SIXTH WATER AND DIAMOND FORK CREEKS
2006 MONITORING REPORT

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

SUBMITTED TO:
Utah Reclamation Mitigation and Conservation Commission
230 South 500 East Suite 230
Salt Lake City, Utah 84102

COVER PHOTOS

Top Left: Sixth Water Creek.

Bottom: Confluence of Sixth Water Creek (right) and Diamond Fork Creek (left) during high flow. Notice the turbid water coming from upper Diamond Fork Creek during high flow.

Top Right: Lower Diamond Fork Creek.

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1.0 INTRODUCTION

Diamond Fork Creek and its tributary, Sixth Water Creek, are part of the Spanish Fork River Watershed (Figure 1.1). Between 1916 and 2004, these two streams conveyed water diverted from Strawberry Reservoir in the Uinta Basin to the Wasatch Front. This trans-basin diversion increased flows in Diamond Fork Creek and Sixth Water Creek, and caused severe impacts to the stream channels and aquatic ecosystem. Currently, the Diamond Fork System of the Bonneville Unit, completed in 2004, delivers the imported water directly into Diamond Fork Creek just upstream from its confluence with Spanish Fork River (Figure 1.2). Water deliveries from Strawberry Reservoir, with the exception of releases for minimum instream flows, can now completely bypass Sixth Water Creek and Diamond Fork Creek. Opportunities for managing water deliveries into the two streams for ecological restoration objectives may now exist.

The Utah Reclamation Mitigation and Conservation Commission (Mitigation Commission) initiated a long-term monitoring project, in conjunction with State and Federal agencies, in order to assess existing geomorphic and ecologic conditions, monitor stream channel response to the altered flow regime, and address aquatic and riparian habitat restoration objectives. This report describes the long-term monitoring project and documents the results of the first 2 years of monitoring for the initial 3-year program.

The report is organized by topic, starting with an overall introduction and project description. The introduction is followed by chapters describing the monitoring methods and results in the following order: Chapter 2 (Cross-section and Longitudinal Profile Surveys), Chapter 3 (Substrate), Chapter 4 (Sediment Transport), and Chapter 5 (Benthic Macroinvertebrates). Chapter 2 details the survey methods used to complete cross-section and longitudinal profile surveys of specific study sites and discusses the results of the 2005 and 2006 surveys. Chapter 3 discusses methods used to monitor the size distribution of bed materials and the results of these monitoring efforts for 2005 and 2006. Chapter 4 describes monitoring methods, results, and load calculations for both bedload and suspended sediment transport at numerous locations in Diamond Fork Creek and Sixth Water Creek. Chapter 4 also includes a discussion of these results and implications understood after 2 years of monitoring. Chapter 5 discusses the methods and results of benthic macroinvertebrate sampling generally throughout the study area and above and below the sulfur-impacted reach in Diamond Fork Creek above Three Forks. The report concludes with Chapter 6, which is a discussion of results and includes recommendations for the next monitoring session along with possible long-term management implications.

1.1 WATERSHED DESCRIPTION

The Diamond Fork Creek Watershed (Figure 1.1) covers over 150 square miles and is the largest headwater tributary of the Spanish Fork River. Streams in the upper watershed are generally high-gradient and confined between steep side-slopes or within canyons. The lower reaches of Diamond Fork Creek are flatter and much less confined within a relatively wide alluvial valley (Plate 1.1).

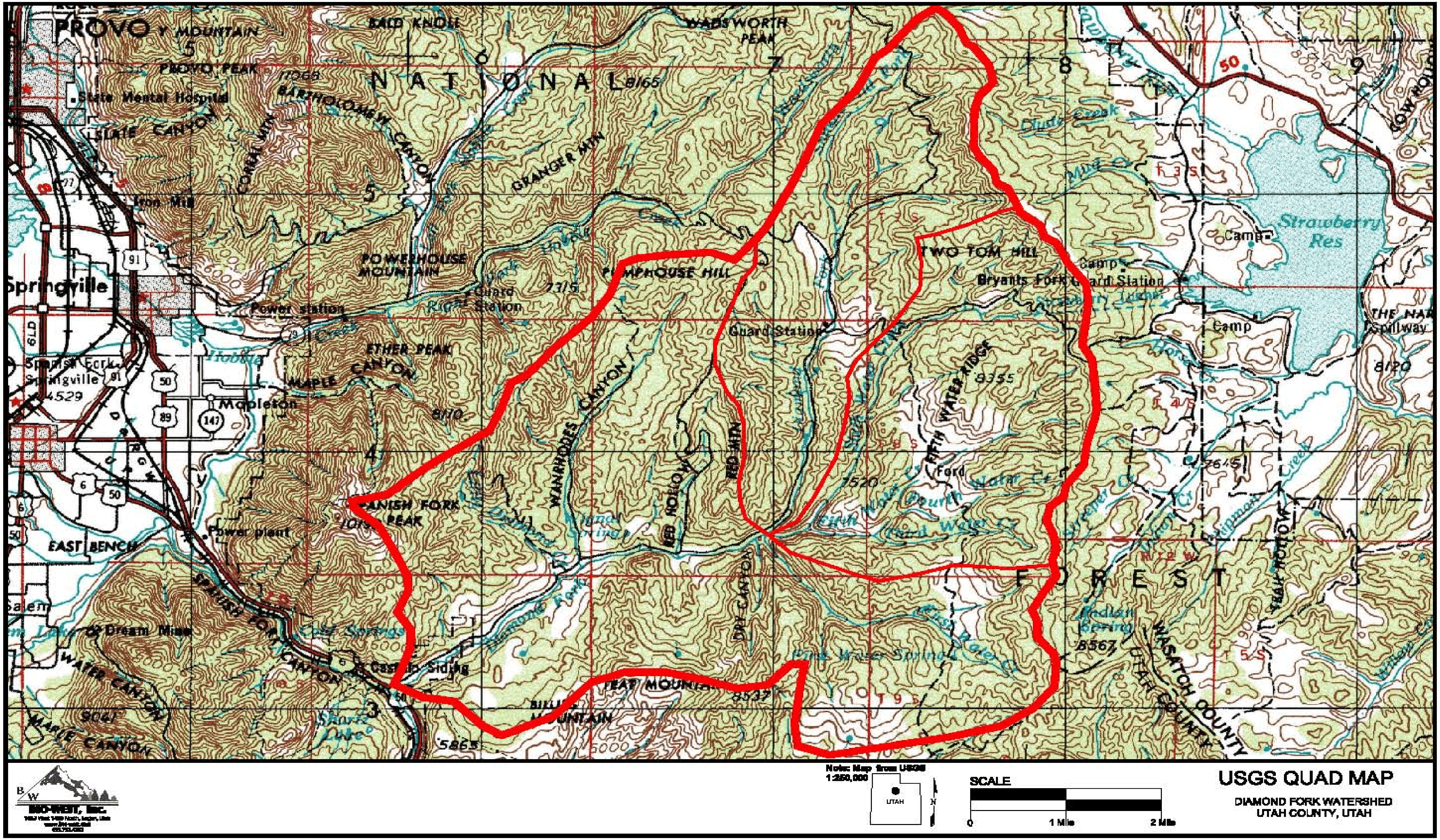


Figure 1.1. General location of the Diamond Fork Watershed.

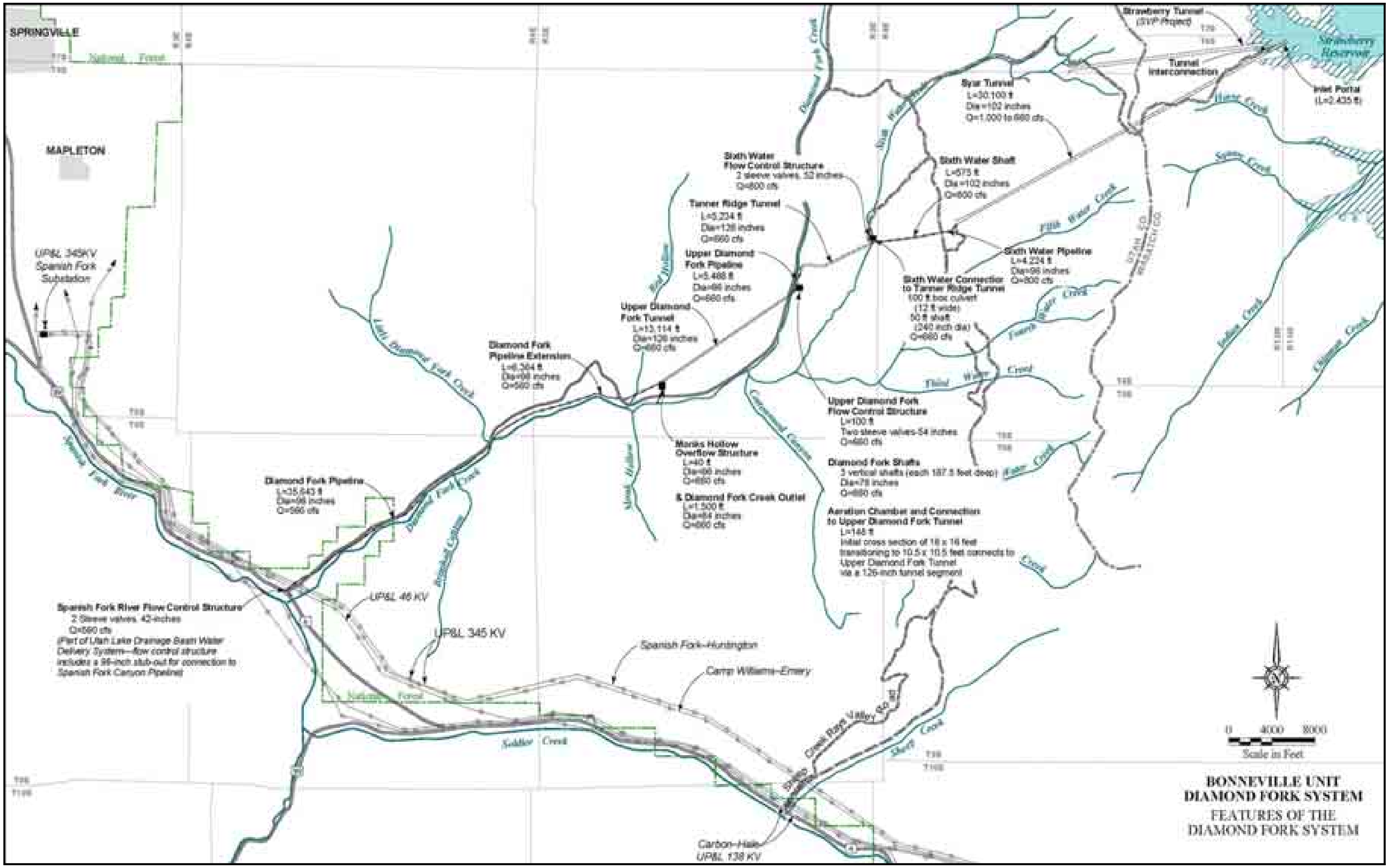


Figure 1.2. The Diamond Fork System, comprised of a series of tunnels and pipelines, delivers water from Strawberry Reservoir to the Spanish Fork River and avoids placing flows directly into Sixth Water Creek and Diamond Fork Creek. Strawberry Tunnel was replaced by Syar Tunnel, but it is still used to convey instream flows to Sixth Water Creek (map provided by the Central Utah Watery Conservancy District [CUWCD]).

Plate 1.1. Channel gradient and floodplain widths are extremely varied between the upper watershed (Sixth Water Creek below Syar Tunnel, top) and lower reaches of Diamond Fork Creek (bottom).

Historically the watershed has been used for agriculture, timber harvesting, livestock grazing, and recreation. Only small portions of the watershed are still used for agriculture and grazing. Some of the watershed is part of the Uinta National Forest and managed by U.S. Forest Service. Recently, the Diamond Fork Watershed has become a popular recreation area because of its many recreational uses including both motorized and non-motorized activities. Numerous improved and unimproved roads exist to allow access to most parts of the watershed. Watershed conditions vary from pristine to highly degraded. The degraded areas of the watershed exhibit "above natural" erosion rates and exacerbate siltation problems in the watershed's streams (Plate 1.2).

Diamond Fork Creek and Sixth Water Creek were used as early as 1916 to divert water to the Spanish Fork River from Strawberry Reservoir through Strawberry Tunnel in order to support irrigation needs in the lower watershed area and Utah County (Mitigation Commission 2000). These streams carried a significant amount of imported water during the irrigation season, thereby creating artificially high flows for an extended duration; causing significant changes in the sediment-transport regime; and affecting channel dimensions, pattern, profile, and its interaction with the floodplain. These morphological impacts to the channel and floodplain have in turn affected the type and extent of riparian and wetland vegetation, water quality, and aquatic communities.

1.2 BACKGROUND HISTORY OF THE COLORADO RIVER STORAGE PROJECT ACT (CRSP), CENTRAL UTAH PROJECT (CUP), AND CENTRAL UTAH PROJECT COMPLETION ACT (CUPCA)

The Diamond Fork System is a series of tunnels and pipelines that transport water from Strawberry Reservoir in the Colorado River Basin to Spanish Fork River in the Bonneville Basin. This system is a part of the Bonneville Unit of the Central Utah Project (CUP), which develops a portion of the water from the Upper Colorado River system allocated to Utah under interstate compacts. The CUP was authorized by Congress in 1956 through the Colorado River Storage Project Act (CRSP) of 1956 (43 U.S.C. Sec 620 et seq.). The Bonneville Unit is the largest unit of the CUP (USBOR 2005). This system of reservoirs, aqueducts, pipelines, pumping plants, and conveyance facilities enables trans-basin water diversion to occur between the Colorado River Basin (Uinta Mountains) and the Bonneville Basin. The Central Utah Water Conservation District (CUWCD) manages this water, which is allocated to municipal and industrial uses, irrigation, and instream flows for areas in Utah. Other systems in the Bonneville Unit include the Starvation Collection System, the Strawberry Aqueduct and Collection System (SACS), the Municipal and Industrial System, and the Utah Lake Drainage Basin Water Delivery System (ULS).

Before the present-day Diamond Fork System was completed, imported water went directly into the headwaters of Sixth Water Creek via Strawberry Tunnel. The Strawberry Valley Project, completed by the U.S. Bureau of Reclamation, pre-dates the CUP by several decades. Strawberry Tunnel transported water from Strawberry Reservoir into the headwaters of Sixth Water Creek, down Diamond Fork Creek and Spanish Fork River. In 1990 the Syar Tunnel was constructed as a CUP feature to replace Strawberry Tunnel. By 1996 water from Syar Tunnel flowed through the

Plate 1.2 Roads, unstable slopes, and other nonpoint sources of pollution have been observed to increase sedimentation problems from stormwater runoff at many locations throughout the Diamond Fork Watershed.

Sixth Water Aqueduct and entered Sixth Water Creek 6 miles farther downstream than it had when Strawberry Tunnel was the primary flow conveyance. Strawberry Tunnel is now used to convey minimum instream flows to the head of Sixth Water Creek (USBOR 2005).

In 1992 the U.S. Congress enacted the Central Utah Project Completion Act (CUPCA) (Title II through VI of Public Law 102-575, as amended), which authorized further construction to complete the Bonneville Unit of the CUP that was started in 1966. The CUPCA also provided the authorization to plan and construct several modifications to the original design of the Bonneville Unit. This legislation also established a minimum instream flow requirement. Currently, this requirement is 25 to 32 cubic feet per second (cfs) for Sixth Water Creek and 60 to 80 cfs for Diamond Fork Creek.

Under CUPCA in 1996, construction began on the Diamond Fork Pipeline, also known as Phase 1 of the Diamond Fork System of the CUP. This phase was completed in 1997 (Mitigation Commission 2000). Construction on Phase 2, the Diamond Fork Tunnel Alternative, was started in 2000 and completed in 2004. The Diamond Fork Tunnel Alternative is a pipeline and tunnel system that carries water from Syar Tunnel to the Diamond Fork Pipeline. The Diamond Fork Pipeline and Diamond Fork Tunnel provide the operational capability to remove most of the flows imported from Strawberry Reservoir to Sixth Water Creek and Diamond Fork Creek, except for minimum instream flows, during most years.

The CUPCA also established the Mitigation Commission, a Federal agency responsible for mitigating impacts from construction of the Bonneville Unit on fish, wildlife, and related recreation resources. Congress also established standards for the Mitigation Commission to follow when coordinating and implementing plans for mitigation projects. The overall mitigation commitments concerning Sixth Water Creek and Diamond Fork Creek are monitoring Ute ladies'-tresses (*Spiranthes diluvialis*) populations, riparian vegetation, leatherside chub (*Gila copei*) populations, water quality and stream channel responses to altered flow regimes following completion of the Diamond Fork System; supporting the June Sucker (*Chasmistes liorus*) Recovery Program, and planning and implementing restoration measures to the Sixth Water and Diamond Fork ecosystems.

1.3 IMPACTS TO THE DIAMOND FORK SYSTEM

Prior to completion of the Diamond Fork System, trans-basin imports from Strawberry Reservoir increased flow in Sixth Water Creek and Diamond Fork Creek, particularly in the summer growing season during periods of high irrigation demand (Figure 1.3). These artificially high flows caused channel widening and incision, especially in the upper reaches of Sixth Water Creek, in order to accommodate the higher and longer-duration peak flows. The channel also widened and braided in the lower reaches of Diamond Fork Creek in order to accommodate increased sediment loads. The changes in stream geomorphology and flow regime resulted in "severely limited fish production, loss of soils, loss of riparian and wetland habitat, and reduced recreation experiences" (Mitigation Commission 2005).

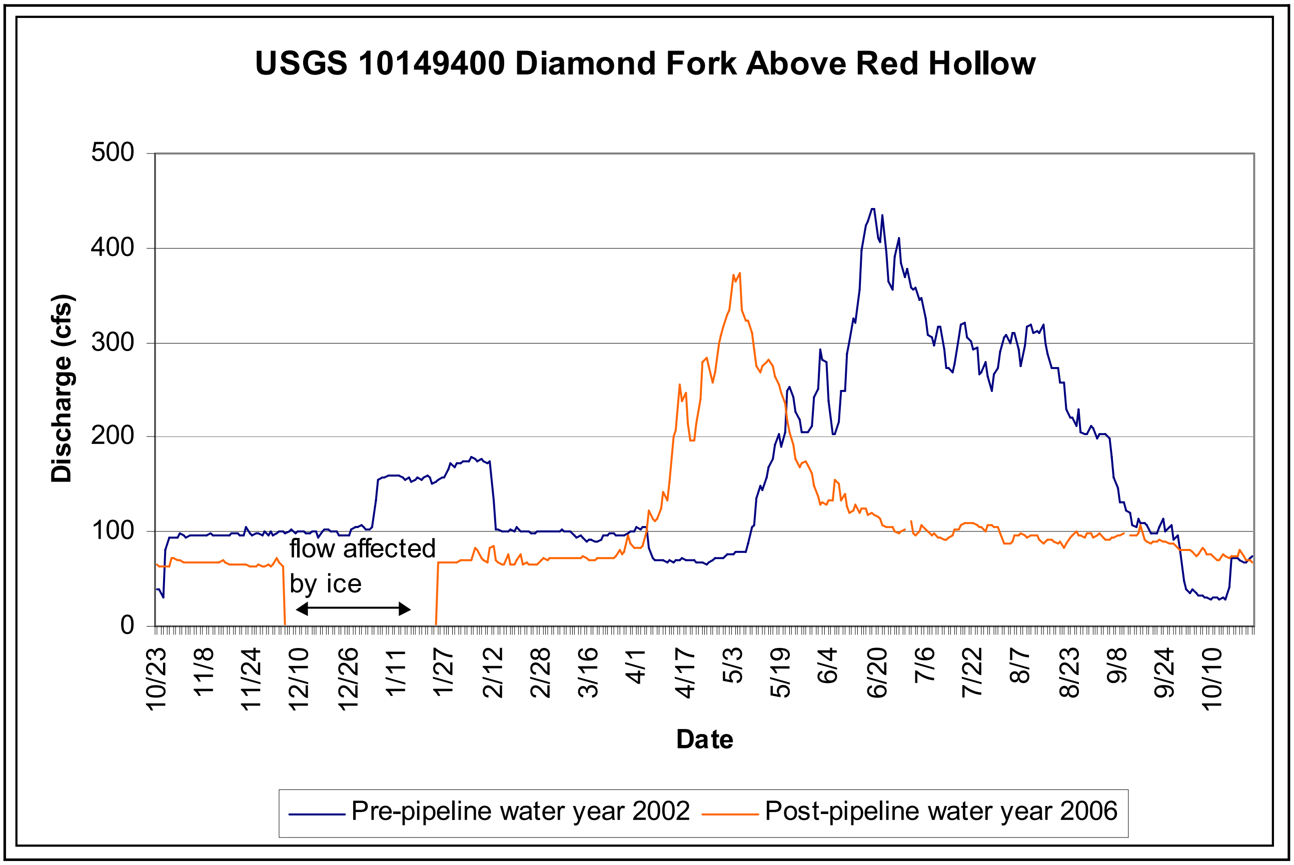


Figure 1.3. Flow before and after pipeline construction in Upper Diamond Fork Creek. (Source: USGS NWIS real-time data.)

Before it was used to transport water from Strawberry Reservoir, Diamond Fork Creek was most likely a single-thread, meandering channel with minor backwaters and an active floodplain estimated to be about 200- to 300-feet wide (Mitigation Commission 2000) from its mouth to Brimhall Canyon. Runoff was largely controlled by spring snowmelt, with peak flow occurring in mid May. Flows would return to baseflow by late June with periodic, short-term increases in flow caused by storms. Gage station data show annual peak flows before 1915 at 200 cfs near Red Hollow and 250 cfs near Brimhall Canyon (Mitigation Commission 2000).

Using the streams to convey imported water resulted in changes in magnitude, duration, and timing of peak flows, which in turn caused major changes to the geomorphology and adjacent riparian areas in both Sixth Water and Diamond Fork Creeks. From 1915 until 2004, when imported water was taken out of the streams, the annual hydrographs of Sixth Water Creek and Diamond Fork Creek were primarily controlled by the releases from Strawberry Reservoir, not natural runoff. Peak flows were approximately 450 cfs sustained for the duration of irrigation season, which lasted approximately 140 days (Mitigation Commission 2000). In Sixth Water Creek bank erosion occurred, and the channel incised an average of 12 to 15 feet. Compared with 1939 conditions, parts of Diamond Fork Creek have become much wider, straighter, and steeper, particularly in the lower 3 miles (Mitigation Commission 2000). Diamond Fork Creek has incised an average of 2 to 4 feet where the channel is confined. In areas where the valley is wide, the channel has become braided in response to higher sediment loads and increased flows (Mitigation Commission 2000).

Removal of most of the riparian forest in the early 1900s for agriculture compounded the impacts of increased flow on the channel and riparian areas. Rapid lateral migration, estimated at 40- to 60-feet per year, further impacted the existing riparian forest. High summer flows altered riparian and wetland communities by increasing the duration and extent of floodplain inundation as well as artificially increasing groundwater elevations.

A plant species of particular concern is the Ute ladies'-tresses, which is listed as threatened by the Federal government. According to recent surveys, populations of this orchid were not documented in the Diamond Fork Watershed until 1992. Currently, the Diamond Fork Watershed populations are thought to contain about 95 percent of all individuals known to occur along the Wasatch Front. The species grows in moist areas, particularly near springs and perennial streams. The plants occur primarily within the 2- to 10-year floodplain and seem to be adapted to areas disturbed by channel migration or other sources of disturbance in the floodplain. Much of current habitat for the Ute ladies'-tresses in the Diamond Fork Watershed seems to have developed in areas where lateral stream migration is occurring and willows (*Salix* spp.), cottonwoods (*Populus* spp.), and other types of riparian vegetation have been flooded out. It is possible that impacts from substantially increased flows in Diamond Fork Creek have created conditions that are favorable for Ute ladies'-tresses establishment (Mitigation Commission 2000).

Impacts have also occurred because of Diamond Fork Tunnel Alternative construction activities. Sulfur springs in the watershed were tributary to Diamond Fork Creek prior to tunnel construction. During the construction of Phase 2, an unexpected source of hydrogen sulfide-laden water began flooding the original tunnel. This tunnel was closed and abandoned. A new tunnel with an alternative design route was constructed to complete Phase 2 (CUWCD 2003). The hydrogen sulfide associated with drilling during construction of the original tunnel continues to leak into Diamond Fork Creek upstream of Three Forks, causing some water quality impacts that likely affect fish and benthic macroinvertebrates. Other impacts related to construction of the pipeline have been mitigated with varying amounts of erosion and sediment control, stream restoration, and riparian area restoration.

1.4 ISSUES AND PURPOSE OF STUDY

Mitigation of impacts resulting from the Diamond Fork System is required under CUPCA (1992). The Mitigation Commission has committed to several general areas of mitigation: monitoring Ute ladies'-tresses, riparian vegetation, leatherside chub populations, water quality and stream channel responses to altered flow regimes following completion of the Diamond Fork System, supporting the June Sucker Recovery Program, and planning and implementing restoration measures to the Sixth Water and Diamond Fork ecosystems. These commitments have led the Mitigation Commission to establish a long-term monitoring program to assess the existing geomorphic and ecological conditions and evaluate changes related to altering the flow regime by piping imported water instead of sending it through Sixth Water Creek and Diamond Fork Creek. This report addresses the commitment to assess and evaluate geomorphic and ecological changes in Sixth Water Creek and Diamond Fork Creek as these riverine ecosystems respond to a more natural flow regime.

The need for physical and biological monitoring is threefold:

1. Quantify baseline conditions of the channel affected by altered flow regimes related to transmitting irrigation water deliveries.

2. Acquire adequate data to analyze changes over time in order to set and prioritize restoration efforts and adaptively maintain the riverine and riparian ecosystem in a desirable and functional condition.

3. Use best available scientific knowledge to ensure that the Mitigation Commission meets all commitments to Sixth Water Creek and Diamond Fork Creek as set forth under CUPCA (1992).

The purpose of the work reported herein is to establish and implement a long-term monitoring program that involves periodically measuring channel cross sections, channel longitudinal profiles, areas of inundation, substrate particle-size distribution, sediment loads, and benthic macroinvertebrate assemblages in specific study sites in Sixth Water Creek and Diamond Fork Creek. Monitoring results will assist the Mitigation Commission with establishing and prioritizing restoration efforts and returning Sixth Water Creek and Diamond Fork Creek to desirable conditions with functional ecologic, hydrologic, and geomorphic processes.

1.5 MONITORING PLAN

The study area includes four study sites and six sediment monitoring bridges (Figure 1.4). Three study sites are located in the lower reaches of Diamond Fork Creek, and one study site is located on Sixth Water Creek. Channel monitoring, substrate monitoring, and benthic macroinvertebrate monitoring occurred at all four study sites. Channel monitoring consisted of surveying cross sections and longitudinal profiles at low flow. Substrate monitoring consisted of conducting pebble counts through cross sections and on distinct depositional patches, as well as substrate mapping. Benthic macroinvertebrate sampling was also conducted twice at each study site, once during both the spring and fall. Additional study sites were established for macroinvertebrate sampling above and below the area affected by hydrogen sulfide inputs on Diamond Fork Creek above Three Forks.

The six bridges along Diamond Fork Creek and Sixth Water Creek were chosen for sediment sampling sites. Sediment-load monitoring consisted of taking bedload and suspended-sediment samples from the bridge locations throughout the year; most of the samples were collected during the spring runoff period. Bedload samples were also taken during low flow at each sediment sampling site to determine whether the minimum flows were high enough to maintain transport of coarse sediment.

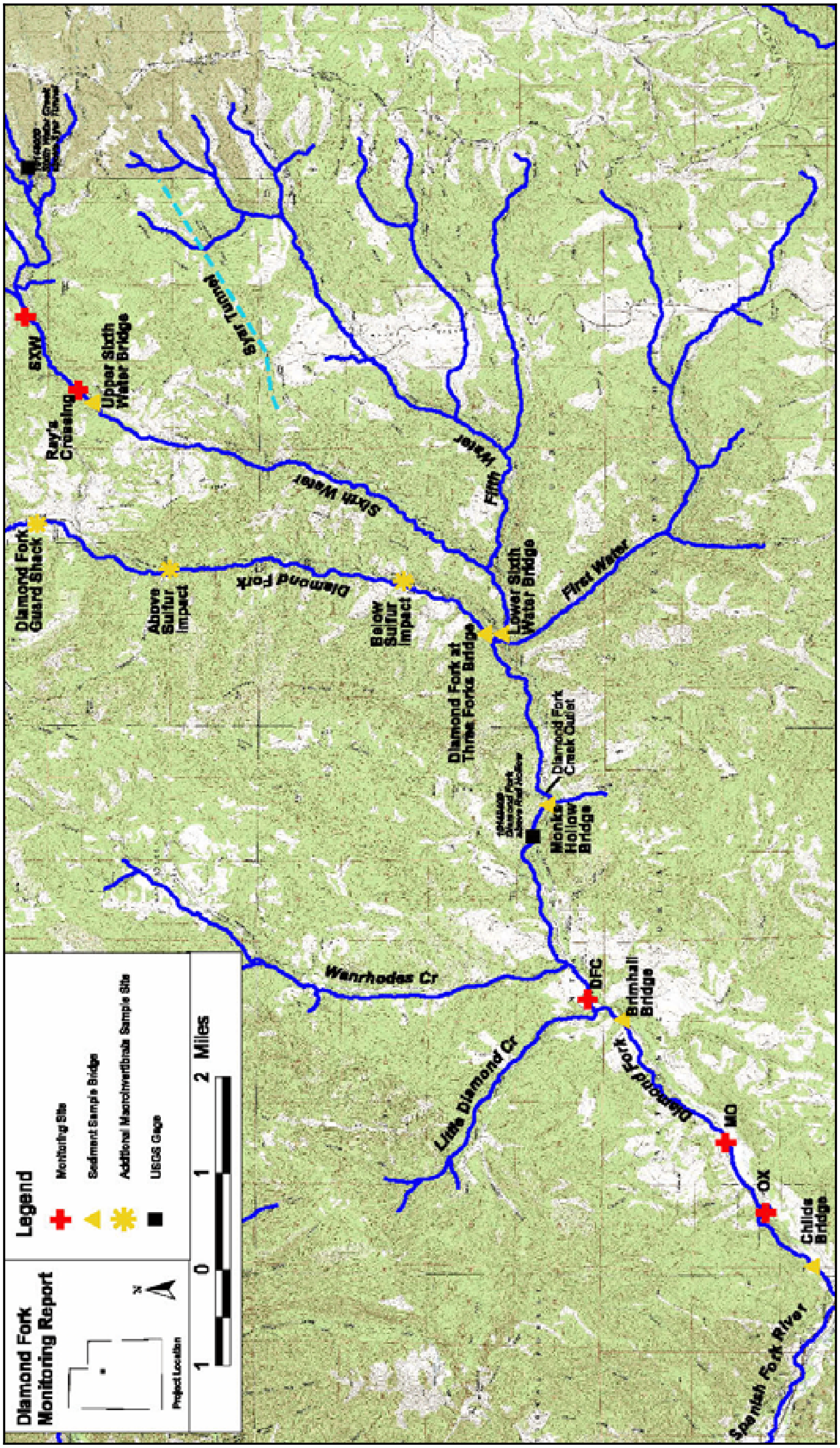


Figure 1.4. Map of the study area showing drainage names and study sites.

2.0 CROSS SECTIONS AND LONGITUDINAL PROFILES

2.1 INTRODUCTION

Initial surveys of the established, permanent transects (cross sections) and longitudinal profile were completed at each of the four study sites in the Diamond Fork Watershed in spring 2005. These surveys were repeated in fall 2006. The 2005 baseline survey data were compared with 2006 survey data to monitor changes in channel geometry, bed complexity, and slope over time. These data may also be used in hydraulic modeling and other analyses that are often the basis for flow recommendations and other adaptive maintenance activities for Diamond Fork and Sixth Water Creeks. Such recommendations and activities will assist the Mitigation Commission and CUWCD with restoring the streams to a desirable condition. Monitoring data will also help the Mitigation Commission meet all other commitments to restore the Diamond Fork Watershed, particularly those concerning Ute ladies'-tresses habitat.

2.2 METHODS

2.2.1 Data Collection

In April 2005 BIO-WEST established permanent transects (cross sections) in each of the four study sites. The four study sites are Sixth Water (SXW) (Figure 2.1), Diamond Fork Campground (DFC) (Figure 2.2), Mother (MO) (Figure 2.3), and Oxbow (OX) (Figure 2.4). The site names Mother and Oxbow are taken from long-standing Ute ladies'-tress monitoring protocols. The SXW and MO sites each contain six transects. The DFC site contains seven transects and the OX site contains eight transects. Transects were also established at the downstream side of each sediment sampling bridge (bridge) (see Figure 1.3). The bridges include Upper Sixth Water (SXW-U), Lower Sixth Water (SXW-L), Diamond Fork at Three Forks (DI), Monks (MK), Brimhall (BR), and Childs (CH). High flows in 2005 washed out the culvert at the Diamond Fork at Three Forks Bridge. Hence a new cross section upstream of the former bridge location was established in November 2006.

Each transect is denoted by two endpoints, one on each side of the stream, which anchored to the ground by rebar. The endpoints mark either the left endpoint (LEP) or right endpoint (REP), corresponding to the side of the stream while facing downstream. The endpoint is also stamped with the study site abbreviation and transect number. Some transects share endpoints; therefore, each transect associated with an endpoint has the transect number stamped onto the cap. For example, the LEP for transects 5, 6, and 7 at the DFC site single caps stamped as "DFC LEP 5, 6, 7." A sub-meter-grade global positioning system (GPS) was used to determine real-world horizontal coordinates in NAD83 data and elevations in NAVD 1988 feet for transect endpoints at the study sites and bridges.

Transect surveys were conducted April 14-20, 2005, using a theodolite (total station), data collector, and prism/rod. In 2006 transects were surveyed in late summer and fall. Sixth Water site transects were surveyed August 8-9, 2006. Transects at the DFC, MO, and OX sites were surveyed November 8-10, 2006. The survey dates were chosen based on accessability and vegetation. The SXW was surveyed earlier because rain and snowfall make the site inaccessible later in the year. The other

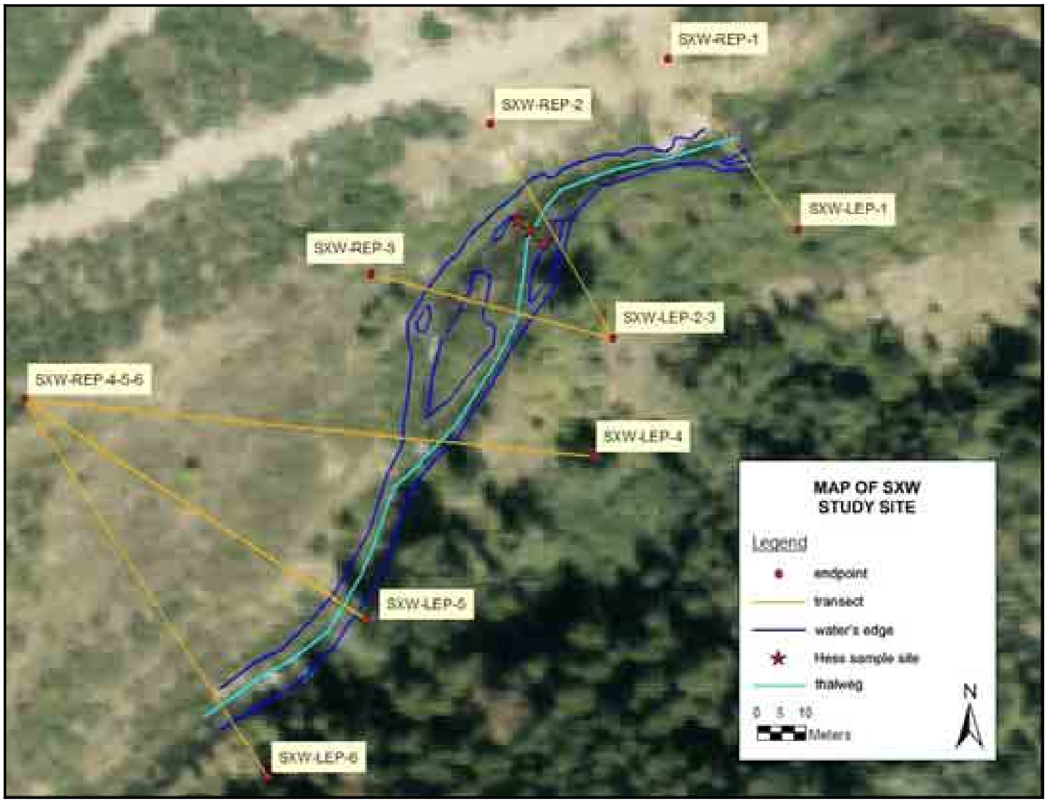


Figure 2.1. Sixth Water (SXW) study site map. Aerial photo from 2006.

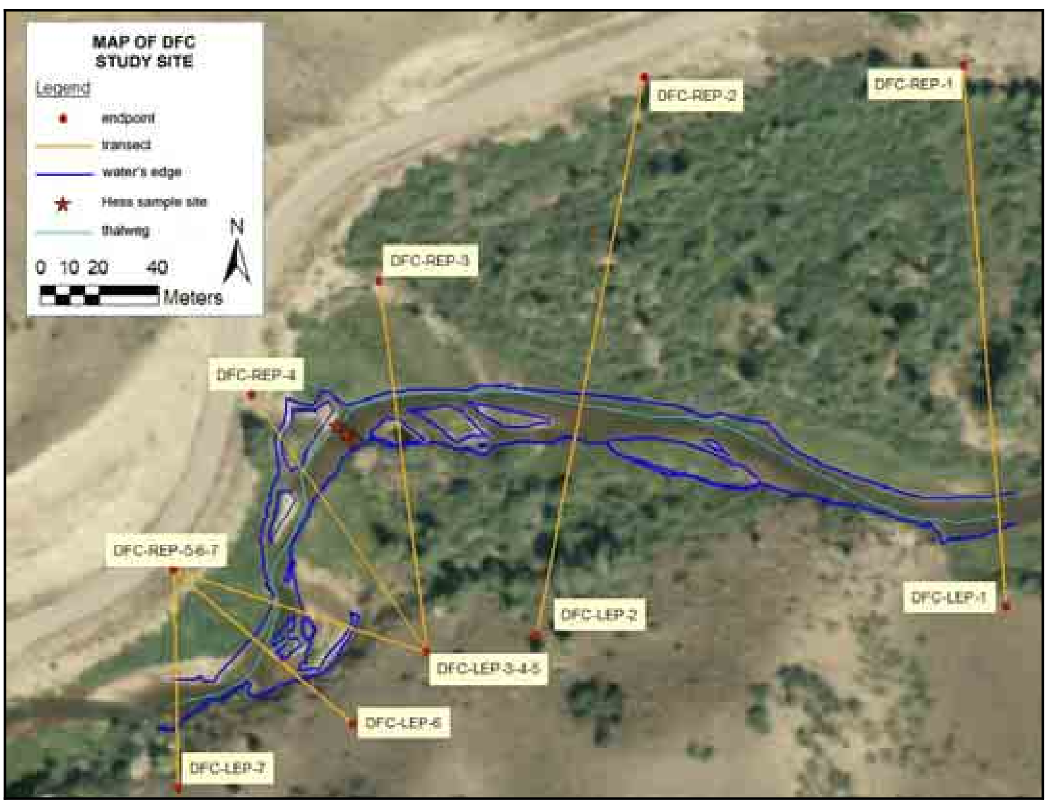


Figure 2.2. Diamond Fork Campground (DFC) study site map. Aerial photo from 2006.

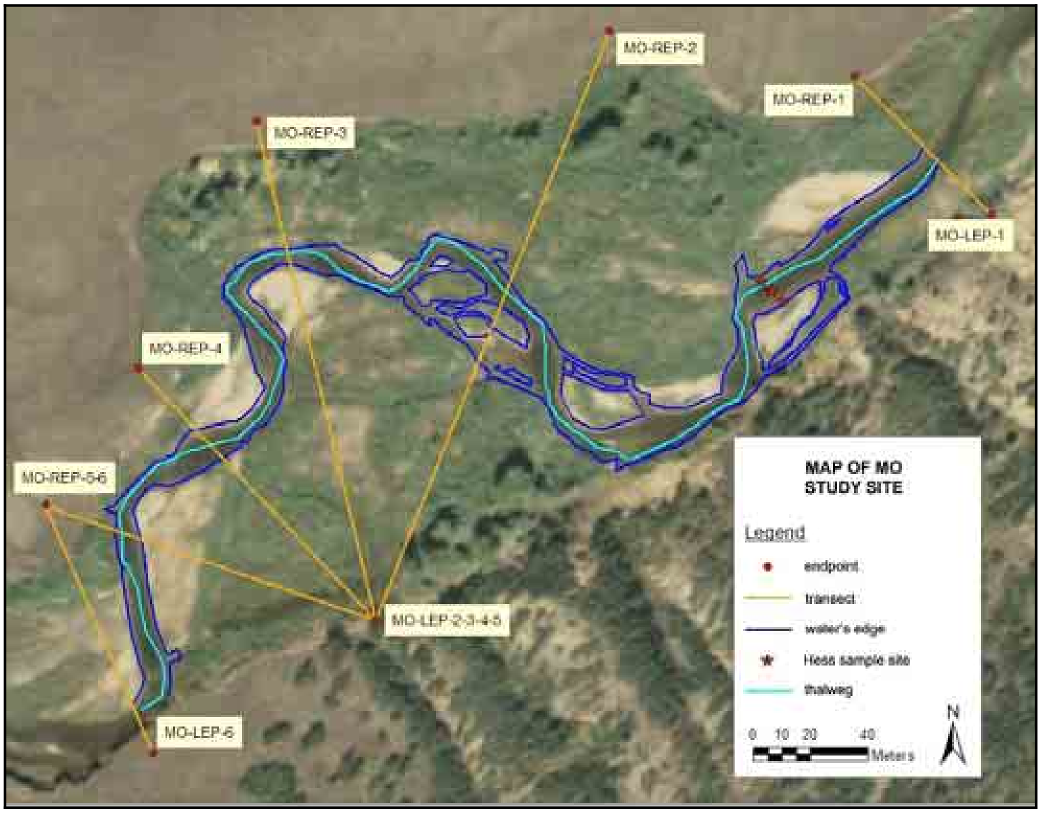


Figure 2.3. Mother (MO) study site map. Aerial photo from 2006.

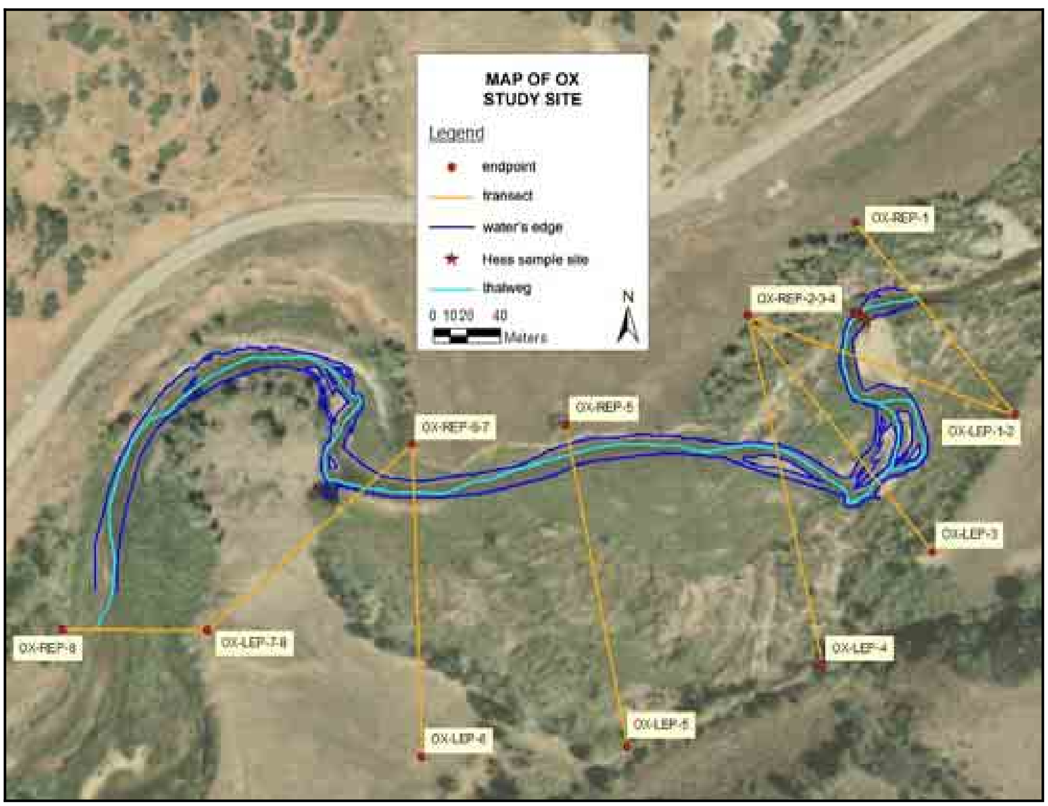


Figure 2.4. Oxbow (OX) study site map. Aerial photo from 2006.

sites were surveyed after vegetation, particularly leaves, had fallen, since dense, leafed-out trees often block the line of site along the transect. Sixth Water site endpoints were resurveyed with a total station in August 2006. The endpoints were tied to one set of GPS coordinates for endpoints that matched most closely with total station survey data. The updated endpoint coordinates for SXW are presented in Table 2.1.

The total station was set up over one endpoint and assigned the real-world coordinates of that endpoint in the datalogger. The corresponding transect endpoint with real-world coordinates was used as the backsight. The survey data have northings, eastings, and elevations relative to the two endpoint caps, thereby placing the subsequent transect survey data in the coordinate system with elevations in NAVD 1988.

To complete a transect, first the backsight endpoint cap was resurveyed with the total station to check for differences between the total station survey coordinates and the GPS coordinates for the endpoint. The rod person then placed the rod at points in a straight line (0 degrees plus or minus 5 minutes) between the two endpoints (Figure 2.5). Surveyed points included major changes in topography, both the left and right edges of water, the edges of backwaters, changes in vegetation, channel features such as bars and islands, presence of large woody debris, and the thalweg (deepest part of the stream at the transect). Four photographs of each transect were also taken to show the REP, LEP, and upstream and downstream views of the transect (Appendix 2.1.A).

In 2005 the longitudinal profile was surveyed concurrently with the transects at SXW and MO during low flow. The sub-meter GPS was used to survey the longitudinal profile and edge of water at low flow for OX and DFC. The total station was used to survey the longitudinal profiles at each site in 2006.

2.3 RESULTS

2.3.1 Endpoint Coordinates

Real-world coordinates for study site transect endpoints are compiled in Table 2.1. Bridge transect endpoint coordinates, including the coordinates for the new Diamond Fork at Three Forks transect, are shown in Table 2.2. Northing and easting values are provided in NAD83 UTM meters. Elevations are in NAVD 1988 feet. Transects corresponding to an endpoint are denoted by number on the endpoint label. As described earlier, some study site transects share endpoints. All transects corresponding to a specific endpoint are stamped on the endcap that marks the transect endpoint.

2.3.2 Cross Sections

Photographs of each cross section are included in Appendix 2.1.A. Cross-section plots are compiled in Appendix 2.2.A. These plots include baseline (2005) cross sections and plots of the 2006 transect data. Future surveys will also be conducted and results compared with data from 2005 and 2006 to determine changes in channel geometry over the study period. However, only distance and elevation data from the 2006 cross-section surveys are provided in Appendix 2.2.B. Since SXW site endpoint coordinates were resurveyed for 2006, the elevation data from 2005 were adjusted to match 2006 endpoint elevations. These adjusted transect data are in Appendix 2.2.C.

Table 2.1. Endpoint coordinates for cross sections in study sites using NAD83 UTM meters.

CROSS-SECTION ENDPOINT [a]	NORTHING (METERS)	EASTING (METERS)	ELEVATION (NAVD88 FEET)
SXW 1 REP	4,445,801.13	476,057.70	6,952.05
SXW 2 REP	4,445,787.82	476,020.79	6,949.62
SXW 3 REP	4,445,756.59	475,995.48	6,916.38
SXW 4-5-6 REP	4,445,731.04	475,922.93	6,928.65
SXW 1 LEP	4,445,764.73	476,084.76	6,926.19
SXW 2-3 LEP	4,445,742.51	476,046.11	6,923.57
SXW 4 LEP	4,445,717.89	476,041.60	6,921.66
SXW 5 LEP	4,445,684.05	475,994.53	6,914.02
SXW 6 LEP	4,445,652.31	475,973.60	6,920.56
DFC 1 REP	4,435,557.77	462,855.08	5,190.97
DFC 2 REP	4,435,553.85	462,746.59	5,194.35
DFC 3 REP	4,435,484.22	462,656.15	5,178.00
DFC 4 REP	4,435,445.24	462,612.84	5,185.31
DFC 5-6-7 REP	4,435,385.24	462,586.02	5,183.52
DFC LEP 1	4,435,372.65	462,869.86	5,197.23
DFC LEP 2	4,435,363.03	462,709.62	5,207.53
DFC 3-4-5 LEP	4,435,357.40	462,672.33	5,206.85
DFC 6 LEP	4,435,332.72	462,647.07	5,206.43
DFC 7 LEP	4,435,310.52	462,587.46	5,203.44
MO 1 REP	4,432,997.96	460,101.28	5,073.03
MO 2 REP	4,433,013.97	460,015.58	5,075.86
MO 3 REP	4,432,982.20	459,892.22	5,069.28
MO 4 REP	4,432,895.62	459,850.80	5,065.26
MO 5-6 REP	4,432,848.00	459,818.58	5,061.64
MO 1 LEP	4,432,949.67	460,149.02	5,081.36
MO 2-3-4-5 LEP	4,432,807.72	459,933.75	5,082.52
MO 6 LEP	4,432,761.33	459,856.05	5,073.54
OX 1 REP	4,432,364.02	458,756.92	5,031.04
OX 2-3-4 REP	4,432,308.61	458,693.33	5,028.13
OX 5 REP	4,432,244.07	458,585.88	5,021.99
OX 6-7 REP	4,432,232.76	458,495.21	5,031.94
OX 8 REP	4,432,123.25	458,288.55	5,007.85
OX 1-2 LEP	4,432,250.13	458,850.94	5,026.19
OX 3 LEP	4,432,169.14	458,802.24	5,024.20
OX 4 LEP	4,432,102.14	458,737.36	5,025.39
OX 5 LEP	4,432,054.02	458,621.93	5,020.37
OX 6 LEP	4,432,047.81	458,500.76	5,019.39
OX 7-8 LEP	4,432,122.37	458,374.45	5,017.11

[a] SXW = Sixth Water, DFC = Diamond Fork Campground, MO = Mother, OX = Oxbow, LEP = left endpoint, and REP = right endpoint.

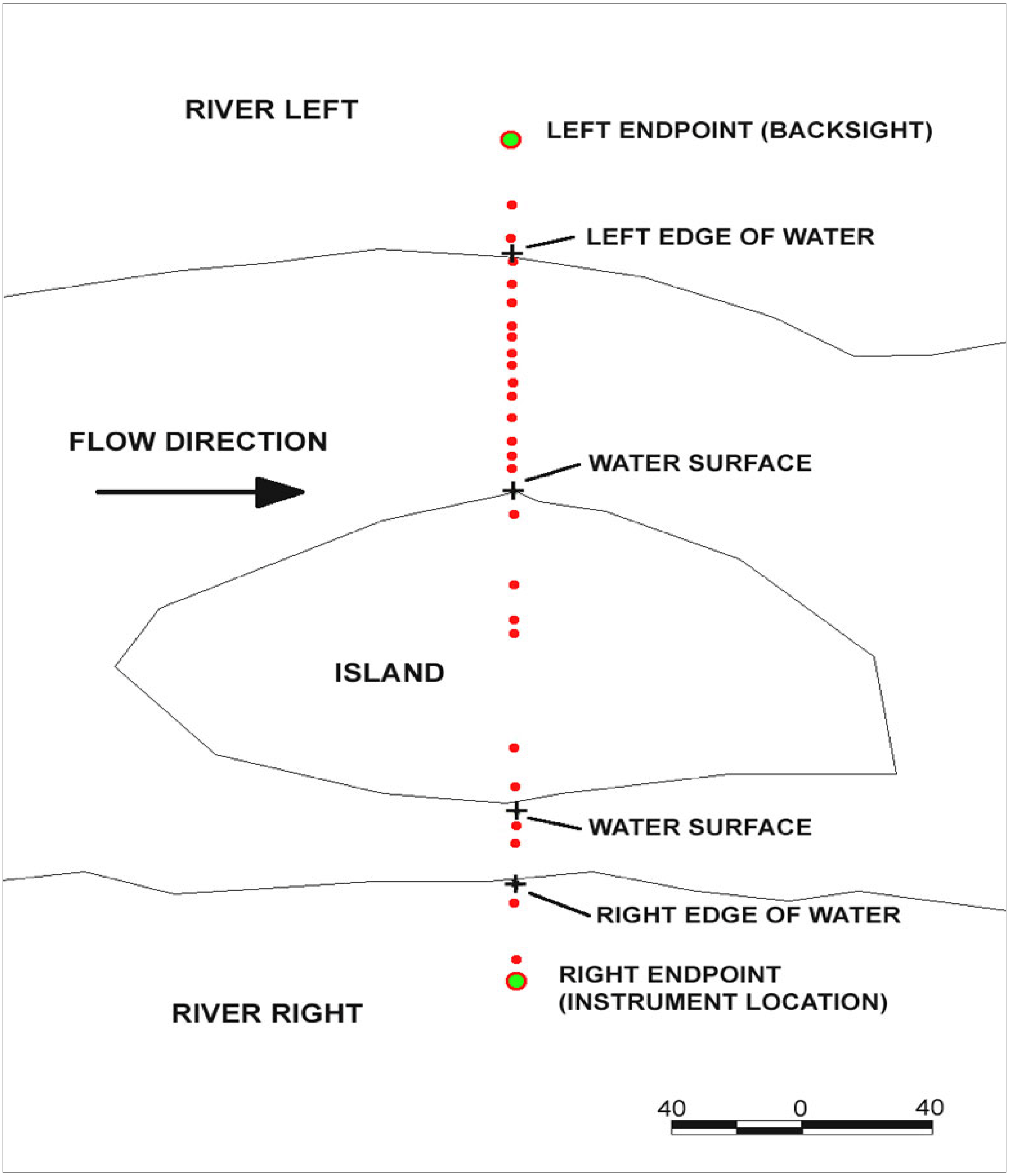


Figure 2.5. Methods for surveying permanent cross sections using a total station. The instrument is set over a permanent endpoint (a labeled aluminum cap on a 3-foot rebar stake) with known coordinates. Survey points are taken along the transect between the endpoints at 20-foot intervals or when the 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.

Table 2.2. Endpoint information for bedload sediment sampling bridge cross sections in NAD83 UTM meters.

BRIDGE ENDPOINT[a]	NORTHING (METERS)	EASTING (METERS)	ELEVATION (NAVD88 FEET)
SXW-U (UPPER) REP	4,444,563.95	474,339.22	6,678.93
SXW-U (UPPER) LEP	4,444,547.85	474,351.87	6,680.31
SXW-L (LOWER) REP	4,437,175.55	469,738.65	5,532.54
SXW-L (LOWER) LEP	4,437,148.74	469,724.09	5,538.27
MK REP	4,436,163.28	466,530.07	5,345.31
MK LEP	4,436,144.34	466,532.04	5,345.20
BR REP	4,434,815.50	462,310.67	5,148.17
BR LEP	4,434,809.78	462,324.34	5,148.63
CH REP	4,431,335.68	457,521.45	4,977.31
CH LEP	4,431,322.12	457,538.52	4,976.35

[a] SXW-U = Upper Sixth Water, SXW-L = Lower Sixth Water, DI = Diamond Fork at Three Forks), MK = Monks, BR = Brimhall, CH = Childs, LEP = left endpoint, and REP = right endpoint.

Plots of changes in the position of the low-flow edge of water from 2005 to 2006 are shown in Figures 2.6, 2.7, 2.8, and 2.9. Thalweg location shifts are shown in Figures 2.10, 2.11, 2.12, and 2.13.

The SXW site cross sections are on Sixth Water Creek between Strawberry Tunnel and Syar Tunnel. This area was formerly used to deliver water from Strawberry Reservoir to Spanish Fork via Strawberry Tunnel. When Syar Tunnel was completed, minimal flow was sent through Strawberry Tunnel. All six transects are in straight-channel riffle areas, which are typical of the reach. Transect SXW3 crosses the toe of an island, and transect SXW6 is in a wider part of the channel compared with upstream transects. Cross-section plots show no change in cross-section shape between the 2005 and 2006 surveys. Some difference in cross-section elevations between 2005 and 2006 in the SXW site may be related to placing the rod next to (versus on top of) large, boulder-sized material in the channel.

The DFC transects are all downstream of Diamond Fork Campground. Transects DFC1 and DFC2 are in a straight, run-type section. Transect DFC3 marks the transition into a meander and island complex. Transect DFC4 is primarily a riffle, with flow split around islands. Transect DFC6 is in a riffle-type section with many small islands and large woody debris. Transect DFC6 contains a deep pool to river left that starts just downstream of transect DFC5. Transect DFC7 crosses an island on river right. Transect DFC7 is farthest downstream and located where the stream channel starts to cut back toward the road.

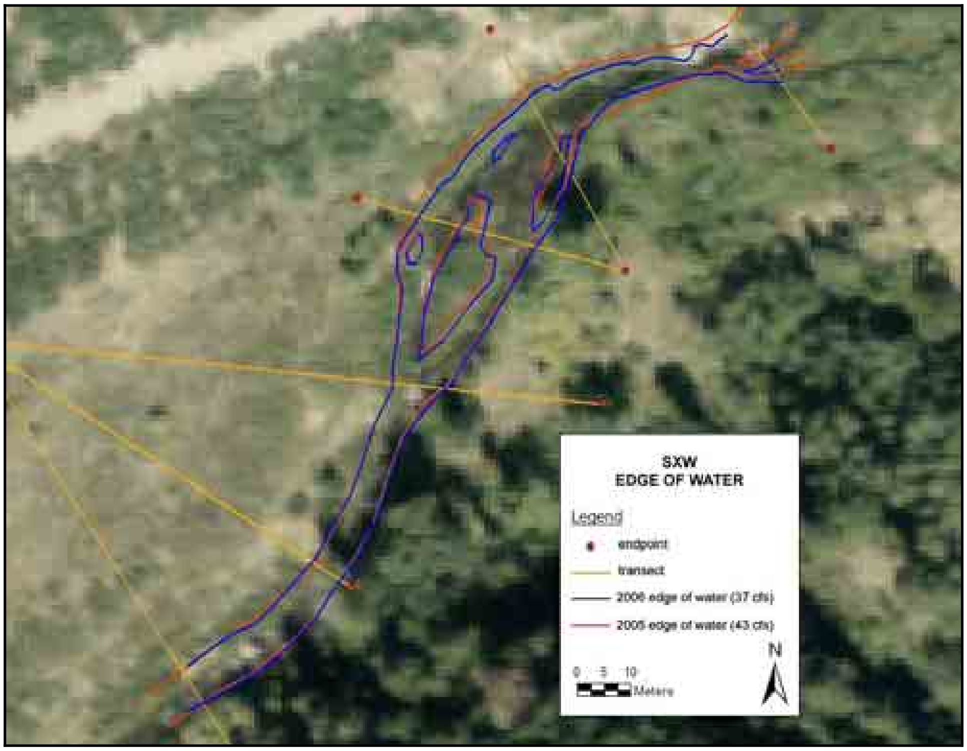


Figure 2.6. Location of the surveyed edge of water at the Sixth Water (SXW) site in 2005 (43 cfs) compared with 2006 (37 cfs). Aerial photograph from 2006.

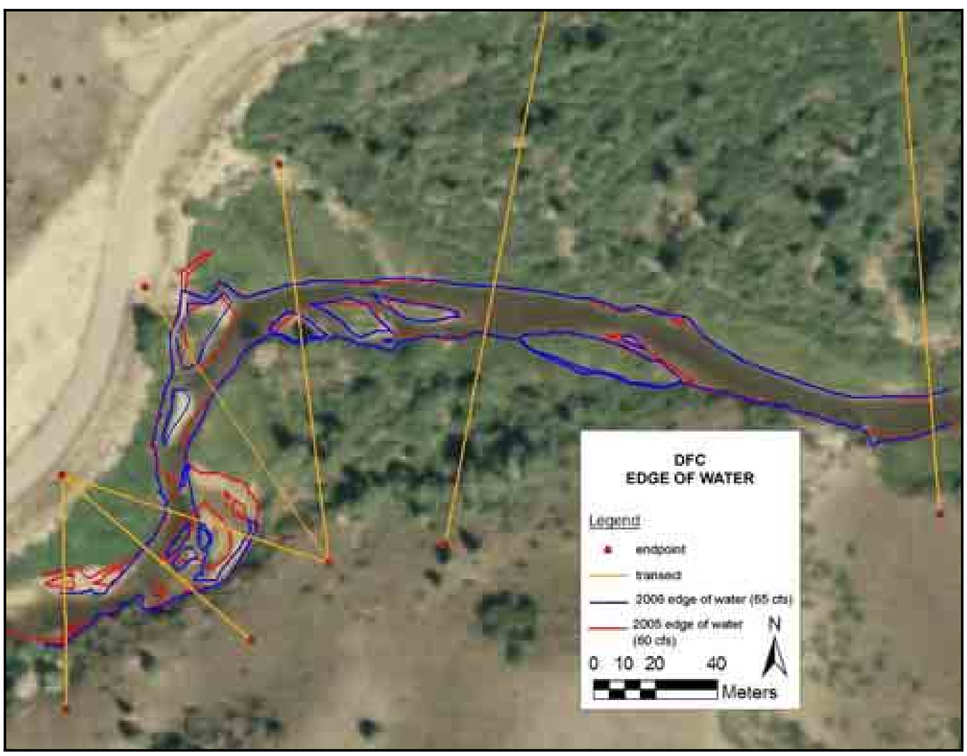


Figure 2.7. Location of the surveyed water edge at the Diamond Fork Campground (DFC) site in 2005 (60 cfs) compared with 2006 (65 cfs). Aerial photograph from 2006.

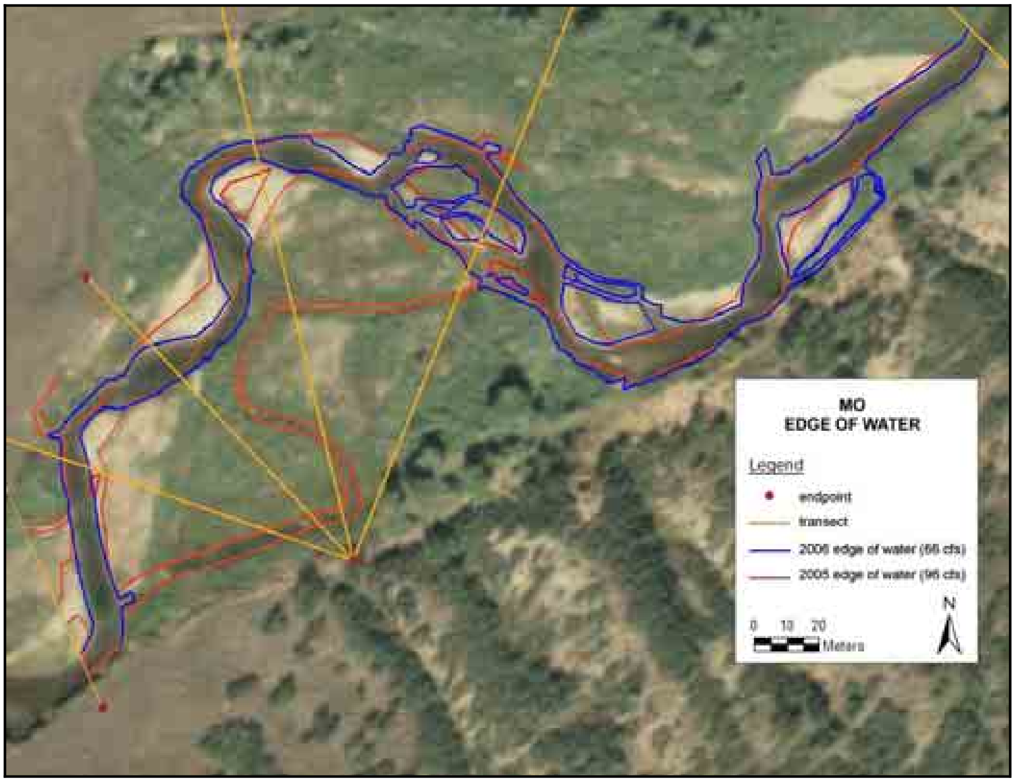


Figure 2.8. Location of the surveyed water edge Mother (MO) site in 2005 (96 cfs) compared with 2006 (66 cfs). Aerial photograph from 2006.

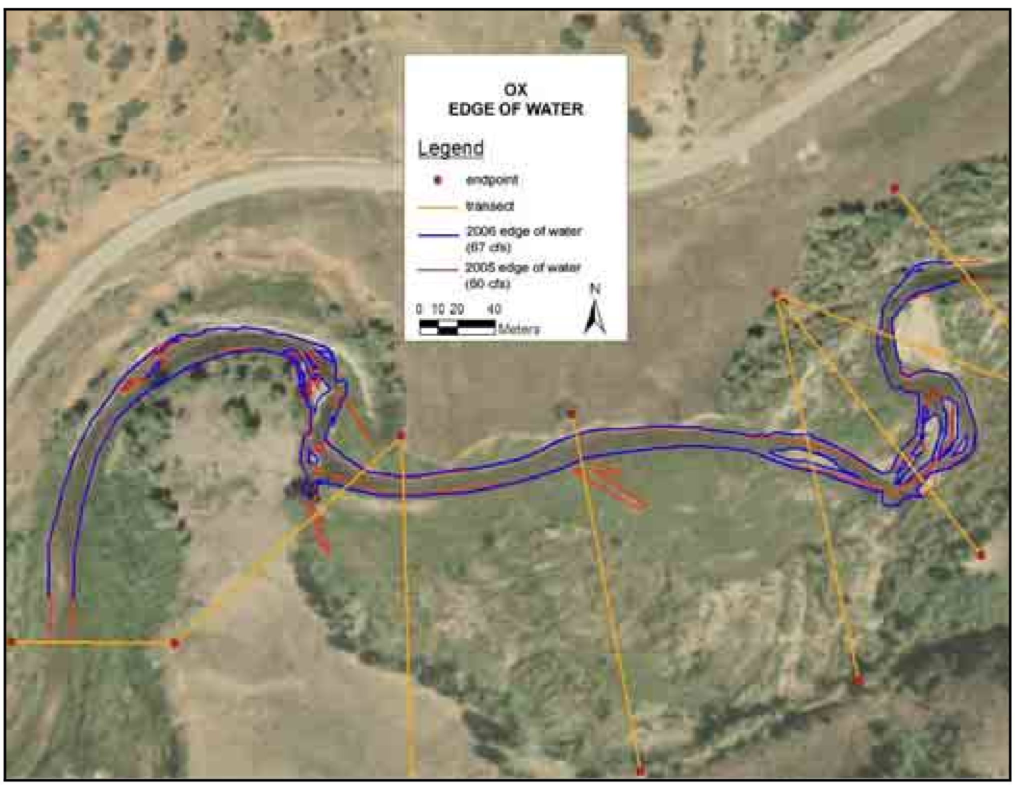


Figure 2.9. Location of the surveyed edge of water at the Oxbow (OX) site in 2005 (60 cfs) compared with 2006 (67 cfs). Aerial photograph from 2006.

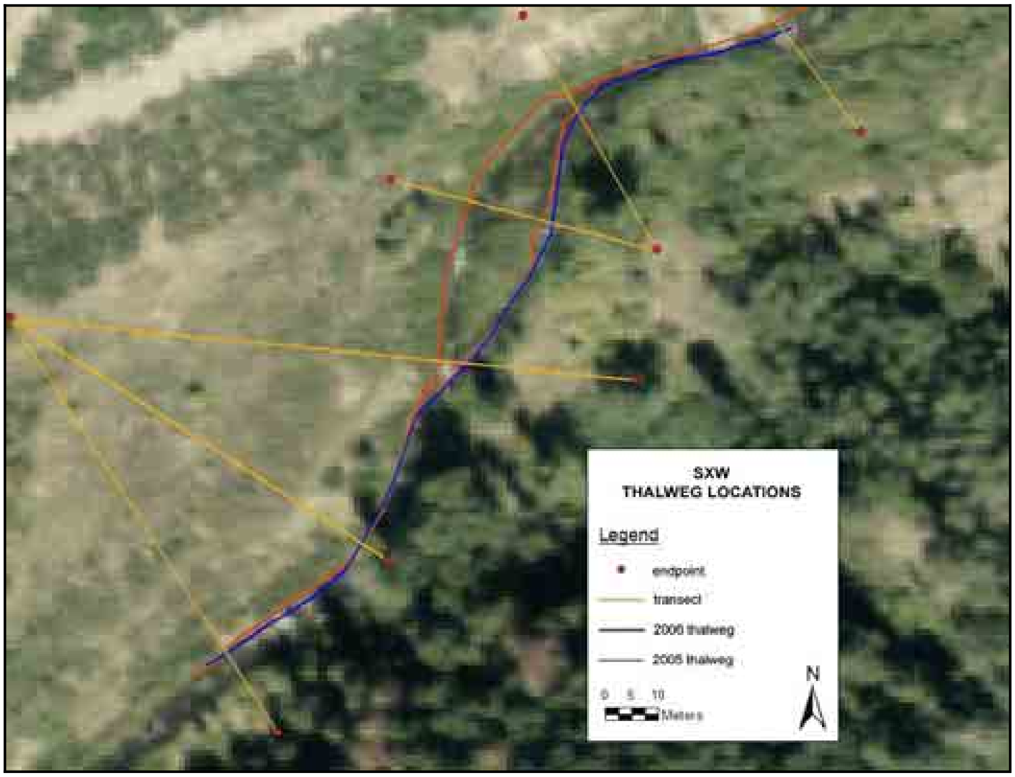


Figure 2.10. Location of the surveyed thalweg at the Sixth Water (SXW) site in 2005 compared with 2006.

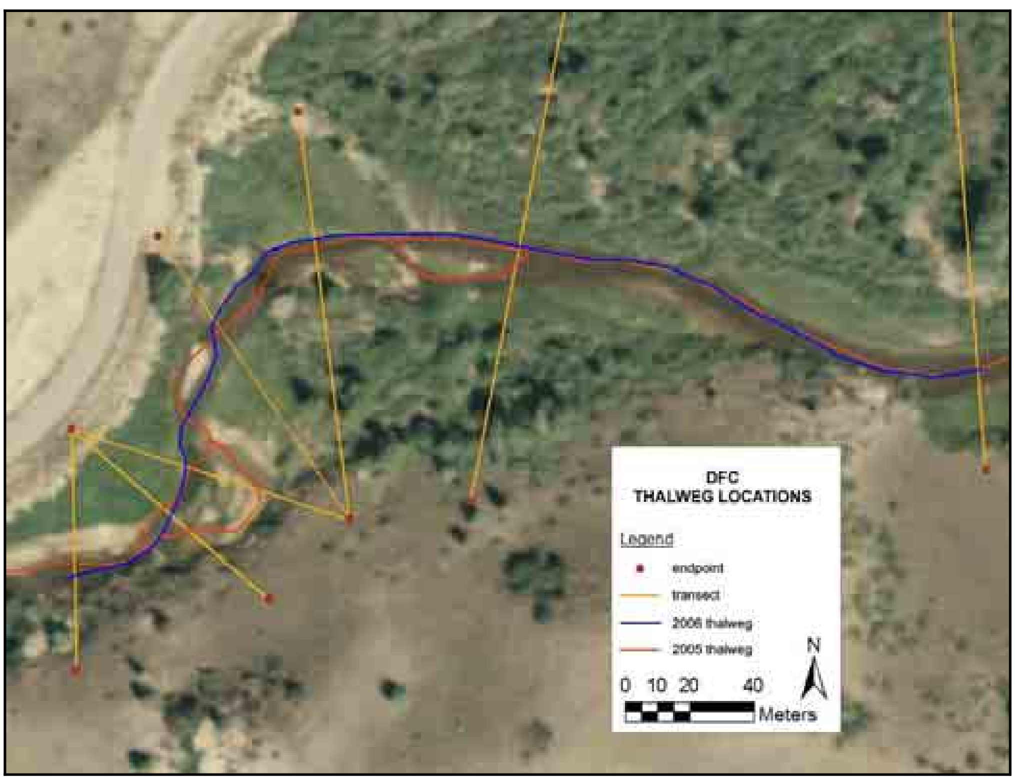


Figure 2.11. Location of the surveyed thalweg at the Diamond Fork Campground (DFC) site in 2005 compared with 2006.

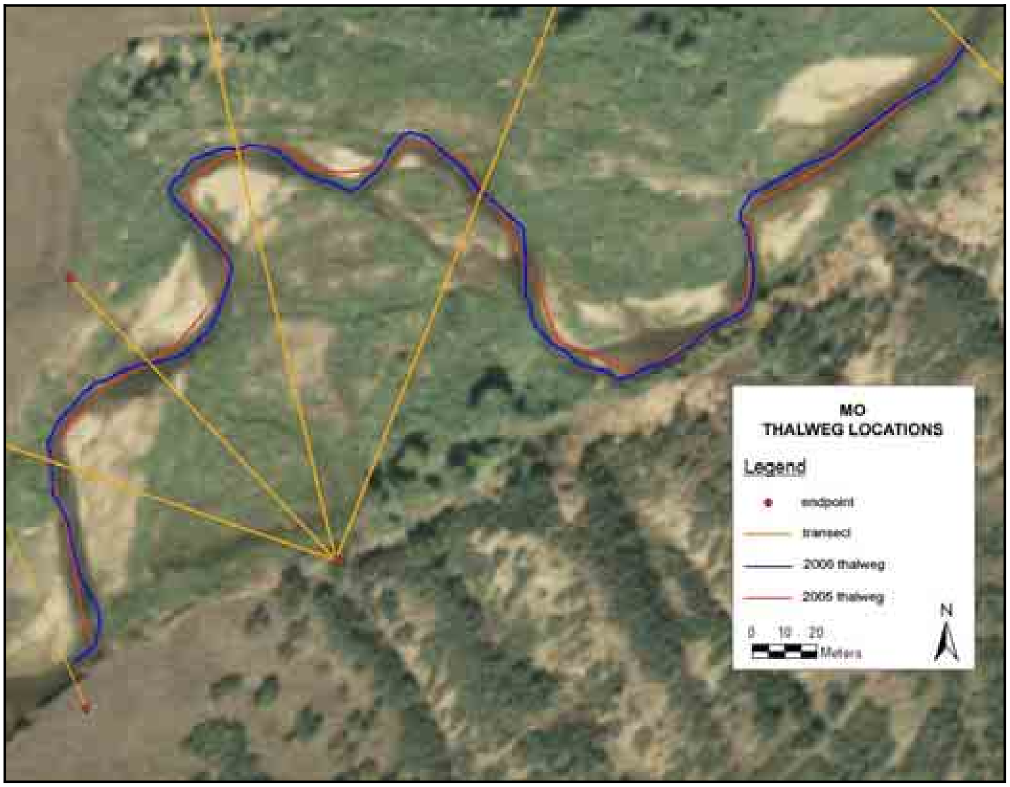


Figure 2.12. Location of the surveyed thalweg at the Mother (MO) site in 2005 compared with 2006.

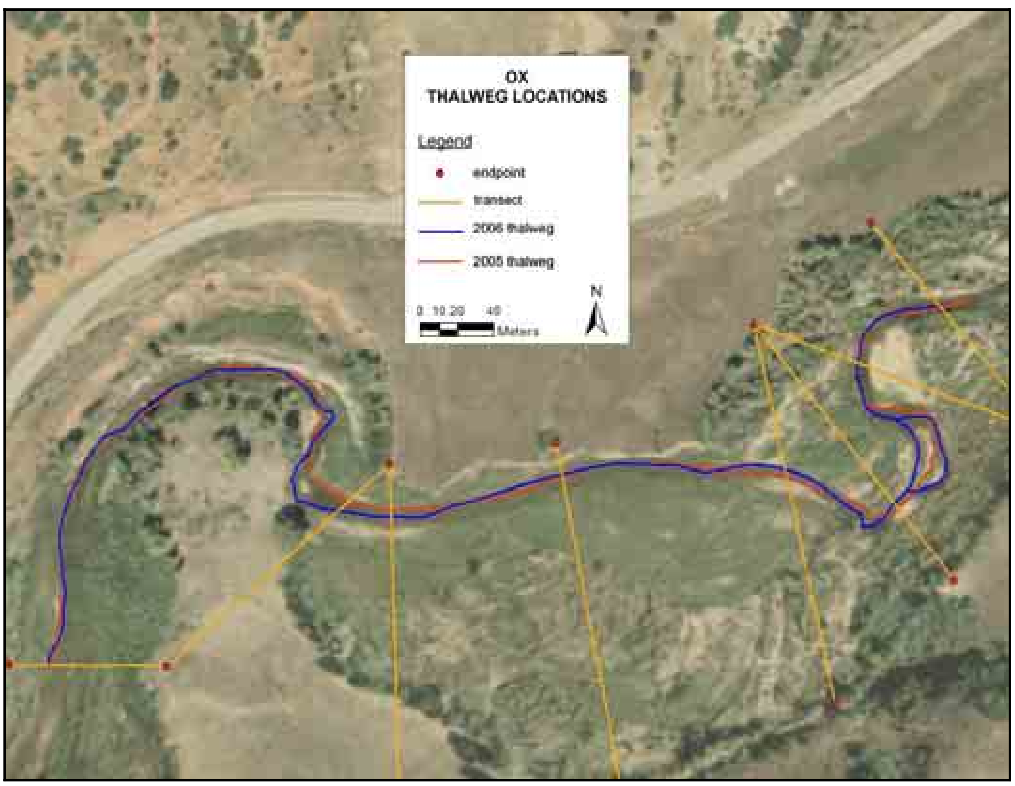


Figure 2.13. Location of the surveyed thalweg at the Oxbow (OX) site in 2005 compared with 2006.

Changes at the DFC site transects are shown in cross-section plots (Appendix 2.2.A). The large change at DFC 1 on the right bank is not an indication that slope failure occurred. This area is a fairly stable hill slope with piles of dead willows at the toe of the slope. This elevation change is most likely a rod height error. Transects DFC 2 and DFC 3 show very little change between the 2005 and 2006 surveys except that the thalweg is slightly higher in the 2006 transect than it was in the 2005 transect. Transects DFC3 and DFC4 indicate more deposition and bar development in the channel between 2005 and 2006. All of these transects are in a relatively straight section of the site.

Cross-section changes between the 2005 and 2006 surveys are more noticeable in transects DFC4 and DFC5. The channel begins to meander in this part of the site. Additionally, the channel narrows and then becomes substantially wider just before transect DFC5. In this wider channel area, the in-stream features—such as bars and location of pools, riffles, and side channels—are more dynamic. Some of these changes might be seen at 150 feet from the LEP in transect DFC5. The transect does show deepening of pools along the outside meander at transect DFC5. These in-stream feature changes may be more apparent in the substrate mapping. Some erosion occurred on the left bank at DFC6, but the rest of the transect did not change between 2005 and 2006. Changes in the plot of the left bank of transect DFC7 could be indicative of bank erosion, but they could also reflect rod placement as indicated by the squareness of the 2006 plot. Aggradation can also be seen in transect DFC7.

The plots of water edge and thalweg changes also reflect the relatively stable nature of the upstream half of the DFC site and the more dynamic nature of the downstream half of the site (Figure 2.7, Figure 2.11). In addition to shifts in the size and shape of islands, the spring floods in 2005 and 2006 eroded a large portion (about 15-feet wide and 25-feet long) of the right bank just upstream of DFC5 (Figure 2.7). Another significant change was the erosion of the gravel bar that was attached to the island spanned by DFC4 in 2005 and the deposition of a new gravel bar downstream between DFC4 and DFC5 (Figure 2.7).

The MO transects are in a geomorphically complex section of Diamond Fork, which contains many small islands and bars. Transect MO1 is in a straight, run-type section. Transects MO2 and MO3 are farther downstream in the meandering section of the study site. These transects cross an island and two side channels. Transects MO4 and MO5 have deep pools on river right and cross the side channel closest to the left bank. Transect MO6 is the farthest downstream cross section and in a riffle section with flow split around an island. This cross section is also downstream of the active side channel crossed by transects MO2-MO5.

Comparing 2005 and 2006 plots of the MO transects shows some change at each transect in the site. Transect MO1 shows approximately 3 feet of erosion on the left bank and aggradation in the channel and floodplain. Transect MO2 shows aggradation of up to 2 vertical feet in the channel. The bed at MO2 in the main channel is higher than in 2005. There may also be some initiation of change in the side channel on the left bank. Since substrate tends to be cobble sized or smaller in this section of the stream, measured elevational differences reflect true channel bed changes, not just the difference between placing the survey rod on top of or in between boulders. At MO3, the thalweg has become deeper by approximately 3 feet, with some deposition occurring mid channel. Transect MO4 shows about 10 feet of erosion at the left bank of the main channel but fairly minimal change across the remainder of the transect. It appears that the side channel along the left-side hill is also filling in. Alternatively, transects MO5 and MO6 each show incision in the main channel. Data plots of MO5 show the area near the right bank eroding slightly and the channel becoming deeper by 2 feet along the right bank. Transect MO6 shows the thalweg becoming deeper by about 1 foot and the channel becoming wider due to erosion of the bar deposit on the right side of the thalweg.

The dynamic nature of the MO site is also reflected in the thalweg and edge of water plots (Figure 2.8, Figure 2.12). In addition to the changes observed at the surveyed transects, shifts also occurred in between transects. The side channel along the right side of the point bar upstream of MO2 became active at low flow, and the side channel to the left of the islands crossed by MO2 now carries more flow than in 2005 (Figure 2.8). Significant bank erosion along the outside of the bends within the lower half of the site also is evident, suggesting that sinuosity may be increasing (Figure 2.8). This tendency toward increased sinuosity is also reflected in the thalweg plots (Figure 2.12).

The OX site is the farthest downstream monitoring site in the watershed and contains eight transects. Transect OX1 is the farthest upstream and crosses a relatively narrow section of the stream at a riffle. Transect OX2 is similar to OX1, except it crosses the stream at a bend. Transect OX3 crosses a mid-channel island that splits flow around the island. This transect is located on a meander bend. Transect OX4 crosses a riffle at the downstream end of the bend. Transect OX5 is located in the middle of a relatively straight section of Diamond Fork. This straight section has a large floodplain area to the south and an eroding terrace to the north. Transect OX5 also crosses a backwater that extends farther into the floodplain. Transect OX6 marks the lower boundary of the straight section and is the start of a large meander bend. Transect OX7 crosses this meander bend just below OX6. The transect cuts across a point bar and part of a backwater that is initiated farther downstream. Transect OX8 is the most downstream cross section. Like OX1, this cross section is in a straight, single channel section of the stream with no major in channel features or backwaters. Because of their length, all transects in the OX site also cover the active, present-day floodplains, as well as large areas of abandoned floodplains that formed as Diamond Fork and Sixth Water began to downcut when these channels were used to transport water.

Transect OX1 did not change between 2005 and 2006. Transect OX2 showed some deepening (1.3 feet) of the thalweg in 2006 and some deposition and bar building. Several changes between 2005 and 2006 are noticeable at OX3. The thalweg has moved to the right, eroding part of the mid-channel island, and the stream has deposited material near the left bank. Some of this deposition may be material from the left bank upstream of transect OX3, which eroded substantially between the 2005 and 2006 surveys (Figure 2.9). Transect OX4 shows the same trend as OX3, with the thalweg migrating toward the right bank and deposition converting what was previously a shallowly inundated gravel bar into a flow-splitting, mid-channel bar (Figures 2.9 and 2.13). Plots of transect OX5 show some deposition in the backwater area to the left of the main channel in 2006. No significant change is shown at transect OX6 between the 2005 and 2006 surveys. Plots water edge and thalweg changes also indicate relatively stable conditions within this straight, central portion of the study site (Figure 2.9, Figure 2.13). Transect OX7 shows the channel becoming shallower. The thalweg on the right side of the channel has moved toward the left (see Figure 2.13) and filled in. The deep part of the channel near the left bank is the thalweg in 2006. The left bank also eroded by about 20 feet at OX7. Significant changes also occurred in the meandering reach below transect OX7 (Figure 2.9, Figure 2.13). Bank erosion occurred at the outsides of bends, suggesting a trend toward increasing sinuosity similar to the MO site. A new gravel bar formed just downstream of transect OX7 and below that the island-bar complex was reshaped between 2005 and 2006 (Figure 2.9). Transect OX8 is another straight section of the site and did not change significantly in 2006.

2.3.3 Longitudinal Profiles

Longitudinal profiles for each study site are included in Appendix 2.3.A. These profiles represent the baseline conditions with which future surveys can be compared in order to identify temporal changes in streambed elevation and slope. Distance and elevation data used in longitudinal profile plots are in Appendix 2.3.B.

Similar to cross-section (or transect) plots, the longitudinal profile plots illustrate the in-channel habitat diversity of the study sites. In 2005 the SXW longitudinal profile shows a straight and steeply sloped channel bed (slope = 3%). The DFC, MO, and OX site longitudinal profiles showed a greater range of features and shallower slopes of 0.9 percent, 0.6 percent, and 0.7 percent, respectively. The 2006 longitudinal profiles showed almost no change in Sixth Water Creek, with the slope remaining at 3 percent. The DFC site also maintained a similar 0.9 percent slope. The lower sites (MO and OX) have slightly different slopes in 2006: The MO site slope is 0.5 percent and the OX site slope is 0.6 percent. Even though there is evidence of aggradation at these two sites, these differences in slope are most likely related to a slightly different survey distance in 2006 compared with 2005, and possibly differences in GPS and total station surveys for the OX study site.

In 2006 the SWX study site is still a steeply sloped section with primarily riffle features. The DFC study site longitudinal profile shows a less-steep gradient. With the more moderate slope, the site has developed primarily riffle- or run-type features in the channel. Some pools, particularly along meander bends, are present. The MO study site shows the most diversity, with pool, riffle, and run habitat types. The OX study site also contains several pools, riffles, and runs. The most notable feature on the OX longitudinal profile is the long, straight portion of the stream constituting a run in the middle to lower part of the OX study site.

2.3.4 Discussion and Summary

The 2005 study site cross sections showed that the study sites span a range of channel types from the relatively simple, single-threaded channel in the SXW site to highly complex cross sections that traverse side channels, backwaters, and/or islands and bars, particularly at MO. Even though the SXW site has an island, it is the least complex of the study sites; the channel is more confined and primarily single threaded in the stream reach. The MO site is the most geomorphically complex site, with a side channel that remains active at all flows and a wide floodplain. The DFC and OX study sites are between the SXW and MO study sites in channel complexity. As expected, the longitudinal profiles show SXW as a steep and fairly straight channel, while the other sites have lower slopes with more channel complexity in the lower study sites.

The 2006 data verify these findings. Comparison of 2005 and 2006 data indicates that some change has occurred in most sites. The SXW site cross sections are essentially the same between 2005 and 2006. The lower three sites show areas of change such as bank erosion, deposition onto surfaces, or change in location or depth of the thalweg. Some channel shifting also occurred.

The 2005 and 2006 data seem to indicate that the lower three sites are active and adjusting, particularly in the meandering sections of the river. These areas show a trend toward increasing sinuosity and evidence of aggradation. Straight sections of the lower three sites, however, are relatively stable. As expected, MO and OX showed the most change at cross sections between the 2 years. However, these results are only indicative of a relatively short period (2 years) after pipeline completion. Given more time, vegetation encroachment and continuing geomorphic processes will also affect the channel. Moreover, many changes occurred over the entire reach and may not have been indicated by the cross sections. These changes may be shown in the substrate maps in Chapter 3.

3.0 CHANNEL SUBSTRATE

3.1 INTRODUCTION

Channel substrate provides habitat for many aquatic species and constitutes spawning areas for some fish species in Diamond Fork Creek. This chapter describes the methods and results of the first two years of monitoring channel substrate in the Diamond Fork study sites and its tributary, Sixth Water Creek. Monitoring substrate determines what substrate is present and what changes in substrate have occurred over time, which is important relative to habitat condition and as an indication of recent geomorphic activity. Monitoring substrate can help determine whether restoration efforts are required to maintain Diamond Fork Creek in a desired condition and the Mitigation Commission is fulfilling its commitments concerning Diamond Fork Creek. The pebble count results are also used as inputs to sediment transport equations as part of bedload modeling efforts (see Chapter 4).

3.2 METHODS

3.2.1 Substrate Mapping

Substrate classifications throughout each monitoring site were hand delineated in the field on plots generated from the topographic surveys (see Chapter 2) completed in fall 2006 (Table 3.1). To help ensure consistency in substrate size classification, a single individual conducted the mapping, which was done at low flow. This individual delineated substrate into visibly homogeneous substrate types based on dominant and sub-dominant particle sizes. Classification was based on a modified Wentworth scale (Table 3.2).

Table 3.1. Substrate mapping dates and flows.

SITE [a]	DATE(S) OF MAPPING	AVERAGE FLOW DURING MAPPING
SXW	8/9/06	37 cfs [b]
DFC	11/15/06 11/17/06	67 cfs 66 cfs
MO	11/17/06 11/20/06 11/26/06	66 cfs 66 cfs 63 cfs
OX	11/26/06 12/13/06	63 cfs 64 cfs

[a] SXW = Sixth Water, DFC = Diamond Fork Campground, MO = Mother, OX = Oxbow.
[b] cubic feet per second.

In 2005 detailed classification of main channel substrate was not possible because of poor visibility caused by turbid water conditions (BIO-WEST 2006). In 2006 mapping was completed in the fall, when conditions were less turbid, and main channel areas were classified based on specific percentages of the substrate types listed in Table 3.2. At the DFC, MO, and OX sites, it was not possible to map several areas because flows were too deep or fast for wading; these areas were classified as “unknown” substrate polygons.

Table 3.2. 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 GIS layer using ArcMAP software with the 2006 National Agricultural Imagery Program (NAIP) orthophotos as base images. Within ArcMAP each substrate patch (polygon) was attributed with the percentage of the polygon in each substrate size class. These values were multiplied by the area of each polygon to determine the total area of each size class within the entire monitoring site. For mapping purposes, a simplified dominant size class was also identified for each polygon.

3.2.2 Island and Riparian Vegetation Mapping

Qualitative mapping of island and streamside riparian vegetation types was completed in conjunction with substrate mapping at the DFC, MO and OX sites. Riparian mapping was not completed at the SXW site in 2006. Mid-channel deposits containing grass were mapped as islands rather than as substrate polygons, even if they had significant portions of bare cobble, gravel, sand, or silt as well as grass. Riparian vegetation was only mapped along the immediate streamside area visible from the main channel. Riparian vegetation growing in floodplain areas beyond the streamside corridor was not mapped as part of this effort. It should also be noted that this mapping effort is not intended to be a species-specific or quantitatively accurate technique; rather, it is meant to be a simple way to collect general information on dominant vegetation categories and observe general changes through time.

Areas were mapped according to the combination of vegetation (e.g., grass, willow, cottonwood) and ground cover (e.g., sand/silt, gravel, rock [rip-rap]) present. Some island and bar areas contained cobble-sized material in addition to gravel. In order to keep categories relatively simple, no “cobble” category was specified; rather, the “gravel” category was used more broadly to include both gravel- and cobble-sized material. The “bare” category was used for streamside areas devoid of vegetation such as tall eroding terraces, rip-rap banks, or deposits of clean cobble or gravel material.

Riparian maps were digitized into a GIS layer using ArcMAP software with the 2006 NAIP orthophotos as base images. Within ArcMAP each riparian patch (polygon) was attributed with its vegetation category as well as any additional notes (e.g., qualitative estimate of vegetation height, maturity, density).

3.2.3 Pebble Counts

In addition to the visual substrate mapping effort, quantitative pebble counts (Wolman 1954) were completed at discreet patches and at cross sections within each monitoring site. Pebble counts were located in riffles or on gravel bar deposits to facilitate sampling.

Six pebble counts were completed in each of the four monitoring sites. A single pebble count was also conducted at the downstream side of each sediment-monitoring bridge. Each pebble count consisted of 100 pebbles. Particles were grouped into 10 size classifications (upper limits of 2 mm, 4 mm, 8 mm, 16 mm, 32 mm, 64 mm, 128 mm, 256 mm, 512 mm, and 1,024 mm) and plotted to determine grain sizes of the D16, D25, D50, D75, and D84 particles.

3.3 RESULTS

3.3.1 Substrate Maps

Maps of individual substrate polygons for each monitoring site are included in Appendix 3.1A. Accompanying attribute tables are provided Appendix 3.1B.

The maps of major/dominant substrate types illustrate some differences in streambed particle-size distributions among the different monitoring sites (Figure 3.1a-d). The differences observed among sites in 2006 are similar to those observed in 2005 (BIO-WEST 2006). The SXW Site generally contains coarser bed material than the downstream monitoring sites (Figure 3.2, Figure 3.3) and has the smallest percentage of area in the sand/silt category. The coarseness of the site is a function of the site's high position within the watershed, steep slope, and confined channel condition. Changes in substrate composition of the SXW site between 2005 and 2006 were minimal (Figure 3.2). The most significant change was the development of a new cobble-gravel patch on river right below transect 1, where the high, steep bank eroded and slumped into the channel (Figure 3.1a).

Based on the 2006 mapping results, the DFC, MO, and OX Sites are all dominated by gravel-sized material (Figures 3.1b-d, Figure 3.2, Figure 3.3). This result is in contrast to the 2005 mapping results, which indicated cobble was as dominant as gravel (Figure 3.2). However, the 2005 results were biased by the fact that the turbid main channel areas were estimated as containing "50% cobble and 50% gravel," which artificially increased the cobble percentage. Because the 2006 mapping was completed under better water clarity conditions, the 2006 results more accurately reflect the true proportion of cobble at the DFC, MO, and OX Sites. In 2006 most main channel areas contained a small percentage (~10-20%) of finer-grained sand in addition to gravel. This sand was overlooked in the 2005 estimates of main channel substrate types. Therefore, the apparent increase in the proportion of sand/silt between 2005 and 2006 at the three Diamond Fork sites (Figure 3.2) is largely a function of the improved mapping conditions and does not necessarily indicate that the sites are becoming more embedded with fines. Assuming that water clarity is good during the fall 2007 monitoring period, comparing the 2006 and 2007 results will provide a better indication of temporal trends in overall substrate composition.

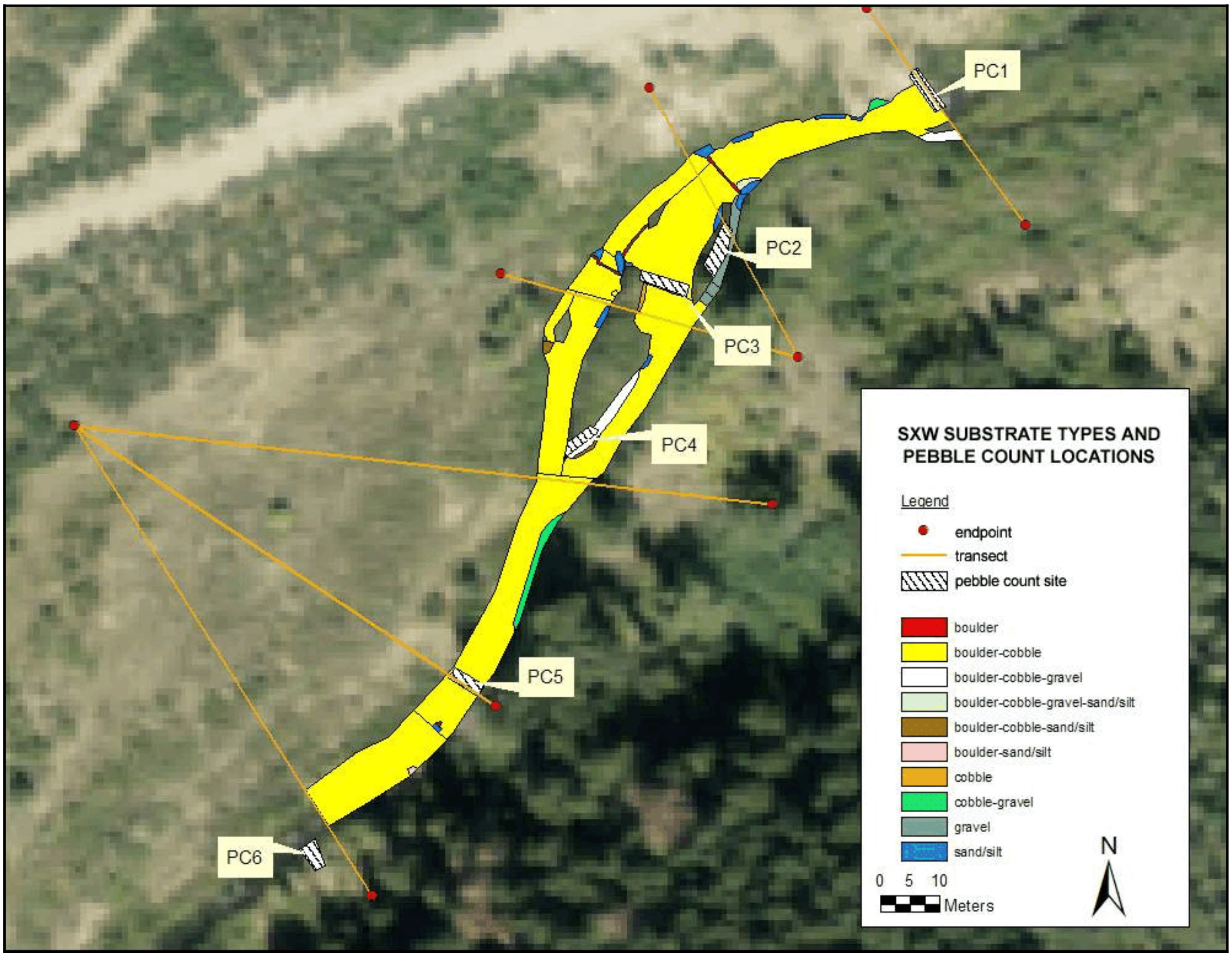


Figure 3.1a. Major substrate types and pebble count patch locations at the Sixth Water (SXW) monitoring site. Aerial photo from 2006.

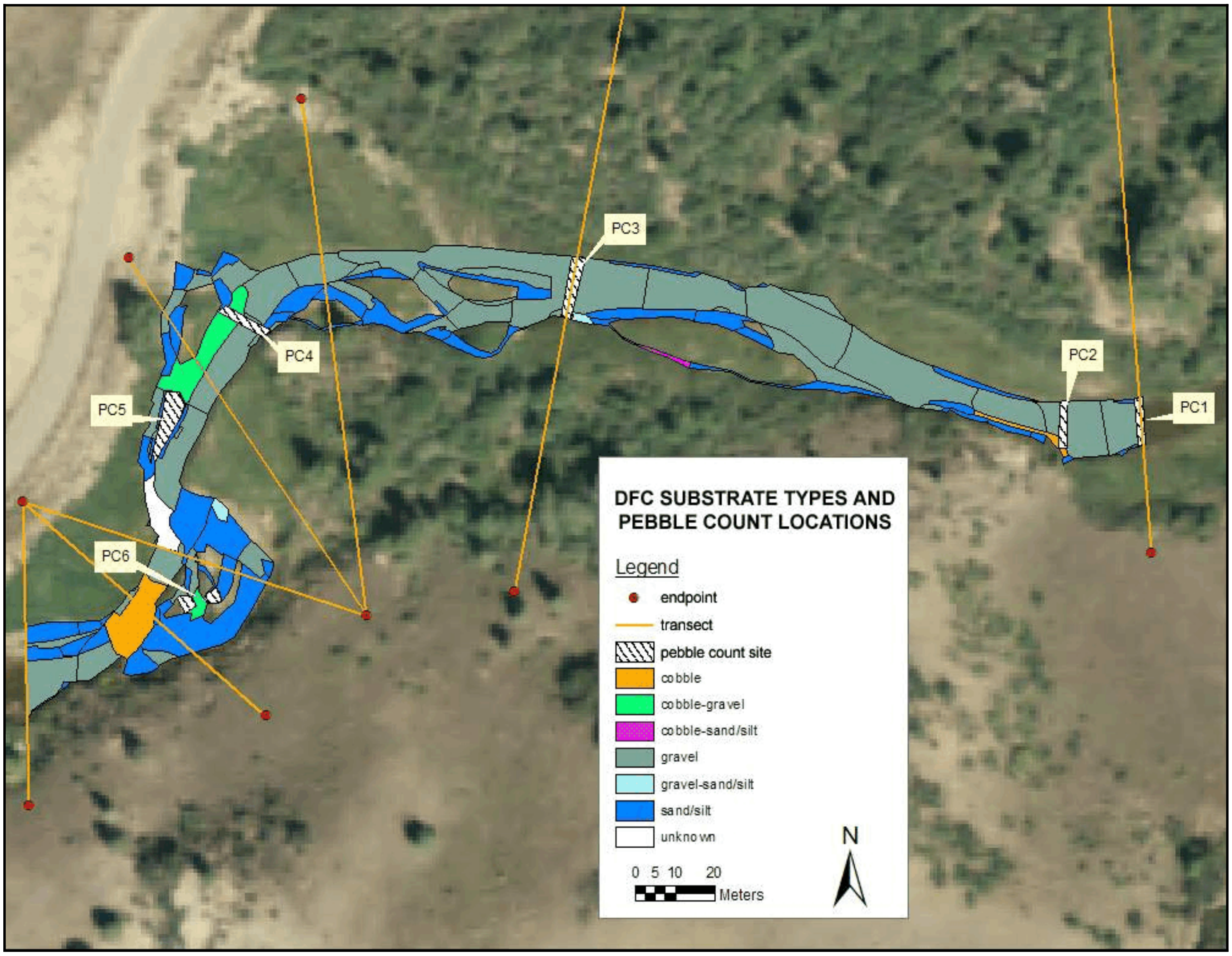


Figure 3.1b. Major substrate types and pebble count patch locations at the Diamond Fork Campground (DFC) monitoring site. Aerial photo from 2006.

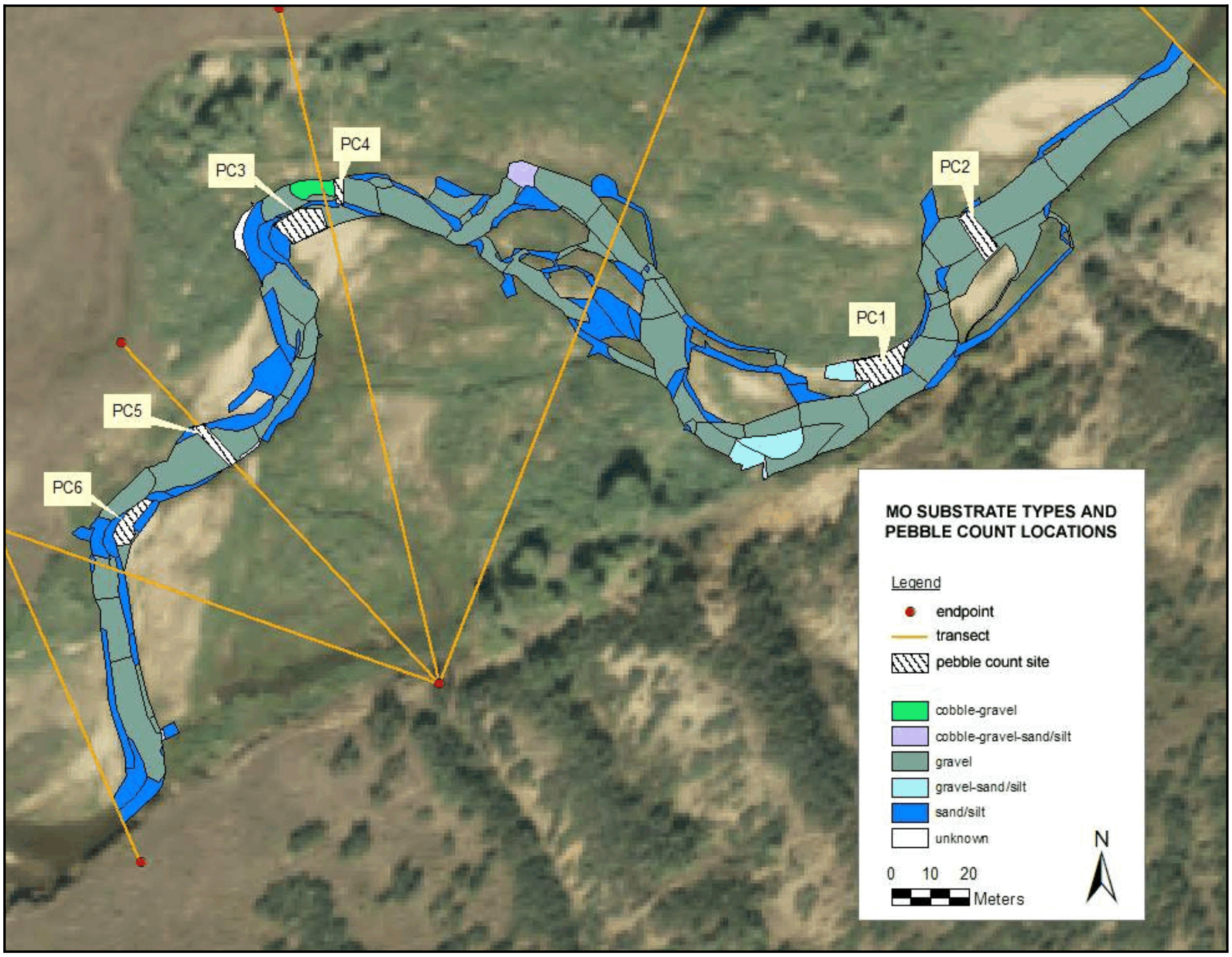


Figure 3.1c. Major substrate types and pebble count patch locations at the Mother (MO) monitoring site. Aerial photo from 2006.

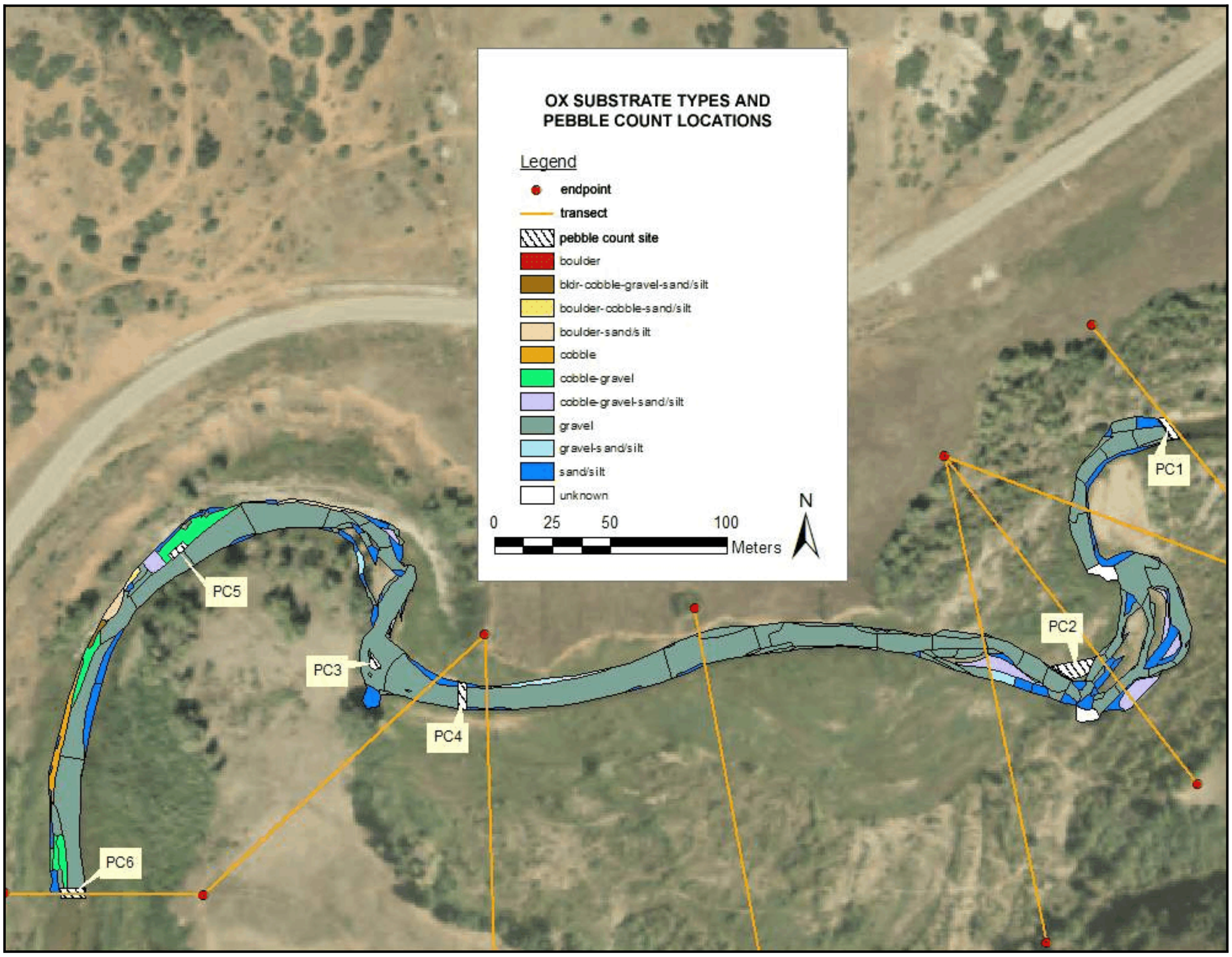


Figure 3.1d. Major substrate types and pebble count patch locations at the Oxbow (OX) monitoring site. Aerial photo from 2006.

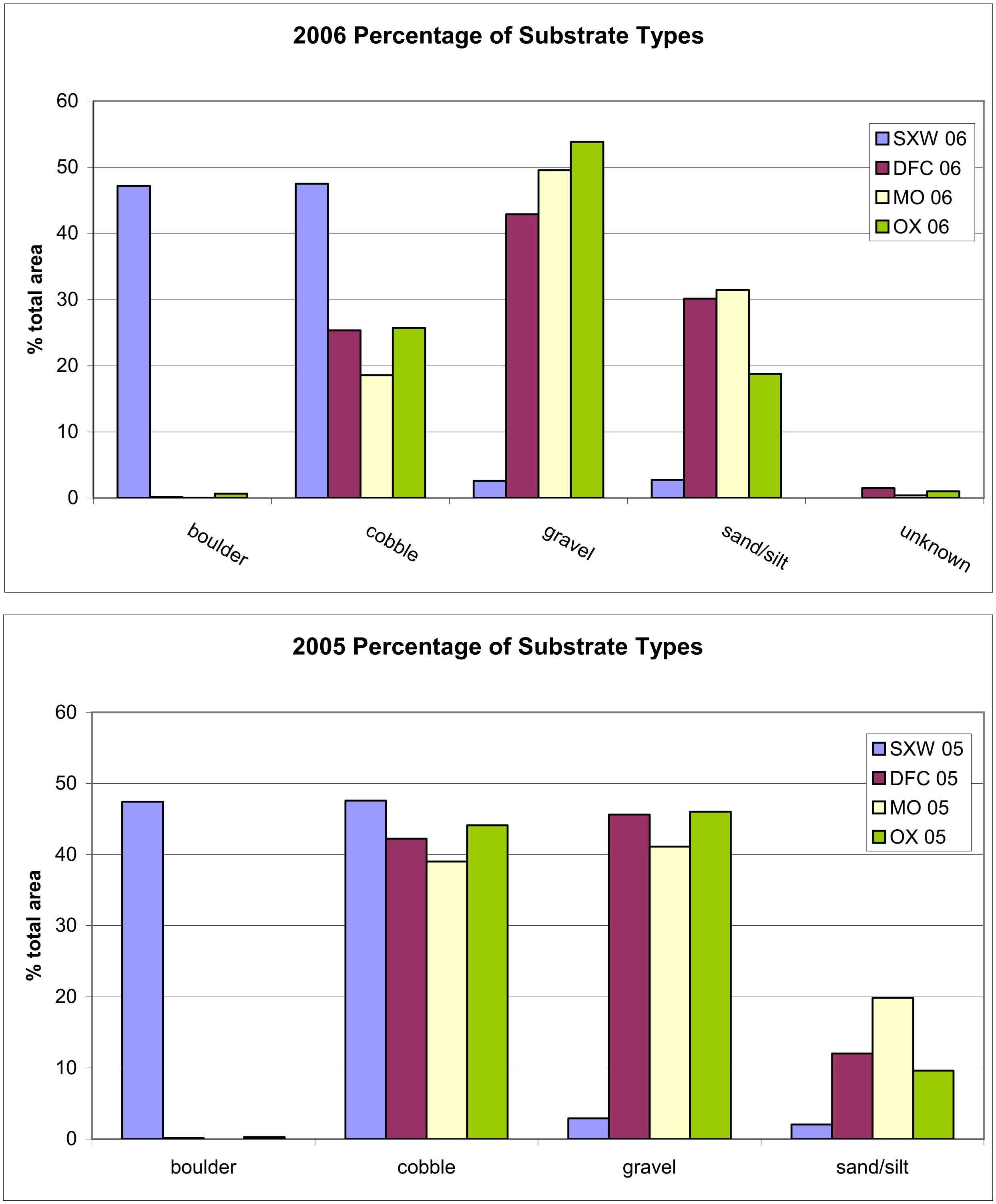


Figure 3.2. Proportion of monitoring site area occupied by various substrate size classes in 2005 and 2006.

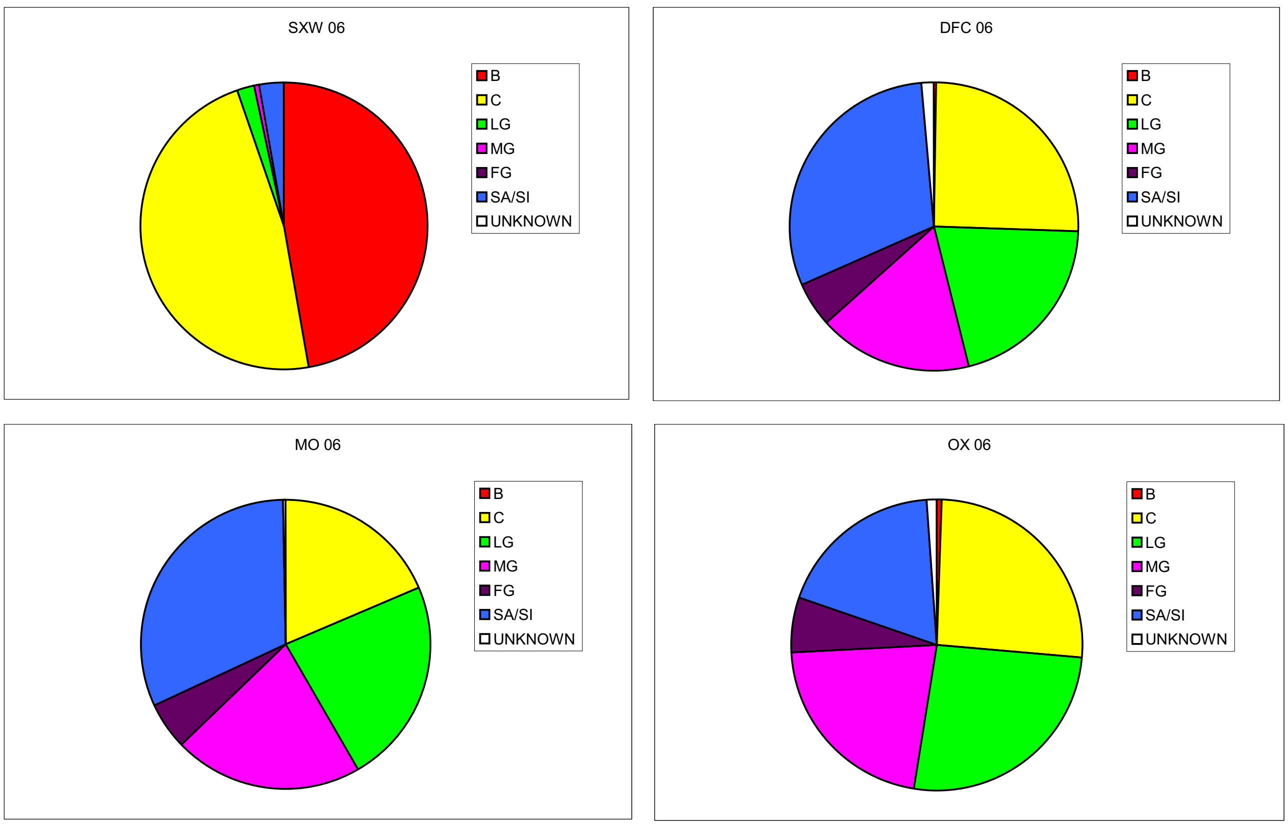


Figure 3.3. Individual plots of proportion of monitoring sites occupied by different substrate sizes, including detailed gravel sizes.

Based on the 2006 mapping, the DFC and MO sites each contain about 30% sand/silt material, while the proportion of fines at the OX site is lower (Figure 3.3). This is likely due to the fact that sand/silt deposits typically occur in backwaters or protected channel margin areas, and these complex channel features occur with greater frequency within the DFC and MO sites. The long, straight run section of the OX site between transects 4 and 6 (Figure 3.1d) does not contain significant silt deposits, and it reduces the overall proportion of fine material at the site while increasing the overall proportion of gravel. Although the percentage of total gravel varies somewhat among the three Diamond Fork sites, the relative percentages of individual gravel sizes (fine, medium, large) are very consistent (Figure 3.3). Of the total amount of gravel at each site, about 48% is large gravel, 41% is medium gravel, and 11% is fine gravel. This contrasts with the coarser SXW Site, where 80% of the total gravel is large gravel, 19% is medium gravel, and only 1% is fine gravel.

3.3.2 Island and Riparian Vegetation Mapping

Maps of riparian and island vegetation polygons for each Diamond Fork Creek monitoring site are shown in Figure 3.4a-c. Although riparian vegetation was not specifically mapped at the SXW site in 2006, general observations made during substrate mapping indicate that riparian conditions remain similar to those observed in 2005 when willows dominated the vegetation distribution.

As in 2005 the three Diamond Fork sites showed greater variety and complexity in vegetation types than the SXW site. Although willows occupy much of the streamside area at the DFC site, large areas of grass (particularly on islands) or mixed grass and willow are also present (Figure 3.4a). Stands of mixed grass and willow are dominant along the streamside areas of the MO site, while various combinations of grass, gravel, and sand occupy island areas (Figure 3.4b). The OX site contains the greatest area of streamside cottonwoods of the four monitoring sites, and it also contains areas of willow, mixed grass and willow, and grass (Figure 3.4c). As with the other Diamond Fork sites, islands within the OX site contain combinations of grass, gravel, and sand.

Two consistent temporal trends in riparian vegetation were observed at all three of the Diamond Fork sites. These trends are illustrated using the 2005 versus 2006 maps of the MO site as an example (Figure 3.5). One trend was that many areas mapped as grass in 2005 were mapped as grass-willow in 2006. At the DFC site some areas mapped as grass-willow in 2005 were mapped as willow in 2006. This trend toward increased area of streamside willows with reduced grass dominance is what would be expected given the change in hydrology associated with pipeline completion. Now that floodplain-inundating flows are less frequent, willows are able to colonize areas that used to only be suitable for herbaceous vegetation.

The second trend observed at all three Diamond Fork sites was an increase in the amount of sand and silt material observed on islands and channel margin deposits. In 2005 most of these areas were mapped as grass-cobble-gravel, with only minor amounts of finer material present (BIO-WEST 2006). This trend is readily illustrated by the maps of the MO site, where most islands were mapped as grass-sand/silt in 2006 (Figure 3.5). In addition, several areas mapped as combinations of grass, gravel, and cobble in 2005 were mapped as fully vegetated grass areas in 2006. The conversion of coarser gravel-cobble deposits to areas of grass or grass-sand/silt necessitated shifts in

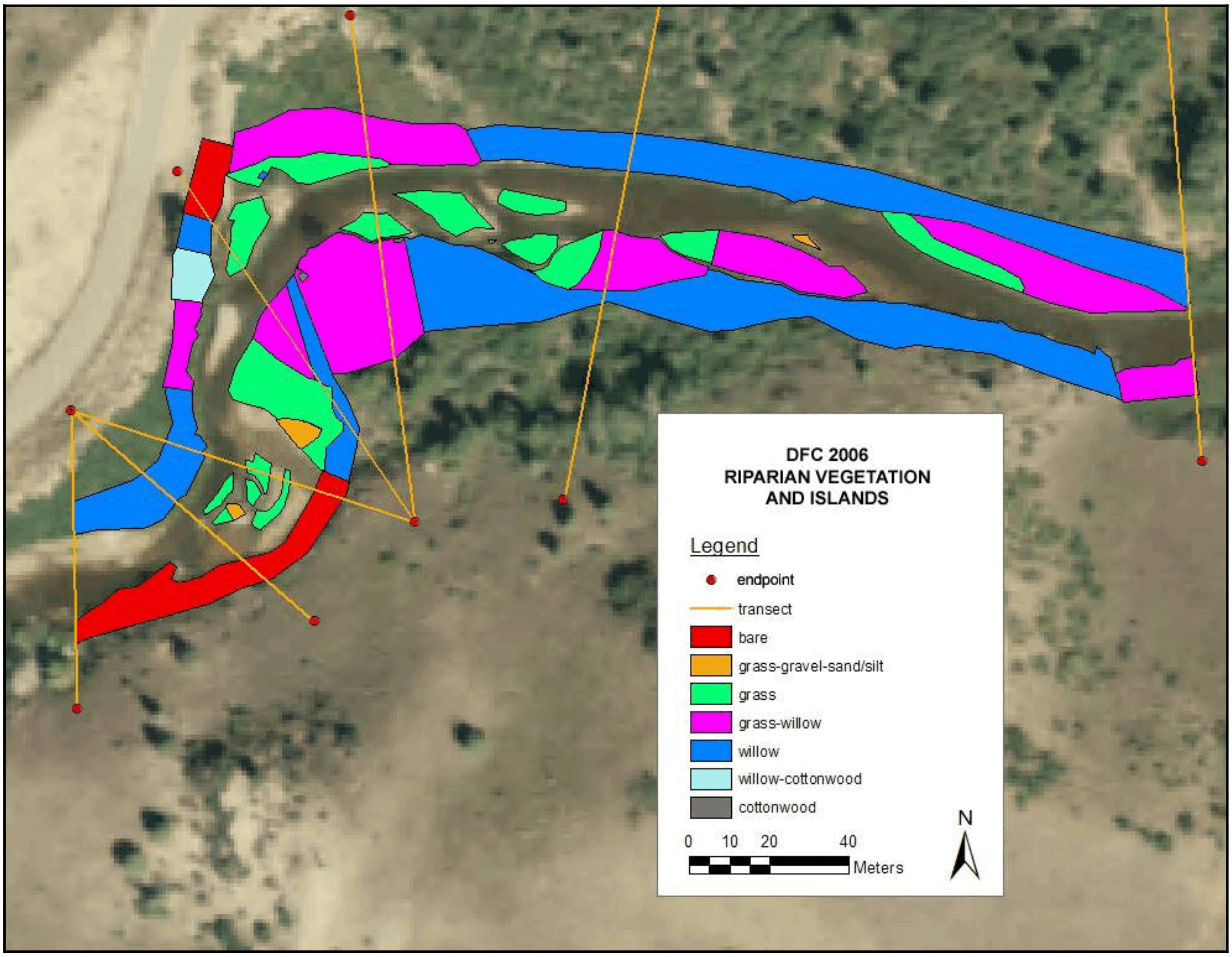


Figure 3.4a. Island and riparian vegetation types at the Diamond Fork Campground (DFC) monitoring site. Aerial photo from 2006.

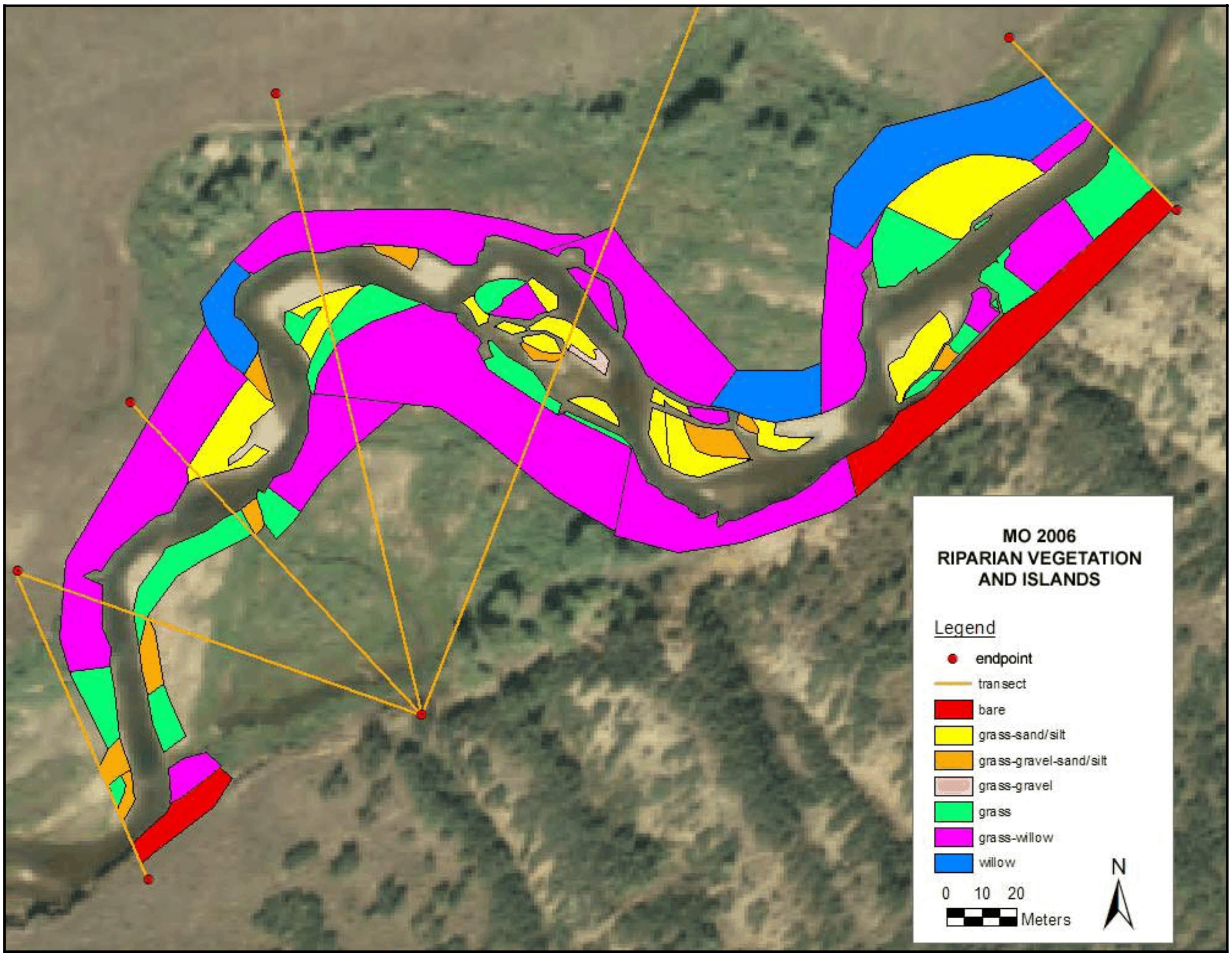


Figure 3.4b. Island and riparian vegetation types at the Mother (MO) monitoring site. Aerial photo from 2006.

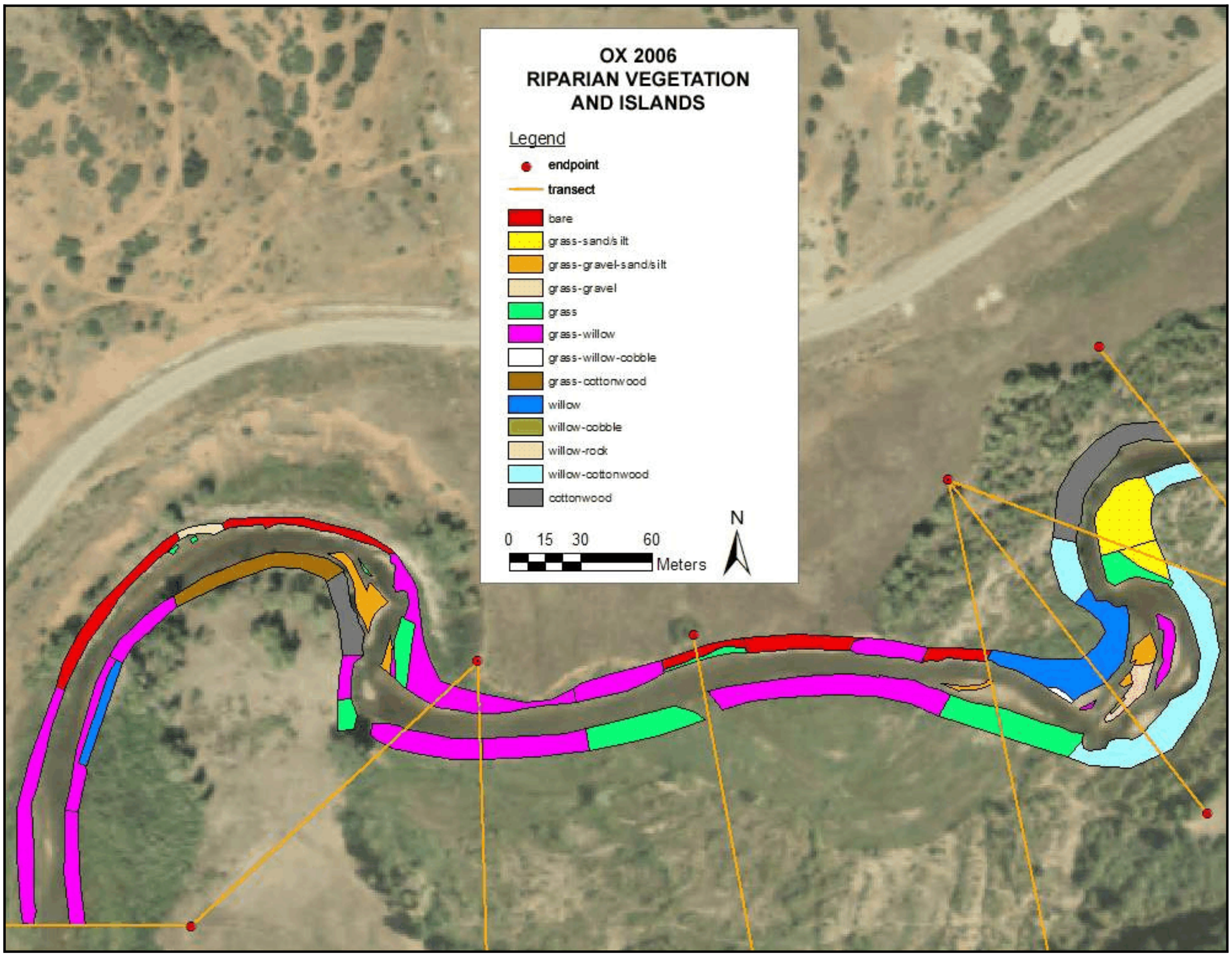


Figure 3.4c. Island and riparian vegetation types at the Oxbow (OX) monitoring site. Aerial photo from 2006.

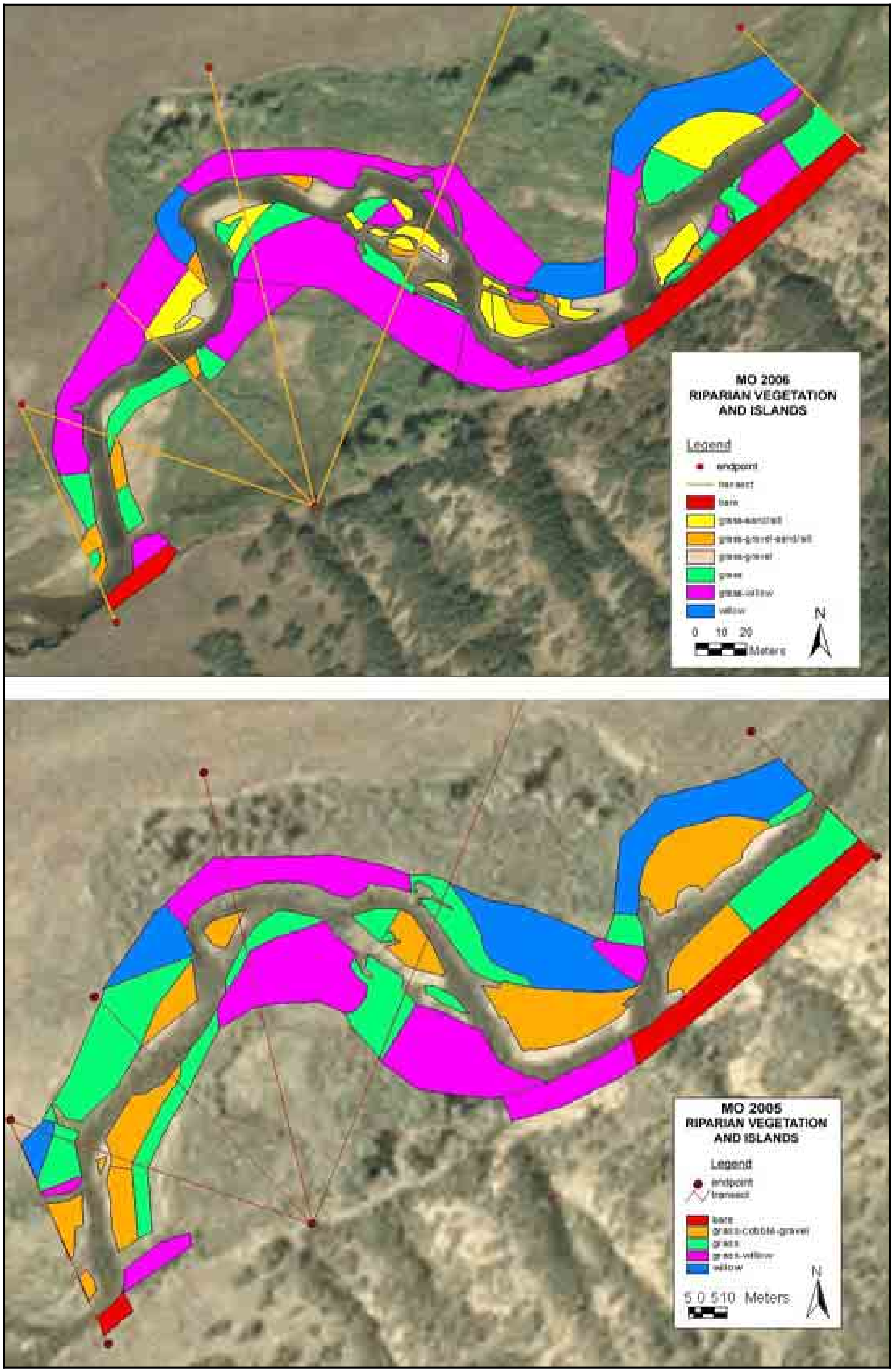


Figure 3.5 Comparison of 2005 and 2006 maps of riparian vegetation at the Mother (MO) monitoring site.

at least one pebble count sampling location at each of the Diamond Fork monitoring sites (see Section 3.3.3 below).

3.3.3 Pebble Counts

The D16, D25, D50, D75, and D84 values for 2005 and 2006 are listed for each pebble count at the study sites in Table 3.3. Results for pebble counts conducted at the bedload sampling sites (bridges) are listed in Table 3.4. Pebble count plots are shown in Appendix 3.2.

Table 3.3. Pebble count results for channel monitoring sites.

SIXTH WATER (SXW)	SXW1		SXW2		SXW3		SXW4		SXW5		SXW6	
	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006
D_{16}	22	18	25	6	25	10	12	3	10	60	62	38
D_{25}	46	27	32	12	43	20	29	13	50	112	75	60
D_{50}	110	74	67	41	82	81	92	92	145	190	97	103
D_{75}	181	140	120	102	125	163	152	159	221	270	134	142
D_{84}	260	190	160	140	152	190	185	200	265	312	153	160
Class of D_{50} [a]	C	C	C	LG	C	C	C	C	C	C	C	C
DIAMOND FORK CAMPGROUND (DFC)	DFC1		DFC2		DFC3		DFC4		DFC5		DFC6	
	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006
D_{16}	28	17	32	21	38	15	20	16	41	5	15	3
D_{25}	34	26	44	29	43	21	33	27	46	11	21	6
D_{50}	68	64	72	53	60	48	75	58	60	55	34	24
D_{75}	99	112	112	85	105	84	117	93	83	80	56	44
D_{84}	116	142	125	103	113	110	140	111	92	86	64	51
Class of D_{50} [a]	C	C	C	LG	LG	LG	C	LG	LG	LG	LG	MG
MOTHER (MO)	MO1		MO2		MO3		MO4		MO5		MO6	
	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006
D_{16}	11	2	25	20	14	3	23	15	19	21	5	5
D_{25}	15	12	31	24	20	6	31	21	29	29	7	12
D_{50}	22	36	47	42	29	23	41	31	47	41	31	33
D_{75}	31	51	71	67	38	36	56	55	73	55	49	62
D_{84}	35	61	90	74	45	41	64	68	82	59	59	74
Class of D_{50} [a]	MG	LG	LG	LG	MG	MG	LG	MG	LG	LG	MG	LG
OXBOW (OX)	OX1		OX2		OX3		OX4		OX5		OX6	
	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006
D_{16}	26	19	12	10	7	13	16	9	17	51	21	16
D_{25}	31	22	15	12	16	22	25	12	59	61	26	20
D_{50}	47	44	21	21	25	38	35	23	75	73	45	36
D_{75}	65	82	29	30	45	51	69	45	90	94	66	50
D_{84}	80	92	33	33	51	60	85	67	100	102	79	60
Class of D_{50} [a]	LG	LG	MG	MG	MG	LG	LG	MG	C	C	LG	LG

[a] C = cobble, MG = medium gravel, LG = large gravel.

Table 3.4. Pebble count results for bedload sampling sites [a].

CLASS	SXW-U BRIDGE		SXW-L BRIDGE		DI BRIDGE		MK BRIDGE		BR BRIDGE		CH BRIDGE	
	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006
D_{16}	22	28	74	15	20	7	71	5	26	3	21	7
D_{25}	39	40	100	38	32	10	88	10	35	11	25	14
D_{50}	87	120	143	130	75	33	130	28	55	34	34	32
D_{75}	190	206	223	177	118	71	180	117	86	95	51	52
D_{16}	244	260	263	210	141	89	220	160	112	115	58	70
D_{25}	Cobble	Cobble	Cobble	Cobble	Cobble	Large Gravel	Cobble	Medium Gravel	Large Gravel	Large Gravel	Large Gravel	Large Gravel

[a] SXW-U = Upper Sixth Water, SXW-L = Lower Sixth Water, DI = Diamond Fork at Three Forks, MK = Monks, BR = Brimhall, CH = Childs.

Table 3.5 summarizes the 2006 pebble count data. It lists all pebble count locations, type (riffle, bar, etc.), D50 (2005 and 2006), and relative changes between 2005 and 2006 pebble counts.

An alternative way to analyze the pebble count data is to analyze the in-channel riffle pebble counts separately from the counts completed in depositional bar ("patch") areas. The average D16, D25, D50, D75, and D84, as well as the maximum D84 and minimum D16 from the in-channel riffle pebble counts are shown in Table 3.6.

Table 3.6. Average, minimum, and maximum diameters of particles counted in riffles at the four study sites.

STUDY SITE [a]	DIAMETER CLASSES															
	NUMBER OF RIFFLES		AVERAGE D16 (MM)		AVERAGE D25 (MM)		AVERAGE D50 (MM)		AVERAGE D75 (MM)		AVERAGE D84 (MM)		MINIMUM D16 (MM)		MAXIMUM D84 (MM)	
	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006
SXW	3	3	19	29	46	53	112	115	176	191	226	231	10	10	265	312
DFC	3	4	33	17	40	26	67	56	105	94	118	117	28	15	125	142
MO	2	3	22	19	30	25	47	38	72	59	86	67	19	15	90	74
OX	3	3	21	15	27	18	42	34	67	59	81	73	16	9	85	92

[a] Site abbreviations: SXW = Sixth Water, DFC = Diamond Fork Campground, MO = Mother, OX = Oxbow.

The average D16, D25, D50, D75, and D84, as well as the maximum D84 and minimum D16 for the bar/patch pebble counts are shown in Table 3.7.

Table 3.5. Descriptive summary of changes in pebble count locations and results.

PEBBLE COUNT SITE	TYPE	LOCATION	D50 2005	D50 2006	SUMMARY
SIXTH WATER					
SXW PC1	wet riffle	Riffle near cross section 1.	110	74	Small increase in fine material. The D50 is smaller size but remains classified as cobble. Largest increase in is medium gravel.
SXW PC2	wet side channel	Side channel on the left side of the island near cross section 2.	67	41	Biggest change at this site. The D50 changed from Cobble to Large Gravel. Reduction in Cobble sized particles and increase in sand/silt and medium gravel.
SXW PC3	wet riffle	Macroinvertebrate sampling site located upstream of cross section 3 and just above the mid-channel island.	82	81	Increase in cobbles as well as in medium gravel and sand silt. This balances out to make the D50 nearly the same for 2005 and 2006.
SXW PC4	wet bar	Inundated area at the downstream tip of the mid-channel island near cross section 4.	92	92	Little change. Increase in sand/silt.
SXW PC5	wet riffle	Main channel riffle at cross section 5.	145	190	Increase in boulders (phi class 512) measured and decrease in medium gravel causes coarsening of this patch.
SXW PC6	dry bar	Dry bar near cross section 6 near the left edge of water.	97	103	Little change.
DIAMOND FORK CAMPGROUND					
DFC PC1	wet riffle	Riffle near transect 1.	68	64	Little change.
DFC PC2	wet riffle	20 meters (m) downstream from pebble count DFC1.	72	53	Small increase in fine material measured as medium gravel (phi class 16 and 32). The D50 classification changed from cobble to large gravel.
DFC PC3	wet riffle	Crosses the main channel at transect DFC3.	60	48	Increase in medium gravel with a decrease in large gravel. D50 remains classified as large gravel.
DFC PC4	wet riffle	Macroinvertebrate sampling site located between river left and the upper tip of the island downstream from transect DFC3.	75	58	Increase in fine material (large and medium gravel) with a decrease in cobble. The D50 classification changes from cobble to large gravel.
DFC PC5	dry bar	Bar sampled in 2005 eroded; in 2006 sampled new mid-channel bar ~25 m downstream, below transect 4.	60	55	Large increase in sand/silt with a decrease in large gravel. The D16 (5mm) changed from large gravel to fine gravel and the D25 (11mm) changed from large gravel to medium gravel. Little changed occurred with the D50 and larger sizes.
DFC PC6	dry bar	Bar sampled in 2005 became vegetated; in 2006 sampled new gravel deposits adjacent to 2005 sample location.	34	24	Large increase in sand/silt and fine gravel with a decrease in large and medium gravel and cobble. The D50 decreased in size from large gravel to medium gravel. The D25 and D16 changed from medium gravel to fine gravel.
MOTHER					
MO PC1	dry bar	Area sampled in 2005 became silted/vegetated; in 2006 sampled gravel deposit ~60m downstream.	22	36	Increase in fine material and larger material. Increase in sand/silt, large gravel, and cobble. Largest decrease in medium gravel. This balances out to an overall increase in the D50 from medium gravel size to large gravel.
MO PC2	wet riffle	Macroinvertebrate sampling site located between transects 1 and 2.	47	42	Little change.
MO PC3	dry bar	Bar/island sampled in 2005 became larger; in 2006 sampled area just slightly north of 2005 location.	29	23	Large increase in sand/silt with a decrease in large and medium gravel. The D50 is smaller in 2006, but remains classified as medium gravel.
MO PC4	wet riffle	Side channel sampled in 2005 became silted/filled in; in 2006 sampled main channel at transect 3, just north of 2005 location.	41	31	Increase in fine material. The increase in medium gravel and decrease in large gravel changes the D50 from large gravel to medium gravel.
MO PC5	wet riffle	Riffle at cross section 4.	47	41	Little overall change. Decrease in cobble and an increase in large gravel. The D50 remains classified as large gravel.
MO PC6	dry bar	Bar sampled in 2005 became larger; in 2006 sampled area ~6 m west of 2005 location.	31	33	Increase in large gravel and cobble. The D50 classification changes from medium gravel to large gravel.
OXBOW					
OX PC1	wet riffle	Macroinvertebrate sampling site located near a riffle near transect 1.	47	44	Little change.
OX PC2	dry bar	High bar deposit between transects 2 and 3.	21	21	Little change.
OX PC3	dry bar	Area sampled in 2005 became vegetated; in 2006 sampled new mid channel bar ~50 m downstream.	25	38	Increase in large gravel and cobble. The D50 changes from medium gravel to large gravel.
OX PC4	wet riffle	Riffle between transects 6 and 7.	35	23	Increase in fine material (fine gravel and medium gravel) and decrease in cobble. The D50 classification changed from large gravel to medium gravel.
OX PC5	wet bar	Shallow mid channel bar between cross sections 7 and 8.	75	73	Little change.
OX PC6	wet riffle	Riffle at transect 8.	45	36	Small increase in fine material with a marked decrease in cobble. The D50 decrease from 45 mm to 36 mm and remains classified as large gravel.

Table 3.7. Average, minimum, and maximum diameters of particles counted in depositional bar/patch counts at the four study sites.

STUDY SITE [a]	DIAMETER CLASSES															
	NUMBER OF PATCHES		AVERAGE D16 (MM)		AVERAGE D25 (MM)		AVERAGE D50 (MM)		AVERAGE D75 (MM)		AVERAGE D84 (MM)		MINIMUM D16 (MM)		MAXIMUM D84 (MM)	
	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006
SXW	3	3	33	16	45	28	85	79	135	134	166	167	12	3	185	200
DFC	3	2	25	4	33	9	56	40	85	62	99	69	15	3	140	86
MO	4	3	13	3	18	10	31	31	44	50	51	59	5	2	64	74
OX	3	3	12	25	30	32	40	44	55	58	61	65	7	13	100	102

[a] Site abbreviations: SXW = Sixth Water, DFC = Diamond Fork Campground, MO = Mother, OX = Oxbow.

Several general trends are apparent from the pebble count results. As in 2005 the SXW site had the coarsest main channel substrate material (average riffle D50 of 115 mm), the DFC site had the next coarsest material (average riffle D50 of 56 mm), and the MO and OX sites had the finest main channel material (average riffle D50s of 38 and 34 mm, respectively). These findings are expected, given the fact that the SXW site is the steepest monitoring site (3% slope), DFC is the second steepest site (0.9% slope), and the MO and OX sites are the flattest gradient sites (0.5% and 0.6% slope, respectively).

At the SXW site little change is evident between 2005 and 2006 in the pebble count results for in-channel riffle locations (Table 3.6). However, the patch count results suggest a slight trend toward fining: the D126, D25, and D50 all became smaller at these sites between 2005 and 2006 (Table 3.7). This trend is partly the result of an increase in the amount of sand- and silt-sized particles (2 mm and smaller) at all sites except PC5 (Appendix 3.2).

The pebble count results at the DFC site also show an increase in fines within depositional areas (Table 3.5, Table 3.7, Appendix 3.2). This result matches substrate mapping observations, which noted that the high spring flows in 2006 deposited a layer of sand/silt material across many of the low bar/floodplain surfaces at the Diamond Fork sites. The in-channel riffle pebble counts at DFC also show a fining trend, due to an increase in sand/silt material as well as an increase in medium gravel (Table 3.5, Table 3.6, Appendix 3.2).

Pebble count results at the MO site exhibit tendencies similar to the DFC site, although the changes are generally not as consistent or significant. The 2006 in-channel riffle results are slightly finer than in 2005 (Table 3.6); however, most of this change is the result of including the PC4 sample in the 2006 riffle analysis. The PC4 location shifted between 2005 and 2006. The locations of the PC2 and PC5 riffle samples did not shift, and their results exhibited little change between 2005 and 2006 (Table 3.3, Table 3.5, Appendix 3.2). The pebble count results for depositional bar areas at the MO site are mixed (Table 3.5). An increase in sand/silt material was observed at the PC 1 and PC3 bars, while a decrease was observed at PC6 (Appendix 3.2).

As with the other Diamond Fork sites, the OX in-channel riffle results show a trend towards fining (Table 3.6). At the OX site this appears to be the result of increased amounts of medium gravel rather than increased amounts of sand or silt (Appendix 3.2). Pebble count results for depositional bar areas show a slight coarsening trend at OX (Table 3.7). This is due to an increase in large gravel at PC3; the results for the other bar counts (PC 2 and PC5) show little change. The change at PC3 is most likely the result of the shift in its sampling location from a channel margin area to a mid-channel deposit (Table 3.5). Although the OX pebble count results do not demonstrate a fining trend in depositional areas, substrate and riparian mapping results do indicate that several low floodplain areas within the OX site were silted in and/or vegetated following the 2006 spring flood.

3.4 DISCUSSION AND SUMMARY

Because it was not possible to map main channel substrate areas in detail in 2005, the ability to compare 2006 and 2005 substrate mapping results is limited. The more detailed 2006 main channel maps demonstrate that gravel is the dominant substrate type within the three Diamond Fork sites, while cobble material is less dominant than was estimated during the turbid 2005 mapping effort. The dominance of gravel matches the pebble count results, which show that most D50 sizes are either large or medium gravel.

Pebble counts completed in riffle areas show a trend toward fining at the three Diamond Fork sites, while riffle results at the SXW site show little change. Counts completed in depositional bar patches at the SXW and DFC sites show an increase in fine material, while this trend is less apparent at the MO and OX sites. It is difficult to know exactly what is responsible for these changes. Several significant rainstorm events occurred during summer and fall 2006, and these storms contributed turbid, silty water to Diamond Fork Creek. The finer size distribution in riffle areas may also be part of the ongoing adjustment of the stream system to a reduced flood regime that is less able to transport large particle sizes and to the unnaturally high legislated base flows and associated sediment transport. A trend toward increased embeddedness could be cause for concern because fine sediments degrade the quality of spawning gravels. Monitoring activities planned for 2007 will include techniques to more specifically measure embeddedness and how it changes seasonally.

During the 2006 substrate mapping, several substrate patches at the three Diamond Fork sites were noted as appearing “cemented.” In these areas gravel- and cobble-sized particles are embedded in a matrix of fine-grained material (sand and silt) that forms a semi-cohesive”brick.” In some locations abrupt drops in bed elevation were observed where pieces of this material had eroded away and formed an underwater “cut bank.” It is unclear what chemical and physical processes are responsible for this cemented substrate. For 2007 additional monitoring techniques are planned to help better understand this phenomenon and determine how it evolves seasonally from the spring runoff period through the fall.

Results of riparian mapping at the Diamond Fork sites show trends toward increasing willow dominance and siltation and vegetation of bar/island deposits. These trends are indicative of more stable conditions that could potentially lead to channel-narrowing trend. These adjustments are expected, given the hydrologic shift toward a more natural flood regime on Diamond Fork Creek, although these changes could be cause for concern if they result in a substantial reduction in overall riparian vegetation diversity. However, channel surveys indicate that dynamic processes—such as bank erosion, gravel bar deposition, and scour—are still occurring under the new flow regime (see Chapter 2 of this report). Therefore, based on the limited monitoring results to date, loss of riparian diversity does not appear to be a problem.

4.0 SEDIMENT TRANSPORT

4.1 INTRODUCTION

This chapter describes the methods and results of sediment transport monitoring for the first 2 years of this study (2005-2006). The sediment flux, or type and amount of sediment, moving in and out of specific reaches is highly correlated with upstream supplies and the magnitude and duration of peak flows. Annual and seasonal variations in sediment flux influences the biological health of Sixth Water Creek and Diamond Fork Creek and are vital components of the riverine ecosystem. Since the completion of the Diamond Fork System in 2004, the amount of imported water flowing in Sixth Water Creek and Diamond Fork Creek has been reduced and streamflow has been returned to a more natural flow regime (Figure 1.3), except for the relatively high, established instream flows of 25 to 32 cfs in Sixth Water Creek and 60 to 80 cfs in lower Diamond Fork Creek.

Prior to completion of the Diamond Fork System, decades of elevated peak flows caused massive amounts of streambed and streambank erosion (Mitigation Commission 2005). For example, it appears that the streambed in the upper reaches of Sixth Water Creek dropped by nearly 30 feet at some locations. Channel incision in other downstream reaches initiated near-channel slumping and accelerated mass erosion on unstable side slopes. It is likely that the channel incision process migrated headward into other tributary streams as each tributary had to adjust to a new confluence elevation. The majority of the eroded material from Sixth Water Creek and other tributaries has likely been periodically and size-selectively transported to downstream reaches over the past 8 decades. These overwhelming sediment loads, combined with elevated peak flows, resulted in extensive streambank erosion and channel braiding in the flatter reaches of lower Diamond Fork Creek. It is apparent that sedimentation problems caused by the imported water still persist in the flatter reaches of the channel network, foremost the lower reaches of Diamond Fork Creek (Photo 4.1). The current levels of substrate embeddedness, including other problems caused by sedimentation, likely continue to impair the biological integrity and productivity of the stream and riparian ecosystems.

The active channel is abnormally wide and shallow. Construction of the Diamond Fork System is certainly a major step toward restoration of the impacted streams. However, there will be a lag between restoring the flow regime and regaining a more natural sediment transport regime, especially during the first decade as channel and floodplain dimensions are adjusting to reduced peak flows, new meander patterns develop, riparian vegetation becomes established, and established vegetation stabilizes some of the old active bars, newly inactive side channels, and dried up backwaters. It is anticipated that channel dimensions, floodplain characteristics, and aquatic habitat will eventually stabilize (i.e., not change so often) under the new flow regime. However, water imports in the form of the minimum instream flows continue to increase sediment yields in Sixth Water Creek and Diamond Fork Creek. Therefore, according to the data collected in 2005 (BIO-WEST 2006), the potential of the Diamond Fork System to fully restore the impacted streams (aquatic habitat and riparian ecosystem) is only partially being realized, given the levels of sediment transport caused by the relatively high, established instream flows.

Photo 4.1. High levels of siltation embedding gravels and cobbles in the low flow channel are prevalent at all study sites in lower Diamond Fork Creek. This photo looks upstream at the OX4 cross section and was taken November 2006 at 76 cfs. Notice the silty streambed in contrast to the relatively clean gravel bar. A constant supply of silt is coming from Sixth Water Creek during low flows.

4.2 METHODS

4.2.1 Stream Discharge

Streamflows during sampling were determined primarily using hourly flow data supplied by the CUWCD. Provisional 15-minute and average daily flow data from U.S. Geological Survey (USGS) were used to supplement any missing flows in the hourly data. The four gaged flows used to calculate streamflow are the U.S. Geological Survey (USGS) gaging stations #10149400 (Sixth Water above Syar Tunnel), #10149000 (Diamond Fork above Red Hollow) and the Strawberry and Syar Tunnels. The tunnel flows release water into the study area and were used to calibrate streamflow at locations where gaged flows were not available (Figure 1.3). The 15-minute and average daily flow data were copied from the USGS web site (USGS 2006), whereas hourly flow data for all the gaged flows were supplied by the CUWCD.

Because accurate gage records were lacking for all but the SXW-U and MK sediment monitoring bridges, streamflows for the SXW-L, DI, BR, and CH sediment monitoring bridges had to be calculated. Discharge measurements were taken at the DI and SXW-L sediment monitoring bridges, and on Cottonwood Creek, Wanrhodes Creek, and Little Diamond Creek. Three discharge measurements were taken at peak, medium, and base flow. The new discharge measurements indicate that the 2005 flows (BIO-WEST 2006) were proportionally over estimated at the Diamond Fork above Three Forks bridge and underestimated at the SXW-L, BR, and CH sediment monitoring bridges. Therefore, correction factors were applied to the gaged flows to assure that each site matched the three measured flows (Table 4.1). After the corrected flows were established for the three discharge measurements, a linear ascending or descending correction factor was applied to generate hydrographs for the ungaged tributaries (Figure 1 of Appendix 4.A).

The SXW-L calculations take into account the added discharge of Syar Tunnel and a correction factor to account for inflow from Fifth Water Creek and other tributary inputs. Estimating flow during spring runoff at Diamond Fork above Three Forks involved subtracting the SXW-L calculated flows and Cottonwood Creek measured flows from the Diamond Fork at Red Hollow Gage (USGS Station #10149400). The discharge calculation at Diamond Fork above Three Forks was accurate to with in 10 percent of the discharge measurement. During base flow the Diamond Fork above Three Forks flow was calculated to one-sixth of the Red Hollow Gage, which matched the discharge measurements taken during medium and base flow very well. The BH and CH bridges discharge calculations take into account the added flow from the Wanrhodes and Little Diamond Creeks. The MK and SXW-U bridge flow data came from the hourly USGS gage data supplied by the CUWCD. Table 4.2 shows the gaging station, correction factor, tributary, and/or pipeline calculation used at each sediment monitoring site. Figure 4.1 shows hydrographs used for each of these sites.

A problem with this method is that during the summer, spikes in the hydrograph produced negative values for some of the calculations. The spikes were said to be errors in the gaging stations (J. Croft 2006, pers. comm.). The spike errors were replaced with correlating 15-minute and average daily data or averaged hourly flow data from before and/or after the spike. These spike values did not occur during natural peak flow. At the Diamond Fork above Three Forks bridge cross section, the stage/discharge

Table 4.1. Discharge measurement dates and correlating calculated streamflow.

DATE AND LOCATION OF DISCHARGE MEASUREMENT	MEASURED DISCHARGE	CALCULATED DISCHARGE
Diamond Fork above Three Forks - 5/5	169	189
Diamond Fork above Three Forks - 7/31	17	17
Diamond Fork above Three Forks - 10/27	11	12
Lower Sixth Water - 5/5	216	216
Lower Sixth Water - 7/31	61	61
Lower Sixth Water - 10/27	73	73
Cottonwood Creek - 5/5	29	
Cottonwood Creek - 7/31	3	
Cottonwood Creek - 10/27	1	
Wanrhodes Creek - 5/5	35	
Wanrhodes Creek - 7/31	3	
Wanrhodes Creek - 10/27	1	
Little Diamond Creek - 5/5	22	
Little Diamond Creek - 7/31	4	
Little Diamond Creek - 10/27	2	
Calculation used for the BR and CH sites to account for the added discharge of Little Diamond and Wanrhodes Creeks	Red Hollow Gaged Discharge	Brimhall and Childs Bridges Calculated Discharge
Diamond Fork at Red Hollow Gage - 5/5	434	491
Diamond Fork at Red Hollow Gage - 5/5	104	111
Diamond Fork at Red Hollow Gage - 5/5	74	77

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

SITE	DATA SOURCE/ CALCULATION TECHNIQUE
Upper Sixth Water Bridge (SXW-U)	USGS Station #10149000 (Sixth Water Above Syar Tunnel) (hourly flow data supplemented with 15-minute real-time and average daily data)
Lower Sixth Water Bridge (SXW-L)	USGS Station #10149000 (Sixth Water Above Syar Tunnel) + Syar Pipeline + Lower Sixth Water Correction Factor (hourly flow data supplemented with 15-minute real-time and average daily data)
Diamond Fork at Three Forks Bridge (DI)	USGS Station #10149400 (Diamond Fork above Red Hollow) - Lower Sixth Water Bridge - Cottonwood Creek for spring runoff flow and one sixth of USGS Station #10149400 (Diamond Fork above Red Hollow) for base flow (hourly flow data supplemented with 15-minute real-time and average daily data)
Monks Bridge (MK)	USGS Station #10149400 (Diamond Fork above Red Hollow) (hourly flow data supplemented with 15-minute real-time and average daily data)
Brimhall and Childs Bridges (BR, CH)	USGS Station #10149400 (Diamond Fork above Red Hollow) + Little Diamond and Wanrhodes Creeks (hourly flow data supplemented with 15-minute real-time and average daily data)

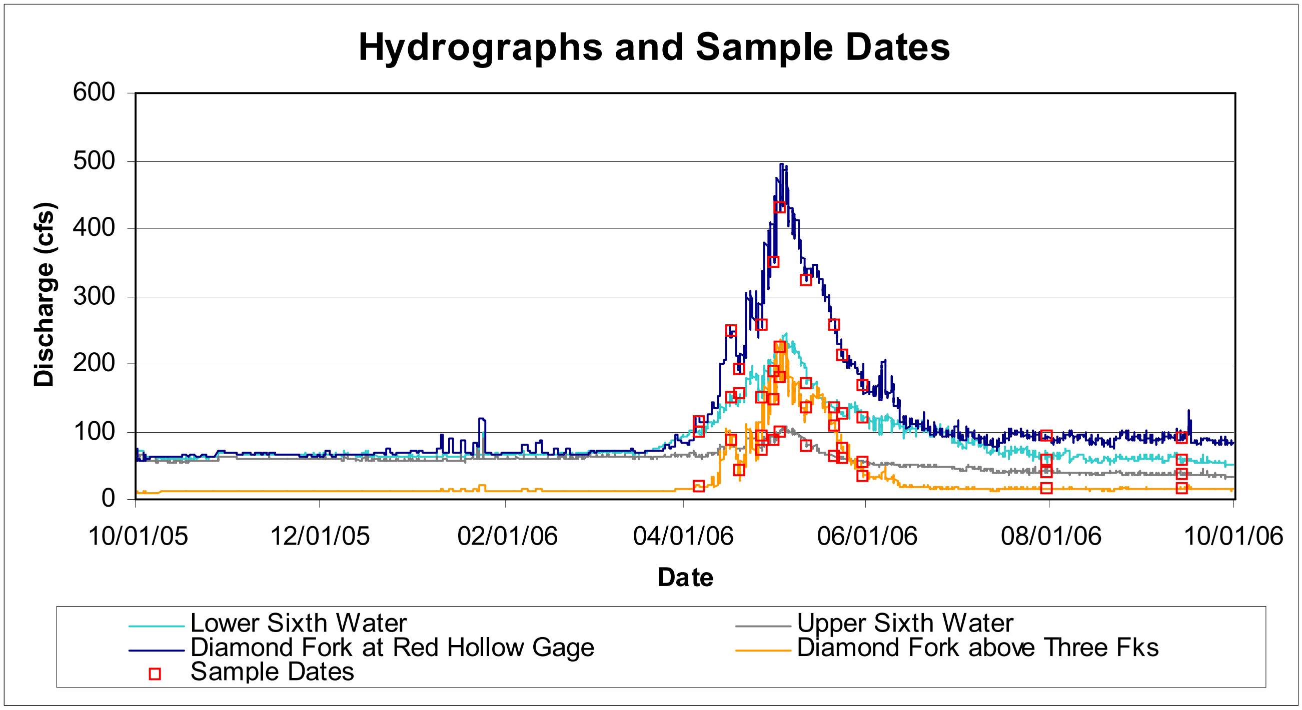


Figure 4.1. Hydrographs and sample dates for the various monitoring sites.

measurement location was re-established after it was destroyed in 2005. Unfortunately, the high sediment yield buried and ruined this stage/discharge measurement location again. In fall 2006 a new stage/discharge measurement location was established about 30 meters (m) upstream of the previous site; this site will be used for further studies.

4.2.2 Suspended Sediment Monitoring

Sediment samples were collected at fairly regular discharge intervals during the rising and falling limbs of the 2005 and 2006 spring runoff hydrographs and periodically during low flow (Figure 4.1). Average suspended sediment concentrations in the water column 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 Depth-Integrated Hand Line Type Model US DH-76 Suspended Sediment Sampler (Photo 4.2), which was dipped from the surface to the bottom of the water column at a minimum of ten equal intervals across the channel. Sample bottles were labeled in the field, stored until the end of the sampling season, and analyzed for total suspended sediments concentrations at the Utah State University (USU) Soils Lab using standard filter and oven-drying methods.

For each sample suspended sediment concentrations and stream flow 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 transport rate in tons per day. These values were used to develop an empirically derived suspended-sediment transport rating curve for each monitoring site, thereby showing the relationship between flow and suspended-sediment transport rate.

Photo 4.2. Depth-integrated hand line type model US DH-76 suspended sediment sampler.

4.2.3 Bedload Monitoring

Field samples of bedload were collected at the six sediment monitoring bridges using both 3- and 6-inch Helley-Smith type samplers (Photos 4.3 and 4.4), depending on vehicle access and wadeability of the sampling site. In 2005 all samples were collected with the 6-inch sampler, except at the Lower Sixth Water site where all samples were collected with the 3-inch sampler due to access limitations. In 2005 it was determined that the 6-inch sampler was not necessary based on the size of material in transport. Therefore, in 2006 the 6-inch sampler was only used when the sample site was not wadeable; otherwise the 3-inch sampler was preferable given the unevenness of the bed at most sites and the minimal disturbance caused by setting the sampler on the streambed (no sample contamination). Extreme care was used to avoid scooping or setting the sampler down in a way that influenced the sample.

To sample bedload the sampler was lowered onto the bottom of the channel. Ten 3-minute sub samples were taken at equally spaced locations across the active bed. The width of active bedload transport was estimated during each sample 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 millimeter (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. Before sorting digital photographs were taken of each sample using a penny for scale. These photographs were used to compare sample characteristics of the different sites and from different collection dates. Bedload samples (measured in grams collected with either the 3- or 6-inch sampler for 30 minutes) were converted to daily loads (in tons across the active channel width for the entire day). These values

Photo 4.3. Bedload sampling using the 3-inch hand-held sampler. Photo taken at the Diamond Fork above Three Forks monitoring site.

Photo 4.4. Bedload sampling using the 6-inch cable-operated sampler. Photo taken at the Monks Hollow monitoring site.

were plotted against stream flow at the time of sampling to develop an empirically derived bedload-transport rating curve for each sediment monitoring site. The rating curves show the existing relationship between flow and bedload transport rate at each sediment monitoring bridge.

4.2.4 Bedload Calculations

The Wilcock two-fraction sediment transport equation within BAGS, bedload-transport modeling software program developed by the U.S. Department of Agriculture's Forest Service Rocky Mountain Research Station, was used to model bedload transport at each bridge. The water discharge, typical cross section, reach average water surface slope, surface grain-size distribution, and total weight of each bedload sample—including gravel/sand fractions—were entered into the BAGS program. The output results were graphed and compared with the sample data collected at the sediment monitoring bridges in the study site. The Wilcock two-fraction model did not represent the transport results well when all the bedload data were used in the calibration. All of the sediment monitoring sites were either over estimated at peak flow or under estimated at base flow. It was decided that the high-discharge bedload transport samples best represented the rate of gravel/sand transported in the incoming loads, and so the three highest values were used in the Wilcock equation while the other bedload samples were marked as outliers. This input adjustment to the Wilcock equation provided rating curves that represented the raw data more accurately. The empirically derived rating curves for each site were also used to calculate the total annual bedload and compare results from the Wilcock equation.

4.2.5 Total Load Calculations

The empirically derived rating curves are assumed to best represent suspended sediment transport, whereas both empirically derived bedload rating curves and the Wilcock two-fraction sediment transport equations were used to calculate total bedload transport. The daily suspended sediment and bedload transport rates (or daily loads) were calculated by applying the rating curve (power equation derived for each monitoring site) to the discharge values as described in section 4.2 (Table 4.1). The daily transport rates were summed for total annual loads for each study site (Appendix 4A, Table 1).

4.3 SEDIMENT TRANSPORT RESULTS

4.3.1 Sediment Transport / Flow Relationships

According to data collected over the past 2 years, there is almost no relationship between flow and bedload transport on Sixth Water Creek and a fairly weak relationship on Diamond Fork Creek below Three Forks (Figure 4.2). The "best fit line" could almost be drawn at any angle through the Sixth Water Creek data points (Figure 4.2). Fine- and coarse-grained sediment transport are very active in Sixth Water and Diamond Fork Creeks, particularly during summer instream flows when transport rates would, under natural flows, approach near zero in this watershed (as evident from comparing data collected in Diamond Fork above Three Forks [Tables 1 and 2 of Appendix 4A, and Appendix 4B]). The ratio of peak flow to base flow is much lower in Diamond Fork Creek (less than 10:1) and even lower in Sixth Water Creek (less than 4:1), than would naturally occur in this mountainous setting and hydrophysiographic region. The repeatedly measured high-bedload

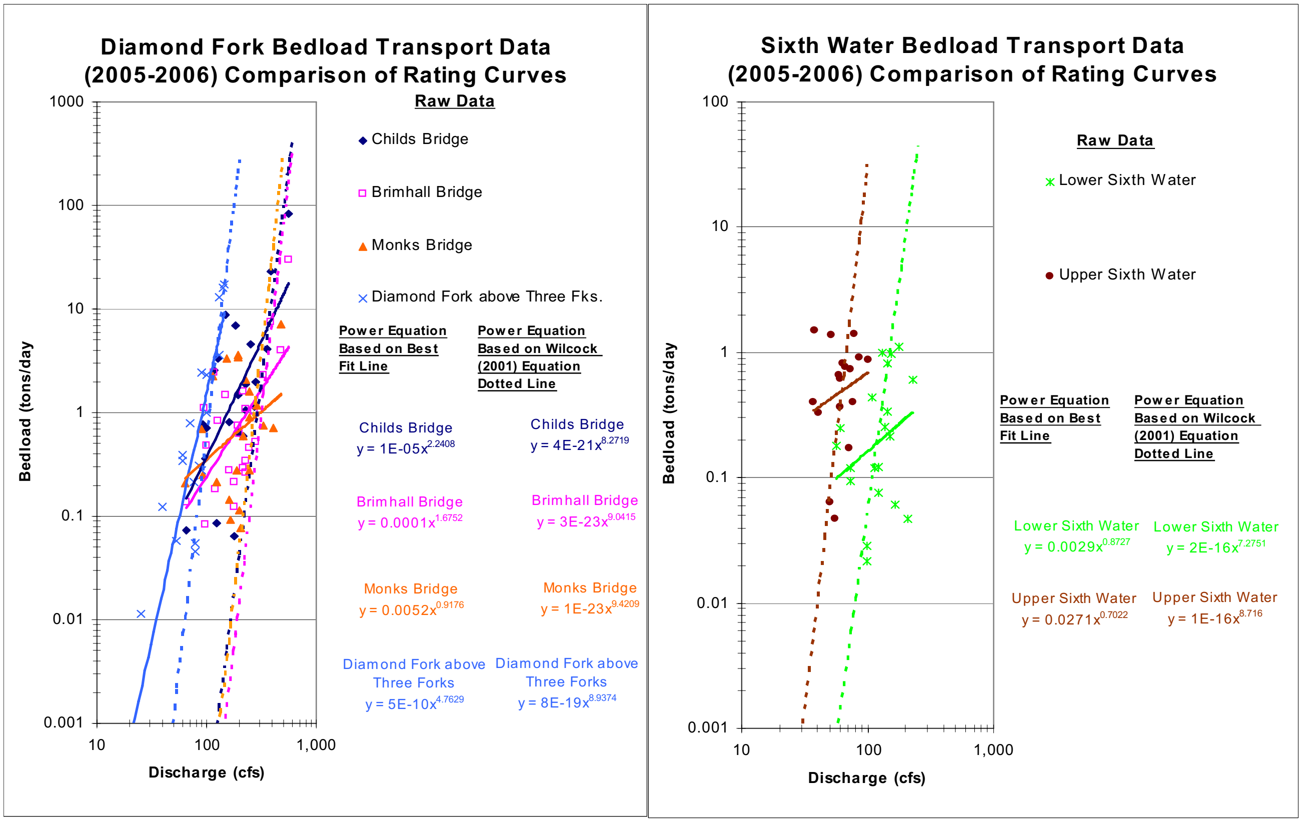


Figure 4.2. Power equations for bedload rating curves based on the Wilcock two-fraction transport equation (Wilcock 2001) (dotted lines) and a “best fit line” through empirical data (solid lines) for the Sixth Water and Diamond Fork Creek sediment monitoring bridges (2005 and 2006 data).

transport (both sand and gravel as seen in Appendix 4B) during summertime instream flows essentially flattens the otherwise-steep flow/transport relationship (i.e., rating curve) as shown in the comparison between observed (empirical data/best fit line) and predicted (Wilcock 2001) power equations for bedload transport at the five affected sediment monitoring bridges (Figure 4.2). The observed verses predicted relationships for bedload transport (steepness of the rating curves) are much more similar at the Diamond Fork above Three Forks monitoring site (Figure 4.2), which is the only site unaffected by imported flows.

Relatively high summertime bedload transport rates in Sixth Water Creek likely embed cobbles and other protruding particles in Diamond Fork Creek during low flow, which in turn increases supplies and transport rates in Diamond Fork Creek during high flows. An increase in cobble embeddedness alters the physical conditions of the bed during low flow to the point of enhancing bedload transport during both low- and high-flow periods (Figure 4.2). Over time, the interstitial spaces of streambed facies fill up and are covered by fine-grained material (fines), eventually reducing the effectiveness of any protruding particles on the bed for creating “hiding places” around them as normally occurs in gravel-cobble bedded streams. The particle-size distribution of the streambed seems to change (become smaller or more filled with fines) seasonally during low flow and then is somewhat reset with clean gravel annually during peak flows. As a result, the Wilcock (2001) equation overestimates annual loads (Table 4.3), compared with the empirical data, supposedly because of seasonal variations in streambed particle-size distributions. For example, the D_{50} likely is smaller

Table 4.3 Comparison of annual loads based on the use of empirical equations and the "best fit" Wilcock (2001) bedload transport equation results.

CALCULATED ANNUAL BEDLOAD TOTALS USING DIFFERENT EQUATIONS (TONS/YEAR)						
Equation	SEDIMENT MONITORING BRIDGES					
	Upper Sixth Water	Lower Sixth Water	Diamond Fork above Three Forks	Monks	Brimhall	Childs
Empirical (Power Equation)	166	50	418	140	140	304
Wilcock (Two-fraction Model 2001)	422	312	2085	742	578	670

when pebble counts are performed in October than the actual D_{50} during peak flows (after many of the fine particles have been removed). This scenario could cause the Wilcock equation to overestimate transport during high flows. Furthermore, the empirical equation probably underestimates transport during high flow; however, it seems to more accurately estimate transport during low flow than the Wilcock equation.

The expected hysteresis pattern in suspended sediment loads is evident at all six monitoring sites as seen in the suspended-sediment rating curves (Figure 4.3). Suspended sediment loads are higher at any given flow during the rising limb of the hydrograph and lower at the same flow during the falling limb. Total suspended sediment concentrations are higher for a given flow when flows increase because flood waters mobilize sediments that have been stored on channel fringes and floodplain surfaces since the last flood event. Suspended sediment concentrations are much lower during the falling limb or when flows stabilize at certain stages for long periods of time. The suspended sediment data clearly show a separation between rising and falling limb concentrations. Therefore, separate rising and falling limb power equations (Figure 4.3) for each site were used to calculate daily loads of suspended sediment.

The bedload samples did not show any distinct patterns in the rising and falling limb data except for a weak correlation between discharge and transport rates. Power equations for both suspended sediment (Figure 4.3) and bedload (Figure 4.2) rating curves were applied to hourly discharge data measured or calculated at each monitoring site to generate sedigraphs (daily transport rates plotted over an entire water year) for each site (Figure 4.4).

4.3.2 Total Sediment Yields

The results are clear that water imports in Sixth Water Creek increase daily suspended sediment yields during base flows at all impacted reaches by approximately one order of magnitude (0.1 to 1.0 ton per day). Changes in suspended sediment yields caused by the imported water during peak flows are not as apparent. Daily suspended sediment loads peak at just over 100 tons per day from Sixth Water and Diamond Fork above Three Forks, respectively. Daily loads of suspended sediment peak at nearly 500 tons per day at all three lower monitoring sites in lower Diamond Fork Creek, indicating that three-fifths of the suspended sediment yield during peak flows come from tributaries and other sediment sources downstream of Three Forks. Over 90 percent of the daily suspended sediment yield during base flows come from Sixth Water Creek.

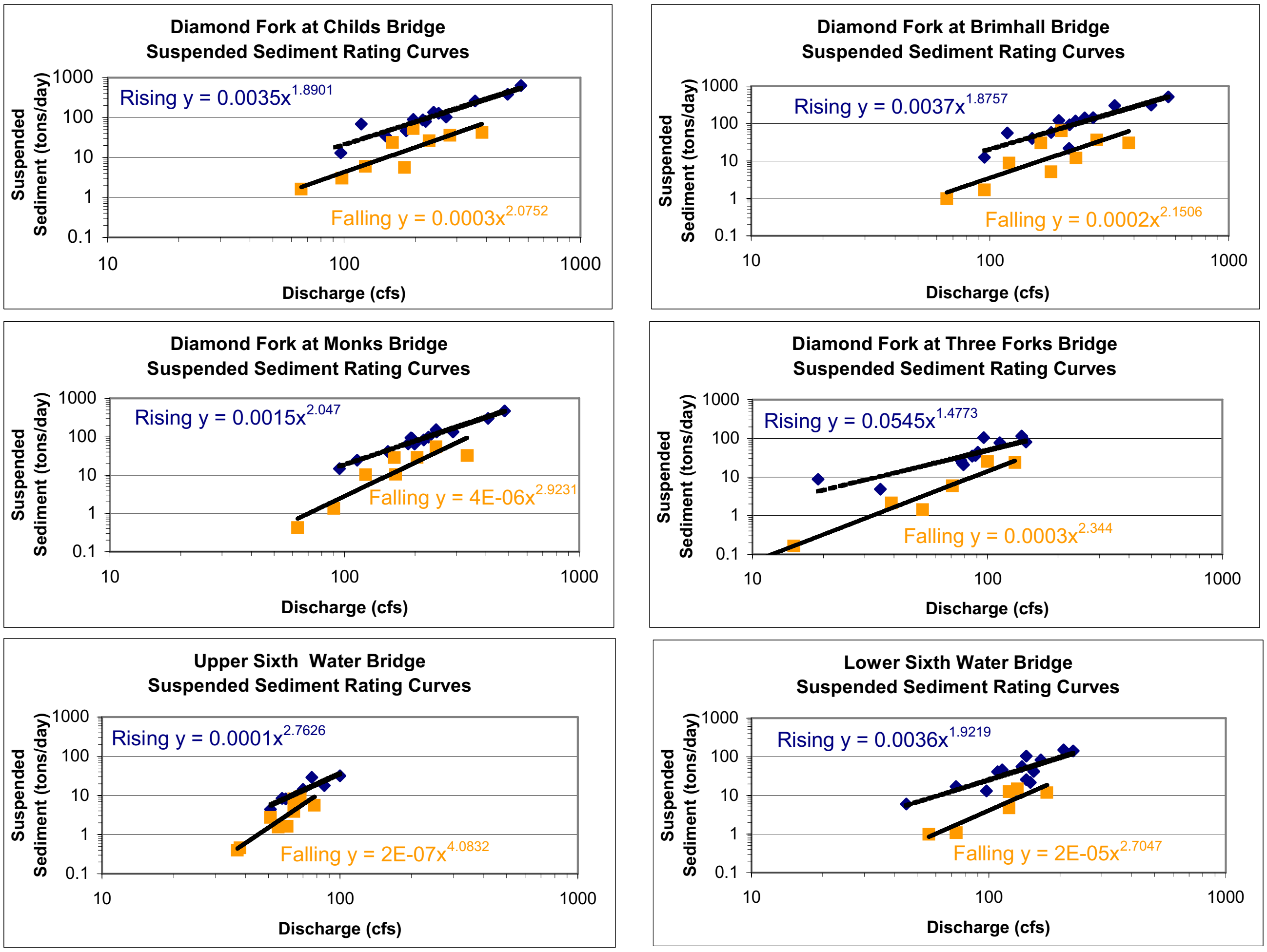


Figure 4.3. Empirically derived suspended-sediment rating curves for the Sixth Water and Diamond Fork sediment monitoring bridges (2005 and 2006 data).

The results also illustrate that water imports in Sixth Water Creek increase bedload transport (both sand and gravel) during base flow at all impacted reaches. Nearly 0.5 ton per day of bedload sediments is exported during base flows from upper Sixth Water Creek, with approximately 0.1 ton per day of bedload passing under the BH sediment monitoring bridge and entering the flatter reaches of lower Diamond Fork Creek. Most of this sediment (over 90%) presumably becomes deposited throughout the year and is temporarily stored in the low-velocity margins of the channel until annual spring runoff events export the stored material into Spanish Fork River. Seasonal fining of the bed impacts the pebble count results and causes the Wilcock equation to overestimate bedload transport rates during peak runoff compared with the empirical data at all monitoring sites except for Diamond Fork above Three Forks, which is the only site not affected by water and sediment imports. Approximately 32 tons per year of bedload sediments are exported from Sixth Water Creek during base flows and presumably become deposited in the flatter reaches of Diamond Fork Creek (Figure 4.4).

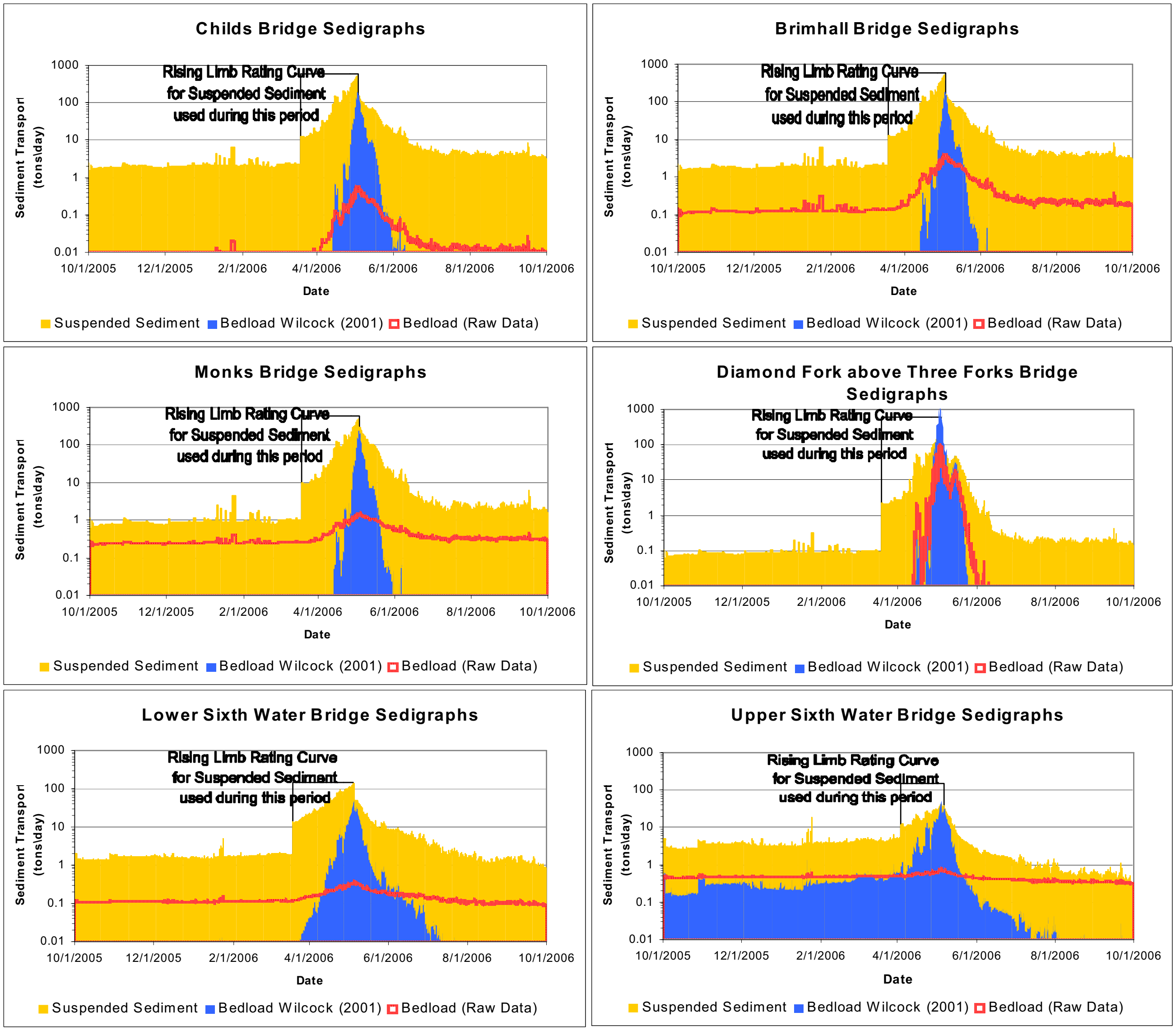


Figure 4.4 Daily sediment loads for the Diamond Fork and Sixth Water sediment monitoring bridges (2006 water year).

Annual loads (the sum of the daily loads computed between October 1, 2005, and September 31, 2006) were individually evaluated for each sediment monitoring site (Figure 4.5). The suspended-sediment yield dominates the sediment-transport regime in Diamond Fork Creek with an approximate export load of 7,600 tons per year in 2006, which was a relatively high runoff year. In total, approximately 6,900 tons of sediment were exported as suspended load and 700 tons of sediment were exported as bedload (Figure 4.5). Sixth Water Creek yields approximately 65 percent more suspended sediment than Diamond Fork Creek, primarily as a result of the increased transport rates during base flows (Figure 4.5). The majority of the bedload sediments are coming from Diamond Fork above Three Forks, during peak flows only. The abnormally high bedload yields coming out of Diamond Fork above Three Forks during peak runoff are probably associated with the removal of the culvert, placement of fill across the channel, and the subsequent large bar that formed

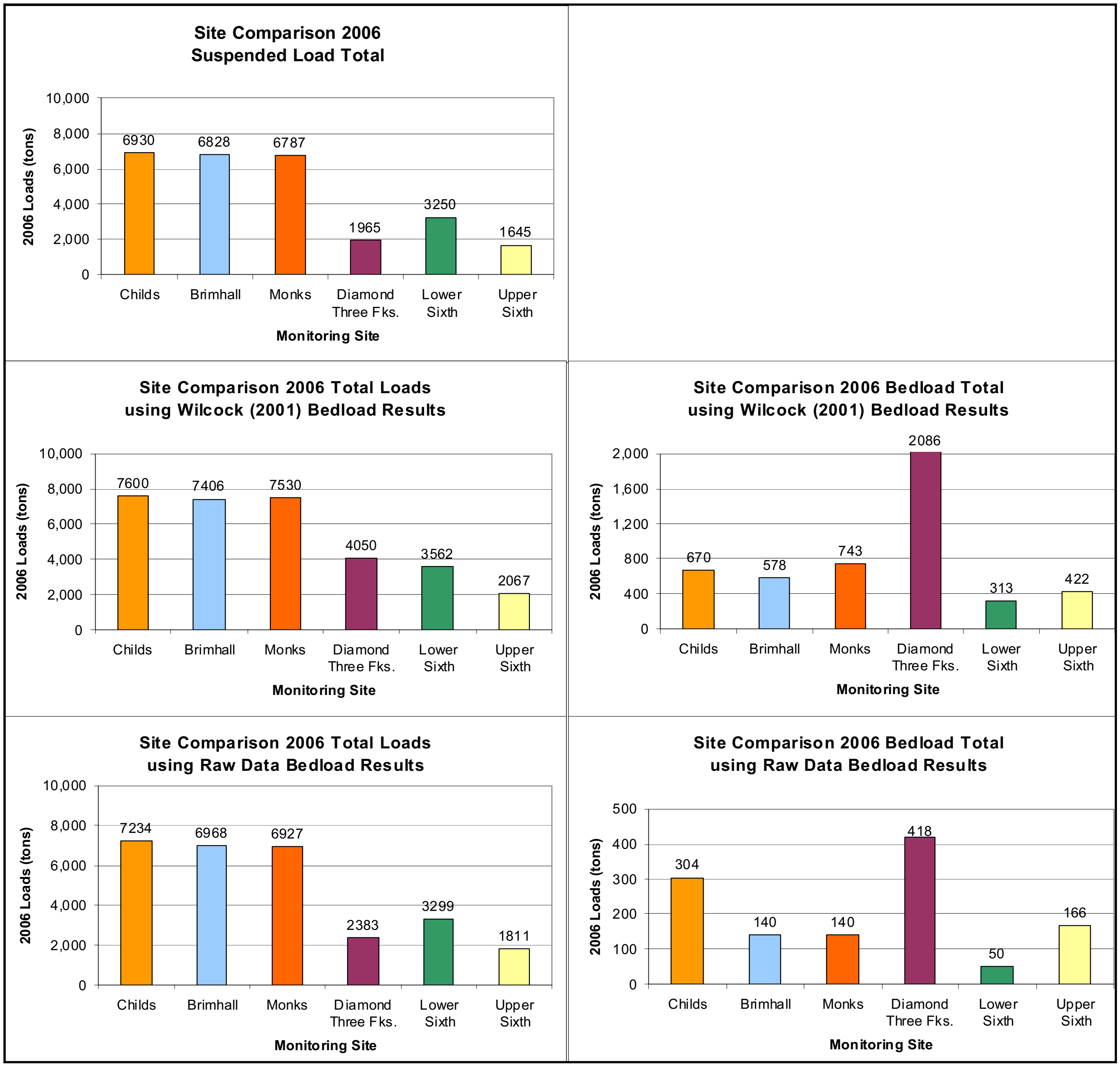


Figure 4.5 Total sediment yields for the Diamond Fork and Sixth Water monitoring bridges (2006 water year).

just above the confluence with Sixth Water Creek. Bedload transport rates at the Diamond Fork above Three Forks monitoring site will likely decrease dramatically when construction activities at the old culvert site are complete and the banks stabilize.

The proportion of sand to gravel in the bedload samples is relatively even at all sites except for Brimhall Bridge (Figure 4.6). There is approximately 20 percent more sand than gravel in the bedload samples from Diamond Fork above Three Forks and Sixth Water, and approximately 5 percent more gravel than sand at two of the three monitoring sites in lower Diamond Fork. It is not apparent why the proportion of sand to gravel is so much different at Brimhall Bridge than the other

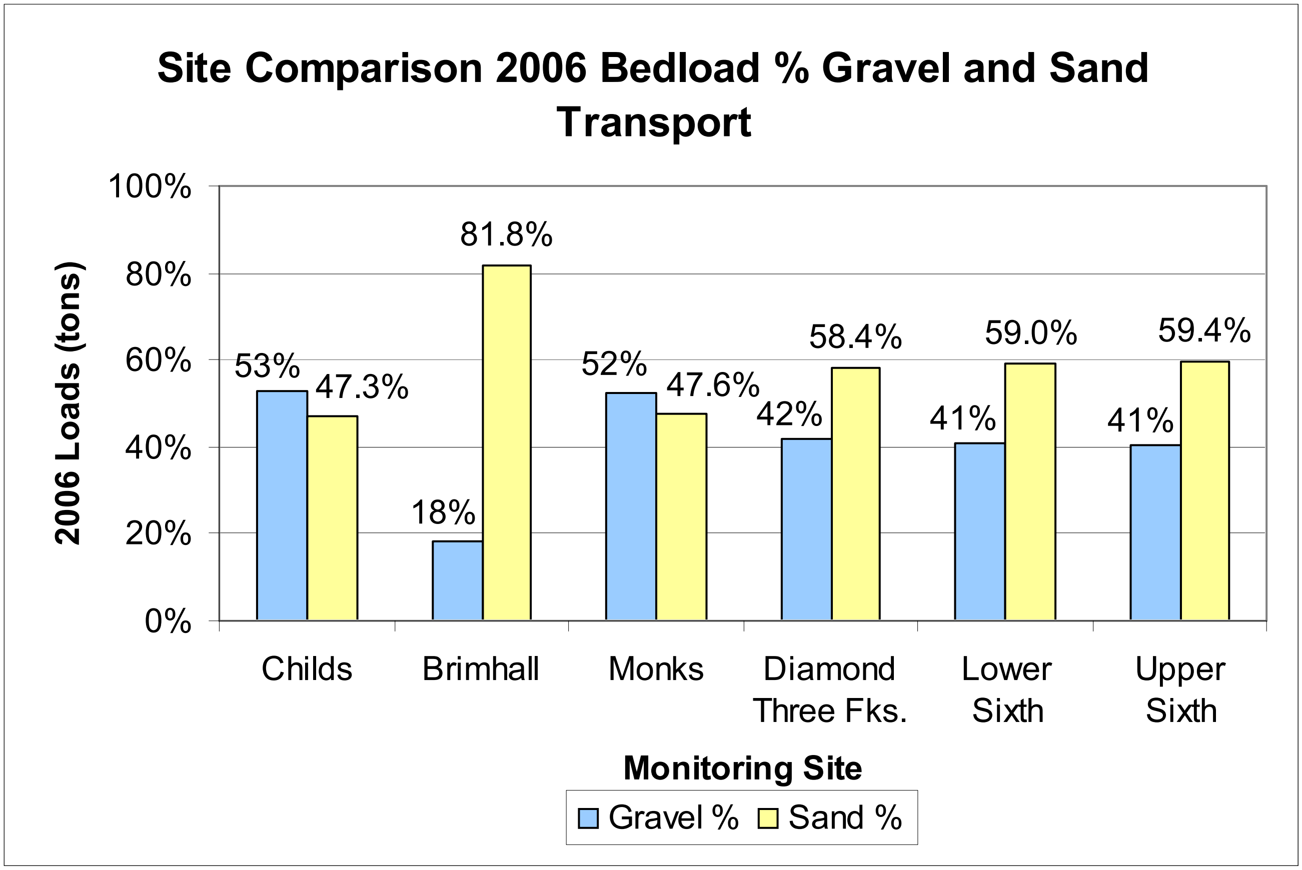


Figure 4.6 Proportion of sand and gravel in bedload samples for the Diamond Fork and Sixth Water sediment monitoring bridges.

sediment monitoring sites. The results for the proportion of sand and gravel are different than last year's results because the 2005 proportions were only representative of one sample, whereas the 2006 results were averaged from the proportions of all samples.

4.3.3 Sediment Transport During Established Instream Flows

The question about how the established instream flows may or may not affect water quality, fluvial processes, and channel conditions in the high-gradient Sixth Water Creek and in the lower-gradient Diamond Fork Creek is partially answered by the low-flow sediment data collected in 2005 and 2006 (Tables 1 and 2 of Appendix 4A, Figure 4.4). Two years of monitoring results show that the instream flows of 25 to 32 cfs for Sixth Water Creek and 60 to 80 cfs in lower Diamond Fork Creek significantly alter suspended-sediment concentrations, the duration of bedload transport, and total sediment yields in both stream systems. The current instream flows exceed bedload transport thresholds in these relatively steep channels, thus impairing water quality and degrading channel conditions. Temporal changes in transport and streambed particle-size distributions will be evaluated more carefully during the 2007 summer and fall seasons.

Water quality, siltation, and gravel-cobble embeddedness are influenced by suspended-sediment concentrations and sediment yields. Suspended-sediment concentrations and total sediment yield are significantly higher with the current instream flows than would occur naturally (without the imported water). The current instream flows cause year-round sand and gravel transport. No gravel and only small amounts of sand are transported at the Diamond Fork at Three Forks sediment monitoring bridge (Appendix 4A), a monitoring site unaffected by imported water. The data suggest that the established instream flows cause significant amounts of sand and gravel transport at all affected monitoring bridges. Therefore, the instream flows do affect fluvial processes and channel conditions in both Sixth Water Creek and Diamond Fork Creek during summer, fall, and winter months.

4.4 SEDIMENT-TRANSPORT DISCUSSION AND RECOMMENDATIONS

The first 2 years of sediment monitoring have been insightful. The watershed experienced average runoff in 2005 and above average runoff in 2006 with flows reaching 550 cfs in the lower reaches of Diamond Fork Creek. A potentially alarming problem is the continuation of fine- and coarse-grained sediment transport and the associated sedimentation and embeddedness, especially in the lower reaches of Diamond Fork Creek. The summertime instream flows are high enough to keep sediment more mobile than would occur under a natural flow regime. The geomorphic monitoring plan will be adapted in 2007 to focus on these potential concerns.

Sediment-monitoring results indicate that the established instream flows exceed thresholds for significant transport of suspended and bedload sediments. A large disparity in discharge rates between the Diamond Fork above Three Forks monitoring site and the other monitoring sites affected by water imports is seen at all times of the year, except during spring runoff (Figure 4.7). In an attempt to further illustrate the effects of imported water, natural hydrographs for 2006 (i.e., actual flows minus imported flows) were generated at specific locations within the study area (Figure 4.8). Although some differences are noticeable in the shape and duration of peak flows during spring runoff, base flows are nearly identical at the lower Sixth Water site and Diamond Fork above Three Forks site without the water imports (Figure 4.8). Additional comparisons (Figure 4.9) illustrate the fluvial geomorphic significance of the imported water where the threshold of gravel transport lies somewhere between natural base flows and the current “instream” base flows. The geomorphic monitoring plan in 2007 will include test flows in the impacted reaches to specifically determine transport thresholds.

Discharge of imported water in Sixth Water Creek causes the proportion between base flow and peak flow to be approximately 1:2 in Sixth Water Creek and less than 1:10 in Diamond Fork Creek, whereas the natural proportions would be greater than 1:20 as seen at Diamond Fork above Three Forks (above the confluence with Sixth Water and Cottonwood Creeks). The proportions of base flow to peak flow at Diamond Fork above Three Forks is more typical of a natural snowmelt-dominated stream in this hydrophysiographic area. In summary, the elevated base flows in Sixth Water Creek are unnatural and causing abnormally high yields of both suspended and bedload sediments during all times of the year. It is apparent that the elevated sediment yields are causing excessive sedimentation and embeddedness problems in downstream reaches.

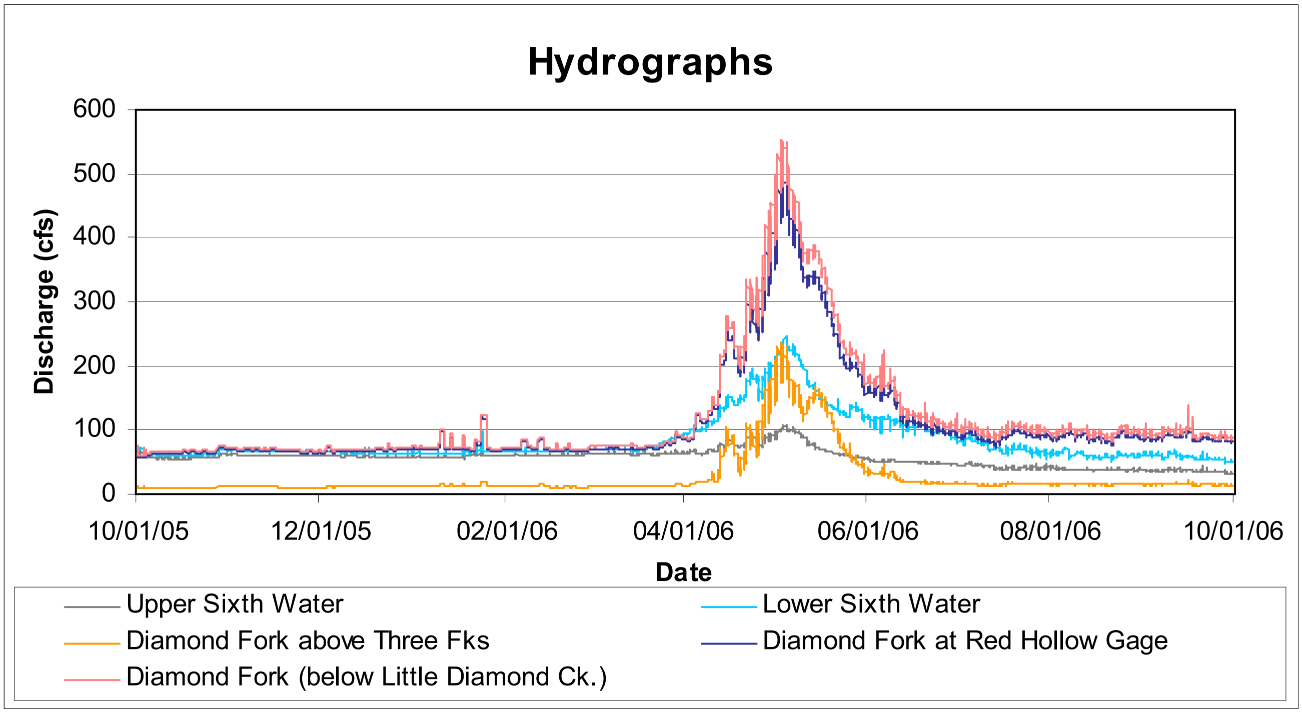


Figure 4.7 The 2006 water year hydrographs for various reaches in Sixth Water and Diamond Fork Creeks. Notice the difference in base flows between Diamond Fork above Three Forks and the other reaches affected by water imports.

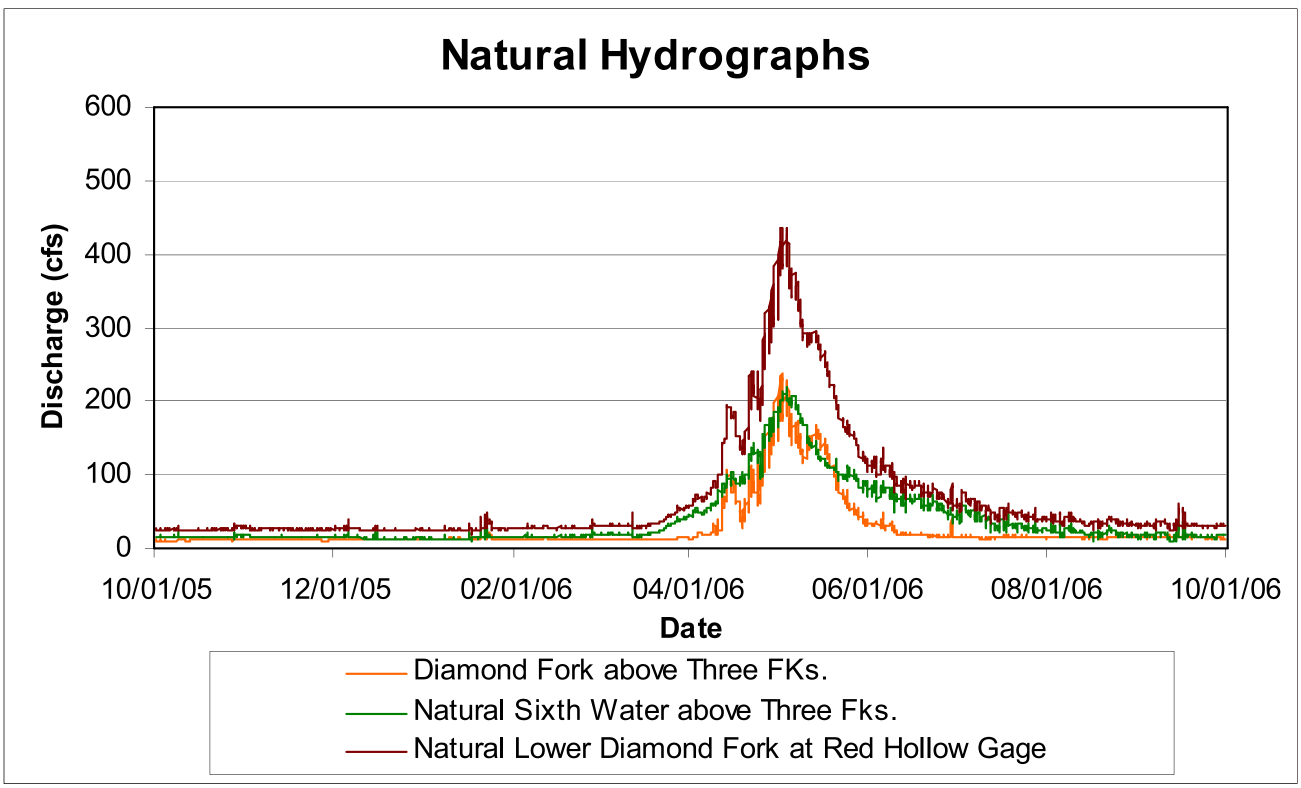
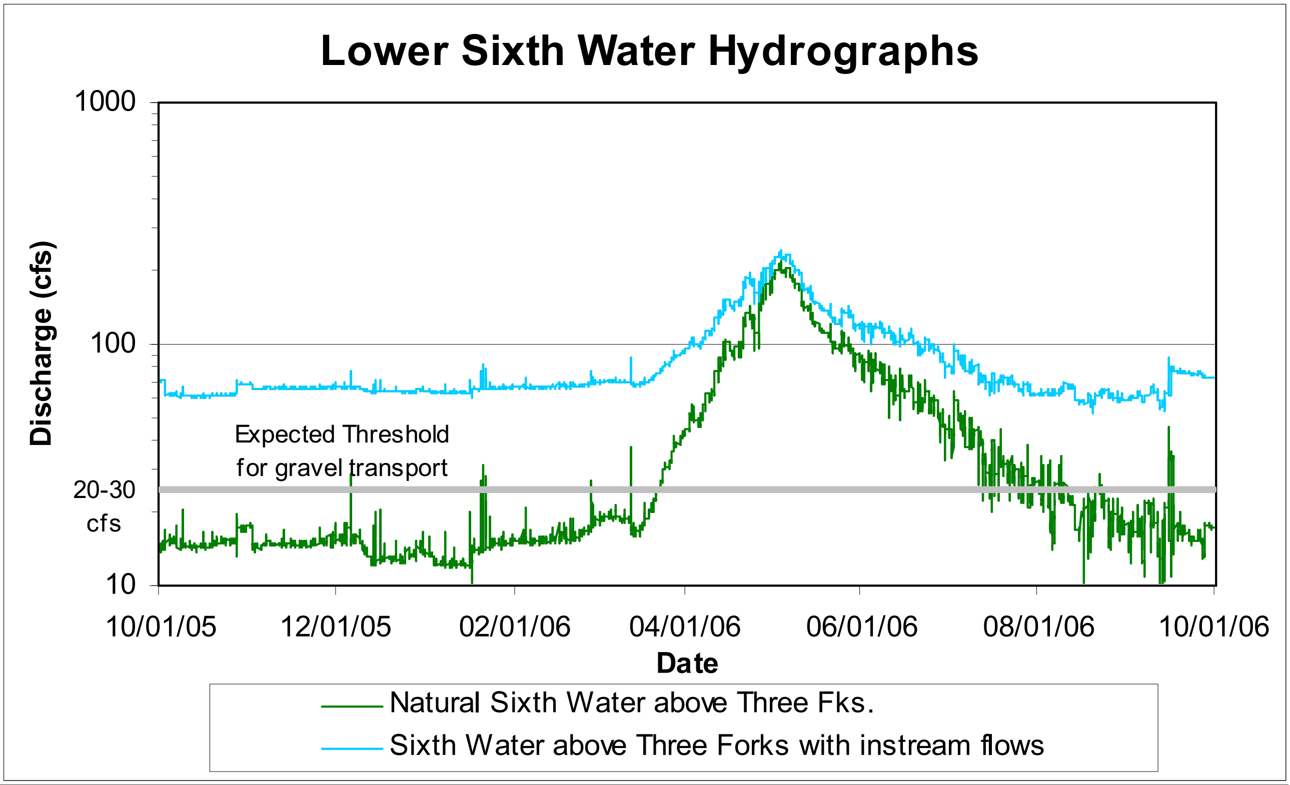


Figure 4.8 Hypothetical natural hydrographs for the 2006 water year for lower Sixth Water and lower Diamond Fork Creeks in comparison with upper Diamond Fork above Three Forks, which is not affected by water imports.



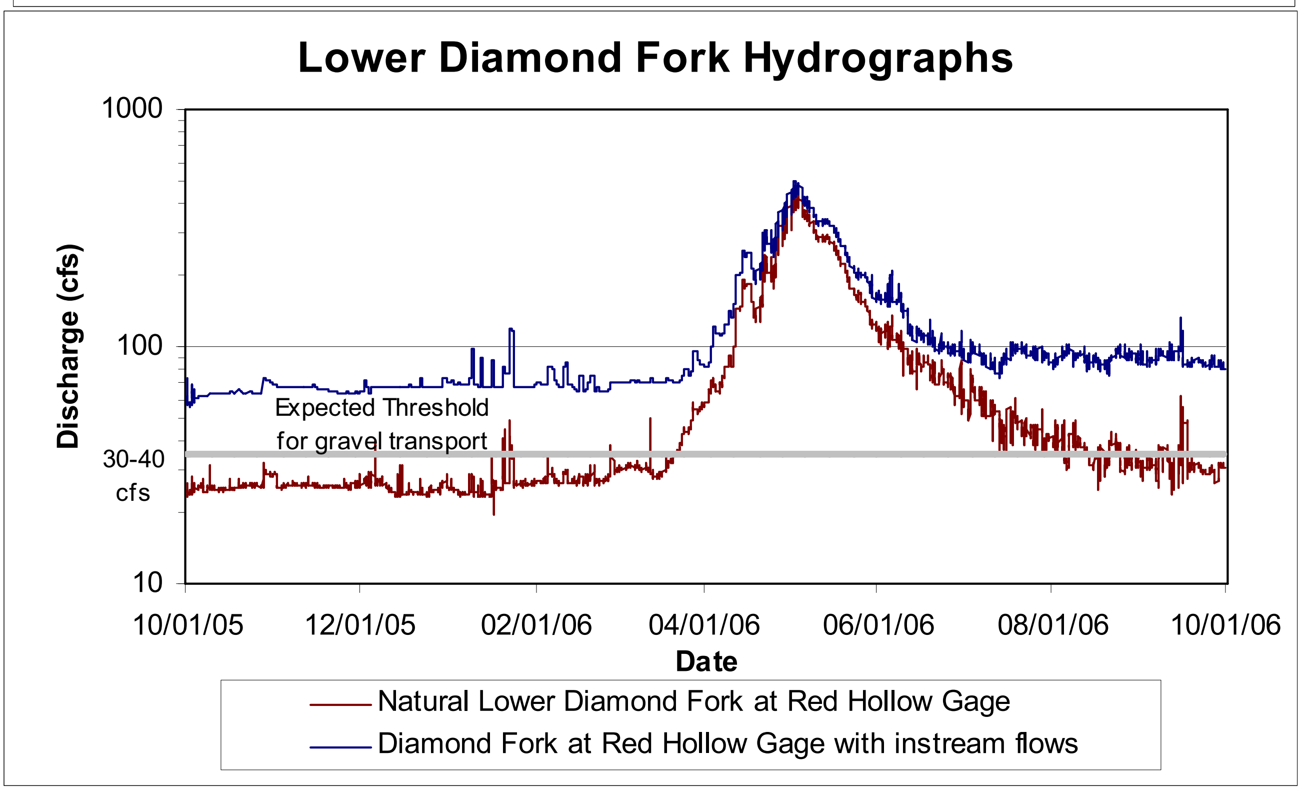


Figure 4.9 Changes in the 2006 water year hydrographs in Sixth Water and lower Diamond Fork Creeks caused by water imports. The expected threshold for gravel transport was estimated based on particle-size distribution data collected over the past 2 years when the substrate was fairly embedded.

In general, snowmelt-dominated, gravel-bedded rivers move very little bedload sediments during base flow. All study sites with imported water exhibited elevated bedload transport during base flow. In contrast, the Diamond Fork above Three Forks site yielded small amounts of bedload sediment during base flow. Establishing more natural base flows for Sixth Water and lower Diamond Fork Creeks would reduce the elevated summertime sediment loads that are currently be deposited in lower Diamond Fork Creek.

The channel is much steeper in Sixth Water Creek than lower Diamond Fork Creek; therefore, material originating in Sixth Water Creek is transported through the canyon and steeper reaches, and it often becomes deposited in the valley and flatter reaches of Diamond Fork Creek. The longitudinal profile or energy gradient of the study area (Figure 4.10, Table 4.4), combined with channel dimensions, affects the ability of each reach to stabilize under the new flow regime on a unique temporal scale. For example, a flat and shallow channel (i.e., Diamond Fork below Brimhall Bridge) that cannot pass incoming sediment loads will aggrade and probably migrate laterally more significantly and more often (annually and sometimes even seasonally) than a steeper reach (i.e., Diamond Fork above Brimhall Bridge) that is more in equilibrium with its incoming and outgoing sediment loads. It appears that accelerated channel migration occurs in the lower reaches of Diamond Fork Creek throughout the year, not only during high flow, as would normally be expected. Geomorphic recovery to a stable pattern, dimension, and profile from the types of perturbations that occurred in Diamond Fork and Sixth Water Creeks is interconnected with equilibrated sediment loads (equal incoming and outgoing loads): It and often takes a decade or more to regain stable conditions once the perturbations are removed, and the perturbations to the sediment-transport regime have been reduced with the Diamond Fork System but not removed entirely.

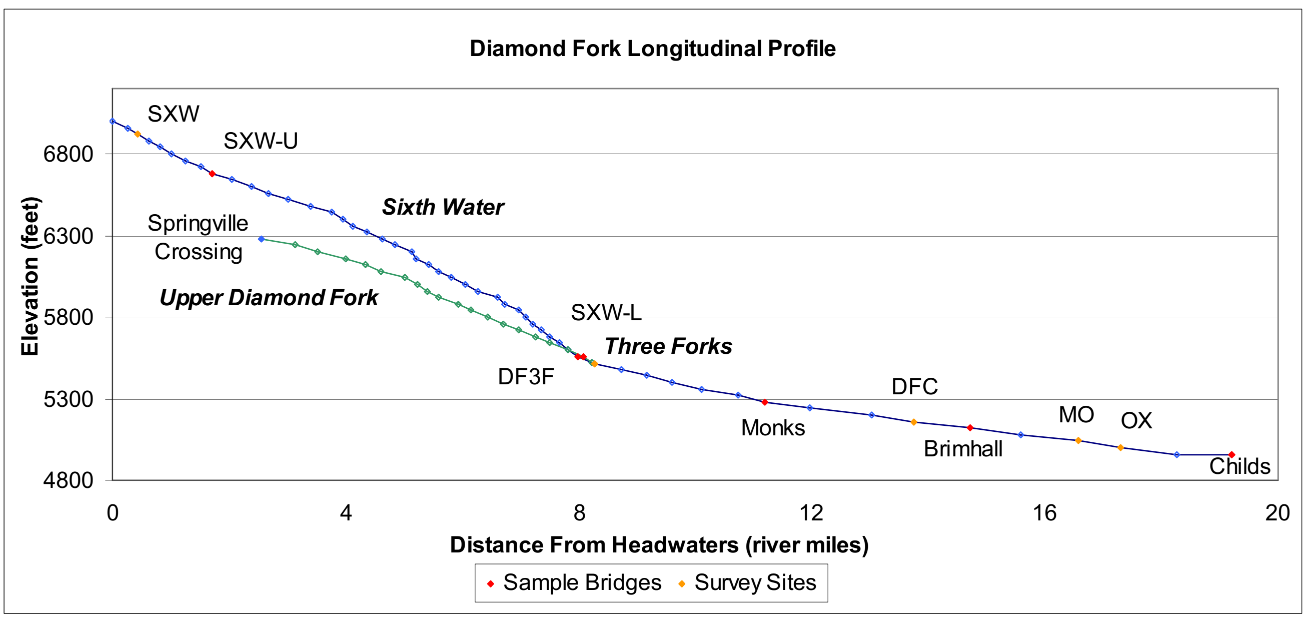


Figure 4.10. Sixth Water and Diamond Fork longitudinal profile from U.S. Geological Survey (USGS) topographical maps.

Table 4.4. Approximate channel slopes of various reaches in the Diamond Fork Watershed.

REACH	APPROXIMATE CHANNEL SLOPE (PERCENT)
SIXTH WATER CREEK	
Headwater to Ray's Crossing (Upper Sixth Water Bridge)	4.0
Ray's Crossing to Sixth Water Canyon	2.3
Upper Sixth Water Canyon	3.5
Lower Sixth Water Canyon to Lower Sixth Water Bridge (Three Forks)	5.3
DIAMOND FORK CREEK	
Springville Crossing to Sulfer Springs	1.7
Sulfer Springs	3.3
Diamond Fork at Three Forks	2.9
Three Forks to Monks Hollow	1.7
Monks Hollow to below Oxbow	0.9
Below Oxbow to Childs Bridge	0.1

5.0 MACROINVERTEBRATE MONITORING

5.1 INTRODUCTION

This section describes the results of the second year of quantitative benthic macroinvertebrate monitoring on Diamond Fork and Sixth Water Creeks following the completion of water conveyances that allow deliveries from Strawberry Reservoir, with the exception of minimum instream flows, to completely bypass the natural channels. One goal for the restoration of Sixth Water and Diamond Fork Creeks is to benefit the fishery, which appears to be negatively impacted by artificially high summer flows seen during the historical water delivery regime. Monitoring the macroinvertebrate community can provide information on changes in water quality and habitat, as well as an index for the quantity and quality of food available for the fishery. Such information can then be used to determine if and what types of adaptive maintenance activities are needed to assist in returning Diamond Fork and Sixth Water Creeks to a more desirable condition. Monitoring the health of the macroinvertebrate community will also help to ensure that the restoration is maintaining and improving biological integrity and recreation.

5.2 METHODS

In April 2006the four long-term monitoring sites described in previous chapters (Figure 1.3 and Figures 2.1–2.4) were not sampled due to high flows. Higher-than-normal air temperatures in spring 2006 resulted in an early runoff and inability to conduct sampling during the site visit. Following these higher flows (in early June), quantitative and qualitative sampling was conducted for benthic macroinvertebrates in three sites used to evaluate the water quality impacts of hydrogen sulfide inputs resulting from conveyance tunnel construction. In 2005 two sites were selected for this purpose, one “control” (~7.25 kilometers [km] upstream of Three Forks and believed to be free of hydrogen sulfide impacts) and one “impacted” site located downstream near the highest concentration of hydrogen sulfide inputs (~2.1 km upstream of Three Forks). These sites were referred to as the Sawmill Canyon (SC) and Sulfur Impact (SI) sites, respectively. In June 2006 the physical condition of the SC site was not conducive to effective sampling, and an alternate site was selected further upstream near a guard shack (GS) to provide a control sample. In September 2006 quantitative and qualitative sampling efforts were conducted in each of the seven monitoring sites.

In each sample location, one riffle was chosen as the site for collection of three replicate benthic macroinvertebrate samples. A pre-requisite of an appropriate site was sufficient size to permit collection of three samples and physical characteristics conducive to the sampling gear. Each of the individual samples were taken using a Hess-type, cylindrical, square-foot bottom sampler with a 250-micron mesh net. The requirements for sampling with this device include substrate sizes ranging from gravel to small cobble, water depth of less than 2 feet, and water velocity that was not too great to prevent holding the sampling gear in place. Hess samplers provide a quantitative estimate of both the density (number per area) and composition of the macroinvertebrate community in riffle-type habitats within each monitoring site. Since similar habitat types were sampled in each site using the Hess sampler, estimates of richness and abundance are directly comparable among sites.

In addition to the three samples collected with the Hess-type sampler, one multi-habitat, composite, kick-net sample was collected at each site. This sample was comprised of 20 individual samples collected in various habitat types, in proportion to their abundance within the site, using a D-frame kick net (Barbour et al. 1999). At the SI and SC sites, a multi-habitat sample was collected within a 200-m reach including the quantitative Hess sample sites. In each of the 20 sample sites a 0.5-m area of substrate was disturbed in front of the D-frame kick net 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. Areas with low velocity or large amounts of aquatic vegetation 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 organisms within the benthic macroinvertebrate samples. Samples were spread over a gridded pan and sub-sampled by randomly selecting a grid and sorting and identifying all organisms within that grid.Grids were randomly selected and sorted until either 500 organisms had been picked or the entire sample had been sorted. Macroinvertebrate counts from the sorted grids were extrapolated to the remaining grids to estimate 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 the family level, and worms, which were identified to the class level. Quality assurance and control (QA/QC) procedures included a QA sorting on all samples to ensure at least 90 percent sorting efficiency. Also, a synoptic reference collection was created, which was checked by a second taxonomist to ensure taxonomic accuracy. The number of each taxa collected was then entered into a spreadsheet, which was used to generate a list of approximately 50 metrics that can be used as an index of the quality and health of the macroinvertebrate community. EcoAnalysts provided the raw data and metrics to BIO-WEST, along with the synoptic reference collections.

5.2.1 Data Analysis

Several commonly used metrics were selected to look for differences between the sites and seasons sampled in 2006. Total abundance of organisms observed in the 2006 Hess samples was converted into density estimates for the sample site using the 0.086-square-meter area for the open bottom of the Hess sampler (WILDCO 2006) and calculating the number of organisms per square meter. A variety of data transformations was used to fit the selected metrics to the normal distribution, and an analysis of variance (ANOVA) was used to test for differences among sites. Where appropriate, Tukey’s multiple comparison test was used to compare all differences between means. Differences in the selected metrics within sites were compared between seasons using multiple paired t-tests and Bonferroni-adjusted probabilities.

5.3 RESULTS

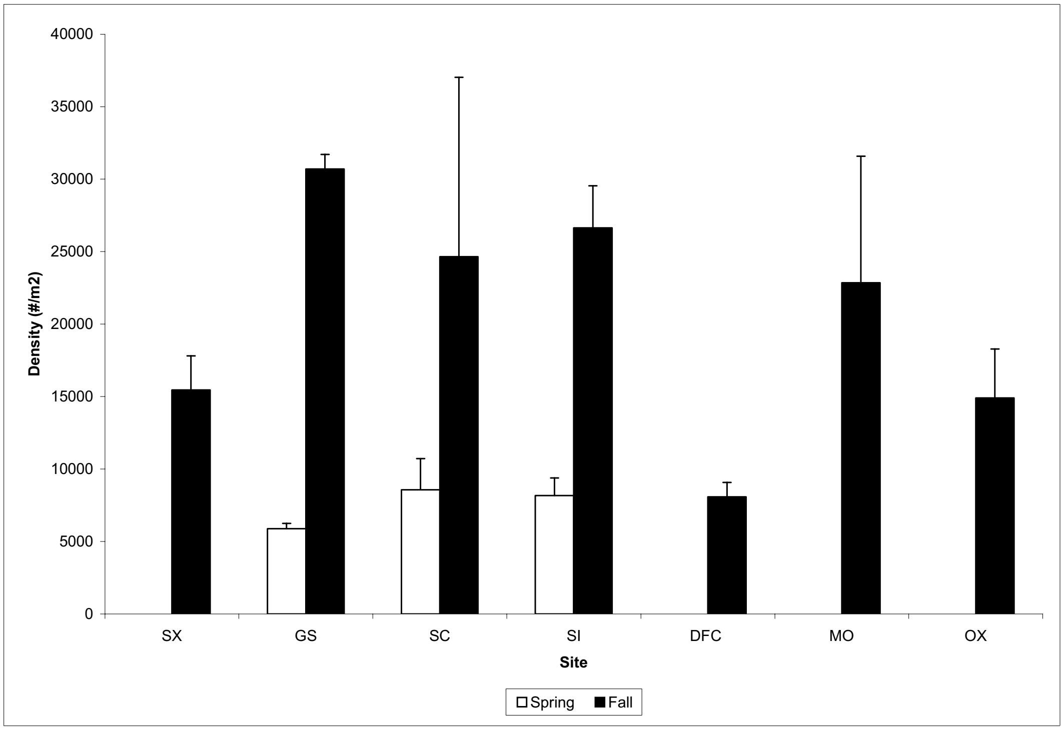
5.3.1 2006 Collections

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

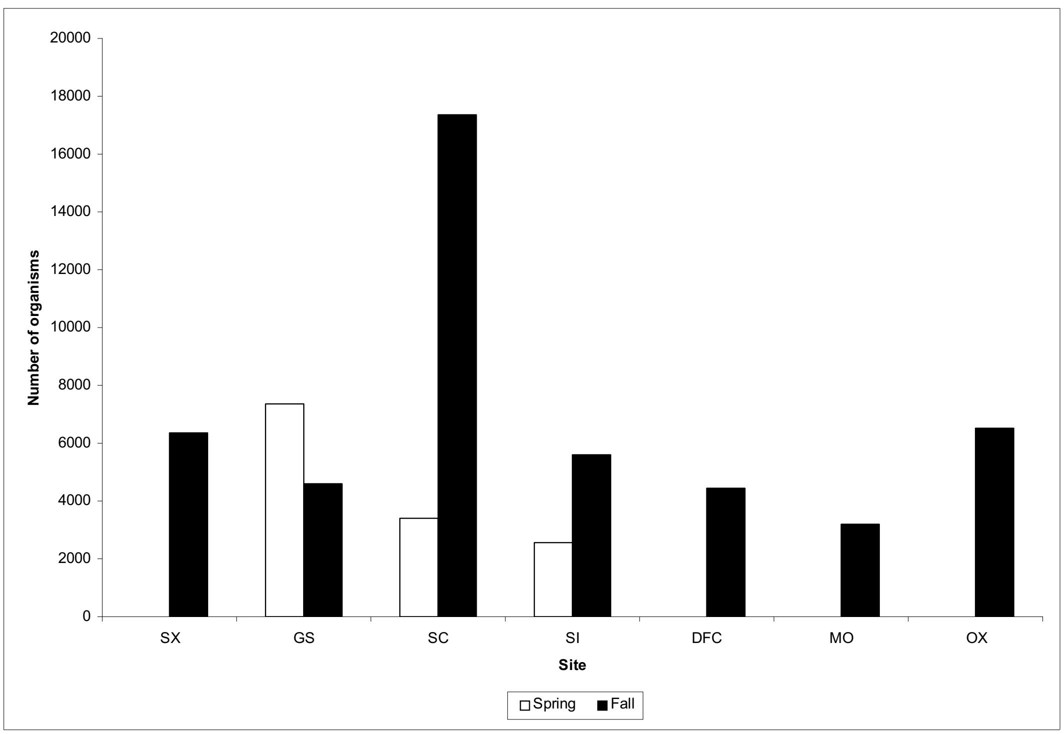
Estimates of the total density of macroinvertebrates provide a coarse method of comparing biological conditions across sites. It is “coarse” because a high overall density may not indicate a high-quality macroinvertebrate community if it results from an abundance of tolerant species. In fact, higher total density is often associated with nutrient enrichment and a degraded condition. The second “control” site selected for evaluation in 2006 (GS) had a total macroinvertebrate density similar to the original control (SC) and the impact (SI) sites, though slightly lower in spring and higher in autumn (Figure 5.1a). Despite variation in total density among the seven sample sites in September 2006, there were no significant differences among sites during either season. Comparing across seasons within a site, all three of the sites sampled during both seasons had higher total densities of all macroinvertebrates in September 2006 compared with June 2006 and significant differences between seasons for the GS and SI sites ($p < 0.002$ and $p < 0.02$, respectively).

In the qualitative kick-net samples, total abundance of macroinvertebrates was highest in the GS site among the three sites sampled in June 2006 (Figure 5.1b). Samples collected in the SC and SI in September 2006 had higher total abundance sites compared with the June 2006 samples in those same sites (there was a 5-fold increase in the SC site) while the GS site had reduced total abundance in September relative to the June sample. Among the four long-term monitoring sites, total abundance of macroinvertebrates was similar with the MO site yielding the lowest and OX the highest abundance. While the kick-net sample data indicate trends, the estimates of total abundance from these samples are less reliable than the density estimates generated from the Hess samples for two reasons. First, despite the attempts to standardize the amount of area sampled, there is no real control on how much area is sampled with the composite kick-net sampler. Second, unlike Hess samples that are all taken from similar habitats, the composite kick-net samples come from a variety of different habitat types, which may have a higher or lower macroinvertebrate density than riffles.

The EPT taxa are generally thought of as taxa sensitive to anthropogenic disturbance and provide a means of comparing macroinvertebrate community dynamics among sites at a finer scale than comparing total density of all organisms. Hess samples had low EPT density in all three sites sampled in June 2006, but EPT density estimates were higher and more variable among all sites sampled in September 2006 (Figure 5.2a). Although the average EPT density was higher in September in each of the three sites sampled during both seasons in 2006, only the GS site was significantly higher ($p < 0.02$). Among all sites the SI site had the lowest density of EPT taxa during both of the seasons sampled, but there were no significant differences. Both the SC and GS sites had

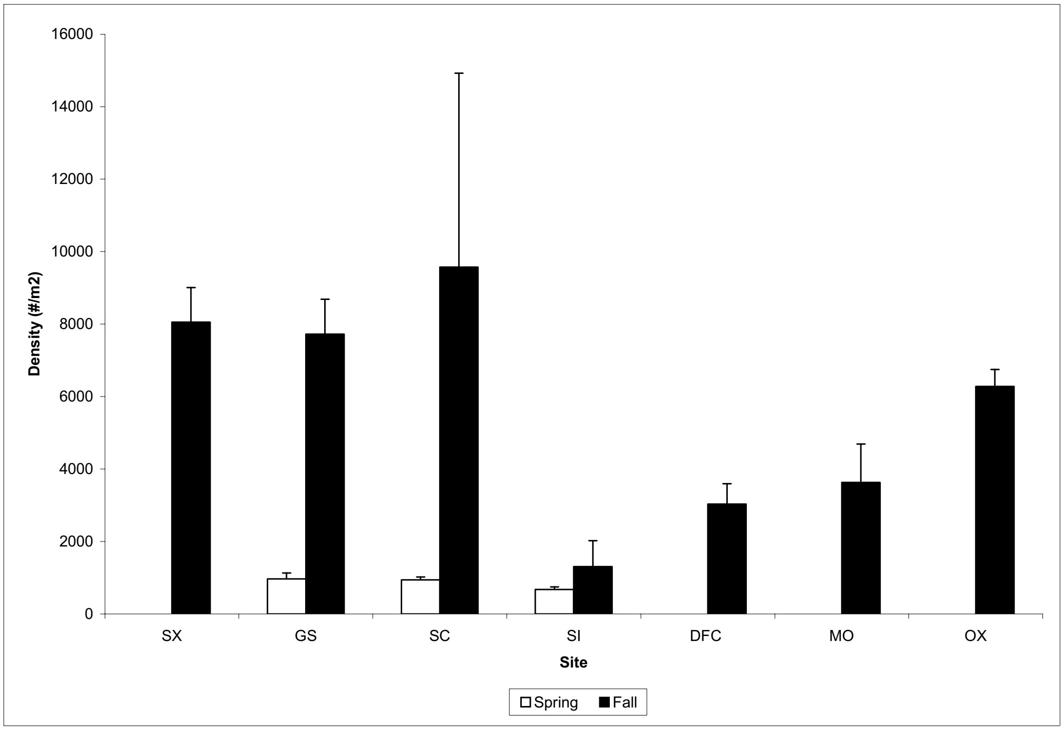


(a) Hess samples.

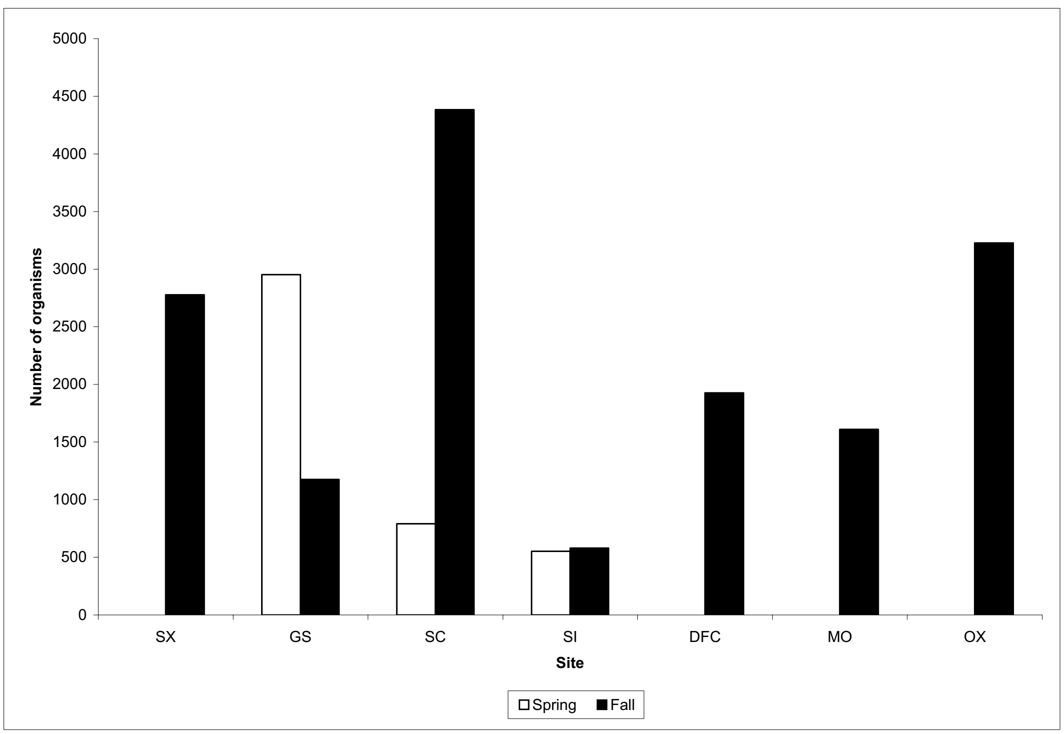


(b) Kick-net samples.

Figure 5.1. Average density of all macroinvertebrates collected in Hess samples (a), and relative abundance of all macroinvertebrates from qualitative kick-net samples (b) taken in June (spring) and September (fall) 2006.



(a) Hess samples.



(b) Kick-net samples.

Figure 5.2. Average density of EPT taxa collected in Hess samples (a), and relative abundance of all macroinvertebrates from qualitative kick-net samples (b) taken in June (spring) and September (fall) 2006.

high EPT density in the autumn, but there was high variability in density estimates among the three SC Hess samples.

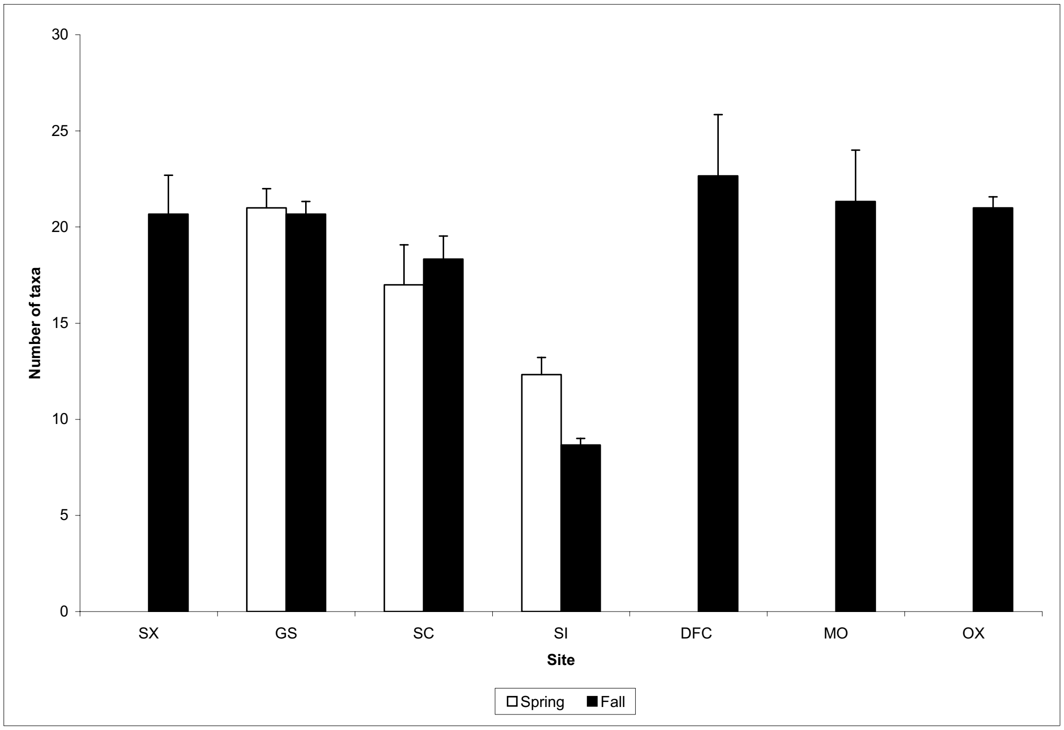
The qualitative kick-net collections (Figure 5.2b) yielded different results than the Hess samples taken in June; the GS sample had a much higher abundance of EPT taxa than either the SC or SI samples. In the samples taken during September 2006, the SC, OX, and SXW sites had a higher number of EPT taxa than the other samples. One consistent result between Hess and kick-net samples was that the SI site had the lowest EPT density/abundance among all sites.

Taxa richness provides an index for evaluating community diversity, but as with total density, it does not discriminate taxa by tolerance to altered conditions. As in 2005 taxa richness of macroinvertebrates in Hess samples (Figure 5.3a) and kick-net samples (Figure 5.3b) was lowest at the SI site in both June and September 2006. Average taxa richness in Hess samples from the SI site was significantly lower than in samples from all other sites during both collection times ($p < 0.02$). In September 2006 all sites had very similar taxa richness, with the exception of SI. Total taxa richness from qualitative kick-net samples indicated that the three sites sampled in June had similar taxa richness, which was much higher than any of the September samples. As in the Hess samples, taxa richness was lowest in the SI site during both seasons.

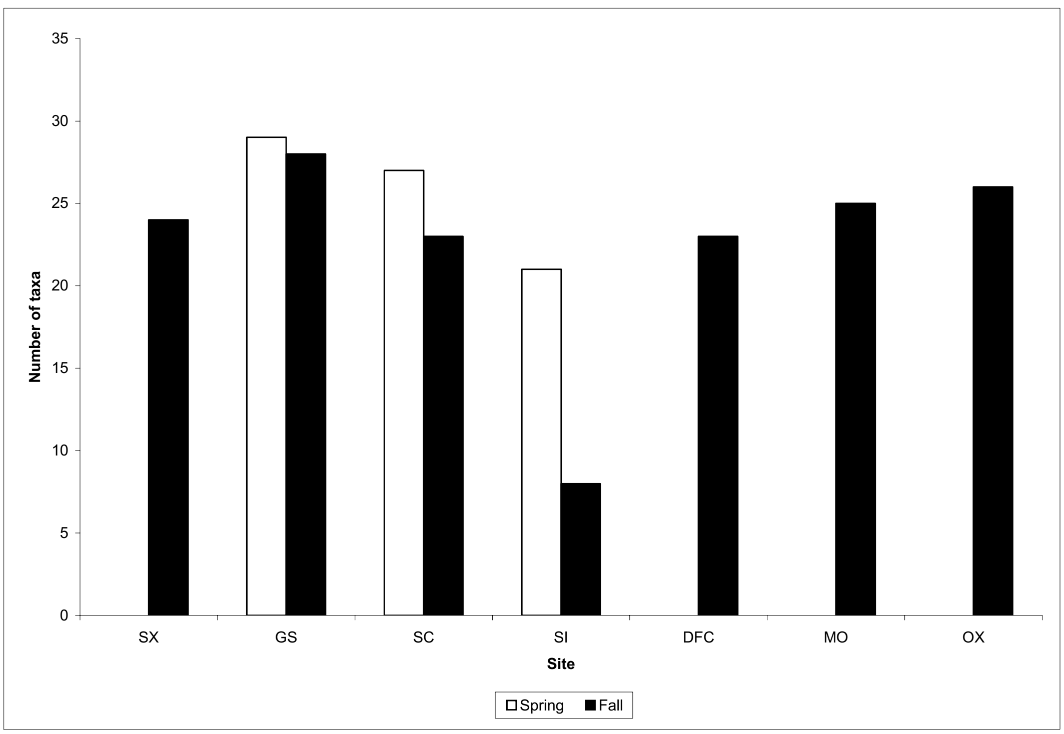
The EPT taxa richness followed a trend similar to total taxa richness (Figures 5.4a and 5.4b). The average EPT taxa richness from SI site Hess samples was the lowest value among samples in each season. The difference was not significant in June, but EPT taxa richness at the SI site was significantly lower than all sites (except SC) in September 2006 ($p < 0.02$). There was also a significant decrease in EPT richness at the SI site between June and September 2006 ($p < 0.01$); while values were also lower in September in the other two sites, no significant difference was observed. Qualitative kick-net samples also yielded the lowest EPT taxa richness at the SI site in each season and showed a decline between June and September in each of the three sites sampled during both seasons.

The HBI provides an indication of the overall pollution tolerances of the macroinvertebrate community in a site from the taxa collected. This index has been used to detect nutrient enrichment, high sediment loads, low dissolved oxygen, and thermal impacts (Hilsenhoff 1988), but it was originally developed to detect organic pollution. Individual families were assigned an pollution-tolerance 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.

As in 2005 the SXW site had the lowest HBI value, and SI had the highest HBI value in Hess samples (Figure 5.5a) and qualitative kick-net samples (Figure 5.5b) in both June 2006 and September 2006. The average HBI value from Hess samples at the SI site was significantly higher than at the other two sites in June and all but the GS and MO sites in September 2006 ($p < 0.03$). The average HBI value at the SXW site was also significantly lower than at all sites in September 2006 ($p < 0.001$). The HBI values were similar in June and September in each of the three sites sampled during both seasons in both Hess and qualitative kick-net samples.

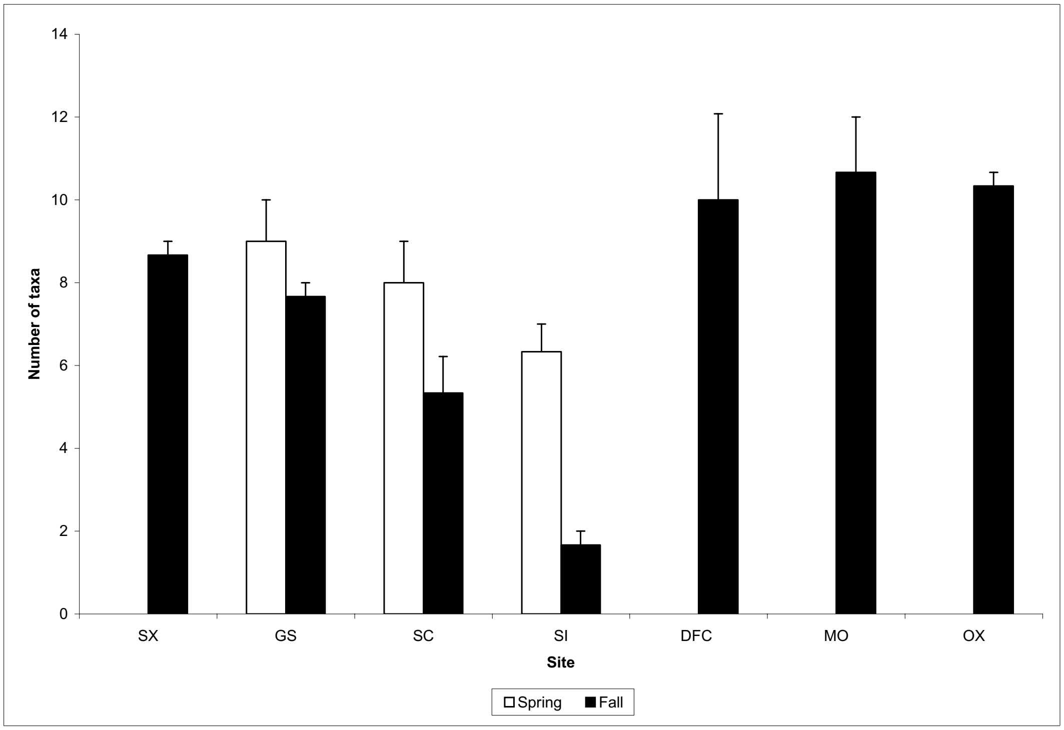


(a) Hess samples.

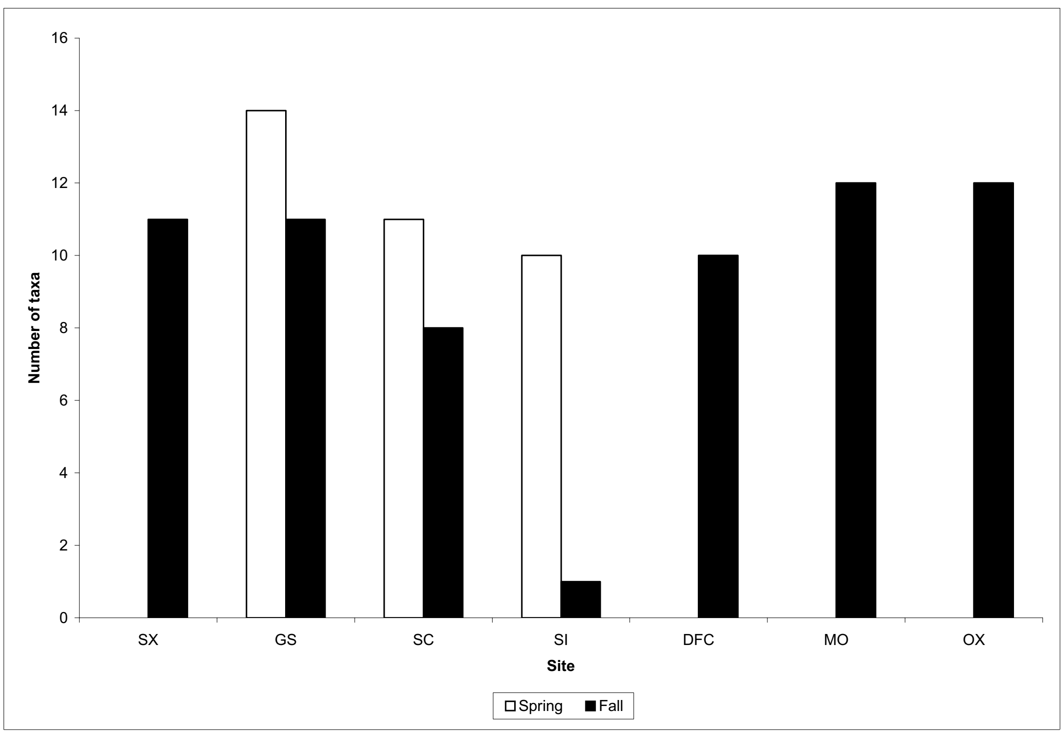


(b) Kick-net samples.

Figure 5.3. Average taxa richness in Hess samples (a), and taxa richness in qualitative kick-net-samples (b) collected in June (spring) and September (fall) 2006.

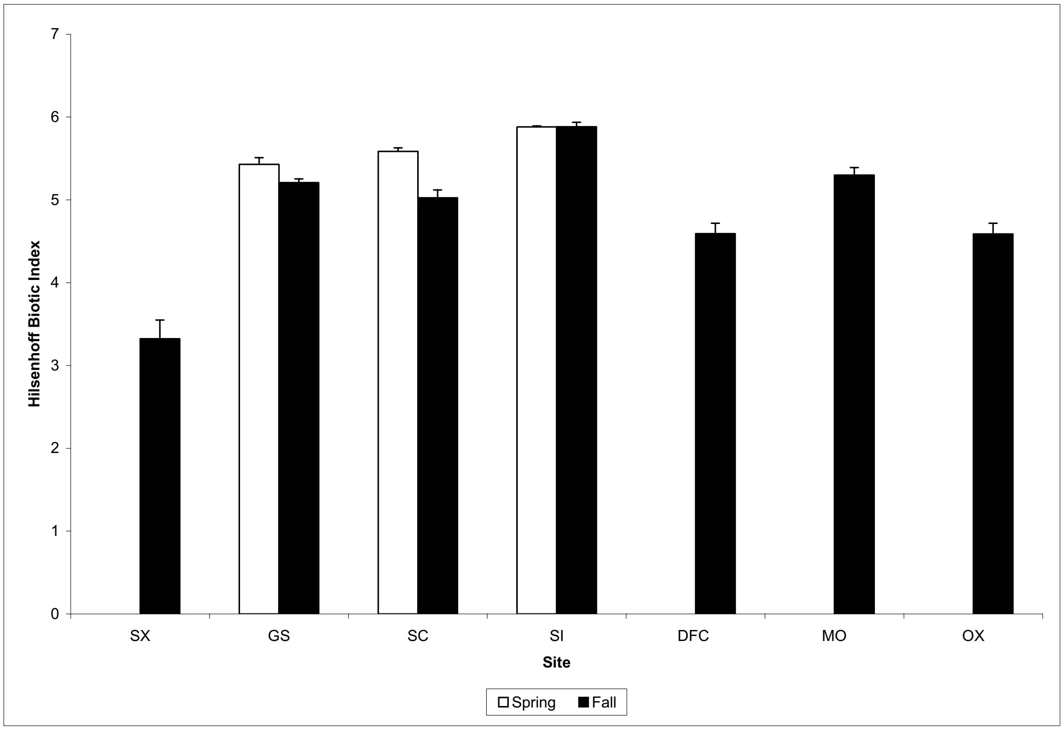


(a) Hess samples.

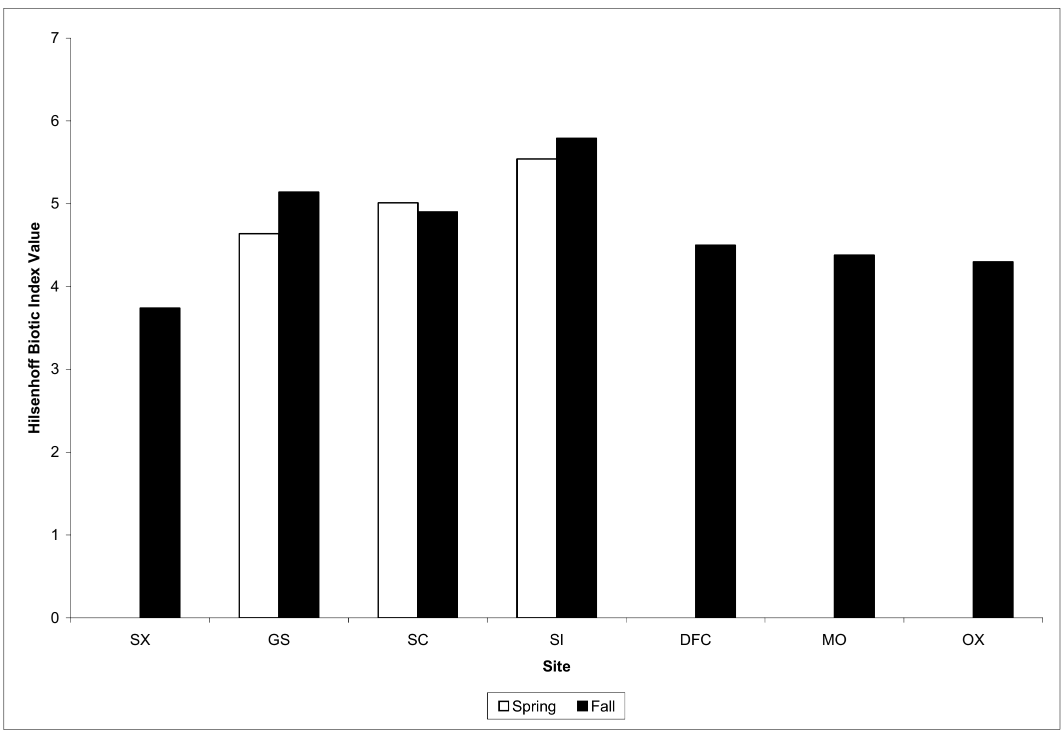


(b) Kick-net samples.

Figure 5.4. Average EPT taxa richness in Hess samples (a), and EPT taxa richness in qualitative kick-net samples (b) collected in June (spring) and September (fall) 2006.



(a) Hess samples.



(b) Kick-net samples.

Figure 5.5. Average Hilsenhoff Biotic Index (HBI) value from Hess samples (a), and HBI value from qualitative kick-net samples (b) collected in June and September 2006.

Examining the proportion of the macroinvertebrate community that is comprised of the three most dominant taxa provides an index of evenness in the community. Up to 21 percent of the total number of organisms might be found in the most dominant taxon in high-quality streams in the Wasatch and Uinta Mountains, while the three most dominant taxa might comprise up to 50 percent of the total number of organisms (Grafe 2002a, Lester 2005). Additionally, examining the three dominant taxa at a site can provide additional information about what may be impacting that site. As in 2005 the SI site had the highest percentage of its community comprised of the three most dominant taxa in each season in 2006, in both Hess (Figure 5.6a) and qualitative kick-net samples (Figure 5.6b). The higher proportion of the three dominant taxa in the SI site, compared with the other sites, was not significant in June, but it was significant compared with the DFC and OX sites in September 2006 ($p < 0.03$).

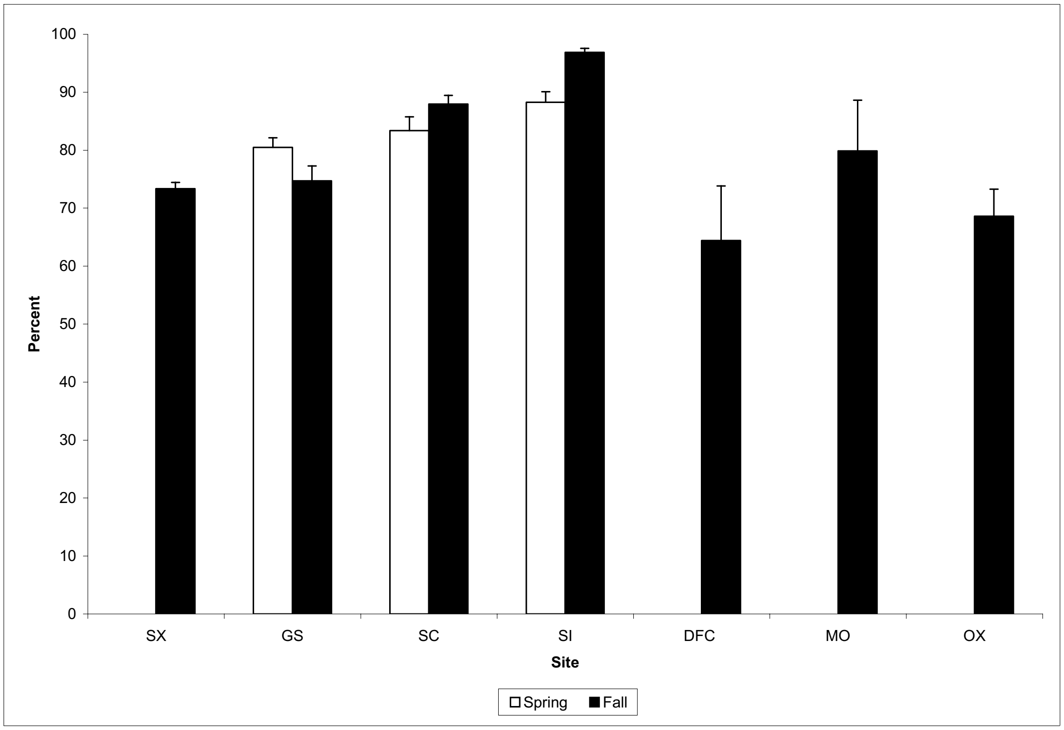
In June 2006 all three sites had only one EPT taxon among the three most dominant taxa, *Baetis tricaudatus,* which is not a pollution-sensitive species (Table 5.1). Midges (Chironomidae) were the most abundant taxa in each of the three sites sampled in June, and the other taxa was different in each site including the fast-colonizing blackfly (*Simulium* sp.), worms (Oligochaeta), and a riffle beetle (*Optioservus* sp.).

In June 2006 the SI site community was dominated by pollution-tolerant taxa in Diptera order (true flies). A few pollution-intolerant taxa were found at this site. Of the EPT species, there were between three and four mayfly taxa, two stonefly taxa, and between two and four caddisfly taxa in each of the SI site samples. In other site samples there were higher numbers of mayfly taxa (between two and seven) but similar numbers of stonefly and caddisfly taxa. Though the range of taxa richness among individual samples in the SI site was higher than observed in 2005 samples (Table 5.2), overall EPT richness for the SI site was only 11 taxa compared with 17 and 18 taxa for the GS and SC sites, respectively. In addition, the number of individuals was more evenly distributed among taxa in each of the EPT groups in the latter two sites.

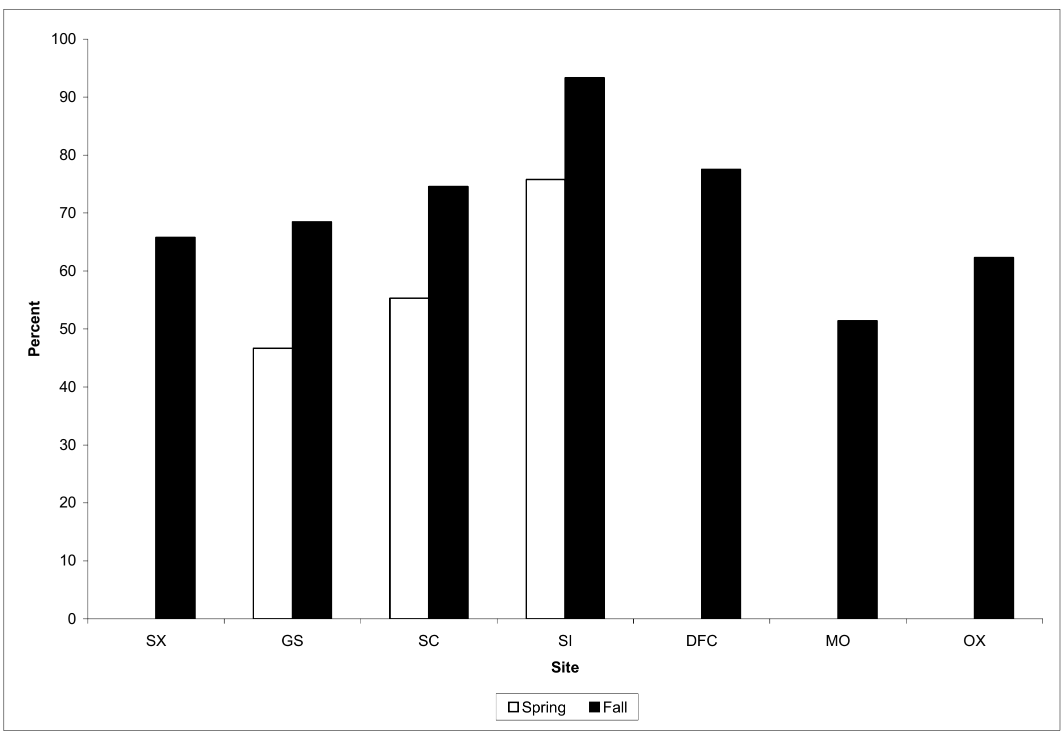
In September 2006 four taxa made up the top three most dominant taxa for six of the seven sites. These included midges, blackflies, mayfly (*Baetis tricaudatus*), and riffle beetle (*Optioservus* sp.). The only difference in the top three taxa was the most dominant taxa at the SXW site which, similar to samples from 2005, was the pollution-intolerant caddisfly (*Oligophlebodes* sp.). In this autumn sample the distinction between the SI site and other sites was more apparent than in the spring: Only two mayfly, one caddisfly, and no stonefly taxa were captured in all samples. Overall EPT richness was only three taxa in the SI site, but it ranged from 14 to 18 taxa in all other sites (DFC, OX, and MO all had 18 EPT taxa). The few intolerant taxa found at the SI site were single specimens in a community dominated by relatively tolerant individuals in the order Diptera including approximately 85 percent midges among all SI site samples in September 2006.

5.3.2 Comparisons with Historical Data

During 1999-2002 the National Aquatic Monitoring Center (NAMC) collected several samples near some of the sites sampled for this study (NAMC 2006, Vinson 2006). Samples from this period would have been collected prior to the complete bypass of irrigation deliveries and the institution of the minimum-flow requirements on Sixth Water and Diamond Fork Creeks. These samples would also have been collected before the increased leaching of hydrogen sulfide into the system.



(a) Hess samples.



(b) Kick-net samples.

Figure 5.6. Average percentage of the community comprised by the three most dominant taxa from Hess samples (a), and percentage of the community comprised by the three most dominant taxa from qualitative kick-net samples (b) collected in June and September 2006.

Table 5.1. The three most dominant taxa at the six sampling sites in June and September 2006.

DOMINANCE	SIXTH WATER (SXW)	CONTROL SITE (SC)	CONTROL SITE (GS)	IMPACT SITE (SI)	DIAMOND FORK CAMPGROUND (DFC)	MOTHER (MO)	OXBOW (OX)
June 2006							
First		Chironomidae	Chironomidae	Chironomidae			
Second		*Simulium* sp.	*Baetis tricaudatus*	*Baetis tricaudatus*			
Third		*Baetis tricaudatus*	*Optioservus* sp.	Oligochaeta			
September 2006							
First	*Oligophlebodes* sp.	Chironomidae	Chironomidae	Chironomidae	*Simulium* sp.	Chironomidae	*Baetis tricaudatus*
Second	Chironomidae	*Baetis tricaudatus*	*Optioservus* sp.	*Baetis tricaudatus*	Chironomidae	*Simulium* sp.	Chironomidae
Third	*Optioservus* sp.	*Optioservus* sp.	*Baetis tricaudatus*	*Simulium* sp.	*Baetis tricaudatus*	*Baetis tricaudatus*	*Simulium* sp.

Table 5.2. The three most dominant taxa at the six sampling sites in April 2005 and September 2005.

DOMINANCE	SIXTH WATER (SXW)	CONTROL SITE (SC)	IMPACT SITE (SI)	DIAMOND FORK CAMPGROUND (DFC)	MOTHER (MO)	OXBOW (OX)
April 2005						
First	Chironomidae	Oligochaeta	Chironomidae	Chironomidae	Chironomidae	Chironomidae
Second	*Baetis tricaudatus*	Chironomidae	Oligochaeta	*Baetis tricaudatus*	Oligochaeta	Oligochaeta
Third	*Micrasema* sp.	*Optioservus* sp.	*Simulium* sp.	*Ephemerella inermis/ infrequens*	Nematoda	Nematoda
September 2005						
First	*Oligophlebodes* sp.	Chironomidae	Chironomidae	Chironomidae	Chironomidae	Chironomidae
Second	Chironomidae	*Optioservus* sp.	*Baetis tricaudatus*	Oligochaeta	*Optioservus* sp.	Oligochaeta
Third	*Micrasema* sp.	*Hydropsche* sp.	Oligochaeta	*Optioservus* sp.	Oligochaeta	*Optioservus* sp.

Unfortunately there were no historical data from locations near each of the sites sampled for this study, and the collection methods used for it differed from those of the NAMC (Table 5.3).

There were some differences between the NAMC kick-net sample collection methods and the sample collection methods used for this study. The NAMC sample protocol was one kick in a riffle, while samples for this study were collected by performing 20 kicks throughout multiple habitats. Hence the Hess samples collected for this study may be more comparable with the kick-net samples

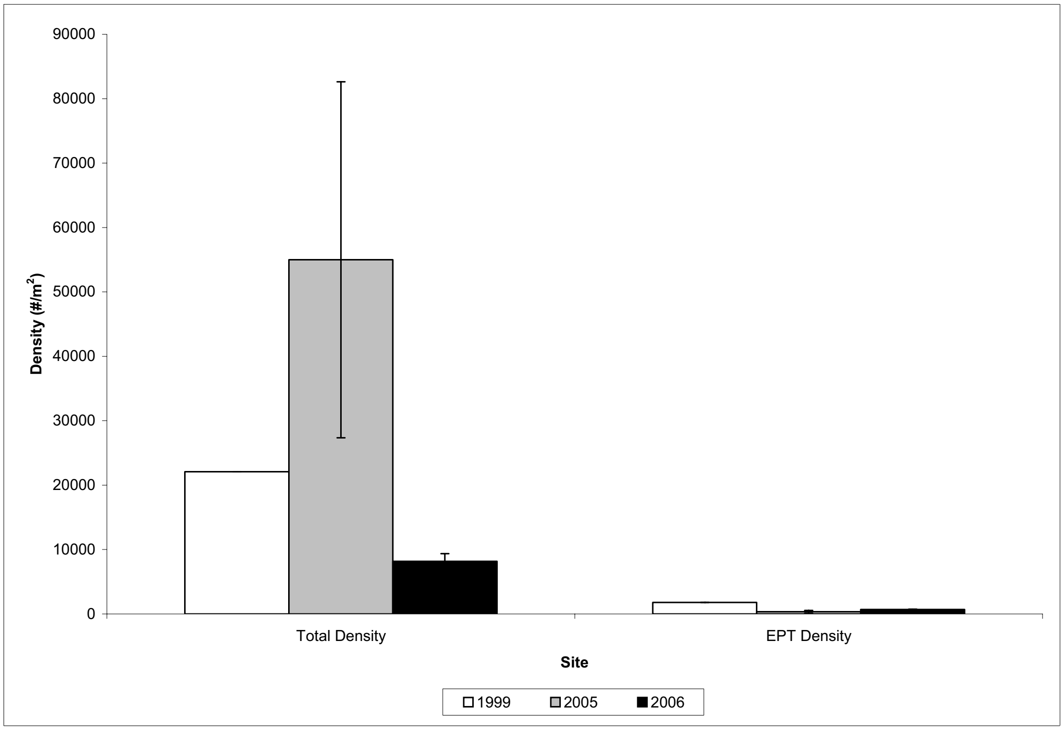
Table 5.3. Historical sampling near 2005-2006 sampling sites and the number and types of samples collected.

CURRENT SITE	HISTORICAL SAMPLES	1999	2000	2001	2002
Sixth Water	No	N/A	N/A	N/A	N/A
Control Site	No	N/A	N/A	N/A	N/A
Impact Site	Yes (near Three Forks confluence)	1 D-frame	N/A	3 D-frame	N/A
Diamond Fork Campground	Yes (near current site)	N/A	N/A	N/A	1 D-frame
Mother	Yes (near current site)	1 D-frame	N/A	N/A	N/A
Oxbow	Yes (near confluence with Spanish Fork River)	1 Basket sample	1 Hess sample	N/A	N/A

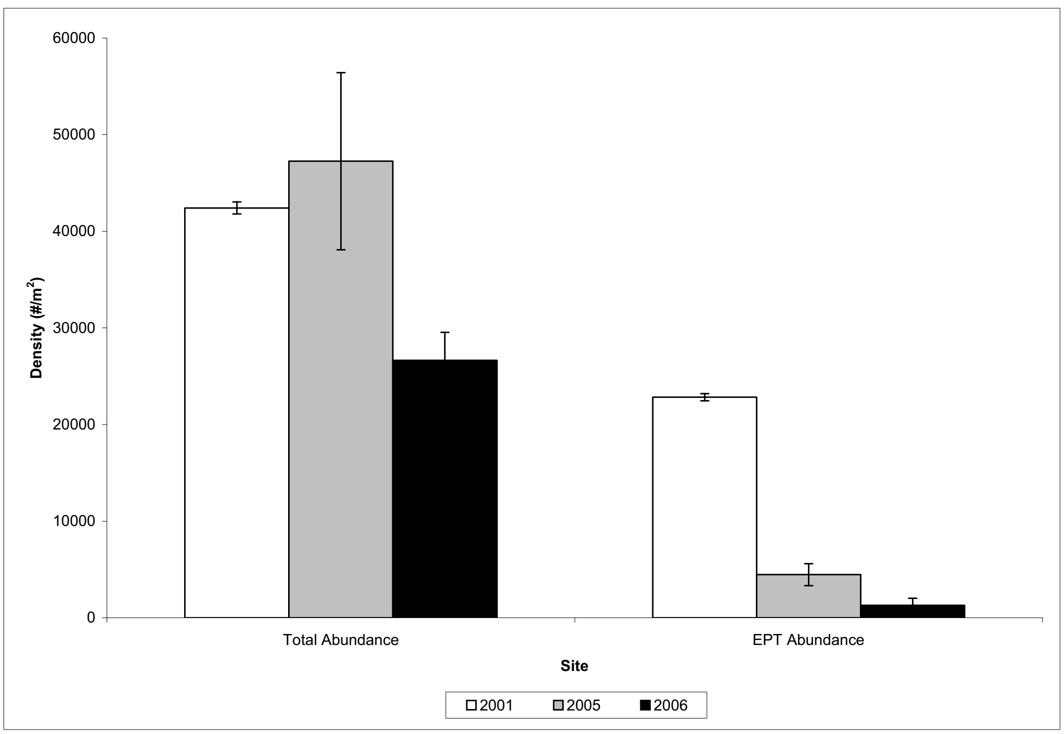
collected by the NAMC. Preliminary analyses showed conflicting trends when total abundance and total density from kick-net samples taken by NAMC and kick-net samples collected in 2005 for this study were compared. Additionally, since kick-net samples for this study were taken throughout multiple habitats, they should have higher taxa richness values. Preliminary analyses confirmed these expectations. Therefore, the Hess sample data collected for this study (2005 and 2006) were compared with the kick-net information and Hess sample information collected by the NAMC.

The site with the most historical information was SI, although the comparison NAMC site was 2.1 km downstream near the confluence with Three Forks. One D-frame kick-net sample was collected by NAMC in June 1999, and three replicate D-frame kick-net samples were collected in November of 2001 from the NAMC site above Three Forks. June 2006 data collected for this study were compared with NAMC's June 2005 sampling data and the April 2005 data. The September 2006 data from this study were compared with NAMC's November 2001 data and the September 2005 data. Total density of macroinvertebrates at the SI site in both spring (Figure 5.7a) and autumn 2006 (Figure 5.7b) was lower than in the NAMC samples in 1999 and 2001, as well as the 2005 samples taken during this study. The EPT density in the autumn 2006 was also lower than all previous samples. The spring 2006 density was slightly higher than in 2005, but it was still lower than in 1999 and 2001. Total taxa richness and EPT taxa richness were similar to 2005 samples taken in both spring (Figure 5.8a) and autumn 2006 (Figure 5.8b), and were substantially lower than in the samples taken in 1999 and 2001. As in 2005 there was also a higher HBI value (Figure 5.9) and percentage of the community dominated by the three most abundant taxa (Figure 5.10) at the SI site in 2006 compared with samples taken there in 1999 and 2001.

The dominant taxa (midges: *Diptera chironomidae*) were fairly similar between the 1999/2001 and 2005/2006 collections in the SI site and comparable NAMC site, although the riffle beetle (*Optioservus* sp.) was the second most abundant taxa in June 1999. The big difference in the community between the 1999/2001 and 2005/2006 collections was in the number of EPT taxa. Four stonefly taxa (*Pteronarcella badia*, *Pteronarcys califonica*, *Isoperla* sp., and Chloroperlidae), two caddisfly taxa (*Rhyacophila* sp., *Arctopsyche* sp.), and one mayfly taxa (*Tricorythodes* sp.) were found in the 1999/2001 collections but not in the 2005 or September 2006 collections.

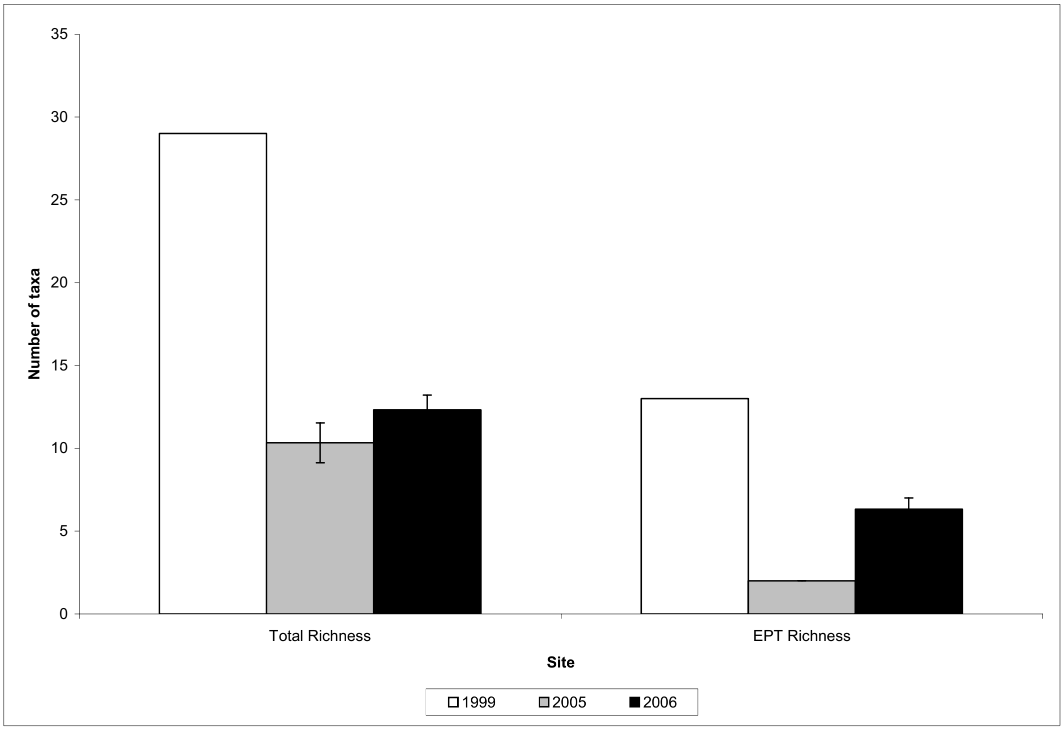


(a)

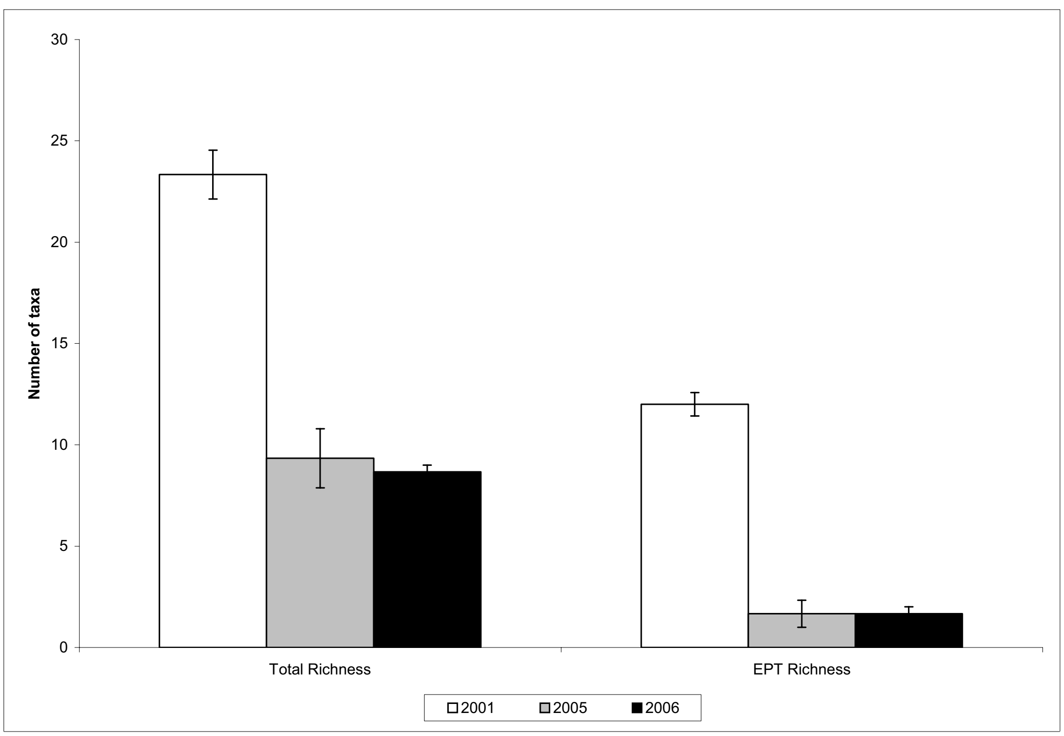


(b)

Figure 5.7. Total density and EPT taxa density from kick-net samples and Hess samples taken near the impact site (SI) in (a) spring 1999, 2005, and 2006, and (b) autumn 2001, 2005, and 2006.



(a)



(b)

Figure 5.8. Total taxa richness and EPT taxa richness from kick-net samples and Hess samples taken near the impact site (SI) in (a) spring 1999, 2005, and 2006, and (b) autumn 2001, 2005, and 2006.

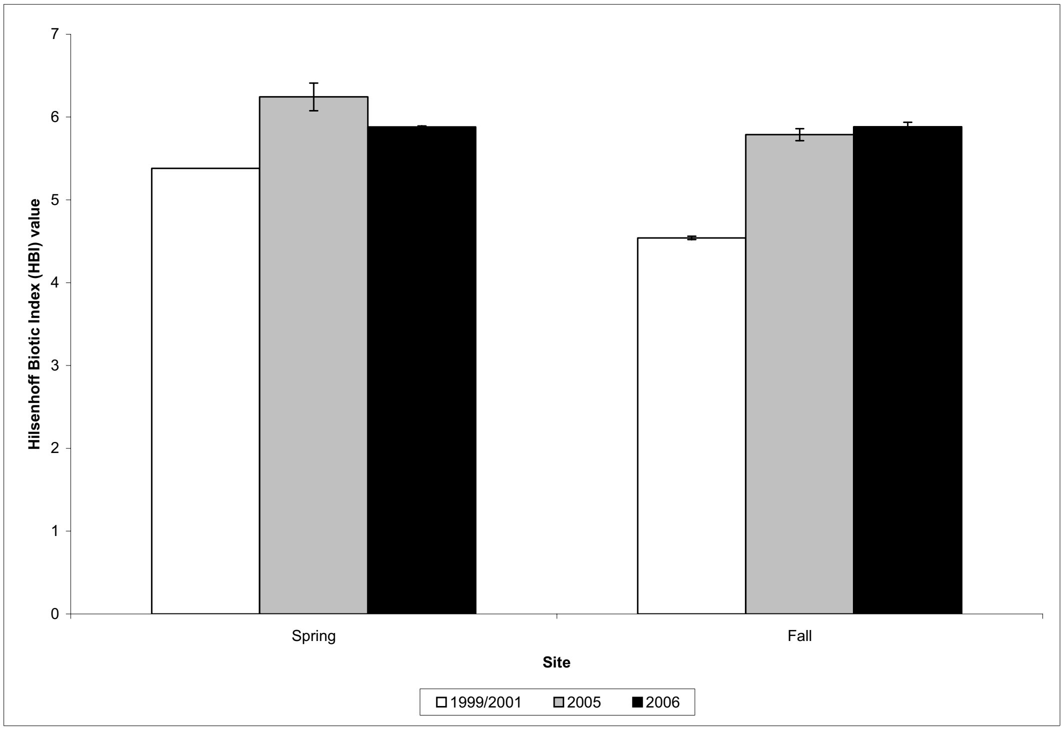


Figure 5.9. Hilsenhoff Biotic Index (HBI) values from kick-net samples and Hess samples taken near the impact site (SI) in spring 1999, 2005, and 2006, and autumn 2001, 2005, and 2006.

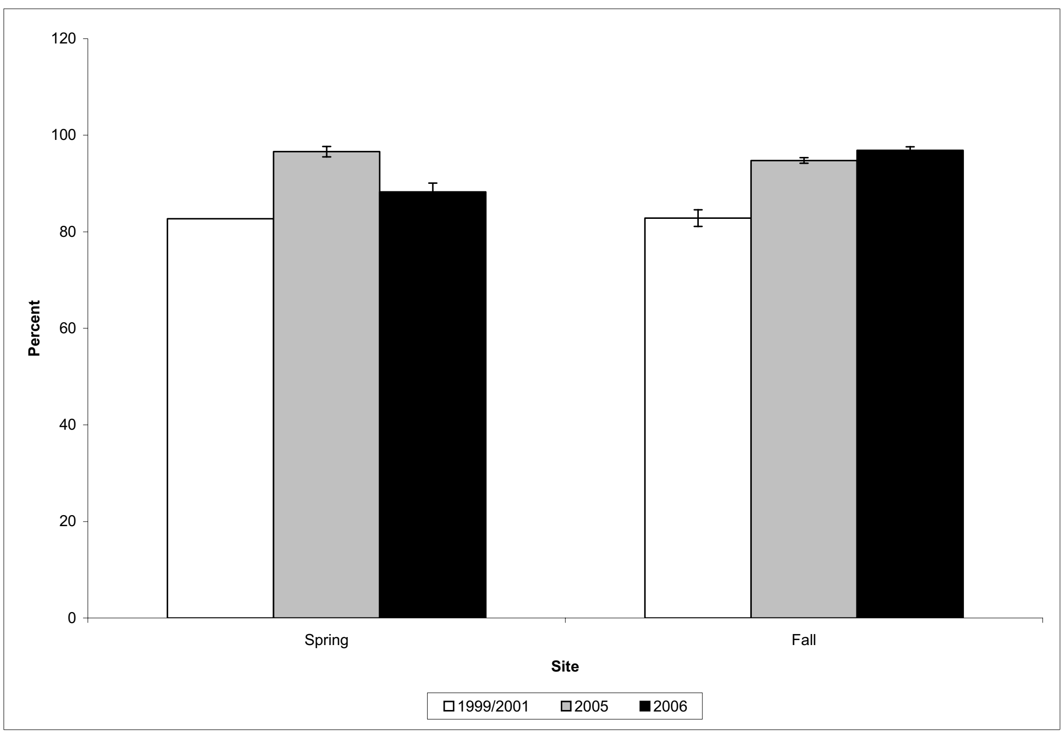


Figure 5.10. Percentage of the community comprised of the three most abundant taxa from kick-net samples and Hess samples taken near the SI site in spring 1999, 2005, and 2006, and autumn 2001, 2005, and 2006.

In the June 2006 sample, several *Pteronarcella* sp. were observed, along with one *Rhyacophila coloradensis*. In addition, those EPT taxa that were collected in the 2005/2006 samples were generally found in lower abundance than in the 1999/2001 samples.

The NAMC also collected a kick-net sample near DFC in January 2002, a kick-net sample near MO in June 1999, and a Hess sample downstream of OX (near the confluence with the Spanish Fork River) in March 2000. In the 2005 report (BIO-WEST 2006), Hess samples collected at these sites in April 2005 for this study were compared with the historical NAMC data; however, no data were collected at these sites in April 2006 due to high flows. For this report, the September 2006 data were compared with the earlier samples. Total density of macroinvertebrates in September 2006 samples was closer to the 1999-2002 samples than the 2005 data, which were generally lower than the 2005 samples (Figure 5.11). The EPT density was similar among all collection years at MO but lower in September 2006 at DFC than in previous years. At OX the 2000 NAMC collection had a substantially higher density of EPT taxa than samples collected in April 2005 or September 2006 for this study (Figure 5.12). Total taxa richness and EPT taxa richness were similar (or within the range of variability among samples) between the NAMC collections and collections for this study (Figures 5.13 and 5.14). The HBI values of historical collections were lower than in the April 2005 and September 2006 collections, most notably at OX in 2000 (Figure 5.15). In 2005 and 2006 all sites fell into the enriched category, whereas the samples from OX in 2000 and DFC in 2002 fell into the slightly enriched category.

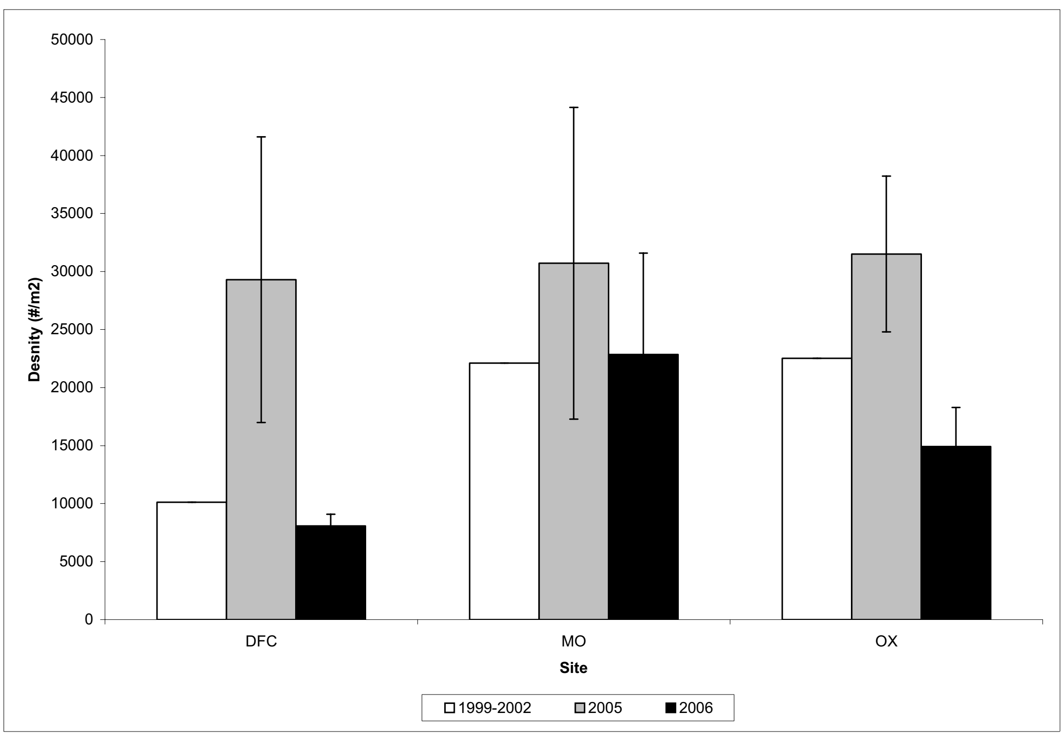


Figure 5.11. Total macroinvertebrate density from historical data, April 2005, and September 2006 samples from the Diamond Fork (DFC), Mother (MO), and Oxbow (OX) sampling sites.

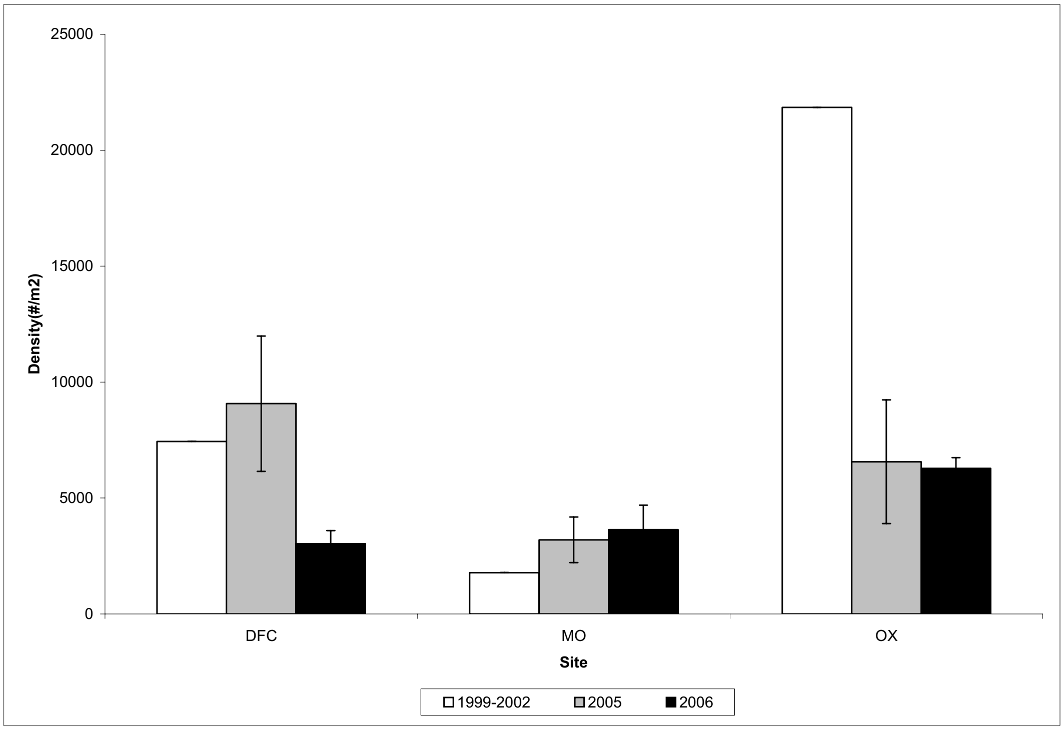


Figure 5.12. Total EPT density from historical data, April 2005 samples, and September 2006 samples from Diamond Fork (DFC), Mother (MO), and Oxbow (OX).

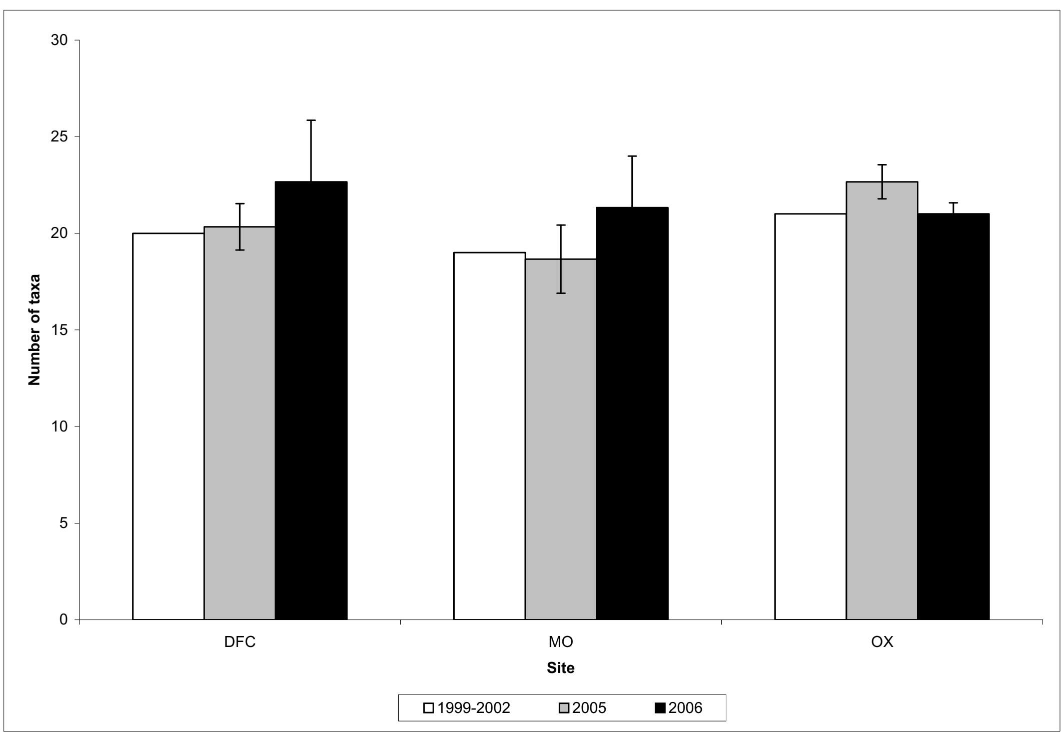


Figure 5.13. Total taxa richness from historical data, April 2005 samples, and September 2006 samples from Diamond Fork (DFC), Mother (MO), and Oxbow (OX).

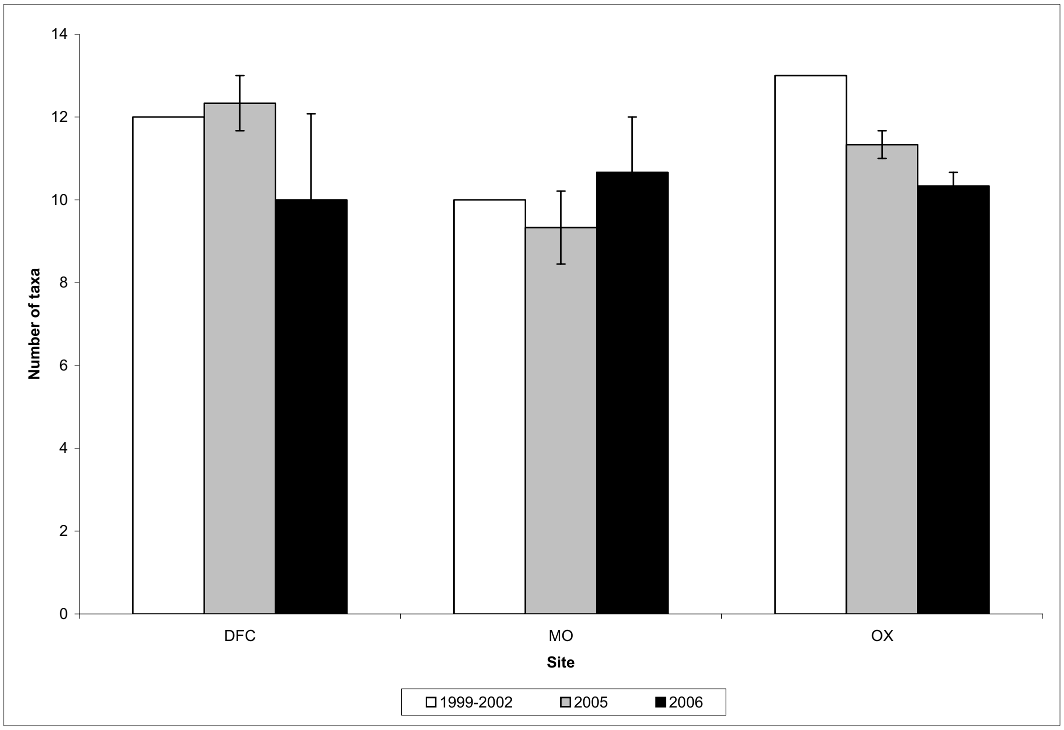


Figure 5.14. Total EPT richness from historical data, April 2005 samples, and September 2006 samples from Diamond Fork (DFC), Mother (MO), and Oxbow (OX).

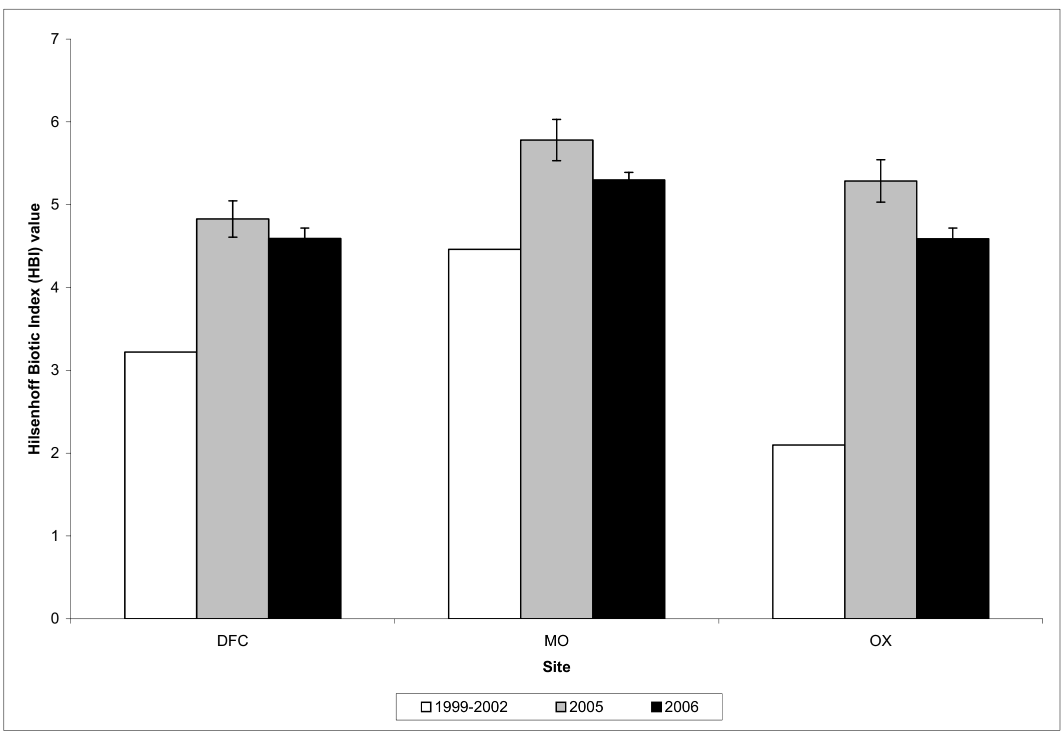


Figure 5.15. Hilsenhoff Biotic Index (HBI) values from historical data, April 2005 samples, and September 2006 samples from Diamond Fork (DFC), Mother (MO), and Oxbow (OX).

The percentage of the community comprised of the three most dominant taxa was nearly identical at OX between 2000 and 2005/2006 (Figure 5.16). Despite the fact that the same percentage of the community was comprised of three dominant taxa at OX in 2000 and 2005/2006, the three most dominant taxa in 2000 were the caddisfly taxon *Brachycentrus* sp. and the mayfly taxa Ephemerellidae and *Rhithrogena* sp., compared with the dominance of midges and worms found at OX in 2005 and 2006. In 2000 almost the entire community OX at was comprised of EPT taxa. While there were differences in the abundance of certain taxa found at OX in 2000 and 2005/2006, all the EPT taxa found in the 2000 NAMC samples were also found in the April 2005 samples, and all but one taxa (Ephemeroptera *Heptageniidae* sp.) were found in the September 2006 sample. Hence the major difference was the abundance of midges and worms in the 2005/2006 samples.

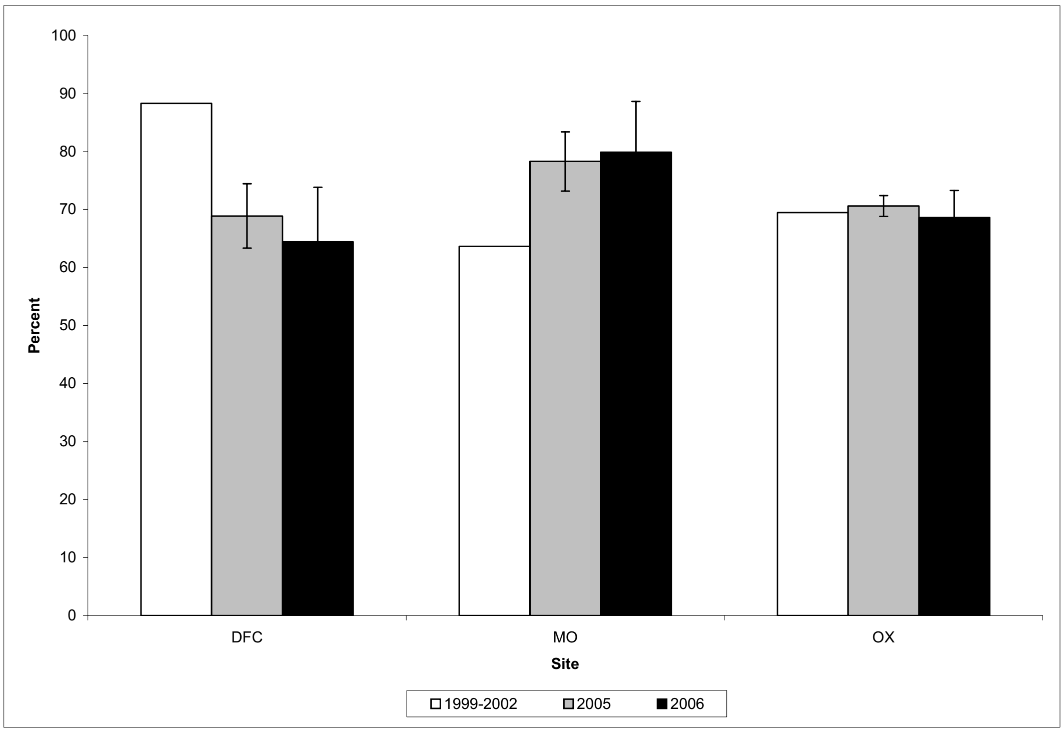


Figure 5.16. Percentage of communities comprised of the three most dominant taxa from NAMC data compared with April 2005 and September 2006 data.

In April 2005 and September 2006, approximately 15 percent more of the MO community was comprised of the three dominant species compared with the June 1999 NAMC collection. As with OX in 2000, EPT taxa were more abundant at MO in 1999 than in 2005/2006. Midges, the mayfly family Ephemerellidae, and the mayfly *Baetis tricaudatus* were the three most abundant taxa at MO in June 1999. In April 2005 midges, worms, and round worms (Nematoda) were the three most abundant taxa, while in September 2006 midges, blackflies, and the mayfly *Baetis tricaudatis* were most abundant. However, all of the EPT taxa found in the NAMC sample collected in June 1999 were found in the April 2005 sample, and all but one (Ephemeroptera *Heptageniidae* sp.) was found in the September 2006 sample. The main difference between the recent collections and those in 1999 was the abundance of midges and worms in the more recent samples.

In the DFC site approximately 20 percent less of the community was comprised of the three dominant taxa in April 2005 and September 2006, compared with the 2002 sample. The caddisfly *Brachycentrus occidentalis* dominated the community in 2002, along with the mayfly *Baetis tricaudatus* and midges. In April 2005 midges dominated the community, along with the mayflies *Baetis tricaudatus* and *Ephemerella inermis/infrequens*. In September 2006 midges, blackflies, and the mayfly *Baetis tricaudatus* were dominant.

5.4 DISCUSSION

5.4.1 Long-term Monitoring Sites

Although 2006 only provided a single monitoring effort (in the autumn) in each of the four long-term monitoring sites (SXW, DFC, MO, and OX) the numbers of macroinvertebrate and EPT taxa were very similar among sites during that sample, as observed in 2005. Also like 2005, the 2006 HBI value was similar among sites (though lowest in SXW) and percent occurrence of the three dominant species was similar among these sites. The major differences among sites in both years were total density of all macroinvertebrates, which varied widely among sites within years, and the density of EPT taxa, which was generally highest in the SXW site. These differences suggest a slightly less degraded macroinvertebrate community higher in the watershed than in the downstream sites. However, there are some differences that would be expected between the SXW site and the others based on the river continuum concept and the general pattern found in undisturbed Rocky Mountain streams (Vannote et al. 1980; Grafe 2002a, 2002b) that were not observed. The SXW site is in a second-order tributary to Diamond Fork Creek, while the remaining three long-term monitoring sites are fourth-order sites on the main stem of Diamond Fork Creek itself. According to the river continuum concept, taxa richness should increase in a downstream direction and thus be lowest in the SXW site. Instead, the total number of taxa and number of EPT taxa at the DFC, MO, and OX sites was similar to or lower than at the SXW site in both quantitative Hess samples and qualitative multi-habitat kick-net samples. This suggests that the sites in the lower portion of the river are still adapting to the changes in the flow patterns. Further monitoring will determine whether these sites will continue to progress toward the conditions of the SXW site and even surpass that site in terms of taxa richness and diversity. The upstream SXW site will provide a source of new macroinvertebrates for these lower sites if conditions are conducive to supporting populations of these species.

One of the most interesting observations in 2006 resulted from a comparison of EPT taxa richness among years and within sites. In all four long-term monitoring sites, the autumn samples in 2006 had lower EPT richness compared with autumn samples in 2005. With the restoration of more normal flow conditions, the richness of sensitive EPT taxa would be expected to increase, or at least remain similar, in the short term and begin to increase over a multi-year time frame. The decrease in EPT taxa richness in the second year after flows were reduced may be a result of interannual variation in the data, but it may also indicate that conditions have not been returned to a suitable condition to promote an improvement in this critical component of the macroinvertebrate community. As discussed in previous sections, the flow conditions may still be too high for the physical dimensions of this stream channel and have not permitted sediment-transport conditions that support a robust macroinvertebrate community. Although there was an apparent shift toward taxa that are more intolerant of fine sediment in 2006 compared with 2005 (discussed below), unstable sediment dynamics may still affect the number of EPT taxa present.

The data from the four long-term monitoring sites were also compared with similar streams in the region. No review of macroinvertebrate data from streams in Utah was available, so a comparison was made with Idaho streams (Grafe 2002a). The average number of taxa found in Hess samples at SXW in 2005 was similar to the average found in non-impacted small streams in the mountains of Idaho, but in autumn 2006 the average had declined into the range of averages for impacted sites. In spring 2005 and autumn 2006, the average number of taxa found at the DFC, MO, and OX sampling sites was lower than within the range of averages at impacted sites (Grafe 2002a). In autumn 2005 the average taxa richness at DFC and MO were within the range of non-impacted streams. In qualitative, multi-habitat, kick-net samples, the taxa richness at all four sites was near or above the average found in non-impacted streams in both 2005 and 2006. Similarly, the average number of EPT taxa from Hess samples and the total number found in qualitative kick-net samples was near or above the average found in non-impacted small streams. These comparisons are based on Diamond Fork Creek's small-stream classification, but lower Diamond Fork Creek (MO and OX) is almost considered a large river (Grafe 2002b). If classified as such and compared with other large rivers in Idaho, the number of EPT taxa found there (MO and OX sites) in 2005-2006 would be more indicative of impacted sites.

The HBI values indicate some level of impacts at all four of these sites. The MO, OX, and DFC sites fell into the "enriched" category for HBI values during each season in 2005 and in September 2006, while the HBI value at the SXW site was in the enriched category in April 2005 and the slightly enriched category in September 2005 and September 2006. Additionally, only the HBI values at the SXW site in autumn 2005 and 2006 fell close to the average value for least-impacted small streams in Idaho (Grafe 2002a). The HBI values at the MO and OX sites were within the range of impacted small streams in both seasons and well above the median of 4.0 listed for larger rivers in Idaho (Grafe 2002a, 2002b). Some caution must be employed when interpreting taxa richness and HBI indices for these data because of the level of taxonomic resolution used in this study. Since midges were only identified to the family level and worms to class, multiple taxonomic groups likely occur within these designations. In other words, several individual taxa are combined into Chironomidae and Oligochaeta. This reduces taxa richness and also may impact HBI values. However, since Grafe (2002a, 2002b) used a similar measure of taxonomic resolution, comparisons of this study's data with that data should be valid.

The lingering effects of nearly 90 years of altered flows are probably responsible for the depressed taxa richness and elevated HBI values seen in the macroinvertebrate community in 2005 and 2006. Changes in the seasonal timing of flow and temperature regimes of a system can impact the life-history characteristics of individual species (Stanford and Ward 1979, Vannote and Sweeney 1980, Power et al. 1996). These changes can often result in reductions in species diversity like those in Diamond Fork Creek (Ward 1974, Stanford and Ward 1979). Snaddon and Davies (1998) showed that elevated summer flows from an interbasin transfer in South Africa resulted in a decrease in taxa richness in the receiving river. One of the more common community changes from elevated flows and cooler temperatures below large dams is an increase in dipteran and worm populations, while mayfly, stonefly, and other benthic orders are generally significantly reduced. Changes in water velocity can impact the channel-forming flows that structure the bedform and substrate composition of a stream. Reducing spring peak flows can alter the maintenance of certain habitat types. More constant, higher flows can lead to the development of uniform substrates, which reduces the number of niches available. All of these factors may have worked to limit the diversity of habitat available for macroinvertebrates during the past century of water deliveries through Sixth Water and Diamond Fork Creeks.

Another potential reason for the reduced number of macroinvertebrate taxa in Diamond Fork Creek compared with other streams is the high level of sediment, as noted in Chapter 4. Fine sediment transport and deposition negatively impact aquatic invertebrates (Waters 1995, Relyea et al. 2000). The higher-than-average transport of gravel and fine sediments could be impacting the diversity of macroinvertebrates found at these four sites. With the exception of the SXW site, the average-weighted Fine Sediment Biotic Index (FSBI) scores for each site suggest that the macroinvertebrate communities at these sites are predominantly comprised of organisms at least moderately tolerant to fine sediments (Appendix 5.1). However, the caddisfly *Arctopsyche grandis*, which is classified as intolerant to fine sediment, was present at all four of these sites (Relyea et al. 2000). The average-weighted FSBI score at the SXW site indicated a community predominantly comprised of individuals moderately tolerant to sediment in April 2005 and September 2006, but in September 2005 it indicated individuals moderately intolerant to sediment. In addition to *Arctopsyche grandis,* another caddisfly that is intolerant of fine sediment, *Oligophlebodes* sp., was abundant at the SXW site. In general, weighted FSBI scores were lower in autumn 2006 than in 2005 (except at SXW), which suggests a macroinvertebrate shift toward a higher number of individuals intolerant or moderately intolerant to accumulations of fine sediment, but this factor still clearly impacts the community. There continues to be some variability in the FSBI score among samples, and the presence of taxa intolerant or moderately intolerant of sediment at all four sites makes an evaluation of the impact of sedimentation on the macroinvertebrate communities unclear. Hopefully, continued data collection will allow a more detailed analysis of how elevated levels of sediment may be impacting the biological communities on Diamond Fork Creek.

Although there may have been a shift toward larger numbers of taxa that are more intolerant to fine sediments, the higher transported quantity of these sediments may still influence macroinvertebrate densities. In 2005 there was a large decrease in macroinvertebrate densities between April and September that may have been influenced by high volumes of suspended sediment. It is also possible that sediment deposition in these areas could have been responsible for the reduction in invertebrate density directly, through mortality and transport, or indirectly, through decreasing primary productivity (Waters 1995). The high spring flows in 2005 could also have caused the decrease in macroinvertebrate density at the MO and OX sites in September 2005. Since only one sample was taken from the four long-term monitoring sites in 2006 seasonal shifts could not be evaluated, but additional monitoring may further clarify whether this was an isolated event or a long-term trend.

In addition to comparisons among sites and years, and with data from impacted and non-impacted streams in Idaho, the data collected in recent samples (2005-2006) were also compared with historical information. There were three sites for which historical samples exist (DFC, MO, and OX), and comparisons revealed similarities to the samples taken 3 to 7 years ago, although midges and worms were more abundant in the 2005-2006 samples. One possible explanation for the higher number of midges and worms is the difference in laboratories conducting the sorting; it is possible that EcoAnalysts' sorting and identification methods may have been different enough from other laboratory methods to affect the observed results. EcoAnalysts has found that when they process samples during other monitoring programs the number of organisms, particularly small organisms like midges and worms, increases substantially (Lester 2005).

Despite the multiple impacts that may have affected invertebrate diversity at SXW, DFC, MO, and OX, these sites still maintain fairly large numbers of long-lived taxa and taxa that are intolerant of disturbance. The presence of these sensitive taxa indicates that, while some impacts have occurred, the benthic community has still managed to maintain much of its integrity. In addition, the density of macroinvertebrates are such that no food limitation exists for sport fishes in the river. In instances where a food limitation for trout has been documented in other rivers, the invertebrate densities were orders of magnitude lower than those observed in Diamond Fork Creek (Cada et al. 1987, Newcomb et al. 2001). According to fisheries surveys conducted in Diamond Fork Creek in 2005, mean length and weight of brown trout (*Salmo trutta*) were greater than measurements obtained during surveys in 2003 in two of the three monitoring sites; however, condition factor of the fish was lower in 2005 and the number of trout per mile had decreased substantially in all sites (Hepworth and Wiley 2006). Bonneville cutthroat trout (*Oncorhynchus clarki utah*) were also caught, but their numbers were too low to make any meaningful comparisons with previous data. One hypothesis for the recent decline in fish numbers is that there was a very productive year class in 2001, but subsequent spawning runs were not as successful (R. Hepworth, UDWR aquatic biologist, pers. comm.). The increase in size accompanying the decrease in abundance may appeal to anglers and be natural variation in the fish population. Additional monitoring will help identify any trends in these data. A response in the fish community to altered streamflow may not be apparent as quickly as changes in the macroinvertebrate community (the fisheries survey occurred within 1 year of the changes in flow), but there is no indication that there is a limitation in the density of food items for the trout. The types of potential prey organisms also do not appear to be limiting. Though midges dominate the Middle Provo River, these small organisms are common in the drift and frequently consumed by trout in large numbers. The common mayfly *Baetis tricaudatus* is a species that tends to enter the drift to move among feeding locations. If the increase in fine sediment transport is affecting macroinvertebrates as suspected, this condition may also impact success of fish spawning.

The greatest continued impacts to the macroinvertebrate community in Diamond Fork Creek are believed to be associated with sediment dynamics, and it appears that the macroinvertebrate communities have not changed/improved drastically as a result of the changes in discharge. Additional monitoring in 2007 will provide the opportunity to evaluate whether the modifications to discharge in Diamond Fork Creek have been sufficient to promote recovery of benthic macroinvertebrate communities beyond previous conditions. If all or most of the metrics used to evaluate community dynamics remain within the same range of variability in 2007, there will be enough data to suggest that the community remains in a stable condition and will not change substantively without additional modifications to sediment transport.

5.4.2 Sulfur-Impact Evaluation Sites

Although the four long-term monitoring sites have maintained much of their integrity, the sites representing areas impacted by increased hydrogen sulfide inputs above the Three Forks area following the January 2002 pipeline incident contained severely impacted benthic communities. Similarly, the fish community appears to be influenced by this condition, particularly in the autumn when discharge is low and inputs are concentrated. The Utah Department of Wildlife Resources

(UDWR) found that fish held in cages downstream of the hydrogen sulfide inputs during the autumn only survived for about an hour (R. Hepworth, UDWR aquatic biologist, pers. comm.). In general, the macroinvertebrate communities at the control sites (SC in 2005, SC and GS in 2006) were more diverse and comprised of more intolerant species than the community in the impact site. This suggests that there are impacts directly associated with the hydrogen sulfide inputs beyond any effects of the historical water flow conditions observed in the "control" sites. The use of a second control site in 2006 stemmed from the lack of suitable habitat for sampling with the Hess device in the SC site. The SC site was chosen originally as the best habitat that was within a short distance of the impact site (between Sawmill Canyon and Springville Crossing [Hepworth 2005]), but poor habitat conditions led the field crew to find an alternate control site just upstream of Springville Crossing in 2006.

Comparisons of the various metrics between the SI and SC/GS sites revealed some important differences in 2005 and 2006 that indicate the level of impact from the hydrogen sulfide inputs. Higher macroinvertebrate density in the SI site compared with the control sites during both years seems to contradict the hypothesis that the hydrogen sulfide is negatively impacting the macroinvertebrate community in the immediate vicinity, but this higher density is a result of high densities of midges and blackflies, which are generally very tolerant of degraded conditions. Similarly, the EPT density suggests no dramatic impact in the SI site relative to the control sites, which had very similar numbers among sites in each season, but the total EPT density in the SI site is dominated by a relatively tolerant colonizing mayfly, *Baetis tricaudatus*. The HBI value was slightly higher in the SI site but not high enough to result in a different category rating for the SI site compared with the other sites. Taxa richness, EPT taxa richness, and the proportion of the community comprised of the three most dominant taxa had more distinct differences between the SI and control sites. Similar to results in 2005, the SI site had significantly lower overall taxa richness compared with all other sites during each season, substantially lower EPT taxa richness than all other sites in June (not significant), and significantly lower EPT taxa richness than all of the other sites sampled in September 2006. Additionally, the SI site had a higher proportion of the macroinvertebrate community comprised of the three dominant taxa and the highest average HBI value from Hess samples in both seasons during 2005 and 2006. However, unlike in 2005, the 2006 data were not all significant (only OX and MO were significantly lower in September 2006). This low taxa richness and the dominance of only a few taxa indicates poor diversity at the SI site and a considerably higher level of disturbance than at the control sites (Barbour et al. 1999).

One promising observation from these comparisons was the relatively high value of EPT taxa richness in the June 2006 sample (which was conducted immediately after runoff rather than prior to runoff as in 2005) compared with the two control sites. The April 2005 sample from this site had very low EPT taxa richness and, if this was similar in 2006 prior to runoff, it suggests that during runoff the sulfur inputs to the stream are diluted and the macroinvertebrate community is capable of becoming much more diverse (with a relatively diverse group of EPT species) as a result of downstream dispersal during higher flows. With the reduced impact from diluted hydrogen sulfide inputs during that time, many of the organisms settle into the SI site area. By September, however, we saw a reduction in EPT taxa richness. Overall, this is a good indicator that if/when hydrogen sulfide inputs are diminished, the macroinvertebrate community will be able to recover to some degree in a short time period. Similarly, there was a higher taxa richness in the three sites sampled in June 2006 compared with September 2006 samples, whereas the April 2005 samples had lower taxa richness than the subsequent September sample. Again, assuming that April 2006 data would have been similar to 2005, this observation indicates that runoff results in a temporary reduction in taxa richness and returns to the higher value by autumn. Taxa richness then appears to increase until runoff conditions the following year, which again reduce the number of taxa. However, it is also possible that some taxa had low numbers during early June as a result of emergence and those taxa were not collected in the samples, which therefore yielded the lower richness values.

One of the critical determinations for the 2006 study is whether the SC site was an adequate control site and whether a more suitable site could be found. In June 2006 a site (GS) that appeared to be more suitable from a physical habitat perspective was identified, but this site was further upstream than the SC site. Both sites were sampled in 2006, but to minimize repetitive collection efforts only one site should be maintained as the control site in 2007 and beyond. Moving the control site too far upstream presents problems with comparable stream type, but using a site with very different habitat conditions also complicates the comparison. With only two seasonal samples collected at each control site in 2006 it is difficult to identify which site most accurately represents a true control site for the area, so we evaluated both sites and anticipated switching from the SC to GS site unless there was something unusual in the data to suggest that the GS site would not be an appropriate control site. In general, the data collected from the second control site (GS) sampled in 2006 compared very well with data collected from the SC site in 2006. Though there were some differences in absolute value of some of the metrics, the range of variation among individual Hess samples indicated that the data were similar for most comparisons. In addition, the change in each individual metric between June and September 2006 followed a similar trend between sites for nearly every parameter. Because of the similarity of results between the two sites, we believe that the GS site is an adequate replacement for the SC site as a control site with habitat characteristics similar to the SI site.

During most samples at the SI site, there was a clearly diminished quality in the macroinvertebrate community compared with other sites in Diamond Fork Creek. Several sensitive species of mayfly (e.g., *Ephemerella inermis/infrequens*), stonefly (e.g., *Pteronarcella badia*, *Pteronarcys californica*, *Isogenoides* sp.), and caddisfly (e.g., *Arctopsyche grandis*, *Glossosoma* sp., *Lepidostoma* sp.) that were common at most of the other Diamond Fork sites, including SC, were absent from SI site in both 2005 and September 2006 samples (Olsen 2006, Appendix 5.1). However, in June 2006, when samples were conducted immediately after runoff, several of the taxa listed above were found in the SI site, including each of the mayflies and stoneflies and one of the three caddisflies identified as common in other sites (*Lepidostoma* sp.). This observation gives further credence to the concept that when the sulfur inputs to the stream are diluted, the macroinvertebrate community is capable of becoming much more diverse (with a relatively diverse group of EPT species) as a result of downstream dispersal during higher flows. As described in Olsen (2006), comparisons with historical samples above the Three Forks confluence prior to the hydrogen sulfide incident (1999, 2001) show a community much more similar to the other sites sampled on Diamond Fork Creek in 2005-2006. When compared with all SI site samples in 2005-2006 (except the June 2006 sample), the historical samples, taken less than 2.1 km downstream, show a substantially higher density and diversity of EPT taxa and a substantially lower HBI value. The only known major impact to the system above Three Forks between 2001and 2005 was the increased input of hydrogen sulfide that began in 2002. Therefore, the assumption is that the increased hydrogen sulfide is responsible for the impacts seen in the invertebrate community at the SI site. Water quality samples taken with a HydroLab during September 2005 (Table 5.4) and 2006 (Table 5.5) sampling show elevated levels of conductivity and dissolved solids at the SI site compared with the SC site, which are probably the result of the increased hydrogen sulfide.

Table 5.4. HYDROLAB readings taken at the control site (SC) and the impact site (SI) on September 28, 2005.

WATER QUALITY CONSTITUENT	SC SITE	SI SITE
Temperature (F)	8.84	10.54
Specific conductivity (umohs)	336.0	551.8
pH	7.95	7.91
Dissolved oxygen (mg/L)	9.16	8.35
Total dissolved solids (mg/L)	0.2153	0.3525
Turbidity (NTUs)	101.6	696.9

Table 5.5. HYDROLAB readings taken at the control site (SC) and the impact site (SI) on September 19, 2006.

WATER QUALITY CONSTITUENT	GS SITE	SC SITE	SI SITE
Temperature (F)	11.02	5.32	9.47
Specific conductivity (umohs)	327.0	392.0	645.0
pH	8.46	8.40	8.23
Dissolved oxygen (mg/L)	10.59	12.24	11.05

The data collected in the SI, SC, and GS sites were also compared with the data collected in each of the long-term monitoring sites. Although the SC site appeared to be substantially different than the four long-term monitoring sites sampled on Sixth Water and Diamond Fork Creeks in overall macroinvertebrate and EPT density in 2005, no substantial difference was observed in overall macroinvertebrate density between any of the sulfur-impacted sites and the long-term monitoring sites in 2006. The only difference in EPT density was a much lower value in the SI site compared with all other sites in September 2006 (the EPT density was similar among the three sulfur-impacted sites in June). As discussed above, overall taxa richness was lower in SI than all other sites in 2005 and 2006, but the two control sites were similar to the four long-term monitoring sites. The EPT taxa richness was lowest in SI among all sites, but the SC site was similar to the four long-term monitoring sites in 2005. In 2006 the SI site was again the lowest among all sites sampled, but the two control sites were both lower than the four long-term monitoring sites. In general, EPT taxa richness was much lower overall in 2006 compared with 2005. It is not clear whether the lower values in 2006, particularly the low numbers in SC and GS, were a result of flow conditions that did not promote an increase in the EPT component of the macroinvertebrate community or an indicator of natural inter-annual variability. Additional monitoring will help identify whether this is a trend in the data or natural variability.

Historical data from samples taken by the CUWCD and available on STORET (http://www.epa.gov/storet/dbtop.html) were also analyzed to determine any changes in water quality between 2004-2006 (Figure 5.17). Although sulfur levels have declined progressively toward a level that is below detection limits for the most recent data point (collected in September 2005), sulfur-level data have been high since 2004 in the SI site. Although there are still hydrogen sulfide inputs, above the SC site, all measurements near that site were below detection limits. Other water quality parameters that were higher in the SI site than the SC site were specific conductance and total dissolved solids.

5.5 SUMMARY

Benthic macroinvertebrate samples collected in 2005-2006 indicated that the benthic communities at the four long-term monitoring sites were fairly similar, but that the most upstream site (in the Sixth Water Creek tributary), had the highest density of EPT taxa. Additionally, the scant historical information seemed to indicate that these communities had changed very little in the past 6 years, including the most recent 2 years in which the water conveyance system has been in place. With the exception of the Sixth Water site, macroinvertebrate communities appeared to be degraded, compared with “least-impacted sites” from a similar ecoregion in Idaho. The persistence of artificially high flows over the last century is probably responsible for this erosion from optimum conditions. However, the current flows may still be too high to promote recovery of the macroinvertebrate community. Within the current flow regime, elevated sediment loads may prolong the length of time that the macroinvertebrate community remains depressed. Despite the depressed state, there appears to be sufficient food for the sport fish in the river. The hydrogen sulfide inputs have impacted the portion of the river immediately downstream and may be contributing to the depressed state in the more distant downstream sites, but if that were the case one would expect a trend of diminishing effects downstream. Because the three long-term monitoring sites downstream of the sulfur inputs have similar macroinvertebrate community dynamics, it appears that the majority of the impact is localized. The SI site has significantly lower diversity and much lower abundance of taxa sensitive to disturbance when compared with both the upstream control site and all the other sites sampled throughout the system. Sporadic historical information indicated that in 1999 and 2001 the community at this site was probably very similar to the remainder of the system. Since hydrogen sulfide leaching began in 2002, it is a likely suspect in the degradation of the macroinvertebrate community above Three Forks. Finally, benthic communities can exhibit a large degree of variability from year to year. Unfortunately, no records of long-term trends in the macroinvertebrate community leading up to 1999 were available, and only sporadic information from between 1999 and 2002 was available. Based on this paucity of data, it is recommended that a solid baseline dataset be developed for this monitoring program with at least one more year of pre- and post-runoff data. Annual sampling should be considered for several years thereafter. In addition to developing this valuable baseline data, continued macroinvertebrate monitoring should help further clarify how the new conveyance of irrigation water and minimum flow requirements on Sixth Water and Diamond Fork Creeks will influence the biological community.

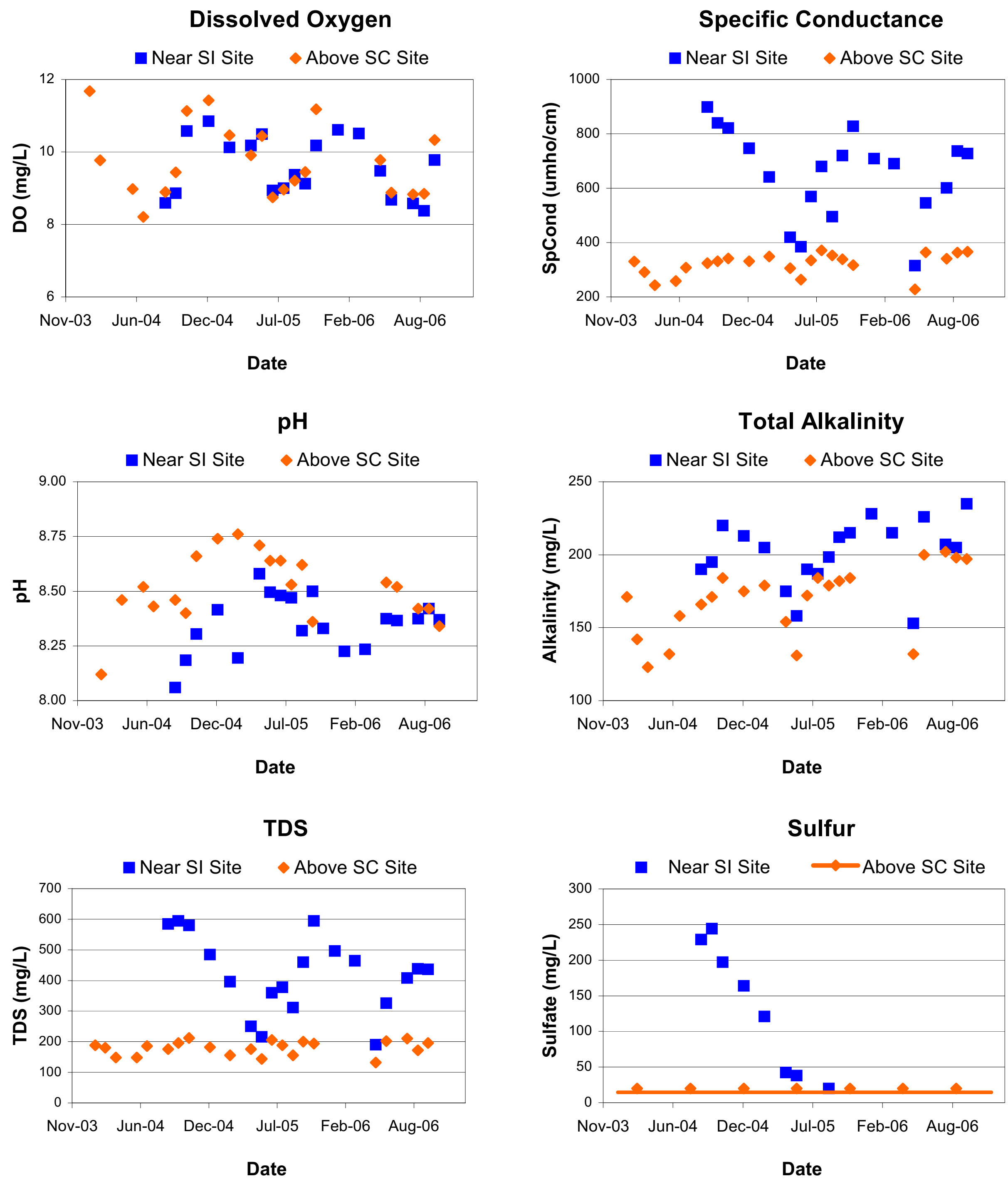


Figure 5.17. Water quality data from STORET. The Above SC site data are from STORET site number 4995710, Diamond Fork Creek above Sixth Water Creek. The Near SI site data are from STORET site number 4995760, Diamond Fork Creek at Ray's Valley Crossing.

6.0 SUMMARY AND DISCUSSION

For many years, Diamond Fork Creek and its tributary Sixth Water Creek conveyed water imports from Strawberry Reservoir to the Wasatch Front as an important component of the Strawberry Valley Project. Such flows ceased with the completion of the Diamond Fork System, which is part of the Bonneville unit in the CUP. Today, the Diamond Fork System transports imported water through a series of tunnels and pipes to lower Diamond Fork River with the capability of bypassing the streams to a large degree. The only flows sent through Sixth Water and Diamond Fork Creeks are water imports used to satisfy the instream flow requirements and water deliveries when the pipe is at capacity.

Mitigation of impacts that were caused by the Diamond Fork System is required under CUPCA (1992). In order to fulfill these commitments, the Mitigation Commission established a long-term monitoring program to evaluate the geomorphic and ecological changes related to the new flow regime set by instream flow requirements. Long-term monitoring will allow analysis of change over time in order to set and prioritize restoration efforts and adaptively maintain the riverine and riparian ecosystem in a desirable and functional condition. The main study objectives include channel transect and inundated areas mapping, substrate monitoring, sediment transport monitoring, and macroinvertebrate monitoring. This report documents the findings of the 2005 and 2006 monitoring efforts.

The first 2 years of monitoring have been enlightening. The watershed experienced average runoff in 2005 and high runoff in 2006 with flows reaching 550 cfs in May 2006 in the lower reaches of Diamond Fork Creek. The anticipated response and recovery of aquatic and riparian habitat to the previously altered Diamond Fork System is still pending. Channel dimensions and meander patterns, although still dynamic, have not changed significantly with two years of “natural” flows. Sixth Water Creek is essentially the same, and even though the meanders of Diamond Fork Creek continue to migrate it shows no signs of stabilizing or narrowing except for increased vegetation of bars that were bare in 2005. The bugs (i.e., benthic macroinvertebrate data) indicate that the conditions have become more degraded in the lower portions of Diamond Fork Creek instead of improving as we had hoped.

A potentially alarming problem is the continuation of fine- and coarse-grained sediment transport and the associated sedimentation and embeddedness in the lower reaches of Diamond Fork Creek. The summertime instream flows are high enough to keep sediment more mobile than would occur under a natural flow regime. The geomorphic monitoring plan will be adapted in 2007 to focus on these potential concerns.

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