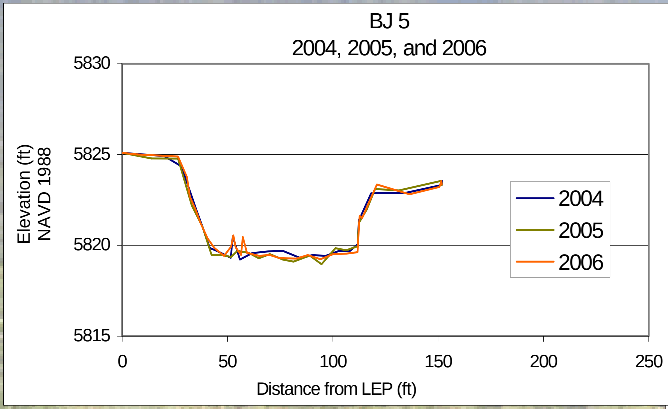
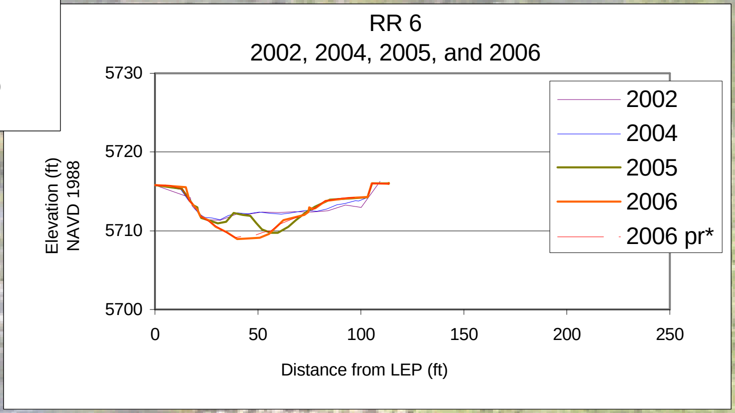
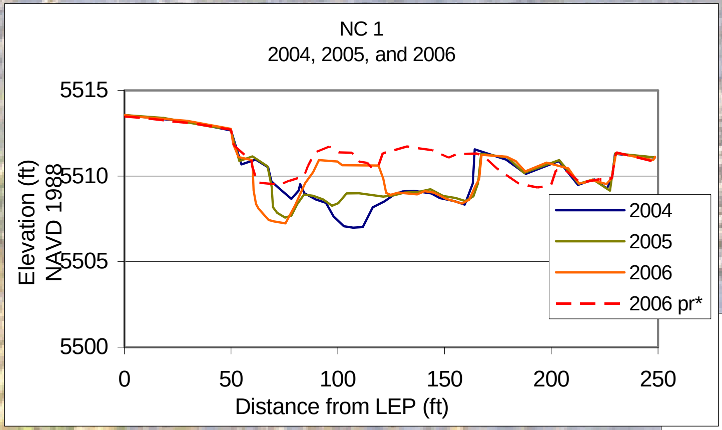
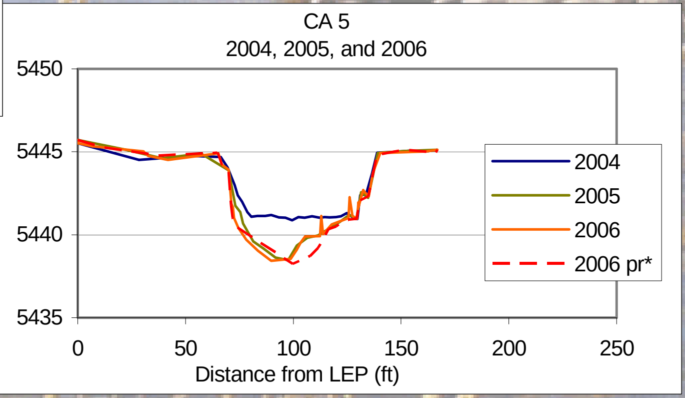
MIDDLE PROVO RIVER
2006 MONITORING REPORT









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EXECUTIVE SUMMARY

INTRODUCTION

This report describes the 2006 channel geometry, substrate, sediment transport (geomorphic) and benthic macroinvertebrate (ecological) monitoring results for the middle Provo River. Trends observed over the initial 3-year monitoring period, from 2004–2006, are also summarized, and recommendations for future monitoring are included. 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 in Wasatch County, Utah, in 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. 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 naturally within the range of hydrologic patterns predicted for the future operation of Jordanelle Dam. Channel reconstruction activities began in 1999 and are anticipated to be completed by the end of 2007.

Understanding the complex relationships between hydrology, fluvial geomorphology, and stream ecology is necessary to adaptively manage the PRRP, especially because the project is located below a dam that limits the supply of sediment into the reconstructed river. The monitoring program described in this report was designed to collect data that will assist in explaining these interrelated processes and inform adaptive management decisions to maximize the long-term resource value of the project.

The data included in this report are the results of the third (and final) year of an initial monitoring program that has periodically measured and analyzed 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 this initial monitoring program include the following:

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

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

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

GEOMORPHOLOGY AND CHANNEL DYNAMICS

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. Cross section and profiles were surveyed in spring 2004, spring 2005, spring 2006, and in summer 2006 (post runoff).

In each year, plots of the profiles and cross sections illustrate the diversity of channel width, depth, and local slope within the monitoring sites. Riffle, run, and pool areas are present within each monitoring site. However, the four sites have shown different responses to flows since 2004. The BJ site, located about 1.2 river miles below Jordanelle Dam, has remained nearly static since 2004. Dynamic channel processes, such as overbank flooding, meander migration, and gravel deposition, are limited at this upstream site. These processes create and maintain important habitat for riparian vegetation, fish, and other organisms, and their relative absence at the BJ site could limit restoration success within this upper reach of the Provo River.

The RR site, located about 3.5 miles below Jordanelle Dam, shows some evidence of dynamic channel processes, although the extent of channel change has been smaller than changes observed at the downstream monitoring sites. Although much of the main channel within the RR site has remained fairly static throughout the monitoring period, the high spring flows in 2005 initiated significant bank erosion and plan form changes within the side channel at RR. In conjunction with these side channel changes, bed degradation and bar building have been observed at the RR6 main channel transect.

The NC site, located about 8.2 miles below Jordanelle Dam, is extremely dynamic and has shown substantial changes in plan form, gravel bar locations, and bed elevation following each high flow event. The nearly unlimited supply of sediment available within the never-channelized reach appears to be associated with a highly dynamic channel condition where habitat available to various species increases in area at times, decreases at other times, and regularly migrates throughout the channel.

The CA site, located about 10.5 miles below Jordanelle Dam, is the most recently restored of the monitoring sites. Channel reconstruction was completed in early 2004, and the channel profile, bed elevation, and bank locations adjusted significantly following the spring 2004 high flows. Trends observed between 2004 and 2005, such as bank erosion and channel degradation, generally continued between 2005 and 2006 but at much slower rates than those observed following the 2004 flood.

CHANNEL SUBSTRATE

Monitoring changes in channel substrate composition through time is one way to evaluate the long-term influence of sediment trapping by Jordanelle Dam. One potential effect of this reduced sand and gravel supply could be coarsening of the substrate material and net evacuation of gravel-sized particles from the river, particularly in the areas closest to the dam. Substrate monitoring data from spring 2004 through summer 2006 do not indicate that this temporal coarsening trend is happening on the middle Provo River.

However, monitoring results demonstrate that the upstream monitoring sites (BJ and RR) have substantially coarser substrate than the downstream monitoring sites (NC and CA). The upstream sites, particularly BJ, also exhibit less year-to-year variability in the distribution of substrate patches.

In contrast, the NC site has been extremely dynamic through the 2004–2006 monitoring period, with major changes occurring in gravel bar locations and associated substrate patches. The CA site has also exhibited more bank erosion and gravel bar development than the upstream sites.

SEDIMENT TRANSPORT

The 2006 sediment transport monitoring results indicate, as in other years, that the middle Provo River above White Bridge (WB) is a sediment supply-limited reach. Calculated total sediment loads, particularly for gravel-sized material, are highly suppressed at the upstream sampling sites (WB and River Road [RR] Bridge) relative to the downstream sites. At WB and RR, the sand-sized portions of total bedload are half that at Midway Bridge (MID; located 8.8 miles below Jordanelle) and one-third that at Charleston (CA; located 11.4 miles below Jordanelle). Gravel loads at the upstream sites are two orders of magnitude smaller than the load at CA, and three orders of magnitude smaller than the load at MID. Gravel loads are extremely high (> 2,000 tons per year) at the Midway Bridge site, which is located just below the Never-Channelized reach. Sampling results also indicate that suspended sediment loads are greatest at the CA site, and increase with distance downstream from Jordanelle Dam.

Sediment transport monitoring efforts in 2006 were focused on assessing the accuracy and precision of measured loads, and on evaluating any differences associated with different sampling techniques (e.g., sampling in three locations across the channel versus ten locations). Results indicate that sampling methods are precise to within 1–2 times variance with less variance at peak flows. The results of the 2006 monitoring also show that a three sub-sample method is as accurate and precise as the ten sub-sample method. However, it is also recognized that judgement error on exact placement of the sampler is less likely when using the ten sub-sample method. Since there is no difference in the results yet, there is less opportunity for judgement error; the ten sub-sample method is recommended for any future bedload sampling of the middle Provo River.

MACROINVERTEBRATES

Macroinvertebrate sampling results in 2006 were generally similar to trends observed in 2004–2005. Of the four sites that were monitored, CA provided the most direct opportunity to evaluate recovery of the biological community following restoration activities. Sampling results in 2004, immediately following channel reconstruction, indicated that the CA site recovered very rapidly from construction activities. However, data collected in 2005–2006 revealed significant differences in the number of species relative to the previous year, even 3 years after the restoration. Data were not collected immediately after restoration activities in either the RR or BJ sites, but both of those appeared to have already recovered from restoration activities and had relatively stable conditions during the three years of monitoring data.

Over the 3 years of data, the macroinvertebrate community in the two most downstream sites (CA and NC) was very similar, but the communities at both of these sites differed from the communities seen upstream at BJ and RR. The NC and CA sites exhibited greater overall diversity, but included more pollution-tolerant taxa and a higher abundance and diversity of scraper taxa than the upstream sites. These differences may indicate some level of nutrient enrichment at the two downstream sites. The greater overall diversity at these sites could also be influenced by the higher substrate and habitat heterogeneity at NC and CA relative to BJ and RR. This explanation may be most directly supported by the consistently lower taxa richness of sensitive species (EPT taxa) in the BJ site, where sediment is most homogenous, compared with the three other sites. Overall taxa richness results indicate that the downstream sites (NC and CA) had values similar to those for “minimally impacted” rivers in the region (Grafe 2002), while the BJ and RR sites were below this reference value. Differences in other variables such as water temperature and nutrient loads may also be responsible for the macroinvertebrate community differences among sites.

Comparison of the 2004–2006 sampling results with data collected in August 1999 (prior to channel reconstruction) shows that macroinvertebrate density has apparently increased significantly throughout the study area since 1999. Both the past and current levels of macroinvertebrate density are relatively high, and are well above levels shown to have caused food limitation to trout in other studies. All sites except BJ show a significant increase in taxa richness (diversity) since 1999.

DISCUSSION

Because of the disparity in sediment loads between the upstream and downstream monitoring sites, and because of the relatively static nature of the upstream sites, active gravel replenishment is recommended as an adaptive management measure. Specifically, we recommend that a “gravel slope” be built at an accessible location on the Provo River between Jordanelle Dam and River Road and be used to supply 150 to 400 tons per year of sand and gravel to the river depending on the magnitude and duration of peak flows. Initially, adding gravel to accessible constructed gravel bars within this reach is also recommended.

Although monitoring results to date do not indicate that the channel is systematically degrading or coarsening, the potential for this channel response still exists given the lack of sediment supply to the middle Provo River. Therefore, we recommend modifications to our monitoring program to more specifically assess substrate size and bed elevation trends at a broader scale. Specific recommendations for full river air photo-based and reach-scale monitoring are included in this report. We also recommend adding a fifth smaller-scale monitoring site between the RR site and the NC site, above the river reach that was never channelized. Bedload sampling and surveys of main channel riffle areas should be completed periodically at this additional site as well as at the established study sites in order to assess possible channel degradation trends. Data collected at the new monitoring site will also provide information on how quickly the river recovers from the upstream sediment supply limitations, and on how far downstream gravel augmentation efforts will be needed. Continued macroinvertebrate sampling at all five study sites is also recommended, particularly if gravel augmentation measures are pursued.

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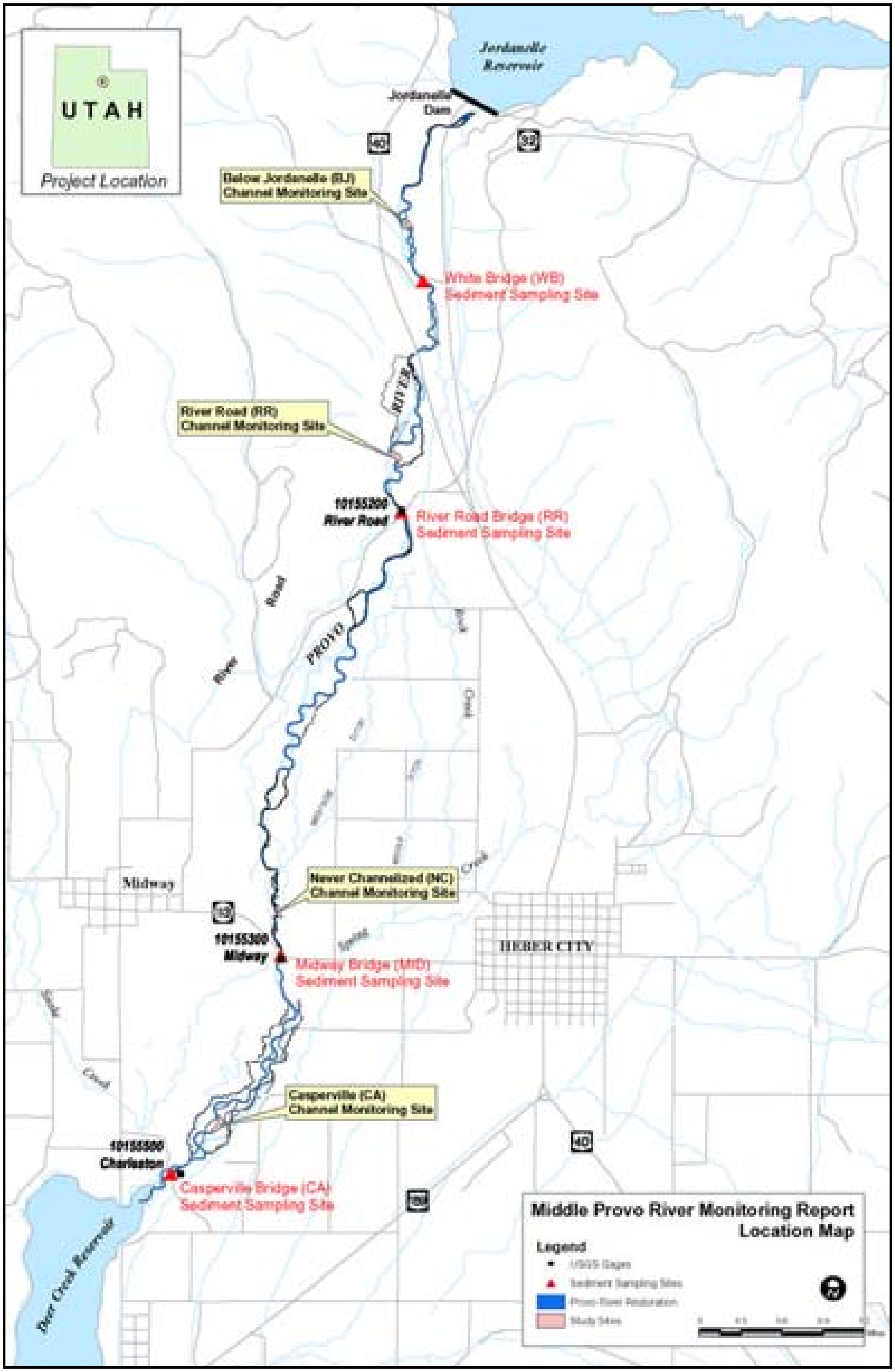
1.0 INTRODUCTION

The portion of Provo River between Jordanelle Dam and Deer Creek Reservoir in Wasatch County, Utah, is commonly known as the middle Provo River (Map 1.1). The Utah Reclamation Mitigation and Conservation Commission (Mitigation Commission) has undertaken a large-scale channel and floodplain reconstruction effort to restore the middle Provo River to a more natural channel form and restore functional fluvial processes. The Provo River Restoration Project (PRRP) was 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 entered the final stages of construction. This report documents the findings of the third year of post-construction geomorphic and macroinvertebrate monitoring in the middle Provo River. Pertinent data, such as channel cross section surveys, substrate maps and particle size distribution plots, bedload samples and benthic macroinvertebrate samples collected before 2004, are used where applicable.

Many controls on the form and function of the middle Provo River may individually or cumulatively cause channel changes. The most obvious control on channel geometry is the magnitude and duration of peak flows. The flow duration curves indicate that, generally, only peak flows exceed 1,000 cubic feet per second (cfs). Peak flows have increased each year since the low peak in 2000. Peak flows in 2005 were much higher than any year since Jordanelle Dam closed in 1996. The 2006 monitoring data shows the effects of these flows on cross sections and substrate at the monitoring sites (Figure 1.1).

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). These chapters are followed by a discussion and summary (Chapter 6) and a list of cited literature (Chapter 7). Chapter 2 describes 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 monitoring particle size and delineations of textured patches over the past 3 years at the study sites. Chapter 4 describes the precision of suspended and bedload samples at two monitoring bridges. 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 3 years of monitoring and makes recommendations for future monitoring and adaptive management needs.



Map 1.1. Map of the middle Provo River.

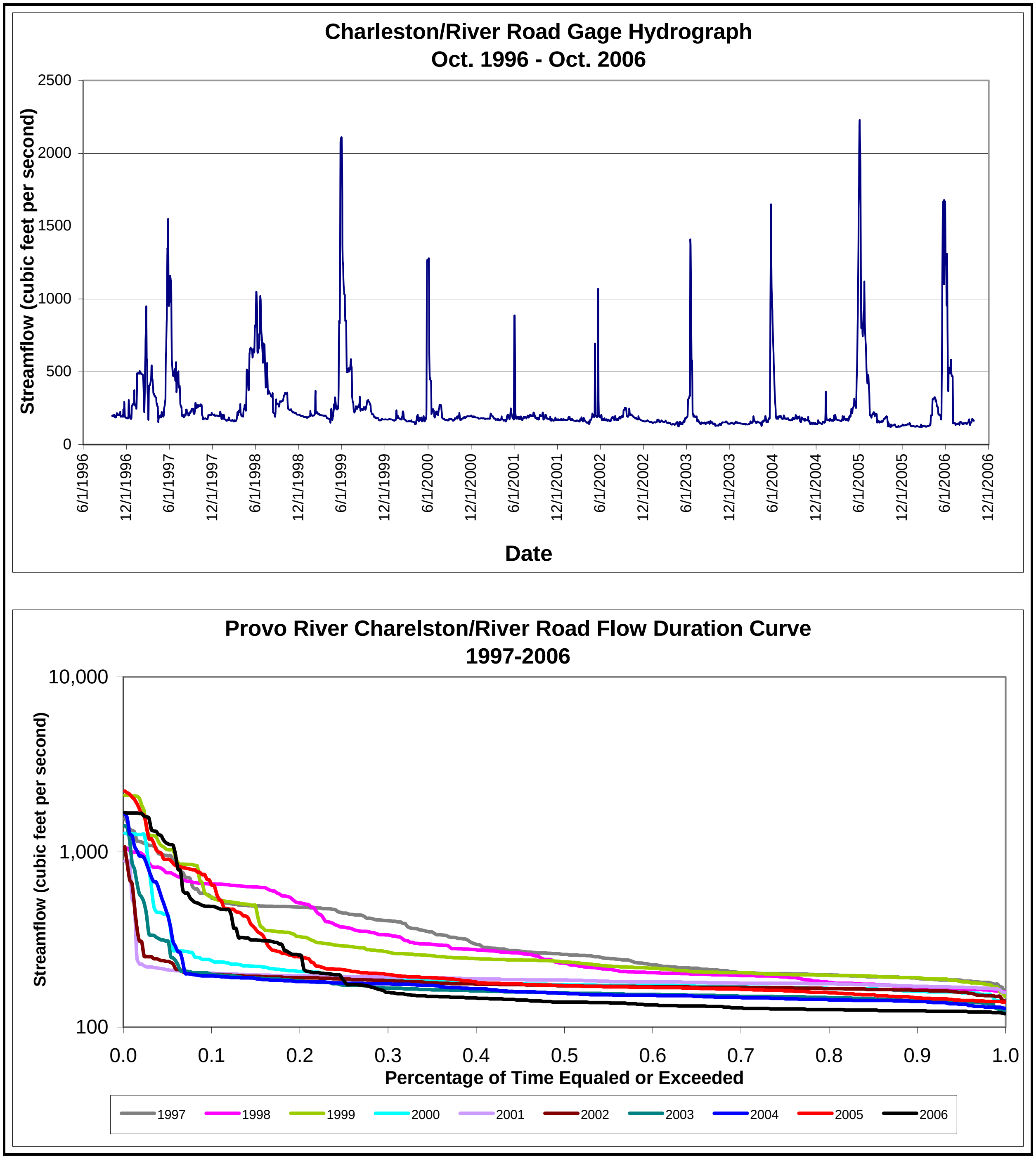


Figure 1.1. Hydrographs and flow duration curves for all post-Jordanelle Dam water years.

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, 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.

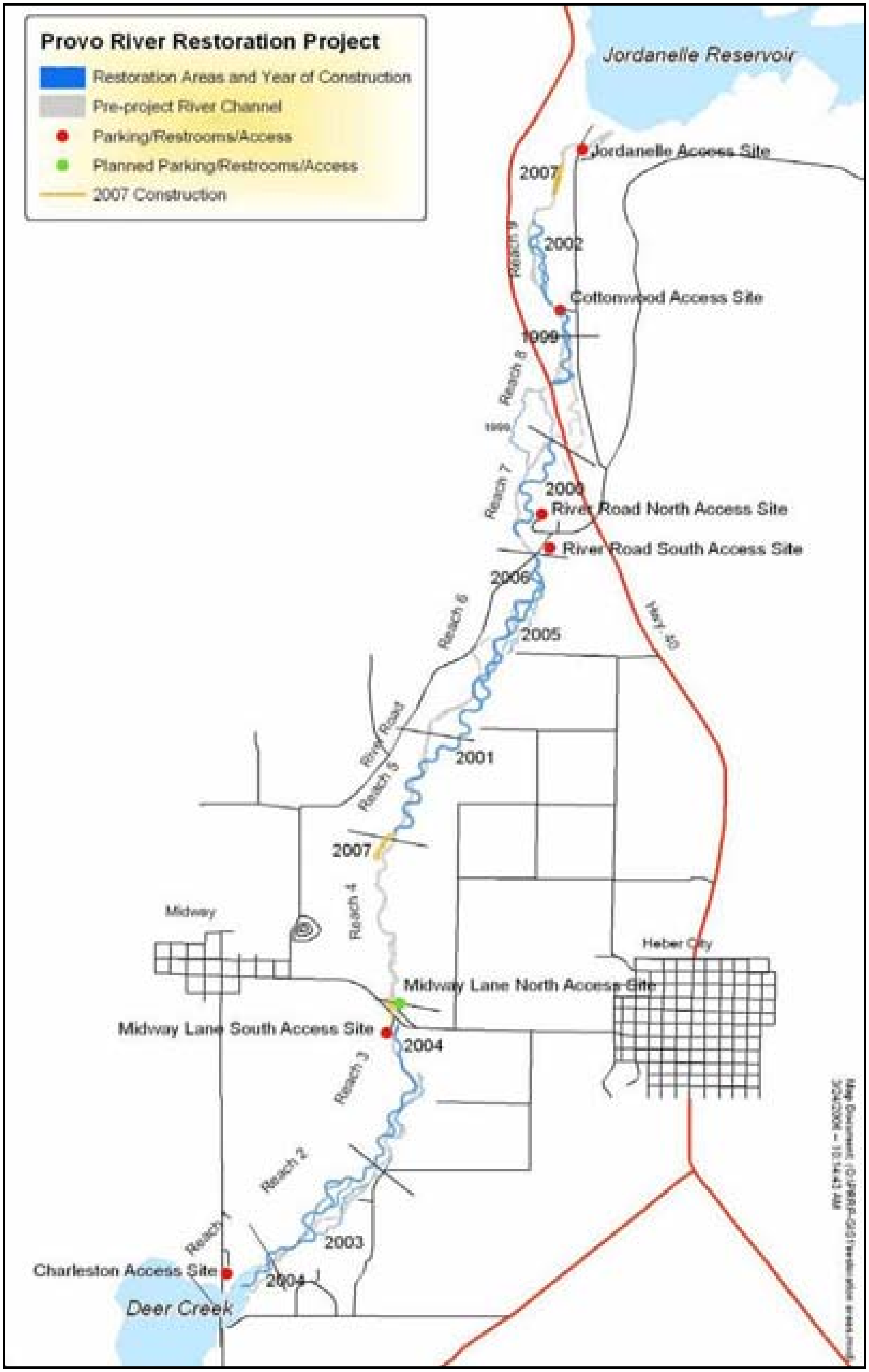
1.2 Central Utah Project (CUP) Background

The Provo River Restoration Project is a mitigation and conservation feature of the Central Utah Project (CUP). The Bonneville Unit of the CUP is a system of reservoirs, aqueducts, pipelines, and conveyance facilities that primarily 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 (M&I) (Map 1.2). Construction of the 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 2021.

The Bonneville Unit includes facilities to collect water from streams in the Duchesne River system and 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 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



Map 1.2. The most current map of the Provo River Restoration Project.

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 helped reduce 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 (UDWR), 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.

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 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 bed degradation, 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. It is likely that this disequilibrium in fluvial processes will 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 desirable conditions in the middle Provo River, with functional ecological, hydrologic, and geomorphic processes. Adaptive maintenance activities will likely be centered on flow recommendations and maintaining a dynamic channel in the restored reaches below Jordanelle Dam.

2.0 CROSS SECTIONS AND LONGITUDINAL PROFILES

2.1 Introduction

An initial set of cross sections and longitudinal profiles was established prior to spring runoff in 2004, re-surveyed prior to spring runoff in 2005 and 2006, and then surveyed again after spring runoff in 2006. The surveys were conducted in four reaches of the middle Provo River to establish a post-restoration baseline and monitor 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.

2.2 Methods

2.2.1 Data Collection

On May 10, 2004, a minimum of six permanent transects (cross sections) were established in each of the four monitoring sites (Figures 2.1a–2.1d). These transects were re-surveyed May 2–5, 2005, and April 12–14 2006. Additional post-runoff 2006 surveys were conducted August 21–23, 2006. All cross sections in BJ and cross sections 1 and 2 in the upstream section of the RR site were not included in the post-runoff surveys because the cross sections have shown little noticeable change through the previous surveys. The surveys were conducted using a theodolite (total station), data collector, and prism/rod. 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 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).

One endpoint was used as the instrument location. The other endpoint was used for a backsight (Figure 2.2). 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).

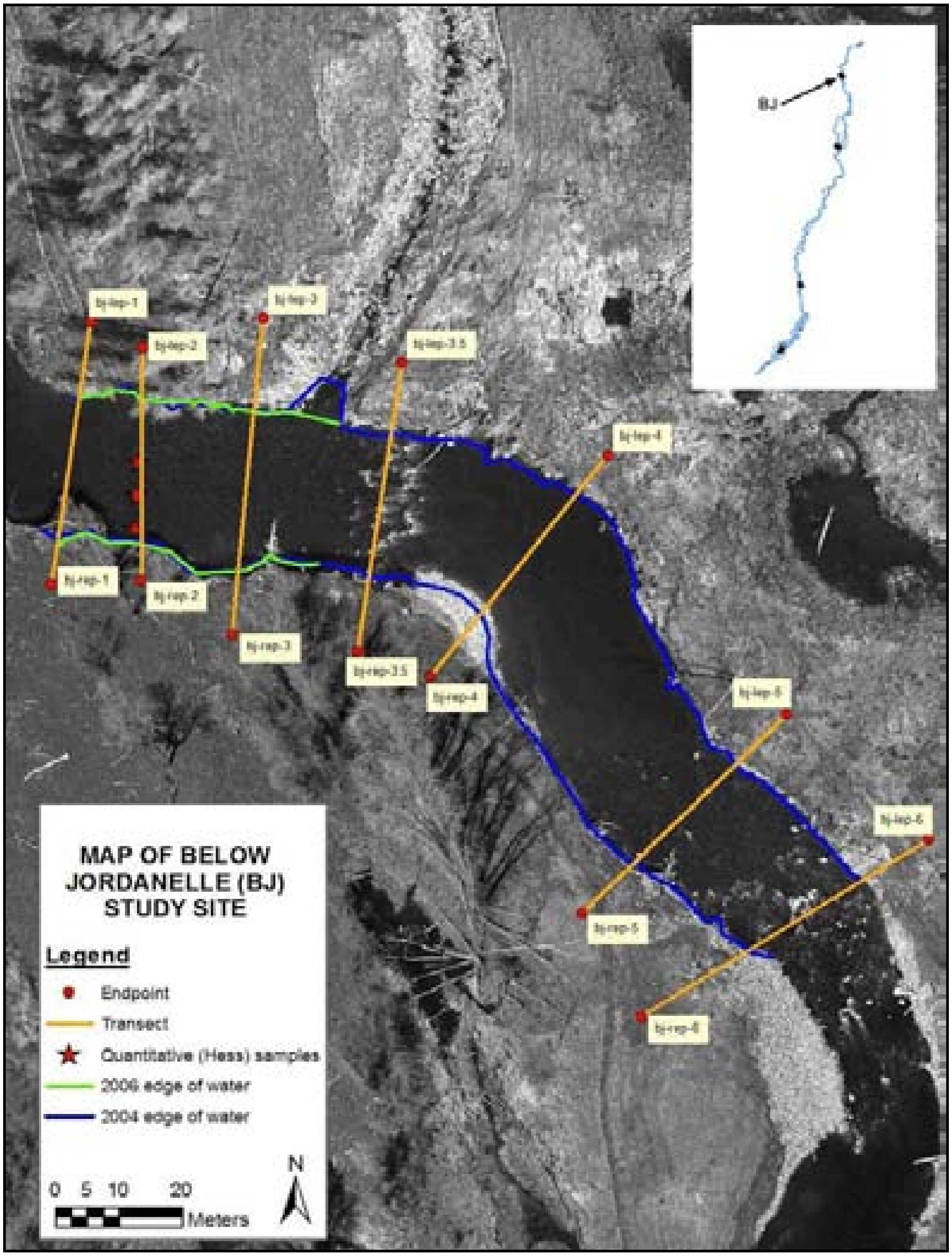


Figure 2.1a. Map of the Below Jordanelle Dam (BJ) Monitoring site. Quantitative (Hess) samples are marked with stars; LEP and REP are abbreviations for left endpoint and right endpoint. Aerial photo from 2004. Edge of water surveyed at 137 cfs in May 2004, 315 cfs in April 2006. No edge of water surveys were completed at this site in 2005 or 2006 post-runoff.

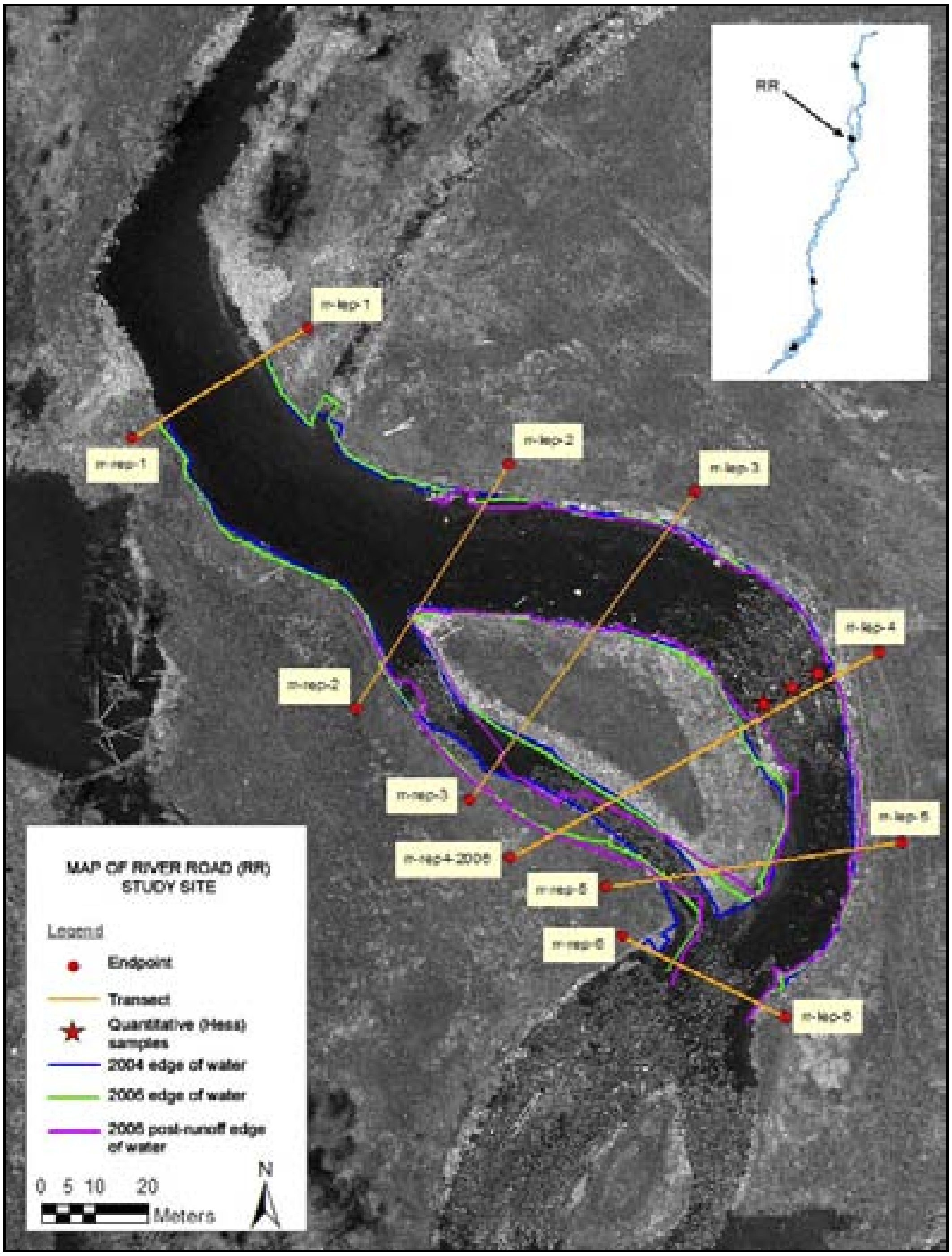


Figure 2.1b. Map of the River Road (RR) Monitoring site. Quantitative (Hess) samples are marked with stars; LEP and REP are abbreviations for left endpoint and right endpoint. Aerial photo from 2004. Edge of water surveyed at 131 cfs in 2004, 315 cfs in April 2006 and 145 cfs in August 2006. No edge of water survey was completed at this site in 2005.

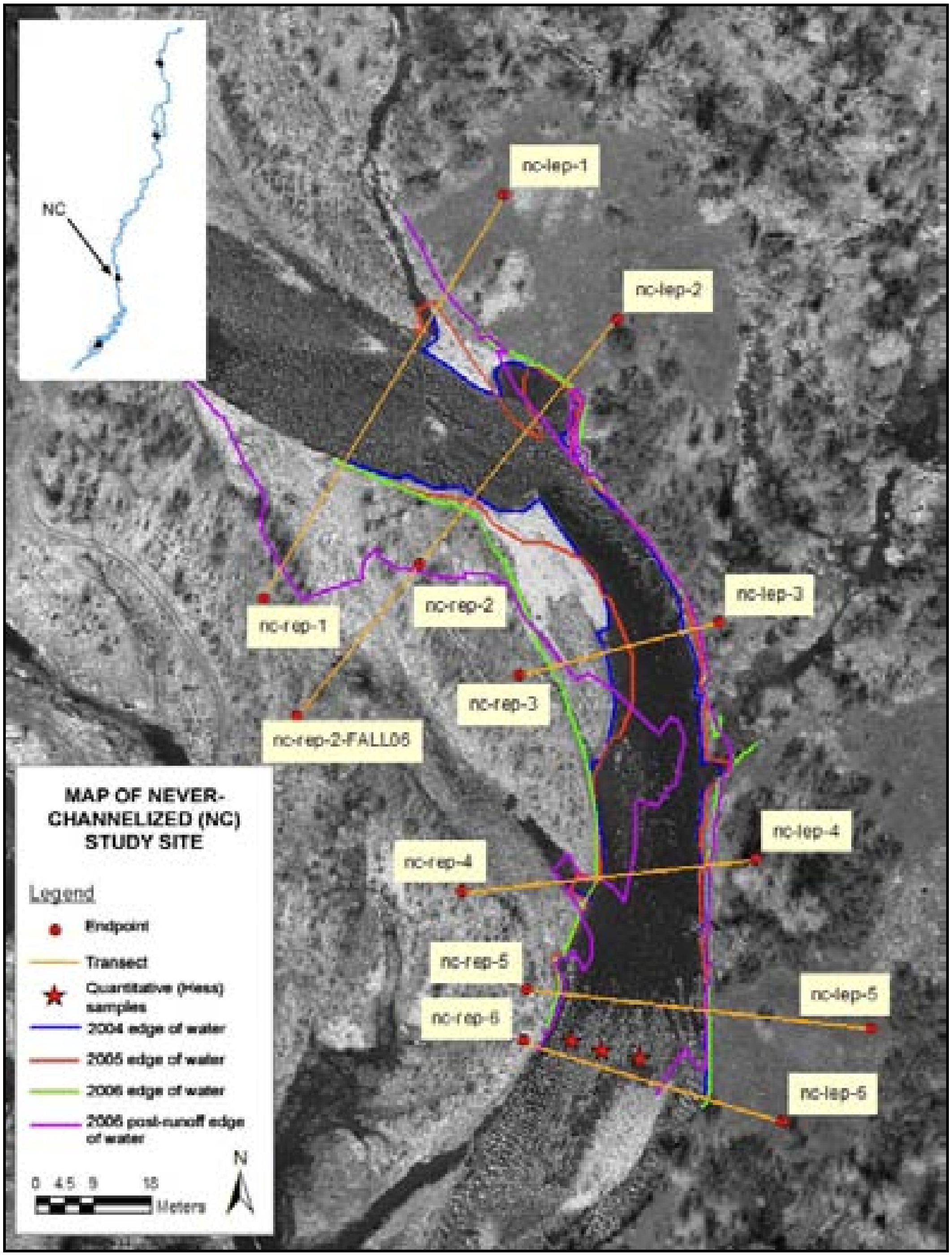


Figure 2.1c. Map of the Never-Channelized (NC) Monitoring site. Quantitative (Hess) samples are marked with stars; LEP and REP are abbreviations for left endpoint and right endpoint. Aerial photo from 2004. Edge of water surveyed at 130 cfs in May 2004, 180 cfs in May 2005, 314 cfs in April 2006, and 147 cfs in August 2006.

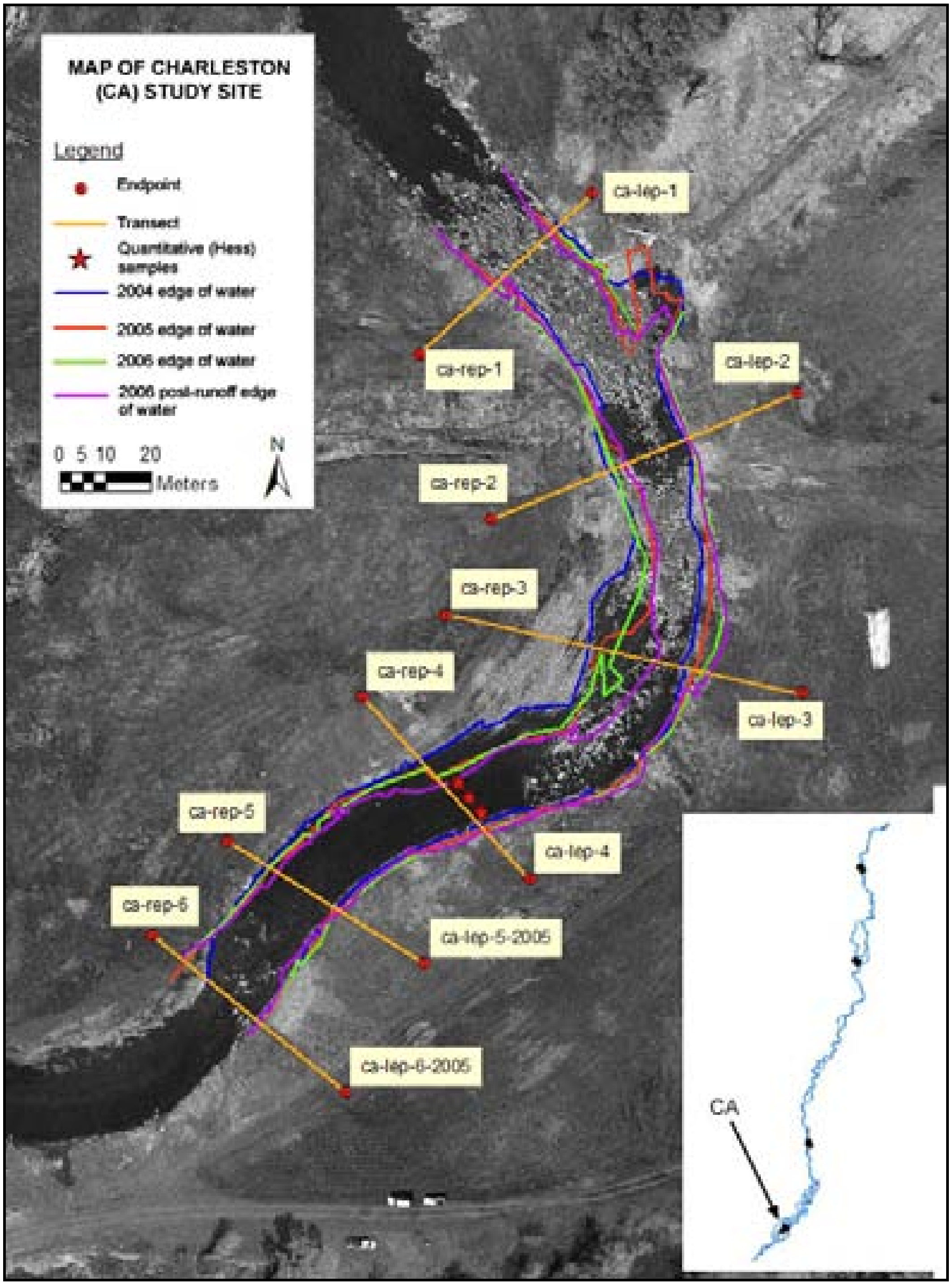


Figure 2.1d. Map of the Charleston (CA) Monitoring site. Quantitative (Hess) samples are marked with stars; LEP and REP are abbreviations for left endpoint and right endpoint. Aerial photo from 2004. Edge of water surveyed at 175 cfs im May 2004, 250 cfs in May 2005, 333 cfs in April 2006, and 158 cfs in August 2006.

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	1658896.14	7381916.43	463379.09	4492598.69	5826.72
bj-lep-2	1658922.77	7381902.34	463387.18	4492594.35	5826.10
bj-lep-3	1658985.32	7381919.15	463406.26	4492599.37	5827.16
bj-lep-3.5	1659057.03	7381895.23	463428.07	4492591.95	5826.65
bj-lep-4	1659164.06	7381845.69	463460.59	4492576.68	5826.05
bj-lep-5	1659257.40	7381705.53	463488.79	4492533.81	5825.09
bj-lep-6	1659331.36	7381637.75	463511.21	4492513.03	5825.55
bj-rep-1	1658876.47	7381773.81	463372.85	4492555.27	5826.95
bj-rep-2	1658922.59	7381775.95	463386.91	4492555.84	5827.12
bj-rep-3	1658970.27	7381746.96	463401.38	4492546.93	5825.81
bj-rep-3.5	1659034.89	7381738.18	463421.05	4492544.14	5823.42
bj-rep-4	1659072.83	7381724.88	463432.59	4492540.02	5823.94
bj-rep-5	1659151.89	7381596.66	463456.46	4492500.82	5823.55
bj-rep-6	1659183.31	7381540.83	463465.93	4492483.76	5824.20
rr-lep-1	1658569.52	7372987.21	463264.09	4489878.64	5718.97
rr-lep-2	1658694.98	7372899.93	463302.16	4489851.83	5719.60
rr-lep-3	1658810.17	7372882.87	463337.22	4489846.43	5720.63
rr-lep-4	1658925.04	7372779.83	463372.04	4489814.84	5718.99
rr-lep-5	1658939.84	7372657.18	463376.34	4489777.44	5717.07
rr-lep-6	1658868.30	7372543.43	463354.348	4489742.91	5715.78
rr-rep-1	1658461.75	7372915.34	463231.13	4489856.92	5718.57
rr-rep-2	1658601.29	7372740.69	463273.34	4489803.47	5716.96
rr-rep-3	1658671.52	7372682.43	463294.63	4489785.59	5716.42
rr-rep-4	1658723.30	7372660.15	463310.37	4489778.72	5716.32
rr-rep-4 2006	1658697.80	7372645.03	463302.58	4489774.16	5716.04
rr-rep-5	1658756.71	7372626.89	463320.49	4489768.53	5716.25
rr-rep-6	1658767.13	7372594.83	463323.61	4489758.74	5715.98
nc-lep-1	1654251.22	7355452.12	461918.01	4484543.29	5513.56
nc-lep-2	1654309.63	7355385.86	461935.69	4484523.01	5512.22
nc-lep-3	1654362.42	7355224.06	461951.49	4484473.62	5510.17
nc-lep-4	1654381.85	7355097.82	461957.19	4484435.12	5511.13
nc-lep-5	1654441.82	7355007.48	461975.31	4484407.49	5510.57
nc-lep-6	1654396.24	7354957.72	461961.33	4484392.41	5509.66
nc-rep-1	1654129.34	7355235.53	461880.49	4484477.51	5511.08
nc-rep-2	1654208.95	7355254.31	461904.79	4484483.10	5510.59
nc-rep-2 post-runoff 2006	1654147.00	7355173.22	461885.77	4484458.50	5510.33
nc-rep-3	1654260.12	7355195.38	461920.27	4484465.05	5510.20
nc-rep-4	1654231.56	7355079.58	461911.37	4484429.82	5508.97
nc-rep-5	1654265.66	7355027.75	461921.67	4484413.97	5508.55
nc-rep-6	1654263.53	7355000.60	461920.98	4484405.70	5508.57
ca-lep-1	1652090.67	7347294.53	461245.64	4482061.47	5449.24
ca-lep-2	1652238.21	7347149.97	461290.34	4482017.17	5449.50
ca-lep-3	1652242.21	7346931.72	461291.19	4481950.66	5447.42
ca-lep-4	1652049.10	7346795.35	461232.11	4481909.45	5446.13
ca-lep-5 2004	1651974.42	7346732.81	461209.25	4481890.52	5445.51
ca-lep-5 2005	1651974.5	7346732.73	461209.28	4481890.49	5445.72
ca-lep-6 2004	1651887.85	7346664.24	461182.76	4481869.78	5443.96
ca-lep-6 2005	1651918.18	7346638.87	461191.95	4481861.99	5445.84
ca-rep-1	1651967.77	7347176.23	461207.99	4482025.63	5447.95
ca-rep-2	1652019.44	7347057.43	461223.53	4481989.35	5446.99
ca-rep-3	1651988.06	7346987.16	461213.84	4481967.99	5446.65
ca-rep-4	1651928.27	7346926.86	461195.52	4481949.72	5446.47
ca-rep-5	1651833.11	7346821.18	461166.35	4481917.69	5445.13
ca-rep-6	1651780.30	7346753.01	461150.14	4481897.01	5444.32

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

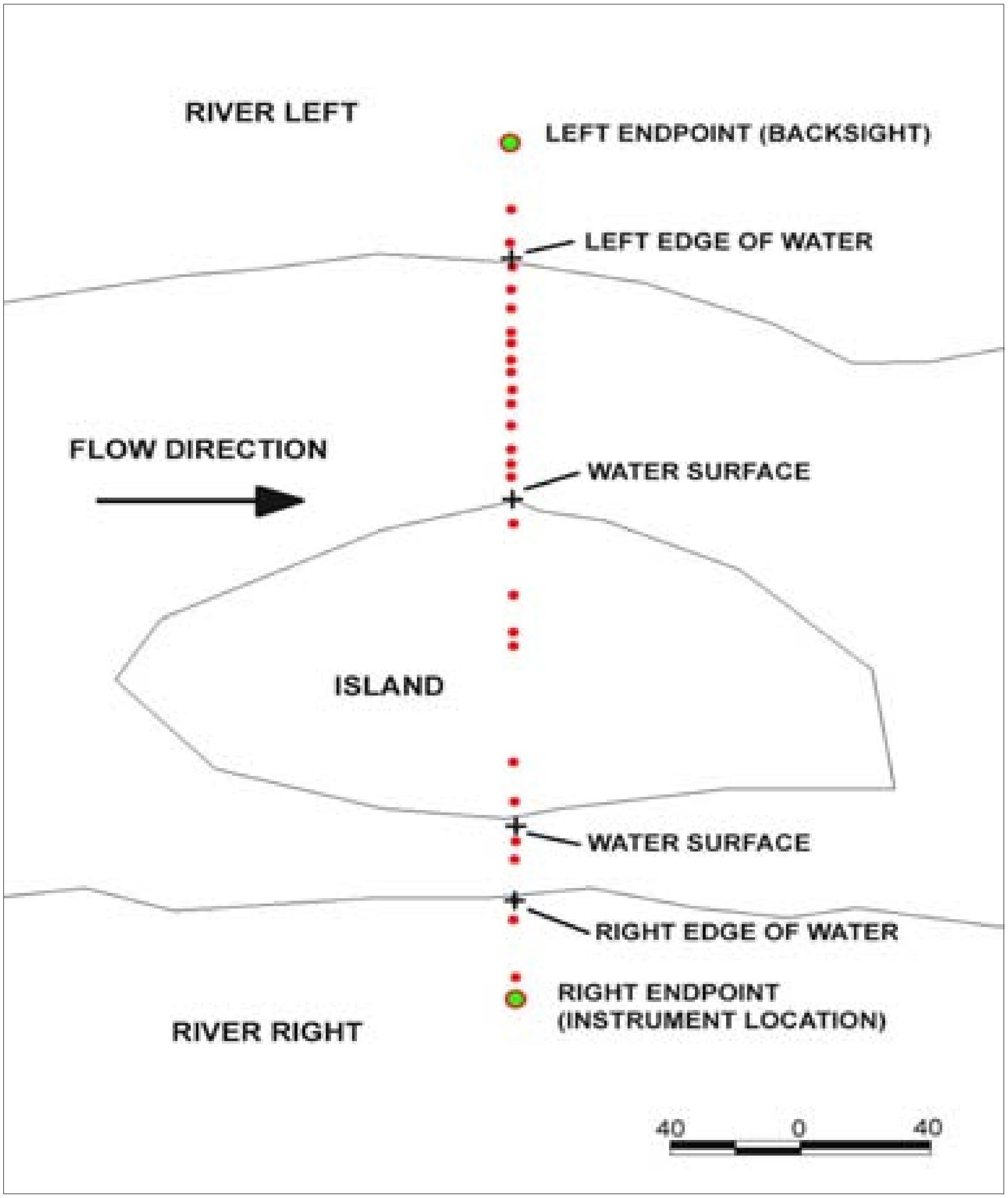


Figure 2.2. Methods for surveying permanent cross sections using a total station. The instrument is set over a permanent endpoint (a labeled aluminum cap on a 3-foot Rebar stake) with known coordinates. Survey points are taken along the transect between the endpoints at 20-foot intervals or when the 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 endpoints.

To complete a transect, the survey rod was placed on points in a straight line (0 degree angle +/- 5 minutes) between the two endpoints (see 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.

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

2.2.2 Over-bank Flooding Analysis

To comprehensively assess stage-discharge relationships at the monitoring sites, the 2006 cross section data were used to develop HEC-RAS hydraulic models for the BJ and CA sites. The most recent (August 2006) cross section survey data were used to model the CA site. The BJ site was not surveyed in fall 2006, so the April 2006 cross section survey data were used to model the BJ site. The water surface elevations measured at each transect during the cross section surveys were used to calibrate the hydraulic models. The BJ surveys were completed at a flow of 315 cfs, while the CA surveys were completed at a flow of 158 cfs.

Within HEC-RAS, flows were modeled as steady, subcritical flow with downstream normal depth boundary conditions. For each site, the surveyed average water surface slope was used as an approximation of the average energy slope for establishing the model boundary conditions. As in the 2005 models, where distances between surveyed cross sections were greater than about 70 feet, additional cross sections were interpolated using the “XS Interpolation Between 2 XS’s” tool in HEC-RAS. At each site, low-flow conditions (315 cfs at BJ; 158 cfs at CA) were modeled using a single, reach-average roughness (Manning’s N) value, which was adjusted until the modeled water surface elevations provided good agreement with the surveyed values throughout the site. Because high-flow surveys were not completed in 2006, the high-flow roughness (Manning’s N) values determined using the 2005 data were used with the 2006 cross-section topography to model 2006 high-flow water surface conditions. These high-flow HEC-RAS model results using the 2006 data were compared with the results using 2005 data to evaluate temporal changes in channel capacity and stage-discharge relationships at the BJ and CA monitoring sites.

The RR and NC sites are complex sites with multiple channel threads and significant areas prone to overbank flooding. The surveyed cross sections at these sites were established as a way to monitor channel change through time in a variety of habitat types and were not originally intended to be used to develop HEC-RAS models. Because of site complexity, several additional cross sections would need to be surveyed at each site in order to develop accurate HEC-RAS models, and such a level of effort was beyond the scope of work of this project. Therefore, instead of developing reach-scale HEC-RAS models at RR and NC, the software WinXSPRO3.0 (Hardy et al. 2004) was used to estimate hydraulic properties of the individual RR and NC site cross sections. This model estimates hydraulics at a cross section and does not interpolate between cross sections.

The text files of cross-sectional data were converted to .sec files for input into the program. In 2006 the high flow water surface elevations were not measured. To model the RR and NC sites, the high-flow elevations from 2005 were used with the low flow elevations measured during the cross-section surveys in fall 2006.

In some cases, high flows in 2005 fully inundated the transect endpoints, leaving all section points below the high-flow stage. To expand these cross sections, “artificial” points were added to the ends of the cross sections at a slope of about 50:1. Adding these points did not change the original surveyed points – it just added enough height to the cross section to allow for accurate high-stage calculations.

Within WinXSPRO, the user-defined Manning’s “N” option was used to determine hydraulic properties of the cross sections. The stage, slope, and Manning’s “N” at low and high stages are the primary inputs for the user-defined Manning’s “N” option.

Low-flow slope information was determined from the edge of water elevations surveyed during the 2006 cross section surveys. At the RR site, edge of water elevations were surveyed in April 2006 at a flow of 315 cfs. Transects RR3, RR4, RR5, and RR6 were also surveyed in August 2006 at a flow of 145 cfs; this lower-flow survey was used to model the lower RR transects. At the NC site, edge of water elevations were surveyed in August 2006 at a flow of 147 cfs. These elevations were also used to back-calculate low-flow “N” values. Since no high-flow surveys were completed in 2006, it was assumed that the high-flow slope and roughness values determined from the 2005 surveys remained the same. These values were used to model high flows using the 2006 cross section geometry.

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. In 2005 an additional set of endpoints was added at BJ to establish cross section 3.5, located between cross sections 3 and 4. In the same year, construction activities destroyed the LEPs for cross sections CA5 and CA6. The LEP at CA5 was reestablished in the same location. The LEP at CA6 was re-established on the same line, but about 50 feet farther from the REP. In 2006 RR4 REP was replaced in Spring and NC 2 REP was replaced in August for the post-runoff surveys.

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 the 2004 baseline data set and the 2005, 2006, and 2006 post-runoff surveys to show temporal changes in channel geometry (e.g., channel width and depth). Appendix 2.2b provides the raw coordinate data collected for the 2006 and 2006 post-runoff cross section surveys . Comparison of baseline (2004) data with the data collected in 2005, 2006, and 2006 post-runoff shows changes in transects, particularly at the NC and CA sites.

The BJ and RR sites have seemed very stable through the monitoring period, while NC and CA sites had noticeable changes in multiple cross sections from 2004 to post-runoff 2006. 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 (Appendix 2.2a). Transect 3.5 was established in a riffle/step type area for the purposes of improving HEC-RAS modeling. The plot of transect 4 (Figure 2.3a) 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 (Appendix 2.2a). The BJ site is a very stable section of the Provo River. Plots for transect 2, 3, and 4 (Appendix 2.2a, Figures 2.3a–2.3b) show little or no change for each transect. Transect 1 indicates that there has been some erosion on the right bank that occurred in 2004 (Appendix 2.2a). The right bank remained the same between 2005 and 2006, perhaps indicating that the bank is stable. Transect 5 indicates a small drop in bed elevation in the middle of the channel, from 2004 to 2005, but no change is evident between 2005 and 2006 (Figures 2.4a-2.4b). However, given the variability in rod placement, which can be either on or next to larger bed material such as boulders, a more substantial lowering of bed elevation is necessary to definitively show degradation. This magnitude of change is evident in cross section 6 (Figures 2.5a-2.5b). The data show deepening in the channel near the right bank and the small bed elevation change seen in 2005 increased in 2006. This relatively small change, a deepening on the right side by approximately 0.8 feet may also be an indication of eastward channel migration. The erosion at cross section 6 may also be an early indication of degradation in the lower areas of BJ.

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. The 2005 transect surveys are very similar to the transect surveys conducted in 2004 for all transects at the site (except RR 6). The 2006 data show changes in cross sections 3–6. Post-runoff surveys from 2006 for cross sections 3–6 also show changes in channel geometry from pre-runoff surveys (Appendix 2.2a).

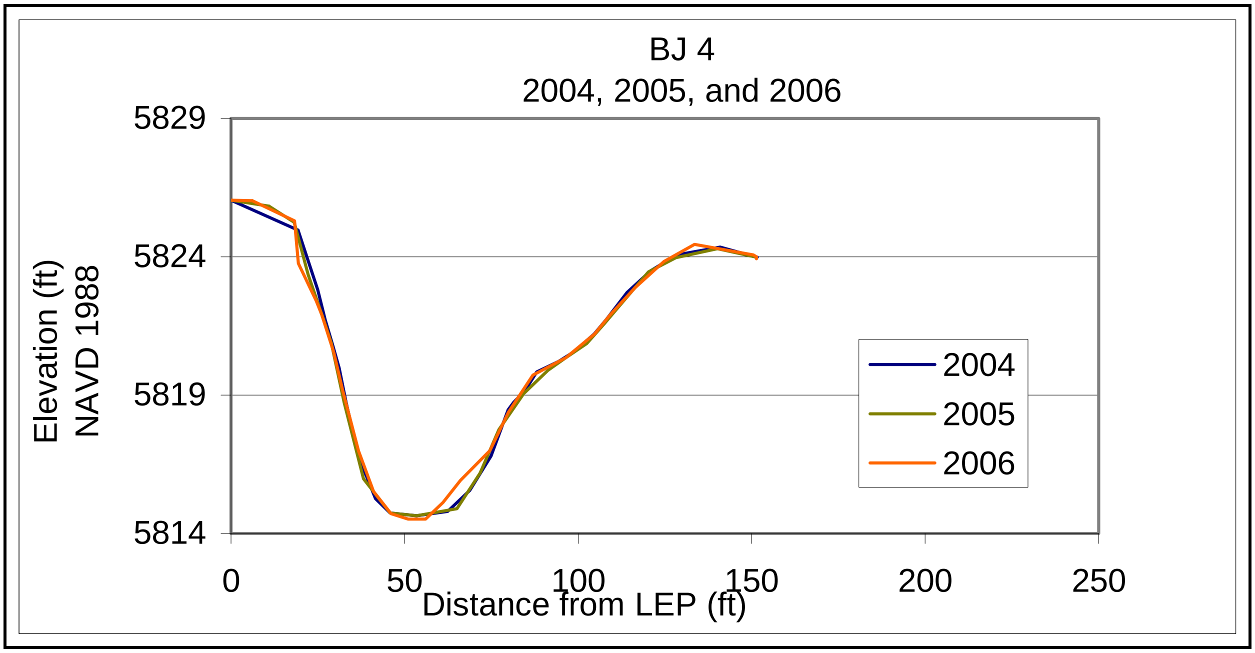


Figure 2.3a. Transect BJ4 shows little change between 2004 and 2006. No post-runoff surveys were conducted at Below Jordanelle (BJ) site.

2004 136 cfs

2005 199 cfs

2006 315 cfs

Figure 2.3b. Photos of transect BJ4 between 2004 and 2006.

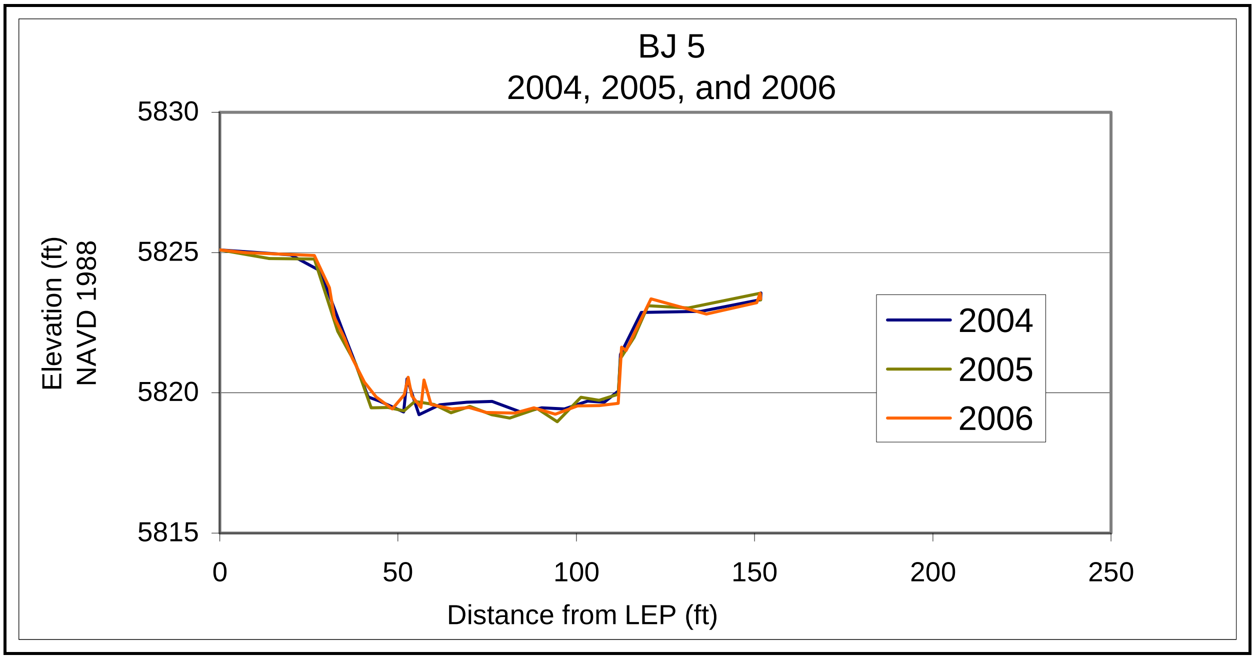


Figure 2.4a. **Transect BJ 5 shows little change between 2004 and 2006.**

2004 136 cfs

2005 199 cfs

2006 315 cfs

Figure 2.4b. Photos of transect BJ 5 between 2004 and 2006.

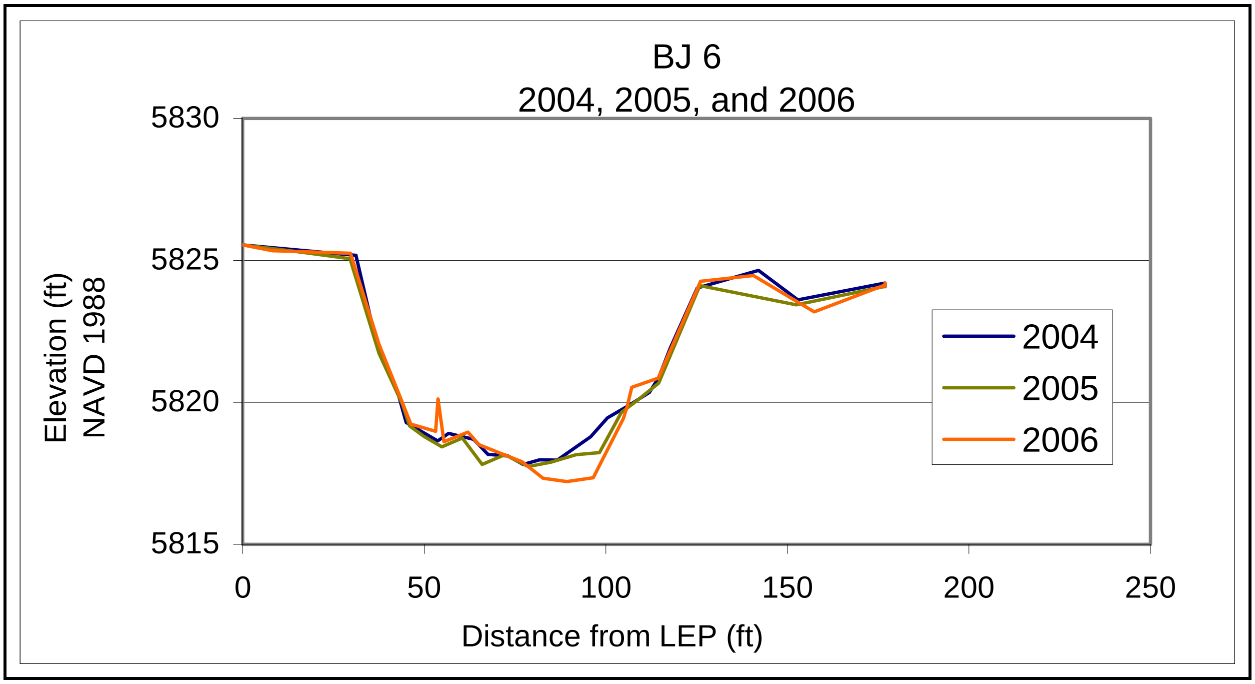


Figure 2.5a. **Some degradation occurred at BJ 6 in 2005 and 2006.**

2004 136 cfs

2005 199 cfs

2006 315 cfs

Figure 2.5b. Photos of transect BJ 6 from 2004 though 2006.

The main channel portions of RR, with the exception of transects RR 4 and 6, have changed very little since 2004 (Appendix 2.2a). Most of the geomorphic changes at the RR site involve the side channel, which appears to have initiated small meanders (Figure 2.6). If the side channel continues to widen and divert water from the main channel it could become the primary channel. Transect 3 shows bank erosion on the right bank and some deepening along the right side of the side channel (Appendix 2.2a). Transect 4 shows the side channel becoming wider (Figure 2.7a). The REP for this transect was set farther back from the bank in spring and the original REP endcap was eroded away with the bank during the 2006 flood cycle. At transect 4 (Figures 2.7a-2.7b), the right bank of the side channel is approximately 25 feet farther west from the 2004 location. Again at transect 5 (Figures 2.8a-2.8b), the main channel has remained stable through the 2006 post-flood survey. However, the side channel began eroding the left bank in 2006 (Figures 2.8a-2.8c). The 2006 post-flood survey shows continuing erosion and is nearly 15 feet east from the 2004 location. Compared with transect 4 data, one might infer that the side channel is starting to cut meander bends.

The confluence of the main channel and side channel is just upstream of transect 6. This location may be why this transect has changed between 2002 and 2006 (Figures 2.9a–2.9b). Channel shape is also influenced by the gravel deposit on the right side of the channel, which forces flow toward the middle of the channel, which is becoming deeper. Both the 2006 and post-flood 2006 surveys show a single channel with the thalweg in the center. However, there was very little change in channel geometry between the 2006 and post-flood 2006 surveys, indicating at the very least temporary stability. Flow may deepen along river left, particularly if flow and meandering in the side channel increases and if the point bar that has become much larger on river right continues to accumulate material.

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 2.9a, some changes in channel shape are evident among the 2002, 2004, 2005, and 2006 surveys. The apparent difference in the shape of the left bank of transect RR6 between the 2002 and 2004 surveys 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 did not change between 2002 and 2004, even though this plot shows some change. Similarly, the different right bank shape shown in Figure 2.9a is merely a function of fewer points in the 2002 survey and does not indicate a true change in bank shape. Monitoring methods established in 2004 have prevented these types of inconsistencies between the 2004, 2005, and 2006 data. Survey objectives and resolution of data points are consistent between 2004, 2005, and monitoring in 2006.

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.

2004 upstream 131 cfs

2006 post-runoff downstream 145 cfs

2006 upstream 315 cfs

2006 post-runoff upstream 145 cfs

Figure 2.6. Photos of the side channel at River Road (RR) site between 2004 and 2006 post-runoff.

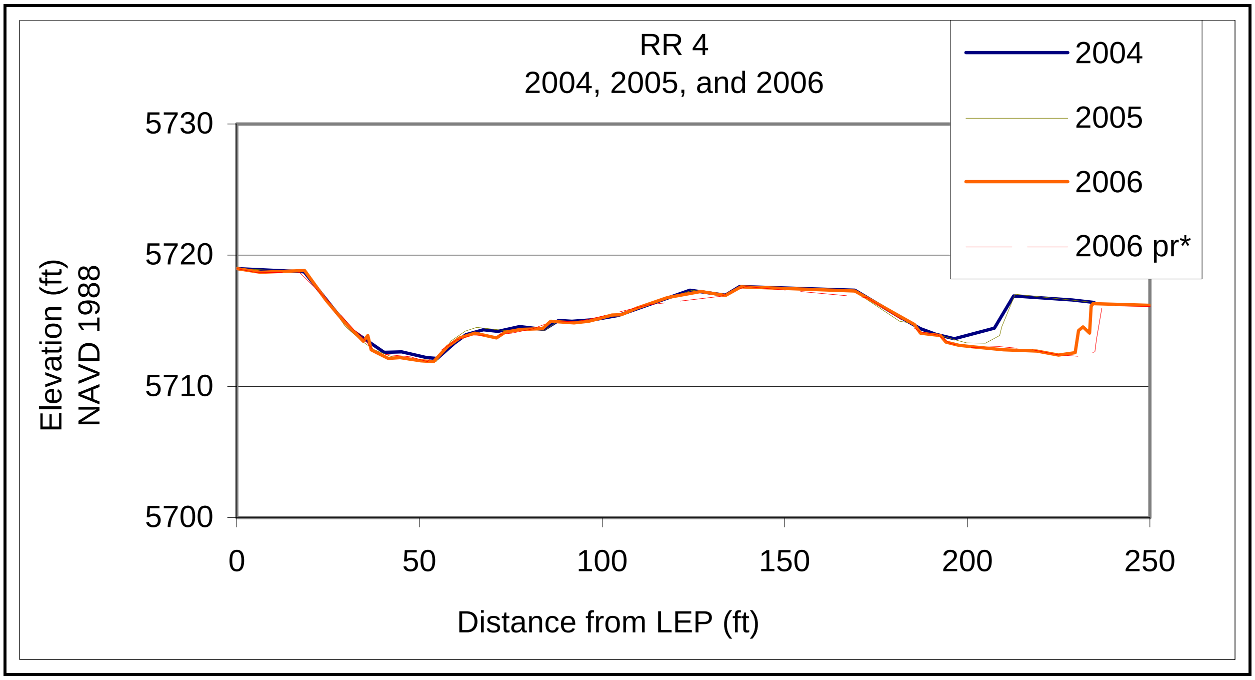


Figure 2.7a. Comparison of transect RR4 from 2004 through 2006 post-runoff.

2004 131 cfs

2005 166 cfs

2006 315 cfs

2006 post-runoff 145 cfs

Figure 2.7b. Photos of transect RR4 from 2004 through 2006 post-runoff.

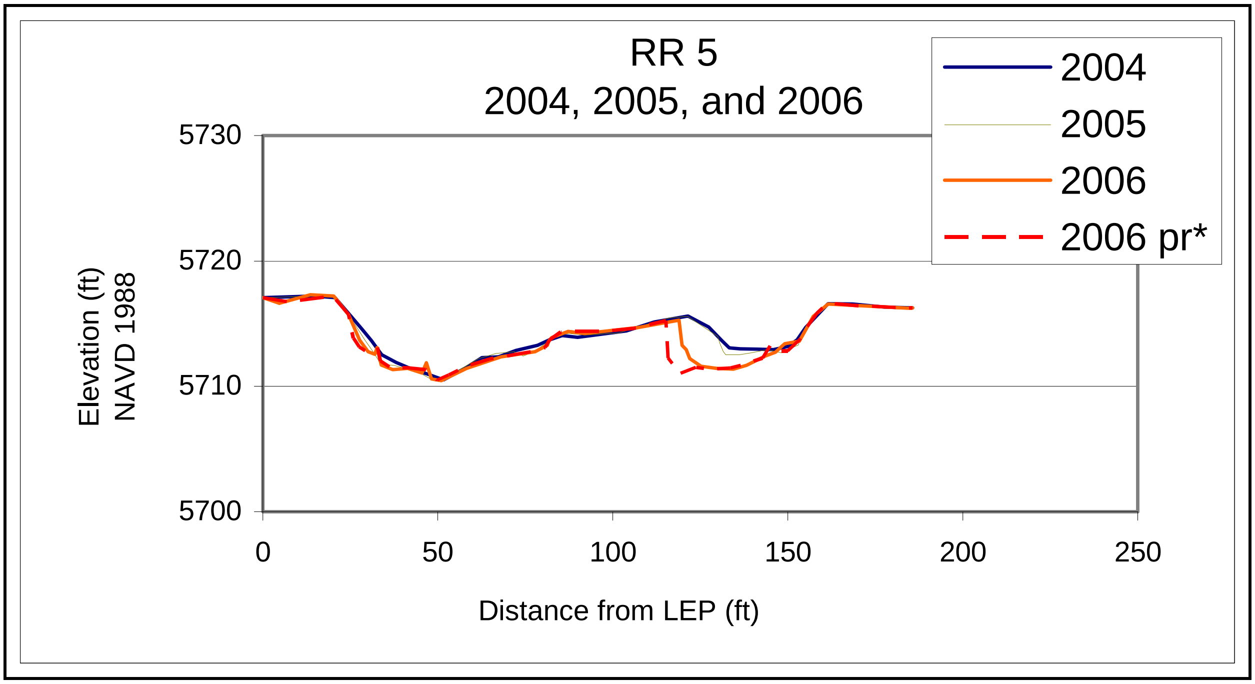


Figure 2.8a. Transect RR5 shows that change in the main channel at River Road (RR) is small. Most change occurred in the side channel.

2004 131 cfs

2005 166 cfs

2006 315 cfs

2006 post-runoff 145 cfs

Figure 2.8b. Photos of transect RR5 from 2004 through post-runoff 2006.

2004 131 cfs

2005 166 cfs

2006 315 cfs

2006 post-runoff 145 cfs

Figure 2.8c. Photos of the side channel at transect RR 5.

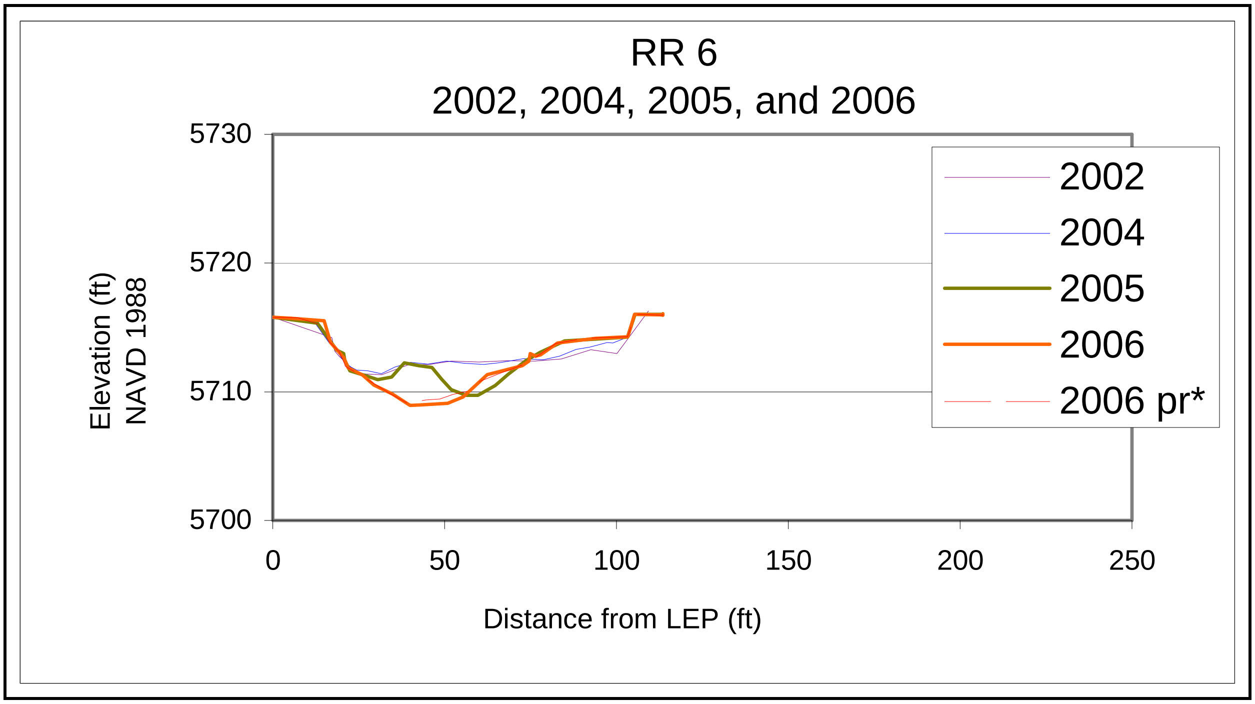


Figure 2.9a. River Road (RR 6) transect 6 surveys (May 2004, May 2005, April 2006, and August 2006) compared with study site 8 cross section 1 (May 2002 survey).

2004 131 cfs

2005 166 cfs

2006 315 cfs

2006 post-runoff 145 cfs

Figure 2.9b. Photos of transect RR 6 from 2004 through post-runoff 2006.

This site was very dynamic, with each cross section showing some change with each survey (Appendix 2.2a). The three upstream transects were noticeably altered by flows between 2004 and 2006 and even more so between 2006 and the 2006 post-runoff surveys. At transect 1 (Figures 2.10a-2.10b), the thalweg migrated to the left side of the channel and the old thalweg section of the transect became shallower. The 2004 thalweg was slightly deeper than the thalweg in 2005. Transect 2 (Figures 2.11a-2.11b) was also different in 2005 compared to 2004. A mid-channel bar built up in 2005 and a slightly deeper thalweg formed on the right side of the channel.

The 2006 survey showed aggradation and channel migration or widening in the upper transects, particularly after the 2006 high flows. The lower transects became slightly deeper and the thalweg was mid-channel. The 2006 post-flood survey showed a large amount of aggradation in the upper three transects and channel widening in the upper two transects. The cross section 2 REP was eroded away during the 2006 high flows and was replaced much farther back from the original position because of the change in the location of the edge of water. Water was inundating willows and floodplain areas during the 2006 post runoff survey in the upper two cross sections. Deposits of large gravel, cobble, and boulder-sized material in the upper part of the NC site are influencing flow in transects 1 and 2. Channel adjustments may have also occurred upstream of the site and are affecting flow through these first two transects.

At transect 3 between 2004 and 2005, the channel shifted to the left, eroded the left bank, and deposition occurred on the right bank; however, the general shape of transect 3 remained the same (Appendix 2.2a). The 2006 survey showed the bed higher by about 2 feet, with a deep pool on the right bank. This pool filled in during the 2006 high flows. The entire bed at cross section 3 aggraded approximately 2 feet between May 2005 and August 2006.

The lower three transects were relatively stable compared to the upper three transects. There were small changes in transects 4, 5, and 6 at the NC site between 2004 and 2005 (Appendix 2.2a). The transects also changed in 2006. At transect 4, most of the change occurred during the 2006 high flows. Some erosion occurred on the left bank, but the thalweg moved toward the right bank. A mid-channel bar may be forming as noted by the rise in the center of the transect. Flow will split around this feature if it remains in its location. Transects 5 and 6 (Figure 2.12a) show change between 2005 and 2006, with no major adjustments in the 2006 post-runoff survey data. The stream at transect 5 is a straight run feature with the thalweg in the center of the channel. At transect 6 (Figures 2.12a-2.12b) a bar creates a small flow divergence to the left bank. However, the majority of the flow is in the center of the channel.

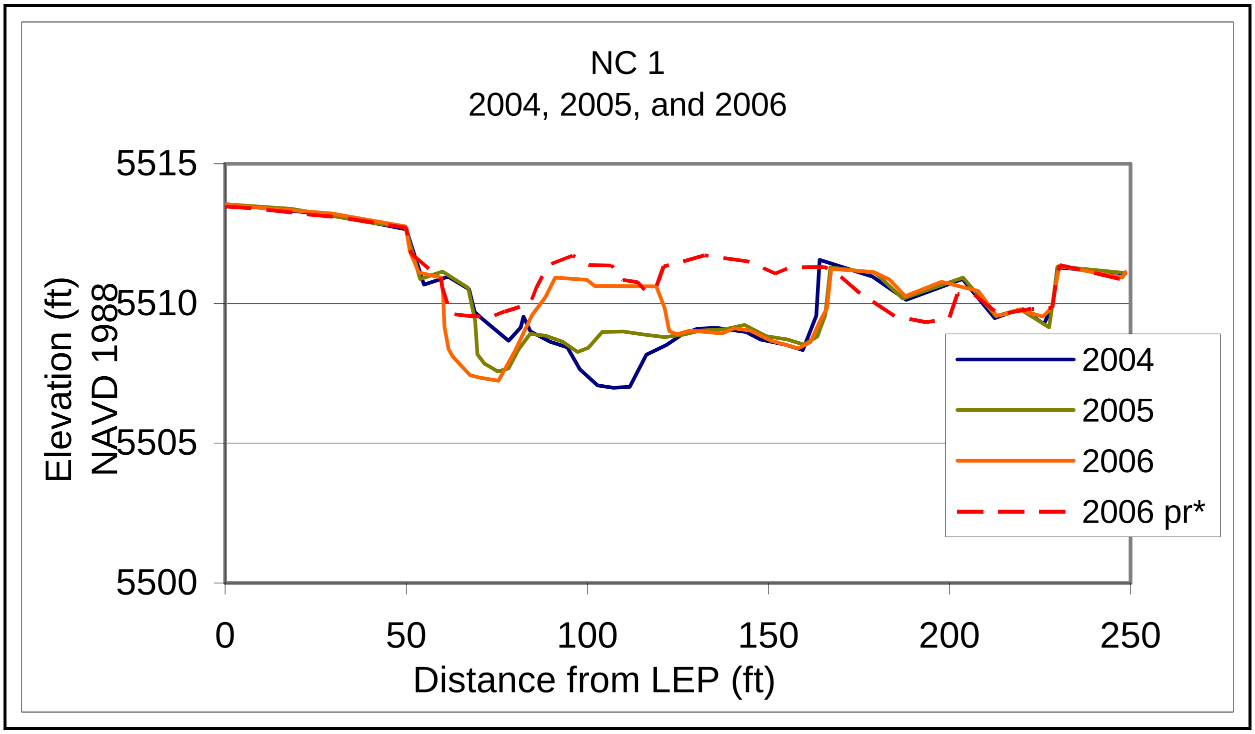


Figure 2.10a. Never-Channelized (NC) site 1 shows noticeable change from 2004 to 2006 post-runoff.

2004 130 cfs

2005 180 cfs

2006 314 cfs

2006 post-runoff 147 cfs

Figure 2.10b. Photos of transect NC1 between 2004 and post-runoff 2006.

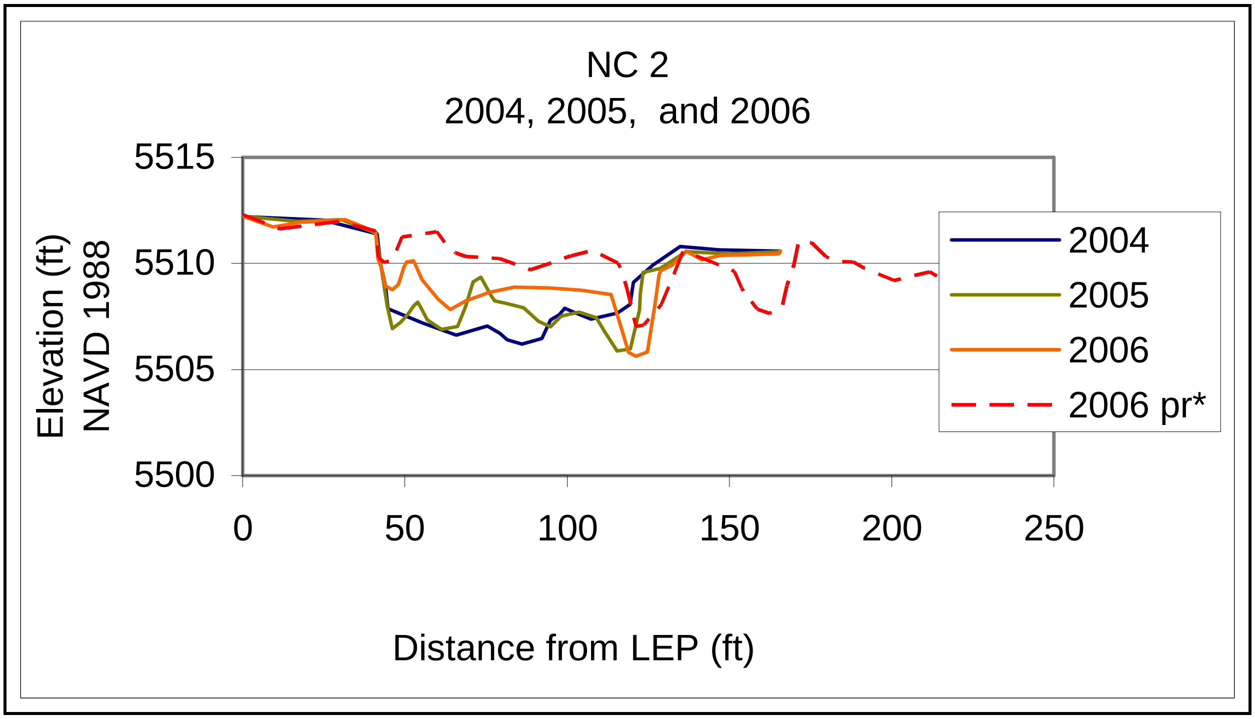
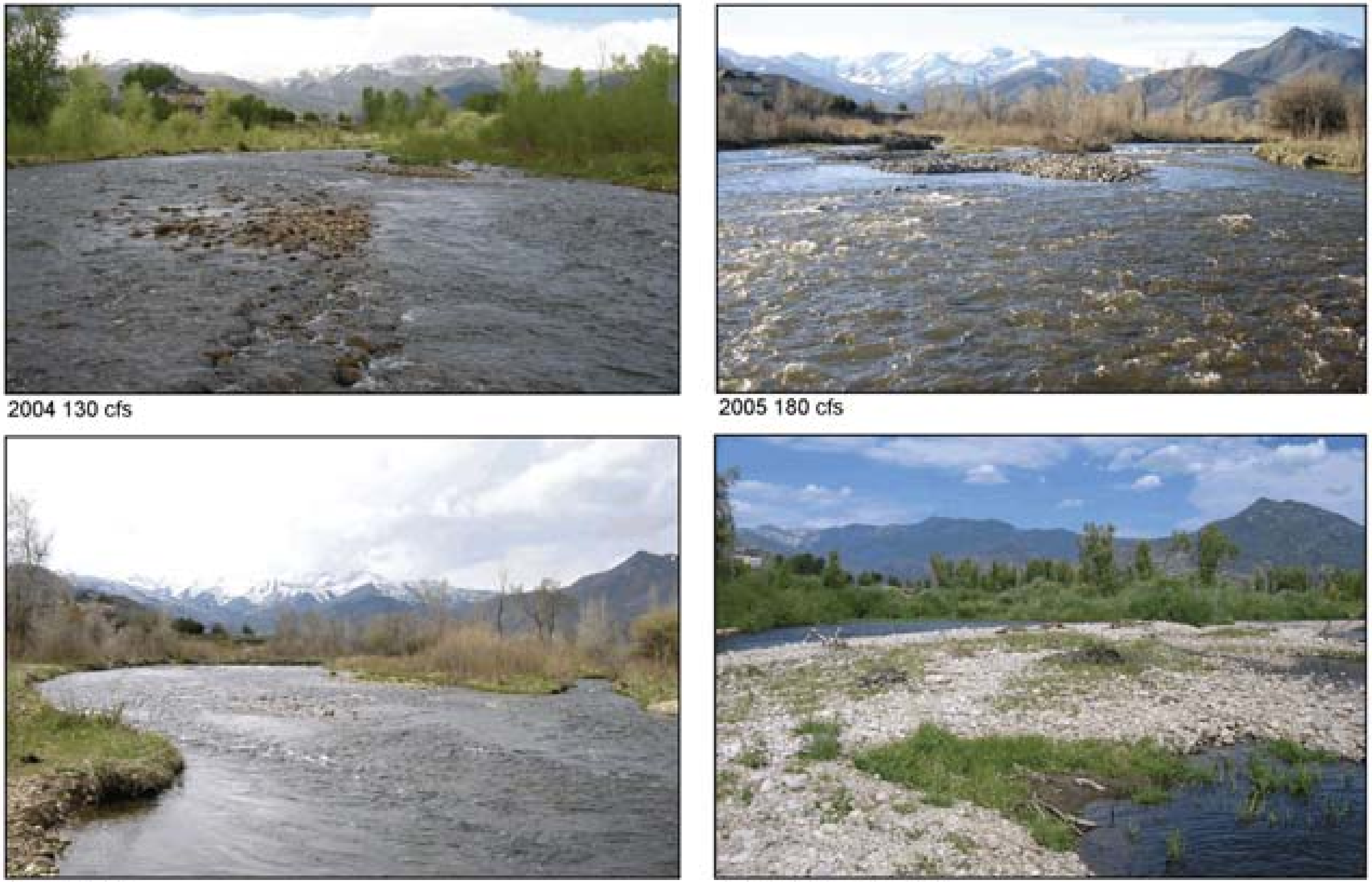


Figure 2.11a. **Transect NC2 shows a lot of geomorphic activity in the upper part of the Never-Channelized (NC) site over the monitoring period.**



2004 130 cfs

2005 180 cfs

2006 314 cfs

2006 post-runoff 147 cfs

Figure 2.11b. Photos of transect NC 2 between 2004 and post-runoff 2006.

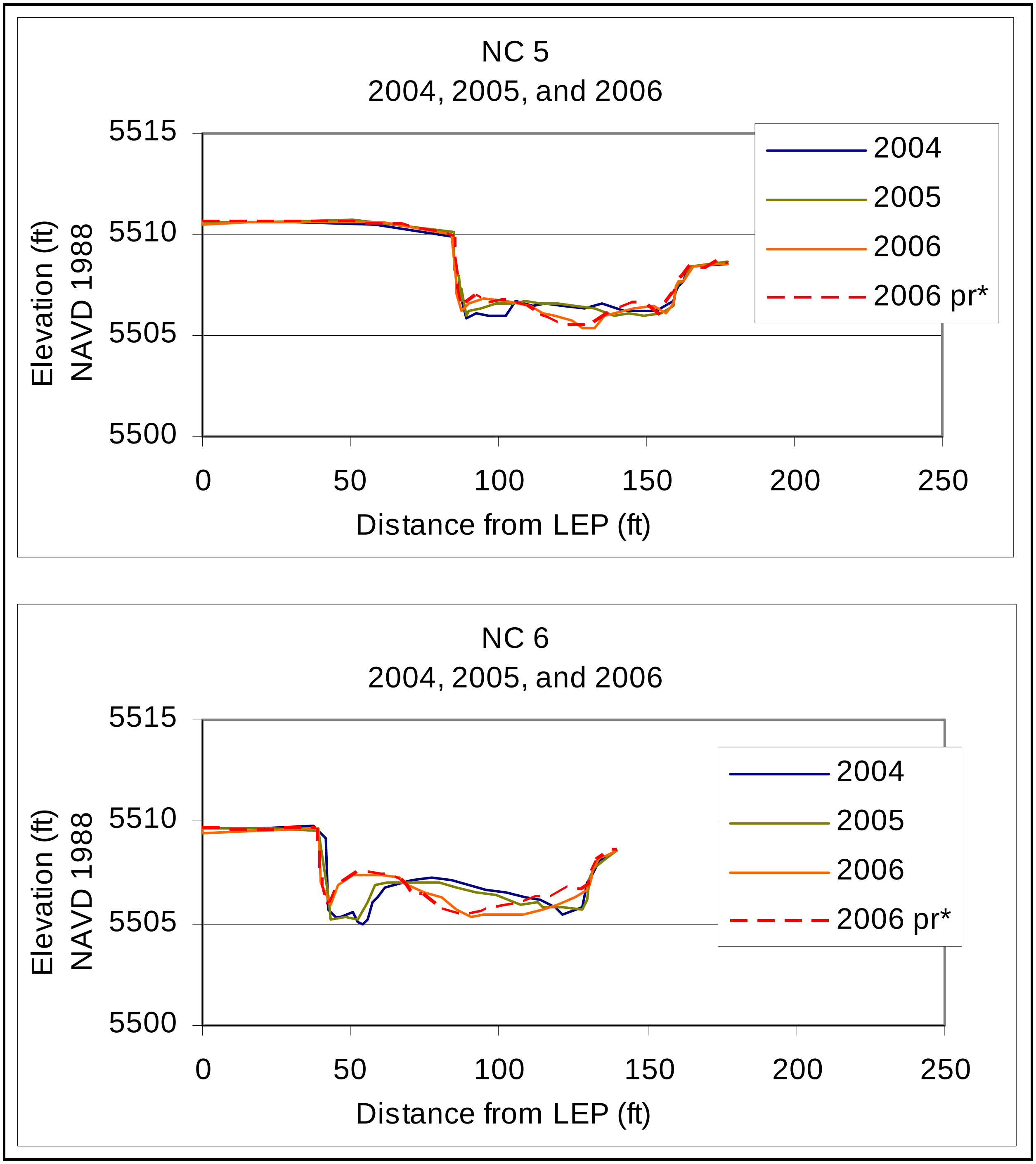
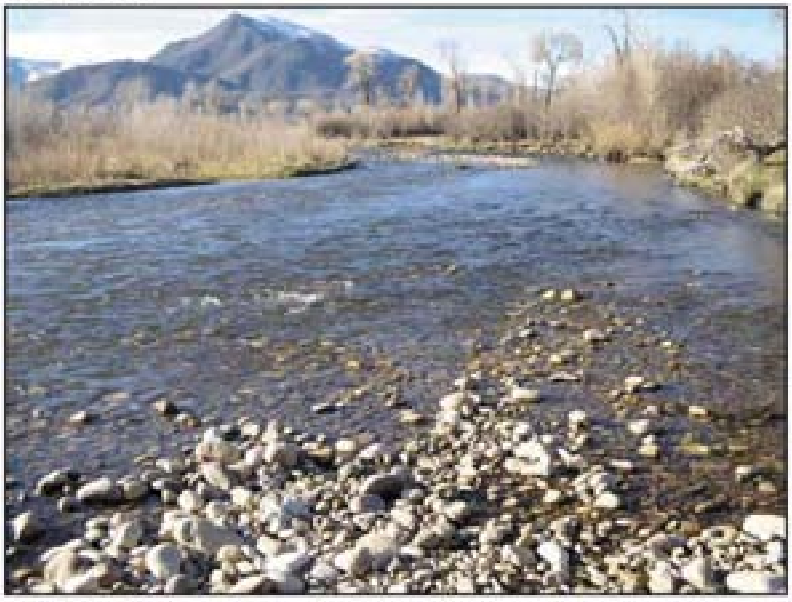


Figure 2.12a. **The NC transects 5 and 6 show some activity each year, but are less dynamic than the upper three cross sections. The major changes occurred between 2005 and 2006. Runoff in 2005 was exceptionally high.**

2004 130 cfs

2005 180 cfs



2006 314 cfs

2006 post-runoff 147 cfs

Figure 2.12b. Photos of transect NC 6 between 2004 and 2006 post-runoff.

Relative to transects 4, 5, and 6, the first three transects in the upper part of the NC site have experienced more change. A change in slope between transects 3 and 4, as indicated by the longitudinal profile (Figure 2.13) might be one reason for this difference. Under high flows, the steeper sloped upper section of the site would transport larger material downstream. Bedload sampling shows large material moving through Midway Bridge, directly downstream from the NC site. However, under low-flow conditions, these large particles will not be transported and probably become deposited as the slope change creates a change in flow velocity, reducing the particle size the stream can transport. Moreover, transects 5 and 6 have been the most stable cross sections at the site, with change occurring between the 2005 and 2006 surveys. The stream bed slope between these two cross section is fairly flat and about 200 feet downstream from the point where the bed slope changes to a slight incline.

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.

Flows and construction greatly altered the CA site transects between 2004 and 2005 (Appendix 2.2a). The channel at transect 1downcut, resulting in a lower bed elevation in 2005. Transect 2 had no notable changes except some areas of deposition on the right side of the channel. Transect 3 shows aggradation of the bed (Figures 2.14a-2.14b). The thalweg became shallower and moved farther to the left of the channel. Deposition reduced the depth of the thalweg by 2 feet. Transect 4 shows some widening caused by bank erosion on the left side of the channel (Appendix 2.2a). Transect 5 (Figures 2.15a-2.15b) has downcut about 3 feet in 2005 compared to 2004. The 2004 survey shows a fairly uniform, flat channel shape while the 2005 survey shows a more natural shape, with the thalweg forming in the mid-left side of the channel. Some erosion occurred on the left bank. Transect 6 (Figure 2.16a-2.16b) in 2005 was extremely different compared with 2004 because construction altered the original cross section. A side channel was constructed where the original LEP 6 was established and the original LEP was never found. The transect was extended and a new LEP 6 was established approximately 50 feet from the original endpoint. Flows also altered transect 6. The channel shifted to the right bank, effectively cutting away and steepening the right bank. Deposition occurred on the left side of the channel.

Compared to the 2005 data, the 2006 and 2006 post-runoff data show moderate channel adjustment throughout the site. Transect 1 shows little change from 2005, with small amounts of erosion on the right bank (Appendix 2.2a). Transect 2 shows gradual bank erosion on the left bank between 2004 and 2006 post runoff (Appendix 2.2a). Transect 3 displays the expected results of dynamic equilibrium. With each high-flow cycle the right side of the channel is storing sediment and creating a higher surface, while the left bank is eroding (Figures 2.14a-2.14b)). Transect 4 shows change from 2005 in the form of channel widening at the left bank in the 2006 and 2006 post runoff data (Appendix 2.2a). Transect 5 (Figures 2.15a-2.15b) showed relatively little change between 2005 and 2006 but did become wider and deeper toward the right bank side of the channel between the 2006 and 2006 post-runoff surveys.

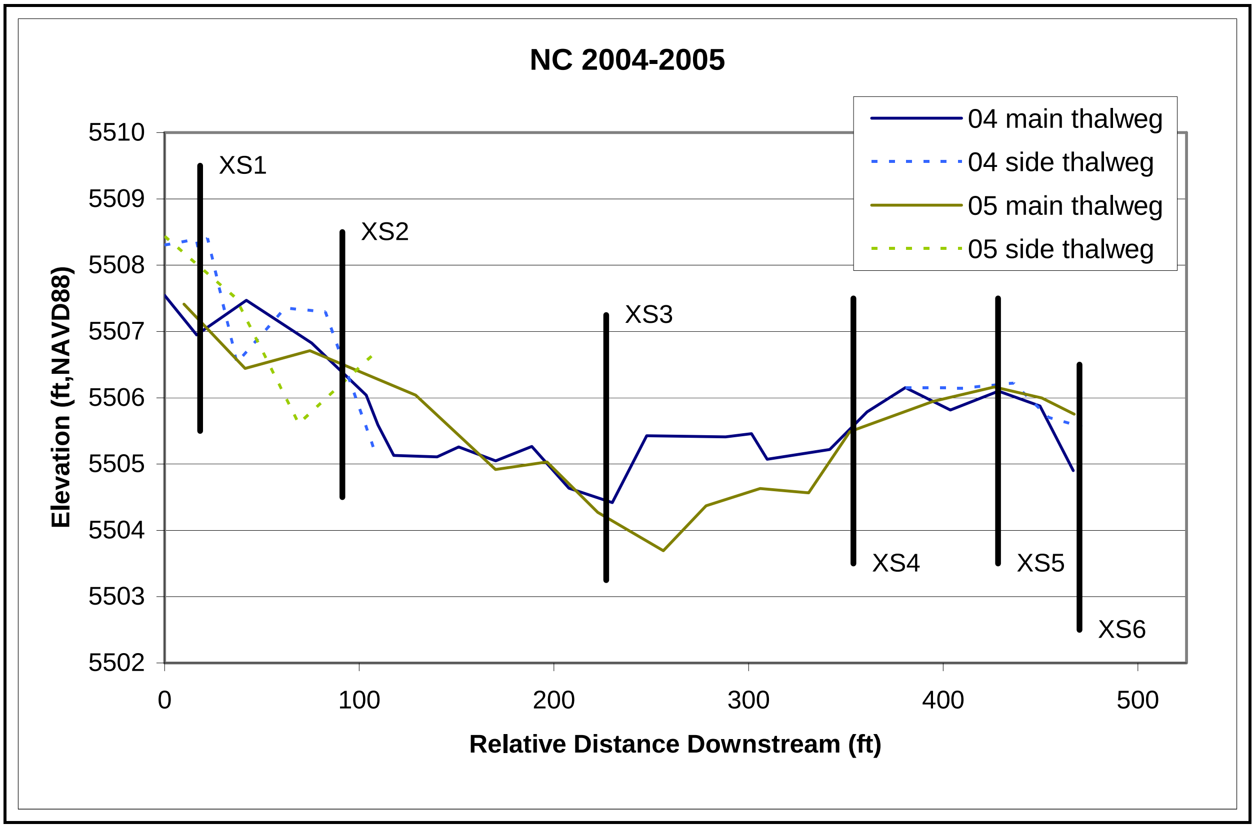


Figure 2.13. **Plot of 2004 and 2005 longitudinal profiles at the Never-Channelized (NC) site.**

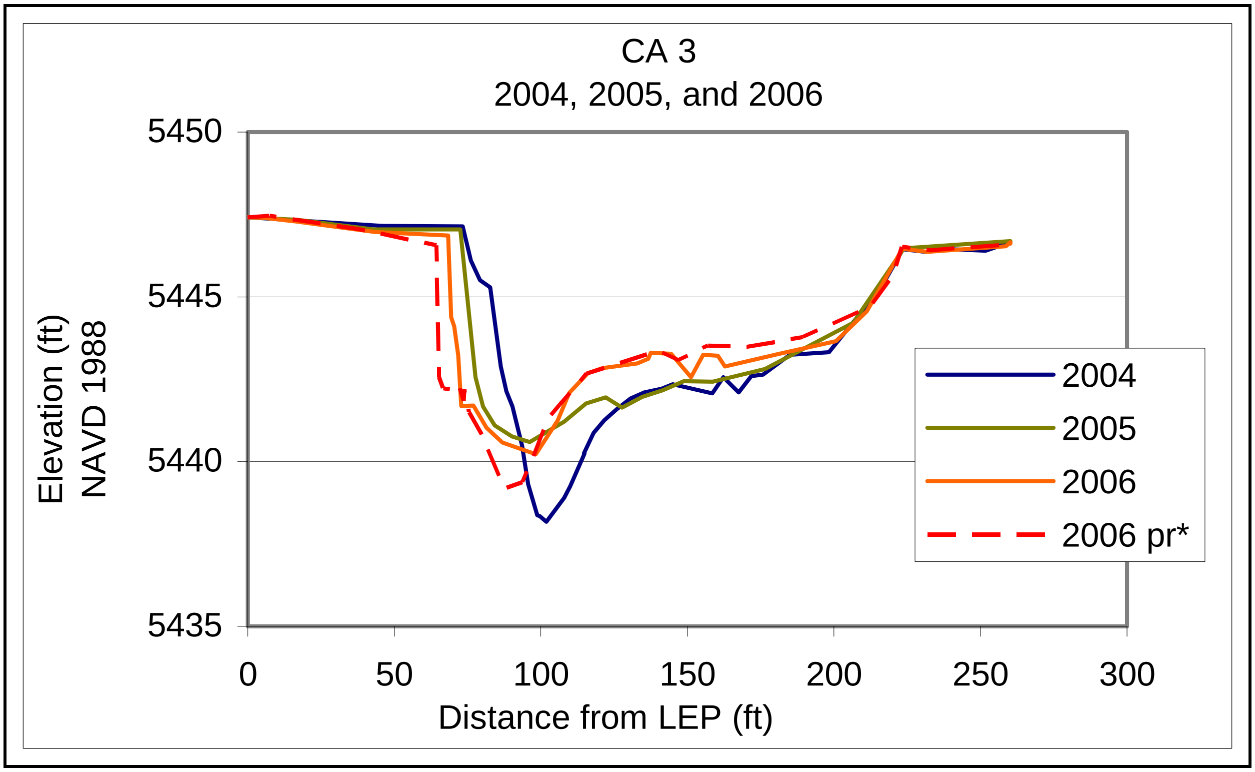
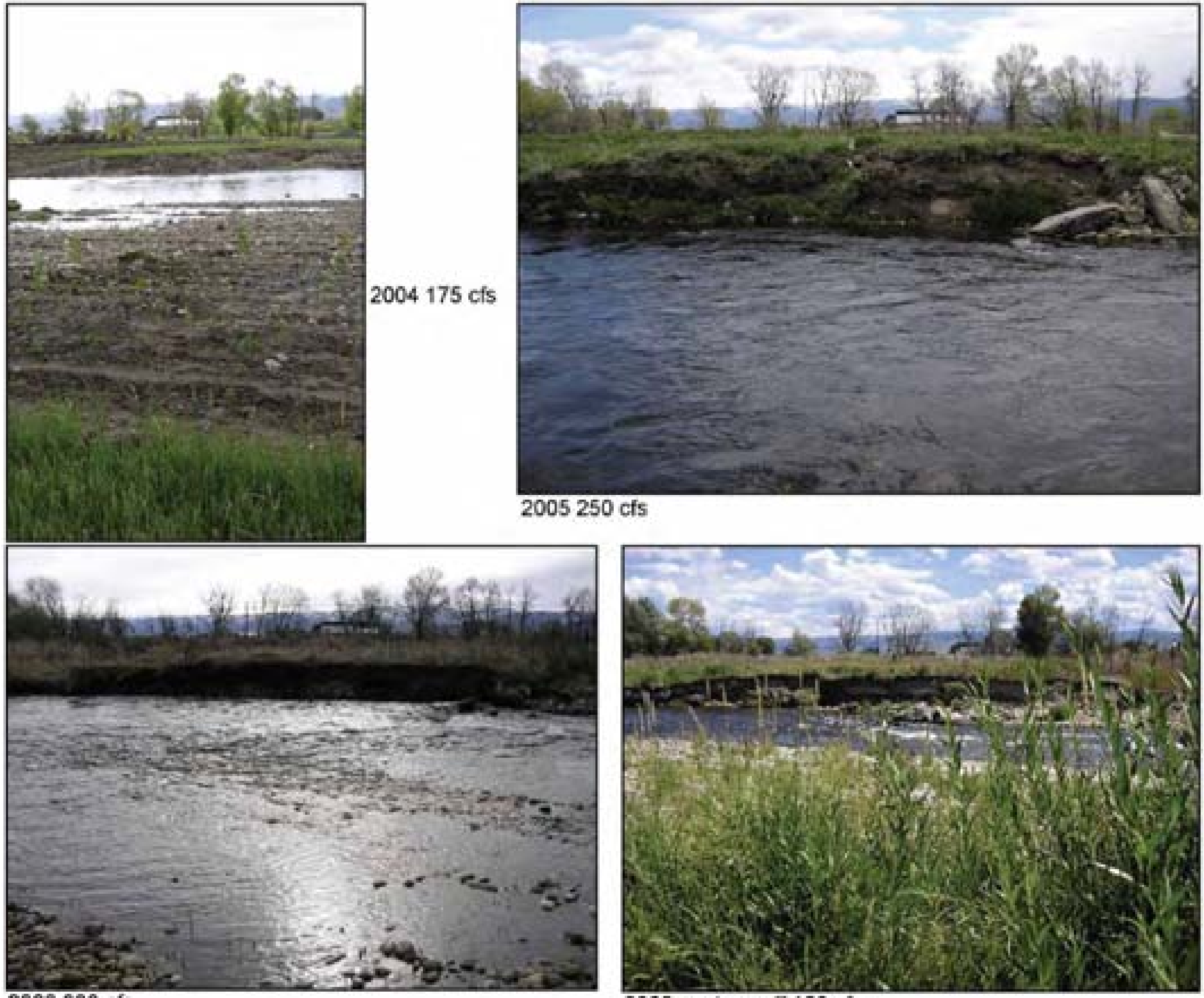


Figure 2.14a. **The Charleston (CA) CA 3 transect shows some patterns indicative of dynamic equilibrium.**



2004 175 cfs

2005 250 cfs

2006 333 cfs

2006 post-runoff 158 cfs

Figure 2.14b. Photos of transect CA 3 between 2004 and post-runoff 2006.

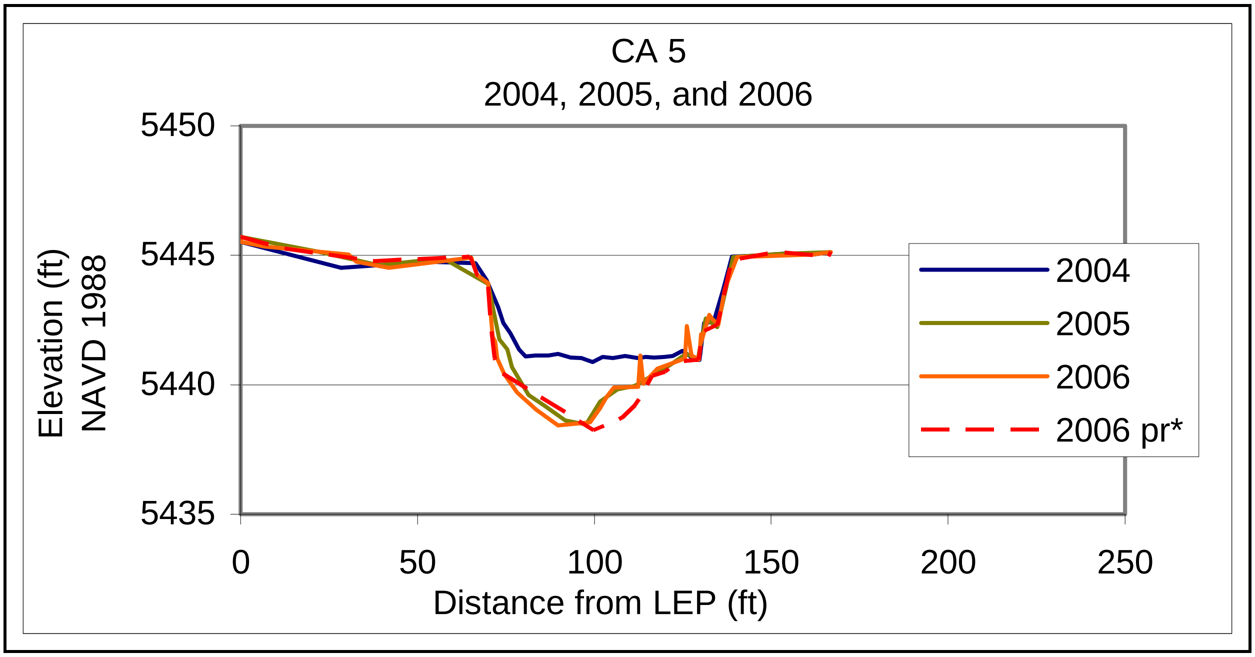


Figure 2.15a. Transect CA5 shows degradation in the first post-construction year, with considerably less downcutting in following years.

2004 175 cfs

2005 250 cfs

2006 333 cfs

2006 post-runoff 158 cfs

Figure 2.15b. Photos of transect CA 5 between 2004 and post-runoff 2006.

At first glance transect CA 6 seems to have changed considerably (Figures 2.16a-2.16b). However, the side channel was constructed between the 2004 and 2005 surveys. The patterns are similar to other transects in that most of the change (other than the addition of a side channel) occurred between 2004 and 2005. Since 2005 there has also been incrementally small (but continuous) erosion on the right bank and bar development on the left side of the channel, essentially shifting the thalweg from the left to right through time. The right bank was severely eroded during the 2004 high flows.

2.3.3 Longitudinal Profiles

As with the cross section plots, the 2004 plots provide a baseline data set. The 2005, 2006, and post-runoff 2006 survey data show short-term temporal change in streambed elevations over an entire meander sequence. Raw data collected for the profile plots are provided in Appendix 2.3.

The longitudinal profile plots (Figures 2.17a-2.17d), like transects, illustrate the diversity of in-channel habitat within the monitoring sites. The profiles for BJ, NC, and CA are similar in that at each site 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. 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.

The BJ and RR sites have more stable longitudinal profiles (Figures 2.17a-2.17b). The BJ data indicate slight (0.5 feet) downcutting; however, the coarse boulder-cobble bed material is difficult to survey to within 0.5 feet. Rod placement may be next to or on top of a neighboring particle, and a more substantial difference between surveys is necessary to definitely show degradation at the BJ site (see Figure 2.17a).

The RR site’s longitudinal profile (Figure 2.17b) shows some cutting and filling along the entire stream section in the monitoring site, but no major changes in channel slope. Site RR contains secondary, side thalweg profile plots for the side channel as well as the main channel thalweg plot. The side channel longitudinal profile indicated more change and adjustment over the four monitoring periods (Figure 2.17b).

The NC site longitudinal profile (Figure 2.17c) shows change in the upper part of the monitoring site, with the lower part of the site past 300 feet remaining similar from 2004 through post-runoff 2006. Scouring occurred throughout the site, but primarily between 250 feet and 350 feet from the top of the monitoring site in 2005. This becomes an area of deposition in 2006 and post-runoff 2006. Slope over the reach seems to increase slightly from 2004 to post-runoff 2006.

Between 2004 and 2005, the longitudinal profile for CA (Figure 2.17d) changed the most compared to the other monitoring sites. The longitudinal profile shows changes in location of riffles and pools, as shown in the cross section plots, and has an increased channel slope. Between 2004 and 2005, a deep pool filled about 350 feet downstream from the top of the monitoring site, while the lower part of the site became shallower compared to the previous year. The channel degraded somewhat in the lower portion of CA between 2004 (immediately after construction) and 2005 (a year after

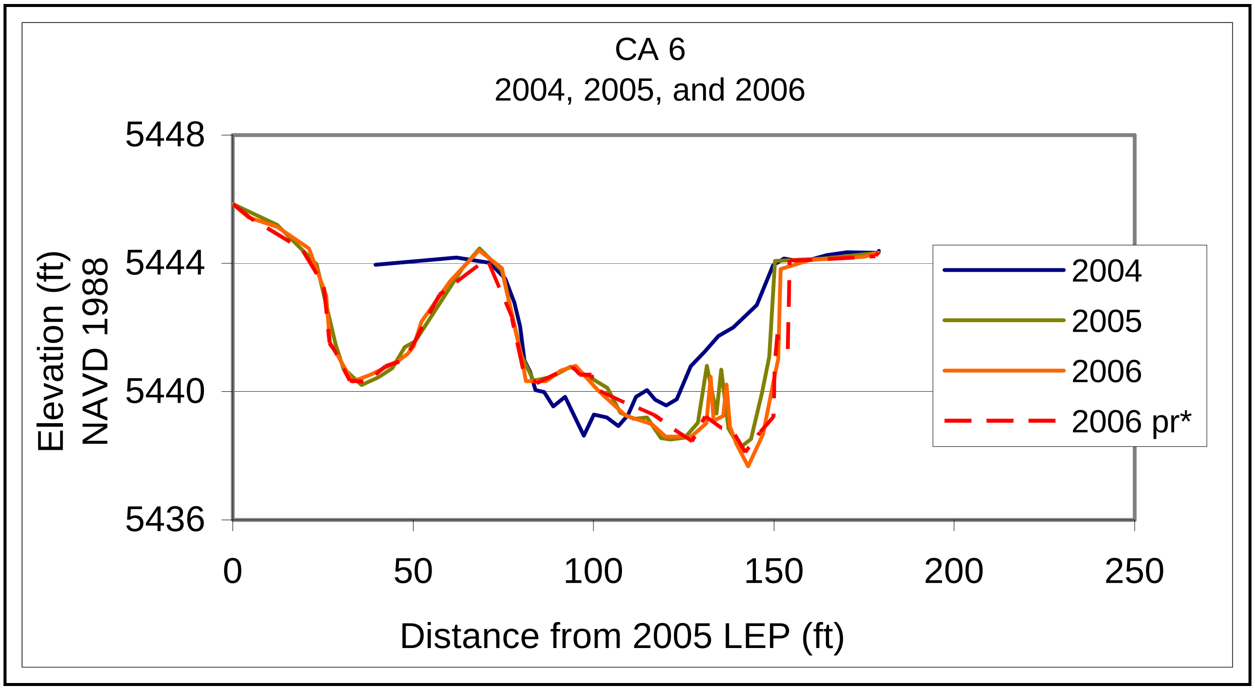


Figure 2.16a. The side channel at the cross section CA6 was added in 2005. The main channel is eroding the right bank and moving west.

2004 175 cfs

2005 250 cfs

2006 333 cfs

2006 post-runoff 158 cfs

Figure 2.16b. Photos of transect CA 6 between 2004 and 2006 post-runoff.

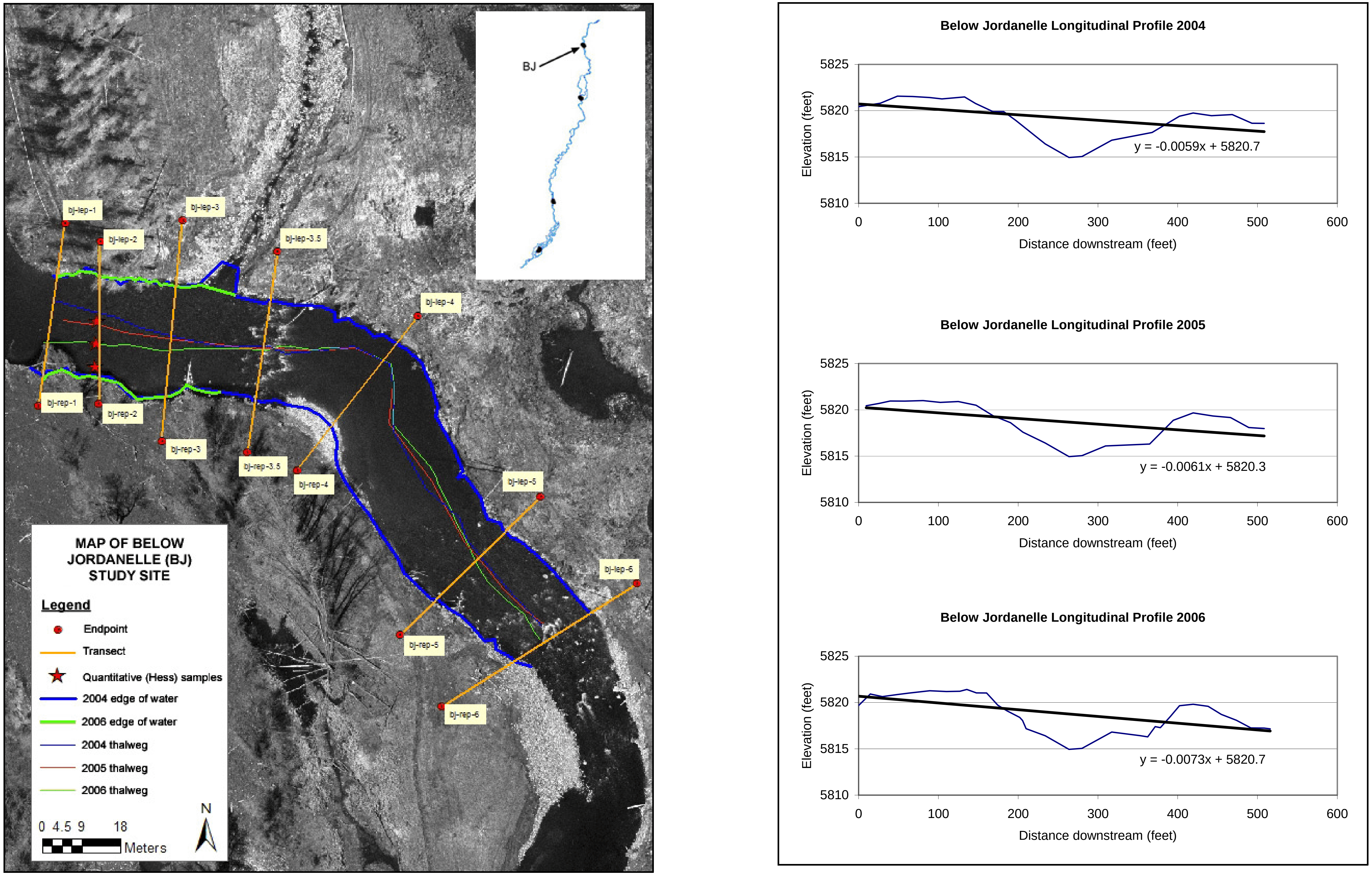


Figure 2.17a. Longitudinal profile and thalweg location at the Below Jordanelle (BJ) site between 2004 and 2006. Aerial photo from 2004.

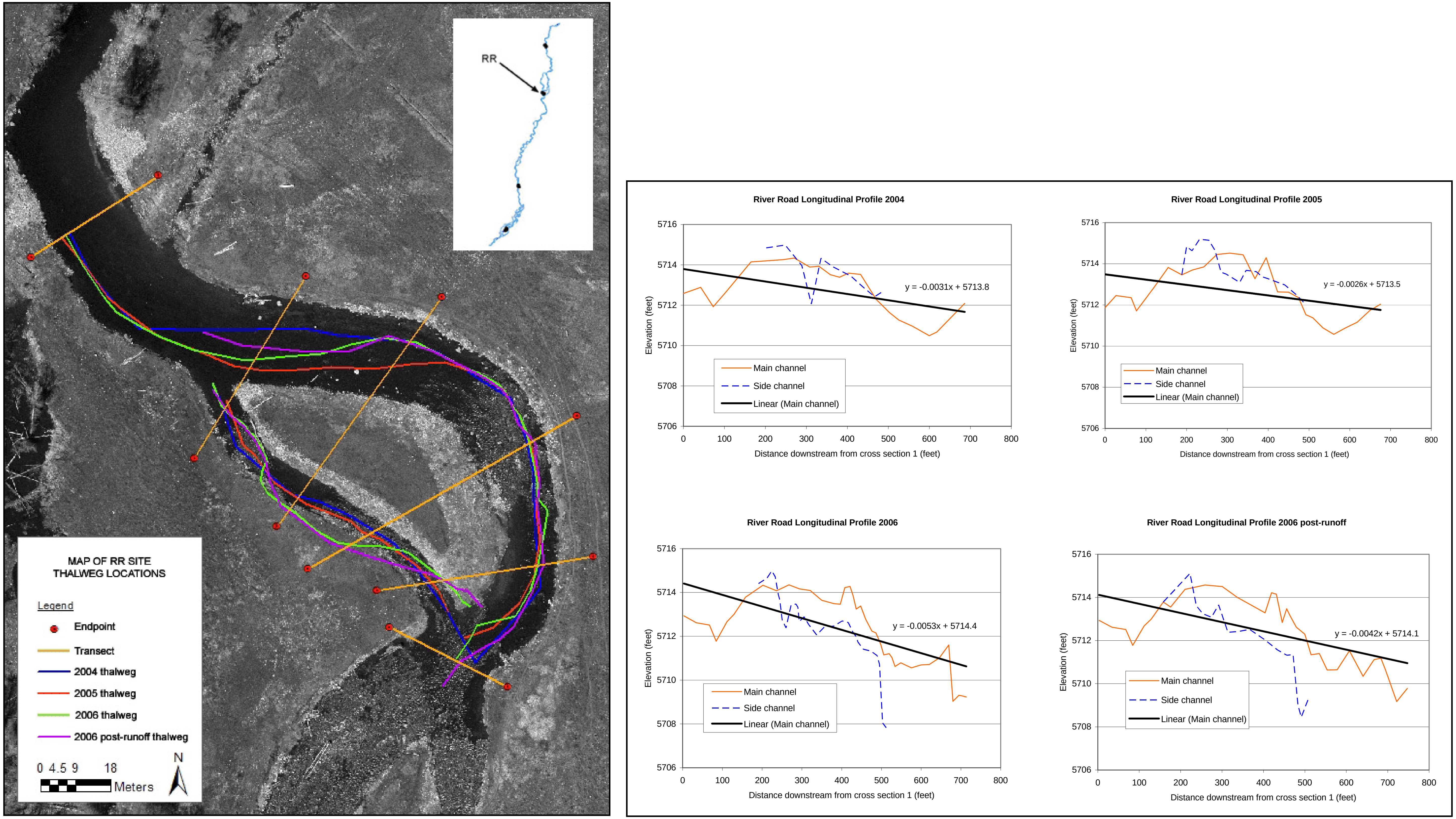


Figure 2.17b. **Longitudinal profile and thalweg location at the River Road (RR) site between 2004 and 2006 post-runoff. Aerial photo from 2004.**

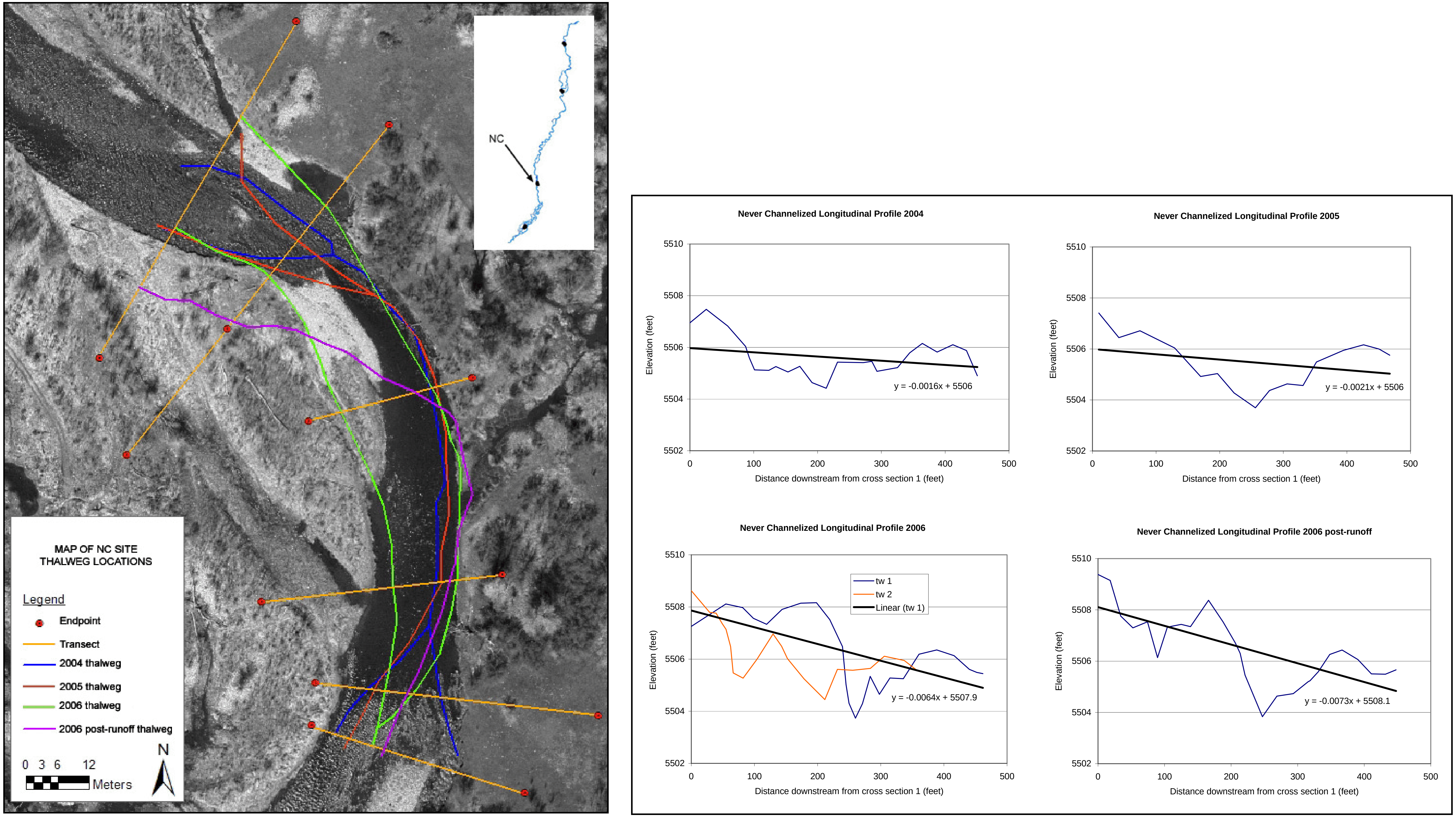
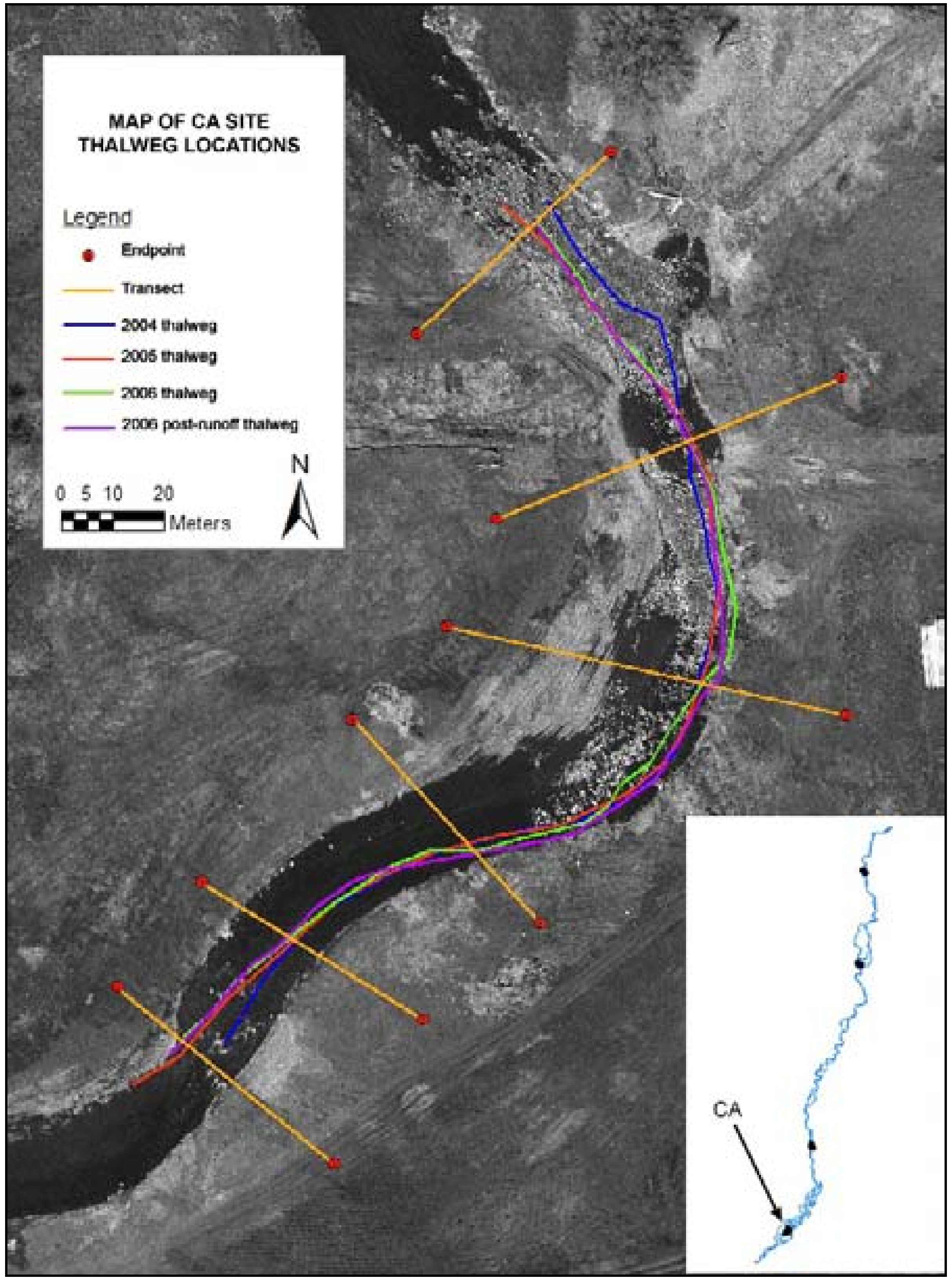


Figure 2.17c. Longitudinal profile and thalweg location at the Never-Channelized (NC) site between 2004 and 2006 post-runoff. Aerial photo from 2004.



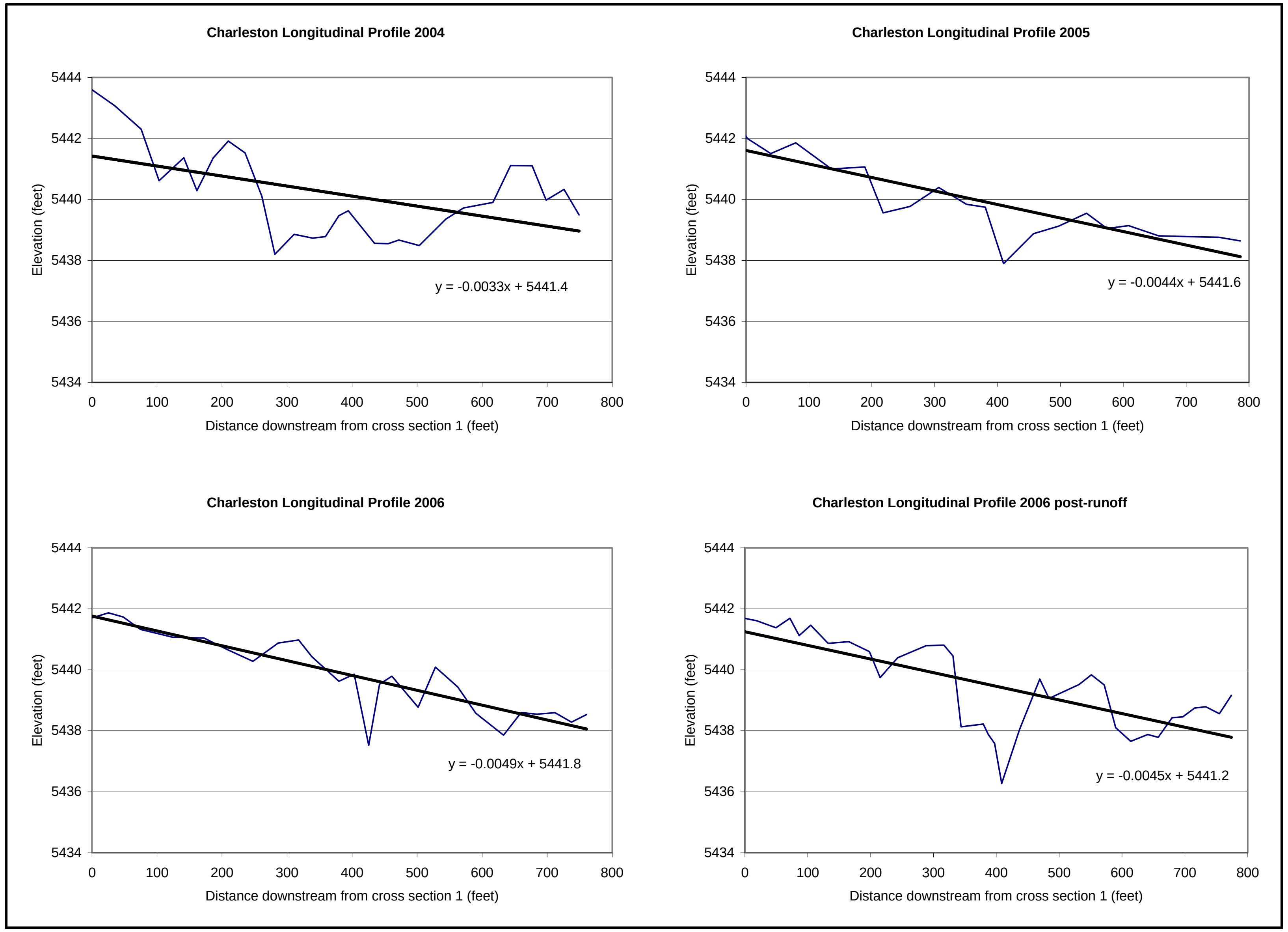


Figure 2.17d. Longitudinal profile and thalweg location at the Charleston (CA) site between 2004 and 2006 post-runoff. Aerial photo from 2004.

construction). It is assumed that this change is well within the anticipated initial adjustment to a relatively high peak flow event following major channel construction. However, between 2005 and 2006, the longitudinal profiles seem to have stabilized somewhat, with deepening at the lower section of the site beyond 600 feet from transect 1. It also appears that some filling occurred between 2005 and 2006. Between 2006 and post-runoff 2006, the only significant change was a 1-foot deepening of the pool at 400 feet from transect 1 (Figure 2.17d).

2.3.4 Over-bank Flooding Analysis

Results of the 2006 low-flow water surface elevation surveys used for HEC-RAS and WinXSPRO model calibration are provided in Table 2.2.

Table 2.2. Dates, flows, and surveyed water-surface elevations used in model calibration.

SITE	WATER SURFACE ELEVATION (FEET)	
BJ Date:	April 13-14, 2006	
BJ Flow:	315 cubic feet per second	
BJ1	5823.27	
BJ2	5823.18	
BJ3	5823.02	
BJ3.5	5821.80	
BJ4	5821.90	
BJ5	5821.36	
BJ6	5819.88	
RR Date:	August 21-22, 2006	April 13, 2006
RR Flow:	145 cubic feet per second	315 cubic feet per second
RR1	n/a	5716.40
RR2	n/a	5716.33
RR3	5715.83	n/a
RR4	5714.50	n/a
RR5	5713.10	n/a
RR6	5712.23	n/a
NC Date:	August 22-23, 2006	
NC Flow:	147 cubic feet per second	
NC1	n/a	
NC2	n/a	
NC3	n/a	
NC4	n/a	
NC5	5507.10	
NC6	5506.90	
CA Date:	august 21, 2006	
CA Flow:	158 cfs	
CA1	5443.92	
CA2	5442.95	
CA3	5441.97	
CA4	5441.26	
CA5	5440.97	
CA6	5440.67	

2.3.4.1. Below Jordanelle Dam (BJ) Site

When a low-flow (315 cfs) roughness (Manning's "N") value of 0.08 is used, the water surface elevation modeled by HEC-RAS is in close agreement with surveyed values at the BJ site (Figure 2.18, Table 2.2). As discussed in the methods section above, the high-flow roughness (Manning's "N") value (0.06) that was calibrated to the water surfaces surveyed during high-flow conditions in 2005 was also used to model high flows with the 2006 cross-section data. High-flow model results using the 2006 cross section geometry are similar to the high-flow results from 2005 (Figure 2.18), indicating that no significant changes in channel capacity have occurred at the BJ site.

Modeling results indicate that between 900 and 1,300 cfs, flows begin to overtop the right bank along the inside of the bend beginning just upstream of transect BJ3.5 (Appendix 2.4). Between 1,300 and 1,650 cfs, additional overtopping occurs farther upstream and opposite transect BJ4 along the right bank (see Appendix 2.4). Flows also slightly overtop the left bank at transect BJ2 at 1,650 cfs (see Appendix 2.4). These model results provide good agreement with observations made during the June 2005 water surface elevation surveys, and further confirm that no significant changes in channel capacity have occurred at BJ.

2.3.4.2. River Road (RR) Site

Results of the WinXSPRO analysis at the RR site indicate aggradation in the upper portion of the study site and degradation in the lower portion of the study site (Table 2.3 and Appendix 2.5). Changes in channel capacity and modeled water surface elevations at different flows between 2005 and 2006 varied among the different transects. In 2005 the 1,650 cfs water level filled the channel at transect RR1 but did not quite overtop the banks (Appendix 2.5). The streambed aggradation that occurred during the 2005 and 2006 floods increased the modeled water surface elevations during all flows at RR1, and model results indicate that overtopping of the banks would now occur between 960 and 1,650 cfs (Table 2.3 and Appendix 2.5). Changes in modeled water surface elevations between 2005 and 2006 at transects RR2 and RR2 are variable depending on flow (Table 2.3): they are mostly slightly higher during higher flows. Results at these transects are difficult to interpret because they span an island and side channel, and the one-dimensional WinXSPRO model can not account for the different water elevations in the main channel versus the side channel. The water surface elevation was higher at all flows in 2005 than 2006 at RR4, RR5, and RR6. Results at transect RR6, where the channel is single-threaded, can be interpreted with more validity. At this transect, the streambed deepened and increased in area between 2005 and 2006, and modeled water surface elevations for the 900 cfs and 1,820 cfs water levels dropped by 0.5 and 0.8 foot, respectively (Table 2.3 and Appendix 2.5). This result suggests that the downstream portion of the RR site is becoming less susceptible to overbank flows whereas the opposite is occurring in the upstream portion of this study site.

It is important to keep in mind that the WinXSPRO program models cross sections independently, without taking into account upstream or downstream controls on grade and water level. Actual field measurements of inundation at high flows would be a better way to accurately assess temporal changes in channel capacity on the Provo River, particularly in complex, multi-threaded channel reaches.

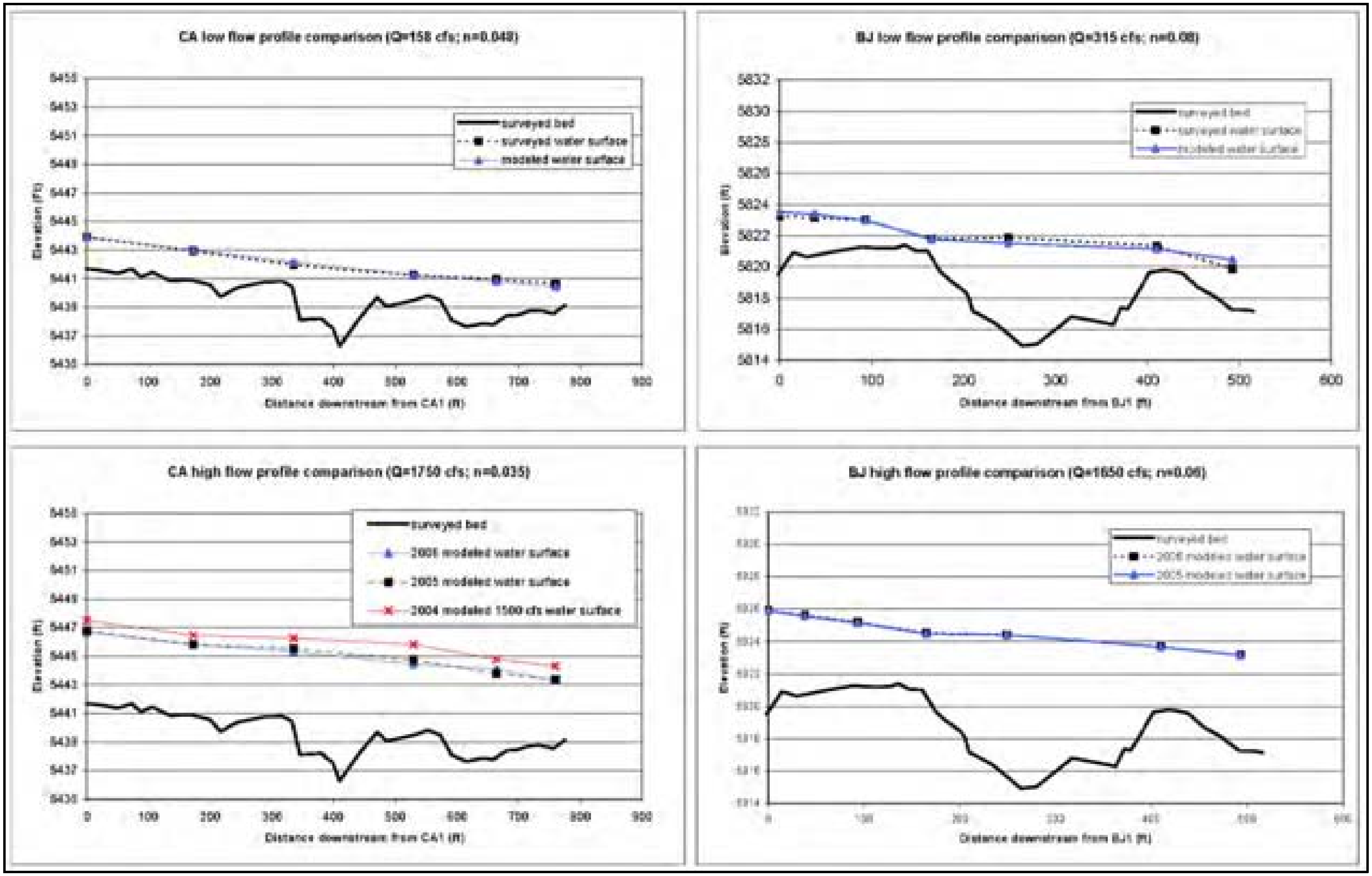


Figure 2.18. Modeled (HEC-RAS) and Surveyed Water Surface Profiles.

Table 2.3. The 2006 WinXSPRO output for low, medium, and high flows at the River Road (RR) site.

CROSS SECTION	STAGE (FEET)	AREA (FEET)	TOP WIDTH (FEET)	HYDRAULIC RADIUS (FEET)	SLOPE (FEET/FOOT)	MANNING'S "N"	AVERAGE VELOCITY (FEET/SECOND)	Q (CUBIC FEET PER SECOND)	2006 WATER SURFACE ELEVATION (FEET)	2005 WATER SURFACE ELEVATION (FEET)
RR1	3.82	155.48	77.4	1.98	0.007	0.095	2.07	322	5716.40	5716.23
RR1	5.74	317.72	91.25	3.42	0.0064	0.09	3.01	955	5718.32	5717.69
RR1	6.84	469.83	194.51	2.39	0.0067	0.062	3.52	1654	5719.42	5718.6
RR2	2.06	104.02	103.19	0.99	0.007	0.039	3.18	331	5715.76	5716.1
RR2	4.04	388.28	205.9	1.86	0.0064	0.073	2.47	959	5717.74	5717.47
RR2	4.62	516.75	237.03	2.16	0.0067	0.062	3.28	1696	5718.32	5718.29
RR3	5.58	464.64	231.4	1.96	0.0064	0.094	1.99	928	5719.35	5717.28
RR3	6.14	613.17	305.27	1.97	0.0067	0.071	2.7	1656	5719.91	5718.21
RR4	2.6	136.23	101.12	1.32	0.007	0.14	1.07	146	5714.49	5714.57
RR4	3.68	262.37	132.54	1.94	0.0062	0.051	3.58	939	5715.57	5716.16
RR4	4.6	411.13	208.16	1.94	0.0067	0.048	3.96	1627	5716.49	5717.24
RR5	2.6	105.96	87.2	1.19	0.007	0.1	1.4	148	5713.09	5713.72
RR5	4.44	293.41	126.18	2.24	0.0063	0.064	3.16	928	5714.93	5714.95
RR5	5.02	369.16	132.89	2.67	0.0066	0.053	4.39	1621	5715.51	5716.04
RR6	3.12	95.28	53.4	1.77	0.007	0.121	1.51	144	5712.24	5713.11
RR6	4.08	149.88	60.44	2.45	0.0064	0.036	6.01	901	5713.2	5713.74
RR6	4.16	154.75	61.16	2.5	0.0066	0.019	11.72	1814	5713.28	5714.05

2.3.4.3. Never-Channelized (NC) Site

Results of the WinXSPRO analysis at the NC site are provided in Table 2.4. Transect plots of modeled water surface elevations are included in Appendix 2.5.

Table 2.4. The 2006 WinXSPRO output for low, medium, and high flows at the never-channelized (NC) site.

CROSS SECTION	STAGE (FEET)	AREA (FEET)	TOP WIDTH (FEET)	HYDRAULIC RADIUS (FEET)	SLOPE (FEET/FOOT)	MANNING'S "N"	AVERAGE VELOCITY (FEET/SECOND)	Q (CUBIC FEET PER SECOND)	2006 WATER SURFACE ELEVATION (FEET)	2005 WATER SURFACE ELEVATION (FEET)
NC5	1.6	62.2	73.13	0.85	0.0088	0.052	2.4	149.57	5507.09	5507.28
NC5	3.34	203.31	106.12	1.88	0.0058	0.04	4.33	879.64	5508.83	5508.61
NC5	4.18	310.19	148.37	2.06	0.006	0.034	5.49	1702.62	5509.67	5509.7
NC6	1.5	55.26	68.33	0.8	0.0088	0.045	2.68	148.15	5506.89	5506.37
NC6	2.62	148.96	93.03	1.57	0.0056	0.025	6.04	899.06	5508.01	5508.48
NC6	4.6	445.55	339	1.3	0.006	0.037	3.72	1659.22	5509.99	5509.72

In the 2006 water year the NC site changed drastically at cross sections NC1–NC4 (Appendix 2.2a). Large amounts of bedload filled and altered the channel enough that comparisons of WinXSPRO modeling results between previous water years and the 2006 water year are confounded for the upper four cross sections. Transects NC5 and NC6 remained more stationary, and results at these sites can be compared validly.

At NC5 and NC6, some changes did occur in streambed shape between 2005 and 2006; however, changes in modeled high flow water surface elevations were fairly minor (Table 2.4, Appendix 2.5). At both transects, the flows are out-of-bank on river right at the 1,650 cfs discharge level. In 2005 the 1,650 cfs water level was very close to the top of the left bank at NC6; in 2006, the model results show that the left bank is just overtopped at this discharge (see Appendix 2.5). Similarly, in 2005 the 880 cfs water level was very close to the top of the right bank at NC5; in 2006 the model results show that the right bank is just overtopped at this discharge (Appendix 2.5). These results suggest a tendency toward slightly reduced channel capacity. However, the modeled 900 cfs water level at NC6 is somewhat lower in 2006 than in 2005, suggesting an opposite trend. These inconsistent results illustrate the limitations of using a one-dimensional, at-a-station model such as WinXSPRO to evaluate trends in channel capacity. Actual field measurements of inundation at high flows would be a better way to accurately assess temporal changes in channel capacity on the Provo River, particularly in complex, multi-threaded channel reaches.

2.3.4.4. Charleston (CA) Site

The 2006 post-runoff HEC-RAS model results provide good agreement with surveyed water surface elevations when a Manning's "N" of 0.048 is used to model low flows (Table 2.3 2.2, Figure 2.18). In 2005 a low-flow"N" of 0.040 provided the best agreement with measured elevations (Olsen 2006), which suggests that roughness may have increased between 2005 and 2006. However, a higher flow (232 cfs) was used for the 2005 low flow modeling than in 2006 (158 cfs), which may account for some of the difference in roughness, because roughness typically decreases with increased discharge. However, streambed profile variability did increase substantially between the 2005 and 2006 post-runoff surveys (see section 2.3.3), which would tend to increase site roughness. Substrate also became slightly coarser at the CA site between 2005 and 2006 post-runoff (see section 3). Overall, however, changes between 2005 and 2006 were much less substantial than those observed between 2004 and 2005, when the site adjusted to the first flood following channel construction (Olsen 2006).

It appears that channel capacity at CA remained fairly stable between 2005 and post-runoff 2006 (see Figure 2.18). High-flow model results using the 2006 cross-section geometry and an "N" value of 0.035 (same "N" used in 2005 high flow modeling) generated water surface elevations about 0.1 foot lower than the high-flow water surface elevations modeled using the 2005 geometry (Figure 2.18). This change is minimal relative to the large increase in capacity that occurred at the site between 2004 and 2005 (Olsen 2006), and suggests that the channel size is stabilizing.

However, in its current condition, the CA monitoring site channel capacity remains too large to be susceptible to over-bank flooding even at the highest modeled discharge of 1,750 cfs (see Appendix 2.4). Flows remain well within the streambanks at this discharge, and substantially higher discharge would be needed to inundate the floodplain at this site. This is in contrast to the upstream monitoring sites (BJ, RR, and NC), where flows begin to overtop some of the banks at flows between 690 and 900 cfs, and substantial floodplain inundation occurs at the 1,650–1,750 cfs discharge level. Because the site is not susceptible to inundation, floodplain processes such as riparian vegetation recruitment and nutrient cycling may be limited at the CA site. However, during 2006 fieldwork, numerous new willow and cottonwood saplings were observed growing on the point bar near transect 3. As this vegetation grows, the site may narrow and become more susceptible to flooding. Continued vegetation growth along the left bank may also increase bank stability and limit further width increases. Future monitoring of this site is recommended to determine trends in overbank flooding susceptibility.

2.4 Discussion and Recommendations

The four monitoring sites have shown very different responses to flows since 2004. Overall, BJ remains the most stable site, with little channel adjustment since 2004. However, transect 6 shows indication of bed lowering and erosion, which could indicate further changes. The rate of change may be dependent on the bed material and the degree of armoring. The RR site main channel appears to be fairly static as well, with only minor bank erosion occurring near the island along transect 4. Most of the geomorphic changes are occurring in the side channel on the west side of the island. Transects show overall widening and potential initiation of meanders along the side channel. There is also a possibility that the side channel could become the main channel in the future. The channel through the NC site appears to be very dynamic in the upper three cross sections and more stable in the lower reach, namely in transects 5 and 6. The Provo River through the CA site has made mostly small adjustments. Although initially thought to be very dynamic, most change occurred between the 2004 and 2005 surveys at the CA site. This magnitude of change is possibly related to the fact that channel construction was completed just before the 2004 survey was conducted. The changes between 2005 and 2006 appear to be continual, small adjustments.

Given the response of the transects at each of the sites, annual monitoring is probably not necessary, unless it would be used to protect structures or support adaptive maintenance activities. Monitoring should be done in the following circumstances:

1. After prolonged and sustained higher than normal peak flow releases from Jordanelle Dam.

2. After a major geomorphic change in the stream (for example slope failure, side channel capture of the main stream flow, notable degradation, major shift in bankline/location of the stream).

3.0 CHANNEL SUBSTRATE

3.1 Introduction

Channel substrate creates habitat for a variety of aquatic species and serves as spawning area for some fish species of the middle Provo River. This chapter describes the results of the first (2004), second (2005), and third (2006) years of monitoring channel substrate in the study sites along the middle Provo River. Monitoring the substrate allows the Mitigation Commission to determine what substrates are 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 to maintain desirable conditions the middle Provo River 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). In 2006 April and May flows were too high to develop substrate maps for the "pre-snowmelt runoff" period. Therefore, substrate mapping was delayed until the post-runoff period. Substrate field mapping was completed between September 26, 2006, and October 24, 2006.

At the BJ site, mapping was conducted by drawing revised polygon boundaries and classifications on laminated copies of the 2005 substrate maps. At the RR and CA sites, maps of the 2005 substrate polygons overlain with revised edge of water plots (surveyed in 2006) were used for the 2006 substrate mapping. At the NC site changes in the location of gravel bars and streambanks were substantial, and new field maps based on fall 2006 surveys of edge of water and gravel bars were used for the 2006 mapping. To help ensure consistency in substrate size classification, all mapping was conducted during low flow by the same individual. 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 gravel was divided into three size categories (fine, medium, large). Cobble and boulder materials were not divided into sub-categories. Figure 3.1 of the 2004 report (Olsen 2005) shows photos of several sample substrate patches and their visually determined size class breakdowns. Visual assessment of the substrate composition within the pool area near transect 3 at the BJ site was not possible because it was too deep, and the area was labeled "unknown." This was also the case for the deep pool area below transect 3 at the CA site, and for two steep riffles at the NC site that were too fast to wade.

Substrate maps were digitized into a geographic information system (GIS) layer using ArcGIS software with the April 2004 orthophotos as base images. Within ArcGIS 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

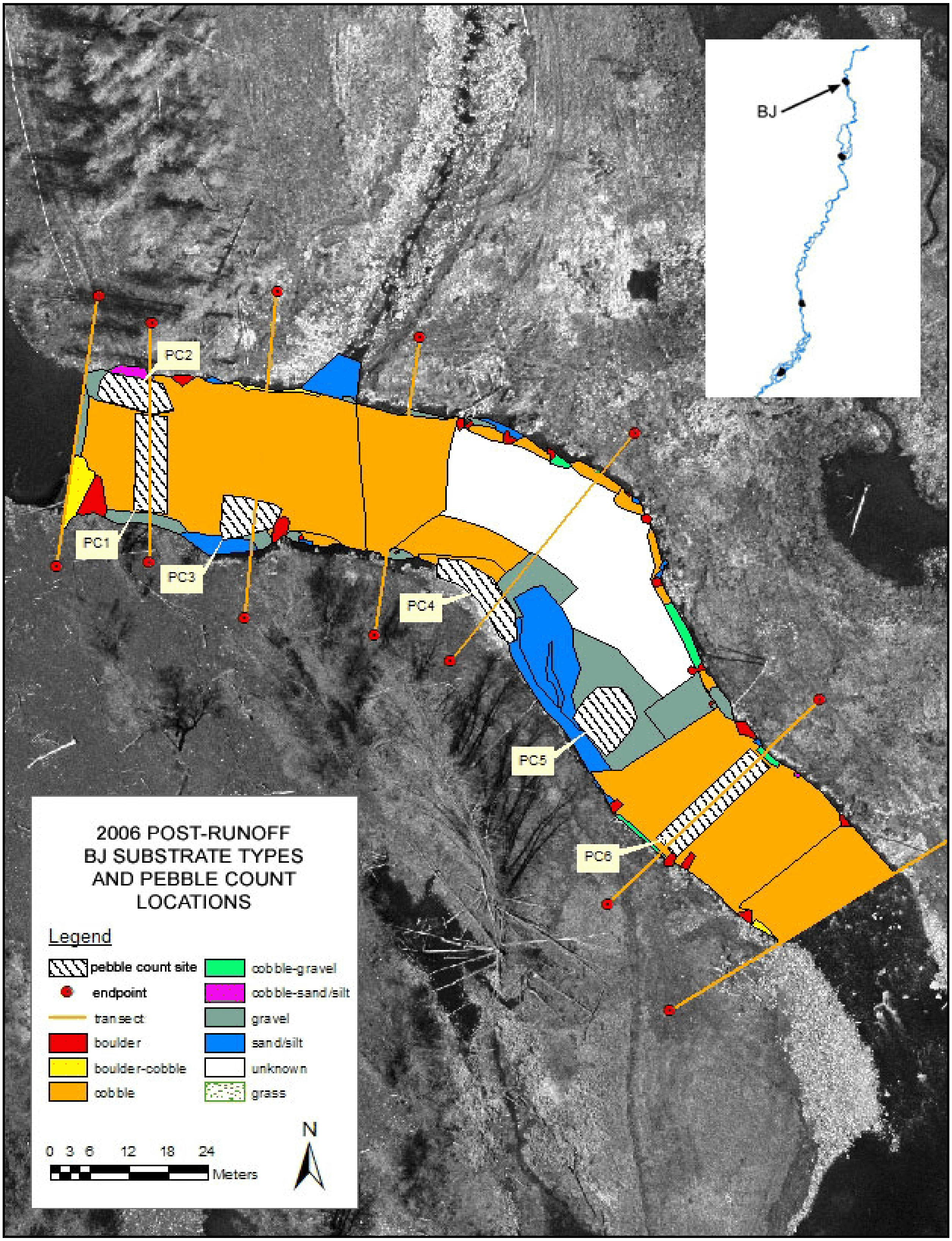


Figure 3.1a. **Substrate types and pebble count locations at the Below Jordanelle (BJ) monitoring site.**

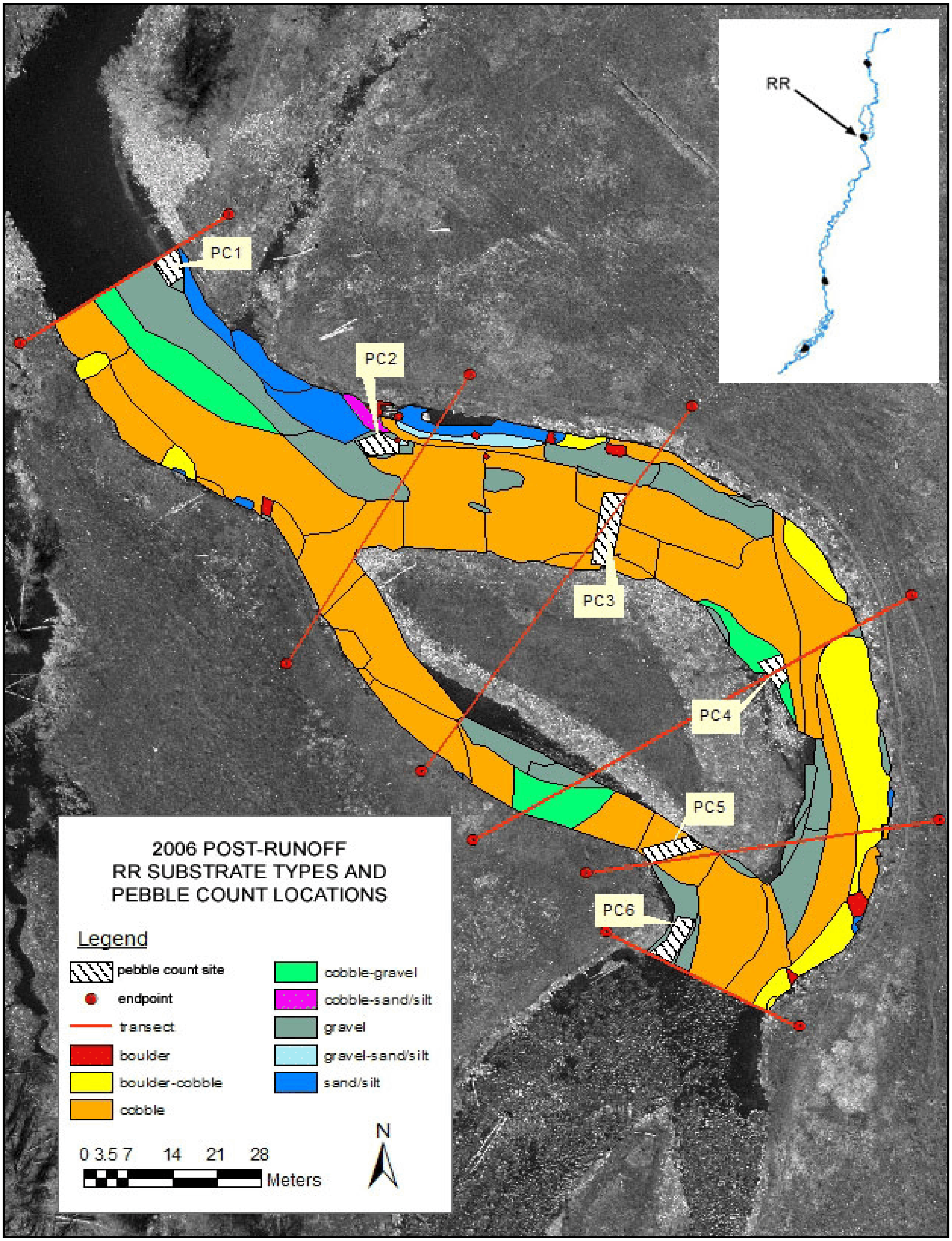


Figure 3.1b. Substrate types and pebble count locations at the River Road (RR) monitoring site.

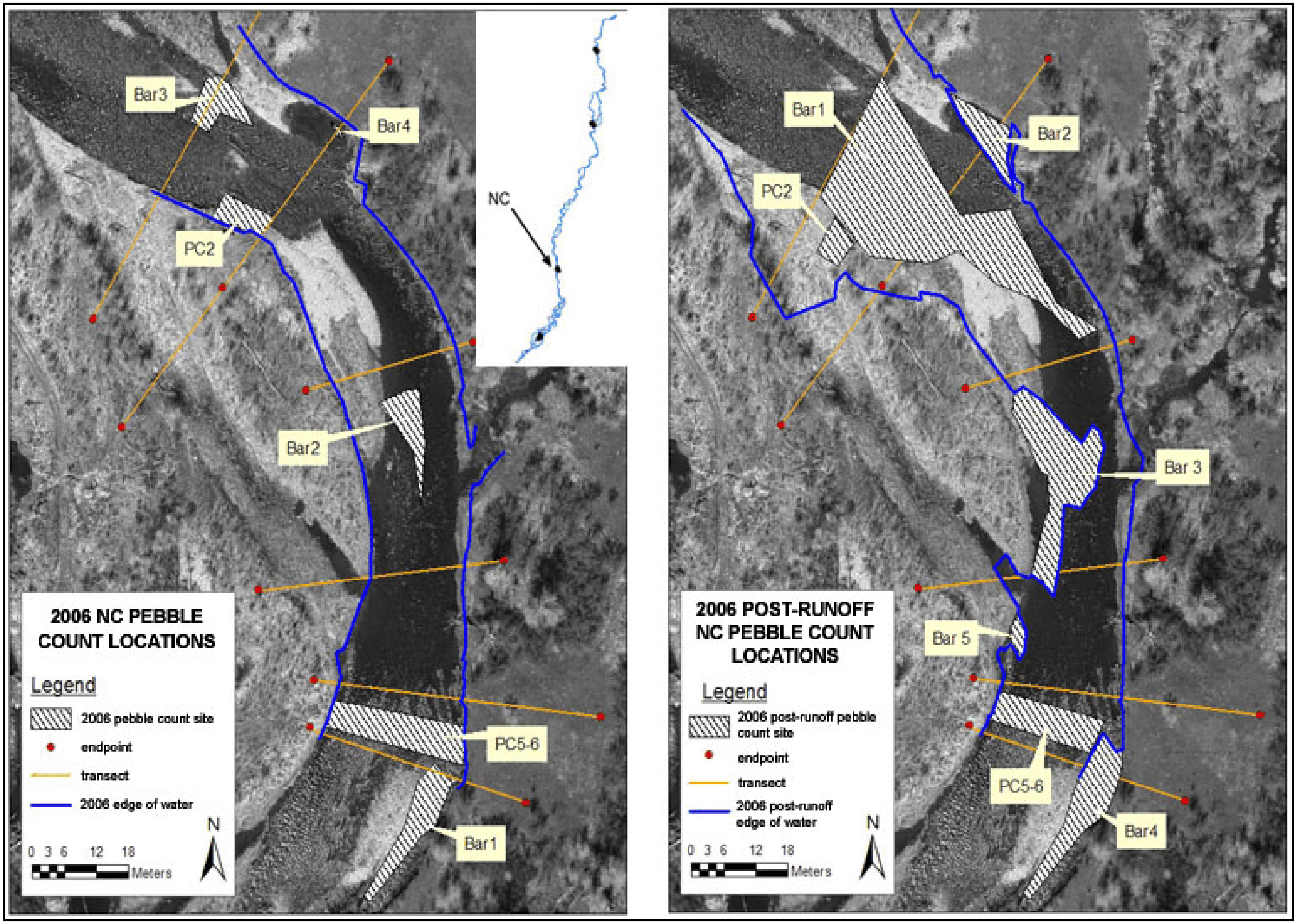


Figure 3.1c. Pebble count locations at the Never-Channelized (NC) site.

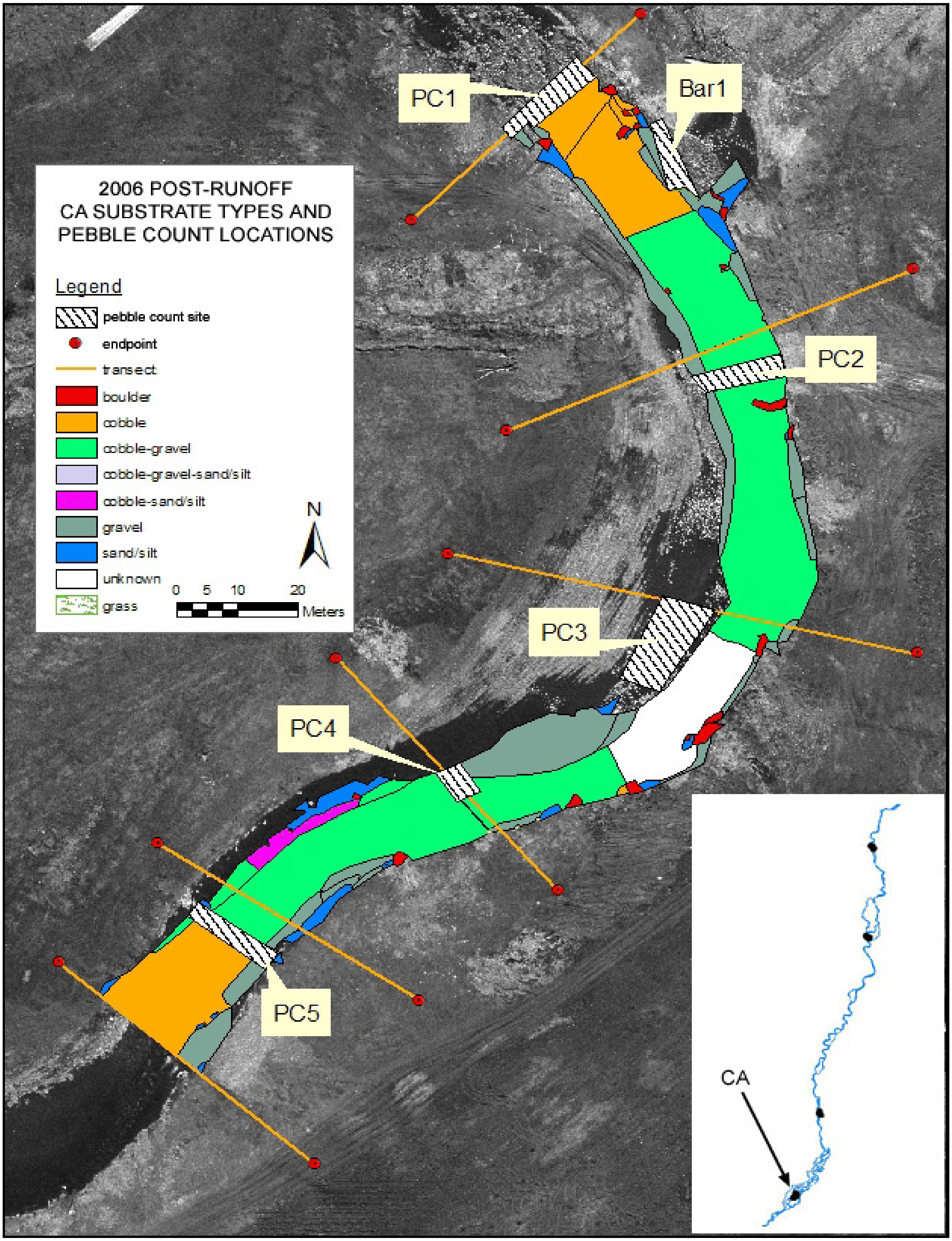


Figure 3.1d. Substrate types and pebble count locations at the Charleston (CA) monitoring site.

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

mapping purposes. Because the smaller-sized gravel particles are of particular concern, maps showing the combined percentage of fine and medium gravel in each substrate polygon were also created.

In addition to the visual substrate mapping effort, quantitative pebble counts (Wolman 1954) were completed at discrete locations within each monitoring site. In 2006 pebble counts at the RR, NC, and CA sites were completed both in the spring (before snowmelt runoff) and in the fall (post-runoff). Pebble counts at the BJ site were only completed in the spring. The timing of the spring 2006 counts is consistent with previous years' sampling; however, because of high snowpack conditions in 2006, flows increased early and were between 272–330 cfs during sampling. In previous years, pebble counts were completed in early spring under base flow conditions (typically about 150–200 cfs). Slight shifts in the position of the sample sites were made to accommodate the deeper, higher flow conditions. Post-runoff pebble counts were completed under low-flow conditions (~150 cfs) in the fall of 2006.

At the BJ site, 2006 pebble counts were completed at the same six locations sampled in 2004 and 2005 (Figure 3.1a). The 2006 post-runoff pebble count locations for the RR site are shown in Figure 3.1b. These sample locations approximately match the 2004 and 2005 sample locations, with slight shifts made to accommodate changes in streambank, bar, and edge of water locations. At the RR site, these shifts have been most significant in the vicinity of PC5 and PC6 (Figure 2.1b). Spring 2006 pebble counts at the RR site were made at approximately the same six locations, again with slight shifts made to accommodate the position of streambanks and edge of water. Counts of 100 rocks per sample site were made at each pebble count location within the BJ and RR sites.

At the NC site, all pebble count sample locations except PC5 and PC6 changed between 2005 and spring 2006, and changed again between the spring and fall 2006 sample periods (Figure 3.1c). These adjustments in pebble count locations were made in response to significant shifts in streambank and gravel bar locations following the 2005 and 2006 spring floods (Figure 2.1c, Figure 2.3c). As in previous years, a 100-rock count was completed at PC2, and a 200-rock count was completed at PC5 and PC6 for both the spring and fall 2006 samples. Because the position of bars at the NC site typically shifts from year to year, it is not possible to repeat bar samples in comparable locations. Therefore, for the spring and fall 2006 samples, comprehensive 2006 samples, comprehensive pebble counts of all bar surfaces within the NC site were completed (Figure 3.1c).

For the 2006 pre-runoff samples, the results for Bar1, Bar2, and Bar3 were lumped into a single "NC gravel bar" size distribution curve (Table 3.2). For the 2006 post-runoff period, the results for Bar1, Bar3, and Bar4 were lumped into a single size distribution curve and compared to the spring results. NC 2006 post-runoff Bar2 and Bar5 are smaller, finer-grained, bank-attached bars (Figure 3.1c); the results of the counts at these bars were combined and compared to the results of the spring 2006 Bar4 sample. The number of rocks counted at each bar varied with the size of the bar, with measurements being taken at approximately a 1-meter "grid" spacing (Table 3.2).

Table 3.2. Never-Channelized (NC) Site pebble count descriptions.

PEBBLE COUNT SITE	DESCRIPTION	NUMBER OF ROCKS COUNTED	ANALYSIS
PC2 (2006 spring)	in-channel near right bank just upstream of XS2; location shifted slightly toward southwest to accommodate bank erosion.	100	analyzed separately and compared to 2004, 2005, and 2006 post-runoff PC2 results.
PC2 (post-runoff 2006)	in-channel spanning main thalweg area between XS1 and XS2; location shifted to west/upstream because of new gravel bar at old sample location.	100	analyzed separately and compared to 2004, 2005, and 2006 post-runoff PC2 results.
PC56 (spring 2006)	in-channel in riffle spanning full width between XS5 and XS6.	200	analyzed separately and compared to 2004, 2005, and 2006 post-runoff PC5-6 results.
PC56 (post-runoff 2006)	in-channel in riffle spanning nearly full width between XS5 and XS6; location adjusted slightly to accommodate growth of gravel bar on river left.	200	analyzed separately and compared to 2004, 2005, and 2006 spring PC5-6 results.
Bar1 (spring 2006)	large mid-channel bar that extends from XS6 downstream.	180	combined with Bar2 and Bar3.
Bar2 (spring 2006)	large mid-channel bar between XS3 and XS4.	100	combined with Bar1 and Bar3.
Bar3 (spring 2006)	large mid-channel bar spanning XS1.	120	combined with Bar1 and Bar2.
Bar4 (spring 2006)	very small bar near left bank at XS2.	61	analyzed separately and compared to 2006 post-runoff Bar2+Bar5 size distribution.
Bar1 (post-runoff 2006)	very large mid-channel bar between XS1 and XS3.	200	combined with Bar3 and Bar4.
Bar2 (post-runoff 2006)	smaller bar attached to left bank at XS2.	100	combined with Bar5 and compared to spring 2006 Bar4 size distribution.
Bar3 (post-runoff 2006)	large bar between XS3 and XS4.	200	combined with Bar1 and Bar4.
Bar4 (post-runoff 2006)	large mid-channel bar that extends from XS6 downstream (same location as spring 2006 Bar1).	100	combined with Bar1 and Bar3.
Bar5 (post-runoff 2006)	very small bar attached to right bank between XS4 and XS5.	21	combined with Bar2 and compared to spring 2006 Bar4 size distribution.

Pebble count sample locations for the CA site in 2006 are shown in Figure 3.1d. For PC1, PC2, PC3, and PC4, pebble counts were completed in locations comparable to the 2004 and 2005 samples, with minor shifts made to accommodate changes in edge of water position. The PC5 sample location was shifted downstream slightly in spring 2006 to a position directly spanning XS5. This change was made because of increased water depth at the original location. For the same reason, the 2006 post-runoff PC5 sample location was shifted still farther downstream to the location shown in Figure 3.1d. The CA count PC6 was abandoned in 2006 due to the disappearance of the bar deposit originally sampled. Instead, a new gravel bar (called "Bar1") located on river left between XS1 and XS2 was sampled in both spring and fall of 2006. Counts of 100 rocks were made at each of the CA sample locations except PC3. At PC3, which is located on a dry point bar, 301 rocks were counted in spring 2006, and 207 rocks were counted in fall 2006.

At all sites pebble count 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 D16, D25, D50, D75, and D84 particles.

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. When used with the maps prepared for the 2004 and 2005 monitoring reports (Olsen 2005, Olsen 2006), the 2006 maps allow for detailed review of changes in the distribution and composition of individual substrate patches at the monitoring sites. Summary graphs are provided in Figures 3.2a–3.2d and Figure 3.3. The discussion below provides a review of more general trends and changes in the substrate composition and distribution at the study sites.

3.3.1.1 Below Jordanelle (BJ) 2005 vs. 2006

There were minimal changes in substrate composition at the BJ site between 2005 and 2006. Differences between the 2 years generally consisted of minor shifts in the boundaries or composition of small polygons along the channel margins (Figure 3.1a, Appendix 3.1a, Appendix 3.2). These changes are often associated with shifts in the position of logs/large woody debris along the channel margins. The overall percentages of medium gravel and sand/silt dropped slightly in 2006, with a corresponding increase in the percent of cobble material (Figure 3.2a). These changes appear to be the result of coarsening of a substrate patch at the inside of the bend just upstream of XS4 and a mid-channel patch upstream of XS5 (Figure 3.1a, Appendix 3.2), along with flushing of silt from several channel margin deposits. Overall, the total proportion of medium and fine gravel at the BJ site remains small relative to cobble, large gravel, and boulder-sized material (Figure 3.3). In 2006 much of the substrate within lower-velocity areas along channel margins was coated with brown algae, and macrophytes were growing in areas with silt substrate. The amount of algae was greater than what was noted in previous years, and may be the result of shifting the timing of monitoring to the fall.

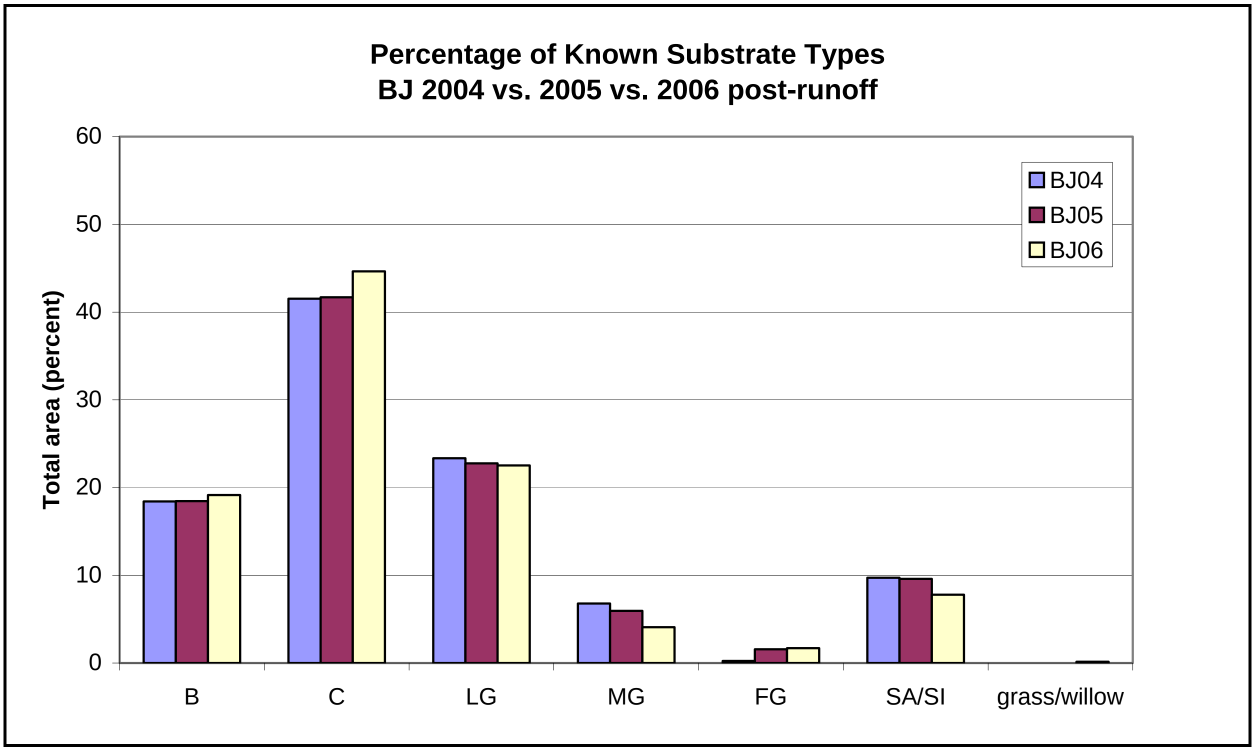


Figure 3.2a. Temporal changes in the area occupied by various substrate size classes at the Below Jordanelle (BJ) monitoring site.

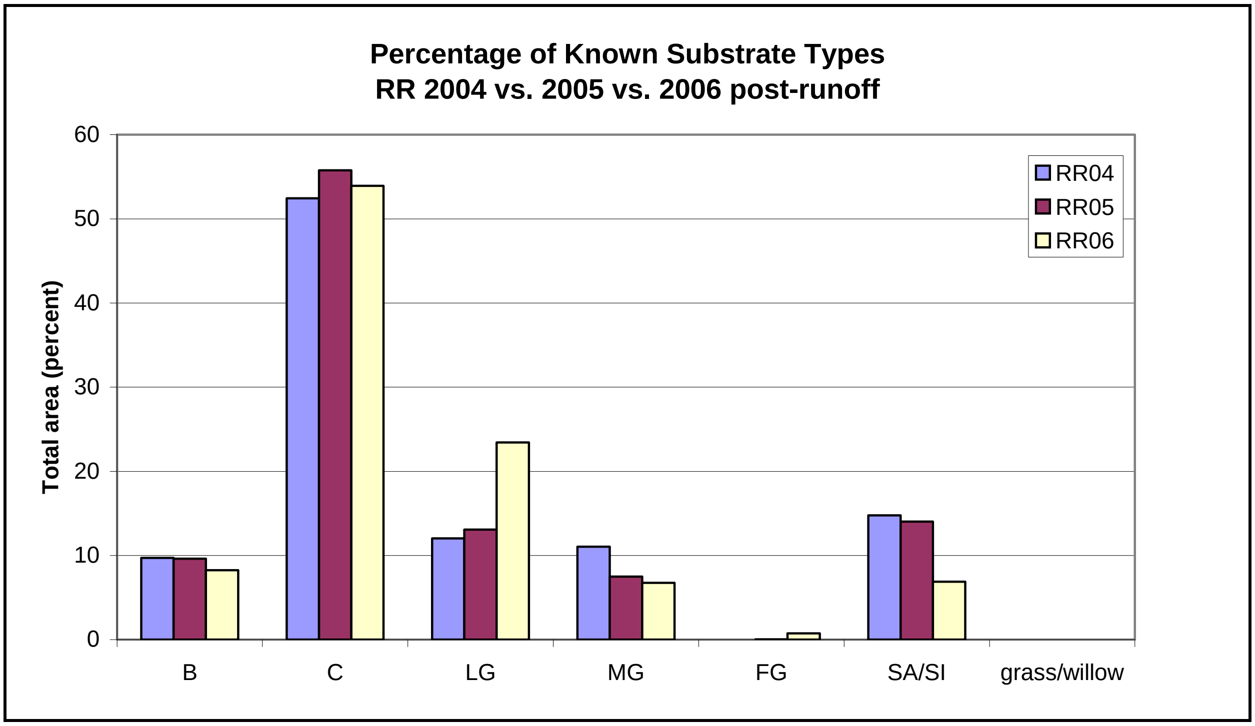


Figure 3.2b. Temporal changes in the area occupied by various substrate size classes at the (River Road) RR monitoring site.

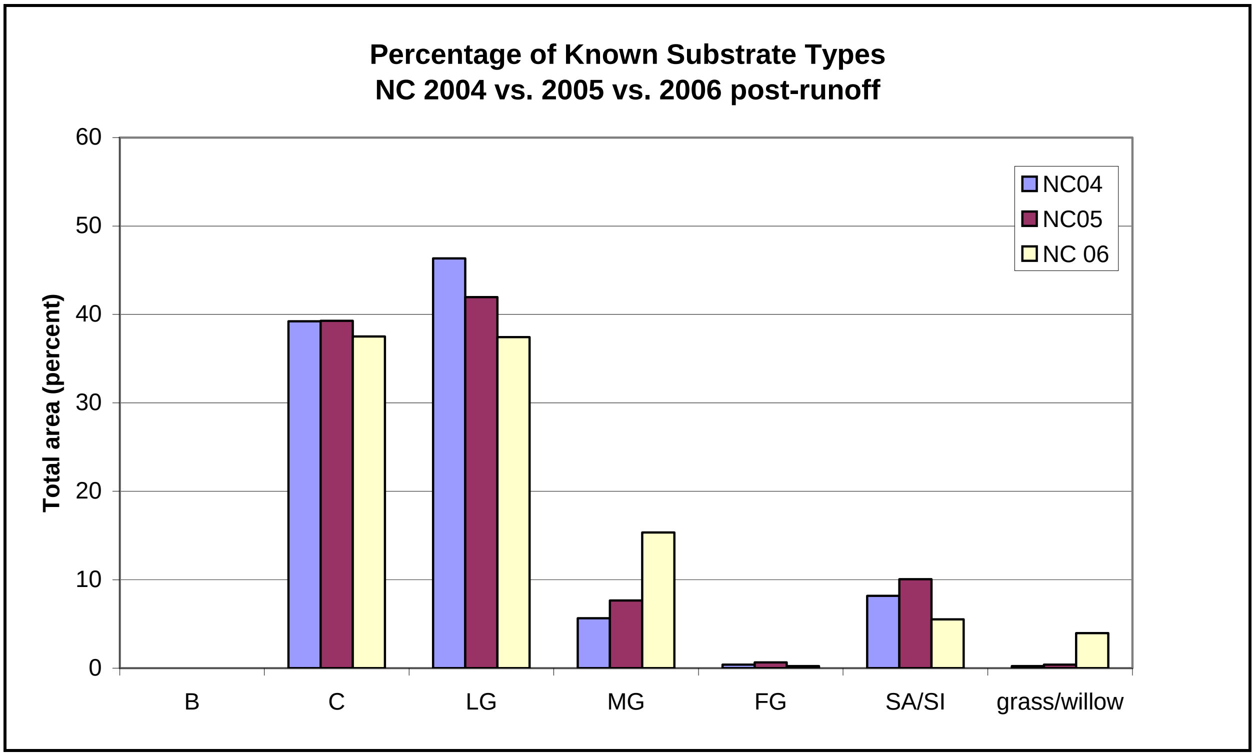


Figure 3.2c. Temporal changes in the area occupied by various substrate size classes at the Never Channelized (NC) monitoring site.

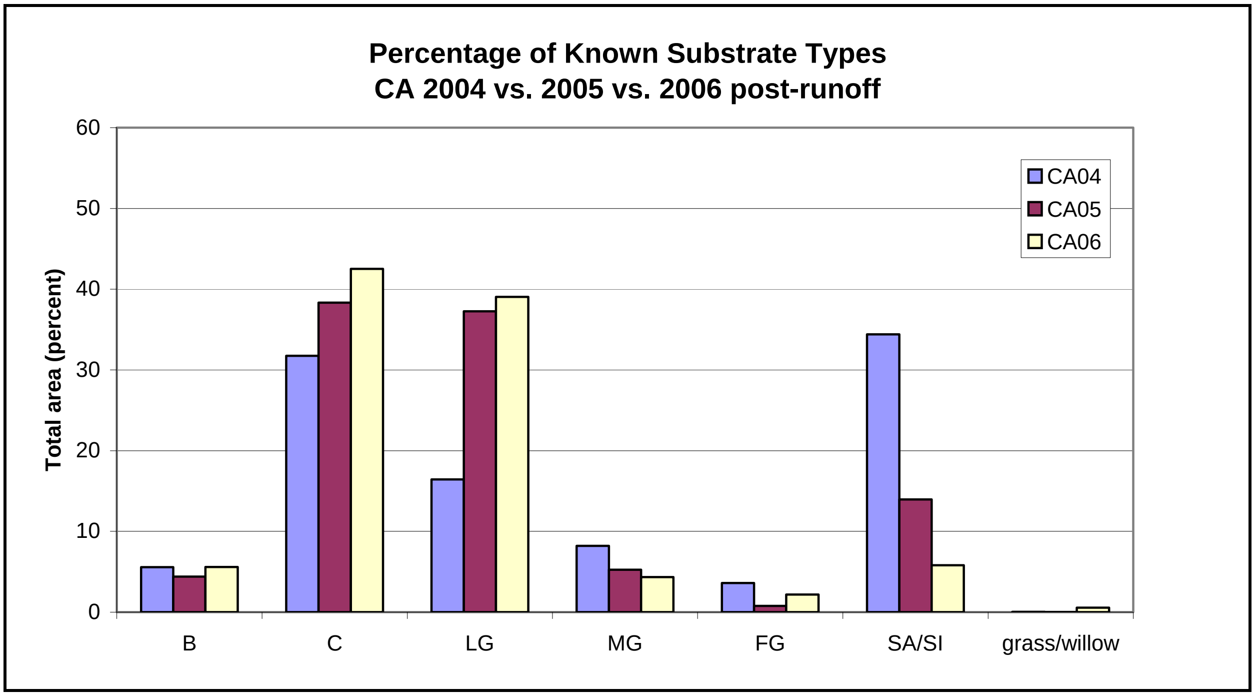


Figure 3.2d. Temporal changes in the area occupied by various substrate size classes at the Charleston (CA) monitoring site.

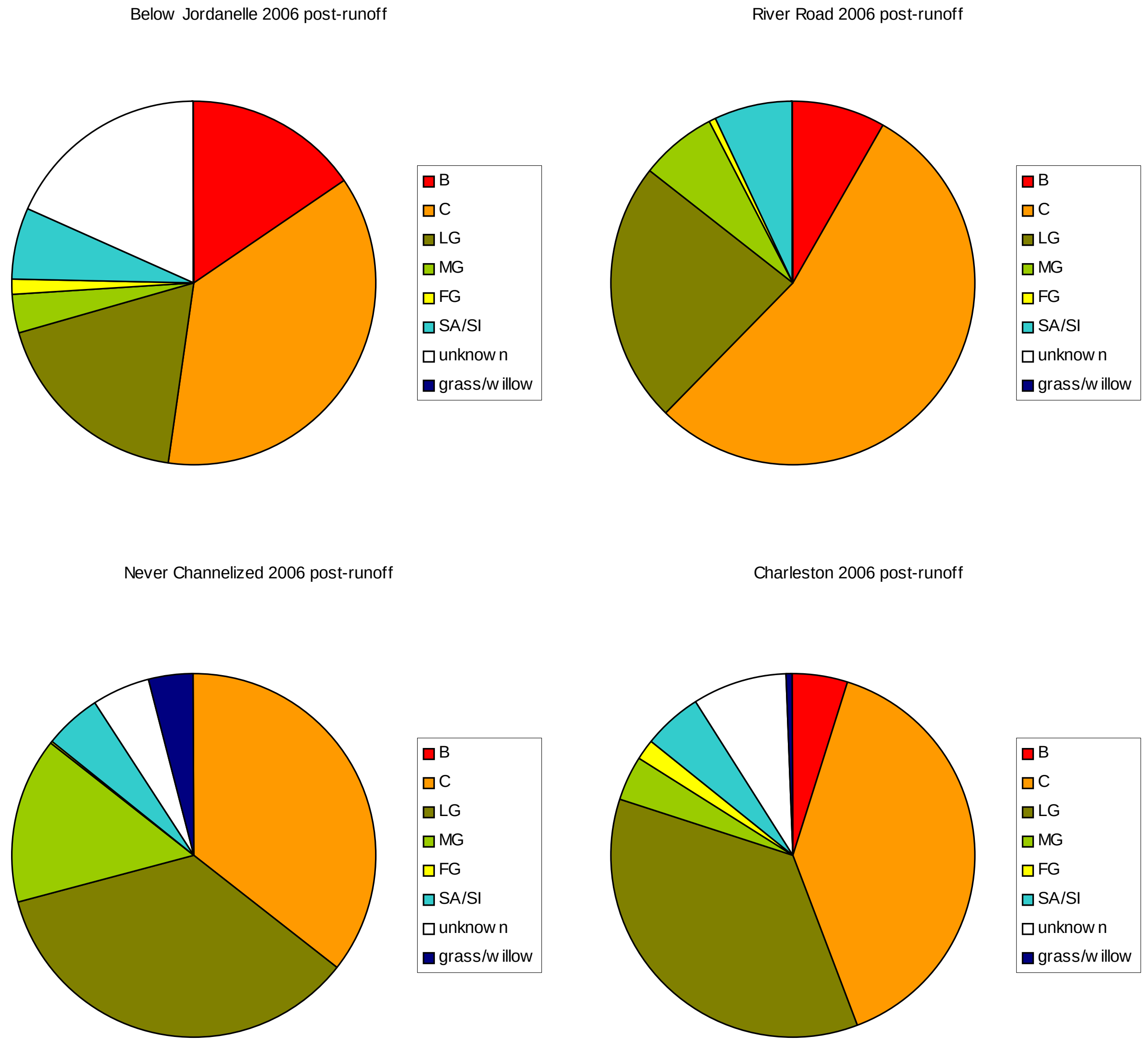


Figure 3.3. Proportion of monitoring site area occupied by various substrate size classes. Plots include areas mapped as “unknown” substrate size.

3.3.1.2 River Road (RR) 2005 vs. 2006

Overall, changes in the substrate composition of the RR site between 2004, 2005, and 2006 were relatively minor (Figure 3.1b, Figure 3.2b). Cobble remains the highly dominant substrate size at the site (Figure 3.3), as has been the case since the initial years of monitoring. The main shift in 2006 was a 10 percent increase in the proportion of large gravel at the site (Figure 3.2b). This increase appears to be the result of the continued increase in size of the gravel bar on river right near XS6, the development of a new gravel bar within the side channel, and a reduction in the amount of silt stored within the lower half of the site (Figure 3.1b) (Olsen 2006). As in 2005 some changes in patch boundaries and composition were observed in the depositional area along the inside bend of the main channel near transect RR5 (Appendix 3.1a). This area has continued to aggrade and vegetate, resulting in a reduced proportion of inundated fine-grained material in this area. The combined proportion of medium and fine gravel within the RR site remained essentially constant between 2005 and 2006 (Figure 3.2b, Appendix 3.2). As with the BJ site, considerable amounts of algae and macrophytes were observed in the lower-velocity portions of the channel in 2006. In some locations, this made it challenging to accurately identify the sizes of the bed material.

3.3.1.3 Never-Channelized (NC) 2005 vs. 2006

In 2006 significant shifts in the distribution of substrate patches occurred in conjunction with the channel changes caused by the 2005 and 2006 spring floods (Figure 3.4). In the current 2006 post-runoff channel condition, large gravel bars occupy much of the NC site, with a considerable portion of the total flow now running down the previously-abandoned side channel on river right (Figure 3.1c). This large volume of bar material is reflected in the increase in the area of medium gravel within the site (Figure 3.2c). A new substrate category called “flooded willows” was created to reflect the current conditions on river right at the upstream end of the site (Figure 3.4). In addition to a doubling of the percentage of medium gravel and an increase in the grass/willow category, slight decreases in the percentages of cobble. large gravel, and sand/silt were also observed between the 2005 and 2006 post-runoff periods (Figure 3.2c). Most of the existing main channel at the NC site is now constricted between bar deposits, and as a result is steep and high velocity. This probably accounts for the reduction in sand/silt at the site. This may also be the reason that algae and macrophytes were noted much less frequently at the NC site than at the other monitoring sites. The reduced quantities of large gravel and cobble are likely caused by the overall reduction of main channel area relative to bars, which are typically finer-grained. Overall, however, cobble and large gravel remain the dominant size classes within the NC site (Figure 3.3).

3.3.1.4 Charleston (CA) 2005 vs. 2006

Changes in the overall substrate composition of the CA site between the 2005 and 2006 post-runoff mapping efforts were more subtle than the changes observed between 2004 and 2005 (Figure 3.2d). This was to be expected, given that the 2005 substrate maps reflected the changes that occurred during the first post-restoration flood. In 2006 slight increases in the proportion of cobble, large gravel, and fine gravel were observed, while the amounts of medium gravel and sand/silt decreased slightly (Figure 3.2d). These changes appear to be associated with coarsening of channel margin deposits in areas including the left bank area between XS1 and XS2, the right bank area between XS3 and XS4, and the left bank area between XS5 and XS6 (Figure 3.1d, Appendix 3.2). These trends continue the trends observed between 2004 and 2005 at the CA site (e.g., erosion of left bank,

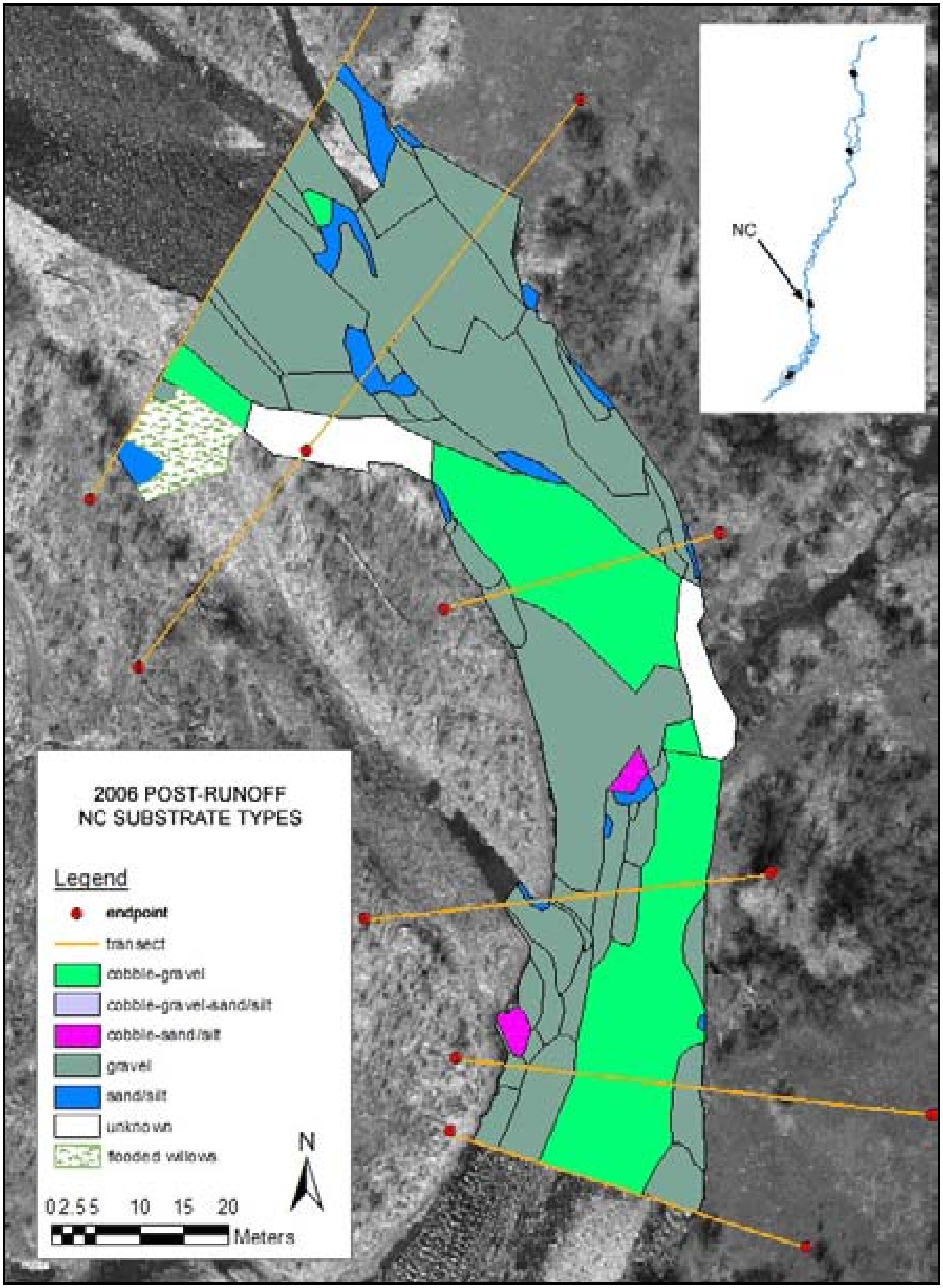


Figure 3.4. Substrate types at the Never-Channelized (NC) monitoring site.

deposition/ building of right bank mid-site, etc.). As with the other monitoring sites, cobble and large gravel are the dominant substrate sizes at the CA site (Figure 3.3, Figure 3.5).

3.3.2 Pebble Counts

Particle size distribution based upon pebble counts conducted in 2006 showed little overall change when compared to 2004 and 2005. Table 3.3 summarizes the D_{16}, D_{25}, D_{50}, D_{75}, and the D_{84} for all pebble counts conducted from 2004 through 2006. This table also categorizes the size class of the D50 for all pebble counts using the ranges listed in Table 3.1 (sand/silt, fine gravel, medium gravel, large gravel, cobble, and boulder). Appendix 3.3 contains all pebble count plots comparing data for all patches for years 2004 through 2006.

Descriptions and result summaries for all pebble counts conducted in 2006 are located in Table 3.4. It describes the patch type (bar, riffle, run), patch location, D50 size for 2004, 2005, and 2006, and relevant changes in bed material size.

Pebble count results were analyzed for relative gravel percentage changes at all sites for years 2004, 2005, 2006, and post-runoff 2006 to identify possible trends in gravel movement through the river system. Figure 3.6 illustrates trends in total gravel (phi size class 2 mm to 64 mm) and fine and medium gravel (phi size class 2 mm to 32 mm) using combined data from all pebble count locations. A second analysis shows relative gravel changes using only the pebble count patches located on fixed transects that do not vary from year to year (Figure 3.7). The pebble counts on fixed transects include: BJ PC1 and PC6, RR PC3 and PC5, NC PC5 and PC6, and CA PC1, PC2, and PC5.

Results from the gravel percentage analysis on all patches illustrate that there is not a noticeable evacuation of gravel-sized material occurring within the current monitoring time frame. Total percentages of gravel measured in 2006 and post-runoff 2006 are very similar to the percentages measured in 2004 at the BJ, RR, and CA sites (Figure 3.6). The 2006 post-runoff result at the NC site shows an increase in the total amount of gravel relative to 2004 (Figure 3.6). These results are similar to those seen when only the stable in-channel pebble count data are analyzed (Figure 3.7). At the RR site, the transect-only data show a slight decrease in total gravel; however, this change is largely driven by recent coarsening at PC5, which is located in the dynamic side channel area (Figure 2.1b).

Pebble count results also do not indicate a trend toward reduced percentages of fine and medium gravel (Figure 3.6, Figure 3.7). The most recent data at the BJ, RR, and NC sites show slight increases in the percentages of medium and fine gravel relative to the 2004 results. The 2006 results for the CA site show a slight decrease relative to 2004; however, this is most likely because of an artificially high proportion of fine material at the site in 2004, when measurements were taken immediately after channel construction and prior to the site experiencing any flushing flows. The 2006 post-runoff results at CA show an increase in fine and medium gravel relative to the spring 2006 data (Figure 3.6, Figure 3.7). Several more years of monitoring data will be needed to determine whether these increases in fine and medium gravel are indicative of a long-term trend, a "natural" annual variability, or perhaps the temporary result of ongoing river restoration construction activities that add gravel to the river.

Table 3.3. Pebble count size class descriptions for 2004, 2005, and 2006.

Below Jordanelle	BJ PC1				BJ PC2				BJ PC3				BJ PC4				BJ PC5				BJ PC6			
	2004	2005	2006		2004	2005	2006		2004	2005	2006		2004	2005	2006		2004	2005	2006		2004	2005	2006	
D_{16}	82	95	55		14	28	18		24	23	16		11	5	9		10	8	7		115	55	63	
D_{25}	115	120	90		23	35	28		30	30	23		28	25	20		19	11	9		125	80	86	
D_{50}	155	165	165		44	62	58		40	43	37		58	80	58		43	23	17		173	160	165	
D_{75}	205	210	245		71	88	125		58	72	68		90	125	96		58	43	29		217	240	205	
D_{84}	226	250	270		86	86	170		68	90	85		110	170	120		67	57	45		245	260	232	
Class of D_{50}	Cobble	Cobble	Cobble		Large gravel	Large gravel	Large gravel		Large gravel	Large gravel	Large gravel		Large gravel	Cobble	Large gravel		Large gravel	Medium Gravel	Medium Gravel		Cobble	Cobble	Cobble	
River Road	RR PC1				RR PC2				RR PC3				RR PC4				RR PC5				RR PC6			
	2004	2005	2006	2006 pr[a]	2004	2005	2006	2006 pr[a]	2004	2005	2006	2006 pr[a]	2004	2005	2006	2006 pr[a]	2004	2005	2006	2006 pr[a]	2004	2005	2006	2006 pr[a]
D_{16}	11	3	15	10	20	21	12	14	33	39	27	27	38	40	28	31	45	34	31	58	32	29	4	10
D_{25}	17	6	19	12	24	34	18	17	37	44	36	33	45	49	31	43	51	44	51	65	37	33	7	20
D_{50}	27	13	30	20	36	60	39	29	64	88	72	74	60	82	66	80	75	76	110	113	49	46	15	39
D_{75}	42	26	45	26	50	90	92	48	110	160	130	127	86	120	120	125	123	150	186	168	67	62	31	65
D_{84}	49	35	54	34	55	105	110	65	136	180	185	180	100	148	141	155	156	185	220	206	75	78	42	76
Class of D_{50}	Medium gravel	Medium gravel	Medium gravel	Medium gravel	Large gravel	Large gravel	Large gravel	Medium gravel	Cobble	Cobble	Cobble	Cobble	Large gravel	Cobble	Cobble	Cobble	Cobble	Cobble	Cobble	Cobble	Large gravel	Large gravel	Medium gravel	Large gravel
Never-Channelized	NC PC1[b]		NC PC2				NC PC3-4[b]		NC PC5-6				large bar combined		small bar combined		-		-		-		-	
	2004	2005	2004	2005	2006	2006 pr[a]	2004	2005	2004	2005	2006	2006 pr[a]	2006	2006 pr[a]	2006	2006 pr[a]	-		-		-		-	
D_{16}	24	43	42	47	42	43	30	41	52	42	39	40	38	35	26	16	-		-		-		-	
D_{25}	30	51	51	51	54	48	36	50	61	54	47	46	46	43	29	18	-		-		-		-	
D_{50}	48	70	76	73	74	70	51	70	83	85	76	72	75	60	36	28	-		-		-		-	
D_{75}	65	89	100	94	115	95	74	104	119	128	123	115	111	87	46	41	-		-		-		-	
D_{84}	77	100	117	110	132	120	90	116	146	155	145	135	132	106	49	49	-		-		-		-	
Class of D_{50}	Large gravel	Cobble	Cobble	Cobble	Cobble	Cobble	Large gravel	Cobble	Cobble	Cobble	Cobble	Cobble	Cobble	Large gravel	Large gravel	Medium gravel	-		-		-		-	
Charleston	CA PC1				CA PC2				CA PC3				CA PC4				CA PC5				CA PC6[b]		CA Bar1	
	2004	2005	2006	2006 pr[a]	2004	2005	2006	2006 pr[a]	2004	2005	2006	2006 pr[a]	2004	2005	2006	2006 pr[a]	2004	2005	2006	2006 pr[a]	2004	2005	2006	2006 pr[a]
D_{16}	42	49	58	54	22	52	42	22	15	9	28	26	6	22	22	19	24	44	45	37	8	9	12	22
D_{25}	51	62	68	65	26	61	60	33	31	10	38	32	10	32	30	27	33	58	56	47	28	19	26	33
D_{50}	84	100	106	102	51	83	88	55	54	29	51	49	38	55	47	46	66	94	84	68	47	30	48	55
D_{75}	122	150	155	140	86	117	130	70	83	55	74	69	54	75	61	70	96	125	132	103	101	43	71	70
D_{84}	131	155	185	148	109	128	142	81	96	79	90	76	60	87	80	90	112	138	150	130	130	48	89	81
Class of D_{50}	Cobble	Cobble	Cobble	Cobble	Large gravel	Cobble	Cobble	Large gravel	Large gravel	Medium Gravel	Large gravel	Large gravel	Large gravel	Large gravel	Large gravel	Large gravel	Cobble	Cobble	Cobble	Cobble	Large gravel	Medium Gravel	Large gravel	Large gravel

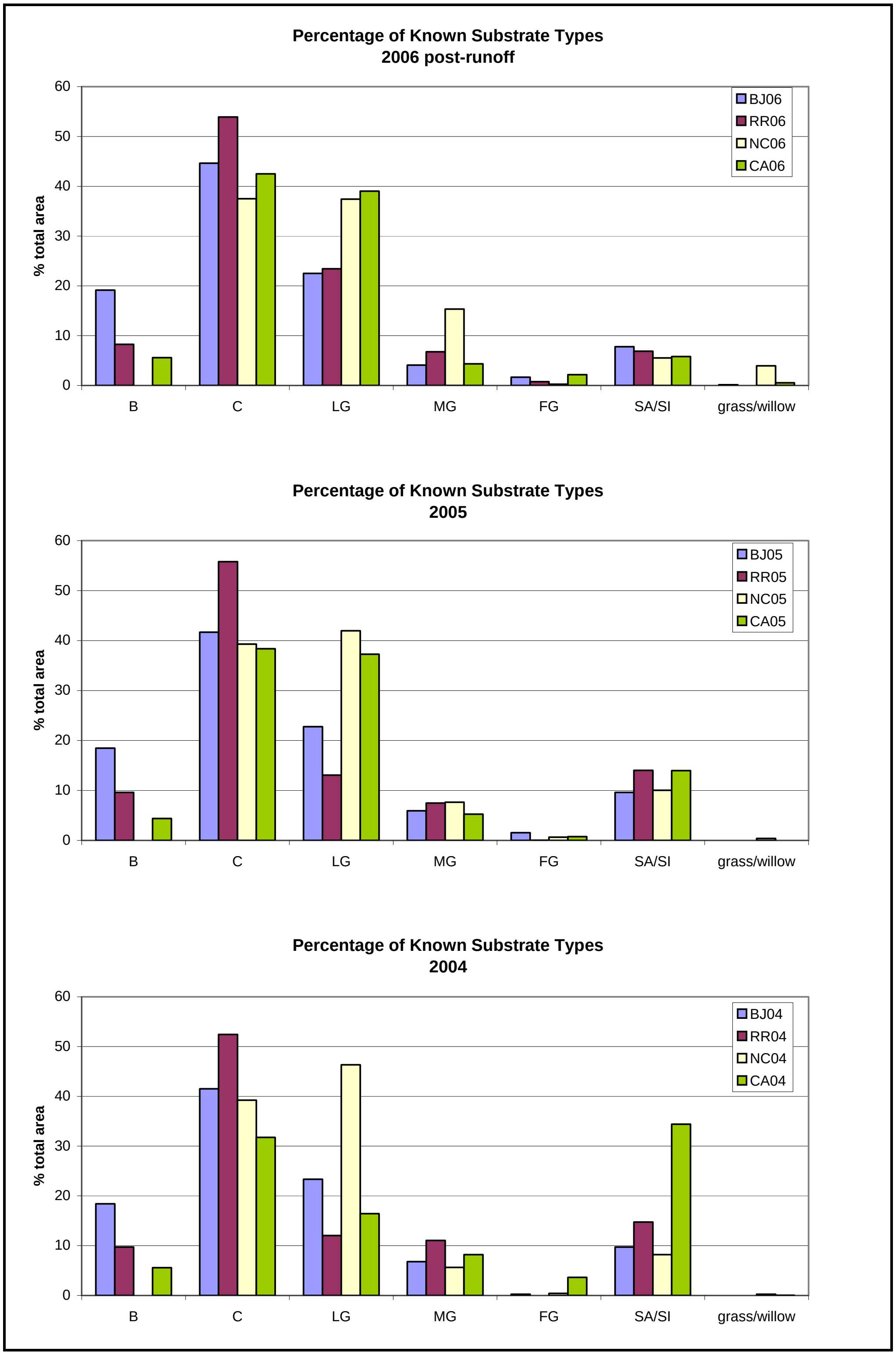
[a] PR = post-runoff.

[b] Pebble count not repeated in 2006.

Table 3.4. Pebble count patch location and relative change description for 2006.

PEBBLE COUNT SITE	TYPE	2006 LOCATION	D50				2006 SUMMARY
			2004	2005	2006	2006 POST-RUNOFF	
BELOW JORDANELLE							
BJ PC1	Run	Run at top of monitoring site along transect BJ2	155	165	165	a	Little change.
BJ PC2	Patch in Run	Gravel patch on river left in run.	44	62	58	a	Increase in coarse material over 2005 with an increase in the cobble count. D50 still classified as large gravel because of the increased count of medium gravel.
BJ PC3	Patch in Run	Gravel patch in run on right side of transect BJ3	40	43	37	a	Little change.
BJ PC4	Dry Bar	Bar on river right at transect BJ4	58	80	58	a	Little change. The D50 shifted back to the large gravel category (as in 2004) from cobble (2005) with a higher count of medium gravel.
BJ PC5	Patch in Eddy/Run	Low velocity area on river right between transects BJ4 and BJ5	43	23	17	a	Increase in fine material (sand/silt, medium and large gravel), with small decrease in cobble sized material. D50 remains classified as medium gravel
BJ PC6	Riffle	In channel along transect BJ5	173	160	165	a	Little change.
RIVER ROAD							
RR PC1	Patch in Run	Gravel patch river left downstream from transect RR1	27	13	30	20	Little change between 2005 and 2006. 2006 post-runoff count showed increase in fine material (medium gravel) and decrease in cobble sized material.
RR PC2	Patch in Run	Gravel patch mid-channel in run upstream from transect RR2.	36	60	39	29	Increase in fine material between 2005 and 2006. 2006 post-runoff showed an greater increase in fine material (medium gravel) over 2006 and the D50 changed from large gravel to medium gravel classification.
RR PC3	Run	In channel along transect RR3	64	88	72	74	Little change.
RR PC4	Patch in Riffle	Gravel patch river right at transect RR4	60	82	66	80	Little change.
RR PC5	Riffle	Riffle in side channel near transect RR5	75	76	110	113	Increase in coarse material. Count for phi class 256 (cobble) for 2006 is 3 versus 42 for 2006post-runoff. There is also a decrease in large gravel. The D50 remains classified as cobble.
RR PC6	Dry Bar	Bar on river right at transect RR6	49	46	15	39	Increase in fine material over 2004 and 2005. The finest material was sampled during 2006 with the D50 classified as medium gravel. The 2006 post-runoff sample had less fine material and the D50 is classified as large gravel. This is the River Road patch with the most change.
Never-Channelized							
NC PC2	Riffle	see Table 3.2	76	73	70	74	Little change.
NC PC5-6	Riffle	In channel in riffle spanning full width between transect NC5 and NC6	83	85	76	72	Little change.
Large Bar Combined	Dry Bar	2006 NC PCBAR 1, 2, 3 combined. 2006 post-runoff NC PC BAR 1, 3, 4 combined. See figure 3.1c for relative locations.	b	b	75	60	The D50 changed from cobble classification(2006) to large gravel (2006 post-runoff). The primary change was the reduction by nearly half of larger cobble in the phi size class 256 and a increase in large gravel.
Small Bar Combined	Dry Bar	2006 NC PC BAR 4. 2006 post-runoff NC PC BAR 2, 5 combined. See figure 3.1c for relative locations.	b	b	36	28	The D50 changed from large gravel (2006) to medium gravel (2006 post-runoff). The data show a shift from large gravel (phi class 64) to medium gravel.
Charleston							
CA PC1	Riffle	In channel in riffle at transect CA1	84	100	106	102	Little change.
CA PC2	Riffle	In channel just below transect CA2	51	83	88	55	Increase in fine material since 2005. The 2006 post-runoff results show and increase in fine material relative to the 2006 results with a change in the D50 classification from cobble to large gravel. The data show an increase in large and medium gravel and a decrease in cobble.
CA PC3	Dry Bar	Bar on right side of channel just below transect CA3	54	29	51	49	Little change.
CA PC4	Riffle (2006) Run (2005) Eddy/Pool (2004)	Right half of channel at transect CA4	38	55	47	46	Little change.
CA PC5	Riffle (2005-2006) Run (2004)	In channel between transects CA5 and CA6	66	94	84	68	Little change.
CA BAR 1	Dry Bar	Bar on river right below transect CA1	b	b	48	55	This site replaces PC#6, which was not sampled during 2006. There is little change at this site during 2006.

a = Pebble count not conducted during 2006 post-runoff at this location.
b = Pebble count not conducted during 2004 and 2005 at this location.


Percentage of Known Substrate Types 2006 post-runoff

Percentage of Known Substrate Types 2005

Percentage of Known Substrate Types 2004

Figure 3.5. Comparison of area occupied by various substrate size classes at each monitoring site in 2004, 2005, and post-runoff 2006.

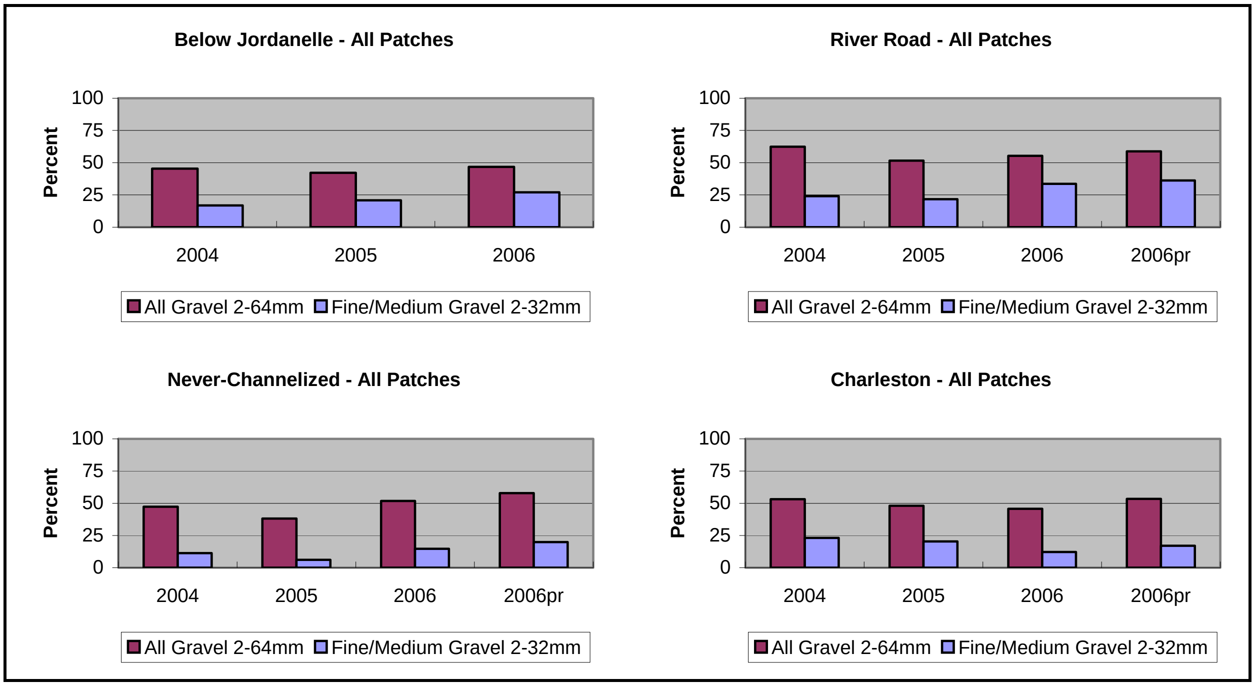


Figure 3.6. Percentage of gravel over the past 3 years for all sampled patches.

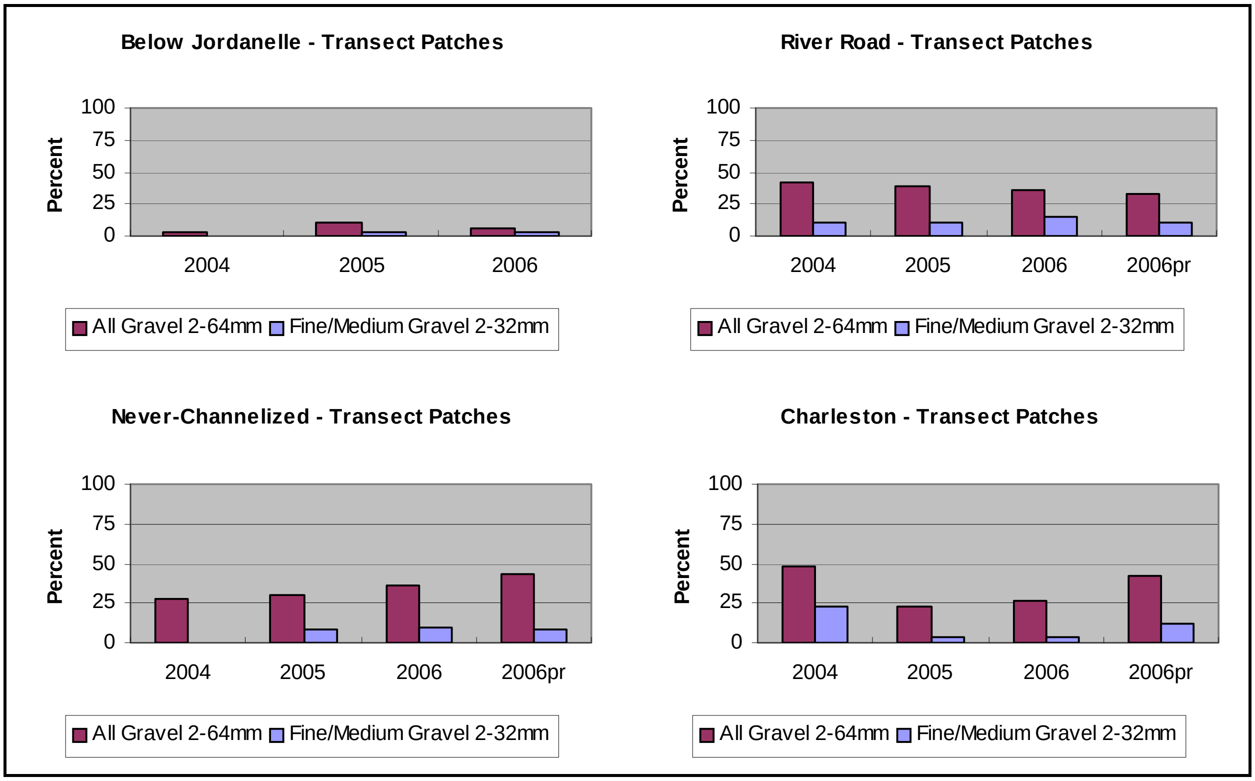


Figure 3.7. Percentage of gravel over the past 3 years for the transect patches only.

The pebble count data also demonstrate that there is very little gravel in the in channel transect patches at the BJ study site relative to the downstream sites, and this is not changing (Figure 3.7).

3.4 Channel Substrate Discussion

Monitoring changes in channel substrate composition through time is one way to evaluate the long-term influence of sediment trapping by Jordanelle Dam. One potential effect of this reduced sand and gravel supply could be coarsening of the substrate material and net evacuation of gravel-sized particles from the river, particularly in the areas closest to the dam. Substrate monitoring data from spring 2004 through fall 2006 do not indicate that this is happening.

However, monitoring results demonstrate that the upstream monitoring sites (BJ and RR) have substantially coarser substrate than the downstream monitoring sites (NC and CA). Gravel and sand-size particles comprise less than 40 percent of the surface substrate at the upstream sites, but close to 60 percent at the downstream sites. The upstream sites, particularly BJ, also exhibit less year-to-year variability in the distribution of substrate patches. The BJ site has remained nearly static despite large-magnitude floods in 2005 and 2006. At the RR site these floods did result in significant channel movement within the side channel, with associated shifts in substrate distribution. Relatively little change occurred within the remainder of the RR site, however.

In contrast, the NC site has been extremely dynamic through the 2004, 2005, and 2006 monitoring period, with major changes occurring in gravel bar locations and associated substrate patches. The CA site has also exhibited more bank erosion and gravel bar development than the upstream sites. However, as vegetation becomes more established within the recently-restored CA site, and as gravel from the never-channelized reach is transported into CA, the year-to-year substrate dynamics of the CA site may adjust. Over the long term, the lack of channel and substrate change at the BJ site could be a concern, as it limits the availability of disturbed surfaces for riparian vegetation establishment. It may also be a concern in terms of meeting the restoration goal of re-establishing functional fluvial processes such as channel migration.

3.5 Channel Substrate Recommendations

Future monitoring of channel substrate is recommended. Several adjustments to monitoring techniques and frequency are suggested to ensure that monitoring is as effective and cost-efficient as possible. Specifically, substrate monitoring should focus on determining whether (1) there is evidence of a loss of deposits of gravel-sized material (either in-channel or bar deposits) from the monitoring sites, and (2) whether there is evidence of a trend toward overall substrate coarsening. Specific recommendations are provided in Chapter 6.

4.0 SEDIMENT TRANSPORT

4.1 Introduction

The results of the 2006 bedload and suspended load monitoring in the middle Provo River are described in this chapter. Data collected during previous years for the purpose of developing rating curves, as described in the Provo River Flow Study (Olsen et al. 2004), the 2004 Provo River Monitoring Report (Olsen 2005) and the 2005 Provo River Monitoring Report (Olsen 2006) are not duplicated in this report. The 2006 bedload and suspended load data were collected to test standard methods for sediment sampling in the Provo River and to determine potential error associated with previous load estimates.

The purpose of sediment monitoring in 2006 is to better understand the precision of sediment transport monitoring previously conducted on the middle Provo River. This test of the sediment transport monitoring methods will help finalize the recommendations of the quantity of coarse sediment replenishment below Jordanelle Dam as an adaptive maintenance activity to maintain a healthy riverine ecosystem and keep desirable conditions in the middle Provo River. Such data may also help determine if the Mitigation Commission has been fulfilling the environmental commitments concerning fish, wildlife, and recreation.

4.2 Sediment Transport Methods

4.2.1 Monitoring Sites

Bedload and suspended sediment samples were collected at two bridge locations between Jordanelle Dam and Deer Creek Reservoir. The first bridge, White Bridge (WB), which was monitored in 2006, is less than 2 miles below the dam, whereas the second bridge, Midway Bridge (MID), is nearly 9 miles below the dam (Table 4.1). The WB and MID monitoring bridges were selected for their lack of vehicle traffic during the sample days and because they had the lowest and highest bedload volume, respectively, in the study area. The bridge structures enabled workers to collect samples across the entire width of the channel during sustained flows when the river was unwadeable. A full description and photos of each monitoring site are included in the 2004 monitoring report (Olsen 2005).

Table 4.1. Approximate distances between sediment transport monitoring bridges. All distances were measured along the thalweg of the restored channel.

SEDIMENT TRANSPORT MONITORING BRIDGE	DISTANCE BETWEEN BRIDGES	TOTAL RESTORED RIVER MILES BELOW JORDANELLE DAM
White Bridge (WB)	-	1.76
Midway Bridge (MID)	7.08	8.84

4.2.2 Stream Discharge

Streamflows encountered during the 2006 sampling were determined using real time, provisional 15-minute flow data at the River Road U.S. Geological Survey (USGS) gaging station located in the project area (Table 4.2). The data were acquired from the USGS web site (USGS 2006).

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

MONITORING BRIDGE	DATA SOURCE/ CALCULATION TECHNIQUE
White Bridge (WB)	USGS Station #10155200 (Provo River at River Road Bridge) 15-minute real-time data downloaded in 2006
Midway Bridge (MID)	USGS Station #10155200 (Provo River at River Road Bridge) 15-minute real-time data downloaded in 2006

There was an above-average snowpack in the upper watershed in spring 2006, which provided flows high enough to transport coarse sediments in the middle Provo River. Sediment samples were collected at two discharges during the spring runoff hydrograph (Figure 4.1). This schedule met water delivery needs and was patterned to achieve a high flow of 1,750 cfs that was sustained over a period of days then held again at 1,350 cfs that was sustained over another period of days (Figure 4.1) to test the precision of the sediment transport monitoring. Sediment samples were collected after each of the two flow levels stabilized.

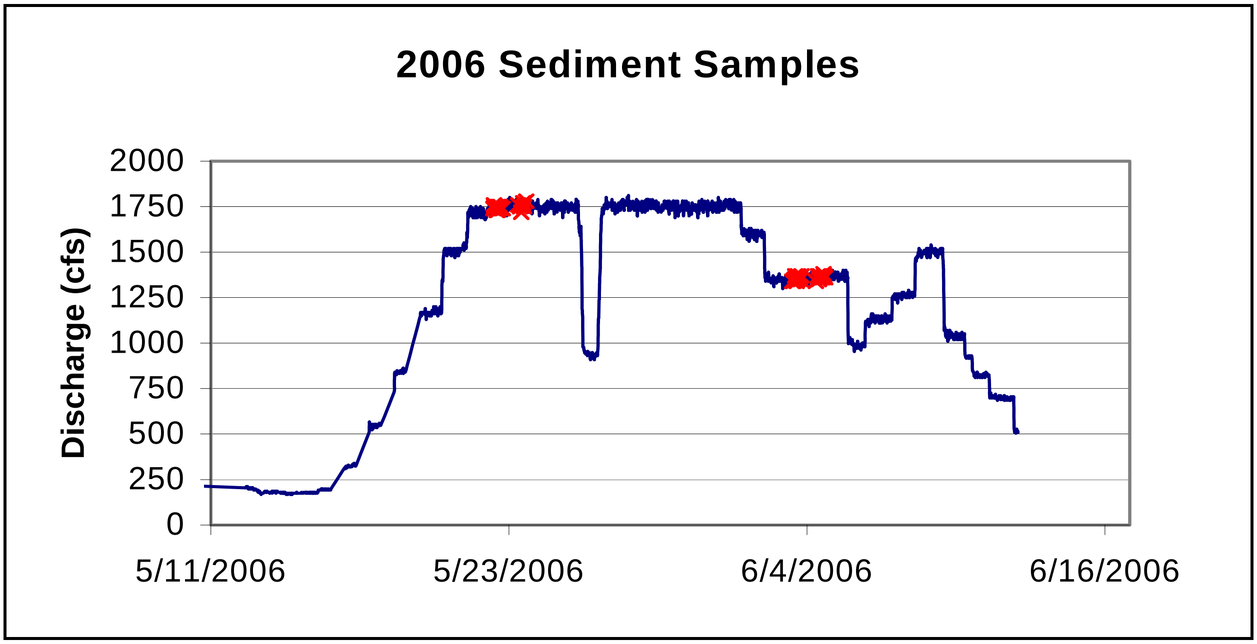


Figure 4.1. The 2006 spring runoff hydrograph showing when numerous repeat sediment samples were collected (indicated by red “x”s) on May 22-23 and June 3-4 at approximately 1,750 and 1,350 cfs.

4.2.3 Suspended Sediment Monitoring

A number of repeat sediment samples were collected at WB and MID during sustained discharges of 1,750 and 1,350 cfs. Average suspended sediment concentrations in the water column were determined for each sample 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 Depth-Integrated Hand Line Type Model US DH-76 Suspended Sediment Sampler (Photo 4.1), which was dipped from the surface to the bottom of the water column at a minimum of ten equal intervals across the channel. Sample bottles were labeled in the field, stored until the end of the sampling season, and analyzed for total suspended sediments concentrations at the Utah State University (USU) Soils Lab using standard filter and oven-drying methods.

4.2.4 Bedload Monitoring

Field samples of bedload were collected at the two bridge locations using a 6-inch Helley-Smith-type sampler. Bedload samples were collected at WB on May 22 and June 3 when flows were constant at 1,750 cfs and 1,350 cfs respectively. Bedload samples were collected at MID on May 23 and June 4 when flows were constant at 1,750 cfs and 1,350 cfs respectively. To sample bedload, the sampler was lowered onto the bottom of the channel for a total of 30 minutes. The samples were composites of either three 10-minute sub-samples or ten 3-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: > 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 visually 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 (in tons across the active channel width for the entire day).

4.3 Sediment Transport Results

Results of the 2006 monitoring are provided in Figures 4.2 –4.4. All raw sediment data (2002–2005) and the empirically derived suspended and bedload sediment transport rating curves for each monitoring site, showing the relationship between flow and transport rates, are provided in Appendix 4.1 of the 2005 Provo River Monitoring Report (Olsen 2006).

Photo 4.1. Depth-Integrated Hand Line Model US DH-76 and sampler holder.

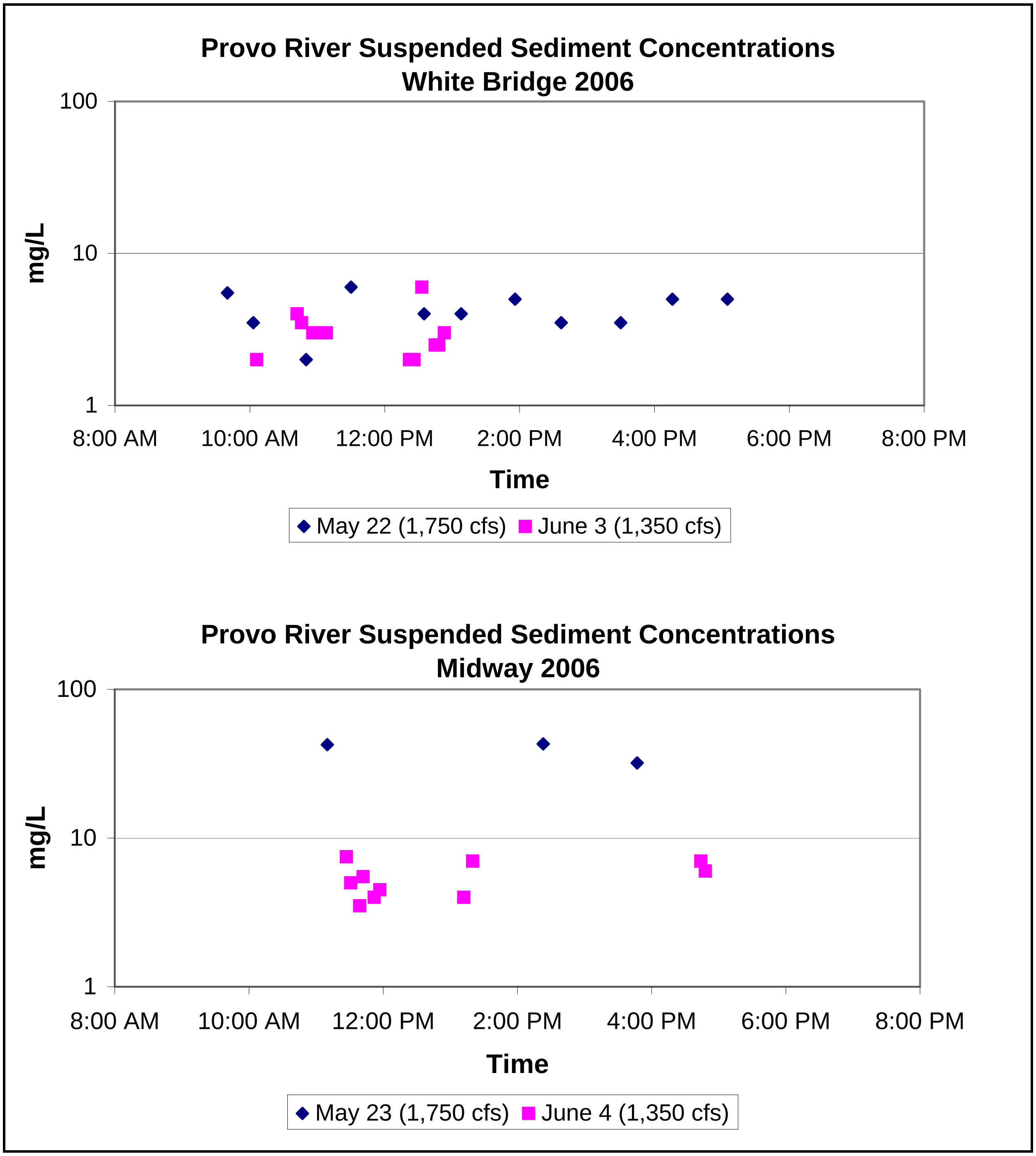


Figure 4.2. Provo River suspended sediment sample concentrations (milligrams per liter) during two high flows at White Bridge and Midway Bridge in 2006.

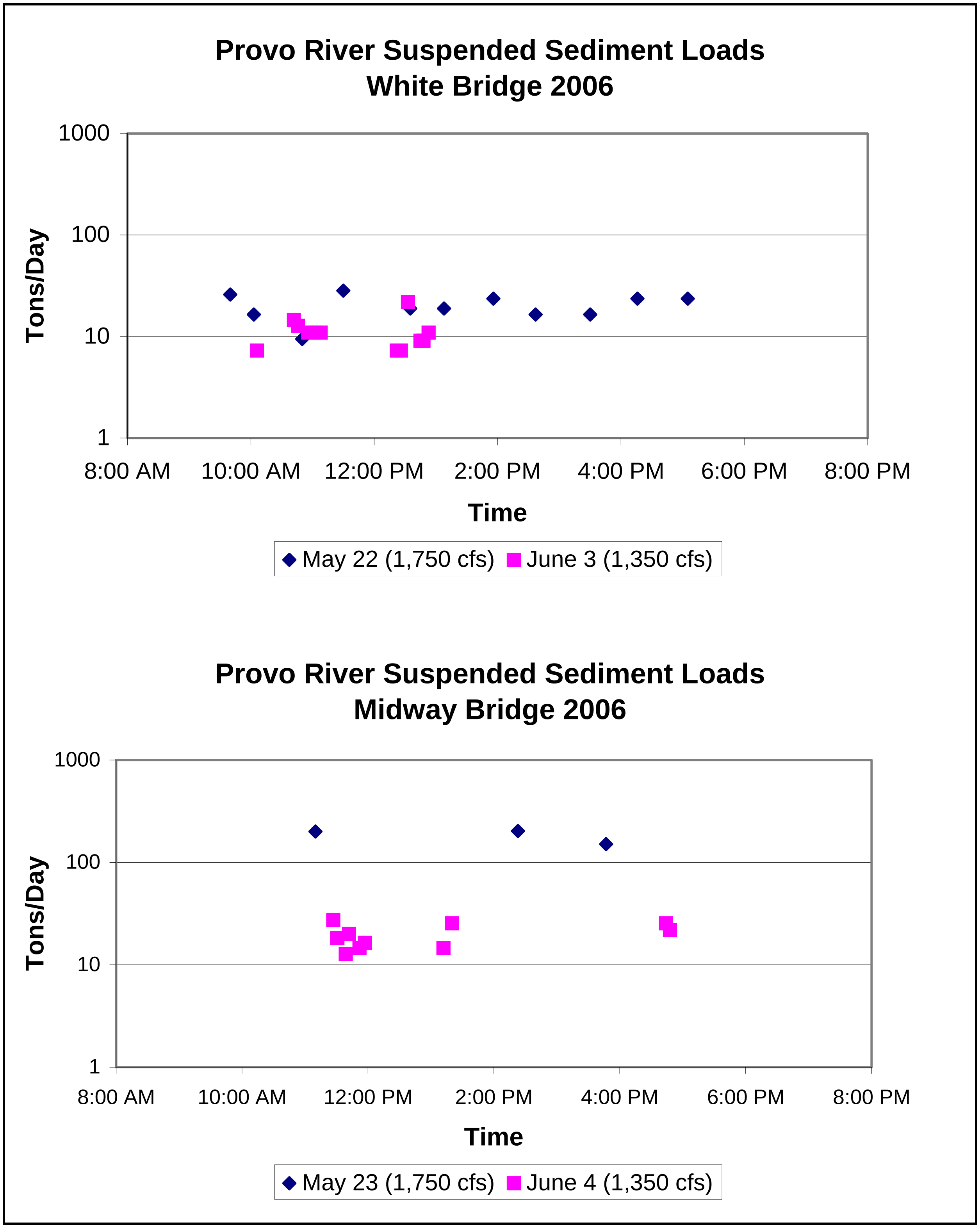


Figure 4.3. **Provo River suspended sediment loads (tons per day) during two high flows at White Bridge and Midway Bridge in 2006.**

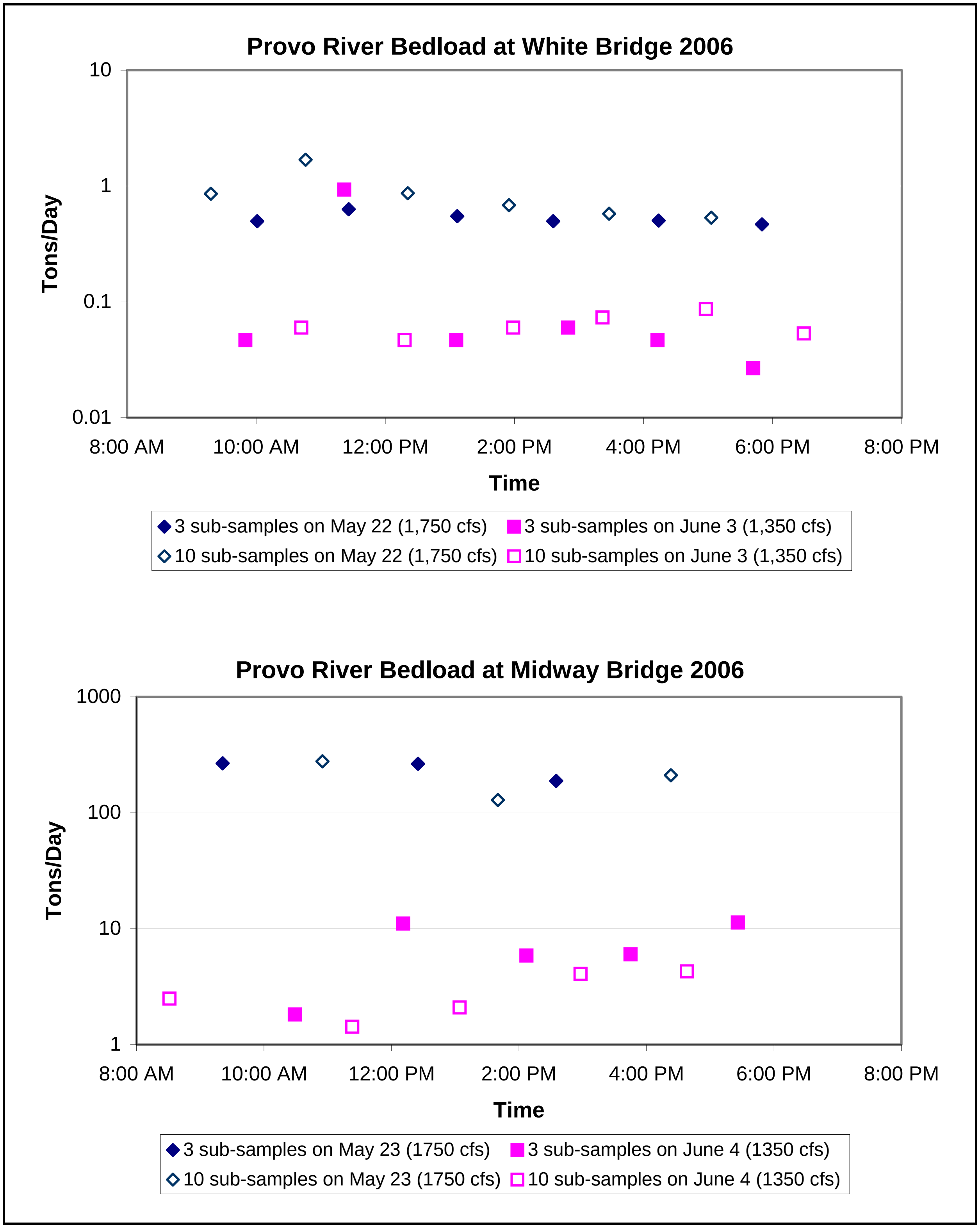


Figure 4.4. **Provo River bedloads (tons per day) at two high flows at White Bridge and Midway Bridge in 2006.**

4.3.1 2006 Suspended Sediment Transport Results

Suspended sediment concentrations were graphed over time to illustrate the variability between samples during the same day and same flow (Figure 4.2). Additionally, streamflow values were converted to daily suspended sediment loads by multiplying the suspended sediment concentration (milligrams per liter) by the flow (cfs) and applying a conversion factor (0.002697) to make the units consistent and provide a suspended sediment transport rate in tons per day (Figure 4.3).

Concentrations and loads of suspended sediment at the WB site show little difference between the 1,750 and 1,350 cfs repeat samples, whereas concentrations and loads of suspended sediment farther downstream at the MID Bridge are very different (more than one order of magnitude) between the 1,750 and 1,350 repeat samples (Figure 4.2 and Figure 4.3). Suspended sediment concentrations at the MID Bridge site are higher than the WB site at the same flows. The difference between concentrations at the two sites becomes greater as flows increase. Sampling precision increases at the MID site as flows increase.

When the suspended sediment concentrations are applied to the volume of water moving through the study sites over the course of 1 day WB has little difference in transport between the two sampled flow stages. Midway transports one order of magnitude more suspended load during the 1,750 cfs flows than the 1,350 cfs flows (Figure 4.3).

4.3.2 2006 Bedload Transport Results

Bedload transport results for WB and MID are very flow dependant and are also highly influenced by distance from Jordanelle Dam (Figure 4.4). Bedload transport at WB is one-order of magnitude higher when flows are at 1,750 cfs than when flows are decreased to 1,350 cfs. Bedload transport at MID is nearly two-orders of magnitude higher when flows are at 1,750 cfs than when flows are decreased to 1,350 cfs. Therefore, changes in flow between 1,350 cfs and 1,750 cfs affect bedload transport rates more significantly at MID than WB.

Transport rates also vary greatly between sites at the same flow. At 1,350 cfs and 1,750 cfs, the WB site transports around 0.1 and 1.0 ton of bedload sediment per day, respectively, while the MID site transports around 2.0 and 200 tons of bedload per day, respectively, at the same flow. Bedload transport increases by more than two orders of magnitude between sites during peak flows. The sites are only 7.08 miles apart without any known sources of sediment other than “in-channel”sources between the sites.

As in the case of suspended sediment, the bedload monitoring results are more precise at both sites at the 1,750 cfs flow than 1,350 cfs regardless of methods (three verses ten sub-samples). Precision between samples are better when transport rates are greater.

The 11:30 A.M. 1,350 cfs bedload sample at WB is an outlier. The method used for this sample was the three sub-sample method. One thing to consider as an explanation for this outlier is that the overall sample weight (on average) is very low at this site at this flow, and a few particles of gravel could influence the load calculations significantly. The repeat samples at the same flow using both methods indicates that there was either more bedload moving and we happened to catch it in only one sample, or that for some reason this sample was contaminated (bad placement of the sampler on the bed causing the sampler to scoop some of the "stationary" bed material, or something like that). We suspect that this sample inadvertently collected more particles than was actually moving on average during the day, whether it was sampling error or an anomaly that we happened to capture. This flow is near the threshold for bedload transport at this site so it is possible to capture small short duration surges in transport rates. This result indicates a need for repeat samples at the same flow to assure consistency, especially during lower flows.

One other noticeable difference in the data is that the ten sub-samples at WB at 1,750 cfs on average is slightly greater than the three sub-samples, especially early in the day. The precision of the three sub-samples is greater at the WB site at 1,750 cfs, and more consistent throughout the day. Even though there is a slight difference in mean transport rate at this site at this flow, either method adequately demonstrates significant differences in bedload transport between flows within a site, and at the same flow between sites.

the result of this analysis indicates that previously developed rating curves and the previously documented differences between monitoring sites are not significantly affected by sampling method. Although some outlier sample points have occurred over several years of bedload sampling, the ten sub-sample versus the three sub-sample method has little to no effect on precision or accuracy of monitoring bedload at the WB and MID Bridges (Figure 4.4).

4.4 Sediment Transport Discussion and Recommendations

The daily suspended sediment transport methods used in previous Provo River Monitoring Reports (Olsen et al, 2005 and 2006) are precise within a 1–2 times variance with less variance at peak flows. While the results of the 2006 monitoring data show that a three sub-sample method is as accurate and precise as the ten sub-sample method, it is also recognized that judgement error on exact sampler placement is less likely when using the ten sub-sample method. Therefore, the ten sub-sample method is recommended for any future bedload sampling of the middle Provo River. Previous bedload estimates/calculations reported on the middle Provo River are considered accurate based on the 2006 data and the recommendations developed from such numbers remain unchanged.

Sediment transport is affected by increased peak flows more at the MID site than directly below Jordanelle Dam at the WB site. This result is not surprising because there are limited supplies of in-channel sediment near Jordanelle Dam. The small amount of bedload transport occurring at the WB site indicates that the middle Provo River above WB is a source-limited reach, meaning that there is very little material for the river to transport in this reach regardless of peak flows. To ensure a healthy riverine ecosystem it is further suggested that bedload and suspended load monitoring be repeated every 3–5 years to access the effectiveness of gravel augmentation activities on the middle Provo River.

The empirical equations developed from bedload monitoring over the past 5 years (Figure 4.5) are relatively accurate and can effectively be used in determining the amount of gravel that needs to be augmented below Jordanelle Dam. The flat flow/bedload transport relationships at BJ and RR are unnatural and directly related to the trapping influence of Jordanelle Dam. Gravel is of upmost importance to the PRRP given a constant supply is essential in promoting channel dynamics and maintaining a healthy riverine ecosystem. It is recommended that annual augmentation rates are based on the projected hydrograph, which is available by early May for the middle Provo River and the bedload transport power equation developed at the CA site. The CA site was selected because it represents a moderate amount of channel dynamics (more than BJ and RR but much less than NC), and is the best site to quantify outgoing loads from the middle Provo River.

Sand is also an important component of bedload transport and promotes cottonwood recruitment. However, a decision needs to be made whether to augment the suppressed sand and gravel supplies below Jordanelle Dam using the total bedload transport equation (left graph) or just gravel (right graph) in Figure 4.5. See Chapter 6 for a complete list of future monitoring and adaptive management recommendations.

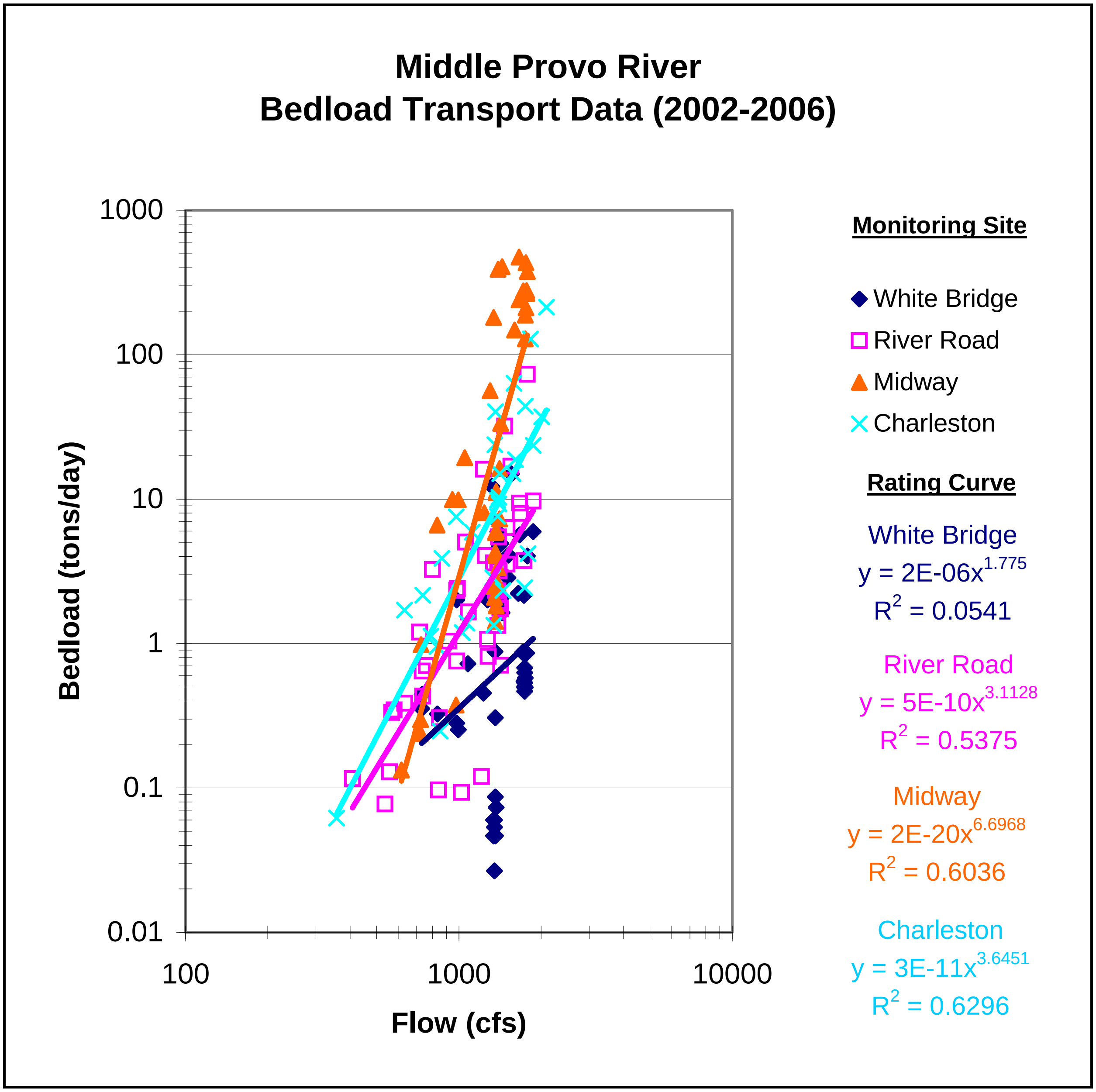


Figure 4.5. Empirically derived bedload rating curves for the middle Provo River.

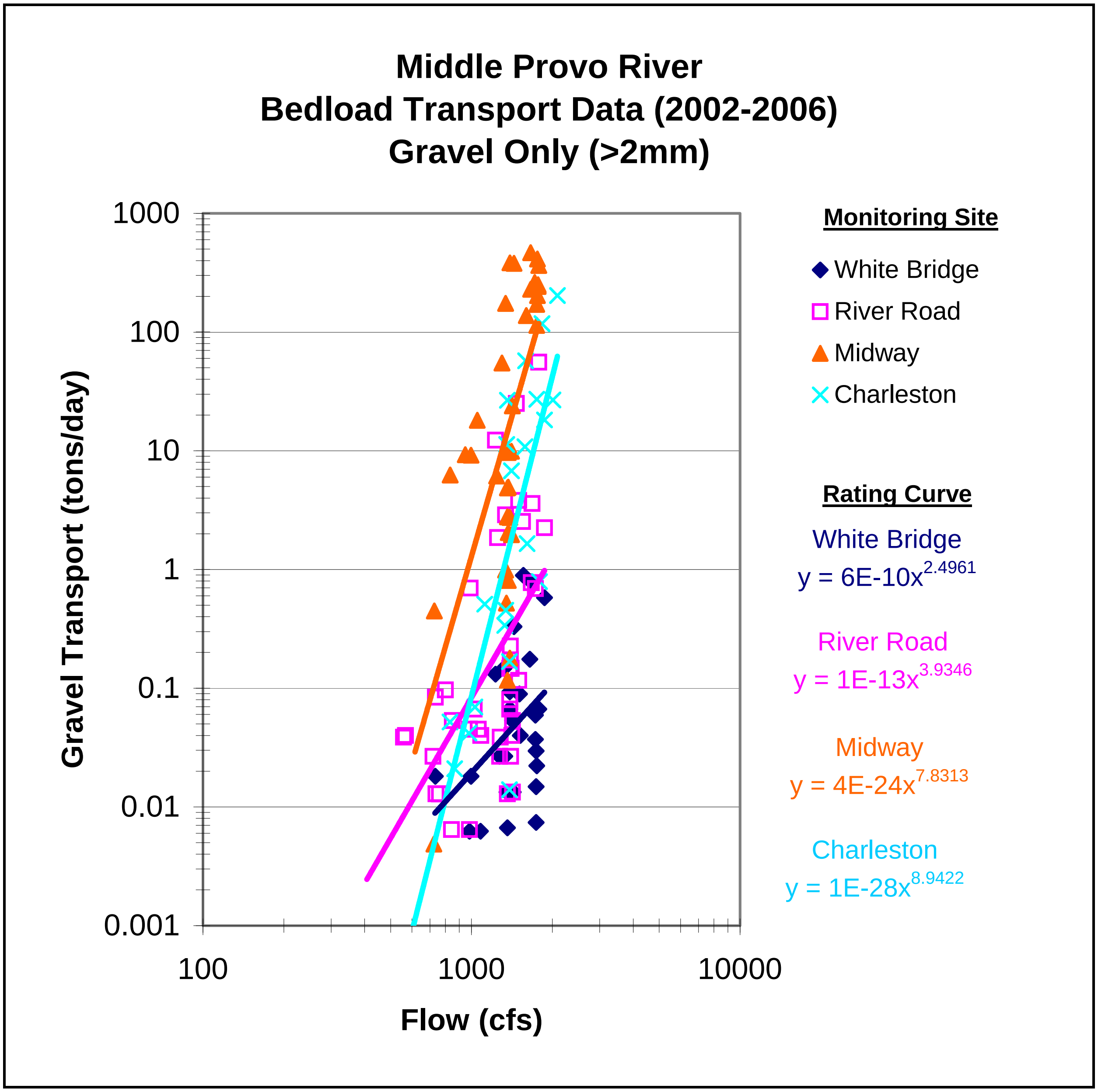


Figure 4.5. Empirically derived bedload rating curves for the middle Provo River (cont.).

5.0 MACROINVERTEBRATE SAMPLING

5.1 INTRODUCTION

This section describes the results of the 3 years of quantitative, benthic macroinvertebrate monitoring on the middle Provo River conducting after the PRRP project. Macroinvertebrates are a critical component of a healthy trout fishery and adequate 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

Quantitative and qualitative sampling for benthic macroinvertebrates was conducted in April/May (spring sample) and again in September (autumn sample) of each year between 2004–2006 within each of the four long-term monitoring sites outlined in the previous chapters. A riffle was chosen within each site 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, depth, and water velocity 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 habitats sampled with a Hess sampler are very similar, estimates of richness and abundance between sites should be directly comparable. The location of the nearest cross section to each quantitative (Hess) sample site (three replicate samples) is shown on the map of monitoring sites (Figures 2.1a–2.1d). In most cases, the same riffles were sampled in each site during each successive sample, but some variation in habitat conditions (particularly in the CA site) resulted in changes in location to areas that are conducive to collecting Hess samples.

In addition to the Hess samples, one multi-habitat, composite kick net sample was collected at each site. The composite kick net sample involved sampling 20 locations using a D-frame kick net (Barbour et al. 1999) in a combination of habitat types that were in proportion to their availability in each monitoring site. To conduct composite kick net sampling, 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 the 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 areas were disturbed and the D-frame net was 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 (ml) and 500 ml 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 randomly selecting a grid and picking all organisms out of that grid. Grids were selected and sorted in this way until 500 organisms had been picked or until the entire sample had been sorted. Extrapolating counts from the number of grids sorted to the remaining grids allowed for estimates of the total number (abundance) of each taxa collected in each sample. All organisms were identified to the genus/species level, except for midges, which were identified to family, 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 years and sites sampled in 2004–2006. 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 from the 1999 samples is presented as invertebrate density values (number per square meter). To be comparable to past data, and to account for any areal differences in the sampling gear, abundance data from the 2004–2006 samples were converted into density values. Hess samplers have a 0.086-square meter open bottom area for sampling (WILDCO 2006), which was used to convert macroinvertebrate abundance data into density values (numbers per square meter). A variety of data transformations were used to fit the selected metrics to the normal distribution. The data were segregated by season and an analysis of variance (ANOVA) was used to test for differences between sites within years and within sites between years. 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 2004–2006 sites) with data from the samples collected in September 2004–2006.

5.3 RESULTS

5.3.1 2004–2006

A complete list of the taxa found and metrics generated for each sample can be found in Appendix 5.1. The metrics used for comparing macroinvertebrate communities are total density of all macroinvertebrates (total abundance for kick-net samples), density/abundance of Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies) (collectively referred to as EPT), total taxa richness, EPT taxa richness, the Hilsenhoff Biotic Index (HBI), and the proportion of the community that is comprised of the three most dominant taxa. The relevance of and calculated values for each of these metrics from 2006 samples is described below.

Estimates of the total density of macroinvertebrates provide a coarse method of comparing biological conditions across sites. It is coarse because a high overall density may not indicate a high quality macroinvertebrate community if it results from an abundance of tolerant species. In fact, higher total density is often associated with nutrient enrichment and a degraded condition. Hess samples collected in 2006 showed generally similar total macroinvertebrate density at the BJ, NC, and CA sites in the spring with much higher density in the RR site (RR density was significantly higher than CA [p = 0.028]). By autumn density had decreased in RR and increased slightly in CA such that all four sites had similar density values (Figure 5.1).

Evaluating the data collected over the 3 years of sampling provides more insight about recent trends in the macroinvertebrate community. Among spring samples, the total density in most sites was highest in 2005 in most sites, followed by 2006, with the lowest densities in 2004. An ANOVA test of the combined density from all sites within each spring sample showed a significant difference among years (p = 0.024) with 2005 significantly higher than 2004; the mean density for 2006 was slightly lower than in 2005, but not significantly higher than 2004. The three autumn samples were very similar in most sites except in the RR site, where density was higher in 2005 than either 2004 or 2006, but no significant difference was found in combined data among years. An ANOVA test of the combined density among all sites within each autumn sample showed no significant difference among years. When the total macroinvertebrate density data were combined across the 3 years and a comparison conducted among sites, no significant differences were found between sites in spring, but in autumn, BJ had a significantly lower total density than RR (p = 0.049).

When the total macroinvertebrate density data were evaluated without combining across years or sites, most comparisons were not significant. An ANOVA conducted on the data comparing among sites within years, found only one significant difference: the total density at RR was significantly higher than in CA during spring 2006 (p = 0.028). When an ANOVA was conducted to compare among years within sites, only two significant differences were observed: in spring samples at BJ there was a significantly higher density in 2005 than 2004 (p = 0.047), and in spring samples in RR there was a significantly higher density in 2006 than 2004 or 2005 (p = 0.029).

Total abundance information from qualitative kick net samples supported the primary trend of higher values in spring 2005 compared with spring 2004 seen in the density data collected using the quantitative Hess sampler in 2004 and 2005 (Figure 5.2). Total abundance information indicated higher numbers of macroinvertebrates in spring 2005 vs. spring 2004 at all sites. The opposite was true in autumn kick-net samples (values from all sites were higher in 2004 than 2005), but this does not compare well with in the autumn data collected with the Hess sampler which indicated no distinct trends. In 2006, the results were more variable. Higher total abundance of macroinvertebrates were collected in BJ and NC during spring 2006 compared to 2005, but the abundance was much lower than previous samples in CA and RR during spring 2006. All sites had higher abundance in autumn 2006 compared with 2005, but three of the four sites were still lower than in 2004 (NC was the exception). Among sites NC had the lowest total abundance in qualitative

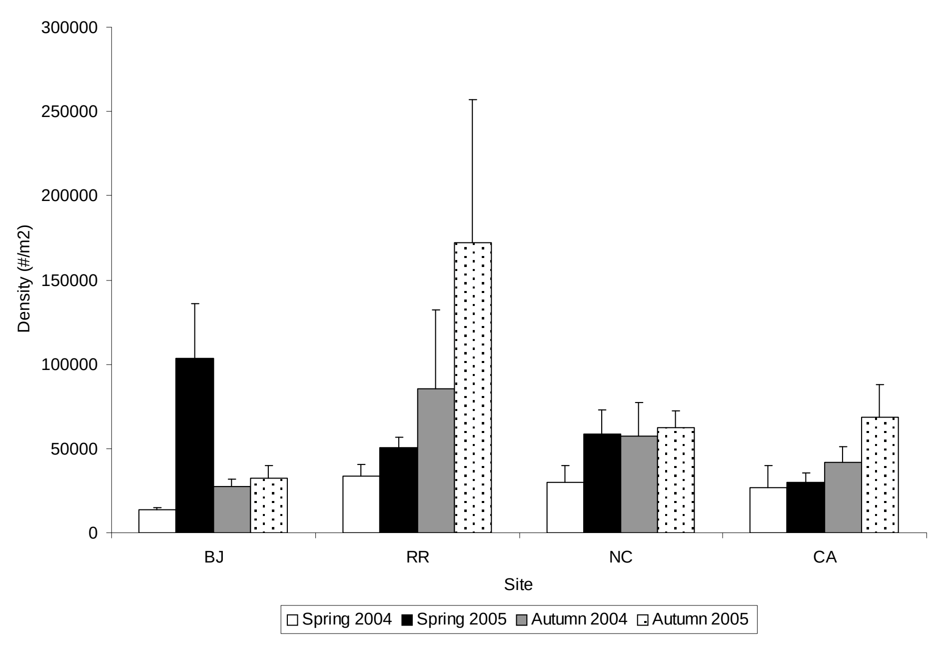


FIGURE 5.1. AVERAGE DENSITY OF MACROINVERTEBRATES (NUMBERS PER SQUARE METER) CALCULATED FROM THE THREE HESS SAMPLES TAKEN AT EACH SITE IN SPRING AND AUTUMN 2004 AND 2005. ERROR BARS REPRESENT +/- 1 STANDARD ERROR.

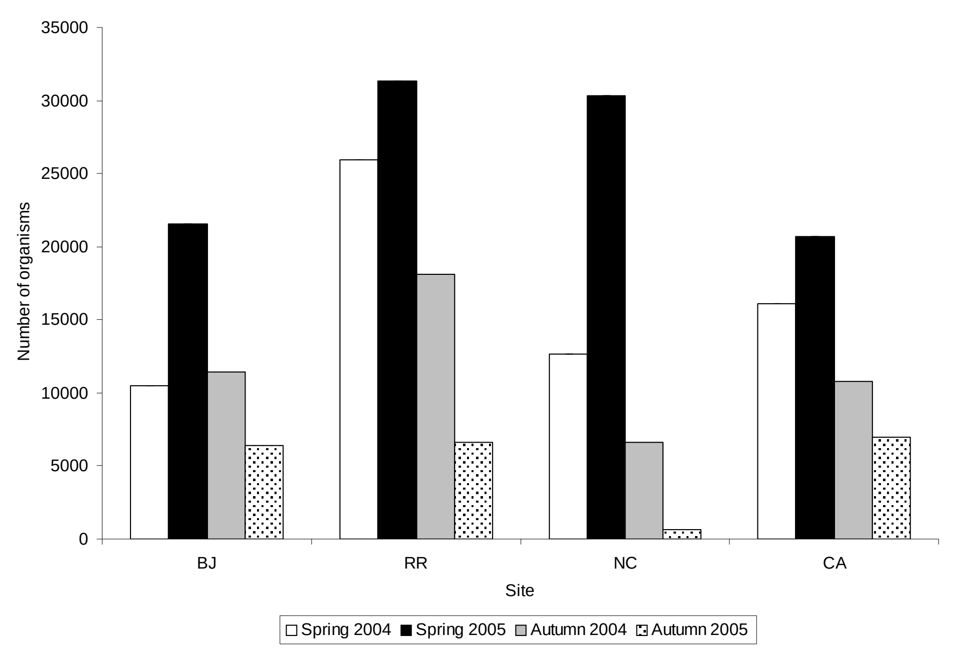


FIGURE 5.2. TOTAL ABUNDANCE OF MACROINVERTEBRATES COLLECTED IN COMPOSITE D-FRAME KICK NET SAMPLES AT EACH SITE IN SPRING AND AUTUMN 2004 AND 2005.

kick net samples in autumn of 2004 and 2005, but had the highest value among sites in autumn 2006. There were no apparent trends among sites in spring samples. It should be noted that the estimates of total abundance from the composite kick net samples are less reliable than the density estimates generated from the Hess samples. There are two reasons for this. First, despite the attempts to standardize the amount of area 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, which may have a higher or lower macroinvertebrate density than riffles.

The EPT taxa are generally thought of as sensitive to anthropogenic disturbance and provide a means of comparing macroinvertebrate community dynamics among sites at a finer scale than just comparing total density of all organisms. Hess samples collected in 2006 generally had similar EPT taxa density at the RR, NC, and CA sites in the spring and much lower value at BJ (significantly lower than NC [$p = 0.04$] and RR [$p = 0.027$]) (Figure 5.3). In autumn 2006, both BJ and RR were lower than the NC and CA sites, but no significant differences were observed.

Over the 3 years of sampling, Hess sample data from all sites combined showed that, similar to total macroinvertebrate density, EPT taxa density was significantly higher in spring 2005 and 2006 compared to spring 2004 ($p < 0.021$), but showed no significant difference in EPT taxa density among autumn samples. Data from samples collected in the spring of all 3 years combined indicated no significant differences among sites in EPT taxa density (prior to 2006, a significant difference was noted between BJ and NC ($p < 0.03$), but the 2006 data negated this difference). A similar lack of significant difference occurred among sites in combined data from autumn samples.

When the EPT taxa density data were evaluated without combining data across years or sites more trends in these data became apparent. In the BJ site, there has been a decreasing trend in EPT taxa abundance during autumn over the 3 years (though no significant differences among those samples) and what appeared to have been an increasing trend in the spring in this site between 2004 and 2005 (BJ had significantly higher EPT taxa density in spring 2005 than the other two spring samples [$p = 0.003$]) was negated by a dramatic decrease in EPT taxa density in that site during spring 2006. The RR site has shown a steady increase in the spring (RR had significantly higher EPT taxa density in spring 2006 than previous spring samples [$p < 0.001$]) and decrease in the fall over the 3 years of sampling. The NC and CA sites both had steady increases over the 3 years in the spring (NC had significantly higher EPT taxa in spring 2006 than previous spring samples [$p = 0.014$]) and fairly stable EPT taxa densities in the autumn over the 3 years. No significant differences were observed among years within any site during autumn samples.

In general, there were not consistent differences among sites within years, but there were two significant differences observed when an ANOVA was conducted on this data. The EPT taxa density at BJ was significantly higher than all other sites during spring 2005 ($p = 0.004$) and BJ had significantly lower EPT taxa than NC or RR in spring 2006 ($p = 0.017$).

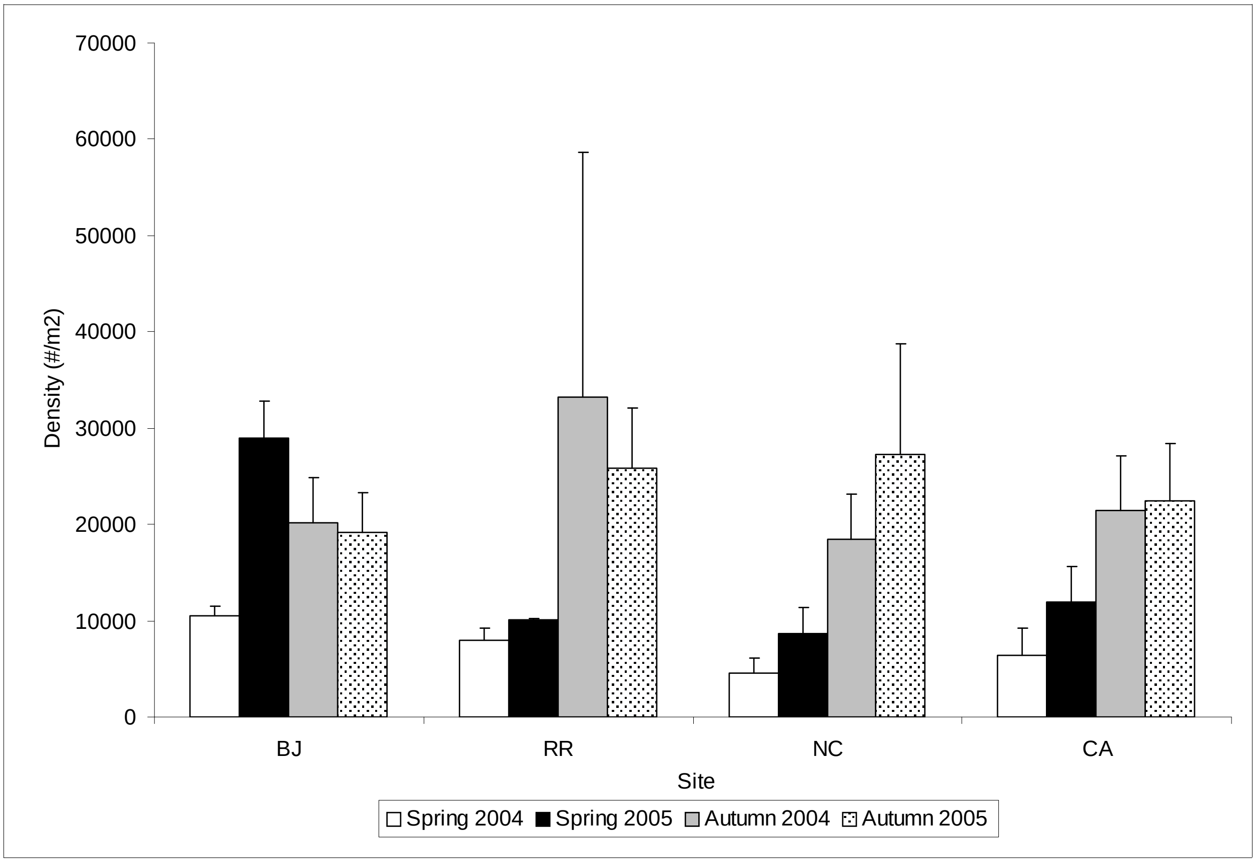


FIGURE 5.3. AVERAGE EPT TAXA DENSITY (NUMBERS PER SQUARE METER) CALCULATED FROM THE THREE HESS SAMPLES TAKEN AT EACH SITE IN SPRING AND AUTUMN 2004 AND 2005. ERROR BARS REPRESENT +/- 1 STANDARD ERROR.

Similar to total density, total abundance, and EPT taxa density, EPT taxa abundance from spring qualitative kick net samples was higher in 2005 than in 2004 (Figure 5.4), but data from 2006 did not continue on that trend. In BJ and NC, the spring 2006 EPT taxa abundance was similar to the spring 2005 sample, but in CA and RR the spring 2006 data was lower than the spring 2005 sample (this latter result was similar to the differences in total density between 2005 and 2006 in CA and RR). The changes in EPT taxa abundance in kick net samples varied greatly among sites in the autumn samples. In the BJ site the density increased in 2006 back to the 2004 level after a decline in autumn 2005. In the RR site there was a steady trend of decreasing values (similar to the Hess sample data). In the NC site there was an increase in autumn 2006 relative to 2005 and resulted in a value that was higher than in 2004. In the CA site the decrease that was observed between 2004 and 2005 was maintained at approximately the same value in autumn 2006.

Taxa richness provides an index for evaluating community diversity, but as with total density, does not discriminate taxa by tolerance to altered conditions. In 2006 there was a general trend of increasing taxa richness in a downstream direction in the spring, with the lowest value at BJ, an increase at RR, and the highest values in NC and CA (richness at BJ was significantly lower than CA and NC ($p = 0.023$ and $p = 0.013$, respectively) (Figure 5.5). In the autumn all sites had very similar taxa richness in 2006.

Over the 3 years of sampling, Hess sample data from all sites combined show that taxa richness did not differ substantially between years in either spring or autumn. Similarly, there were no substantial differences in either spring or autumn among sites when data were combined over the 3 years. When the data were evaluated within years there were significant differences among sites during spring 2004, autumn 2005, and spring 2006, but no consistent trend over time. In spring 2004 taxa richness in CA was significantly lower than the three other sites ($p < 0.001$). In fall 2005 taxa richness in the RR site was significantly lower than the CA and NC sites ($p < 0.01$). In spring 2006 taxa richness in BJ was significantly lower than in CA or NC ($p = 0.023$ and $p = 0.013$, respectively). When the data were evaluated within sites there were significant differences among years in the spring samples in NC and CA. In the NC site taxa richness was significantly higher in spring 2006 than previous spring samples ($p < 0.01$). In the CA site there has been a distinct trend of increasing taxa richness over the 3 years. In that site taxa richness was significantly lower in spring 2004 than spring 2005 ($p = 0.001$) or spring 2006 ($p < 0.001$). Taxa richness was also significantly higher in spring 2006 than spring 2005 ($p = 0.035$).

Similar to the Hess samples, taxa richness in qualitative kick net samples also showed a trend of increasing taxa richness downstream with NC and CA generally having higher taxa richness than BJ and RR (Figure 5.6). Both the BJ and RR sites have a trend of decreasing taxa richness over time in autumn and the BJ site also has a similar trend across spring samples. In the NC and CA sites, there is generally a trend of increasing taxa richness over time in both spring and autumn (except in the most recent autumn sample in NC). The results in the CA site are consistent with the significant increase in taxa richness observed over the 3 years in Hess samples during spring.

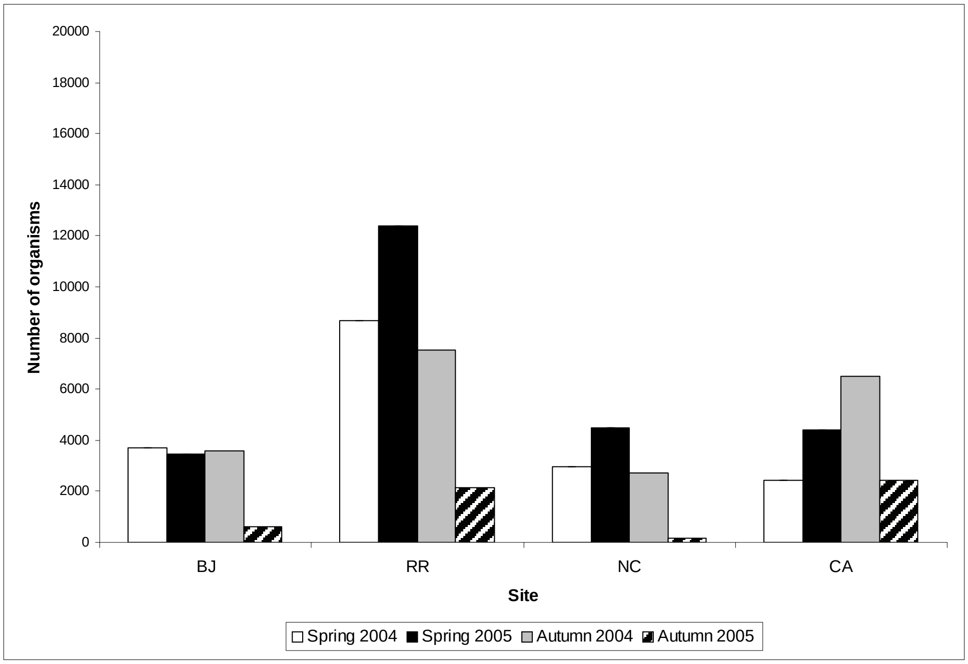


FIGURE 5.4. ABUNDANCE OF EPT TAXA COLLECTED IN COMPOSITE D-FRAME KICK NET SAMPLES AT EACH SITE IN SPRING AND AUTUMN 2004 AND 2005.

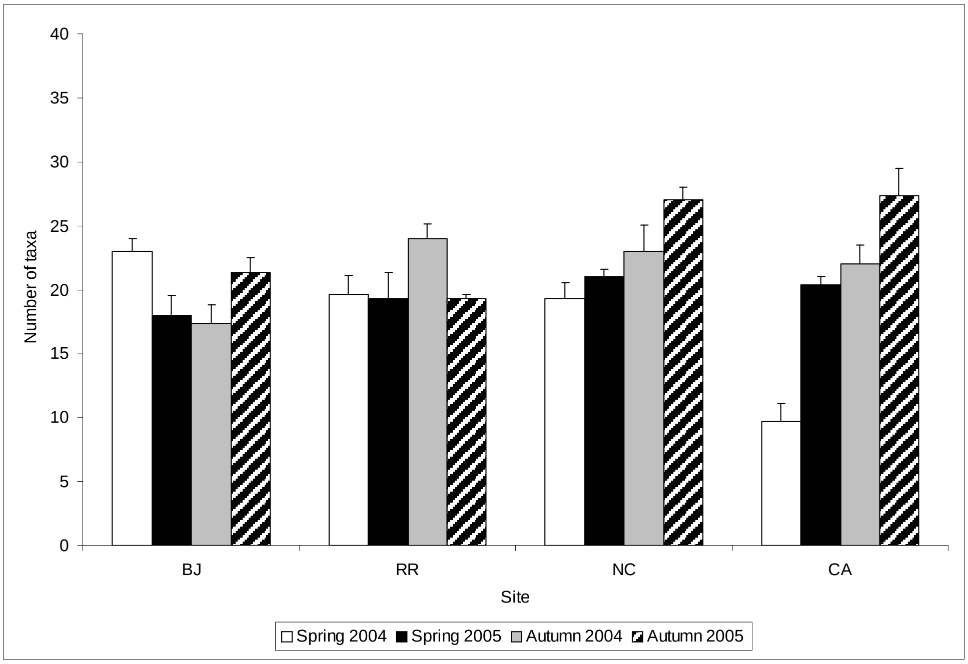


FIGURE 5.5. AVERAGE TAXA RICHNESS CALCULATED FROM THE THREE HESS SAMPLES TAKEN AT EACH SITE IN SPRING AND AUTUMN 2004 AND 2005. ERROR BARS REPRESENT +/- 1 STANDARD ERROR.

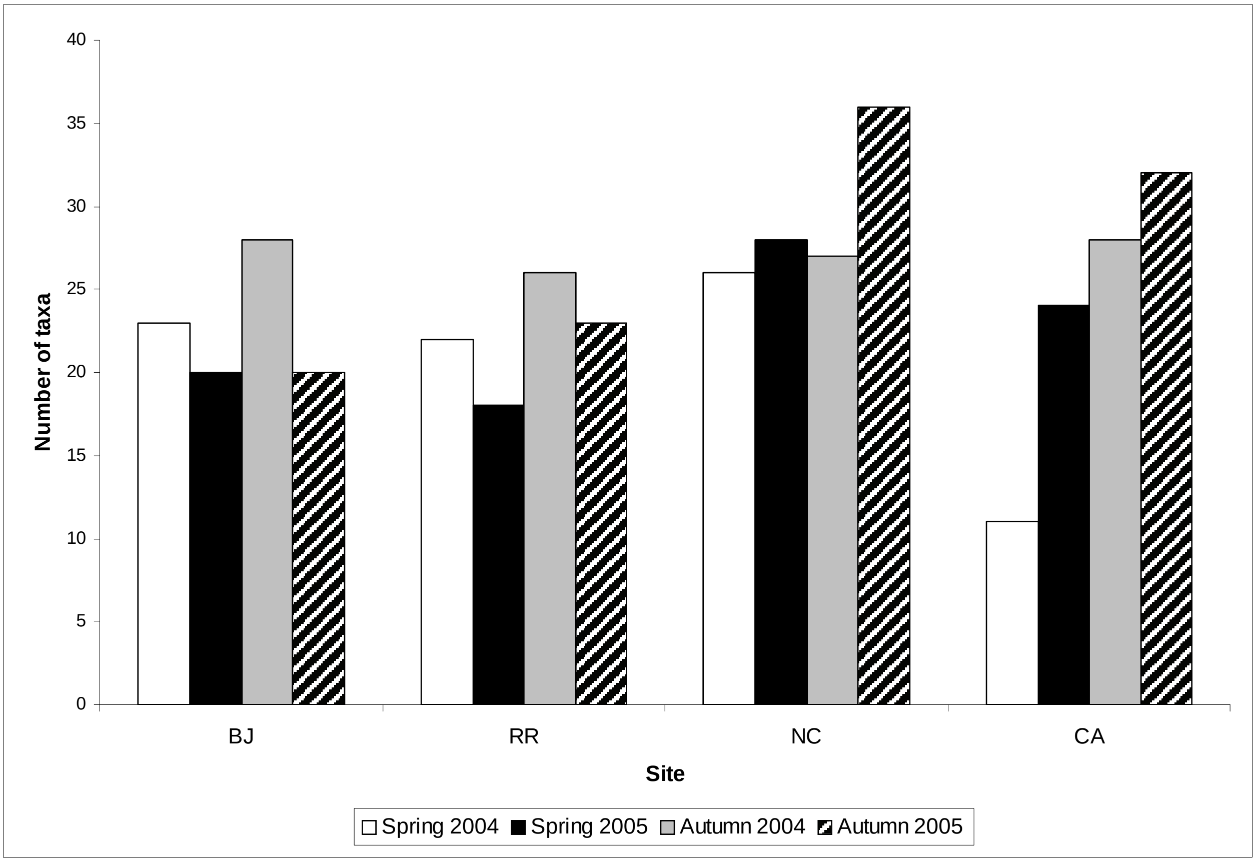


FIGURE 5.6. TAXA RICHNESS IN COMPOSITE D-FRAME KICK NET SAMPLES AT EACH SITE IN SPRING AND AUTUMN 2004 AND 2005.

The EPT taxa richness (Figure 5.7) followed a trend similar to total taxa richness. Data collected in spring 2006 had fewer taxa in the upstream sites, while in autumn the number of taxa was similar at all sites. When the data for each site were combined, no significant differences were observed among years either in spring or autumn samples. When the data were combined across years, there was a significant difference among sites in the autumn, with the NC site significantly higher than the BJ site ($p = 0.039$). Prior to collection of the 2006 data, CA had significantly lower EPT taxa richness in spring when data were combined for 2004 and 2005, which may have been influenced by the low richness observed immediately after restoration activities in 2004. The EPT taxa richness was significantly higher in spring 2005 than spring 2004 ($p = 0.001$), which was collected immediately following construction activities. In spring 2006 the EPT taxa was again significantly higher than the previous spring sample ($p = 0.026$). Average EPT taxa richness from Hess samples at CA in spring 2004 was significantly lower than that from the remaining sites sampled in spring 2004 ($p < 0.002$). Comparisons among sites within years also revealed that BJ had significantly lower EPT taxa richness than NC and RR in autumn 2004 ($p = 0.027$) and lower than NC and CA in spring 2006 ($p = 0.011$). Richness of EPT taxa from qualitative kick net samples at each site supported these results (Figure 5.8). EPT taxa richness in kick net samples showed a stable taxa richness in the BJ site, which was generally lower than the other sites and an increasing trend over time at RR and CA.

The HBI provides an indication of the overall pollution tolerances of the macroinvertebrate community in a site from 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.

In 2006 the mean HBI value among the three replicate Hess samples at each site was similar among sites during both spring and autumn (Figure 5.9). In the 2004 and 2005 data, the BJ site tended to have a lower HBI score among sites within each year (Figure 5.10). When data from both 2004 and 2005 were combined, the average spring and autumn HBI value from Hess samples at BJ was significantly lower than the remaining three sites ($p < 0.03$). With the 2006 data added, the HBI value at BJ remained significantly lower than RR in the autumn ($p = 0.001$) but not the other two sites. The HBI value also remained significantly lower in BJ than NC ($p = 0.008$) in the spring when 2006 data were added, but not the other two sites. With the exception of the spring 2004 HBI value from BJ, average HBI scores from Hess samples at all sites in both seasons and all 3 years would fall into the “enriched” category. The average HBI value at BJ in spring 2004 was in the “slightly enriched” category. Overall, there appears to be a trend of increasing HBI values in BJ and to a lesser extent in RR and a decreasing trend in both NC and CA.

The HBI values from qualitative kick net samples do not indicate a lower score at BJ and would place all sites in the enriched category for all collection times. The lowest HBI scores in kick net samples were seen at RR, and no trend was evident at any of the sites.

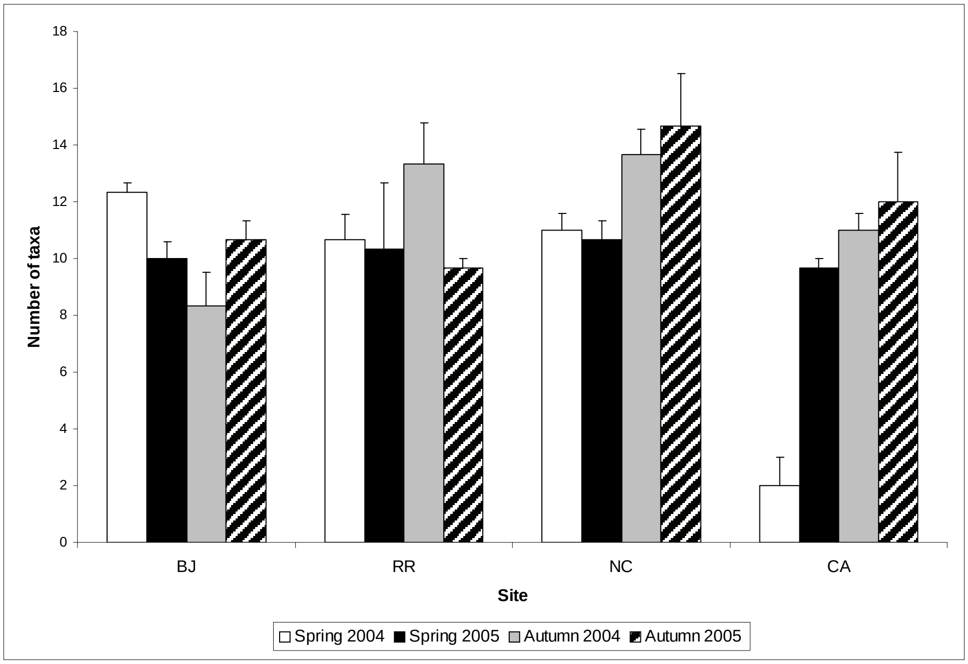


FIGURE 5.7. AVERAGE EPT TAXA RICHNESS CALCULATED FROM THE THREE HESS SAMPLES TAKEN AT EACH SITE IN SPRING AND AUTUMN 2004 AND 2005. ERROR BARS REPRESENT +/- 1 STANDARD ERROR.

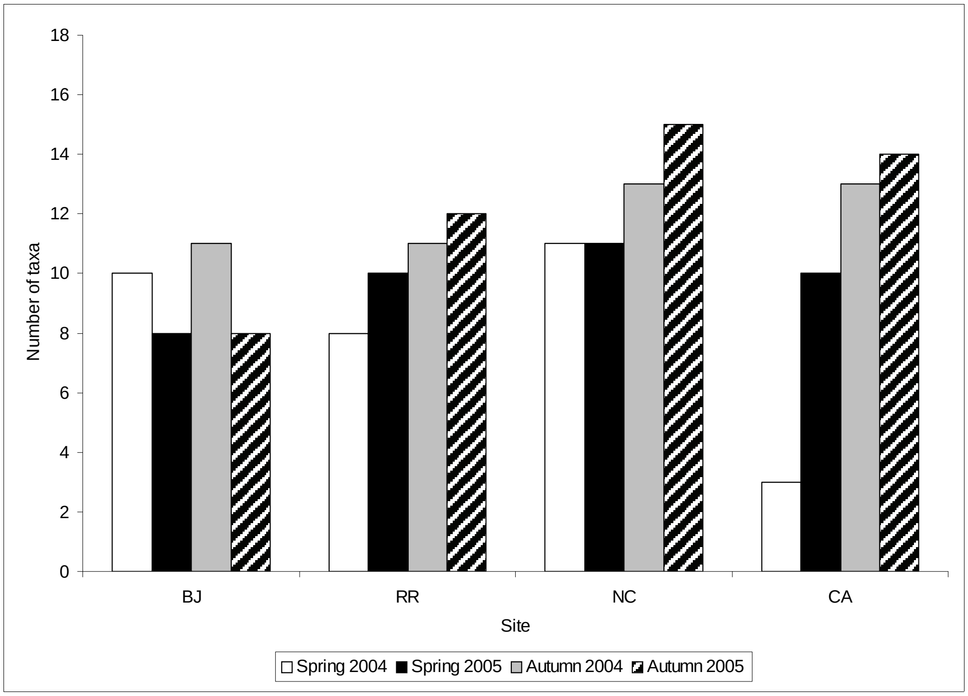


FIGURE 5.8. EPT TAXA RICHNESS IN COMPOSITE D-FRAME KICK NET SAMPLES AT EACH SITE IN SPRING AND AUTUMN 2004 AND 2005.

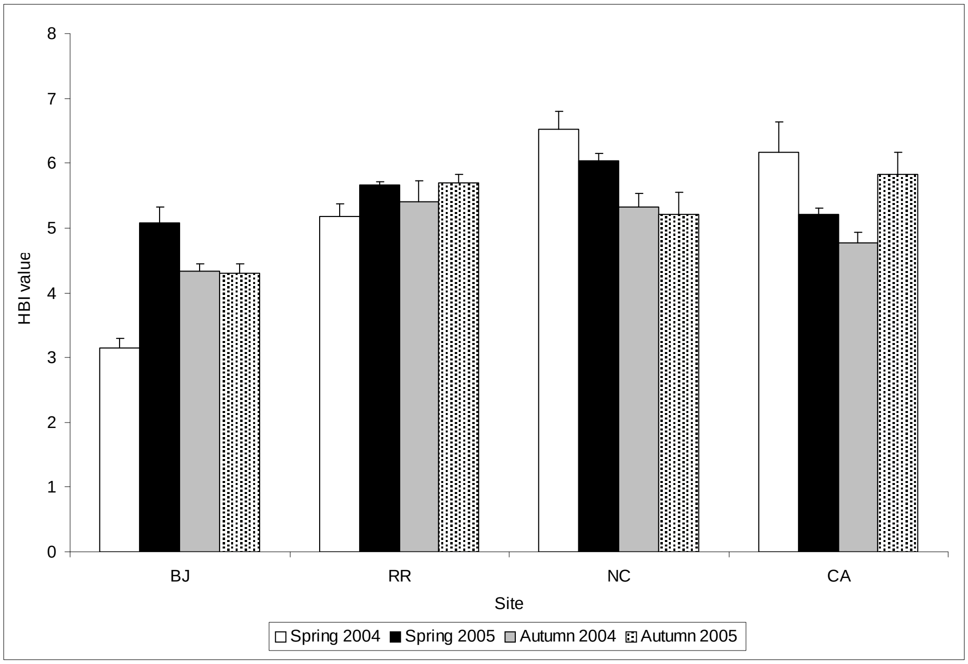


FIGURE 5.9. AVERAGE HILSENHOFF BIOTIC INDEX (HBI) VALUE CALCULATED FROM THE THREE HESS SAMPLES TAKEN AT EACH SITE IN SPRING AND AUTUMN 2004 AND 2005. ERROR BARS REPRESENT +/- 1 STANDARD ERROR. A HBI SCORE OF 0-2 = CLEAN, 2-4 = SLIGHTLY ENRICHED, 4-7 = ENRICHED, AND 7-10 = POLLUTED.

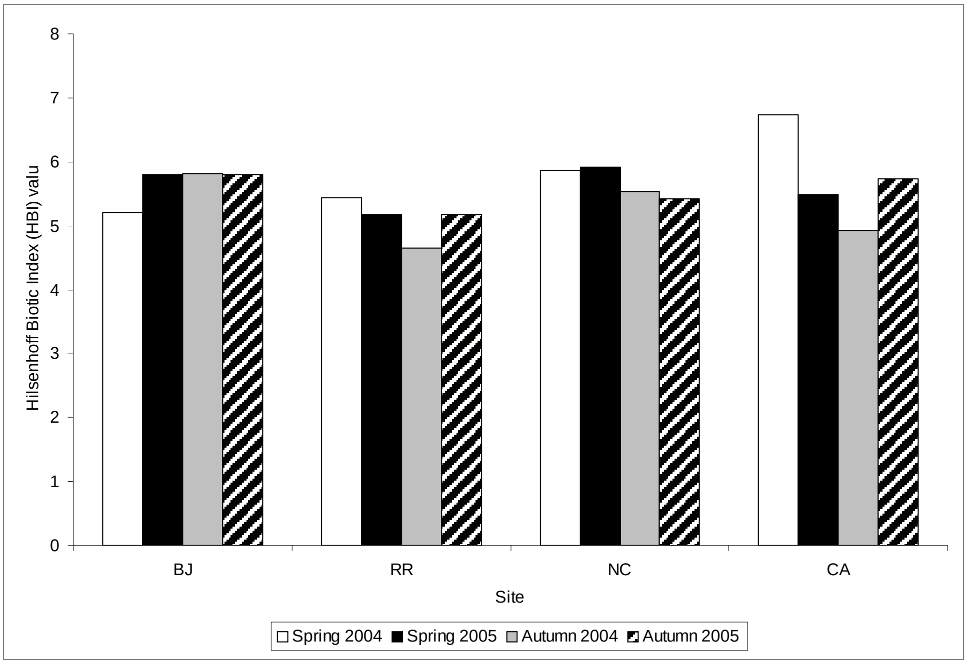


FIGURE 5.10. HILSENHOFF BIOTIC INDEX (HBI) VALUE IN COMPOSITE D-FRAME KICK NET SAMPLES AT EACH SITE IN SPRING AND AUTUMN 2004 AND 2005. A HBI SCORE OF 0-2 = CLEAN, 2-4 = SLIGHTLY ENRICHED, 4-7 = ENRICHED, AND 7-10 = POLLUTED.

Examining the proportion of the community that is comprised of the three most dominant taxa provides an index of evenness in the community. Up to 21 percent of the total number of organisms might be found in the most dominant taxon in high-quality streams in the Wasatch and Uinta Mountains, while the three most dominant taxa might comprise up to 50 percent of the total number of organisms (Grafe 2002a, Lester 2005). Additionally, examining the three dominant taxa at a site can provide additional information about what impacts may be affecting that site. The average proportion of the community made up of the three dominant taxa was higher than 60 percent in all sites and sample periods during the 3 years of monitoring (Figure 5.11). There was some variation in the data among sites and years, however. The proportion of the three dominant taxa at CA in autumn (all years combined) was significantly lower than all other sites ($p < 0.035$). The CA site generally had the lowest proportion of the macroinvertebrate community made up the of the three dominant taxa in all sample periods, except in autumn 2004, when the proportion in BJ was significantly lower than all other sites ($p < 0.002$). There appears to be a trend of increasing proportion of the community made up of the three dominant taxa in autumn and a decreasing trend in spring, but these trends are not significant.

Qualitative kick net samples also showed that CA had a trend of decreasing proportion of its community comprised of the three dominant taxa over 2004–2006, and generally had a lower proportion than BJ and RR during each sample period (Figure 5.12). The NC site also tended to be lower than BJ and RR, but remained generally constant over time. The RR site has also had a consistent proportion of its community comprised of the three dominant taxa over time, while the BJ site has had an increase over time.

Many of the same patterns in taxa noted in 2004 (Olsen 2005) and 2005 (Olsen 2006) were also present in 2006. Midges (Chironomidae), worms (Oligochaeta), and the mayfly *Baetis tricaudatus* remained a large component of the communities at all four sites during both seasons (Tables 5.1, 5.2, and 5.3). All of these taxa are fairly tolerant to disturbance and are vagile species (capable of quickly colonizing areas after a disturbance). The only pollution-sensitive taxa among the three most dominant taxa in all sites in 2006 was the mayfly *Ephemerella inermis/infrequens*, which was only dominant at BJ. In 2005 a caddisfly in the genus *Brachycentrus* sp. was also a dominant species in BJ, but this was not the case in 2006 (though several individuals were collected in both spring and autumn 2006). Prior to 2006 both of these taxa were also more common in the RR site than the NC or CA sites, but the abundance of each was similar among those three sites in 2006. There was a very large increase in the number of *E. inermis/infrequens* in the CA site in 2006 (there were more collected in CA than BJ even though it was one of the three most dominant species in BJ). The *Brachycentrus* sp. numbers did remain higher in BJ and RR in 2006 than in CA or NC, however. In CA and NC, the riffle beetle *Optioservus* sp. and the caddisfly *Hydropsyche* sp. (both moderately tolerant of pollution) comprised a large portion of the community during 2004–2005 (with only a few individuals collected at either BJ or RR) and that was the case again in 2006. There were also differences between CA and NC vs. BJ and RR regarding functional feeding groups. With the exception of the spring 2004 collection at CA, all collections at NC and CA had a higher percentage of macroinvertebrates in the scraper functional feeding group and/or a higher number of taxa in the scraper functional feeding group than the BJ and RR sites. Similarly, the percentage of the community comprised of caddisflies in the family Hydropsychidae was consistently higher at CA and NC.

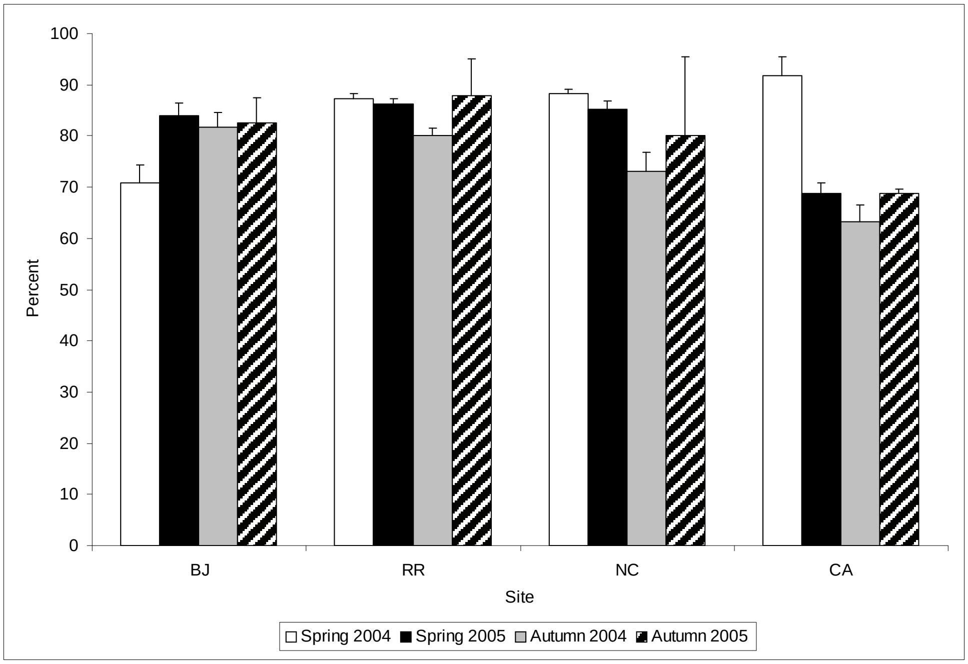


FIGURE 5.11. AVERAGE PROPORTION OF THE COMMUNITY COMPRISED OF THE THREE DOMINANT TAXA CALCULATED FROM THE THREE HESS SAMPLES TAKEN AT EACH SITE IN SPRING AND AUTUMN 2004 AND 2005. ERROR BARS REPRESENT +/- 1 STANDARD ERROR.

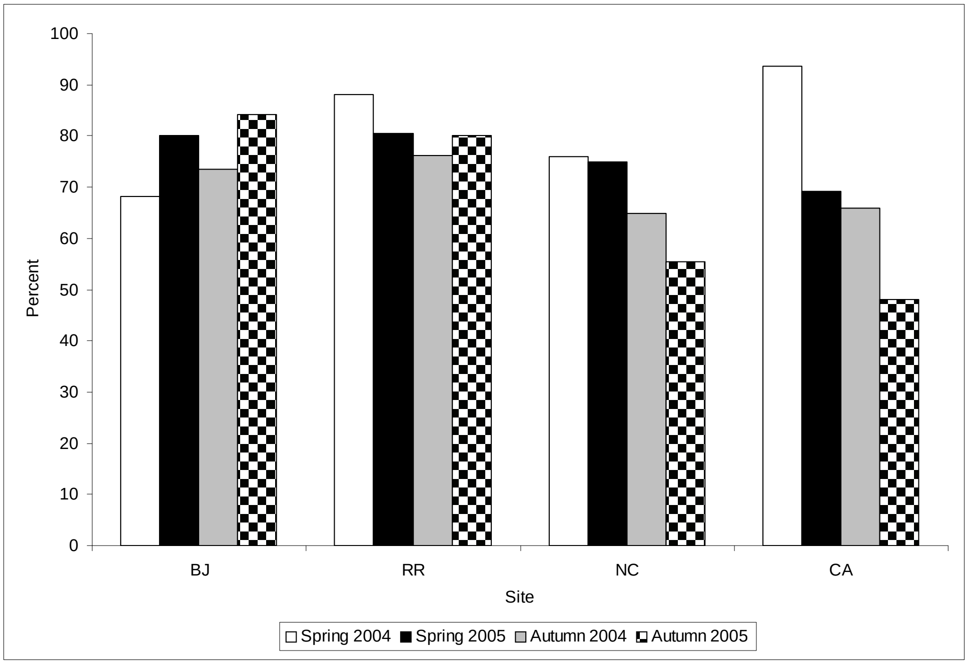


FIGURE 5.12. AVERAGE PROPORTION OF THE COMMUNITY COMPRISED OF THE THREE DOMINANT TAXA IN COMPOSITE D-FRAME KICK NET SAMPLES AT EACH SITE IN SPRING AND AUTUMN 2004 AND 2005.

Table 5.1. Three dominant taxa at each sampling site combining Hess and composite kick-net data in spring and autumn 2004.

ORDER OF ABUNDANCE	BELOW JORDANELLE DAM (BJ)	RIVER ROAD (RR)	NEVER-CHANNELIZED (NC)	CHARLESTON (CA)
		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.

Table 5.2. Three dominant taxa at each sampling site combining Hess and composite kick-net data in spring and autumn 2005.

ORDER OF ABUNDANCE	BELOW JORDANELLE DAM (BJ)	RIVER ROAD (RR)	NEVER-CHANNELIZED (NC)	CHARLESTON (CA)
		April 2005		
First	Chironomidae	Chironomidae	Chironomidae	Chironomidae
Second	*Baetis tricaudatus*	*Baetis tricaudatus*	Oligochaeta	Hydropsyche sp.
Third	*Ephemerella inermis/infrequens*	Oligochaeta	*Baetis tricaudatus*	*Baetis tricaudatus*
		September 2005		
First	Chironomidae	Chironomidae	Chironomidae	Chironomidae
Second	*Baetis tricaudatus*	*Baetis tricaudatus*	*Baetis tricaudatus*	Oligochaeta
Third	*Brachycentrus americanus*	Oligochaeta	Hydropsyche sp.	Hydropsyche sp.

Table 5.3. Three dominant taxa at each sampling site combining Hess and composite kick-net data in spring and autumn 2006.

ORDER OF ABUNDANCE	BELOW JORDANELLE DAM (BJ)	RIVER ROAD (RR)	NEVER-CHANNELIZED (NC)	CHARLESTON (CA)
		April 2006		
First	Chironomidae	Chironomidae	Chironomidae	Chironomidae
Second	*Baetis tricaudatus*	Oligochaeta	Hydropsyche sp.	*Baetis tricaudatus*
Third	*Ephemerella inermis/infrequens*	*Baetis tricaudatus*	Oligochaeta	*Optioservus sp.*
		September 2006		
First	Chironomidae	Chironomidae	Chironomidae	Chironomidae
Second	*Baetis tricaudatus*	Oligochaeta	*Baetis tricaudatus*	Hydropsyche sp.
Third	Oligochaeta	*Baetis tricaudatus*	Hydropsyche sp.	*Optioservus sp.*

5.3.2 COMPARISONS TO HISTORICAL DATA

A series of quantitative macroinvertebrate samples were collected near the BJ, RR, NC, and CA sites in late August 1999 using a surber sampler (NAMC 2002). Similar metrics and analyses were used to look for changes in the benthic community between those August 1999 surber samples and the Hess samples collected during September of 2004, 2005, and 2006.

Total density of macroinvertebrates has been higher in all sites during 2004–2006 than in the 1999 samples (Figure 5.13). The EPT taxa density has not been as consistent across sites; EPT taxa density was higher in BJ and CA during 2004–2006 than in the 1999 samples and remained approximately the same over time in NC (Figure 5.14). Prior to 2006 EPT density at RR had been higher in the recent samples compared with 1999 samples, but the autumn 2006 value was lower than in 1999.

Similar to total density of macroinvertebrates, taxa richness was higher in all sites during 2004–2006 than in the 1999 samples (Figure 5.15). EPT taxa richness has not been consistently higher at all sites (Figure 5.16). In NC and CA, EPT taxa richness was higher in each autumn sample in 2004–2006 compared with the 1999 samples. The BJ and RR sites have maintained approximately the same values during this period.

The HBI values increased in all sites since 1999. All 2004–2006 samples were higher than 1999 samples in the same sites. Prior to 2006 recent collections in BJ resulted in HBI values that were slightly higher than in 1999, but autumn 2006 HBI values were much higher than those in the previous samples. The HBI value in BJ remained close to 4.0, which is the lower limit of the enriched category, but the average value of 5.3 in 2006 is not close to the lower value. The other three sites have also increased from a range of 1.5–3.5 (from clean to slightly enriched) in 1999 to over 5.0 (enriched) in 2004–2006. The average HBI value at NC in 1999 was the lowest observed at any site in all 1999–2006 samples and was significantly lower than the HBI value at all other sites in all other study years (Figure 5.17, $p < 0.001$). The average HBI value at NC in 1999 falls into the clean category for describing pollution history from the aquatic invertebrate community.

As noted in previous reports (Olsen 2005, Olsen 2006), the dominant taxa at the study sites in 1999 were different than what was seen in 2004–2006 (Table 5.4). The *Baetis* sp. identified by USU in 1999 samples were probably *Baetis tricaudatus* (Vinson 2004), which has been abundant in the 2004–2006 samples as identified by EcoAnalysts for this project. However, the RR, NC, and CA sites all had blackfly (Simuliidae) larvae and an unidentified caddisfly (Trichoptera) larvae as the other two most abundant taxa in 1999, which were not among the dominant taxa for these sites in 2004–2006. The BJ site had midge (Chironomidae) larvae (a common taxon in 2004–2006) and blackfly larvae as the other two most abundant taxa in 1999. As in the 2004–2006 samples, caddisflies in the family Hydropsychidae were more abundant in samples from NC than at BJ and RR in 1999, but samples at CA also showed a lower abundance of Hydropsychidae caddisflies. No differences were seen in the number of scraper taxa or in scraper abundance in 1999 samples, as in the 2004–2006 samples. The 1999 samples also showed a trend of decreasing caddisfly taxa richness in a downstream direction and the abundance of true flies (Diptera) increasing in a downstream direction. Neither of these trends is apparent in the 2004–2006 collections.

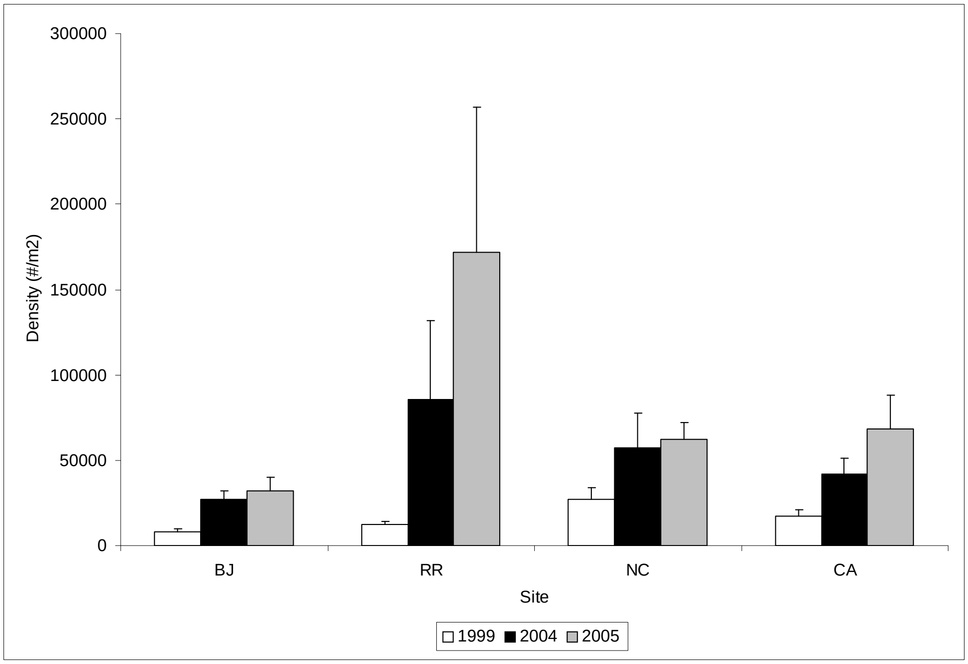


FIGURE 5.13. AVERAGE DENSITY OF MACROINVERTEBRATES (NUMBERS PER SQUARE METER) CALCULATED FROM QUANTITATIVE SAMPLES TAKEN AT EACH SITE IN AUTUMN 1999, 2004, AND 2005. ERROR BARS REPRESENT +/- 1 STANDARD ERROR.

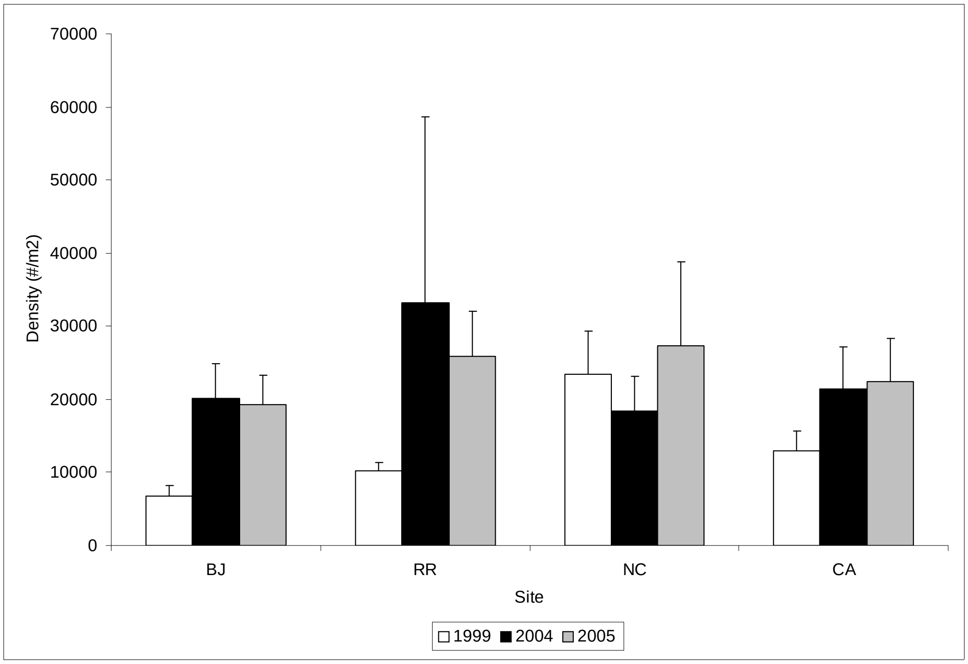


FIGURE 5.14. AVERAGE DENSITY OF EPT TAXA (NUMBERS PER SQUARE METER) CALCULATED FROM QUANTITATIVE SAMPLES TAKEN AT EACH SITE IN AUTUMN 1999, 2004, AND 2005. ERROR BARS REPRESENT +/- 1 STANDARD ERROR.

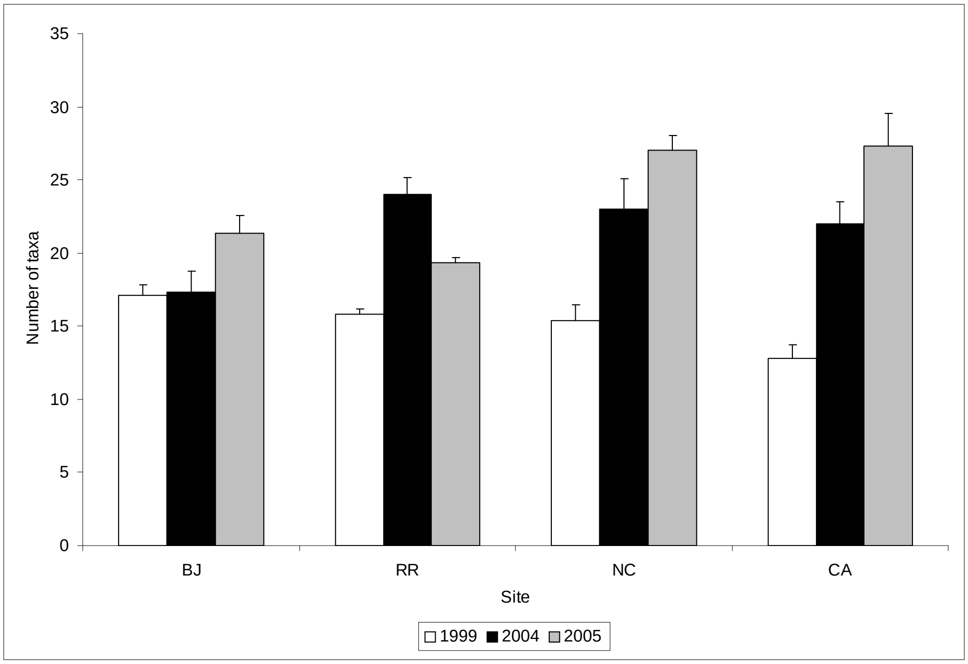


FIGURE 5.15. AVERAGE TAXA RICHNESS CALCULATED FROM QUANTITATIVE SAMPLES TAKEN AT EACH SITE IN AUTUMN 1999, 2004, AND 2005. ERROR BARS REPRESENT +/- 1 STANDARD ERROR.

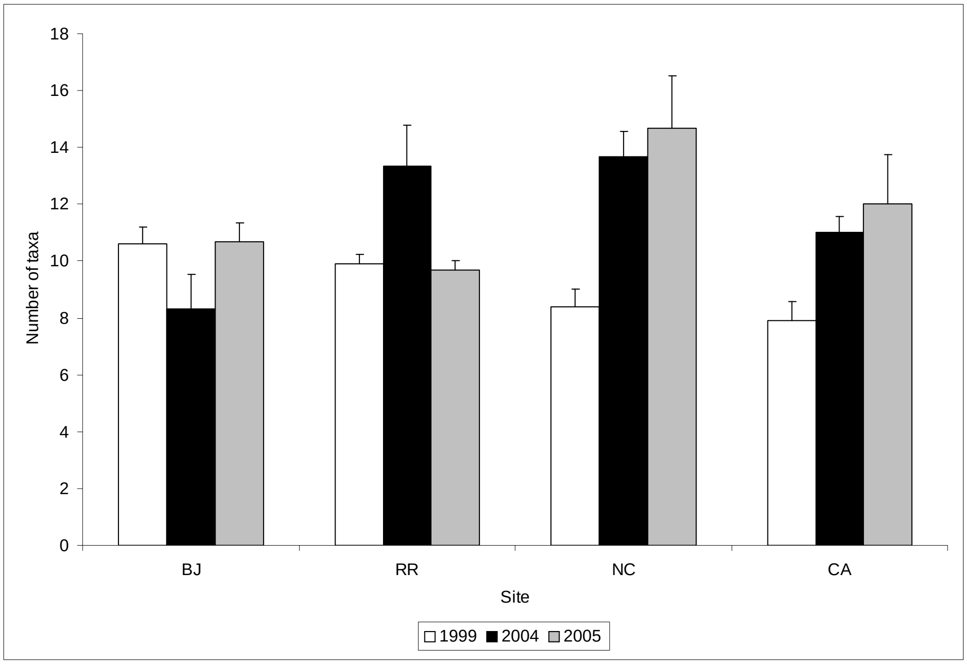


FIGURE 5.16. AVERAGE EPT TAXA RICHNESS CALCULATED FROM QUANTITATIVE SAMPLES TAKEN AT EACH SITE IN AUTUMN 1999, 2004, AND 2005. ERROR BARS REPRESENT +/- 1 STANDARD ERROR.

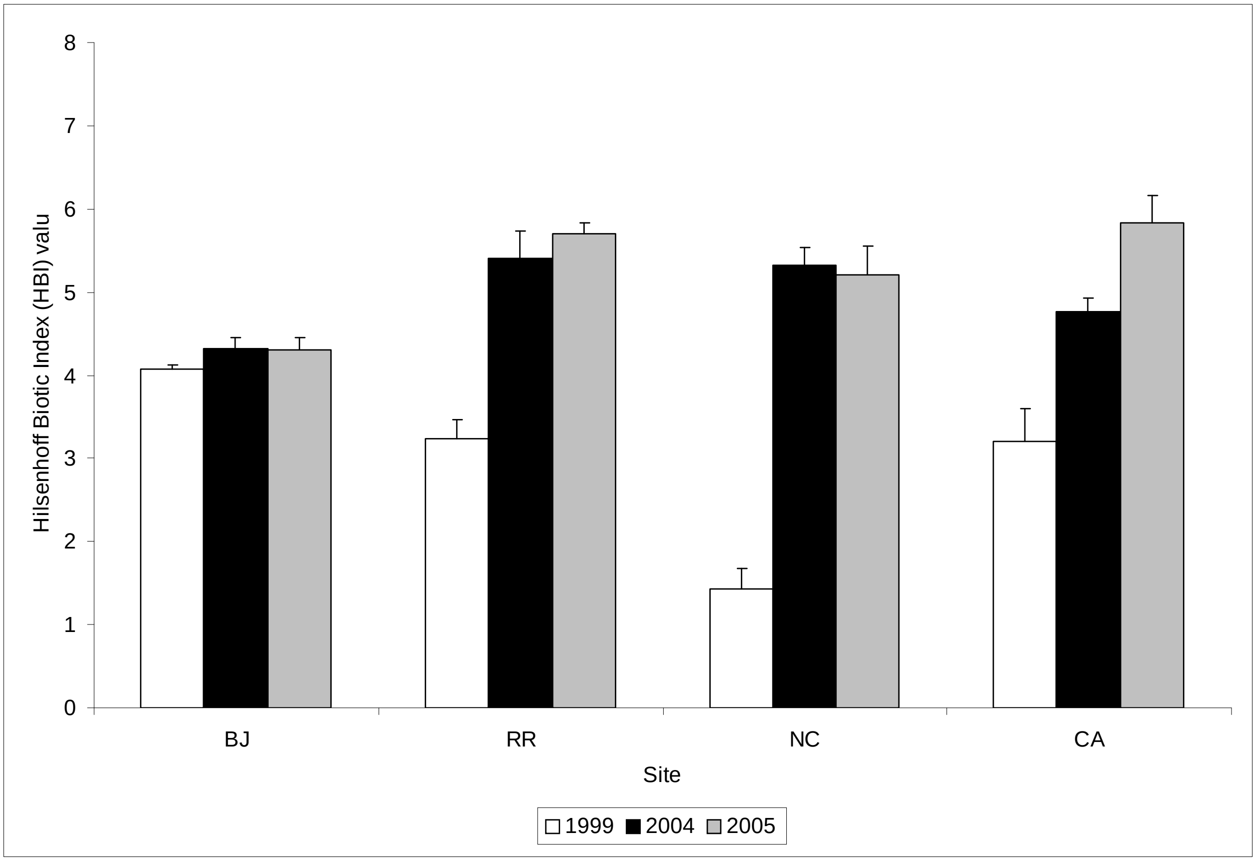


FIGURE 5.17. HILSENHOFF BIOTIC INDEX (HBI) VALUES FROM EACH SITE IN 1999, 2004, AND 2005.

TABLE 5.4. 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 (BJ)	RIVER ROAD (RR)	NEVER CHANNELIZED (NC)	CHARLESTON (CA)
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.

5.4 DISCUSSION

During the 2004–2006 period of the current study, macroinvertebrate communities from four sites with different restoration histories were compared over varying lengths of “recovery” periods after restoration activities were completed. Restoration work was completed just weeks before sampling began at CA in May 2004, in 2002 at BJ, and in 2001 at RR. In addition to the three restored sites, the NC site was sampled as a “control” site that had never been channelized. While this site had never been channelized, it is not free from historic and current impacts. When the upstream reaches were channelized, silt, sand, and fine gravel was often deposited in this area because it had a wider channel than the remainder of the river. The deposition of large amounts of sediment resulted in very dynamic channel conditions. 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 to a control site that exists in the project area, even though it has had other anthropogenic disturbances. In addition to evaluating the relative differences among sites as they may relate to time since restoration, there is also a longitudinal component to this evaluation. Variation in upstream to downstream community composition can be used to determine the influence of various physical characteristics of the stream or water or other inputs into the stream at various locations. Finally, these recent monitoring data were also compared with historical data that were collected in the same general areas prior to the initiation of restoration projects in the middle Provo River to determine overall influence of the river restoration on macroinvertebrate community dynamics in each site.

After the 2004 collections, it appeared that the macroinvertebrate community at CA had recovered to a large degree from any construction-related impacts that may have occurred during channel restoration (Olsen 2005). The current study found total macroinvertebrate density and density of EPT taxa at CA in the first post-project collection in May 2004 to be similar to that found in the other sites during the same sample effort and higher than historical collections from pre-construction conditions at the CA site (1999). Taxa richness and EPT taxa richness were not as high as the three other sites during that initial sample at CA (though still higher than the historical samples), but by the September 2004 sample, and during all subsequent samples, taxa richness and EPT taxa richness was very similar to the three other sites. Furthermore, the macroinvertebrate community at CA was nearly identical to that of the control site, NC, by September 2004. Other studies have noted that macroinvertebrate density can take a year or more to recover from restoration-related construction activities, and diversity can take more than 3 years to recover (Friberg et al. 1998, Laasonen et al. 1998). Though much of the “recovery” of the CA macroinvertebrate community occurred very quickly, there has been a steady increase in taxa richness and EPT taxa richness over the 3 years of post-restoration monitoring (a statistically significant increase annually during spring samples). In addition, there has been a decrease in the proportion of the community comprised of the three dominant species since the completion of restoration-related construction activities. Compared with historical data collected in 1999 prior to any restoration work in the middle Provo River, all metrics (except the HBI value) appear to be greatly improved at CA as well as all of the other sites. Although diversity and density of organisms appears to be increasing steadily over time, the dominant taxa do tend to be those that are relatively tolerant to pollution and the three most dominant taxa tend to comprise a very high proportion of the community (60–75%). The site is clearly improving, from any construction activities and from pre-restoration conditions, but further improvements are still possible and may occur into the future.

The BJ and RR sites also underwent restoration efforts similar to CA, but the macroinvertebrate communities in these sites in 2004 were different than those at CA and NC (Olsen 2005). As the “control” site among the four sampled, the NC site should provide an indication of the type of macroinvertebrate community that is likely to occur after the restoration efforts. Yet it was the most recently restored site, which would presumably have some lingering effects of the restoration-related construction efforts, that was most similar to the control site in 2004. Over the course of sampling in 2004–2006 a distinction between the macroinvertebrate communities at BJ and RR vs. NC and CA was maintained, suggesting that something more than recovery from restoration activities is affecting differences among sites. Grafe (2002) indicated that median taxa richness for “minimally impacted” rivers in Idaho was 25. Average taxa richness values at NC and CA exceeded this median value in autumn 2005 and spring 2006 (but declined again to below 25 in autumn 2006). With the wider range of habitats sampled using the D-frame kick nets, every collection at NC was at or above 25 taxa and four of six samples at CA were at or above 25 taxa. Conversely, average taxa richness from Hess samples at the BJ and RR sites never reached the median value of 25 listed by Grafe (2002). Taxa richness from qualitative kick net samples at BJ fell below the median value of 25 in five of the six collections between 2004–2006 and in four of the six collections at RR. The lower taxa richness in the BJ and RR sites indicates that these two sites are continuing to return to a “restored” state at a slower rate than the CA site, or that some other factor is limiting these sites from reaching their full potential in terms of diversity of the macroinvertebrate community. However, both sites did have higher taxa richness (and other indicators of an improved macroinvertebrate community) in 2004–2006 compared with pre-restoration samples.

As with total taxa richness, the EPT taxa richness in qualitative kick net samples at NC and CA was generally higher than at BJ and RR. The data from Hess samples were more variable, sometimes highest in NC and other times there were similar values among sites. The richness values for all sites were lower than the range expected for minimally impacted rivers in Idaho (Grafe 2002). A decrease in both EPT taxa richness and total taxa richness is expected in disturbed habitats (Barbour et al. 1999, Grafe 2002), which suggests that while the macroinvertebrate communities in the middle Provo River have experienced an improvement in community dynamics relative to pre-restoration conditions, there are still indications of disturbance.

Further distinctions are apparent between the two pairs of sites in composition of macroinvertebrate taxa collected in both Hess and kick-net samples. Midges, worms, and the disturbance-tolerant mayfly *Baetis tricaudatus* were dominant taxa at all of the sites. However, the upstream sites, BJ and RR, had higher densities of the pollution-intolerant *Ephemerella inermis/infrequens* (although CA had very high numbers of this species in 2006) and the caddisfly genus *Brachycentrus* sp., while the communities at NC and CA had higher densities of the moderately tolerant riffle beetle *Optioservus* sp. and the moderately tolerant caddisfly *Hydropsyche* sp. The recent increase in *E. inermis/infrequens* in the CA site suggests that the community there is still adjusting to post-restoration conditions and that the site may be able to support more intolerant species than the low numbers at the NC (control) site may suggest.

In addition to a community comprised of more tolerant taxa in the downstream sites, there was also a difference in the functional feeding groups between the upstream sites and the downstream sites. *Ephemerella inermis/infrequens* is a gathering collector, feeding on detritus and other fine particulates, while *Optioservus* sp. is a grazer/scraper, feeding on periphyton and algae attached to hard substrates. The richness and/or abundance of taxa in the scraper functional feeding group was consistently higher at NC and CA in collections after May 2004. While scraper taxa are hypothesized to decrease in the presence of disturbance, their higher abundance in the downstream sites is also a sign of increased primary production, potentially resulting from nutrient enrichment. The two downstream sites also had a higher abundance of *Hydropsyche* sp., which is a widespread species commonly found in areas with organic enrichment. *Hydropsyche* sp. is in the filtering collector functional feeding group. Filtering collectors use webs, nets, and appendages to trap fine particles in the drift. Therefore, the increase in *Hydropsyche* sp. could indicate an increased amount of fine particulates in transport at the downstream site. This observation corresponds with the higher amount of fine sediment transport noted at the two downstream sites. Average HBI values were higher at all sites downstream from BJ, which indicate that the community there is more tolerant of increased organic enrichment or some other disturbance. The HBI values have also been significantly higher in recent samples compared to historical samples at all sites except for BJ.

The high macroinvertebrate densities found in the middle Provo River, particularly downstream from BJ, further indicate potential enrichment. Productive mid-order streams and rivers often have macroinvertebrate densities between 5,000 and 10,000 organisms per square meter. During the current study of the middle Provo River, average densities ranged from 13,000 organisms per square meter to 170,000 organisms per square meter. This is largely due to high numbers of midges, which was among the most dominant taxa in each sample, but nonetheless still indicates high productivity. In 1999, when numbers of midges were much lower (possibly due to differences in laboratory counting protocols), average densities still ranged from 8,000 to 27,000 organisms per square meter.

Increased organic enrichment provides one possible explanation for the differences in HBI value and community composition at the two downstream sites, NC and CA, compared with the two upstream sites, BJ and RR. In addition to changes in HBI value and community structure, one would expect to see increased overall macroinvertebrate density (high abundance of very tolerant organisms), lower taxa richness, and dominance by only a few taxa at the sites impacted by organic enrichment. Conversely, with the exception of the spring 2004 and autumn 2006 collections, sampling results showed higher taxa richness at NC and CA. Taxa richness at these two sites was closer to what one might expect for rivers in this region (Grafe 2002), whereas samples from BJ and RR showed decreased richness. In addition, the percentage of the community comprised of the three most abundant taxa at NC and CA was similar to BJ and RR in 2004 collections, and lower than BJ and RR in 2005. These observations, along with the fact that differences in HBI value were relatively small, suggest that any impacts from nutrient enrichment are minimal.

Another possibility for differences in macroinvertebrate communities among sites is substrate composition and sediment transport conditions. 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. Studies of these conditions in the middle Provo River indicate that differences exist in the current size and diversity of substrate at the four sample sites (Chapter 3 and Chapter 4). These efforts showed a higher percentage of cobble and boulder substrates, as well as limited in-channel sand and gravel supplies at the BJ and RR sites compared to the NC and CA sites. This difference in substrate composition could be influencing the macroinvertebrate communities. Greenwood et al. (1999) found that coarsening of substrates resulted in changes in the macroinvertebrate 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. Their results indicating higher diversity with larger substrates have been corroborated in many other studies (see Vinson and Hawkins 1998 for review). Conversely, this study found that the sites with the largest substrate, BJ and RR, had the lowest richness of macroinvertebrate taxa.

While many studies have indicated a more diverse macroinvertebrate community occurs in areas with coarser substrates, some studies have also shown that substrate and habitat heterogeneity can increase macroinvertebrate diversity (Minshall 1985, Allan 1995, Angradi 1996, Schmude et al. 1998, Angradi 1999). While substrate is coarser at RR and BJ in particular, it is also more homogenous. The immobility of the bed and lack of new sediment influx contributes to the substrate homogeneity seen at BJ and, to a somewhat lesser extent, at RR. Conversely, both NC and CA show an influx of gravel and fine substrates leading to more a more diverse habitat for benthic invertebrates.

In addition to increased substrate heterogeneity, the streambed is more mobile at both NC and CA. The increased bed movement at NC and CA may contribute to increased mesohabitat and microhabitat heterogeneity and likely result in a more diverse invertebrate community (Angradi 1996, Angradi 1999). A greater diversity of habitat types have been noted during composite kick net sampling efforts at NC. In particular, the side channel habitats at this site offer more low-velocity refugia for macroinvertebrates, submerged aquatic vegetation, and fish. This may explain the higher abundance of certain lentic taxa compared with other sites, such as the mayfly *Tricorythodes* sp., and snails (Gastropoda) at this site and at CA.

The more mobile bed also results in higher disturbance than the upstream sites. While most empirical studies have shown that disturbance has a negative impact on both macroinvertebrate density and diversity (Vinson and Hawkins 1998), some researchers have found evidence to support Connell (1978) and his intermediate disturbance hypothesis. The intermediate disturbance hypothesis states that organism diversity should peak at an intermediate disturbance level by allowing pioneer species and species favored by competitive interactions to persist. McCabe and Gotelli (2000) manipulated the frequency, intensity, and areal extent of disturbance in a Vermont river and found a higher species diversity in all disturbance treatments vs. undisturbed areas. Similarly, the disturbance of the mobile bed at NC and CA may explain the higher species richness at these sites.

Vinson and Hawkins (1998) provide a review of factors that influence the diversity of stream insects. While substrate size, substrate heterogeneity, habitat heterogeneity, and disturbance have all been found to impact richness, results from many studies regarding the impact of these factors are conflicting. The conflicting results cloud direct interpretation of data collected for this study. Also, within individual systems many other factors, such as nutrients, flow, and temperature dynamics, may be acting in conjunction with substrate and habitat to produce the patterns in species richness apparent at any one site. Temperature can exert a strong influence on the structure of macroinvertebrate communities (Vannote and Sweeney 1980). 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). 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. The differences in macroinvertebrate communities apparent at NC and CA vs. BJ and RR are probably the result of a variety of factors working synergistically.

Regardless of the cause of differences among sites, the macroinvertebrate communities at all sites have changed appreciably since the samples collected in 1999. The greatest changes during this period of stream restoration have occurred at the downstream sites of NC and CA. Results of substrate, sediment transport, and channel geometry monitoring indicate that the greatest physical habitat changes are occurring at the NC and CA sites and that the BJ site is the most static. Therefore, while increased nutrient enrichment and temperature differences may influence the community at NC and CA, substrate and habitat heterogeneity, sediment transport, and bed mobility may also be responsible for the differences in the benthic community between the upstream and downstream sites.

Although diversity and composition of the macroinvertebrate community is itself an indication of stream condition, another of the primary goals of this monitoring was to evaluate macroinvertebrates in the context of their importance in supporting a high quality sport fishery in the middle Provo River. The high densities of macroinvertebrates in recent samples compared with historical (1999) samples, suggest that the restoration, or changes in water quality and productivity, may be providing a larger invertebrate food base for trout than previously existed in the middle Provo River. In instances where a food limitation for trout has been documented in other rivers, the invertebrate densities were orders of magnitude lower than those observed in the Provo River (Cada et al. 1987, Newcomb et al. 2001). One concern is that the average size of available prey items may be smaller than it was in the past, and the dominance of midges and small *Baetis tricaudatus* mayflies supports this theory, however, there are moderate numbers of stoneflies and *Hydropsyche* sp. caddisflies in the CA and NC sites.

The increase in average densities of macroinvertebrates has also corresponded with an increase in the number of trout seen throughout the restoration reach (Hepworth et al. 2004). However, despite the increase in density of trout, a decline in the condition of these fish in the restoration area has been observed between 1997–2004. This trend was reversed in 2005 as trout density decreased, a change that occurred in concert with changes in fishing regulations that allowed anglers to retain more fish (Hepworth and Wiley 2006). Prior to this apparent correlation between angling regulations and condition factor of the trout, a decline in food resources associated with construction activities or benthic community changes related to the restored channel was identified as a potential cause. However, in addition to this recent observation, the surveys completed for this study have shown that macroinvertebrate density rebounded quickly after construction activities were completed in each reach and has remained high. Future monitoring of fish populations will permit evaluation of angling regulations as a primary variable influencing trout condition factors of in the middle Provo River since there appears to be sufficient food sources.

In addition to the influence of angling pressure, other current environmental conditions may be limiting trout condition. 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 in Virginia 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. The comparison of 1999 and 2004 invertebrate community data in the Provo River indicate that changing abiotic factors (e.g., sediment transport, flow, and/or temperature changes) may be interacting with restoration efforts to produce the results seen in the biological community. Similar impacts may be affecting higher trophic levels, too.

There have been many insights into the value of the stream channel restoration gained in the 3 years of monitoring the macroinvertebrate communities in the middle Provo River. Without additional perturbations, monitoring could likely be substantially reduced in frequency without significant reduction in monitoring long-term trends in the community dynamics. It is likely that the communities will continue to change, but less dramatically than initially after restoration. The CA site clearly responded quickly after restoration, with many metrics used to evaluate the macroinvertebrate community stabilizing quickly. There have been some indications of additional changes into 2006, however, with significantly higher taxa richness and EPT taxa richness in spring 2006 compared to spring 2005 (and to spring 2004). If the monitoring is reduced too much and conducted infrequently, it may not accomplish another important goal: being able to identify substantive changes in the macroinvertebrate communities that might indicate a degradation in habitat conditions. However, additional restoration activities are planned in the middle Provo River, with the potential introduction of additional sediment supplies near the BJ site. If implemented, this could change the substrate and sediment dynamics of the two upstream sites and will likely affect the macroinvertebrate communities. Therefore, a continuation of annual sampling of all four sites is recommended for the next 3 years. As observed in the CA site following restoration, the recovery period from perturbation is rapid in these sites. Therefore, much of the change in these communities is likely to occur in the first year, but some changes occur over a longer time frame. Although sampling has occurred during both spring and autumn in 2004–2006, the frequency of sampling can be reduced to just one season. We have found in 2004–2006 that many of the patterns observed in one season are mirrored in the other season, but often at different scales. There are some discrepancies between seasons, such as the trend of increasing EPT density in the RR site in spring and decreasing EPT density in that same site in autumn (Figure 5.3). However, over time, one annual sample will capture the general trends in the data and provide a means of evaluating changes associated with the sediment inputs. In the springtime, physical site conditions in terms of streamflow, water temperature, and snow cover are more variable, and it can be challenging to consistently time sampling efforts to immediately precede snowmelt runoff each year. To avoid these potentially confounding influences, we recommend sampling in autumn when physical conditions are more reliably consistent.

5.5 SUMMARY

There has been a positive response in the density and diversity of macroinvertebrates between samples collected in 1999 and samples collected in 2004–2006. The amount of post-restoration change has been greater in the two downstream sites (NC and CA) compared with the two upstream sites (BJ and RR). While the NC site served as a “control” among our sites because it had not been directly disturbed (channelized) in the past, there was obviously enough influence from past activities upstream to result in degraded conditions at this site prior to restoration. After restoration of the upstream sites, macroinvertebrate community dynamics at the NC site improved and continued to change over time in a similar manner as the restored CA site downstream. These changes in the NC site and less-distinct changes in the upstream restored sites (BJ and RR) indicate that there is more influencing these sites than just recovery from restoration. There appear to be several distinctions between the two upstream and two downstream sites and a number of variables that likely have some influence. Among those variables discussed as potentially influencing variability among sites in this document were increased nutrient enrichment, temperature differences, substrate and habitat heterogeneity, sediment transport, and bed mobility. This variability in upstream to downstream macroinvertebrate communities appears to be greater than the variability within each site over time. Almost immediately after restoration, the macroinvertebrate community in the CA site had “recovered” dramatically in macroinvertebrate density and composition. However, there were additional improvements in the metrics used to evaluate community dynamics over the remainder of the monitoring period (particularly changes in taxa richness) that suggest that some recovery occurs over a longer time scale. The other two restored sites, BJ and RR, appeared to have already approached some sort of “equilibrium” with the metrics used for this evaluation by the first monitoring effort in 2004, and did not vary as dramatically over time (within individual metrics) as the distinct upstream to downstream pattern that was observed. The 3 years of monitoring has also shown that, as food for the sport fish population, macroinvertebrate densities are not limited and do not appear to be the cause for the reduced condition factors seen in the brown trout population. Recent fish population data has shown an increase in trout condition factors that may be related to fishing pressure. In addition, the change in the fish community may be symptomatic of the other changes in river operation and function, which also appear to be influencing the macroinvertebrate community. Finally, macroinvertebrate communities can exhibit a large degree of variability from year to year. Unfortunately, there is no record of long-term trends in the macroinvertebrate community leading up to 1999, and while information is available between 2000-2003, it was collected using a different methodology (Shiozawa et al. 2002).

The macroinvertebrate communities at each of these sites will undoubtedly continue to change, even in the absence of any further restoration efforts, and may continue to improve, but without further intervention, it appears that the majority of the initial post-restoration changes have occurred. If plans to augment sediment are implemented, however, the habitat conditions for macroinvertebrates in the upstream sites (BJ and RR) will become more dynamic and may, as a result of these effects, increase the potential for habitat heterogeneity, which would likely increase species diversity. Continued macroinvertebrate monitoring will provide additional insight into the influence of the various physical restoration efforts of the stream on biological components of the system. If a new change in channel dynamics is introduced into the upstream sites, it will be valuable to document how the macroinvertebrate communities respond to the more mobile and heterogeneous substrate conditions. Additional monitoring is recommended annually during the autumn over the next 3 years to track the adjustments associated with the altered conditions.

6.0 SUMMARY AND RECOMMENDATIONS

The original objectives of the initial 3 years of monitoring were:

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 effectively adapt management activities to maintain the riverine ecosystem in a desirable and functional condition.
3. To use the "best available scientific knowledge" to ensure the Mitigation Commission meets all fish, wildlife, and recreation mitigation commitments.

To date, monitoring activities from 2004–2006 have quantified baseline geomorphic and macroinvertebrate conditions within distinct reaches of the middle Provo River. Monitoring efforts have also documented specific post-flood adjustments within each study site following the 2004, 2005, and 2006 spring runoff periods. Macroinvertebrate monitoring has documented biological response and recovery following channel restoration, and has also highlighted differences in conditions among distinct reaches of the middle Provo River. Sediment transport monitoring has provided information about disparities in sediment loads in different parts of the river and suggested that, with increasing time, the need to augment gravel below Jordanelle Dam will also increase.

Because the PRRP is located below a sediment-trapping dam, one concern is that the restored channel will be subject to channel degradation and substrate coarsening/armoring caused by a lack of sediment supply. If the channel becomes overly coarse and the bed degraded, dynamic channel processes, such as overbank flooding, meander migration, and gravel bar deposition, will be compromised. These processes create and maintain important habitat for riparian vegetation, fish, and other aquatic and terrestrial organisms. Geomorphic monitoring efforts have attempted to identify whether channel armoring and degradation are occurring, and have also documented the extent to which dynamic channel processes are active within distinct reaches of the river.

Some of the trends and spatial differences in monitoring results suggest a need to implement adaptive management efforts in certain parts of the middle Provo River. Our recommendations for adaptive management are provided in Section 6.2 below. In addition, results to-date indicate that certain specific monitoring techniques have been more effective than others in answering questions about temporal and spatial trends in channel behavior. We apply the lessons learned during the 2004–2006 monitoring period to our specific recommendations for future monitoring discussed in Section 6.3 below.

6.1 Summary of Results

6.1.1 Geomorphology and Channel Dynamics

The four monitoring sites have shown different responses since 2004. The BJ site, located about 1.2 river miles below Jordanelle Dam, has remained nearly static since 2004. The RR site, located about 3.5 miles below Jordanelle Dam, shows some evidence of dynamic channel processes, although the extent of channel change has been smaller than changes observed at the downstream monitoring sites. Although much of the main channel within the RR site has remained fairly static throughout the monitoring period, the high spring flows in 2005 initiated significant bank erosion and plan form changes within the side channel at RR. In conjunction with these side channel changes, bed degradation and bar building have been observed at the RR6 main channel transect.

The NC site, located about 8.2 miles below Jordanelle Dam, is highly dynamic relative to the other study sites and has shown measurable and evident changes in plan form, gravel bar locations, and bed elevation following each high flow event. The nearly unlimited supply of sediment available within the never-channelized reach appears to be associated with a highly dynamic channel condition where physical habitat types available to various species may increase in area at times, decrease at other times, and regularly shift throughout the channel. The CA site, located about 10.5 miles below Jordanelle Dam, is the most recently restored of the monitoring sites. Channel reconstruction was completed in early 2004, and the channel profile, bed elevation, and bank locations adjusted significantly following the spring 2004 high flows. Trends observed between 2004 and 2005, such as bank erosion and channel degradation, generally continued between 2005 and 2006 but at much slower rates than those observed following the 2004 flood.

6.1.2 Channel Substrate

Monitoring changes in channel substrate composition through time is one way to detect trends in substrate condition and evaluate the long-term influence of sediment trapping by Jordanelle Dam. One potential effect of this reduced sand and gravel supply could be coarsening of the substrate material and net evacuation of gravel-sized particles from the river, particularly in the areas closest to the dam. Substrate monitoring data from spring 2004 through fall 2006 do not indicate that this temporal coarsening trend is happening on the middle Provo River.

However, monitoring results demonstrate that the upstream monitoring sites (BJ and RR) have substantially coarser substrate than the downstream monitoring sites (NC and CA). The upstream sites, particularly BJ, also exhibit less year-to-year variability in the distribution of substrate patches.

In contrast, the NC site has been extremely dynamic through the 2004–2006 monitoring period, with major changes occurring in gravel bar locations and associated substrate patches. The CA site has also exhibited more bank erosion and gravel bar development than the upstream sites.

6.1.3 Sediment Transport

The 2006 sediment transport monitoring results indicate, as in other years, that the middle Provo River above White Bridge (WB) is a sediment supply-limited reach. Calculated total sediment loads, particularly for gravel-sized material, are highly suppressed at the upstream sampling sites (WB and River Road [RR] Bridge) relative to the downstream sites. At WB and RR, the sand-sized portions of total bedload are half that at Midway Bridge (MID; located 8.8 miles below Jordanelle) and one-third that at Casperville (CA; located 11.4 miles below Jordanelle). Gravel loads at the upstream sites are two orders of magnitude smaller than the load at CA, and three orders of magnitude smaller than the load at MID. Gravel loads are high (> 2,000 tons/year) at the Midway Bridge site, which is located just below the never-channelized reach. Sampling results also indicate that suspended sediment loads are greatest at the CA site, and increase with distance downstream from Jordanelle Dam.

Sediment transport monitoring efforts in 2006 were focused on assessing the accuracy and precision of measurement methods, and on evaluating any differences associated with different sampling techniques (e.g., sampling in three locations across the channel versus ten locations). Results indicate that sampling methods are precise to within 1–2 times variance with less variance at peak flows. The results of the 2006 monitoring also show that a three sub-sample method is as accurate and precise as the ten sub-sample method. However, it is also recognized that judgement error is less likely when using the ten sub-sample method. Both methods are comparable in terms of effort and cost; therefore, the ten sub-sample method is recommended for any future bedload sampling of the middle Provo River.

6.1.4 Macroinvertebrates

Macroinvertebrate sampling results in 2006 were generally similar to trends observed in 2004–2005. Of the four sites that were monitored, CA provided the most direct opportunity to evaluate recovery of the biological community following restoration activities. Statistical analysis of the quantitative (Hess) samples and visual analysis of the composite kick samples in 2004 indicated that for many of the metrics used to evaluate the macroinvertebrate community dynamics, the CA site recovered from construction activities more quickly than expected compared to results from other studies. However, data collected in 2005–2006 revealed significant differences in the number of species collected relative to the previous year, even 3 years after the restoration. Data were not collected immediately after restoration activities in either the RR or BJ sites, but both of those appeared to have already recovered from restoration activities and had relatively stable conditions during the 3 years of monitoring.

In addition to observations of recovery from restoration efforts, we were able to evaluate relative differences in macroinvertebrate composition among sites as an evaluation of other potential factors influencing biological conditions throughout the middle Provo River. Over the 3 years of monitoring, the macroinvertebrate community in the two most downstream sites (CA and NC) was very similar, but the communities at both of these sites differed from the communities seen upstream at BJ and RR. The NC and CA sites exhibited greater overall diversity but included more pollution-tolerant taxa and a higher abundance and diversity of scraper (benthic algae-consuming) taxa than the upstream sites. These differences may indicate some level of nutrient enrichment at the two downstream sites. Alternatively, or perhaps in association with higher nutrient composition, the increased overall diversity in the macroinvertebrate community at these sites could be influenced by the higher substrate and habitat heterogeneity than at BJ and RR. This may be most directly supported by the observation of consistently lower taxa richness of sensitive species (EPT taxa) in the BJ site, where substrate is most homogenous, compared with the three other sites. Overall taxa richness results indicate that the downstream sites (NC and CA) had values similar to those for "minimally impacted" rivers in the region (Grafe 2002), while the BJ and RR sites never reached the median reference value of 25 during the monitoring period. Overall, differences in substrate and habitat heterogeneity are probably at least partially responsible for the increased species richness and other community differences seen at NC and CA compared with BJ and RR. Differences in other variables such as water temperature and nutrient loads may also be responsible for the macroinvertebrate community differences among sites.

Comparison of the 2004–2006 sampling results with data collected in August 1999 (prior to channel reconstruction) shows that macroinvertebrate density has apparently increased significantly throughout the study area since 1999. Both the past and current levels of macroinvertebrate density are relatively high, and are well above levels shown to have caused food limitation to trout in other studies. All sites except BJ show a significant increase in taxa richness (diversity) since 1999. The static bed and coarse channel substrate at BJ are the likely cause of the stability observed in the macroinvertebrate community.

6.2 Adaptive Management Recommendations

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. 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.

Monitoring results to-date indicate that many of these objectives have been met: macroinvertebrate communities have improved relative to pre-restoration (1999) conditions, and evidence of dynamic riparian and geomorphic processes (natural riparian recruitment, bar building, meander migration, etc.) is seen at the CA site, in portions of the RR site, and at the Never-Channelized (NC) site. However, monitoring results also highlight several trends that may be of concern in terms of meeting restoration objectives. Adaptive management measures may be needed to address these concerns and ensure that restoration goals are met to the greatest degree possible. Specific concerns are discussed below.

6.2.1 Concern 1: Disparity in Sediment Loads

Sediment transport monitoring results clearly illustrate that gravel loads within the first 4.2 miles below Jordanelle Dam (i.e., at least as far downstream as the RR monitoring bridge) are dramatically suppressed relative to loads measured downstream below the gravel source provided by the never-channelized reach. As was anticipated, Jordanelle Dam appears to be substantially limiting available gravel supplies within the upstream portions of the middle Provo River. The limitation on sand supplies does not appear to be as significant.

The lack of gravel supply is a concern because it appears to be associated with the lack of dynamic channel processes at the BJ study site and the limited extent of channel dynamics at the RR site relative to the downstream sites (see Section 6.2.2 below). As an adaptive management measure, active gravel replenishment is recommended for the upper reaches of the Provo River between Jordanelle Dam and River Road. Initially, gravel should be imported and shaped into constructed gravel bars where access is available. In addition, a permanent "gravel slope" should be built at a convenient location where loads of gravel can be supplied to the river on an annual basis. Based on sampling results to date, it is recommended that approximately 150 to 400 tons of mixed coarse-grained sediments (1:1 ratio of sand and gravel) be supplied annually below Jordanelle Dam. The total amount and ratio of gravel to sand should vary annually, depending on the magnitude and duration of peak flows expected. To do this, the bedload rating curve developed at the CA site (Figure 4.4) provides a reasonable relationship between transport and flow, and therefore a reasonable estimate of annual loads exported from the middle Provo River. It is recommended that the power equation from data collected at this site be applied to the anticipated spring runoff hydrograph (daily discharge values) to calculate annual gravel augmentation needs.

In addition to initiating gravel augmentation efforts, we also recommend that another sediment monitoring site be established between the RR and MID bridges. Ideally, this new site would be located just a few hundred meters upstream of the never-channelized reach. This additional "Above Never-Channelized" (ANC) monitoring site is needed in order to quantify the amount of sediment being supplied by in-channel, hillslope, and streambank sources (i.e., passive/ non-augmented sources) between RR and the never-channelized reach. This information could then be used to help determine appropriate locations and quantities for gravel augmentation efforts. The new monitoring site would also provide a better comparison with results at the CA site, because sediment transport appears to be extremely high at the MID site. Specific recommendations for future sediment transport monitoring frequencies, locations, and methods are provided in Section 6.3 below.

6.2.2 Concern 2: Lack of Dynamic Channel Processes at Upstream Sites

Geomorphic monitoring results indicate that flows between 2004–2006 have not resulted in gravel bar development, bank erosion, or significant scour/fill at the BJ site. Channel changes have also been minimal within the main channel portion of the RR site, although the RR side channel has been active and bar building has occurred immediately below the site. The lack of channel dynamics observed at the BJ site suggests that the PRRP goal of restoring natural processes needed for a self-sustaining river ecosystem is not being met within the upstream reach of the river. In addition, the static channel condition at BJ limits channel complexity and suppresses natural recruitment of native riparian species such as willow and cottonwood, which require freshly disturbed surfaces for seed germination. Lack of substrate motion/disturbance may also be contributing to the suppressed macroinvertebrate taxa richness values at the upstream sites.

To address this concern, the gravel augmentation efforts described above are recommended. In addition, a new reach-scale assessment of gravel bar development and streambank migration is recommended. This assessment would be completed using aerial/orthophotography. Additional details are provided in Section 6.3 below. In combination with sediment transport data obtained from the new ANC monitoring site, this reach-based assessment of channel dynamics will provide information on how far below the dam the river "recovers" from the effects of sediment supply limitations. This information will be useful in determining whether or not gravel replenishment is needed in areas below River Road.

6.2.3 Concern 3: Potential for Substrate Coarsening

Substrate monitoring results to-date do not provide evidence of any temporal trends of substrate coarsening or bed "armoring" in response to the sediment supply limitations at the BJ and RR sites. This implies that the substrate at these sites is largely immobile, and/or that hillslope and in-channel sediment sources are adequate to re-supply the sediment that is transported out of these sites. Because vegetation is still in the process of fully establishing itself along the restored channel, existing in-channel and streambank sediment supplies may be elevated relative to anticipated long-term levels. In addition, minor channel reconstruction activities within the upstream portions of the middle Provo River have been ongoing during the 2004–2006 monitoring period and may also be contributing sediment to the system that will not be available in the future.

Although substrate coarsening does not appear to be an immediate concern at this time, it is possible that it may become a concern in the future as in-channel and streambank sediment supplies decrease. It is also possible that the scale of our current substrate monitoring effort (which only encompasses two riffles at BJ and one at RR) is not adequate to capture coarsening trends occurring in other parts of the river. At this time, we do not recommend any substrate-focused adaptive management measures, but we do recommend future monitoring of channel substrate. Specific recommendations, including implementing pebble count monitoring at a reach-scale, are provided in Section 6.3 below.

6.2.4 Concern 4: Potential for Channel degradation

As with the concern regarding substrate coarsening, monitoring results to-date do not provide strong evidence of progressive channel incision below Jordanelle Dam. The greatest amount of bed degradation was measured at the CA site, located downstream from the never-channelized reach which provides a virtually unlimited supply of gravel. However, much of the change observed at CA was likely just initial adjustment immediately following channel reconstruction, and measurements in 2006 suggest that the CA bed elevation is now stabilizing. No adaptive management measures specifically addressing channel incision are recommended at this time. However, continued periodic monitoring is recommended to assess trends in bed elevation and channel capacity and ensure that the PRRP goal of a connected channel-floodplain system is being achieved.

6.2.5 Concern 5: Reduced Macroinvertebrate Species Richness at Upstream Sites

The lower species richness values found at the BJ and RR sites may be associated with the relative coarseness of the substrate at these sites and/or with the lack of sediment transport at these sites. The macroinvertebrate community differences may also be associated with general longitudinal trends in water temperature or water quality/nutrient inputs that are not caused by sediment supply limitations. Future macroinvertebrate monitoring is recommended, particularly if gravel augmentation efforts are implemented. Establishing an additional macroinvertebrate monitoring site at/near the proposed ANC sediment monitoring site is also recommended as a way to help assess where along the river the shift in community type occurs. Specific recommendations are provided below.

6.3 Recommendations for Future Monitoring

Continued monitoring of the response of the Provo River to PRRP activities is strongly recommended. Recent literature discussing river restoration initiatives emphasizes the importance of adequate post-project monitoring to evaluate restoration success and funding effectiveness (Wohl et al. 2005, Bernhardt et al. 2005). Monitoring also provides information needed to evaluate and adapt ongoing river management activities such that restoration effectiveness can be maximized (Williams et al. 1997).

Long-term monitoring of the PRRP should focus on assessing whether the reconstructed channel-floodplain system is meeting restoration goals. Schmidt and Wilcock (2007) also make this recommendation, and also emphasize the need to better quantify PRRP objectives by defining target levels of channel migration, substrate size, gravel bar frequency, overbank flow frequency, etc.

The concerns listed in Section 6.2 have the potential to hinder the success of the PRRP, and should be specifically addressed as part of monitoring efforts. We provide our recommendations for future monitoring below, organized by type and scale of monitoring, and list the specific concerns each recommendation addresses.

6.3.1 Full-River Air Photo-Based Monitoring

As mentioned above, and as discussed by Schmidt and Wilcock (2007), there is a need to implement a broader-scale assessment of spatial and temporal geomorphic trends throughout the middle Provo River. This is particularly important for addressing Concern 2, lack of dynamic channel processes. Currently, our monitoring results indicate that the channel is overly static at BJ and that some "recovery" of dynamic processes occurs by the RR site. Reach-level assessment is needed to answer the following questions:

1. How much of the reach between Jordanelle Dam and the RR site is in an "overly static" condition?

2. Where, in terms of distance below the dam, do dynamic channel processes become evident?

3. Does the channel gradually become more dynamic in a downstream direction, or is the change abrupt?

4. How much influence does the never-channelized reach (i.e., supply of gravel) appear to have on the degree of dynamic channel processes observed?

To address these questions, we recommend an analysis of available orthophotography from 2003 and 2006. For the river reaches that had been reconstructed as of the 2003 photography date, the left and right edges of water should be digitized in a GIS and compared for the two time periods to determine channel migration rates. Unvegetated gravel bars should also be digitized and analyzed for the two periods. Specific metrics should include bar frequency (i.e., number of bars per river mile or similar index) and bar dynamics (i.e., number of new gravel bars per mile, number of bars "lost" per mile, number of bars showing significant size change per mile, total bar area, etc.). Completing this analysis will be helpful in dividing the middle Provo River into reaches that demonstrate similar behavior. Additional photo-based metrics such as average wetted channel width, sinuosity, and riffle frequency could also be calculated and used to refine reach divisions. This type of analysis will also be helpful in determining where any additional smaller-scale field study sites are needed to adequately represent conditions in each distinct reach.

Because much of the channel reconstruction work had not yet been completed at the time of the 2003 orthophotography flight, additional flights are recommended for the future. Channel reconstruction activities are anticipated to be completed by the end of 2007; we recommend that the river be flown during typical, low-flow conditions shortly after all substantive channel work is complete. After that, flights and associated reach-level analyses are recommended at a 3–5 year frequency during typical low flow conditions.

6.3.2 Define Geomorphic Reaches

The results of the initial analysis of 2003 and 2006 orthophotography should be used to comprehensively define the currently distinct geomorphic reaches of the middle Provo River. These reach definitions would be used for the reach-scale field monitoring efforts described below. At this time, it is anticipated that this process will result in five or six reaches being defined:

Reach A: From Jordanelle Dam to a point somewhere between the WB and RR monitoring sites. This reach is characterized by static, coarse-bedded conditions with minimal sediment transport.

Reach B: From the bottom of Reach A to a point somewhere between River Road and the upstream end of the never-channelized reach. This reach is characterized by limited channel migration, bar building, and suppressed sediment transport.

Reach C:	From the bottom of Reach B to the top of the never-channelized reach. This reach is characterized by moderate levels of channel migration, bar building, and sediment transport. If no substantial recovery of dynamic processes occurs within this reach, it may be combined with Reach B.
Reach D:	The Never-Channelized Reach (identified as Reach 4 in URMCC planning documents). This reach is characterized by extremely high levels of channel migration, bar building, and sediment transport.
Reach E:	From the bottom of the never-channelized reach (at Midway Lane Bridge) to Deer Creek Reservoir. This reach is characterized by high levels of channel migration, bar building, and sediment transport. Depending on the results of the orthophotography analysis, it may be necessary to further divide Reach E.

6.3.3 Reach-Scale Channel Substrate Monitoring

Additional channel substrate monitoring is recommended to address Concern 3, potential for substrate coarsening. However, we recommend shifting the monitoring approach from the existing intensive, small-scale study site approach to a broader reach-scale approach. While the existing approach does a good job of tracking detailed substrate changes within each study site, it does not provide information on how applicable the trends observed at each site are to the whole river.

As a reach-scale assessment of channel substrate, we recommend completing sets of pebble counts at eight main-channel riffle heads within each geomorphic reach (defined as described in Section 6.3.2 above). For the purposes of this protocol, we define a "riffle head" as the shallow area of calmer water immediately upstream of the start of turbulent water that indicates a riffle. Sampling in these areas is recommended because riffle heads are easily identified channel units, they typically hold gravel-sized material that would be mobile under expected high flows, and they are shallow and calm enough to sample conveniently and consistently. Counts of 100 rocks per riffle head are recommended, traversing the full wetted channel width. If deposits of fines (sand and silt) are present along channel margins, they should be noted but excluded from the count. Pebble counts should be done in the late summer when flows are at regular, low-flow discharge levels. The eight counts (i.e. 800 measurements) for each reach should be composited and plotted to determine the size distribution of riffle head substrate for the entire reach. These counts should be completed every 3 years and the results analyzed to determine temporal trends.

In order to select the specific riffle heads to sample, a starting spot within the reach should be randomly selected, and the nearest four riffle heads upstream and downstream of that spot should be sampled. If this protocol leads to selection of a riffle head beyond the established reach boundary, additional riffle heads should be added upstream or downstream as appropriate such that counts are completed at eight locations within each reach. A new starting spot should be randomly selected each time monitoring is performed.

Because the locations of individual channel units such as riffles can shift with time, comprehensively sampling a specific channel unit type provides a more robust picture of temporal trends in substrate size than attempting to re-sample a specific spot in the channel where results may be confounded by localized changes.

6.3.4 Channel Incision Monitoring

Future monitoring of streambed elevation and overbank discharge is recommended in order to address Concern 4, potential for channel incision. However, we recommend shifting the monitoring protocol to a broader-scale approach that provides information representative of each defined geomorphic reach. To achieve this, we suggest expanding the established study sites so that they encompass a length of 20 bankfull channel widths. This is the accepted guideline for a "representative" geomorphic study site (Harrleson et al. 1994). An additional study site 20 bankfull widths in length should also be established in Reach C (the "above never-channelized" [ANC] site discussed in Section 6.2 above). As suggested by Schmidt and Wilcock (2007), we recommend measuring water stage relative to streambank height at each main channel riffle within each expanded or new study site. New monumented cross section endpoints (real world coordinates and elevations) should be established across the central part of each new riffle included in each expanded site, and across each riffle within the new ANC study site. Complete topography at each of these new riffle transects should initially be surveyed; however, repeat measurements would only need to include water stage unless significant changes were observed. The water stage measurements should be made at both left and right edges of water, and at the edges of any mid-channel islands crossed by the riffle transects. Stage measurements should be made in the summer/fall during typical low flow conditions, as well as at a designated high flow level (such as 1,100 cfs) to assess any temporal changes in the extent of overbank flooding. We recommend that these measurements be made every 3 years.

6.3.5 Sediment Transport Monitoring

To better assess Concern 1, disparity in sediment loads, we agree with the recommendation by Schmidt and Wilcock (2007) to establish a new bedload sampling site above the never-channelized reach (ideally within or adjacent to the new ANC geomorphic study site suggested above). Measurements (ten sub-sample technique) should be made during the high flow period at this new site and used to determine a transport rating curve and annual sediment load for the site. These results should be compared with reported 2004–2006 loads at the WB, RR, MID, and CA bedload sites to help determine how far downstream the sediment-trapping effects of Jordanelle Dam extend. If and when gravel augmentation efforts are implemented on the middle Provo River, we also suggest that bedload and suspended load monitoring be done at all five monitoring sites every 3 to 5 years to assess the effectiveness of sediment replenishment on the middle Provo River.

6.3.6 Macroinvertebrate Monitoring

To better assess Concern 5, reduced macroinvertebrate species richness at upstream sites, we recommend continuing macroinvertebrate sampling. Continued assessment of macroinvertebrate communities at the existing sampling sites will also be important for documenting biological recovery following the completion of all restoration activities within the middle Provo River. Substrate evaluations and macroinvertebrate sampling should also be completed within the proposed new ANC geomorphic study site. Establishing a macroinvertebrate monitoring station in this area would help identify whether the observed difference between the upstream (BJ and RR) sites and downstream (NC and CA) sites is closely associated with the change in substrate stability or help identify other factors contributing to the shift in community composition. Although monitoring the macroinvertebrates in both the spring and fall provides valuable information on short-term trends in each season (some trends were observed in only one or the other during the 2004–2006 monitoring efforts) the long-term trends of recovery and rehabilitation of these biological communities resulting from restoration efforts should be apparent during either seasonal sample. Thus, monitoring could be reduced to include sampling only one season with a sampling frequency of once every 3 years. We recommend the seasonal sampling be consistent each year and because of the logistic difficulties associated with sampling immediately prior to spring runoff, we suggest monitoring in the fall. Results from the fall samples also appear to be more consistent and repeatable and, therefore, may be a better data set for detecting temporal trends than data collected in the spring when physical conditions are more variable. We believe that continued macroinvertebrate monitoring is important to evaluate the longitudinal differences in community composition within the middle Provo River, but the continuation of monitoring will be particularly important if and when gravel augmentation efforts are implemented.

7.0 REFERENCES

Allan J.D. 1995. Stream ecology: structure and function of running waters. Kluwer Academic Publishers, Norwell, MA. 388 p.

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.

Bernhardt E.S. et al. 2005. Synthesizing U.S. River Restoration Efforts. Science 308: 636-637.

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

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 American Fisheries Society 116: 692-702.

Connell J.H. 1978. Diversity in tropical rainforests and coral reefs. Science 199: 1302-1309.

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.

Grafe C.S.(ed.). 2002. Idaho River Ecological Assessment Framework: an Integrated Approach. Idaho Department of Environmental Quality; Boise, Idaho. 222 p.

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.

Hardy T., P. Panja, and D. Mathias. 2004. WinXSPRO, a Channel Cross Section Analyzer, User's Manual, Version 3.0. Gen. Tech. Rep. RMRS-GTR-147. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Mountain Research Station. 95 p.

Harrelson, Cheryl C; Rawlins, C. L.; Potyondy, John P. 1994. Stream channel reference sites: an illustrated guide to field technique. Gen. Tech. Rep. RM-245. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 61 p.

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.

Hepworth, R.D. and D.E. Wiley. 2006. Middle Provo River fish population monitoring 2005. Utah: Department of Natural Resources. Final Report. 9 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.

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.

Lester G. 2005. Biologist, EcoAnalysts, Inc. Personal communication with Mike Golden regarding percentages of communities made up of three most dominant taxa. 1/19/2005.

McCabe D.J. and N.J. Gotelli. 2000. Effects of disturbance frequency, intensity, and area on assemblages of stream macroinvertebrates. Oecologia 124: 270-279.

Minshall G.W. 1985. Developments in stream ecosystem theory. Journal of Fisheries and Aquatic Science 42: 1045-1055.

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

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. 2005. Middle Provo River 2004 Monitoring Report. BIO-WEST, Inc., Logan, UT. 103 p. plus appendices.

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, recreational uses, 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.

Schmidt J.C. and Wilcock P.R. 2007. A Review of Channel Monitoring and Sediment Transport Measurements at the Provo River Restoration Project. Draft report, April 2007, submitted to the Utah Reclamation Mitigation and Conservation Commission. 14p. plus appendices.

Schmude K.L., M.J. Jennings, K.J. Otis, and R.R. Piette. 1998. Effects of habitat complexity on macroinvertebrate colonization of artificial substrates in north temperate lakes. Journal of the North American Benthological Society 17(1): 73-80.

[USGS] U.S. Geologic Survey. 2006. Web site with USGS gage information. Located at: http://waterdata.usgs.gov/nwis/uv?10149400. 6/06.

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. and C.P. Hawkins. 1996. Effects of sampling area and subsampling procedure on comparisons of taxa richness among stream. Journal of the North American Benthological Society 15:392-399.

Vinson M.R. and C.P. Hawkins. 1998. Biodiversity of stream insects: variation at local, basin, and regional scales. Annual Review of Entomology 43: 271-293.

WILDCO. 2/15/2006. Description and specifications of the WILDCO Hess sampler. Located at: http://www.wildco.com/vw_prdct_mdl.asp?prdct_mdl_cd=16. 2/15/06.

Williams, J.E., C.A. Wood, and M.P. Dombeck, editors. 1997. Watershed Restoration: Principles and Practices. American Fisheries Society, Bethesda, Maryland.

Wohl E., Angermeier P., Bledsoe B., Kondolf G., MacDonnell L., Merritt D., Palmer M., Poff N., Tarboton D. 2005. River restoration. Water Resources Research 41(W10301): 12 p.

Wolman M.G. 1954. A method of sampling coarse river-bed material. American Geophysical Union Transactions 35(6):951-956.