MIDDLE PROVO RIVER 2005 MONITORING REPORT

White Bridge, 1.76 miles below Jordanelle Dam.

River Road, 4.18 miles below Jordanelle Dam.

Midway Bridge, 8.84 miles below Jordanelle Dam.

Charleston Bridge, 11.39 miles below Jordanelle Dam.

Representative bedload samples during 2005 peak flows at the sediment transport monitoring bridges.

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EXECUTIVE SUMMARY

INTRODUCTION

This report summarizes the 2004 and 2005 channel geometry, substrate, sediment transport (geomorphic), and benthic macroinvertebrate (ecological) monitoring results for the middle Provo River. These monitoring efforts were conducted in support of the Utah Reclamation Mitigation and Conservation Commission's (Mitigation Commission's) Provo River Restoration Project (PRRP), which involves large-scale channel and floodplain reconstruction of the Provo River between Jordanelle Dam and Deer Creek Reservoir – a section of river known as the middle Provo River.

The purpose of the PRRP is to enhance biological productivity and diversity of aquatic habitat, riparian areas, and other environmental resources within the river corridor. 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 construction activities are nearly complete.

Understanding the complex relationships between hydrology, fluvial geomorphology, and riparian ecology is necessary to adaptively manage the PRRP, especially because the project is located below a dam. The monitoring program described in this report is designed to collect data that will assist in explaining these interrelated processes and support adaptive management techniques to maximize the long-term resource value of the project. For example, data collected to-date supports the need to replenish a variable amount of coarse-grained sediments below Jordanelle Dam to maintain habitat diversity and prevent long-term channel degradation and/or incision. The results of the monitoring program will help the Mitigation Commission develop effective techniques to maintain the middle Provo River in a desirable condition.

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

1. 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 the that Mitigation Commission meets all fish, wildlife, and recreation mitigation commitments.

CROSS SECTIONS AND LONGITUDINAL PROFILES

An initial set of cross sections and longitudinal profiles were surveyed in four monitoring sites on the middle Provo River to establish a baseline from which to monitor changes in channel geometry and slope over time. The four monitoring sites, in upstream-to-downstream order, are the Below Jordanelle Dam (BJ) site, the River Road (RR) site, the Never-Channelized (NC) site, and the Charleston (CA) site. The BJ, RR, and CA sites are located in reaches reconstructed as part of the PRRP, while the NC site is located in a reach that was never straightened or leveed.

Plots of the 2004 and 2005 streambed profiles and cross sections illustrate the diversity of channel width, depth, and slope within the restored reaches of the Provo River. Riffle, run, and pool areas are illustrated for each monitoring site.

The upper reaches of the middle Provo River are extremely stable and lack some of the dynamics normally seen in natural streams, such as meander migration and bar development. Based on the 2005 monitoring results, channel cross sections at BJ and RR have been relatively static; they exhibit very little change from 2004. There are some slight indications of downcutting and widening in these upper reaches. However, the lowest cross section at the RR site (RR6) changed dramatically between 2004 and 2005. The thalweg dropped by more than 1 foot and shifted to the middle of the channel, and the gravel bar on river right continued to expand as compared to the 2002 and 2004 surveys.

The lower reaches of the middle Provo River were much more dynamic between the 2004 and 2005 surveys. The cross sections at NC show extensive bed shifting; however, the slope of the bed remained stable with nearly equal amounts of scouring and filling within the study site. The meander at NC3 migrated approximately 5 feet toward the left endpoint. No significant change in bed elevations occurred at the NC site; whereas there was an overall drop in bed elevations at the CA site. The CA site was the most dynamic monitoring site between the 2004 and 2005 surveys. The bed may have been extremely sensitive to high flows between the two surveys because of the recently completed restoration activities at this site.

CHANNEL SUBSTRATE

Within each monitoring site (BJ, RR, NC, and CA), streambed material was delineated into visibly homogenous patches based on dominant and subdominant particle sizes. The percentage of material within each of six size categories (sand/silt, fine gravel, medium gravel, large gravel, cobble, boulder) was noted for each patch. In addition, quantitative pebble counts (Wolman 1954) were completed at four to six discreet “patches” within each monitoring site. Patches were sampled in a variety of habitats such as riffles, runs, depositional bars, and eddies. Particle size data were grouped into 10 size categories and plotted to determine grain sizes of the D_{16}, D_{25}, D_{50}, D_{75}, and D_{84} particles.

Based on the 2005 monitoring results, the dominant substrate class remains cobble and large gravel. Some patches of small and medium gravel-sized particles remain, but such patches represent a small proportion of the overall substrate. The patches at NC and CA also became coarser. This is most likely a result of shifts in sampling locations because of changes in the channel and/or changes in the locations of the patches. The most recently constructed site, CA, experienced the most change. The 2004 sampling occurred after construction but prior to spring runoff. The 2005 sampling shows the changes caused by the first peak flow through the newly constructed channel. These changes include a loss of silty material that was most likely deposited during construction. The substrate at the CA site is now coarser and more like substrate at the other sites, particularly NC.

SEDIMENT TRANSPORT

Bedload and suspended sediment samples were collected at four bridge locations between Jordanelle Dam and Deer Creek Reservoir. In upstream-to-downstream order, the bridge sites are White Bridge (WB), River Road (RR), Midway Bridge (MID), and Charleston (CA). Samples were collected at regular discharge intervals during the rising and falling limbs of the 2005 spring hydrograph (May and June).

The majority of the total sediment load throughout the middle Provo River moves in suspension and not as bedload, which is typical of most gravel-bed rivers. Suspended sediment loads increase uniformly with increased distance downstream of Jordanelle Dam, with approximately 617 tons at WB, 1,071 tons at RR, 2,127 tons at MID, and 4,939 tons at CA in 2005. The originally high suspended sediment loads in 2005 at CA is attributed to nearby channel construction activities. Low-flow suspended sediment concentrations were slightly higher immediately below Jordanelle Dam than the next two monitoring sites; however, low-flow concentrations were highest at the CA site just upstream of Deer Creek.

As with previous monitoring results (Olsen et al. 2004, Olsen 2005), bedload remains severely suppressed in the upper 4-6 miles of the middle Provo River at the BJ and RR sites, with approximately 47 and 74 tons, respectively, in 2005. The never-channelized reach, located immediately upstream of the MID site, generated abnormally high amounts of bedload transport (4,291 tons) in 2005. Most of the bedload from the never-channelized reach is deposited in the reach immediately downstream of the MID site. Bedload transport returns to “normal” at the CA site (315 tons in 2005), 11.4 miles below Jordanelle Dam and 2.5 miles below the Midway Bridge.

MACROINVERTEBRATE SAMPLING

In May and September 2004 and 2005, quantitative and qualitative sampling for benthic macroinvertebrates was conducted within each of the four established channel monitoring sites (BJ, RR, NC, and CA). Three replicate quantitative samples were taken in a riffle at each site using a Hess-type sampler with a 250-micron mesh net. Additionally, one multi-habitat composite kick net sample was collected at each site using a D-frame kick net. Samples were rinsed, preserved, and shipped to EcoAnalysts, Inc., for processing and identification. Organisms were identified to the genus/species level, except for midges, which were identified to the family level, and worms, which were identified to the class level. The number of each taxa collected was entered into a spreadsheet for statistical analysis and generation of biological metrics.

Statistical analysis of the Hess samples and visual analysis of the composite kick samples shows that the CA site has recovered from construction activities more quickly than expected from other studies. In addition, the macroinveretebrate community at CA is very similar to NC, but the communities at both these sites differ from the communities seen upstream at BJ and RR. A shift to more pollution-tolerant taxa and an increased abundance and diversity of scraper taxa at NC and CA may indicate some level of nutrient enrichment at these two sites. Conversely, the increased overall diversity in the macroinvertebrate community at these sites could be an indicator of higher substrate and habitat heterogeneity than at BJ and RR. 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.

Comparison of the 2004 and 2005 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 macroinverebrate 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 channel coarsening shown to be prevalent at BJ are the likely cause of lack of change observed in the macroinverebrate community.

DISCUSSION

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

Flow, in conjunction with sediment supply, controls channel geometry and profile, the streambed particle size distribution, and the rate, timing, and size characteristics of sediment transport through a channel reach of given size and slope. The imbalance of incoming and outgoing sediment loads below Jordanelle Dam, if not mitigated over the long run, will cause several miles of the restored channel to become degraded, incised, and disconnected from its floodplain, similar in function to the degraded, pre-restoration state. Many of the improved beneficial uses associated with the PRRP will not be maintained without mitigating some of the coarse-grained sediments below Jordanelle Dam on an annual basis. Specific recommendations to this regard are made in this report.

TABLE OF CONTENTS

1.0 INTRODUCTION 1-1
  1.1 Recent History of the Middle Provo River 1-4
  1.2 Central Utah Project (CUP) Background 1-5
  1.3 Purpose of and Need for the Monitoring Program 1-9

2.0 CROSS SECTIONS AND LONGITUDINAL PROFILES 2-1
  2.1 Introduction 2-1
  2.2 Methods 2-1
    2.2.1 Data Collection 2-1
    2.2.2 Over-bank Flooding Analysis 2-8
    2.2.3 Plan View Changes in the Never-Channelized Reach 2-9
  2.3 Results 2-10
    2.3.1 Endpoint Coordinates 2-10
    2.3.2 Cross Sections 2-10
    2.3.3 Longitudinal Profiles 2-15
    2.3.4 Over-bank Flooding Analysis 2-15
    2.3.5 Plan View Changes in the Never-Channelized Reach 2-21

3.0 CHANNEL SUBSTRATE 3-1
  3.1 Introduction 3-1
  3.2 Methods 3-1
  3.3 Results 3-2
    3.3.1 Substrate Maps 3-2
    3.3.2 Pebble Counts 3-11
  3.4 Channel Substrate Discussion and Recommendations 3-17

4.0 SEDIMENT TRANSPORT 4-1
  4.1 Introduction 4-1
  4.2 Sediment Transport Methods 4-1
    4.2.1 Monitoring Sites 4-1
    4.2.2 Stream Discharge 4-2
    4.2.3 Suspended Sediment Monitoring 4-2
    4.2.4 Bedload Monitoring 4-3
  4.3 Sediment Transport Results 4-4
    4.3.1 2005 Sediment Loads 4-4
    4.3.2 Relationship between Sediment Transport and Discharge 4-8
  4.4 Sediment Transport Discussion and Recommendations 4-10

5.0 MACROINVERTEBRATE SAMPLING 5-1
  5.1 Introduction 5-1
  5.2 Methods 5-1
    5.2.1 Data Analysis 5-2
  5.3 Results 5-2
    5.3.1 2004 and 2005 5-2
    5.3.2 Comparisons to Historical Data 5-13
  5.4 Discussion 5-16
  5.5 Summary 5-22

6.0 SUMMARY AND RECOMMENDATIONS 6-1
  6.1 Summary of Results 6-1
  6.2 Adaptive Management Recommendations 6-2

7.0 REFERENCES 7-1

APPENDIX 2.1 CROSS SECTION PHOTOS

APPENDIX 2.2a CROSS SECTION PLOTS

APPENDIX 2.2b CROSS SECTION DATA

APPENDIX 2.3a LONGITUDINAL PROFILES

APPENDIX 2.3b LONGITUDINAL DATA

APPENDIX 2.4 PROFILE COMPARISONS

APPENDIX 2.5 HEC-RAS OUTPUT PLOTS

APPENDIX 2.6 PLOTS OF SURVEYED WATER LEVELS AT THE RR AND NC MONITORING SITES

APPENDIX 2.7 MAPS OF THE ACTIVE CHANNEL IN THE NEVER-CHANNELIZED REACH IN 1993, 1999, AND 2004

APPENDIX 3.1a SUBSTRATE MAPS

APPENDIX 3.1b SUBSTRATE POLYGON ATTRIBUTE TABLES

APPENDIX 3.2 SUBSTRATE TYPE (PERCENT GRAVEL IN EACH POLYGON)

APPENDIX 3.3 PEBBLE COUNT RESULTS

APPENDIX 4.1 SUSPENDED SEDIMENTS AND BEDLOAD RESULTS

APPENDIX 5.1 MACROINVERTEBRATE TAXA RESULTS

LIST OF TABLES

Table 2.1. Middle Provo River monitoring sites coordinates and elevations. 2-6

Table 2.2. Dates, flows, and surveyed water-surface elevations. 2-16

Table 2.3. Back-calculated roughness (Manning’s “N”) values based on water surface levels surveyed in May 2005. 2-17

Table 2.4. WinXSPRO output for low, medium, and high flows at the River Road (RR) site. 2-18

Table 2.5. WinXSPRO output for low, medium, and high flows at the Never-Channelized (NC) site. 2-20

Table 2.6. Never-channelized reach channel area, width, and sinuosity in different years, showing percent change from previous orthophotos. 2-21

Table 3.1. Size classes used for substrate mapping. 3-1

Table 3.2. Pebble count results for channel monitoring sites. 3-14

Table 3.3 Pebble count patch location changes between 2004 and 2005. 3-16

Table 4.1. Approximate distances between sediment transport monitoring bridges. 4-1

Table 4.2. Data sources used to determine streamflow at the various monitoring bridges. 4-2

Table 5.1. Three dominant taxa at each sampling site combining Hess and composite kick-net data in spring and autumn 2004. 5-11

Table 5.2. Three dominant taxa at each sampling site combining Hess and composite kick-net data in spring and autumn 2005. 5-13

Table 5.3. 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. 5-17

LIST OF FIGURES

Figure 1.1. Hydrographs and flow duration curves for all post-Jordanelle Dam water years. 1-3

Figure 2.1a. Map of the Below Jordanelle Dam (BJ) Monitoring Site. 2-2

Figure 2.1b. Map of the River Road (RR) Monitoring Site. 2-3

Figure 2.1c. Map of the Never-Channelized (NC) Monitoring Site. 2-4

Figure 2.1d. Map of the Charleston (CA) Monitoring Site. 2-5

Figure 2.2. Methods for surveying permanent cross sections using a total station. 2-7

Figure 2.3. River Road (RR) transect 6 (May 2004 and 2005 survey) compared with Study Site 8 cross section 1 (May 2002 survey). 2-11

Figure 2.4. Change in low-flow edge of water location between 2004 and 2005 at the NC monitoring site. 2-12

Figure 2.5. Change in low-flow edge of water location between 2004 and 2005 at the CA monitoring site. 2-14

Figure 2.6. Hydrograph of Provo River flows at the Charleston gage for water years 1992-1996. 2-22

Figure 3.1a. Substrate types and pebble count locations at the Below Jordanelle (BJ) monitoring site. 3-3

Figure 3.1b. Substrate types and pebble count locations for the River Road (RR) monitoring site. 3-4

Figure 3.1c. Substrate types and pebble count locations at the Never-Channelized (NC) Monitoring Site. 3-5

Figure 3.1d. Substrate types and pebble count locations at the Charleston (CA) monitoring site. 3-6

Figure 3.2a. Comparison of area at the Below Jordanelle (BJ) Monitoring Site occupied by various size classes in 2004 and 2005. 3-7

Figure 3.2b. Comparison of area at the River Road (RR) Monitoring Site occupied by various size classes in 2004 and 2005. 3-7

Figure 3.2c. Comparison of area at the Never-Channelized (NC) Monitoring Site occupied by various size classes in 2004 and 2005. 3-8

Figure 3.2d. Comparison of area at the Charleston (CA) Monitoring Site occupied by various size classes in 2004 and 2005. 3-8

Figure 3.3. Proportion of monitoring site area occupied by various substrate size classes. 3-9

Figure 3.4. Comparison of area occupied by various size classes at each monitoring site in 2004 and 2005. 3-12

Figure 4.1. Year 2005 spring runoff hydrograph showing when sediment samples were taken on the rising and falling limbs. 4-3

Figure 4.2. Suspended (solid yellow) and bedload (orange dots) sediment transport during the 2005 Water Year based on USGS flow records and empirically derived rating curves shown in Appendix 4.1. 4-5

Figure 4.3. Sediment transport rates in the Middle Provo River during the 2005 spring runoff. 4-6

Figure 4.4. Total annual loads in the middle Provo River during the 2005 Water Year. 4-7

Figure 4.5. Totals and gravel loads in the Middle Provo River during the 2005 Water Year. 4-9

Figure 4.6. Measured bedload transport rates and total loads at the River Road (RR) monitoring site compared to modeled transport rates and loads based on Parker's (1990) bedload equation for the 2005 hydrograph. 4-11

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. 5-3

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. 5-4

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. 5-5

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. 5-6

Figure 5.5. Average taxa richness calculated from the three Hess samples taken at each site in spring and autumn 2004 and 2005. 5-6

Figure 5.6. Taxa richness in composite D-frame kick net samples at each site in spring and autumn 2004 and 2005. 5-7

Figure 5.7. Average EPT taxa richness calculated from the three Hess samples taken at each site in spring and autumn 2004 and 2005. 5-8

Figure 5.8. EPT taxa richness in composite D-frame kick net samples at each site in spring and autumn 2004 and 2005. 5-8

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. 5-9

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. 5-10

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. 5-11

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. 5-12

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. 5-14

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. 5-14

Figure 5.15. Average taxa richness calculated from quantitative samples taken at each site in autumn 1999, 2004, and 2005. 5-15

Figure 5.16. Average EPT taxa richness calculated from quantitative samples taken at each site in autumn 1999, 2004, and 2005. 5-15

Figure 5.17. Hilsenhoff Biotic Index (HBI) values from each site in 1999, 2004, and 2005. 5-17

LIST OF MAPS

Map 1.1. Map of the middle Provo River. 1-2

Map 1.2. Map of the Provo River Restoration Project. 1-6

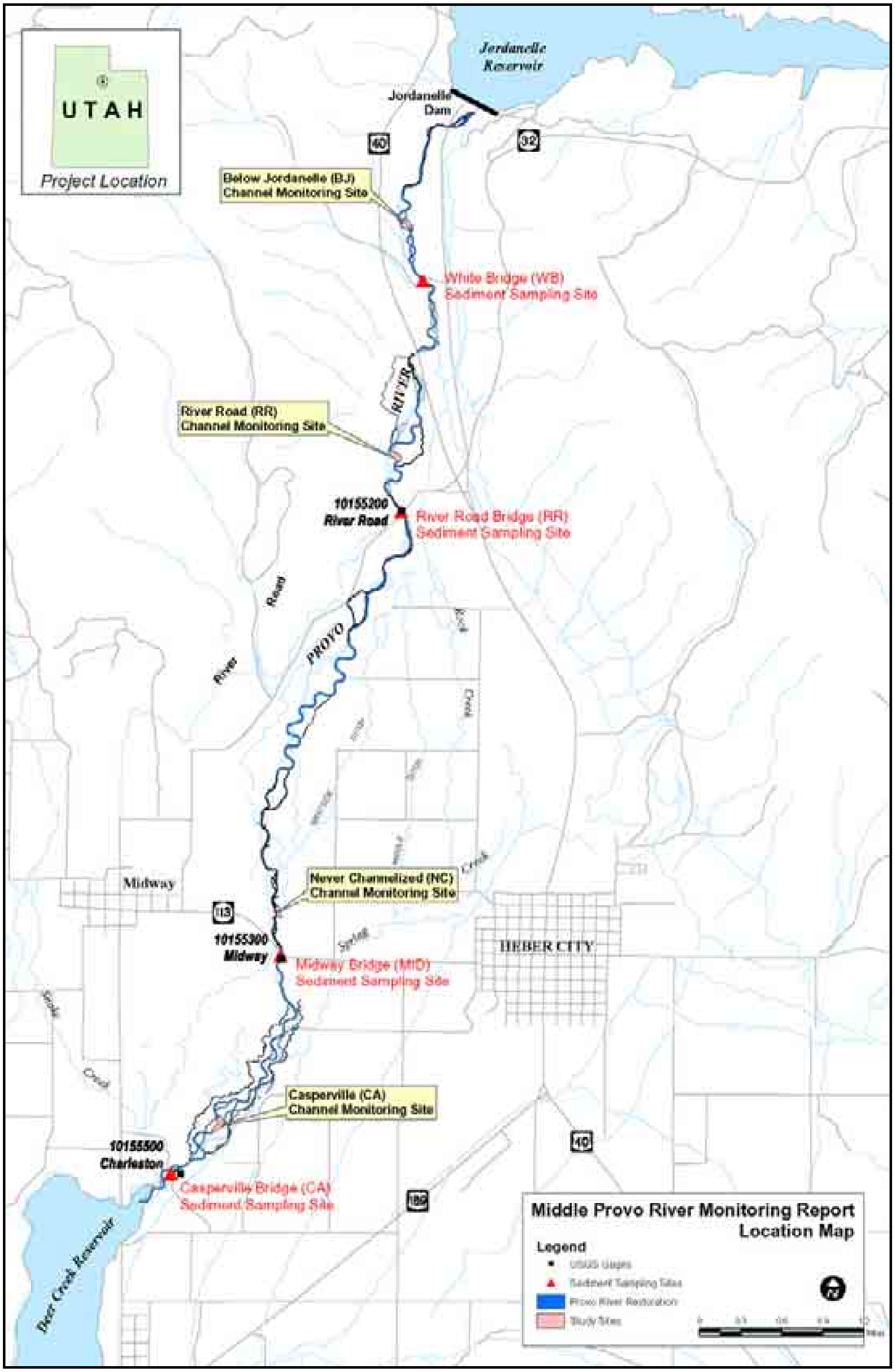
1.0 INTRODUCTION

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

Monitoring specific elements of success and potential maintenance needs began in 2004 as the PRRP entered the final stages of construction. This report documents the findings of the second 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 only peak flows generally exceed 1,000 cubic feet per second (cfs). Peak flows have increased each year since the low peak in 2000. Peak flow in 2005 were much higher than any year since Jordanelle Dam closed in 1996. The 2006 monitoring should show 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). 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 first-year monitoring particle size and delineations of textured patches at the study sites. Chapter 4 discusses the imbalance of sediment transport in the reaches below Jordanelle Dam, shows results of suspended sediment and bedload monitoring sampling at four bridges between Jordanelle Dam and Deer Creek, and discusses proposed actions for addressing sediment issues – particularly the lack of gravel below Jordanelle Dam. Chapter 5 discusses the methods and results of benthic macroinvertebrate sampling. Chapter 6 provides a discussion of the results and a summary of the findings from the first year of monitoring.



Map 1.1. Map of the middle Provo River.

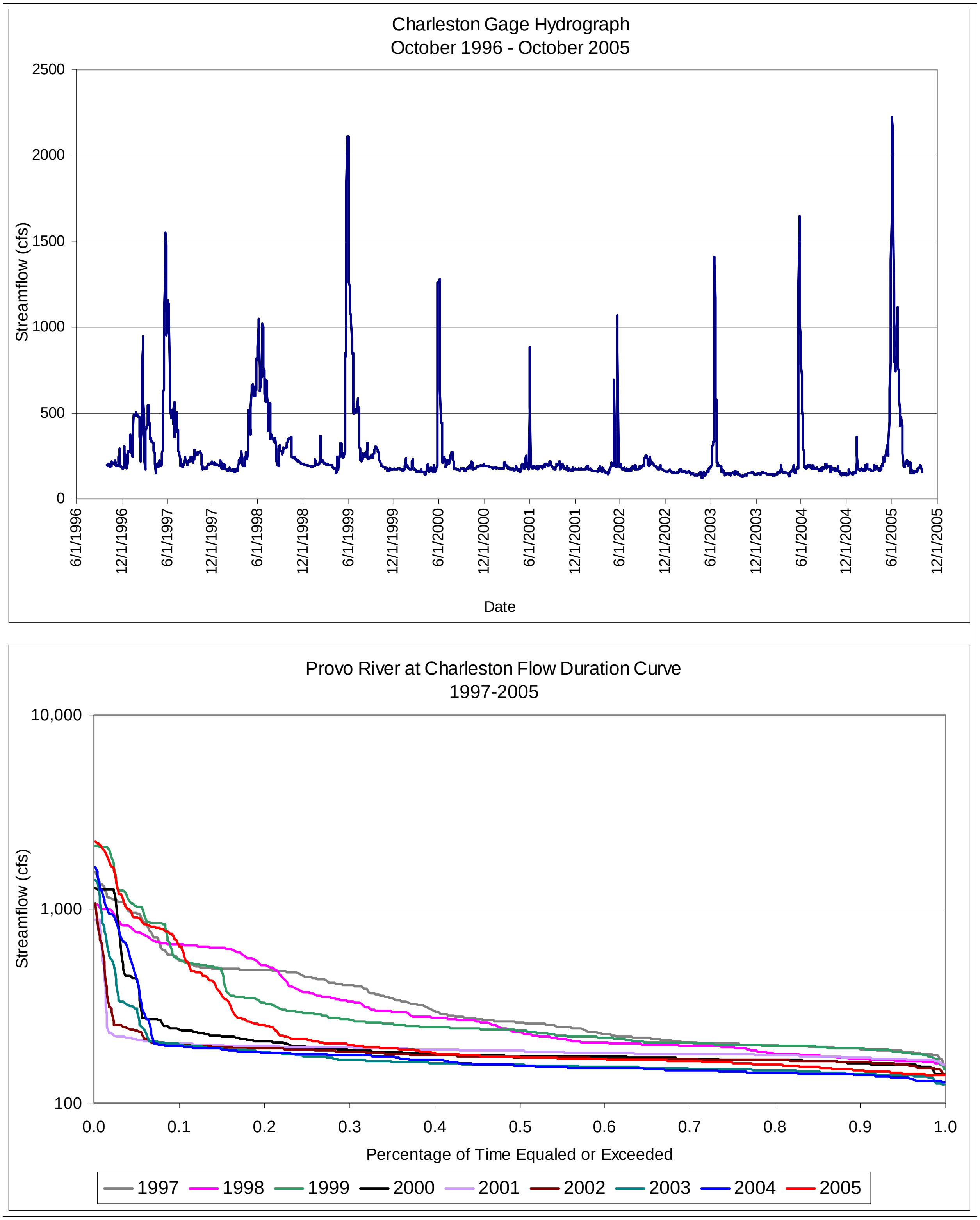


FIGURE 1.1. HYDROGRAPHS AND FLOW DURATION CURVES FOR ALL POST-JORDANELLE DAM WATER YEARS.

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.

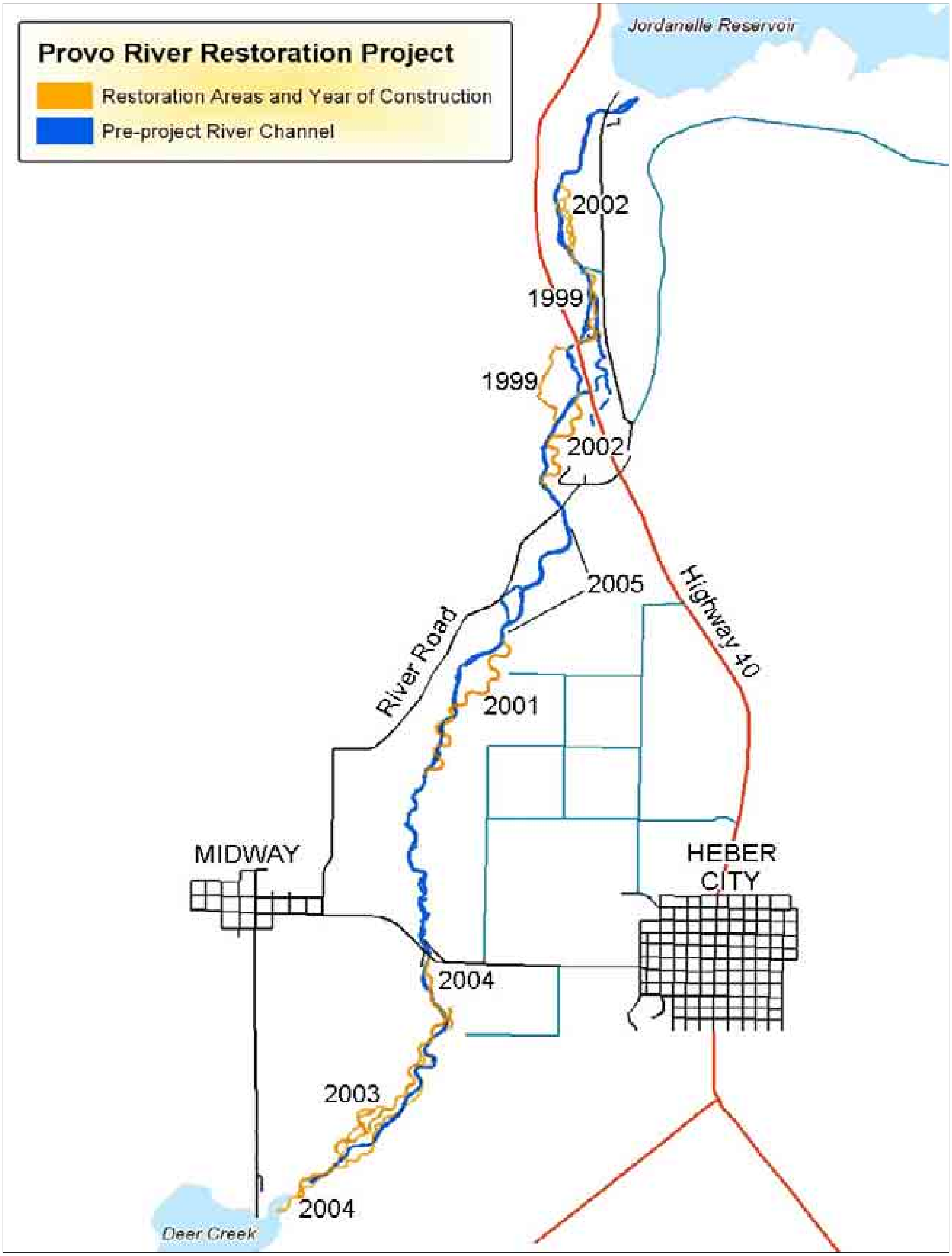
1.2 CENTRAL UTAH PROJECT (CUP) BACKGROUND

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 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 to release it through the Wasatch Mountains as needed in the Bonneville Basin along the Wasatch Front. One of the systems in the unit is the SACS, which diverts flows from nine Duchesne River tributaries through approximately 40 miles of tunnels and aqueducts for storage in Strawberry Reservoir. That water is then carried to Utah Lake through the Diamond Fork System and the Spanish Fork River in Utah County. The water delivered from Strawberry Reservoir to Utah Lake is used as replacement water, allowing for the exchange and/or storage of Provo River flows in Jordanelle Reservoir, located on the Provo River in Heber Valley, approximately 10 miles upstream of Deer Creek Reservoir. Jordanelle Reservoir on the Provo River is the principal feature of the 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. 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. About 75 percent of the channel and floodplain have been reconstructed since that time (Map 1.2) and work should be complete in 2006 or 2007.

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 incision, habitat degradation, reduced fluvial dynamics, poor recruitment and impaired health of riparian vegetation, and diminished diversity and abundance of aquatic biota. Unless releases from the dam are managed to support ecosystem restoration objectives, and unless sediment supplies are not limited below the dam, the physical, chemical, and biological processes vital to ecosystem health may not be maintained.

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

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

1.3 PURPOSE OF AND NEED FOR THE MONITORING PROGRAM

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

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

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

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

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

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2.0 CROSS SECTIONS AND LONGITUDINAL PROFILES

2.1 INTRODUCTION

An initial set of cross sections and longitudinal profiles were established in 2004 and re-surveyed in 2005 following a relatively high runoff year (Figure 1.1) in four reaches of the middle Provo River in order to establish a 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. Monitoring data can also be used to show that the Mitigation Commission is meeting all fish, wildlife, and recreation mitigation commitments.

2.2 METHODS

2.2.1 DATA COLLECTION

On May 10, 2004, six permanent transects (cross sections) were established in each of the four monitoring sites (Figure 2.1a-d) and re-surveyed May 2-5, 2005. A cross section was added to the BJ site between transect 3 and 4 in 2005 to aid HEC-RAS modeling. The new transect is called BJ 3.5. Each transect has two endpoints, a left endpoint (LEP) and right endpoint (REP), which correspond to the side of the river the endpoint is on when facing downstream. Each endpoint was permanently monumented in the field by installing Rebar stakes capped with aluminum. Each aluminum cap is stamped with the transect number and study site abbreviation. A survey-grade (centimeter accuracy) global positioning system (GPS) was used to determine the location of each endcap in real-world coordinates. The endpoint coordinates are provided in NAD83 Utah State Plane feet as well as NAD27 UTM meters. Elevation is provided in NAVD88 feet (Table 2.1).

Transect and longitudinal profile data were originally collected May 10-21, 2004, and re-surveyed May 2-5, 2005, using a theodolite (total station), data collector, and prism/rod. One endpoint was used as the instrument location. The other endpoint was used for a backsight (Figure 2.2). In order to orient the transect surveys, each endpoint was assigned its real-world coordinate value as determined through the GPS survey described above. Since the survey data are relative to the instrument location and backsight, the subsequent survey points have real-world coordinates (northing, easting, elevation).

To complete a transect, the survey rod was placed on points in a straight line (0 degree angle +/- 5 minutes) between the two endpoints (Figure 2.2). Survey points included areas in the channel, on the streambanks, and at the right and left (facing downstream) edges of water. Survey points also delineated vegetation, features such as bars or large woody debris, and changes in topography. The

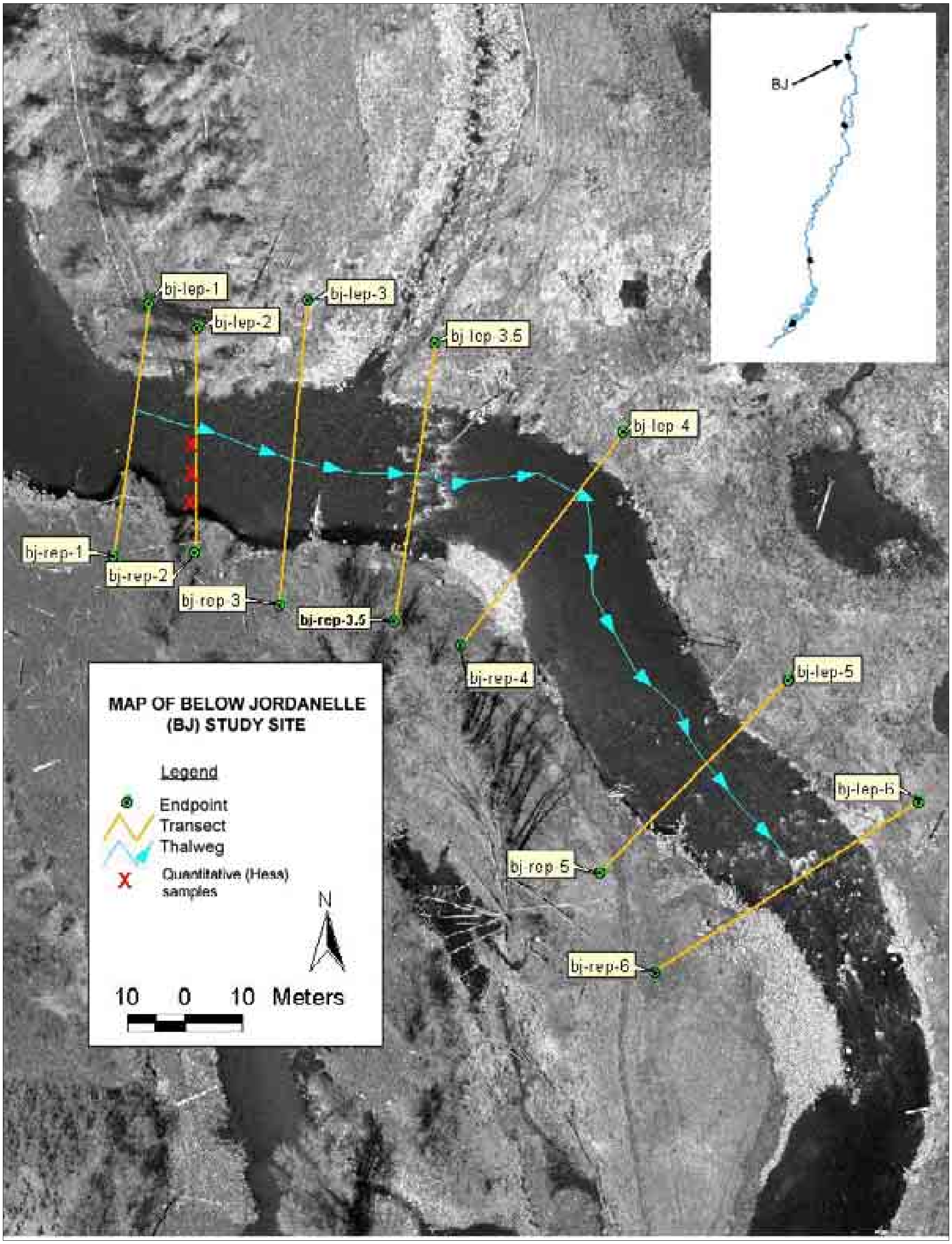


FIGURE 2.1A. MAP OF THE BELOW JORDANELLE DAM (BJ) MONITORING SITE. QUANTITATIVE (HESS) SAMPLES ARE MARKED WITH RED "X"S; LEP AND REP ARE ABBREVIATIONS FOR LEFT ENDPOINT AND RIGHT ENDPOINT. AERIAL PHOTO FROM 2004.

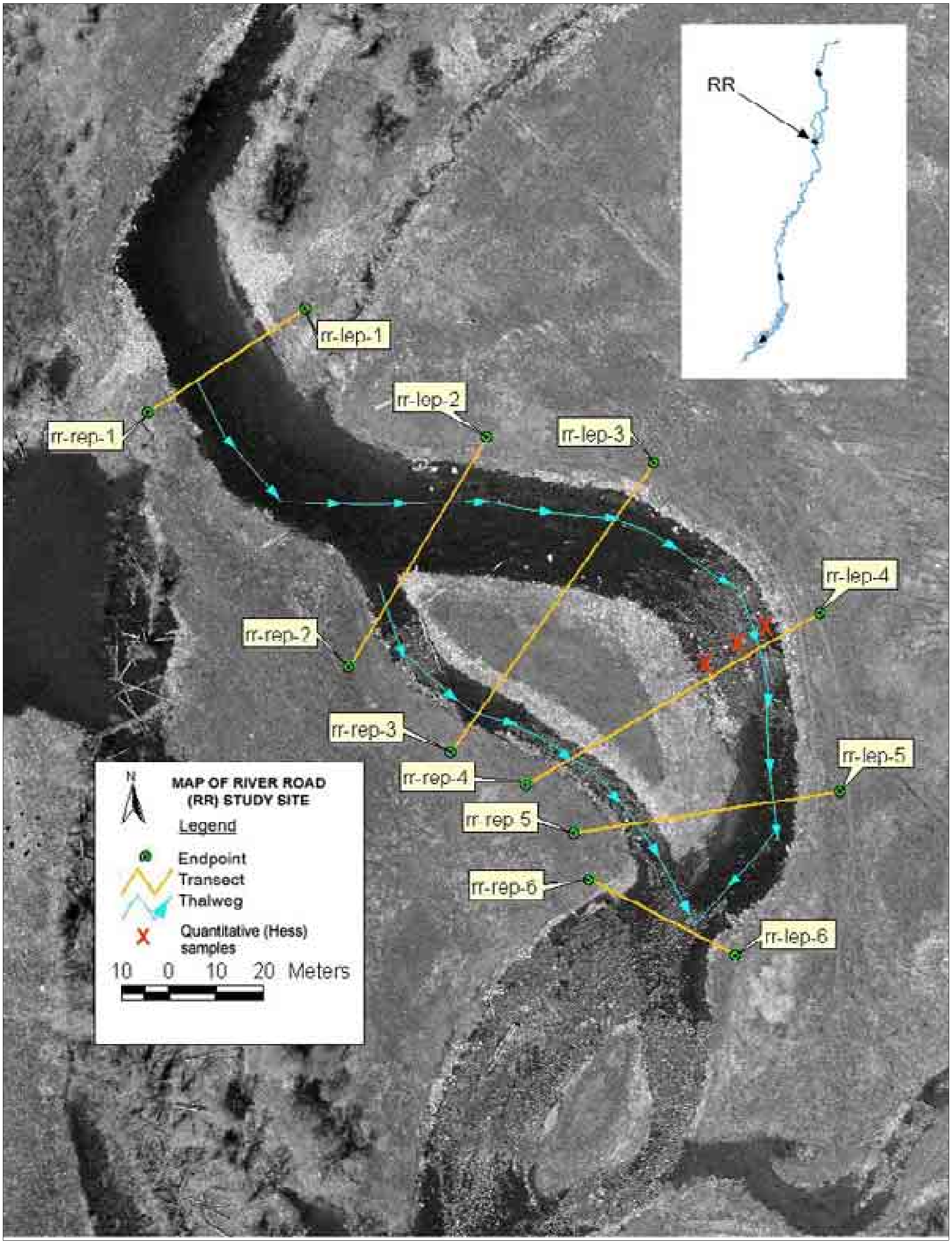


FIGURE 2.1B. MAP OF THE RIVER ROAD (RR) MONITORING SITE. QUANTITATIVE (HESS) SAMPLES ARE MARKED WITH RED "X"S; LEP AND REP ARE ABBREVIATIONS FOR LEFT ENDPOINT AND RIGHT ENDPOINT. AERIAL PHOTO FROM 2004.

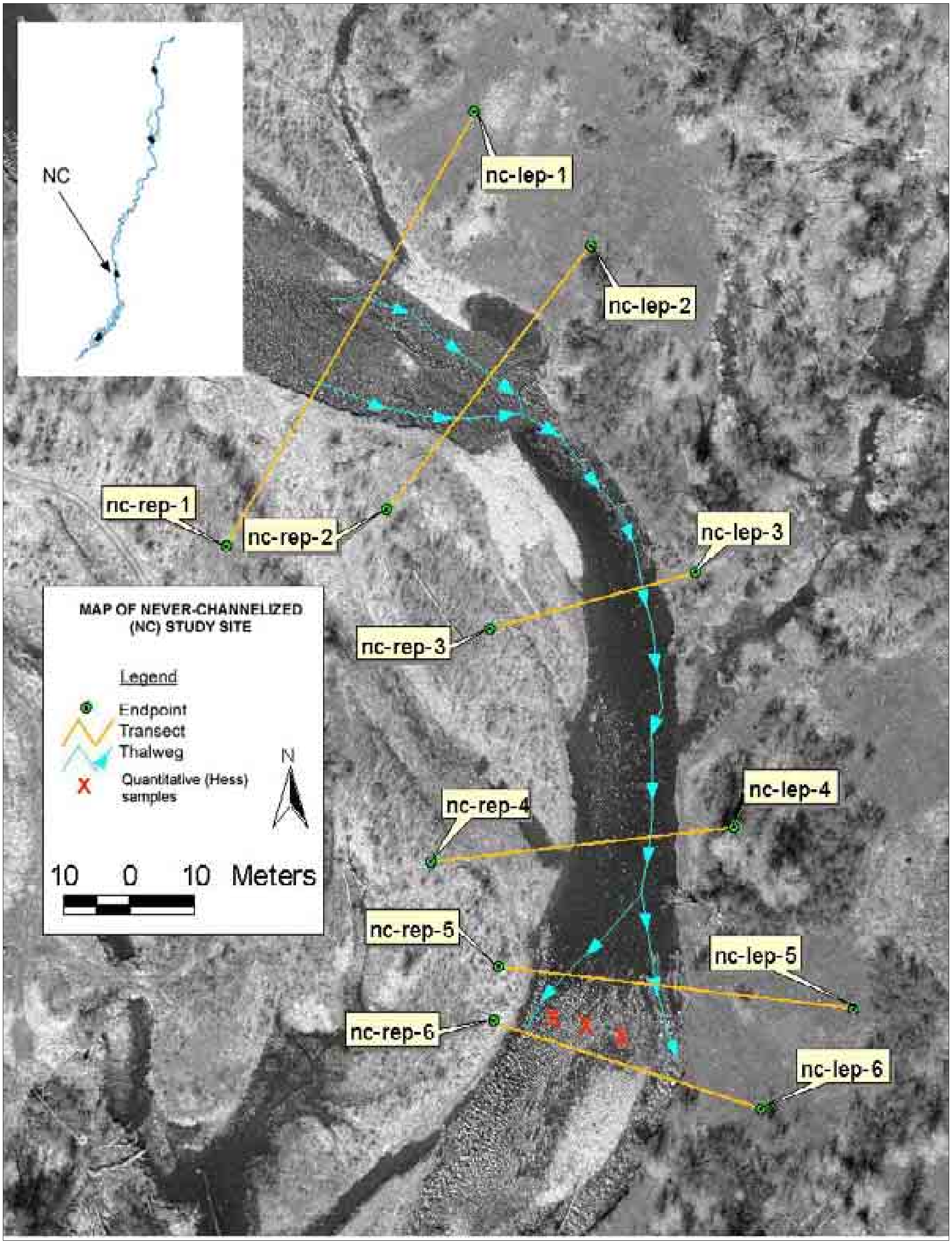


FIGURE 2.1C. MAP OF THE NEVER-CHANNELIZED (NC) MONITORING SITE. QUANTITATIVE (HESS) SAMPLES ARE MARKED WITH RED "X"S; LEP AND REP ARE ABBREVIATIONS FOR LEFT ENDPOINT AND RIGHT ENDPOINT. AERIAL PHOTO FROM 2004.

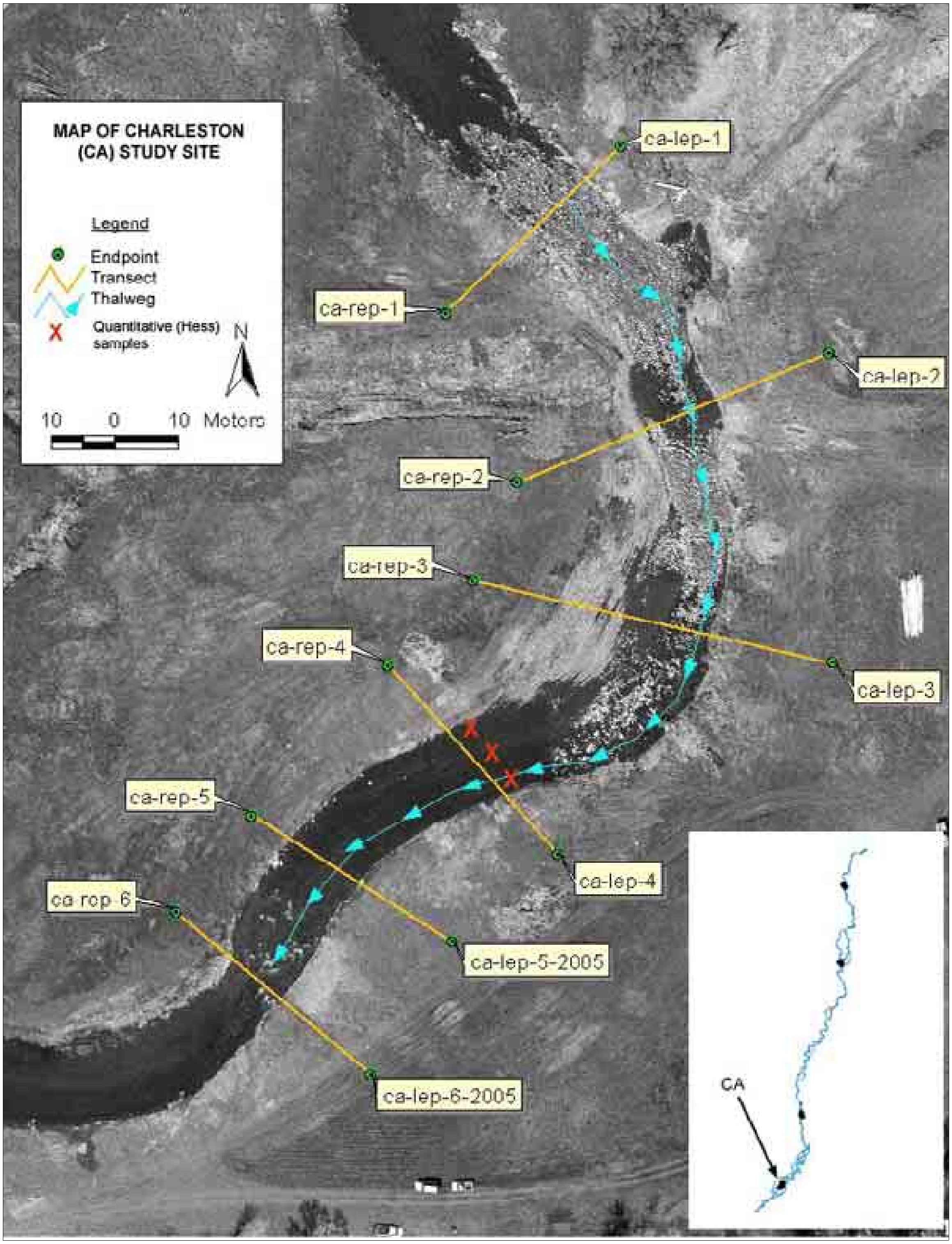


FIGURE 2.1D. MAP OF THE CHARLESTON (CA) MONITORING SITE. QUANTITATIVE (HESS) SAMPLES ARE MARKED WITH RED "X"S; LEP AND REP ARE ABBREVIATIONS FOR LEFT ENDPOINT AND RIGHT ENDPOINT. AERIAL PHOTO FROM 2004.

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-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-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 = site, LEP = Left endpoint, REP = Right endpoint.

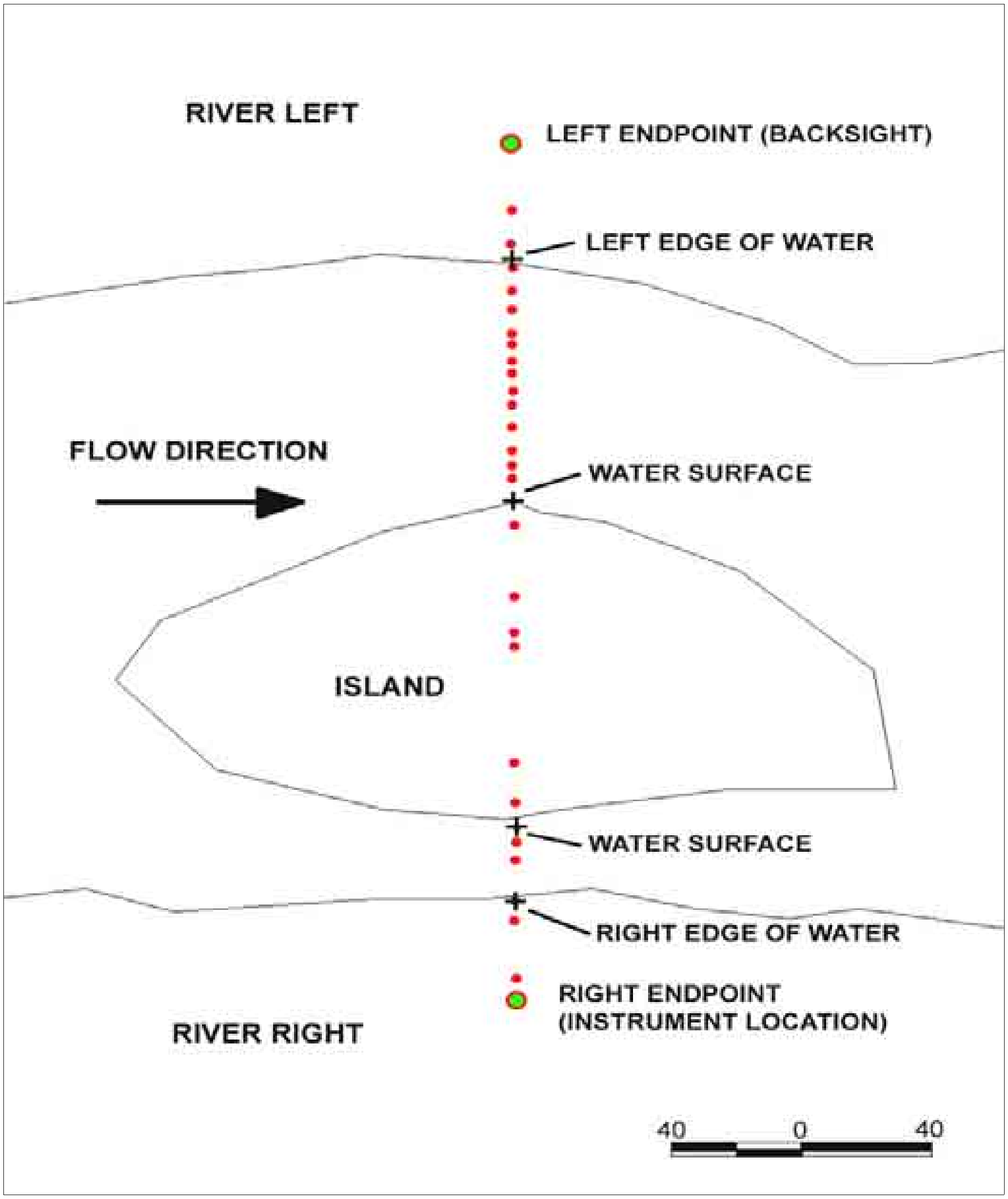


FIGURE 2.2. METHODS FOR SURVEYING PERMANENT CROSS SECTIONS USING A TOTAL STATION. THE INSTRUMENT IS SET OVER A PERMANENT ENDPOINT (A LABELED ALUMINUM CAP ON A 3-FOOT REBAR STAKE) WITH KNOWN COORDINATES. SURVEY POINTS ARE TAKEN ALONG THE TRANSECT BETWEEN THE ENDPOINTS AT 20-FOOT INTERVALS OR WHEN THE 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.

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 were surveyed. Thalweg locations are shown in Figure 2.1. Surveys of the left and right edges of water and prominent features, such as boulders and logs, were also completed in order to create base maps of the sites for use in substrate mapping (see Chapter 3).

2.2.2 OVER-BANK FLOODING ANALYSIS

To comprehensively assess stage-discharge relationships at the monitoring sites, the cross section data were used to develop HEC-RAS hydraulic models for the BJ and CA sites. At each site, water surface elevations were surveyed at the left edge-of-water at each transect during three moderate-to-high flow stages to calibrate roughness values for input into the hydraulic models during near bankfull and over-bank conditions. These water surface elevations, along with those measured during the May 2005 low-flow transect surveys, were used to back-calculate low and high flow Manning's "N" (roughness) values for the different cross sections. Results were compared to the values calculated in 2004 (Olsen 2005).

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 recommended in the 2004 Provo River Monitoring Report (Olsen et al. 2004), an additional cross section (transect BJ3.5; see Figure 2.1a) was established and surveyed within the riffle area at the BJ site to improve modeling accuracy. This cross section was incorporated into the 2005 HEC-RAS model. For both the BJ and CA models, where distances between surveyed cross sections were greater than 50 feet, additional cross sections were interpolated using the "XS Interpolation Between 2 XS's" tool in HEC-RAS. HEC-RAS model results using the 2005 data were compared to the results using 2004 data to evaluate temporal changes in channel capacity and stage-discharge relationships at the BJ and CA monitoring sites.

Channel complexity at the RR and NC sites requires establishment of more cross sections in certain areas within each study site to correctly model flow through each of the sites. Given the number and location of cross sections in these study sites, this limitation makes HEC-RAS an inappropriate model for over-bank flooding analysis,. Instead, WinXSPRO3.0 (Hardy et al. 2004) was used to estimate hydraulic properties of the 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 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.

In 2006 BIO-WEST plans to field-survey additional points where possible to expand these cross sections to the full extent of high-flow inundation.

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. Water surface elevations were surveyed at the left edge-of-water at each RR and NC transect during three moderate-to-high flow stages. These data were used in conjunction with the low-flow cross section survey data to calculate a reach average water surface slope for both low and high stage. The Manning's "N" value at the different flows was adjusted within WinXSPRO until the stage correlated with surveyed low-flow and high-flow water surface elevations. Output from the WinXSPRO program was compiled in a table to compare the stage discharge relationship for low, medium, and high flows at each transect.

2.2.3 PLAN VIEW CHANGES IN THE NEVER-CHANNELIZED REACH

Channel boundaries were delineated on historic and recent aerial photographs to determine temporal changes in channel location, plan form, complexity, average width, and sinuosity within the never-channelized reach. The channel delineation lines were overlain onto the most recent aerial photography to illustrate how the channel has adjusted to changes in the incoming sediment loads as a result of completion of Jordanelle Dam, peak flow reductions, and upstream levee removal and channel restoration activities.

Specifically, rectified orthophotos from August 23, 1993, November 5, 1999, and April 2004 were obtained and displayed within ArcView software. Streamflow conditions were low (52, 171, and 157 cfs, respectively, measured at the Charleston USGS gage) during each of the orthophoto flights. The 1993 photography has a pixel resolution of 1 meter, while the 1999 and 2004 imagery have considerably higher resolution (approximately 0.15-meter pixel size). Within ArcView, the right and left edges of "active channel" were outlined for each imagery set. For the purposes of this analysis, the "active channel" was considered to include areas of water and unvegetated gravel bars. Vegetated islands were included within the active channel if they were surrounded by water or dry, unvegetated gravel side channels. If side channels or bar areas appeared to be predominantly vegetated, they were excluded from the "active channel" boundary.

Once the active channel was digitized, a centerline was drawn through the middle of the active channel polygon for each year of imagery. This centerline distance was used to determine sinuosity (centerline length divided by straight-line valley length) for each year. The centerline distance was also used to calculate average channel width (area of active channel polygon divided by centerline length) for each year.

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. An additional set of endpoints was added at BJ to establish cross section 3.5, located between 3 and 4. 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.

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 resurvey that shows temporal changes in channel geometry (e.g., channel width and depth). Appendix 2.2b provides the raw coordinate data collected for the cross section surveys. Comparison of baseline (2004) data with the data collected in 2005 shows some changes in transects. The BJ and RR sites seem very stable, while NC and CA sites had dramatic changes in multiple cross sections. 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. Transect 3.5 was established in a riffle/step type area for the purposes of improving HEC-RAS modeling. The plot of transect 4 illustrates the shape of the deep pool located in the middle of the site. Transects 5 and 6 illustrate the shape of the riffle at the downstream end of the monitoring site. The BJ site is a very stable section of the Provo River. Plots for transect 2, 3, and 4 show little or no change for each transect. Transect 1 indicates that there has been some erosion on the right bank, while transects 5 and 6 indicate a small drop in bed elevation. This change may indicate initiation of incision at the site. However, given the variability in rod placement, which can be either on or next to larger bed material like boulders, a more substantial lowering of bed elevation is necessary to definitively show incision.

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 re-surveyed transects are very similar to the transect surveys conducted in 2004 for all transects at the site except RR6.

Transect RR6 was placed in the same location as a previously surveyed transect (Study Site 8, cross section 1) that was established as part of the 2002 field work for the Provo River Flow Study (Olsen et al. 2004). As seen in Figure 2.3, some changes in channel shape are evident among the 2002, 2004, and 2005 surveys. Channel shape is influenced by the gravel deposit on the right side of the channel, which forces flow toward the middle of the channel, where it is becoming deeper. The channel on the right in 2004 remains a side channel in 2005.

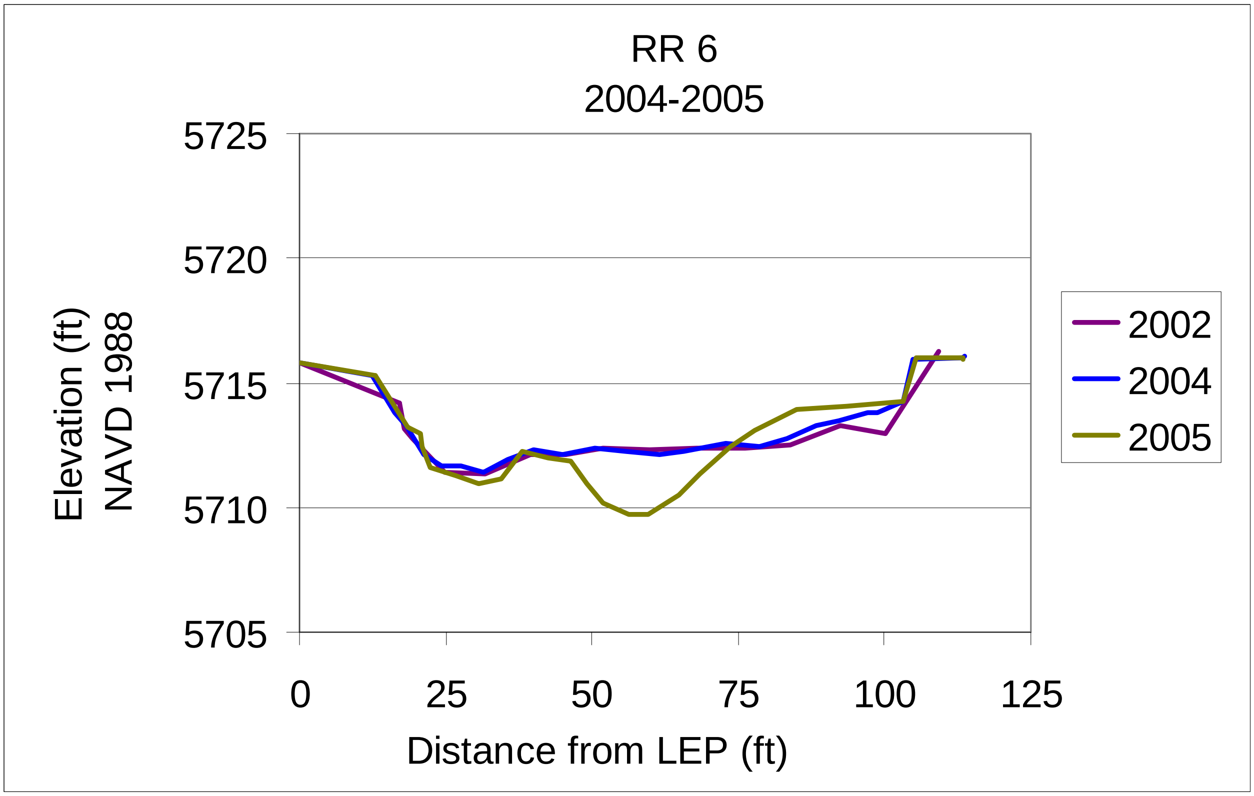


FIGURE 2.3. RIVER ROAD (RR) TRANSECT 6 (MAY 2004 AND 2005 SURVEY) COMPARED WITH STUDY SITE 8 CROSS SECTION 1 (MAY 2002 SURVEY).

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 2.3 is merely a function of fewer points in the 2002 survey and does not indicate a true change in bank shape. Methods established in 2004 for monitoring have prevented these types of inconsistencies between this and future reports. 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.

This site was very dynamic between 2004 and 2005. The three upstream transects were noticeably altered by flows between 2004 and 2005 (Figure 2.4). At transect 1, 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 was also different in 2005 compared to

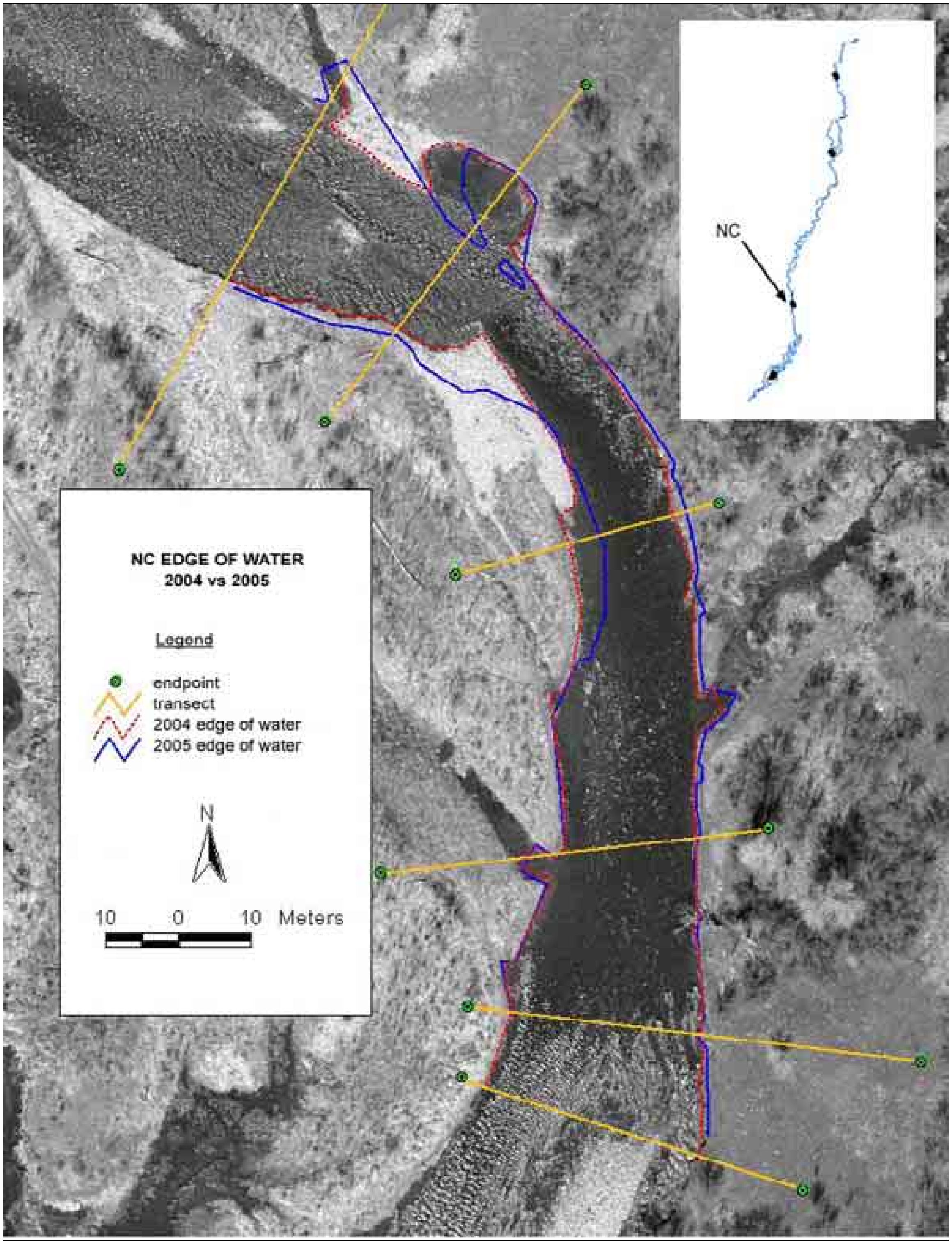


Figure 2.4. Change in low-flow edge of water location between 2004 and 2005 at the NC monitoring site. 2004 survey completed at 130 cfs; 2005 survey completed at 180 cfs.

2004. A mid-channel bar built up in 2005 and a slightly deeper thalweg formed on the right side of the channel.

In transect 3 the channel shifted to the left, eroded the left bank, and deposition occurred on the right bank. The general shape of transect 3 remained the same.

The lower three transects were remarkably stable compared to the upper three transects. There were no major changes in transects 4, 5, or 6 at NC site. Survey data indicate a lower bed elevation in transect 4 in 2005 compared with 2004, possibly indicating early incision. However, change in bed elevation might also be the result of different rod placement between 2004 and 2005. The bed contains some large boulder material, and bed elevation will be higher if the rod was placed on the top of a rock instead of next to a rock. Therefore, small changes in bed elevation may or may not be related to incision. Some erosion and aggradation occurred at transect 5. The relatively equal amounts of erosion and deposition at transect 5 may indicate dynamic equilibrium at this transect. In transect 6 the survey data indicate a small channel shift to the left.

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 (Figure 2.5). 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. The thalweg became shallower and moved farther to the left of the channel.

Deposition reduced the depth of the thalweg by two feet. Transect 4 shows some widening caused by bank erosion on the left side of the channel. Transect 5 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 in 2005 was extremely different compared with 2004 because construction altered the original cross section. A side channel was constructed where the original LEP6 was established and the original left endpoint 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.

Cross sections showed a wide range of stability between sites and among sites. The BJ site was most stable, with few changes in cross section shape. There are a few indications of downcutting in some areas in the BJ reach. The RR site shows little change in most of the cross sections. Some change has occurred in cross section 6. These changes are probably caused by the side channel and gravel deposits on the right side of the channel. Dramatic changes in cross section shape occurred in the NC and CA sites. Cross sections in the upper part of the NC site show a lot of change from 2004 to 2005. The CA site also showed a lot of channel adjustment, most likely related to channel construction in the site that was completed 2004.

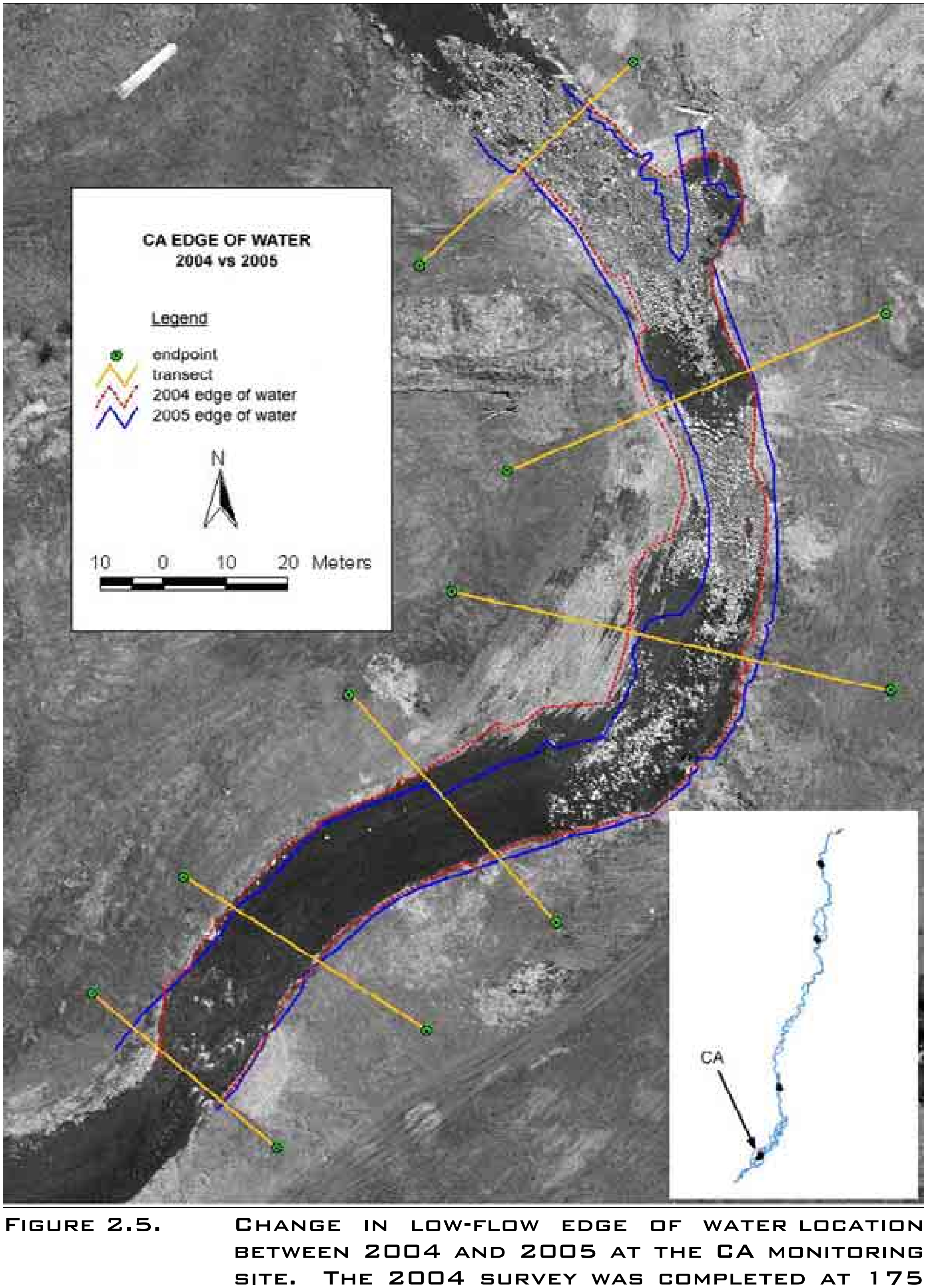


Figure 2.5. Change in low-flow edge of water location between 2004 and 2005 at the CA monitoring site. The 2004 survey was completed at 175 cfs; 2005 survey completed at 250 cfs. Aerial photo from 2004.

2.3.3 LONGITUDINAL PROFILES

Longitudinal profile plots for each monitoring site are included in Appendix 2.3a. As with the cross section plots, the 2004 plots provide a baseline data set whereas the 2005 resurvey shows short-term temporal change in streambed elevations over an entire meander sequence. Raw data collected for the profile plots are provided in Appendix 2.3b.

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

Between 2004 and 2005, the longitudinal profile for CA 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 incised somewhat in the lower portion of CA between 2004 (immediately after construction) and 2005 (an entire year after 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. Additional longitudinal profile monitoring at this site is highly recommended.

The NC site longitudinal profile shows change in the upper part of the monitoring site, with the lower part of the site past 300 feet remaining similar from 2004 to 2005. Scouring occurred throughout the site, but occurred primarily between 250 feet and 350 feet from the top of the monitoring site. The BJ and RR sites have more stable longitudinal profiles. The BJ data indicates 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 incision at the BJ site. The RR site's longitudinal profile shows some cutting and filling along the entire stream section in the monitoring site, but no major changes in channel slope as seen at CA.

Sites RR and NC both have areas where the flow splits around bars or islands, so the profile plots for those sites include a secondary "side thalweg" plot as well as the main channel thalweg plot (Appendix 2.3a). Between 2004 and 2005, the side channel at the NC site seems to have become more uniform in depth at the top and scoured a deeper pool at the bottom of the side channel. The RR side channel longitudinal profile indicates little change in the side channel other than some filling of a small pool.

2.3.4 OVER-BANK FLOODING ANALYSIS

Results of the 2005 low, moderate, and high-flow water surface elevation surveys are provided in Table 2.2.

Table 2.2. Dates, flows, and surveyed water-surface elevations.

SITE	WATER SURFACE ELEVATION (FEET)			
BJ Date:	5/4/2005	6/15/2005	6/21/2005	6/1/2005
BJ Flow:	178 cubic feet per second	690 cubic feet per second	900 cubic feet per second	1,650 cubic feet per second
BJ1	5823.02	5824.34	5824.79	5825.99
BJ2	5823.00	5824.29	5824.68	5825.77
BJ3	5822.82	5823.78	5824.07	5825.18
BJ3.5	5821.72	5822.77	5823.06	5824.53
BJ4	5821.64	5823.08	5823.52	5824.60
BJ5	5821.12	5821.90	5822.02	5822.91
BJ6	5820.02	5820.78	5821.17	5822.44
RR Date:	5/3/2005	6/15/2005	6/21/2005	6/1/2005
RR Flow:	175 cubic feet per second	690 cubic feet per second	920 cubic feet per second	1,650 cubic feet per second
RR1	5716.23	5717.34	5717.69	5718.60
RR2	5716.10	5717.11	5717.47	5718.29
RR3	5716.06	5716.91	5717.28	5718.21
RR4	5714.57	5715.85	5716.16	5717.24
RR5	5713.72	5714.68	5714.95	5716.04
RR6	5713.11	5713.44	5713.74	5714.05
NC Date:	5/2/2005	6/15/2005	6/21/2005	6/1/2005
NC Flow:	130 cubic feet per second	690 cubic feet per second	900 cubic feet per second	1,640 cubic feet per second
NC1	5509.36	5511.58	5511.76	5512.56
NC2	5508.51	5510.88	5511.15	5512.03
NC3	5507.50	5509.21	5509.57	5510.91
NC4	5507.53	5508.61	5508.91	5511.20
NC5	5507.28	5508.35	5508.61	5509.70
NC6	5506.37	5508.17	5508.48	5509.72
CA Date:	5/2/2005	6/15/2005	6/21/2005	6/1/2005
CA Flow:	216 cubic feet per second	730 cubic feet per second	890 cubic feet per second	1,750 cubic feet per second
CA1	5444.39	5445.71	5445.99	5446.76
CA2	5443.16	5444.91	5445.24	5445.96
CA3	5442.50	5444.35	5444.62	5445.69
CA4	5441.69	5443.02	5443.22	5444.73
CA5	5441.34	5442.47	5442.65	5443.73
CA6	5441.10	5441.96	5442.27	5443.36

2.3.4.1. Below Jordanelle Dam (BJ) Site

As in 2004, the 2005 back-calculated low-flow roughness values for all seven BJ transects are quite high (Table 2.3). However, values for several transects decreased slightly relative to 2004 values. As in 2004, transects BJ1 and BJ4 have the highest back-calculated roughness values. These transects are located in deep pool/run portions of the channel where water surface elevations are elevated because of a backwater effect from downstream riffles. This reach-scale phenomenon causes the independently calculated "N" values to be artificially high. Transect BJ 3.5 has the lowest back-calculated "N" value, 0.048. This transect is located in a steep riffle where water surface elevation at low flow is less affected by reach-scale hydraulics. Overall, however, roughness at the BJ site remains quite high because of the coarse, boulder-cobble bed material and extreme variability in bed profile caused by the deep pool in the middle of the site.

Table 2.3. Back-calculated roughness (Manning's "N") values based on water surface levels surveyed in May 2005. 2004 values included for comparison.

SITE	HEC-RAS STATION	HYDRAULIC RADIUS (FEET)	REACH AVERAGE SLOPE	WETTED WIDTH (FEET)	AREA (FEET)	AVERAGE DEPTH (FEET)	DISCHARGE (CUBIC FEET PER SECOND)	VELOCITY (FEET PER SECOND)	MANNING'S "N"	MANNING'S "N" (2004)
BJ1	60	2.45	0.006	76.73	190.77	2.49	178	0.93	0.224	0.273
BJ2	50	1.53	0.006	76.71	118.02	1.54	178	1.51	0.101	0.150
BJ3	40	1.44	0.006	85.46	124.19	1.45	178	1.43	0.102	0.152
BJ3.5	35	0.97	0.006	75.79	75.35	0.99	178	2.36	0.048	--
BJ4	30	4.00	0.006	80.89	331.72	4.10	178	0.54	0.541	0.731
BJ5	20	1.59	0.006	74.62	120.49	1.61	178	1.48	0.106	0.135
BJ6	10	1.57	0.006	64.52	102.21	1.58	178	1.74	0.089	0.123
CA1	60	1.41	0.005	50.78	71.96	1.42	232	3.22	0.044	0.043
CA2	50	1.25	0.005	44.26	55.53	1.25	232	4.18	0.031	0.054
CA3	40	0.84	0.005	84.09	70.6	0.84	232	3.29	0.031	0.087
CA4	30	1.29	0.005	49.59	64.45	1.30	232	3.60	0.037	0.103
CA5	20	1.51	0.005	54.27	83.06	1.53	232	2.79	0.053	0.046
CA6	10	1.39	0.005	68.55	99.52	1.45	232	2.33	0.060	0.038

The addition of transect BJ3.5 appears to have substantially improved HEC-RAS model accuracy at the BJ monitoring site (Appendix 2.4). When a low-flow roughness (Manning's "N") value of 0.12 is used, the modeled water surface elevation is in close agreement with surveyed values (Appendix 2.4). When a high-flow roughness (Manning's "N") value of 0.06 is used, the modeled water surface elevation at high flow also provides good agreement with surveyed values (Appendix 2.4). High-flow model results using the 2005 cross section geometry are similar to the high-flow results from 2004, indicating that no significant changes in channel capacity have occurred at the BJ site (Appendix 2.4).

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 2.5). Between 1,300 and 1,650 cfs, additional overtopping occurs farther upstream along the right bank (Appendix 2.5). Flows also slightly overtop the left bank at transect BJ2 at 1,650 cfs (Appendix 2.5). These model results provide good agreement with observations made during the June 2005 water surface elevation surveys (Table 2.2).

2.3.4.2. River Road (RR) Site

Results of the WinXSPRO analysis at the RR site are provided in Table 2.4. Transect plots of surveyed water surface elevations are included in Appendix 2.6.

Table 2.4. WinXSPRO output for low, medium, and high flows at the River Road (RR) site.

CROSS SECTION	STAGE (FEET)	AREA (FEET)	WETTED PERIMETER (FEET)	TOP WIDTH (FEET)	HYDRAULIC RADIUS (FEET)	HYDRAULIC DEPTH (FEET)	SLOPE (FEET/FEET)	MANNING'S "N"	AVERAGE VELOCITY (FEET/SECOND)	Q (CUBIC FEET PER SECOND)
RR1	4.3	166.31	79.26	78.04	2.1	2.13	0.0054	0.175	1.03	170.55
RR1	6.1	316.7	91.11	89.26	3.48	3.55	0.0064	0.09	3.02	957.97
RR1	6.7	373.1	110.02	108.05	3.39	3.45	0.0067	0.062	4.44	1656.62
RR2	2.1	148.13	122.85	122.06	1.21	1.21	0.0055	0.102	1.22	181.08
RR2	3.7	384.36	201.78	200.38	1.9	1.92	0.0064	0.073	2.51	963.1
RR2	4.3	514.77	235.81	234.32	2.18	2.2	0.0067	0.062	3.31	1705.3
RR3	3	189.68	117.43	115.56	1.62	1.64	0.0054	0.17	0.89	168.19
RR3	4.7	472.93	250.94	248.25	1.88	1.91	0.0064	0.094	1.95	919.86
RR3	5.2	615.16	310.44	307.66	1.98	2	0.0067	0.071	2.71	1665.89
RR4	2.7	88.08	80.92	79.77	1.09	1.1	0.0054	0.055	2.12	186.69
RR4	4.3	255.24	126.27	124.09	2.02	2.06	0.0062	0.051	3.7	943.45
RR4	5.3	420.73	225.41	222.63	1.87	1.89	0.0067	0.048	3.83	1612.33
RR5	3.2	114.48	77.58	76.25	1.48	1.5	0.0054	0.093	1.53	174.7
RR5	4.9	288.82	127.64	125.24	2.26	2.31	0.0063	0.064	3.21	925.88
RR5	5.5	368.61	138.48	135.88	2.66	2.71	0.0066	0.053	4.37	1612.05
RR6	3.4	108.33	60.34	59.03	1.8	1.84	0.0055	0.098	1.66	180.12
RR6	4.15	155.93	68.99	67.51	2.26	2.31	0.0064	0.036	5.77	899.15
RR6	4.35	170.12	78.75	77.23	2.16	2.2	0.0066	0.019	10.74	1827.12

At the RR site, flows remain within bank at transects RR5 and RR6 even at the highest discharge (1,650 cfs) at which stage was surveyed (Appendix 2.6). At transect RR1, the 1,650 cfs water level is right at the top of the bank, and the banks would be overtopped if flows were any higher (Appendix 2.6). At transects RR2, RR3, and RR4, the 1,650 cfs water level overtops the right bank, and also just overtops the island at RR3. At RR2 and RR4, the overtopping of the right bank occurs between 920 and 1,650 cfs, while at RR3 flows get out-of-bank at a slightly lower flow between 690 and 920 cfs (Appendix 2.6).

Calibrated low-flow roughness values for the RR site are fairly high (0.055 to 0.175), reflecting the coarse cobble bed material at the site (Table 2.4). At most transects, the 2005 roughness values are quite similar to the values calculated using the 2004 transect geometry (Olsen 2005), suggesting that the overall site hydraulics did not change significantly between 2004 and 2005. However, the low-flow roughness value at RR6 changed from 0.068 in 2004 to 0.098 in 2005, reflecting the deepening and narrowing that occurred at this transect (Appendix 2.2a).

2.3.4.3. NEVER-CHANNELIZED (NC) SITE

Results of the WinXSPRO analysis at the NC site are provided in Table 2.5. Transect plots of surveyed water surface elevations are included in Appendix 2.6.

At the NC site, flows are out-of-bank throughout the site at the 1,650 cfs discharge level (Appendix 2.6). At transects NC 3 and NC4, both the right and left banks are inundated at 1,650 cfs, while only the right bank is inundated at the other transects. However, the 1,650 cfs water level is very close to the top of the left bank at NC1, NC2, and NC6, and the left bank would be overtopped at flows above 1,650 cfs (Appendix 2.6). At transects NC1 and NC2, overtopping of the right bank appears to occur at flows slightly below 690 cfs, while at the downstream transects overtopping does not occur until flows exceed 900 cfs. These results are consistent with hydraulic modeling results from 2004, which indicated that substantial inundation of the right floodplain would occur at 900 cfs, and that the left bank at NC3 would be overtopped at 1,500 cfs (Olsen 2005). Based on this comparison of the 2004 and 2005 results, it does not appear that substantial changes in channel capacity occurred at the NC monitoring site.

2.3.4.4. CHARLESTON (CA) SITE

The 2005 HEC-RAS model results provide good agreement with surveyed water surface elevations when a Manning's "N" of 0.04 is used to model low flows, and an "N" of 0.035 is used to model high flows (Appendix 2.4). In 2004 a low-flow "N" value of 0.045 provided the best agreement with measured elevations (Olsen 2005). It appears that the overall average roughness of the site has decreased slightly, perhaps because of the reduced variability in the streambed profile (Appendix 2.3a).

Initially following construction the channel was probably susceptible to geomorphic changes that affect roughness values. The streambed adjusted from high peak flows during the previous spring runoff. The channel changes were large enough to cause a measurable change in overall modeled roughness values. The initial change in roughness does not have lasting significance other than causing slight differences in stage at this site for any given flow. The post-construction roughness adjustment is thought to be a one-time event and should not change as significantly in future years.

Table 2.5. WinXSPRO output for low, medium, and high flows at the Never-Channelized (NC) site.

CROSS SECTION	STAGE (FEET)	AREA (FEET)	WETTED PERIMETER (FEET)	TOP WIDTH (FEET)	HYDRAULIC RADIUS (FEET)	HYDRAULIC DEPTH (FEET)	SLOPE (FEET/FEET)	MANNING'S "N"	AVERAGE VELOCITY (FEET/SECOND)	Q (CUBIC FEET PER SECOND)
NC1	1.8	62.58	100.11	98.98	0.63	0.63	0.0053	0.037	2.15	134.41
NC1	3.9	352.71	218.59	215.17	1.61	1.64	0.0058	0.062	2.51	886.43
NC1	5	622.24	278.54	274.87	2.23	2.26	0.006	0.075	2.63	1636.32
NC2	2.6	80.63	73.98	71.6	1.09	1.13	0.0053	0.075	1.53	123.51
NC2	5.1	309.52	149.02	144.75	2.08	2.14	0.0058	0.064	2.89	896.03
NC2	6.1	481.57	207.83	203.35	2.32	2.37	0.006	0.059	3.41	1640.58
NC3	3.2	65.79	34.87	33.46	1.89	1.97	0.0053	0.081	2.06	135.32
NC3	5.7	217.89	96.63	93.69	2.25	2.33	0.0058	0.048	4.09	890.48
NC3	6.6	346.08	190.41	187.45	1.82	1.85	0.006	0.036	4.77	1652.46
NC4	2.2	101.43	66.61	65.16	1.52	1.56	0.0053	0.115	1.25	126.62
NC4	4.8	437.12	201.7	199.15	2.17	2.19	0.0058	0.097	1.95	852.8
NC4	5.9	693.07	272.32	269.71	2.55	2.57	0.006	0.09	2.39	1659.27
NC5	1.3	65.1	74.79	73.14	0.87	0.89	0.0053	0.053	1.87	121.46
NC5	3	204.57	110.86	107.89	1.85	1.9	0.0058	0.04	4.29	876.95
NC5	3.8	305.83	148.81	145.28	2.06	2.11	0.006	0.034	5.57	1703.26
NC6	1.2	26.79	45.26	44.37	0.59	0.6	0.0053	0.015	5.11	136.81
NC6	2.8	149.64	95.27	93.17	1.57	1.61	0.0056	0.025	6	898.47
NC6	4.6	369.04	212.86	210	1.73	1.76	0.006	0.037	4.55	1677.86

It also appears that channel capacity at CA increased substantially between 2004 and 2005. High-flow model results using the 2004 cross section geometry generated water surface elevations about 0.85 feet higher than the high-flow water surface elevations modeled using the 2005 geometry (Appendix 2.4). This change is probably caused in large part by the significant (2 feet) incision at the downstream riffle at CA6 that controls grade through much of the site (Appendix 2.3a). The widening that occurred between 2004 and 2005 at transects CA1, CA3, CA4, and CA6 also may have contributed to the increased channel capacity of the site (Appendix 2.2a).

In its current condition, the CA monitoring site is not susceptible to over-bank flooding even at the highest modeled/surveyed discharge of 1,750 cfs (Appendix 2.5). 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 690-900 cfs, and substantial floodplain inundation occurs at the 1,650-1,750 cfs discharge level.

2.3.5 PLAN VIEW CHANGES IN THE NEVER-CHANNELIZED REACH

Maps of the active channel area in 1993 vs. 1999, 1993 vs. 2004, and 1999 vs. 2004 are provided in Appendix 2.7. These maps show some substantial changes in channel planform over the 11 year period examined. Between 1993 and 1999, the active channel widened in some areas and narrowed in other areas. Bank erosion and meander migration occurred at several bends (Appendix 2.7). Overall, the total active channel area, average width, and sinuosity remained similar between 1993 and 1999 (Table 2.6).

TABLE 2.6. NEVER-CHANNELIZED REACH CHANNEL AREA, WIDTH, AND SINUOSITY IN DIFFERENT YEARS, SHOWING PERCENT CHANGE FROM PREVIOUS ORTHOPHOTOS.

ORTHO-PHOTO YEAR	TOTAL ACTIVE CHANNEL AREA		CENTERLINE LENGTH		CALCULATED AVERAGE CHANNEL WIDTH		SINUOSITY	
	SQUARE METERS	PERCENT CHANGE	METERS	PERCENT CHANGE	METERS	PERCENT CHANGE	METER/METER	PERCENT CHANGE
1993	96334	-	2318	-	41.6	-	1.13	-
1999	96440	<1%	2351	1%	41.0	1%	1.14	<1%
2004	77783	-19%	2428	3%	32.0	-22%	1.18	4%

A more significant overall change was observed between 1999 and 2004. Between these years, the active channel became about 20 percent narrower, and sinuosity increased from 1.14 to 1.18 (Table 2.6). Most of this change was because of apparent vegetation encroachment into areas that were active, unvegetated bars and side channels in 1999 (Appendix 2.7).

The period between the November 1999 and April 2004 photo flights was a time of fairly low-magnitude spring floods. Flows did not exceed 1,500 cfs during this time period (Figure 1.1), and the mean annual flow at the Charleston gage for water years 2000-2003 was only 196.3 cfs. The lack of high flows and large flood events allowed vegetation to become established in previously active channel areas. In contrast, the period between water year 1994 and 1999 had a mean annual flow of 269.7 cfs, and springtime flood peaks exceeded 1,500 cfs four times (Figure 1.1, Figure 2.6). Another likely reason that the 1993 and 1999 orthophotos show large areas of unvegetated, active channel is that both photos were flown in the summer/fall after very large spring floods that exceeded 2,000 cfs at the Charleston gage (Figure 1.1, Figure 2.6). These large flood events may have scoured away accumulated vegetation on bars and in side channels.

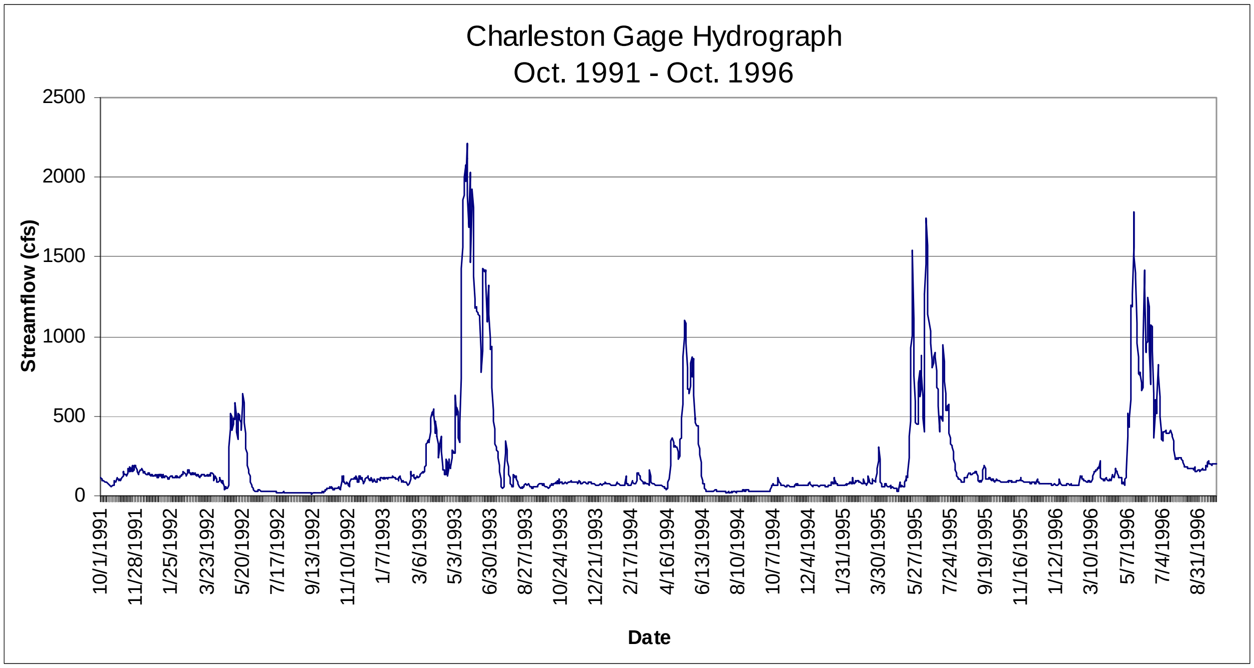


FIGURE 2.6. HYDROGRAPH OF PROVO RIVER FLOWS AT THE CHARLESTON GAGE FOR WATER YEARS 1992-1996. WATER YEARS 1996-2005 ARE SHOWN IN FIGURE 1.1.

Since the April 2004 air photo flight, 2 years of relatively large spring floods (peak flows greater than 1,500 cfs) have affected the never-channelized reach (Figure 1.1). Additional monitoring will be needed to determine if the trend towards a narrower, more sinuous, and more vegetated channel corridor continues or is reversed in response to these high peak flow years.

3.0 CHANNEL SUBSTRATE

3.1 INTRODUCTION

Channel substrate creates habitat for a variety of aquatic species and constitutes spawning areas for some fish species of the middle Provo River. This chapter describes the results of the first (2004) and second (2005) years of monitoring channel substrate in the study sites along the middle Provo River. Monitoring the substrate allows the Mitigation Commission to determine what substrate is present and what changes in substrate have occurred, which are important indicators of habitat condition. Substrate data can help determine if adaptive maintenance is required to maintain the middle Provo River in a desirable condition and if the Mitigation Commission is fulfilling commitments concerning fish, wildlife, and recreation.

3.2 METHODS

Substrate classifications throughout each monitoring site were hand-delineated in the field on plots generated during the topographic surveys (see Chapter 2). At the BJ and RR sites, mapping was conducted by drawing revised polygon boundaries/classifications on laminated copies of the 2004 substrate maps. At the NC and CA sites, this was not possible because of substantial changes in the locations of gravel bars and streambanks that occurred between 2004 and 2005. At these sites, the edge of water was re-surveyed in May 2005 and plots of these surveys were used for substrate mapping. To help ensure consistency in substrate size classification, all mapping was conducted by a single individual during low flow. The individual delineated substrate into visibly homogeneous substrate types based on dominant and subdominant particle sizes. Classification was based on a modified Wentworth scale (Table 3.1). Gravel-sized material is a resource of concern because of the trapped sediment behind Jordanelle Dam, so 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."

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

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

In addition to the visual substrate mapping effort, quantitative pebble counts (Wolman 1954) were completed at discrete patches within each monitoring site. Six patches were chosen at the BJ, RR, and CA sites. The NC site had four patches. In two of these patches, 100 pebbles were measured. At the other two patches, 200 pebbles were measured. Particle size data were grouped into 10 size categories (with upper limits of 2, 4, 8, 16, 32, 64, 128, 256, 512, and 1,024 millimeters [mm]) and plotted to determine grain sizes of the D_{16}, D_{25}, D_{50}, D_{75}, and D_{84} particles. Pebble count (PC) patch locations sampled in 2005 are shown in Figure 3.1a-d. At the NC site, the locations of PC1, PC2, and PC3-4 were shifted somewhat from the 2004 locations by meander migration and changes in the position of gravel bars. At the CA site, the locations of PC2, PC4, PC5, and PC6 were also shifted slightly for similar reasons (see Olsen 2005 for 2004 PC locations).

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 monitoring report (Olsen 2005), the 2005 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-d 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) 2004 VS. 2005

Changes in the substrate composition of the BJ site between 2004 and 2005 were minimal. 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). The overall percentage of fine gravel increased slightly in 2005 because of the presence of a minor amount of fine gravel in the eddy area along the inside of the bend just downstream from transect BJ4 (Figure 3.2a, Appendix 3.2). However, 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).

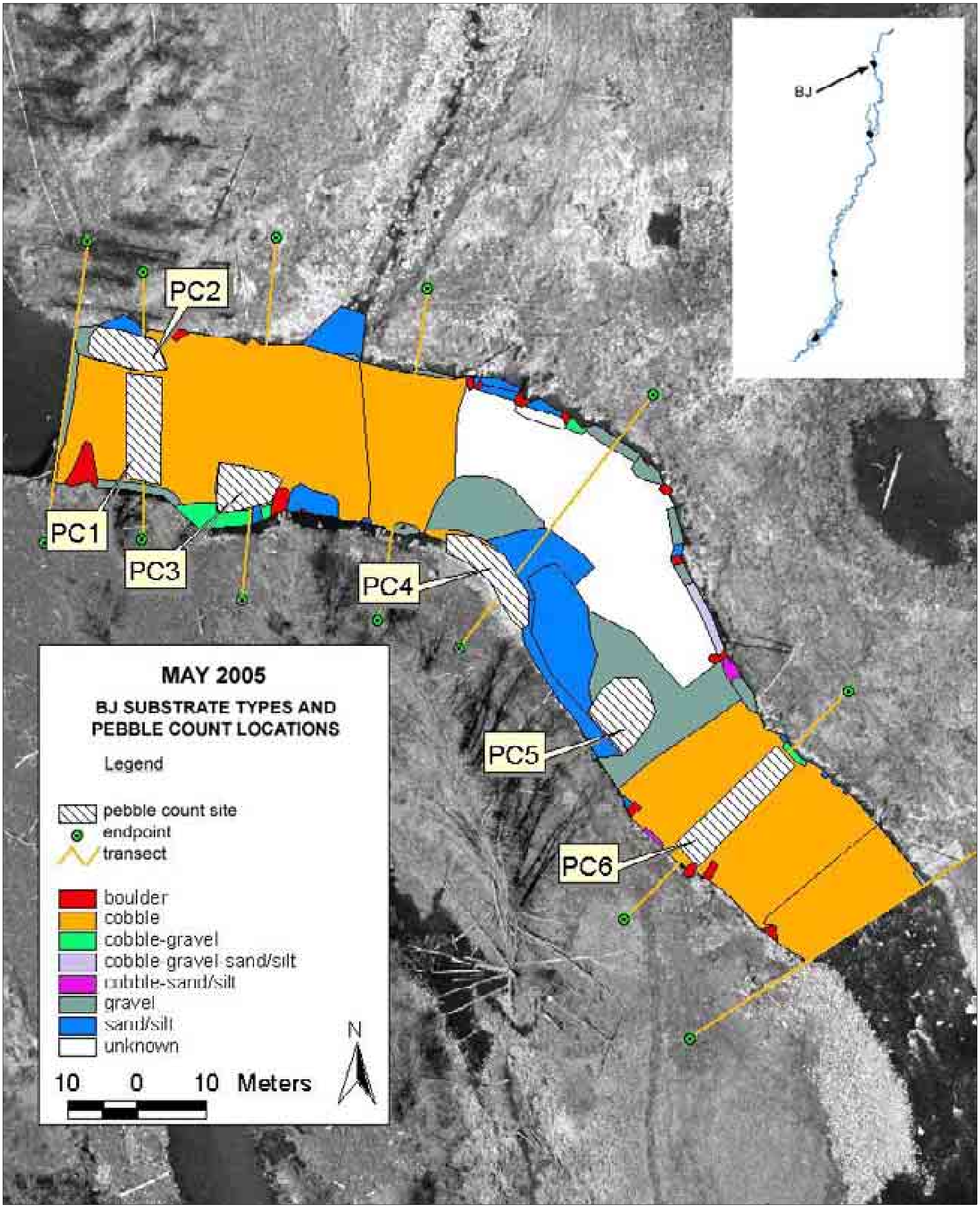


Figure 3.1a. Substrate types and pebble count locations at the Below Jordanelle (BJ) Monitoring Site.

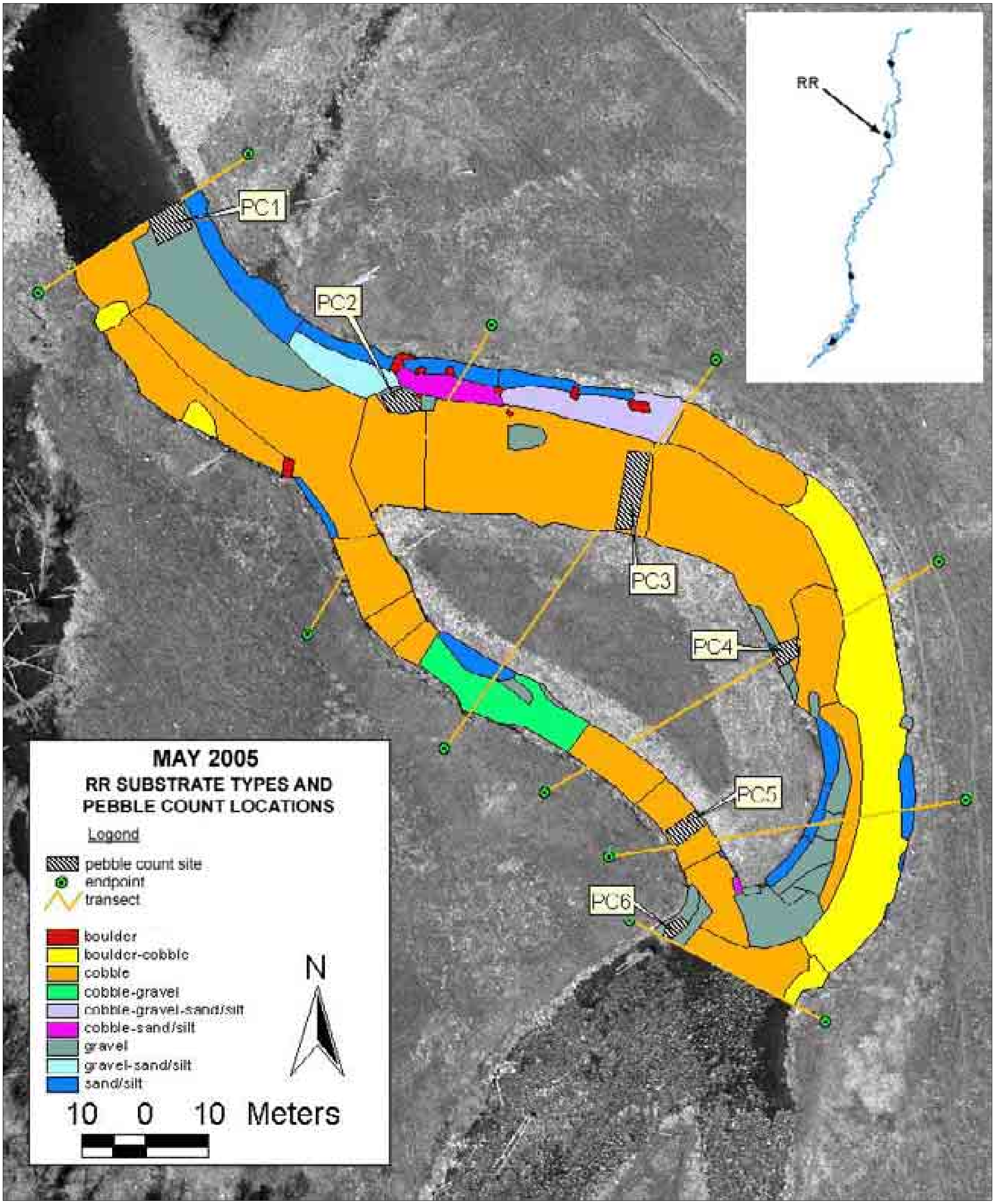


Figure 3.1b. Substrate types and pebble count locations for the River Road (RR) Monitoring Site.

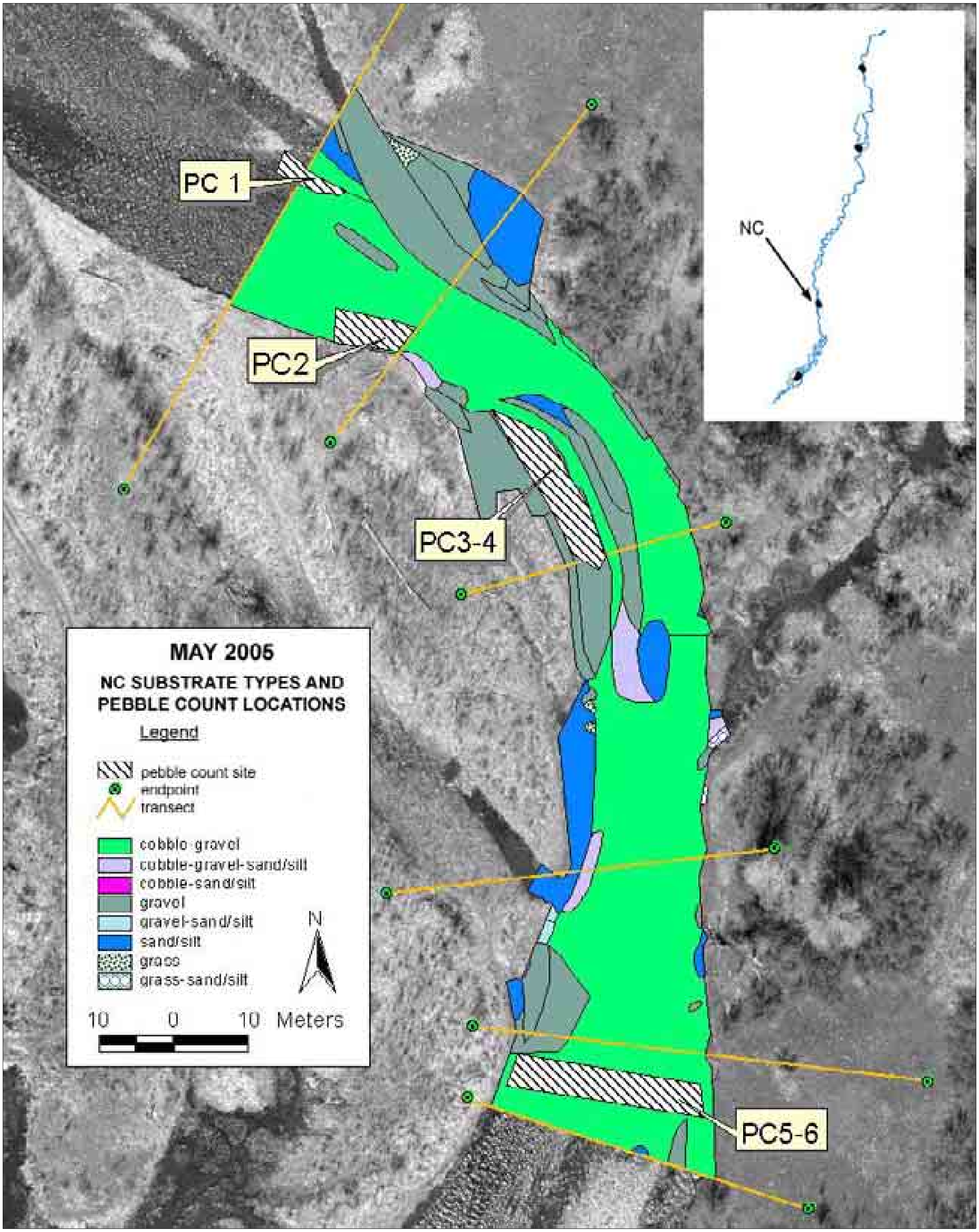


Figure 3.1c. Substrate types and pebble count locations at the Never-Channelized (NC) Monitoring Site.

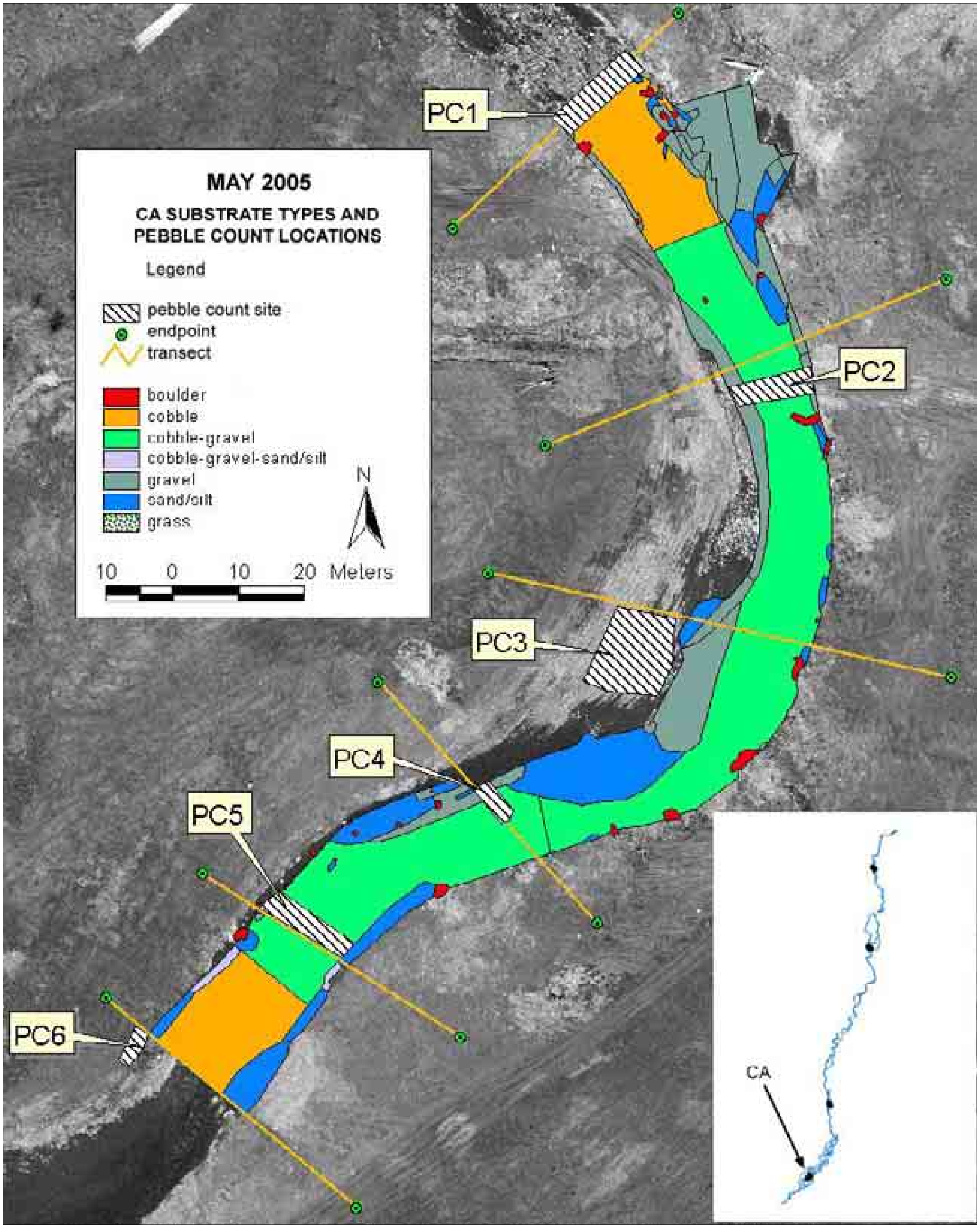


FIGURE 3.1D. SUBSTRATE TYPES AND PEBBLE COUNT LOCATIONS AT THE CHARLESTON (CA) MONITORING SITE.

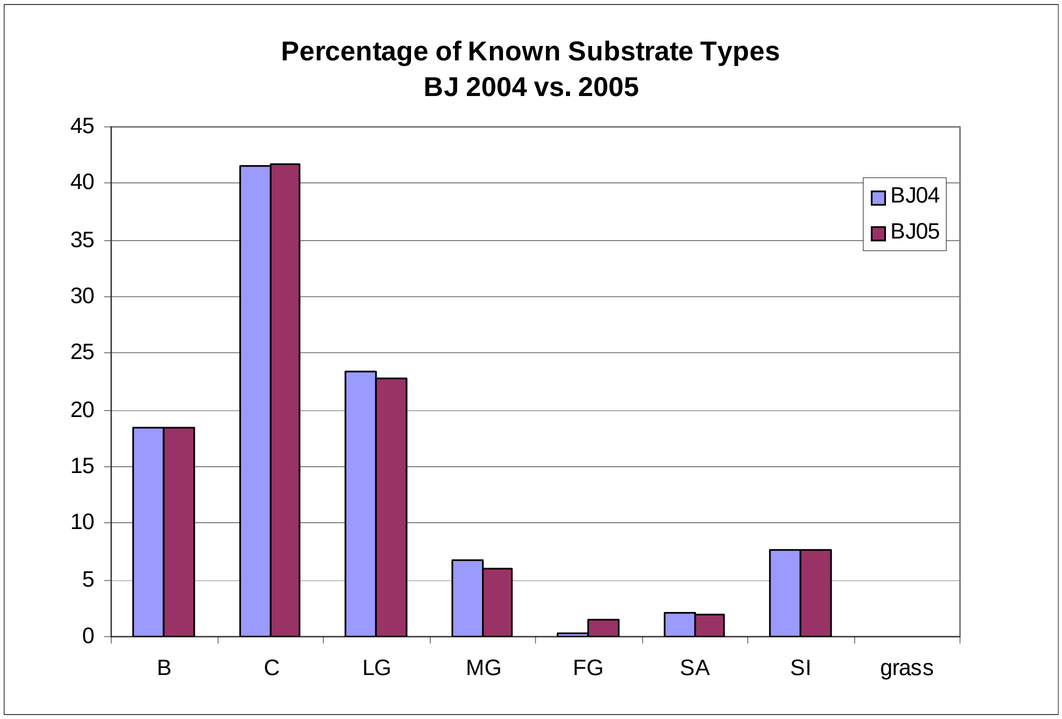


FIGURE 3.2A. COMPARISON OF AREA AT THE BELOW JORDANELLE (BJ) MONITORING SITE OCCUPIED BY VARIOUS SIZE CLASSES IN 2004 AND 2005.

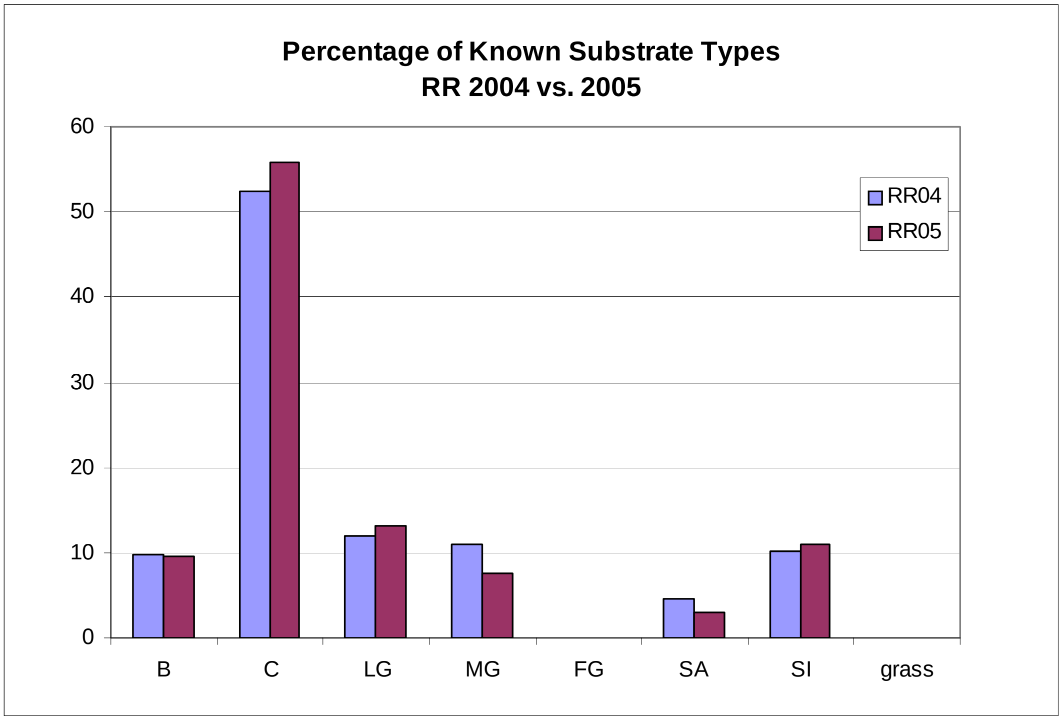


FIGURE 3.2B. COMPARISON OF AREA AT THE RIVER ROAD (RR) MONITORING SITE OCCUPIED BY VARIOUS SIZE CLASSES IN 2004 AND 2005.

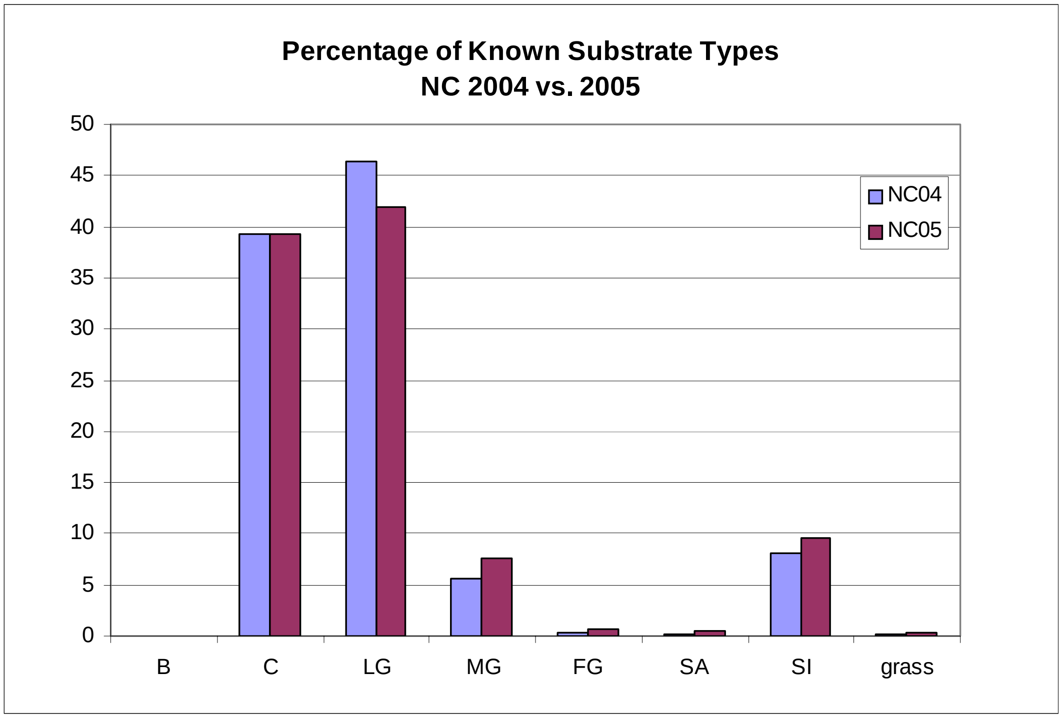


FIGURE 3.2C. COMPARISON OF AREA AT THE NEVER-CHANNELIZED (NC) MONITORING SITE OCCUPIED BY VARIOUS SIZE CLASSES IN 2004 AND 2005.

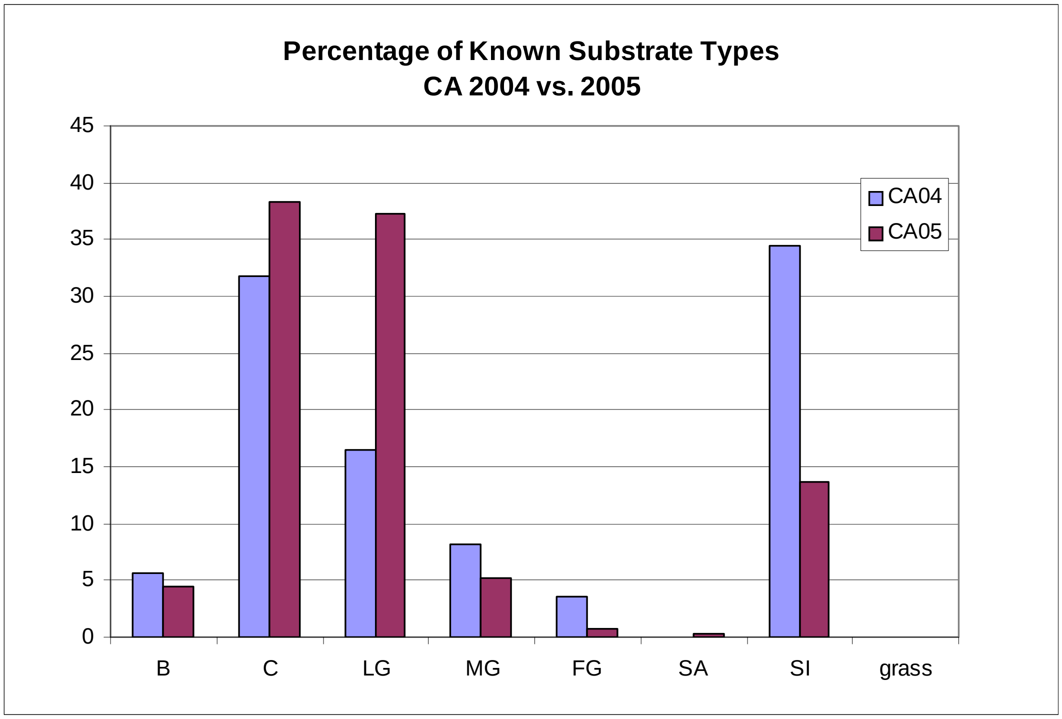
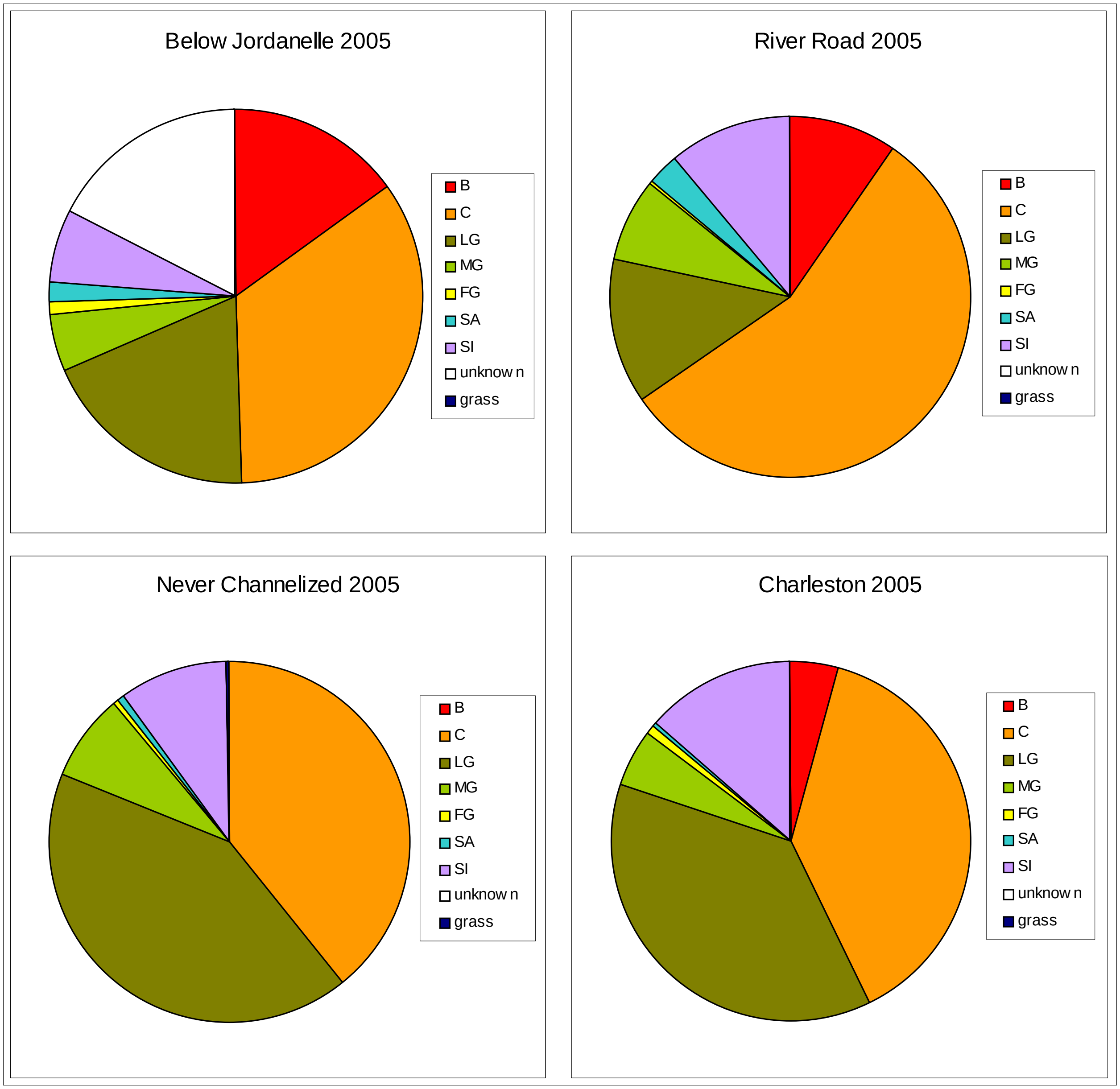


FIGURE 3.2D. COMPARISON OF AREA AT THE CHARLESTON (CA) MONITORING SITE OCCUPIED BY VARIOUS SIZE CLASSES IN 2004 AND 2005.



Below Jordanelle 2005

River Road 2005

Never Channelized 2005

Charleston 2005

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

3.3.1.2 River Road (RR) 2004 vs. 2005

Overall, changes in the substrate composition of the RR site between 2004 and 2005 were minor (Figure 3.1b, Figure 3.2b). Cobble remains the dominant substrate size at the site (Figure 3.3). 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 bar appears to have been aggrading slightly and vegetating, and the distribution of individual sand and gravel-dominated patches has shifted somewhat. Another area of change occurred along the right bank near transect RR6. The gravel deposit that increased in size between 2002 and 2004 (Olsen 2005) continued to grow between 2004 and 2005, increasing the proportion of gravel in this part of the channel (Figure 3.1b, Appendix 3.2). Two small new gravel deposits (including some medium-sized gravel) were mapped in the side channel near transect RR3 (Appendix 3.2). A shift in the composition of the substrate patch in the main channel between transects RR3 and RR4 was also observed (Appendix 3.1, Figure 3.1b, Appendix 3.2). This patch was mapped as including 30 percent medium gravel in 2004, but in 2005 no medium gravel was noted and the area was mapped as 70 percent cobble and 30 percent large gravel. In this area, the sizes of many of the particles are close to the size breaks between cobble and large gravel (64 mm) and between large and medium gravel (32 mm), so the apparent difference between 2004 and 2005 may be partly attributable to the qualitative nature of visual substrate mapping. However, the number of medium gravel-sized particles measured in pebble count patch PC4 also decreased slightly, from 14 to 10, between 2004 and 2005 (see Section 3.3.2).

3.3.1.3 NEVER-CHANNELIZED (NC) 2004 VS. 2005

Although changes in the overall substrate composition of the NC site between 2004 and 2005 were relatively small (Figure 3.2c), significant shifts in the locations of individual bars and substrate patches occurred (Figure 3.1c). These changes in substrate distribution were associated with the channel changes described in Chapter 2. The left bank gravel bar between transects NC 1 and NC2 lengthened, the left side channel near NC1 widened, and the right bank gravel bar between transects NC2 and NC3 eroded at its upstream end but lengthened and was built up downstream. In addition, a new deposit containing 20 percent medium gravel was mapped mid-channel between transects NC2 and NC3 (Appendix 3.2). Fewer changes were noted within the downstream half of the site, although an area along the right side of the channel that was mapped in 2004 as containing 10 percent medium gravel was not found to contain medium gravel in 2005 (Appendix 3.2). In addition, a thin coating of silt and brown algae was noted on many of the cobble and large gravel particles within the main channel, particularly in the downstream part of the site. This silt may be associated with the erosion that occurred along the left bank between the 2004 and 2005 mapping dates and/or upstream construction activities. Overall, the proportion of medium and fine gravel at the NC site increased slightly from 2004 to 2005 (Figure 3.2c), but large gravel and cobble remained the dominant particle sizes (Figure 3.3).

3.3.1.4 CHARLESTON (CA) 2004 VS. 2005

The overall substrate composition of the CA site changed substantially between 2004 and 2005 (Figure 3.2d). This was expected, given the site had just been constructed (restored) prior to the 2004 mapping effort, and had not yet experienced any high flow events. The biggest changes observed were a reduction in the proportion of silt from 34 percent in 2004 to 14 percent in 2005, and an increase in the proportion of large gravel from 16 percent in 2004 to 37 percent in 2005. Reductions in the percentages of medium and fine gravel were also observed, suggesting that much of the fine material that was present in the site immediately after construction was flushed away by the spring 2004 high flows. Cobble and large, gravel-sized particles either replaced the finer material or was exposed when the finer material was flushed away (Figure 3.2d, Appendix 3.2). The overall substrate composition of the CA site now more closely matches that of the other study sites, and is particularly similar to the NC site (Figure 3.3, Figure 3.4). A substrate comparison between 2005 and 2006 should show the changes in coarser material more clearly than substrate comparisons between 2004 and 2005 because the construction-related silt found in 2004 has been flushed downstream.

Substantial changes in the distribution of individual substrate patches were observed between 2004 and 2005 (Figure 3.1d). A large gravel bar formed along the left bank between transects CA1 and CA2 (Appendix 3.2). The main channel area between transects CA2 and CA5 has coarsened and is now dominated by cobble and large gravel material (Figure 3.1d). Much of this area also became shallower between 2004 and 2005 (Appendix 2.2a, Appendix 2.3a), allowing areas that were unwadable and mapped as "unknown" in 2004 to be waded and mapped in 2005. However, some portions of the main channel were still too deep in 2005 for the substrate to be fully visible; in these areas, the bed material was mapped by feeling the bed with the feet and probing with a survey rod.

The depositional area along the inside bend near transect CA3 also changed in shape and composition (Figure 3.1d). This area appears to be building, causing the right edge of water to shift toward the east. Much of the silt that dominated the channel in this area in 2004 has been replaced by gravel material, although a silt deposit is still present just upstream of transect CA4 (Figure 3.1d). A new silt deposit formed along the left bank between transects CA4 and CA6, perhaps because of the bank erosion along the left bank at this site (Appendix 2.2a, Figure 2.4). Irregularly-spaced patches of macrophytes (presumably growing in silty material) were also observed within the main channel throughout much of the site. These areas may be remnants of the 2004 silt deposits that avoided scour because of their position in a protected/lower velocity area or because of stabilization by macrophyte vegetation.

3.3.2 PEBBLE COUNTS

Particle size distribution changed very little between 2004 and 2005 (Table 3.2, Appendix 3.3). Some coarsening was evident in some of the stationary patches measured at BJ and RR. Patch locations generally shifted at NC and CA; however, overall sizes remained relatively similar to the sizes reflected in the 2004 data.

3.3.2.1 BELOW JORDANELLE (BJ) MONITORING SITE

Patch PC#1 did not move and became slightly coarser in 2005 compared to 2004 (Figure 3.1a, Table 3.2, Appendix 3.3). Located in a run at the top of the monitoring site, it is the coarsest patch at the BJ site and consists almost entirely of cobble-sized particles.

Patch PC#2 is a gravel patch located on the left side of the channel in a run. This patch did not move and showed a decrease in fine material from 2004 to 2005 (Figure 3.1a, Table 3.2, Appendix 3.3). The D_{50} changed from 44 mm to 62 mm, but remained in the large gravel category. A reduction in particles sized 8 mm and smaller was significant (13 particles in 2004 and only one particle in 2005).

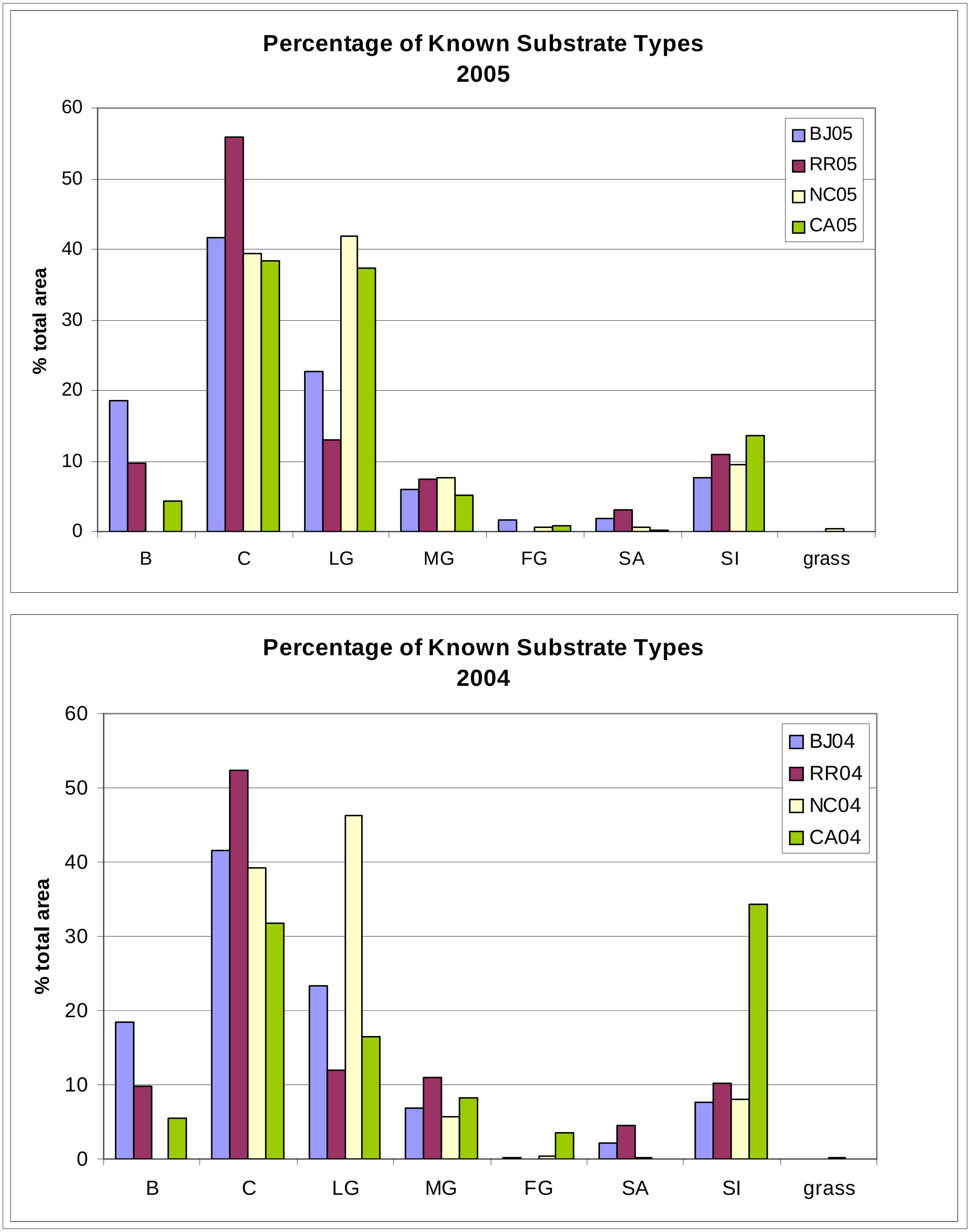


FIGURE 3.4. COMPARISON OF AREA OCCUPIED BY VARIOUS SIZE CLASSES AT EACH MONITORING SITE IN 2004 AND 2005.

Patch PC#3, a gravel patch located in a run near the right side of transect BJ3, did not move and showed a minor reduction in finer material from 2004 to 2005 (Figure 3.1a, Table 3.2, Appendix 3.3). Cobble-sized particles increased from 17 to 28 particles and a boulder-sized particle was sampled in 2005. Sand and silt decreased to 0, but the percentage of medium gravel increased slightly.

Patch PC#4 is a bar beyond the right edge of water, near transect BJ4 (Figure 3.1a). Samples from 2005 illustrate mixed results with an increase in sand/silt, a decrease in large gravel, and an increase in cobble (Table 3.2, Appendix 3.3). The D_{50} changed from large gravel (58 mm) to cobble (80 mm). Overall, the patch did not move and shows coarsening in 2005.

Patch PC#5 did not move and is located in a low-velocity area on river right between transects BJ4 and BJ5 (Figure 3.1a). This is the only BJ patch that has an increase in fine material from 2004 to 2005 (Table 3.2, Appendix 3.3). Fine gravel and medium gravel increased, while large-gravel decreased. The D_{50} changed from large gravel (43 mm) to medium gravel (23 mm).

Patch PC#6 did not move and is still one of the coarsest BJ patches in 2005, but there is a small increase in fine material. The D_{16} decreased from cobble (115 mm) to large gravel (55 mm) and the D_{50} decreased from 173 mm to 160 mm, but remained categorized as cobble.

3.3.2.2 RIVER ROAD (RR) MONITORING SITE

Patch PC#1 did not move and is located in the middle of the channel in the pool area just downstream of transect RR1 (Figure 3.1b). This is the only RR patch that had an increase in fine material (sand/silt and fine gravel) in 2005 (Table 3.2, Appendix 3.3). Large gravel decreased and cobble remained nearly the same. The D_{50} particle size reduced from 27 mm to 13 mm.

Patch PC #2 did not move and is a gravel patch located mid-channel near transect RR2 in a low-velocity run area (Figure 3.1b). It shifted from primarily a large gravel dominated patch to a mixed large gravel and cobble patch (Table 3.2, Appendix 3.3). The increase in cobble changed the D_{50} from 36 mm to 60 mm, but it is still classified as large gravel.

Patch PC#3 did not move and crosses the main channel width at transect RR3 (Figure 3.1b). It was slightly coarser in 2005, with a decrease in fine material (sand/silt, fine gravel, and medium gravel) size 32 mm and smaller (Table 3.2, Appendix 3.3). This coarsening included an increase in cobble- and boulder-size particles. The D_{50} increased from 64 mm to 88 mm and remained classified as cobble.

Patch PC#4 did not move and is located near the right side of transect RR4 (Figure 3.1b). This patch coarsened slightly in 2005, with a decrease in medium and large gravel and an increase in cobble (Table 3.2, Appendix 3.3). The D_{50} classification changed from large gravel (60 mm) to cobble (82 mm). This trend matches the coarsening trend observed in the substrate mapping results for this portion of the channel (see Section 3.3.1.2 above).

TABLE 3.2. PEBBLE COUNT RESULTS FOR CHANNEL MONITORING SITES. VALUES ARE IN MILLIMETERS. SHADED AREAS INDICATE WHERE PATCHES/BARS SHIFTED AND PEBBLE COUNT LOCATIONS WERE ADJUSTED ACCORDINGLY.

BELOW JORDANELLE	BJ PC#1		BJ PC#2		BJ PC#3		BJ PC#4		BJ PC#5		BJ PC#6	
YEAR	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005
D_{16}	82	95	14	28	24	23	11	5	10	8	115	55
D_{25}	115	120	23	35	30	30	28	25	19	11	125	80
D_{50}	155	165	44	62	40	43	58	80	43	23	173	160
D_{75}	205	210	71	88	58	72	90	125	58	43	217	240
D_{84}	226	250	86	86	68	90	110	170	67	57	245	260
CLASS OF D_{50}	COBBLE	COBBLE	LARGE GRAVEL	LARGE GRAVEL	LARGE GRAVEL	LARGE GRAVEL	LARGE GRAVEL	COBBLE	LARGE GRAVEL	MEDIUM GRAVEL	COBBLE	COBBLE
RIVER ROAD	RR PC#1		RR PC#2		RR PC#3		RR PC#4		RR PC#5		RR PC#6	
YEAR	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005
D_{16}	11	3	20	21	33	39	38	40	45	34	32	29
D_{25}	17	6	24	34	37	44	45	49	51	44	37	33
D_{50}	27	13	36	60	64	88	60	82	75	76	49	46
D_{75}	42	26	50	90	110	160	86	120	123	150	67	62
D_{84}	49	35	55	105	136	180	100	148	156	185	75	78
CLASS OF D_{50}	MEDIUM GRAVEL	MEDIUM GRAVEL	LARGE GRAVEL	LARGE GRAVEL	COBBLE	COBBLE	LARGE GRAVEL	COBBLE	COBBLE	COBBLE	LARGE GRAVEL	LARGE GRAVEL
NEVER-CHANNELIZED	NC PC#1		NC PC#2		NC PC#3-4		NC PC#5-6		-		-	
YEAR	2004	2005	2004	2005	2004	2005	2004	2005				
D_{16}	24	43	42	47	30	41	52	42	-		-	
D_{25}	30	51	51	51	36	50	61	54	-		-	
D_{50}	48	70	76	73	51	70	83	85	-		-	
D_{75}	65	89	100	94	74	104	119	128	-		-	
D_{84}	77	100	117	110	90	116	146	155	-		-	
CLASS OF D_{50}	LARGE GRAVEL	COBBLE	COBBLE	COBBLE	LARGE GRAVEL	COBBLE	COBBLE	COBBLE	-		-	
CHARLESTON	CA PC#1		CA PC#2		CA PC#3		CA PC#4		CA PC#5		CA PC#6	
YEAR	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005
D_{16}	42	49	22	52	15	9	6	22	24	44	8	9
D_{25}	51	62	26	61	31	10	10	32	33	58	28	19
D_{50}	84	100	51	83	54	29	38	55	66	94	47	30
D_{75}	122	150	86	117	83	55	54	75	96	125	101	43
D_{84}	131	155	109	128	96	79	60	87	112	138	130	48
CLASS OF D_{50}	COBBLE	COBBLE	LARGE GRAVEL	COBBLE	LARGE GRAVEL	MEDIUM GRAVEL	LARGE GRAVEL	LARGE GRAVEL	COBBLE	COBBLE	LARGE GRAVEL	MEDIUM GRAVEL

Patch PC#5 did not move and is located in a riffle portion of the side channel at the RR monitoring site (Figure 3.1b). There was very little change in this patch from 2004 to 2005 (Table 3.2, Appendix 3.3). The primary difference is an increase in medium gravel. Large gravel and cobble remained at similar numbers. The D_{50} remained essentially unchanged and remains classified as cobble.

Patch PC#6 did not move and is located on a bar beyond the right edge of water at transect RR6 (Figure 3.1b). This patch, like PC#5, showed very little change from 2004 to 2005. It continues to consist primarily of large gravel (Table 3.2, Appendix 3.3). The D_{50}, classified as large gravel, remained essentially unchanged (49 mm in 2004; 46 mm in 2005).

3.3.2.3 NEVER-CHANNELIZED (NC) MONITORING SITE

In 2005 the area sampled for patch PC#1 shifted location upstream to a gravel bar that spans NC1 (Figure 3.1c, Table 3.2). The bar sampled in 2005 was coarser than the bar sampled in 2004, possibly because of different hydraulic conditions at its new position. Specifically, PC#1 showed an increase in cobble-size material and a decrease in sand/silt and gravels (Table 3.2, Appendix 3.3). The number of particles within the cobble size classification (64-128 mm) increased the most and sand/silt decreased to 0. The D_{50} changed from the large gravel category (48 mm) to cobble (70 mm).

Because of bank erosion, the area sampled for Patch PC#2 was shifted toward the right bank and moved slightly upstream relative to the area sampled in 2004 (Figure 3.1c, Table 3.3). This patch changed very little from 2004 to 2005 and was still dominated by cobble with a significant amount of large gravel. A boulder is present in 2005 that was not sampled in 2004. The D_{50} remains classified as cobble and did not change significantly (76 mm to 73 mm).

The area sampled as patch PC#3-4 shifted location downstream because of erosion/re-deposition/shifting of the gravel bar between NC2 and NC3 (Figure 3.1c, Table 3.3). Two hundred pebbles were measured at this patch. A decrease in medium gravel and sand/silt, along with an increase in cobble-sized particles, amounted to a general coarsening of this bar in 2005. Large gravel numbers in 2005 remained similar to those of 2004. The D_{50} classification changed from large gravel (51 mm) to cobble (70 mm).

Patch PC #5-6 spans a riffle area between transects NC5 and NC6 (Figure 3.1c) and remained at the same location. Two hundred pebbles were measured at this patch. This patch showed very little change from 2004 to 2005 (Table 3.2, Appendix 3.3). There was a small increase in fine material (sand/silt and medium gravel) and the D_{16} decreased from 52 mm to 42 mm. Cobble numbers remain similar to 2004. The D_{50} remained classified as cobble and showed no significant change (83 mm to 85 mm).

3.3.2.4 CHARLESTON (CA) MONITORING SITE

Patch PC#1 spans the width of the channel in the riffle at transect CA1 (Figure 3.1d) and remained at the same location. This patch coarsened slightly from 2004 to 2005 (Table 3.2, Appendix 3.3). The primary increase was in cobble- and boulder-size particles. A decrease in large and medium gravel also contributed to the coarsening trend. The D_{50} increased from 84 mm to 100 mm, but remained classified as cobble.

Patch PC#2 crosses the width of the channel near transect CA2 (Figure3.1d) and remained in the same location. The greatest degree of coarsening at CA occurred at PC#2 (Table 3.2, Appendix 3.3). Medium and fine gravel-sized particles reduced to almost none with cobble-sized particles nearly doubling in number. The D_{50} classification changed from large gravel (51 mm) to cobble (83 mm).

Patch PC#3 is located on a bar on the right side of the channel near transect CA3 (Figure 3.1d) and remained at the same location. This patch (along with PC#6) showed a significant increase in fine material and a reduction in cobble sized particles (Table 3.2, Appendix 3.3). The primary sample increase was in fine and medium gravel. The D_{50} classification changed from large gravel (54 mm) to medium gravel (29 mm).

Patch PC#4 is located on the right side of the channel in an eddy/pool area near CA4. The area sampled for PC#4 shifted slightly to the left in 2005 because of bank aggradation (Figure 3.1d, Table 3.3). This patch shows a general reduction in fine material and an increase in cobble from 2004 to 2005 (Table 3.2, Appendix 3.3). Even with this visible shift, the D_{50} classification's current state is still large gravel, changing from 38 mm to 55 mm.

TABLE 3.3 PEBBLE COUNT PATCH LOCATION CHANGES BETWEEN 2004 AND 2005.

SITE	PATCH NUMBER	2004 LOCATION	2005 LOCATION	REASON FOR SHIFT
NC	PC#1	GRAVEL BAR ON LEFT SIDE OF CHANNEL JUST DOWNSTREAM FROM TRANSECT 1	MOVED UPSTREAM AND TOWARDS CENTER OF CHANNEL TO GRAVEL BAR THAT SPANS TRANSECT 1	ORIGINAL GRAVEL BAR WAS REWORKED/MOVED
NC	PC#2	RIGHT PORTION OF CHANNEL UPSTREAM OF TRANSECT 2	SHIFTED TO RIGHT AND EXTENDED SLIGHTLY FARTHER UPSTREAM	RIGHT BANK AT TRANSECT 2 ERODED/WIDENED
NC	PC#3-4	GRAVEL BAR ON RIGHT SIDE OF CHANNEL BETWEEN TRANSECTS 2 AND 3	SHIFTED DOWNSTREAM TO NEW LOCATION OF GRAVEL BAR BETWEEN TRANSECTS 2 AND 3	ORIGINAL GRAVEL BAR WAS REWORKED/MOVED
CA	PC#4	RIGHT PORTION OF CHANNEL UPSTREAM OF TRANSECT 4	SHIFTED TO LEFT	RIGHT EDGE OF WATER AGGRADED/MOVED TO LEFT
CA	PC#5	FULL WIDTH OF MAIN CHANNEL CENTERED ON TRANSECT 5	SHIFTED UPSTREAM SLIGHTLY	CHANNEL DEEPENED ON DOWNSTREAM SIDE OF TRANSECT 5
CA	PC#6	GRAVEL BAR ON RIGHT SIDE OF CHANNEL JUST DOWNSTREAM FROM TRANSECT 6	SHIFTED TO RIGHT	RIGHT BANK AT TRANSECT 6 ERODED/WIDENED

Patch PC#5 crosses the full channel width slightly upstream of transect CA5 (Figure 3.1d). The location shifted slightly upstream in 2005 (Table 3.3). This patch had a reduction in fine material, primarily medium gravel, from 2004 to 2005 (Table 3.2, Appendix 3.3). The D_{50} classification remained in the cobble category with a size increase from 66 mm to 94 mm.

Patch PC#6 is located on a gravel bar on the right bank just below transect CA6 (Figure 3.1d). The location of the area sampled shifted to the right in 2005 because of bank erosion/widening (Table 3.2). The new area sampled (along with PC#3) showed a significantly greater proportion of fine material relative to the bar area sampled in 2004 (Table 3.2, Appendix 3.3). The changes included a large increase in medium and large gravel and a large reduction in cobble-sized particles. Cobble numbers reduced from 41 particles to 1 particle (phi class size 128 mm). The D_{50} changed from large gravel (47 mm) to medium gravel (30 mm).

3.3.2.5 PEBBLE COUNT LOCATION SHIFTS AT NC AND CA SITES

The high flows that occurred during the 2005 run-off season caused channel shifting, bank erosion, and the movement of pebble count patch locations between the 2004 and 2005 monitoring periods. A total of six patches moved at the NC and CA study sites; three patches moved at each site (see shaded portions of Table 3.2). The patches shifted slightly for a variety of reasons (Table 3.3). The overall trend in the shifted NC and CA patches is an increase in particle size. All patches show an increase in material size except CA PC#6, which was shifted to the right toward the eroding bank and shows a decrease in particle size. The particle size decrease is likely caused by an input of finer material into the patch from the eroding bank.

3.4 CHANNEL SUBSTRATE DISCUSSION AND RECOMMENDATIONS

Monitoring changes in channel substrate composition through time is one way to evaluate the long-term influence of sediment trapping by Jordanelle Dam. Based on the May 2004 and May 2005 data, minor levels of coarsening are evident in the upper sites (BJ and RR). At the lower sites (NC and CA), changes in patch/bar locations and substrate were more noticeable.

However, limited amounts of gravel-sized particles are present in the upper study sites. Gravel at the BJ site increased slightly from 2004 to 2005, but the substrate is still dominated by larger material. A similar change was seen at RR, where gravel is being deposited at cross section 3 and the gravel patch near cross section 6 is becoming larger. Again, cobble is still the dominant class size. The more noticeable changes in substrate occurred at the lower sites, NC and CA. At NC there were significant shifts in the location of bars and substrate patches. Fewer changes were noted in the downstream section of the site. These shifts reflect the reworking of the substrate and shifts in channel location (see Chapter 2) that occurred between 2004 and 2005. At NC fine and medium gravel in the substrate may have increased slightly, but gravel and cobble remain the dominant particle size. The 2005 sampling at CA showed dramatic differences in substrate from 2004. The site is adjusting to the restored (constructed) channel. The site is far less silty and has become coarser overall. The CA site has become similar to the other sites since the fines were flushed.

The 2005 peak flows were much higher and high flows were sustained for a longer period of time than in previous years. The results of those flows will not be determined until sampling is completed for 2006. Given the 2004 and 2005 data, we expect that BJ and RR will have some change. However, the most change will probably occur in the upper parts of NC and all of CA. Because it has been through only one flood cycle since construction was completed, CA is expected to continue to show changes as the newly adjusted channel adjusts for the next few years.

4.0 SEDIMENT TRANSPORT

4.1 INTRODUCTION

The results of the 2005 bedload and suspended load monitoring in the middle Provo River are described in this chapter. Data collected during previous years (2002, 2003, and 2004), as described in the Provo River Flow Study (Olsen et al. 2004) and the 2004 Provo River Monitoring Report (Olsen 2005), were included where applicable. These data, along with the channel cross section and substrate data, help determine sediment loads moving into, through, and out of specific reaches of the middle Provo River.

The purpose of this effort is to better understand sediment transport processes in the middle Provo River and quantify coarse sediment replenishment needs below Jordanelle Dam as an adaptive maintenance activity to maintain a healthy riverine ecosystem and keep restored sections of the middle Provo River in a desirable condition. 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 four bridge locations, which are almost equally spaced between Jordanelle Dam and Deer Creek Reservoir (Map 1.1). Table 4.1 shows distances between bridges that were used for sediment transport monitoring. The bridge structures enabled workers to collect samples across the entire width of the channel during peak flows when the river was unwadeable. 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.

SEDIMENT TRANSPORT MONITORING BRIDGE	DISTANCE BETWEEN BRIDGES[a]	TOTAL RESTORED RIVER MILES BELOW JORDANELLE DAM
WHITE BRIDGE (WB)	-	1.76
RIVER ROAD (RR)	2.42	4.18
MIDWAY BRIDGE (MID)	4.66	8.84
CHARLESTON (CA)	2.55	11.39

[a] All distances were measured along the thalweg of the restored channel.

4.2.2 STREAM DISCHARGE

Streamflows encountered during sampling were determined using real time, provisional 15-minute flow data at the River Road and Charleston U.S. Geological Survey (USGS) gaging stations located in the project area (Map 1.1). The data were acquired from the USGS web site (USGS 2005). Data from the Midway USGS gaging station were not available from the USGS in 2005, but is now available from the CUWCD. Table 4.2 shows which gaging station was used at each monitoring bridge.

TABLE 4.2. DATA SOURCES USED TO DETERMINE STREAMFLOW AT THE VARIOUS 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 2005
RIVER ROAD BRIDGE (RR)	USGS STATION #10155200 (PROVO RIVER AT RIVER ROAD BRIDGE) 15-MINUTE REAL-TIME DATA DOWNLOADED IN 2005
MIDWAY BRIDGE (MID)	USGS STATION #10155300 (PROVO RIVER AT RIVER ROAD) 15-MINUTE REAL-TIME DATA DOWNLOADED IN 2005
CHARLESTON (CA)	USGS STATION #10155500 (PROVO RIVER NEAR CHARLESTON) 15-MINUTE REAL-TIME DATA DOWNLOADED IN 2005

There was an above-average snowpack in the upper watershed in spring 2005, which provided flows high enough to transport coarse sediments in the middle Provo River. Sediment samples were collected at fairly regular discharge intervals during the rising and falling limbs of the spring runoff hydrograph and seasonally during base flow (Figure 4.1). Prior to spring runoff a peak flow release schedule was proposed in a meeting with the CUWCD and BIO-WEST, Inc. (BIO-WEST). This schedule met water delivery needs and was patterned to achieve a high peak flow and gradual receding limb for sediment transport and cottonwood recruitment purposes. The Mitigation Commission also used the flow release schedule to determine what problems might arise if the dam were operated in this manner. The proposed flow release schedule was implemented with some last-minute modifications to the duration of peak flows; however, the magnitude and duration of the peak flows in 2005 were among the highest since Jordanelle Dam became fully operational (Figure 1.1). Sediment samples were collected at predetermined flow rates after each new flow level stabilized.

4.2.3 SUSPENDED SEDIMENT MONITORING

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

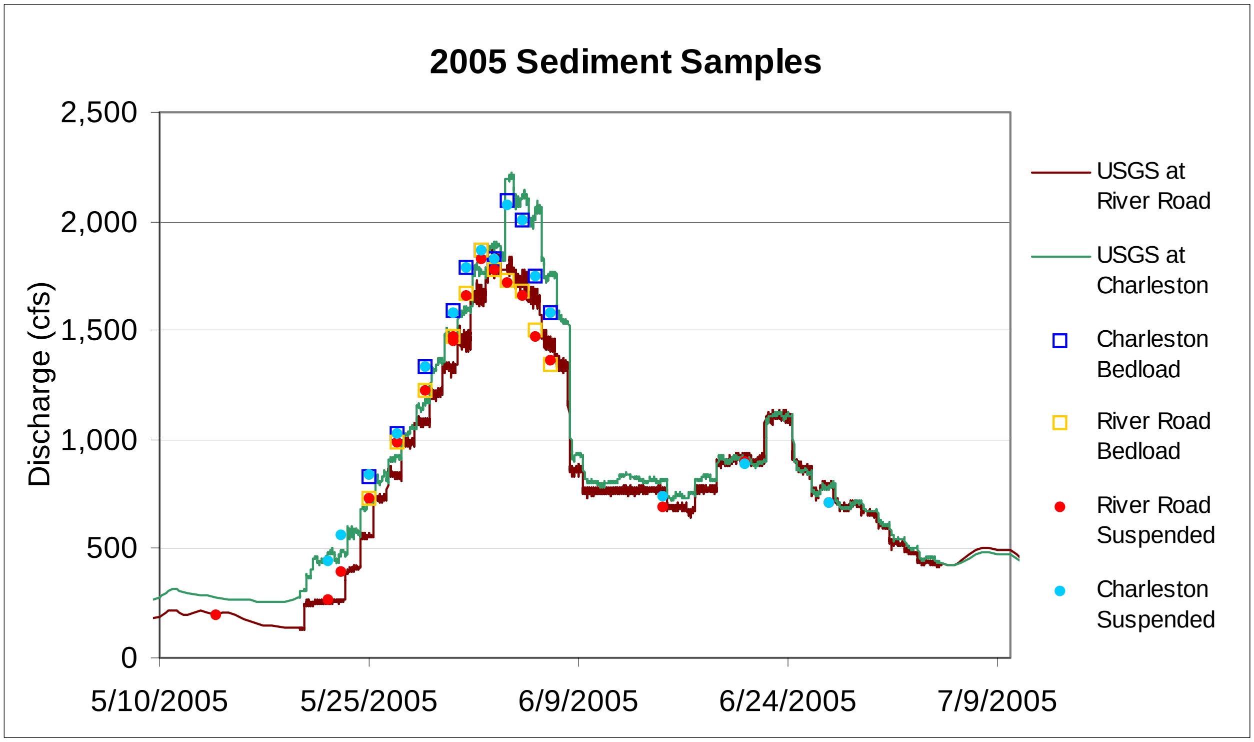


FIGURE 4.1. YEAR 2005 SPRING RUNOFF HYDROGRAPH SHOWING WHEN SEDIMENT SAMPLES WERE TAKEN ON THE RISING AND FALLING LIMBS. THE OPEN BOXES SHOW WHEN SUSPENDED SAMPLES WERE TAKEN, WHEREAS THE ORANGE FILLED BOXES SHOW WHEN BOTH SUSPENDED AND BEDLOAD SAMPLES WERE TAKEN.

For each sample, suspended sediment concentrations and 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. These values were used to develop an empirically derived suspended sediment transport rating curve (Appendix 4.1) for each monitoring site, which shows the relationship between flow and suspended sediment transport rate.

4.2.4 BEDLOAD MONITORING

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

Each field-collected bedload sample was dried and sorted into the following size categories using standardized sieves: > 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). These values were plotted against streamflow at the time of the sample to develop an empirically derived bedload transport rating curve for each monitoring site, showing the relationship between flow and bedload transport rate. Where applicable, bedload data collected in 2002 and 2003 (Olsen et al. 2004) were added to the 2004 and 2005 data.

Daily transport rates and total annual loads were calculated by applying the power equation derived for each monitoring site to the discharge values (x) from the USGS gaging stations for the 2005 Water Year. Hydraulic and bed material size information was available at the River Road bridge; therefore, a separate rating curve was developed at the River Road bridge using the Parker (1990) bedload transport equation. Total annual loads were also calculated by applying the Parker equation to the average daily flows encountered during the 2005 water year.

4.3 SEDIMENT TRANSPORT RESULTS

The 2005 spring runoff provided some of the highest peak flows in the middle Provo River (Figure 1.1), and subsequently some of the coarsest sediment transport, since the closure of Jordanelle Dam. 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. Photos of the 2005 bedload samples are also provided in Appendix 4.1.

4.3.1 2005 SEDIMENT LOADS

Daily transport rates of suspended and bedload sediments were relatively low at all times of the year except during spring runoff when daily loads spiked by more than 2 or 3 orders of magnitude (Figure 4.2). Spikes of this magnitude are typical of snowmelt-dominated, gravel-bedded rivers. The low flow suspended sediment transport rates have been less than 1 ton/day at all sites between Jordanelle Dam and Deer Creek. It is interesting that there was more suspended sediment transport during low flow at WB than at RR and MID (Figure 4.2); however, total annual loads remain driven by peak transport rates during high flows, which increase somewhat linearly with increasing distance below Jordanelle Dam (Figures 4.3 and 4.4). Suspended sediment loads were highest at the CA monitoring site during all flows. It is uncertain why there is more suspended sediment during low flow at WB than RR and MID. There were several sources of suspended sediment in the middle Provo River immediately upstream of the CA site, including the stormwater outfall from Heber City.

A comparative graph of daily transport rates during spring runoff for all sediment monitoring sites (Figure 4.3) shows a distinct pattern of increasing suspended and bedload sediment transport rates with increasing distance below Jordanelle Dam, except for the aberration of bedload at the MID monitoring bridge (below the never-channelized reach). Peak flow bedload transport rates range

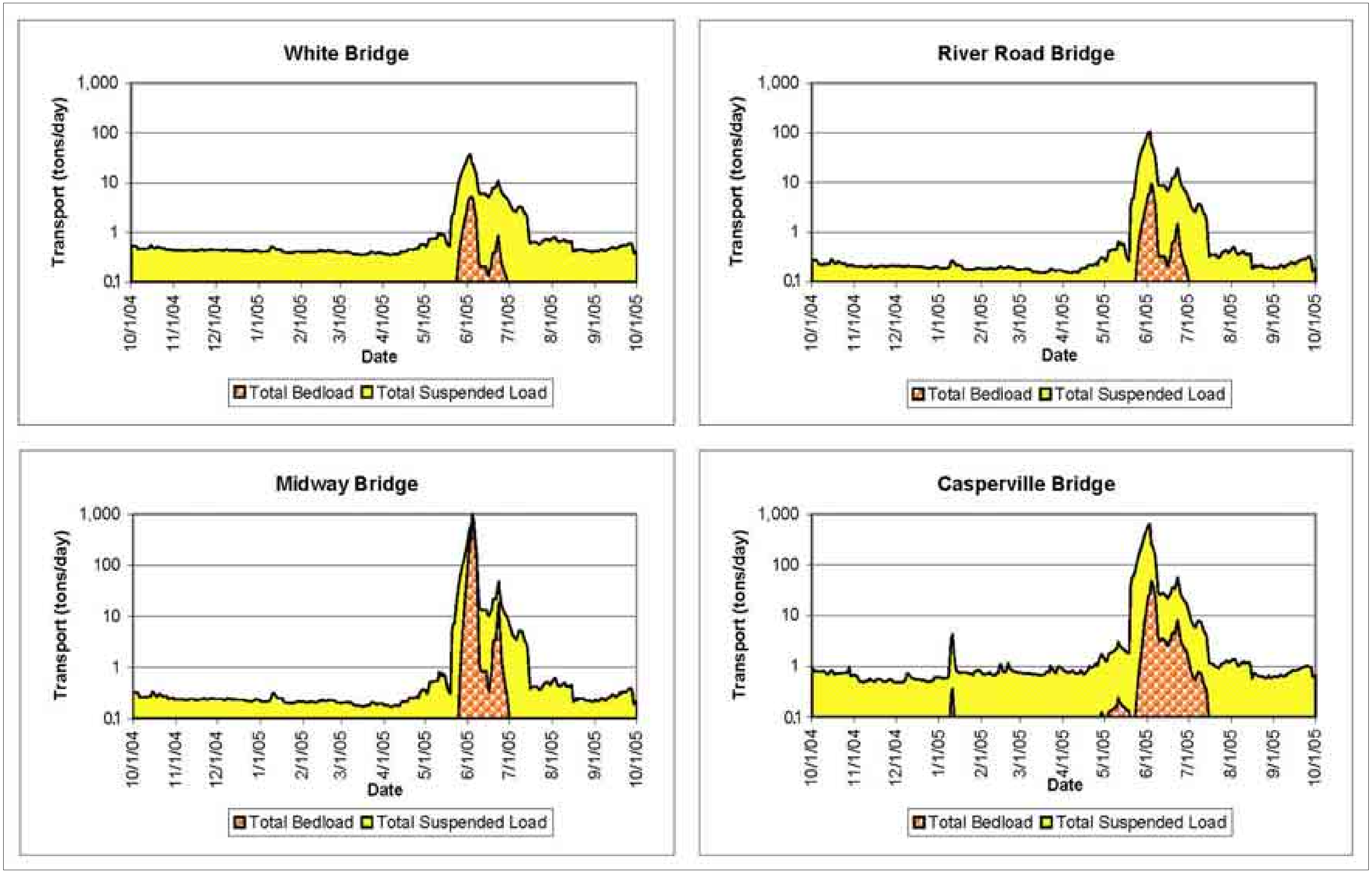


FIGURE 4.2. SUSPENDED (SOLID YELLOW) AND BEDLOAD (ORANGE DOTS) SEDIMENT TRANSPORT DURING THE 2005 WATER YEAR BASED ON USGS FLOW RECORDS AND EMPIRICALLY DERIVED RATING CURVES SHOWN IN APPENDIX 4.1. TOTAL TRANSPORT RATES ARE DRIVEN BY THE PEAK SPRING RUNOFF PERIOD, WHICH INCREASE IN THE DOWNSTREAM DIRECTION.

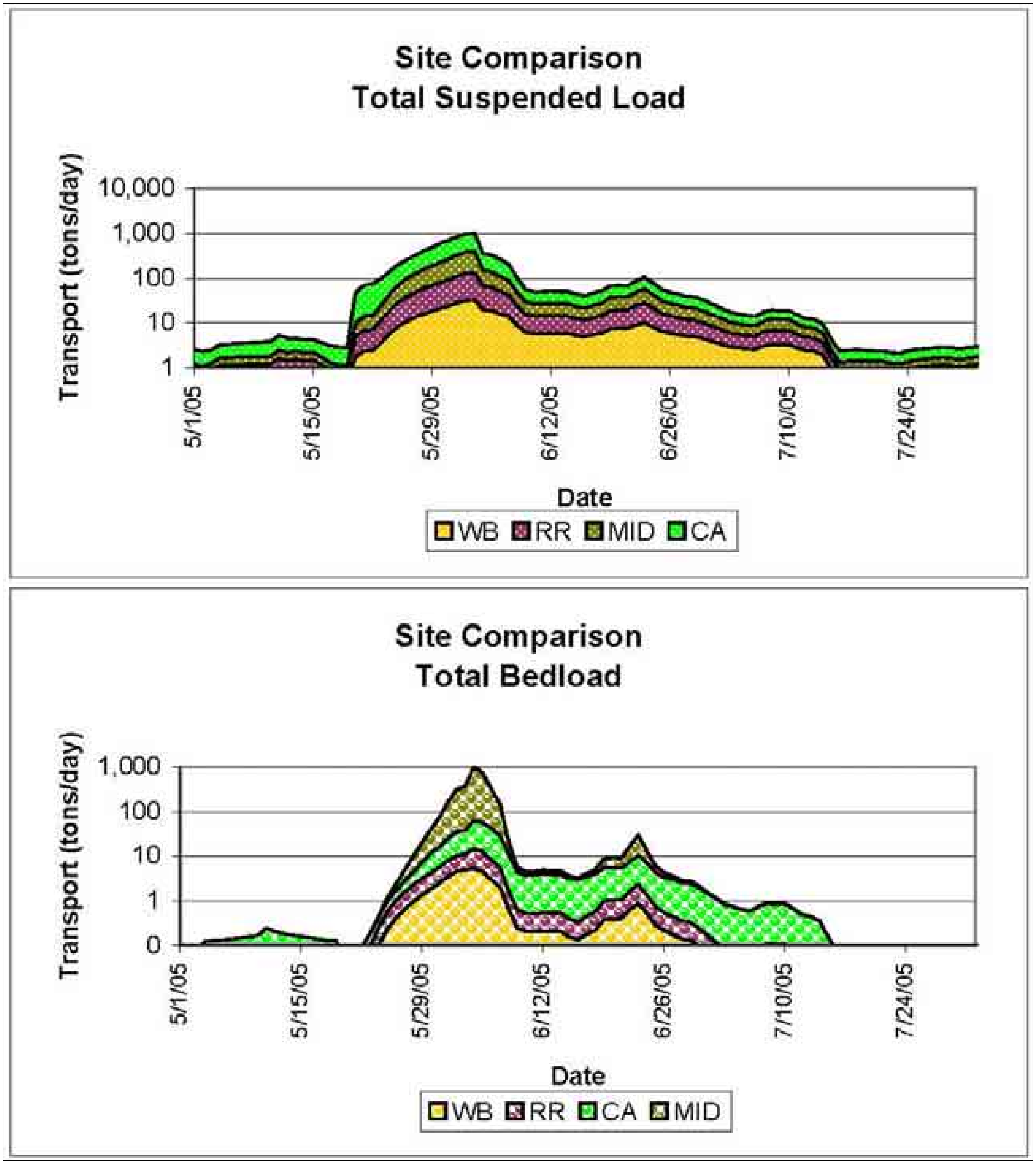


FIGURE 4.3. SEDIMENT TRANSPORT RATES IN THE MIDDLE PROVO RIVER DURING THE 2005 SPRING RUNOFF. THESE GRAPHS SHOW GREATER TRANSPORT AS DISTANCE INCREASES BELOW JORDANELLE DAM, EXCEPT FOR EXTREMELY HIGH BEDLOAD TRANSPORT AT THE MIDWAY (MID) MONITORING BRIDGE (BELOW THE NEVER-CHANNELIZED REACH).

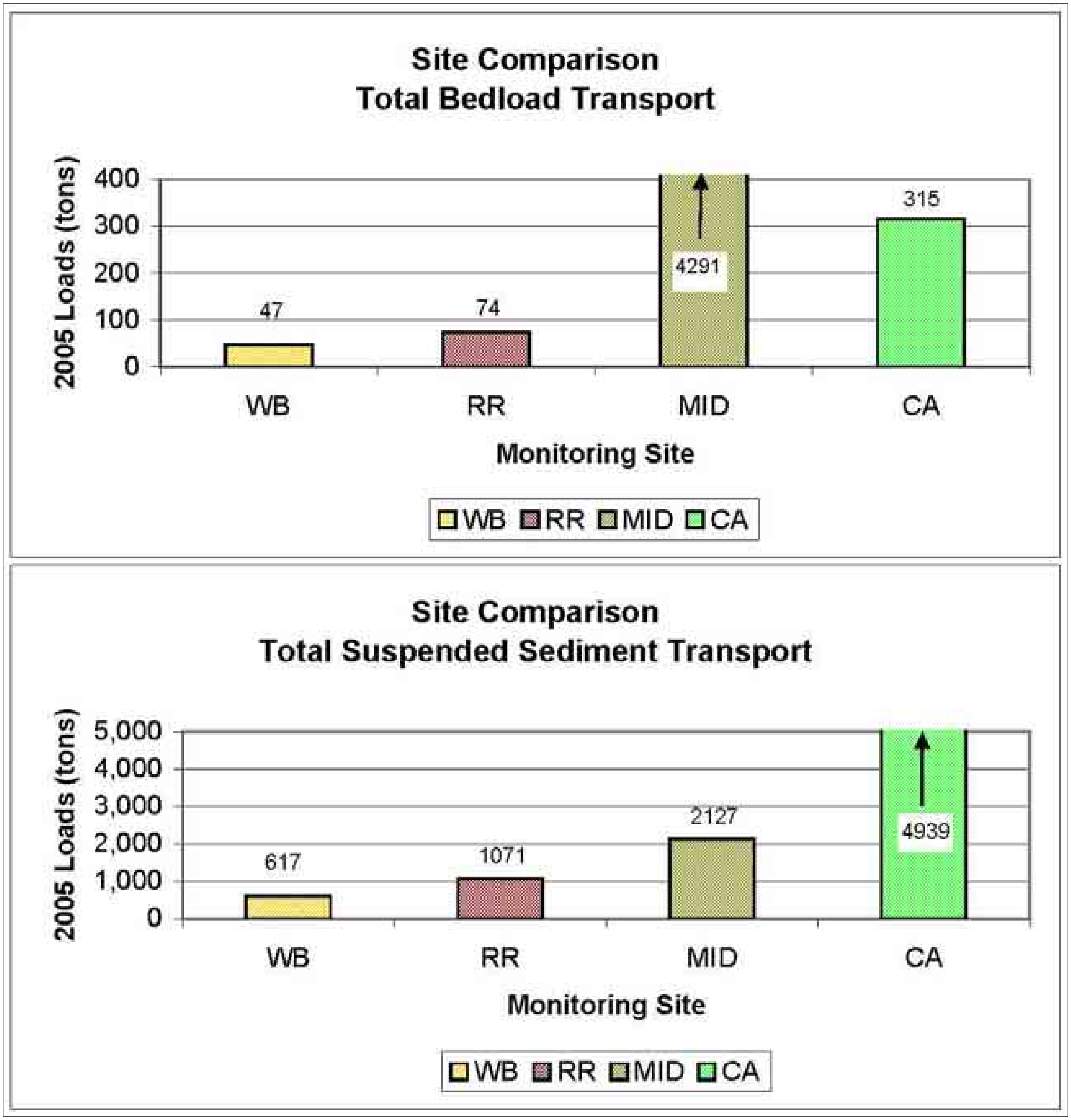


FIGURE 4.4. TOTAL ANNUAL LOADS IN THE MIDDLE PROVO RIVER DURING THE 2005 WATER YEAR. THESE GRAPHS SHOW INCREASING SEDIMENT LOADS WITH INCREASING DOWNSTREAM DISTANCE FROM JORDANELLE DAM, WITH THE EXCEPTION OF EXTREMELY HIGH BEDLOADS AT THE MIDWAY (MID) MONITORING BRIDGE (BELOW THE NEVER-CHANNELIZED REACH).

from approximately 3 to 34 tons per day at the WB and CA monitoring bridges respectively (Figure 4.3), with an abnormal peak of 274 tons per day of bedload at the MID monitoring bridge. Peak daily and total annual bedload is more than an order of magnitude higher at MID than the other monitoring sites. The aberration of bedload at the MID monitoring bridge has been unique to bedload and does not apply to suspended sediment loads (Figure 4.4). Loads of suspended sediment follow a progressive increase in the downstream direction. Suspended sediment transport rates double between each monitoring site (every 2-3 miles) with a total increase of more than 8 times between WB and CA monitoring bridge, a distance less than 10 river miles.

4.3.2. RELATIONSHIP BETWEEN SEDIMENT TRANSPORT AND DISCHARGE

As with previous years, all monitoring sites exhibited higher suspended sediment loads during the rising limb, while lower suspended sediment loads were observed during the falling limb (Figure 1 of Appendix 4.1), a pattern known as “hysterisis.” A distinct hysterisis pattern was not observed with the bedload data (Figure 2 of Appendix 4.1) at the BJ and RR sites, but a hysterisis in bedload data was apparent in 2005 at the MID and CA monitoring sites. The rising vs. falling limb separation in bedload data was greater in 2005 than observed in 2002-2004, probably because runoff in 2005 produced higher magnitude and longer duration peak flows.

Note the reversed hysterisis in the bedload data (higher bedload transport rates during the falling limb) compared to the suspended sediment hysterisis. The reason suspended sediment concentrations were higher during the rising limb is that flowing water starts inundating surfaces that have stored sediment since the last flood event. Suspended sediment concentrations were much lower at any given flow during the falling limb or when flows stabilize at a certain stage for a long time. The reason bedload transport was higher during the falling limb at MID and CA monitoring sites is most likely that the bed armoring must have been removed or severely weakened in the lower reaches, whereas the armor layer remained strong and suppressed bedload transport during the entire hydrograph at WB and RR (the reaches immediately below Jordanelle Dam).

The suspended sediment data clearly shows that the rating curve separation, hysterisis, gets stronger in the downstream direction (reaches with less supply limitations). Therefore, the rising and falling limb power equations for each site (shown in Figure 1 of Appendix 4.1) were used to calculate suspended sediment loads; however, to be consistent with 2004 results, the single power equation for each site (shown in Figure 3 of Appendix 4.1) was used to calculate bedload, even though there was an apparent separation in rising and falling limb transport rates in the bedload data during 2005 at the MID and CA monitoring sites. The high flows in 2005 exposed the fact that the bed was less armored at the downstream monitoring sites (from 8 to 12 river miles downstream of Jordanelle Dam); whereas the bed remained well armored in the first 4 river miles below Jordanelle Dam at the WB and RR sites (Table 4.1).

Peak transport rates of bedload sediments were more than 2 orders of magnitude greater at the MID monitoring site than BJ and RR. Again, these results indicate severe supply limitations of coarse-grained sediments in reaches immediately downstream of Jordanelle Dam (Figure 4.2).

Gravel transport and the ambient supplies of gravel below Jordanelle Dam remains a concern in the middle Provo River because gravel from upstream sources are known to deposit in the reservoir, and in-channel gravel supplies (e.g., gravel bars) are essential for maintaining high-quality aquatic habitat and desirable channel conditions. To assess gravel transport and supplies, bedload samples were separated into sand (< 2 mm) and gravel (> 2 mm) fractions, and separate sand and gravel rating curves were developed for each monitoring site (Figure 4 of Appendix 4.1). Similar to the results shown in the 2004 report (Olsen 2005), separating the sand parts from the gravel parts in the bedload samples (Figure 4.5) shows that the disequilibrium in bedload transport is related primarily to gravel supplies and only moderately to sand supplies.

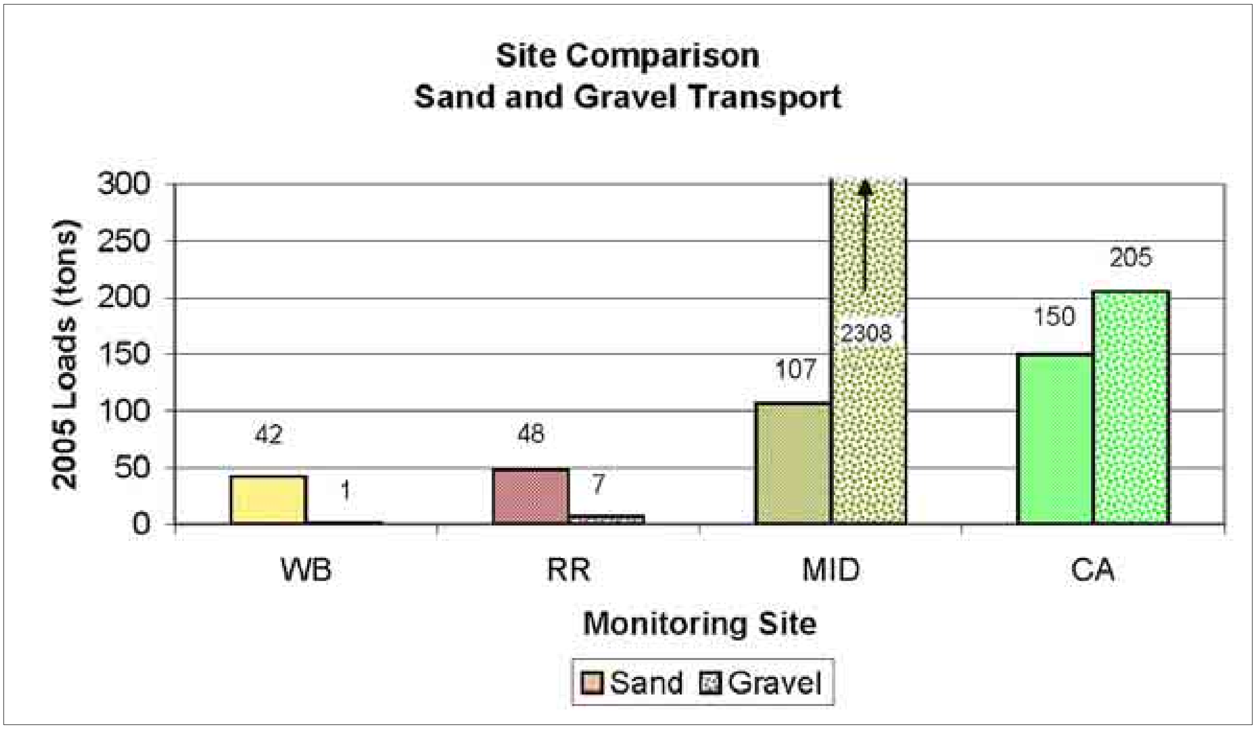


FIGURE 4.5. TOTALS AND GRAVEL LOADS IN THE MIDDLE PROVO RIVER DURING THE 2005 WATER YEAR. GRAVEL LOADS ARE EXTREMELY LOW (ALMOST NONEXISTENT) AT THE WB AND RR MONITORING BRIDGES, YET EXTREMELY HIGH AT THE MIDWAY (MID) MONITORING BRIDGE (BELOW THE NEVER-CHANNELIZED REACH). GRAVEL LOADS RETURN TO EXPECTED LEVELS AT THE CA MONITORING BRIDGE, APPROXIMATELY 2.5 MILES BELOW THE MID MONITORING BRIDGE.

4.4 SEDIMENT TRANSPORT DISCUSSION AND RECOMMENDATIONS

The sediment transport results demonstrate the need for channel maintenance activities (i.e., replenishing coarse-grained sediment supplies) in the restored reaches of the middle Provo River below Jordanelle Dam. The bedload equation (Parker 1990) calculated at the RR monitoring bridge is currently considered the expected transport rate without the dam-induced supply limitations given flows experienced during the 2005 runoff (Figure 4.6). Replenishment supplies of approximately 300 tons of coarse-grained sediments (sand and gravel) would have been necessary in 2005.

Cumulatively, data collected over the past 4 years has shown in-channel sand resources to be moderately limited and in-channel gravel resources to be severely limited in the reaches immediately below Jordanelle Dam. The effects of severe supply limitations, such as bed armoring, are expected to worsen over time and extend farther downstream as existing in-channel gravel supplies are depleted. Below Jordanelle Dam, channel dynamics such as bar and floodplain development will be limited with the low transport rates and subsequent static channel conditions.

There seems to be minor amounts of non-point sources of sand below Jordanelle Dam, yet gravel is being exported from these reaches without any known replenishing supplies. As described earlier, if the coarse-grained sediments continue to be exported from below Jordanelle Dam without a replenishment of similarly sized materials, the restored riverine ecosystem will always be vulnerable to the undesirable effects of channel incision and habitat degradation because of the effects of the upstream reservoir. This trend is evident in the channel surveys, substrate sampling and macroinvertebrate data. Channel cross sections, longitudinal profiles, and substrate will continue to be monitored in this reach to quantify changes.

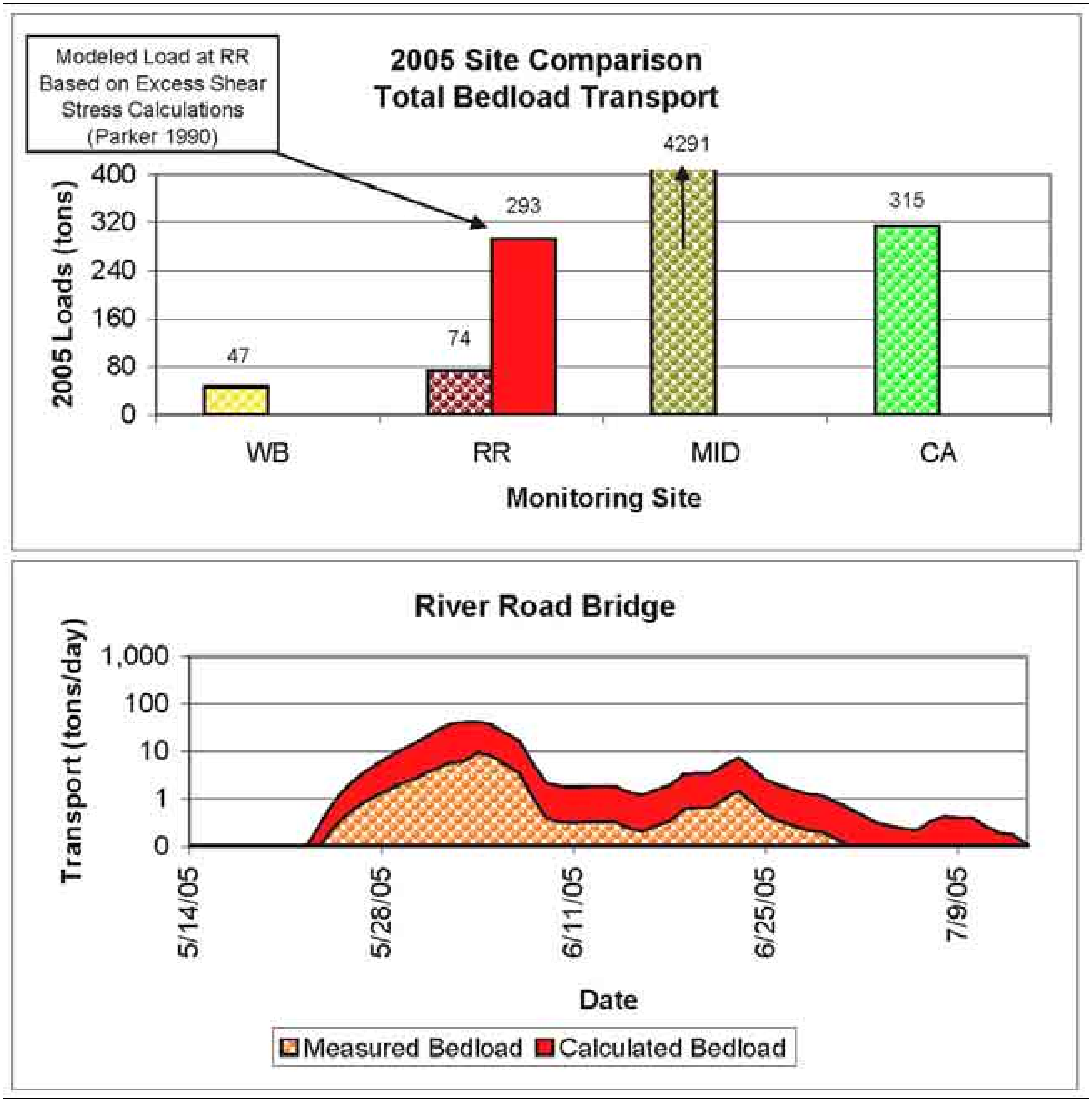


FIGURE 4.6. MEASURED BEDLOAD TRANSPORT RATES AND TOTAL LOADS AT THE RIVER ROAD (RR) MONITORING SITE COMPARED TO MODELED TRANSPORT RATES AND LOADS BASED ON PARKER'S (1990) BEDLOAD EQUATION FOR THE 2005 HYDROGRAPH. THE LOWER GRAPH SHOWS THE CALCULATED DAILY TRANSPORT RATES WHEREAS THE UPPER GRAPH SHOWS THE CALCULATED DAILY TRANSPORT RATES SUMMED FOR THE ENTIRE YEAR.

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5.0 MACROINVERTEBRATE SAMPLING

5.1 Introduction

This section describes the results of the first 2 years of quantitative, post-project benthic macroinvertebrate monitoring on the middle Provo River for this project. One aspect of the success of the PRRP is connected to maintaining a healthy trout fishery and fish habitat. Monitoring the macroinvertebrate community can provide information on changes in water quality and habitat, as well as provide an index for the quantity and quality of food available for the trout fishery. Such information can then be used to determine if and what types of adaptive maintenance activities are needed to maintain the middle Provo River in a desirable condition. Monitoring the health of the macroinvertebrate community will also help to ensure that the restoration is achieving its commitments to maintaining and improving biological integrity and recreation.

5.2 Methods

In May 2004, September 2004, April 2005, and September 2005, quantitative and qualitative sampling for benthic macroinvertebrates was conducted 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 the same habitat type is sampled with a Hess sampler, estimates of richness and abundance between sites should be directly comparable. The location and nearest cross section to the series of quantitative (Hess) samples is shown on the map of monitoring sites (Figure 2.1a-d). The same riffles used for quantitative Hess samples in 2004 were also used in 2005 at all sites except CA. In September 2005 the Hess samples at CA were collected from a riffle near LEP4, which was downstream from the riffle between LEP1 and LEP2 used in the three previous collections. As the habitat at this station has adjusted to the restoration, the depth and flow in certain areas has changed, making the riffle at LEP4 more conducive to collecting Hess samples.

Additionally, one multi-habitat, composite kick net sample was collected at each site. The composite kick net sample involved sampling 20 habitats in proportion to their availability in each monitoring site, using a D-frame kick net (Barbour et al. 1999). 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 randomly selected and sorted until 500 organisms had been picked or until the entire sample had been sorted. Applying 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 and 2005. 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 expressed invertebrate numbers in terms of density (number per square meter). To be comparable to past data, and to account for any areal differences in the sampling gear, abundance information from the 2004 samples was converted into density information. Hess samplers have a 0.086-square meter open bottom area for sampling (WILDCO 2006). Utilizing this known area of each sample, abundance information was converted into density information in numbers per square meter. A variety of data transformations were used to fit the selected metrics to the normal distribution. 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 sites) with data from the samples collected in September 2004 and 2005.

5.3 RESULTS

5.3.1 2004 AND 2005

A complete list of the taxa found and metrics generated for each sample can be found in Appendix 5.1. Combining data from Hess samples at all sites indicated that total density was significantly higher in spring 2005 than in spring 2004 (Figure 5.1, $p < 0.02$). No difference was seen between

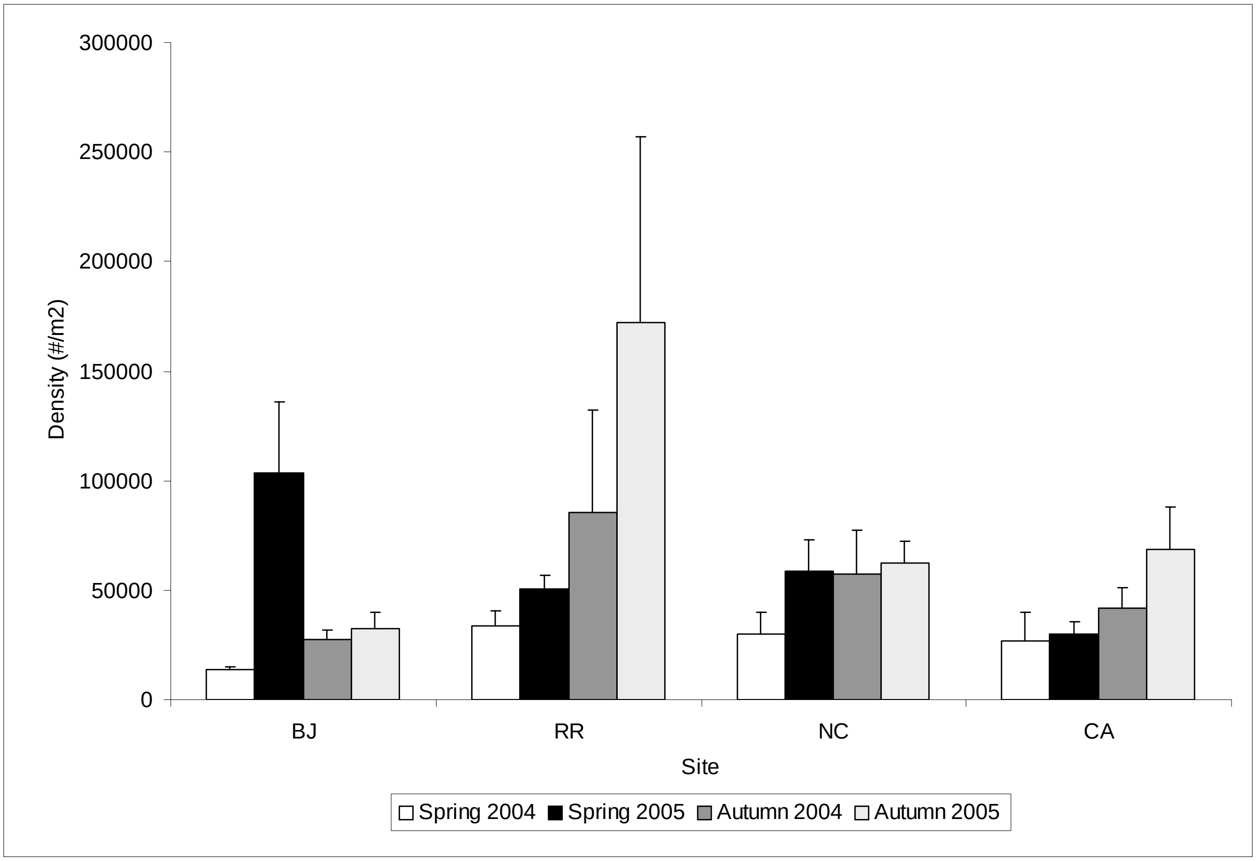

Figure 5.1. Average density of macroinvertebrates (numbers per square meter) calculated from the three Hess samples taken at each site in spring and autumn 2004 and 2005. Error bars represent +/- 1 standard error.

the 2 years in autumn. Using Hess sample data from both 2004 and 2005, no significant differences were found between sites in spring, but BJ had a significantly lower total density than RR in autumn. No significant differences were found between sites within years or between years within sites in spring or autumn. Total macroinvertebrate density in 2005 was highest at RR and lowest at BJ. Total density information was variable at all sites and in both seasons during the past 2 years. All four sites have shown a trend towards increasing density in each season throughout the project.

Total abundance information from qualitative kick net samples did not support all the trends seen in the density information collected using the quantitative Hess sampler in 2004 or 2005 (Figure 5.2). Total abundance information indicated higher numbers of macroinvertebrates in spring 2004 vs. spring 2005 at all sites, but showed lower numbers in autumn 2005 at all sites. The NC site had the lowest total abundance in qualitative kick net samples in autumn of both years, but no trends were evident at the remaining sites. 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 for two reasons.

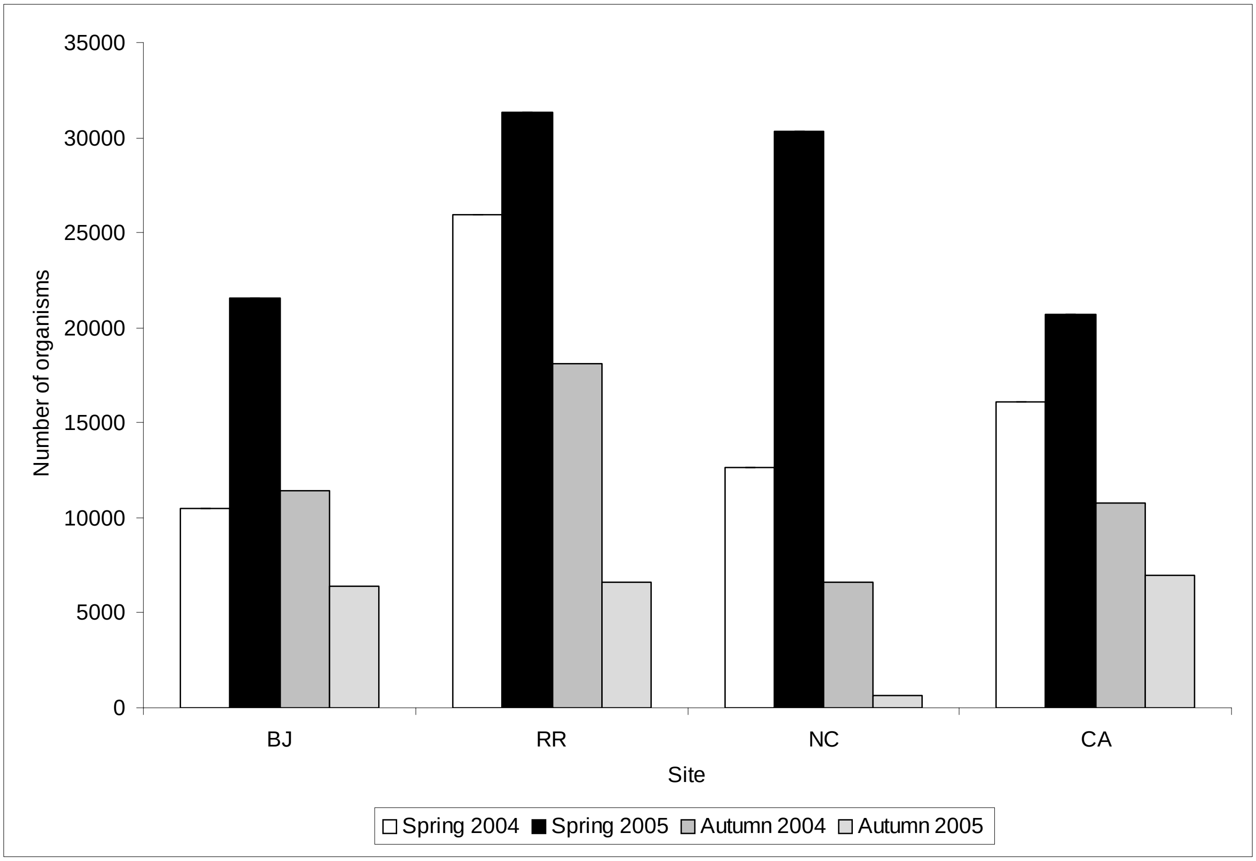

FIGURE 5.2. TOTAL ABUNDANCE OF MACROINVERTEBRATES COLLECTED IN COMPOSITE D-FRAME KICK NET SAMPLES AT EACH SITE IN SPRING AND AUTUMN 2004 AND 2005.

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.

Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies) taxa are generally thought of as taxa sensitive to anthropogenic disturbance. They are referred to as the “EPT taxa.” Hess sample data from all sites showed that EPT taxa density was also significantly higher in spring 2005 than in spring 2004, but showed no difference in EPT taxa density between autumn 2004 and autumn 2005 (Figure 5.3, $p < 0.008$). Hess sample data from spring samples in both years indicated that BJ had significantly higher EPT taxa density than NC ($p < 0.03$); however, this was not reflected in the autumn samples. No significant differences were found between sites within years or between years within sites in spring or autumn. As with total macroinvertebrate density, EPT taxa density was variable at all sites and in both seasons in 2004 and 2005. Density of EPT taxa in the spring is highest at BJ in both years, but appears to be similar at all sites in autumn. During both study years EPT taxa density has shown an increasing trend at NC and CA in both spring and autumn.

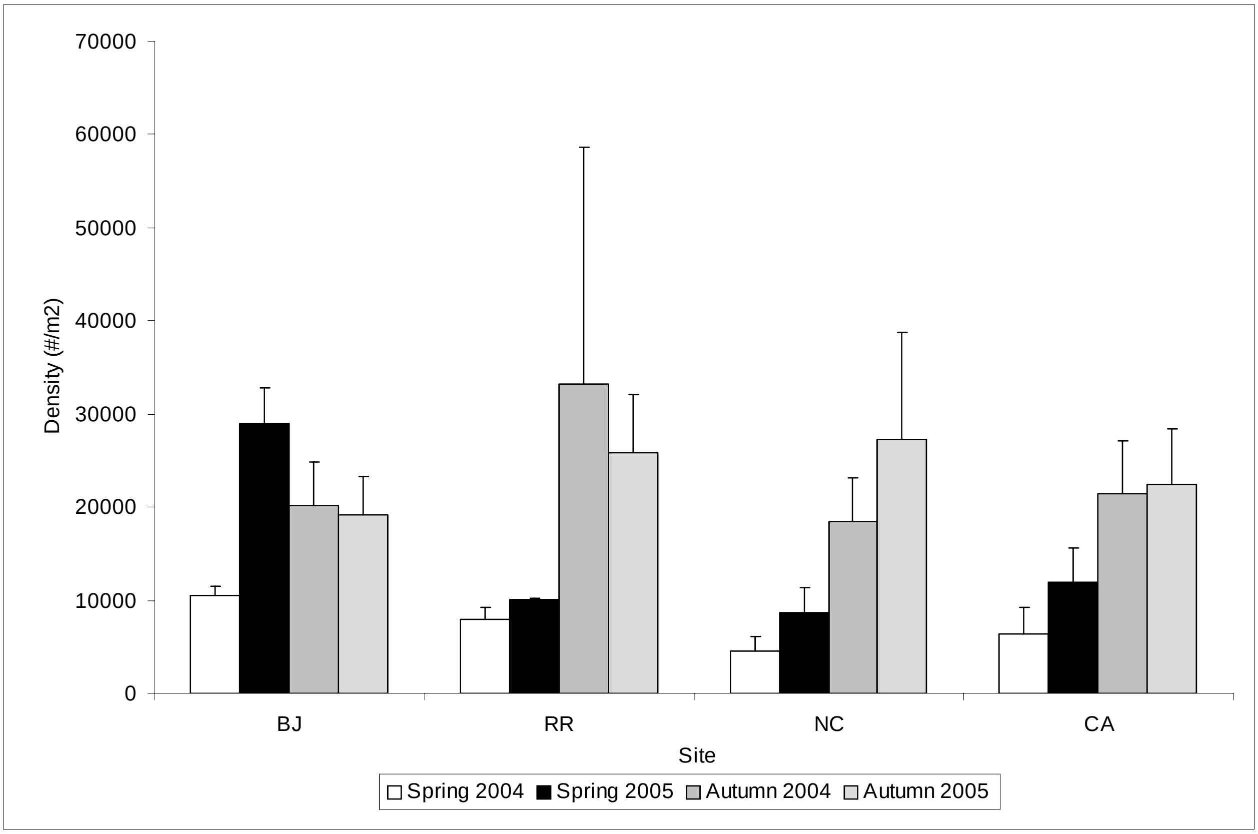

FIGURE 5.3. AVERAGE EPT TAXA DENSITY (NUMBERS PER SQUARE METER) CALCULATED FROM THE THREE HESS SAMPLES TAKEN AT EACH SITE IN SPRING AND AUTUMN 2004 AND 2005. ERROR BARS REPRESENT +/- 1 STANDARD ERROR.

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). Also similar to total abundance, EPT taxa abundance was lower at all sites in autumn 2005 than in any of the other collections. The RR site had the highest EPT taxa abundance in both seasons in 2004 and NC had the lowest EPT taxa abundance in both seasons in 2005. No other trends in EPT abundance were readily apparent.

Taxa richness provides an index for community diversity. In spring 2004 Hess samples from CA had a significantly lower average taxa richness than other sites from spring 2004 and all sites in spring 2005 (Figure 5.5, $p < 0.008$). Hess samples from all sites in autumn 2005 showed that taxa richness was higher than in autumn 2004, and Hess samples from all years showed that taxa richness was higher at CA and NC, when compared to BJ and RR. Autumn 2005 Hess samples from NC and CA had a significantly higher taxa richness than autumn 2005 Hess samples from RR and autumn 2004 samples from BJ ($p < 0.04$). Taxa richness from qualitative kick net samples also showed that NC and CA generally had higher taxa richness than BJ and RR (Figure 5.6). Additionally, Hess samples and kick net samples in spring and autumn at NC and CA showed trends of increasing taxa richness between 2004 and 2005.

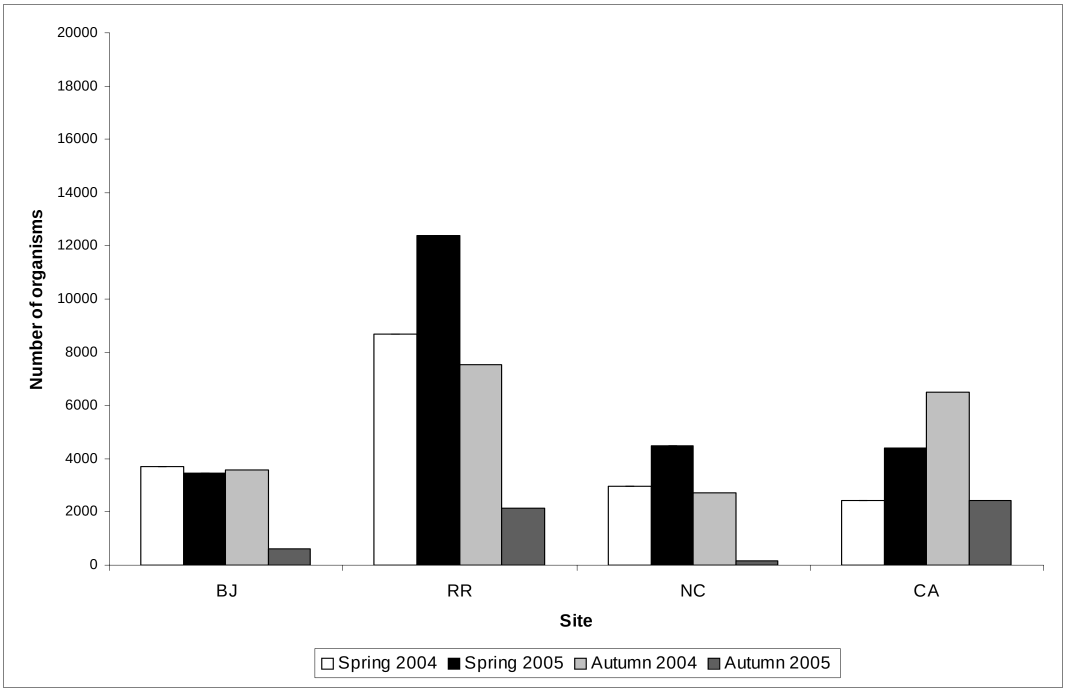

FIGURE 5.4. ABUNDANCE OF EPT TAXA COLLECTED IN COMPOSITE D-FRAME KICK NET SAMPLES AT EACH SITE IN SPRING AND AUTUMN 2004 AND 2005.

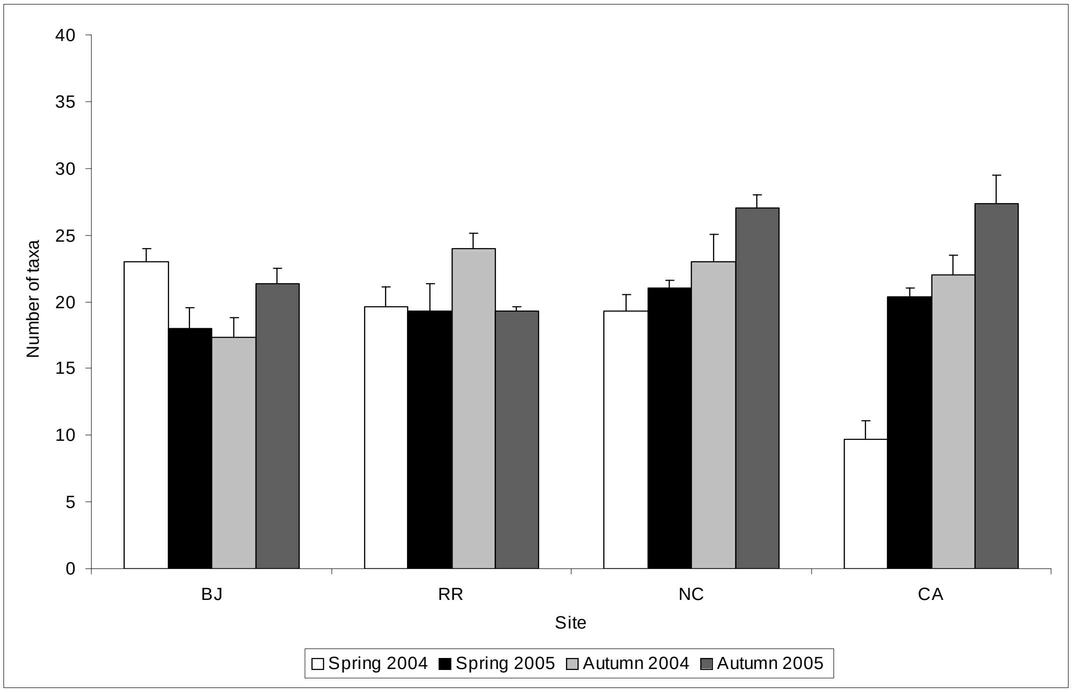

FIGURE 5.5. AVERAGE TAXA RICHNESS CALCULATED FROM THE THREE HESS SAMPLES TAKEN AT EACH SITE IN SPRING AND AUTUMN 2004 AND 2005. ERROR BARS REPRESENT +/- 1 STANDARD ERROR.

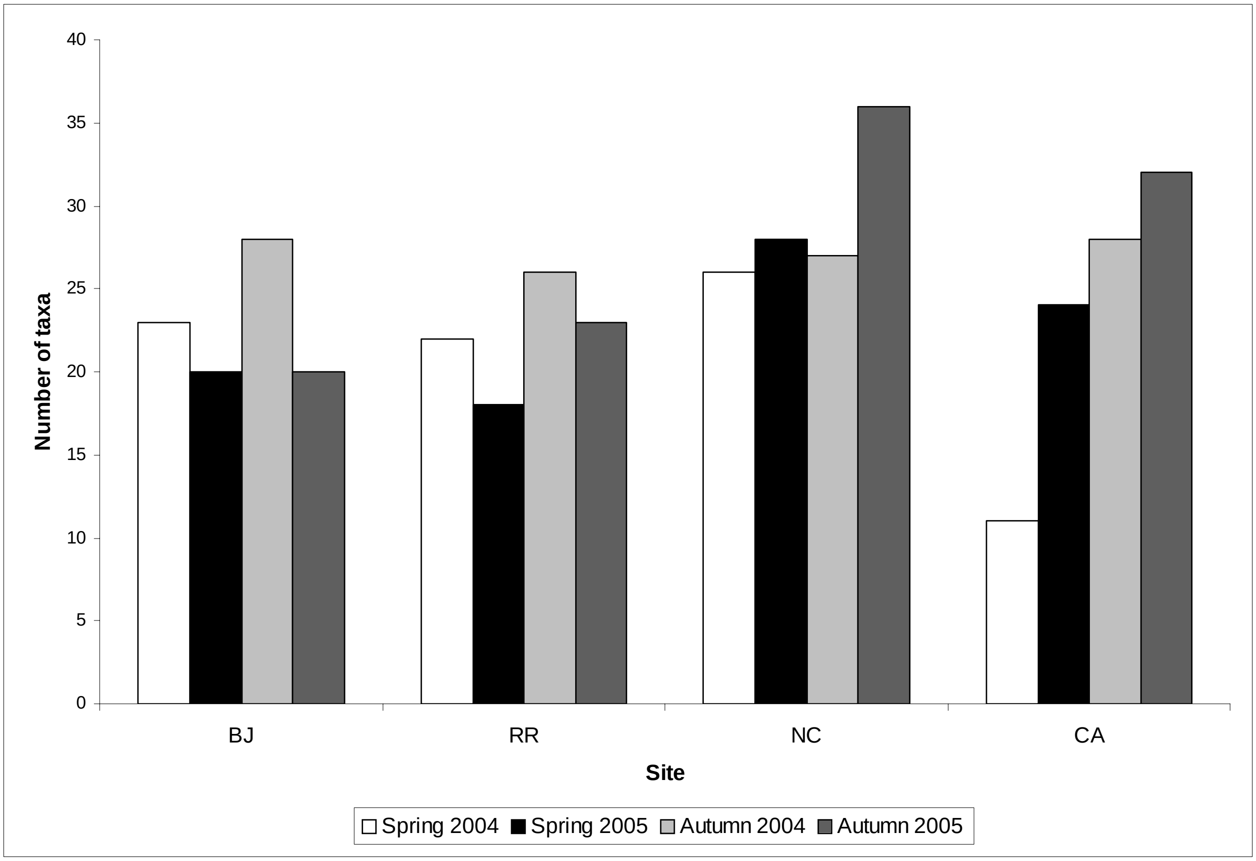

FIGURE 5.6. TAXA RICHNESS IN COMPOSITE D-FRAME KICK NET SAMPLES AT EACH SITE IN SPRING AND AUTUMN 2004 AND 2005.

Combining Hess sample data from 2004 and 2005 showed that CA had significantly lower EPT taxa richness in spring, which was the result of the low EPT taxa richness at CA in spring 2004, immediately following construction activities. 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, along with all sites sampled in spring 2005 (Figure 5.7, $p < 0.002$). Hess sample data from autumn in both years showed that BJ had significantly lower EPT taxa richness than RR ($p = 0.009$). No significant differences were found between sites within years or between years within sites in autumn. Richness of EPT taxa from qualitative kick net samples at each site supported these results (Figure 5.8). While EPT taxa richness in kick net samples showed an increasing trend between 2004 and 2005 at RR and CA, Hess sample data only showed an increasing trend at CA.

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

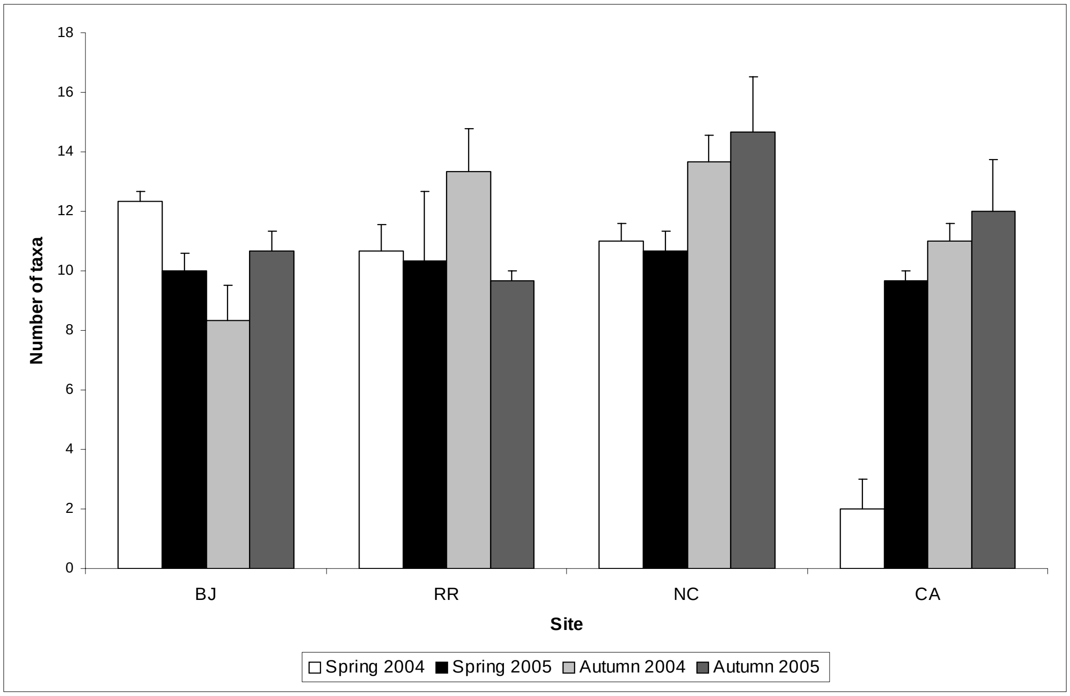

FIGURE 5.7. AVERAGE EPT TAXA RICHNESS CALCULATED FROM THE THREE HESS SAMPLES TAKEN AT EACH SITE IN SPRING AND AUTUMN 2004 AND 2005. ERROR BARS REPRESENT +/- 1 STANDARD ERROR.

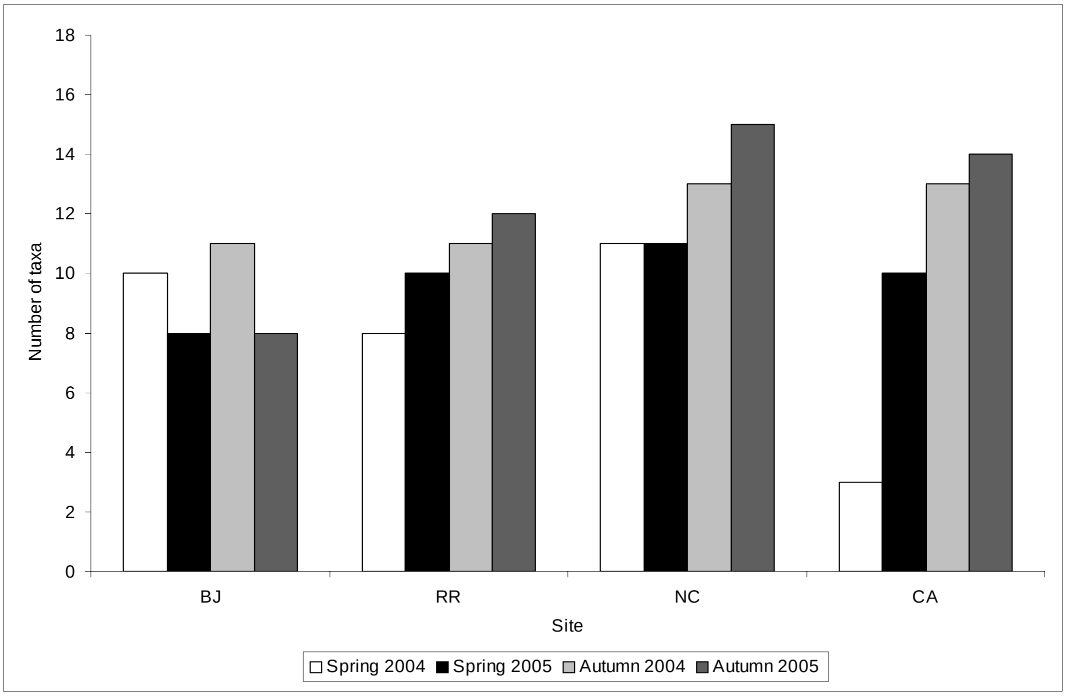

FIGURE 5.8. EPT TAXA RICHNESS IN COMPOSITE D-FRAME KICK NET SAMPLES AT EACH SITE IN SPRING AND AUTUMN 2004 AND 2005.

The average spring and autumn HBI value from Hess samples at BJ was significantly lower than the remaining three sites when data from both years were combined (Figure 5.9, $p < 0.03$). The primary reason for this was that the spring 2004 HBI value at BJ was significantly lower than all remaining sites sampled in spring 2004, and all sites sampled in 2005 ($p < 0.001$). In autumn, however, there was no significant differences between sites within years or between years within sites. The average HBI value from Hess samples at NC in spring 2004 was significantly higher than the average HBI values from RR in spring 2004 and BJ and CA in spring 2005 (Figure 5.10, $p < 0.02$). With the exception of the spring 2004 HBI value from BJ, average HBI scores from Hess samples at all sites in both seasons and both years would fall into the enriched category. The average HBI value at BJ in spring 2004 was in the slightly enriched category. Overall, BJ had the lowest average HBI values, while the remaining sites showed variability between years and seasons. The NC site showed a decreasing trend in both spring and autumn from 2004 to 2005.

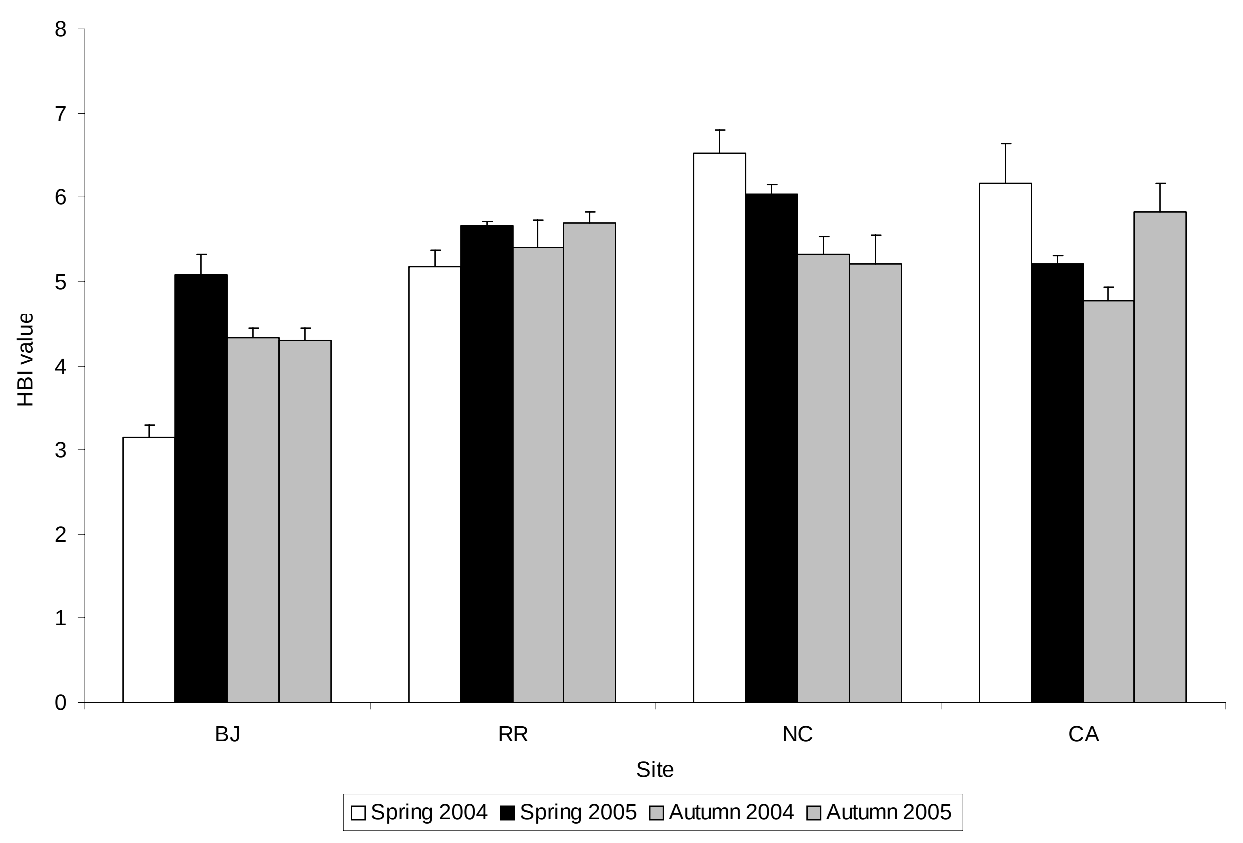

FIGURE 5.9. AVERAGE HILSENHOFF BIOTIC INDEX (HBI) VALUE CALCULATED FROM THE THREE HESS SAMPLES TAKEN AT EACH SITE IN SPRING AND AUTUMN 2004 AND 2005. ERROR BARS REPRESENT +/- 1 STANDARD ERROR. HBI SCORE OF 0-2 = CLEAN, 2-4 = SLIGHTLY ENRICHED, 4-7 = ENRICHED, AND 7-10 = POLLUTED.

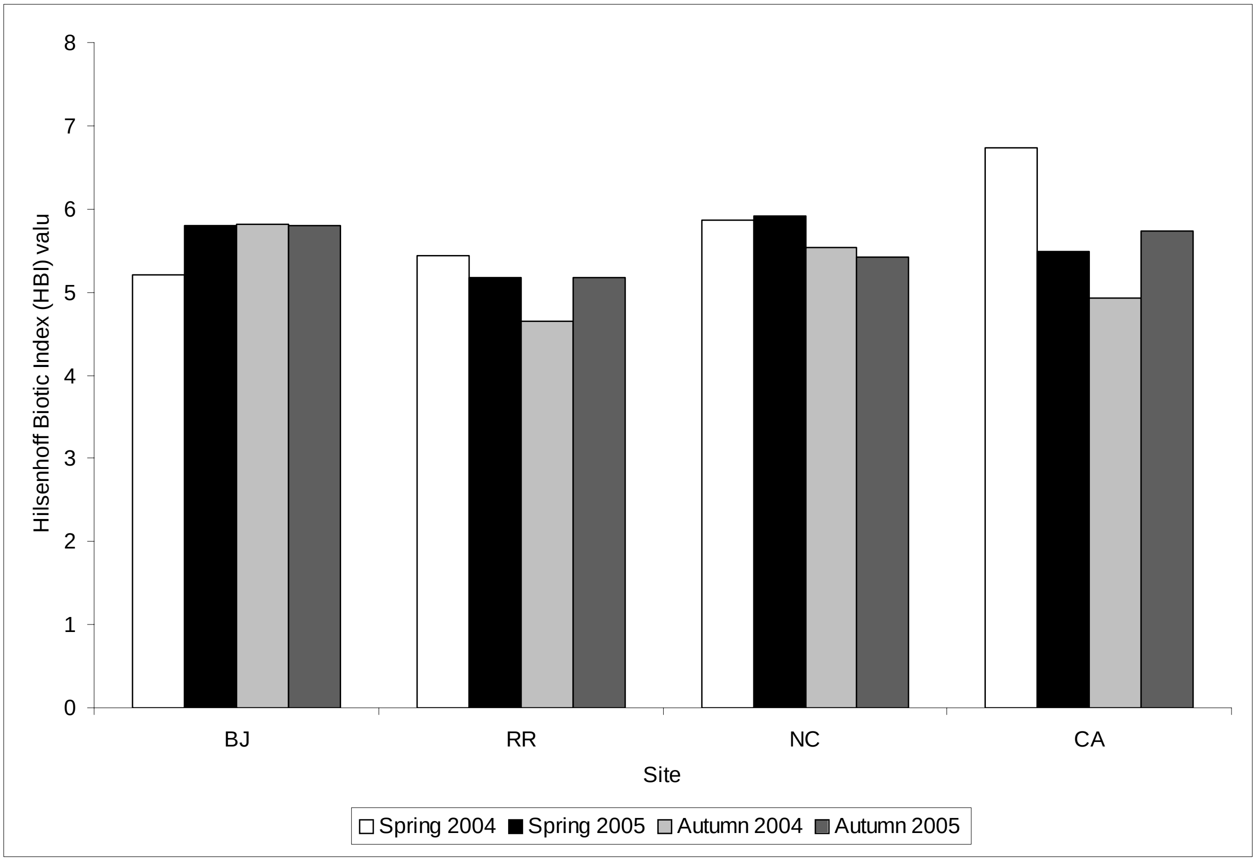

FIGURE 5.10. HILSENHOFF BIOTIC INDEX (HBI) VALUE IN COMPOSITE D-FRAME KICK NET SAMPLES AT EACH SITE IN SPRING AND AUTUMN 2004 AND 2005. HBI SCORE OF 0-2 = CLEAN, 2-4 = SLIGHTLY ENRICHED, 4-7 = ENRICHED, AND 7-10 = POLLUTED.

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.

Examining the proportion of the community that is comprised by the three most dominant taxa provides an index of evenness in the community (Table 5.1). In high-quality streams in the Wasatch and Uinta Mountains, up to 21 percent of the total number of organisms might be found in the most dominant taxa (Grafe 2002), while the three most dominant taxa might comprise up to 50 percent of the total number of organisms (G. Lester, personal communication). Additionally, examining the three dominant taxa at a site can provide additional information about what impacts may be affecting that site. The average proportion of the community made up of the three dominant taxa at BJ in spring 2004 and CA in spring 2005 was significantly lower than all other sites in spring of both years (Figure 5.11, $p < 0.02$). The average proportion of the community made up of the three dominant taxa from all stations combined was significantly higher in autumn 2005 than autumn 2004. Additionally, Hess samples from both years showed that the average proportion of the

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.

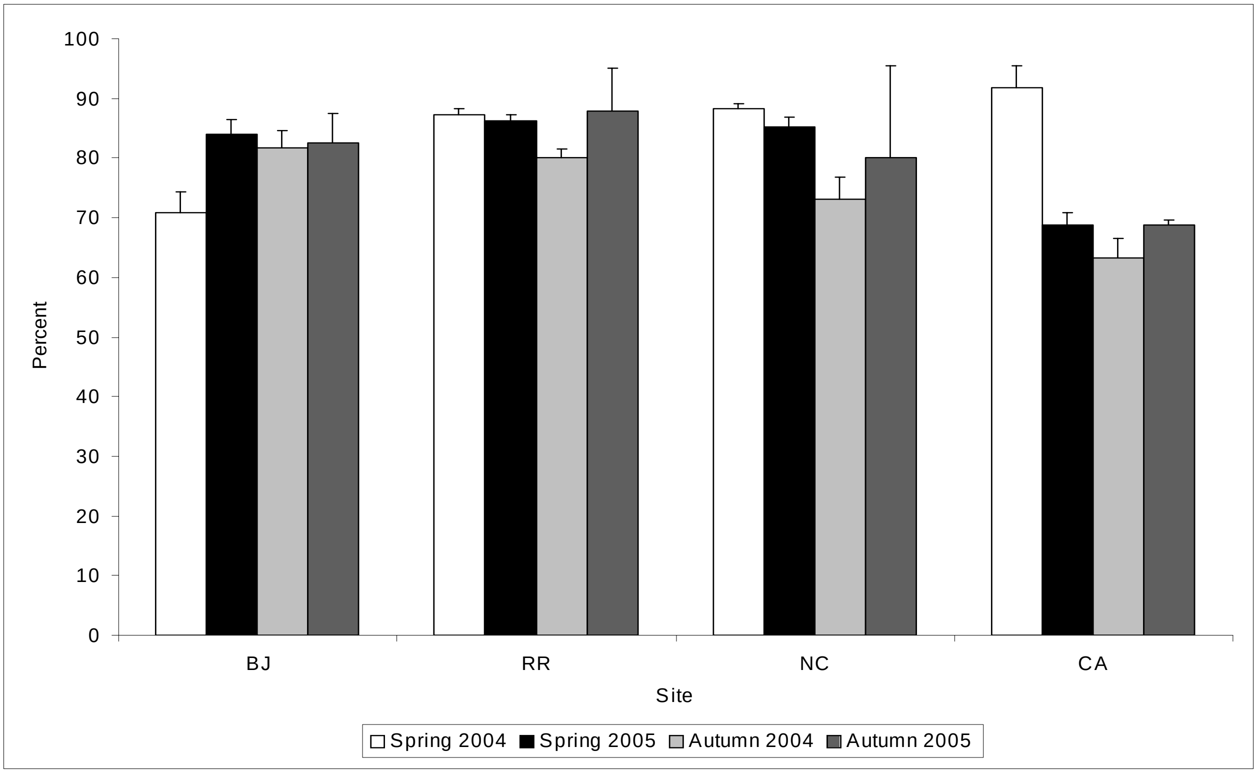

Figure 5.11. Average proportion of the community comprised of the three dominant taxa calculated from the three Hess samples taken at each site in spring and autumn 2004 and 2005. Error bars represent +/- 1 standard error.

community made up of the three dominant taxa was significantly lower at CA in autumn ($p < 0.02$). No significant differences were seen between sites within years or within sites between years in autumn.

Qualitative kick net samples also showed that CA generally had a lower proportion of its community comprised of the three dominant taxa than did BJ and RR (Figure 5.12). The NC site also showed this pattern. Both NC and CA showed a declining trend in the percentage of the community comprised of the three dominant taxa during the 2 study years.

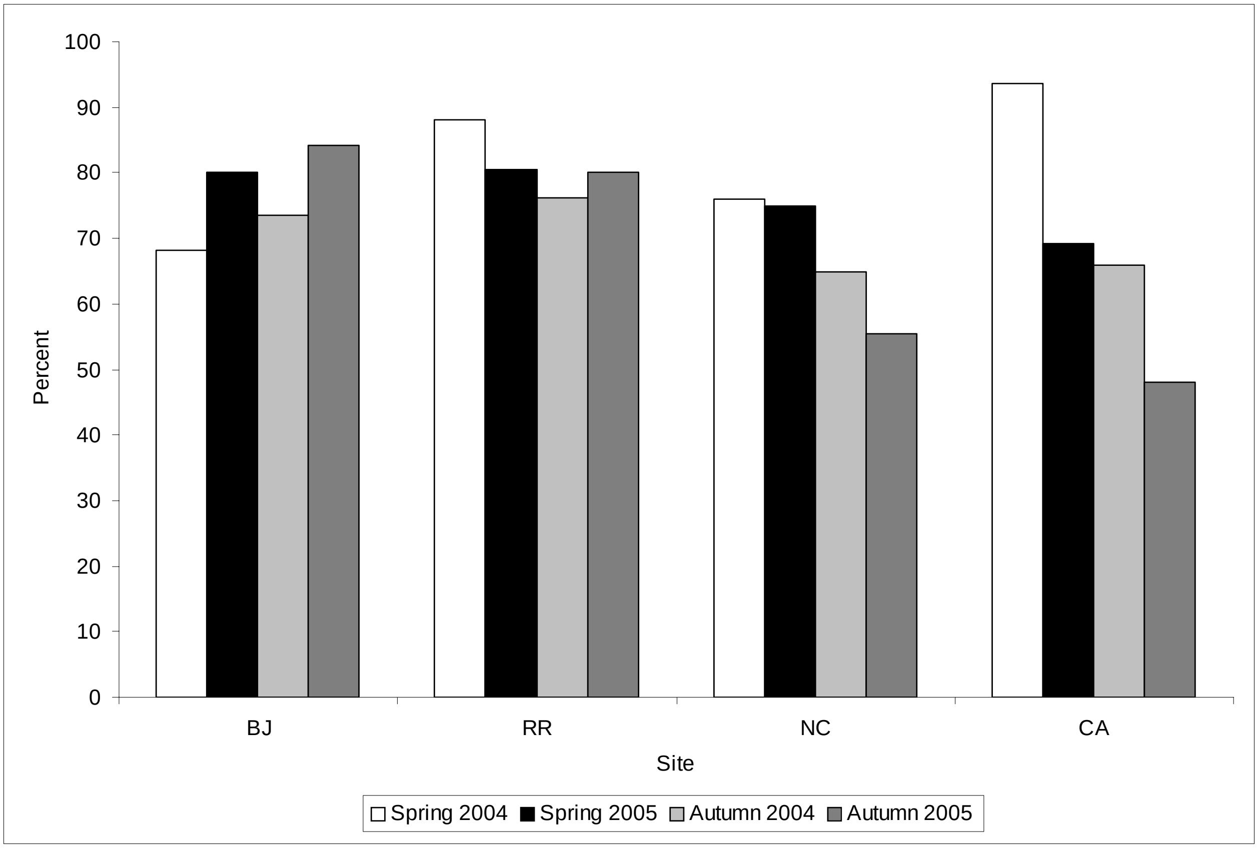

FIGURE 5.12. AVERAGE PROPORTION OF THE COMMUNITY COMPRISED OF THE THREE DOMINANT TAXA IN COMPOSITE D-FRAME KICK NET SAMPLES AT EACH SITE IN SPRING AND AUTUMN 2004 AND 2005.

Many of the same patterns in taxa noted in 2004 (Olsen 2005) were also present in 2005. Midges (Chironomidae), worms (Oligochaeta), and the mayfly *Baetis tricaudatus* remain a large component of the communities at all four sites during both seasons (Tables 5.1 and 5.2). All of these taxa are fairly tolerant to disturbance and are vagile species, quickly colonizing areas after a disturbance. The pollution-sensitive mayfly *Ephemerella inermis/infrequens* and caddisflies in the genus *Brachycentrus* sp. remain a larger component of the communities at BJ and RR than the communities at NC and CA. Conversely, the riffle beetle *Optioservus* sp. and the caddisfly

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.

Hydropsyche sp. comprise a larger portion of the community at NC and CA than at BJ and RR. With the exception of the spring 2004 collection at CA, all the 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 both 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.

5.3.2 COMPARISONS TO HISTORICAL DATA

A series of quantitative samples were collected near the BJ, RR, NC, and CA sites in late August 1999. Similar metrics and analyses were used to look for changes in the benthic community between the August 1999 surber samples and the September 2004 and September 2005 Hess samples.

Total density and EPT taxa density were significantly higher in samples collected in 2004 and 2005 than in samples collected in 1999 (Figures 5.13 and 5.14, $p < 0.002$). No differences were seen in total density, or EPT taxa density, within stations between years and between stations within years.

Similarly, taxa richness and EPT taxa richness were significantly higher in 2004 and 2005 than in 1999 (Figure 5.15 and 5.16, $p < 0.001$). Differences between sites and years reflected the overall difference between 1999 and the more recent years. Collections at BJ in 1999 had significantly higher taxa richness than at CA in 1999, but significantly lower taxa richness than collections at NC and CA in 2004 and 2005 ($p < 0.04$). Collections at BJ in 2004 also had significantly lower taxa richness than collections at NC and CA in 2005. Collections at RR in 1999 had significantly lower taxa richness than all sites in 2004 except for BJ, but only NC and CA in 2005. With the exception of collection at BJ in 2004 and RR in 2005, taxa richness in collections at NC in 1999 were

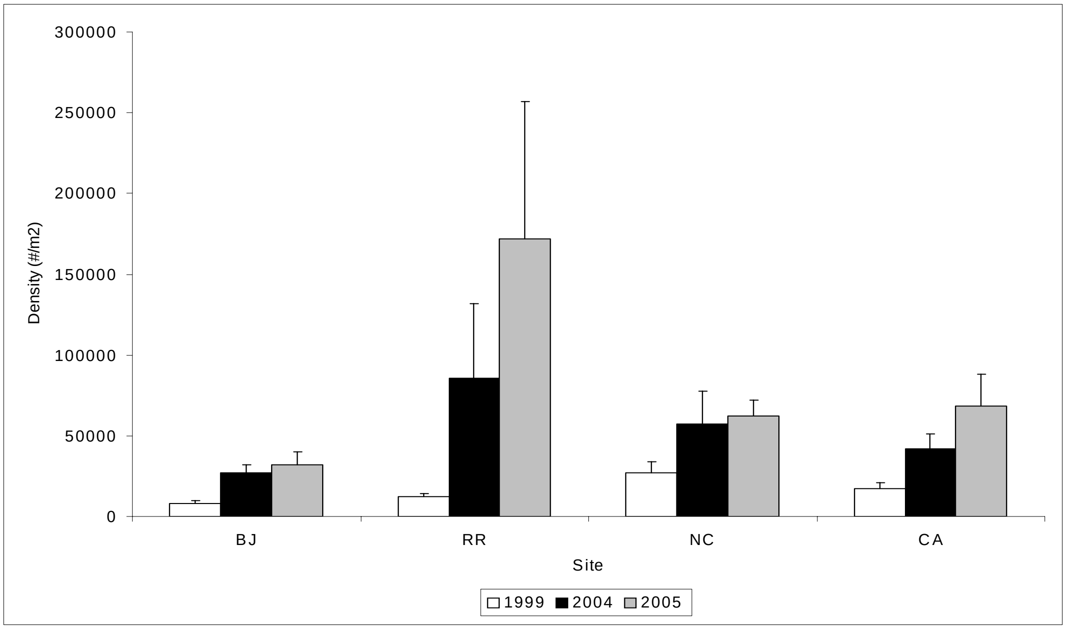

FIGURE 5.13. AVERAGE DENSITY OF MACROINVERTEBRATES (NUMBERS PER SQUARE METER) CALCULATED FROM QUANTITATIVE SAMPLES TAKEN AT EACH SITE IN AUTUMN 1999, 2004, AND 2005. ERROR BARS REPRESENT +/- 1 STANDARD ERROR.

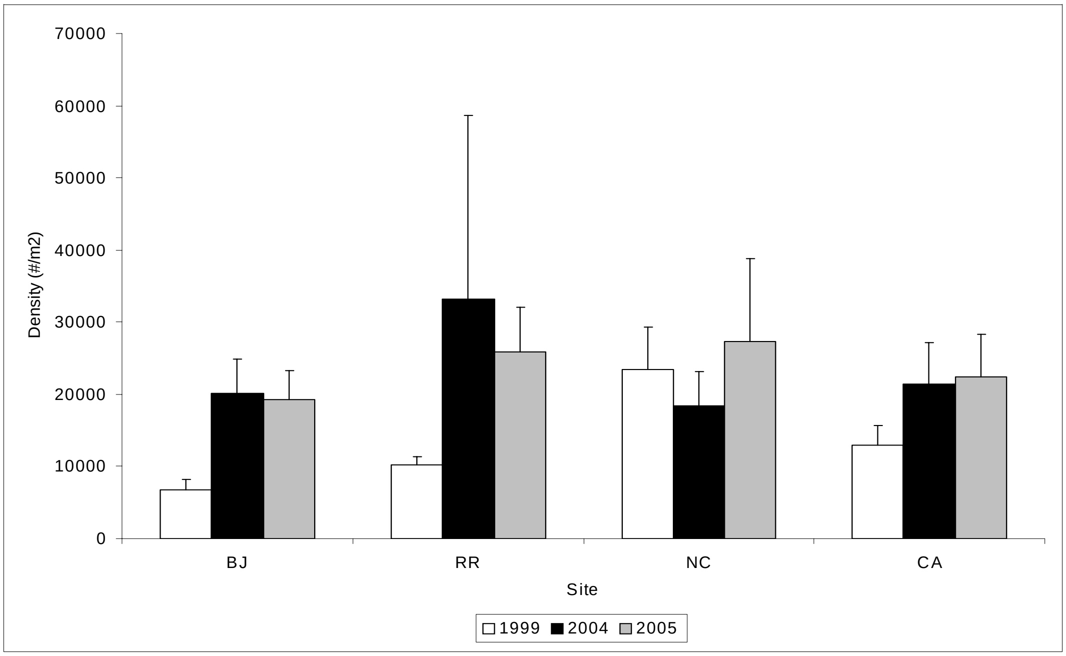

FIGURE 5.14. AVERAGE DENSITY OF EPT TAXA (NUMBERS PER SQUARE METER) CALCULATED FROM QUANTITATIVE SAMPLES TAKEN AT EACH SITE IN AUTUMN 1999, 2004, AND 2005. ERROR BARS REPRESENT +/- 1 STANDARD ERROR.

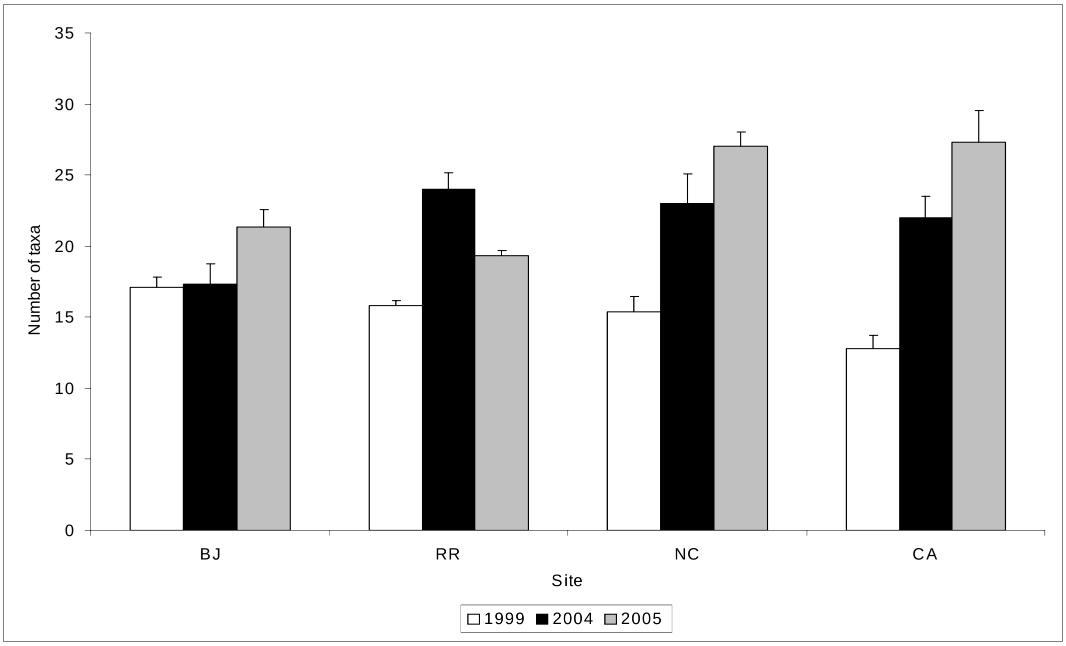

FIGURE 5.15. AVERAGE TAXA RICHNESS CALCULATED FROM QUANTITATIVE SAMPLES TAKEN AT EACH SITE IN AUTUMN 1999, 2004, AND 2005. ERROR BARS REPRESENT +/- 1 STANDARD ERROR.

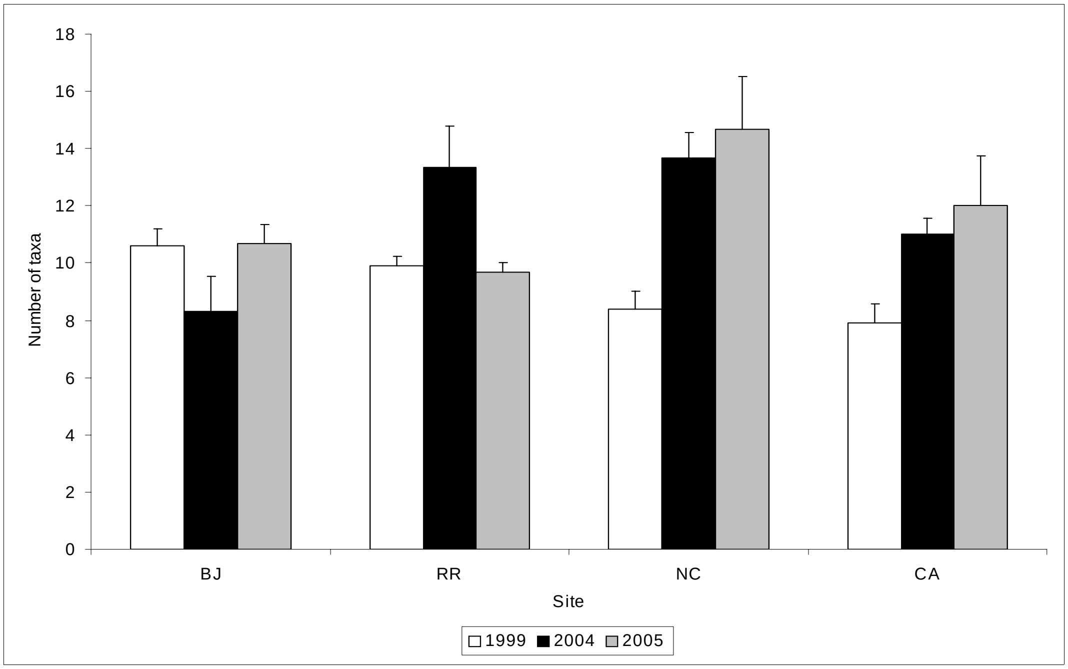

FIGURE 5.16. AVERAGE EPT TAXA RICHNESS CALCULATED FROM QUANTITATIVE SAMPLES TAKEN AT EACH SITE IN AUTUMN 1999, 2004, AND 2005. ERROR BARS REPRESENT +/- 1 STANDARD ERROR.

significantly lower than all collections made in 2004 and 2005 ($p < 0.03$). Similarly, collections from CA in 1999 had significantly lower taxa richness than collections from all sites in 2005, and all sites except BJ in 2004. Finally, taxa richness in collections from CA in 2005 was significantly higher than collections from RR in the same year ($p < 0.02$).

While overall EPT taxa richness was higher in 2004 and 2005 than in 1999, fewer stations showed significant differences between years. Collections from NC in 2004 and 2005 had the highest EPT taxa richness. With the exception of BJ, collections at NC in 2005 had a significantly higher taxa richness than all sites in 1999 ($p < 0.02$). Similarly, collections from NC in 2004 had a significantly higher EPT taxa richness than collections at NC and CA in 1999 ($p < 0.02$). Finally, collections at NC in 2004 and 2005 had a higher EPT taxa richness than collections at BJ in 2004 ($p < 0.05$).

The HBI value at NC in 1999 was the lowest seen at any site in all 3 study years 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. The HBI values from all sites combined were significantly higher in 2004 and 2005 than in 1999. While the HBI value at BJ remained similar between study years, the values at the remaining three sites reflected the increase in 2004 and 2005. The HBI values at RR and NC in 2004 and RR, NC, and CA in 2005 were significantly higher than all sites except BJ in 1999. At BJ the HBI value has remained close to 4.0, which is the lower limit of the enriched category. Conversely, the other three sites have shown an increase from 1.5 - 3.5 (from clean to slightly enriched) to over 5.0 (enriched) between 1999 and 2005.

As noted after first study year (Olsen 2005), the dominant taxa at the study sites in 1999 were different than what was seen in 2004 and 2005 (Table 5.3). While the *Baetis* sp. identified by USU (Vinson 2004) in 1999 are probably the *Baetis tricaudatus* identified by EcoAnalysts for this project, the RR, NC, and CA sites all had blackfly (Simuliidae) larvae and an unidentified caddisfly (Trichoptera) larvae as the other two most abundant taxa. The BJ site had midge (Chironomidae) larvae and blackfly larvae as the other two most abundant taxa. As in 2004 and 2005, caddisflies in the family Hydropsychidae were more abundant in samples from NC than at BJ and RR, but samples at CA also showed a lower abundance of Hydropsychid caddisflies. No differences were seen in the number of scraper taxa or in scraper abundance, as was seen did in the 2004 and 2005 samples. Historical samples also showed the number of caddisfly taxa decreasing 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 and 2005 collections.

5.4 DISCUSSION

During the course of the current study, macroinvertebrate communities from four sites with different restoration histories have been able to be compared at several increments after restoration activities were completed . Additionally, these recent data were compared with historical data collected from the same general areas prior to the initiation of restoration projects in the middle Provo River. 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, because it

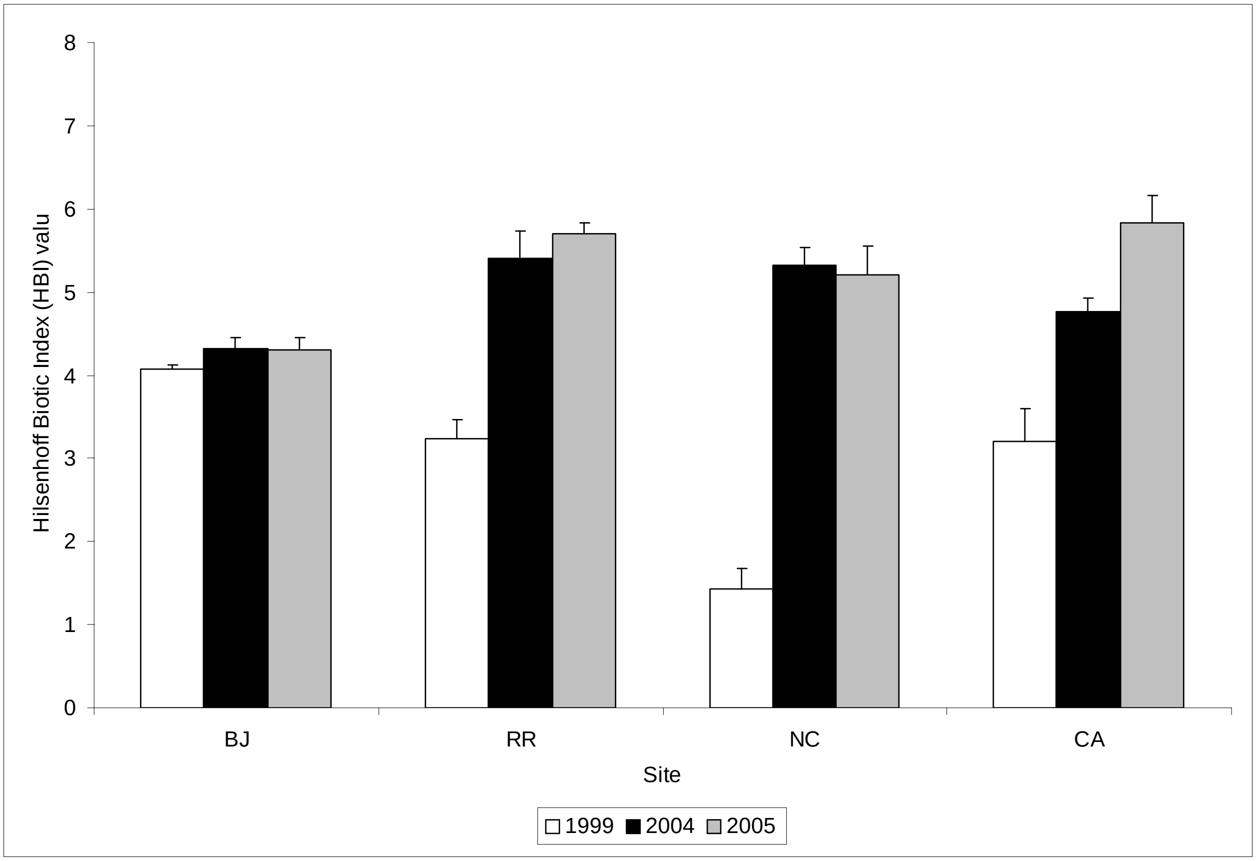

FIGURE 5.17. HILSENHOFF BIOTIC INDEX (HBI) VALUES FROM EACH SITE IN 1999, 2004, AND 2005.

TABLE 5.3. 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.

was never been channelized. While the NC site had never been channelized, it is not free from historic and current impacts. When upstream reaches were channelized, silt, sand, and fine gravel often deposited in this area because it had a wider channel than the remainder of the river. The deposition of large amounts of sediment made for a very dynamic channel. Additionally, construction activities during restoration efforts probably introduced fine sediments into the NC site.

However, since the site has never been channelized, it is the closest to a "control" site that exists in the project area, even though it has had other anthropogenic disturbances.

After the 2004 collections, it appeared that CA recovered extremely well from the construction activities associated with channel restoration (Olsen 2005). 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). The current study found that macroinvertebrate density at CA was similar to or higher than other sites and historical collections in the first post-project collection in May 2004. By September 2004, taxa richness and EPT taxa richness at CA were similar to or higher than other sites and historical collections. Furthermore, the macroinvertebrate community at CA was nearly identical to that of NC by September 2004. The 2005 collections showed that the macroinvertebrate community at CA had maintained or increased both its density and diversity during the 12-18 months following completions of restoration-related construction activities.

Despite the fact that BJ and RR underwent restoration similar to CA, the 2004 results showed that the macroinvertebrate communities at BJ and RR were different than the macroinvertebrate communities seen at CA and NC (Olsen 2005). The data collected in 2005 provided additional evidence of the distinction between BJ and RR vs. NC and CA. With the quick recovery seen at the CA site, it would be expected that the BJ site and RR site would also have recovered with benthic communities similar to the NC site, if that site was representative of desired river conditions. Instead, taxa richness found at NC and CA was higher than at RR, and even more so at BJ.

Grafe (2002) indicated that median taxa richness for "minimally impacted" rivers in Idaho was 25. Average taxa richness values at NC and CA in autumn 2005 exceeded this median value. In addition, taxa richness estimates from D-frame kick nets at these two sites were near or above this value during nearly all of the collections. Conversely, average taxa richness from Hess samples at the BJ and RR sites never reached the median value of 25 listed by Grafe (2002), and taxa richness in at least two of the collections fell outside the range expected for minimally impacted sites. Taxa richness from qualitative kick net samples at BJ and RR fell below the median value of 25 in three of the four collections.

Average EPT taxa richness was variable between collection times at all sites, but was lower than the range expected for minimally impacted rivers in Idaho (Grafe 2002). Richness of EPT taxa in qualitative kick net samples fell below the expected range at all sites. However, EPT taxa richness in qualitative kick net samples at NC and CA was higher than at BJ and RR. Both EPT taxa richness and taxa richness are expected to decrease in response to disturbance (Barbour et al. 1999, Grafe 2002).

Examining composition of the communities at the three sites revealed more differences between the two groups of sites. Midges, worms, and the disturbance-tolerant mayfly *Baetis tricaudatus* are dominant taxa at all of the sites. However, the upstream sites, BJ and RR, have higher densities of the pollution-intolerant *Ephemerella inermis/infrequens* and the caddisfly genus Brachycentrus sp., while the communities at NC and CA have higher densities of the moderately tolerant riffle beetle *Optioservus* sp. and the moderately tolerant caddisfly *Hydropsyche* sp. In addition to a change toward more tolerant taxa in the downstream sites, there is also a shift 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 increased abundance is also a sign of increased primary production, potentially resulting from nutrient enrichment at the downstream sites. The two downstream sites also had an increased 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* could indicate an increased amount of fine particulates in transport at the downstream site. This fits well with the higher amount of fine sediment transport noted at the two downstream sites (Chapter 4). Average HBI values are higher at all sites downstream from BJ, and HBI values have shown a significant increase over historical samples at all sites except for BJ. Increased HBI values are also an indication of increased organic enrichment or some other disturbance. Therefore, one explanation for the different communities seen at the BJ and RR over NC and CA is that a nutrient enrichment source exists downstream from BJ.

The high macroinvertebrate densities found in the Middle Provo River, particularly downstream from BJ, are another indicator of 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. In 1999 average densities ranged from 8,000 to 27,000 organisms per square meter.

Some caution must be used when comparing macroinvertebrate densities between samples collected in 1999 and samples collected in 2004 and 2005, because differences in lab methods may have influenced the results (G. Lester, EcoAnalysts, personal communication). Subsampling protocols and the use of different collection methods can influence density and diversity of macroinvertebrates found in samples (Vinson and Hawkins 1996, Ostermiller and Hawkins 2004). It is possible that the sorting and identification methods of EcoAnalysts may have been different enough from other laboratories to affect the observed results. EcoAnalysts has found that when they have processed samples in the middle of existing monitoring programs, substantial increases in the number of organisms have been observed (G. Lester, EcoAnalysts, personal communication). Regardless of these differences, macroinvertebrate densities are fairly high in both the recent and historical samples.

The increase in the number of trout seen throughout the restoration reach (Hepworth et al. 2004) may be another indication that the area may be undergoing mild to moderate enrichment. The decline in the condition of sport fish in the restoration area is lingering concern in the middle Provo River. Since 1997 fish surveys on the middle Provo River by the UDWR have shown an increase in the density and biomass of trout in the restored area, but a decline in the condition factor

(Hepworth et al. 2004). One potential reason for this would be a decline in food resources associated with construction activities or benthic community changes related to the restored channel. However, the surveys completed for this study have shown that macroinvertebrate density rebounds quickly after construction activities are completed, and it appears that macroinvertebrate density has remained high. Additionally, macroinvertebrate density in samples from 2004 and 2005 was significantly higher than from samples collected in 1999, indicating 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. Finally, studies that have shown food limitation for trout in other rivers occurs at invertebrate densities that are orders of magnitude lower than those observed in the Provo River (Cada et al. 1987, Newcomb et al. 2001). Therefore, food availability does not appear to be a limiting factor to the trout fishery in the middle Provo River.

Other current environmental conditions may be limiting trout growth. Newcomb et al. (2001) and Orth et al. (2004) found that in addition to any problems caused by the reduced forage base, trout condition was also heavily impacted by the dam operations 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 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.

Increased organic enrichment provides one possible explanation for the differences in HBI value and community composition at the two downstream sites, NC and CA, vs. the two upstream sites, BJ and RR. In addition to changes in HBI value and community structure, one would expect to see lower diversity and increased macroinvertebrate density, particularly within the most dominant taxa, at the sites impacted by organic enrichment. Conversely, with the exception of the spring 2004 collection at CA, sampling results showed an increased taxa richness at NC and CA during all collections. 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. Serious impacts from organic enrichment should increase the percent of the community contained in the dominant taxa.

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

While many studies have indicated a more diverse macroinvertebrate community with coarser substrates, some studies have also shown that substrate heterogeneity 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, which may result in a more diverse invertebrate community (Angradi 1996, Angradi 1999). Workers have noticed more habitat types at NC when conducting composite kick net samples. 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 increased abundance of certain more lentic taxa, such as the mayfly *Tricorythodes* sp., and snails (Gastropoda) at this site and at CA.

The increased disturbance from a more mobile bed could also contribute to increased macroinvertebrate diversity. 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 (2004) 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 more mobile bed at NC and CA is more easily disturbed by flow changes, possibly allowing for 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 nutrient, 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 sites (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 results of a variety of factors working synergistically. The fact remains that the communities at all sites except BJ have changed appreciably since the samples collected in 1999. The greatest changes have occurred at the downstream sites of NC and CA. The most obvious alteration in the middle Provo River during that time period has been the ongoing channel restoration efforts. Results of substrate, sediment transport, and channel geometry monitoring indicate that the greatest changes are occurring at the NC site and the CA site 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.

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 and 2005. However, the restored BJ site has shown little change since 1999, while the two most downstream sites, NC and CA, have shown considerable change. While the NC site may have been impacted by upstream restoration activities, the change seen at this never-channelized site, combined with the lack of change seen at the restored BJ site, indicate that factors other than the restoration may be at play. The different communities seen at the RR and BJ sites may be the result of the channel coarsening observed during the substrate and sediment transport studies conducted in 2004 and 2005. Macroinvertebrate metrics also indicate that nutrient enrichment may be partially responsible for the changes in the macroinvertebrate community observed at NC and CA. Nutrient enrichment could also explain the increase in macroinvertebrate density seen in 2004 and 2005 vs. 1999. The macroinvertebrate densities indicate that food limitation is not the cause for the reduced condition factors seen in the brown trout fishery. However, the change in the fish community may be symptomatic of the other changes in river operation and function, which also appear to be influencing the benthic community. Finally, benthic 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). Data collected in 2005 supported the information presented from the first year of post-project monitoring (Olsen 2005). Continued macroinvertebrate monitoring should further elucidate how the channel restoration and other factors related to channel process may be influencing the biological community of the middle Provo River.

6.0 SUMMARY AND RECOMMENDATIONS

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

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

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

6.1 SUMMARY OF RESULTS

The 2005 monitoring results show that the upper reaches of the middle Provo River (approximately 5 miles below Jordanelle Dam) have remained relatively static over the past 2 years. The channel cross sections and substrate sizes have not changed at the BJ and RR sites except for some minor amounts of channel incision and slight coarsening of gravel patches. The lower reaches of the middle Provo River (approximately 5-12 miles below Jordanelle Dam) have been much more dynamic, with some major shifts in thalweg locations and significant redistribution (both scour and fill) of bed materials. Active meander migration was evident at both downstream sites. Many of the post-construction fines measured on the bed at the CA site in 2004 were transported out of the reach. The bed material particle size distribution at the CA site became coarser, similar to the upstream reaches; however, there seemed to be more scour than fill between 2004 and 2005 with an overall lowering of the thalweg elevation within the CA site, most notably at cross sections 1 and 5. Next year's surveys will determine if there is a trend of incision at this site or if the bed lowering was simply associated with a removal of post-construction fines and/or the amount of error associated with rod placement on the bed.

The relatively high-magnitude, long-duration peak flows in 2005 produced above-average sediment loads compared to previously monitored years; however, the pattern of severe sediment supply limitations below Jordanelle Dam were magnified by the higher flows. With the high flows, the disparity in daily transport rates and annual loads enlarged between the reaches immediately below Jordanelle Dam and reaches below the never-channelized reach (above the MID site). The bed material being transported out of the never-channelized reach was deposited in the reach below the MID site. Currently, bedload transport rates return to "normal" within 2.5 miles of the MID bridge, upstream of the CA site.

There has been a positive response in the density and diversity of macroinvertebrates between samples collected in 1999 and samples collected in 2004 and 2005. However, the restored BJ site has shown little change since 1999, while the two most downstream sites, NC and CA, have shown considerable change. While the NC site may have been impacted by upstream restoration activities, the change seen at this site, combined with the lack of change seen at the restored BJ site, indicate that factors other than the restoration may be at play, including water temperature, sediment supplies, nonpoint source pollution, etc.

The different benthic communities seen at the RR and BJ sites may be the result of channel coarsening observed during the substrate and sediment transport studies conducted in 2004 and 2005. Macroinvertebrate metrics also indicate that nutrient enrichment may be partially responsible for the changes in the macroinvertebrate community observed at NC and CA. Nutrient enrichment could also explain the increase in macroinvertebrate density seen in 2004 and 2005 vs. 1999. The macroinvertebrate densities indicate that food limitation does not appear to be the cause for the reduced condition factors seen in the brown trout fishery. However, the change in the fish community may be symptomatic of the other changes in river operation and function, which also appear to be influencing the benthic community.

6.2 ADAPTIVE MANAGEMENT RECOMMENDATIONS

The objective of replenishing coarse-grained sediments (bedload) below Jordanelle Dam is to restore natural fluvial processes, such as channel dynamics, meander migration, bar/floodplain development, and periodically creating recruitment areas for cottonwood and other riparian vegetation in the upper reaches of the middle Provo River. Adding coarse-grained sediments will help eliminate the disequilibrium in incoming and outgoing bedloads below a major dam. To this end, restoration of these fluvial processes is instrumental in meeting the goals and objectives of the PRRP.

Recommendations detailed in the 2004 monitoring report for replenishing bedload supplies below Jordanelle Dam continue to be validated with the 2005 monitoring data. The quantity and size distribution of the replenishing supplies can be adjusted annually early in the spring (before snowmelt) depending on runoff forecasts. A model should be included in the 2006 monitoring report, which determines the appropriate quantity of material within specified size categories to be supplied on an annual basis.

Initially, gravel bars should be rebuilt between Jordanelle Dam and River Road where access is available. Second, a permanent "gravel slope" should be built at a convenient location downstream of the dam and facilities where loads of coarse-grained sediments can be supplied to the river on an annual basis. This gravel slope should be designed to allow the moving water to entrain the coarse-grained particles, and it should be designed so that it is easy to determine the quantity of material actually entrained each year. Periodic measurements of the BJ and RR monitoring sites will show when and how much of the replenishing supplies are retained in the upper reaches of the middle Provo River. Bedload and suspended sediment sampling should be continued to help determine the downstream affects of the replenishing sediment supplies below Jordanelle. It is anticipated that the replenishing sediment supplies will affect transport at the WB and RR bridges, but have an unmeasurable effect at the MID and CA bridges because the lower monitoring sites are much less supply limited.

A more natural amount of gravel in the middle Provo River is necessary to maintain a healthy population of benthic organisms as described in Chapter 5. Benthic 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). Continued macroinvertebrate monitoring should further elucidate how the channel restoration and other factors related to channel process may be influencing the biological community of the middle Provo River.

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