MIDDLE PROVO RIVER

2004 MONITORING REPORT

SUBMITTED DECEMBER 2005 BY:
Darren Olsen, BIO-WEST, Inc.
1063 West 1400 North
Logan, Utah 84321

Submitted to:
Mark Holden, Utah Reclamation, Mitigation
and Conservation Commission
102 West 500 South, Suite 315
Salt Lake City, Utah 84101

The cover photograph, taken by Tyler Allred, shows the recently restored Charleston (CA) monitoring site during high flows in 2004.

EXECUTIVE SUMMARY

Introduction

This report describes the 2004 channel geometry, substrate, sediment transport (geomorphic), and benthic macroinvertebrate (ecological) monitoring results for the middle Provo River. These monitoring efforts were conducted in support of the Utah Reclamation Mitigation and Conservation Commission's (Mitigation Commission's) Provo River Restoration Project (PRRP), which involves large-scale channel and floodplain reconstruction of the Provo River between Jordanelle Dam and Deer Creek Reservoir – a section of river known as the middle Provo River.

The purpose of the PRRP is to enhance biological productivity and diversity of aquatic habitat, riparian areas, and other environmental resources within the river corridor. To date, the PRRP has reconstructed approximately 75 percent of the middle Provo River channel and floodplain, and work is scheduled for completion in 2006. The overriding goal of PRRP activities is to restore the physical, hydrological, chemical and biological processes needed for a healthy, self-sustaining river ecosystem, not merely to create a static channel and floodplain pattern fixed in space and time. Toward this end, the PRRP has been designed to function within the range of hydrologic patterns predicted for the future operation of Jordanelle Dam.

Understanding the complex relationships between hydrology, fluvial geomorphology, and riparian ecology is necessary to adaptively manage for the PRRP. The monitoring program described in this report is designed to collect data that will assist in explaining these interrelated processes and support adaptive management techniques to maximize the long-term resource value of the project. For example, because Jordanelle Dam traps all bedload sediment that would otherwise be supplied to the middle Provo River, active management of bedload sediment supplies below the dam will be necessary to prevent long-term channel degradation and incision, thus negatively impacting aquatic and riparian habitats. The results of the monitoring program will help the Mitigation Commission develop techniques to maintain the middle Provo River in a desirable condition.

The data included in this report are the results of the first year of a long-term monitoring program that will periodically measure and analyze the following: channel cross sections, channel longitudinal profiles, channel substrate, sediment transport, and benthic macroinvertebrate assemblages in select reaches of the middle Provo River. Specific objectives of the monitoring program include the following:

1. To quantify baseline conditions of the restored and un-restored river reaches and track change over time.

2. To acquire adequate data and analysis capabilities over time to adaptively maintain the riverine ecosystem in a desirable and functional condition.

3. To use the "best available scientific knowledge" to assure the Mitigation Commission meets all fish, wildlife, and recreation mitigation commitments.

Cross Sections and Longitudinal Profiles

An initial set of cross sections and longitudinal profiles were surveyed in four monitoring sites on the middle Provo River to establish a baseline from which to monitor changes in channel geometry and slope over time. The four monitoring sites, in upstream-to-downstream order, are the Below Jordanelle Dam (BJ) site, the River Road (RR) site, the Never-Channelized (NC) site, and the Charleston (CA) site. The BJ, RR, and CA sites are located in reaches reconstructed as part of the PRRP, while the NC site is located in a reach that was never straightened or leveed. These models were used to establish stage-discharge relationships at the monitoring sites that can be tracked through time to analyze processes such as channel aggradation, incision, bank erosion, bar deposition, and overbank flooding.

Plots of the 2004 streambed profiles and cross sections illustrate the diversity of channel width, depth, and slope within the restored reaches of the Provo River. Riffle, run, and pool areas are illustrated for each monitoring site.

Channel Substrate

Within each monitoring site (BJ, RR, NC, and CA), stream bed material was delineated into visibly homogenous patches based on dominant and subdominant particle sizes. Patches were hand drawn in the field on maps generated from topographic surveys. The percentage of material within each of six size categories (sand/silt, fine gravel, medium gravel, large gravel, cobble, boulder) was noted for each patch. For analysis purposes, the field substrate maps were digitized into a GIS layer using ArcView software with April 2004 orthophotos as a base image.

In addition, quantitative pebble counts (Wolman 1954) were completed at four to six discreet "patches" within each monitoring site. Patches were sampled in a variety of habitats such as riffles, runs, depositional bars, and eddies. Particle size data were grouped into 10 size categories and plotted to determine grain sizes of the D_{16}, D_{25}, D_{50}, D_{75}, and D_{84} particles. Channel substrate field work was completed in May 2004.

Based on the 2004 monitoring results, cobble-sized material occupies the greatest area at the RR and BJ monitoring sites, which are located closest to Jordanelle Dam. The dominant substrate size at the NC site is large gravel, and at the recently reconstructed CA site, silt and large gravel are the most common particle sizes. The combined proportion of fine and medium-sized gravel material is greatest at the RR and CA sites. Although pebble count results vary based on the type of habitat sampled, the majority of the median (D_{50}) particle sizes for all samples lie within the cobble or large gravel size categories.

Sediment Transport

Bedload and total suspended sediment (TSS) samples were collected at four bridge locations, which are almost equally spaced between Jordanelle Dam and Deer Creek Reservoir. In upstream-to-downstream order, the bridge sites are White Bridge (WB), River Road (RR), Midway Bridge

(MID), and Charleston (CA). Samples were collected at regular discharge intervals during the rising and falling limbs of the 2004 spring hydrograph (May and June). Total suspended sediment samples were collected in a depth- and cross-sectionally integrated manner and analyzed for TSS concentrations at a laboratory using standard filter and oven-drying methods.

Bedload was measured using a 6-inch Helley-Smith-type sampler to collect three 10-minute sub samples (30 minutes total collection time) at equally spaced locations across the active streambed. The sub samples were composited and the total width of active bedload transport was recorded. After collection, bedload samples were dried, sieved, and weighed by size category. Results of the suspended and bedload transport were converted to daily loads and plotted against stream discharge to develop rating curves at each sample site.

At all sites TSS results demonstrate a hysteresis pattern of higher loads (relative to discharge) on the rising limb of the hydrograph vs. the falling limb. Suspended sediment loads consistently increase with increasing distance below Jordanelle Dam, and are between 3 and 65 times greater than total bedload at all sites. Results for total bedload do not follow as simple a pattern: total bedload amounts are nearly identical at the WB and RR sites; the amount at the CA site (lowest site) is about four times greater; and the total load at the MID bridge is nearly 10 times greater than at the CA site. The extremely high bedload at the MID bridge is likely because of the readily available sediment supplies within the never-channelized reach just upstream from the MID bridge. When bedload is separated into sand vs. gravel fractions, it becomes apparent that the high total loads at the MID bridge are the result of extremely high gravel transport rates, while the sand proportion of total bedload at the MID bridge is actually lower than the amount at the CA site downstream.

The differing sediment loads at the monitoring sites indicate that sediment supplies, particularly gravel, are substantially limited in the reaches immediately below Jordanelle Dam. While there are some non-point sources of sand below Jordanelle Dam, gravel is being exported from these reaches without any known replenishing supplies. This disequilibrium makes the reconstructed/restored middle Provo River vulnerable to the undesirable effects of channel incision and habitat degradation, suggesting that there is a need to actively augment sand and gravel supplies below the dam. Although additional monitoring will be needed to determine an appropriate total annual replenishment amount, results to date suggest the total amount and gravel-to-sand augmentation ratios should be as follows: approximately 400 tons (about 3:1 gravel-to-sand) during high-runoff years when peak flows are $\geq$2,000 cfs; approximately 170 tons (about 2:1 gravel-to-sand) during average-runoff years when peak flows are <1,800 cfs; and approximately 50 tons (about 1:1 gravel-to-sand) during low-water years when peak flows are <1,500 cfs.

Macroinvertebrate Sampling

In May and September 2004, quantitative and qualitative sampling for benthic macroinvertebrates was conducted within each of the four established channel monitoring sites (BJ, RR, NC, and CA). Three replicate quantitative samples were taken in a riffle at each site using a Hess-type sampler with a 250-micron mesh net. Additionally, one multi-habitat composite kick net sample was collected at each site using a D-frame kick net. Samples were rinsed, preserved, and shipped to EcoAnalysts, Inc., for processing and identification. Organisms were identified to the genus/species level, except for midges, which were identified to the family level, and worms, which were identified to the class level. The number of each taxa collected was entered into a spreadsheet for statistical analysis and generation of biological metrics.

Statistical analysis of the Hess samples shows that collections made in September 2004 had a significantly higher total macroinvertebrate density than collections made in May 2004, but that no significant differences were present between sites within each sampling period. At the CA site, where restoration work had been completed just days before the May 2004 sampling, taxa richness increased significantly between the May and September samples, suggesting that the benthic community recovered rapidly from disturbance. Based on the total number and diversity of taxa and the presence/absence of certain species, it appears that the BJ and RR sites have similar benthic communities that are distinctly different from the communities present at the NC and CA sites.

Comparison of the 2004 sampling results with data collected in August 1999 (prior to channel reconstruction) shows that total taxa richness and richness of mayflies, stoneflies, and caddisflies were significantly higher in 2004 at all sites except the BJ site. The BJ site is the closest site to Jordanelle Dam and has severely limited gravel patches, as shown in Chapter 3 of this report, which discusses the channel substrate. All the sites showed a large increase in the density of invertebrates over the 1999 samples. However, these positive temporal trends at the RR, NC, and CA sites were accompanied by an increase in the Hilsenhoff Biotic Index (HBI) score, which is a negative trend indicative of increased anthropogenic disturbance. It is hoped that continued macroinvertebrate monitoring will resolve some of these confounding trends and help elucidate how channel restoration and other factors influence the biological community of the middle Provo River.

Discussion

The various aspects of the streamflow regime, including the magnitude, duration, and timing of floods and low flows, exert a strong influence on the characteristics of the riverine ecosystem. Flow, in conjunction with sediment supply, controls the depositional patterns, the streambed particle size distribution and the rate, timing, and size characteristics of sediment transport through a channel reach of given size and slope.

The PRRP has successfully restored, where possible, the form and function of the middle Provo River and its riparian ecosystem to a more natural and productive condition. The PRRP has transformed and renaturalized this highly visible and popular section of river from its former degraded, disconnected, and channelized state. Even though restoration activities are not completely finished, many benefits have already occurred, including increased fish populations, increased populations and diversity of aquatic and terrestrial organisms, increased acres and functions of wetlands, increased acres of floodplain and successful recruitment of desirable riparian vegetation, and increased recreational opportunities. Construction and land acquisition costs to implement the PRRP have been significant.

The monitoring efforts described in this report are intended to collect necessary data and provide ongoing evaluations of the form and function of the restored river system, and make recommendations for adaptive management needs to maintain desirable conditions in this dynamic riverine ecosystem. Rivers and associated floodplains are dynamic, integrated systems that are naturally formed and maintained by both short- and long-term fluxes of water and sediment received from the watersheds they drain. The water and sediment flux of the middle Provo River are significantly influenced by Jordanelle Reservoir. Water is released from Jordanelle Dam year round at recommended discharges. Improvements to the flow regime in the middle Provo River are made each year of operation. However, nearly 100 percent of the coarse- and fine-grained sediments entering Jordanelle Reservoir from the upper Provo River are trapped in this large impoundment and will not be released in the foreseeable future. Jordanelle Dam essentially cuts off the flow of sediment resources to the middle Provo River from the upper watershed and initiates an imbalance between incoming and outgoing loads in the reaches immediately below the dam.

A natural amount of gravel in the streambed is necessary to maintain a healthy population of benthic organisms. Gravel is certainly necessary for spawning and reproduction of trout. Sand is also important for cottonwood recruitment. Once a floodplain becomes heavily vegetated there are no viable surfaces for cottonwood recruitment in the middle Provo River without fresh depositional areas of sand occasionally on the upper portions of bars and across the floodplain. Gravel and sand resources (coarse-grained sediments) are extremely scarce in the reaches immediately below Jordanelle Dam even though the dam has only been in operation for the past 8 years. The coarse-grained sediments become less scarce several miles below Jordanelle Dam in the never-channelized reach.

The imbalance of incoming and outgoing sediment loads below Jordanelle Dam, if not mitigated, will cause several miles of the restored channel to become degraded, incised, and disconnected from its floodplain, similar to the pre-restored state without the levees. Although the longitudinal extent varies, the phenomenon of degraded river conditions below dams has been well documented in hundreds of rivers around the world. Many of the improved beneficial uses associated with the PRRP will not be maintained without mitigating a natural amount of coarse-grained sediments below Jordanelle Dam on an annual basis. Specific recommendations are made in this report with regard to sediment replenishment.

(This page intentionally left blank.)

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PHOTOGRAPHS

LIST OF MAPS

LIST OF DIAGRAMS

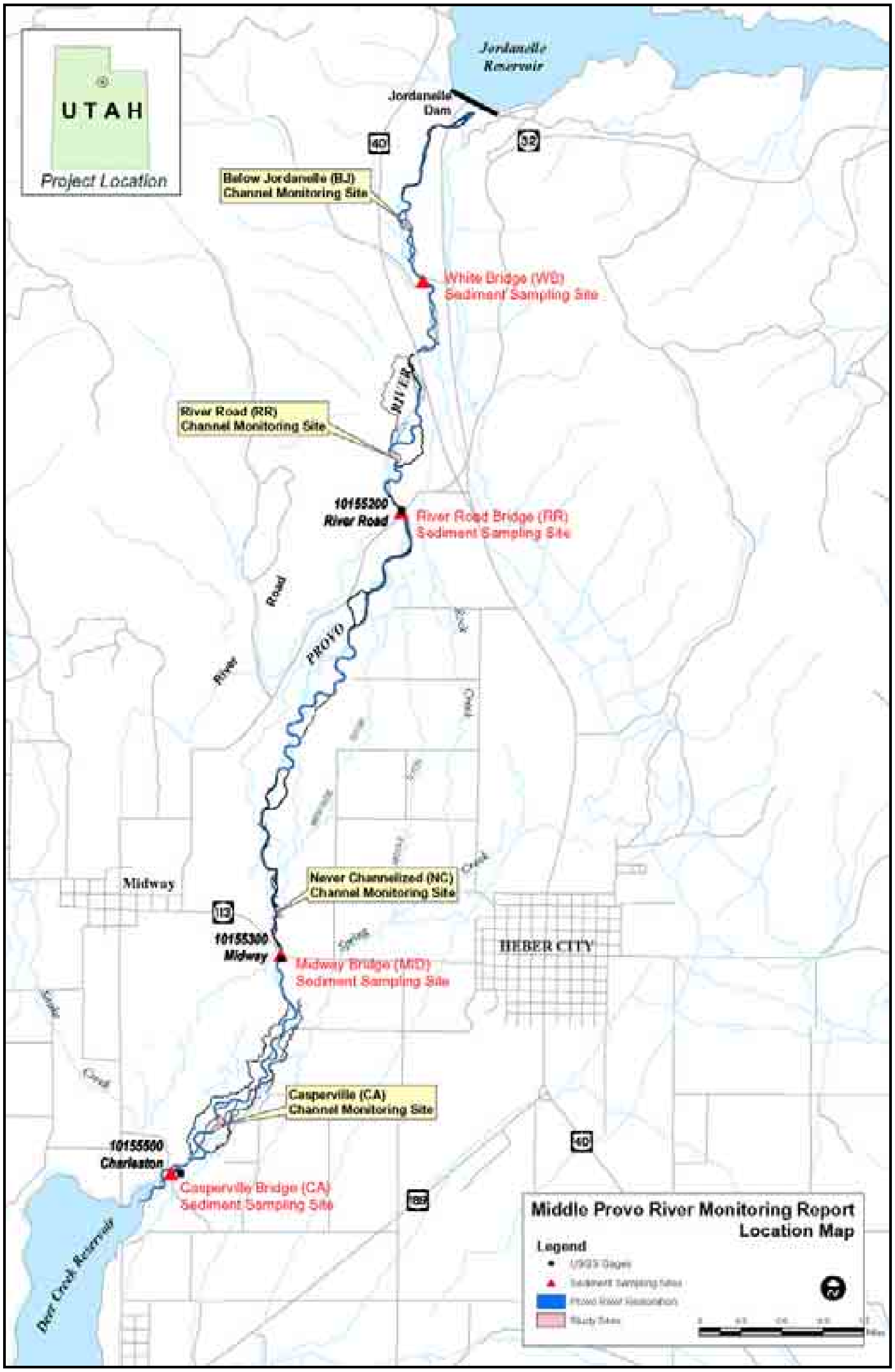
1.0 INTRODUCTION

The portion of Provo River between Jordanelle Dam and Deer Creek Reservoir is commonly known as the middle Provo River (Map 1.1). The Utah Reclamation Mitigation and Conservation Commission (Mitigation Commission) is undertaking large-scale channel and floodplain reconstruction efforts to restore the middle Provo River to a more natural channel form and restore functional fluvial processes. The Provo River Restoration Project (PRRP) is designed to make modifications to the channel shape, bed slope, plan and alignment of the middle Provo River and floodplain to create a more naturally functioning riverine ecosystem. The purpose of the PRRP is to enhance biological productivity and diversity of the fish habitat, riparian areas, and other environmental resources in the river corridor. Public access is provided to the area for angling and other compatible, low-impact uses.

Monitoring specific elements of success and potential maintenance needs began in 2004 as the PRRP enters the final stages of construction. This report documents the findings of the first year of post-construction geomorphic and macroinvertebrate monitoring in the middle Provo River. This report is organized by topic, starting with an overall introduction and project description (Chapter 1). This introduction chapter is followed by chapters describing the specific methods and results of the various geomorphic and ecological parameters in the following order: channel cross sections and longitudinal profiles of streambed elevations (Chapter 2), substrate sizes and the distribution of spawning gravels (Chapter 3), sediment transport (Chapter 4), and benthic macroinvertebrates (Chapter 5). Chapter 2 describes cross section and longitudinal profiles chapter details survey methods and analysis techniques used to complete cross section and longitudinal profile survey work. This chapter and corresponding appendices contain the results of these topographical surveys. Chapter 3 describes the substrate monitoring methods and, along with corresponding appendices, contains the results of first-year monitoring particle size and delineations of textured patches at the study sites. Chapter 4 discusses the imbalance of sediment transport in the reaches below Jordanelle Dam, shows results of suspended sediment (TSS) and bedload monitoring sampling at four bridges between Jordanelle Dam and Deer Creek, and discusses proposed actions for addressing sediment issues – particularly the lack of gravel below Jordanelle Dam. Chapter 5 discusses the methods and results of benthic macroinvertebrate sampling. Chapter 6 provides a discussion of the results and a summary of the findings from the first year of monitoring.

1.1 Recent History of the Middle Provo River

The hydrologic, geomorphic, and biological characteristics of the middle Provo River have been greatly altered by a variety of historical anthropogenic influences. Water storage and diversion features involving the Provo River were developed as early as the late 1800s to provide municipal and irrigation water to portions of the Wasatch Front. The most organized and extensive of these efforts, collectively known as the Provo River Project, was authorized and constructed with the approval of the Federal government beginning in 1933. As part of the original Provo River Project plan authorized by the U.S. Congress, portions of the Provo River, including the middle reaches,



Map 1.1. Map of the middle Provo River.

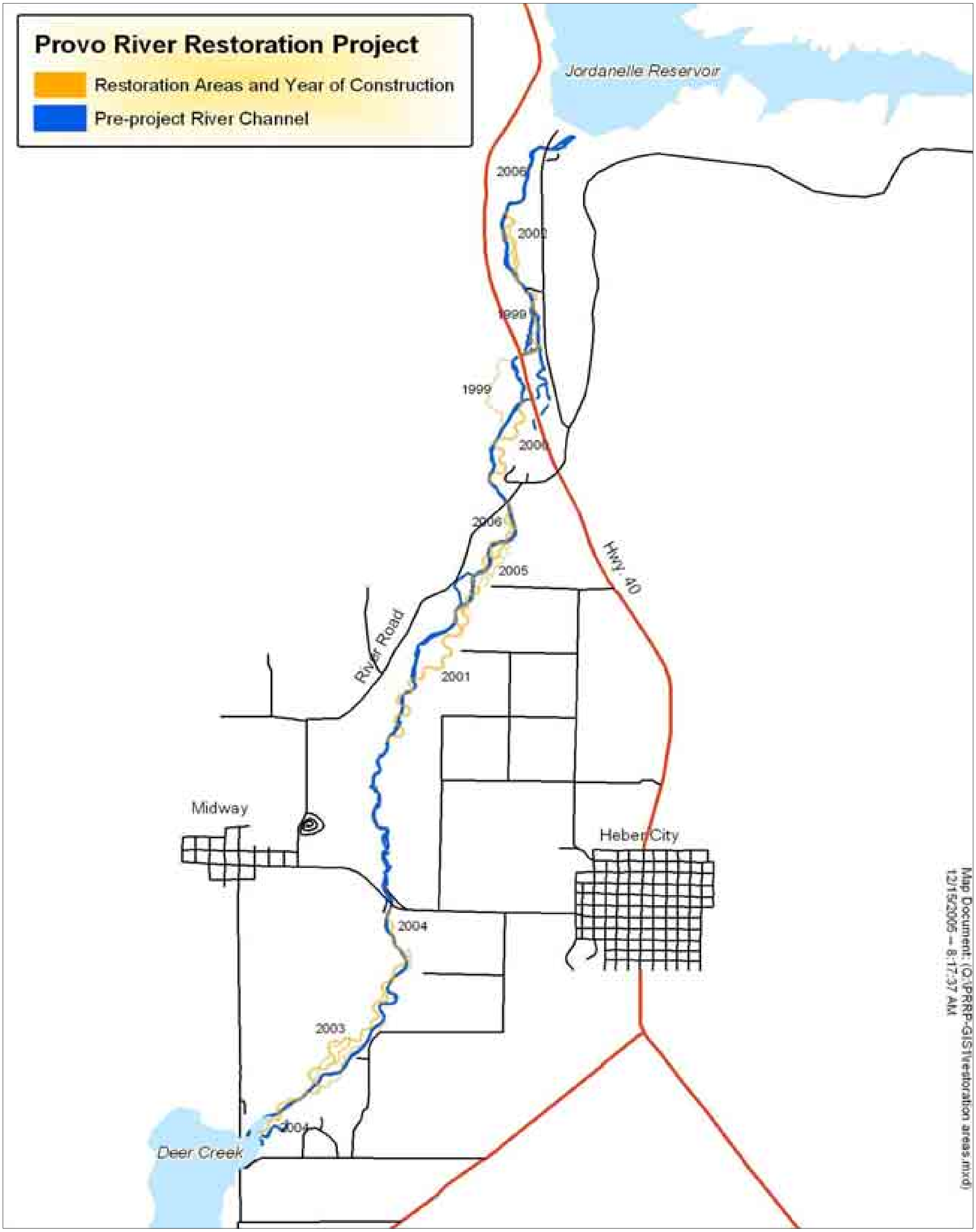
were straightened and channelized during the period from late 1944 to early 1953. This work was done with the intent of "bettering" the Provo River and reducing flood risks, and included clearing the channel, placing dikes, placing sills, and constructing several small timber bridges. This work was initiated by the Federal government from 1944 through 1951, and was completed under contracts with private firms from 1951 through 1953. Most features of the Provo River Project were built by or under the supervision of the U.S. Department of the Interior, Bureau of Reclamation (Reclamation) from 1938 to 1958. Other activities included the construction of (1) Deer Creek Dam, completed in 1941; (2) the Salt Lake Aqueduct, also completed in 1941, to transfer water stored in Deer Creek Reservoir to the Salt Lake Valley; (3) the Duchesne Tunnel, completed in 1952, to transfer water from the headwaters of the Duchesne River to the Wasatch Front via the Provo River; and (4) enlargement of the Weber-Provo Diversion and Canal, completed in 1948, to transfer water from the Weber River to the Provo River. Other important features of the Provo River Project include, among others, the Murdock Diversion and Provo Reservoir Canal (also known as Murdock Canal).

After several years of Provo River Project operation, it became apparent that the existing channel was not adequate to convey the imported waters and the natural flows of the Provo River without flooding adjacent lands and eroding large sections of streambank. This problem became worse as recreational pressure and other developments occurred along the river corridor. In 1959 the Provo River Channel Revision Project was authorized as a Reclamation project. This was in addition to the channelization activities on the middle Provo River, described above. Between 1959 and 1965 additional channelization, clearing, and diking of the Provo River occurred. In connection with channelization work that began in the 1940s and continued through the 1960s, Reclamation acquired fee lands and flood and construction easements for the United States that embraced all sections of the Provo River in the Heber Valley and some upstream sections. These activities along the Provo River channel adversely affected the river's formerly abundant and diverse natural resources, especially forested riparian areas and instream fish habitats. Natural lateral migration of the river was therefore restricted, as was channel-floodplain connectivity. In general, the lack of large, functional floodplain areas connected to the river severely reduced the spatial and temporal diversity of instream habitat, limited natural recruitment, and reduced the extent of riparian vegetation.

1.2 Central Utah Project (CUP) Background

The PRRP and the Central Utah Project (CUP) are interconnected. The Bonneville Unit of the CUP is a system of reservoirs, aqueducts, pipelines, and conveyance facilities that transport water from the Uinta Basin to the Bonneville Basin in Utah. The CUP is intended to develop a portion of Utah's share of water from the Upper Colorado River system according to interstate compacts. The CUP was authorized by Congress in 1956 through enactment of the Colorado River Storage Project Act of 1956 (43 U.S.C. §§ 620 et seq.).

The Bonneville Unit is the largest unit of the CUP. The completed systems of the Bonneville Unit are the Starvation Collection System, the Strawberry Aqueduct and Collection System (SACS), the Diamond Fork System, and the Municipal and Industrial System (Map 1.2). Construction of the



Map 1.2. Map of the Provo River Restoration Project.

Utah Lake Drainage Basin Water Delivery System, also known as the Utah Lake System (ULS), has been approved but not yet initiated. Construction of the ULS is planned to begin in 2007 and end in 2016.

The Bonneville Unit includes facilities to collect water from streams in the Duchesne River system and to release it through the Wasatch Mountains as needed in the Bonneville Basin along the Wasatch Front. One of the systems in the unit is the SACS, which diverts flows from nine Duchesne River tributaries through approximately 40 miles of tunnels and aqueducts for storage in Strawberry Reservoir. That water is then carried to Utah Lake through the Diamond Fork System and the Spanish Fork River in Utah County. The water delivered from Strawberry Reservoir to Utah Lake is used as replacement water, allowing for the exchange and/or storage of Provo River flows in Jordanelle Reservoir, located on the Provo River in Heber Valley, approximately 10 miles upstream of Deer Creek Reservoir. Jordanelle Reservoir on the Provo River is the principal feature of the municipal and industrial (M&I) system, providing municipal and industrial water to Salt Lake County, Utah County, and Wasatch County, and supplemental irrigation water to Summit and Wasatch counties.

In 1992, Congress enacted the Central Utah Project Completion Act (CUPCA) (Titles II through VI of Public Law 102-575). Among other things, CUPCA raised the Bonneville Unit appropriations ceiling, required local cost-sharing of project capital costs, authorized various water conservation and wildlife mitigation projects, and allowed local entities to construct certain project features under the direction of the U.S. Secretary of the Interior. The CUPCA provided for the creation of the Mitigation Commission, a Federal agency, which is responsible for mitigating impacts of the Bonneville Unit on fish, wildlife and related recreation resources. Under Section 301 of CUPCA, the Mitigation Commission was created to perform several specific tasks that had previously been carried out by the U.S. Secretary of the Interior through Reclamation. Specifically recognized by Congress in CUPCA was the fact that many prior fish and wildlife mitigation efforts, such as CUP and other Reclamation projects throughout the western United States, had lagged behind construction of other project features, and that when implemented, these efforts were often inadequate in terms of modern environmental standards. Congress therefore specifically addressed this shortcoming by establishing standards for the Mitigation Commission to follow when developing, coordinating and implementing plans for mitigation projects. The Mitigation Commission is required to include in its fish and wildlife mitigation plans measures that it determines will ***“ . . . restore, maintain, or enhance the biological productivity and diversity of natural ecosystems within the State and have substantial potential for providing fish, wildlife, and recreation mitigation and conservation opportunities,”*** and ***“ . . . be based on, and supported by, the best available scientific knowledge.”***

Construction of Jordanelle Dam with a designated flood-control pool eliminated the need to maintain the levees and channelization of the middle Provo River for flood control purposes. The Mitigation Commission began implementing the PRRP as partial mitigation for impacts on stream fishery resources, riparian habitat, and wetlands caused by the SACS and M&I systems, and as partial mitigation for the adverse impacts of the Provo River Project, which initially constructed the dikes and channelized the river. Starting in 1999, the Mitigation Commission, in partnership with Reclamation and Utah Division of Wildlife Resources, undertook large-scale channel reconstruction efforts to restore large sections of the middle Provo River to a more natural channel form, and to restore functional fluvial processes. About 75 percent of the channel and floodplain have been reconstructed since that time (Map 1.2) and work should be complete in 2006.

The restoration approach of the PRRP has been to reconstruct and realign a majority of the existing river channel in a meandering riffle-pool sequence that is reconnected with its floodplain. In most locations, existing levees have been removed and 100-year flood protection is provided by Jordanelle Reservoir upstream and by the expanded floodplain or new setback levees. In some areas this has been accomplished by incorporating the present channel. In other areas the present channel was abandoned and a new channel alignment developed. Where possible, the river channel will be able to respond to changing hydrologic or geomorphic factors by adjusting its alignment within the designed meander width. Disturbed areas along the new floodplain would be revegetated with indigenous species using artificial and natural means. Multiple-story riparian vegetation would be restored within the floodplain of the corridor.

Historic aerial photographs from the 1930s and early 1950s demonstrate the middle Provo River floodplain corridor once consisted of a diverse array of geomorphic and hydrologic features, which supported a diverse riparian vegetation community. Through the PRRP restoration work, opportunities for reconnecting or creating side channels, wetlands, and ponds will occur throughout the length of the middle Provo River corridor. These features add significant habitat diversity to the project.

The overriding principle of the PRRP restoration work is to restore the physical, hydrological, chemical and biological ***processes*** needed for a healthy, self-sustaining aquatic and riparian communities, not merely to restore or recreate a set of conditions by reconstructing features. Construction or reconstruction of features is a key component of the PRRP, but they are not intended to merely produce a stable, static, channel and floodplain pattern that is fixed in space and time. Toward this end, the PRRP has been designed to function within the range of hydrologic patterns predicted for the future operation of Jordanelle Dam. The Mitigation Commission, Central Utah Water Conservancy District, and others work interactively to attempt to provide flow regimes that are not only compatible with PRRP objectives but that are conducive to supporting a self-sustaining ecosystem. Understanding the complex, vital relationship between hydrology, fluvial geomorphology, and riparian ecology is necessary to manage the PRRP. The monitoring program described in this report is designed to develop data from which to learn about those interrelated processes and to promote better management of the integrated resources associated with the riverine ecosystem.

Biological resource monitoring to date has shown the PRRP is successfully providing substantial fish, wildlife, and recreation mitigation and conservation opportunities. Rivers are dynamic, integrated systems that are ultimately formed and maintained by the long-term flux of water and sediment. Sediment transport regimes, channel conditions, and the quality of habitat for aquatic organisms are interconnected. Proposed changes to the water operations on the Provo River could result in short-term and long-term changes to the physical and ecological characteristics of the river system, including its riparian corridor. However, because Jordanelle Dam regulates flows and diminishes sediment supplies below the dam, the newly constructed channel and floodplain will be susceptible to an imbalanced sediment transport regime. Releases from Jordanelle Dam to the Provo River are devoid of sediment, and this water has an unmet capacity to entrain and transport sediment. This "hungry water" phenomenon downstream of large impoundments can cause channel incision, habitat degradation, reduced fluvial dynamics, poor recruitment and impaired health of riparian vegetation, and diminished diversity and abundance of aquatic biota. Unless releases from the dam are managed to support ecosystem restoration objectives, and unless sediment supplies are not limited below the dam, the physical, chemical, and biological processes vital to ecosystem health may not be maintained.

Recent sampling activities have shown that sediment loads increase as the distance downstream from Jordanelle Dam increases (Olsen et al. 2004). Thus, more sediment is being exported on an annual basis from reaches near Jordanelle Dam than is replenished from upstream, instream or near-stream sources. This disequilibrium in fluvial processes will likely eventually have undesirable impacts to channel conditions (i.e., channel degradation) and could negatively affect habitat quality for aquatic organisms.

Jordanelle Dam essentially captures all sediment that would otherwise be supplied to the middle Provo River from upstream sources. Persistent reductions in sediment supply can have profound effects on long-term fluvial geomorphic activity and consequently on ecological functions. A number of assumptions had to be made with respect to water-sediment flux to conduct some of the prior Provo River studies (such as the two-dimensional aquatic habitat modeling [Olsen et al. 2004]). Those models were based on the assumption that channel morphology and roughness characteristics of the study sites will remain static during and following changes to water operations. While this assumption may be accurate in the short-term (months to years), it is most likely inaccurate in the long-term (years to decades) if there are significant changes to the sediment or water flux. Therefore, an additional application of the results of this monitoring study may provide a better understanding of the long-term consequences of changes in sediment supply; changes in this parameter could alter the projected habitat-flow relationships as well as ecological activity.

1.3 Purpose of and Need for the Monitoring Program

The need for physical and biological monitoring of the PRRP can be separated into three important categories:

1. To quantify baseline conditions of the restored and un-restored river reaches and track change over time.

2. To acquire adequate data and analysis capabilities over time to adaptively maintain the riverine ecosystem in a desirable and functional condition.

3. To use the "best available scientific knowledge" to assure the Mitigation Commission meets all fish, wildlife, and recreation mitigation commitments.

The purpose of the study described in this report is to establish and implement a long-term monitoring program that will periodically measure and analyze the following: channel cross sections, channel longitudinal profiles, channel substrate, sediment transport, and the benthic macroinvertebrate assemblages in select reaches of the middle Provo River. Monitoring results will assist the Mitigation Commission to maintain the middle Provo River in a desirable condition with functional ecological, hydrologic, and geomorphic processes. Adaptive maintenance activities will likely be centered on flow recommendations and maintaining equilibrium sediment flux in reaches below Jordanelle Dam.

2.0 CROSS SECTIONS AND LONGITUDINAL PROFILES

2.1 Introduction

An initial set of cross sections and longitudinal profiles were surveyed in four reaches of the middle Provo River in order to establish a baseline from which to monitor the change in channel geometry and slope over time. These data can be used in hydraulic modeling and other analyses that will be the basis for flow recommendations and other adaptive maintenance activities. Such recommendations and activities will assist the Mitigation Commission in maintaining desirable conditions for the middle Provo River and its floodplain. Monitoring data can also be used to show that the Mitigation Commission is meeting all fish, wildlife, and recreation mitigation commitments.

2.2 Methods

2.2.1 Data Collection

On May 10, 2004, six permanent transects (cross sections) were established in each of the four monitoring sites (Figure 2.1a-d). Each transect has two endpoints, a left endpoint (LEP) and right endpoint (REP), which correspond to the side of the river the endpoint is on when facing downstream. Each endpoint was permanently monumented in the field by installing Rebar stakes capped with aluminum. Each aluminum cap is stamped with the transect number and study site abbreviation. A survey-grade (centimeter accuracy) global positioning system (GPS) was used to determine the location of each endcap in real-world coordinates. The endpoint coordinates are provided in NAD83 Utah State Plane feet as well as NAD27 UTM meters. Elevation is provided in NAVD88 feet (Table 2.1).

Transect and longitudinal profile data were collected May 10-21, 2004, using a theodolite (total station), data collector, and prism/rod. One endpoint was used as the instrument location. The other endpoint was used for a backsight (Figure 2.2). In order to orient the transect surveys, each endpoint was assigned its real-world coordinate value as determined through the GPS survey described above. Since the survey data are relative to the instrument location and backsight, the subsequent survey points have real-world coordinates (northing, easting, elevation).

To complete a transect, the survey rod was placed on points in a straight line (0 degree angle +/- 5 minutes) between the two endpoints (Figure 2.2). Survey points included areas in the channel, on the streambanks, and at the right and left (facing downstream) edges of water. Survey points also delineated vegetation, features such as bars or large woody debris, and changes in topography. The backsight was surveyed in order to evaluate any differences between the total station survey and the endpoint coordinate values determined by GPS. In addition, four photographs were taken at each transect to show the REP, LEP, and the views upstream and downstream from the transect.

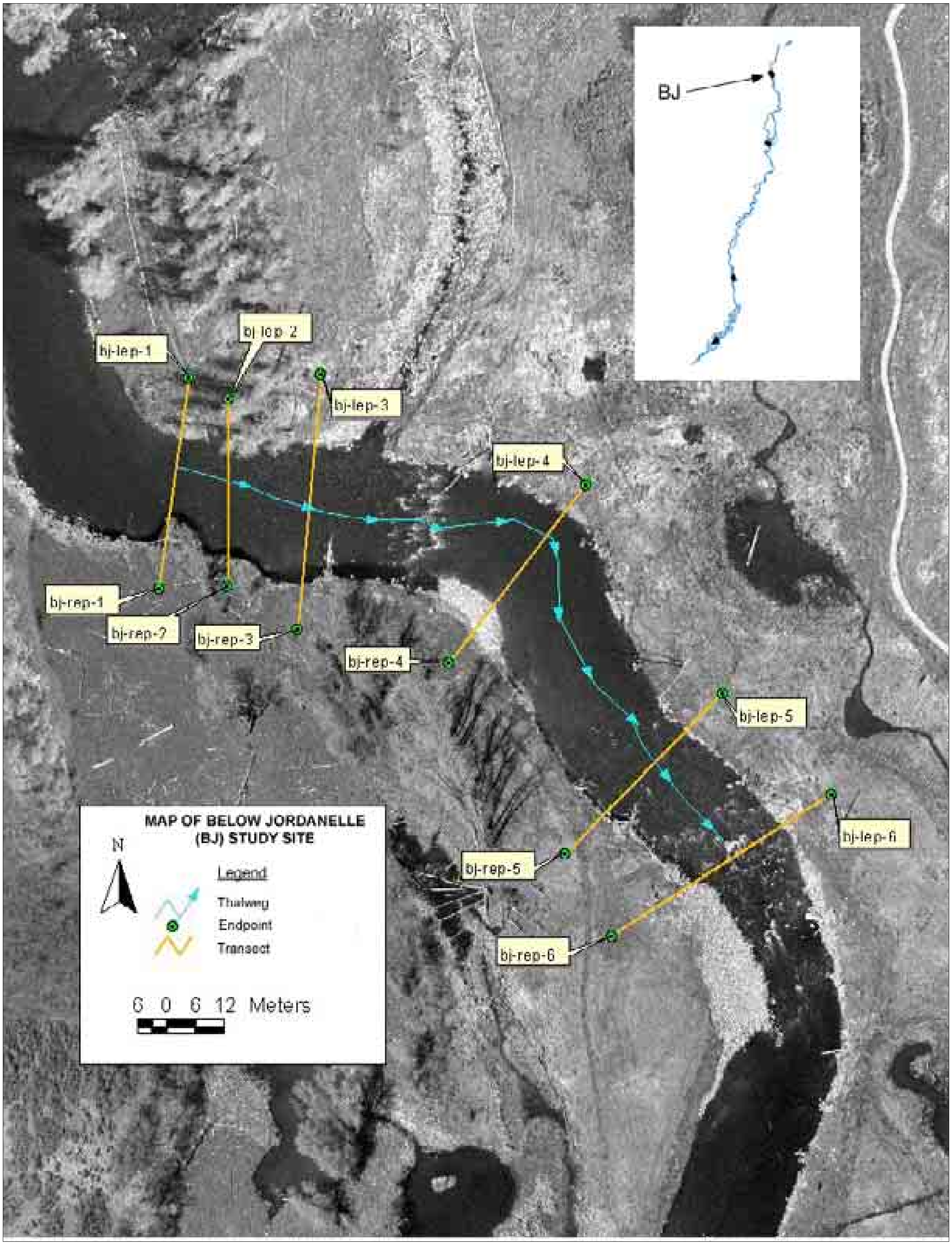


FIGURE 2.1A. MAP OF THE BELOW JORDANELLE DAM (BJ) MONITORING SITE. LEP AND REP ARE ABBREVIATIONS FOR LEFT END POINT AND RIGHT END POINT.

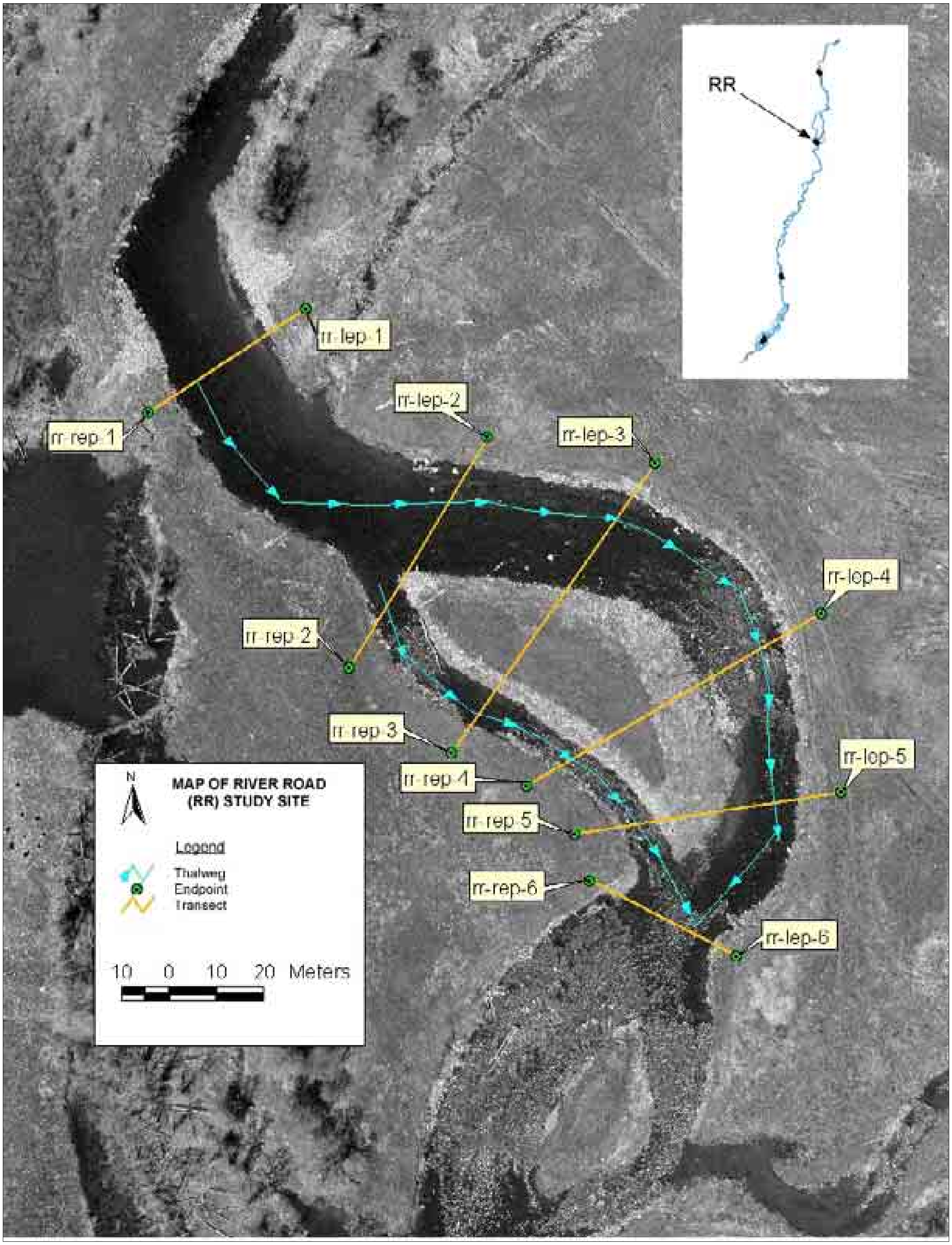


FIGURE 2.1B. MAP OF THE RIVER ROAD (RR) MONITORING SITE. LEP AND REP ARE ABBREVIATIONS FOR LEFT END POINT AND RIGHT END POINT.

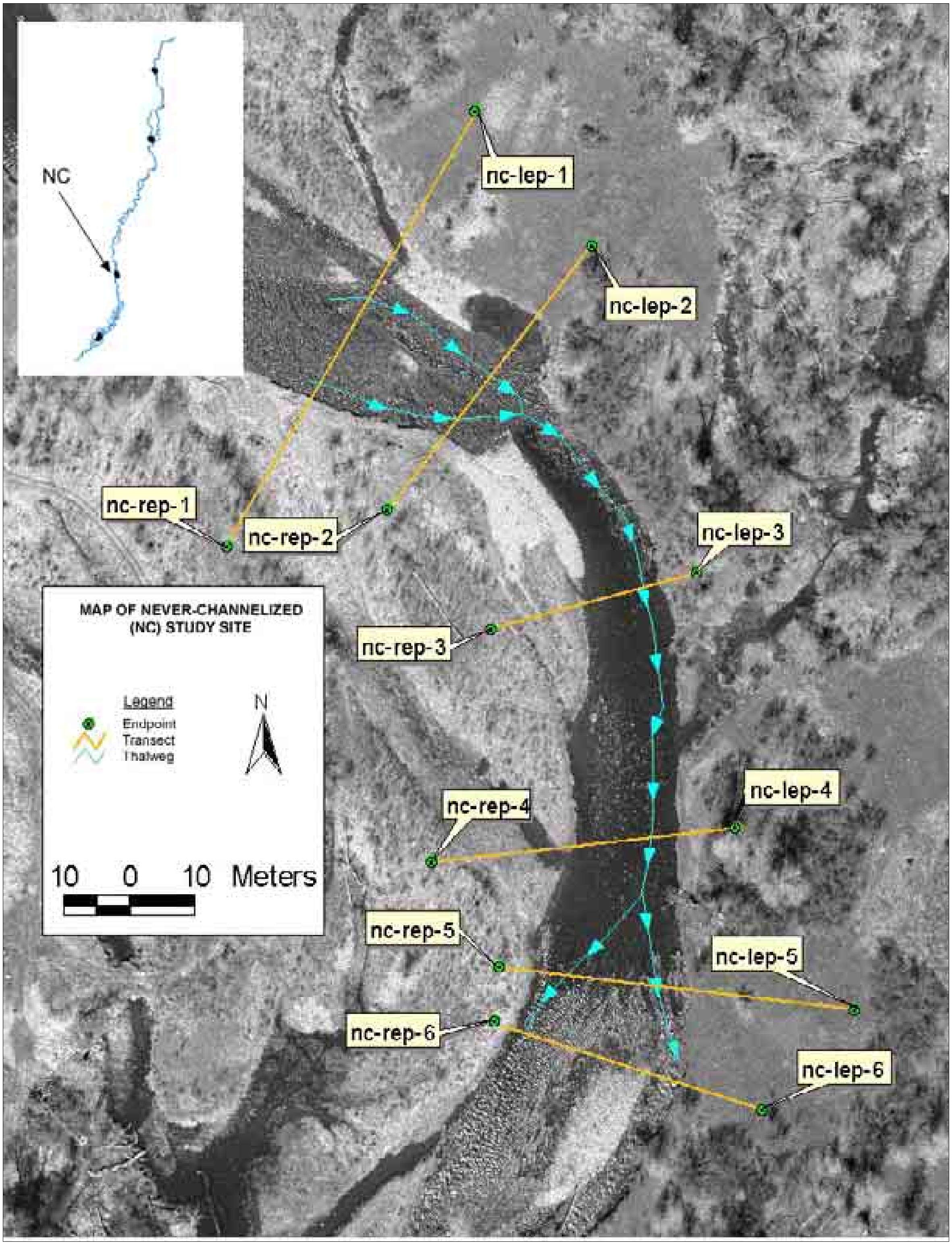


FIGURE 2.1C. MAP OF THE NEVER-CHANNELIZED (NC) MONITORING SITE. LEP AND REP ARE ABBREVIATIONS FOR LEFT END POINT AND RIGHT END POINT.

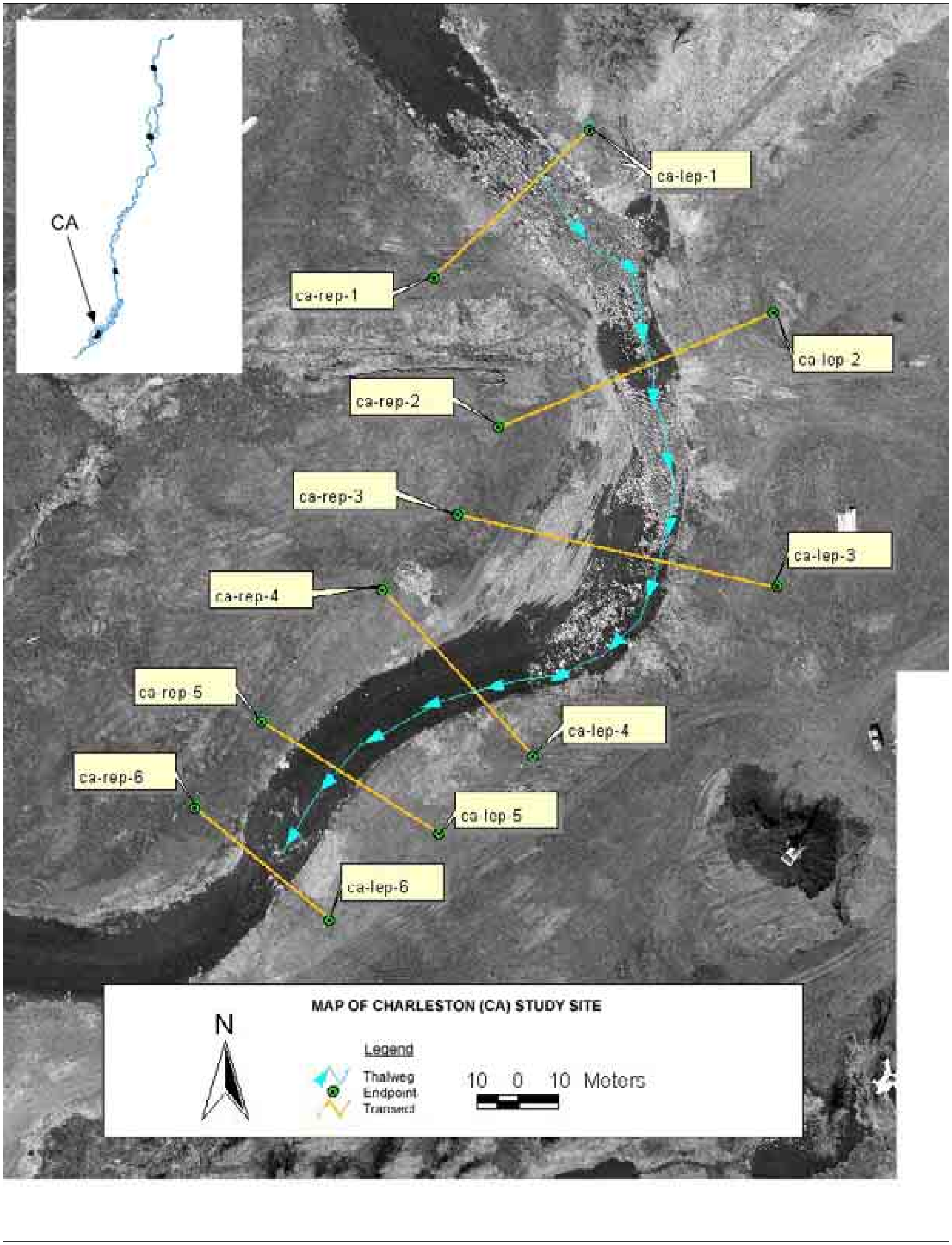


FIGURE 2.1D. MAP OF THE CHARLESTON (CA) MONITORING SITE. LEP AND REP ARE ABBREVIATIONS FOR LEFT END POINT AND RIGHT END POINT.

Table 2.1. Middle Provo River monitoring sites coordinates and elevations.

End-point name[a]	Coordinates				Elevation_ NAVD88_ft
	E_NAD83_ft	N_NAD83_ft	E_UTM27_m	N_UTM27_m	
BJ-LEP-1	1658896.1419	7381916.4269	463379.0904	4492598.6920	5826.7157
BJ-LEP-2	1658922.7738	7381902.3426	463387.1799	4492594.3548	5826.1031
BJ-LEP-3	1658985.3179	7381919.1536	463406.2646	4492599.3692	5827.1622
BJ-LEP-4	1659164.0566	7381845.6901	463460.5938	4492576.6779	5826.0475
BJ-LEP-5	1659257.3978	7381705.5260	463488.7891	4492533.8110	5825.0882
BJ-LEP-6	1659331.3606	7381637.7544	463511.2060	4492513.0345	5825.5501
BJ-REP-1	1658876.4706	7381773.8085	463372.8496	4492555.2720	5826.9525
BJ-REP-2	1658922.5923	7381775.9467	463386.9053	4492555.8440	5827.1185
BJ-REP-3	1658970.2665	7381746.9588	463401.3800	4492546.9297	5825.8094
BJ-REP-4	1659072.8300	7381724.8781	463432.5900	4492540.0253	5823.9357
BJ-REP-5	1659151.8949	7381596.6563	463456.4564	4492500.8216	5823.5513
BJ-REP-6	1659183.3112	7381540.8271	463465.9312	4492483.7571	5824.2003
RR-LEP-1	1658569.5172	7372987.2135	463264.0861	4489878.6359	5718.9673
RR-LEP-2	1658694.9848	7372899.9343	463302.1614	4489851.8270	5719.6044
RR-LEP-3	1658810.1667	7372882.8674	463337.2247	4489846.4286	5720.6276
RR-LEP-4	1658925.0353	7372779.8259	463372.0433	4489814.8354	5718.9974
RR-LEP-5	1658939.8347	7372657.1825	463376.3396	4489777.4419	5717.0660
RR-LEP-6	1658868.3015	7372543.4305	463354.3480	4489742.9061	5715.7848
RR-REP-1	1658461.7484	7372915.3404	463231.1272	4489856.9226	5718.5694
RR-REP-2	1658601.2879	7372740.6920	463273.3382	4489803.4690	5716.9580
RR-REP-3	1658671.5152	7372682.4252	463294.6336	4489785.5949	5716.4230
RR-REP-4	1658723.2975	7372660.1452	463310.3716	4489778.7173	5716.3225
RR-REP-5	1658756.7101	7372626.8874	463320.4939	4489768.5266	5716.2468
RR-REP-6	1658767.1310	7372594.8323	463323.6132	4489758.7418	5715.9376
NC-LEP-1	1654251.2249	7355452.1171	461918.0083	4484543.2948	5513.5558
NC-LEP-2	1654309.6297	7355385.8620	461935.6879	4484523.0069	5512.2188
NC-LEP-3	1654362.4180	7355224.0600	461951.4908	4484473.6164	5510.1745
NC-LEP-4	1654381.8471	7355097.8232	461957.1915	4484435.1196	5511.1277
NC-LEP-5	1654441.8166	7355007.4804	461975.3061	4484407.4898	5510.5692
NC-LEP-6	1654396.2420	7354957.7176	461961.3344	4484392.4058	5509.6607
NC-REP-1	1654129.3412	7355235.5320	461880.4979	4484477.5126	5511.0848
NC-REP-2	1654208.9524	7355254.3088	461904.7860	4484483.0968	5510.5909
NC-REP-3	1654260.1201	7355195.3783	461920.2734	4484465.0532	5510.1981
NC-REP-4	1654231.5589	7355079.5809	461911.3708	4484429.8198	5508.9682
NC-REP-5	1654265.6592	7355027.7546	461921.6705	4484413.9701	5508.5500
NC-REP-6	1654263.5343	7355000.5995	461920.9760	4484405.6998	5508.5659
CA-LEP-1	1652090.6860	7347294.5252	461245.6433	4482061.4677	5449.2422
CA-LEP-2	1652238.2126	7347149.9635	461290.3422	4482017.1678	5449.5003
CA-LEP-3	1652242.2119	7346931.7195	461291.1848	4481950.6645	5447.4182
CA-LEP-4	1652049.0954	7346795.3530	461232.1118	4481909.4471	5446.1302
CA-LEP-5	1651974.4166	7346732.8104	461209.2512	4481890.5195	5445.5110
CA-LEP-6	1651887.8549	7346664.2407	461182.7598	4481869.7759	5443.9564
CA-REP-1	1651967.7733	7347176.2255	461207.9909	4482025.6344	5447.9517
CA-REP-2	1652019.4378	7347057.4342	461223.5273	4481989.3513	5446.9886
CA-REP-3	1651988.0578	7346987.1581	461213.8455	4481967.9929	5446.6516
CA-REP-4	1651928.2676	7346926.8586	461195.5249	4481949.7231	5446.4721
CA-REP-5	1651833.1061	7346821.1784	461166.3494	4481917.6871	5445.1333
CA-REP-6	1651780.3013	7346753.0072	461150.1436	4481897.0069	5444.3218

[a] BJ = Below Jordanelle site, RR = River Road site, NC = Never Channelized site, CA = site, LEP = Left endpoint, REP = Right endpoint.

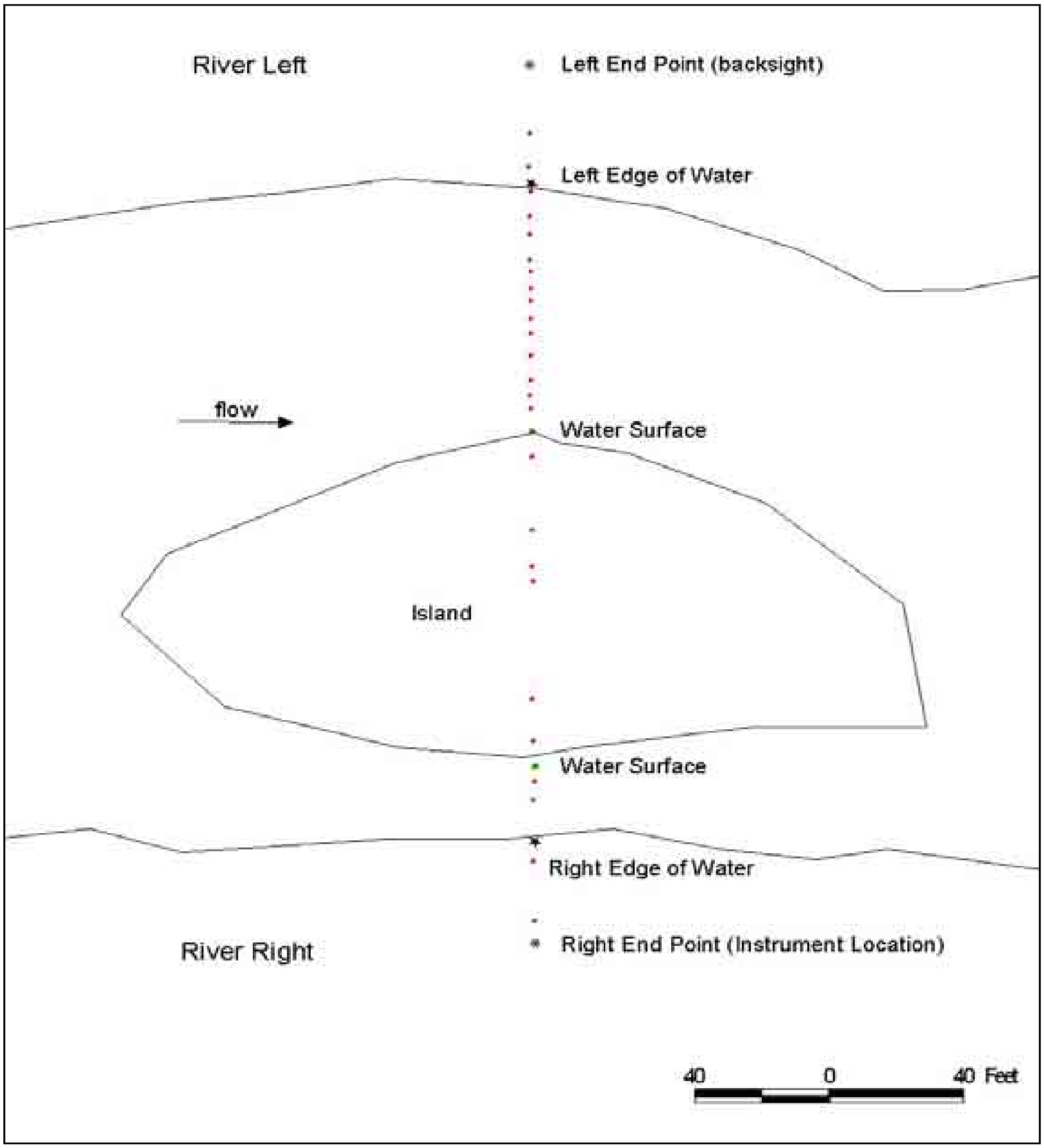


FIGURE 2.2 Methods for surveying permanent cross sections using a total station. The instrument is set over a permanent end point (a labeled aluminum cap on a 3-foot Rebar stake) with known coordinates. Survey points are taken along the transect between the end points at 20-foot intervals or when the bed elevation changes by more than 0.5 foot. Large cobbles and boulders, therefore, can be seen on cross section plots. A laser on the total station, not tapes and taglines, is used to align the survey points and determine distances between the end points.

Along with cross sections, the longitudinal profile of the streambed thalweg through each monitoring site were surveyed. Thalweg locations are shown in Figure 2.1. Surveys of the left and right edges of water and prominent features, such as boulders and logs, were also completed in order to create base maps of the sites for use in substrate mapping (see Chapter 3).

2.2.2 Overbank Flooding Analysis

In order to more comprehensively assess stage-discharge relationships at the monitoring sites, the cross section data were used to develop preliminary HEC-RAS hydraulic models. Preliminary models were developed for the CA, NC, and BJ sites. Water surface elevations measured by BIO-WEST during the May 2004 low-flow transect surveys were used to back-calculate Manning's "n" (i.e., roughness) values for the different cross sections. These back-calculated "n" values were used to help estimate roughness input values for modeling.

Flows were modeled as steady, subcritical flow with downstream normal depth boundary conditions. For each monitoring site, the surveyed average water surface slope was used as an approximation of the average energy slope for establishing the model boundary conditions. Where distances between surveyed cross sections were greater than 50 feet, additional cross sections were interpolated.

At all four monitoring sites, the suitability of the established cross sections was evaluated for accurate model development. The potential need for additional calibration data (water surface elevation surveys) was also evaluated. Repeating the HEC-RAS modeling effort using future cross section data will make it possible to evaluate processes such as channel incision and streambed aggradation and how they affect overbank flooding dynamics within Provo River. The repeat modeling will also provide a way to detect changes in channel capacity through time.

2.3 Results

2.3.1 Endpoint Coordinates

Table 2.1 shows the real-world coordinate values for each endpoint. Northing and easting values are provided in both NAD27 UTM meters and in NAD83 Utah State Plane feet. Elevations are provided in NAVD88 feet.

2.3.2 Cross Sections

Photos of each cross section are included in Appendix 2.1. Cross section plots are included in Appendix 2.2a. These plots provide a baseline data set that will allow future surveys to identify future temporal changes in channel geometry (e.g., channel width and depth). Appendix 2.2b provides the raw coordinate data collected for the cross section surveys.

At the RR monitoring site, transect RR6 was placed in the same location as a previously surveyed transect (Study Site 8, cross section 1) that was established as part of the 2002 field work for the Provo River Flow Study (Olsen et al. 2004). As seen in Figure 2.3, some changes in channel shape is evident between the 2002 and 2004 surveys. Some deposition of gravel has occurred near the right bank from approximately 80 to 105 feet from the LEP, but the exact thalweg and average bed elevations have not changed substantially. The apparent difference in the shape of the left bank is a function of the fact that in 2002 the second point surveyed after the LEP was on top of a temporary Rebar stake installed to measure water surface elevation. Therefore, the shape and location of the left bank has not actually changed, even though this plot shows some change. Similarly, the different right bank shape shown in Figure 2.3 is merely a function of fewer points in the 2002 survey and does not indicate a true change in bank shape. Methods established in 2004 for monitoring with repeat surveys will prevent these types of inconsistencies because the survey objectives and resolution of data points will be consistent.

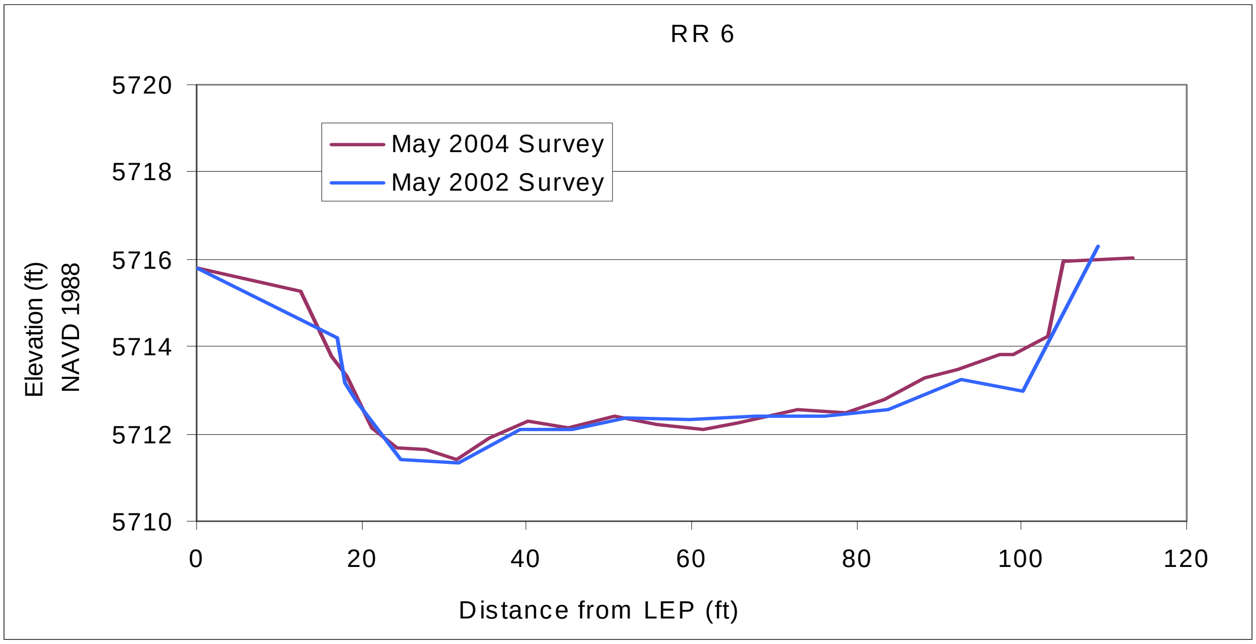


FIGURE 2.3. RIVER ROAD (RR) TRANSECT 6 (MAY 2004 SURVEY) COMPARED WITH STUDY SITE 8 CROSS SECTION 1 (MAY 2002 SURVEY).

As seen in the plots in Appendix 2.2a, cross section shape varies considerably from transect to transect within each monitoring site, reflecting the complex, diverse morphology of the restored and never-channelized portions of Provo River.

At the BJ site, the plots of transects 1, 2, and 3 illustrate the cross-sectional shape of a run channel unit. The plot of transect 4 illustrates the shape of the deep pool located in the middle of the site. Transects 5 and 6 illustrate the shape of the riffle at the downstream end of the monitoring site.

At the RR site, transects 1 and 2 are located in pool and run areas. Transects 3, 4, and 5 are wide transects that span the island in the middle of the study site. Transect 6 crosses the riffle area at the downstream end of the monitoring site.

At the NC site, transect 1 crosses a riffle area in the main channel and also spans a wide bar/floodplain area on river right. Transect 2 is located in a riffle, while transects 3 and 4 are located in deeper run areas. Transects 5 and 6 span a riffle area at the downstream end of the study site.

At the CA site, transect 1 crosses a riffle at the upstream end of the site. Transects 2, 3, and 4 span the deep pool located at the bend in the middle of the monitoring site. Transect 5 crosses the transitional run area between the pool and downstream riffle, and transect 6 spans the riffle at the downstream end of the site.

2.3.3 Longitudinal Profiles

Longitudinal profile plots for each monitoring site are included in Appendix 2.3a. As with the cross section plots, these plots provide a baseline data set that will allow future surveys to be conducted to identify future temporal changes in streambed elevation. Raw data collected for the profile plots are provided in Appendix 2.3b.

As with the cross section plots, the longitudinal profile plots illustrate the diversity of in-channel habitat present within the monitoring sites. The profiles for the BJ, NC, and CA sites are similar in that at each site on the river starts in a relatively steep riffle, then flows into a flatter-gradient, deeper pool/run section where the river bends, and then transitions back into a steep riffle at the downstream end of each monitoring site (Appendix 2.3a, Figure 2.1). The profile for RR starts in a deep, flat pool/run, and then steepens into a riffle toward the middle of the site, and then flattens again into a run.

Sites RR and NC both have areas where the flow splits around bars or islands, so the profile plots for those sites include a secondary "side thalweg" plot as well as the main channel thalweg plot (Appendix 2.3a).

2.3.4 Overbank Flooding Analysis

2.3.4.1 Below Jordanelle Dam (BJ) Site

As seen in Table 2.2, the back-calculated roughness values for all six transects are quite high. This is most likely because the BJ site contains the largest sized bed material of any of the monitoring sites (see Section 3 of this report). At low flow, the boulder and cobble bed material creates high relative roughness in the channel. Transects BJ4 and BJ1, which have the highest back-calculated roughness values, are located in deep pool/run portions of the channel that have flat gradients relative to the average slope of the overall study site (see Appendix 2.3a). At low flow, the water surface elevations at these transects are controlled by the downstream riffles, where bed elevations increase and cause a backwater effect. This effect causes the upstream water surface elevation to be much greater than it would be if the pool transects were analyzed in isolation. Therefore, the independently back-calculated "n" values are artificially high at these transects. Overall, the "n" values at the BJ site are on the high end of the values typically reported for natural streams.

As seen in Appendix 2.4, the HEC-RAS model underestimates water surface elevations at the BJ transects when an in-channel "n" of 0.12 is used. The underestimation is greatest at transects BJ4

Table 2.2. Back-calculated roughness (Manning's "n") values based on water surface levels surveyed in May 2004.

Site	HEC-RAS Station	Hydraulic Radius (feet)	Reach Average Slope (ft/ft)	Wetted Width (feet)	Area (feet)	Average Depth (feet)	Discharge (cubic feet per second)[a]	Velocity (feet per second)	Manning's "n"
BJ1	60	2.3	0.006	77.45	182.17	2.35	134	0.74	0.273
BJ2	50	1.63	0.006	77.08	125.96	1.63	134	1.06	0.150
BJ3	40	1.54	0.006	85.56	132.64	1.55	134	1.01	0.152
BJ4	30	4.03	0.006	81.14	335.92	4.14	134	0.40	0.731
BJ5	20	1.54	0.006	74.85	118.1	1.58	134	1.13	0.135
BJ6	10	1.55	0.006	68.7	107.24	1.56	134	1.25	0.123
RR1	60	1.99	0.005	71.82	145.13	2.02	130	0.90	0.186
RR2	50	1.22	0.005	121.93	149.23	1.22	130	0.87	0.138
RR3	40	1.49	0.005	118.32	179.75	1.52	130	0.72	0.190
RR4	30	0.88	0.005	61.94	54.92	0.89	130	2.37	0.041
RR5	20	1.31	0.005	71.85	94.84	1.32	130	1.37	0.092
RR6	10	1.09	0.005	72.54	79.81	1.10	130	1.63	0.068
NC1	60	1.00	0.005	99.86	100.4	1.01	125	1.25	0.084
NC2	50	1.33	0.005	75.5	101.36	1.34	125	1.23	0.103
NC3	40	1.87	0.005	40.71	79.04	1.94	125	1.58	0.101
NC4	30	1.40	0.005	65.55	94.3	1.44	125	1.33	0.099
NC5	20	0.88	0.005	72.86	64.91	0.89	125	1.93	0.050
NC6	10	0.84	0.005	62	54.1	0.87	125	2.31	0.040
CA1	60	1.21	0.005	54.01	65.89	1.22	184	2.79	0.043
CA2	50	1.35	0.005	57	77.3	1.36	184	2.38	0.054
CA3	40	1.37	0.005	88.87	123.3	1.39	184	1.49	0.087
CA4	30	1.86	0.005	63.1	119.16	1.89	184	1.54	0.103
CA5	20	1.20	0.005	58.19	70.86	1.22	184	2.60	0.046
CA6	10	1.23	0.005	46.5	57.99	1.25	184	3.17	0.038

[a] Discharge values were obtained from provisional U.S. Geological Survey (USGS) data accessed via internet in January 2005.

and BJ3. Simply increasing the "n" values for these individual transects does not fully resolve this problem – it appears to be at least partly a function of the locations and wide spacing between transects BJ3, BJ4, and BJ5 (Figure 2.1). The interpolated cross sections over-simplify the streambed profile (Appendix 2.5), leading to discrepancies in the modeled water surface profiles. Adding one field-surveyed transect in the steep riffle area between BJ3 and BJ4 and another between BJ4 and BJ5 would improve modeling accuracy and better represent low-flow conditions at the site.

Relative channel roughness decreases at higher flows when water depths become substantially greater than the bed material size. Therefore, a channel roughness value of 0.06 (0.13 for overbank areas) was used to model high flows (900, 1,200, and 1,500 cubic feet per second [cfs]) at the BJ site. Modeling results indicate that between 900 and 1,200 cfs, flows begin to overtop the right bank along the inside of the bend between transects BJ4 and BJ5 (Appendix 2.5). At 1,500 cfs, the entire right floodplain is inundated below BJ4 (Appendix 2.5). Based on the configuration of the overall site, this area is the portion of the floodplain that is most susceptible to inundation. Therefore, it appears that the model results are reasonable. However, field surveys of the site at high discharge would be needed to more accurately calibrate the model and the roughness values used.

2.3.4.2 River Road (RR) Site

The back-calculated roughness values for the RR site range from 0.056 to 0.19 (Table 2.2). The values at transects RR1, RR2, and RR3 are very high. Transects RR1 and RR2 are located in lower-gradient pool/run areas where the water surface elevation is increased by the backwater effect from the downstream riffle. This results in an overly high, back-calculated "n" value. The values calculated for transects RR3, RR4, and RR5 are skewed because the flow is divided around an island in this portion of the site, and thalweg elevations and water levels are not flat across the entire transects (Figure 2.1). Since the proportion of flow in each channel was not measured, it is difficult to accurately back-calculate roughness values at these transects. The back-calculated "n" for transect RR6 (0.068) is probably the best estimate of roughness conditions throughout the monitoring site.

No preliminary HEC-RAS model was developed for the RR site. Because of the island, developing an accurate model would likely require surveying additional cross sections, developing a flow-split relationship to divide flow around the island, and/or performing intensive manual model manipulations that were beyond the scope of this first-year monitoring project.

2.3.4.3 Never-Channelized (NC) Site

Overall, the back-calculated roughness values at the NC site are somewhat lower than the values at the upstream sites (BJ and RR), but greater than the values for the CA site (Table 2.2). This result is consistent with the general differences in dominant bed material sizes among the four sites (see Chapter 3). The back-calculated "n" values for transects NC5 and NC6 are lower than the values for the upstream transects. At NC6 this could be because the surveyed water level at the left (eastern) bank was used for the roughness back-calculation. The surveyed water surface was higher along the right bank at NC6 – if this higher value were used instead, the resulting "n" value would be closer to the values calculated for transects NC1 through NC4. This discrepancy illustrates one of the limitations in using a one-dimensional model such as HEC-RAS to model water surface elevations in complex channels with divided flow, where water elevations are not flat horizontally across the channel.

Using an in-channel "n" value of 0.07, the modeled low-flow water surface profile underestimates the water surface elevation at transects NC1 and NC2, but overestimates it at transects NC3-NC6 (Appendix 2.4). The apparently large overestimation at NC6 is again a function of the split flow at the transect and variable left bank vs. right bank water surface elevations. The model results more closely approximate the water surface elevation at the right bank, and do not reflect the steep drop that occurs along the left bank riffle (Figure 2.1, Appendix 2.4). Because of the various topographic complexities within the NC site, it is difficult to calibrate the model using the six established monitoring transects. The bed material size and roughness elements are quite consistent throughout this site (see Chapter 3). Therefore, the difficulties with calibration are more likely a function of oversimplifying the complexities in topography and bed elevation rather than simply a function of incorrect roughness inputs (Appendix 2.5).

The six monitoring transects at the NC site were not specifically established for HEC-RAS modeling purposes, and interpolating between the results in some substantial inaccuracies. For example, transect NC2 spans a backwater/eddy area on river left (Figure 2.1). Although in reality this is a distinct, relatively small feature, the interpolated transects between NC2 and NC3 artificially "translate" this feature downstream and represent the channel as being wider than it truly is. Similarly, transect NC4 spans the mouth of a side channel on river right (Figure 2.1), and the model artificially extends this feature upstream and downstream, "widening" the channel beyond its actual banks. The NC1 and NC4 REPs completely span the high-flow cutoff channel, but the NC2 and NC3 REPs do not. This leads to incorrect representations of channel and floodplain topography in the HEC-RAS model. Because NC is a complex site, surveying additional cross sections and/or intensive manual model manipulations would be needed in order to accurately represent channel and floodplain topography.

High flows were modeled using an in-channel "n" of 0.04 (0.13 overbank), and results indicate that substantial overbank flow occurs along the right floodplain at 900 cfs (Appendix 2.5). At 1,500 cfs, flows begin to overtop the left bank in the vicinity of transect NC3. It seems unlikely that so much flow truly gets out of bank at a discharge as low as 900 cfs; however, field calibration of water surface elevations/inundation extent (high flow roughness values) at higher flows would be needed to determine whether the model predictions are accurate (this has been added to the 2005 workplan). Also, because the right floodplain cut-off channel is not modeled as a continuous feature, flow is artificially forced to remain in the main channel. This may also account for the suspiciously early overtopping of the banks. Again, improved/extended transect data would be needed to more accurately model overbank flooding at the NC site.

2.3.4.4 Charleston (CA) Site

As seen in Table 2.2, the back-calculated roughness values for the CA site are generally low compared to the other monitoring sites. This is because the bed material at CA is finer-grained than the other sites (see Chapter 3). As with the BJ site, the highest back-calculated "n" values are in the deep pool areas – transects CA3 and CA4 at the Charleston site (Table 2.2, Figure 2.1). Again, this is likely because water surface elevations at low flow are elevated by the backwater effect from the downstream riffles.

The HEC-RAS model provides generally good agreement with measured water surface elevations when an in-channel "n" of 0.045 is used (Appendix 2.4). The modeled water surface elevation at transect CA5 is somewhat low; again, this is may be a function of the over-simplified bed profile generated by interpolating cross sections (Appendix 2.4, Appendix 2.5). Adding another surveyed transect between CA4 and CA5 may help resolve this discrepancy; however, the existing set of transects do a reasonable job of approximating actual low-flow conditions.

High flows at the CA site were modeled using an in-channel "n" value of 0.035 (0.13 overbank). With these roughness inputs, no overbank flow occurs even at the highest modeled flow of 1,500 cfs, although the water surface is quite close to the top of the banks (Appendix 2.5). If an "n" value of 0.045 is used, some overbank flow occurs between 1,200 and 1,500 cfs on the left bank downstream from CA5. Surveying water surface profiles and/or field-mapping the extent of inundation during high flows would allow for calibration of high-flow roughness at this site and would improve modeling accuracy (this has been added to the 2005 workplan).

(This page intentionally left blank.)

3.0 CHANNEL SUBSTRATE

3.1 Introduction

Channel substrate creates habitat for a variety of aquatic species and constitutes spawning areas for some fish species of the middle Provo River. This chapter describes the results of the first year of monitoring channel substrate in the study sites along the middle Provo River. Monitoring the substrate allows the Mitigation Commission to determine what substrate is present and what changes in substrate have occurred, which are important indicators of habitat condition. Substrate data can help determine if adaptive maintenance is required in order to maintain the middle Provo River in a desirable condition and if the Mitigation Commission is fulfilling commitments concerning fish, wildlife, and recreation.

3.2 Methods

Substrate classifications throughout each monitoring site were hand-delineated in the field on plots generated during the topographic surveys (see Chapter 2). To help ensure consistency in substrate size classification, all mapping was conducted by a single individual during low flow. The individual delineated substrate into visibly homogeneous substrate types based on dominant and subdominant particle sizes. Classification was based on a modified Wentworth scale (Table 3.1). Gravel-sized material is a resource of concern because of the trapped sediment behind Jordanelle Dam, so we included three size categories for gravel (fine, medium, large), but did not break down cobble and boulder material into sub-categories. Figure 3.1 shows photos of several sample substrate patches and their visually determined size class breakdowns. Visual assessment of the substrate composition at the BJ and CA monitoring sites was not possible within the deep pool areas. These areas were labeled “unknown.”

Table 3.1. Size classes used for substrate mapping.

Size Class (millimeters)	Description	Abbreviation
<2	sand/silt	SA/SI
2-8	fine gravel	FG
8-32	medium gravel	MG
32-64	large gravel	LG
64-256	cobble	C
>256	boulder	B

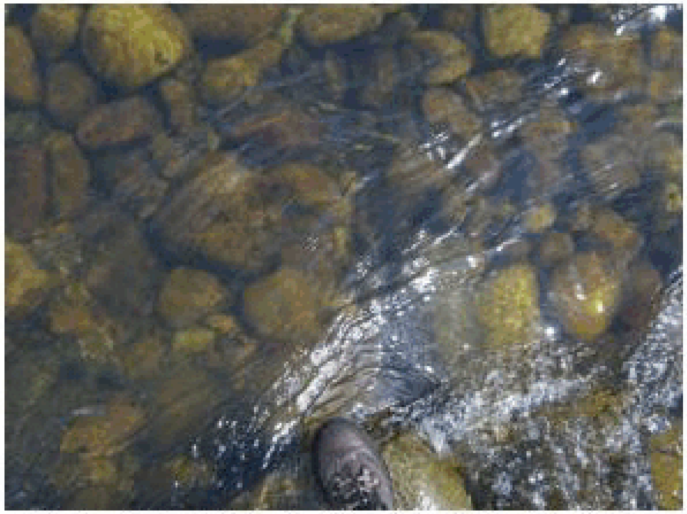


Photo of riffle at BJ site (boot for scale): 40% cobble, 35% boulder, 25% large gravel

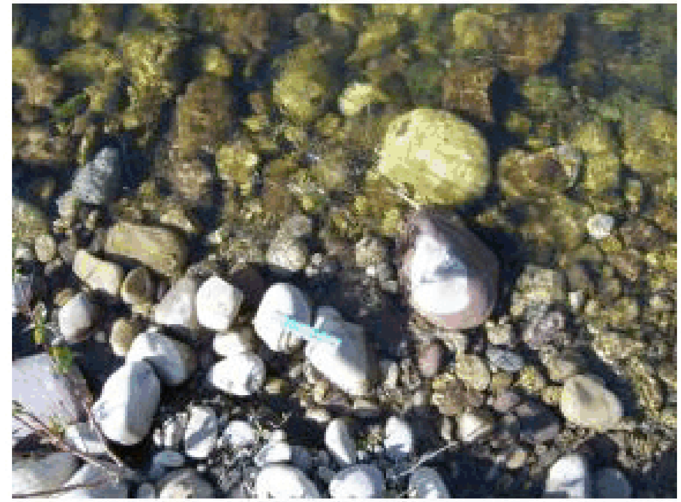


Photo of patch at BJ site (blue 152mm ruler for scale): 50% cobble, 25% medium gravel, 25% large gravel

Photo of patch at NC site (blue 152mm ruler for scale): 50% cobble, 50% large gravel

Photo of patch at NC site near PC#1 (blue 152mm ruler for scale): 30% cobble, 35% large gravel, 35% medium gravel

FIGURE 3.1. PHOTOGRAPHS OF SEVERAL SAMPLE SUBSTRATE PATCHES AND THEIR VISUALLY DETERMINED SIZE CLASS BREAKDOWNS.

Photo of patch on bar at NC site (blue 152mm ruler for scale): 20% large gravel, 35% medium gravel, 35% fine gravel, 10% sand

Photo of patch at CA site near PC#4: 50% silt, 20% fine gravel, 10% medium gravel, 10% large gravel, 10% cobble

Photo of patch at CA site near PC#2 (blue 300 mm ruler for scale): 40% cobble, 35% large gravel, 25% medium gravel

FIGURE 3.1. PHOTOGRAPHS OF SEVERAL SAMPLE SUBSTRATE PATCHES AND THEIR VISUALLY DETERMINED SIZE CLASS BREAKDOWNS (CONT.).

Substrate maps were digitized into a GIS layer using ArcView software with the April 2004 orthophotos as a base image. Within ArcView, each substrate patch (polygon) was attributed with the percentage of the polygon in each substrate size class (e.g., 40% cobble, 40% large gravel, 20% sand/silt). These values were multiplied by the area of each polygon to determine the total area of each size class within the entire monitoring site. A simplified dominant size class (sand/silt, gravel, cobble, boulder) was also identified for each polygon for mapping purposes. Because the smaller-sized gravel particles are of particular concern, maps were also created showing the combined percentage of fine and medium gravel in each substrate polygon.

In addition to the visual substrate mapping effort, quantitative pebble counts (Wolman 1954) were completed at discreet "patches" within each monitoring site. Six patches were chosen at the BJ, RR, and CA sites. The NC site had four patches. One hundred pebbles were measured from each patch except for two patches at the NC monitoring site; 200 pebbles were measured at these two patches. Particle size data were grouped into 10 size categories (with upper limits of 2, 4, 8, 16, 32, 64, 128, 256, 512, and 1,024 millimeters [mm]) and plotted to determine grain sizes of the D_{16}, D_{25}, D_{50}, D_{75}, and D_{84} particles. Pebble count (PC) patch locations are shown in Figure 3.2a-d.

3.3 Results

3.3.1 Substrate Maps

Maps of individual substrate polygons for each monitoring site are included in Appendix 3.1a. Accompanying attribute tables are provided in Appendix 3.1b. These maps provide a baseline data set that will allow future surveys to identify temporal changes in channel substrate characteristics.

The substrate maps illustrate some differences in streambed particle size distributions among the different monitoring sites. Cobble-sized material occupied the greatest area at the RR and BJ monitoring sites, which are located farthest upstream and closest to Jordanelle Dam. Large gravel was the most common substrate size at the NC site, while silt and large gravel were the most common sizes at the CA site (Figure 3.2, Figure 3.3, Figure 3.4). Restoration/construction of the CA site was only completed in late 2003, and at the time of the May 2004 mapping the site had not yet experienced a high-flow event. Construction activities were ongoing just upstream of the CA site during the May 2004 mapping. The recent construction of the CA site accounts for the high proportion of silt material on the streambed. At the other monitoring sites, silt was typically only present in eddies and slackwater areas along the channel margins (Figure 3.2).

As seen in Figures 3.3, 3.4, and Appendix 3.2, the combined proportion of fine and medium-sized gravel material (particles between 2 mm and 32 mm) was greatest at the RR and CA sites. At the RR site, most of this material was medium-sized gravel located in the pool at the upstream end of the site (between transects RR1 and RR2) and along the inside of the bend in the shallow riffle between transects RR3 and RR4 (Appendix 3.2, Figure 2.1). Additional medium-size gravel was present in the eddy areas along the inside of the bend near the downstream end of the reach. At the CA site, most of the medium-sized and fine gravel was found in the eddy area along the inside of the bend between transects CA3 and CA4. The CA site contained the largest proportion of fine gravel of any of the sites.

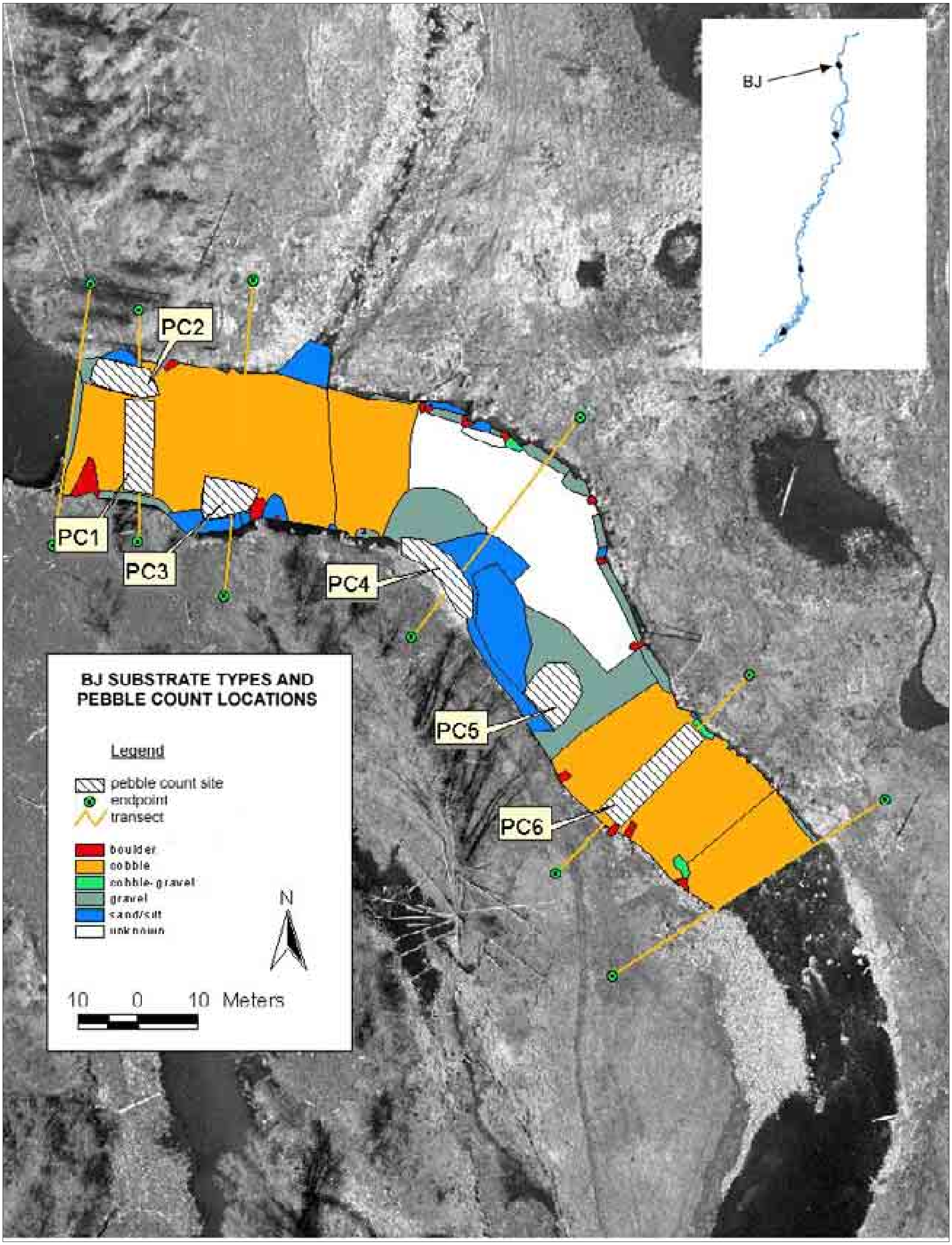


FIGURE 3.2A. PEBBLE COUNT PATCH LOCATIONS AND MAJOR SUBSTRATE TYPES AT THE BELOW JORDANELLE DAM (BJ) MONITORING SITE.

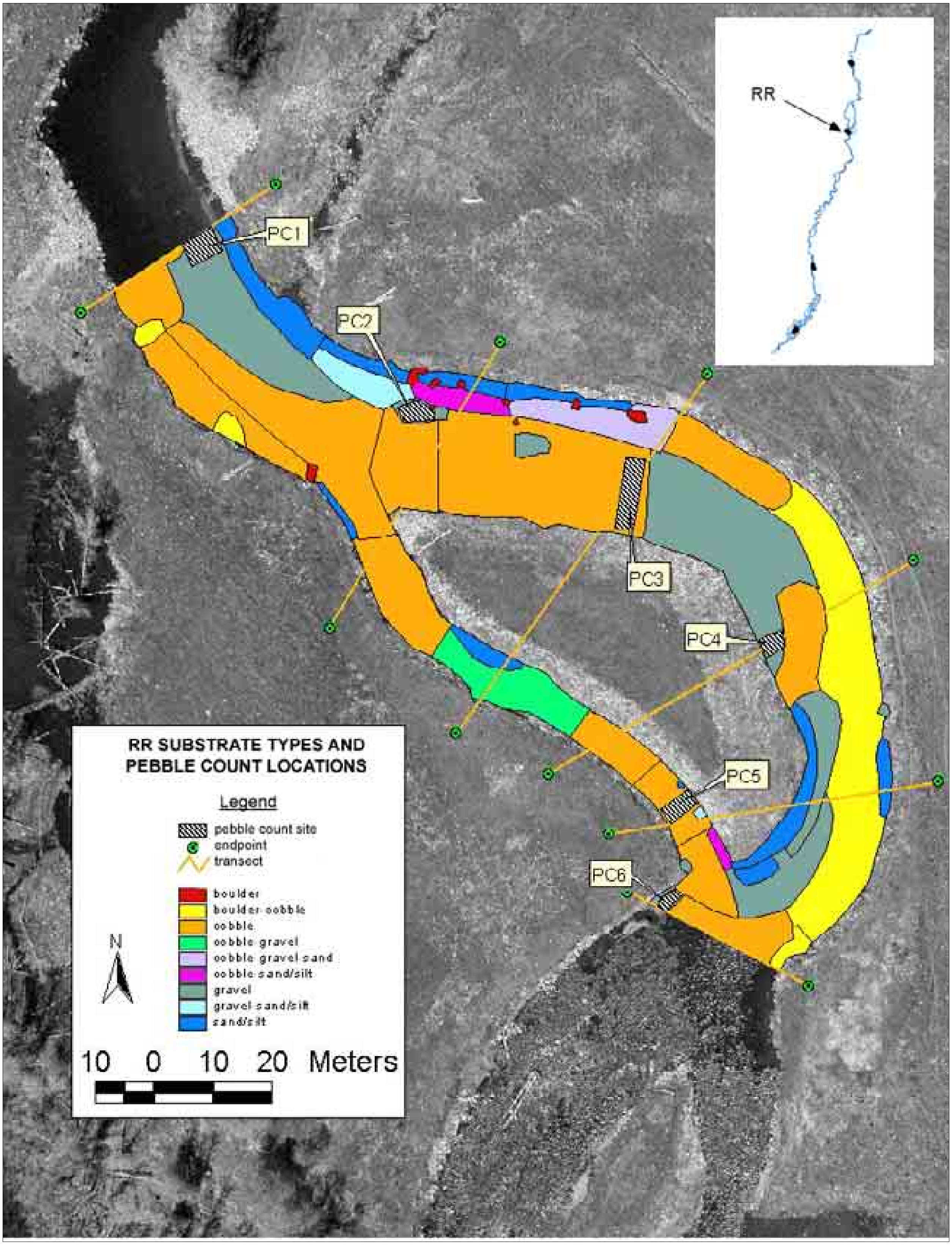


Figure 3.2b. Pebble count patch locations and major substrate types at the River Road (RR) monitoring site.

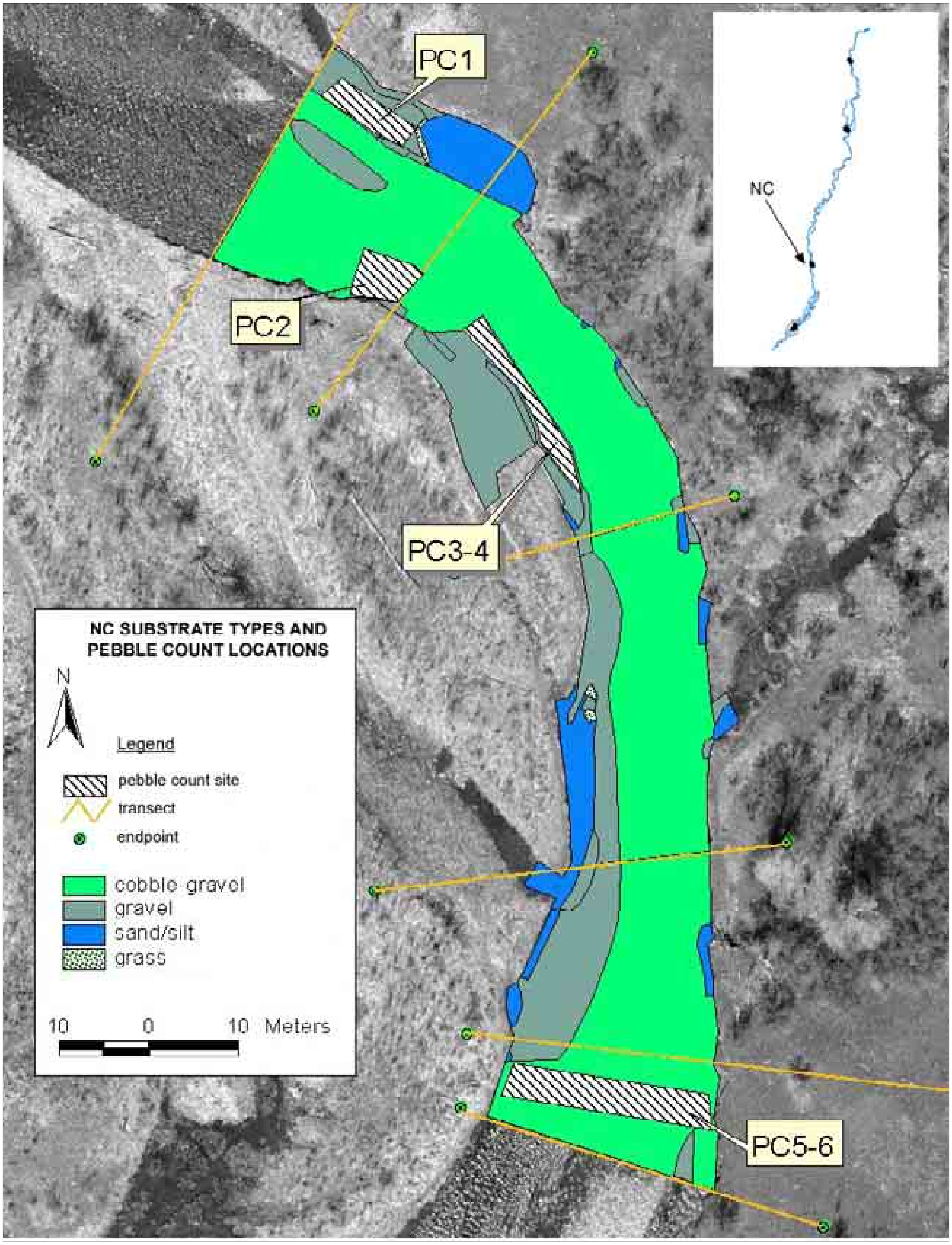


FIGURE 3.2C. PEBBLE COUNT PATCH LOCATIONS AND MAJOR SUBSTRATE TYPES AT THE NEVER-CHANNELIZED (NC) MONITORING SITE.

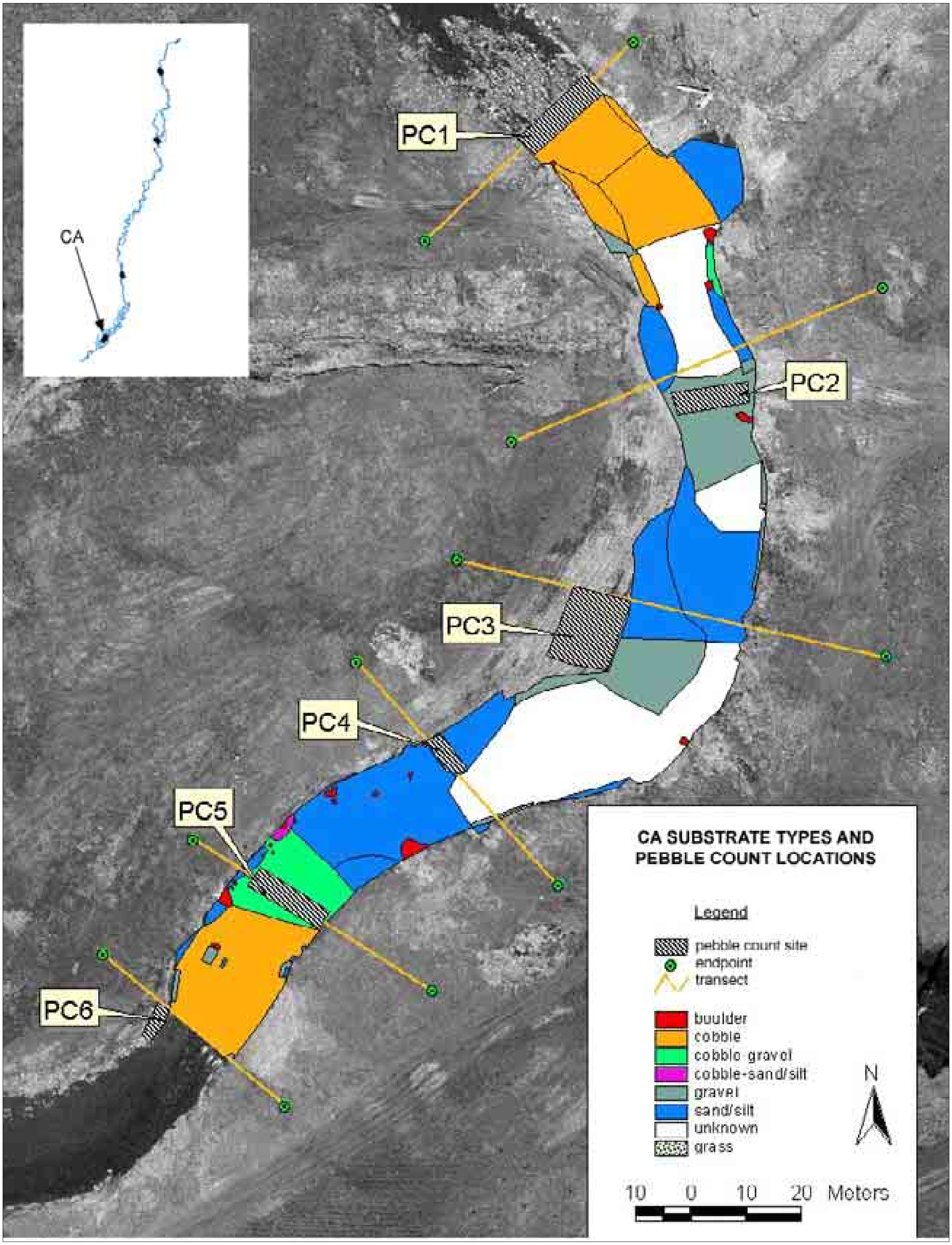


FIGURE 3.2D. PEBBLE COUNT PATCH LOCATIONS AND MAJOR SUBSTRATE TYPES AT THE CHARLESTON (CA) MONITORING SITE.

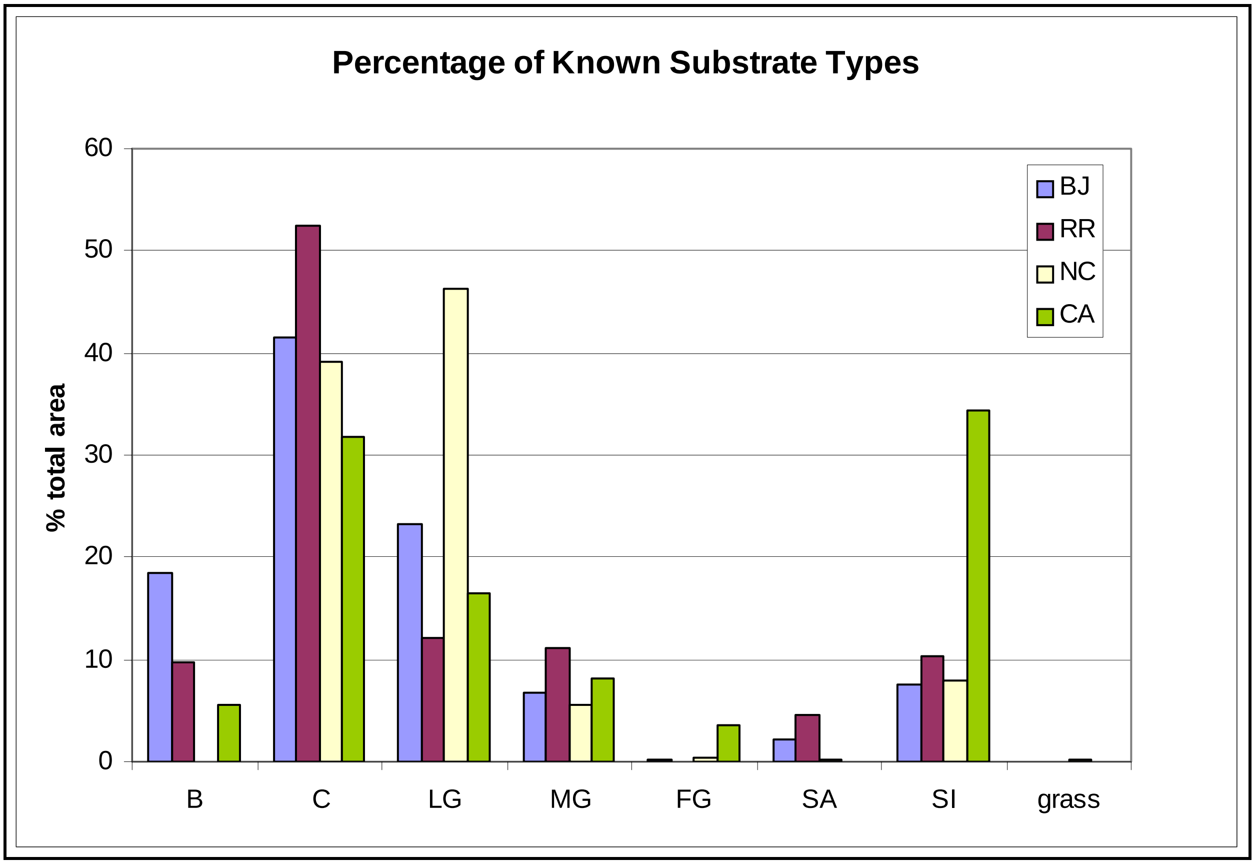


FIGURE 3.3. PROPORTION OF MONITORING SITE AREA OCCUPIED BY VARIOUS SUBSTRATE SIZE CLASSES. PLOT DOES NOT INCLUDE DEEP POOL AREAS MAPPED AS "UNKNOWN."

3.3.2 RIVER ROAD (RR) 2002 VS. 2004

Previous substrate mapping was completed in May 2002 at the RR site (then known as "Site 8" [Olsen et al. 2004]). The 2002 mapping effort was completed in order to provide channel roughness information for use in developing a two-dimensional hydrodynamics model of the site, not to provide a baseline map for future substrate monitoring. Size categories used in 2002 were the same as those in the 2004 effort except that in 2002 cobble material was separated into three size categories. Gravel-sized material was not a specific concern in the 2002 mapping effort; therefore, some of the smaller gravel-dominated patches delineated in 2004 may have been lumped into larger polygons when mapped in 2002. These differences in methods and purpose should be kept in mind when drawing comparisons between the 2002 and 2004 maps. Nevertheless, comparing the two maps does provide some indication of general trends in substrate composition within the RR monitoring site.

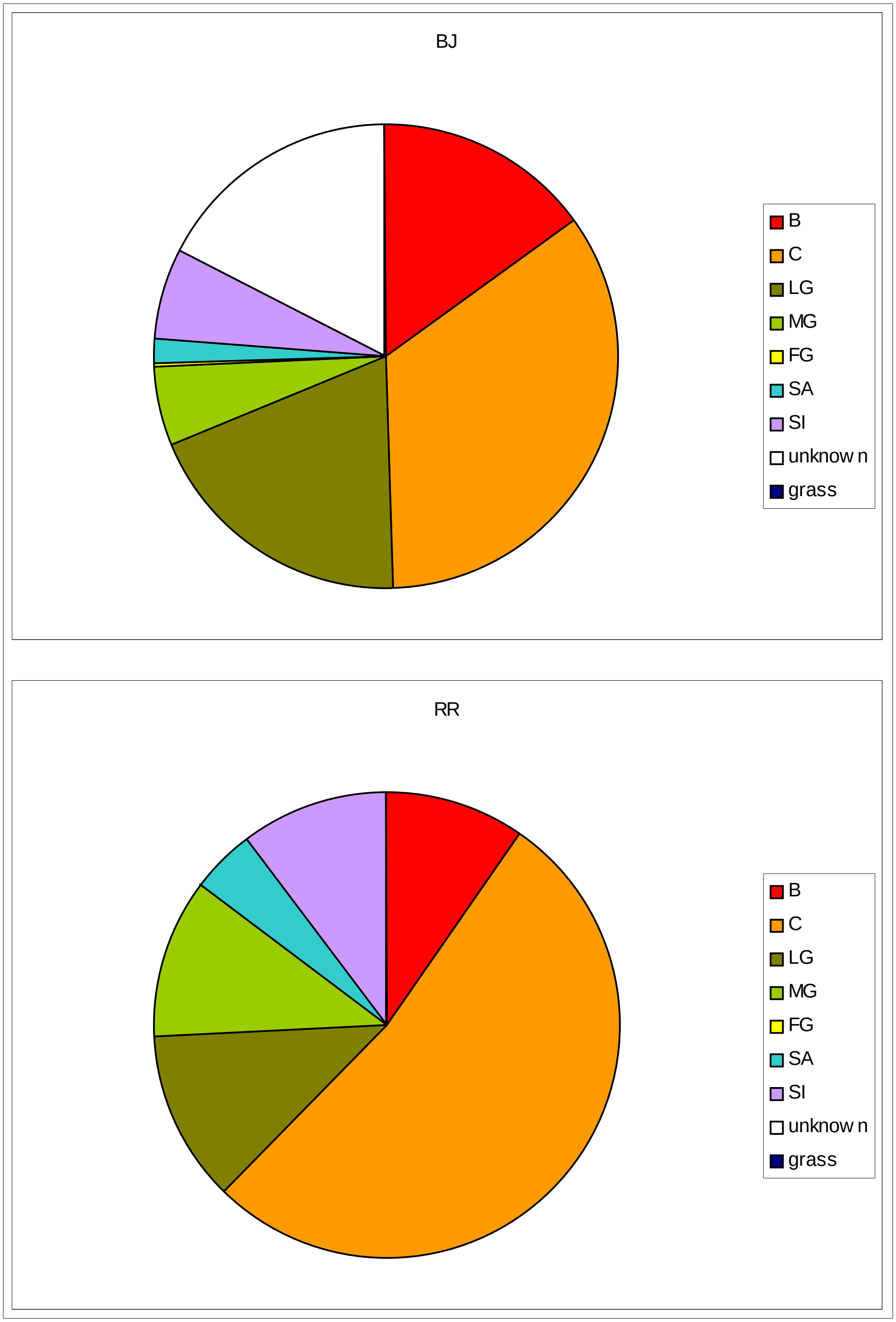
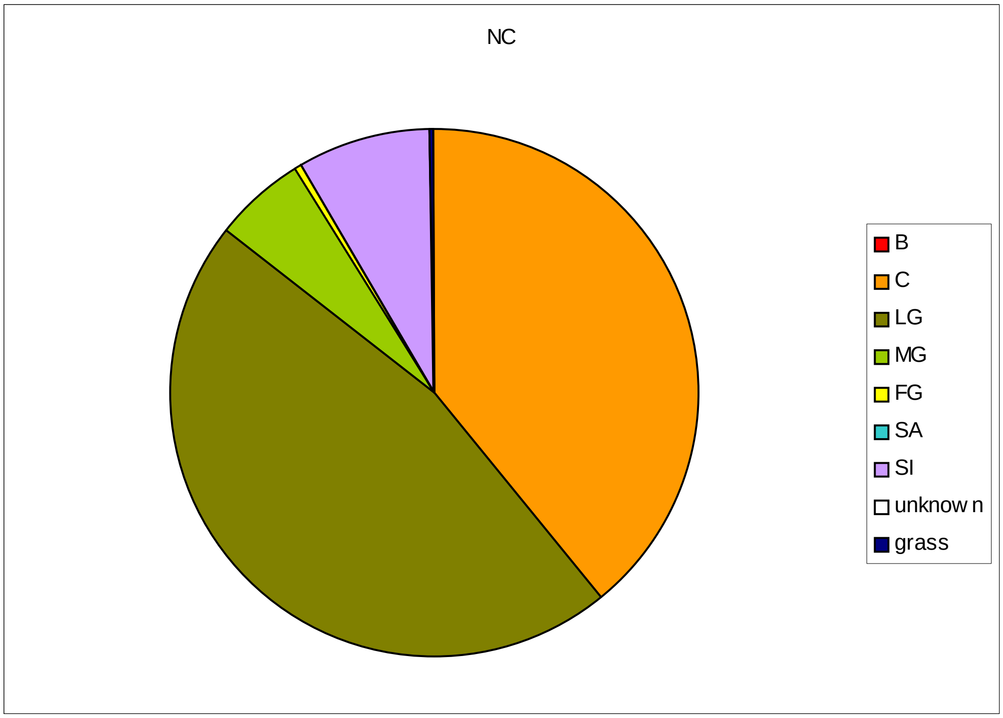


FIGURE 3.4. PROPORTION OF MONITORING SITE AREA OCCUPIED BY VARIOUS SUBSTRATE SIZE CLASSES. PLOTS INCLUDE DEEP POOL AREAS MAPPED AS "UNKNOWN" SUBSTRATE SIZE.



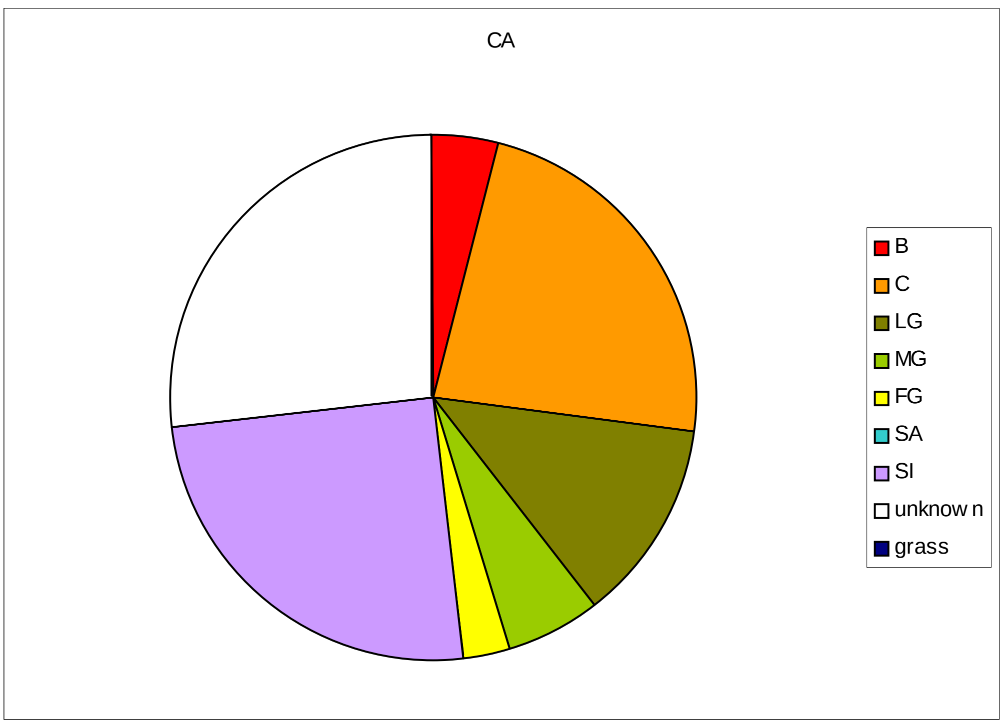


FIGURE 3.4. PROPORTION OF MONITORING SITE AREA OCCUPIED BY VARIOUS SUBSTRATE SIZE CLASSES. PLOTS INCLUDE DEEP POOL AREAS MAPPED AS "UNKNOWN" SUBSTRATE SIZE (CONT.).

As seen in Figure 3.5, the proportion of the total channel area at the RR site composed of large gravel, medium gravel, and silt increased between 2002 and 2004, while the area composed of cobble and sand decreased. Not surprisingly, since boulder-sized particles are generally immobile under typical flood magnitudes, the proportion of the area occupied by boulders was the same in 2002 and 2004. This result is interesting because individual patches of boulder were delineated somewhat differently in 2002 than in 2004. In 2004, the boulders present along the left side of the main channel between transects 2 and 3 were individually delineated, while in 2002 they were lumped into larger polygons and counted as a proportion of those polygons (Figure 3.6). Similarly, more of the boulders along the left side of the main channel between transects RR5 and RR6 were individually delineated in 2002 than in 2004 (Figure 3.6).

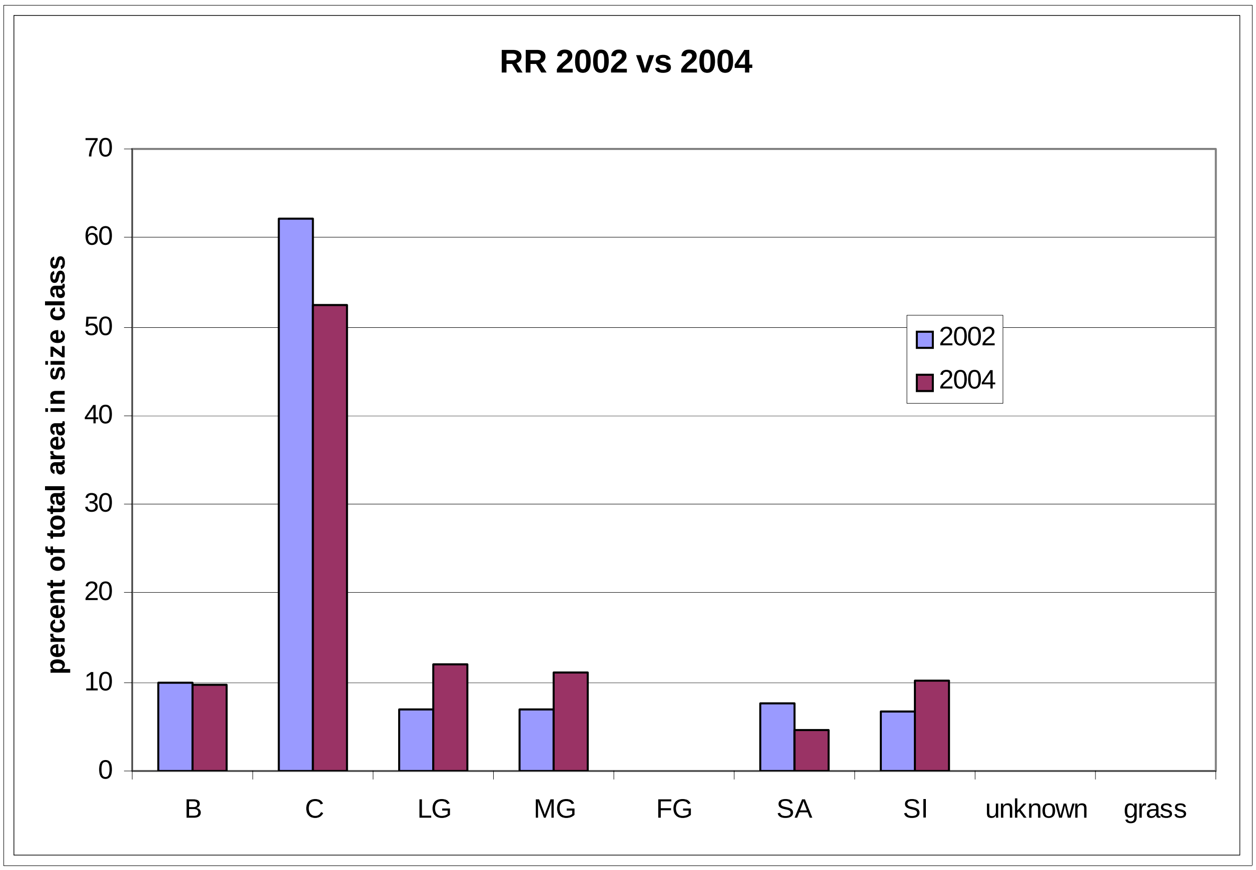


FIGURE 3.5. COMPARISON OF AREA AT THE RIVER ROAD (RR) MONITORING SITE OCCUPIED BY VARIOUS SIZE CLASSES IN 2002 AND 2004.

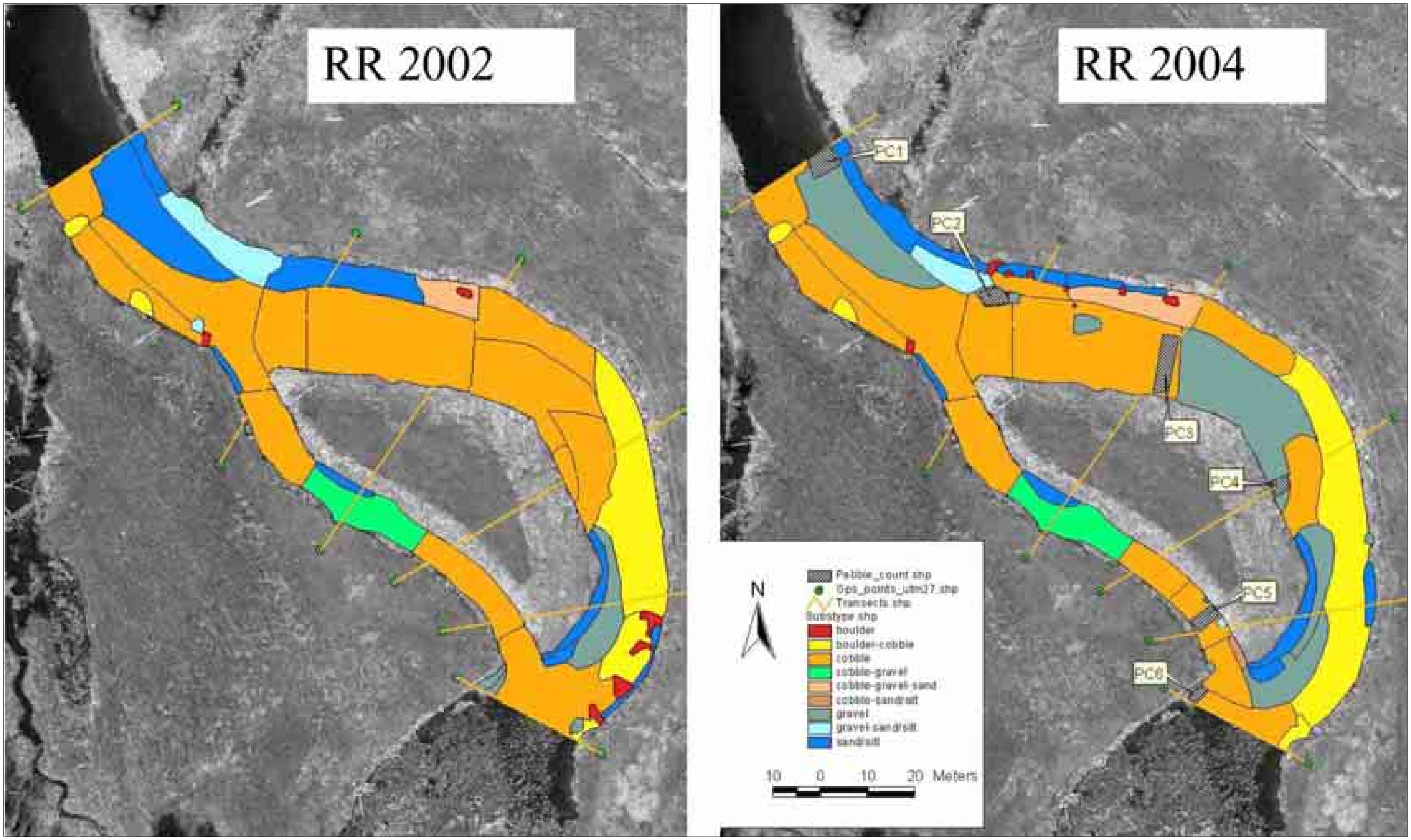


FIGURE 3.6. SUBSTRATE MAPS OF RIVER ROAD (RR) CHANNEL MONITORING SITE IN MAY 2002 VS. MAY 2004.

Based on comparison of the substrate maps for the different years, it appears that the increase in gravel occurred through deposition in the pool area between transects RR1 and RR2, deposition in the shallow riffle area on the right side of the main channel between transects RR3 and RR4, and through expansion of the gravel point bar deposit along the inside of the bend between transects RR5 and RR6 (Figure 3.6). Some additional silt appears to have deposited along the far left side of the channel between transects RR1 and RR2, and on the left side of the side channel near transect RR3. The substrate map comparison indicates that gravel deposition has occurred at the site between 2002 and 2004, and this is consistent with the evidence of deposition found in the comparison of the transect RR6 plots for 2002 vs. 2004 (see Chapter 2).

3.3.3 Pebble Counts

Pebble count results are provided in Table 3.2 and in Appendix 3.3.

3.3.3.1 Below Jordanelle (BJ) Monitoring Site

The coarsest patches at the BJ site are PC#1 and PC#6 (Figure 3.2, Table 3.2, Appendix 3.3), which consisted almost entirely of cobble-sized particles. Patch PC#1 is located in a run, while patch PC#6 is located in a steep riffle area.

Patch PC#2 is located on the left side of the channel in a run, and it consisted primarily of a mix of gravel of all sizes and some cobble (Figure 3.2, Table 3.2, Appendix 3.3).

Patch PC#3 is a gravel-dominated patch in a run near the right side of transect BJ3 (Figure 3.2). This patch seems to have had the most uniform size distribution because it shows the smallest difference between the D_{16} (24 mm) and the D_{84} (68 mm) (Table 3.2, Appendix 3.3). Although the particles range from <2 to 140 mm, most particles fall into the classification of medium- or large-sized gravel particles.

Patch PC#4 is a bar beyond the right edge of water near transect BJ4 (Figure 3.2). This patch was above the water surface during the sampling period. Patch PC#4 had a wider size distribution than most of the other patches. The D_{84} was an order of magnitude greater than the D_{16} for this patch. The D_{50} was slightly larger than those from Patch PC#2, PC#3, or PC#5 (Table 3.2).

Patch PC#5 is located on river right between transects BJ4 and BJ5 (Figure 3.2). Patch PG#5 had a relatively fine particle size distribution, but was still dominated by large gravel. It was the smallest in most size classes compared to other BJ patches (Table 3.2). However, the particles ranged in size from <2 mm to 150 mm (Appendix 3.3), indicating the presence of a few larger and some finer material.

3.3.3.2 River Road (RR) Monitoring Site

Patch PC#1 is located in the middle of the channel in the pool area just downstream of transect RR1 (Figure 3.2). This patch contained primarily medium- and large-sized gravel particles (Table 3.2, Appendix 3.3). Although the range of particle sizes was between <2 mm and 145 mm, the majority of particles were under 49 mm.

Table 3.2. Pebble count results[a] for channel monitoring sites. Values are in millimeters.

Below Jordanelle	BJ PC#1	BJ PC#2	BJ PC#3	BJ PC#4	BJ PC#5	BJ PC#6
D_{16}	82	14	24	11	10	115
D_{25}	115	23	30	28	19	125
D_{50}	155	44	40	58	43	173
D_{75}	205	71	58	90	58	217
D_{84}	226	86	68	110	67	245
Class of D_{50}	Cobble	Large gravel	Large gravel	Large gravel	Large gravel	Cobble
River Road	**RR PC#1**	**RR PC#2**	**RR PC#3**	**RR PC#4**	**RR PC#5**	**RR PC#6**
D_{16}	11	20	33	38	45	32
D_{25}	17	24	37	45	51	37
D_{50}	27	36	64	60	75	49
D_{75}	42	50	110	86	123	67
D_{84}	49	55	136	100	156	75
Class of D_{50}	Medium gravel	Large gravel	Cobble	Large gravel	Cobble	Large gravel
Never-Channelized	**NC PC#1**	**NC PC#2**	**NC PC#3-4**	**NC PC#5-6**	**-**	**-**
D_{16}	24	42	30	52	-	-
D_{25}	30	51	36	61	-	-
D_{50}	48	76	51	83	-	-
D_{75}	65	100	74	119	-	-
D_{84}	77	117	90	146	-	-
Class of D_{50}	Large gravel	Cobble	Large gravel	Cobble	-	-
Charleston	**CA PC#1**	**CA PC#2**	**CA PC#3**	**CA PC#4**	**CA PC#5**	**CA PC#6**
D_{16}	42	22	15	6	24	8
D_{25}	51	26	31	10	33	28
D_{50}	84	51	54	38	66	47
D_{75}	122	86	83	54	96	101
D_{84}	131	109	96	60	112	130
Class of D_{50}	Cobble	Large gravel	Large gravel	Large gravel	Cobble	Large gravel

[a] All values are in millimeters.

Patch PC#2 is located mid-channel near transect RR2 in a slow-velocity run area. Patch PC#2, like PC#1, consisted primarily of medium- and large-sized gravel. There was little variation in particle sizes, with only a 35 mm difference between the D_{16} and the D_{84}.

Patch PC#3 crosses the main channel width at transect RR3. This patch was slightly coarser than PC#1 or PC#2. Patch PC#3 was mostly large gravel and cobble. The range of particle sizes (<2 mm to 282 mm) indicates that there were some boulder-sized particles in the patch, however, the D_{84} (136 mm) shows that most of the patch was cobble sized or smaller.

Patch PC#4 is located near the right side of transect RR4 (Figure 3.2). There were large gravel- and cobble-sized particles in this patch, similar to PC#3. Particle sizes in PC#4 ranged from 8 mm to 240 mm (Appendix 3.3). This size range indicates that there was little, if any, fine material in this patch. Based on the D_{84}, most particles are smaller than 100 mm (Table 3.2).

Patch PC#5 describes the bed material in a riffle portion of the side channel at the RR monitoring site. This patch was the coarsest at the RR monitoring site. Particles ranged in size from 20 mm to 240 mm (Table 3.2, Appendix 3.3). There was no fine material in this patch and very few particles were smaller than large gravel. Most of the patch consisted of large gravel and cobbles. The D_{16} and D_{84} show that most particles were between 45 mm and 156 mm.

Patch PC#6 is located on a bar beyond the right edge of water at transect RR6. The patch consisted mostly of gravel that was somewhat coarser than that found at PC#2. The particles ranged in size from 18 mm to 300 mm, but the majority of particles were between 32 and 75 mm (Table 3.2).

3.3.3.3 Never-Channelized (NC) Monitoring Site

Patch PC#1 is located just downstream from transect NC1, on the exposed gravel bar adjacent to the left bank. This patch contained smaller-sized particles than the other patches at this monitoring site. The range of particle sizes was <2 mm to 145 mm (Table 3.2, Appendix 3.3). The D_{84} indicates that the majority of the particles were under 77 mm, about half the size of the largest particle measured. The patch also contained few fine particles, indicated by a D_{16} of 24 mm. Most particles were medium to large gravel and cobble.

Patch PC#2 starts at the top of a riffle near the center of transect NC2 and extends to the right bank. The patch was composed of large gravel and cobble. The pebbles ranged in size from 3 mm to 220 mm (Appendix 3.3). Boulder-sized particles were not present in this patch.

Patch PC#3-4 is located on a large exposed gravel bar that starts just downstream of transect 2 and ends about halfway between transects NC2 and NC3. Two hundred pebbles were measured at patch PC#3-4. The particles ranged in size from <2 mm to 190 mm (Appendix 3.3), and the distribution was dominated by large gravel.

Patch PC#5-6 spans a riffle area between transects NC5 and NC6 (Figure 3.2), and had the coarsest size distribution at the NC site. Large gravel- and cobble-sized particles dominated the distribution. PC#5-6 particles ranged from 32 mm to 250 mm (Appendix 3.3). Even though the ranges show a few large cobbles present in the patch, most particles were smaller 150 mm (Table 3.2).

3.3.3.4 Charleston (CA) Monitoring Site

Patch PC#1 covers the width of the channel in the riffle at transect CA1. This patch is the coarsest among the CA patches with particle sizes ranging from 7 mm to 800 mm (Appendix 3.3). Each of the diameter classifications at this patch was higher than those of the other patches in the CA monitoring site (Table 3.2). The distribution at PC#1 was dominated by cobble.

Patch PC#2 crosses the width of the channel near transect CA2. The patch is in a run just upstream of a riffle. The particle sizes ranged from <2 mm to 220 mm, but only one measurement was <2 mm. The next largest particle was 11 mm, indicating limited presence of fine sediment in this patch. (Appendix 3.3). The largest particle measured in PC#2 (220 mm) was about twice as large as the

D_{84} (109 mm) (Table 3.2). Most of the particles were smaller then 100 mm in this patch, but larger boulder-sized particles were present as well.

Patch PC#3 is located on a bar that was above the water surface during the sampling period. The bar is located on the right side of the channel near transect CA3. Patch PC#3 contained particle sizes similar to those found in PC#2. Particle sizes in PC#3 ranged from <2 mm to 167 mm (Appendix 3.3). The patch primarily consisted of cobble and large gravel with smaller percentages of medium gravel and sand/silt material.

Patch PC#4 is located on the right side of the channel in an eddy/pool area centered on transect CA4 (Figure 3.2). Patch PC#4 is the finest-grained patch at the CA monitoring site. The particle sizes ranged from <2 mm to 130 mm. The D_{16} (6 mm) was also lower than the other CA patches (Table 3.2). The D_{84} of PC#4 was less than half the size of the D_{84} of the coarsest patch (PC#1). Patch PC#4 also seemed to be the most uniform, having the smallest difference between the D_{16} and D_{84}. Most of the patch was gravel.

Patch PC#5 crosses the full channel width at transect CA5, and consisted primarily of cobble material with large and medium gravel also present. The patch is located in a slower-velocity run upstream of a riffle that contained coarser boulder- and cobble-sized particles. The PC#5 size distribution was similar to the PC#2 distribution, but slightly coarser (Table 3.2). The particle sizes in patch PC#5 ranged from <2 mm to 235 mm (Appendix 3.3). However, the D_{84} (112 mm) indicates that most particles were much smaller than the largest particle.

Patch PC#6 is located on a gravel bar on the right bank just below transect 6 that was exposed above the water surface during sampling. This patch had the widest range of particle sizes at the CA site. Particle sizes ranged from <2 mm to 350 mm. A D_{16} of 8 mm shows that there was finer material and a few very large boulder-sized particles in this patch. However, a D_{84} of 130 mm shows that most particles were much smaller than the maximum size (Table 3.2).

3.4 Channel Substrate Discussion and Recommendations

Monitoring changes in channel substrate composition through time will be one way to evaluate the long-term influence of sediment trapping by Jordanelle Dam. Based on the May 2004 baseline substrate maps, several differences among the four monitoring sites are apparent. The BJ and RR sites, which are located farthest upstream and closest to Jordanelle Dam, contained the largest proportion of coarse (cobble- and boulder-sized) substrate material (Figure 3.3). The NC site contained the largest proportion of gravel-sized (total of fine, medium, and large gravel size classes) substrate material. Relative to the restored sections of channel, the never-channelized reach of the Provo River appears to be characterized by much larger, more frequent, and finer-grained gravel bars. Sediment transport monitoring results from the MID bridge sampling site (see Chapter 4) indicate that much of the gravel from the never-channelized reach is being mobilized and transported downstream. Future substrate mapping results should document if there is a reduction in gravel at the NC site and/or a complimentary increase in gravel at the CA site downstream because of inputs and deposition from the NC site.

The 2004 substrate maps also document an unusually high proportion of fine material (sand and silt) at the CA site. This is most likely because of the recent construction at the CA site (no high flows had passed through the newly constructed channel at the time of mapping) and because construction activities were ongoing just upstream of the CA site during the May 2004 monitoring period. It is likely that the spring 2004 high flows (which occurred after the 2004 channel substrate monitoring) mobilized much of this fine material, and it is anticipated that the May 2005 substrate mapping and pebble count results for the CA site will demonstrate a reduction in fine sediments at the site.

Future substrate monitoring at the RR site will help to determine whether the apparent increase in gravel at the RR site between 2002 and 2004 continues as a longer-term trend. Channel reconstruction activities occurred upstream of the RR site during 2002 (after the May 2002 mapping effort), and may have been the source of the gravel and silt that was apparently deposited in the RR site. Additional substrate mapping, repeat pebble counts, and repeat cross-sectional/longitudinal profile surveys in future years will provide a more robust, comprehensive indication of trends such as channel degradation or aggradation at the RR site and other sites.

4.0 SEDIMENT TRANSPORT

4.1 Introduction

The results of the first year of bedload and suspended load monitoring and transport modeling is described in this chapter. Some bedload data from previous years (2002 and 2003), as described in the Provo River Flow Study (Olsen et al. 2004), are included where applicable. These data will be used in determining a sediment budget and necessary adaptive maintenance activities to keep restored sections of the middle Provo River in a desirable condition. Such data may also help determine if the Mitigation Commission is fulfilling commitments concerning fish, wildlife, and recreation.

4.2 Sediment Transport Methods

4.2.1 Monitoring Sites

Bedload and TSS samples were collected at four bridge locations, which are somewhat equally spaced between Jordanelle Dam and Deer Creek Reservoir (Map 1.1). Table 4.1 shows distances between bridges that were used for sediment transport monitoring. The bridge structures enabled workers to collect samples across the entire width of the channel during peak flows when the river was unwadeable.

The White Bridge (WB) sediment transport monitoring bridge (Photo 4.1) is located approximately 1.76 river miles downstream of Jordanelle Dam. In-channel sediment supplies are thought to be very restricted between Jordanelle Dam and the WB monitoring bridge because of the short distance between the dam and the WB bridge. Also, the sediment supplies on the bed (and the well-vegetated banks) are relatively armored and immobile, consisting primarily of cobbles and boulder-sized materials. Gravel bars, eroding streambanks, and other significant sediment sources are extremely limited above WB with the exception of a short segment of the river where the channel runs adjacent to an eroding side hill. See Appendix 4.1 for additional photos of the bridge structure, upstream channel conditions, and the eroding side hill.

Table 4.1. Approximate distances between sediment transport monitoring bridges.

Sediment Transport Monitoring Bridge	Distance Between Bridges[a]	Total Restored River Miles Below Jordanelle Dam
White Bridge (WB)	-	1.76
River Road (RR)	2.42	4.18
Midway Bridge (MID)	4.66	8.84
Charleston (CA)	2.55	11.39

[a] All distances were measured along the thalweg of the restored channel by the Utah Mitigation and Conservation Commission.

PHOTO 4.1. THE WHITE BRIDGE (WB) SEDIMENT TRANSPORT MONITORING BRIDGE (MIDDLE RIGHT SIDE OF PHOTO). DIRECTION OF FLOW IS FROM RIGHT TO LEFT. HIGHWAY 40 BRIDGE (TOP LEFT) IS NOT A MONITORING SITE.

The River Road (RR) sediment transport monitoring bridge (Photo 4.2) is located approximately 4.18 river miles downstream of Jordanelle Dam. This site has an additional 2.42 miles of channel length below the WB monitoring bridge to pick up available sediments. However, our field observations indicate that the bed and banks above the RR monitoring bridge are also stable, similar to those above the WB monitoring bridge, and there was limited available sediment during the sampled flow stages (less than 2,000 cfs). The channel between these two bridges is fairly well buffered from hillside erosion and other out-of-channel sediment sources, with the exception of a couple small, hillside-channel linked sections as shown in Photo 4.2. See Appendix 4.1 for additional photos of the bridge structure, the restored reaches upstream of the RR Bridge monitoring site, and potential areas of bank erosion during high flow stages.

The Midway Bridge (MID) sediment transport monitoring bridge (Photo 4.3) is located approximately 8.84 river miles downstream of Jordanelle Dam, between the towns of Midway and Heber City near Highway 113. This bridge is located downstream of 1.2 miles of river channel that has not yet been restored, 2.3 miles of river channel that was restored in 2001, and a reach about 2.1 miles immediately upstream of the MID bridge that was never channelized (Map 1.2). The never-channelized portion of the middle Provo River (shown on the bottom right side of Photo 4.3)

PHOTO 4.2. THE RIVER ROAD (RR) SEDIMENT TRANSPORT MONITORING BRIDGE (BOTTOM LEFT). DIRECTION OF FLOW IS FROM RIGHT TO LEFT. NOTICE THE RESTORED MEANDERS UPSTREAM OF THE ERODING SIDE HILL.

has an enormous supply of potentially mobile bedload material. The gravel deposits in the never-channelized reach appear to be a remnant of past channelization practices and high peak flows between 1938 and 1995. Many large gravel bars and other in-channel sediment sources currently exist in the never-channelized portion of the Provo River, conceivably adding to current sediment transport rates at the MID monitoring bridge. See Appendix 4.1 for additional photos of the bridge structure, gravel bars just upstream of the bridge, an aerial photo of the never-channelized reach, and a diversion structure between the never-channelized reach and the Midway Bridge.

The Charleston (CA) sediment transport monitoring bridge (Photo 4.4) is located approximately 13.39 river miles downstream of Jordanelle Dam, just below the Heber Valley Railroad crossing and the U.S. Geological Survey (USGS) gaging station near Charleston. This bridge is the lowest monitoring site on the middle Provo River, and is just upstream of Deer Creek Reservoir's full pool zone of influence. During the May/June 2004 sampling period, channel restoration activities were occurring just upstream of the CA monitoring bridge, presumably adding to this year's TSS and the fine-grained (<2 mm size fraction) bedload transport rates. See Appendix 4.1 for additional photos of the bridge structure, upstream and downstream channel conditions, and an aerial photo of the recently restored reach just upstream of this monitoring site.

PHOTO 4.3. THE MIDWAY BRIDGE (MID) SEDIMENT TRANSPORT MONITORING BRIDGE (MIDDLE LEFT). DIRECTION OF FLOW IS FROM BOTTOM RIGHT (NEVER-CHANNELIZED PORTION OF THE MIDDLE PROVO RIVER) TO UPPER LEFT (HEBER VALLEY SEWER IMPROVEMENT DISTRICT'S WASTEWATER TREATMENT PONDS).

4.2.2 STREAM DISCHARGE

Streamflows encountered during sampling were determined using real time, provisional 15-minute flow data at the three USGS gaging stations located in the project area (see Map 1.1) copied from the USGS web site (USGS 2004). Table 4.2 shows which gaging station was used at each monitoring bridge.

Sediment samples were collected at fairly regular discharge intervals during the rising and falling limbs of the 2004 spring runoff hydrograph (Figure 4.1). Prior to spring runoff a flow release schedule was proposed that met water delivery needs and was patterned to achieve a high peak flow and gradual receding limb for sediment transport and cottonwood recruitment purposes. The Mitigation Commission also used the flow release to determine what problems might arise if the dam were operated in this manner. The proposed flow release schedule was implemented with some slight modifications to the duration of peak flows. Sediment samples were collected at predetermined flow rates after each new flow level stabilized.

Photo 4.4. The Charleston (CA) sediment transport monitoring bridge (middle right). Direction of flow is from right to left. Notice Snake Creek coming into the Provo River from the top of the photo and the Heber Valley Railroad crossing and the Charleston USGS Gauging Station on the far right side of the photo (upstream direction).

Table 4.2. Data sources used to determine streamflow at the various monitoring bridges.

Site	Data Source/ Calculation Technique
White Bridge (WB)	USGS Station #10155200 (Provo River at River Road Bridge) 15-minute real-time data
River Road Bridge (RR)	USGS Station #10155200 (Provo River at River Road Bridge) 15-minute real-time data
Midway Bridge (MID)	USGS Station #10155300 (Provo River near Midway) 15-minute real-time data
Charleston (CA)	USGS Station #10155500 (Provo River near Charleston) 15-minute real-time data

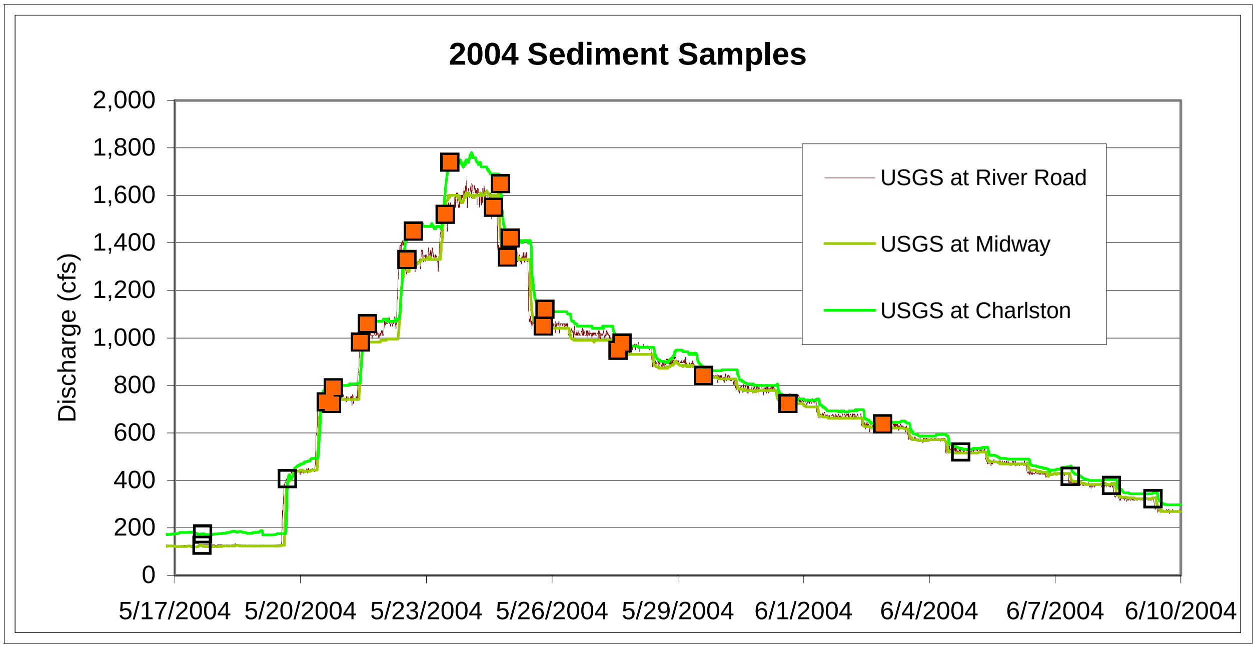


FIGURE 4.1. YEAR 2004 SPRING RUNOFF HYDROGRAPH SHOWING WHEN SEDIMENT SAMPLES WERE TAKEN ON THE RISING AND FALLING LIMBS. THE OPEN BOXES SHOW WHEN SUSPENDED SAMPLES WERE TAKEN, WHEREAS THE ORANGE FILLED BOXES SHOW WHEN BOTH SUSPENDED AND BEDLOAD SAMPLES WERE TAKEN.

4.2.3 Suspended Sediment (TSS) Monitoring

Suspended sediment concentrations were determined by collecting samples of the flowing water at each bridge in a cross-sectional and depth-integrated manner. Techniques to achieve cross-sectional and depth-integrated samples at each bridge included the use of a weighted sleeve and a 1-liter Nalgene bottle, which was dipped from the surface to the bottom of the water column at equal intervals across the channel (see Photo 4.5). Sample bottles were labeled in the field, stored until the end of the sampling season, and analyzed for TSS concentrations at the Utah State University (USU) Soils Lab using standard filter and oven-drying methods.

For each sample, TSS concentrations and streamflow values were converted to daily TSS loads by multiplying the TSS concentration (milligrams per liter) by the flow (cfs) and applying a conversion factor (0.002697) to make the units consistent and provide a TSS transport rate in tons per day. These values were used to develop an empirically derived TSS transport rating curve (Appendix 4.2) for each monitoring site, which shows the relationship between flow and TSS transport rate.

PHOTO 4.5. PHOTOGRAPH OF THE DEVICE USED TO OBTAIN SUSPENDED SEDIMENT (TSS) SAMPLES FROM BRIDGES.

4.2.4 BEDLOAD MONITORING

Field samples of bedload were collected at the four bridge locations using a 6-inch Helley-Smith-type sampler (Photos 4.6 - 4.8). Bedload samples were not collected when flows were below 600 cfs (Figure 4.1). To sample bedload, the sampler was lowered onto the bottom of the channel for 30 minutes total, which is a composite of three 10-minute sub samples at equally spaced locations across the active bed. The width of active bedload transport was noted so that total transport calculations across the entire active bed could be performed.

Each field-collected bedload sample was dried and sorted into the following size categories using standardized sieves: $\geq$16 mm, 8 mm, 4 mm, 2 mm, 1 mm, and <1 mm. After sieving, each size category was individually weighed using a digital scale accurate to 1 gram. When practical, organic matter present in the sample was removed before weighing. Additionally, before sorting, digital photographs were taken of each sample using a penny for scale. These photographs were used to compare sample characteristics for the different sites and collection dates. Bedload samples (measured in grams collected in the 6-inch sampler for 30 minutes) were converted to daily loads

Photo 4.6. BIO-WEST's 6-inch Helley-Smith-type cable suspended bedload sampler.

Photo 4.7. BIO-WEST's 6-inch Helley-Smith-type bedload sampler is lowered from the White Bridge (WB) monitoring bridge using an AutoCrane.

Photo 4.8. Bedload material is removed from sampler and put in zip lock bags at each monitoring site. Bedload samples are dried, sieved, and weighed in a laboratory. Photos of each sample are provided in Appendix 4.2.

(in tons across the active channel width for the entire day). These values were plotted against streamflow at the time of the sample to develop an empirically derived bedload transport rating curve for each monitoring site, showing the relationship between flow and bedload transport rate. Where applicable, bedload data collected in 2002 and 2003 (Olsen et al. 2004) were added to the 2004 data.

Daily transport rates and total annual loads were calculated by applying the power equation derived for each monitoring site to the discharge values (x) from the USGS gaging stations for the 2004 Water Year. Daily average discharge values were used during most of the year (the 15-minute instantaneous discharge values were used from May 10 through June 9, when flows were actively changing during the day).

4.3 Sediment Transport Results

The raw sample and the empirically derived suspended and bedload sediment transport rating curves for each monitoring site, showing the relationship between flow and transport rate, are provided in Tables 1-2 and Figures 1-3 of Appendix 4.2. Photos of bedload samples are also provided in Appendix 4.2.

Figure 1 of Appendix 4.2 shows that at all monitoring sites higher TSS loads were observed during the rising limb, while lower TSS loads were observed during the falling limb, a pattern known as "hysterisis." A distinct hysterisis pattern was not observed with the bedload data (Figure 2 of Appendix 4.2), except at the CA monitoring site. Note the reversal (higher bedloads during the falling limb) compared to the suspended sediment hysterisis. The reason TSS concentrations are higher during the rising limb is that flowing water starts inundating surfaces that have stored sediment since the last flood event. Suspended sediment concentrations are much lower at any given flow during the falling limb or when flows stabilize at a certain stage for a long time. The TSS data clearly shows a separation between rising and falling limb concentrations, and the separation gets stronger in the downstream direction (reaches with less supply limitations). Therefore, the rising and falling limb power equations for each site, shown in Figure 1 of Appendix 4.2, are used to calculate TSS loads, and the single power equation for each, site shown in Figure 3 of Appendix 4.2, is used to calculate bedloads.

Gravel transport and the ambient supplies of gravel below Jordanelle Dam are of particular concern in the middle Provo River because gravel from upstream sources are known to deposit in the reservoir, and in-channel gravel supplies (e.g., gravel bars) are essential for maintaining high-quality aquatic habitat and desirable channel conditions. To assess gravel transport and supplies, bedload samples were separated into sand ($\leq$ 2 mm) and gravel (>2 mm) fractions, and separate sand and gravel rating curves were developed for each monitoring site (Figure 4 of Appendix 4.2).

Daily transport rates are graphed for each monitoring site individually (Figure 4.2). This graph shows that transport rates are low at all times of the year except during spring runoff, and TSS transport rates are approximately 3 to 65 times greater than bedload transport rates at the various sites during any given flow. The sediment transport pattern shown in Figure 4.2 is typical of gravel-bedded rivers with snowmelt-dominated runoff. However, it is important to note that the relationship between streamflow and sediment transport is fairly dissimilar between monitoring sites, with the exception of the WB and RR bridges, where bedloads are nearly identical. Because of the dissimilarities, each reach will have a unique response to a single high-flow event, an indication of fluvial disequilibrium.

A comparative graph of daily transport rates during spring runoff for all sediment monitoring sites is provided in Figure 4.3. This graph shows a distinct pattern of increasing suspended and bedload sediment transport rates with increasing distance below Jordanelle Dam, except for the aberration of bedload at the MID monitoring bridge (below the never-channelized reach). Suspended sediment transport rates increase by more than 2 times between each monitoring site with a total increase of more than 32 times between WB and CA monitoring bridge, a distance less than 12 river miles.

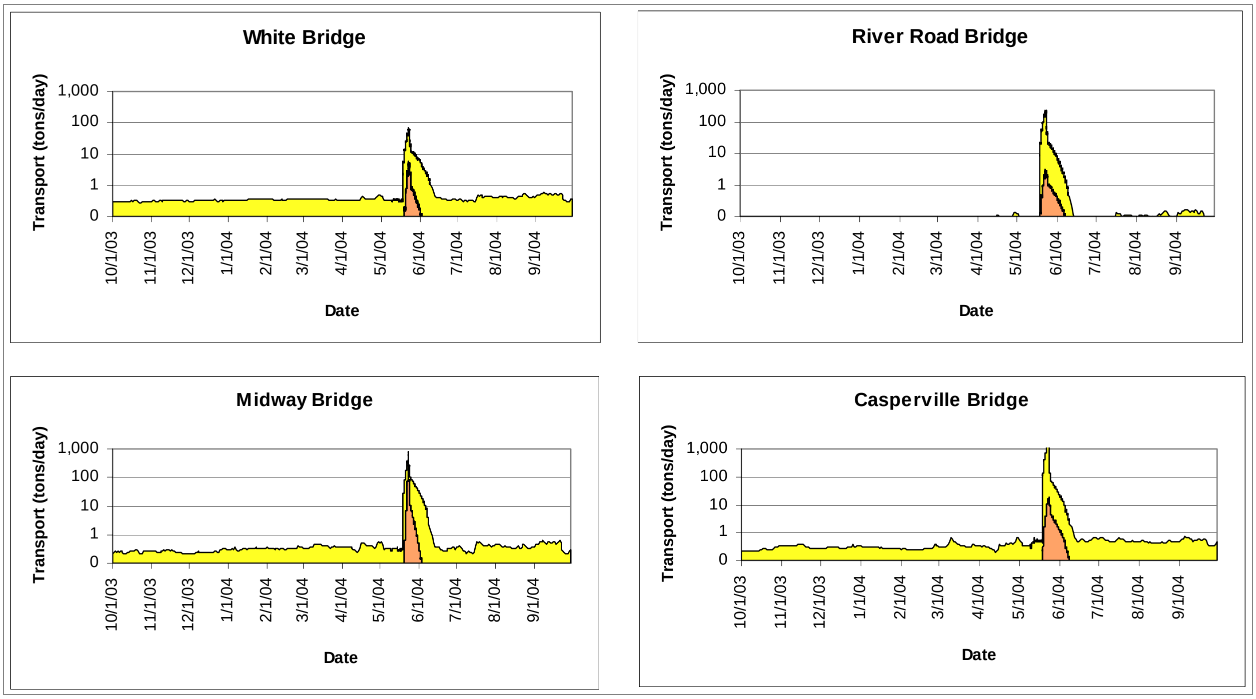
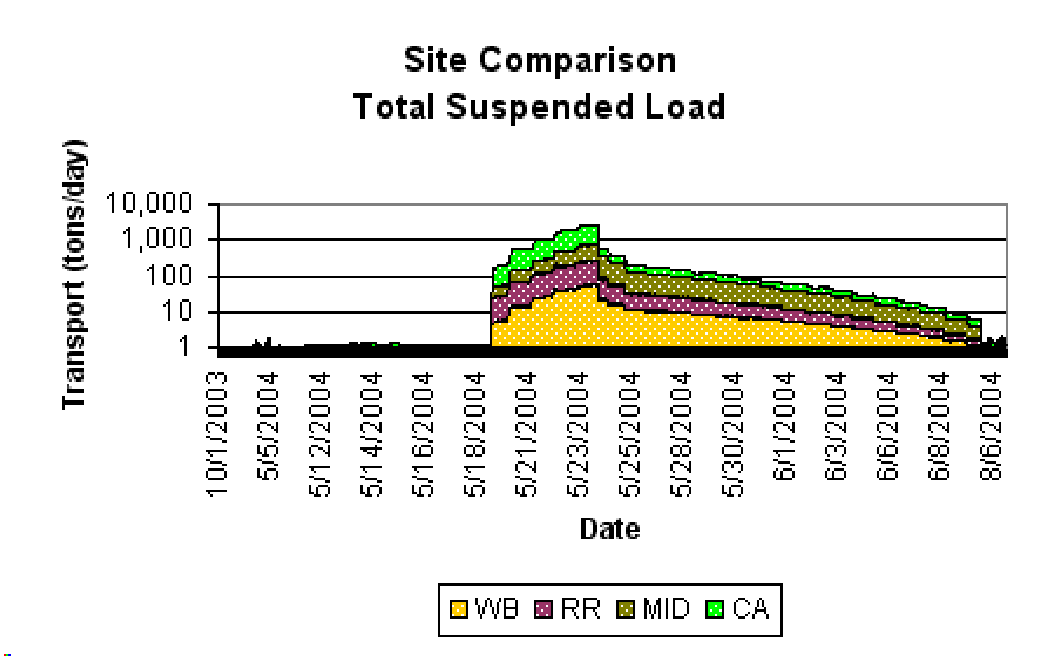


FIGURE 4.2. SUSPENDED (SOLID YELLOW) AND BEDLOAD (ORANGE DOTS) SEDIMENT TRANSPORT DURING THE 2004 WATER YEAR BASED ON USGS FLOW RECORDS AND EMPIRICALLY DERIVED RATING CURVES SHOWN IN APPENDIX 4.2. TOTAL TRANSPORT RATES ARE DRIVEN BY THE PEAK SPRING RUNOFF PERIOD. TRANSPORT RATES INCREASE IN THE DOWNSTREAM DIRECTION. ALL SITES SHOW EXTREMELY LOW SUSPENDED AND NO BEDLOAD TRANSPORT DURING LOW FLOW, WITH RIVER ROAD SHOWING THE LOWEST SUSPENDED TRANSPORT RATES DURING LOW FLOW. HOWEVER, MINIMAL SUSPENDED SEDIMENT SAMPLES WERE TAKEN IN 2004 AS SHOWN IN FIGURE 4.1. ADDITIONAL SUSPENDED SEDIMENT SEDIMENT SAMPLES WILL BE TAKEN IN FUTURE YEARS DURING LOW FLOW TO IMPROVE THIS PORTION OF THE RATING CURVE.

A comparison of total annual loads at each site during the 2004 Water Year (Figure 4.4) shows a similar pattern of increasing sediment loads with increasing distance downstream from Jordanelle Dam, with the exception of extremely high bedloads at the MID monitoring bridge (below the never-channelized reach). Separating the sand parts from the gravel parts in the bedload samples (Figure 4.5) shows that the disequilibrium in bedload transport is related primarily to gravel supplies and only moderately to sand supplies.



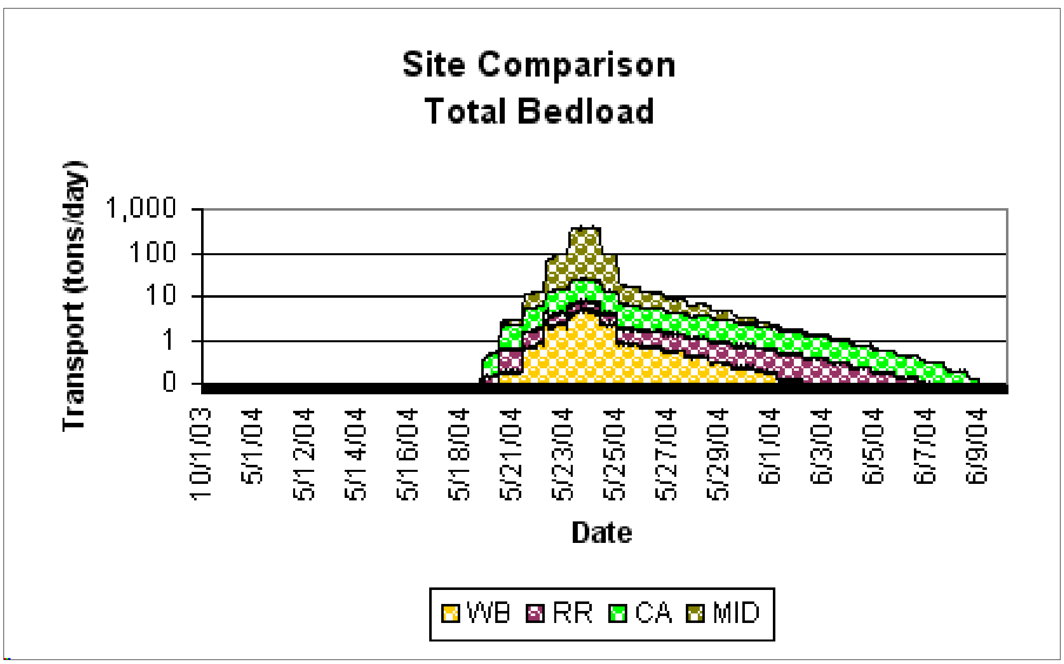
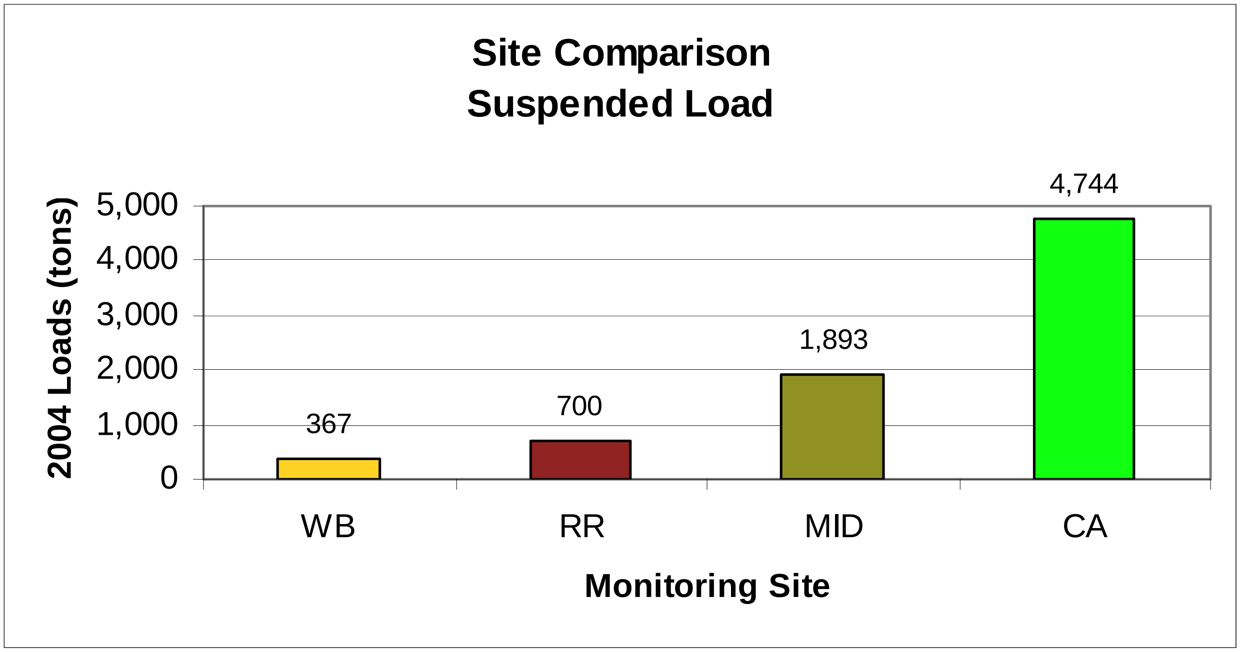


FIGURE 4.3. SEDIMENT TRANSPORT RATES IN THE MIDDLE PROVO RIVER DURING THE 2004 SPRING RUNOFF. THESE GRAPHS SHOW GREATER TRANSPORT AS DISTANCE INCREASES BELOW JORDANELLE DAM, EXCEPT FOR EXTREMELY HIGH BEDLOAD TRANSPORT AT THE MIDWAY (MID) MONITORING BRIDGE (BELOW THE NEVER-CHANNELIZED REACH).



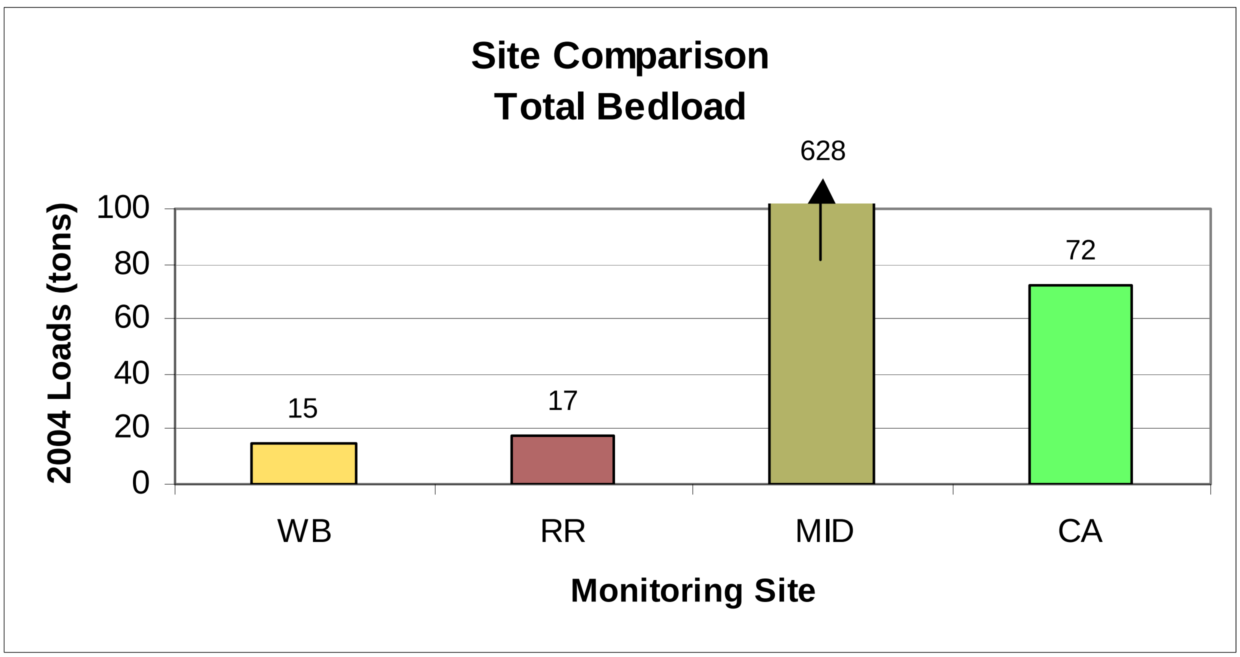


FIGURE 4.4. TOTAL ANNUAL LOADS IN THE MIDDLE PROVO RIVER DURING THE 2004 WATER YEAR. THESE GRAPHS SHOW INCREASING SEDIMENT LOADS WITH INCREASING DOWNSTREAM DISTANCE FROM JORDANELLE DAM, WITH THE EXCEPTION OF EXTREMELY HIGH BEDLOADS AT THE MIDWAY (MID) MONITORING BRIDGE (BELOW THE NEVER-CHANNELIZED REACH).

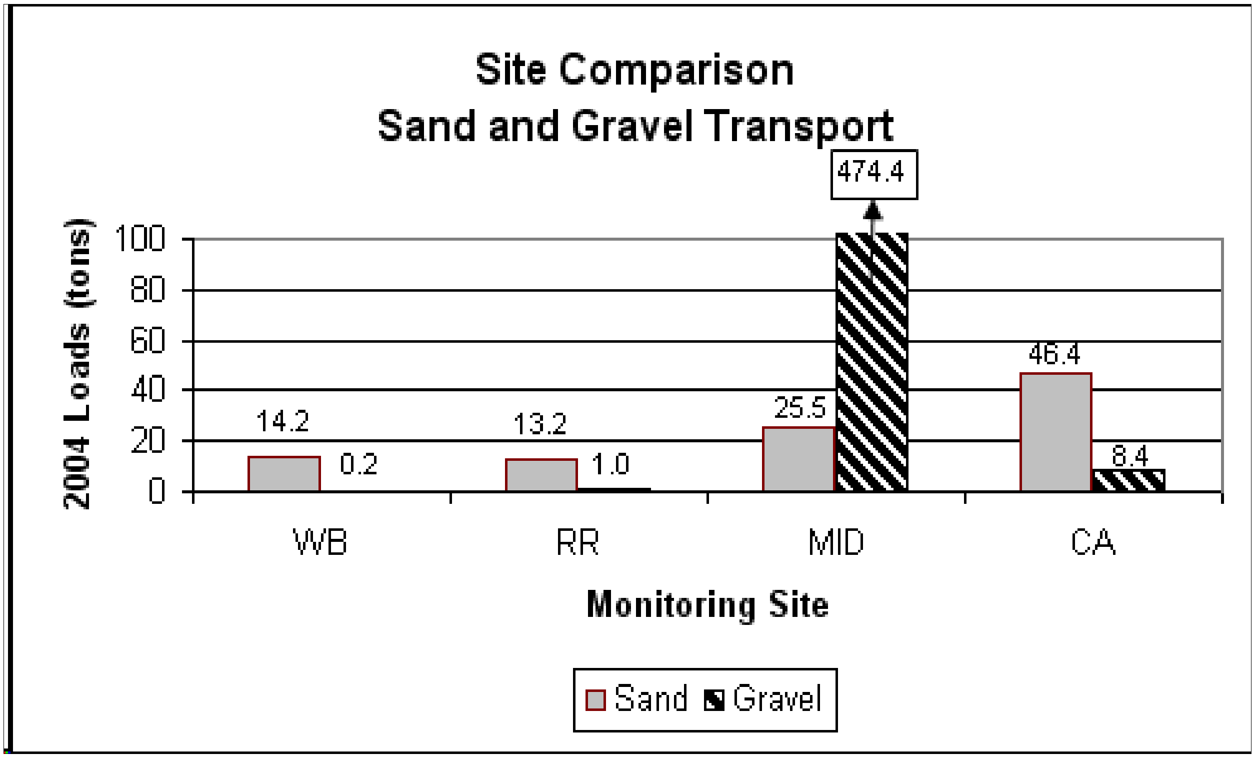


FIGURE 4.5. TOTAL SAND AND GRAVEL LOADS IN THE MIDDLE PROVO RIVER DURING THE 2004 WATER YEAR. THIS GRAPH SHOWS RELATIVELY LOW SAND LOADS BELOW JORDANELLE DAM AT THE WHITE BRIDGE (WB) AND RIVER ROAD (RR) MONITORING BRIDGES YET RELATIVELY HIGH SAND LOADS AT THE CHARLESTON (CA) MONITORING BRIDGE, WHICH IS LOCATED JUST BELOW THE NEWLY CONSTRUCTED CHANNEL. GRAVEL LOADS ARE EXTREMELY LOW (ALMOST NON-EXISTENT) AT THE WB AND RR MONITORING BRIDGES, YET EXTREMELY HIGH AT THE MIDWAY (MID) MONITORING BRIDGE (BELOW THE NEVER-CHANNELIZED REACH).

4.4 SEDIMENT TRANSPORT DISCUSSION AND RECOMMENDATIONS

The sediment transport results demonstrate the need for channel maintenance activities (i.e., replenishing sediment supplies) in the restored reaches of the middle Provo River below Jordanelle Dam. Data has shown in-channel sand resources to be moderately limited and in-channel gravel resources to be severely limited in the reaches immediately below Jordanelle Dam. Supply limitations are expected to worsen over time as existing supplies are depleted. There are some non-point sources of sand below Jordanelle Dam, yet gravel is being exported from these reaches without any known replenishing supplies. As described earlier, if the coarse-grained sediments continue to be exported without a replenishment of similarly sized materials below Jordanelle Dam, the restored riverine ecosystem is vulnerable to the undesirable effects of channel incision and habitat degradation.

There is a practical solution to the sediment imbalance below Jordanelle Dam. The bedload data collected from 2002 to 2004 be used to define, within the constraints of the flows experienced during the past 3 years, the amount of gravel and sand imports necessary to offset deficits caused by Jordanelle Dam to maintain an "equilibrium" sediment flux in downstream reaches.

Determining Annual Sand and Gravel Replenishment Needs below Jordanelle Dam?
To decide on the exact, long-term average amount of sand and gravel is probably premature at this time, given that the channel conditions below Jordanelle Dam and the dam operations have only been in place for a short time. The magnitude and duration of spring runoff events have been fairly sporadic since 1997, when Jordanelle Dam became fully operational. During this period, snowpack was highly variable, there were numerous requests for "test flows," and there were occasional needs for water exchanges between Jordanelle Reservoir and Deer Creek Reservoir. With limited post-Jordanelle streamflow data in mind, we applied Parker's (1990) bedload equation to the 2004 daily and 15-minute instantaneous streamflow data and compared measured vs. modeled daily transport rates and total annual loads for the 2004 Water Year (Figure 4.6). For comparisons with a longer period of record, contrast the modeled potential transport rates in 2004 at the RR monitoring bridge (84 tons per year) with effective discharge calculations (totaling 171 tons per year) based on 1997-2001 streamflow data and the same bedload equation (Olsen et al. 2004).

Modeled bedload transport was down in 2004 (84 tons) compared to 1997-2001 (average of 171 tons per year) because the duration of peak flows in 2004 (when transport rates were highest) was relatively short. These results indicate that, on average, an annual, artificial supply of approximately 170 tons per year of sand and gravel resources will be required below Jordanelle Dam. It is anticipated that this number could range annually between 50 and 400 tons depending on actual runoff conditions during relatively dry and wet years. Runoff forecasts can be used to predict the peak flow hydrograph and therefore determine the amount of sand and gravel needed on an annual basis.

Determining Proportions of Sand and Gravel on an Annual Basis
Both sand and gravel transport are important below Jordanelle Dam. Gravel supplies are essential for creating and maintaining channel habitats, such as spawning areas for brown trout, whereas sand supplies are necessary for cottonwood recruitment (cottonwood seeds need to set on fresh sand deposits). Although there is a tremendous amount of noise in the data, we need to determine the proportion of sand compared to gravel for dissimilar water years in the coarse sediments being replenished below Jordanelle Dam. Currently, sand transport rates are higher at all flows at all sites except for the MID sediment transport monitoring bridge where gravel transport rates are always higher (Appendix 4.2, Table 2 and Figure 4).

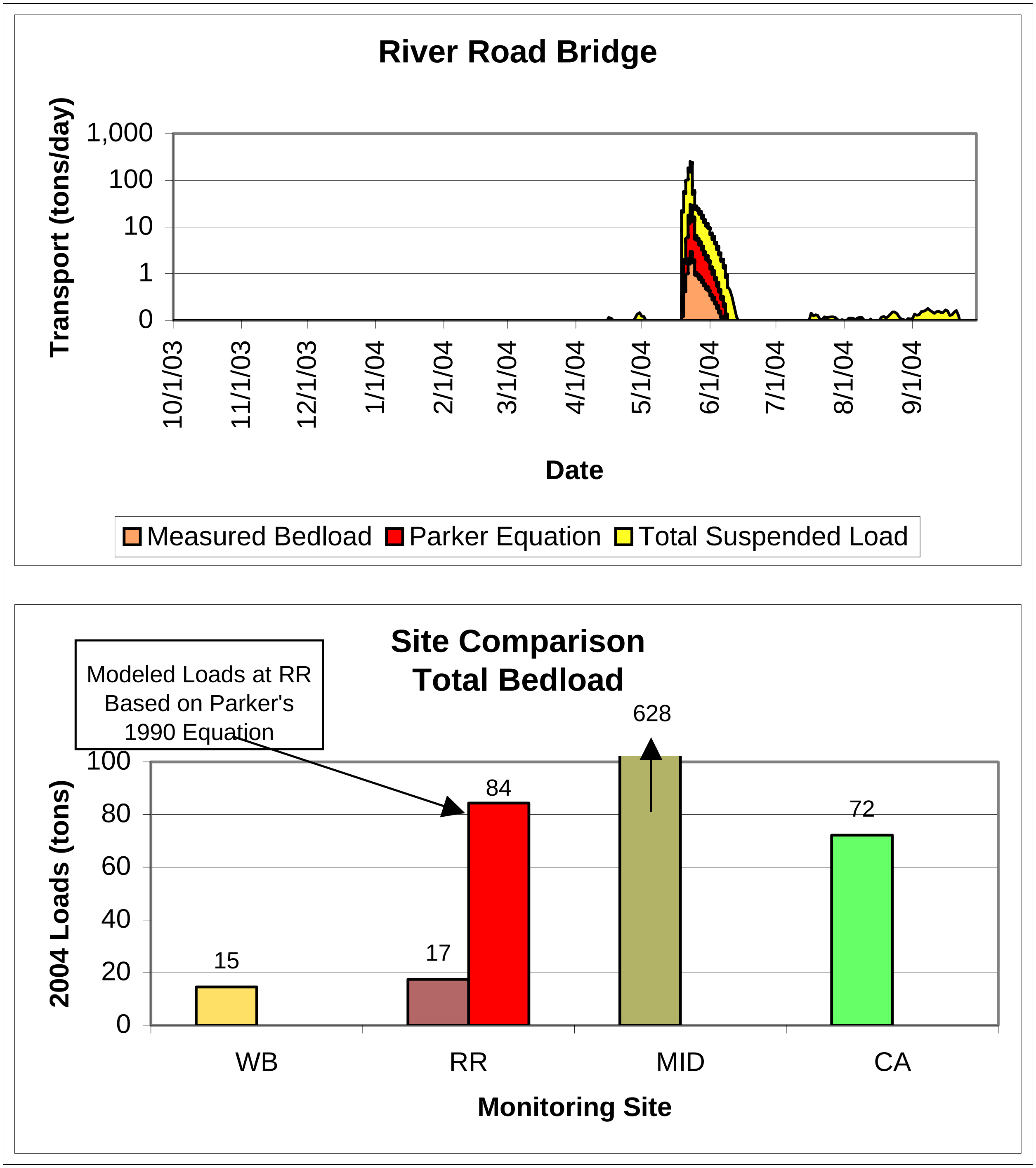


FIGURE 4.6. MEASURED BEDLOAD TRANSPORT RATES AND TOTAL LOADS AT THE RIVER ROAD (RR) MONITORING SITE COMPARED TO MODELED TRANSPORT RATES AND LOADS BASED ON PARKER'S (1990) BEDLOAD EQUATION. THE MODELED TRANSPORT RATES AND LOADS ARE FROM MEASURED PARTICLE SIZE DISTRIBUTIONS (D50 = 90 MM), SURVEYED CROSS SECTIONS, AND SHEAR STRESS CALCULATIONS IN THE RESTORED REACH UPSTREAM FROM THE RR BRIDGE REACH (OLSEN ET AL. 2004). THIS REACH WAS CONSTRUCTED IN 2000.

Sand transport is expected to exceed gravel transport during low-runoff years because shear stresses are expected to be just high enough to winnow sand-sized materials around the more stable gravel-sized particles (i.e., Phase I bedload transport). It appears from all the bedload samples collected at the MID sediment transport monitoring bridge that Phase I transport transitions to Phase II transport at approximately 1,000 cfs during the rising limb and transitions back to Phase I transport at approximately 800 cfs during the falling limb. The transition occurs at discharges closer to 1,500 cfs at the other monitoring sites.

Our best guess is that the gravel-to-sand ratio should be approximately 1:1 during relatively dry years when peak flows are expected to be less than 1,500 cfs. If total transport during years when peak flows are expected to be less than 1,500 cfs is calculated at 50 tons, then the mixture should be 25 tons gravel and 25 tons sand. The ratio of gravel to sand would be higher at higher peak flows (greater than 1,500 cfs). The gravel-to-sand ratio should be 2:1 (e.g., 100 tons gravel and 50 tons sand) during average years when peak flows are expected to be between 1,500 and 1,800 cfs. Full bed mobilization (i.e., Phase II bedload transport) is expected to occur during average years when peak flows exceed 1,500 cfs, but the duration of these full mobilization flows is expected to remain relatively short. The gravel-to-sand ratio should be approximately 3:1 (e.g., 300 tons gravel and 100 tons sand) during high-runoff years when lots of bedload transport is predicted because peak flows are expected to reach 2,000 cfs for a relatively long period of time. Phase II bedload transport is expected to occur for relatively long durations at these higher peak flows.

Determining Where Replenishing Supplies of Sand and Gravel Should be Applied

First, some channel coarsening has probably already occurred in some of the restored reaches below Jordanelle Dam (Olsen et al. 2004). Monitoring data (described in Chapters 2 and 3) is intended to quantify the degree and extent of streambed incision and/or coarsening over time (if it does occur). Hopefully, the processes of coarsening and incision can be pro-actively prevented. As described earlier, the restored channel is fairly well armored against becoming deeply incised because large materials were used to construct grade control riffles. However, in-channel supplies of sand and gravel have been exported to reaches below the dam for the past 7 years (since the Jordanelle Dam became fully operational) without any known replacements except in-channel supplies. Upstream channel restoration and construction activities have supplied a temporary source of fine-grained bedload (i.e., sand) and TSS, but gravel replenishment has apparently not been equal to the gravel export that has occurred.

The recommended first step is to add small amounts (1-10 tons) of coarse-grained sediments (mixed gravel and sand at a ratio of 1:1) to the channel at many (20-30) strategic and accessible locations between Jordanelle Dam and above the never-channelized reach. The coarse-grained sediments should be placed to create and/or enhance gravel bars in such a way that the material extends into pools or other peak-flow, high-energy zones, where a portion of it would become mobilized during high flows. This initial bar replenishment project will reset the transport equilibrium throughout the upper reaches of the middle Provo River.

The second recommended step is to supply approximately 150 tons of mixed coarse-grained sediments annually to the Provo River immediately below Jordanelle Dam. The total amount and ratio of gravel to sand will vary annually, depending on the magnitude and duration of peak flows and the duration of Phase I or Phase II transport expected (Olsen et al. 2004).

Third, bedload supplies do not seem limited within the section of the river extending from the never-channelized reach to Deer Creek Reservoir. Therefore, neither sand or gravel should be supplemented in reaches below the never-channelized reach at this time.

Supplying a "natural" amount of sand and gravel resources below Jordanelle Dam relative to the current flow regime should replenish some of the material losses currently occurring in the never-channelized reach (above the MID sediment monitoring bridge). It is not feasible or necessary to replenish all material losses in this never-channelized reach. We can expect the channel in this reach to adjust by becoming more single threaded and less complex as it incises. Channel cross sections, longitudinal profiles, and substrate will be monitored in this reach to quantify changes. We recommend additional plan view monitoring via aerial photography at this site.

5.0 MACROINVERTEBRATE SAMPLING

5.1 Introduction

This section describes the results of the first year of quantitative, post-project benthic macroinvertebrate monitoring on the middle Provo River for this project. One measure of success of the PRRP is connected to maintaining a healthy trout fishery and fish habitat. Monitoring the macroinvertebrate community can provide information on changes in water quality and habitat, as well as provide an index for the quantity and quality of food available for the trout fishery. Such information can then be used to determine if and what types of adaptive maintenance activities are needed to maintain desirable conditions in the middle Provo River. Monitoring the health of the macroinvertebrate community will also help to ensure that the restoration is achieving its commitments to maintaining and improving biological integrity and recreation.

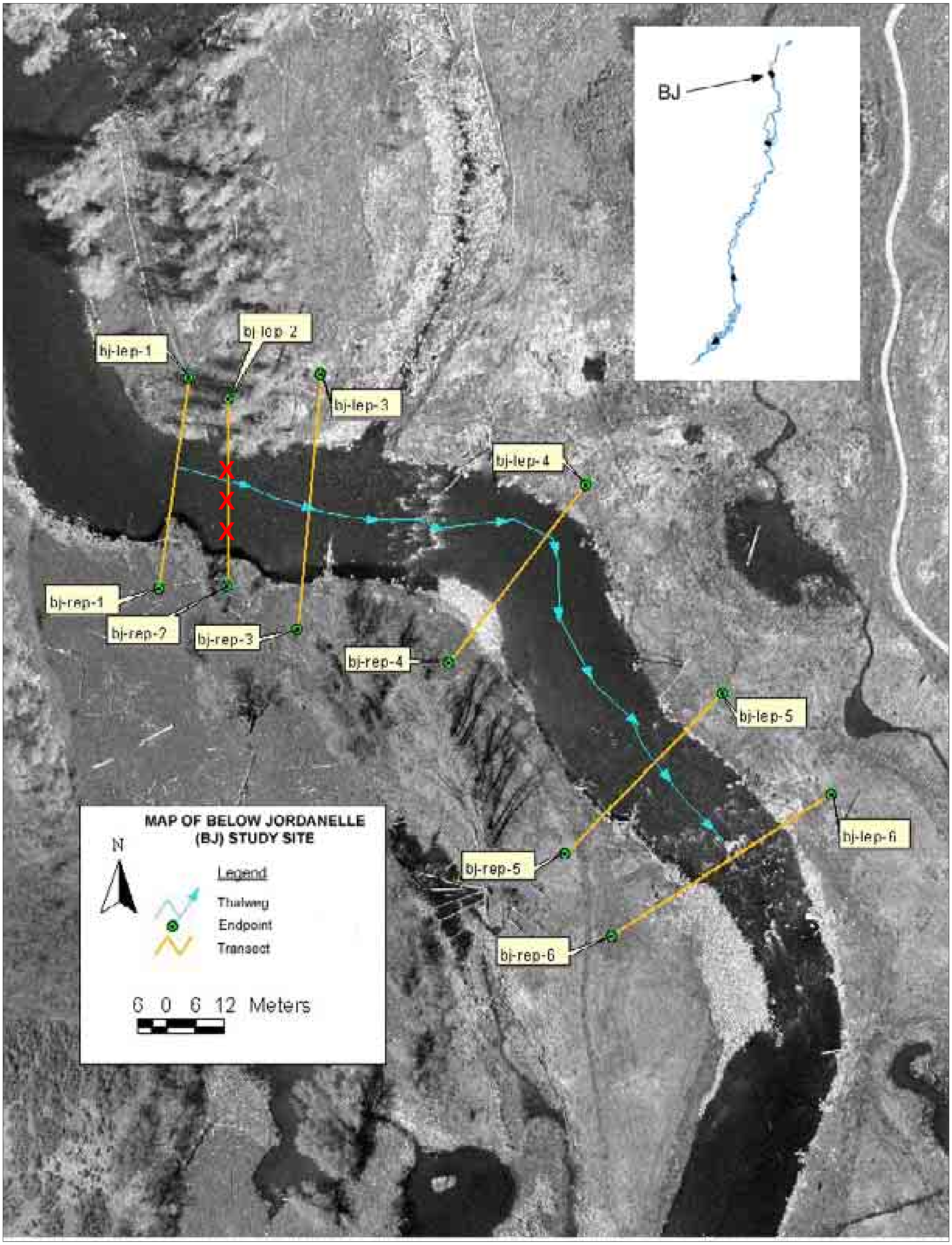
5.2 Methods

In May and September 2004, quantitative and qualitative sampling for benthic macroinvertebrates was conducted within each of the four long-term monitoring sites described in the previous chapters. A riffle within each site was chosen and three replicate quantitative samples were taken, using a Hess-type cylindrical square-foot bottom sampler (similar to Crist and Trinca 1988) with a 250-micron mesh net. Riffles with substrate, depths, and water velocities conducive to using the Hess sampler were chosen for sampling. Hess samplers provide an estimate of both the density (number per area) and composition of the macroinvertebrate community in riffle-type habitats within each monitoring site. Since the same habitat type is sampled with a Hess sampler, estimates of richness and abundance between sites should be directly comparable. The location and nearest cross section to the series of quantitative (Hess) samples is shown on the map of monitoring sites (Map 5.1a-d).

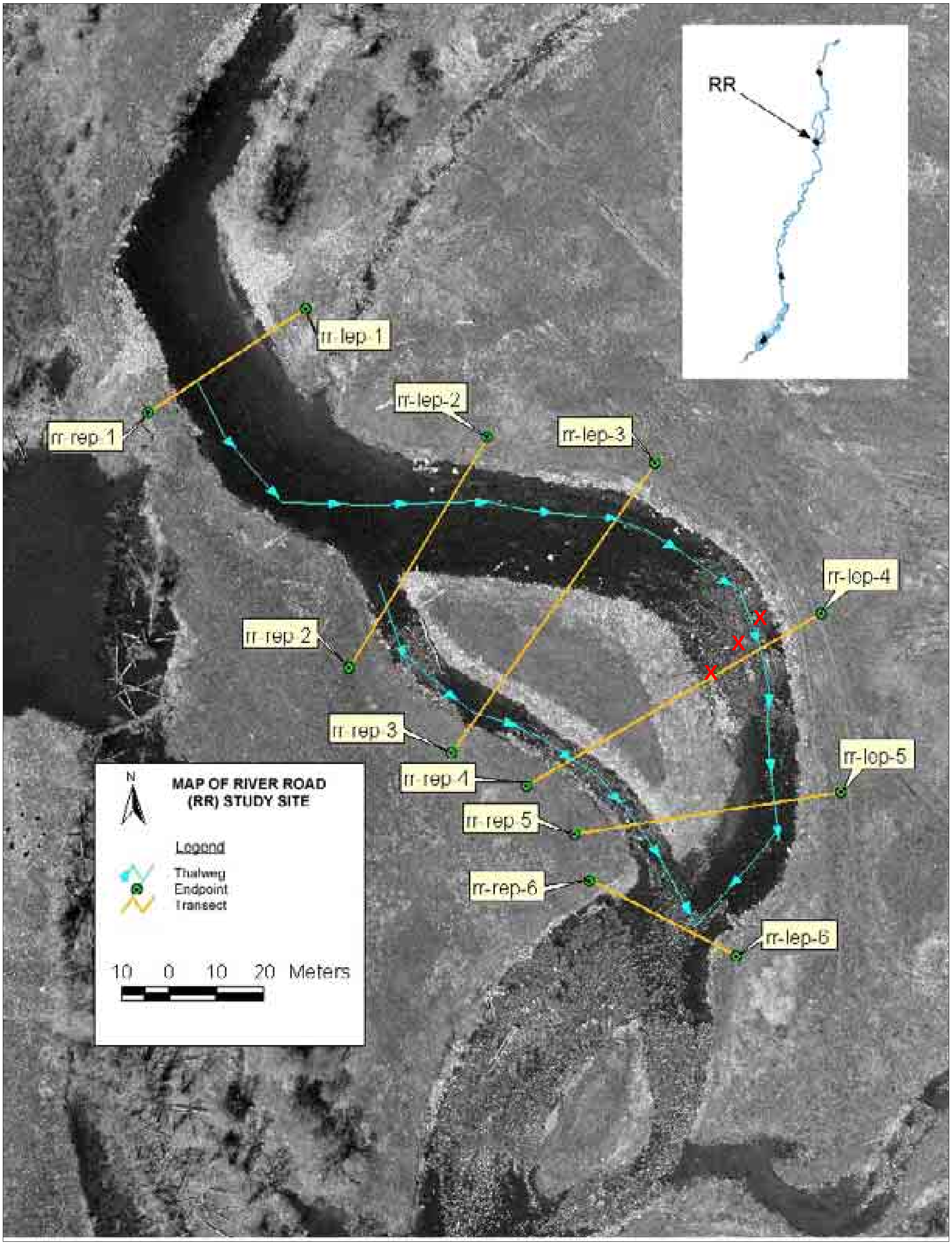
Additionally, one multi-habitat composite kick net sample was collected at each site. The composite kick net sample involved sampling 20 habitats in proportion to their availability in each monitoring site, using a D-frame kick net (Barbour et al. 1999). A 0.5-meter area of substrate in front of the D-frame kick net was disturbed by kicking at the substrate. In areas with moderate to high velocities the current carried invertebrates and periphyton from the disturbed area into the D-frame kick net below. In areas with low velocity or large amounts of aquatic vegetation, the sample areas were disturbed and the D-frame nets were passed through the water column throughout the disturbed area.

Sample processing and preservation in the field included rinsing large debris over a 250 micron mesh sieve, and removing it from the sample. Samples were then rinsed, placed into a series of 1,000-milliliter and 500-milliliter wide-mouth Nalgene containers, preserved in 70 percent ethanol, and shipped to EcoAnalysts, Inc. (EcoAnalysts), in Moscow, Idaho, for further processing and identification.

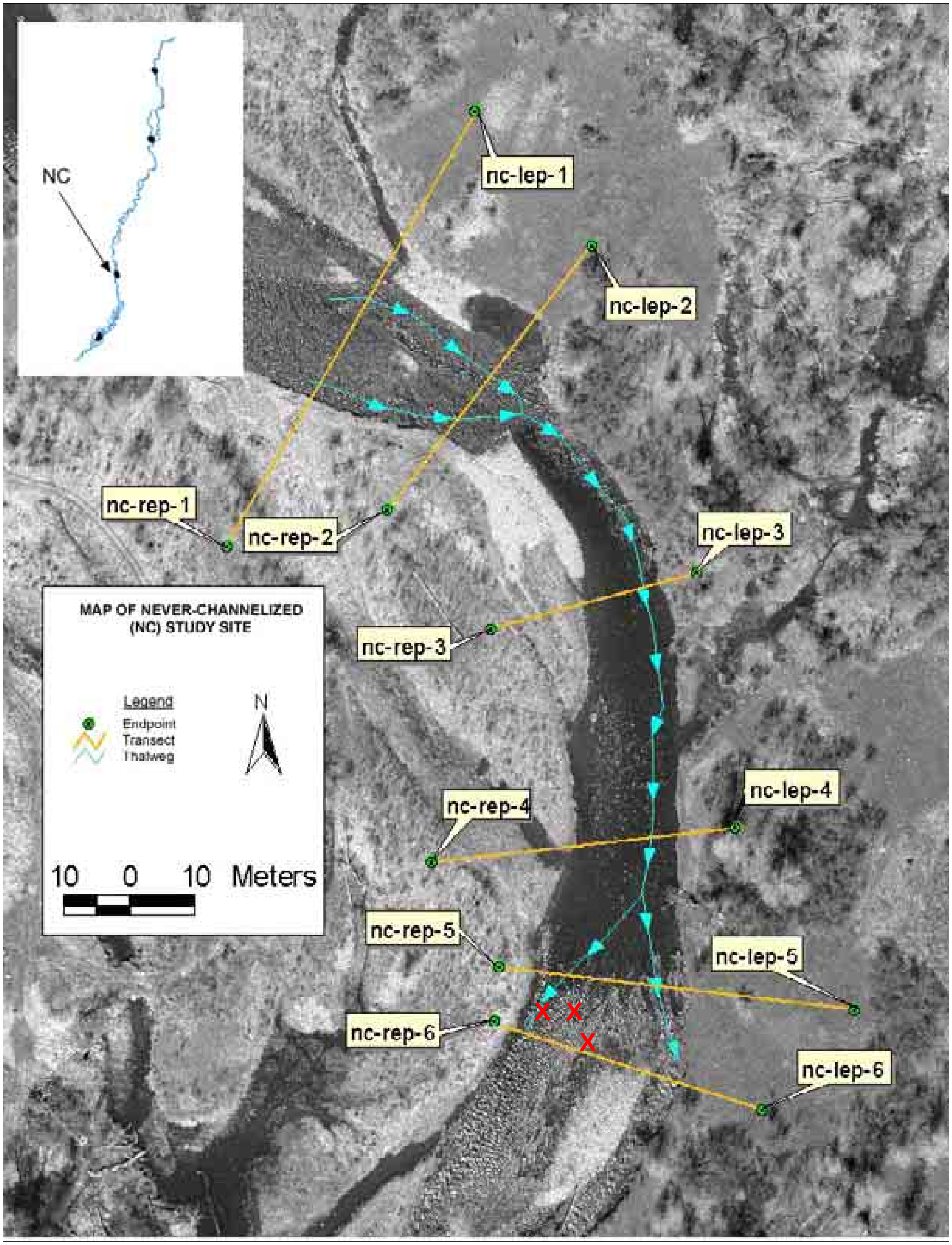
EcoAnalysts processed and identified the benthic macroinvertebrate samples. Samples were sorted by spreading the entire sample over a gridded pan. Sorting commenced by taking all organisms from a randomly selected grid. Grids were randomly selected and sorted until 500 organisms had



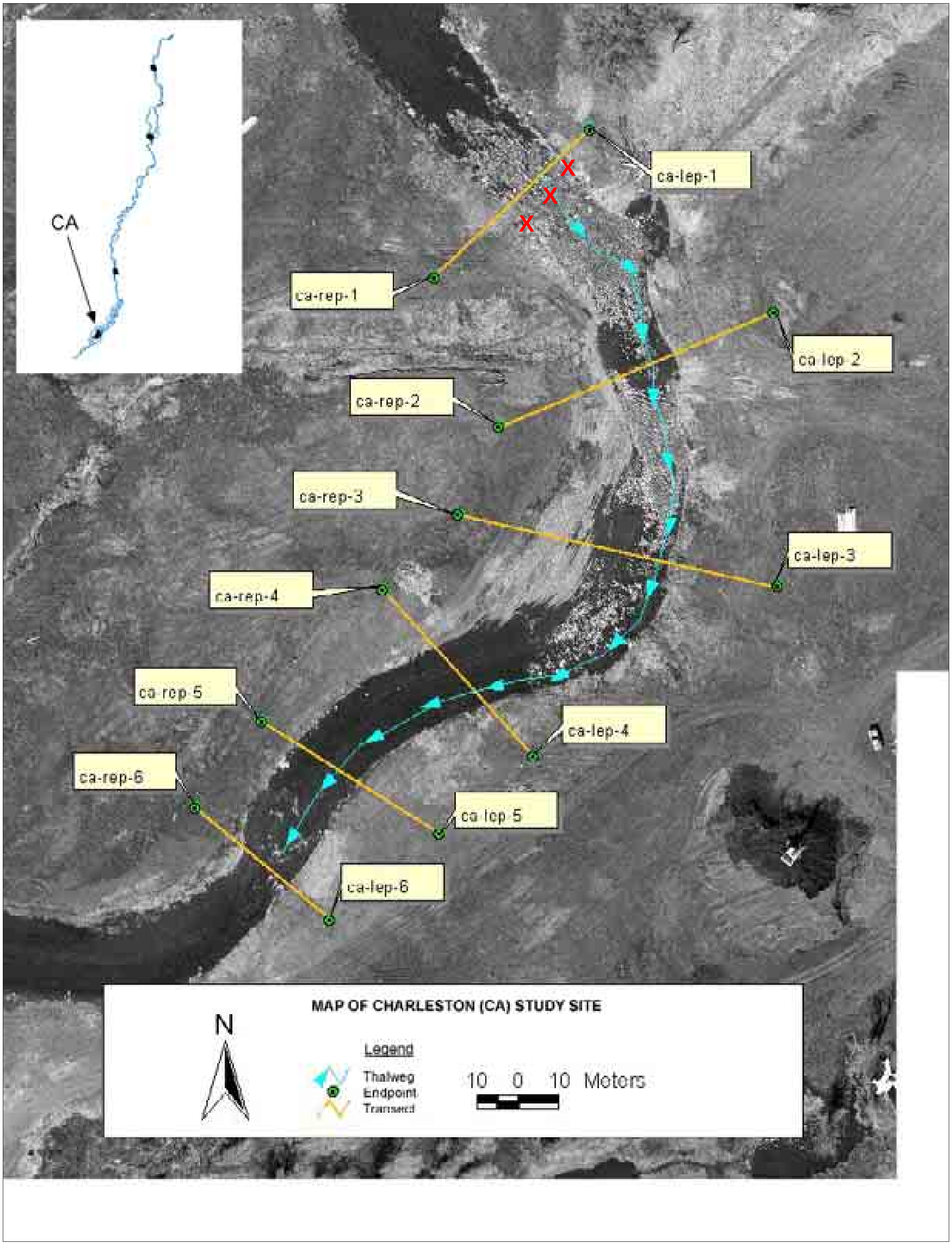
MAP 5.1A. MAPS OF THE LOCATIONS AND NEAREST CROSS SECTIONS TO THE SERIES OF QUANTITATIVE (HESS) SAMPLES (MARKED WITH RED "X"S).



Map 5.1b. Maps of the locations and nearest cross sections to the series of quantitative (Hess) samples (marked with red "X"s). (cont.)



Map 5.1c. Maps of the locations and nearest cross sections to the series of quantitative (Hess) samples (marked with red "X"s). (cont.)



Map 5.1d. Maps of the locations and nearest cross sections to the series of quantitative (Hess) samples (marked with red "X"s). (cont.)

been picked, or until the entire sample had been sorted. Applying counts from the number of grids sorted to the remaining grids allowed estimates of the total number (abundance) of each taxa in each sample. All organisms were identified to the genus/species level, except for midges, which were identified to the family level, and worms, which were identified to the class level. Quality assurance and control (QA/QC) procedures included a QA sorting on all samples to ensure 90 percent sorting efficiency. Also, a synoptic reference collection was created, which was checked by a second taxonomist to ensure taxonomic accuracy. The number of each taxa collected was then entered into a spreadsheet, which was used to generate a list of approximately 50 metrics that can be used as an index of the quality and health of the macroinvertebrate community. EcoAnalysts provided the raw data and metrics to BIO-WEST, along with the synoptic reference collections.

5.2.1 Data Analysis

Several commonly used metrics were selected to look for differences between the sites and sample times in 1999 and 2004. In 1999, prior to restoration efforts, a series of macroinvertebrate samples were collected near the BJ, RR, NC, and CA sites. The samples collected in 1999 were collected using a surber sampler, another quantitative sampling device. The data available for the 1999 samples expressed invertebrate numbers in terms of density (number per square meter). To be comparable to past data, and to account for any areal differences in the sampling gear, abundance information from the 2004 samples was converted into density information. Hess samplers have a 0.086-square meter open bottom area for sampling (WILDCO 2004). Utilizing this known area of each sample, abundance information was converted into density information in numbers per square meter. A variety of data transformations were used to fit the selected metrics to the normal distribution, and an analysis of variance (ANOVA) with Bonferroni-adjusted probabilities was employed to test for differences between sites and between sampling periods. Where appropriate, Tukey's Honestly Significant Difference multiple comparison test was used to compare all differences between means. The same techniques were used to compare data from August 1999 samples (collected near the 2004 sites) to the samples collected in September 2004.

5.3 Results

5.3.1 2004 Sampling

A complete list of the taxa found and metrics generated for each sample can be found in Appendix 5.1. Average density of macroinvertebrates collected in Hess samples was lower at the BJ site than at the other three sites in both the spring and the fall (Figure 5.1). September 2004 collections had a significantly higher total density than collections made in May 2004 ($p < 0.03$), but no significant differences were present between sites within each sampling period. Interestingly, the CA site showed a similar macroinvertebrate density and abundance to the other three sites in May 2004, despite the fact that restoration of this site had only been completed days before the samples were taken.

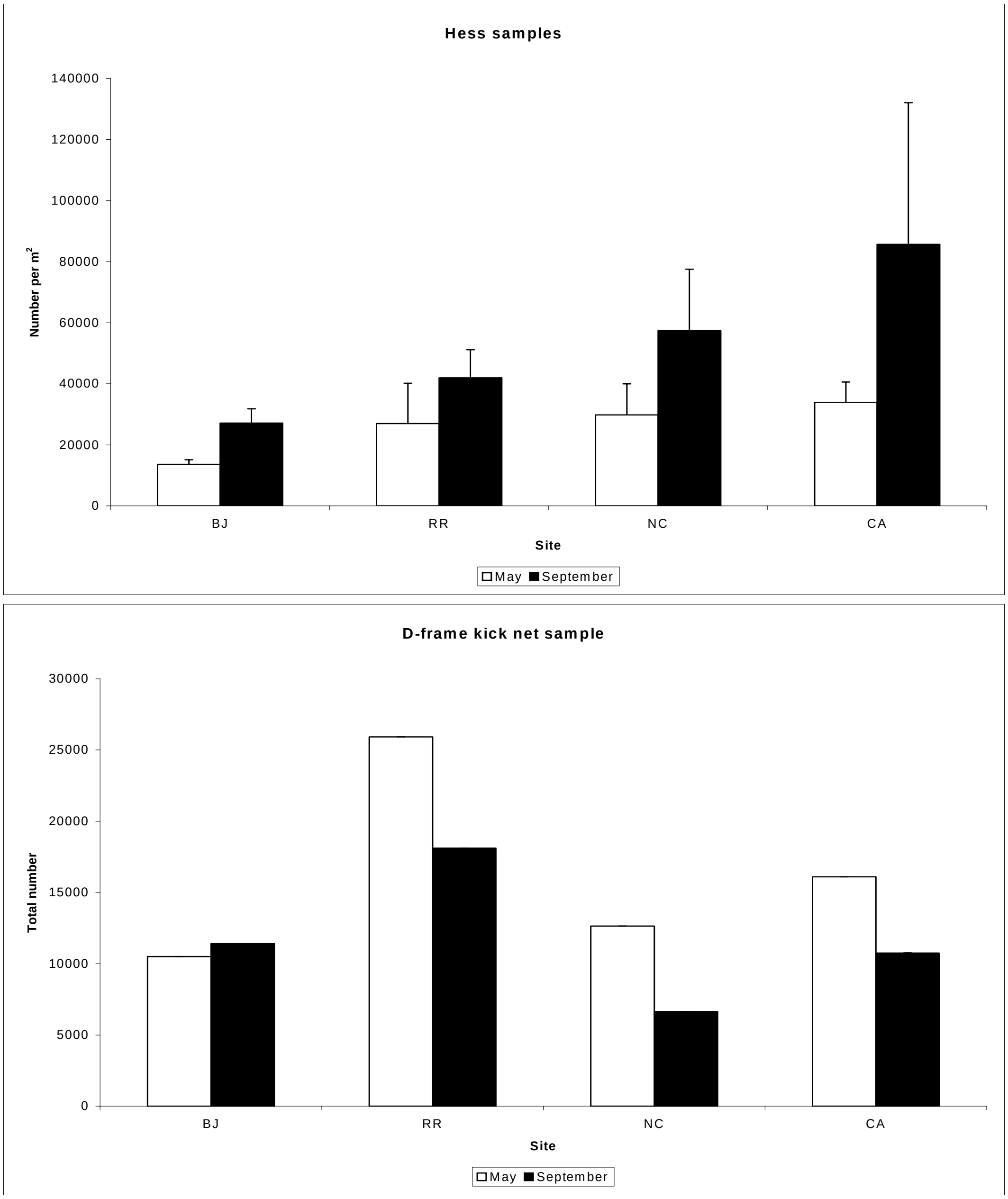


FIGURE 5.1. AVERAGE TOTAL DENSITY OF MACROINVERTEBRATES (NUMBERS PER SQUARE METER) CALCULATED FROM THE THREE HESS SAMPLES TAKEN AT EACH SITE IN MAY AND SEPTEMBER 2004 (TOP). TOTAL ABUNDANCE OF MACROINVERTEBRATES COLLECTED IN COMPOSITE D-FRAME KICK NET SAMPLES AT EACH SITE IN MAY AND SEPTEMBER 2004 (BOTTOM).

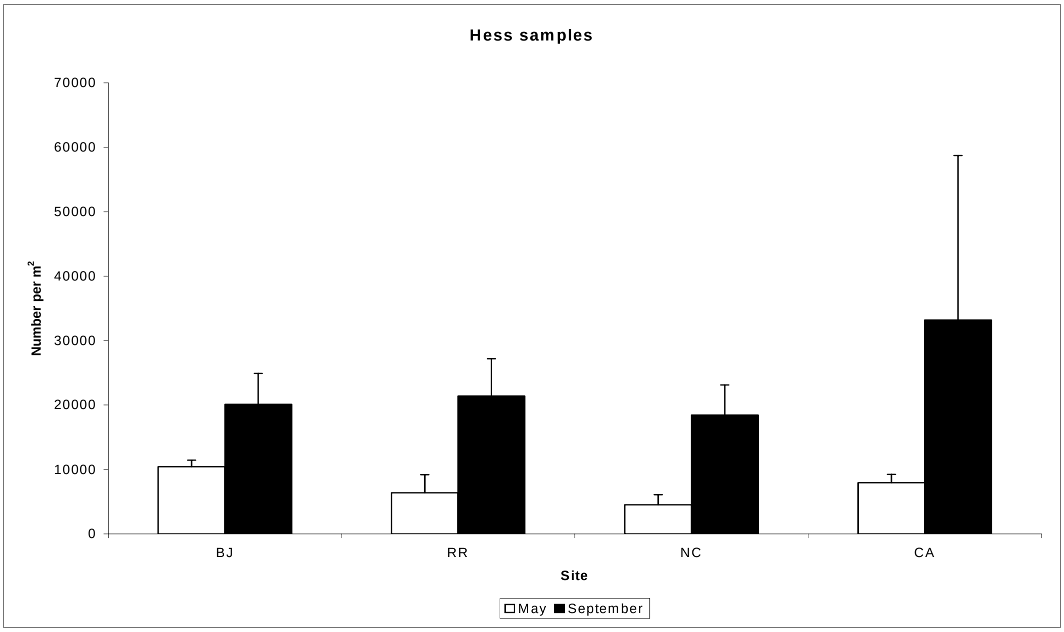
The qualitative kick net samples collected in May 2004 had a higher total macroinvertebrate abundance than the samples collected in September 2004. The qualitative samples taken at the RR site in both May and September 2004 had a higher total number of invertebrates than the remaining three sites (Figure 5.1). However, the estimates of total abundance from the composite kick net samples are less reliable than the density estimates generated from the Hess samples for two reasons. First, despite the attempts to standardize the amount of areas sampled, there is no real control on how much area is sampled with the composite kick net sampler. Second, unlike the Hess samples which are all taken from similar habitats, the composite kick net samples come from a variety of different habitat types, each of which may have a higher or lower macroinvertebrate density than riffles.

Ephemeroptera (mayflies), *Plecoptera* (stoneflies), and *Trichoptera* (caddisflies), known as EPT taxa, are generally thought of as taxa sensitive to anthropogenic disturbance. Average EPT taxa density was significantly higher in September 2004 collections than in May 2004 collections ($p < 0.002$), but no significant differences were present between sites within each sampling period. While the Hess data indicated a higher EPT density in the September 2004 samples, the composite kick net samples showed the RR site having a higher abundance of EPT taxa than the other three sites in both May and September 2004, but did not indicate a higher overall abundance of EPT taxa in the September 2004 collections (Figure 5.2).

Taxa richness provides an index for community diversity. Total taxa richness of macroinvertebrates collected in the Hess samples and D-frame samples was lowest at the CA site in May 2004 (Figure 5.3). We found that in the Hess samples the CA site had a significantly lower average total taxa richness than the BJ and RR sites ($p < 0.039$), but not the NC site ($p < 0.054$) in the May 2004 collection. No significant differences were seen between sites by September 2004. No significant differences were seen at individual sites between the May and September 2004 sampling periods. Taxa richness found in composite kick net samples as similar to that found in the Hess samples.

Richness of EPT taxa richness followed a trend similar to total taxa richness (Figure 5.4). We found that the CA site had significantly lower EPT taxa richness than the other three sites in May 2004 ($p < 0.02$). Additionally, we found that the BJ site had significantly lower EPT taxa richness than the RR and NC sites in September 2004 ($p < 0.02$). The composite kick net sample did not show lower EPT taxa richness at the BJ site in September 2004. We found no significant differences within sites between sampling periods.

The Hilsenhoff Biotic Index (HBI) summarizes the overall pollution tolerances of the taxa collected. This index has been used to detect nutrient enrichment, high sediment loads, low dissolved oxygen, and thermal impacts (Hilsenhoff 1988). It was originally developed to detect organic pollution. Individual families were assigned an index value from 0 to 10. Taxa with HBI values of 0-2 are considered intolerant, clean-water taxa. Taxa with HBI values of 9-10 are considered pollution tolerant taxa. A family level HBI was calculated for each sample. Samples with HBI values of 0-2 are considered clean, 2-4 slightly enriched, 4-7 enriched, and 7-10 polluted.



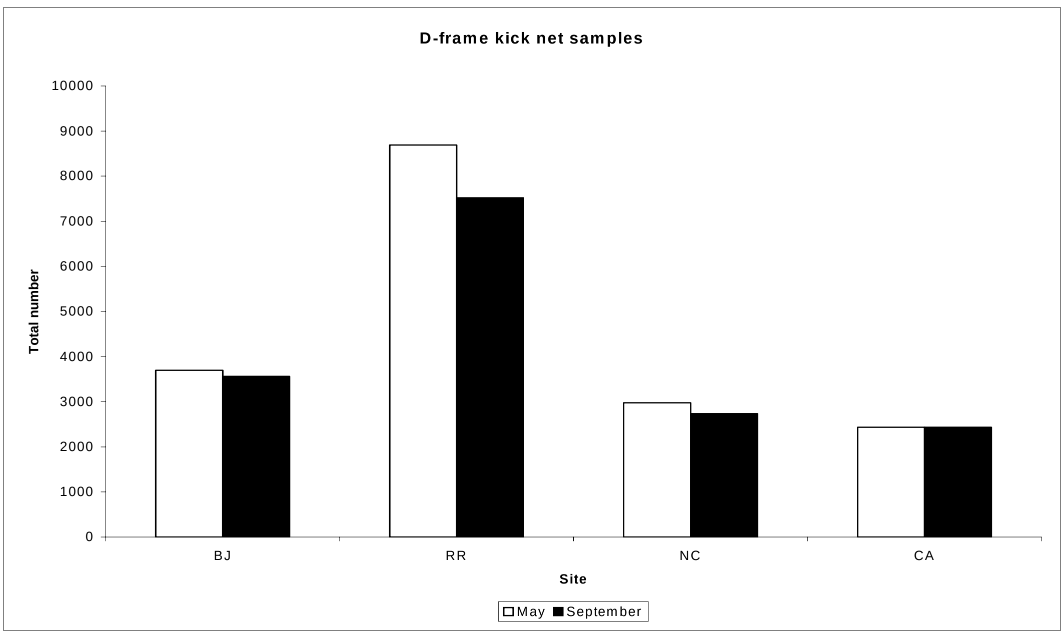


FIGURE 5.2. AVERAGE DENSITY (NUMBERS PER SQUARE METER) OF *EPHEMEROPTERA*, *PLECOPTERA*, AND *TRICHOPTERA* (EPT) TAXA CALCULATED FROM THE THREE HESS SAMPLES TAKEN AT EACH SITE IN MAY AND SEPTEMBER 2004 (TOP). TOTAL ABUNDANCE OF EPT TAXA COLLECTED IN COMPOSITE D-FRAME KICK NET SAMPLES AT EACH SITE IN MAY AND SEPTEMBER 2004 (BOTTOM).

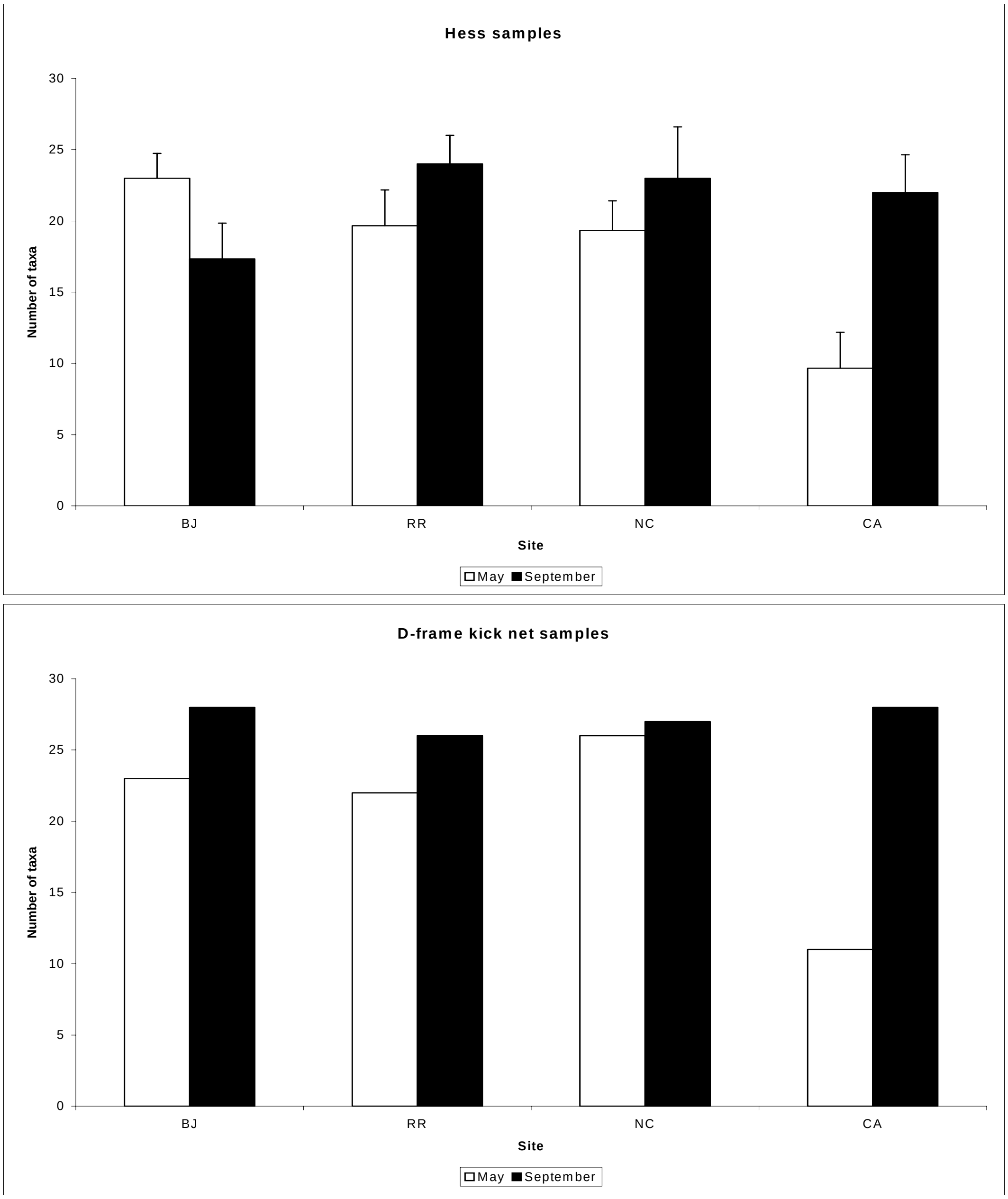


FIGURE 5.3. TAXA RICHNESS FROM (TOP) THREE HESS SAMPLES AND (BELOW) ONE COMPOSITE KICK NET SAMPLE COLLECTED AT EACH SITE IN MAY AND SEPTEMBER 2004.

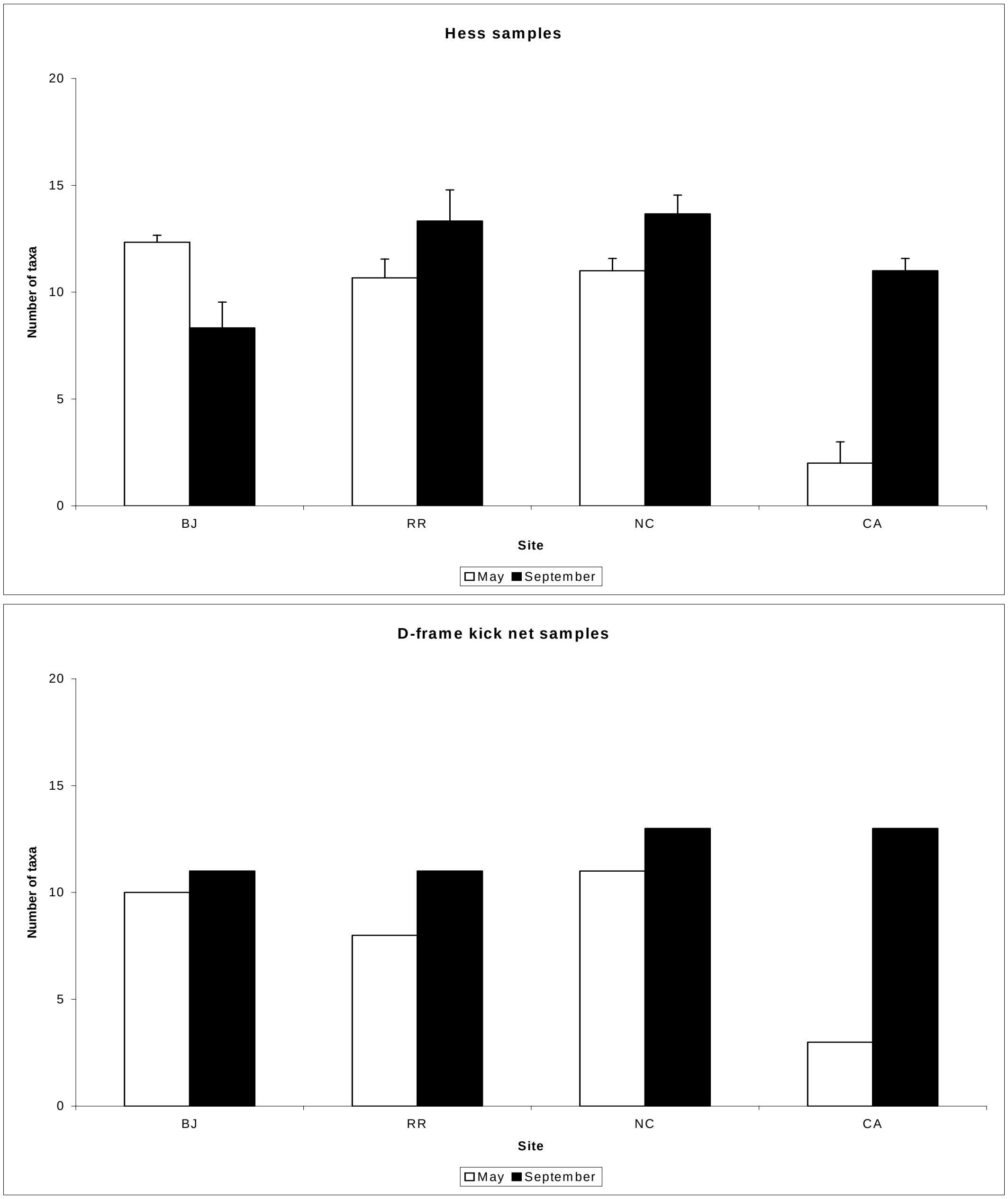


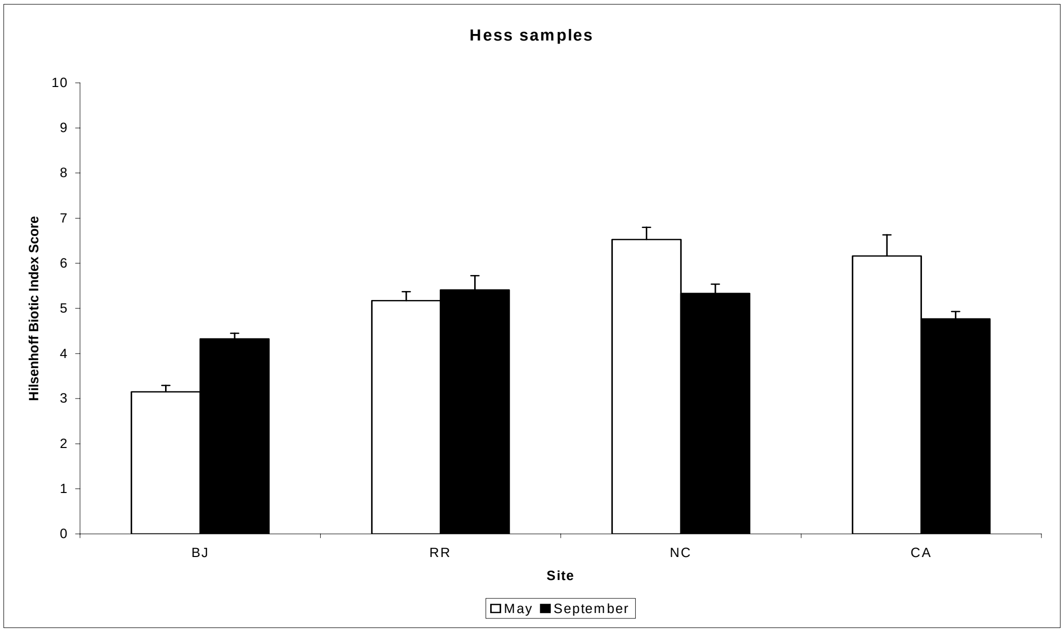
FIGURE 5.4. *EPHEMEROPTERA*, *PLECOPTERA*, AND *TRICHOPTERA* (EPT) TAXA RICHNESS FROM (TOP) THREE HESS SAMPLES AND (BOTTOM) ONE COMPOSITE KICK NET SAMPLE COLLECTED AT EACH SITE IN MAY AND SEPTEMBER 2004.

The HBI score for the BJ site was significantly lower than all three other sites in May 2004 ($p < 0.001$). Additionally, the RR site had a significantly lower HBI score than the NC site in May 2004 ($p < 0.04$). Finally, a significant decrease in the HBI score was observed at the CA site between May and September 2004 ($p < 0.008$) (Figure 5.5). While the BJ site had the lowest average HBI score from Hess samples from May and September 2004, the BJ site had the lowest HBI score in May 2004, but the highest in September 2004 (Figure 5.5). The NC site had the highest average HBI score from Hess samples in May 2004, and the RR site had the highest average HBI score in September 2004. The composite kick net samples showed the CA site having the highest HBI score in May 2004.

Examining the proportion of the community that is comprised by the three most dominant taxa provides an index of evenness in the community (Table 5.1). In high quality streams in the Wasatch and Uinta Mountains up to 21 percent of the total number of organisms might be found in the most dominant taxa (Idaho DEQ 1996), while the three most dominant taxa might comprise up to 50 percent of the total number of organisms (G. Lester, personal communication). Additionally, examining the three dominant taxa at a site can provide additional information about what impacts may be affecting that site. No significant differences were found in the proportion of the invertebrate community comprised of the three most dominant taxa between sites within sampling periods or between sampling periods within sites. In the May 2004 Hess and composite kick net samples, the BJ site had the lowest percentage of its community comprised of the three most dominant taxa, while the CA site had the highest (Figure 5.6). This pattern was switched in the September 2004 Hess samples. The percentage of the community made up of the three most dominant taxa was high at all four sites (70-90% in May and 65-75% in September).

In May 2004 there were two different patterns of dominant taxa at the four sampling sites. The BJ and RR sites had two mayfly (*Ephemeroptera*) taxa in the three most dominant taxa, including the pollution sensitive *Ephemerella inermis/infrequens*. *Ephemerella inermis/infrequens* was absent from the CA site and much reduced at the NC site. These two sites were dominated by worms (*Oligochaeta*) and midges (*Chironomidae*). Worms and midges are generally associated with average to poor water quality and/or fine sediments.

In September 2004 the mayfly *Baetis tricaudatus* and midges were the two most abundant taxa at all four sampling sites. However, the third most abundant taxa varied between sites. At the BJ site worms were the third most dominant taxa. Worms were also present in similar abundances at the other three sites. At the RR site the relatively intolerant caddisfly *Brachycentrus* sp. was the third most dominant taxa. While *Brachycentrus* sp. was present in similar densities at the BJ site, densities of *Brachycentrus* sp. were reduced at the NC and RR sites. Finally, the riffle beetle *Optioservus* sp. was the third most dominant taxa at the NC and CA sites. While *Optioservus* sp. was present at the BJ and RR sites, densities were considerably lower than those at the NC and RR sites.



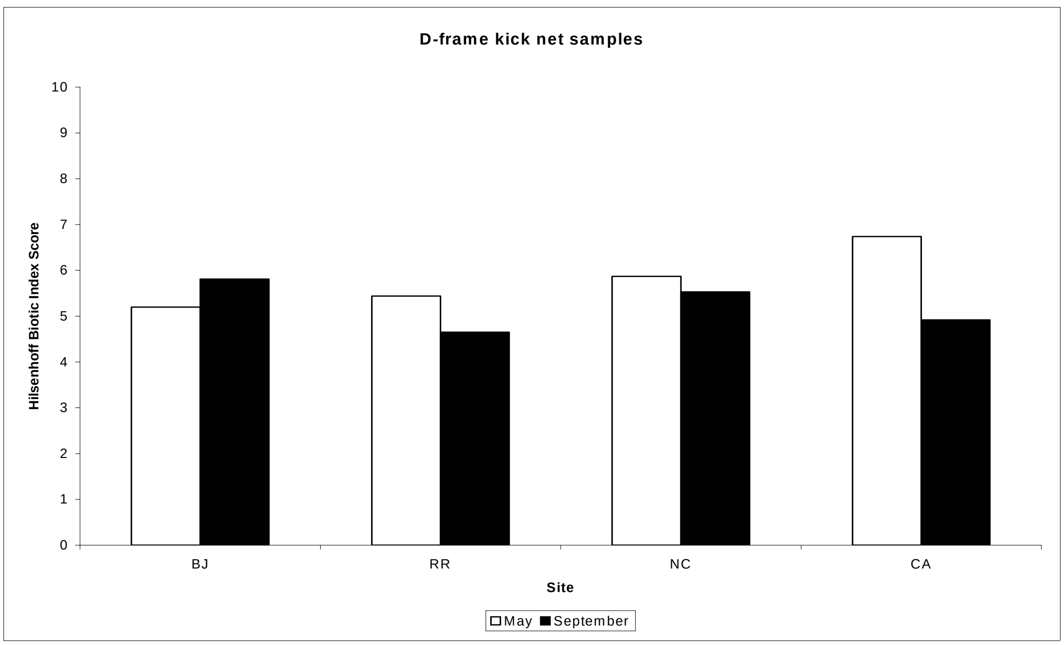


FIGURE 5.5. HILSENHOFF BIOTIC INDEX (HBI) SCORE GENERATED FROM (TOP) THREE HESS SAMPLES AND (BOTTOM) ONE COMPOSITE KICK NET SAMPLE COLLECTED AT EACH SITE IN MAY AND SEPTEMBER 2004. A SCORE OF 0-2 = CLEAN, 2-4 = SLIGHTLY ENRICHED, 4-7 = ENRICHED, AND 7-10 = POLLUTED.

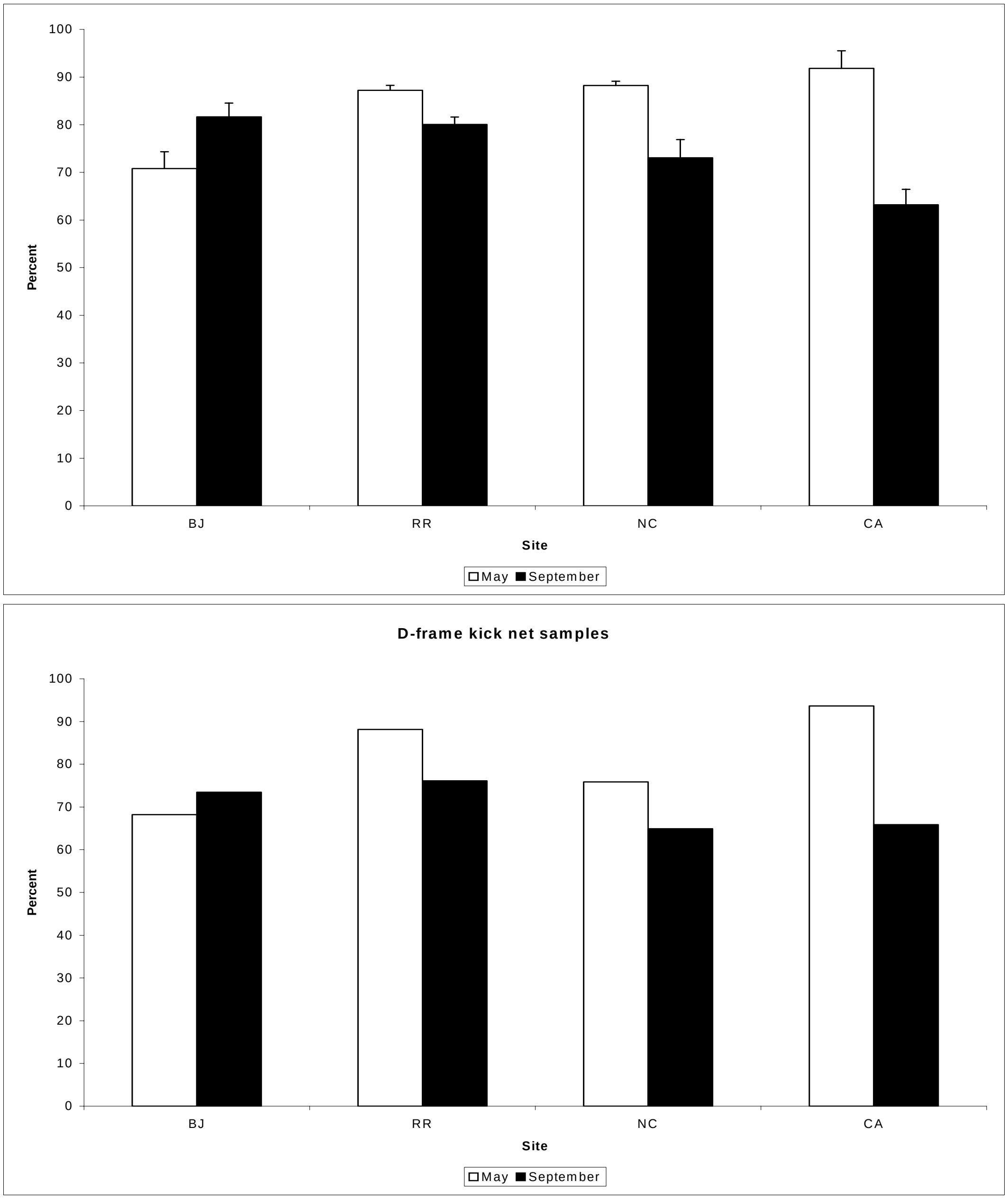


FIGURE 5.6. THE PERCENTAGE COMPRISED OF THE (TOP) TOTAL DENSITY FROM THREE HESS SAMPLES AND (BOTTOM) ABUNDANCE FROM ONE COMPOSITE KICK NET SAMPLE BY THE THREE DOMINANT TAXA COLLECTED AT EACH SITE IN MAY AND SEPTEMBER 2004.

Table 5.1. Three dominant taxa at each sampling site combining Hess and composite kick-net data.

Order of abundance	Below Jordanelle Dam	River Road	Never-Channelized	Charleston
May 2004				
First	*Baetis tricaudatus*	Chironomidae	Oligochaeta	Oligochaeta
Second	*Ephemerella inermis/infrequens*	*Baetis tricaudatus*	Chironomidae	*Baetis tricaudatus*
Third	Chironomidae	*Ephemerella inermis/infrequens*	*Baetis tricaudatus*	Chironomidae
September 2004				
First	*Baetis tricaudatus*	Chironomidae	Chironomidae	*Baetis tricaudatus*
Second	Chironomidae	*Baetis tricaudatus*	*Baetis tricaudatus*	Chironomidae
Third	Oligochaeta	Brachycentrus sp.	Optioservus sp.	Optioservus sp.

5.3.2 Comparisons to Historical Data

A series of quantitative samples was collected near the BJ, RR, NC, and CA sites in late August 1999. Similar metrics and analyses were used to look for changes in the benthic community between the August 1999 surber samples and the September 2004 Hess samples. The total density of macroinvertebrates from all samples collected in 2004 was significantly higher than from all samples collected in 1999 ($p < 0.001$), but there were no significant differences between years within sites (Figure 5.7). It was also found that EPT density was significantly higher in 2004 ($p < 0.01$) than in the 1999 samples (Figure 5.8).

Total taxa richness and EPT taxa richness were significantly higher in 2004 than in 1999 ($p < 0.001$) (Figures 5.9 and 5.10). Total taxa richness was significantly higher at the CA, NC, and RR sites in 2004 ($p < 0.001$), but not the BJ site. Additionally, the BJ site had a significantly lower taxa richness than the other three sites in 2004 ($p < 0.03$). Richness of EPT taxa was significantly higher in 2004 than in 1999 at the NC and RR sites ($p < 0.02$), but not at the CA and BJ sites. Richness of EPT taxa was significantly lower at the BJ site than at the RR and NC sites in 2004 ($p < 0.01$).

The overall average HBI score was also significantly higher for samples collected in 2004 than for samples collected in 1999 ($p < 0.001$) (Figure 5.11). The RR and NC sites had significantly higher HBI scores in 2004 ($p < 0.001$), but HBI scores for the BJ and CA sites did not differ significantly between 1999 and 2004. The NC site had a significantly lower HBI score than the other three sites in 1999 ($p < 0.001$).

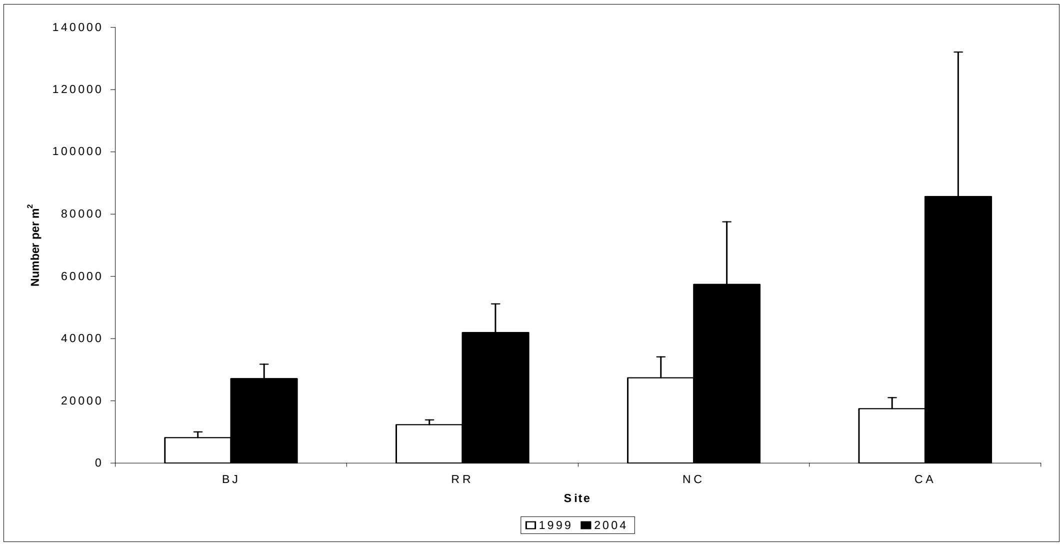


FIGURE 5.7. AVERAGE DENSITY (NUMBERS PER SQUARE METER) OF MACROINVERTEBRATES COLLECTED IN QUANTITATIVE SAMPLES NEAR THE BELOW JORDANELLE (BJ) SITE, THE RIVER ROAD (RR) SITE, THE NEVER-CHANNELIZED (NC) SITE, AND THE CHARLESTON (CA) SITE IN 1999 AND 2004.

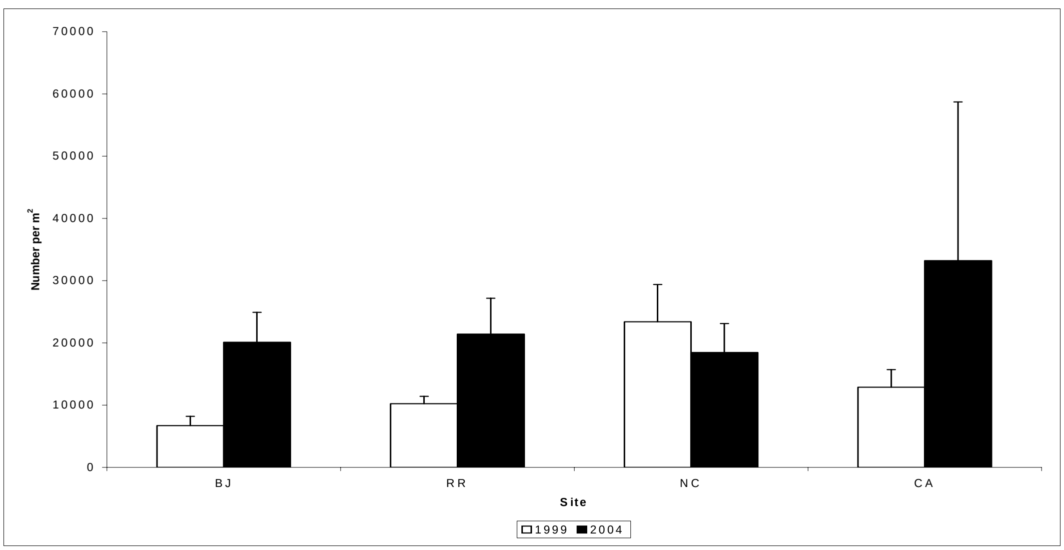


FIGURE 5.8. DENSITY (NUMBERS PER SQUARE METER) OF *EPHEMEROPTERA*, *PLECOPTERA*, AND *TRICHOPTERA* (EPT) TAXA COLLECTED IN QUANTITATIVE SAMPLES NEAR THE BELOW JORDANELLE (BJ) SITE, THE RIVER ROAD (RR) SITE, THE NEVER-CHANNELIZED (NC) SITE, AND THE CHARLESTON (CA) SITE IN 1999 AND 2004.

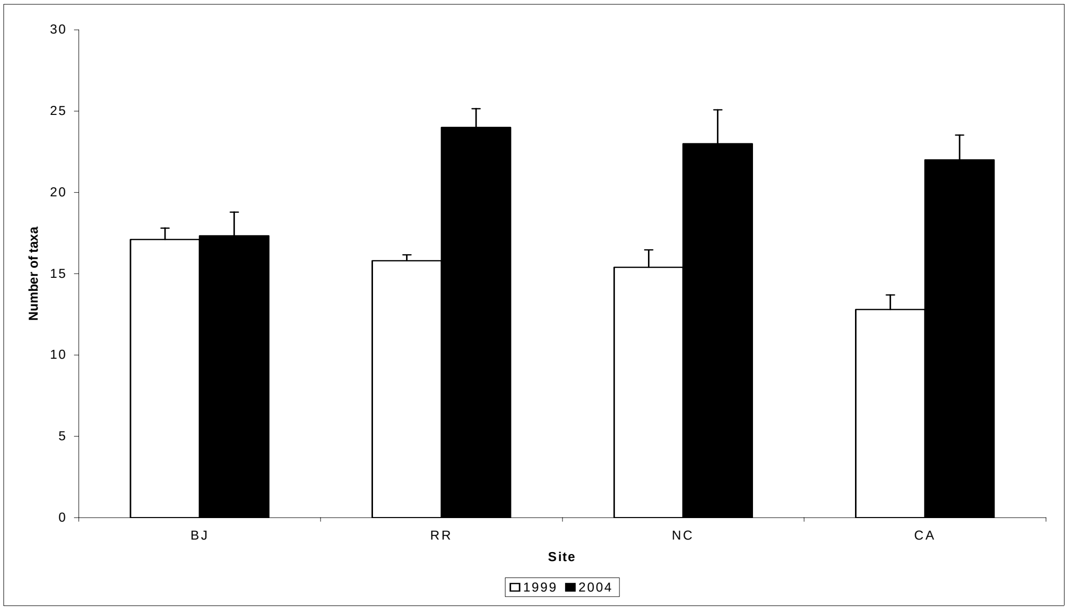


FIGURE 5.9. TOTAL TAXA RICHNESS OF MACROINVERTEBRATES COLLECTED IN QUANTITATIVE SAMPLES NEAR THE BELOW JORDANELLE (BJ) SITE, THE RIVER ROAD (RR) SITE, THE NEVER-CHANNELIZED (NC) SITE, AND THE CHARLESTON (CA) SITE IN 1999 AND 2004.

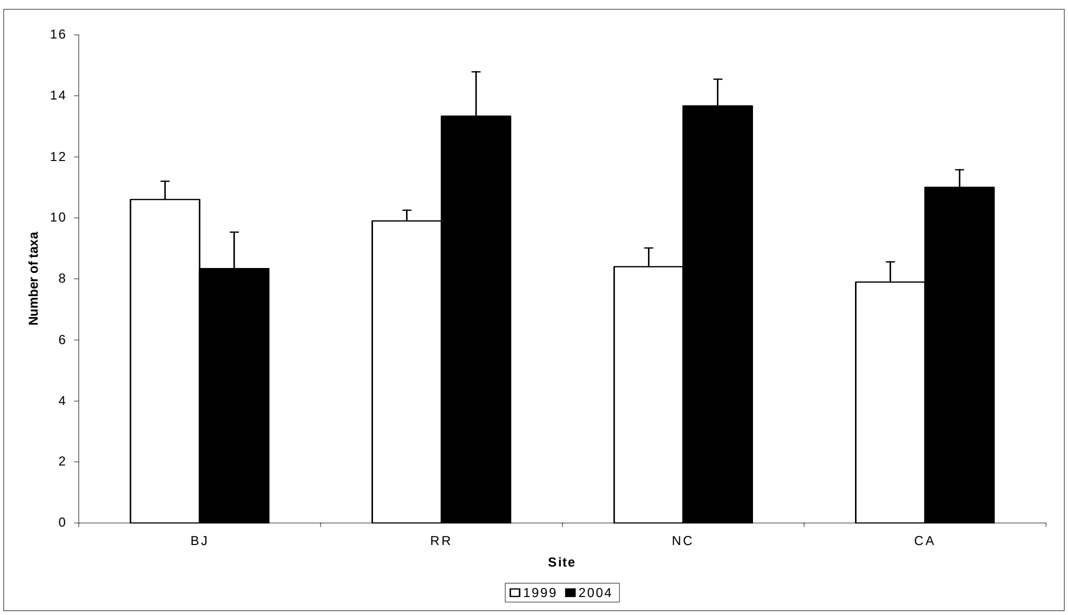


FIGURE 5.10. TAXA RICHNESS OF *EPHEMEROPTERA*, *PLECOPTERA*, AND *TRICHOPTERA* (EPT) COLLECTED IN QUANTITATIVE SAMPLES NEAR THE BELOW JORDANELLE (BJ) SITE, THE RIVER ROAD (RR) SITE, THE NEVER-CHANNELIZED (NC) SITE, AND THE CHARLESTON (CA) SITE IN 1999 AND 2004.

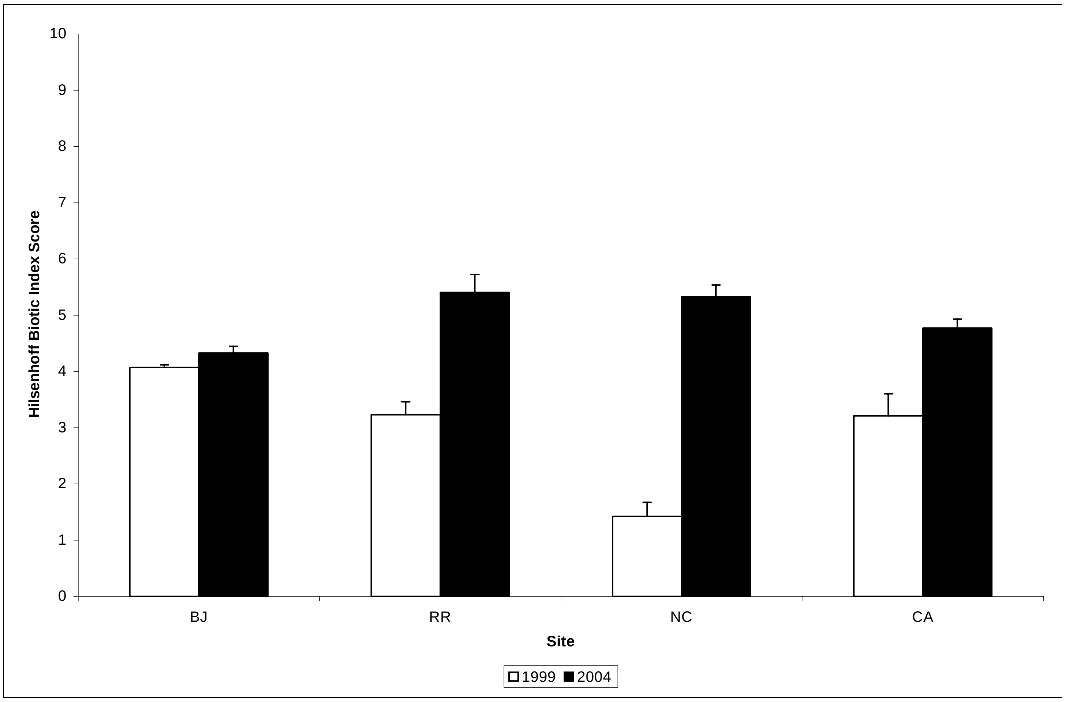


FIGURE 5.11. AVERAGE HILSENHOFF BIOTIC INDEX (HBI) SCORES CALCULATED FROM QUANTITATIVE SAMPLES TAKEN FROM NEAR THE BELOW JORDANELLE (BJ) SITE, THE RIVER ROAD (RR) SITE, THE NEVER-CHANNELIZED (NC) SITE, AND THE CHARLESTON (CA) SITE IN 1999 AND 2004.

No significant differences between sites or between years were seen in the percentage of the most dominant taxa (Table 5.2). While a significant different was not seen in the percentage of the community comprised of the three most dominant taxa between years, there was a difference in what the dominant taxa were. While the *Baetis* sp. identified by USU (Vinson 2004) are probably the *Baetis tricaudatus* identified by EcoAnalysts for this project, the RR, NC, and CA sites all had blackfly (*Simuliidae*) larvae and an unidentified caddisfly (*Trichoptera*) larvae as the other two most abundant taxa, and the BJ site had midge (*Chironomidae*) larvae and blackfly larvae as the other two most abundant taxa.

5.4 DISCUSSION

While macroinvertebrates are commonly accepted as good indicators of aquatic system health and anthropogenic disturbance, their value in assessing the success of river restoration has been questioned (Brooks et al. 2002, Mazeika et al. 2004). Several studies have shown that macroinvertebrates can be heavily influenced by microhabitats at a much smaller scale than restoration projects (Angradi 1996, Angradi 1999). Additionally, several studies were found that suggest that restored river reaches quickly recover macroinvertebrate density and diversity to pre-

TABLE 5.2. THE THREE MOST ABUNDANT TAXA COLLECTED FROM QUANTITATIVE SAMPLES IN 1999 AT THE BELOW JORDANELLE DAM (BJ), RIVER ROAD (RR), NEVER-CHANNELIZED (NC), AND CHARLESTON (CA) SITES.

ORDER OF ABUNDANCE	BELOW JORDANELLE DAM	RIVER ROAD	NEVER-CHANNELIZED	CHARLESTON
FIRST	*BAETIS* SP.	*BAETIS* SP.	UNIDENTIFIED *TRICHOPTERA*	UNIDENTIFIED *TRICHOPTERA*
SECOND	*SIMULIUM* SP.	UNIDENTIFIED *TRICHOPTERA*	*SIMULIUM* SP.	*BAETIS* SP.
THIRD	CHIRONOMIDAE	*SIMULIUM* SP.	*BAETIS* SP.	*SIMULIUM* SP.

restoration conditions, but showed little improvement over unrestored control sites (Biggs et al. 1998, Friberg et al. 1998, Laasonen et al. 1998, Moerke et al. 2004). We found few studies indicating an improved benthic community following restoration (Gortz 1998).

Sites were sampled that had been restored 0 (CA), 2 (BJ), and 3 (RR) years prior to sampling efforts. In addition to the three restored sites, the NC site was also sampled because it has never been channelized. While the NC site had never been channelized, it is not free from historic and current impacts. When upstream reaches were channelized, silt, sand, and fine gravel often deposited in this area, because it had a wider channel than the remainder of the river. The deposition of large amounts of sediment made for a very dynamic channel. Additionally, construction activities during restoration efforts probably introduced fine sediments into the NC site. However, since the site has never been channelized, it is the closest we have to a "control" site in the middle Provo River, even though it has had other anthropogenic disturbances.

Friberg et al. (1998) found that macroinvertebrate densities had recovered within 1 year after restoring meanders to channelized section of a Danish river, but that it took 2 years to restore the diversity to pre-restoration levels. Laasonen et al. (1998) found that it took 1-3 years to recover the density and diversity of the macroinvertebrate communities of Finnish streams restored from channelized conditions to pre-restoration levels. We apparently saw a faster recovery of the benthic community at the CA site, where densities recovered almost immediately after restoration activities in the spring of 2004, and taxa richness recovered by September 2004.

In May 2004 the community at CA was dominated by species that can colonize quickly after a disturbance and by species that are tolerant to pollution and disturbance, such as *Baetis tricaudatus*, *Simulium* sp., *Chironomidae*, and *Oligochaeta*. By September 2004 the CA site had similar macroinvertebrate density and richness to the other three sites, and was not significantly different from the NC site, the closest site upstream, in any of the metrics we examined. Additionally, the CA site had the same three most abundant taxa as the NC site by September 2004. The HBI score also decreased significantly at the CA site between May 2004 and September 2004, indicating that the benthic community had improved during that time. The CA site seemed to recover more quickly from restoration disturbance than several studies found in the literature, and had a similar community to the NC site by September 2004.

Strangely, the BJ and RR sites had benthic communities that diverged further from the NC site than the most recently restored site (CA). The BJ site was restored in 2002 and the RR site was restored in 2001. With the quick recovery at the CA site, the BJ site and RR site would be expected to also have similar benthic communities to the NC site if that site was representative of desired river conditions. However, the BJ site had a significantly lower EPT taxa richness than the NC site in May 2004. While this difference was not born out in the September 2004 collections, the most abundant taxa present at the BJ and RR sites, with the HBI score, provided additional evidence of differences in the benthic communities at these two sites when compared to the NC site.

Both the BJ site and the RR site had significantly lower HBI scores in May 2004 than the NC site. The BJ site would be characterized as slightly enriched by its average HBI score, whereas the remaining three sites would fall into the enriched category. Additionally, the three most abundant taxa made up a smaller proportion of the community at the BJ site than at the remaining three sites.

The composition of the most abundant taxa was also different in both May and September 2004 at the BJ and RR sites when compared to the NC site. The BJ and RR sites both had *Ephemerella inermis/infrequens* as a major component of the community in May 2004, while this species was absent from the CA site, and abundance was much reduced at the NC site. *E. inermis/infrequens* is relatively intolerant to pollution and generally inhabits clean, cold streams. Additionally, *Brachycentrus americanus* was more abundant at the BJ and RR sites than the NC site in May 2004. This species was also absent at the CA site. *B. americanus* is also associated with relatively clean, cold streams of the Intermountain West. Conversely, the leech *Helobdella stagnalis* was abundant at the NC and CA sites and nearly absent at the BJ and RR sites. *H. stagnalis* is more tolerant to pollution and warmer temperatures.

In September 2004 we saw additional evidence that the communities at BJ and RR differ from those at the NC and CA sites. Again, caddisflies in the family *Brachycentridae* were common at the BJ and RR sites, but not at the NC and CA sites. The riffle beetle *Optioservus* sp. and the caddisfly *Hydropysche* sp. were abundant at the NC and CA sites, but not at the BJ and RR sites. Both *Hydropsyche* and *Optioservus* are seen as moderately tolerant to pollution.

The absence of *B. americanus* and *E. inermis/infrequens* at the CA site in May 2004 may be a result of the disturbance caused by the recent restoration activities, but the continued similarities to the NC site at the CA site in September 2004 would suggest that this site is developing a community similar to that of the NC site. The increased abundance of several species at the NC and CA sites over the BJ and RR sites, and vice versa, indicate that some abiotic or biotic factors may be influencing the benthic communities differently in these areas. While the general pollution tolerance values of the taxa in question would indicate increased impacts at the NC and CA sites, the increased diversity of stoneflies (*Plecoptera*) at the NC site and the increased abundance of stoneflies in the family *Perlodidae* at both the NC and CA sites suggest that major impacts from sedimentation or enrichment may not be the cause of the differences in the benthic community. However, the increase in the number of trout seen throughout the restoration reach (Hepworth et al. 2004) provide additional evidence that the area may be undergoing mild to moderate enrichment.

The high percentage of the total number of organisms found in the three most dominant taxa also indicates that some level of anthropogenic disturbance is present throughout the middle Provo River. The CA site had more than 90 percent of the total number of organisms in the three most dominant taxa in May 2004, which was probably a function of recently completed restoration activities in the channel at that site. However, the remaining three sites also had a large (68-88%) proportion of the total number of organisms in the three most dominant taxa. Some caution must be employed when interpreting this metric for these data, because of the level of taxonomic resolution used in this study. Since midges were only identified to the family level and worms to the class level, these two groups probably have multiple taxonomic groups lumped underneath them. In other words, several individual taxa are combined in to *Chironomidae* and *Oligochaeta*, which artificially inflates the percentage of the total number of organisms found in those two "taxa". However, other individual taxa, including *Baetis tricaudatus* and *Ephemerella inermis/infrequens* made up 20-30 percent of the individuals in some of the Hess samples.

BIO-WEST placed two thermographs near the RR and CA sites in 2002 and found that temperatures were higher at the CA site (Olsen et al. 2004). Temperature can exert a strong influence on the structure of macroinvertebrate communities (Vannote and Sweeney 1980). If temperatures are increased at the NC and CA sites, which are downstream from the BJ and RR sites, then this could be another factor influencing the difference in macroinvertebrate communities at these sites.

Studies of substrate and sediment transport at the four sites indicate that differences exist in the current diversity of substrates found in the four sites (Chapter 3 and Chapter 4). Substrate is acknowledged to be a primary factor governing colonization by benthic macroinvertebrates (Hynes 1970, Minshall and Minshall 1977, Brown and Brussick 1991, Angradi 1996). Buss et al. (2004) found that substrate type influenced the structure and composition of the macroinvertebrate community more than water quality and environmental integrity scores. Substrate and sediment transport studies in Chapters 3 and 4 showed an increased percentage of cobble and boulder substrates at the BJ and RR sites, as well as limited in-channel sand and gravel supplies at these two sites, which appears to be leading to channel coarsening at the BJ and RR sites. Channel coarsening could be influencing the benthic community seen at these sites. Greenwood et al. (1999) found that coarsening of substrates resulted in changes in the benthic community. The authors found increased diversity of invertebrates in areas with coarser substrate. They attributed the changes to greater hydraulic and substrate diversity, which causes increased habitat diversity. Conversely, the diversity of the macroinvertebrate community at the BJ site appeared reduced compared with the other three sites in September 2004.

BIO-WEST was also able to compare the macroinvertebrate data collected in 2004 to samples collected in similar areas in 1999, prior to the restoration efforts, in an attempt to further evaluate the impacts of the physical changes to the channel. All the sites showed a large (2-4 fold) increase in the density of invertebrates over the 1999 samples. Additionally, all sites except BJ showed increases in taxa richness, EPT taxa richness, and the HBI score. An increase in taxa richness is usually associated with reduced anthropogenic disturbance, while an increase in the HBI score is evidence of increased anthropogenic disturbance. This confounding information makes interpretation difficult. Additionally, variability in the level of taxonomic resolution between the 1999 quantitative samples and the samples we collected in 2004 increase the difficulty in interpretation of these results. It was found that most of the taxa found in qualitative sampling by Shiozawa et al. (2002) in 1999 were still present in 2004.

One explanation for the differences seen in the benthic community between 1999 and 2004 is that the restoration activities have influenced the benthic community. Hepworth et al. (2004) noted an increase in habitat quality and diversity resulting from restoration work that has occurred in the middle Provo River. Physical habitat heterogeneity and community health and diversity should be emphasized in habitat restoration schemes that strive to increase the physical complexity of a river (Brooks et al. 2002). Restorations of a river system's that have restored physical complexity have not always increased the complexity of the benthic community (Biggs et al. 1998, Friberg et al. 1998, Laasonen et al. 1998, Moerke et al. 2004). However, there was an increase in the taxa richness of the RR and CA restored sites between 1999 and 2004, which could be the result of increased physical complexity in these areas.

Since no restoration occurred in the NC reach, and it had never been channelized, it would be expected that the benthic community would remain relatively constant in that reach. However, as with the RR and CA sites, we found increased invertebrate density, richness, and HBI scores at the NC site in 2004 vs. 1999. If channel complexity had increased naturally in this reach, we could still speculate that increased habitat complexity was responsible for these changes. However,the results of channel monitoring in Chapters 2-4 indicate that habitat complexity at the NC site appears to be declining because of an imbalanced sediment flux, which results in a loss of fine sediments and gravel. Therefore, we may be seeing the results of multiple factors that have changed since the inception of Jordanelle Dam operations (altered flow regime, reduced sediment supply, and temperature changes) interacting with the increase habitat complexity available in some areas after the restoration. Additionally, the change in sediment and flow dynamics after channel restoration upstream and/or the introduction of fine sediments from channel restoration upstream may have also impacted the macroinvertebrate community at the NC site between 1999 and 2004.

Alternative environmental factors interacting with habitat restoration could also explain why it appears the benthic community at the BJ site has not undergone the same changes as the other sites. The BJ site still maintains a preponderance of coarse substrate and more closely resembles the channelized conditions present prior to restoration. Additionally, this site has probably undergone the most constant flow and temperature conditions since the dam closure. While changes in the physical environment of the channel may be responsible for the changes we saw in the density and diversity of the macroinvertebrate community, differences in lab methods may also have played a role (G. Lester, EcoAnalysts, personal communication). It is possible that the sorting and identification methods of EcoAnalysts may have been different enough from other laboratories to affect the results we observed. EcoAnalysts has found that when they have begun to process samples in the middle of other monitoring programs they have seen substantial increases in the number of organisms (G. Lester, EcoAnalysts, personal communication). EcoAnalysts could subsample a portion of any remaining samples from past monitoring programs to determine whether this could be a significant factor in the results we found.

Since 1997, Hepworth et al. (2004) have noted a change in the trout fishery in the middle Provo River. The density and biomass of trout has increased in the restored area, but the condition factor of those trout has declined. Increased competition for diminished food supplies could cause a decrease in condition factor. Cada et al. (1987) found macroinvertebrate densities between 241 and 724 per square meter appeared to result in reduced growth and condition factor for both brown trout and rainbow trout in the southern Appalachians. Newcomb et al. (2001) found a decline in the number of large brown trout below Phillipot Dam on the Smith River in Virginia may have been the result of reduced macroinvertebrate abundance and other factors related to dam operations. The density of macroinvertebrate in the middle Provo River was one or two orders of magnitude higher than the aforementioned studies, where trout condition seemed to be impacted. Productive mid-order streams often have macroinvertebrate densities from 5,000-10,000 organisms per square meter (G. Lester, EcoAnalysts, personal communication). We found average densities ranging from 13,000-34,000 organisms per square meter in May 2004 and from 27,000-85,000 per square meter in September 2004, which may also indicate that some level of enrichment may be occurring. Food availability does not appear to be a problem for the trout community in the middle Provo River.

However, current environmental conditions may be limiting trout growth. Newcomb et al. (2001) and Orth et al. (2004) found that in addition to any problems caused by the reduced forage base, trout condition was also heavily impacted by the dam operations on the Smith River. They found that peaking flows, reduced temperatures, and sedimentation from dam operations reduced both survival and growth of young brown trout in the system. Our comparison of 1999 and 2004 invertebrate community data indicate that changing abiotic factors (e.g., sediment transport, flow, and/or temperature changes) may be interacting with restoration efforts to produce the results we see in the biological community. Similar impacts may be affecting higher trophic levels, too.

5.5 Summary

There has been a positive response in the density and diversity of macroinvertebrates between samples collected in 1999 and sample collected in 2004. However, the restored BJ site has shown little change since 1999, while the NC site has shown considerable change. While the NC site may have been impacted by upstream restoration activities, the change seen at this never-channelized site, combined with the lack of change seen at the restored BJ site, indicate that factors other than the restoration may be at play. The different communities seen at the RR and BJ sites may be the result of their location below Jordanelle Dam and the associated channel coarsening that was observed during the substrate and sediment transport studies conducted in 2004. The density of the macroinvertebrate community was higher in 2004 than in 1999, indicating that a reduction in the forage base does not appear to be the cause for the reduced condition factors seen in the brown trout fishery. However, the change in the fish community may be symptomatic of the other changes in river operation and function, changes that also appear to be influencing the benthic community. Finally, benthic communities can exhibit a large degree of variability from year to year. Unfortunately, we do not have a record of long-term trends in the macroinvertebrate community leading up to 1999, and while information is available between 2000 and 2003 it was collected using a different methodology. Hopefully, the continued macroinvertebrate monitoring may further elucidate how the channel restoration and other factors related to channel process may be influencing the biological community of the middle Provo River.

(This page intentionally left blank.)

6.0 DISCUSSION

6.1 THE CONCEPT OF RESOURCE INTEGRATION ON THE MIDDLE PROVO RIVER

The Provo River Flow Study (Olsen et al. 2004) illustrates that both physical and ecological processes in the middle Provo River directly affect individual resources such as fisheries, recruitment of riparian vegetation, recreation, etc., and can change over time in response to altered streamflows and changes to sediment supply. Various aspects of the streamflow regime, including the magnitude, duration, and timing of floods and low flows, exert a strong influence on the characteristics of the riverine ecosystem. Flow, in conjunction with sediment supply, controls the depositional patterns, the streambed particle size distribution and the rate, timing, and size characteristics of sediment transport through a channel reach of given size and slope (Diagram 6.1).

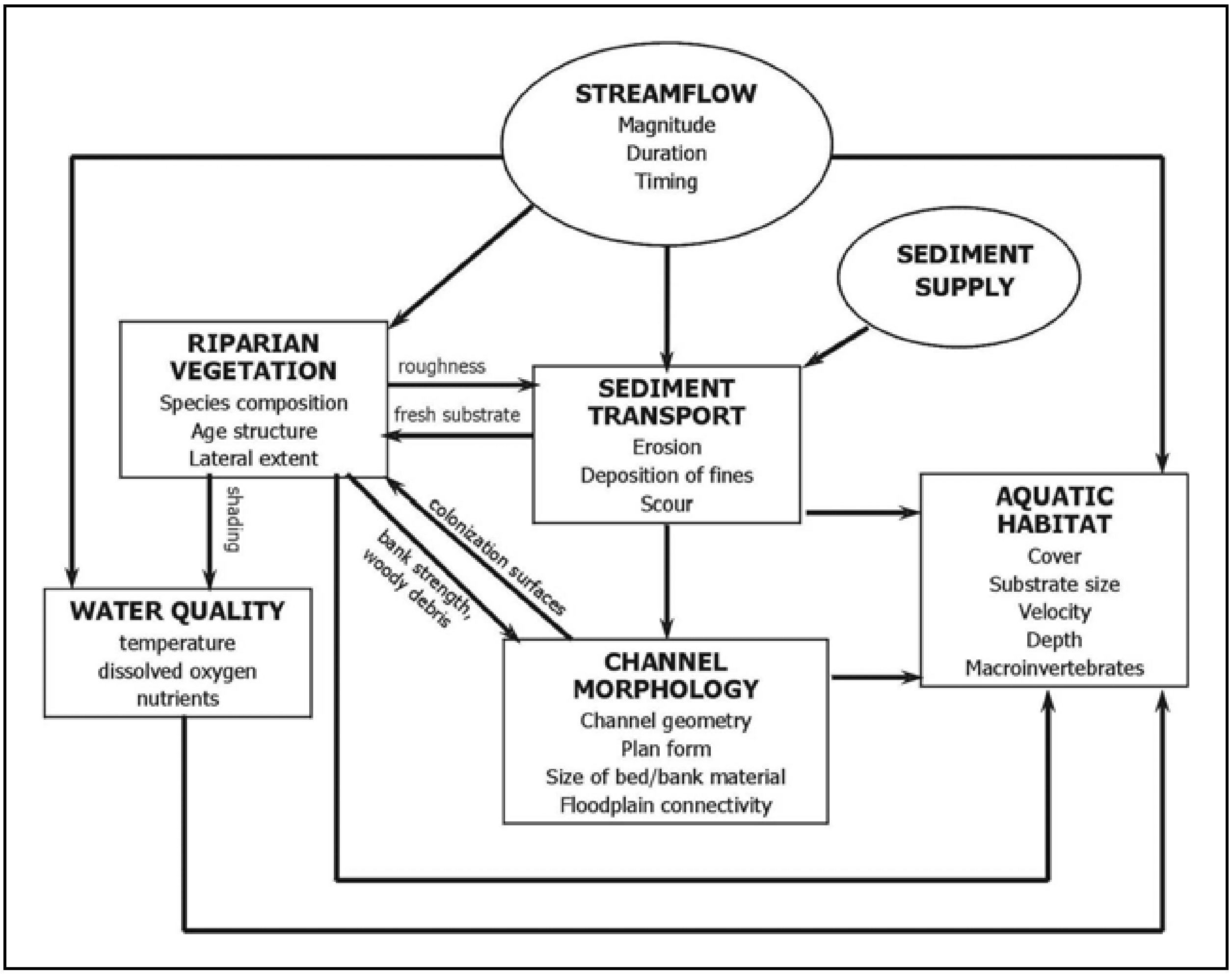


DIAGRAM 6.1. SCHEMATIC ILLUSTRATION OF MAJOR INTERACTIONS AMONG RIVERINE RESOURCES AND PROCESSES.

Sediment transport and channel morphology control the physical aspects of aquatic habitat including substrate sizes, velocity in pools and riffles, and influences the biological aspects of aquatic habitat such as population and diversity of benthic organisms. Although the species, structure and extent of riparian vegetation growing on the floodplain is largely controlled by streamflow, sediment transport and channel morphology, the interactions go both ways where the presence, type and extent of riparian vegetation significantly influences sediment transport and channel morphology.

6.2 The Purpose of Monitoring the Provo River Restoration Project

Where possible, the PRRP has successfully restored the form and function of the middle Provo River and its riparian ecosystem to a more natural and productive condition. The PRRP has transformed and renaturalized this highly visible and popular section of river from its former degraded, disconnected, and channelized state. Even though restoration activities are not completely finished, many benefits have already occurred, including increased fish populations, increased populations and diversity of aquatic and terrestrial organisms, increased acres and functions of wetlands, increased acres of floodplain and successful recruitment of desirable riparian vegetation, and increased recreational opportunities. Construction and land acquisition costs to implement the PRRP have been significant.

The monitoring efforts described in this report are intended to collect necessary data and provide ongoing evaluations of the form and function of the restored river system, and make recommendations for adaptive management needs to maintain desirable conditions in this dynamic riverine ecosystem. The purpose of this work is to: quantify baseline conditions of the restored and un-restored river reaches and track change over time; acquire adequate data and analysis capabilities over time to adaptively maintain the riverine ecosystem in a desirable and functional condition; and, use the "best available scientific knowledge" to assure the Mitigation Commission meets all fish, wildlife, and recreation mitigation commitments in CUPCA.

Additionally, monitoring the PRRP will allow better insight into the success of large-scale river restoration in Utah. The data gathered has allowed us to determine how various components of the Provo River system, both physical and biological, have adjusted to ongoing construction in this riverine ecosystem, and whether the restoration efforts and actions have actually succeeded in or pressed toward attaining the goals that the Reclamation Commission has set for the Provo River.

6.3 Adaptive Management Needs

Rivers and associated floodplains are dynamic, integrated systems that are naturally formed and maintained by both short- and long-term fluxes of water and sediment received from the watersheds they drain. The water and sediment flux of the middle Provo River are significantly influenced by Jordanelle Reservoir. Water is released from Jordanelle Dam year round at recommended discharges. Improvements to the flow regime in the middle Provo River are made each year of operation. However, nearly 100 percent of the coarse- and fine-grained sediments entering Jordanelle Reservoir from the upper Provo River are trapped in this large impoundment and will not be released in the foreseeable future. Jordanelle Dam essentially cuts off the flow of sediment resources to the middle Provo River from the upper watershed and initiates an imbalance between incoming and outgoing loads in the reaches immediately below the dam (Figure 6.1).

A natural amount of gravel in the streambed is necessary to maintain a healthy population of benthic organisms as described in Chapter 5. Gravel is certainly necessary for spawning and reproduction of trout. Sand is also important for cottonwood recruitment. Once a floodplain becomes heavily vegetated there are no viable surfaces for cottonwood recruitment in the middle Provo River without fresh depositional areas of sand occasionally occurring on the upper portions of bars and across the floodplain. As shown in Chapter 3, gravel and sand resources (coarse-grained sediments) are extremely scarce in the reaches immediately below Jordanelle Dam even though the dam has only been in operation for the past 8 years. The coarse grained sediments become less scarce several miles below Jordanelle Dam in the never channelized reach.

The imbalance of incoming and outgoing sediment loads below Jordanelle Dam, if not mitigated, will cause several miles of the restored channel to become degraded, incised, and disconnected from its floodplain, similar to the pre-restored state without the levees. Although the longitudinal extent varies, the phenomenon of degraded river conditions below dams has been well documented in hundreds of rivers around the world. Many of the improved beneficial uses associated with the PRRP will not be maintained without mitigating a natural amount of coarse grained sediments below Jordanelle Dam on an annual basis. Chapter 4 provides specific recommendations.

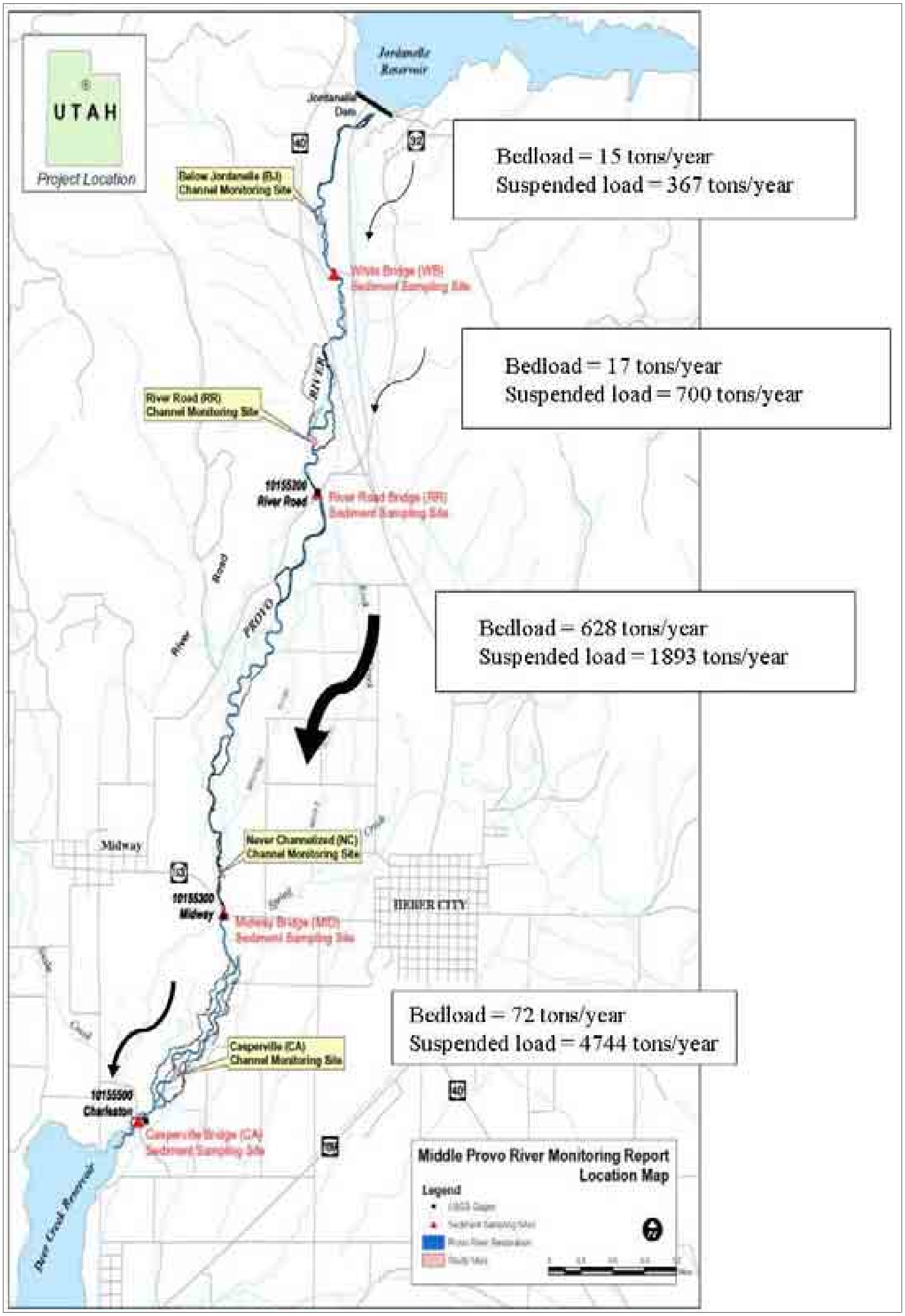


FIGURE 6.1. BEDLOAD AND SUSPENDED LOAD FIGURES FROM THE MIDDLE PROVO RIVER, SHOWING THE IMBALANCE BETWEEN INCOMING AND OUTGOING LOADS IN THE REACHES IMMEDIATELY BELOW THE DAM BASED ON THE 2004 MONITORING RESULTS.

7.0 REFERENCES

Angradi T.A. 1996. Inter-habitat variation in benthic community structure, function and organic matter storage in three Appalachian headwater streams. Journal of the North American Benthological Society 15: 42-63.

Angradi T.R. 1999. Fine sediment and macroinvertebrate assemblages in Appalachian streams: a field experiment with biomonitoring applications. Journal of the North American Benthological Society 18: 49-66.

Barbour, M.T., J. Gerritsen, B.D. Snyder, and J.B. Stribling. 1999. Rapid bioassessment protocols for use in streams and wadeable rivers: Periphyton, benthic macroinvertebrates and fish, Second edition. EPA 841-B-99-002. U.S. Environmental Protection Agency, Office of Water, Washington, D.C.

Biggs, J., A. Corfield, P. Gron, H.O. Hansen, D. Walker, M. Whitfield, and P. Williams. 1998. Restoration of rivers Brede, Cole, and Skerne: a joint Danish and British EU-LIFE demonstration project, V - Short-term influences on the conservation value of the aquatic macroinvertebrate and macrophyte assemblages. Aquatic Conservation: Marine and Freshwater Ecosystems 8: 251-245.

Brown, A.V. and P.P. Brussick. 1991. Comparisons of benthic invertebrate between riffles and pools. Hydrobiologia 220: 99-108.

Brooks, S., M.A. Palmer, B.J. Cardinale, C.M. Swan, and S. Ribblett. 2002. Assessing Ecosystem rehabilitation: Limitation of Community Structure data. Restoration Ecology 10(1): 156-168.

Buss, D.F., D.F. Baptista, J.L. Nessimian, and M. Egler. 2004. Substrate specificity, environmental degradation and disturbance structuring macroinvertebrate assemblages in neotropical streams. Hydrobiologia 518: 179-188.

Cada, G.F., J.M. Loar, and M.J. Sale. 1987. Evidence of food limitation of rainbow trout and brown trout in southern Appalachian soft-water stream. Transactions of the Ameican Fisheries Society 116: 692-702.

Crist, L. and L. Trinca. 1988. Macroinvertebrates of the Provo River and the effect of a temporary flow reduction. BIO-WEST, Inc., Logan, UT. PR-177-1. 23 p.

Friberg, N., B. Kronvag, H.O. Hansen, and L.M. Svendson. 1998. Long-term, habitat-specific response of a macroinvertebrate community to river restoration. Aquatic Conservation: Marine and Freshwater Ecosystems 8: 87-99.

Gortz, P. 1998. Effects of stream restoration on the macroinvertebrate community in the River Esrom, Denmark. Aquatic Conservation: Marine and Freshwater Ecosystems 8: 115-130.

Greenwood, M.T., M.A. Bickerton, A.M. Gurnell, and G.E. Petts. 1999. Channel changes and invertebrate faunas below Nant-Moch Dam, River Rheidol, Wales, U.K.: 35 years on. Regulated Rivers: Research & Management 15(1-3): 99-112.

Hawkins C.P. 1994. What are riparian ecosystems and why are we worried about them? In: Rasmussen G.A. and Dobrowolski J.P., editors. Natural Resource and Environmental Issues Volume I. Proceedings of a symposium on the disturbances, management, economics, and conflicts associated with riparian ecosystems. Utah State University College of Natural Resources, Logan, UT.

Hepworth, R.D., D.E. Wiley, and M.T. Slater. 2004. Middle Provo River fish population surveys 2003. Utah Department of Natural Resources, Salt Lake City, UT. 19 p.

Hilsenhoff, W.L. 1988. Rapid field assessment of organic pollution with a family level biotic index. The Journal of the North American Benthological Society 7:65-68.

Hynes, H.B.N. 1970. The ecology of stream insects. Annual Review of Entomology 15: 25-42.

Knopf F.L., Samson F.B. 1994. Scale perspectives on avian diversity in Western riparian ecosystems. Conservation Biology 8(3):669-676.

Laasonen, P., T. Muotka, and I. Kivijarvi. 1998. Recovery of macroinvertebrates communities from stream habitat restoration. Aquatic Conservation: Marine and Freshwater Ecosystems 8: 101-113.

Mazeika, S., P. Sullivan, M.C. Watson, and W.C. Hession. 2004. Understanding stream geomorphic state in relation to ecological integrity: Evidence using habitat assessments and macroinvertebrates. Environmental Management 34(5)669.

Minshall, G.W. and J.N. Minshall. 1977. Microdistribution of benthic invertebrates in a Rocky Mountain (USA) stream. Hydrobiologia 55: 231-249.

Moerke, A.H., K.J. Gerard, J.A. Latimore, R.A. Hellenthal, and G.A. Lamberti. 2004. Restoration of an Indiana, USA, stream: bridging the gap between basic and applied lotic ecology. Journal of North American Benthological Society 23(3): 647-660.

Newcomb, T.J., K.M. Hanna, and M.R. Anderson. 2001. Macroinvertebrate forage in the Smith River tailwater: Feast or famine? Proclamations of the Annual Conference of the Southeast Association of Fish and Wildlife Agencies 55: 116-125.

Olsen, D.S., M.Stamp, E. Oborny, and C. Addley. 2004. Jordanelle to Deer Creek Provo River flow study, flow-habitat and flow-ecological relationships within the riverine ecosystem: aquatic habitat, riparian vegetation, recreactional uses, and fluvial processes. BIO-WEST, Inc., Logan, UT. 145 p. plus appendices.

Orth, D.A., P. Diplas, C. A. Dolloff, T.J. Newcomb, C.W. Krause, D.A. Novinger, M.R. Anderson, G.M. Buhyoff, A.K. Hunter, and Y. Shen. 2004. Influences of fluctuating releases on stream fishes in the Smith River below Philpott Dam: Final Report. Virginia Polytechnic Institute and State University, Blacksburg, VA. Contract 08220203. 284 p.

Shiozawa, D.K., B.J. Weibell, and E. McLaughlin. 2002. The investigation of the macrobenthos of the Provo River between Jordanelle and Deer Creek Reservoirs: A report to the Utah Reclamation Mitigation and Conservation Commission. Brigham Young University, Provo, UT. 45 p.

Vannote, R.L. and B.W. Sweeney. 1980. Geographical analysis of thermal equilbria: A conceptual model for evaluating the effect of natural and modified thermal regimes on aquatic insect communities. American Naturalist 115: 667-695.

Vinson, M.R. 2004. Biologist, National Aquatic Monitoring Center. Personal communication with Michael Golden of BIO-WEST, Inc., Logan, Utah, regarding macroinvertebrate communities on the Provo River. 08/14/2002.