smaller areas—the upstream riffle crest (or pool tail) and the downstream riffle head. The riffle crest was defined by relatively low velocities and minimal turbulence whereas the riffle head was defined by faster, more turbulent flow. One to 2 transects (depending on substrate variability) were established in the riffle crest and 1 to 2 transects were established in the riffle head. The locations of all transects were determined using a random numbers table.

A total of 42 transects were established for substrate monitoring. Table 7 presents the distribution of transects by reach and the transects used for BMI monitoring.

**Table 7.** Aquatic Habitat and BMI Monitoring Reach Numbers, Locations, Purposes, and Transects

| Reach | Location | Primary Purpose | Substrate Transects | BMI Transects |
|---|---|---|---|---|
| Reach 1 | Middle Fork American River (MFAR) above Otter Creek | Treatment | 1–8 | 1, 3, 7 |
| Reach 2 | MFAR above Volcano Creek | Treatment | 9–15 | 9, 11, 13 |
| Reach 3 | MFAR between North Fork MFAR and Horseshoe Bar | Treatment | 16–19 | 16, 17, 18 |
| Reach 4 | MFAR between Ralston Afterbay Dam and North Fork MFAR | Treatment | 20–24 | 20, 23 |
| Reach 5 | MFAR above Ralston Afterbay | Control | 25–30 | 25, 27, 29 |
| Reach 6 | North Fork MFAR | Control | 31–35 | 31, 33, 35 |
| Reach 7 | Rubicon River above Ralston Afterbay | Control | 36–44 | 36, 40, 43 |

# Substrate Measurements

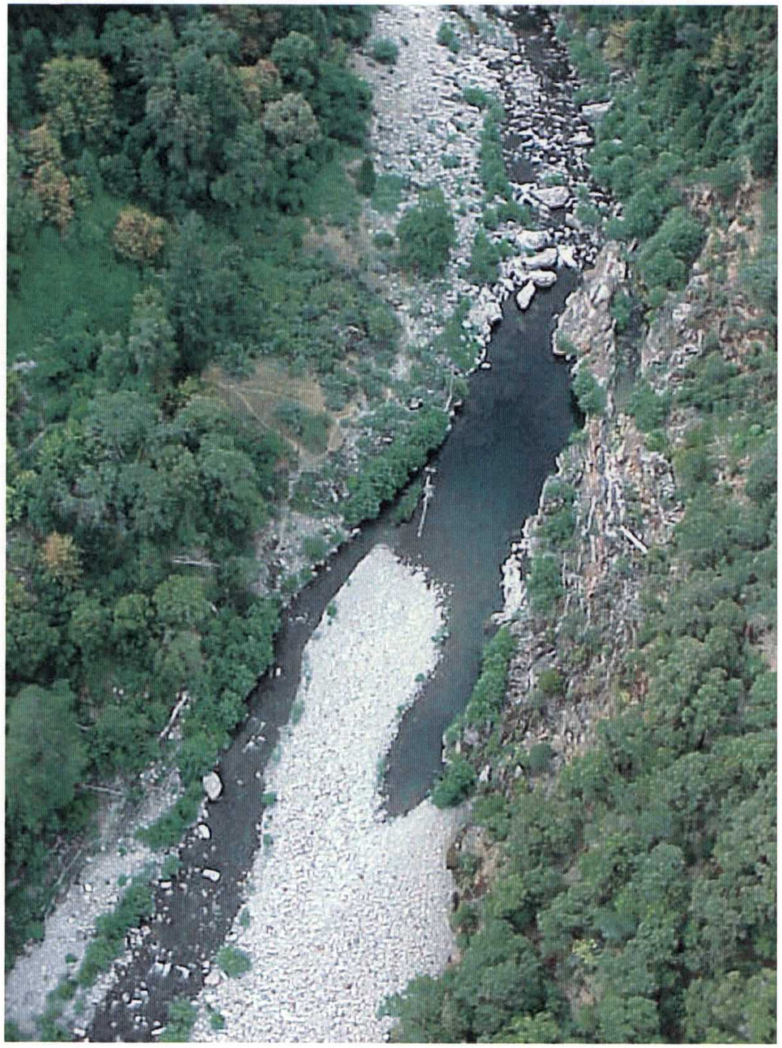
Substrate composition and embeddedness were measured at each transect as described in the monitoring plan (see above). Field measurements were conducted during the period of October 17–23, 2001, when flows downstream of Oxbow Powerhouse were at minimum levels (approximately 100 cfs) during a scheduled maintenance outage of the Ralston and Oxbow Powerhouses. Substrate composition was measured at 5 to 15 locations spaced at regular intervals ranging from every 2 m in the smallest channels to every 9 m in the largest channels. This measurement area was considered sufficient to characterize the observed variability in substrate conditions in all monitoring reaches. All raw data are presented in the appendix tables 1–7.

# BMI Sampling

All field and laboratory methods used to collect and process BMI samples are described in the monitoring plan (see above). Three transects were selected for BMI sampling in each monitoring reach, with the exception of Reach 4, for a total of 20 monitoring transects (table 7). Only 2 BMI monitoring transects were established in Reach 4 because of its relatively short length and uniform substrate, current, and depth. The selected transects were generally in the heads of riffles with moderate to strong currents and water depths between 0.3 and 1 m. Samples were collected on June 24, 25, and 26; August 20, 21, and 25; and October 22, 23, and 24. All laboratory methods are described in the monitoring

Photograph 7. Middle Fork American River between Horseshoe Bar and North Fork of MFAR confluence (Reach 3)

Photograph 8. Middle Fork American River between North Fork of the Middle Fork American River confluence and Ralston Afterbay Dam (Reach 4)



Photograph 9. Rubicon River above Ralston Powerhouse (Reach 7)

Photograph 10. North Fork of the Middle Fork American River above Ralston Afterbay (Reach 5)

Photograph 11. North Fork of the Middle Fork American River (Reach 6)

plan. The data are summarized in the appendix table 8. A complete taxonomic list and numerical database are available from PCWA by request.

# Monitoring Results

## Substrate Composition

Riffle substrates in the monitoring reaches consisted primarily of pebble, cobble, and boulder with small quantities of silt/clay, sand, and gravel (figure 4). The dominant substrate types were pebble in Reach 7; cobble in Reaches 1, 2, and 5; and boulder in Reaches 3, 4, and 6. In Reaches 1 through 4, boulders comprised an increasing percentage of the streambed with increasing proximity to Ralston Dam, with the lowest percentage in Reach 1 (12%) and the highest percentage in Reach 4 (68%).

Figure 5 shows the means and standard deviations of substrate scores for each monitoring reach (based on the numbering system shown in table 5). These statistics provide a means of comparing the average substrate size (or relative coarseness) of the streambed as well as the variation in substrate sizes among reaches. For example, the Otter and Volcano Creek reaches (Reaches 1 and 2) had similar mean substrate scores because of the dominance of cobble substrate in these reaches (photos 9 and 10). However, Reach 2 had higher variation in substrate size (i.e., larger standard deviation) because of the higher percentages of smaller (sand and gravel) and larger (boulder) substrates. Substrate variability in Reach 2 was typical of that observed in other reaches (figure 5).

Higher mean substrate scores in Reaches 3 and 4 reflect the dominance of boulder substrate and a general increase in streambed coarseness between Horseshoe Bar and Ralston Dam (photos 11 and 12). Overall, the highest mean substrate scores were in Reach 4 (Ralston Dam to North Fork MFAR confluence) where 68% of the streambed was composed of boulders. Reach 6 (North Fork MFAR) had a similar substrate composition (photo 13). By comparison, Reach 5 (MFAR above Ralston Afterbay) had moderately coarse riffles (photo 14). Reach 7 (Rubicon River) had the finest substrate composition among all reaches (photo 15).

## Embeddedness

The degree to which coarse materials (gravel, pebble, cobble, boulder) were embedded with fine sediment (silt/clay, sand) ranged from <5% to 25 50% (figure 5). Embeddedness was negligible (<5%) in Reaches 3 and 4, low (5 25%) in Reaches 5 and 6, and moderate (25–50%) in Reaches 1, 2, and 7. A comparison of the 2 graphs in figure 7 shows that the degree of embeddedness generally decreased with increasing coarseness of the streambed.

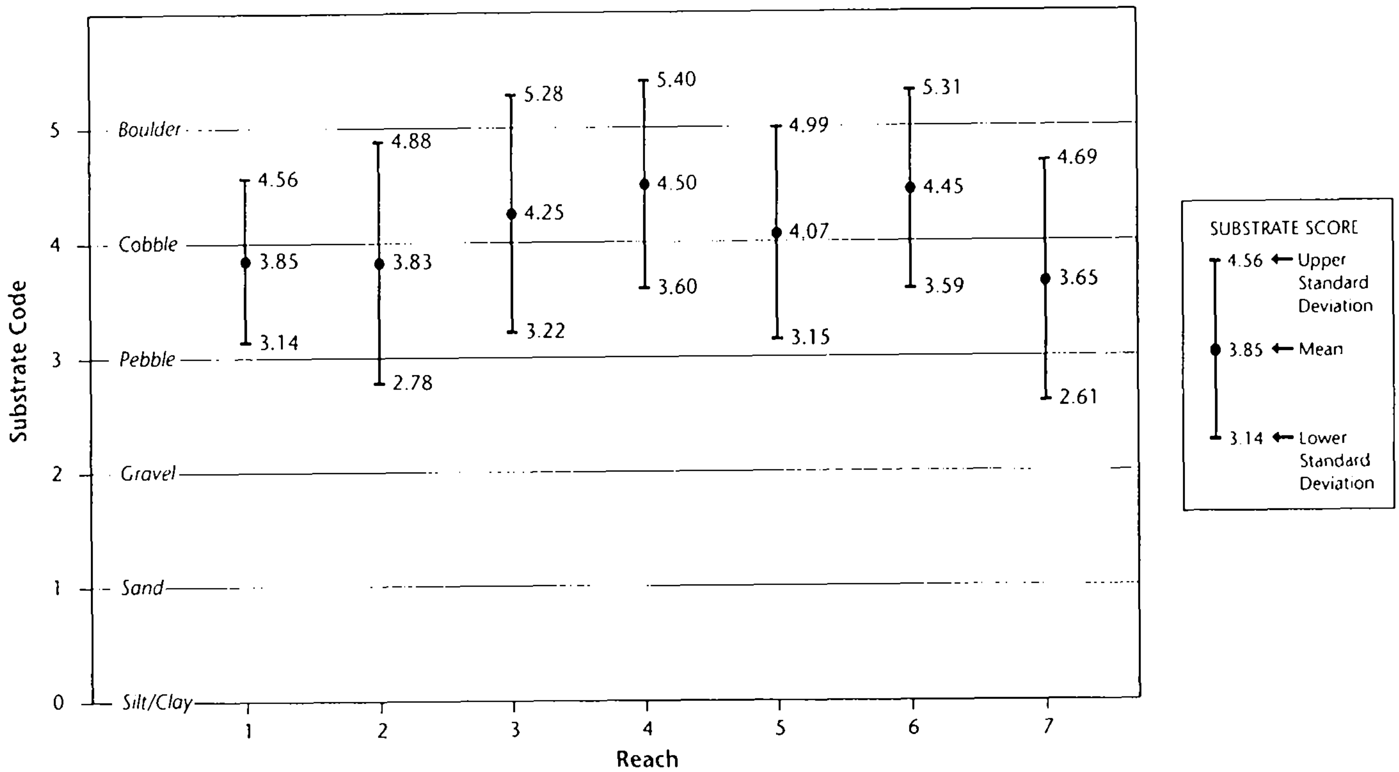
# BMI Density

Invertebrate density (number of individuals/square meter [$m^2$]) by reach and month is presented in table 8 and figure 7. Monthly invertebrate densities ranged from 21 individuals/$m^2$ (Reach 3, August) to nearly 4,000 individuals/$m^2$ (Reach 2, October), with no consistent seasonal trends among reaches.

Invertebrate densities in Reach 1 were relatively low and stable, averaging about 650 individuals/$m^2$. In contrast, invertebrate densities in Reach 2 increased from about 1,000 in June to 4,000 in October. Reach 2 had the highest invertebrate densities and highest seasonal variation than any of the monitoring reaches (excluding Reach 3, see below).

Reach 3 had very low invertebrate densities in June and August (less than 50 individuals/$m^2$) and moderate levels (about 1,900 individuals/$m^2$) in October. In contrast, invertebrate densities changed very little in Reach 4, averaging 760 individuals/$m^2$. Reaches 5, 6, and 7 had low to moderate invertebrate densities, averaging 700–1,040 individuals/$m^2$.

We believe the large seasonal differences observed in Reach 3 were a result, in part, of higher flows in June and August that prevented complete sampling in this reach. BMI samples were collected from Reach 3 on June 25, August 20, and October 23, at flows of 433 cfs, 772 cfs, and 94 cfs, respectively. The lower flow in October was the result of a scheduled maintenance shutdown of the Oxbow Powerhouse. In June and August, high flows and associated strong currents and deep water made it unsafe to sample the middle portion of the channel. At lower flows in October, we found that the locations previously sampled in June and August were dry, and that the locations that were previously inaccessible were the only areas available for sampling. It is known that BMI communities downstream from hydroelectric facilities are affected by flow fluctuations that cause periodic or regular changes in the wetted area of the channel as well as changes in water depths and velocities. The effects of these flow changes on BMI communities can be greatest on the periphery of the channel where the frequency and duration of exposure is highest. Consequently, aquatic invertebrates would be expected to establish larger, more stable populations in the portions of the channel that are continually submerged. This may explain the relatively low BMI metric values in June and August and the higher values in October.



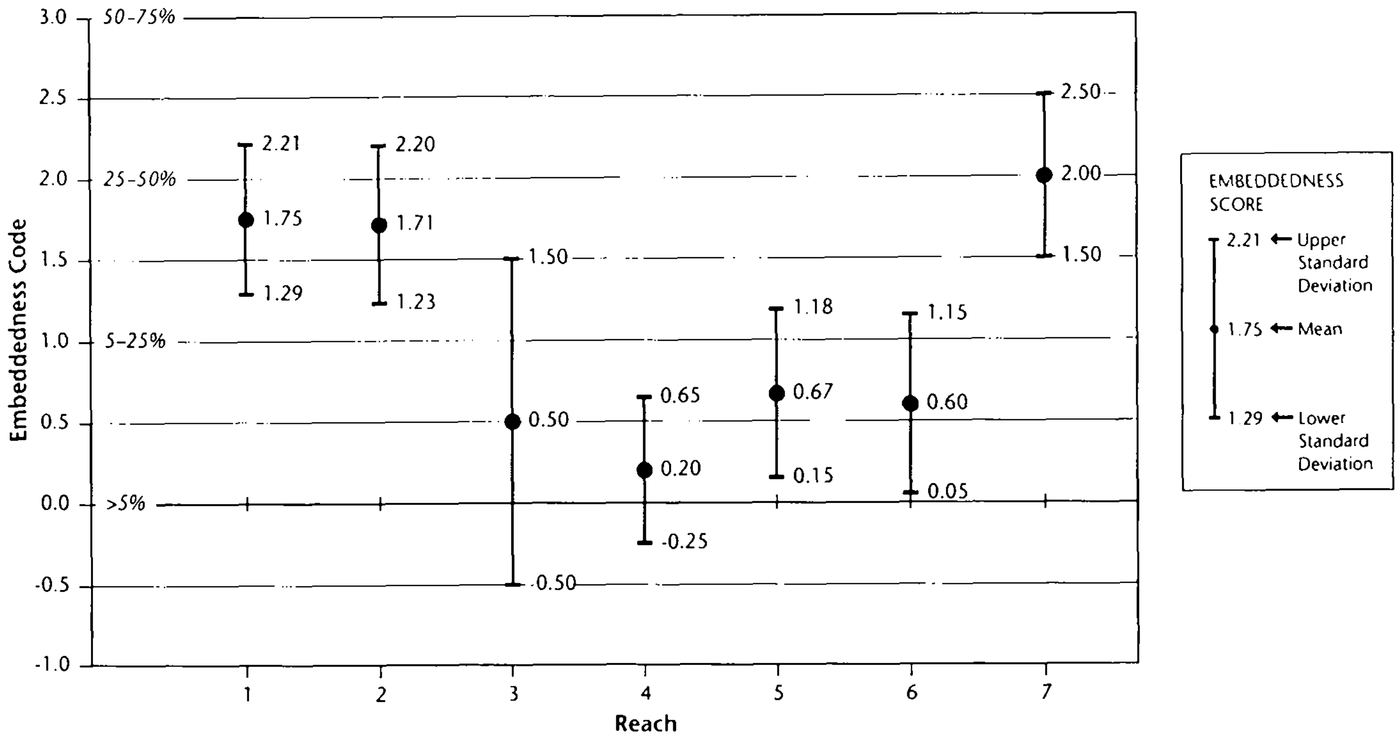




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**Figure 6**
**Means and Standard Deviations of Substrate Scores by Reach**

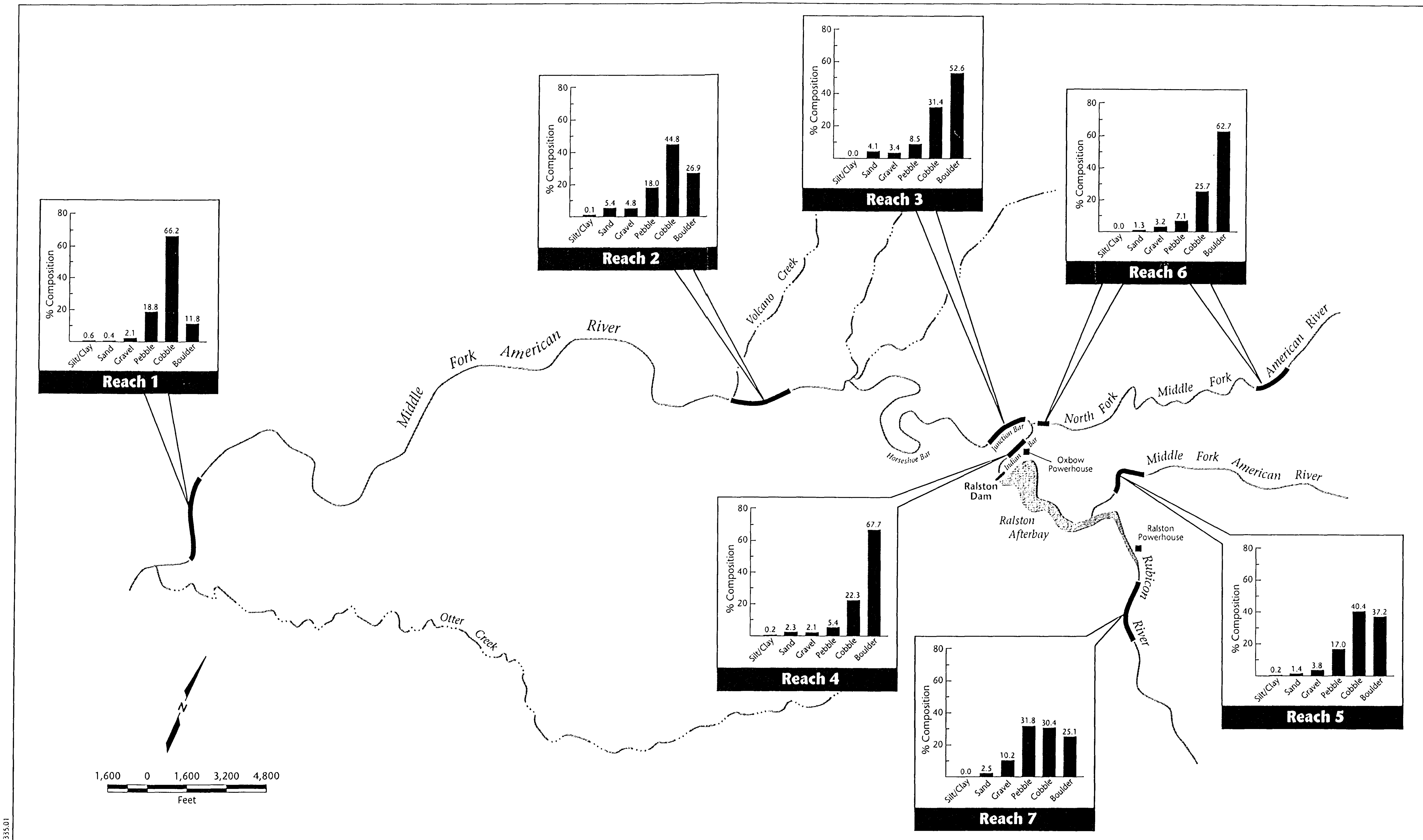


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**Figure 4**
**Substrate Composition by Monitoring Reach**

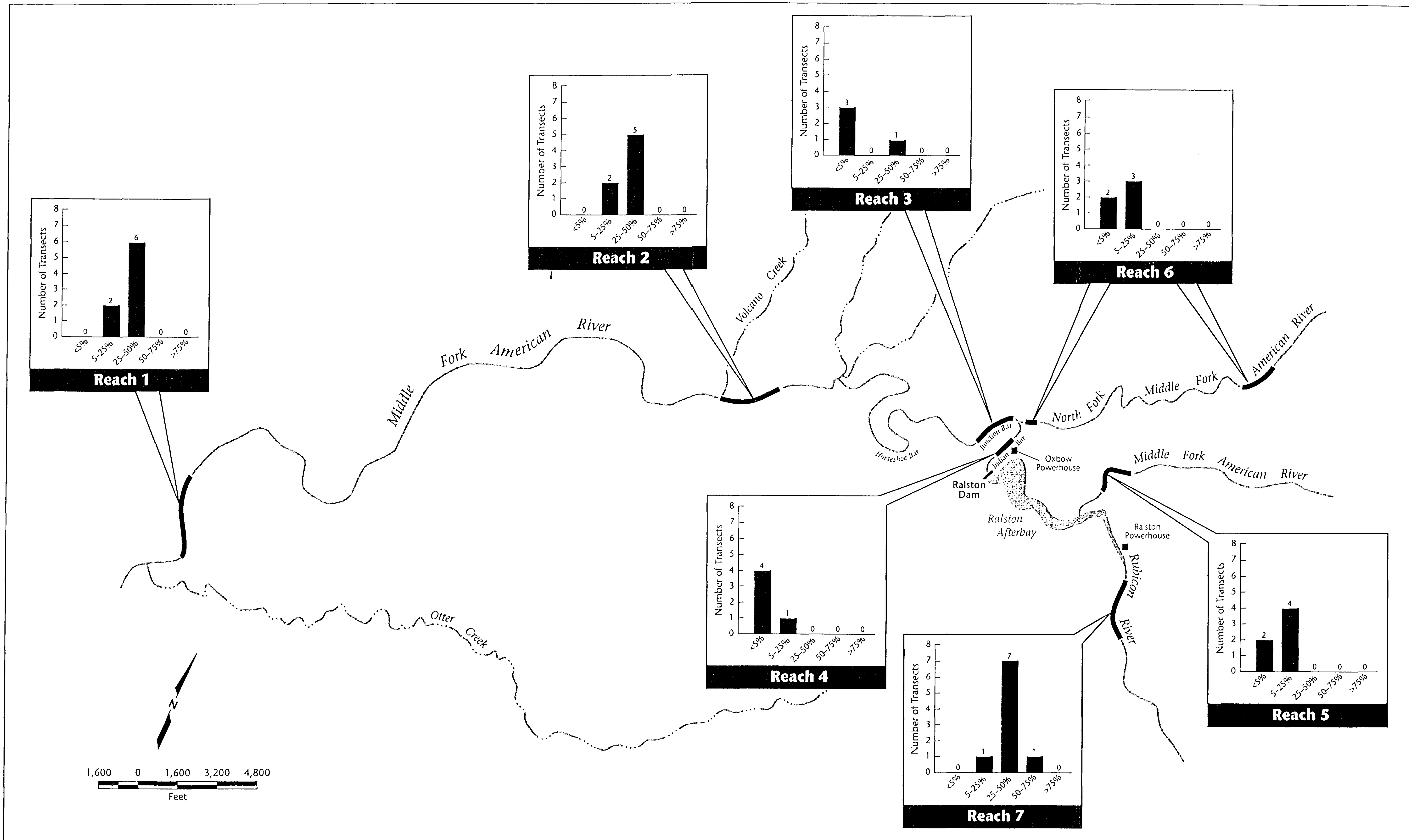


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**Figure 5**
**Embeddedness by Monitoring Reach**

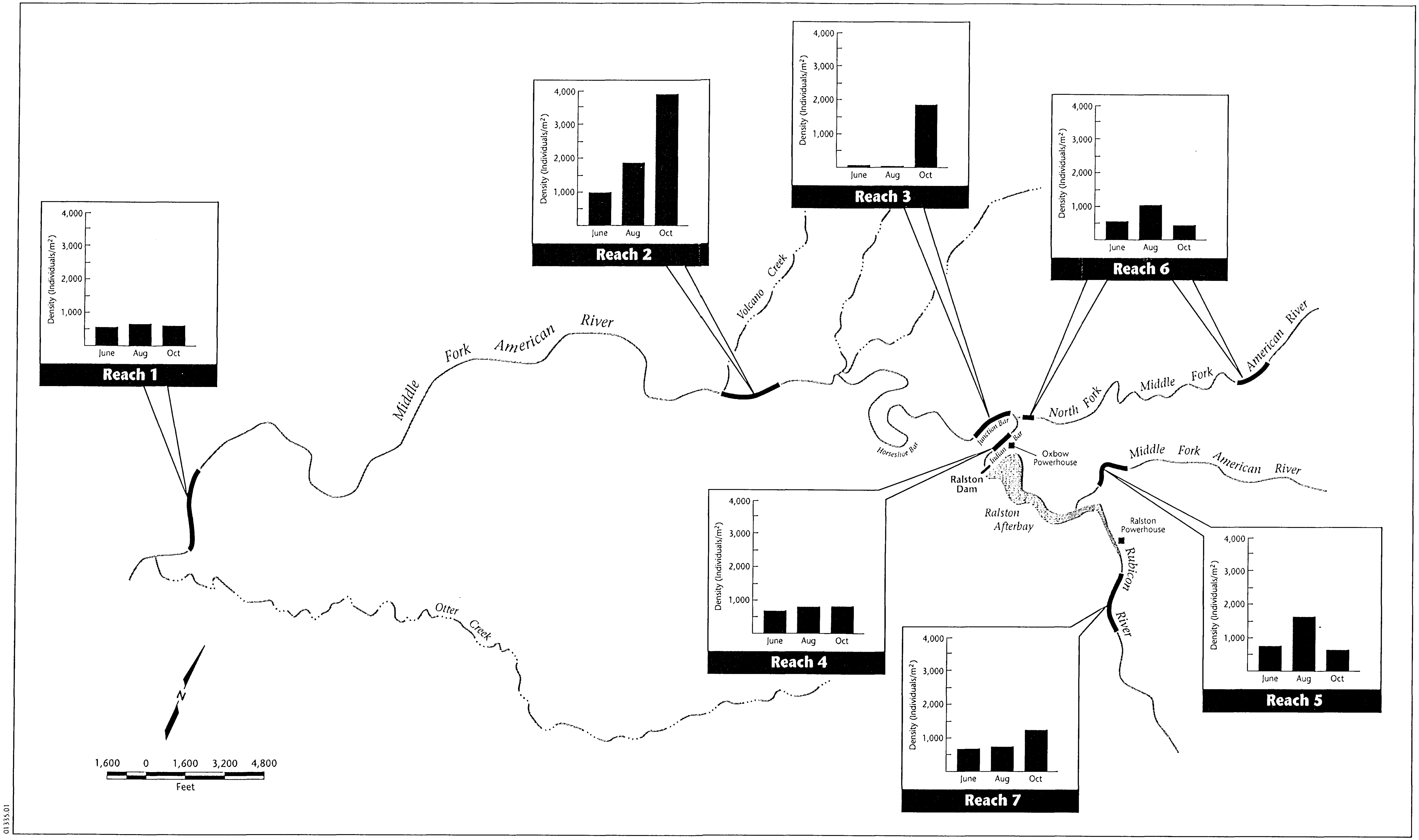


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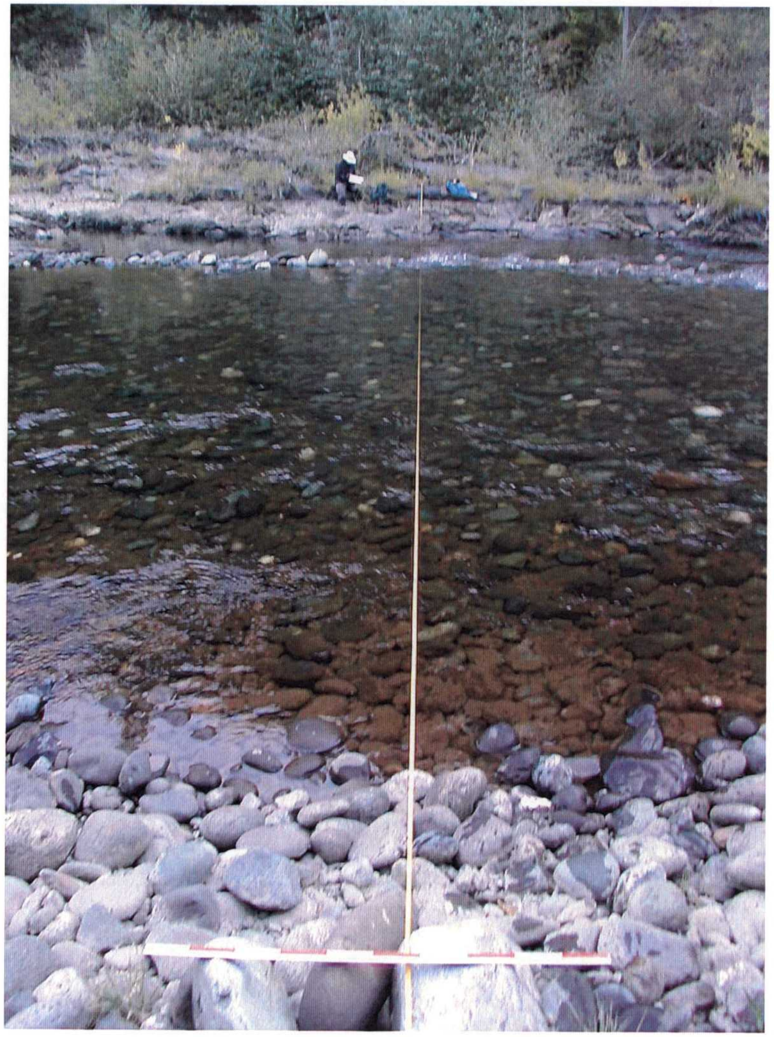
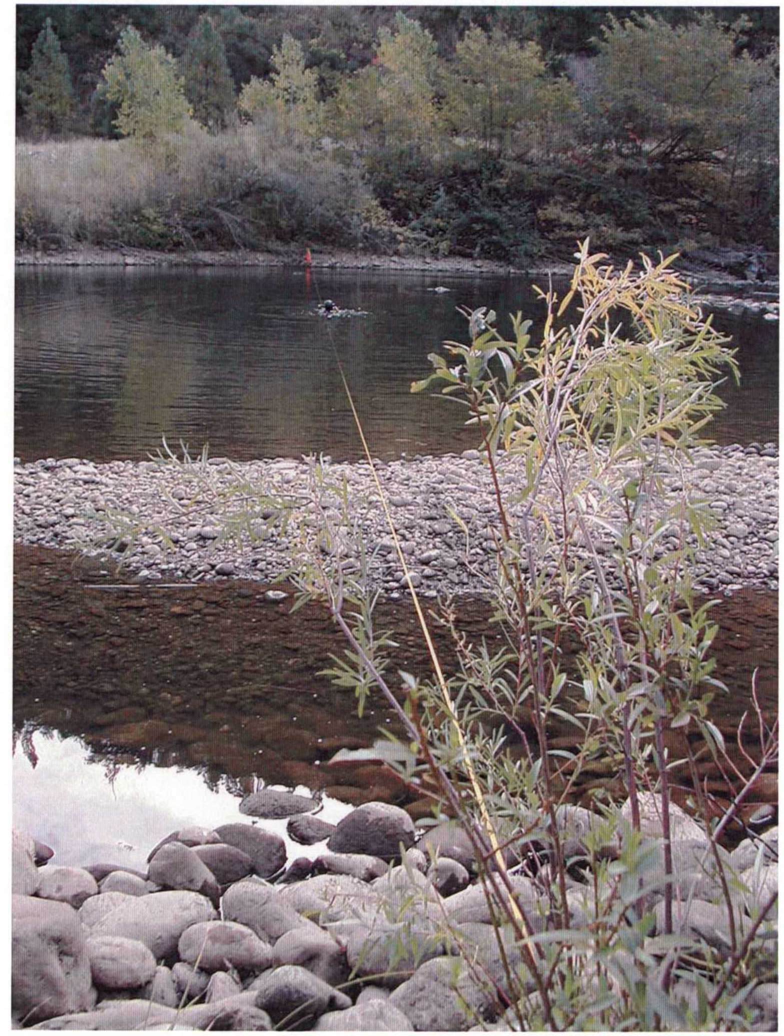
**Figure 7**
**Density of Benthic Macroinvertebrates (individuals/m²) by Monitoring Reach**



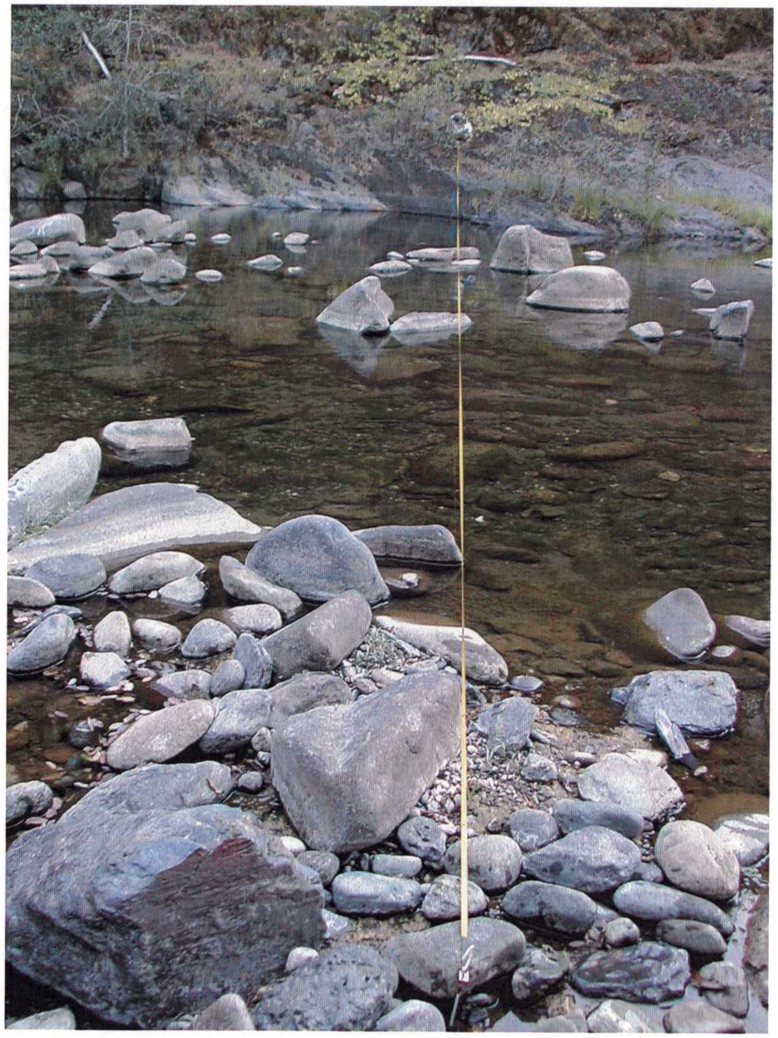
Photograph 12. Middle Fork American River above Otter Creek (Reach 1, Transect 2)



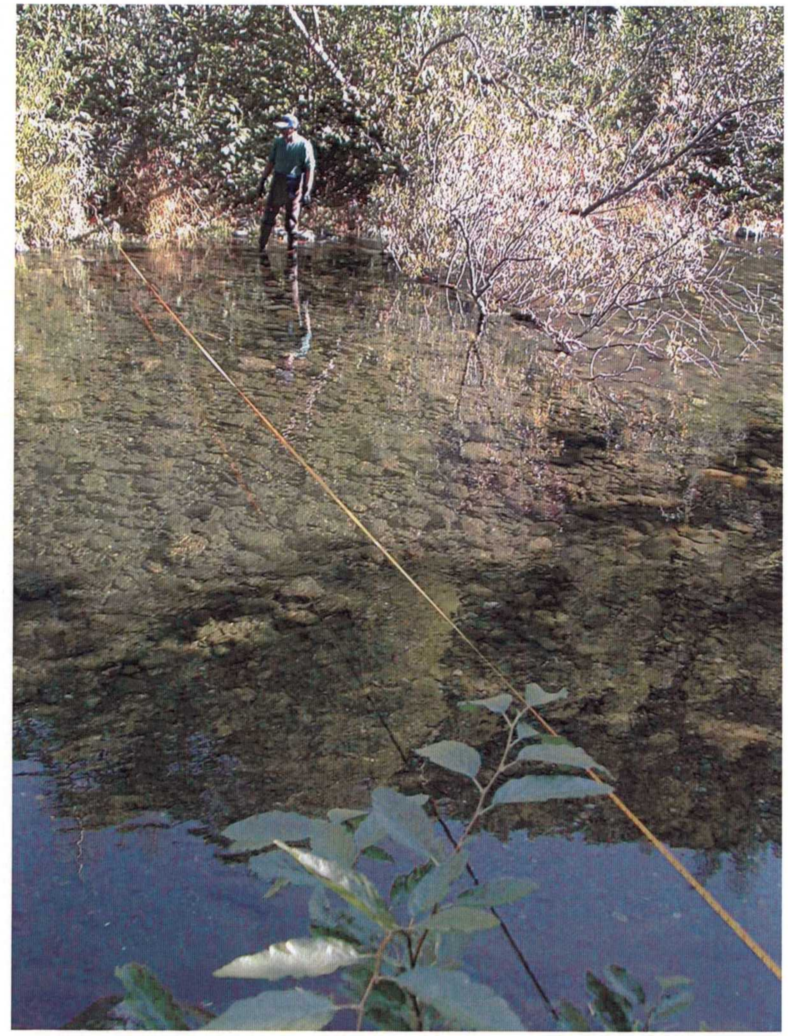
Photograph 13. Middle Fork American River above Volcano Creek (Reach 2, Transect 15)

Photograph 14. Middle Fork American River between Horseshoe Bar and North Fork of the Middle Fork American River confluence (Reach 3, Transect 17)

Photograph 15. Middle Fork American River between North Fork of the Middle Fork American River confluence and Ralston Afterbay Dam (Reach 4, Transect 21)



Photograph 16. North Fork of the Middle Fork American River (Reach 6, Transect 32)



Photograph 17. Middle Fork American River above Ralston Afterbay Reservoir (Reach 5, Transect 26)

Photograph 18. Rubicon River above Ralston Powerhouse
(Reach 7, Transect 42)

**Table 8.** Invertebrate Density

| | June | August | October | Average |
|---|---|---|---|---|
| Reach 1 | 582 | 697 | 673 | 651 |
| Reach 2 | 1,014 | 1,886 | 3,992 | 2,297 |
| Reach 3 | 48 | 21 | 1,896 | 655 |
| Reach 4 | 676 | 800 | 804 | 760 |
| Reach 5 | 798 | 1,656 | 656 | 1,036 |
| Reach 6 | 559 | 1,082 | 454 | 698 |
| Reach 7 | 723 | 746 | 1,300 | 923 |
| Average | 628 | 984 | 1,346 | 1,003 |

# BMI Productivity

BMI productivity (biomass in grams [g] per $m^2$) by reach and month is presented in table 9 and figure 8. Monthly productivity ranged from 0.42 $g/m^2$ (Reach 3, August) to 7.52 $g/m^2$ (Reach 7, October), with no consistent seasonal trends among reaches.

Reaches 1 and 2 had moderate to high productivity compared to other reaches, averaging 4–5 $g/m^2$ during the monitoring period. Reaches 3 and 4 had the lowest productivity (averaging about 2 $g/m^2$), although the unusually low values in Reach 3 in June and August were affected by flows on the day of sampling, as discussed above. Reaches 5 and 6 had moderate productivity, averaging 3–3.5 $g/m^2$. Reach 7 had consistently high productivity through the season, resulting in the highest overall average of any reach (6.18 $g/m^2$).

**Table 9.** Invertebrate Productivity

| | June | August | October | Average |
|---|---|---|---|---|
| Reach 1 | 5.61 | 4.45 | 3.05 | 4.37 |
| Reach 2 | 2.22 | 7.10 | 4.80 | 4.71 |
| Reach 3 | 1.15 | 0.42 | 4.73 | 2.10 |
| Reach 4 | 1.60 | 2.76 | 1.78 | 2.05 |
| Reach 5 | 2.58 | 5.12 | 2.80 | 3.50 |
| Reach 6 | 3.20 | 4.15 | 2.61 | 3.32 |
| Reach 7 | 5.22 | 5.81 | 7.52 | 6.18 |
| Average | 3.08 | 4.26 | 3.90 | 3.75 |

## Taxa Richness

Taxa richness (number of taxa/m$^2$) by reach and month is presented in table 10 and figure 9. Monthly taxa richness ranged from 4.0 taxa/m$^2$ (Reach 3, August) to 40.7 taxa/m$^2$ (Reach 5, June), with no consistent seasonal trends among reaches. Except for Reach 3, all reaches exhibited relatively little variation in taxa richness during the monitoring period. It is important to note that this does not mean that the same taxa were present each month, only that similar numbers of taxa were present.

Taxa richness in Reaches 1 and 2 was very similar and changed little during the monitoring period, averaging 28 taxa/m$^2$. Overall, Reaches 3 and 4 had the lowest taxa richness, averaging 13 and 25 taxa/m$^2$, respectively. Again, the unusually low levels in Reach 3 can be attributed partly to higher flows in June and August that prevented complete sampling in this reach. Overall, Reaches 5, 6, and 7 had the highest taxa richness, averaging 38, 36, and 34 taxa/m$^2$, respectively.

**Table 10.** Benthic Macroinvertebrate (BMI) Taxa Richness

| | June | August | October | Average |
|---|---|---|---|---|
| Reach 1 | 29.3 | 29.3 | 26.0 | 28.2 |
| Reach 2 | 26.3 | 31.3 | 27.0 | 28.2 |
| Reach 3 | 6.7 | 4.0 | 27.0 | 12.6 |
| Reach 4 | 27.0 | 30.0 | 19.0 | 25.3 |
| Reach 5 | 40.7 | 36.7 | 35.5 | 37.6 |
| Reach 6 | 35.7 | 41.0 | 32.0 | 36.2 |
| Reach 7 | 40.0 | 33.3 | 30.0 | 34.4 |
| Average | 29.4 | 29.4 | 28.1 | 28.9 |

# Percent Ephemeroptera, Plecoptera, and Trichoptera (EPT)

Percent EPT (number of individuals in these taxa as a percentage of total numbers) by reach and month is presented in table 11 and figure 10. Monthly percent EPT ranged from 0% (Reach 3, August) to 59.3% (Reach 6, June). The majority of the reaches exhibited a decline in percent EPT during the monitoring period, with the lowest values in October. This pattern reflects the general life history and population dynamics of these taxa.

With the exception of Reach 3, all reaches had relatively high EPT values in June, ranging from 38% to 59%, and had values in October ranging from 4% to 22%. In contrast, EPT values in Reach 1 remained constant at about 38% during this period. Overall, Reaches 3 and 4 had the lowest average EPT values (5%

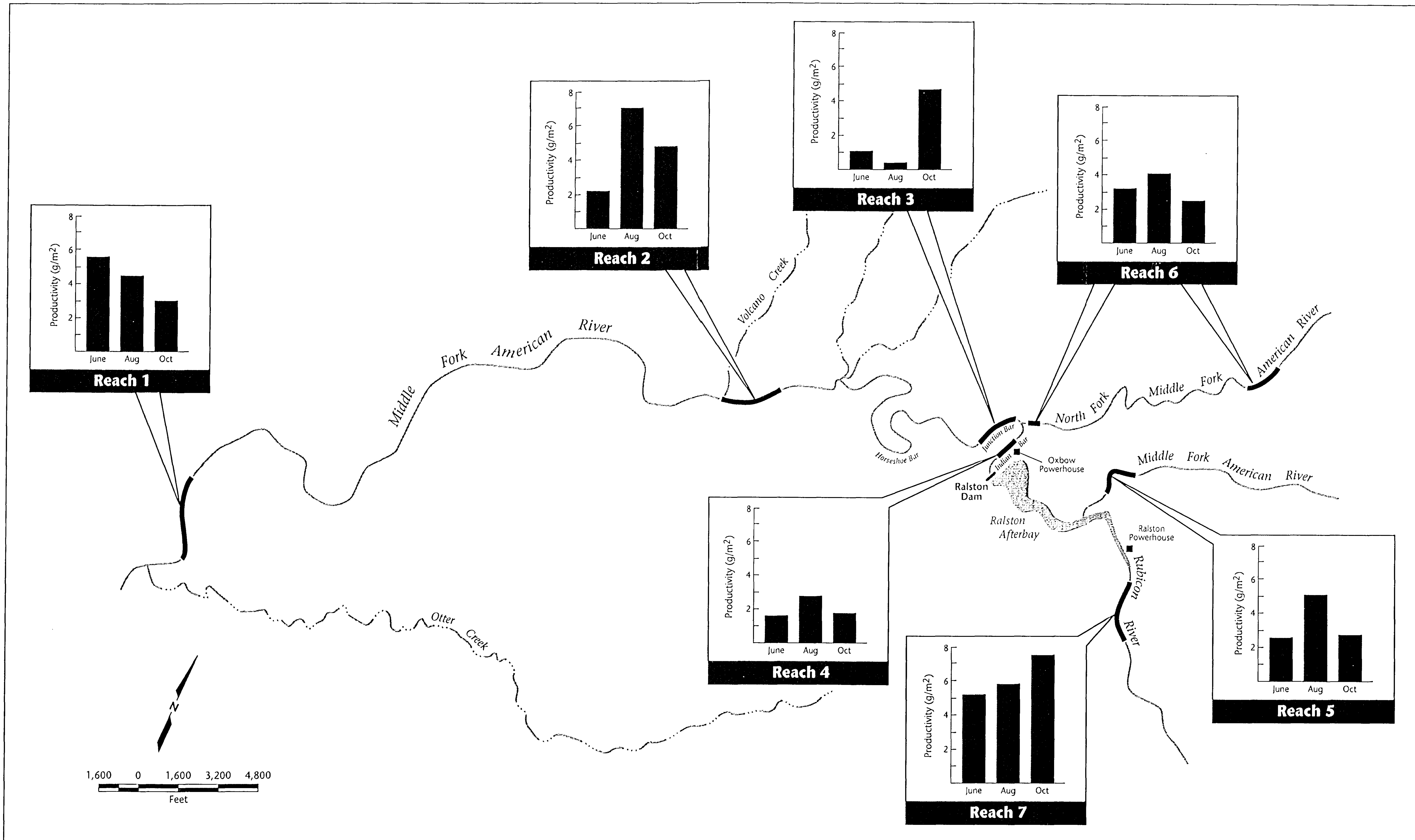



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**Figure 8**
**Productivity of Benthic Macroinvertebrates ($g/m^2$) by Monitoring Reach**

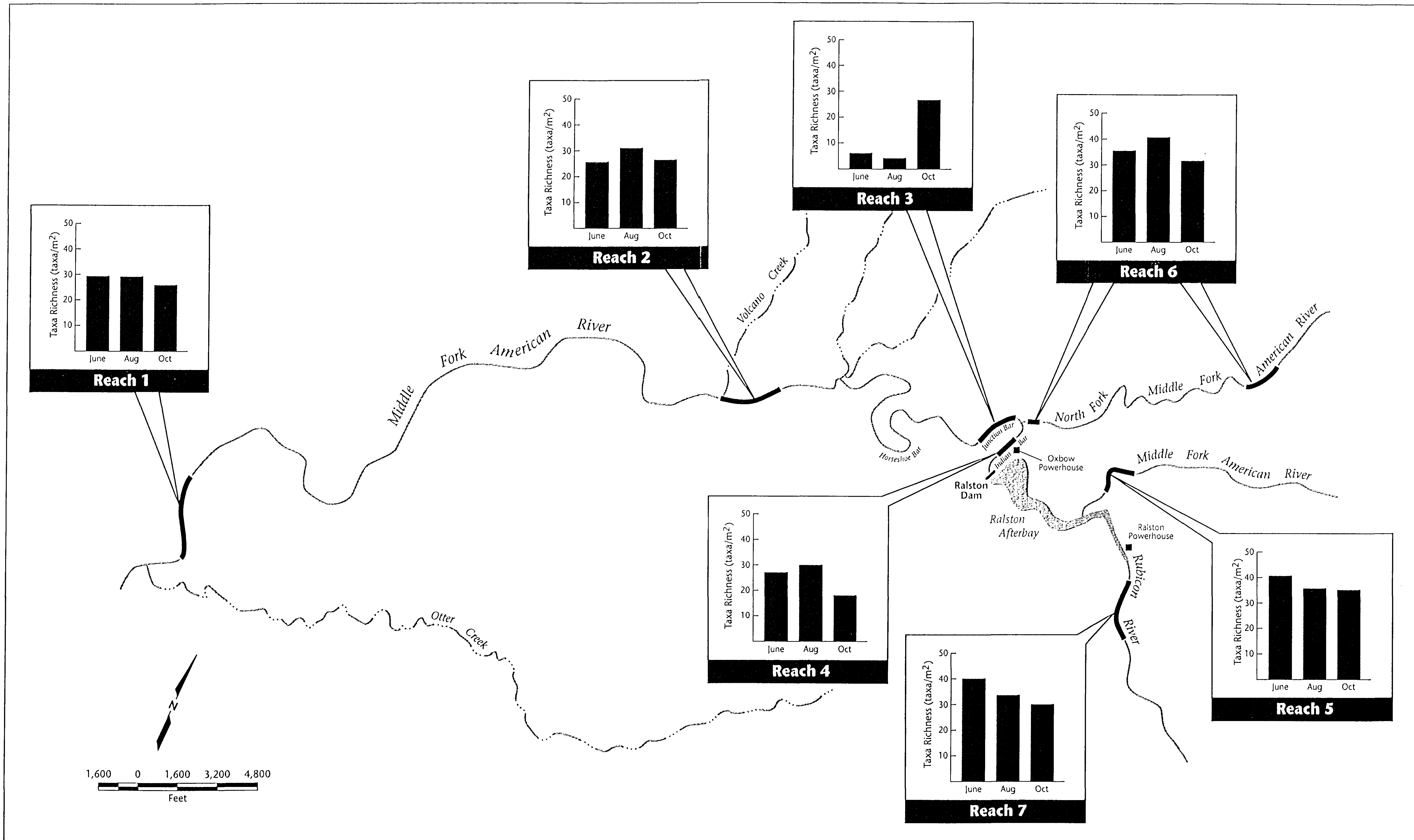


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**Figure 9**
**Taxa Richness of Benthic Macroinvertebrates ($taxa/m^2$) by Monitoring Reach**

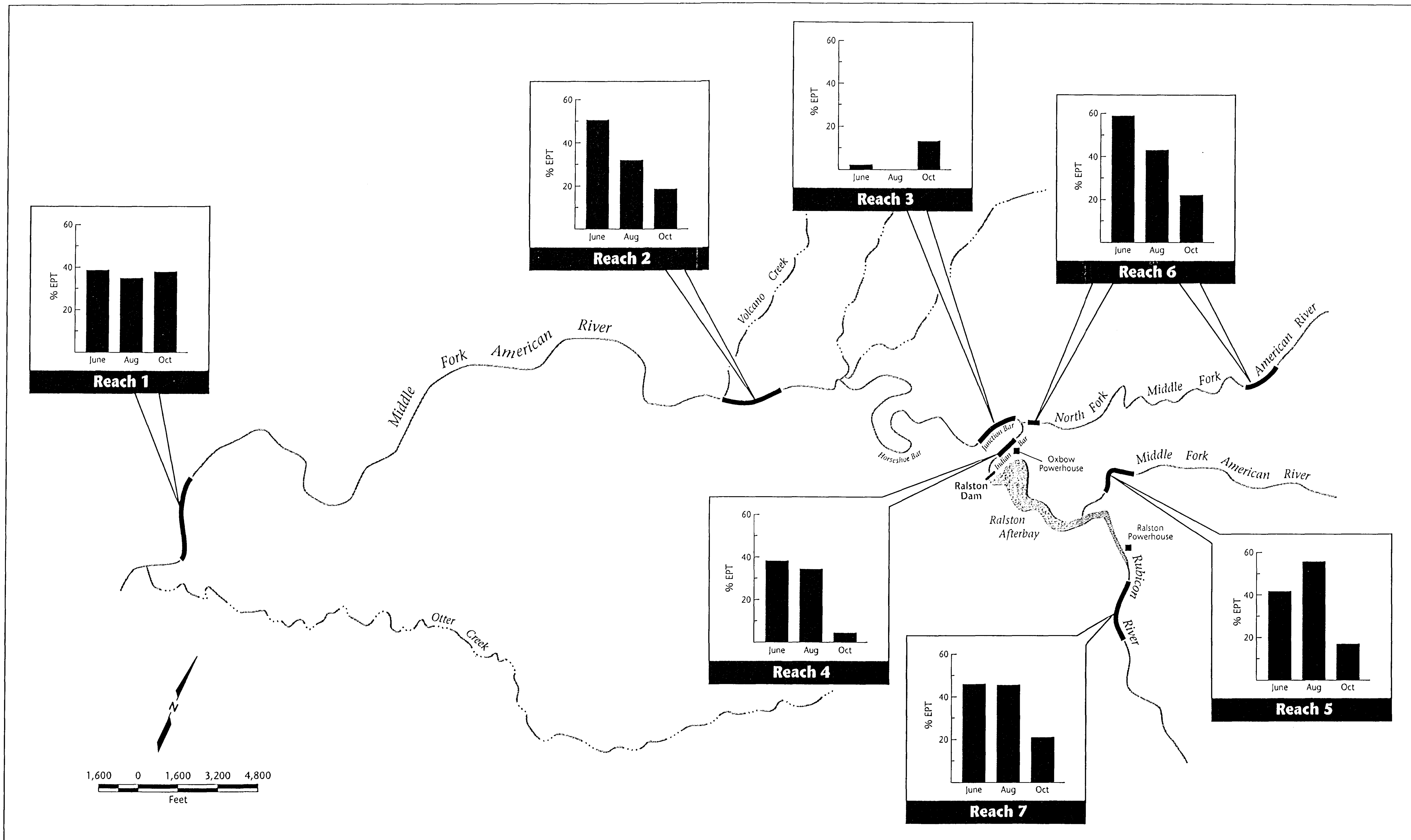


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**Figure 10**
**Percent EPT of Benthic Macroinvertebrates (% EPT) by Monitoring Reach**

and 26%, respectively). All other reaches had averages ranging from 34% to 41%.

**Table 11.** EPT Ratio Expressed as a Percentage

| | June | August | October | Average |
|---|---|---|---|---|
| Reach 1 | 38.9 | 36.3 | 38.5 | 37.9 |
| Reach 2 | 50.3 | 32.1 | 19.2 | 33.9 |
| Reach 3 | 2.3 | 0.0 | 13.2 | 5.2 |
| Reach 4 | 38.3 | 34.4 | 4.4 | 25.7 |
| Reach 5 | 41.4 | 56.9 | 17.1 | 38.5 |
| Reach 6 | 59.3 | 42.8 | 21.8 | 41.3 |
| Reach 7 | 45.9 | 45.4 | 20.9 | 37.4 |
| Average | 39.5 | 35.4 | 19.3 | 31.4 |

# Discussion

## Substrate Conditions

Substrate measurements in each of the monitoring reaches reflect the relatively uniform, coarse-grained nature of the streambed upstream and downstream of Ralston Afterbay. The more alluvial nature of the Otter and Volcano Creek reaches (Reaches 1 and 2) and the Rubicon reach (Reach 7) is evident from their dominant pool-riffle morphology, smaller average substrate size, and larger quantities of fine sediment (higher embeddedness) compared to other monitoring reaches. In contrast, the MFAR above Ralston Afterbay (Reach 5) and the North Fork MFAR (Reach 6) are characterized predominantly by higher-gradient, coarser- grained step-pool channels that lack distinct alluvial features (bars and riffles). The reaches immediately downstream of Ralston Dam (Reaches 3 and 4) appear to be intermediate between these 2 channel types, based on stream gradient, substrate composition, and alluvial features. However, since construction of Ralston Dam, the streambed in these reaches has likely become coarser over time in response to reductions in sediment supply from upstream sources and continued downstream transport of small- to moderate- sized substrates (cobble and finer materials) from these reaches. This is especially evident in Reach 4 where no other major source of sediment exists. Slightly lower average substrate sizes in Reach 3 indicate that this reach may be buffered somewhat by sediment contributions from the North Fork MFAR.

Riffle substrates in each of the monitoring reaches in fall 2001 can be characterized as being in moderate to good condition based on the general habitat requirements of trout and aquatic invertebrates. In general, coarse sediments (gravel and larger materials) and low quantities of fine sediment provide high quality habitat for spawning, embryonic, and rearing life stages of salmon and trout. This relationship is attributed to the importance of interstitial spaces between coarse particles for successful incubation of embryos, emergence of fry, overwintering of juveniles, and production of food. Crouse et al. (1981) developed a substrate quality index for salmonid rearing habitat based on the relationship between substrate composition (dominant particle sizes and embeddedness) and the production of juvenile steelhead and coho salmon in laboratory streams. This index, when applied to the substrate data collected in 2001, indicate that riffle substrates in all of the monitoring reaches were generally of high quality. This conclusion is also consistent with the results of stream and laboratory studies that examined the effect of fine sediment (embeddedness) on abundance and behavior of juvenile salmon and trout under summer and winter habitat conditions (Hillman et al. 1987, Bustard and Narver 1975, Bjornn et al. 1977).

The suitability of riffle substrates for spawning also depends on substrate size and the size of female spawners. In general, maximum usable substrate size increases with female body size (i.e., larger fish can move larger rocks). Kondolf (2000) presents a relationship that suggests that spawning trout can move gravels with a median diameter of up to 10% of their body length. Based on typical growth rates and life spans of rainbow trout in the Rubicon River, most mature rainbow trout probably range from 6 to 12 inches (150 to 300 mm) in length. Brown trout also mature at these sizes but may live longer and attain larger sizes (up to 16–20 inches [400–500 mm]) (Department of Fish and Game 1979). Thus, fish of this size could use gravel with median diameters of up to 30–50 mm. This size range corresponds to the pebble substrate class (table 5). Thus, the occurrence of suitable spawning substrate (pebble and gravel) in the monitoring reaches is limited, comprising only 7–12% of riffle substrates in Reaches 3, 4, and 6: 20–23% of riffle substrates in Reaches 1, 2, and 5; and 42% of riffle substrates in Reach 7.

Sediment sampling was conducted in Ralston Afterbay in October 2001 to test for contaminants and characterize the size composition of sediments proposed for placement at Indian Bar (Placer County Water Agency 2001). A number of particle grain size distribution curves were generated from samples collected at each proposed bar location. All of the sampled sediment was considered acceptable for placement at Indian Bar and a secondary, offchannel location (Ralston Ridge). The size composition of sediment samples (by weight) was 40–50% cobble, 20-25% pebble, 10–20% gravel, and 10–20% sand. Consequently, much of the material that will be deposited at Indian Bar will be within a suitable size range for BMI habitat and trout spawning and rearing habitat.

## Benthic Macroinvertebrates

The results of the first year of BMI monitoring support the general conclusion that aquatic habitat in the project area is in good condition. However, additional monitoring is necessary to characterize annual and seasonal variability in BMI communities and define appropriate thresholds for evaluating project effects in future years. Both the substrate and BMI data indicate that the quality of aquatic habitat in the MFAR immediately below Ralston Dam (Reaches 3 and 4) is lower than that in the reaches farther downstream (Reaches 1 and 2) and the upstream control reaches (Reaches 5, 6, and 7). This pattern appears to be generally correlated with the coarser streambed (higher proportion of boulders) and smaller quantities of finer sediments and lower embeddedness in Reaches 3 and 4. For example, Reach 4 had the lowest average BMI productivity (2.1 g/m$^2$), highest mean substrate size (4.50 or cobble-boulder), and lowest embeddedness (0.20 or

<5%). Conversely, Reach 7 had the highest average BMI productivity (6.2 g/m$^2$), lowest mean substrate size (3.65 or pebble-cobble), and highest embeddedness (2.00 or 25–50%). Reach 6, which had a very similar substrate composition to Reach 4 but higher embeddedness (0.60 or 5–25%), had higher average productivity (3.3 g/m$^2$) than Reach 4. Reach 4 also had lower average taxa richness and EPT values than any other reach (excluding Reach 3 for reasons discussed earlier).

These results support the general observation that riffles with mixtures of intermediate-sized substrates (gravels, pebbles, and cobbles) and low to moderate amounts of fine sediment support larger, more diverse BMI communities than riffles with more uniform substrates of mostly fine (silt and sand) or very coarse sediment (boulder and bedrock) (Minshall 1984). Although large concentrations of fine sediment can reduce BMI abundance (by filling the spaces in which they live), riffle species appear to be adapted to moderate amounts of fine sediment that occur naturally in streams. Higher quantities of fine sediment may also signify higher quantities of particulate organic matter, an important food source for a number of BMI taxa.

Variation in BMI productivity, taxa richness, and EPT ratios among reaches may also reflect differences in other environmental factors or the interaction of these factors with substrate. For example, flow fluctuations associated with hydroelectric operations at dams can alter downstream BMI communities. Periodic dewatering of the stream margins during hydroelectric peaking operations has been shown to limit the ability of aquatic invertebrates to colonize these areas and achieve the densities that occur in areas that are constantly submerged (Gislason 1985). In addition, some taxa are particularly sensitive to changes in depths and water velocities that accompany changes in flows downstream of hydroelectric facilities. Flow fluctuations may also increase downstream drift of some invertebrates, leading to reductions in BMI abundance and diversity in the affected reaches (Cushman 1985). Differences in flow regime may provide a partial explanation for somewhat higher BMI diversity (taxa richness) in the control reaches where flows are relatively stable during the summer and fall.

Differences in water temperature, which can also be influenced by flows, may also explain some of the differences in BMI characteristics observed among the monitoring reaches. Temperature plays a major role in regulating the seasonal development patterns and growth rates of aquatic insects (Ward and Stanford 1982, Ward 1992). For example, it is possible that higher, more stable BMI productivity (biomass) in the Rubicon River (Reach 7) is related to higher water temperatures in this reach, as indicated by measurements taken during the summer and fall of 2001.

# Watershed Conditions in 2001

Ongoing or recent land management activities and disturbances that could affect sediment loads in the project area in future years include the Star Fire and associated landslides, timber sales, and prescription burns in Long Canyon, a major tributary of the Rubicon River (Mai pers. comm.). Suction dredge mining, an ongoing activity in the project area, may have localized effects on streambed conditions in the monitoring reaches. These activities and disturbances will continue to be monitored to determine their potential effects on the monitoring results in future years.

# Star Fire

The Star Fire was the largest and most significant watershed disturbance in the MFAR and Rubicon River watersheds in 2001. In August 2001, the fire burned approximately 16,761 acres of land in the Tahoe and El Dorado Forests upstream of Ralston Afterbay Reservoir, including much of the MFAR and North Fork Long Canyon (tributary to the Rubicon River) watersheds. No fires of this magnitude have been recorded since 1910 when detailed records were first made.

The Forest Service conducted a Cumulative Watershed Effects (CWE) analysis for the MFAR and North Fork Long Canyon watersheds following the Star Fire. CWE are defined as "all effects on beneficial uses of water that occur away from locations of actual land use, which are transmitted through the fluvial system." The purpose of the CWE analysis is to assess the potential for adverse effects on aquatic resources (e.g., increased sediment loads) from multiple land management activities based on the level of past disturbance and watershed sensitivity.

The MFAR watershed covers 5,644 acres and includes the MFAR downstream from French Meadows Reservoir (L. L. Anderson Dam) to its confluence with Duncan Canyon Creek. The Star Fire burned approximately 90% (5,037 acres) of the MFAR watershed. Burn severity, indicating the amount of ground cover and canopy cover remaining, was categorized as 46% high (2,619 acres), 32% moderate (1,796 acres), and 11% low (622 acres).

The North Fork Long Canyon watershed covers 4,197 acres and is drained by North Fork Long Canyon Creek from its headwaters to its confluence with the Rubicon River. The Star Fire burned approximately 45% (1,924 acres) of the watershed. Burn severity was categorized as 46% high (2,619 acres), 32% moderate (1,796 acres), and 11% low (622 acres).

Both the MFAR and North Fork Long Canyon watersheds are considered highly sensitive to disturbance because of climate characteristics (rain-on-snow events), relatively high runoff and peak flows during storm events, and high potential for soil erosion, slope failures, debris flows, and sediment loading to streams. Based on the CWE analysis of current watershed conditions, the potential for adverse cumulative effects from increased flows and/or sediment loading was rated "high" for the North Fork Long Canyon watershed and "very high" for the MFAR watershed. This rating is largely a result of the effect of the Star Fire on the amount of groundcover in the watershed and additional vegetation removal and soil compaction from fire suppression operations. The Forest Service concluded that the chances are very high that a high intensity rainfall or rain-on-snow event will trigger significant soil erosion that could increase sediment input into the MFAR and Rubicon Rivers. It was also predicted that the potential for significant cumulative watershed effects will continue for the next 3–5 years as the watersheds recover from the fire and past management activities.

The greatest potential source for increased sediment delivery to the project area in future years is the Rubicon watershed. Compared to the MFAR watershed, the Rubicon watershed has a greater percentage of geologic parent materials that are less resistant to accelerated surface erosion and mass movement (e.g., landslides). In addition, Interbay Dam serves as a sediment trap for any sediment mobilized from the burned portions of the MFAR watershed. Finally, because the North Fork Long Canyon watershed contains a higher percentage of private lands (70% versus 35% in the MFAR watershed), the ability of the El Dorado National Forest to implement remediation measures is reduced.

## Landslides

Landslide activity in the Long Canyon watershed is recognized as a continuing source of sediment input to the river system. The most recent information is from a slope stability survey conducted in potential timber salvage areas after the Star Fire (Dailey 2001). Of the 14 slides examined (450 acres), most showed some evidence of continued instability, but no recent significant slope failures were identified.

## Timber Operations and Prescription Burns

Several timber sales, salvage operations, and prescribed burns occurred on Forest Service land in the MFAR and Rubicon watersheds in 2001. These activities are not considered to pose major sediment concerns, based on recent observations and required remediation measures (Mai pers. comm., Jue pers. comm.).

## Suction Dredge Mining

In 2001, we observed active suction dredge mining activities in the North Fork MFAR (downstream of Transects 33–35 in Reach 6) and evidence of past activity (dredge pits) in Reaches 4 and 7. An active claim exists in Reach 7. Other locations where suction dredge mining has been observed in recent years is American Bar on the MFAR (downstream of Reach 3) and in the MFAR between Volcano and Otter Creeks (Smith pers. comm.).

# Conclusion

The results of the first year of monitoring support the prediction that the sediment management program has the potential to improve habitat quality downstream of Ralston Afterbay. Both the substrate and BMI data indicate that habitat quality and diversity in the reaches immediately downstream of the dam (Reaches 3 and 4) are lower than other reaches because of channel armoring and associated losses of intermediate-sized materials (gravels, pebbles, and cobbles). These materials—considered critical to maintaining suitable stream habitat for trout and BMI habitat—will be made available once again by the placement of reservoir sediments at Indian Bar. As proposed, preproject monitoring will continue in 2002 to further characterize annual variation in substrate and BMI communities in the treatment and control reaches, further examine relationships between substrate and BMI characteristics, and provide baseline data for evaluating the effects of both SPT operations and sediment disposal once these activities begin.

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Appendix A

# Tables

**Table 1.** 2001 Substrate Size and Embeddedness Data for Reach 1 – Middle Fork American River above Otter Creek (Data collected October 22 and 23, 2001)



| | | Substrate Type | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Embeddedness |
| | **Transect 1** | | | | | | | | | | | |
| Location (m) | 2 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 3 | 4 | |
| | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 4 | 4 | 4 | 4 | |
| | 6 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 4 | 4 | |
| | 8 | 4 | 4 | 4 | 4 | 4 | 5 | 5 | 5 | 4 | 4 | |
| | 10 | 3 | 4 | 4 | 4 | 4 | 4 | 5 | 5 | 5 | 5 | 2 |
| | 12 | 5 | 4 | 4 | 4 | 4 | 4 | 4 | 5 | 5 | 5 | |
| | 14 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 5 | 5 | 5 | |
| | 16 | 4 | 4 | 5 | 5 | 5 | 4 | 3 | 4 | 4 | 3 | |
| | 18 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 5 | |
| | 20 | 4 | 3 | 5 | 5 | 5 | 5 | 5 | 5 | 4 | 4 | |
| | 22 | B | B | B | B | B | B | B | B | B | B | |
| | 24 | B | B | B | B | B | B | B | B | B | B | |
| | **Transect 2** | | | | | | | | | | | |
| Location (m) | 2 | 4 | 4 | 5 | 5 | 5 | 5 | 3 | 5 | 5 | 4 | |
| | 4 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | |
| | 6 | 4 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | |
| | 8 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | |
| | 10 | 4 | 4 | 4 | 4 | 3 | 4 | 4 | 3 | 4 | 4 | 2 |
| | 12 | 4 | 4 | 4 | 4 | 4 | 3 | 4 | 3 | 4 | 4 | |
| | 14 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | |
| | 16 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | |
| | 18 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 4 | 4 | 4 | |
| | 20 | 4 | 4 | 4 | 4 | 4 | 2 | 3 | 4 | 3 | 5 | |
| | 22 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | |
| | 24 | 5 | 5 | 5 | 4 | 4 | 4 | 2 | B | B | B | |
| | 26 | B | 4 | 4 | 4 | 4 | 4 | B | B | B | B | |
| | **Transect 3** | | | | | | | | | | | |
| Location (m) | 5 | 4 | 3 | 3 | 4 | 4 | 4 | 4 | 3 | 4 | 4 | |
| | 10 | 4 | 4 | 4 | 3 | 4 | 4 | 3 | 4 | 4 | 4 | |
| | 15 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | |
| | 20 | 4 | 4 | 4 | 4 | 4 | 3 | 4 | 4 | 2 | 4 | |
| | 25 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 4 | 4 | 4 | |
| | 30 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 3 | 4 | 4 | |
| | 35 | 4 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 4 | |
| | 40 | 3 | 3 | 4 | 4 | 4 | 3 | 4 | 3 | 2 | 4 | 3 |
| | 45 | 4 | 4 | 3 | 4 | 4 | 4 | 4 | 4 | 3 | 4 | |
| | 50 | 3 | 4 | 2 | 4 | 4 | 4 | 3 | 4 | 4 | 3 | |
| | 55 | 4 | 4 | 4 | 4 | 3 | 3 | 3 | 4 | 2 | 4 | |

**Table 1.** Continued



| Location (m) | Substrate Type 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Embeddedness |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Transect 4** | | | | | | | | | | | |
| 5 | 4 | 4 | 4 | 4 | 3 | 4 | 3 | 3 | 4 | 4 | |
| 10 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | |
| 15 | 3 | 4 | 4 | 4 | 4 | 4 | 3 | 4 | 4 | 4 | |
| 20 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 4 | |
| 25 | 3 | 4 | 4 | 4 | 3 | 5 | 5 | 3 | 3 | 4 | |
| 30 | 3 | 4 | 4 | 4 | 5 | 5 | 5 | 4 | 4 | 4 | 3 |
| 35 | 4 | 3 | 4 | 3 | 4 | 4 | 4 | 3 | 4 | 4 | |
| 40 | 4 | 4 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | |
| 45 | 4 | 4 | 3 | 3 | 3 | 4 | 4 | 2 | 4 | 3 | |
| 50 | 5 | 5 | 1 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | |
| **Transect 5** | | | | | | | | | | | |
| 2 | B | B | B | B | B | B | B | B | B | B | |
| 7 | 3 | 3 | 4 | 3 | 4 | 4 | 4 | 3 | 4 | 4 | |
| 12 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | |
| 17 | 5 | 5 | 5 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | |
| 22 | 4 | 4 | 5 | 5 | 5 | 4 | 3 | 4 | 4 | 4 | |
| 27 | 4 | 4 | 4 | 4 | 3 | 4 | 3 | 4 | 4 | 3 | |
| 32 | 3 | 4 | 4 | 3 | 4 | 4 | 3 | 3 | 4 | 4 | |
| 37 | 4 | 4 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | |
| 42 | 4 | 4 | 3 | 4 | 3 | 4 | 2 | 3 | 4 | 4 | |
| 47 | 3 | 3 | 4 | 4 | 3 | 3 | 4 | 4 | 3 | 4 | |
| 52 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 4 | 3 |
| 57 | B | B | B | 4 | 3 | 4 | 2 | 2 | B | B | |
| **Transect 6** | | | | | | | | | | | |
| 1 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | |
| 5 | 4 | 4 | 4 | 4 | 4 | 5 | 5 | 4 | 4 | 4 | |
| 9 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | |
| 13 | 4 | 4 | 4 | 4 | 4 | 4 | 5 | 5 | 5 | 5 | |
| 17 | 4 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 4 | |
| 21 | 3 | 4 | 3 | 4 | 4 | 3 | 4 | 4 | 4 | 4 | |
| 25 | 3 | 4 | 4 | 4 | 4 | 3 | 3 | 3 | 3 | 4 | |
| 29 | 3 | 3 | 3 | 4 | 4 | 3 | 3 | 4 | 4 | 4 | |
| 33 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 4 | 3 | 3 |
| 37 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 3 | 3 | 2 | |
| 41 | 5 | 5 | 3 | 5 | 5 | 4 | 4 | 3 | 4 | 4 | |
| 45 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 1 | 4 | 4 | |

**Table 1.** Continued



| Location (m) | Substrate Type 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Embeddedness |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Transect 7** | | | | | | | | | | | |
| 4 | 4 | 4 | 5 | 5 | 5 | 5 | 5 | 4 | 4 | 4 | |
| 8 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 4 | 4 | |
| 12 | B | B | B | B | B | B | B | B | B | B | |
| 16 | 4 | 4 | 4 | 4 | 4 | 2 | 3 | 4 | 4 | 4 | 3 |
| 20 | 4 | 4 | 4 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | |
| 24 | 4 | 4 | 4 | 3 | 3 | 4 | 3 | 5 | 5 | 4 | |
| 28 | 4 | 4 | 4 | 4 | 4 | 3 | 4 | 4 | 1 | 4 | |
| 32 | 5 | 5 | 3 | 3 | 4 | 4 | 3 | 3 | 3 | 3 | |
| 36 | 4 | 3 | 3 | 3 | 4 | 3 | 4 | 3 | 4 | 4 | |
| 40 | 4 | 4 | 3 | 4 | 4 | 3 | 4 | 3 | 3 | 3 | |
| 44 | 4 | 4 | 4 | 3 | 3 | 4 | 4 | 4 | 2 | 4 | |
| 48 | 3 | 4 | 4 | 4 | 3 | 3 | 3 | 4 | 4 | 2 | |
| **Transect 8** | | | | | | | | | | | |
| 4 | 4 | 4 | 4 | 4 | 5 | 5 | 5 | 5 | 4 | 4 | |
| 8 | 0 | 0 | 0 | 0 | 0 | 5 | 5 | 5 | 2 | 2 | |
| 12 | B | B | B | B | B | B | B | B | B | B | |
| 16 | 4 | 3 | 4 | 4 | 3 | 3 | 4 | 4 | 4 | 4 | |
| 20 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 4 | 4 | 3 |
| 24 | 4 | 4 | 5 | 5 | 4 | 4 | 4 | 1 | 5 | 3 | |
| 28 | 4 | 4 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | |
| 32 | 4 | 4 | 4 | 3 | 3 | 4 | 3 | 4 | 4 | 3 | |
| 36 | 5 | 5 | 5 | 4 | 4 | 5 | 5 | 5 | 3 | 4 | |
| 40 | 3 | 4 | 3 | 4 | 3 | 2 | 2 | 4 | 4 | 4 | |
| 44 | 3 | 3 | 4 | 3 | 4 | 4 | 4 | 4 | 3 | 3 | |
| 48 | 3 | 4 | 3 | 4 | 4 | 4 | 3 | 4 | 3 | 4 | |
| 52 | 4 | 3 | 4 | 4 | 5 | 2 | 3 | 4 | 3 | 3 | |
| 56 | 4 | 4 | 4 | 4 | 3 | 4 | 3 | 4 | 3 | 4 | |

See tables 5 and 6 in report for descriptions of substrate type and embeddedness codes.

B = Bedrock

**Table 2.** 2001 Substrate Size and Embeddedness Data for Reach 2 – Middle Fork American River above Volcano Creek (Data collected October 22, 2001)



| Location (m) | Substrate Type 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Embeddedness |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Transect 9** | | | | | | | | | | | |
| 6 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | |
| 12 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 5 | 5 | 5 | |
| 18 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | |
| 24 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | |
| 30 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 3 | 5 | |
| 36 | 4 | 3 | 3 | 3 | 4 | 3 | 3 | 3 | 4 | 4 | |
| 42 | 4 | 3 | 3 | 3 | 4 | 4 | 3 | 2 | 4 | 3 | |
| 48 | 4 | 3 | 3 | 3 | 4 | 4 | 4 | 3 | 4 | 4 | |
| 54 | 3 | 3 | 4 | 3 | 4 | 3 | 2 | 2 | 3 | 4 | 3 |
| 60 | 3 | 3. | 3 | 4 | 3 | 3 | 3 | 3 | 4 | 4 | |
| 66 | 4 | 4 | 4 | 4 | 4 | 3 | 4 | 4 | 3 | 4 | |
| 72 | 4 | 4 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | |
| 78 | 5 | 5 | 5 | 4 | 4 | 5 | 3 | 4 | 4 | 3 | |
| 84 | 4 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 3 | 4 | |
| 90 | 5 | 4 | 4 | 4 | 3 | 3 | 3 | 4 | 3 | 3 | |
| **Transect 10** | | | | | | | | | | | |
| 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | |
| 10 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | |
| 19 | 2 | 2 | 2 | 2 | 2 | 3 | 2 | 3 | 2 | 2 | |
| 28 | 4 | 4 | 2 | 4 | 3 | 4 | 4 | 2 | 4 | 4 | |
| 37 | 4 | 4 | 4 | 4 | 4 | 2 | 4 | 4 | 3 | 4 | |
| 46 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 4 | 4 | 4 | |
| 55 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 3 | 4 | 2 |
| 64 | 4 | 4 | 3 | 4 | 4 | 3 | 3 | 4 | 4 | 4 | |
| 73 | 4 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | |
| 82 | 4 | 3 | 4 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | |
| 91 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | |
| 100 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | |
| 109 | 4 | 3 | 4 | 4 | 4 | 3 | 4 | 4 | 3 | 4 | |
| 118 | 4 | 4 | 4 | 4 | 3 | 3 | 3 | 3 | 3 | 4 | |
| 127 | 5 | 3 | 5 | 1 | 5 | 5 | 5 | 5 | 5 | 5 | |
| **Transect 11** | | | | | | | | | | | |
| 1 | 4 | 1 | 1 | 4 | 1 | 4 | 5 | 5 | 5 | 4 | |
| 3 | 5 | 5 | 5 | 4 | 4 | 2 | 5 | 5 | 5 | 5 | |
| 5 | 5 | 5 | 4 | 5 | 5 | 5 | 3 | 4 | 5 | 5 | |
| 7 | 5 | 5 | 5 | 4 | 4 | 3 | 5 | 5 | 5 | 5 | |
| 9 | 5 | 5 | 3 | 5 | 5 | 5 | 5 | 4 | 4 | 4 | |
| 11 | 5 | 5 | 5 | 4 | 5 | 5 | 5 | 4 | 4 | 4 | |
| 13 | 5 | 5 | 5 | 5 | 5 | 5 | 3 | 5 | 4 | 5 | |
| 15 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 2 | 5 | 5 | |
| 17 | 5 | 5 | 5 | 5 | 4 | 4 | 2 | 5 | 5 | 5 | |
| 19 | 4 | 4 | 4 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 3 |
| 21 | 5 | 5 | 5 | 5 | 4 | 5 | 4 | 4 | 4 | 4 | |
| 23 | 5 | 3 | 5 | 5 | 5 | 3 | 4 | 3 | 5 | 5 | |
| 25 | 4 | 4 | 4 | 4 | 4 | 3 | B | B | B | B | |
| 27 | B | B | B | B | B | B | B | B | B | B | |
| 29 | B | B | B | B | B | B | B | B | B | B | |

**Table 2.** Continued



| Location (m) | Substrate Type 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Embeddedness |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Transect 12** | | | | | | | | | | | |
| 1 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 5 | 5 | 5 | |
| 3 | 5 | 5 | 5 | 4 | 4 | 4 | 3 | 4 | 4 | 4 | |
| 5 | 4 | 5 | 5 | 5 | 5 | 5 | 5 | 4 | 4 | 4 | |
| 7 | 3 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 4 | |
| 9 | 4 | 4 | 4 | 4 | 2 | 4 | 4 | 3 | 5 | 5 | |
| 11 | 5 | 5 | 5 | 4 | 4 | 4 | 3 | 5 | 5 | 5 | |
| 13 | 4 | 3 | 3 | 4 | 3 | 4 | 4 | 3 | 4 | 4 | |
| 15 | 5 | 4 | 4 | 4 | 4 | 5 | 5 | 5 | 5 | 5 | |
| 17 | 5 | 5 | 4 | 4 | 5 | 5 | 4 | 4 | 3 | 4 | |
| 19 | 4 | 4 | 5 | 5 | 5 | 5 | 5 | 4 | 4 | 4 | |
| 21 | 5 | 5 | 5 | 5 | 5 | 4 | 5 | 5 | 5 | 3 | 3 |
| 23 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 4 | 4 | 4 | |
| 25 | B | B | B | B | B | B | B | B | B | B | |
| 27 | B | B | B | B | B | B | B | B | B | B | |
| 29 | B | B | B | B | B | B | B | B | B | B | |
| **Transect 13** | | | | | | | | | | | |
| 1 | 5 | 4 | 4 | 4 | 5 | 5 | 4 | 3 | 3 | 4 | |
| 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 5 | 5 | |
| 7 | 5 | 4 | 4 | 4 | 5 | 5 | 5 | 5 | 4 | 4 | |
| 10 | 5 | 5 | 5 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | |
| 13 | 4 | 4 | 5 | 4 | 4 | 4 | 3 | 3 | 4 | 3 | |
| 16 | 4 | 4 | 4 | 4 | 4 | 5 | 5 | 5 | 5 | 4 | |
| 19 | 4 | 4 | 4 | 4 | 5 | 5 | 5 | 5 | 5 | 4 | |
| 22 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 4 | 4 | |
| 25 | 4 | 5 | 5 | 5 | 5 | 3 | 4 | 3 | 3 | 5 | |
| 28 | 4 | 5 | 5 | 5 | 4 | 4 | 5 | 5 | 5 | 5 | |
| 31 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 5 | 5 | |
| 34 | 4 | 4 | 4 | 4 | 4 | 5 | 5 | 5 | 5 | 5 | |
| 37 | 4 | 5 | 5 | 5 | 4 | 3 | 4 | 3 | 4 | 4 | 2 |
| 40 | 4 | 4 | 4 | 4 | 3 | 3 | 4 | 4 | 4 | 4 | |
| 43 | 3 | 4 | 4 | 4 | 4 | 2 | 2 | 4 | 5 | 5 | |
| **Transect 14** | | | | | | | | | | | |
| 1 | 4 | 4 | 4 | 4 | 4 | 0 | 4 | 4 | 5 | 5 | |
| 5 | 4 | 4 | 3 | 2 | 2 | 2 | 2 | 3 | 2 | 3 | |
| 9 | 3 | 3 | 3 | 4 | 3 | 4 | 4 | 4 | 4 | 4 | |
| 13 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 4 | 4 | 4 | |
| 17 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 3 | 3 | 5 | |
| 21 | 4 | 4 | 4 | 4 | 5 | 5 | 5 | 4 | 4 | 4 | |
| 25 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | |
| 29 | 4 | 3 | 2 | 2 | 4 | 4 | 3 | 3 | 3 | 4 | |
| 33 | 4 | 4 | 4 | 4 | 4 | 4 | 5 | 2 | 5 | 5 | |
| 37 | 5 | 4 | 3 | 3 | 4 | 3 | 4 | 5 | 5 | 5 | |
| 41 | 4 | 5 | 3 | 4 | 4 | 5 | 5 | 5 | 5 | 5 | |
| 45 | 4 | 4 | 3 | 4 | 4 | 3 | 4 | 4 | 2 | 2 | |
| 49 | 3 | 4 | 4 | 4 | 3 | 3 | 4 | 4 | 3 | 3 | 3 |
| 53 | 3 | 3 | 4 | 4 | 4 | 3 | 4 | 4 | 4 | 3 | |

**Table 2.** Continued



| Location (m) | Substrate Type 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Embeddedness |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Transect 15** | | | | | | | | | | | |
| 3 | 5 | 5 | 4 | 4 | 5 | 5 | 5 | 4 | 4 | 4 | |
| 7 | 3 | 2 | 3 | 3 | 2 | 2 | 3 | 3 | 3 | 3 | |
| 11 | 4 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 3 | 4 | |
| 15 | 4 | 4 | 4 | 3 | 4 | 3 | 4 | 4 | 4 | 4 | |
| 19 | 4 | 4 | 4 | 5 | 5 | 5 | 4 | 4 | 4 | 5 | |
| 23 | 5 | 5 | 4 | 5 | 4 | 4 | 4 | 4 | 4 | 4 | |
| 27 | 5 | 5 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | |
| 31 | 3 | 3 | 1 | 4 | 3 | 5 | 5 | 5 | 5 | 5 | |
| 35 | 4 | 4 | 3 | 4 | 5 | 5 | 5 | 5 | 5 | 4 | |
| 39 | 4 | 4 | 4 | 2 | 5 | 5 | 4 | 4 | 4 | 4 | |
| 43 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| 47 | 3 | 3 | 4 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | |
| 51 | 3 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | |

See tables 5 and 6 in report for descriptions of substrate type and embeddedness codes.

B = Bedrock

**Table 3.** 2001 Substrate Size and Embeddedness Data for Reach 3 – Middle Fork American River between Horseshoe Bar and North Fork of the Middle Fork American River Confluence (Data collected October 19, 2001)



| Location (m) | Substrate Type 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Embeddedness |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Transect 16** | | | | | | | | | | | |
| 1 | B | B | B | B | B | B | B | B | B | B | |
| 5 | B | B | B | B | B | B | B | B | B | B | |
| 9 | 5 | 5 | 3 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | |
| 13 | 4 | 4 | 4 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 1 |
| 17 | 5 | 5 | 5 | 4 | 4 | 5 | 5 | 5 | 5 | 2 | |
| 21 | 5 | 5 | 4 | 4 | 5 | 5 | 5 | 5 | 5 | 3 | |
| 25 | 5 | 5 | 5 | 5 | 2 | 2 | 5 | 5 | 5 | 5 | |
| 29 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 2 | 4 | 4 | |
| 33 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | |
| 37 | 5 | 5 | 5 | 5 | 4 | 4 | 4 | 3 | 4 | 5 | |
| 41 | 3 | 4 | 4 | 4 | 4 | 2 | 5 | 5 | 5 | 5 | |
| 45 | 5 | 5 | 5 | 5 | 3 | 5 | 5 | 5 | 1 | 1 | |
| 49 | 4 | 4 | 4 | 4 | 4 | 3 | 5 | 4 | 4 | 4 | |
| **Transect 17** | | | | | | | | | | | |
| 3 | B | B | 3 | 3 | 4 | B | B | B | B | B | |
| 6 | B | B | 5 | 5 | 5 | 5 | 5 | 5 | 4 | 5 | |
| 9 | 5 | 4 | 4 | 3 | 5 | 5 | 5 | 5 | 5 | 5 | 1 |
| 12 | 5 | 5 | 5 | 4 | 4 | 5 | 5 | 5 | 5 | 5 | |
| 15 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | |
| 18 | 5 | 5 | 5 | 4 | 4 | 4 | 4 | 4 | 3 | 4 | |
| 21 | 5 | 5 | 5 | 5 | 5 | 4 | 4 | 4 | 3 | 4 | |
| 24 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 4 | 4 | |
| 27 | 5 | 5 | 5 | 4 | 5 | 5 | 5 | 5 | 5 | 5 | |
| 30 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | |
| 33 | 4 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 4 | |
| 36 | 4 | 5 | 5 | 1 | 5 | 5 | 5 | 5 | 4 | 4 | |
| 39 | 1 | 1 | 4 | 4 | 5 | 5 | 1 | 1 | 5 | 5 | |
| **Transect 18** | | | | | | | | | | | |
| 3 | B | B | B | B | B | B | B | 3 | 3 | 4 | |
| 6 | 4 | 4 | 4 | 4 | 3 | 5 | 5 | 4 | 3 | 4 | 1 |
| 9 | 5 | 5 | 5 | 5 | 5 | 5 | 1 | 1 | 5 | 5 | |
| 12 | 5 | 1 | 4 | 4 | 3 | 4 | 2 | 4 | 4 | 4 | |
| 15 | 5 | 5 | 2 | 4 | 5 | 4 | 4 | 4 | 4 | 4 | |
| 18 | 1 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 3 | 4 | |
| 21 | 1 | 1 | 2 | 4 | 4 | 5 | 5 | 5 | 5 | 5 | |
| 24 | 4 | 1 | 5 | 5 | 2 | 2 | 5 | 5 | 5 | 5 | |
| 27 | 5 | 5 | 5 | 5 | 5 | 5 | 4 | 5 | 5 | 4 | |
| 30 | 5 | 5 | 3 | 1 | 5 | 5 | 5 | 5 | 5 | 5 | |
| 33 | 4 | 4 | 4 | 4 | 5 | 5 | 5 | 5 | 5 | 5 | |
| 36 | 5 | 5 | 2 | 4 | 4 | 5 | 5 | 5 | 5 | 5 | |
| 39 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | |
| 42 | 5 | 5 | 2 | 2 | 3 | 2 | 4 | 4 | 4 | 4 | |

**Table 3.** Continued



| Location (m) | Substrate Type 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Embeddedness |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Transect 19** | | | | | | | | | | | |
| 2 | B | B | B | B | B | B | 4 | 4 | 5 | 5 | |
| 5 | 4 | 4 | 3 | 4 | 3 | 4 | 4 | 3 | 3 | 4 | |
| 8 | 2 | 5 | 5 | 5 | 3 | 4 | 4 | 3 | 4 | 2 | |
| 11 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 3 | 4 | 4 | |
| 14 | 1 | 3 | 1 | 3 | 4 | 4 | 4 | 4 | 5 | 1 | 3 |
| 17 | 5 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | |
| 20 | 4 | 4 | 4 | 4 | 3 | 4 | 4 | 4 | 4 | 4 | |
| 23 | 5 | 4 | 4 | 5 | 5 | 5 | 5 | 5 | 3 | 4 | |
| 26 | 4 | 4 | 3 | 3 | 5 | 5 | 5 | 4 | 4 | 4 | |
| 29 | 3 | 3 | 4 | 4 | 4 | 4 | 3 | 4 | 4 | 3 | |
| 32 | 3 | 4 | 4 | 3 | 3 | 4 | 4 | 4 | 4 | 1 | |

See tables 5 and 6 in report for descriptions of substrate type and embeddedness codes.

B = Bedrock

**Table 4.** 2001 Substrate Size and Embeddedness Data for Reach 4 – Middle Fork American River between the North Fork of the Middle Fork American River and Ralston Dam (Data collected October 19, 2001)



| | | Substrate Type | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Embeddedness |
| | **Transect 20** | | | | | | | | | | | |
| Location (m) | 1 | 5 | 4 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | |
| | 3 | 4 | 3 | 5 | 4 | 5 | 5 | 5 | 5 | 5 | 5 | |
| | 5 | 5 | 4 | 4 | 4 | 4 | 5 | 5 | 5 | 5 | 4 | 1 |
| | 7 | 5 | 4 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | |
| | 9 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | |
| | 11 | 5 | 4 | 4 | 4 | 4 | 5 | 5 | 5 | 5 | 5 | |
| | **Transect 21** | | | | | | | | | | | |
| Location (m) | 1 | 4 | 4 | 3 | 4 | 5 | 5 | 5 | 5 | 5 | 5 | |
| | 3 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | |
| | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 1 |
| | 7 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | |
| | 9 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | |
| | 11 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | |
| | 13 | 5 | 5 | 5 | 5 | 4 | 5 | 5 | 4 | 4 | 4 | |
| | **Transect 22** | | | | | | | | | | | |
| Location (m) | 1 | 3 | 4 | 5 | 5 | 5 | 4 | 4 | 4 | 4 | 2 | |
| | 3 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | |
| | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 4 | |
| | 7 | 5 | 5 | 5 | 3 | 3 | 5 | 5 | 5 | 5 | 5 | |
| | 9 | 4 | 5 | 5 | 4 | 5 | 5 | 3 | 3 | 4 | 4 | |
| | 11 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 4 | |
| | 13 | 5 | 5 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | |
| | 15 | 4 | 5 | 5 | 5 | 5 | 5 | 4 | 4 | 4 | 4 | 1 |
| | 17 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | |
| | 19 | 5 | 5 | 5 | 5 | 4 | 4 | 5 | 5 | 5 | 5 | |
| | 21 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | |
| | 23 | 4 | 5 | 5 | 5 | 5 | 4 | 4 | 5 | 5 | 5 | |
| | 25 | B | B | B | B | B | B | B | B | B | B | |
| | **Transect 23** | | | | | | | | | | | |
| Location (m) | 1 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 1 | 4 | |
| | 3 | 5 | 3 | 2 | 5 | 4 | 3 | 4 | 5 | 5 | 5 | |
| | 5 | 4 | 3 | 3 | 5 | 5 | 5 | 5 | 2 | 4 | 4 | |
| | 7 | 4 | 4 | 4 | 5 | 5 | 5 | 4 | 4 | 1 | 1 | |
| | 9 | 4 | 5 | 5 | 5 | 5 | 4 | 4 | 2 | 2 | 3 | |
| | 11 | 5 | 5 | 5 | 5 | 4 | 5 | 5 | 3 | 3 | 3 | |
| | 13 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | |
| | 15 | 5 | 5 | 5 | 2 | 4 | 5 | 5 | 5 | 5 | 5 | 1 |
| | 17 | 4 | 4 | 4 | 4 | 3 | 4 | 2 | 2 | 0 | 2 | |
| | 19 | 5 | 5 | 2 | 3 | 4 | 4 | 4 | 4 | 5 | 5 | |
| | 21 | 4 | 4 | 5 | 5 | 5 | 5 | 5 | 4 | 4 | 5 | |

**Table 4.** Continued



| Location (m) | Substrate Type 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Embeddedness |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Transect 24** | | | | | | | | | | | |
| 3 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 4 | 4 | |
| 6 | 5 | 4 | 4 | 5 | 5 | 1 | 5 | 5 | 1 | 5 | |
| 9 | 5 | 5 | 5 | 1 | 1 | 1 | 1 | 1 | 5 | 5 | |
| 12 | 5 | 3 | 4 | 5 | 5 | 5 | 3 | 5 | 5 | 5 | |
| 15 | 5 | 5 | 5 | 3 | 3 | 4 | 4 | 3 | 4 | 4 | |
| 18 | 5 | 5 | 5 | 4 | 4 | 5 | 4 | 5 | 5 | 5 | 2 |
| 21 | 5 | 5 | 5 | 5 | 5 | 5 | 4 | 4 | 5 | 5 | |
| 24 | 4 | 3 | 4 | 5 | 5 | 5 | 4 | 3 | 5 | 5 | |
| 27 | 5 | 5 | 5 | 1 | 5 | 5 | 5 | 5 | 5 | 5 | |
| 30 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | |
| 33 | 5 | 5 | 5 | 5 | 5 | 5 | 4 | 4 | 5 | 5 | |
| 36 | | | | | | | | | | | |
| 39 | 5 | 5 | 5 | 5 | 5 | 5 | 4 | 4 | 4 | 4 | |

See tables 5 and 6 in report for descriptions of substrate type and embeddedness codes.

B = Bedrock

**Table 5.** 2001 Substrate Size and Embeddedness Data for Reach 5 – Middle Fork American River above Ralston Afterbay (Data collected October 18, 2001)



| | Substrate Type | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Location (m) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Embeddedness |
| **Transect 25** | | | | | | | | | | | |
| 2 | 4 | 4 | 4 | 4 | 4 | 3 | 4 | 4 | 4 | 4 | |
| 4 | 4 | 3 | 4 | 3 | 4 | 3 | 4 | 4 | 4 | 4 | |
| 6 | 3 | 4 | 4 | 4 | 4 | 5 | 5 | 5 | 5 | 4 | 1 |
| 8 | 5 | 5 | 4 | 4 | 2 | 4 | 4 | 4 | 3 | 4 | |
| 10 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 4 | 3 | 3 | |
| **Transect 26** | | | | | | | | | | | |
| 2 | B | B | B | 3 | 3 | 3 | 2 | 2 | 2 | 2 | |
| 4 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | |
| 6 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | |
| 8 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 1 |
| 10 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 4 | 4 | |
| 12 | 4 | 4 | 5 | 5 | 5 | 5 | 5 | 5 | 4 | 4 | |
| 14 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | |
| **Transect 27** | | | | | | | | | | | |
| 2 | 5 | 5 | 5 | 5 | 4 | 4 | 4 | 4 | 3 | 4 | |
| 4 | 4 | 4 | 4 | 4 | 3 | 4 | 4 | 4 | 4 | 4 | |
| 6 | 4 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | |
| 8 | 5 | 5 | 5 | 4 | 3 | 4 | 3 | 3 | 5 | 5 | 2 |
| 10 | 3 | 3 | 2 | 4 | 3 | 3 | 3 | 3 | 3 | 3 | |
| 12 | 3 | 4 | 3 | 4 | 3 | 4 | 4 | 2 | 4 | 4 | |
| 14 | 4 | 4 | 3 | 3 | 4 | 1 | 4 | 2 | 4 | 4 | |
| 16 | 4 | 4 | 4 | 3 | 5 | 5 | 5 | 5 | 5 | 5 | |
| 18 | 4 | 3 | 4 | 4 | 4 | 2 | 4 | 4 | 4 | 4 | |
| 20 | 4 | 3 | 4 | 4 | 4 | 3 | 5 | 5 | 5 | 2 | |
| 22 | 5 | 5 | 5 | 3 | 3 | 5 | 5 | 5 | 5 | 4 | |
| 24 | 5 | 4 | 5 | 5 | 5 | 5 | 5 | 5 | | | |
| **Transect 28** | | | | | | | | | | | |
| 1 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | |
| 3 | 5 | 5 | 5 | 4 | 4 | 5 | 5 | 5 | 2 | 4 | |
| 5 | 5 | 5 | 5 | 5 | 4 | 2 | 4 | 4 | 3 | 5 | |
| 7 | 5 | 3 | 3 | 4 | 4 | 4 | 5 | 5 | 5 | 5 | 2 |
| 9 | 3 | 4 | 3 | 4 | 5 | 5 | 5 | 5 | 5 | 5 | |
| 11 | 3 | 2 | 4 | 3 | 5 | 5 | 5 | 3 | 2 | 2 | |
| 13 | 4 | 2 | 3 | 4 | 3 | 4 | 4 | 4 | 3 | 4 | |
| 15 | 5 | 5 | 5 | 5 | 5 | 3 | 3 | 3 | 4 | 4 | |
| 17 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | |
| 19 | 4 | 4 | 4 | 1 | 3 | 3 | 4 | 3 | 4 | 4 | |
| 21 | 4 | 4 | 1 | 1 | 3 | 4 | 0 | 5 | 5 | 5 | |

**Table 5.** Continued



| | | Substrate Type | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Embeddedness |
| | **Transect 29** | | | | | | | | | | | |
| Location (m) | 2 | 1 | 1 | 4 | 1 | 2 | 4 | 3 | 3 | 4 | 4 | |
| | 4 | 4 | 3 | 3 | 4 | 5 | 5 | 5 | 5 | 3 | 4 | |
| | 6 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | |
| | 8 | 5 | 5 | 5 | 5 | 5 | 5 | 4 | 4 | 3 | 3 | 2 |
| | 10 | 5 | 5 | 4 | 5 | 5 | 5 | 5 | 5 | 4 | 4 | |
| | 12 | 4 | 5 | 5 | 5 | 4 | 4 | 5 | 5 | 5 | 5 | |
| | 14 | 5 | 3 | 4 | 3 | 5 | 5 | 5 | 2 | 3 | 4 | |
| | 16 | 5 | 5 | 5 | 4 | 5 | 5 | 5 | 5 | 5 | 5 | |
| | **Transect 30** | | | | | | | | | | | |
| Location (m) | 1 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | |
| | 3 | 4 | 3 | 3 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | |
| | 5 | 3 | 4 | 4 | 3 | 4 | 4 | 4 | 4 | 3 | 5 | |
| | 7 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 2 |
| | 9 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 5 | 5 | |
| | 11 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 4 | 5 | |
| | 13 | 5 | 5 | 5 | 5 | 5 | 5 | 3 | 5 | 5 | 5 | |

See tables 5 and 6 in report for descriptions of substrate type and embeddedness codes.

B = Bedrock

**Table 6.** 2001 Substrate Size and Embeddedness Data for Reach 6 - North Fork of the Middle Fork American River (Data collected October 18, 2001)



| | Substrate Type | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Location (m) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Embeddedness |
| **Transect 31** | | | | | | | | | | | |
| 1 | 4 | 4 | 4 | 3 | 2 | 4 | 4 | 4 | 4 | 4 | |
| 3 | 5 | 5 | 1 | 4 | 1 | 5 | 5 | 5 | 5 | 5 | |
| 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | |
| 7 | 4 | 3 | 4 | 3 | 4 | 5 | 5 | 5 | 5 | 5 | |
| 9 | 5 | 5 | 5 | 3 | 5 | 5 | 4 | 4 | 3 | 3 | |
| 11 | 4 | 4 | 5 | 5 | 5 | 5 | 5 | 4 | 5 | 5 | 1 |
| 13 | 5 | 5 | 4 | 4 | 5 | 5 | 5 | 5 | 5 | 5 | |
| 15 | 5 | 5 | 5 | 5 | 4 | 4 | 4 | 4 | 5 | 5 | |
| 17 | 5 | 5 | 4 | 4 | 5 | 5 | 5 | 4 | 4 | 4 | |
| 19 | 5 | 5 | 5 | 5 | 5 | 4 | 4 | 5 | 4 | 4 | |
| 21 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | |
| 23 | 4 | 4 | 4 | 3 | 3 | 5 | 5 | 4 | 3 | 4 | |
| 25 | 4 | 4 | 4 | 4 | 3 | 4 | 5 | 5 | 4 | 4 | |
| 27 | 5 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | |
| **Transect 32** | | | | | | | | | | | |
| 1 | 4 | 4 | 2 | 4 | 4 | 4 | 4 | 3 | 3 | 2 | |
| 3 | 5 | 1 | 1 | 1 | 1 | 1 | 5 | 5 | 5 | 5 | |
| 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 2 | 5 | |
| 7 | 5 | 5 | 5 | 3 | 4 | 4 | 4 | 3 | 4 | 4 | |
| 9 | 4 | 3 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | |
| 11 | 3 | 5 | 5 | 5 | 5 | 5 | 5 | 4 | 5 | 5 | |
| 13 | 4 | 4 | 4 | 4 | 5 | 5 | 5 | 5 | 5 | 5 | 1 |
| 15 | 5 | 5 | 5 | 5 | 5 | 5 | 4 | 5 | 5 | 5 | |
| 17 | 5 | 5 | 5 | 4 | 5 | 5 | 5 | 5 | 4 | 4 | |
| 19 | 5 | 4 | 4 | 5 | 5 | 5 | 4 | 4 | 4 | 4 | |
| 21 | 4 | 5 | 5 | 3 | 5 | 5 | 5 | 5 | 5 | 5 | |
| **Transect 33** | | | | | | | | | | | |
| 1 | B | B | B | B | B | B | B | B | B | B | |
| 3 | 5 | 5 | 5 | 5 | 5 | 4 | 4 | 4 | 4 | 4 | |
| 5 | 5 | 5 | 5 | 4 | 4 | 2 | 5 | 5 | 3 | 4 | |
| 7 | 5 | 2 | 3 | 2 | 3 | 2 | 4 | 3 | 3 | 4 | 2 |
| 9 | 5 | 5 | 5 | 5 | 5 | 2 | 5 | 5 | 5 | 5 | |
| 11 | 5 | 5 | 5 | 5 | 5 | 4 | 4 | 2 | 2 | 3 | |
| 13 | B | B | B | B | B | B | B | B | B | B | |
| 15 | B | B | B | 4 | 4 | 4 | 5 | 5 | 4 | 4 | |
| 17 | 4 | 3 | 5 | 5 | 5 | 5 | 5 | 5 | 3 | 3 | |
| **Transect 34** | | | | | | | | | | | |
| 1 | B | B | B | B | 5 | 5 | 5 | 5 | 5 | 5 | |
| 3 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | |
| 5 | 5 | 5 | 5 | 5 | 4 | 4 | 4 | 5 | 5 | 5 | |
| 7 | 4 | 4 | 4 | 4 | 5 | 5 | 5 | 5 | 4 | 4 | |
| 9 | 4 | 4 | 4 | 4 | 5 | 5 | 5 | 5 | 5 | 5 | 2 |
| 11 | 5 | 5 | 5 | 5 | 5 | 4 | 4 | 5 | 5 | 5 | |
| 13 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 3 | 5 | |
| 15 | 4 | 3 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | |
| 17 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 4 | |
| 19 | 5 | 5 | 2 | 2 | 5 | 5 | 5 | 5 | 5 | 5 | |

**Table 6.** Continued



| Location (m) | Substrate Type 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Embeddedness |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Transect 35** | | | | | | | | | | | |
| 1 | 2 | 2 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | |
| 3 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | |
| 5 | 5 | 3 | 2 | 2 | 5 | 5 | 5 | 5 | 5 | 5 | |
| 7 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 4 | |
| 9 | 5 | 5 | 5 | 4 | 5 | 5 | 3 | 3 | 5 | 5 | |
| 11 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 4 | 4 | |
| 13 | 5 | 5 | 4 | 5 | 4 | 4 | 5 | 5 | 3 | 3 | 2 |
| 15 | 5 | 5 | 4 | 5 | 5 | 5 | 5 | 5 | 5 | 4 | |
| 17 | 4 | 4 | 4 | 4 | 3 | 5 | 5 | 5 | 5 | 5 | |
| 19 | 5 | 5 | 4 | 4 | 5 | 5 | 5 | 5 | 5 | 5 | |
| 21 | 5 | 4 | 4 | 4 | 3 | 3 | 3 | 5 | 5 | 4 | |
| 23 | 4 | 4 | 5 | 3 | 5 | 5 | 5 | 5 | 5 | 5 | |

See tables 5 and 6 in report for descriptions of substrate type and embeddedness codes.

B = Bedrock

**Table 7.** 2001 Substrate Size and Embeddedness Data for Reach 7 - Rubicon River (Data collected October 17, 2001)



| | Substrate Type | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Location (m) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Embeddedness |
| **Transect 36** | | | | | | | | | | | |
| 1 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | |
| 3 | 5 | 5 | 5 | 4 | 4 | 4 | 4 | 4 | 3 | 5 | |
| 5 | 4 | 4 | 4 | 4 | 5 | 5 | 5 | 5 | 5 | 5 | |
| 7 | 5 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 4 | 2 |
| 9 | 5 | 4 | 4 | 4 | 4 | 3 | 3 | 3 | 3 | 3 | |
| 11 | 3 | 3 | 3 | 3 | 4 | 3 | 3 | 3 | 3 | 3 | |
| 13 | 3 | 3 | 3 | 2 | 2 | 5 | 5 | 5 | 5 | 5 | |
| 15 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 4 | 4 | |
| 17 | 5 | 5 | 2 | 2 | 2 | 4 | 3 | 3 | 3 | 5 | |
| 19 | B | B | B | B | B | B | B | B | B | B | |
| 21 | 5 | 3 | 3 | 4 | 4 | 3 | 5 | 5 | 5 | 5 | |
| 23 | 5 | 5 | 5 | 2 | 5 | 5 | 3 | 3 | 3 | 2 | |
| **Transect 37** | | | | | | | | | | | |
| 2 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | |
| 4 | 5 | 5 | 4 | 3 | 5 | 5 | 4 | 4 | 5 | 4 | |
| 6 | 5 | 5 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 3 |
| 8 | 5 | 3 | 1 | 2 | 3 | 3 | 4 | 3 | 3 | 3 | |
| 10 | 3 | 4 | 4 | 3 | 3 | 4 | 3 | 3 | 4 | 4 | |
| 12 | 4 | 3 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | |
| 14 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | |
| 16 | 4 | 4 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | |
| 18 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 1 | 2 | 4 | |
| 20 | 4 | 3 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | |
| 22 | 4 | 5 | 5 | 4 | 4 | 4 | 5 | 5 | 5 | 5 | |
| 24 | B | B | B | B | B | B | B | B | B | B | |
| **Transect 38** | | | | | | | | | | | |
| 1 | 5 | 5 | 5 | 4 | 5 | 5 | 5 | 4 | 4 | 4 | |
| 3 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | |
| 5 | 5 | 3 | 2 | 2 | 2 | 2 | 3 | 2 | 2 | 2 | 3 |
| 7 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 2 | 2 | 2 | |
| 9 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 3 | 3 | 2 | |
| 11 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | |
| 13 | 3 | 3 | 3 | 3 | 3 | 4 | 3 | 3 | 3 | 3 | |
| 15 | 2 | 3 | 2 | 3 | 2 | 2 | 2 | 2 | 4 | 2 | |
| **Transect 39** | | | | | | | | | | | |
| 23 | 4 | 3 | 4 | 3 | 4 | 3 | 4 | 3 | 4 | 4 | |
| 21 | 3 | 3 | 4 | 3 | 4 | 3 | 4 | 3 | 4 | 2 | |
| 19 | 4 | 3 | 3 | 3 | 4 | 3 | 3 | 3 | 3 | 3 | |
| 17 | 3 | 3 | 3 | 3 | 2 | 3 | 4 | 4 | 3 | 4 | |
| 15 | 4 | 2 | 4 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | |
| 13 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 3 | 4 | 3 | |
| 11 | 3 | 3 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | |
| 9 | 3 | 3 | 2 | 3 | 4 | 3 | 3 | 3 | 4 | 3 | |
| 7 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | | | 4 |
| 5 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | |
| 3 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | |

**Table 7.** Continued



| Location (m) | Substrate Type 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Embeddedness |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Transect 40** | | | | | | | | | | | |
| 2 | 2 | 4 | 4 | 3 | 4 | 4 | 3 | 4 | 4 | 3 | |
| 4 | 4 | 4 | 4 | 4 | 3 | 4 | 4 | 3 | 5 | 5 | |
| 6 | 5 | 4 | 4 | 3 | 4 | 3 | 5 | 5 | 4 | 4 | |
| 8 | 4 | 4 | 4 | 4 | 4 | 3 | 4 | 2 | 3 | 4 | |
| 10 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 4 | 4 | 3 |
| 12 | 1 | 1 | 5 | 5 | 5 | 3 | 3 | 3 | 4 | 4 | |
| **Transect 41** | | | | | | | | | | | |
| 1 | 3 | 3 | 5 | 5 | 5 | 3 | 5 | 5 | 5 | 5 | |
| 3 | 4 | 4 | 4 | 4 | 4 | 4 | 5 | 5 | 3 | 3 | |
| 5 | 5 | 5 | 5 | 5 | 3 | 4 | 4 | 4 | 3 | 3 | |
| 7 | 5 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | |
| 9 | 4 | 3 | 4 | 3 | 4 | 4 | 2 | 4 | 4 | 2 | 3 |
| 11 | 5 | 4 | 4 | 4 | 3 | 3 | 3 | 2 | 4 | 3 | |
| 13 | 4 | 2 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 4 | |
| **Transect 42** | | | | | | | | | | | |
| 1 | 3 | 3 | 2 | 2 | 3 | 3 | 3 | 2 | 3 | 2 | |
| 3 | 2 | 3 | 3 | 2 | 4 | 3 | 3 | 3 | 3 | 3 | |
| 5 | 5 | 3 | 3 | 3 | 4 | 4 | 3 | 2 | 2 | 2 | |
| 7 | 4 | 4 | 4 | 3 | 4 | 4 | 4 | 3 | 3 | 3 | |
| 9 | 3 | 4 | 4 | 5 | 3 | 3 | 2 | 3 | 5 | 5 | |
| 11 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | |
| 13 | 5 | 4 | 3 | 5 | 5 | 5 | 5 | 3 | 4 | 4 | |
| 15 | 3 | 4 | 4 | 3 | 5 | 5 | 5 | 3 | 5 | 5 | |
| 17 | 4 | 3 | 4 | 4 | 3 | 4 | 4 | 4 | 5 | 5 | |
| 19 | 4 | 4 | 4 | 5 | 5 | 5 | 5 | 3 | 4 | 4 | |
| 21 | 4 | 4 | 2 | 3 | 5 | 5 | 5 | 5 | 5 | 5 | |
| 23 | 5 | 5 | 3 | 4 | 3 | 4 | 4 | 4 | 4 | 3 | 3 |
| 25 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 4 | 3 | 2 | |
| 27 | 5 | 5 | 5 | 5 | 5 | 3 | 3 | 4 | 4 | 4 | |
| 29 | 5 | 5 | 5 | 1 | 4 | 1 | 5 | 5 | 5 | 5 | |
| **Transect 43** | | | | | | | | | | | |
| 1 | 5 | 5 | 5 | 5 | 5 | 4 | 5 | 5 | 5 | 5 | |
| 3 | 4 | 3 | 3 | 4 | 4 | 3 | 3 | 4 | 4 | 3 | |
| 5 | 4 | 1 | 4 | 1 | 4 | 3 | 3 | 4 | 4 | 4 | |
| 7 | 4 | 4 | 3 | 4 | 4 | 3 | 4 | 4 | 3 | 3 | |
| 9 | 4 | 3 | 4 | 3 | 4 | 4 | 3 | 4 | 4 | 4 | |
| 11 | 4 | 4 | 4 | 4 | 4 | 3 | 3 | 2 | 3 | 4 | |
| 13 | 3 | 2 | 4 | 4 | 3 | 3 | 3 | 4 | 3 | 4 | |
| 15 | 5 | 3 | 5 | 5 | 5 | 5 | 3 | 3 | 3 | 3 | |
| 17 | 5 | 5 | 5 | 5 | 5 | 3 | 4 | 4 | 4 | 3 | |
| 19 | 4 | 4 | 4 | 5 | 5 | 5 | 3 | 5 | 5 | 4 | 3 |
| 21 | 4 | 4 | 2 | 4 | 5 | 5 | 5 | 5 | 5 | 5 | |
| 23 | 1 | 1 | 1 | 4 | 5 | 5 | 5 | 5 | 5 | 5 | |
| 25 | 3 | 4 | 5 | 5 | 5 | 3 | 3 | 4 | 4 | 2 | |
| 27 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | |

**Table 7.** Continued



| | | Substrate Type | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Embeddedness |
| | **Transect 44** | | | | | | | | | | | |
| Location (m) | 1 | 3 | 4 | 4 | 5 | 4 | 4 | 4 | 3 | 5 | 5 | |
| | 3 | 5 | 5 | 5 | 5 | 5 | 4 | 4 | 4 | 3 | 5 | |
| | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 4 | 2 | 2 | |
| | 7 | 4 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | |
| | 9 | 3 | 4 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | |
| | 11 | 3 | 3 | 2 | 2 | 3 | 4 | 3 | 3 | 4 | 4 | |
| | 13 | 4 | 4 | 3 | 3 | 5 | 5 | 5 | 5 | 5 | 5 | |
| | 15 | 3 | 2 | 3 | 4 | 4 | 4 | 4 | 3 | 3 | 4 | 3 |
| | 17 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 3 | 3 | 3 | |
| | 19 | 3 | 3 | 4 | 4 | 1 | 5 | 5 | 5 | 5 | 5 | |

See tables 5 and 6 in report for descriptions of substrate type and embeddedness codes.
B = Bedrock

**Table 8.** 2001 Benthic Macroinvertebrate Data by Reach and Transect

| | Density | | | Productivity | | | Taxa Richness | | | % EPT | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | June | August | October | June | August | October | June | August | October | June | August | October |
| **Reach 1** | | | | | | | | | | | | |
| Transect 1 | 573 | 774 | ND | ND | ND | ND | 31 | 30 | ND | 24.3 | 31.0 | ND |
| Transect 3 | 390 | 625 | ND | ND | ND | ND | 28 | 27 | ND | 63.1 | 35.2 | ND |
| Transect 7 | 784 | 691 | 673 | 5.61 | 4.45 | 3.05 | 29 | 31 | 26 | 29.5 | 42.5 | 38.5 |
| Average | 582.3 | 696.7 | 673.0 | 5.61 | 4.45 | 3.05 | 29.3 | 29.3 | 26.0 | 38.9 | 36.3 | 38.5 |
| **Reach 2** | | | | | | | | | | | | |
| Transect 9 | 849 | 1,791 | ND | ND | ND | ND | 33 | 38 | ND | 42.2 | 18.6 | ND |
| Transect 11 | 489 | 1,162 | 3,992 | 2.22 | 7.10 | 4.80 | 23 | 24 | 27 | 57.7 | 29.3 | 19.2 |
| Transect 13 | 1,705 | 2,705 | ND | ND | ND | ND | 23 | 32 | ND | 51.2 | 48.4 | ND |
| Average | 1,014.3 | 1,886.0 | 3,992.0 | 2.22 | 7.10 | 4.80 | 26.3 | 31.3 | 27.0 | 50.3 | 32.1 | 19.2 |
| **Reach 3** | | | | | | | | | | | | |
| Transect 16 | 101 | 24 | 1,896 | 1.15 | 0.42 | 4.73 | 9 | 5 | 27 | 2.0 | 0.0 | 13.2 |
| Transect 17 | 20 | 9 | ND | ND | ND | ND | 5 | 3 | ND | 5.0 | 0.0 | ND |
| Transect 18 | 22 | 31 | ND | ND | ND | ND | 6 | 4 | ND | 0.0 | 0.0 | ND |
| Average | 47.7 | 21.3 | 1,896.0 | 1.15 | 0.42 | 4.73 | 6.7 | 4.0 | 27.0 | 2.3 | 0.0 | 13.2 |
| **Reach 4** | | | | | | | | | | | | |
| Transect 20 | 858 | 945 | ND | ND | ND | ND | 29 | 25 | ND | 48.3 | 32.1 | ND |
| Transect 23 | 493 | 654 | 804 | 1.60 | 2.76 | 1.78 | 25 | 35 | 19 | 28.4 | 36.7 | 4.4 |
| Average | 675.5 | 799.5 | 804.0 | 1.6 | 2.76 | 1.78 | 27.0 | 30.0 | 19.0 | 38.3 | 34.4 | 4.4 |
| **Reach 5** | | | | | | | | | | | | |
| Transect 25 | 1,062 | 2,472 | ND | ND | ND | ND | 45 | 39 | ND | 30.0 | 57.6 | ND |
| Transect 27 | 754 | 1,033 | 702 | 2.58 | 5.12 | 2.80 | 35 | 34 | 41 | 45.9 | 55.0 | 19.7 |
| Transect 29 | 577 | 1,463 | 609 | ND | ND | ND | 42 | 37 | 30 | 48.2 | 58.0 | 14.5 |
| Average | 797.7 | 1,656.0 | 655.5 | 2.58 | 5.12 | 2.8 | 40.7 | 36.7 | 35.5 | 41.4 | 56.9 | 17.1 |
| **Reach 6** | | | | | | | | | | | | |
| Transect 31 | 415 | 1,158 | ND | ND | ND | ND | 39 | 37 | ND | 32.8 | 28.8 | ND |
| Transect 33 | 191 | 737 | 454 | 3.20 | 4.15 | 2.61 | 22 | 37 | 32 | 70.7 | 55.8 | 21.8 |
| Transect 35 | 1,070 | 1,351 | ND | ND | ND | ND | 46 | 49 | ND | 74.4 | 43.7 | ND |
| Average | 558.7 | 1,082.0 | 454.0 | 3.20 | 4.15 | 2.61 | 35.7 | 41.0 | 32.0 | 59.3 | 42.8 | 21.8 |
| **Reach 7** | | | | | | | | | | | | |
| Transect 36 | 759 | 892 | 1,300 | 5.22 | 5.81 | 7.52 | 43 | 37 | 30 | 41.9 | 47.4 | 20.9 |
| Transect 40 | 687 | 560 | ND | ND | ND | ND | 36 | 30 | ND | 48.9 | 45.0 | ND |
| Transect 43 | 723 | 786 | ND | ND | ND | ND | 41 | 33 | ND | 46.9 | 43.6 | ND |
| Average | 723 | 746 | 1,300 | 5 | 6 | 8 | 40 | 33 | 30 | 46 | 45 | 21 |

ND = No Data