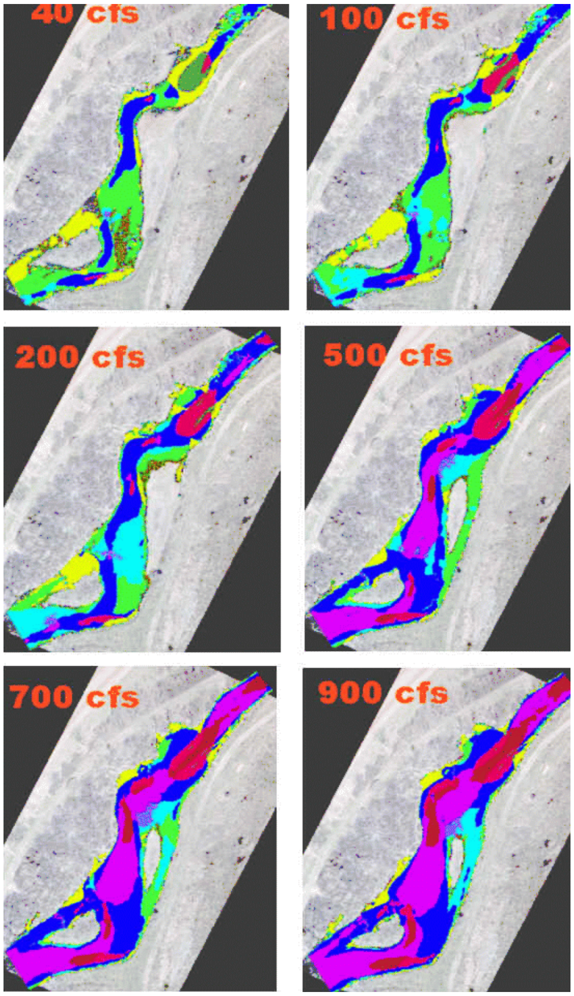
DEER CREEK RESERVOIR TO UTAH LAKE

PROVO RIVER FLOW STUDY

FLOW-HABITAT AND FLOW-ECOLOGICAL RELATIONSHIPS WITHIN THE RIVERINE ECOSYSTEM: AQUATIC HABITAT, RIPARIAN VEGETATION, RECREATIONAL USES, FLUVIAL PROCESSES

MARCH 2003



Spatial Niche

- 🟥 **8** Fast / Deep
- 🟥 **7** Mod. / Deep
- 🟪 **6** Fast / Mid-depth
- 🟦 **5** Mod. / Mid-depth
- 🟪 **4** Fast / Shallow
- 🟦 **3** Mod. / Shallow
- 🟩 **2** Slow / Shallow
- 🟨 **1** Backwater / Edge

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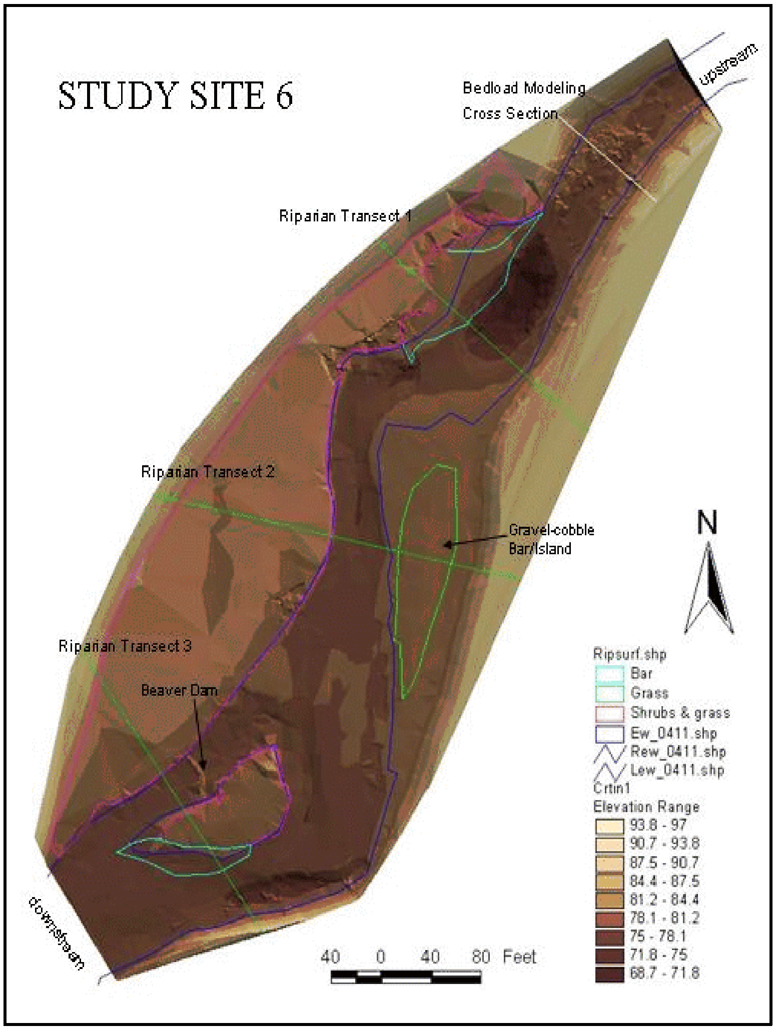

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1.0 INTRODUCTION

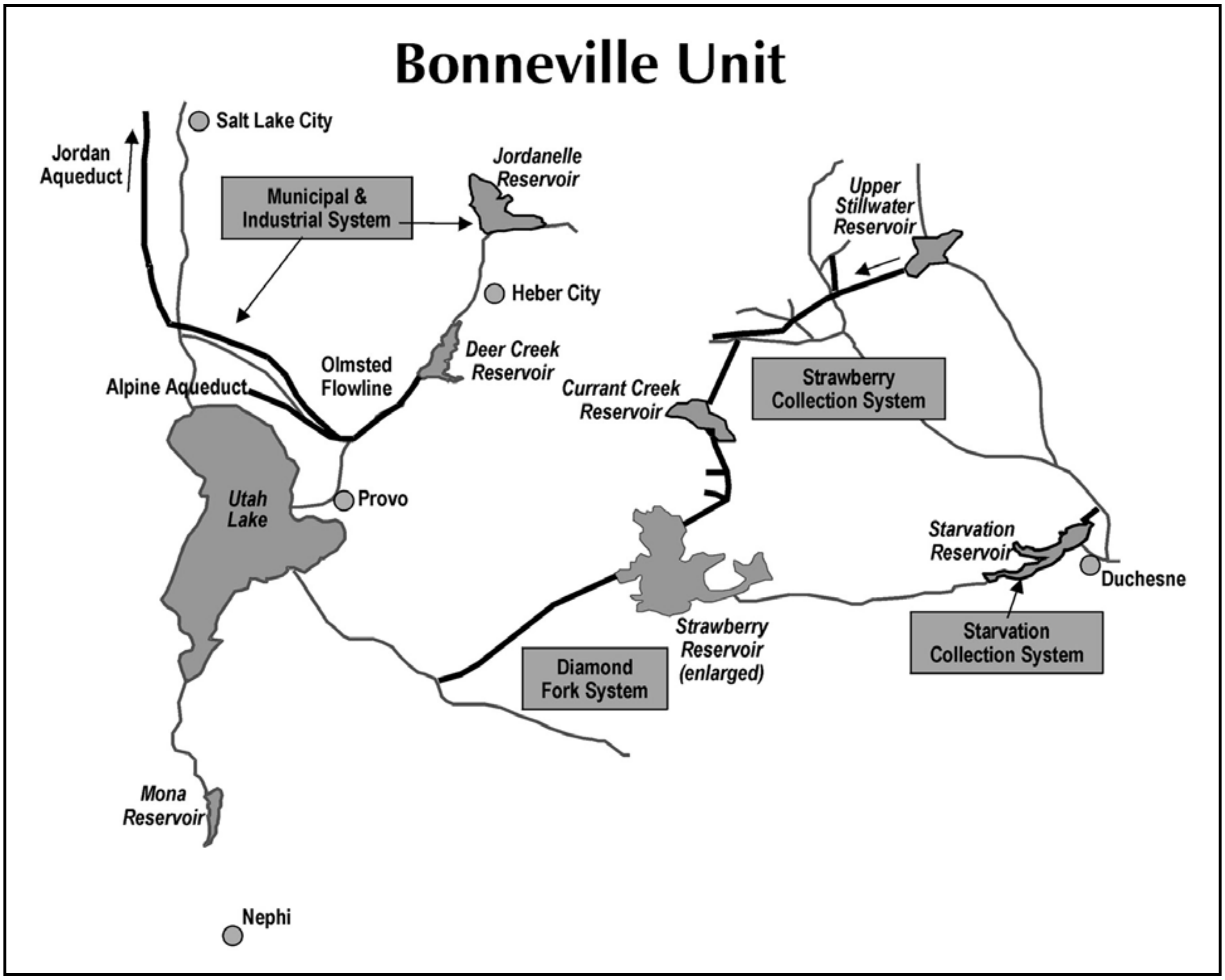
The Provo River is a highly significant water resource within the State of Utah. The river is a major source of drinking water for residents along the Wasatch Front, and is also heavily used for agricultural and recreational purposes. To put the importance of this water body in perspective, Provo River is used to supply drinking water to more than 50 percent of Utah's population. In addition, the section of the Provo River between Deer Creek Reservoir and Olmsted Diversion is known nationally as a blue-ribbon trout fishery. The section of the Provo River between Jordanelle Dam and Deer Creek Reservoir is rapidly achieving that same status, in response to minimum stream flows and habitat restoration projects made possible through the Central Utah Project. Other projects, agencies, etc., also helped make this possible.

1.1 BACKGROUND

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

The Bonneville Unit is the largest unit of the CUP. The Bonneville Unit is composed of the Starvation Collection System, the Strawberry Aqueduct and Collection System, the Diamond Fork System and the Municipal and Industrial System (Map 1.1). This unit includes facilities to collect water from Duchesne River system streams and to release it through the Wasatch Mountains as needed in the Bonneville Basin and Wasatch Front. One of the systems in the unit is the Strawberry Aqueduct and Collection System (SACS), which diverts flows from nine Duchesne River tributaries through approximately 40 miles of tunnels and aqueducts for storage in Strawberry Reservoir. That water is then carried to Utah Lake through the Diamond Fork System and the Spanish Fork River in Utah County. The water delivered from Strawberry Reservoir to Utah Lake is used as replacement water, allowing for the exchange and/or storage of Provo River flows in Jordanelle Dam, located on the Provo River in Heber Valley, approximately 10 miles upstream of Deer Creek Reservoir. Jordanelle Dam and Reservoir on the Provo River is the principal feature of the Municipal and Industrial (M&I) System, providing municipal and industrial water to Salt Lake, Utah and Wasatch Counties, and supplemental irrigation water to Summit and Wasatch Counties.

Even before the Central Utah Project was built, water storage and diversion features involving the Provo River were developed to provide municipal and irrigation water to portions of the Wasatch Front. These efforts, collectively known as the Provo River Project, were authorized and constructed with the approval of the federal government beginning in 1933. Most features of the Provo River Project were built by or under the supervision of the Bureau of Reclamation from 1938 to 1958. These included the building of (1) Deer Creek Dam, first completed in 1941, (2) the Salt



MAP 1.1. FEATURES OF THE BONNEVILLE UNIT, CENTRAL UTAH PROJECT (*MAP PROVIDED BY CUWCD*).

Lake Aqueduct transferring water stored in Deer Creek Reservoir to the Salt Lake Valley (labeled Jordan Aqueduct in Map 1.1), also completed in 1941, (3) the Duchesne Tunnel to transfer water from the headwaters of the Duchesne River to the Wasatch Front via the Provo River, completed in 1952, and (4) enlargement of the Weber-Provo Diversion and Canal to transfer water from the Weber River to the Provo River, completed in 1948. Other important features of the Provo River Project include among others the Murdock Diversion and Murdock Canal. See Map 1.2 for locations of these features.

In 1992, Congress enacted the Central Utah Project Completion Act ("CUPCA," Titles II through VI of Public Law 102-575). Among other things, CUPCA raised the Bonneville Unit appropriations ceiling; required local cost-sharing of project capital costs; authorized various water conservation

Map 1.2. Watershed area map.
[1-page 11x17 map from G/G, color]

This map is available by contacting the Mitigation Commission at: urmcc@uc.usbr.gov

and wildlife mitigation projects; and allowed local entities to construct certain project features under the direction of the Secretary of the Interior. Under CUPCA, the Central Utah Water Conservancy District (CUWCD) was designated as a Federal agency for NEPA compliance and given the authority to administer the CUPCA with executive oversight by the Secretary. CUPCA provided for the creation of a federal agency, the Utah Reclamation Mitigation and Conservation Commission (Mitigation Commission), which is responsible for mitigating impacts of the Bonneville Unit on fish, wildlife and related recreation resources. Under section 301 of CUPCA, the Mitigation Commission was created to perform several specific tasks which had previously been carried out by the Secretary of the Interior through the Bureau of Reclamation. Specifically recognized by Congress in CUPCA was the fact that many prior fish and wildlife mitigation efforts, for CUP and for other reclamation projects throughout the western United States, had lagged behind construction of other project features and when implemented, were often inadequate when compared against modern environmental standards. Congress therefore specifically addressed this shortcoming by establishing standards for the Mitigation Commission to follow when developing and coordinating implementation of plans for mitigation projects. The Commission is required to include in its fish and wildlife mitigation plans measures which it determines will **". . . restore, maintain, or enhance the biological productivity and diversity of natural ecosystems within the State and have substantial potential for providing fish, wildlife, and recreation mitigation and conservation opportunities," and ". . . be based on, and supported by, the best available scientific knowledge."**[1] Enhancement measures may be included in the plans to the extent such measures are designed to achieve improved conservation or mitigation of resources.

1.2 PURPOSE AND NEED FOR THE STUDY

The purposes of this study and report are to determine the relationships among streamflow and various ecological processes and conditions of the Provo River system from Jordanelle Dam to Utah Lake and to develop modeling tools that can be used to evaluate the ecological effects of alternative streamflow regimes. ***This report provides the needed tools to analyze the effects of different flow regimes on ecological components of the Provo River system, including: aquatic habitat, channel processes, sediment transport, riparian vegetation, water quality, and recreational usability.*** This report, along with additional subsequent analyses, are needed to respond to several requirements under CUPCA and related laws, as follows.

- **Address Previous Bonneville Unit Environmental Commitments.**

  At the time of the 1987 Municipal and Industrial System Final Supplement to the Final EIS, it was anticipated that under full operation of the M&I System, higher flows would be released into the Provo River below Deer Creek Reservoir and below Jordanelle Reservoir than had historically occurred prior to the project. A concern was raised regarding the potential effects of those high(er) flows on fishery and recreation resources. The following

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[1] From CUPCA, Sections 301(g)(4)(A) and (B)

Environmental Commitment (EC) was included in the Record of Decision for the M&I System:

> "Post-project fishery studies will be conducted below Deer Creek Dam to more precisely examine the impacts of summer habitat loss and winter habitat gain on the overall brown trout population and assess the feasibility of improving habitat through modification of streamflow regimens."

- **Comply with CUPCA Section 303(d)**

  Recognizing the concern regarding the potential effects of high flows in the Provo River system as a result of the Bonneville Unit being completed and operated, Section 303(d) of CUPCA also authorized the Mitigation Commission to ". . . conduct a study and develop a plan to mitigate the effects of peak season flows in the Provo River . . ."[2]

- **Comply with Section 301(g)(4) and Section 304 of CUPCA**

  Under the ecosystem restoration standards established in CUPCA , fish and wildlife mitigation must meet an ecosystem standard by restoring affected environments and contributing to the biological productivity, integrity and diversity of fish and wildlife resources [CUPCA Section 301(g)(4)]. Construction and operation of the Bonneville Unit and prior Reclamation projects, especially of the Provo River Project, and the Bonneville

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[2] "SECTION 303. STREAM FLOWS.

(d) MITIGATION OF EXCESSIVE FLOWS IN THE PROVO RIVER. – The District shall, with public involvement, prepare and conduct a study and develop a plan to mitigate the effects of peak season flows in the Provo River. Such study and plan shall be developed in consultation with the Fish and Wildlife Service, the Utah Division of Water Rights, the Utah Division of Wildlife Resources, affected water right holders and users, the Commission, and the Bureau. The study and plan shall discuss and be based upon, at a minimum, all mitigation and conservation opportunities identified through –

(1) a fishery and recreational use study that addresses anticipated peak flows;
(2) study of the mitigation and conservation opportunities possible through habitat or stream bed modification;
(3) study of the mitigation and conservation opportunities associated with the operating agreements referred to in section 209;
(4) study of the mitigation and conservation opportunities associated with the water acquisitions contemplated by section 302;
(5) study of the mitigation and conservation opportunities associated with section 202(2);
(6) study of the mitigation and conservation opportunities available in connection with water right exchanges; and
(7) study of the mitigation and conservation opportunities that could be achieved by construction of a bypass flowline from the base of Deer Creek Reservoir to the Olmsted Diversion."

Unit's SACS and M&I Systems, had substantial impacts on terrestrial, riparian and fish habitats in the affected streams and valleys, including the Provo River. Therefore many mitigation measures specifically prescribed by Congress in CUPCA occur or directly affect resources along the Provo River.[3] These specific directives are in addition to the more general directive of Section 304 of CUPCA to complete the fish, wildlife and recreation projects identified in the May 1988 Draft Supplement to the Definite Plan Report for the Bonneville Unit of the CUP. This study and report provides much of the needed scientific knowledge to effectively incorporate fish, wildlife and recreation mitigation measures affecting the Provo River corridor.

- **Utah Lake Drainage Basin Water Delivery System**

  The CUWCD, Department of the Interior, and Mitigation Commission are joint-lead agencies under the National Environmental Policy Act of 1969 (NEPA, stat.) for planning for facilities and features to complete the Bonneville Unit. This completion project has been termed the "Utah Lake Drainage Basin Water Delivery System," often called the Utah Lake System (or ULS). The joint-lead agencies have developed a draft purpose and need statement to guide the planning process for the ULS. The draft purpose and need statement helps define why the ULS is needed and also defines what purposes the ULS is intended to accomplish. Those portions of the purpose and need statement to which this study and report respond are highlighted below.

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[3] See CUPCA, §§ 302(a) and (b) and 303(c)(4) (appropriating funds for the purchase of water rights for the purpose of establishing a minimum flow of 75 cfs in the Provo River from Olmsted Diversion to Utah Lake); 302(b) (appropriating funds for the rehabilitation of diversion dams along the Provo River below the Murdock Diversion); 303(c)(2) and (3) (requiring minimum flows in Provo River of 125 cfs from Jordanelle Dam to Deer Creek Reservoir, and 100 cfs from Deer Creek Dam to Olmsted Diversion); 307(a)(1) (appropriating funds for fish habitat restoration on the Provo River between Jordanelle Dam and Deer Creek Reservoir); 307(a)(2) (appropriating funds for fish habitat restoration on streams impacted by Federal reclamation projects in Utah); 309(a)(1) (appropriating funds for the rehabilitation of the Provo River riparian habitat below Jordanelle Reservoir); 309(a)(4) (appropriating funds for the acquisition of additional recreation and angler accesses and riparian habitats, in accordance with recommendations of the Commission); 311(d)(2) (appropriating funds for recreation facilities along the Provo River corridor in Utah and Wasatch Counties); 311(e) (appropriating funds for riparian habitat acquisition and preservation, stream habitat improvements, and recreation and angler access along the Provo River from the Murdock Diversion to Utah Lake); and 315 (appropriating funds for stream habitat improvements; acquisition of angler access to entire reach of Provo River from Jordanelle Dam to Deer Creek Reservoir; and to acquire and develop 100 acres of wetland at base of Jordanelle Reservoir).

The *Advanced Preliminary Draft Plan Formulation Report* describes the following needs and purposes for the ULS:

> **Needs** - To complete the Bonneville Unit by delivering 101,900 acre-feet on an average annual basis from Strawberry Reservoir to the Wasatch Front Area and project water from other sources to meet some of the M&I demands in the Wasatch Front Area, to implement water conservation measures, to address all remaining environmental commitments associated with the Bonneville Unit, and to fully utilize current and future water supplies for M&I uses associated with the Bonneville Unit.

Purposes -

1) To provide some temporary supplemental Bonneville Unit irrigation water in Utah County.
2) To protect water quality of surface and underground water resources that may be affected by Bonneville Unit completion.
3) To provide creative methods, facilities, and incentives to implement water conservation measures, reuse, and conjunctive use of water resources.
4) To assist with recovery efforts by participating in the June Sucker Recovery Implementation Program.
5) To provide previously committed instream flows and statutorily mandated instream flows and assist in improving fish, wildlife, and recreation resources.
6) To provide for the United States to acquire adequate District water rights in Utah Lake to implement the ULS, and other water rights as authorized by CUPCA
7) To continue to provide Bonneville Unit water in accordance with existing contracts.
8) To develop project power.

1.3 ORGANIZATION OF THIS REPORT

This report provides the needed tools to analyze the effects of different flow regimes on ecological components of the Provo River system, including: aquatic habitat, channel processes, sediment transport, riparian vegetation, water quality, and recreational usability. It is organized into Introduction, Methods, Results and Discussion sections. The Introduction section provides a description of the study area and includes a delineation of Provo River into hydro-geomorphologically defined reaches. Within this section, information is provided that defines, in general terms, both historical and existing conditions. The Methods section of the main document is relatively brief, with more detailed technical methodology descriptions included as appendices. The Methods section provides a description of the study approach, reach mapping, study site selection, and identifies specific tools/models that were selected to analyze the various ecological components of the Provo River and its riparian corridor. The Results section is organized by Study Site, in upstream to downstream order. The Results section covers each study site and channel reach separately and emphasizes the unique relationship between stream flow and the riverine environment, which is specific to geomorphically different channel reaches. The Discussion Section compares and contrasts the results of each study site and channel reach. It concludes with a resource integration discussion, which describes in general terms, the holistic nature of the Provo River ecosystem, including trade-offs between resource components in evaluating alternative flow regimes.

This report covers channel reaches located between Deer Creek Dam and Utah Lake; a separate companion report covers channel reaches located between Jordanelle Dam and Deer Creek Dam – an area known as the "Middle Provo River." However, since the upstream portion of Provo River has a major influence on downstream conditions, a discussion of existing conditions in the Middle Provo is included in the Introduction section of this report.

1.4 RESOURCE INTEGRATION

The intent of this report is to relate stream flow to the riverine environment in a holistic manner. Aquatic habitat, riparian vegetation, sediment transport, and water quality characteristics are all directly influenced by streamflow, and also influence each other either directly or indirectly (Diagram 1.1). Both physical and ecological processes directly affect individual resources (i.e., fish habitat or recreational usability), and can change over time in response to altered streamflows (hydrology) or channel conditions (geomorphology). Therefore, it is important to refer to this report and its results in an integrated context, rather than focusing on the results of a single resource analysis in isolation. Rivers are dynamic, integrated systems that are ultimately formed and maintained by the long-term flux of water and sediment. Proposed changes to the water operations on the Provo River will result in both short-term and long-term changes to sediment transport and the physical and ecological characteristics of the river system, including its riparian corridor. Due to practical necessity, some analyses described within this report (such as the 2-dimensional aquatic habitat modeling) are based on the assumption that channel morphology and roughness characteristics of the study sites will remain static following changes to water operations. While this assumption may be accurate in the short-term (months to years), it is most likely inaccurate in the long-term (years to decades) if there are significant changes to the sediment or water flux. Therefore, the results of the 2-dimensional aquatic habitat modeling should be considered jointly with the results of the sediment transport and riparian vegetation analyses, because changes in these resources could alter the projected stream habitat-flow relationships.

1.4.1 STREAMFLOW AND SEDIMENT TRANSPORT INFLUENCES

The various aspects of the streamflow regime, including the magnitude, duration, and timing of floods and low flows, exert a strong influence on the characteristics of riverine ecosystems. Flow, in conjunction with sediment supply, controls the rate, timing, and size characteristics of sediment transport through a channel reach of given size and slope (Diagram 1.1). The forces associated with moving water (i.e., shear stress[4]) mobilize and transport sediment either as suspended load (typically sand, silt, and clay size particles) or as bedload (typically particles larger than fine sand). As flow magnitude increases, smaller size particles begin to move in suspension, and then once a threshold

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[4] Shear stress (τ) is calculated as : $\tau=\gamma RS$, where γ is the specific weight of water, R is hydraulic radius (approximately equal to water depth in most channels), and S is water surface slope.

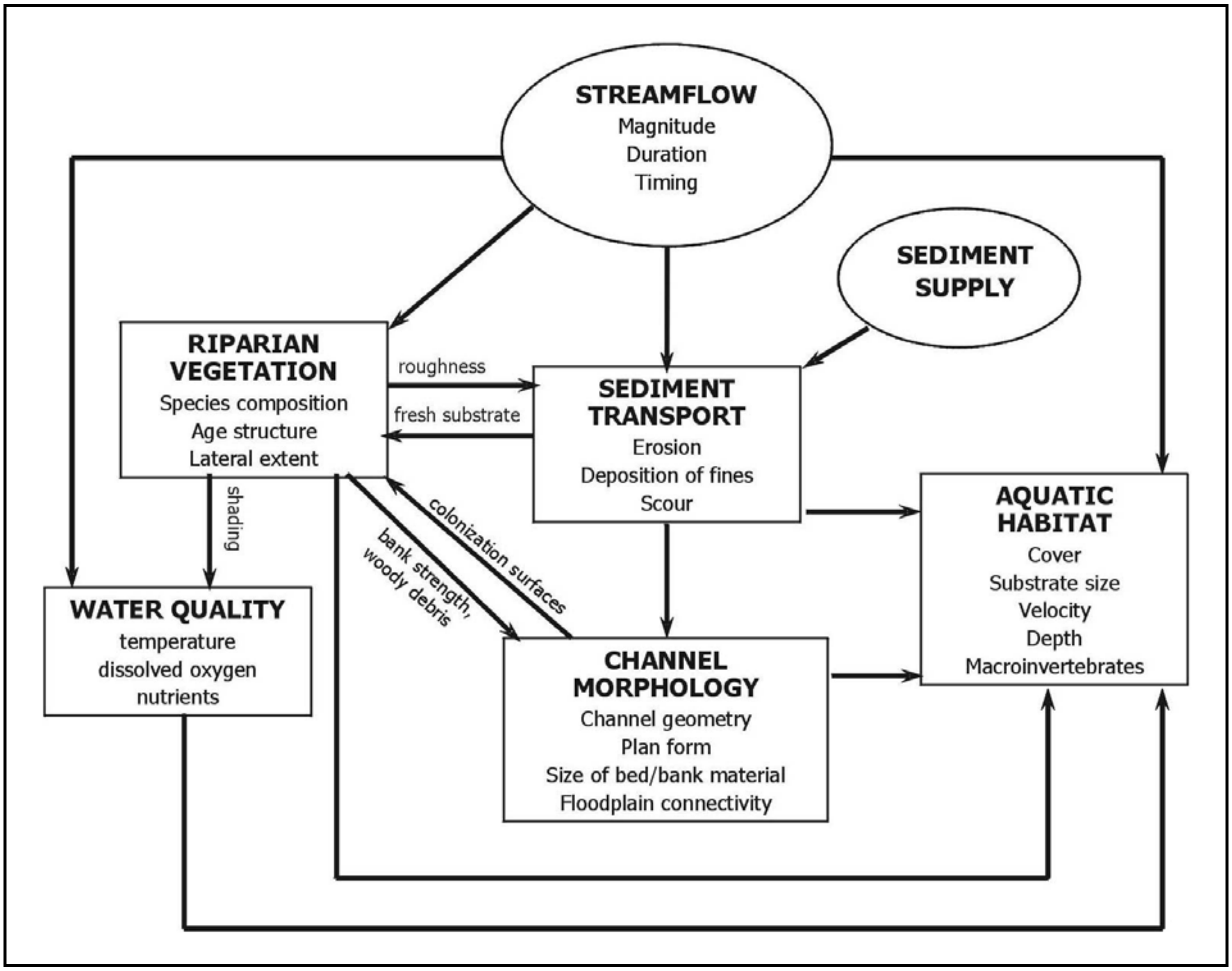

DIAGRAM 1.1. SCHEMATIC ILLUSTRATION OF MAJOR INTERACTIONS AMONG RIVERINE RESOURCES AND PROCESSES.

discharge is reached, bedload transport is initiated and particles begin to roll or saltate over the bed. The rate of sediment transport and maximum mobile particle size increase in a positive relationship with streamflow magnitude (assuming unlimited sediment supply). Streamflow duration also plays an important role in sediment transport. In coarse-bedded (gravel-size or larger) rivers, research has documented multiple phases of bedload movement (Andrews 1994, Jackson and Beschta 1982). In the initial phase, transport is predominantly size selective, and deposits of fine sediment become mobile and are "winnowed" from the bed while the larger grain sizes remain stable. Winnowing primarily occurs in riffles during moderately high flow events and is the process of smaller particles trickling through and around larger stable particles. If flows remain elevated for an adequate length of time, this supply of fine grained material becomes exhausted. If flows exceed the shear stress threshold to transport the larger grain sizes, then transport enters an "equal mobility" phase where a more complete range of particle sizes, including coarser material, are in motion. These dual phases of transport have been observed on the lowermost portions of the Provo River (Olsen et al. 1996), where the transition to the equal mobility phase was found to be important for maintenance of spawning substrate. Flows must be kept high for several days in order to effectively flush accumulations of fines and aquatic plants from spawning gravels (Olsen et al. 1996). Flushing flows are also important for maintenance of substrates that provide habitat for macroinvertebrates.

Through its influence on sediment transport, streamflow also controls the processes of deposition and erosion that shape and maintain channel morphology. When the shear stress associated with moving water exceeds the strength and inertial forces of bed or bank material, erosion occurs. If shear stress decreases, either due to reduced streamflow or due to a change in channel width and slope (i.e., at a transition from a narrow, steep reach to a wider, flatter reach), deposition will occur. Within a channel, specific zones of deposition and erosion vary spatially and temporally. An example of this is the fact that, in gravel-bed streams, riffles become depositional zones during high flows due to velocity reversals. Concave shaped pools are typically zones of slow moving deep water with a relatively flat profile and water surface slope during low flow. Convex shaped riffles, on the other hand, are zones of faster water with a steep profile during low flow due to the amount of drop between the flatter pools. Velocity reversals are caused by large increases in water surface slope over pools as stage increases with a corresponding small change in water surface slope over riffles. These changes in water surface slope cause the shear stress to become greater in pools than riffles during high flows. Therefore, the velocity reversal phenomenon causes sediment that has been entrained in zones of high shear stress (pools) to become deposited in zones of low shear stress (riffles) during high flows. The opposite occurs during low flow. Shear stresses once again become greatest in riffles and some of the finer grained bedload material winnows out of riffles (a continuation of phase I transport), and deposits in downstream pools. The velocity reversal process is important for the maintenance of pool and riffle habitats, and alterations to the streamflow regime could disrupt this process and alter the distribution and diversity of instream habitat types, including macroinvertebrate assemblages and the food source for fishery resources.

Streamflow also controls other aspects of channel morphology. Although non-alluvial influences such as bedrock outcrops and valley confinement can alter local channel characteristics, the size and shape of a channel are predominantly a function of the flux of water and sediment through the system. Flood magnitude and frequency are particularly important in this regard. The bankfull discharge, which is the discharge that just overtops a channel's banks, has been found to be approximately equal to the 1.5 to 2-year recurrence interval flood (Leopold et al. 1964). The bankfull discharge has also been found to be approximately equal to the effective discharge (Andrews 1980, Andrews 1994, Leopold 1992). The effective discharge is defined as the increment of discharge that transports the largest amount of sediment when averaged over the long-term. Streams will adjust their bankfull dimensions to match the new effective discharge if it changes due to flow alteration (Andrews 1986, Andrews 1994). Therefore, effective discharge is a useful predictor of potential channel changes associated with altered flow regimes.

In addition to controlling channel size, flood magnitude and frequency also form and maintain channel macro-features including bars, islands, and floodplains. In unregulated streams that have not been channelized, floodplain surfaces are at an elevation that is inundated on a relatively frequent basis by flood magnitudes on the order of the bankfull discharge. This regular inundation maintains connectivity between the main channel and floodplain areas, ensuring transport, dispersal, and cycling of sediment, nutrients, woody debris, and seeds. These processes are essential for adequate recruitment of riparian vegetation species and maintenance of water quality and habitat complexity. On streams where floods have been reduced due to dams or diversions, or where floodplain surfaces have been eliminated by levee construction, this important connectivity is lost.

The erosive forces associated with larger, infrequent floods (on the order of the 25- to 100-year events) play an important role in the formation and maintenance of habitat complexity. Large floods create and remove bars and islands, cause channel migration, create side channels through channel avlusion, and create and remove log jams. These features provide backwater and refugia habitat for aquatic species. Large floods also create fresh substrate deposits on scour-protected surfaces ideal for colonization by disturbance-dependent riparian species such as cottonwoods.

1.4.2 INTER-RESOURCE INFLUENCES

While streamflow serves as an independent "master" variable with direct influence on the full range of river resources, the individual resources also influence each other in important ways (Diagram 1.1). Riparian vegetation exerts a direct effect on sediment transport and stage-discharge characteristics by serving as a hydraulic roughness element when inundated at high flows. In addition, the roots of streamside vegetation increase bank strength, helping in the creation of undercut banks that provide cover and resting habitat for fish and amphibians. A healthy riparian canopy also provides habitat for birds. Riparian vegetation also functions as a source of logs and rootwads that create woody debris jams that in turn increase habitat complexity. The riparian canopy provides streamside shading, which reduces peak water temperatures and reduces diurnal temperature fluctuations. Water temperature has an important influence on the composition of fish and macroinvertebrate populations, and its seasonal variability provides triggers for critical life cycle functions such as spawning and larval hatches. Water temperature also strongly controls dissolved oxygen levels.

1.4.3 AMPHIBIANS AND RIPARIAN OBLIGATE SPECIES

In addition to their important influences on aquatic habitat, stream morphology, and water quality, riparian zones also play a unique and vital role in providing habitat for amphibians and terrestrial wildlife. Although riparian zones comprise less than 2 percent of all terrestrial habitats, they are used by a greater diversity of wildlife than all the remaining habitats combined (Hawkins 1994). Bird species are particularly dependent on riparian zones for breeding, migratory, and wintering habitat (Knopf and Samson 1994). Riparian zones also provide important linear corridors for animal and bird movement. Riparian floodplain areas that contain side channels, oxbow ponds, or vernal pools provide essential amphibian habitat. Because riparian areas are so vital to wildlife, changes in streamflow patterns that alter riparian characteristics can have ecological effects that extend far beyond the local aquatic environment. We recognize the importance of these off-channel/riparian area habitats along the Provo River on amphibians and riparian obligate species, yet it was beyond the scope of this report and not possible to provide a detailed evaluation of the flow/habitat relationship for amphibian and riparian obligate species at this time.

1.5 STUDY AREA

1.5.1 OVERVIEW OF PROVO RIVER WATERSHED

The Provo River originates in the Uinta Mountains at an elevation of approximately 10,800 feet and flows toward the west into Jordanelle Reservoir. From Jordanelle Dam, the river flows south-southwest into Deer Creek Reservoir and through Provo Canyon. Provo River then flows through the cities of Orem and Provo, ultimately discharging into Utah Lake (Map 1.2). The study area for this project includes the Provo River and its floodplain from the Jordanelle Dam outlet to Utah Lake. Excluding the "lake" portion of the river within Deer Creek Reservoir, a total channel length of approximately 30 miles was evaluated for this study

Average annual precipitation in the study area ranges from 15.7 inches in Heber City (URMCC 1996) to 21 inches at the Olmsted Power Plant near the mouth of Provo Canyon to 13 inches in downtown Provo (BIO-WEST 2000). The majority of this precipitation comes in the form of snow during the winter months and melts and runs off during the spring and early summer months. Therefore, the annual hydrograph is highly influenced by the amount of wintertime snow accumulation throughout the watershed and the rate and/or timing of snowmelt.

1.5.2 DESCRIPTION OF STUDY REACHES

Within the Study Area, the Provo River was divided into a total of 8 distinct study reaches based on differences in hydrologic and geomorphic conditions. The hydrologic factors considered were position relative to dams, diversions, and major tributaries; the geomorphic factors considered were channel slope; degree of valley constraint; and channelization. Figure 1.1 shows a generalized longitudinal profile of Provo River within the Study Area. A total of eight distinct reaches were identified, and are listed in Table 1.1.

1.5.3 HISTORICAL CHANGES FROM "NATURAL" CONDITIONS

The hydrologic, geomorphic, and biological characteristics of the Provo River system have been greatly altered by a variety of historical anthropogenic influences. Within the Study Area, flows are affected by a complicated network of dams, water imports, and water diversions constructed for hydropower, irrigation, and water supply purposes. In addition to the natural runoff of the Provo River basin, there are two transbasin diversions which import water into the basin above Jordanelle Reservoir. The Weber-Provo Diversion and Canal originates from the Weber River approximately near Oakley, Utah and is discharged into the Provo River near Woodland. This feature was enlarged

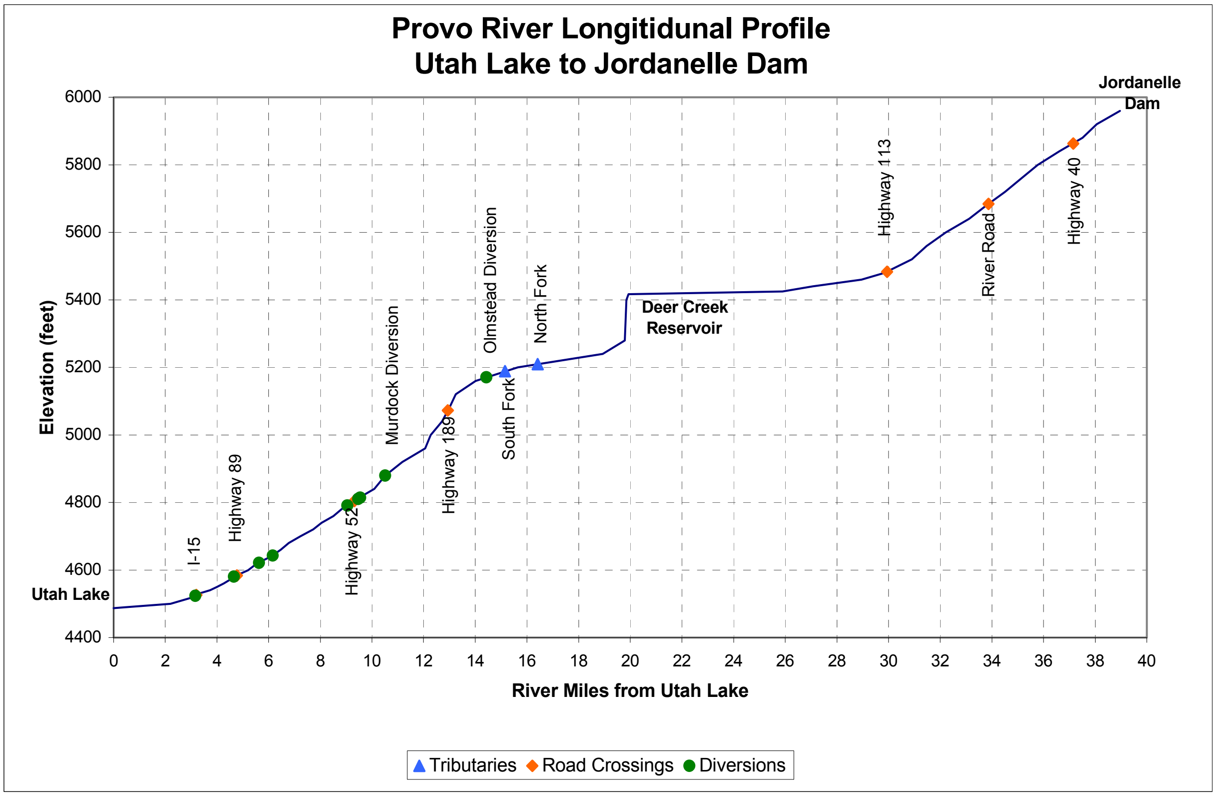

FIGURE 1.1. GENERALIZED LONGITUDINAL PROFILE OF PROVO RIVER WITHIN THE STUDY AREA.

TABLE 1.1. GENERAL REACH INFORMATION.

REACH NUMBER	REACH DESCRIPTION	REACH LENGTH[A] (MILES)
1	UTAH LAKE TO TANNER RACE (LOWER CITY DAM)	3.14
2	TANNER RACE TO MURDOCK DIVERSION	5.95
3	MURDOCK DIVERSION TO OLMSTED DIVERSION (LOWER GRADIENT SECTIONS)	2.27
4	MURDOCK DIVERSION TO OLMSTED DIVERSION (HIGHER GRADIENT SECTIONS)	1.59
5	OLMSTED DIVERSION TO DEER CREEK RESERVOIR OUTLET (CONFINED SECTIONS)	4.24
6	OLMSTED DIVERSION TO DEER CREEK RESERVOIR OUTLET (LESS CONFINED SECTIONS)	0.80
7	DEER CREEK RESERVOIR INLET TO JORDANELLE DAM OUTLET (CHANNELIZED SECTIONS)	5.69
8	DEER CREEK RESERVOIR INLET TO JORDANELLE DAM OUTLET (RESTORED SECTIONS)	4.64

[A] REACH LENGTHS DO NOT INCLUDE BACKWATER AREAS BEHIND DIVERSION DAMS.

in 1948 as part of the Provo River Project. The second transbasin diversion comes from the Duchesne River. It was completed in 1952 and discharges into the Provo River approximately 14 miles upstream of Woodland. Other important features of the Provo River Project include among others the Deer Creek Dam and Reservoir, the Murdock Diversion and Murdock Canal. Various other diversions are present throughout the Study Area. In addition to altering streamflows, the dams and diversions on the Provo River trap large amounts of sediment, altering sediment supply and transport through the system. The diversion structures also create "knick points" in the channel profile that artificially flatten channel gradient in both the upstream and downstream directions and lead to deposition of fine-grained sediment (e.g., sand and silt) within the substrate material. Knick points are abrupt changes (i.e., drop-offs or falls) in the elevation of the streambed. Furthermore, the dams along Provo River have caused population fragmentation and migration corridor blocks in both the upstream and downstream direction.

As part of the original Provo River Project plan authorized by Congress, stretches of the Provo River above Deer Creek Reservoir were straightened and channelized in the period from late 1944 to early 1953. This work was done with the intent of "bettering" the Provo River, and included clearing the channel, placing dikes, placing sills, and constructing several small timber bridges. This work was carried out by the government from 1944 through 1951, and was completed under contracts with private firms from 1951 through 1953. In connection with the channelization work, the Bureau of Reclamation, in the period from the 1940s through the 1950s, acquired some fee lands and flood and construction easements in the name of the United States embracing small sections of the Provo River in the Heber Valley and upstream.

After several years of full project operation, however, the Provo River Project began to experience problems. One problem stemmed from the fact that the entire water supply of the Provo River Project (including natural flows of the Provo River and imported flows of the Duchesne and Weber rivers) could not be conveyed in the Provo River channel without causing bank erosion and flooding in the Heber Valley. This problem resulted in the development and approval of the Provo River Channel Revision project. This was authorized in 1959, and carried out under contracts from 1960 through 1965. In connection with the channel revision work, the Bureau of Reclamation acquired some additional fee lands and flood and construction easements. This project enlarged the capacity of the Provo River channel and further stabilized the banks through diking, straightening and erosion control measures such as placing large riprap along the banks and dikes.

These various activities along the Provo River channel from the 1940s through the 1960s adversely affected the river's formerly abundant and diverse natural resources, especially forested riparian areas that support off-channel wetlands, valuable floodplains, and instream fish habitats.

In Study Reaches 7 and 8, most of the Provo River has also been significantly and extensively affected by channelization activities. With the exception of a 1.3 mile section near Midway that was never leveed, nearly the entire stretch of the Provo River between Jordanelle and Deer Creek Reservoirs (Reaches 7 and 8) was straightened, dredged into the shape of an incised trapezoidal canal, and constrained between levees built to protect adjacent agricultural land from flooding (U.S.

Bureau of Reclamation Dataweb, 2002). Beginning in 1999, the Mitigation Commission has undertaken large-scale channel reconstruction efforts within Reaches 7 and 8 to restore large sections of the river to a more natural channel form. The restoration construction efforts are expected to be completed in 2005 or 2006.

Channelization has also been extensive within the lower portions of the river. In Provo Canyon (Reaches 3-6), the river has been channelized and leveed to enable highway and railroad construction. Natural lateral migration of the river is therefore restricted, as is channel-floodplain connectivity. Similar channelization and levee-building activities have occurred in Reaches 1 and 2 to protect adjacent agricultural and urban development. In general, the lack of large, functional floodplain areas that are connected to the river severely reduces the spatial and temporal diversity of in-stream habitat, and limits natural recruitment and extent of riparian vegetation.

Generally, the Lower Provo River appears to be approximately in the same location today as was mapped by the early settlers in 1856 (Olsen et al., 2002). Prior to anthropogenic influences (e.g. channelization), it is likely that the channel freely meandered within a broad corridor near its current location, being confined only by erodible terraces and Lake Bonneville deposits. The river corridor was likely very dynamic (eroding and depositing significant amounts of fluvial material during floods) and adjusted periodically to climate shifts and occasional high sediment loads transported through the steeper canyon and delivered to the lower segments of Provo River. Entrenched within Lake Bonneville deposits, Provo River meandered through multiple depositional landforms such as alluvial terraces and floodplains, which also provided a continuous sediment supply from fluvial processes associated with lateral channel migration and lateral floodplain development. Although much more complex, the channel itself was likely single threaded (maintained a defined thalweg) with multiple cut-off meanders and side-channels, with a gravel-cobble bed and a pool-riffle morphology. The rate of lateral adjustments would be somewhat high given the high upstream sediment supplies from Provo Canyon.

The main difference relative to existing conditions is that the channel historically had a well developed and active floodplain that would have likely been 2 to 10 times wider than the channel width at bankfull stage (bankfull stage is when the channel is absolutely full and flowing water is on the verge of overtopping the banks and spreading out on the floodplain). This natural configuration maintained a large area adjacent to the active channel that would frequently be inundated with flood water. Frequent flooding is necessary to maintain floodplain functions and dynamic mosaics of riparian-wetland vegetation.

The riparian vegetation would consist of a willow lined channel with several mosaics of different vegetation types such as sedges and cottonwoods depending on relative distance and elevation above the channel. Vegetation communities would be affected by the presence of other water sources such as ponds, ground water discharge zones, and preferential flow paths of abandoned channels and old meander scars. The floodplain would consist of mature cottonwood galleries, bare gravel/cobble deposits, willow lined secondary channels and very wet sedge meadows. The channel would be characterized by the presence of point bars and other depositional features. The spatial variability in flow velocities within the channel would have been much greater than under current conditions. Slow water (velocities less than 1 foot per second) would have occurred along the shallow margins near the vegetated banks, behind various obstructions, and across the floodplain when inundated. High velocities (velocities between 2 to 5 feet per second) would have occurred within constrictions and within well defined riffles (below pools). The range of velocities would have provided ideal staging/resting habitats adjacent to spawning habitats. Fine sediment material would accumulate behind fallen trees, branches, and other obstructions. The streambed material would have been well sorted with finer grained sand/gravel accumulating in pools and clean cobble material dominating riffle habitats.

1.6 EXISTING CONDITIONS: THE MIDDLE PROVO RIVER (REACHES 7 AND 8)

As previously mentioned, this report covers study results for Reaches 1 through 6 only; however, information on existing conditions within Reaches 7 and 8 is included here for the sake of completeness because these upstream reaches influence conditions within Reaches 1 through 6.

1.6.1 HYDROLOGY

The general hydrologic pattern of the Provo River upstream of Jordanelle Reservoir remains predominately that of a snowmelt-dominated system despite several small storage projects (Trial, Lost and Washington Lakes) present on headwater lakes and transbasin inputs from the Weber and Duchesne basins. Flows typically peak in the spring and recede to baseflow levels by mid-summer. Currently, streamflows in the Middle Provo River (Reaches 7 and 8) are controlled by releases from Jordanelle Dam, and are further affected by several agricultural diversions in the Heber Valley. Jordanelle Dam has reduced peak flows and artificially elevated low flows Hydrogeologically, this portion of the Provo River is a gaining stream reach, and groundwater inputs from seeps and springs (including irrigation return flows) augment streamflow before the river discharges into Deer Creek Reservoir. Snake Creek and other smaller tributaries join the Provo River upstream from Deer Creek Reservoir.

A typical flow regime for the Middle Provo River is represented by water year 1999 data from the U.S. Geological Survey (USGS) gage at Charleston and is plotted in Figure 1.2. Flows at the Hailstone gage, which is located upstream of Jordanelle Reservoir and represents the unregulated (i.e., unaffected by large dams) flow regime (despite some transbasin inputs from the Weber and Duchesne basins), are also plotted in Figure 1.2 for comparison purposes only. Currently, a minimum instream flow of 125 cfs is legally required in Reaches 7 and 8.

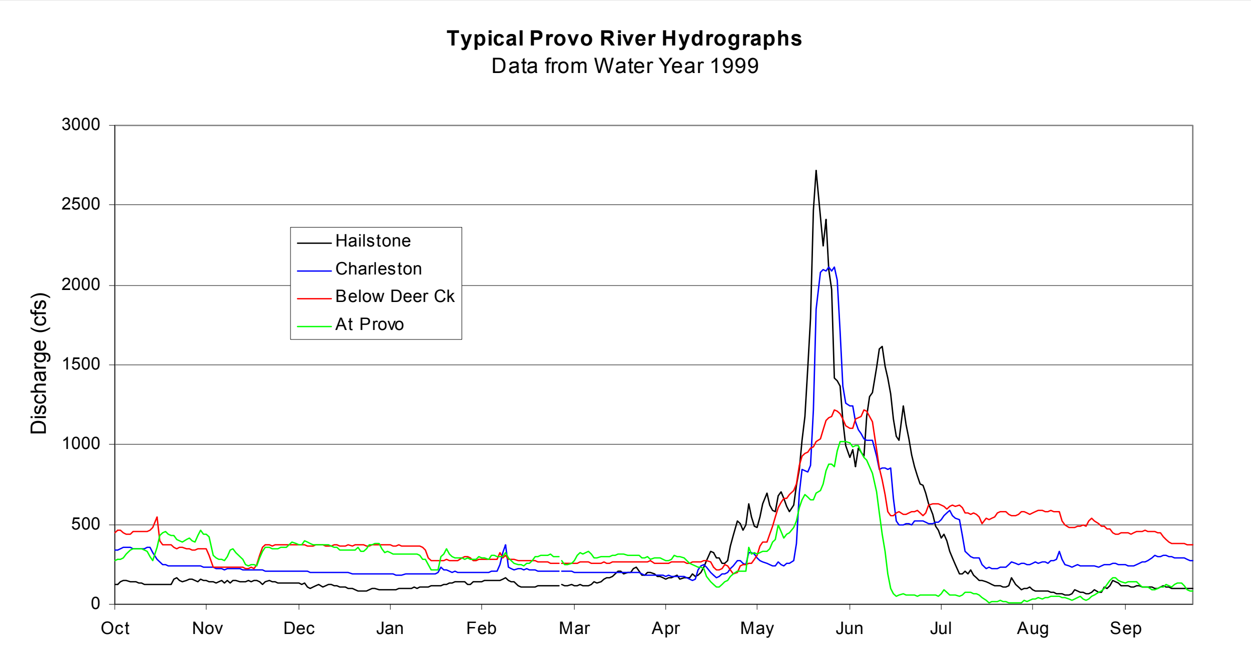

FIGURE 1.2. TYPICAL PROVO RIVER HYDROGRAPHS.

1.6.2 GEOMORPHOLOGY

As previously discussed, the Middle Provo currently includes both straightened, channelized sections (delineated as Reach 7) as well as recently restored and never-channelized sections (delineated as Reach 8) (Map 1.3). Plan form of Reach 7 sections is relatively straight with minor, gradual bends and a single-thread channel pattern; Reach 8 sections, in contrast, have frequent islands, numerous side channels (smaller channels with perennially flowing water connected to the main river channel), and a more sinuous plan form (Map 1.3). Cross-sectionally, Reach 7 sections are relatively narrow and constrained between steep, leveed banks. Reach 8 sections are wider with lower, more gradual banks, and more diverse in-channel topography (Figure 1.3). Because of the presence of levees, Reach 7 sections are disconnected from their floodplain, and the width of inundation is narrow even at high flows.

Sediment supply within the Middle Provo River has been significantly altered by Jordanelle Dam. Essentially no sediment is supplied to Reaches 7 and 8 from upstream due to trapping by the dam. Sediment inputs are therefore restricted to direct inputs from bed and bank erosion or other nonpoint sources.

MAP 1.3. STUDY AREA MAP.

[3-page 11x17 map from G/G, color]

This map is available by contacting the Mitigation Commission at: urmcc@uc.usbr.gov

Map 1.3. Study Area map (cont.).
[3-page 11x17 map from G/G, color]

This map is available by contacting the Mitigation Commission at: urmcc@uc.usbr.gov

Map 1.3. Study Area map (cont.).

[3-page 11x17 map from G/G, color]

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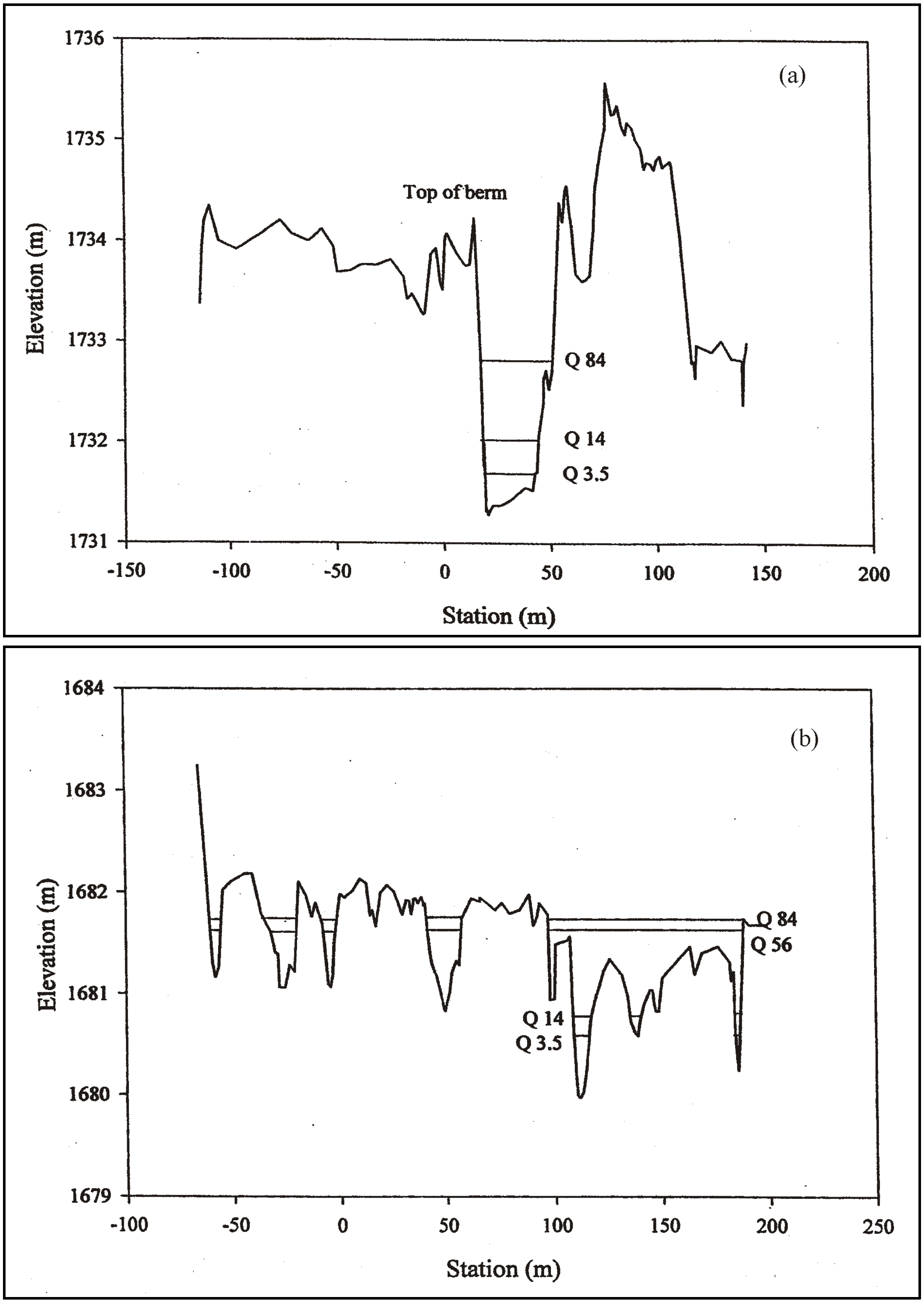

FIGURE 1.3. TYPICAL REACH 7 (A) AND REACH 8 (B) CHANNEL CROSS-SECTIONS (*ADAPTED FROM STROMBERG ET AL. 1999*).

1.6.3 WATER QUALITY

Water quality within the Middle Provo River is generally good, and the river is meeting the standards for its designated beneficial uses. Jordanelle Dam is equipped with a multi-level release structure that enables water to be drawn from various elevations within the reservoir. This structure reduces the temperature and dissolved oxygen impacts that are often associated with reservoir releases, and allows for management of releases to reduce downstream nutrient inputs. Water pollution controls have been implemented in the Heber Valley to improve the quality of water entering Deer Creek Reservoir. Pollutant loads in storm water runoff from developed land and infrequent high magnitude events in Provo River is still unknown.

1.6.4 RIPARIAN VEGETATION

The riparian vegetation characteristics of the Middle Provo River were examined in detail in 1997 and 1998 as part of studies conducted for the Provo River Restoration Project (Stromberg et al. 1999). Dominant riparian tree species include cottonwood (*Populus angustifolia*), box elder (*Acer negundo*), and alder (*Alnus incana*). Dominant shrub species include coyote and yellow willow (*Salix exigua and S. lutea*), red-osier dogwood (*Cornus sericea*), wood's rose (*Rosa woodsii*) and river hawthorn *(Crataegus dougslasii*). A wide variety of herbaceous species including forbs and grasses are present; dominant species include redtop (*Agrostis stolonifera*), bluegrass (*Poa pratensis*), reed canarygrass (*Phalaris arundinacea*), horsetail (*Equisetum arvense*), and thistle (*Cirsium arvense*). In general, riparian species richness is greater in unchannelized river reaches than in channelized reaches, and vertical canopy structure is more diverse (Stromberg et al. 1999). In the 1.3 mile section of Reach 8 near Midway that has historically remained unchannelized, riparian vegetation width is as great as 1300 feet (400 m). In contrast, riparian vegetation width in channelized reaches where the river is disconnected from its floodplain by levees is only 200 to 400 feet (60 to 120 m) (Stromberg et al. 1999). Results of age structure analyses indicate that recruitment of cottonwoods (*Populus angustifolia*) is occurring on point bars and islands in both channelized (Reach 7) and unchannelized (Reach 8) portions of the Middle Provo River (Stromberg et al. 1999). However, the 1.3 mile section of river near Midway that was never channelized displays the greatest variety in cottonwood ages due to its wide diversity of fluvial surfaces, connectivity to its floodplain, and presence of active side channels (Stromberg et al. 1999). This diversity allows for more frequent cottonwood establishment under a greater variety of flow scenarios.

1.6.5 FISHERIES

The Provo River system supports a diverse array of aquatic species that are important for management agencies. Fish assemblages in the Provo River are very different from their historic natural levels. The sport fishery is dominated by trout, primarily brown trout (*Salmo trutta*) (Wiley and Thompson 1998). The Provo River is the most heavily fished stream fishery in Utah and a large segment of the river is managed primarily for brown trout, including the entire Middle Provo River. Special regulations require artificial lures and flies only and special daily bag limits are in place to maintain the high-quality fishery. Since 1975, the Utah Division of Wildlife Resources (UDWR) began managing for wild fish with the discontinuation of hatchery stocking. Rainbow trout (*Oncorhynchus mykiss*) were stocked extensively prior to 1975, but wild populations of this species have not produced the numbers and biomass of fish that brown trout have. Much less abundant are the native sportfish, Bonneville cutthroat trout (*Oncorhynchus clarki utah*) and mountain whitefish (*Prosopium williamsoni*).

Many species of native fishes occur in the Provo River, although most are uncommon to rare in the presence of abundant piscivorus brown trout (Belk and Ellsworth 2000). One species, the mottled sculpin (*Cottus bairdi*), coexists well with the brown trout; abundant cobble substrate provides high quality habitat and refuge from brown trout. Mountain whitefish are also common in reaches containing habitat with greater depths (>3 feet). The species is similar to trout in behavior and habitat requirements, but generally requires slightly greater depths.

The Middle Provo River contains a number of native fish species. Utah sucker (*Catostomus ardens*), longnose dace (*Rhinichthys cataractae*), speckled dace (*Rhinicthys osculus*), mountain sucker (*Catostomus platyrhynchus*), leatherside chub (*Gila copei*), Utah chub (*Gila atraria*), and redside shiner (*Richardsonius balteatus*), are rare to uncommon throughout this section (Belk and Ellsworth 2000). These species are largely restricted to off-channel habitat such as backwaters and cutoff pools in areas with more natural habitat structure. Areas that are channelized with high levees do not afford the escape cover the small native fishes need in the presence of the (larger) non-native brown trout.

1.6.6 MACROINVERTEBRATES

The National Aquatic Monitoring Center has collected and/or processed macroinvertebrate samples from the Provo River at four locations between Jordanelle Dam and Deer Creek Reservoir (Mark Vinson 2002, pers. comm.). They have samples collected in 1996 and 1997 near the crossing of Route 40, and samples collected in 1999 near the Route 113 crossing, and above and below River Road (Map 1.3). These samples encompassed channelized and unchannelized areas of the river, including the area that has recently undergone restoration work below Jordanelle Dam. Shiozawa et al. (2002) also collected samples at similar locations within this area in 1999, 2000, and 2001. Samples collected from 1999-2001 from both these studies showed a relatively diverse community where anywhere from 25-46 taxa were collected at individual stations (Shiozawa et al. 2002). A variety of mayflies, stoneflies and caddisflies were collected throughout the area.

1.6.7 RECREATION

Fishing is the dominant recreational use on the Middle Provo River. Other uses include wading and some rafting.

1.6.8 ISSUES

As described in the Purpose and Need section above, this study is designed to evaluate and determine the relationships among streamflow parameters and habitat/ecological processes within the Middle Provo River. In addition to this general need, several issues and concerns are specific to the Middle Provo River.

This study attempts to provide information and tools to address these issues and questions, which include:

- What is the potential for channel armoring and substrate coarsening due to sediment trapping by Jordanelle Dam?
- What is the habitat value of restored stream reaches relative to channelized stream reaches?
- What are the habitat characteristics of side channels and do they benefit native fish species?

1.7 EXISTING CONDITIONS: PROVO CANYON (REACHES 3-6)

1.7.1 HYDROLOGY

The hydrology of the Provo River within Provo Canyon (Reaches 3-6) is primarily controlled by flow releases from Deer Creek Dam, inputs from tributary streams, and flow diversions by the Salt Lake Aqueduct and Olmsted Diversion. Water is diverted to the Salt Lake Aqueduct directly at Deer Creek Dam; Olmsted Diversion is a large diversion structure located at the boundary between Reach 5 and Reaches 4 and 3 (Map 1.3). Three significant tributaries enter Provo River within Provo Canyon: Little Deer Creek, North Fork, and South Fork (Map 1.3). Streamflow in the tributaries is unregulated and originates as high-elevation snow. The flow regimes of North Fork and Little Deer Creek are dominated by spring snowmelt runoff, with peak flows occurring earlier in the year on Deer Creek due to its lower elevation drainage. Flows are much more constant on South Fork, which is a spring-dominated system (Figure 1.4).

The flow regime of the Provo River within Provo Canyon has been altered from natural historical conditions. Springtime peak flows have been reduced, and summertime flow releases are artificially high because the river is used as a water delivery conduit to supply downstream irrigators and other water users. These alterations are illustrated in Figure 1.2, where flows in the upper portion of the Canyon (Reaches 5 and 6) are represented by the Provo River below Deer Creek gage data. Significant amounts of water are diverted at the Olmsted Diversion during the irrigation season, reducing flows in Reaches 3 and 4 relative to Reaches 5 and 6.

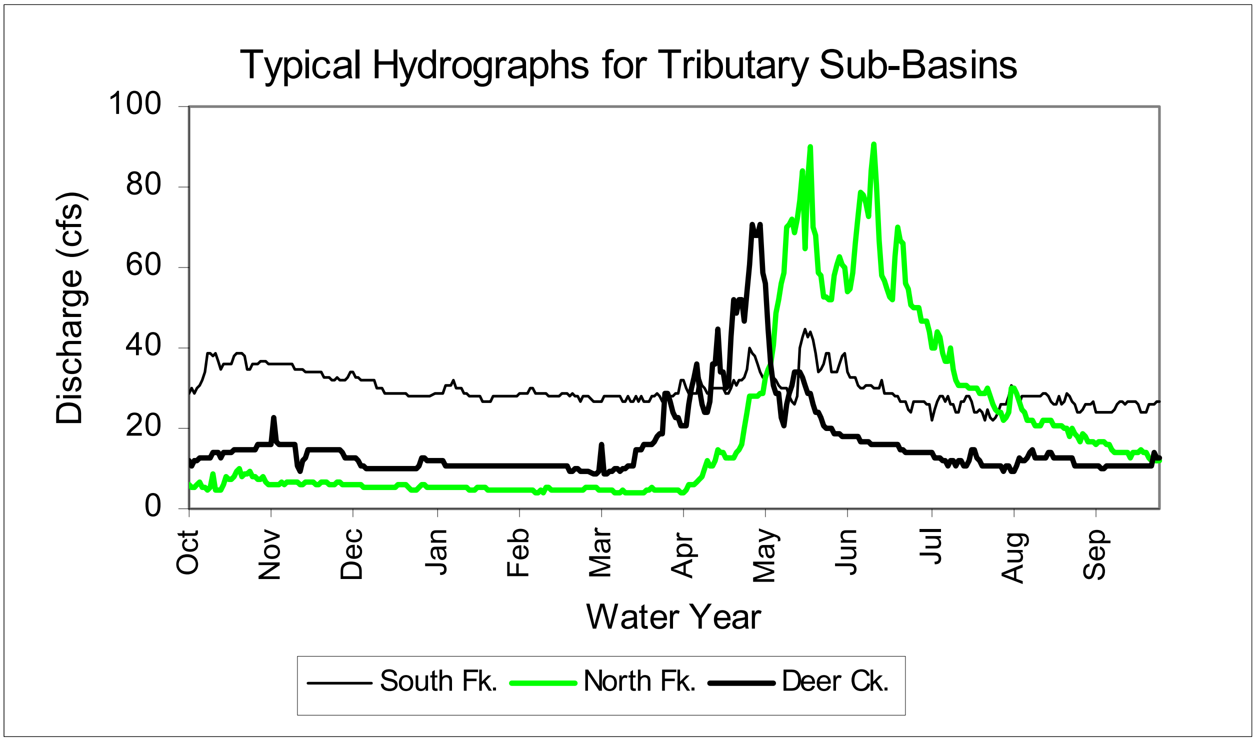

FIGURE 1.4. TYPICAL HYDROGRAPHS FOR PROVO RIVER TRIBUTARIES DURING AVERAGE WATER YEARS. WATER YEAR 1948 SHOWN FOR SOUTH FORK; WATER YEAR 1973 SHOWN FOR NORTH FORK; WATER YEAR 1979 SHOWN FOR DEER CREEK.

Since 1994, attempts to operate the Provo River system to achieve flows more suitable for June sucker (an endangered fish species) spawning and recruitment have been ongoing. New targets for springtime flow releases from Jordanelle and Deer Creek dams have recently been established in an attempt to more closely mimic the natural hydrograph for the benefit of June sucker (Keleher 1999). These target flow releases were implemented experimentally in spring of 1999, 2000, 2001, and 2002 (C. Keleher 2002, pers. comm.).

Minimum instream flow requirements have been established in the canyon by the CUPCA to provide sustained habitat for aquatic species. The year-round minimum instream flow between Deer Creek Dam and Olmsted Diversion is 100 cfs, and the minimum wintertime instream flow below Olmsted Diversion is 25 cfs. Currently, there are no legally-binding summer instream flow requirements for the Provo River below Olmsted; however, this may change in the future. Section 302 of CUPCA authorized funding for acquisition of water rights with the objective of providing a year-round minimum instream flow of 75 cfs. At present, this objective has not been met, although the CUWCD, Commission, and DOI are in the process of acquiring water shares and water rights from willing sellers for this purpose. Environmental commitments in the Diamond Fork FEIS also acknowledge the need to "acquire and protect a block of water for June sucker."

1.7.2 GEOMORPHOLOGY

As previously described, the river in Provo Canyon has historically been channelized and leveed to enable highway, trail, and railroad construction. Natural lateral migration of the river is therefore restricted, as is channel-floodplain connectivity. The degree to which this channel constriction occurs varies with the natural geologic variability in valley width. In areas where the valley is wider, the distance between the highway and railroad or trail is greater and the river has some floodplain access and forms bars and islands. In areas where the valley is narrow, the river is pinned in a single-thread trapezoidal channel between levees and has very limited access to floodplain areas and limited in-channel morphologic complexity. Geologic controls on valley width also influence channel slope within Reaches 3-6. The segment of river between Olmsted Diversion and Murdock Diversion was divided into higher gradient (Reach 4) and lower gradient (Reach 3) sections because of these slope differences. Reach 4 is located in an extremely steep cascade section of river in the vicinity of Bridal Veil Falls.

Sediment supply within Provo Canyon has been significantly altered by Deer Creek Dam and Olmsted Diversion, which trap downstream-moving sediment. Sediment inputs are therefore restricted to local sources such as direct inputs from bank and bed erosion, tributary inputs, and other nonpoint source inputs. Highway construction activities within Provo Canyon have created a number of large eroding road cuts that provide sediment to the river, and several hillslope inputs of sediment occur in geologically-unstable portions of the canyon. A recent water quality study (BIO-WEST 2000) identified several land uses that contribute nonpoint source pollution -- including sediment -- to the river. These land uses include high-use recreation, grazing, active construction, and various roads and parking areas. Eroding streambanks caused by high-intensity foot traffic for fishing access are also relatively common throughout the canyon. However, these nonpoint sediment sources are typically fine-grained (sand-size or smaller), and do not fully compensate for the lack of coarse-grained particles that would naturally be transported into the river from upstream if such sediments were not blocked by Deer Creek Dam and Olmsted Diversion.

1.7.3 WATER QUALITY

Water quality is generally good within the Provo Canyon portion of the Provo River. The Utah Division of Water Quality (DWQ) has monitoring sites below Deer Creek Dam, at Olmsted Diversion, and at Murdock Diversion. The DWQ has established criteria or water quality standards for the purpose of protecting beneficial uses; including cold water fishery, drinking water source, and agricultural water supply. Water quality typically meets state standards and indicator levels at these sites for all beneficial uses, although occasional exceedences occur in total phosphorus (TP), dissolved oxygen, and bacteria (coliform) levels (BIO-WEST 2000). High phosphorus concentrations typically occur during the spring or summer, and most likely are associated with snowmelt inputs of sediment and attached phosphorus from tributaries, and releases of water high in dissolved phosphorus from Deer Creek Dam. Low dissolved oxygen levels are periodically measured during late summer at the site below Deer Creek Dam and appear to be related to releases of deep anoxic reservoir water; however, sampling by the CUWCD indicates that dissolved oxygen levels appear to recover within approximately 0.25 miles downstream (R. Obendorfer 2000, pers. comm.), although other sampling has indicated that this distance may be greater (M.Holden 2002, pers. comm.). Therefore, Deer Creek dam operation has the potential to affect water quality in two ways. First, water quality is affected by the release of dissolved phosphorus, which is readily available to undesirable aquatic plants. Second, water quality is affected by the release of anoxic reservoir water, primarily during late summer.

As discussed previously, various land uses in the Provo Canyon area contribute nonpoint source pollution in the form of sediment and attached nutrients. Roads, active construction areas, grazing, high-intensity recreation, failing septic systems, and bank erosion are some of the main nonpoint sources (BIO-WEST 2000). Nutrient and sediment inputs contribute to occasional build-ups of algae and macrophytes in the channel. This aquatic vegetation can encroach upon spawning gravels and cause accumulations of fine sediments that degrade spawning habitat quality. TMDLs for TP and total suspended solids (TSS) were recently completed for Provo River and its tributaries within the canyon (BIO-WEST 2000), and efforts by the Provo Canyon Water Quality Technical Committee to meet established load reduction goals are ongoing.

1.7.4 RIPARIAN VEGETATION

Dominant riparian tree species within Provo Canyon include box elder and cottonwood; dominant shrub species include red osier dogwood, river hawthorn, and willow; various grasses and herbaceous species occupy the wettest portions of the riparian area and occasionally within the channel. Although mature cottonwood trees are present on terrace areas within the Canyon upstream from Olmsted Diversion, almost no young cottonwood trees or recently-recruited seedlings are present in Reaches 5 or 6. However, below Olmsted Diversion in Reaches 3 and 4, younger cottonwood trees and seedlings are present.

In general, the width of the riparian area within Provo Canyon is narrower than in the Reach 8 (unchannelized) portions of the Middle River. The riparian zone in the canyon is laterally restricted by the presence of levees, roads, trails and etc., and natural geologic constraints on valley width.

1.7.5 FISHERIES

The six-mile reach between Deer Creek and Olmsted Diversion is classified as a Class 1 (highest) category for stream fisheries and accounts for 10% of Utah's total mileage with this designation. Special regulations require artificial lures and flies only and special daily bag limits are in place to maintain the high-quality fishery. Since 1975, the UDWR began managing for wild fish with the discontinuation of hatchery stocking. Rainbow trout (*Oncorhynchus mykiss*) were stocked extensively prior to 1975, but wild populations of this species have not produced the numbers and biomass of fish that brown trout have. Much less abundant are the native sportfish, Bonneville cutthroat trout (*Oncorhynchus clarki utah*) and mountain whitefish (*Prosopium williamsoni*).

As many as 13 species of native fishes occurred in the Provo River, although most are uncommon to rare in the presence of abundant piscivorus brown trout (Belk and Ellsworth 2000). Limited information is available on native fishes specifically in the Provo Canyon as few native fishes have been collected in this reach.

1.7.6 MACROINVERTEBRATES

Winget (1976, 1982), Crist and Trinca (1988), and the National Aquatic Monitoring Center all have information about the macroinvertebrate community of the Provo River downstream from Deer Creek Dam to Murdock Diversion. Crist and Trinca (1988) found 41 different taxa, spanning 14 orders of invertebrates at their three stations from this area. All of these collectors sampled stations relatively close to the confluence of the North Fork and the main stem Provo, so some comparisons among the three can be made. Crist and Trinca (1988) compared their Vivian Park station to information collected by Winget (1976, 1982) from the same general area. They found higher total densities in 1988 than either of the prior two studies. Total number of taxa was higher in the 1982 and 1988 samples than the 1975 samples. Some differences in species composition were seen between years, however, variability in the seasonal timing of collections can explain some of this variability in the species composition.

Conversely, National Aquatic Monitoring Center samples collected around the North Fork confluence in 1995 and 1996 show large decreases in the total number of taxa and in the number of mayfly, stonefly, and caddisfly taxa (National Aquatic Monitoring Center, unpublished data). No stoneflies or caddisflies were collected in the 1996 samples. However, the Utah Division of Environmental Quality (UDEQ) collected samples above Murdock Diversion in 1999 and 2000 that were more similar to those collected by Winget (1975, 1982) and Crist and Trinca (1988).

1.7.7 RECREATION

Throughout the Provo River, fishing is the dominant recreational use. Because of the proximity of Highway 189, the Heber Creeper Railroad, and the Provo Canyon Trail to the river, public fishing access is excellent in Reaches 3-6. Fishing pressure is high throughout Provo Canyon.

The Provo Canyon portion of Provo River also receives significant boating use with rafts, kayaks, canoes, and tubes. A commercial rafting business operates within the canyon during the summer months, and kayakers run the whitewater stretches of the canyon during springtime high flow releases from Deer Creek Dam.

1.7.8 ISSUES

As described in the Purpose and Need section above, the relationships among streamflow parameters and habitat/ecological processes within Provo Canyon must be examined as part of required environmental studies for the M&I System, for the Utah Lake System project, and for compliance with CUPCA. In addition, several issues and concerns are specific to Provo Canyon.

This study attempts to provide information and tools to address these issues and questions, which include:

- What are the effects of streamflow regimes implemented under the M&I System on aquatic habitat within the Canyon reaches?
- How would habitat change if summertime flows were further increased?
- What are the effects of streamflow regimes implemented under the M&I System on recreational accessability (wading)?
- How would further increases in summertime flows affect recreational accessability (wading)?
- What are the effects of streamflow regimes implemented under the M&I System on riparian vegetation (especially cottonwood recruitment) within Reaches 5 and 6?
- What alternative flow scenarios would promote riparian vegetation (especially cottonwood) recruitment?
- Has channel armoring and substrate coarsening occurred below Deer Creek Dam due to altered flows and sediment trapping?
- What "flushing flow" characteristics are needed to scour algae from spawning gravels?

1.8 EXISTING CONDITIONS: LOWER PROVO RIVER (REACHES 1-2)

1.8.1 HYDROLOGY

As with the upstream study reaches, water operations have altered the streamflow hydrograph within Reaches 1 and 2 from natural historical conditions. In addition to the hydrologic alterations caused by Jordanelle Dam, Deer Creek Dam, and Olmsted Diversion, Reaches 1 and 2 are affected by eight additional water diversions (Map 1.3). Murdock Diversion is the largest of these diversions, and commonly diverts more than 250 cfs from the river during the height of the summer irrigation season (BIO-WEST 2001). Cumulatively, the eight diversions on the lower Provo divert an average of 300 to 500 cfs from the river between May and September (BIO-WEST 2001). The effects of these diversions and upstream water operations are illustrated by data from the USGS gage at Provo, which is located downstream of all the diversions (Figure 1.2). Peak flows at this gage site have been reduced by approximately 66% and occur approximately two weeks later than they would have naturally (UDWR 1999).

As discussed above, attempts to operate the Provo River system to provide flows more suitable for June sucker spawning and recruitment have been ongoing since 1994, and target spring spawning releases have been implemented since 1999. However, the objective of providing a year-round minimum flow of 75 cfs in the lower river has not yet been met. Summer flows as low as 2 cfs have recently been recorded at the Provo USGS gage, and portions of the lower river between diversion structures are commonly dewatered (BIO-WEST 2001). Additionally, the target flows for June sucker spawning and recruitment described in Keleher (1999) have not been met during the recent drought years, largely a result of shorter duration high "flushing" flows and an over-steepened receding limb.

1.8.2 GEOMORPHOLOGY

The Lower Provo River is highly urbanized and flows through the cities of Orem and Provo (Map 1.3) are highly regulated to allow for residential and commercial development along the historic floodplain. The river has been channelized and leveed throughout Reaches 1 and 2 in order to reduce flooding and accommodate residential, commercial, and industrial land uses. Because of these channel modifications, floodplain width is minimal, streambanks are overly steep and tall, and natural geomorphic processes such as point bar deposition and channel avulsion are limited. Flood flows are fully contained between the levees, greatly limiting overall floodplain area, function, and floodplain-channel connectivity. A conceptual illustration of the historical alterations to the morphology of the lower Provo River is provided in Figure 1.5.

As with the upstream portions of the Study Area, sediment supply to the lower Provo River has been reduced by the presence of dams and diversions that trap sediment. Sediment inputs are limited to bank and bed erosion and nonpoint source inputs. Substrate in Reach 2 and the upper section of Reach 1 is coarse, consisting primarily of cobble material. In the lower portion of Reach 1, stream gradient flattens (Figure 1.1) and gravel comprises a larger proportion of the bed material.

The lowermost 1.6 miles of Provo River (Utah Lake to the UDWR Fish Weir) is all "lake habitat" even though the trapezoidal channel gives the appearance of a river. This habitat type makes up 15.6 acres of the available 34 acres of river habitat available to June sucker (below Lower City Diversion). Channel substrate in this reach consists mostly of fine (silty) material. Water depths range from 6 to 10 feet depending on Utah Lake water levels. In this reach, water depths are not controlled by flows in Provo River because of the overwhelming influence of Utah Lake. Water velocities are slow to stagnant depending on total stream discharge. Water velocities are fairly uniform across the entire channel due to the absence of natural channel irregularities or obstructions. There is essentially no emergent or submergent vegetation in this reach because of the steep

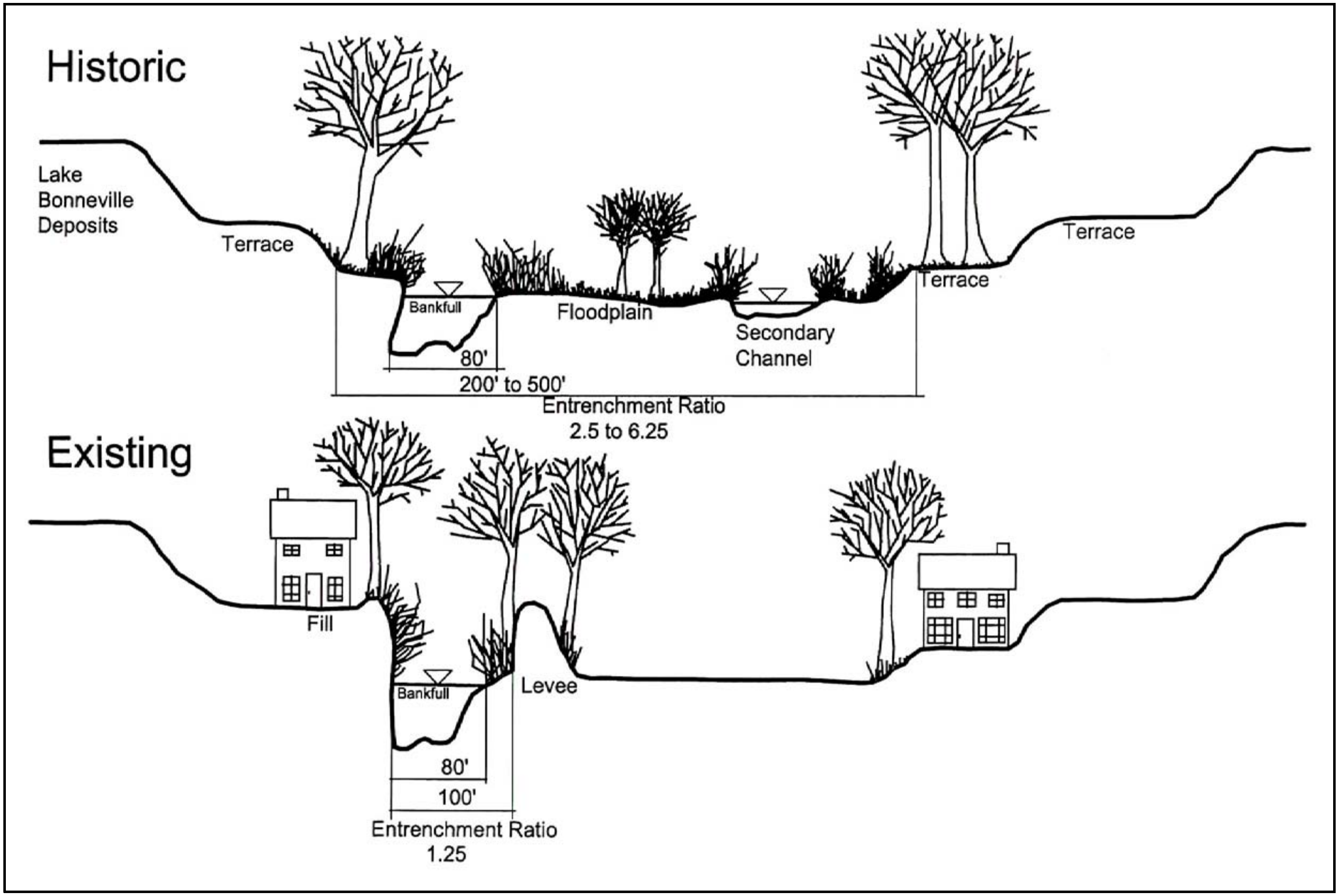

FIGURE 1.5. CONCEPTUAL DRAWING OF THE PAST AND PRESENT CONDITION OF PROVO RIVER AND ITS FLOODPLAIN (*OLSEN ET AL. 2002*).

embankments on both sides of the channel. The isolated pool adjacent to the channel (Sheet 4 of the Provo River Flow Study Aquatic Habitat and Riparian Vegetation Reach Scale Maps) is kept separated from the river because of the unculverted levee/trail system immediately north of Provo River. This oxbow provides some habitat diversity; however it is physically and hydrologically disconnected from the main channel by the levee/trail system.

1.8.3 WATER QUALITY

Water quality data are collected by the DWQ near Geneva Road, and by the CUWCD near Harbor Drive (Map 1.3). Although the Provo River is not included on Utah's year 2000 303(d) list of impaired water bodies, water quality is typically poor in the river's lower reaches during summer months due to low dissolved oxygen levels and elevated temperatures. Below Upper City Dam (Map 1.3), polluted storm water runoff from urbanized areas contributes a large portion of the streamflow during storm events. Fish kills associated with polluted runoff are possible in the lower reaches of the river if these storm events occur during low flow periods (USFWS 1999). Nutrient and sediment inputs, combined with warm temperatures and shallow water depths, contribute to summertime build-ups of algae and macrophytes within the channel. This aquatic vegetation can cause armoring of spawning gravels and accumulations of fine sediments that degrade spawning habitat quality.

1.8.4 RIPARIAN VEGETATION

The width and overall density of riparian vegetation in the lower Provo River is low relative to the Provo Canyon and Middle Provo portions of the Study Area. As previously discussed, channelization and bank armoring (i.e. rip rap) are extensive in the lower river, and vegetation establishment surfaces are therefore very limited. Common species include willow, cottonwood, box elder, and various grasses. Exotic invasive species including tamarisk *(Tamarisk* sp.), Russian olive (*Elaeagnus angustifolia*), and common reed (*Phragmites australis*) are also present at various locations within Reaches 1 and 2. Plant diversity is artificially increased in the lower river because of the proximity of landscaped stream side residential and commercial properties. These landscaped areas are often irrigated, supplying an additional source of water that alters riparian vegetation patterns from what would occur naturally if the river were the only water source. Cottonwood recruitment is occurring to a limited extent on bar and bank surfaces within the lower river.

1.8.5 FISHERIES

Reach 1 is designated as Critical Habitat for June sucker and management focuses on conservation and enhancement of the species relative to guidelines outlined in the June Sucker Recovery Plan (USFWS 1999). Additionally, the lowermost portions of Reach 1 (i.e., lake habitat) is managed as a Wildfish Water for white bass (*Morone chrysops*), black bass (*Microprous* sp.), walleye (*Stizostedion vitreum vitreum*), channel catfish (*Ictalurus punctatus*), and brown trout. The nonnative fish are a threat to the continued existence of June sucker. Wildfish Waters are those that can be naturally sustained, and the fishery is maintained via natural reproduction. Reach 2 is managed as an Intensive Yield Water for rainbow trout where 10,000 catchable trout are stocked annually. Intensive Yield Waters are those that provide fishing opportunities in areas where angling pressure is extensive or where habitat is marginal for fishery success (UDWR 2000).

The June sucker was federally listed as an endangered species in 1986. Reach 1, from Tanner Race Diversion (Lower City Dam) downstream to Utah Lake, was designated as critical habitat. The documented wild population size at time of listing was less than 1,000 individual spawning adults with a current estimate of approximately 300 individual spawning adults (USFWS 1999).

The Provo River is used by adult June suckers for spawning in late May and June. After hatching, larvae drift downstream to Utah Lake. Fort Field Diversion is located approximately three miles upstream of the mouth of the Provo River and is likely a migration barrier during most spawning seasons (C. Thompson 2000, pers. comm.). Tanner Race Diversion, located at the upstream end of Reach 1, is a barrier to migration at any flow due to a drop in streambed elevation of approximately 8 feet at the diversion structure.

The UDWR performed a fisheries inventory that included the lower river during winter and spring 1975 (UDWR 1976). Electrofishing in Reach2 sampled 793 fish which were comprised of 99.5 percent brown trout, 0.1 percent rainbow trout, and 0.4 percent whitefish. Nongame fish were identified during this sampling but not collected, and included sculpin, mountain sucker, and dace.

1.8.6 MACROINVERTEBRATES

The National Aquatic Monitoring Center has processed macroinvertebrate samples taken by the UDEQ from one station near the U-114 crossing of the Provo River, which is close to Reach 1 of this study (Mark Vinson 2002, pers. comm.). The data from this site has shown lower taxonomic diversity than sites upstream from the Murdock Diversion (National Aquatic Monitoring Center, unpublished data). No stoneflies have been found in collections taken from this area in 1999-2001. Mayfly and caddisfly diversity appears depressed at this site compared to upstream areas, also. The community here seems dominated by midges and more pollution tolerant mayflies in the Baetidae family.

1.8.7 RECREATION

As discussed previously, fishing is the dominant recreational use of the Provo River. Although these lower sites extend through Orem and experience less fishing pressure relative to the Middle or Provo Canyon sections, they are still frequented by anglers. The lower Provo River also receives recreational boating use with rafts, kayaks, canoes, and tubes. Boating and floating uses are most common during the summer months. The Parkway Trail System that extends into the Canyon Reaches is located adjacent to Provo River and is heavily used during all months of the year.

1.8.8 ISSUES

As described in the Purpose and Need section above, the relationships among streamflow parameters and habitat/ecological processes within the lower Provo River must be examined as part of required environmental studies for the Utah Lake System project and to guide future management decisions affecting the June sucker and other aquatic resources in this reach. In addition to this general need, several issues and concerns are specific to the lower Provo River. This study attempts to provide information and tools to address these issues and questions, which include:

- What are the effects of existing flow regimes on aquatic habitat within the lower river?
- How would aquatic habitat be affected if the goal of a year-round minimum flow of 75 cfs were achieved?
- What are the effects of streamflow regimes implemented under the M&I System on aquatic habitat within the lower river?
- What are the effects of existing flow regimes on recreational boating opportunities?
- How would recreational boating opportunities be affected if the goal of a year-round minimum flow of 75 cfs were achieved?
- What are the effects of streamflow regimes implemented under the M&I System on recreational boating opportunities within the lower river?
- Has channel armoring and substrate coarsening occurred in the lower river due to altered flows and sediment trapping?
- What "flushing flow" characteristics are needed to scour algae from spawning gravels?
- Does the existing flow regime support adequate riparian vegetation recruitment?
- What are the effects of streamflow regimes implemented under the M&I System on riparian vegetation recruitment?
- How would riparian vegetation recruitment be affected if the goal of a year-round minimum flow of 75 cfs were achieved?

2.0 METHODS

2.1 Channel Reach Mapping

Maps of the entire river channel in the Study Area from Jordanelle Dam to Utah Lake were developed in order to determine the most appropriate study site locations and study site length that best represent the complexity of habitats within each channel reach. An atlas of 1" = 200' USGS orthophoto sheets was prepared for the entire Study Area for field mapping purposes. Aquatic and riparian habitat polygons (Tables 2.1 and 2.2) were hand-drawn directly on the orthophoto sheets in the field. Mapping was completed during the weeks of March 26-29 and April 8-13, 2002 at flows ranging from 100 to 125 cfs. The hand drawn polygons were then digitized into GIS for spatial analysis. Total acreage and proportion of each habitat type within the various channel reaches was quantified. This information was used to initially locate appropriate study sites that included the range of habitat types present within the various reaches. Before the sites were finalized, the preliminary study site locations were visited in the field by members of the Provo Flow Study Group (including BIO-WEST staff, Montgomery Watson Harza staff, Craig Addley [USU], Mark Holden [URMCC], Chris Keleher [CUWCD], and Ralph Swanson [Department of Interior]) to ensure that the sites would be acceptable to the parties involved. Final minor adjustments to the study site boundaries were made by field survey crews to ensure that the sites would be feasible/practical to survey. Study sites were numbered such that the numbering matches the reach numbers (i.e., Site 1 represents Reach 1, etc.).

The channel reach maps were also used to extrapolate modeled habitat at the "Site" scale to total habitat available within the "Reach." Methods for data extrapolation are described in section 2.3.6 below.

2.1.1 Aquatic Habitat Types

The categories used to map aquatic habitat at the reach scale are shown in Table 2.1. These categories are based on standard habitat types used in fisheries biology; however, the categories have been modified and expanded to fit the specific conditions encountered on the Provo River.

2.1.2 Riparian Habitat Types

The categories used to map riparian vegetation types at the channel reach scale are listed in Table 2.2. In addition to these broad categories, dominant species types within each category were noted on the field maps, and areas with young cottonwood trees (i.e., areas exhibiting recent cottonwood recruitment) were specifically noted.

Table 2.1. Aquatic Habitat Types Used in Channel Reach Mapping.

Code	Habitat Type[A]	Broad Habitat Type[B]	Description
IS	Island	Island	Any parcel of land within the flood plain that is surround by either wetted channel or dry channel that is periodically inundated during higher flows.
MR	Moderate Run	Run	An area of moderately flowing water, with little surface agitation and approximately uniform flow. Generally comprising the thalweg and the majority of the channel.
SR	Slow Run	Run	An area of slowly flowing water, with little surface agitation and approximately uniform flow. Usually adjacent to the thalweg and the majority of the channel.
PR	Pooled Run	Run	Slow to fast flowing reaches, with little surface agitation and approximately uniform flow. This habitat type possesses increased depth as compared to other run types and better provides resting and cover habitat.
RI	Riffle	Riffle	A shallow area with turbulent, swiftly flowing water and some partially exposed cobble or large gravel substrate.
CA	Cascade	Riffle	The steepest riffle habitat, consisting of alternating small waterfalls and shallow pools usually with bedrock, concrete riprap and boulder substrate.
BW	Back Water	Pool	A zero velocity habitat found along the margin of the stream resulting from back-flooding upstream and usually separated from the channel by a gravel bar.
EP	Eddy Pool	Pool	A pool type habitat with a circular current of water branching from, and initially flowing opposite to, the main current.
PO	Pool	Pool	A portion of the stream with diminished current velocity and depths considerably larger than the surrounding area, thereby providing resting and cover habitat.
CP	Corner Pool	Pool	A lateral pool formed at a bend in the channel sufficient to concentrate flows and scour a depression.
DP	Dammed Pool	Pool	Pool type habitat created by a channel obstruction, usually resulting from a diversion structure. Depths vary from inches to feet depending on height of structure.
PP	Plunge Pool	Pool	Habitat found where the river passes over either a partial or complete channel obstruction. The pool is usually formed and maintained by the velocity of the water passing over the obstruction and scouring out a depression.

DC	Dry Channel	Island	Any side channel which had no flow during mapping but possessed evidence of use during higher flows.
SW	Slack Water	Run	Zero velocity water along the edge of the channel.
PWR	Pocket Water Run	Run	Deep run with boulders and/or large cobbles that provide small pools.
CB	Cobble Bar	Bar	Depositional area of the channel dominated by cobble-sized substrate which was not inundated during mapping.
GB	Gravel Bar	Bar	Depositional area of the channel dominated by gravel-sized substrate which was not inundated during mapping.

[A] These categories used for field mapping of channel reaches.
[B] These categories used for extrapolation of modeling results.

Table 2.2. Riparian Vegetation Types Used in Channel Reach Mapping.

Vegetation Type	Description
Wooded	Areas dominated by trees. Common species included cottonwood and box elder. Stand age (young vs. mature) was noted on field maps
Scrub-shrub	Scrub-shrub riparian area. Dominant species included red osier dogwood, willow, and hawthorn.
Herbaceous	Riparian areas consisting mostly of grasses, sedges, and/or rushes.
Disturbed	Disturbed areas consisting of bare ground, rip rap, etc.

2.2 DETERMINATION OF STREAMFLOWS

2.2.1 TARGETED STREAMFLOWS

Target streamflows were identified to address specific concerns within each reach prior to the development of the work plan. In general, the goal of this study is to evaluate flows ranging from 0 to at least 1,500 cfs. The overriding study objectives required that the approach be able to assess flow-habitat relationships and ecological processes over the full range of flows anticipated within each reach (including peak or over-bank flows where possible), and that models be calibrated or fine-tuned around the flows of specific concern. A flow proposal was developed for the various reaches and submitted to Provo River system dam and diversion operators for implementation. A commitment was made by participating organizations to implement the flow proposal. Although drought conditions during spring runoff in 2002 made it challenging to deliver adequate peak flows for this study, cooperating agencies worked together and delivered the requested flows. Provision of the flow releases needed for this study occurred in consultation with the June Sucker Flow Work Group to ensure releases were coordinated with provision of targeted June sucker spawning and nursery flows.

2.2.2 STREAMFLOW DETERMINATION

Actual streamflows encountered during sampling were determined using a combination of "real time" provisional data at USGS and CUWCD gauging stations and field measurements. Table 2.3 provides data sources and calculation techniques used to determine streamflows for each study site, and gage locations are shown on Map 1.3.

TABLE 2.3. DATA SOURCES AND CALCULATION TECHNIQUES USED TO DETERMINE STREAMFLOW AT THE VARIOUS STUDY SITES.

SITE	DATA SOURCE/ CALCULATION TECHNIQUE
STUDY SITE 1	USGS STATION # 10163000 (PROVO RIVER AT PROVO) 15 MINUTE REAL-TIME DATA.
STUDY SITE 2	CUWCD STATIONS "OLMSTEAD TAIL RACE" + "PAST MURDOCK" HOURLY DATA.
STUDY SITE 3 & 4	CUWCD STATIONS "PROVO RESERVOIR CANAL" + "PAST MURDOCK" HOURLY DATA. AN ADDITIONAL 5 CFS WAS ADDED FOR BRIDAL VEIL TRIBUTARY INPUTS.
STUDY SITE 5	USGS STATION # 10159500 (PROVO RIVER BELOW DEER CREEK DAM)15 MINUTE REAL-TIME DATA + LITTLE DEER CREEK (AVERAGE DAILY FLOW USING CUWCD REAL-TIME DATA) + NORTH FORK (FIELD MEASUREMENT).
STUDY SITE 6	USGS STATION # 10159500 (PROVO RIVER BELOW DEER CREEK DAM)15 MINUTE REAL-TIME DATA + LITTLE DEER CREEK (AVERAGE DAILY FLOW USING CUWCD REAL-TIME DATA).

2.3 PHYSICAL AQUATIC HABITAT MODELING

Modeling of physical habitat consisted of 1) generating detailed digital terrain models (DTMs) of each intensive study site, 2) overlaying substrate types onto the DTMs for modeling hydraulic roughness and for modeling fish and riparian habitat, 3) two dimensional modeling of flow fields at each site over a range of flows from 10 to 1,500 cfs, and 4) habitat modeling (details in Appendix A). Two-dimensional models were developed for Study Sites 1, 2, 3, 5 and 6, and these models were used to represent habitat in Reaches 1, 2, 3, 5 and 6, respectively. Study Site 4 was not suitable for hydraulic modeling due to its steep cascading gradient and boulder substrate; habitat-flow relationships at this site were evaluated using a point-sampling technique (see section 2.3.7).

2.3.1 DETAILED TOPOGRAPHIC SURVEYS

At each of the study sites, complete channel and near channel floodplain topographic data were surveyed in the field using total station equipment. Approximately 1,800-3,000 topographic data points were typically surveyed at each site. Survey data were reviewed for completeness (missing data, holes in the topography, etc.) on a daily basis using ArcView software, and supplementary topographic surveying was conducted to ensure that data density was adequate for accurate terrain model development. A final editing of the topography was accomplished in the office using OrthoMax 3D visualization software. Terrain points were added interactively to insure that the terrain interpolation algorithm (triangular irregular network [TIN] with break lines) accurately represented the channel topography.

2.3.2 SUBSTRATE AND RIPARIAN MAPPING

Substrate and riparian vegetation classifications throughout the study sites were hand-delineated in the field on prints of the terrain maps generated from the topographic surveys. Mapping was completed at low flow (between approximately 30 to 150 cfs, depending on the site) when the entire channel was visible, and mapping for all main-stem study sites was completed by the same individual to ensure consistency. Substrate was delineated into visibly homogeneous substrate types based on dominant and subdominant particle sizes. Classification was based on a modified Wentworth scale (Table 2.4). Disturbed or rip-rapped areas were placed into the size class that most closely corresponded to the size of the rip rap or disturbed soil. Riparian vegetation was delineated into the following broad categories: grass/herbaceous, scrub-shrub, and mature tree. Substrate and riparian maps were digitized into a GIS layer using ArcView software.

TABLE 2.4. SIZE CLASSES[A] USED FOR SUBSTRATE MAPPING.

SIZE CLASS (MM)	DESCRIPTION
<2	SAND/SILT
2-8	FINE GRAVEL
8-32	MEDIUM GRAVEL
32-64	LARGE GRAVEL
64-96	SMALL COBBLE
96-192	MEDIUM COBBLE
192-256	LARGE COBBLE
256-512	SMALL BOULDER
512-1024	MEDIUM BOULDER
>1024	LARGE BOULDER

[A] SIZE CLASSES ARE BASED ON A MODIFIED WENTWORTH SCALE.

2.3.3 HYDRAULIC CALIBRATION

Field surveys of water surface profiles were completed using total station equipment at a minimum of four different discharge levels at each study site. Supplementary stage information for intermediate discharge (flow) levels was collected by measuring water surface elevation relative to the elevation of installed upstream and downstream stage rebars with a tape measure. Specific flow levels surveyed or measured at each site are listed in Table 2.5. Measured water surface elevation data were used to generate stage discharge relationships at the upstream and downstream boundaries of each study site that were then used for model calibration.

TABLE 2.5. DISCHARGE LEVELS FOR WATER SURFACE ELEVATION MEASUREMENTS.

STUDY SITE	DISCHARGE (CFS) AND DATE SURVEYED			
	LOW	MEDIUM	MEDIUM-HIGH	HIGH
SITE 1	60 MAY 29, 2002	325[A] MAY 6, 2002	535 MAY 8, 2002	700 MAY 11, 2002
SITE 2	50 APRIL 16, 2002	215 MAY 15, 2002	575 MAY 8, 2002	800 MAY 11, 2002
SITE 3	36.5 APRIL 24, 2002	248 MAY 15, 2002	600 MAY 7, 2002	810 MAY 11, 2002
SITE 5	131 APRIL 13, 2002	690 MAY 6, 2002	915 MAY 8, 2002	1065 MAY 10, 2002
SITE 6	123 APRIL 11, 2002	658 MAY 6, 2002	916 MAY 8, 2002	1059 MAY 10, 2002

A STAGE MEASURED AT REBAR USING TAPE MEASURE.

2.3.4 TWO DIMENSIONAL HYDRODYNAMICS MODELING

Hydrodynamic modeling at the intensive study sites was accomplished using STAGR (a research code developed by Jonathan Nelson of the USGS). The model solves the two-dimensional vertically averaged flow equations using a spatially variable, scalar eddy viscosity (turbulence closure) that emphasizes vertical diffusion of momentum. The program utilizes spatially variable channel roughness. STAGR is a 2-D / quasi-3-D model used extensively in a research mode by Jonathan Nelson of the USGS and has recently been implemented into visual interface for general use by the USGS. When supplied good data on topography and flow and stage boundary conditions, STAGR will calculate velocities, water surface elevations and boundary shear stresses in the channel. It has been used in channels with or without islands and in both high and low Froude number flows[1]. The program was slightly modified at Utah State University to enhance the wetting-drying and initial conditions capabilities.

2.3.4.1 *COMPUTATIONAL MESHES*

Curvilinear orthogonal meshes were generated at each of the study sites from a smooth (gradually varying radius) stream centerline. Meshes were refined as much as practical given the size of the intensive study sites and limitations of computational time. These meshes were used both for the hydrodynamics modeling and for the habitat modeling.

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[1] Froude number (Fr) is the ratio of mean flow velocity (u) to critical velocity and defines whether the flow is subcritical ($Fr<1$), critical ($Fr=1$), or supercritical ($Fr>1$). It is calculated as $Fr=u/(gD)^{1/2}$ where g is the acceleration due to gravity and D is mean depth of flow.

2.3.4.2 WATER SURFACE MODELING

The two-dimensional model was calibrated to the measured water surfaces at each sampled discharge by adjusting substrate and riparian vegetation roughness. The substrate maps at each site included an estimated hydraulic roughness height based on the size of the largest particle sizes in each substrate category. Approximate roughness was calculated for riparian vegetation types from standard Manning's "n" versus vegetation type references (Chow 1959, Arcement and Schneider 1989).

During the calibration phase of the hydrodynamics modeling, the roughness heights across all substrate types were increased or decreased by a constant percentage until the modeled water surface matched the measured water surface. This was first done at the high calibration flow. We then checked that the calibrated roughness performed accurately at the medium and low calibration flows. A roughness modifier relationship (log [flow] versus log [roughness modifier]) was used where necessary to account for changes in relative roughness at different flows (typically roughness increases at lower flows). When a roughness height adjustment (relationship versus flow) was obtained throughout the study site that generated accurate modeled water surface elevations for all measured water surface elevations, the hydrodynamics model was assumed to be calibrated. All subsequent hydrodynamics modeling of the various flows for habitat modeling was done with the same calibrated channel roughness height relationship. Fifteen to 20 flows ranging from 10 to 1,500 cfs were modeled at each site. An example of the difference between modeled and measured water surface elevations for three calibration flows at Site 5 is shown in Appendix B, Figure B1. Most of the measured versus modeled water surface differences are in the range of 2 cm (0.02 m on the legend).

2.3.4.3 VELOCITY MODELING

Vertically averaged velocities are generated during the solution of the two-dimensional hydrodynamics equations at each of the mesh nodes. No "calibration" of the velocity modeling is done. Accuracy of modeled velocities is primarily dependent on the accuracy of the channel topography, the accuracy of the channel roughness inputs, accuracy of the water surface elevations, and the hydrodynamics model itself (appropriateness of equations used in the model and the turbulence model used). In natural rivers, the STAGR model has been shown to generate accurate mean column velocities across the channel (Lisle et al. 2000, Nelson and Smith 1989, Shimizu et al. 1989) and accurately model the size of recirculation zones (Nelson and McDonald forthcoming). An example of measured versus modeled velocities on the Flathead River is provided in Appendix B, Figure B2. Notice in Figure B2 both the accuracy of the velocity magnitude and direction and the location and size of the recirculation zones.

2.3.5 FISH HABITAT MODELING

2.3.5.1 HABITAT SUITABILITY CRITERIA

To determine availability of aquatic habitat to fishes under various discharge scenarios, pre-defined curves of suitability ranges (Habitat Suitability Index or HSI curves) for individual parameters are often used. These curves indicate what range of a parameter may be considered suitable for a species or life history stage to occupy an area. For each parameter for which an HSI curve is developed, individual observations of a species/life history stage in various habitats are used to identify habitat preferences. The more frequent a species/life history stage is observed in a particular habitat type, the higher a suitability index value; habitats in which the species/life history stage are found infrequently are given a low suitability index value. The habitat suitability index value is based on the number of observations in a habitat type relative to the total observations. The individual suitabilities for depth, velocity, and/or substrate were multiplied to produce a combined suitability that ranged between 0 and 1 (1=completely suitable, 0=not suitable).

For each of the Provo River Sites, fish habitat modeling consisted of associating each node in the flow solution mesh with an area (i.e., area of each computational cell) and then computing habitat suitability for each cell based on depth, velocity, and/or substrate at each flow. Individual parameters have differing relative importance to each species or life history stage (fry, YOY [young-of-year], juvenile, adult, spawning), but for the coldwater species found in the Provo River, depth and velocity are the primary factors that dictate habitat use. Substrate and cover are often important in habitat selection but are not considered primary factors affecting habitat selection in the Provo River (see Appendix A for more details). Modeling of winter conditions may warrant consideration of other (e.g., Provo River 1989) curves.

2.3.5.2 HSI CURVE DEVELOPMENT

A detailed evaluation of existing data for Provo River species included data reviews of UDWR fisheries data, University research (particularly Brigham Young University [BYU] and Utah State University [USU] special studies), URMCC fisheries sampling relating to restoration efforts, existing habitat suitability criteria, recovery program activities (i.e. June sucker research) and previous instream flow studies on the Provo River. In addition, a subcommittee of scientific professionals was assembled to provide input for the selection and use of Habitat Suitability Criteria for this project. The subcommittee consisted of Dr. Paul Holden and Ed Oborny (BIO-WEST), Dr. Mark Belk (BYU), Don Wiley (UDWR), Craig Addley (USU), Larry Crist (USFWS), Chris Keleher (CUWD), and Mark Holden (Mitigation Commission).

HSI curves were developed for depth and velocity suitability of each species/life history stage where possible, but a lack of information on some species and life history stages limited curve development. Therefore, a habitat niche approach was used to incorporate all species found in the Provo River. For each species, the range of values that fell above the 50% suitability threshold on both depth and velocity HSI curves were used to define its habitat "niche." A cluster analysis conducted by Dr. Mark Belk on Provo River fishes (Belk and Elsworth 2000) greatly assisted in grouping fishes for which HSI curves could not be developed with those having similar habitat associations. Species with similar niches were grouped together and ultimately, eight representative habitat niches were selected.

Each species was assigned to one (or more) of the following niches (Figure 2.1):

(1) Backwater / Edge
(2) Slow / Shallow
(3) Moderate / Shallow
(4) Fast / Shallow
(5) Moderate / Mid-Depth
(6) Fast / Mid-Depth
(7) Moderate / Deep
(8) Fast / Deep

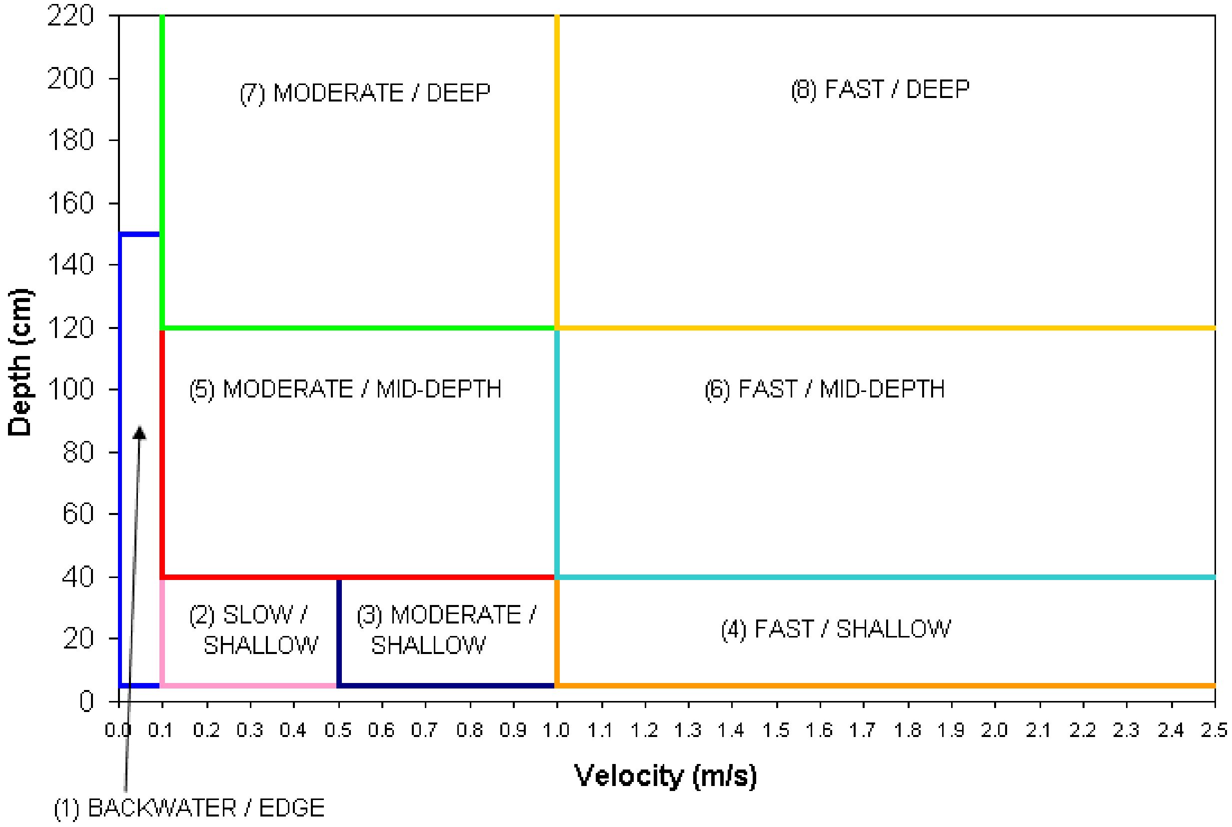

FIGURE 2.1. PROVO RIVER HABITAT NICHES.

Table 2.6 depicts the fishes/life stages represented by each habitat niche. A more thorough description of HSI curve development and the habitat niche approach can be found in Appendix A.

TABLE 2.6. SPECIES USE OF PROVO RIVER HABITAT NICHES.

NICHE	SPECIES	LIFESTAGE	USE[A]
(1) Backwater / Edge	mountain whitefish	fry	Partial (1,5)
	mountain sucker	juvenile, YOY	Full
	Utah sucker	YOY	Full
	speckled dace	YOY	Full
	longnose dace	YOY	Full
	leatherside chub	adult, juvenile, YOY	Full
	redside shiner	adult, juvenile, YOY	Full
(2) Slow / Shallow	brown trout	spawning	Partial (2,3,5)
	all trout	juvenile, fry, spawning	Partial (2,3,5)
	mountain sucker	adult	Partial (2,3,4,5,6)
	mottled sculpin	adult, juvenile	Partial (2,3,4)
	mottled sculpin	YOY	Full
	speckled dace	adult	Partial (2,3)
	speckled dace	juvenile	Full
	longnose dace	adult	Partial (2,3,5)
	longnose dace	juvenile	Full
(3) Moderate / Shallow	brown trout	spawning	Partial (2,3,5)
	all trout	juvenile, fry, spawning	Partial (2,3,5)
	mountain sucker	adult	Partial (2,3,4,5,6)
	mottled sculpin	adult, juvenile	Partial (2,3,4)
	speckled dace	adult	Partial (2,3)
	longnose dace	adult	Partial (2,3,5)
(4) Fast / Shallow	mountain sucker	adult	Partial (2,3,4,5,6)
	mottled sculpin	adult, juvenile	Partial (2,3,4)
(5) Moderate / Mid-depth	brown trout	adult, juvenile, fry	Full
	brown trout	spawning	Partial (2,3,5)
	all trout	adult	Full
	all trout	juvenile, fry, spawning	Partial (2,3,5)
	June sucker	spawning	Full
	mountain whitefish	adult	Partial (5,7)
	mountain whitefish	juvenile, spawning	Full
	mountain whitefish	fry	Partial (1,5)
	mountain sucker	adult	Partial (2,3,4,5,6)
	Utah sucker	adult	Partial (5,7)
	Utah sucker	juvenile	Full
	longnose dace	adult	Partial (2,3,5)
(6) Fast / Mid-Depth	mountain sucker	adult	Partial (2,3,4,5,6)
(7) Moderate / Deep	mountain whitefish	adult	Partial (5,7)
	Utah sucker	adult	Partial (5,7)
(8) Fast / Deep	None		

[A] Full - best habitat suitability within niche, Partial - best habitat suitability shared between niches.

2.3.5.3 Fish Sampling (snorkeling)

Although data from previous studies in nearby/similar habitat were used predominantly to develop habitat suitability curves and habitat niches, some data were gathered on the Provo River to assist in model verification and provide insight where data gaps existed. Several methods were considered, but direct observation through snorkeling was chosen as the most accurate means of assessing true habitat usage. A detailed description of all snorkeling efforts and methodology can be found in Appendix A.

2.3.5.4 Habitat Modeling Techniques

Once the HSI curves and habitat niche approach were developed they were processed with the 2-D hydraulic model results to quantify fish habitat (in terms of Weighted Usable Area [WUA]) at various flow levels available within each stream reach. WUA is defined as the total area per unit length of river that would be expected to provide usable habitat for a niche/individual species/life history stage. WUA is a measure of habitat that can be used to compare alternatives and estimate impacts. Once each discharge (20 flows between 10 and 1,500 cfs) was modeled, the total area that

contained suitable conditions for both parameters (three for spawning life stage) was summed to yield the WUA. Each niche/species/life history stage has its own WUA value for each flow depending on availability of depths and velocities preferred by that niche/species/life history stage. The area (amount) of habitat in each spatial niche bin was summed to determine a relationship between flow and the amount of habitat in each spatial niche bin. In addition, video files were created for specific niche/species/life history stages and are presented in the report as a visual representation of WUA.

2.3.6 DATA EXTRAPOLATION

Results from the study site modeling represent habitat at the site level only. To represent habitat in entire river reaches, results from intensive study sites were extrapolated to the river reaches using the results from the channel reach-scale habitat mapping described in Section 2.1 above. The broad-level habitat types listed in column 3 of Table 2.1 were used for data extrapolation. The detailed study sites were also categorized into these broad habitat types during the field-mapping of substrate and riparian categories, and these habitat types were digitized as a GIS layer using ArcView software. Within each intensive study site, the habitat suitability calculated for each computational cell was assigned to a broad habitat type (pool, riffle, run) using the GIS habitat layer, and the proportion of the overall study site habitat value contributed by each broad habitat type within the site was determined. These proportions were used in conjunction with data on the proportions of the channel reaches in each habitat type (Table 2.7) to calculate overall habitat value for the entire channel reaches.

Some interpretative caution should be used when viewing the results from either the intensive study sites alone or the extrapolated results. The most conservative approach would be to simply use the results from the intensive study sites to represent habitat versus flow relationships. However, proportions of different habitat types are somewhat different in the intensive study sites than in the entire channel reaches. However, when the results from the intensive study sites are extrapolated

TABLE 2.7. PROPORTION OF DIFFERENT AQUATIC HABITAT TYPES IN CHANNEL REACHES ON THE PROVO RIVER.

REACH	BROAD HABITAT TYPE	TOTAL ACREAGE	PERCENT
1	ISLAND	0.19	1
1	POOL	0.66	4
1	RIFFLE	5.99	35
1	RUN	10.29	60
1	**TOTAL**	**17.13**	**100**
2	ISLAND	1.40	4
2	POOL	1.09	4
2	RIFFLE	18.21	58
2	RUN	10.87	34
2	**TOTAL**	**31.57**	**100**
3	BAR	0.37	3
3	ISLAND	0.40	4
3	POOL	0.67	6
3	RIFFLE	6.55	60
3	RUN	3.02	27
3	**TOTAL**	**11.01**	**100**
4	BAR	0.12	1
4	POOL	0.39	4
4	RIFFLE	5.30	60
4	RUN	3.08	35
4	**TOTAL**	**8.89**	**100**
5	BAR	2.13	6
5	ISLAND	0.27	1
5	POOL	1.92	6
5	RIFFLE	9.68	30
5	RUN	18.35	57
5	**TOTAL**	**32.35**	**100**
6	BAR	0.83	9
6	ISLAND	2.37	26
6	POOL	0.87	10
6	RIFFLE	1.25	14
6	RUN	3.71	41
6	**TOTAL**	**9.03**	**100**

to represent the proportion of habitat types in the entire reach, it must be realized that only a few examples of various habitat types are actually represented in the intensive study sites and their ability to actually represent habitat types for the entire reach is limited (e.g., one or two runs/pools/riffles in an intensive site are used to represent all runs/pools/riffles in a reach).

2.3.7 DEPTH-VELOCITY POINT SAMPLE EVALUATION

Study Site 4 was selected to represent the high-gradient cascading sections (i.e., Reach 4 sections) of the Provo River within Provo Canyon (Map 1.3). The complexity of this site, which includes steep gradients, large boulders, shifting areas of pocket water, and swift currents, made it infeasible for computer-based flow modeling. Therefore, nine transects (4 in cascade and 5 in pools) were established in Study Site 4 and velocity and depth measurements were collected at two foot intervals across each transect. Measurements were taken at four different flows ranging from 37 to 154 cfs. To evaluate the transect data, each point along the transect where velocity and depth measurements were taken was assigned a HSI value based on individual species/life stage HSI curves or representative habitat niche. When both the depth and velocity values were greater than a 0.5 suitability using individual species suitability criteria, or when both measurements fell within the defined niche using the habitat niche approach, the distance between points was considered suitable habitat. This area was summed across the transect to yield an estimated proportion of suitable habitat to total habitat along the transect. This proportion was calculated for each transect at each flow level and then compared to assess habitat gains or losses with flow changes for both the cascade and pool sections. Photographs of cross sections and representative conditions were taken during the sampling.

2.4 SEDIMENT TRANSPORT EVALUATION

As discussed in Section 1.4, the type and quantity of sediment transport is highly dependent on streamflow, and the physical attributes of Provo River have primarily been created and maintained by the sediment flux and anthropogenic channelization practices. Thus, the size and amount of sediment transport highly influences the quality and quantity of riparian and fish habitats within the constraints of the existing channelized conditions (Diagram 1-1). Another important factor affecting sediment transport and channel morphology in the Provo River is the presence of dams and diversion structures which trap upstream sediment supplies and interrupt downstream transport. Sediment supplies become limited to local sources (i.e. bank erosion, tributaries, side hill inputs, and bed degradation [erosion]) in reaches downstream of these large sediment traps. Transport equilibrium (influx equaling outflux) becomes skewed downstream of dams, resulting in “sediment mining” and in most cases channel degradation. The degree and length of channel degradation below each dam structure varies depending on the presence or absence of local sediment supplies and flow history.

Two mechanisms of sediment transport were evaluated: bedload, and suspended load. Bedload mostly consists of particles larger than fine sand (>0.25 mm) whereas the suspended load consists of particles in the sand, silt and clay size ranges (0.005 mm to 2 mm). Both types of sediment transport influence channel morphology and aquatic habitat characteristics such as the amount of fines present in spawning gravels, the degree of channel armoring, substrate size characteristics, the location and maintenance of gravel/cobble bar features, and the deposition of fresh sediments needed for riparian vegetation recruitment. Therefore, both types of transport and their relationships to streamflow were examined.

2.4.1 BEDLOAD MODELING

A bedload rating curve (relationship between streamflow and bedload transport) was developed for each study site by calculating bedload transport at even increments of flow from 0 to 2,000 cfs. Bedload calculations were performed using the Meyer-Peter and Muller (1948) equation in WinXSPRO software. This equation models bedload as a positive relationship, producing a correspondent increase in the quantity of bed material in transport as streamflow increases. It is important to note that bedload transport equations assume that sediment supplies are not limited. In other words, modeling bedload transport using available transport equations provides transport potential (i.e., total excess shear stress available to transport streambed materials). The modeled transport rate in tons/day exceeds actual transport rates when supplies are limited as is the case in Provo River. However, new sediment supplies become available for transport at higher flow stages in the Provo River, thus making the bedload rating curve an appropriate modeling tool when evaluating the effects of alternative flow regimes. Consequently, although the positive relationships (rating curve) between flow and transport is correct and calibrated with real bedload data, the actual quantities should be viewed in relative terms (relative to the other study sites) because the actual loads are expected to be less than the modeled loads.

Field data collected to develop bedload rating curves included surveyed channel cross sections, water surface slope, and streambed particle size distributions. Typically, bedload transport modeling is based on a dominant size fraction such as the D_{50} particle size[2]. The D_{50} or median particle size is typically used because it represents the assemblage of bed particles from which the bedload material is derived (Andrews and Nankervis, 1995). This assumption holds true in most natural streams but has been disrupted in the Provo River due to the trapping of sediment supplies behind dams, coarsening effects of channelization, and the dampening effects of flow regulations. To varying degrees, the bed of the Provo River has become more coarse/armored below every dam and diversion structure. As a result, bedload transport has become limited to smaller size fractions. The larger particles (D_{50} to D_{99}) are essentially immobile under the current flow regime in the Provo River from Deer Creek Dam to Utah Lake. These larger sized particles are relics of higher peak flows prior to dam construction and flow regulation.

Because of the over-armored conditions of the Provo River, bedload transport was modeled using smaller size fractions. Field samples (described below) were used to identify flow levels that initiate bedload transport and to determine the mobile particle sizes. As a result, bedload transport modeling was performed using the D_{25} of the streambed (as measured by pebble counts) at Sites 3-6, and the

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[2] These particle size indices represent the percentage of bed material finer than a given size. For example, a D_{50} of 20 mm means that 50% of the particles measured in a pebble count have a median grain diameter equal to or finer than 20 mm.

D_{16} at Sites 1 and 2. The smaller-sized fractions used in the Provo River in this analysis are assumed to represent the assemblages of bed particles from which the bedload material is derived. Again, the smaller size fractions were used because of bed armoring and reduced peak flows within the Study Area. It is important to note that the D_{16} and D_{25} particle sizes of the existing bed are artificially coarse within the Study Area due to upstream sediment trapping. The actual historical D_{50} is unknown.

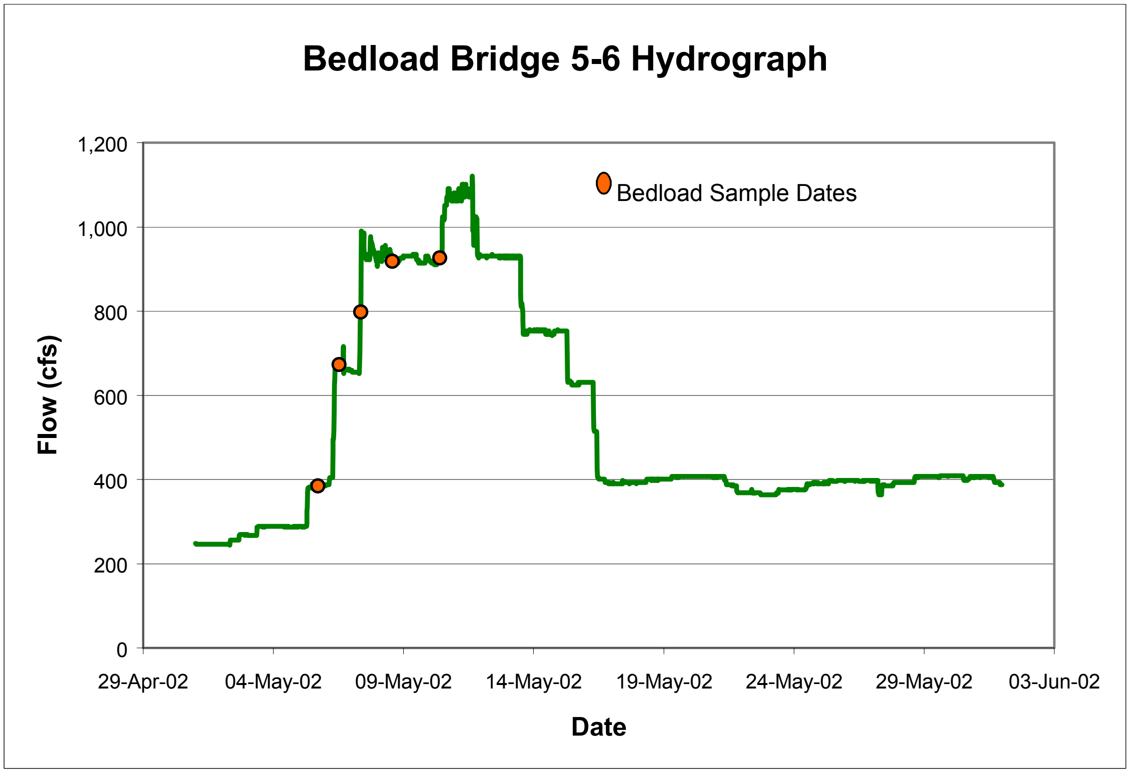
2.4.2 BEDLOAD SAMPLING

Field samples of bedload were collected to identify critical discharge levels when transport begins and to determine the sizes of bed material actually in transport during high flows. Bedload was sampled at 5 bridges within the portion of the Study Area between Deer Creek Dam and Utah Lake (Map 1.3). In general, bedload was sampled from the bridge located nearest each intensive study site. For sites 5 and 6 the nearest bridge was located between the sites (Bridge 5-6) and only one bedload sample was taken to represent both sites.

Bedload was sampled during high flows using a 3 inch handheld Helley-Smith type bedload sampler. At first we attempted to use a 6 inch sampler but were unsuccessful because of the extreme drag encountered during sampling. To sample bedload, the sampler was lowered into the flow and was held firmly to the stream bed. This was done at different locations incrementally across the channel. The sampler was held longest at the location where the most active bedload movement occurred. You can feel when material is in transport because it bumps against the sides of the orifice. Total time for most samples was 20 minutes. However, at Bridge 5-6 on 05/10/02 the total sample time was only 10 minutes due to the high volume of bedload collected in that 10 minute period. Table 2.8 lists the bedload sample dates and associated flows, and Figure 2.2 shows bedload sample dates positioned within the spring runoff hydrograph for Bridge 5-6 and Bridge 1.

TABLE 2.8. BEDLOAD SAMPLING DATES AND FLOWS.

BEDLOAD BRIDGE	DATES SAMPLED	FLOWS SAMPLED (CFS)
1	05/07, 05/08, 05/10	523, 541, 506
2	05/07, 05/08, 05/10	589, 566, 599
3	05/07, 05/08, 05/10	600, 600, 605
4	05/07, 05/08, 05/10	565, 600, 580
5-6	05/05, 05/06, 05/07, 05/08, 05/10	374, 662, 787 AND 962, 915, 924



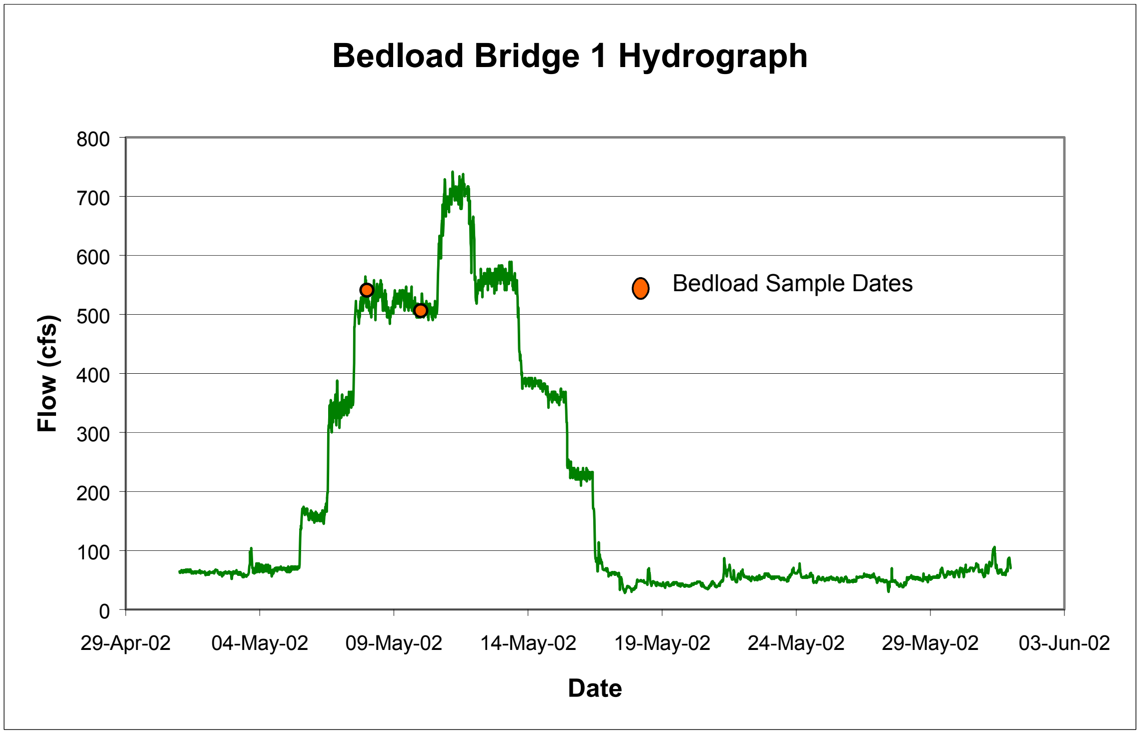


FIGURE 2.2. BEDLOAD SAMPLING DATES POSITIONED WITHIN THE SPRING RUNOFF HYDROGRAPH FOR BRIDGE 5-6 AND BRIDGE 1.

2.4.3 BEDLOAD SIEVING

Each field-collected bedload sample was dried and sorted into the following size categories using standardized sieves: ≥16 millimeters (mm), 8mm, 4mm, 2mm, 1mm and <1mm. 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. The organic material was also individually weighed. Additionally, before sorting, digital photographs were taken of each sample using a penny for scale. These photographs were used to compare sample characteristics for the different sites and collection dates. The largest particle collected in each sample was measured and its size was recorded.

2.4.4 PEBBLE COUNTS

Pebble counts (Wolman 1954) were completed in the field to determine the particle size distribution of the bed material at each cross section where bedload was field-sampled or modeled. Particle size data were plotted and the grain sizes of the D_{16}, D_{25}, D_{50}, D_{75}, and D_{84} particles were determined. Pebble counts were performed at each Study Site in addition to substrate mapping as described in Section 2.3.2.

2.4.5 SUSPENDED SEDIMENT MODELING

Flow and Total Suspended Solids (TSS) data were obtained from the EPA STORET database for selected long-term monitoring sites within the Study Area. TSS data have been collected in the Study Area by Utah Division of Water Quality (DWQ) and CUWCD for the past two decades; however, flow data are not always collected in conjunction with TSS samples, making the overall amount of usable data relatively small. Although additional monitoring stations are present within the Study Area, the only stations with enough data to develop correlations are the DWQ stations at Murdock Diversion (Station #499678) and at Geneva Road (U114) near Utah Lake (Station #499669, Map 1.3). The Murdock TSS and flow data were used to model suspended sediment transport at Sites 3,4,5, and 6; the Geneva Road data were used to model suspended sediment at Sites 1 and 2.

While the use of TSS data to evaluate suspended sediment transport is not uncommon, there are some difficulties with this approach. The TSS data on Provo River were collected by the DWQ as water quality grab samples taken at a single point in the water column, not taken across an entire river transect in a depth- and cross sectionally-integrated manner -- which is the technique that would be used to collect suspended sediment transport data. The other problem with the use of DWQ data is the relative lack of samples collected at high flows. For example, the highest flow for which a TSS measurement is available at the Murdock water quality site is 362 cfs. Therefore, the extrapolated suspended sediment transport rates for high flows may be inaccurate, and analysis results should be interpreted with caution. TSS and flow data were plotted for each monitoring station. For each sample, TSS concentrations were converted to TSS loads by multiplying the TSS concentration (milligrams/liter [mg/L]) by the flow (cfs) and applying a conversion factor (0.002697) to make the units consistent and provide a TSS transport rate in tons/day. These values were used to develop an empirically derived suspended sediment transport rating curve for the two monitoring stations, showing the relationship between flow and TSS transport rate.

2.4.6 EVALUATING ALTERNATIVE HYDROLOGIC REGIMES

Information on the current and historical (i.e., unregulated by Jordanelle or Deer Creek Dams) flow regimes for the different study sites was obtained from USGS gage data (see Appendix C). These data were used to determine the duration (in days/year) of different flow increments and analyze differences in sediment transport resulting from alternative flow regimes. Because water operations on the Provo River system have undergone recent changes with the completion of Jordanelle Dam and the establishment of target flow releases for June sucker, data from water years 1997-2001 were used to develop flow duration information. In order to evaluate flows under historical (unregulated) hydrologic conditions, data from the USGS gage at Hailstone (located above Jordanelle Reservoir, Map 1.3) were adjusted by a mean annual flow ratio to account for the increased watershed area and tributary inputs that occur between Hailstone and Sites 1 through 6 (see Appendix C for details). This adjustment provided a synthetic "unregulated" flow curve for use in analysis. Because no continuous records of daily flows at Sites 2, 3, and 4 were readily available, flow duration curves were not completed for these sites. The effects of alternative flow regimes on sediment transport were evaluated using effective discharge calculations and sedigraphs as described below.

2.4.7 EFFECTIVE DISCHARGE CALCULATIONS

Flow duration information was categorized into 100 cfs increments (0-100, 100-200, etc.). Bedload transport was calculated at the mid-point of each flow increment (50, 150, etc.) using the modeled bedload rating curve. The number of days per year each flow increment occurred was multiplied by the corresponding bedload transport rate to determine the average annual sediment load for each 100 cfs increment. Sediment loads were then graphed to determine the increment of discharge that transports the most bedload sediment over the period of record and identify the effective discharge. As discussed in Section 1.4, the effective discharge is a useful predictor of potential channel changes that would result from proposed flow alterations to the Provo River.

2.4.8 SEDIGRAPHS

Sediment transport was also evaluated in terms of timing, magnitude, and duration using "sedigraphs." Similar to hydrographs for streamflow, sedigraphs show daily sediment transport volumes or loads graphed over an entire water year. Daily sediment loads were calculated by applying the rating curve regression equations to the average daily discharge values shown in Appendix C. Both bedload and suspended sediment loads were used in this analysis. Sedigraphs allow for a slightly different evaluation of alternative flow regimes than effective discharge calculations because sedigraphs incorporate temporal factors of sediment transport such as timing and duration of bedload transport, timing of peak loads, etc. that may be biologically important. For example, two alternative flow regimes that transport the same amount of sediment for each flow increment (i.e., no change in effective discharge) could be significantly different in terms of the timing between the rising and falling limbs of bedload transport by simply shifting the timing of spring runoff. Altering the timing of bedload transport could alter the particle size distribution or percent fines of the streambed during critical spawning windows. The timing and magnitude of sediment transport may also be important for riparian vegetation species that time their seed dispersal immediately following natural peak flows when the likelihood of recruitment in fresh alluvial deposits is greatest.

2.5 RIPARIAN VEGETATION EVALUATION

As described above, riparian vegetation at each study site was delineated in conjunction with substrate mapping efforts. Four broad categories of riparian vegetation were used: grass/herbaceous, scrub-shrub, and mature tree. These riparian types were digitized into a GIS layer using ArcView® software. In addition to delineating broad vegetation types, notes on the specific species present and areas of cottonwood recruitment were made on field maps. Photographs were taken of the different riparian types present at each study site.

In order to evaluate the relationship between streamflow and riparian characteristics, two to three transects spanning different riparian establishment surfaces were selected for each study site. Topographic data for each of these sample transects was extracted from the study site TIN using the Profile Extractor tool in ArcView®. The stage-discharge relationship for each riparian transect was determined using the water surface elevation outputs from the hydraulic modeling (for 20 flows between 10 and 1,500 cfs), and the discharge that inundates each riparian establishment surface was identified. Cross-sectional plots of each transect were generated to illustrate the discharge-riparian surface relationships.

In order to further characterize the hydrologic associations of the different riparian types in terms of inundation depth, frequency, timing, and duration, flow frequency and duration curves were developed from hydrologic data for each study site (see Appendix C for details). Because water operations on the Provo River system have undergone recent changes with the completion of Jordanelle Dam and the establishment of target flow releases for June sucker, the data period of October 1996 to September 2001 was used to develop flow duration and frequency information. Although this is a relatively short data period, it does encompass a climatic range from relatively dry to relatively wet years. The hydrologic characteristics of the riparian establishment surfaces at the study sites were compared to known hydrologic requirements for vegetation recruitment that have been established in the literature (Auble et al. 1994, Mahoney and Rood 1998, Scott et al. 1993, Scott et al. 1996,). Based on these known requirements, the potential for vegetation (particularly cottonwood) establishment/ new recruitment on the different surfaces under the existing flow regime was evaluated.

2.6 WATER QUALITY EVALUATION

2.6.1 TEMPERATURE

Thermistors (Onset optic stowaways) were placed in each study site (except Site 4) along the Provo River and downloaded at regular intervals to provide continuous monitoring of water temperatures in these areas between April 20 and August 15, 2002. Rebar was used to secure the temperature loggers in areas where large woody debris or rootwads were not present. Data was downloaded periodically using a Onset optic shuttle; thermograph condition and proper function was also checked at these times with adjustments being made as necessary. The temperature data was compared to the USGS flow data (for those sites with gage information) to assess thermal fluctuations relative to discharge variations in the Provo River.

2.6.2 OTHER WATER QUALITY PARAMETERS

The Provo River is a highly-used and highly-regulated river in a watershed where there are numerous land use practices which create “point” and “nonpoint” sources of pollution. Water quality issues in the Middle Provo River are primarily associated with pollutants from agricultural practices and limited amounts of urbanization in the Heber Valley. Water quality issues in Provo Canyon are primarily associated with operations of Deer Creek Dam, road/railroad construction, and a multitude of recreational activities. In the Lower Provo River, urbanization is the dominant land use with storm water runoff as the primary source of pollution. Thus, Provo River is subject to many water quality problems associated with multiple sources.

Water quality is highly correlated with streamflow in the Provo River, however, due to the complexity of pollutant inputs and the lack of useful data for modeling, a qualitative evaluation of water quality was performed for the various reaches. The existing water quality data available from the DWQ do not represent conditions during critical times such as runoff events. Available data reflect the quality of water during average flow conditions. Recent studies have begun to evaluate water quality from storm water runoff and the impacts runoff has on Provo River. With the help of the CUWCD, Dr. Larry Gray of Utah Valley State College (UVSC) has collected stormwater samples and intends to publish his findings in a peer-reviewed journal. Unfortunately, his data were not available for this study. Therefore, water quality evaluations will be done as a qualitative description of relationships between concentrations and streamflow in the Provo River.

The following list of pollutants will be considered for each reach:

- sediment
- nutrients
- salts (road de-icing)
- herbicides/pesticides
- heavy metals
- petroleum products
- bacteria/pathogens

2.7 MACROINVERTEBRATE EVALUATION

The Utah Division of Water Quality has one long-term station for macroinvertebrate collection on the Provo River, but it is above Jordanelle Reservoir, near Woodland. Without long-term monitoring information in the study reaches, and with limited sampling from individual research projects, it is difficult to determine impacts of current river operations on macroinvertebrate communities. Crist and Trinca (1988) examined the impact of low-flows on macroinvertebrates of the Provo River, and Shiozawa et al. (2002) are presently investigating the influence of channel restoration on macroinvertebrate fauna between Jordanelle Dam and Deer Creek Reservoir. However, no investigation of multiple delivery rates, where high-flow conditions are included, on macroinvertebrate populations in the Provo River was found. Therefore, two other river systems that have undergone extensive manipulations to the flow regime for water delivery were examined as case studies. Evaluating impacts to macroinvertebrate communities in these systems may yield insight into changes to macroinvertebrate communities that may occur in the Provo River under an altered flow regime.

2.8 RECREATIONAL USABILITY EVALUATION

2.8.1 WADING (FISHING)

With high fishing pressure throughout the river, depth and velocity changes were compared to suitability curves for wading developed by Hyra (1978) and modified by Nestler et al. (1986) in all reaches to evaluate wadeable habitat. The Hyra (1978) curves were developed by the US Fish and Wildlife Service to determine a range outside of which the recreation activity "cannot be engaged." The assessment included the criteria "physical," "safety," and "optimum" to define the range of conditions at which it is physically possible to conduct the activity, to conduct the activity safely, and to provide optimum conditions that maximize usability. The safety range was given a probability of use (suitability index value) of 0.5 (50%), which corresponds to the threshold suitability values used to assess fish habitat value. For fishing/wading the range of safety for depth is 0.75 - 3.5 feet and for velocity it is 0 - 2.5 feet/sec. Hyra notes that these values are dependant on height and weight of the individual and substrate type, but serve as a basic range for assessment. Nestler et al. (1986) modified these curves by direct field measurement of flow conditions in which a group of individuals wearing waders could easily move through the water. These data resulted in a slight increase on the upper end of the velocity range suitability and, based on observations in the Provo River while snorkeling, appear to more accurately reflect conditions in this river. In Nestler et al. (1986), the range for suitable velocity was 0.0-3.5 feet/sec and for depth it was 0.0-3.5 feet. For each study site, these criteria were used to determine the amount of wading/fishing "habitat" for the same range of flows at which fish habitat was modeled.

2.8.2 BOATING

Boating and tubing are also popular uses of the Provo River. As with wading/fishing, the Nestler curves improved upon the curves initially developed by Hyra (1978). For tubing, suitable depths (above the 50% threshold value) are above 3.5 feet and suitable velocities are below 1.5 feet/sec. The suitability of depth for a novice raft user is >1.0 feet, while velocity requirements are between 0.5 feet/sec and 4.5 feet/sec. There are also curves for mid-level raft and canoe users with higher velocity ranges, however, most of the rafting use on the Provo is through rental companies with customers that frequently have limited experience. For each study site, these criteria were used to determine the amount of boating/tubing "habitat" for the same range of flows at which fish habitat was modeled.

3.0 RESULTS

3.1 SITE 6

3.1.1 AQUATIC HABITAT - SITE 6

3.1.1.1 HABITAT NICHE MODELING - SITE 6

As discussed in the methodology section and Appendix A, a habitat niche approach (incorporating depth and velocity suitability simultaneously) was primarily used for assessing Weighted Usable Area (WUA) for Site 6, but individual species/life stage HSI curves were used in some instances. To represent habitat in the entire channel segment from Deer Creek Reservoir to Olmsted Diversion (Reaches 5 and 6), the amount of linear distance represented by Site 5 and Site 6 habitat was determined from the channel reach mapping. It was determined that Site 6 represented approximately 16% of the overall stretch of river. As discussed in the methods, some interpretative caution should be used when viewing the results from either the intensive study sites alone or the extrapolated (reach) results. Due to the similarity in trends between the individual Site 6 and the extrapolated reach, the results for Reach 6 are discussed below.

Each WUA value calculated for the modified Reach 6 represents the total amount of usable area per 1,000 linear feet of stream. Figure 3.1 shows the WUA (ft^2/1,000ft) for each niche per respective flow. The backwater/edge habitat (niche 1) is used by a majority of the native fish species and larval stages of many fish and consists of greater than 28,000ft^2/1,000ft at approximately 10 cfs. Although niche 1 habitat decreases with increasing flows, the beaver dam complex on river right and gravel bar along river left (that becomes inundated at higher flows) (see Map 3.1) allow for areas of slower velocity water to be present even at the highest modeled flows. The presence of this type of habitat in the modified Reach 6 would suggest the potential for native species to inhabit this area. However, routine fisheries data from UDWR and BYU fisheries assessments document only rare occurrences of native fishes in this section of the Provo River. The slow/shallow habitat (niche 2) supports many juvenile and young-of-year (YOY) species. This niche peaks with over 22,000ft^2/1,000ft at approximately 70 cfs with a reduction in habitat as flow increases, finally dropping below 5,000ft^2/1,000ft at approximately 900 cfs. Niche 2 (slow/shallow habitat) and niche 3 (moderate/shallow) overlap in supporting both larval and juvenile life stages for certain species, but niche 3 is broader and includes certain adult species. Niche 3 habitat (moderate/shallow) peaks at approximately 300 cfs and then displays reductions in habitat until stabilizing at approximately 650 cfs. The fast/shallow habitat (niche 4), which provides habitat for mountain sucker adults and mottled sculpin adults and juveniles, is slightly elevated around 400 cfs but remains below 3,500ft^2/1,000ft at all flows. Niche 5 is the primary habitat type for the sportfish in the Provo River including all trout and mountain whitefish adults and juveniles. Niche 5 habitat (moderate/mid-depth) experiences a quick increase in habitat as flows exceed 10 cfs and maintains a large amount (> 20,000ft^2 / 1,000ft) of habitat for the majority of the modeled flows. The complexity (beaver dams, gravel bars, backwater areas) of Reach 6 allows these larger amounts of niche 5 habitat at higher flows. The only species/lifestage documented in niche 6 habitat (fast/mid-depth) is the adult

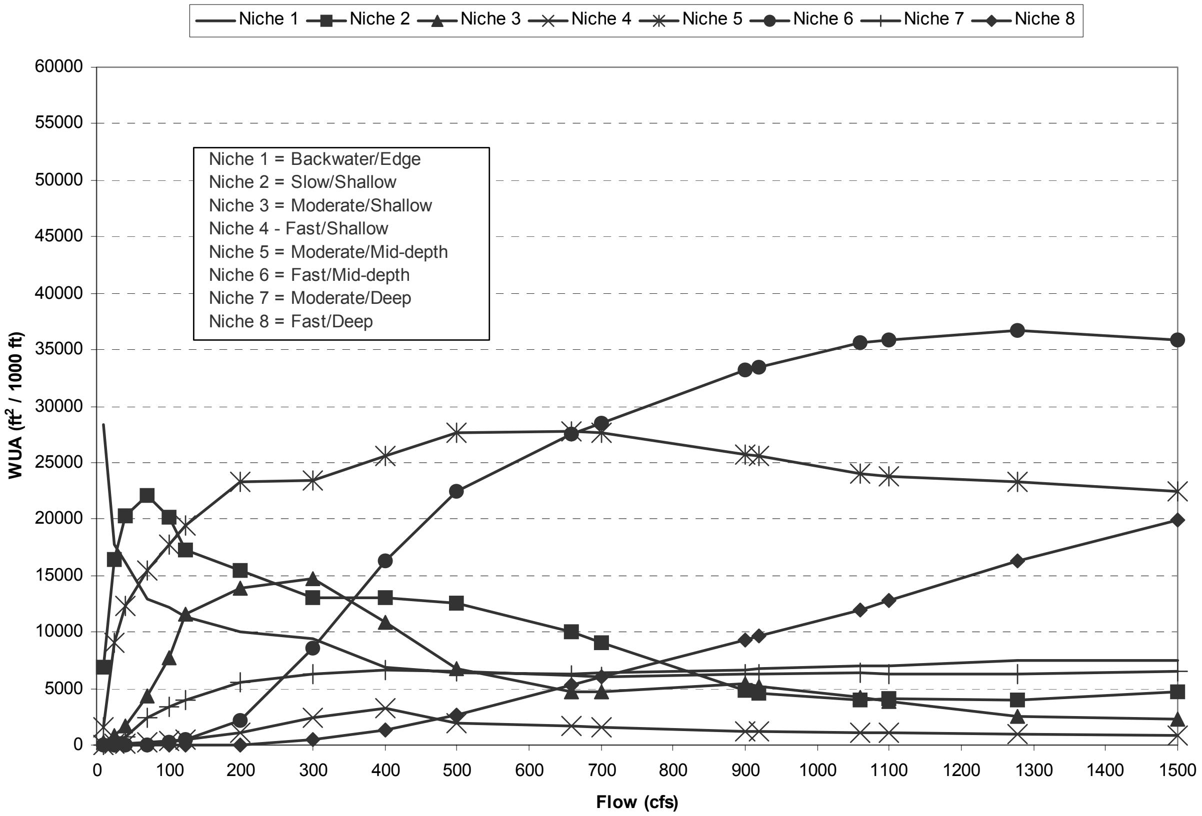
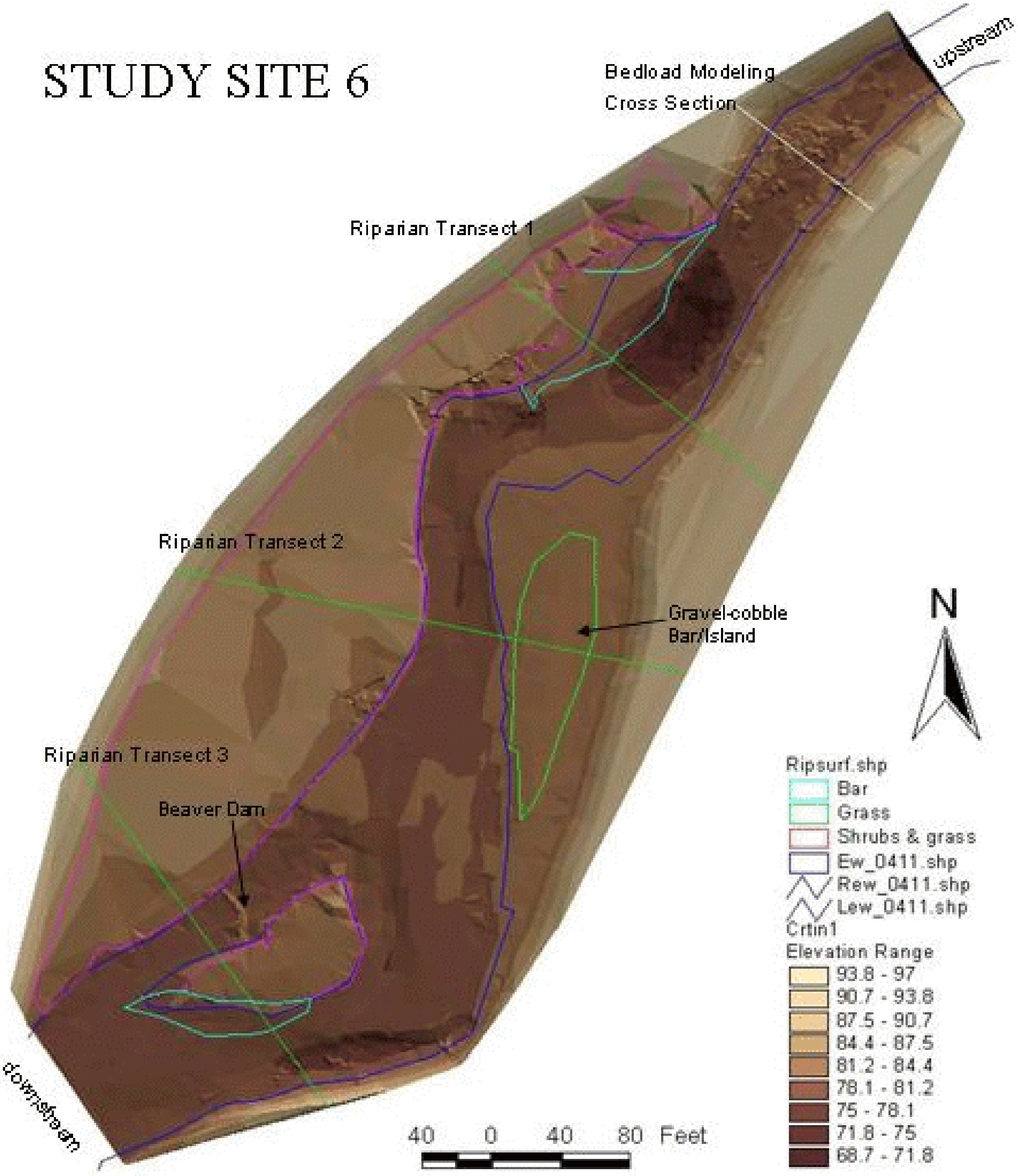


Figure 3.1. Reach 6: Habitat Niches - WUA vs. Flow.

mountain sucker. Niche 6 habitat shows an increase at flows greater than 200 cfs (> 6,400ft^2/1,000ft increase between 200 and 300 cfs alone). Moderate/deep habitat (niche 7) is consistently greater than 5,000ft^2/1,000ft at flows exceeding 200 cfs; this habitat is preferred by adult mountain whitefish and adult Utah sucker. Although the fast/deep (niche 8) does not directly relate to any fish species, it is included to describe how the habitat changes as flows increase; niche 8 shows a nearly linear increase after approximately 300 cfs.

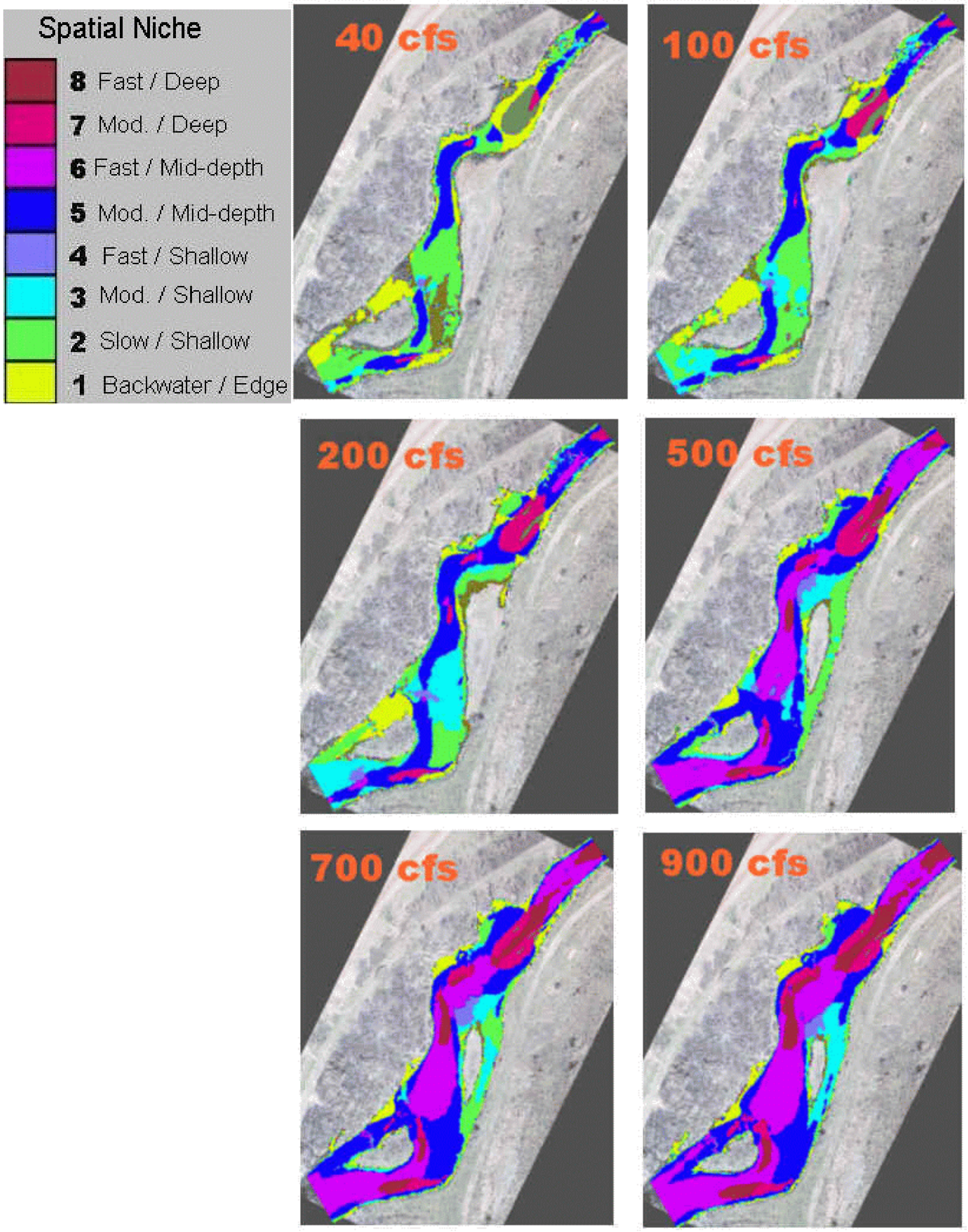
As depicted in Image 3.1 and displayed in Figure 3.1, WUA greater than 10,000ft^2 / 1,000ft is maintained for niches 1, 2, and 3 to approximately 300 cfs, whereas niche 5 (sportfish niche) is maintained at greater than 20,000ft^2 / 1,000ft for all modeled flows higher than approximately 150 cfs. However, an examination of Image 3.1 reveals that although habitat remains, it is truly a function of the unique characteristics present. For instance, at 100 cfs the majority of niche 5 habitat is present in the main channel, whereas at 500 cfs the main channel is predominantly represented by niche 6 habitat. This is similar to what is exhibited at the other more confined sites in the Provo River (results for other sites discussed below). However, the difference with Site 6 is that even at 500 cfs and higher flows, the beaver dam complex on river right (facing downstream) and the large



MAP 3.1. MAP OF STUDY SITE 6 SHOWING RIPARIAN TRANSECT AND BEDLOAD MODELING CROSS SECTION LOCATIONS.

SITE 6

IMAGE 3.1. HABITAT NICHES - WEIGHTED USABLE AREA (SITE 6). THE IMAGES BELOW VISUALLY DEPICT HABITAT NICHES THAT ARE PRESENT AT DISCHARGES OF 40, 100, 200, 500, 700, AND 900 CFS. EACH HABITAT NICHE IS REPRESENTED BY THE COLOR IMMEDIATELY ADJACENT THE NUMBER/DESCRIPTION IN THE LEGEND. FOR EXAMPLE, NICHE 6 = MAGENTA, NICHE 5 = BLUE, NICHE 1 = LIGHT YELLOW, ETC.



gravel bar on river left produce slower velocity habitat. This is visually evident in the image for 500 cfs (Image 3.1) where niche 5 habitat remains in the beaver dam area and just below the large gravel bar.

Overall, the results of the habitat niche modeling for this reach do not support available biological data that very few species other than trout, mottled sculpin, and mountain whitefish have been collected in this reach. The presence of backwater/edge habitat and extension of niche 2 and 3 habitat to flows in the 300 cfs range would lend one to believe that native fish species could inhabit this site. However, trout are extremely abundant in this area and thus, the large population of trout may influence the native fish population in this reach to a greater degree than habitat availability. The niche analysis suggests that suitable habitat for brown trout is distinctly segregated from the backwater/edge habitat that is suitable for many native species and juveniles and YOY of most species. However, the abundance of brown trout and potential threat of predation may influence the presence and/or abundance of some of those species in this site.

3.1.1.2 HSI CURVE MODELING

Using individual HSI curves for brown trout and "all" trout reveal similar trends to the niche 5 results from the habitat niche approach. Figure 3.2 shows the WUA (ft^2/1,000 ft) for each trout species/lifestage per respective flow. To avoid overestimating trout habitat, an "all" trout classification scheme (described in the Methods) was used. In most cases, the brown trout HSI curve encompassed habitat suitability of both cutthroat and rainbow trout (adult, fry, spawning), so it was used to represent the "all trout" classification. However, cutthroat and rainbow trout juveniles have demonstrated use of shallower depths than brown trout juveniles, so a modified "all trout" curve was generated to account for these differences. Adult trout results show that the large amount (> 20,000ft^2 / 1,000ft) of habitat is available at all flows greater than approximately 70 cfs. Although the overall trend is the same between the juvenile brown trout curve and juvenile "all trout" curve, the adjustment to accommodate shallower depths had an impact on estimates of available habitat (Figure 3.2).

As evident in Image 3.2 and Figure 3.2, Reach 6 has approximately 24,000ft^2/1,000 ft adult brown trout habitat at 100 cfs, represented by green and blue areas. As flows reach 500 cfs, the uniqueness/complexity of the site creates slightly more (approximately 28,000ft^2/1,000 ft) habitat. The difference is that at 100 cfs the majority of habitat is in the main channel, but at 500 cfs, habitat is displaced into other areas (i.e. beaver dam area and other pools near gravel bars) with the majority of main channel habitat being unsuitable (red or black). This was very evident during the summer snorkeling event with flows exceeding 400 cfs. At 400 cfs, we observed a diversity of habitat and abundance of brown trout present throughout the reach. As flows approach 1,500 cfs this reach still maintains greater than 22,000ft^2/1,000 ft of adult brown trout habitat within its unique features.

Fry habitat is present in this reach throughout the range of modeled flows (Figure 3.2). Based on field observations and temperature data, Wiley and Thompson (1996) estimated that in 1996, brown trout eggs should have hatched the second week in April and emerged from the substrate approximately the third week in May. However, the high flows present during this time period in 1996 prohibited attempts to verify hatching, swimup or monitor survival (Wiley and Thompson

SITE 6

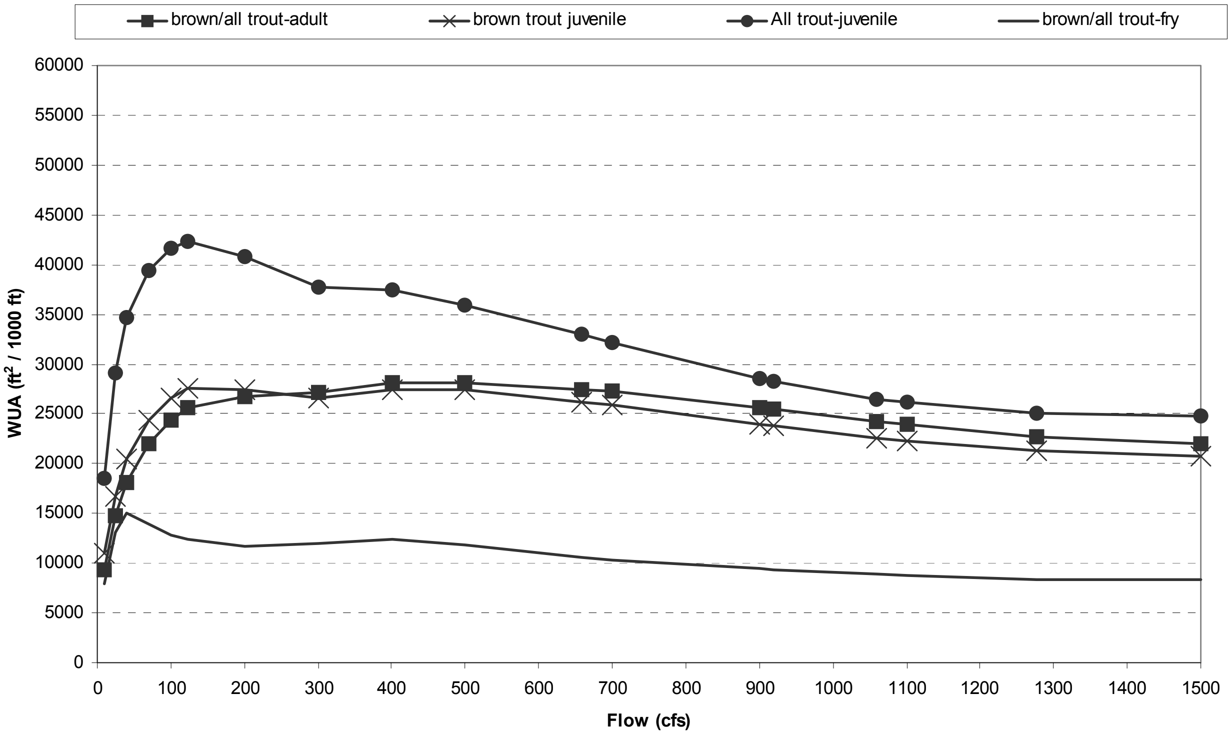
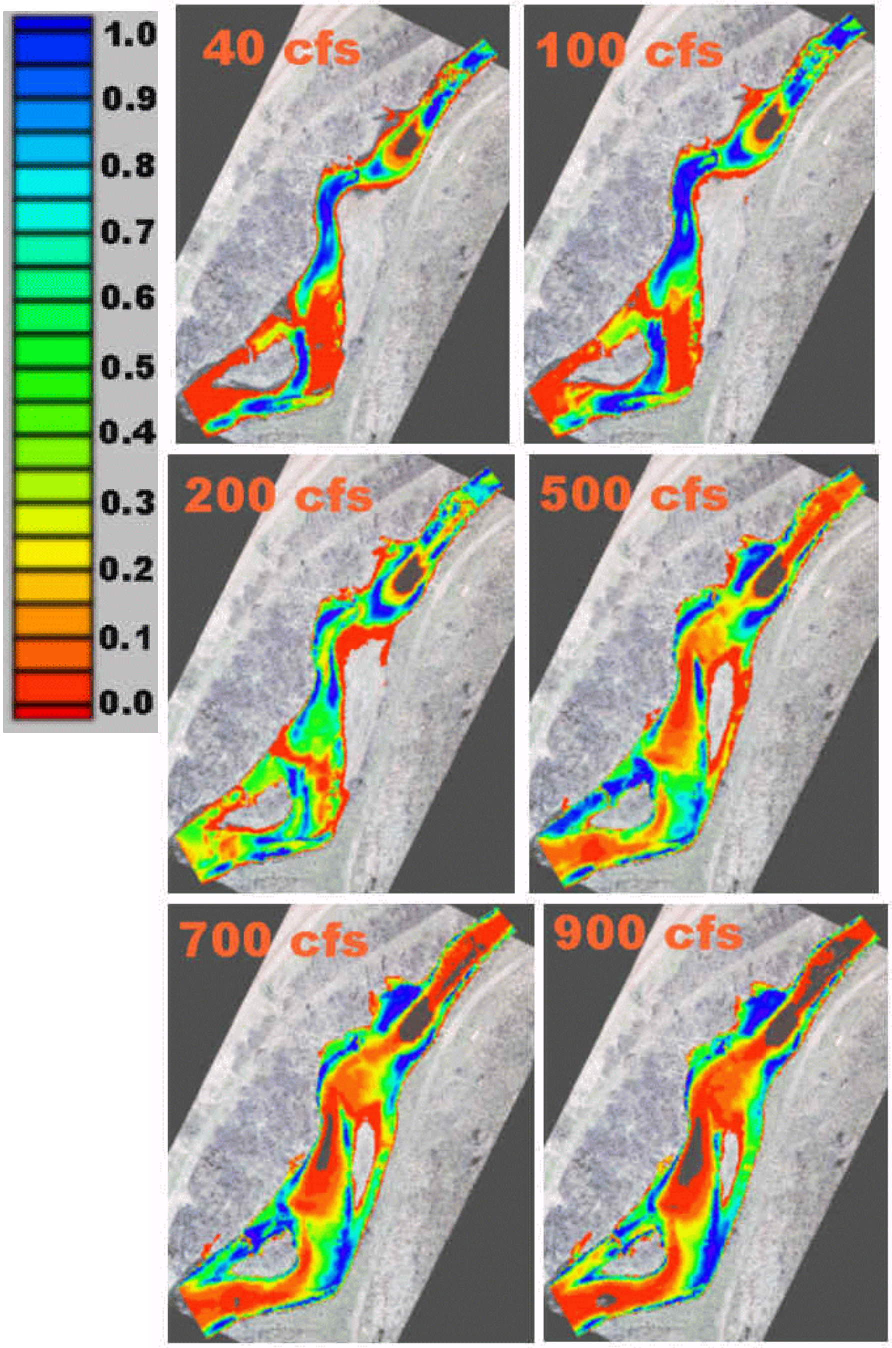


FIGURE 3.2. REACH 6: TROUT - WUA VS. FLOW.

1996). Wiley and Thompson (1996) made the observation that high flows during late April and early May may be detrimental to emerging brown trout fry by perhaps flushing them downstream. This study documents that the peak for fry habitat in Reach 6 is approximately 40 cfs, however, fry habitat (> 8,000ft^2/1,000 ft) remains for all flows. This supports that fry habitat will remain in more complex areas unlike Wiley and Thompson's general observations that fry habitat is lost during high flow spring conditions in confined reaches. The unconfined refugia available at all flows within Reach 6 may help to explain how the recruitment of brown trout throughout the Provo River remains strong even with higher spring flows. As for cutthroat and rainbow trout, fry emergence occurs later in the summer; however continued increased flows may have impacts on their success as well in channelized reaches, but might be dampened by the available habitat in complex areas like Reach 6.

An evaluation of the existing data on spawning criteria revealed that although the brown trout curves encompassed the depth and velocity criteria for rainbow and cutthroat trout, the depth and velocities required for the latter two species differed to a degree where an examination of individual curves versus the "all trout" curve was warranted. As substrate requirements were very similar, it turned out that the requirement for lesser depths and velocities for rainbow trout and lesser yet (depths and velocities) for cutthroat trout resulted in less spawning habitat available (Figure 3.3). There is approximately 23,000ft^2/1,000ft of brown trout spawning habitat at the peak of approximately 125 cfs but is maintained at greater than 15,000ft^2/1,000ft to approximately 500 cfs. Rainbow trout

IMAGE 3.2. ADULT BROWN TROUT - WEIGHTED USABLE AREA (SITE 6). THE IMAGES BELOW VISUALLY DEPICT SUITABLE HABITAT AVAILABLE TO ADULT BROWN TROUT AT DISCHARGES OF 40, 100, 200, 500, 700, AND 900 CFS. THE BEST HABITAT IS REPRESENTED BY SUITABILITY OF 1.0 (BLUE) AND NO HABITAT IS REPRESENTED BY 0 (RED).



Site 6

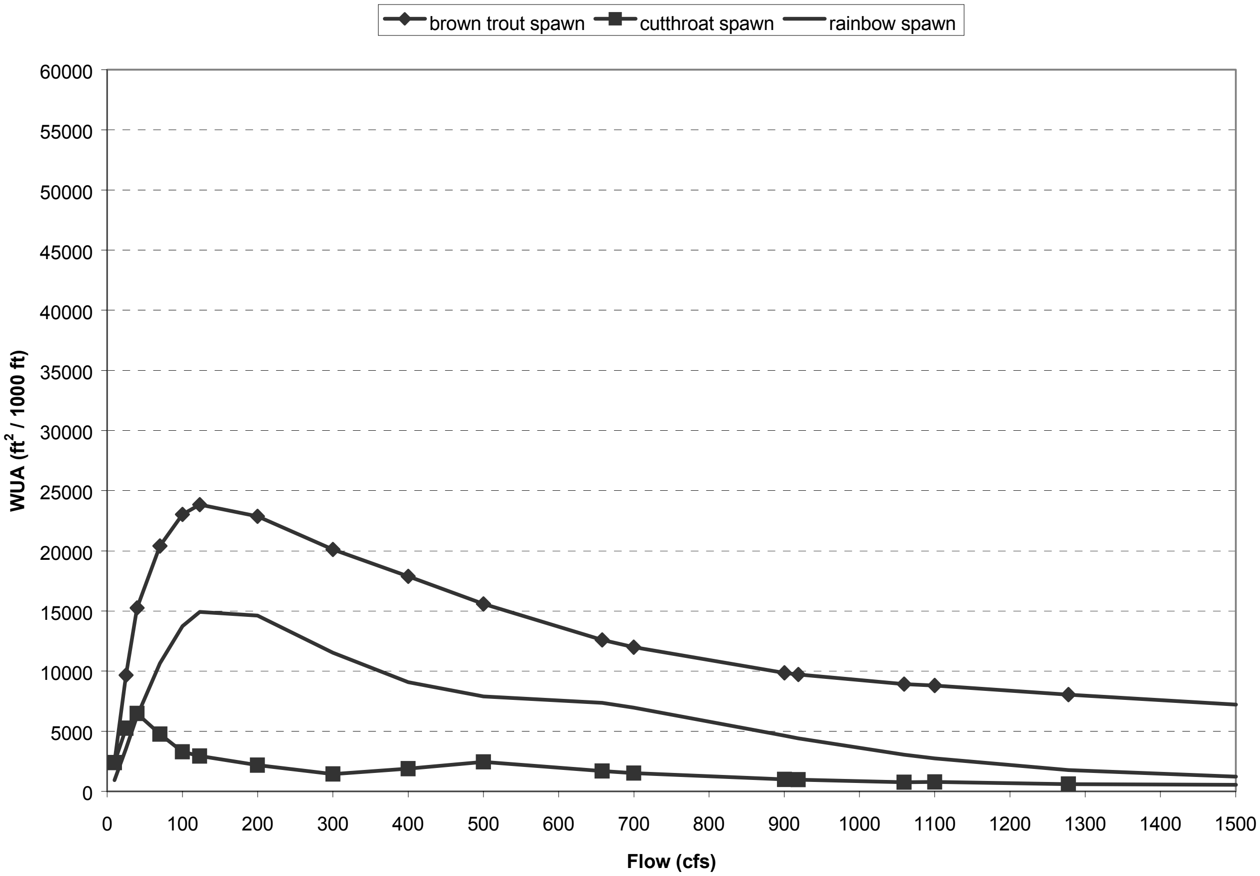


Figure 3.3. Reach 6: Trout Spawning - WUA vs. Flow.

spawning habitat follows the same trend but demonstrates considerably less WUA (< 15,000ft^2/1,000ft at all flows). According to Wiley and Thompson (1996), brown trout spawning occurs in early to mid-November. As demonstrated by Wiley and Thompson (1996) and again by the results of this study, lower flows provide more WUA for brown trout spawning. Wiley and Thompson (1996) modeled sites below Olmsted Diversion and concluded that 26 cfs was the optimum flow for brown trout spawning in that reach. The results of this study suggest that flows ranging from approximately 70 to 300 cfs are optimal in Reach 6. Brown trout spawn in the fall when flows are significantly lower than during spring and early summer when rainbow and the native cutthroat trout spawn. Rainbow and cutthroat trout appear to require similar substrate conditions as brown trout, but more restrictive depth and velocity requirements to spawn; therefore, flows in this reach of the Provo River may be unsuitable for spawning during the late spring and early summer. As evident in Figure 3.3, WUA for spawning cutthroat trout is cut in half from 40 cfs to 100 cfs and continues to decline as flows increase. Thus, the timing of spawning and less WUA for spawning at any flow level puts rainbow and native cutthroat trout at a substantial disadvantage to brown trout.

3.1.2 WATER TEMPERATURE - SITE 6

In November 1995, UDWR installed a temperature logger in a study site below Olmsted Diversion to record water temperature during the period of brown trout spawning and emergence from the substrate. The following mean temperatures were collected from that site from November 1995 through April 1996.

December 1995	5.0 °C
January 1996	2.6 °C
February 1996	2.6 °C
March 1996	4.3 °C
April 1996	6.1 °C

For this study, a thermistor was placed at Site 6 between April 27 and August 16, 2002. The following mean temperatures were observed during the study period.

April (27 - 30)	6.5°C
May	7.7°C
June	9.8°C
July	13.0°C
August (1 - 16)	16.4°C

The temperature data was compared to the flow data at USGS Station # 10159500 (Provo River below Deer Creek Dam) to assess thermal fluctuations relative to discharge variations in the Provo River. Figure 3.4 shows the temperatures and flows recorded over the study period.

Study Site 6 lies approximately one mile downstream from Deer Creek Dam. One flow manipulation occurred at this site during the study period. Due to the close proximity to the reservoir diurnal fluctuations are relatively small with a low flow daily change of around 2.5°C up to May 6. Flows were elevated from May 6 to May 17 with peak flows of 1,100 cfs occurring on May 11. Daily temperature fluctuation under high flows dropped to as little as 0.62°C. Flows were maintained at approximately 400 cfs after May 17th at which diurnal temperature fluctuation remained around 2°C.

Average stream temperature was 6.47°C from May 1 to May 6. During the high flow period average stream temperature was higher at 7.46°C. While daily maximum temperature was lower during this high flow event nightly lows were moderated resulting in an overall increase in average temperature for the high flow period. From May 17 to May 25 the average stream temperature was 7.98°C. Once the flows were stabilized, a typical warming trend with increasing daily temperatures was observed. The temperature changes and diurnal fluctuations may be very important in understanding the macroinvertebrate assemblages (see Macroinvertebrate Case Studies in the Discussion section) and recruitment success of fishes in Reach 6 of the Provo River.

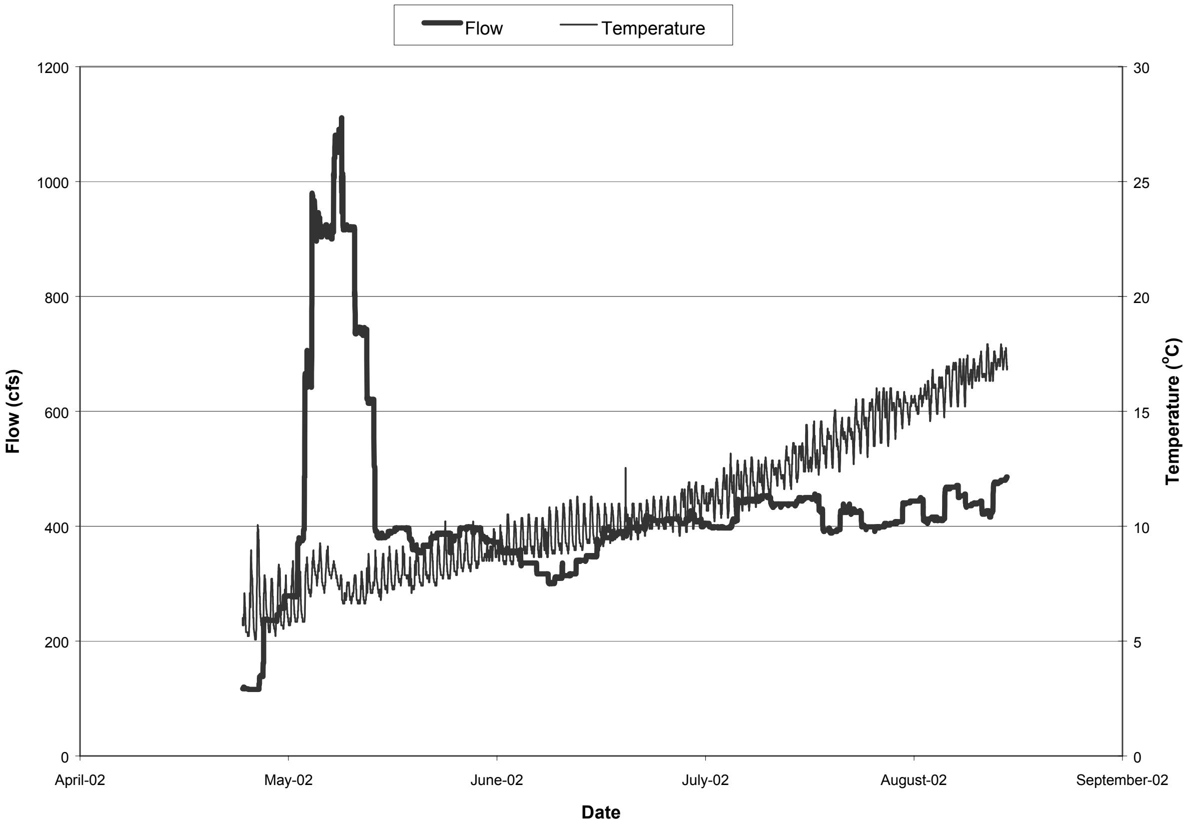


FIGURE 3.4. SITE 6: TEMPERATURE AND FLOW.

3.1.3 RECREATIONAL USABILITY-SITE 6

3.1.3.3 WADING (FISHING)

Pseudo-HSI criteria (Section 2) were used to determine the amount of wading/fishing “habitat” for the same range of flows modeled for fish habitat (10 to 1,500 cfs). Figure 3.5 displays the WUA (ft^2/1,000 ft) for fishing/wading recreational activities. At 125 cfs, approximately 57,000ft^2/1,000 ft of fishing/wading area is provided for recreationalists. However, even at the highest flow modeled (1,500 cfs) over 30,000ft^2/1,000ft of wading/fishing area is present. This was evident when sampling Site 6 during the summer in that even at flows exceeding 400 cfs, numerous fishermen frequented this site. Even though parts of the river remain wadeable at higher flows, much of the wadeable areas are located along the left side of the channel (away from the highway) which requires a longer walk from designated parking areas. Some wadeable areas during high flow are inaccessible from the right side of the channel.

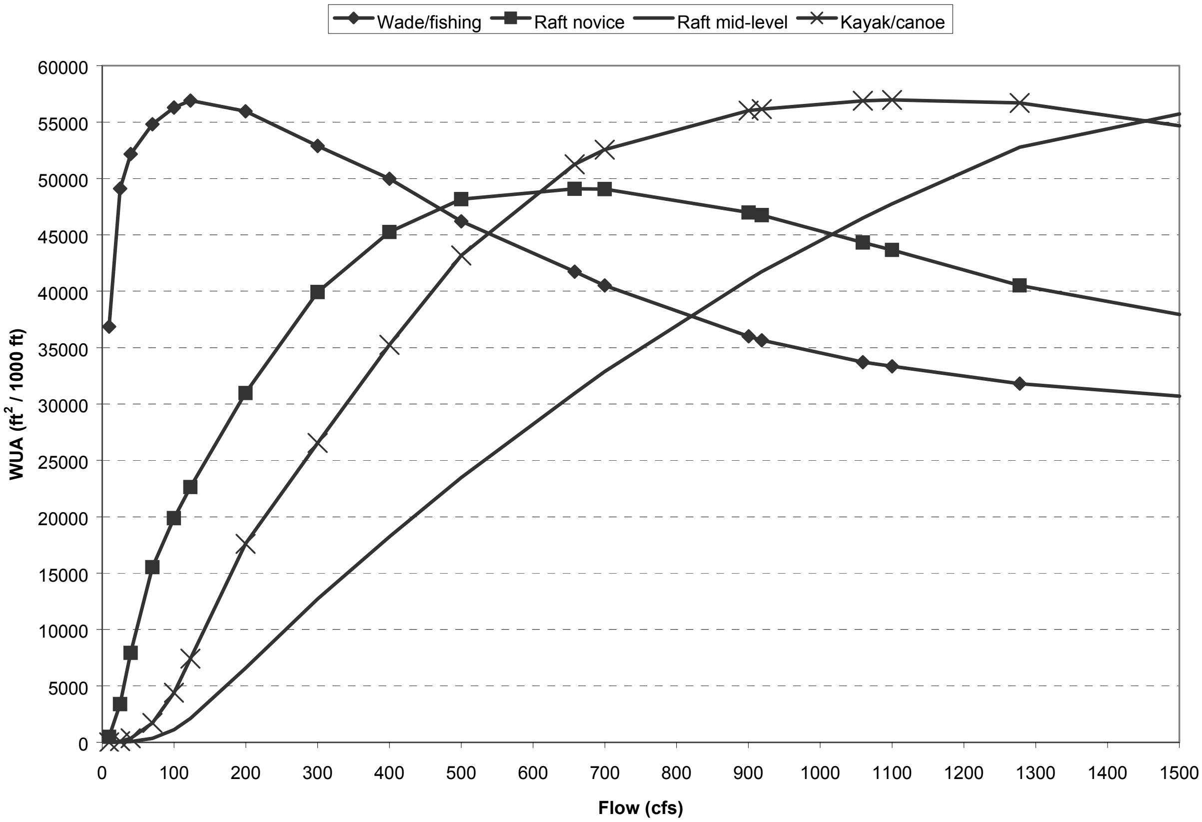


FIGURE 3.5. REACH 6: RECREATION - WUA VS. FLOW.

3.1.3.4 BOATING

HSI criteria (Section 2) were also used to determine the amount of boating “habitat” for the same range of flows modeled for fish habitat (10 to 1,500 cfs). Figure 3.5 displays the WUA for novice rafting, mid-level rafting, and canoeing/kayaking. As evident in Figure 3.5, the amount of suitable area for canoeing/kayaking increases rapidly as flows increase. The tapering off effect at higher flows is a result of a conservative classification that includes safety concerns for both canoes and kayaks. It is recognized that experienced kayakers would welcome the challenge of even higher flows. The rafting component provides greater than 40,000ft^2/1,000 ft of WUA for novices and mid-level rafters above flows of approximately 400 and 750 cfs, respectively.

3.1.4 SEDIMENT TRANSPORT - SITE 6

3.1.4.1 SAMPLING RESULTS

The results of the bedload sampling show that there was essentially no bedload movement at flows less than 400 cfs (Figure 3.6). At 400 cfs, bedload transport was limited to some very fine-grained sand intermixed with organic material (Plate 3.1). Bedload samples were again taken at flows

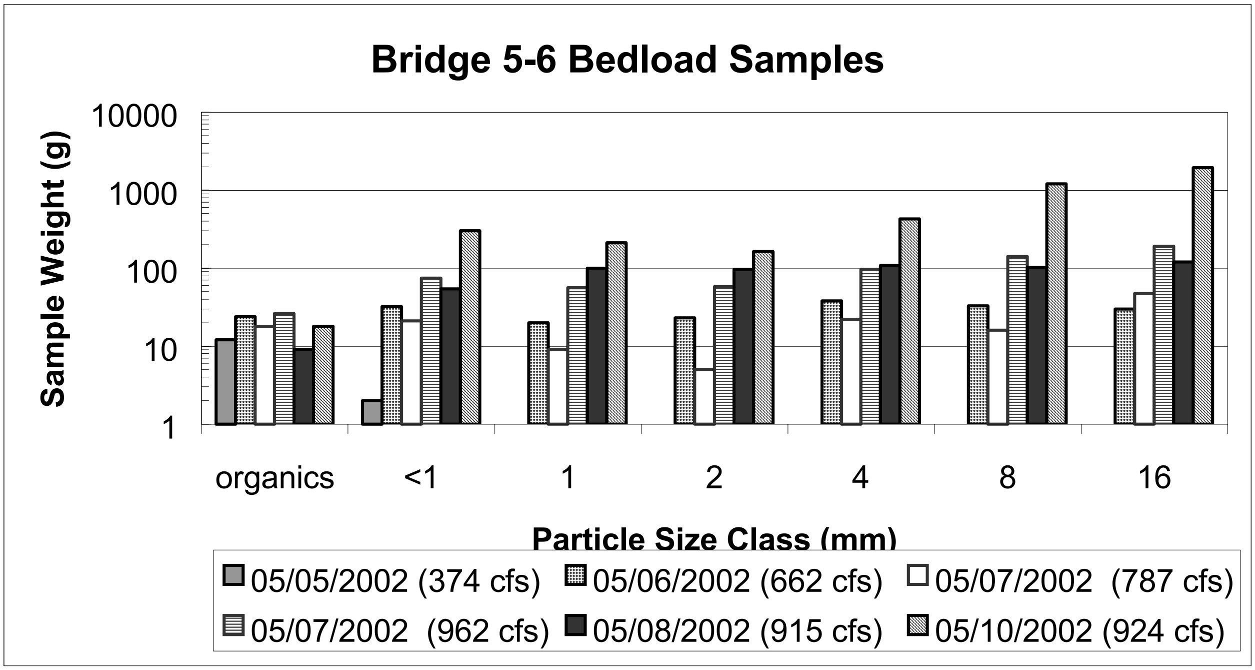


FIGURE 3.6. BRIDGE 5-6 BEDLOAD SAMPLING RESULTS BROKEN INTO SIZE CLASSES.

ranging from 650 to 800 cfs. Although bedload was found to be moving at these moderate flows, the material in transport was dominated by mostly sand-sized particles (Plate 3.1). There was a slight reduction in the amount of material in transport over time between these two sampling times even with higher discharges during the second sample, indicating that the supply of sand sized material may be limited at these moderate flow stages (Figure 3.6).

The amount of bedload material in all size classes increased as flows increased to near 1,000 cfs. Increased transport rates indicate that there were additional supplies of bedload sediment at the higher stages. An interesting transition of bedload particle sizes and total amount in transport was observed after the third consecutive day of flows exceeding 900 cfs. The particles changed from sand- to gravel-dominated grain sizes, and bedload transport rates increased by more than 10 times (Figure 3.6, Plate 3.1). These results indicate that although bedload transport is highly correlated with streamflow, flow duration also has a major influence on the size distribution and total amount of material in transport.

3.1.4.2 MODELING RESULTS

Cross sections, bed material particle size distributions, and flows were found to be fairly similar between the bedload cross sections of Sites 6 and 5, and were therefore modeled together. Figure 3.7 shows the particle size distribution of streambed material at the bedload modeling cross sections and Table 3.1 shows important fractions of the streambed particle size distribution compared to the largest particle captured during bedload sampling at the nearby bridge site (Bridge 5-6).

SITE 6

374 cfs

662 cfs

787 cfs

962 cfs

915 cfs

924 cfs

PLATE 3.1. PHOTOGRAPHS OF BEDLOAD SAMPLES COLLECTED DURING 2002 SPRING RUNOFF.

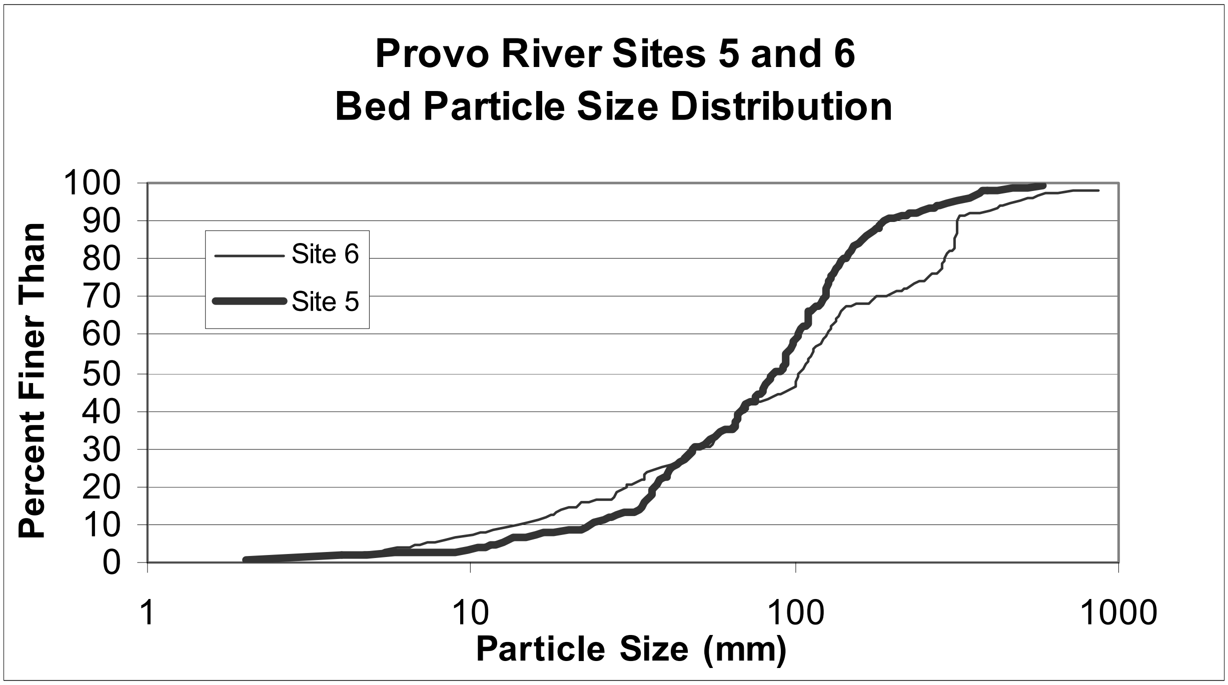


FIGURE 3.7. PARTICLE SIZE DISTRIBUTIONS OF SITES 5 AND 6.

TABLE 3.1. IMPORTANT FRACTIONS OF SITES 6 AND 5 STREAMBED PARTICLE SIZE DISTRIBUTIONS AND LARGEST PARTICLE CAPTURED AT BRIDGE 5-6 DURING BEDLOAD SAMPLING.[A]

SITE	D16	D25	D50	D75	D84	MAXIMUM SIZE AT BRIDGE 5-6 IN TRANSPORT
5	34	42	88	130	158	61
6	22	40	104	260	310	

[A] THE SIZE OF PARTICLES ARE MEASURED IN MM ALONG THE B-AXIS.

The Site 5 D_{25} (particle 42 mm in size) was used to model bedload transport at Sites 5 and 6. Typically, as described in Section 2.4, the D_{50} would be used for this type of analysis but it was determined to be too large in the Provo River because of the over-coarsened condition likely caused by dam construction and flow regulation. Basically, particles ranging from 88 to 104 mm in size (D_{50} of the existing streambed at Sites 5 and 6, respectively) are predicted to remain in-place at flows exceeding 2,200 cfs based on the Meyer-Peter Muller equation ($\tau^* = 0.047$). The bedload rating curve for Sites 5 and 6 based on the D_{25} is shown in Figure 3.8. This graph shows that bedload does not begin to move until flows exceed 500 cfs, and once motion is initiated there is a positive relationship between discharge and bedload transport rates. These results are consistent with the samples collected at Bridge 5-6.

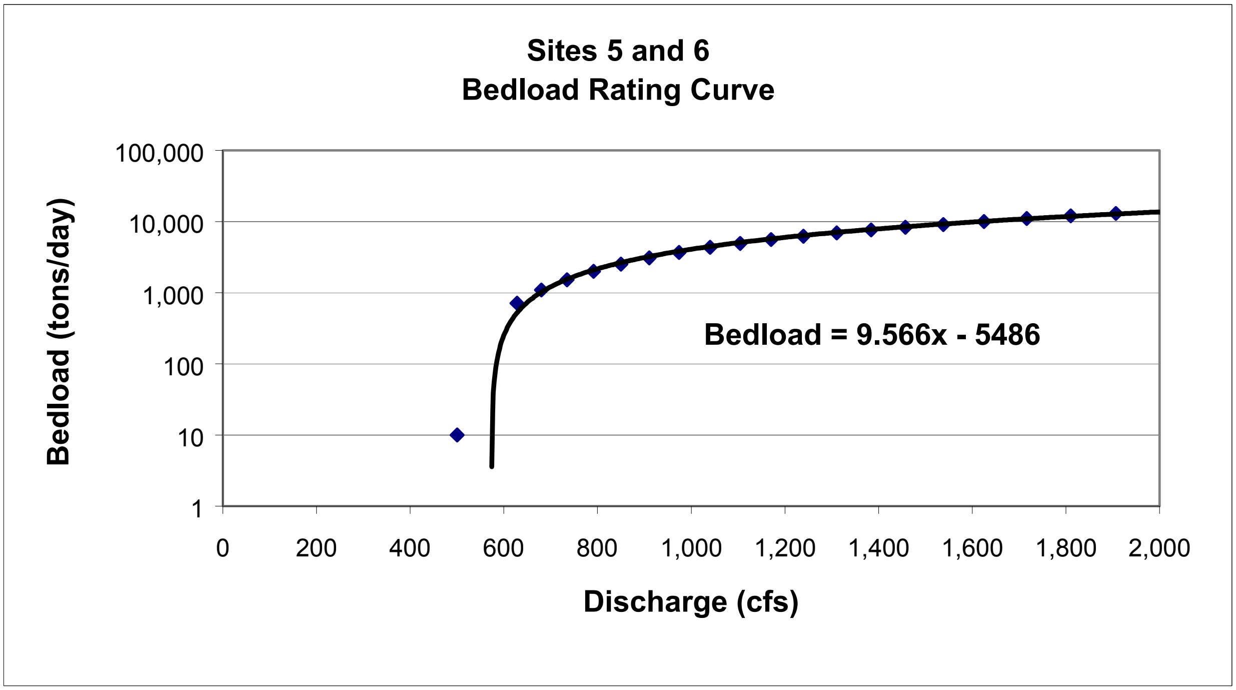


FIGURE 3.8. THE BEDLOAD RATING CURVE FOR SITES 5 AND 6 BASED ON THE D_{25} OF THE EXISTING STREAMBED (PARTICLE 42 MM IN DIAMETER). THIS GRAPH SHOWS THAT BEDLOAD DOES NOT BEGIN TO MOVE UNTIL FLOWS EXCEED 500 CFS.

Figure 3.9 shows the relationship between suspended sediment transport and flow using the Murdock water quality data. Although the relationship shown in Figure 3.9 appears reasonable, caution must be exercised when interpreting the suspended sediment transport data. The transport rating curve is based on only 6 data points, and the TSS data were collected for water quality assessment purposes, not for evaluating suspended sediment transport. The data were collected as water quality grab samples taken at a single point in the water column, not taken across an entire river transect in a depth- and cross sectionally-integrated manner. In addition, the highest flow for which a TSS measurement was available is 362 cfs; no data were available to characterize sediment concentrations during peak flood periods. Therefore, the extrapolated suspended sediment transport rates for high flows may be inaccurate because they are based solely on low-to-moderate flow data. In addition, the established monitoring site is likely influenced by sediment deposition above Murdock Diversion and likely underestimates the suspended load in the free-flowing portions of the river.

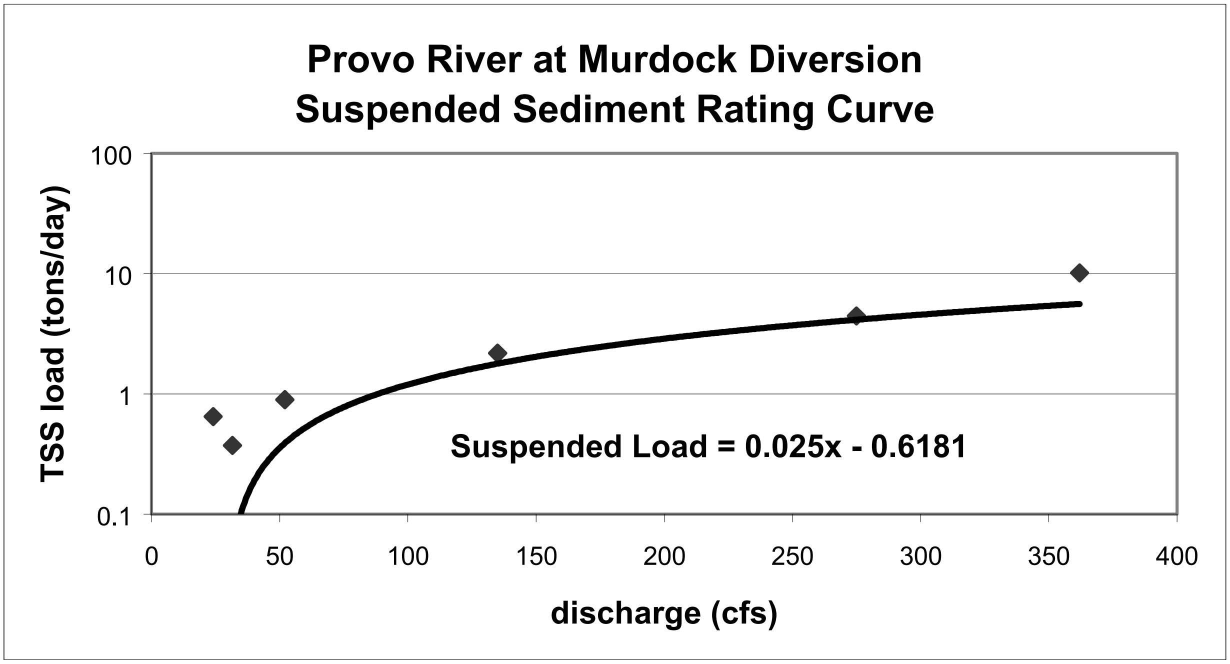
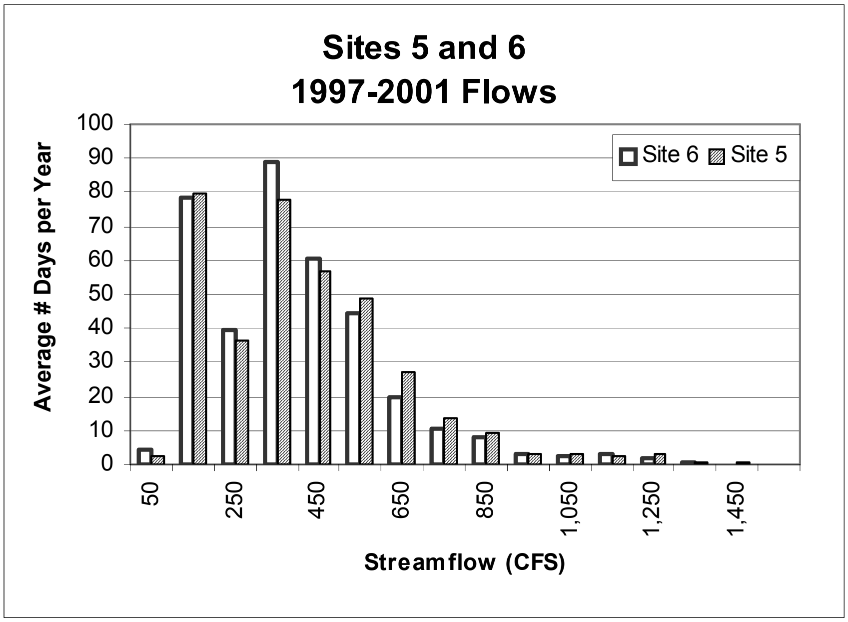


FIGURE 3.9. SUSPENDED SEDIMENT RATING CURVE BASED ON TSS DATA COLLECTED AT THE MURDOCK WATER QUALITY STATION.

As described in Section 1.4, riffles become depositional zones at high flows due to the phenomenon of pool-riffle velocity reversal. Figures 3.8 and 3.9, along with the bedload sampling results, demonstrate that sedimentation of fine grained particles may occur within riffles at Sites 5 and 6 if flows were increased rapidly to peaks less than 1,000 cfs and then were decreased rapidly before bedload had entered the "equal mobility" phase. Suspended sediment concentrations and transport of fine grained bedload (<2 mm) would increase dramatically during the initial rising limb of spring runoff. The size distribution of bedload coarsens over time to a clean gravel (indicating a transition to "equal mobility") when flows are maintained at high stages for an adequate duration. If flows decrease rapidly before bedload transitions into the "equal mobility" stage, then the fine grained material may drop out of transport and deposit on the streambed, causing deposition of fine grained sediment (i.e., "fining") in riffles and runs.

3.1.4.3 EFFECTIVE DISCHARGE RESULTS

Effective discharge calculations show multiple peaks of flow increments transporting the greatest sediment loads at Sites 5 and 6 (Figure 3.10). The first peak occurs at flows ranging from 800-900 cfs. The second peak occurs above the North Fork confluence (Site 6) at flows ranging from 1,100-1,200 cfs, and 1,200-1,300 cfs below the North Fork confluence (Site 5). The multiple peaks are likely a result of the relatively wet and dry runoff conditions over the past five years with no average year. The first peak between 800-900 cfs is influenced by low springtime peak flows during the recent drought years whereas the second peak between 1,100 and 1,300 cfs is influenced by the previous wet years with higher peak runoff conditions. A longer period of record would help define



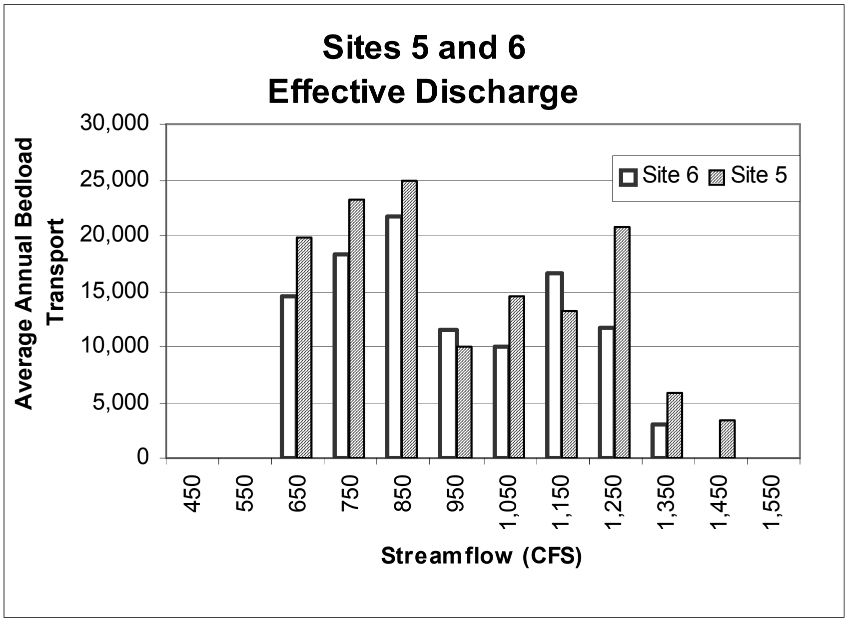


FIGURE 3.10. EFFECTIVE DISCHARGE RESULTS FOR SITES 5 AND 6. THE UPPER GRAPH SHOWS THE AVERAGE NUMBER OF DAYS PER YEAR DURING THE PAST FIVE YEARS THAT STREAMFLOW HAS BEEN WITHIN ANY 100 CFS INCREMENT (0-100, 200-300, ETC.). THE LOWER GRAPH APPLIES THE MODELED BEDLOAD TRANSPORT RATE MULTIPLIED BY THE NUMBER OF OCCURRENCES TO DETERMINE THE STREAMFLOW THAT TRANSPORTS THE MOST BEDLOAD SEDIMENT OVER THE PERIOD OF RECORD.

the true effective discharge at Sites 5 and 6. Channel narrowing would likely result if the number of occurrences in the 1,100-1,300 cfs range decreased over time. Streamflow analysis at Sites 5 and 6 provides some interesting results (Figure 3.10, Appendix C). Flows ranging from 100-600 cfs are dominant in this reach of the river, occurring over 80 percent of the time (300 days/year) during the previous five years. Flows below 600 cfs transport very little bedload sediment and are not considered "effective" in governing channel size and shape. Moving to slightly higher flows, bedload transport starts to occur at flows between 600-800 cfs yet, as described previously, the material being transported within this flow range remains limited to the smaller size fractions and has limited influence on channel size and shape. Flows between 600-800 cfs occur often enough (10% of the time or 35 days/year) and likely influence the amount of fine grained material (fines) building up or winnowing through specific habitats depending on local conditions such as water depth and slope.

Flows between 800-900 cfs only occur approximately 9 days per year (2% of the time) but have transported the most bedload sediment over the past five years. Our analysis shows a second effective discharge peak at 1,100-1,200 cfs and 1,200-1,300 cfs at Sites 6 and 5, respectively. Although the daily transport rates are high during these higher flows, they only occur less than 1% of the time or 2-3 days per year, limiting their morphological influence on the Provo River. Over time (more than a five-year period), it is anticipated that flows between the two peaks (900-1,100 cfs) will occur more often and become more influential on the size and shape of Reaches 5 and 6.

3.1.4.4 SEDIGRAPH RESULTS

A comparison of sediment transport, in terms of timing, magnitude, and duration was made between two alternative flow regimes for Sites 5 and 6 (Figure 3.11). Equations shown in Figures 3.8 and 3.9 defining the suspended sediment and bedload rating curves were applied to average daily flows over the past five years (water years 1997 to 2001) for the "unregulated" flow regime (based on adjusted Hailstone gage data) and Sites 6 and 5 (see Appendix C for details). Average daily flows were used to illustrate flow patterns over multiple years instead of relying on a "typical" year or set of years that may have certain anomalies. The results of this analysis show similar patterns but expose significant differences in timing, magnitude, and duration of the sediment transport regime under different flow scenarios.

First, the initial rise and final decline in sediment transport during spring runoff occurs approximately two weeks later at Sites 5 and 6 than under unregulated conditions. The initial rise begins earlier and decline ends later at Site 5 than Site 6 due to the influence of North Fork. It is interesting to note that the fluctuation in bedload transport (during spring runoff) is much greater at Sites 5 and 6 than under unregulated conditions. However, the total fluctuation in sediment transport over the entire year is much greater overall under unregulated conditions than at Sites 5 and 6. Sites 5 and 6 have much lower loads (mostly in the form of bedload) during spring runoff and much higher loads (mostly in the form of suspended sediment) the remainder of the year.

Suspended sediment loads remain relatively high at Sites 5 and 6 during the irrigation and winter seasons. The elevated suspended sediment loads during the warm summer months likely contributes to the dense coverage of algae and aquatic macrophytes present in Reaches 5 and 6.

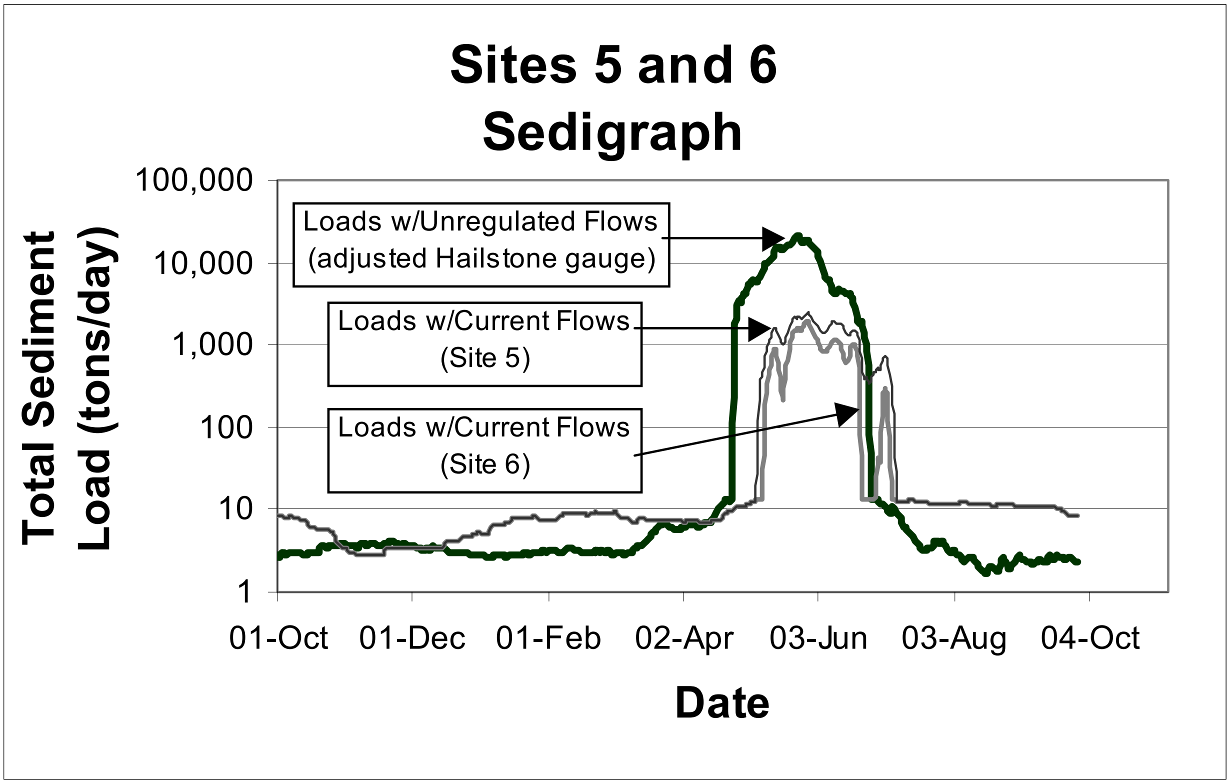


FIGURE 3.11. TIMING, MAGNITUDE, AND DURATION OF SEDIMENT TRANSPORT FOR AVERAGE FLOWS (WATER YEARS 1997-2001) AT SITES 5 AND 6 BASED ON BEDLOAD AND SUSPENDED SEDIMENT RATING CURVES. THE HIGHER CURVE REPRESENTS THE PREDICTED SEDIMENT TRANSPORT WITHOUT THE INFLUENCE OF FLOW REGULATION BY JORDANELLE AND DEER CREEK RESERVOIRS.

The most noticeable difference in the two sediment transport regimes is the magnitude of bedload transport during spring runoff. Peak loads are approximately 1 order of magnitude higher using the unregulated flow regime. Flow duration curves were used to calculate total annual sediment loads. The total annual sediment load for Site 5 and 6 is 147,000 tons and 115,000 tons, respectively, with the North Fork tributary accounting for a 28 percent increase at Site 5 relative to Site 6. However, the total annual sediment load using the unregulated flow data is approximately 665,000 tons (approximately 5 times greater than Sites 5 and 6).

3.1.5 RIPARIAN VEGETATION - SITE 6

Riparian vegetation width at Site 6 is constrained by levees built to protect the railroad on the west side of the stream and a dirt access road on the east side. In areas where the low flow channel abuts these levees, banks are tall, steep, and rocky. Riparian vegetation width in these steep bank areas is narrow, and the steepest areas are devoid of vegetation. Although the presence of the levees has limited the ability of the channel to meander and develop bars and floodplain surfaces, several bars, islands, and floodplain/terrace features are present within the site. The middle and lower portions of Site 6, where the distance between levees is relatively wide, exhibit the greatest diversity of fluvial features.

3.1.5.1 TRANSECT RESULTS

Within Site 6, three transects spanning different riparian establishment surfaces were selected to evaluate the relationships between streamflow and riparian characteristics (Map 3.1). These transects are plotted in Figure 3.12 along with the range of flows that inundate the different establishment surfaces.

On river right (facing downstream), Transect 1 crosses a low sand/gravel bar surface and a "high floodplain" area occupied by grass and shrub (red osier dogwood and willow) vegetation (Plate 3.2, Figure 3.12). The left side of Transect 1 is a steep leveed bank with limited riparian vegetation. The sand/gravel bar is a gently sloping surface that is partially inundated even at low (100 cfs or lower) discharges. The bar surface is completely inundated by discharges of approximately 700 cfs. Based on analysis of average daily flow data from the USGS gage below Deer Creek Dam (gage #10159500) for water years 1997-2001, discharges of 700 cfs are equaled or exceeded less than ten percent of the time (Appendix C). Although this is a relatively short flow duration, it appears to be adequate to prevent the establishment of vegetation on the bar surface.

The "high floodplain" surface crossed by Transect 1 begins to be inundated by flows of approximately 900 cfs, and only the edge of the surface is inundated by the highest modeled flow of 1,500 cfs. High magnitude floods significantly greater than 1,500 cfs would be needed to completely inundate the high floodplain. Flood frequency analysis of peak instantaneous discharges for the period 1953-2001 indicates that the 100-year flood is 2,782 cfs. Based on more recent peak flow data (1997-2001), the 100-year flood is only 1,543 (Appendix C). This suggests that historically this surface has only been completely inundated on an infrequent basis, and that under current river operations it will most likely never be flooded. During field surveys of the site, several small seeps and springs were noted within the high floodplain area. This groundwater-derived water supply most likely helps to support the grass and shrub vegetation present on this surface. Flows between 100-700 cfs occur frequently.

Transect 2 also spans the high floodplain surface on river right, and modeling results indicate that flows greater than the highest modeled flow of 1,500 cfs would be needed to inundate this surface (Figure 3.12). Transect 2 also crosses a grassy, mid-channel "low floodplain" surface that becomes an island at flows of approximately 400 cfs and higher (Plate 3.2). This low floodplain becomes completely inundated at flows of about 1,100 cfs (Figure 3.12). Based on analysis of average daily flows, a flow of 1,100 cfs is equaled or exceeded less than 2% of the time; however, peak instantaneous discharges of 1,100 cfs or greater are relatively common. The post-Jordanelle 2-year flood magnitude is 1,136 cfs (Appendix C).

SITE 6

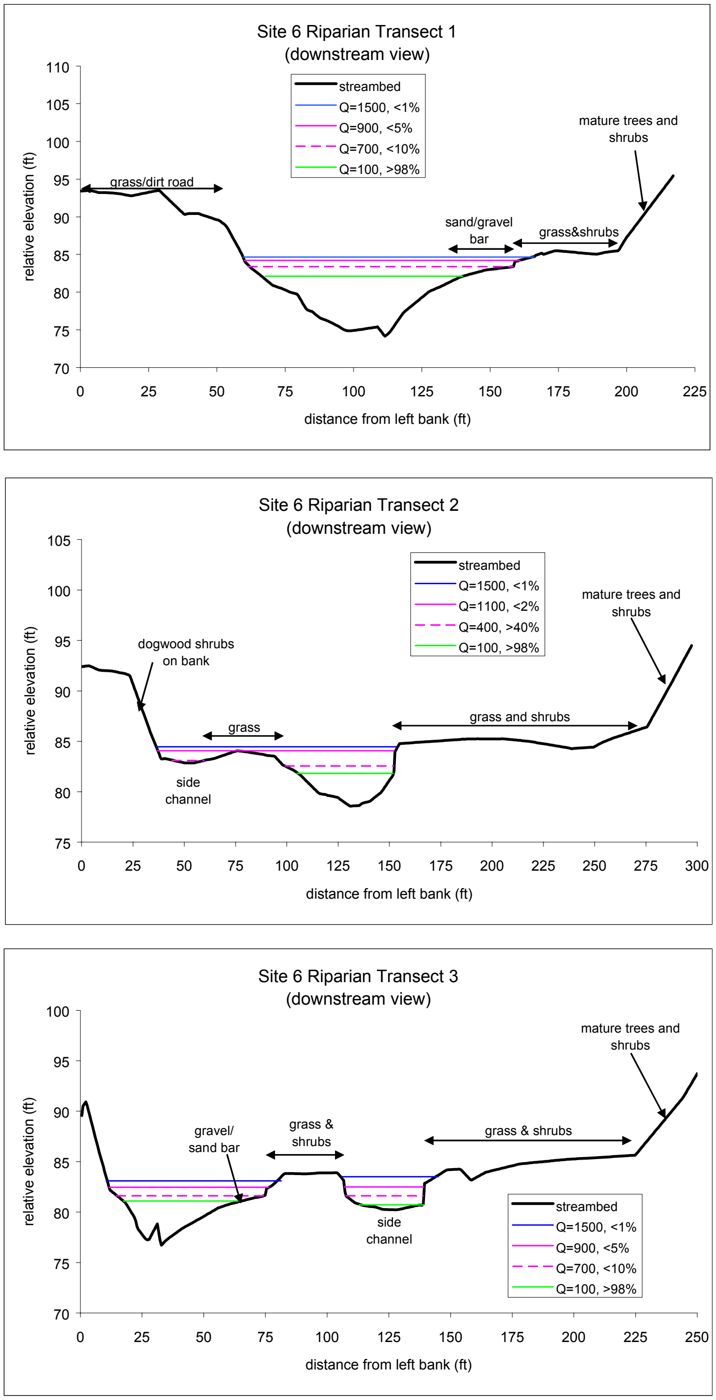


FIGURE 3.12. SITE 6 RIPARIAN TRANSECTS AND INUNDATION DISCHARGES (CFS). PERCENTAGES SHOWN IN LEGEND INDICATE THE PERCENT OF TIME A GIVEN DISCHARGE IS EQUALED OR EXCEEDED.

Site 6

Plate 3.2. Photos of Site 6 Riparian Surfaces. (a) and (b): bar and high floodplain surfaces crossed by Transect 1 on river right. (c) upstream view of side channel and grassy low floodplain surface crossed by Transect 2. (d) upstream view of island, bar, and side channel crossed by Transect 3.

Transect 3 spans a sand/gravel bar, island, side channel, and the same high floodplain surface crossed by Transects 1 and 2 on river right (Map 3.1, Plate 3.2). The vegetative characteristics and elevation of the island are similar to those of the high floodplain. The inundation characteristics of the sand/gravel bar are similar to those of the bar at Transect 1: both bar surfaces become completely inundated by flows of about 700 cfs. Small, grassy cutbanks about 10 inches tall are present at the edge of the bar surface at both transects, and the discharge that reaches the top of the cutbank is about 900 cfs at both transects (Plate 3.2, Figure 3.12). As with the previous two transects, the edge of high floodplain surface (and in this case the island also) is barely inundated by the highest modeled flow of 1,500 cfs.

3.1.5.2 COTTONWOOD RECRUITMENT POTENTIAL

As discussed in the Section 1 of this report, almost no young cottonwoods or recently-recruited seedlings are present in Study Reaches 5 and 6, and no young cottonwoods were observed within Study Site 6. Successful recruitment of cottonwoods requires a specific combination and sequence of fluvial surfaces and hydrologic patterns. Seed-based reproduction requires that the following general conditions be met (Scott et al. 1993):

1. presence of a bare surface with freshly-deposited sediments at the time of seed dispersal,
2. transport and deposition of seeds onto the surface,
3. post-germination decline in water levels at a rate slow enough that seedlings do not dessicate, and
4. absence of post-germination floods that would scour seedlings.

Under its existing geomorphic and hydrologic conditions, the Provo River within Site 6 is limited in its ability to meet these recruitment requirements. Because Deer Creek Dam has reduced the frequency and magnitude of flooding, “high floodplain” surfaces such as the area on river right crossed by the three Site 6 riparian transects are almost never inundated. Because summertime flows are kept artificially high in order to deliver irrigation flows downstream, lower surfaces such as the gravel/cobble side channel crossed by Transect 2 and the sand/gravel bars crossed by Transects 1 and 3 are partly-to-completely inundated throughout the growing season, preventing successful vegetation growth. Grassy vegetation and a few small shrubs occupy the low floodplain/island surface crossed by Transect 2; however, the 2-year flood discharge overtops this surface, and frequent flood scour most likely prohibits more extensive colonization by woody shrubs or cottonwoods.

Despite these obstacles, opportunities may exist to provide flow releases designed to promote cottonwood recruitment within Provo Canyon. At Site 6, the high floodplain surface on river right and on the downstream island may be potential surfaces for cottonwood establishment. However, existing scrub-shrub vegetation on both of these surfaces is quite dense, which makes the presence of barren fresh sediment for establishment (as per requirement 1 above) unlikely. Flood flows considerably greater than 1,500 cfs would be needed in order to scour the existing vegetation and create bare surfaces for establishment. Another alternative would be to mechanically remove the existing shrub vegetation. Even if the vegetation were removed, however, flows would need to significantly exceed 1,500 cfs in order to inundate a significant portion of the high floodplain surface and allow for deposition of sediment, and these flows would need to occur at the same time as seed dispersal. The existing mature cottonwood trees present within the Canyon should provide an adequate seed supply for dispersal by wind and water (meeting requirement 2 listed above). At Site 6, some mature cottonwoods are present along the steep railroad levee that forms the right boundary of the river right high floodplain surface.

Meeting requirement 3 listed above would likely be the most challenging aspect of providing successful cottonwood recruitment flows for the high floodplain surface. Published cottonwood root growth rates vary between 3mm/day to 10 mm/day (Mahoney and Rood 1998, Stomberg et al. 1999), and the alluvial water table decline must not exceed these rates or seedlings will die of dessication. In addition, maximum root growth during the first growing season is 1 m (3.3 ft). Using a maximum recession rate of 5 mm/day (0.016 ft/day), flows would need to remain high for an extended period of time to prevent dessication of the high floodplain surface. Flow stage at Transect 1 at 1,500 cfs is 0.46 feet higher than the stage at 900 cfs. In order not to exceed a recession rate of 0.016 ft/day at this transect, flows would have to slowly be lowered over the course of 29 days. This is a longer period of high flow releases than typically occurs below Deer Creek Dam; however, such a flow release scenario may be possible to execute in wet years when surplus water exists. Because the bank slope of the high floodplain surface is flatter at Transect 1 than at the downstream transects (Figure 3.12), flows would have to be lowered even more slowly at the other transects to prevent dessication.

3.2 SITE 5

3.2.1 AQUATIC HABITAT - SITE 5

3.2.1.1 HABITAT NICHE MODELING

As discussed in Section 2 and Appendix A, a habitat niche approach was primarily used for assessing suitable habitat for Site 5. To represent habitat in the entire channel segment from Deer Creek Reservoir to Olmsted Diversion (Reaches 5 and 6), the amount of linear distance represented by Site 5 and Site 6 habitat was determined from the channel reach mapping. It was determined that Site 5 represents approximately 84% of this stretch of river. As discussed in the methods, some interpretative caution should be used when viewing the results from either the intensive study sites alone or the extrapolated (reach) results. Due to the similarity in trends between the individual site (5) and the extrapolated reach, the results for Reach 5 are discussed below.

Each WUA value calculated for Reach 5 represents the total amount of suitable habitat per 1,000 linear feet of stream. Figure 3.13 shows the WUA (ft^2/1,000 ft) for each niche per respective flow. The backwater/edge habitat (niche 1) is used by a majority of the native fish species and larval stages of many fish and doesn't exceed 10,000ft^2/1,000ft at any flow in this confined reach. Slight increases in niche 1 habitat occur as flows fill out the channel and extend into the backwater area on river left near the middle of the site (Map 3.2). Routine fisheries data from UDWR and BYU fisheries assessments confirm that only rarely have native fishes been collected in confined reaches in the Provo River. The slow/shallow habitat (niche 2) supports juvenile and YOY life stages of many species. This niche supports approximately 25,000ft^2/1,000ft at approximately 40 cfs but decreases rapidly with less than 5,000ft^2/1,000 ft of WUA present at 500 cfs. Niche 2 (slow/shallow habitat) and niche 3 (moderate/shallow) overlap in supporting both larval and juvenile life stages for certain species, but niche 3 is broader and includes certain adult species. Availability of niche 3 habitat is similar to niche 5 (moderate/mid-depth); both have peaks in WUA in the lower end of the flow range. Available niche 3 and niche 5 habitat increases until approximately 150 cfs (approx. 20,000ft^2/1,000ft) and 300 cfs (approx. 18,000ft^2/1,000ft), respectively; then both decrease to below 10,000ft^2/1,000ft at approximately 500 cfs. Niche 5 is the primary habitat type for the sportfish in the Provo River including all trout and mountain whitefish adults and juveniles. In this reach, flows

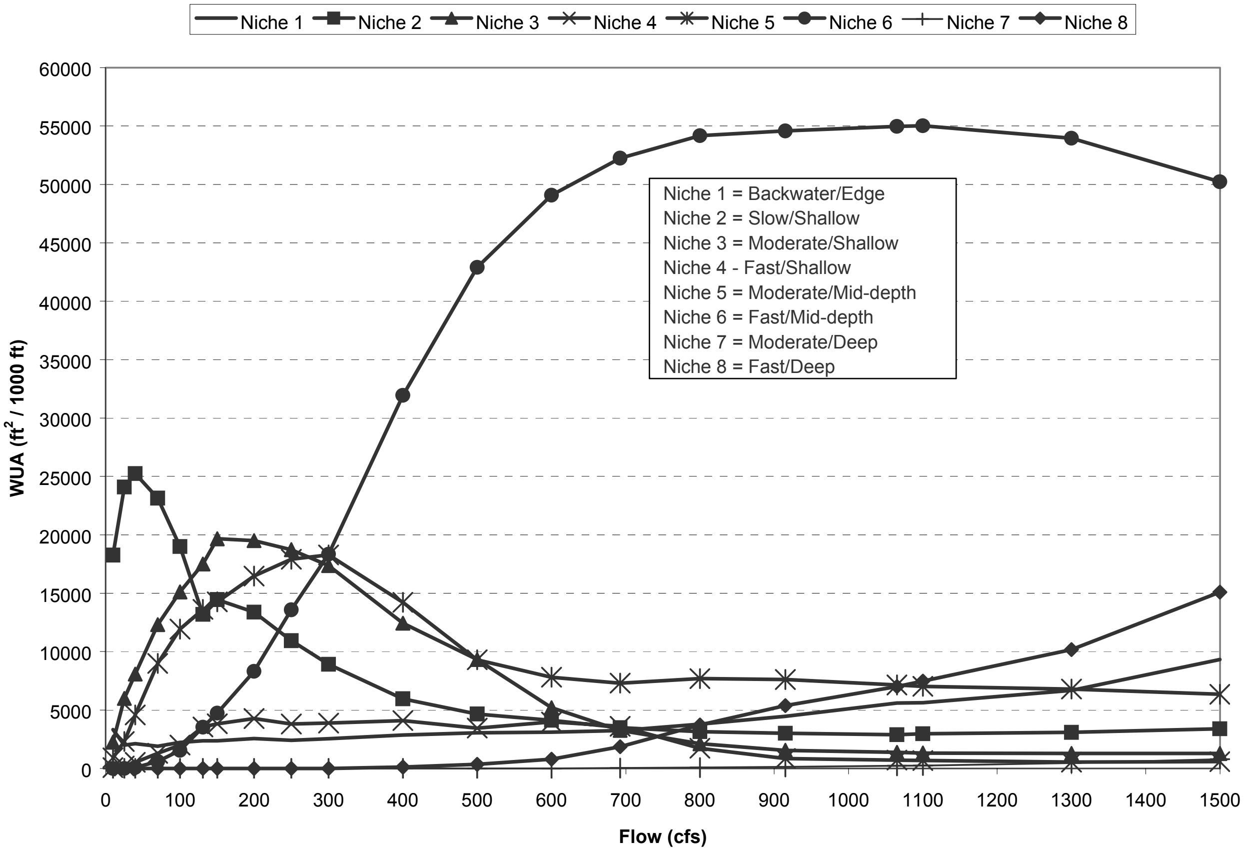
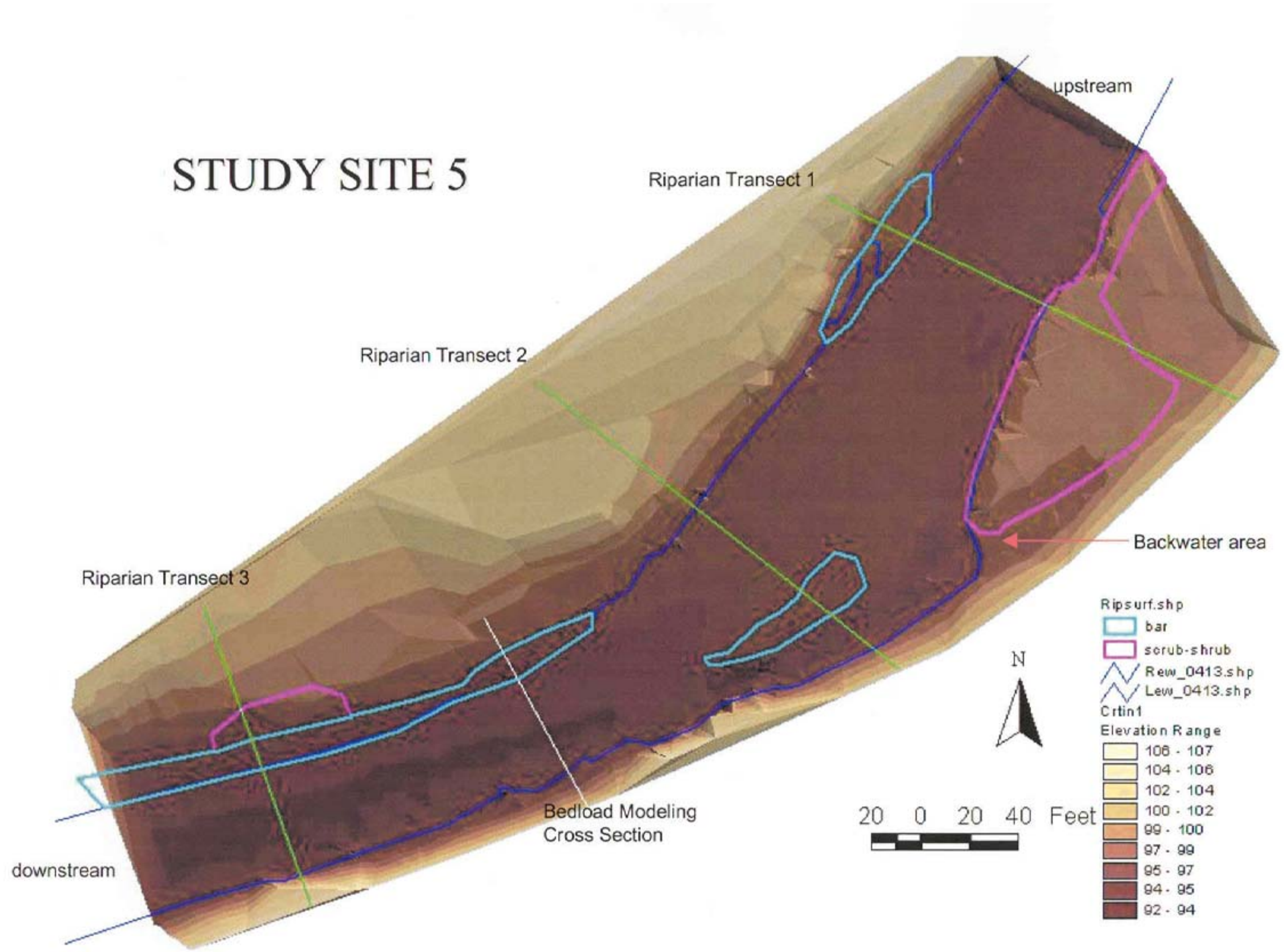


FIGURE 3.13. REACH 5: HABITAT NICHES - WUA VS. FLOW.

ranging from approximately 150 to 400 cfs provide approximately 15,000ft^2/1,000ft or greater niche 5 habitat. The fast/shallow habitat (niche 4), which provides habitat for mountain sucker adults and mottled sculpin adults and juveniles, is slightly elevated between 150 and 700 cfs but overall is very limited (< 5,000ft^2/1,000ft). The only species/lifestage documented in niche 6 habitat (fast/mid-depth) is the adult mountain sucker. Niche 6 habitat increases dramatically (> 40,000ft^2/1,000ft increase from 100 to 500 cfs) and peaks at approximately 1,000 cfs. Very little moderate/deep habitat (niche 7) is available at any flow within Reach 5; this habitat is favored by adult mountain whitefish and adult Utah sucker. Although the fast/deep habitat (niche 8) does not directly relate to any fish species, it is included to describe how the habitat changes as flows increase; niche 8 increases steadily beyond approximately 600 cfs.

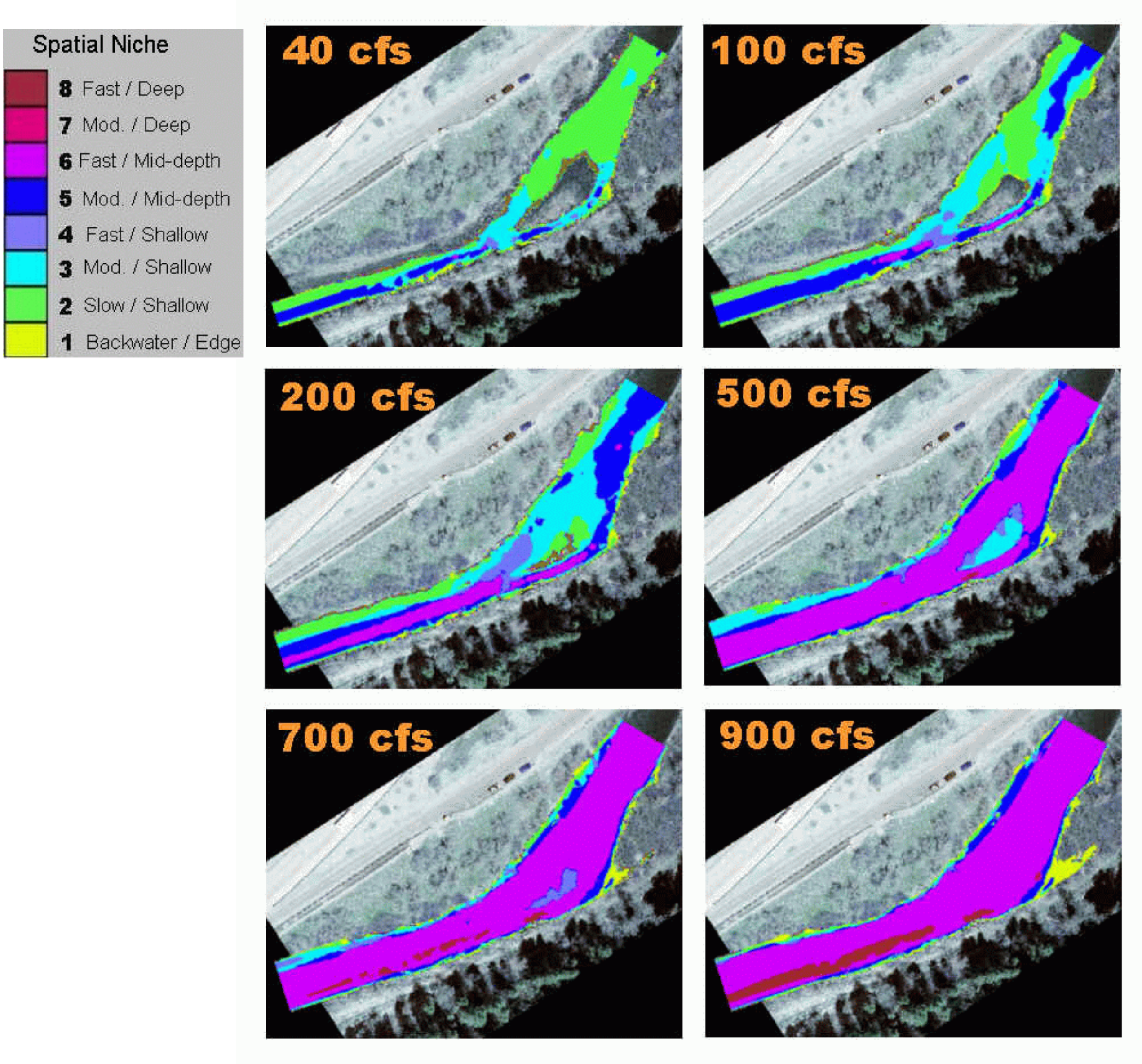
As evidenced in Image 3.3 and in Figure 3.13, 100 cfs provides nearly 15,000ft^2/1,000ft for niches 2, 3, and 5. However, increasing flows at Reach 5 provides a shift to predominantly niche 6 habitat with niches 2, 3, and 5 being restricted to the edges. Overall, the results of the habitat niche modeling at this site support the available biological data which indicate that very few species other than trout, mottled sculpin, and mountain whitefish have been collected in this reach. The lack of



Map 3.2. Map of Study Site 5 Showing Riparian Transect and Bedload Modeling Cross Section Locations. Dark Blue Lines Indicate Water's Edge at Low Flow.

SITE 5

IMAGE 3.3. HABITAT NICHES - WEIGHTED USABLE AREA (SITE 5). THE IMAGES BELOW VISUALLY DEPICT HABITAT NICHES THAT ARE PRESENT AT DISCHARGES OF 40, 100, 200, 500, 700, AND 900 CFS. EACH HABITAT NICHE IS REPRESENTED BY THE COLOR IMMEDIATELY ADJACENT THE NUMBER/DESCRIPTION IN THE LEGEND. FOR EXAMPLE, NICHE 6 = MAGENTA, NICHE 5 = BLUE, NICHE 1 = LIGHT YELLOW, ETC.



backwater/edge habitat and rapid decline in slow/shallow habitat with increasing flows probably limits the success of native fishes and juveniles of many species. The niche approach separates suitable habitat for brown trout from the backwater/edge habitat that is suitable for many native species and juveniles and YOY of most species; however, the abundance of brown trout and potential threat of predation may have an influence on the presence and/or abundance of some of those species in this reach.

3.2.1.2 HSI CURVE MODELING

Using individual HSI curves for brown trout and "all" trout reveal similar trends to the niche 5 results from the habitat niche approach. Figure 3.14 shows the WUA (ft^2/1,000 ft) for each trout species/lifestage per respective flow. To avoid overestimating trout habitat, an "all" trout classification scheme (described in Methods) was used. Based on these HSI curves, the amount of habitat available to each trout species and life stage varies at each flow level, but the greatest amount (> approx. 15,000 ft^2/1,000 ft) for adults and juveniles is between approximately 70 and 400 cfs. Although the overall trend is the same between the juvenile brown trout curve and juvenile "all trout" curve, the adjustment to accommodate shallower depths had an impact on estimates of available habitat (Figure 3.14).

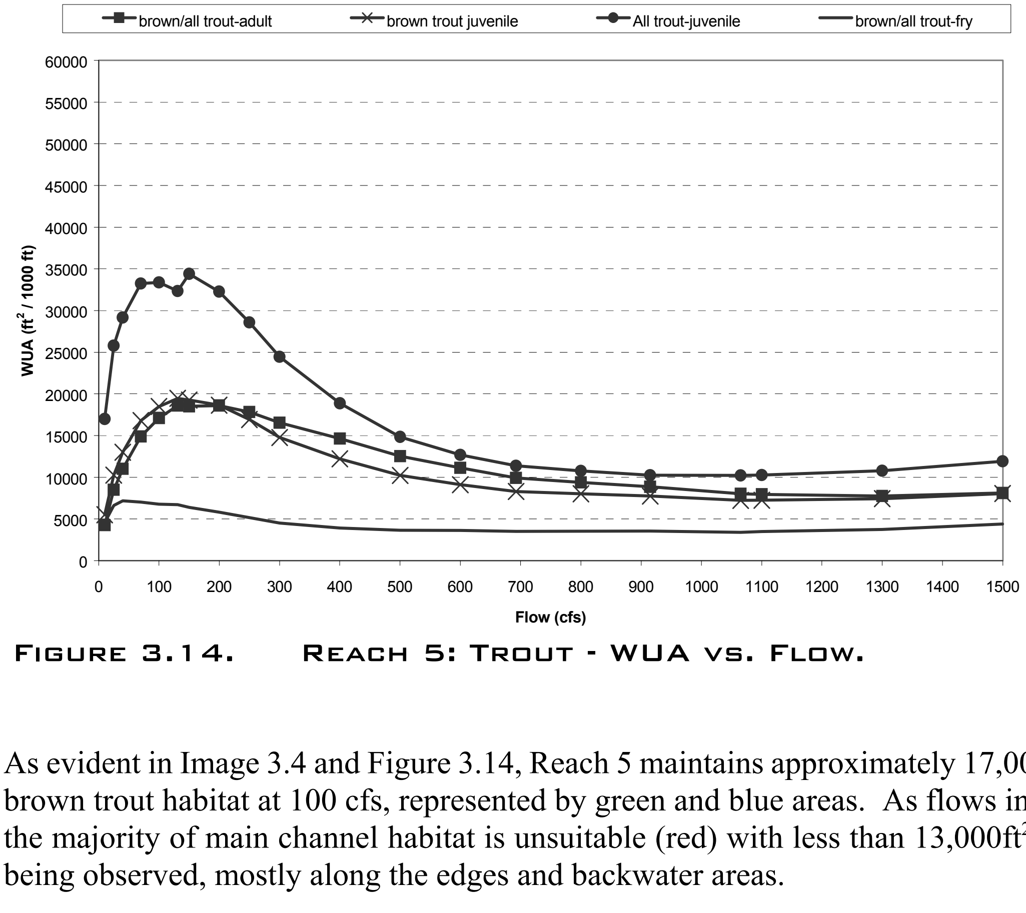


FIGURE 3.14. REACH 5: TROUT - WUA VS. FLOW.

As evident in Image 3.4 and Figure 3.14, Reach 5 maintains approximately 17,000ft^2/1,000ft adult brown trout habitat at 100 cfs, represented by green and blue areas. As flows increase to 500 cfs, the majority of main channel habitat is unsuitable (red) with less than 13,000ft^2/1,000ft of WUA being observed, mostly along the edges and backwater areas.

Site 5

Image 3.4. Adult Brown Trout - Weighted Usable Area (Site 5). The images below visually depict suitable habitat available to adult brown trout at discharges of 40, 100, 200, 500, 700, and 900 cfs. The best habitat is represented by suitability of 1.0 (blue) and no habitat is represented by 0 (red).

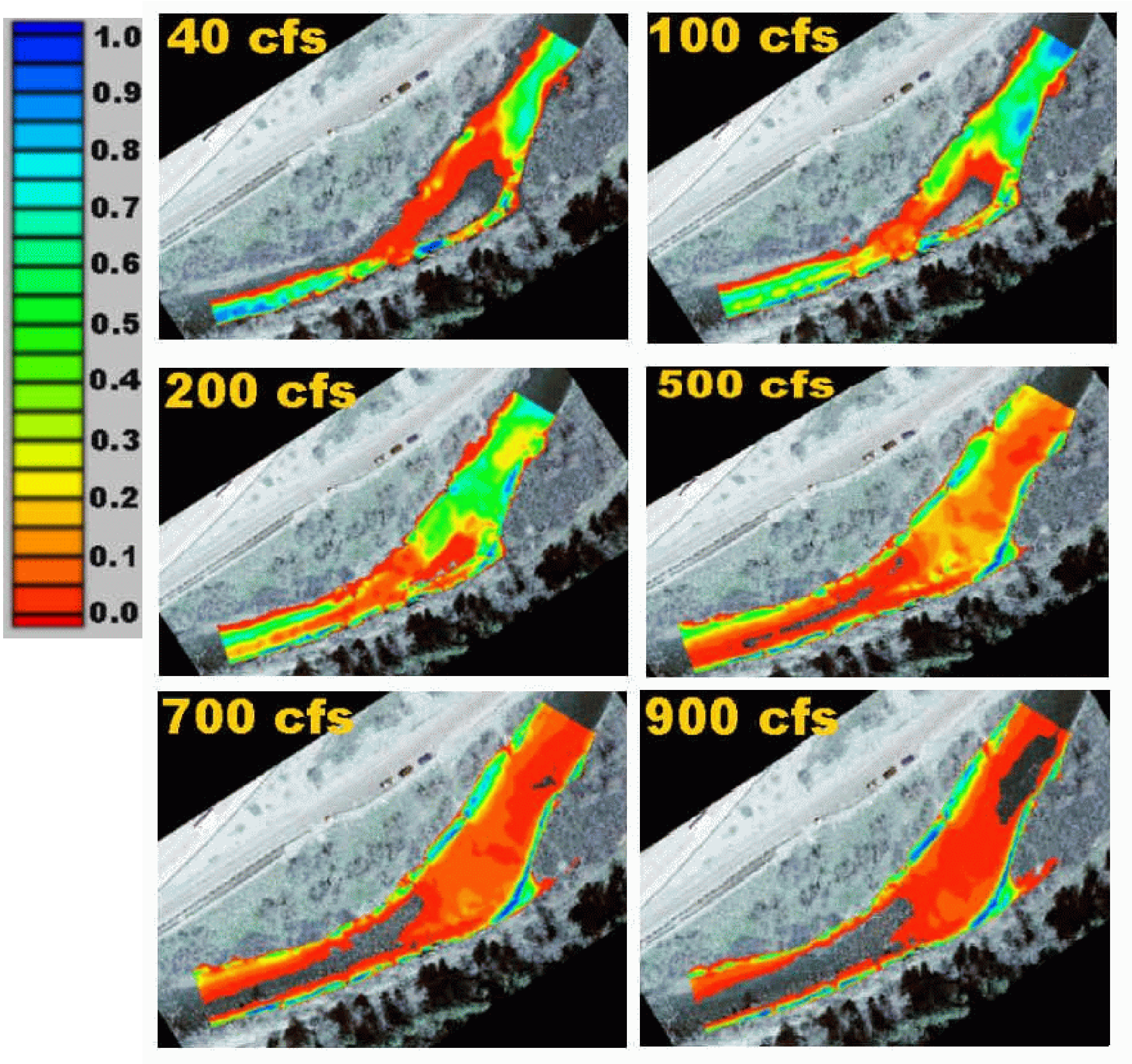


Figure 3.14 reveals that habitat for fry is altogether low (< approx. 7,000ft^2/1,000ft) and falls below 5,000ft^2/1,000ft at flows greater than approximately 275 cfs. The optimal range for fry habitat in Reach 5 is approximately 25 to 150 cfs (> approx. 6,500ft^2/1,000ft). As flow increases, trout fry habitat is reduced. This supports Wiley and Thompson's (1996) observations that fry habitat is lost during high flow spring conditions. However, the recruitment of brown trout throughout the Provo River remains strong which is counter to this detrimental effects hypothesis. As for cutthroat and rainbow trout, fry emergence is later in the spring/summer; however continued increased flows may have impacts on their success as well.

An evaluation of the existing data on spawning criteria revealed that although the brown trout curves encompassed the depth and velocity criteria for rainbow and cutthroat trout, the depth and velocities required for the latter two species differed to a degree where an examination of individual curves versus the "all trout" curve was warranted. As substrate requirements were very similar, it turned out that the requirement for lesser depths and velocities for rainbow trout and lesser yet (depths and velocities) for cutthroat trout resulted in less spawning habitat available (Figure 3.15) There is approximately 27,000ft^2/1,000ft of brown trout spawning habitat at the peak of approximately 150 cfs but is maintained at greater than 15,000ft^2/1,000ft to approximately 400 cfs. Rainbow trout spawning habitat follows the same trend but demonstrates considerably less WUA (< 19,000ft^2/1,000ft at all flows). According to Wiley and Thompson (1996), brown trout spawning occurs in early to mid-November. Wiley and Thompson (1996) modeled sites below Olmsted Diversion and concluded that 26 cfs was the optimum flow for brown trout spawning in that reach. The results of this study suggest that flows ranging from approximately 50 to 300 cfs are optimal in Reach 5. Brown trout spawn in the fall when flows are significantly lower than during spring and early summer when rainbow and the native cutthroat trout spawn. Rainbow and cutthroat trout appear to require similar substrate conditions as brown trout, but more restrictive depth and velocity requirements to spawn; therefore, flows in this reach of the Provo River may be unsuitable for spawning during the late spring and early summer. As evident in Figure 3.15, WUA for spawning cutthroat trout is cut by nearly 70% from 25 cfs to 100 cfs and continues to decline as flows increase. Thus, the timing of spawning and less WUA for spawning at any flow level puts rainbow and native cutthroat trout at a substantial disadvantage to brown trout.

3.2.2 WATER TEMPERATURE -SITE 5

In November 1995, UDWR installed a temperature logger in a study site below Olmsted Diversion to record water temperature during the period of brown trout spawning and emergence from the substrate. The following mean temperatures were collected from that site from November 1995 through April 1996.

December 1995	5 °C
January 1996	2.6 °C
February 1996	2.6 °C
March 1996	4.3 °C
April 1996	6.1 °C

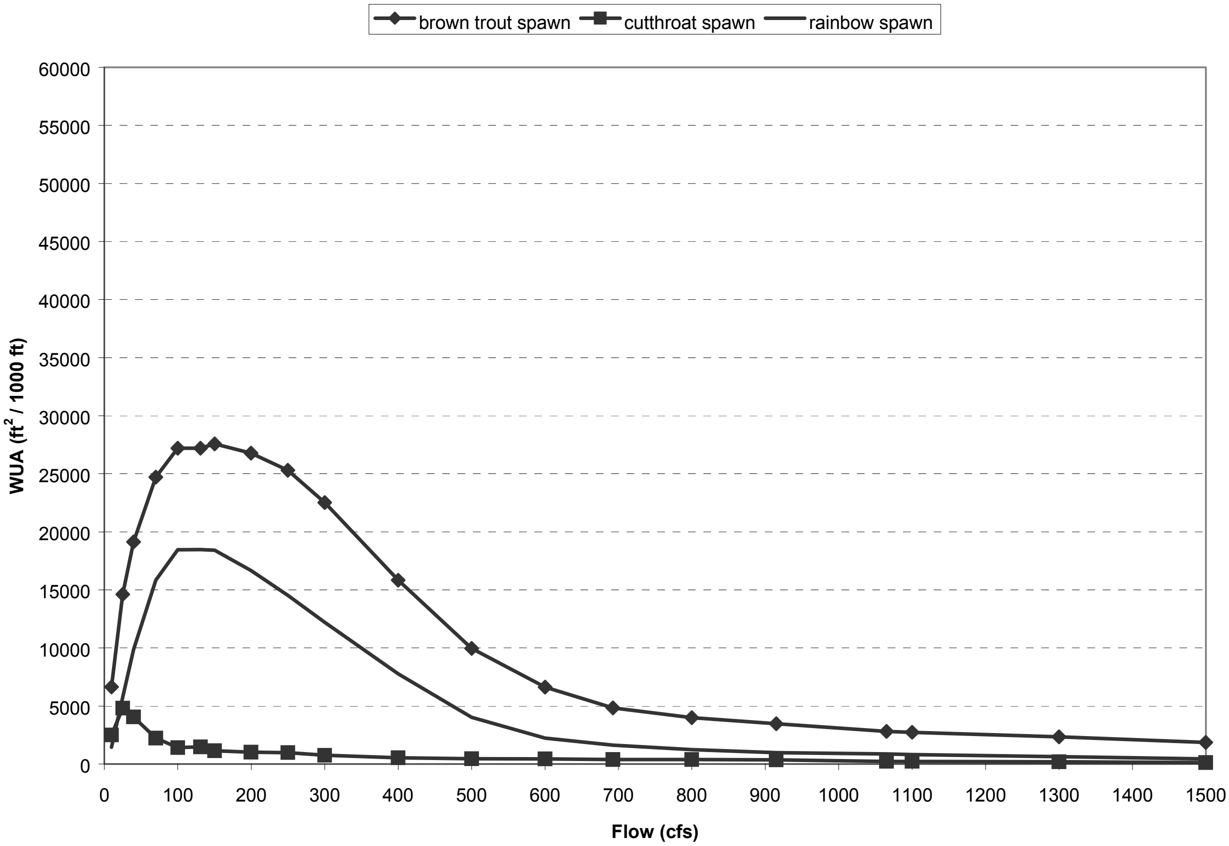


FIGURE 3.15. REACH 5: TROUT SPAWNING - WUA VS. FLOW.

For this study, a thermistor was placed at Site 5 between April 27 and July 18, 2002. The following mean temperatures were observed during the study period.

April (27 - 30)	7.5°C
May	8.4°C
June	10.5°C
July (1-18)	12.7°C

The temperature data was compared to the flow data at USGS Station # 10159500 (Provo River below Deer Creek Dam) to assess thermal fluctuations relative to discharge variations in the Provo River. Figure 3.16 shows the temperatures and flows recorded over the study period.

As evident in Figure 3.16, temperature changes relative to flow were recorded during the flow manipulation period for this study. This occurred in May for Site 5 and the following observations are discussed. Daily temperature fluctuations at Site 5 are considerably greater than Site 6 with a low flow diurnal fluctuation of 4 to 5°C being normal. During the elevated flow period May 6 to May 16, daily temperature fluctuations were around 2.5°C. On May 10,11 when flows peaked over 1,000 cfs diurnal fluctuation dropped to under 1.5°C. From May 17 to May 25 flows were held near

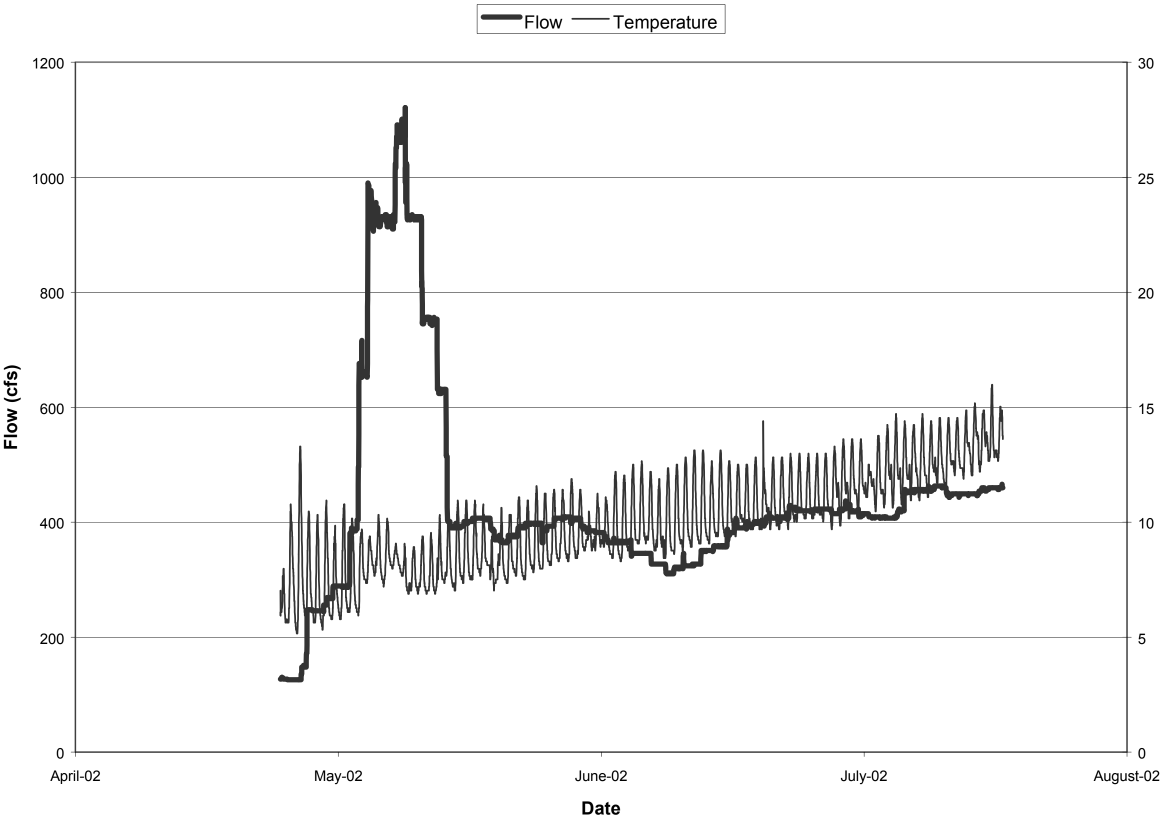


FIGURE 3.16. SITE 5: TEMPERATURE AND FLOW.

400 cfs and diurnal temperature fluctuation held steady at 3.5°C. The average stream temperature from May 1 to May 6 was 7.32 °C. Under high flow conditions May 6 to May 16 the average stream temperature rose to 8.09 °C. Warmer over night temperatures seemed to cause the increase in average temperature despite the fact that daily maximum temperatures were lowered by the flows. At 400 cfs from May 17 to May 25 the average stream temperature was 8.57 °C.

Once the flows were stabilized, a typical warming trend with increasing daily temperatures was observed. The temperature changes and diurnal fluctuations may be very important in understanding the macroinvertebrate assemblages (see Macroinvertebrate Case Studies in the Discussion section) and recruitment success of fishes in Reach 5 of the Provo River.

3.2.3 RECREATIONAL USABILITY - SITE 5

3.2.3.1 WADING (FISHING)

Figure 3.17 shows the Reach 5 WUA (ft^2/1,000ft) for fishing/wading recreational activities. At 150 cfs, approximately 49,000ft^2/1,000ft of fishing/wading area is provided for recreationalists. At flows greater than approximately 500 cfs, suitable fishing/wading area is reduced in half to less than

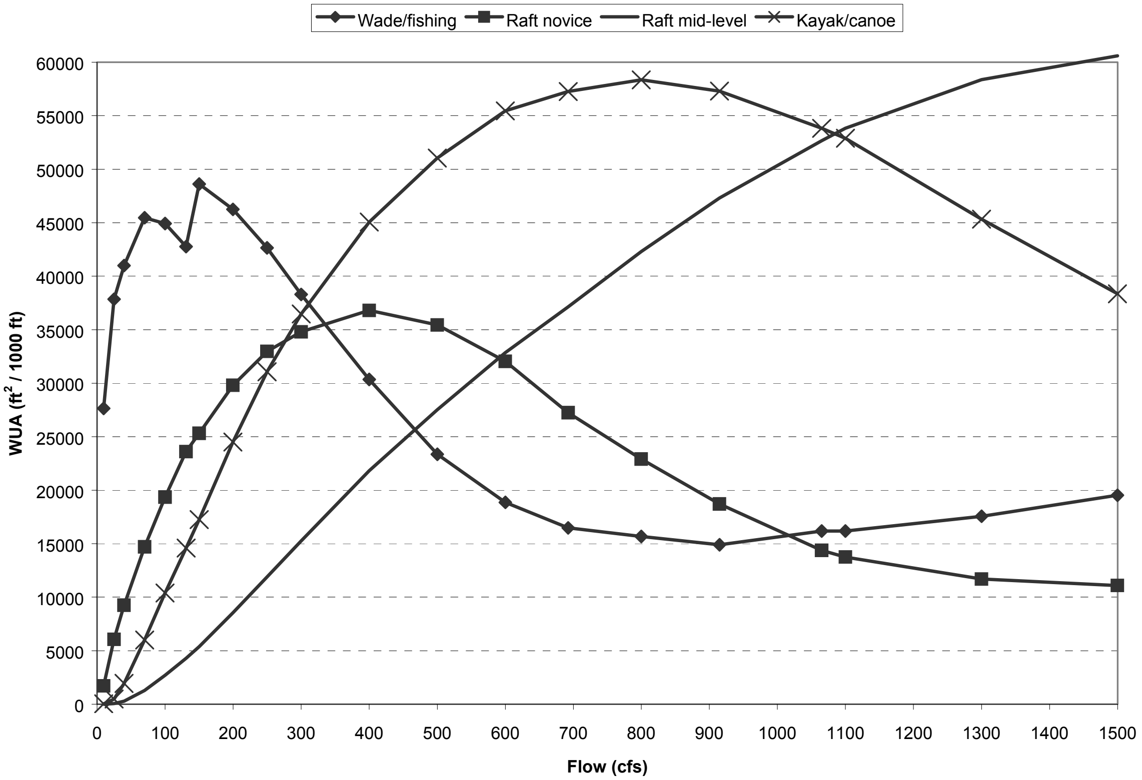


FIGURE 3.17. REACH 5: RECREATION - WUA VS. FLOW.

25,000ft^2/1,000ft. This was very evident when attempting to sample Reach 5 during flows exceeding 400 cfs in that conditions suitable for wading were limited to edge habitat, as high depths and velocities in the center of the channel made it very difficult to wade.

3.2.3.2 BOATING

Figure 3.17 displays the Reach 5 WUA (ft^2/1,000ft) for novice rafting, mid-level rafting, and canoeing/kayaking. As evident in Figure 3.17, the amount of suitable area for canoeing/kayaking increases rapidly as flows increase. The peak at approximately 58,000ft^2/1,000ft and subsequent tapering off effect at flows greater than 800 cfs is a result of a conservative classification that includes safety concerns for both canoes and kayaks. It is recognized that experienced kayakers would welcome the challenge of even higher flows. Reach 5 provides more than 25,000ft^2/1,000ft for novice rafters at a flow range of between approximately 150 and 700 cfs, and for mid-level rafters an almost linear increase in area with increasing flow is observed.

3.2.4 SEDIMENT TRANSPORT - SITE 5

Sediment transport for Site 5 was modeled in conjunction with Site 6; results are discussed above in the Site 6 section.

3.2.5 RIPARIAN VEGETATION - SITE 5

As with Site 6, riparian vegetation width at Site 5 is constrained by levees built on both sides of the stream to protect the highway and railroad. In areas where the low flow channel abuts these levees, banks are tall and steep, and rip rap has typically been placed to protect the streambank. These steep bank areas are typically barren of vegetation or occupied by sparse, mature trees (primarily box elder). Although the presence of the levees has limited the ability of the channel to meander and develop bars and floodplain surfaces, several gravel bars and floodplain/terrace features are present within the site, although the areal extent of these fluvial features is relatively small.

3.2.5.1 TRANSECT RESULTS

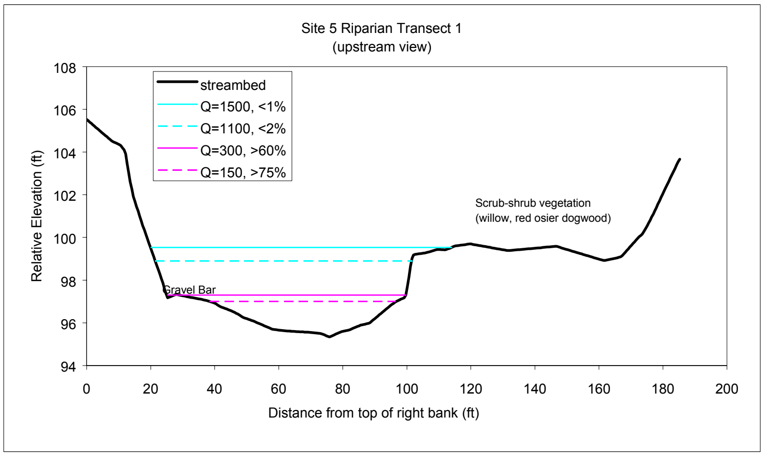
Within Site 5, three transects spanning different riparian establishment surfaces were selected to evaluate the relationships between streamflow and riparian characteristics (Map 3.2). These transects are plotted in Figure 3.18 along with the range of flows that inundate the different establishment surfaces.

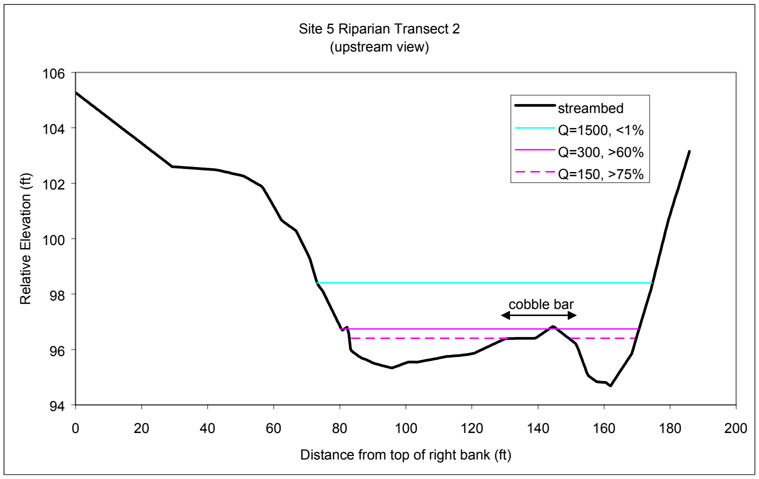
Transect 1 spans a large "high floodplain" area located on river left (facing downstream) at the upstream end of Site 5. This area is occupied by scrub-shrub riparian vegetation consisting of willow and red osier dogwood (Plate 3.3). This surface exhibits evidence of beaver activity, and its characteristics are similar to the high floodplain surface present on river right at Site 6. At Site 5, the edge of this surface begins to be inundated at discharges between 1,100 cfs and 1,500 cfs, although these flows do not completely inundate the entire surface (Figure 3.18). Based on analysis of average daily flow data for water years 1997-2001, discharges of 1,500 cfs are equaled or exceeded less than one percent of the time (Appendix C). However, flood frequency analysis of peak instantaneous discharges for the period 1953-2001 indicates that the edge of the surface has historically been briefly inundated on a relatively frequent basis: the 5-year recurrence interval discharge is 1,774 cfs. Based on more recent peak flow data for 1997-2001, the 5-year flood is only 1,373 cfs and the 25-year flood is only 1,508 cfs (Appendix C).

Transect 1 also crosses a small gravel bar on river right (facing downstream). This bar surface begins to be inundated at a discharge of 150 cfs and is completely inundated at flows of 300 cfs or greater (Figure 3.18). Flows equal to or greater than 300 cfs occur more than 60% of the time at Site 5, and flows are typically greater than 300 cfs throughout the growing season at this site. Similarly, Transect 2 crosses a cobble bar that is also inundated by flows between 150 and 300 cfs (Figure 3.18). No riparian vegetation currently grows on these bars.

Transect 3 also crosses a bare gravel bar surface; however, this surface extends to a slightly higher elevation above the channel thalweg and is not completely inundated until discharge equals 400 cfs (Figure 3.18). Discharges of 400 cfs or greater are equaled or exceeded more than 40% of the time at Site 5. Just up the bank from this gravel bar is a sloping "low floodplain" surface occupied by dense red osier dogwood and willow; this surface begins to be inundated by flows greater than 400 cfs and is completely inundated by flows of 1,500 cfs (Figure 3.18). The 2-year return interval flood

SITE 5





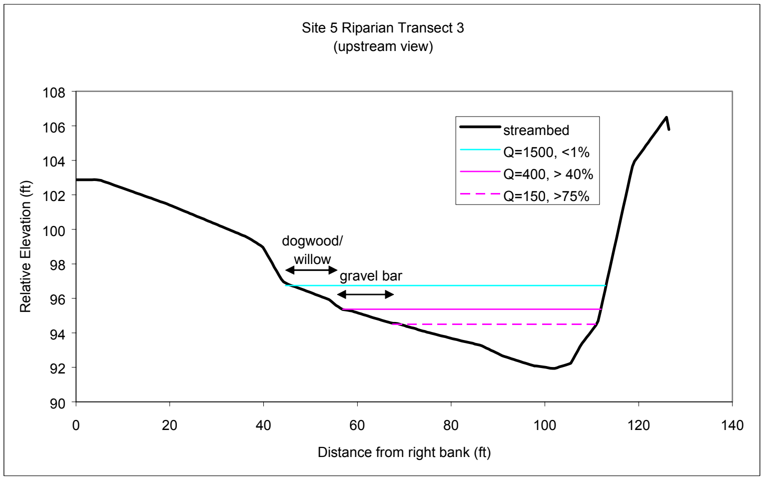


FIGURE 3.18. SITE 5 RIPARIAN TRANSECTS AND INUNDATION DISCHARGES (CFS). PERCENTAGES SHOWN IN LEGEND INDICATE THE PERCENT OF TIME A GIVEN DISCHARGE IS EQUALED OR EXCEEDED.

SITE 5

PLATE 3.3. PHOTOS OF SITE 5 RIPARIAN SURFACES. (A) STEEP LEVEED BANK WITH RIP RAP. (B) UPPER PART OF PHOTO SHOWS DOGWOOD-WILLOW "HIGH FLOODPLAIN" SURFACE CROSSED BY TRANSECT 1; FOREGROUND SHOWS COBBLE BAR CROSSED BY TRANSECT 2. (C) COBBLE BAR CROSSED BY TRANSECT 2. (D) UPSTREAM VIEW OF COBBLE BAR AND "LOW FLOODPLAIN" SURFACE CROSSED BY TRANSECT 3.

below Deer Creek Dam is 1,136 cfs, indicating that this "low floodplain" surface is partially inundated on a frequent basis.

3.2.5.2 COTTONWOOD RECRUITMENT POTENTIAL

As discussed in Section 1 of this report, almost no young cottonwoods or recently-recruited seedlings are present in Study Reaches 5 and 6, and no young cottonwoods were observed within Study Site 5. Successful recruitment of cottonwoods requires a specific combination and sequence of fluvial surfaces and hydrologic patterns, as described in the discussion of riparian vegetation for Site 6 above.

Under its existing geomorphic and hydrologic conditions, the Provo River within Site 5 is limited in its ability to meet these recruitment requirements. Because Deer Creek and Jordanelle Dams have reduced the frequency and magnitude of flooding, "high floodplain" surfaces such as the area crossed by Transect 1 are only rarely, and briefly, inundated. Because summertime flows are kept artificially high in order to deliver irrigation flows downstream, lower gravel bar surfaces are completely inundated throughout the growing season, preventing successful vegetation growth.

Despite these obstacles, opportunities may exist to provide flow releases designed to promote cottonwood recruitment within Provo Canyon. At Site 5, the high floodplain surface on river left (crossed by Transect 1) and the low floodplain on river right (crossed by Transect 3 may be potential surfaces for cottonwood establishment. However, existing scrub-shrub vegetation on both of these surfaces is quite dense, which makes the presence of barren fresh sediment for establishment (as per requirement 1 above) unlikely. Flood flows considerably greater than 1,500 cfs would be needed in order to scour the existing vegetation and create bare surfaces for establishment. Another alternative would be to mechanically remove the existing shrub vegetation. Even if the vegetation were removed, however, flows would need to exceed 1,500 cfs in order to inundate the high floodplain surface and allow for deposition of sediment, and these flows would need to occur at the same time as seed dispersal. Flows would not need to be as high to inundate the low floodplain surface. The existing mature cottonwood trees present within the Canyon should provide an adequate seed supply for dispersal by wind and water (meeting requirement 2 listed above).

Meeting requirement 3 listed above would likely be the most challenging aspect of providing successful cottonwood recruitment flows for the high floodplain surface. Published cottonwood root growth rates vary between 3mm/day to 10 mm/day (Mahoney and Rood 1998, Stomberg et al. 1999), and the alluvial water table decline must not exceed these rates or seedlings will die of dessication. In addition, maximum root growth during the first growing season is 1 m (3.3 ft). Using a maximum recession rate of 5mm/day (0.016 ft/day), flows would need to remain high for an extended period of time to prevent dessication of the high floodplain surface. Flow stage at Transect 1 at 1,500 cfs is 0.63 feet higher than the stage at 1,100 cfs. In order not to exceed a recession rate of 0.016 ft/day at this transect, flows would have to slowly be lowered over the course of 39 days. This is a longer period of high flow releases than typically occurs below Deer Creek Dam; however, such a flow release scenario may be possible to execute in wet years when surplus water exists.

Because the bank slope of the low floodplain at Transect 3 is flatter than that of the high floodplain at Transect 1, flows could drop more quickly without causing dessication of the low floodplain. At Transect 3, the water stage at 1,500 cfs is 0.11 feet higher than the stage at 1,100 cfs. Flows could be gradually lowered from 1,500 to 1,100 over 7 days without causing dessication at Transect 3. Even if this flow release scenario were followed, though, cottonwood recruitment at Site 5 would be unlikely unless the existing vegetation on the low floodplain were removed prior to high flows.

3.3 SITE 4

3.3.1 AQUATIC HABITAT - SITE 4

Figure 3.19 graphically depicts a calculated habitat (> 0.5 suitability - depth and velocity) for each niche at each respective flow. An evaluation of Figure 3.19 reveals that for certain habitat types (i.e. backwater/edge [niche 1] and slow/shallow [niche 2]), total habitat decreased as flow increased to approximately 150 cfs. For other habitat types such as moderate/mid-depth (niche 5) and fast/mid-depth (niche 6), total habitat increased as flow increased. When using this methodology for assessing flow-habitat relationships, the total habitat values are not designed to be precise, it is the trend that is important to understand. For Site 4, it is anticipated that the habitat types showing decreases at 150 cfs would continue to decline at higher flows unless overbanking occurred and additional areas were inundated. In contrast, habitat types increasing would likely increase to some pinnacle and subsequently decrease. Unfortunately, the range of flows evaluated for this reach were not sufficient to describe this apex. Additionally, the moderate/shallow (niche 3) and fast/shallow (niche 4) habitat showed virtually no change with flows in the sampled range. This re-enforces the complex nature of cascading reaches in that as flows increase, pocket water areas shift around and thus the same amount of moderate/shallow habitat is possible at 150 cfs as was present at approximately 40 cfs. The effects of greater flows on these shifting habitat types are unknown, but one might speculate that this shifting habitat function would only hold true to some critical flow at which habitat would start to decline. Finally, niches 7 and 8 (moderate/deep and fast/deep, respectively) did not provide any (> 0.5 suitability) habitat for this site at any surveyed flow.

In addition to evaluating each habitat niche with respect to flow, species specific criteria were applied for juvenile and adult brown trout. As shown in Figure 3.20, total habitat increases for both adult and juvenile brown trout as flows increases from approximately 40 to 150 cfs. As described above, a linear increase with flow would not be anticipated outside of the sampled range. The increase would likely continue until some pinnacle at which time a decline in habitat would likely be experienced. As a means of double checking the applicability of the habitat niche approach, the total habitat predicted for individual adult and juvenile brown trout were compared to the habitat niche (Niche 5 - moderate/mid-depth) that these brown trout life stages are placed in. The comparison shown in Figure 3.20 shows a tight relationship (Slopes = $R^2 \geq 0.95$) between the Niche 5 and adult and juvenile brown trout trends calculated with the aforementioned transect methodology for Site 4.

3.3.2 SEDIMENT TRANSPORT - SITE 4

Sediment transport sampling and modeling results for Site 4 are discussed together with the results from Site 3 in the section that follows.

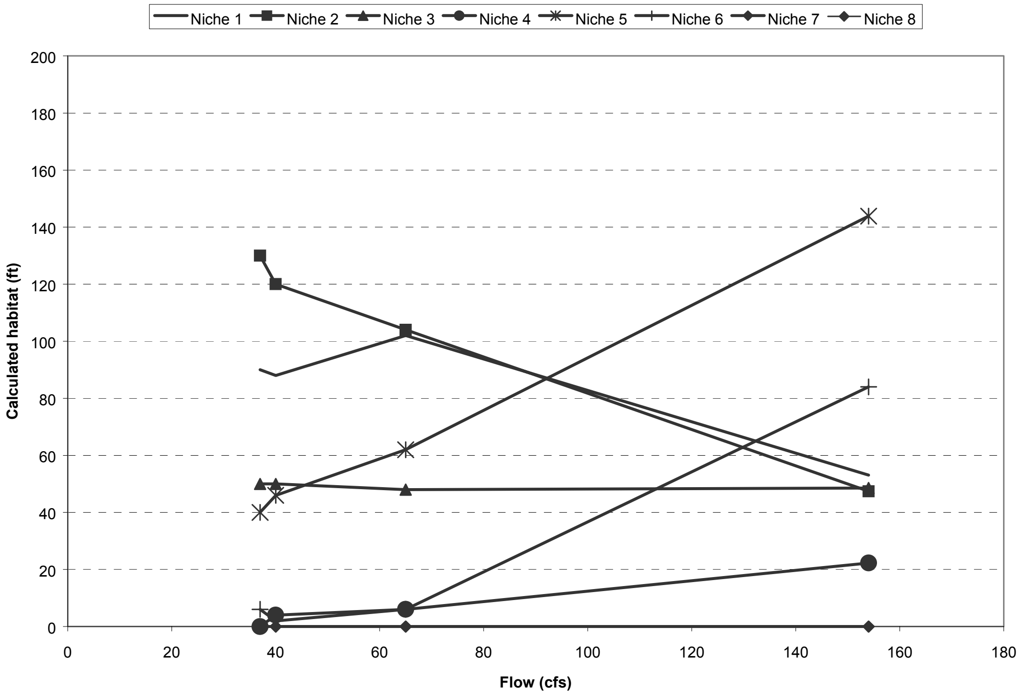


FIGURE 3.19. SITE 4: CALCULATED HABITAT VS. FLOW.

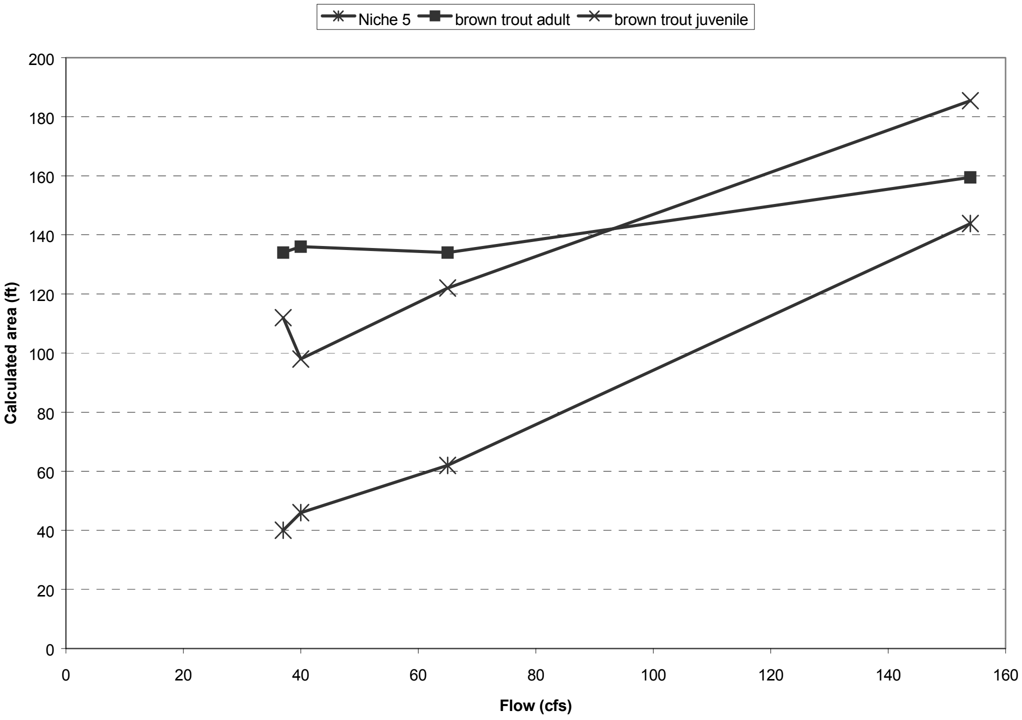


FIGURE 3.20. SITE 4: CALCULATED AREA VS. FLOW.

3.4 SITE 3

3.4.1 AQUATIC HABITAT - SITE 3

3.4.1.1 HABITAT NICHE MODELING

As with the other sites, a habitat niche approach was primarily used for assessing suitable habitat for Site 3. To represent habitat in entire channel stretch within Reach 3, Site 3 results were extrapolated based on the results of the channel reach mapping effort. As discussed in the methods, some interpretative caution should be used when viewing the results from either the intensive study sites alone or the extrapolated (reach) results. Due to the similarity in trends between the individual site (3) and the extrapolated reach, the results for the entire Reach 3 are discussed below.

Each WUA value calculated for Reach 3 represents the total amount of suitable habitat per 1,000 linear feet of stream. Figure 3.21 shows the WUA (ft^2/1,000 ft) for each niche per respective flow. The backwater/edge habitat (niche 1) is used by a majority of native fish species and larval stages of many fish. At approximately 10 cfs, Niche 1 habitat is represented by approximately 17,000ft^2/1,000ft but decreases to below 5,000ft^2/1,000ft before 25 cfs and remains low at higher flows. Routine fisheries data from UDWR and BYU fisheries assessments confirm that only rarely are native fishes collected in confined reaches in the Provo River. The slow/shallow habitat (niche 2) supports many juvenile and YOY species. This niche maintains over 26,000ft^2/1,000ft at approximately 25 cfs but drops below 10,000ft^2/1,000ft as quickly as 100 cfs before falling to below 5,000ft^2/1,000ft just past 200 cfs. Niches 2 (slow/shallow habitat) and 3 (moderate/shallow) overlap in supporting larval and juvenile life stages for certain species, but niche 3 is broader and includes certain adult species. Availability of niche 3 habitat is similar to niche 5 (moderate/mid-depth); both have peaks in WUA in the lower end of the flow range. Available niche 3 and niche 5 habitat increases until approximately 100 cfs with over 18,000 and 8,000ft^2/1,000ft, respectively. Habitat in both niches then decreases until dropping below 5,000ft^2/1,000ft at approximately 300 cfs. Niche 5 is the primary habitat type for the sportfish in the Provo River including all trout and mountain whitefish adults and juveniles. In this reach, niche 5 WUA in excess of 9,000ft^2/1,000ft is not reached, while flows ranging from approximately 40 to 200 cfs provide over 5,000ft^2/1,000ft of habitat. The fast/shallow habitat (niche 4), which provides suitable habitat for mountain sucker adults and mottled sculpin adults and juveniles, peaks at approximately 250 cfs (approx. 9,000ft^2/1,000ft) but decreases beyond that until WUA falls below 1,500ft^2/1,000ft at all flows higher than 500 cfs. The only species/lifestage documented in niche 6 habitat (fast/mid-depth) is the adult mountain sucker. Niche 6 habitat increases dramatically (> 30,000ft^2/1,000ft increase from 100 to 500 cfs) finally peaking at over 35,000ft^2/1,000ft near 600 cfs. Essentially no moderate/deep (niche 7) habitat is available at any flow for Reach 3; this habitat is preferred by adult mountain whitefish and adult Utah sucker. Although the fast/deep habitat (niche 8) does not directly relate to any fish species, it is included to describe how the habitat changes as flows increase; niche 8 increases steadily above 600 cfs but never exceeds 8,000ft^2/1,000ft.

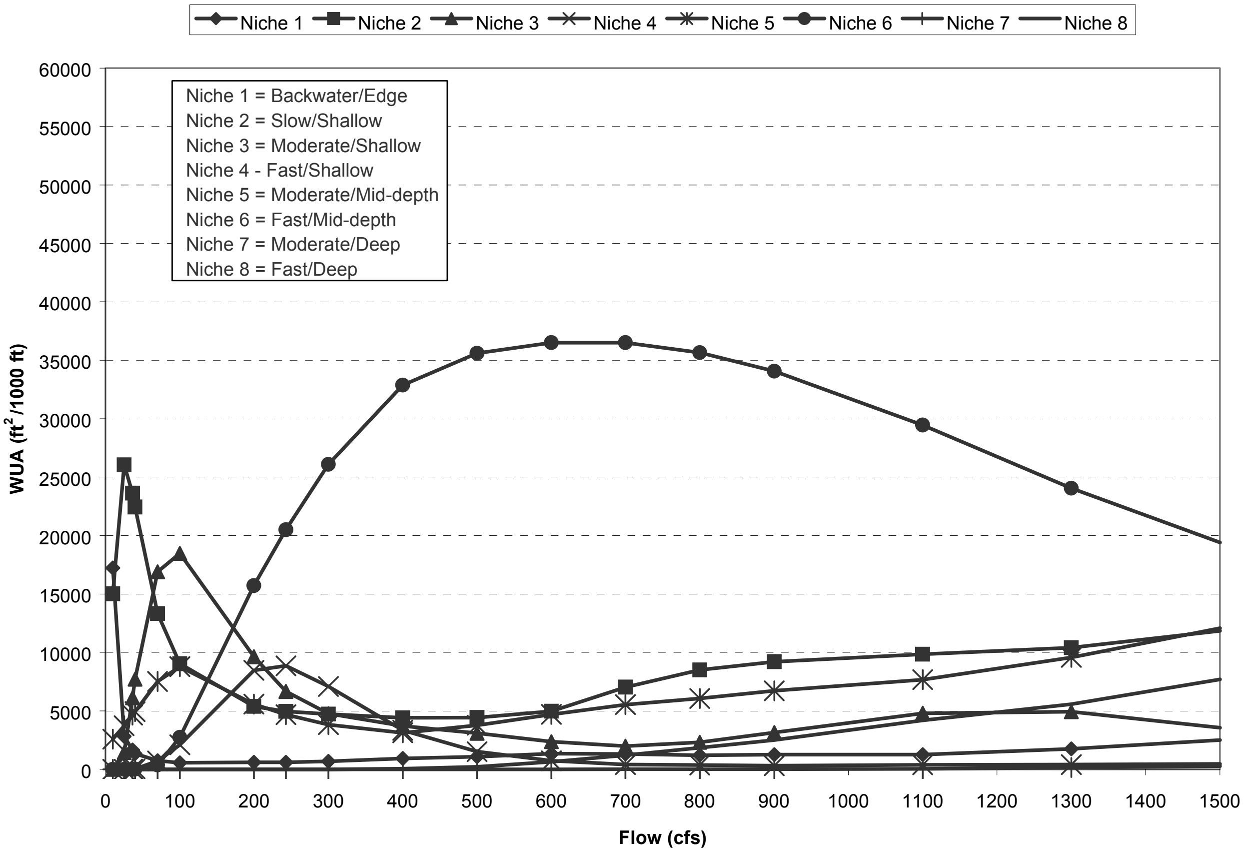
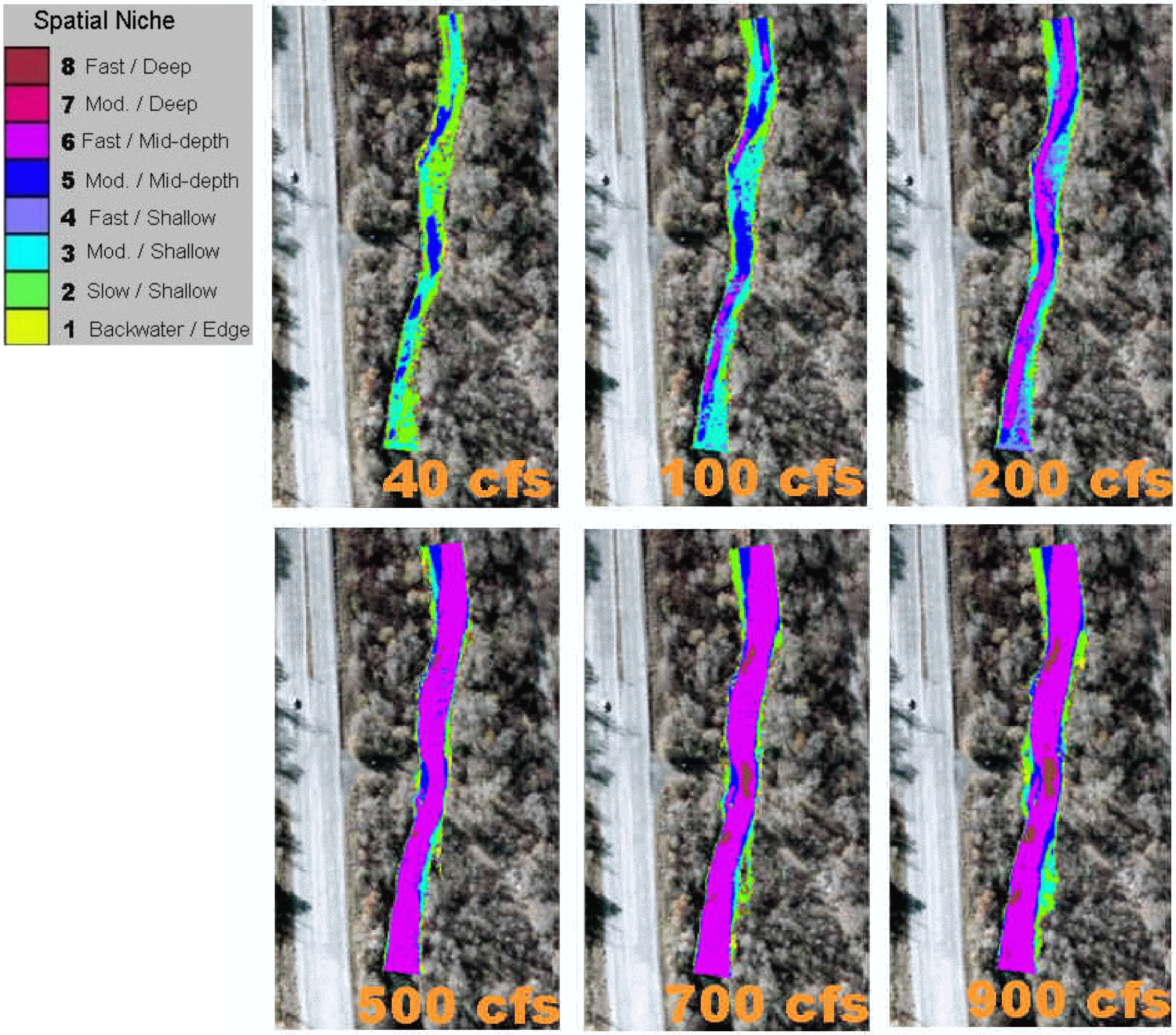


FIGURE 3.21. REACH 3: HABITAT NICHES - WUA VS. FLOW.

An examination of Image 3.5 and Figure 3.21 reveal that at 100 cfs, Reach 3 provides greater than 8,500ft^2/1,000ft of niche 2, 3, and 5 habitat whereas niche 6 habitat dominates at 500 cfs. Figure 3.21 and the images also reveal that flows greater than 500 cfs equate to steady increases in WUA for most all niches. This is a function of overbanking that occurs along this reach at higher flows (most evident at the bottom right of the image for 900 cfs). Overall, the results of the habitat niche modeling at this site support the biological data that very few species other than trout and mottled sculpin have been collected in this reach. The lack of backwater/edge habitat and rapid decrease in slow/shallow habitat probably limits the success of native fishes and juveniles of other species. The niche approach separates suitable habitat for brown trout from the backwater/edge habitat that is suitable for many native species and juveniles and YOY of most species; however, the abundance of brown trout and potential threat of predation may have an influence on the presence and/or abundance of some of those species in this reach.

Image 3.5. Habitat Niches - Weighted Usable Area (Site 3). The images below visually depict habitat niches that are present at discharges of 40, 100, 200, 500, 700, and 900 cfs. Each habitat niche is represented by the color immediately adjacent the number/description in the legend. For example, Niche 6 = magenta, Niche 5 = blue, Niche 1 = light yellow, etc.



3.4.1.2 HSI CURVE MODELING

An examination of the individual HSI curves for brown trout and "all trout" reveal similar trends with those observed above for niche 5. Figure 3.22 shows the WUA (ft^2/1,000 ft) for each trout species/lifestage per respective flow. As in previous reaches, the brown trout adult curve was used to assess habitat availability for all trout species. For adult trout, WUA was greater than 10,000ft^2/1,000ft between approximately 10 and 150 cfs. Although exhibiting different habitat amounts, the juvenile "all trout" and brown trout curves reveal a similar trend with the highest WUA between 10 and 150 cfs. As with the niche modeling, Figure 3.22 also reveals that flows greater than 500 cfs equate with increases in WUA for trout life stages.

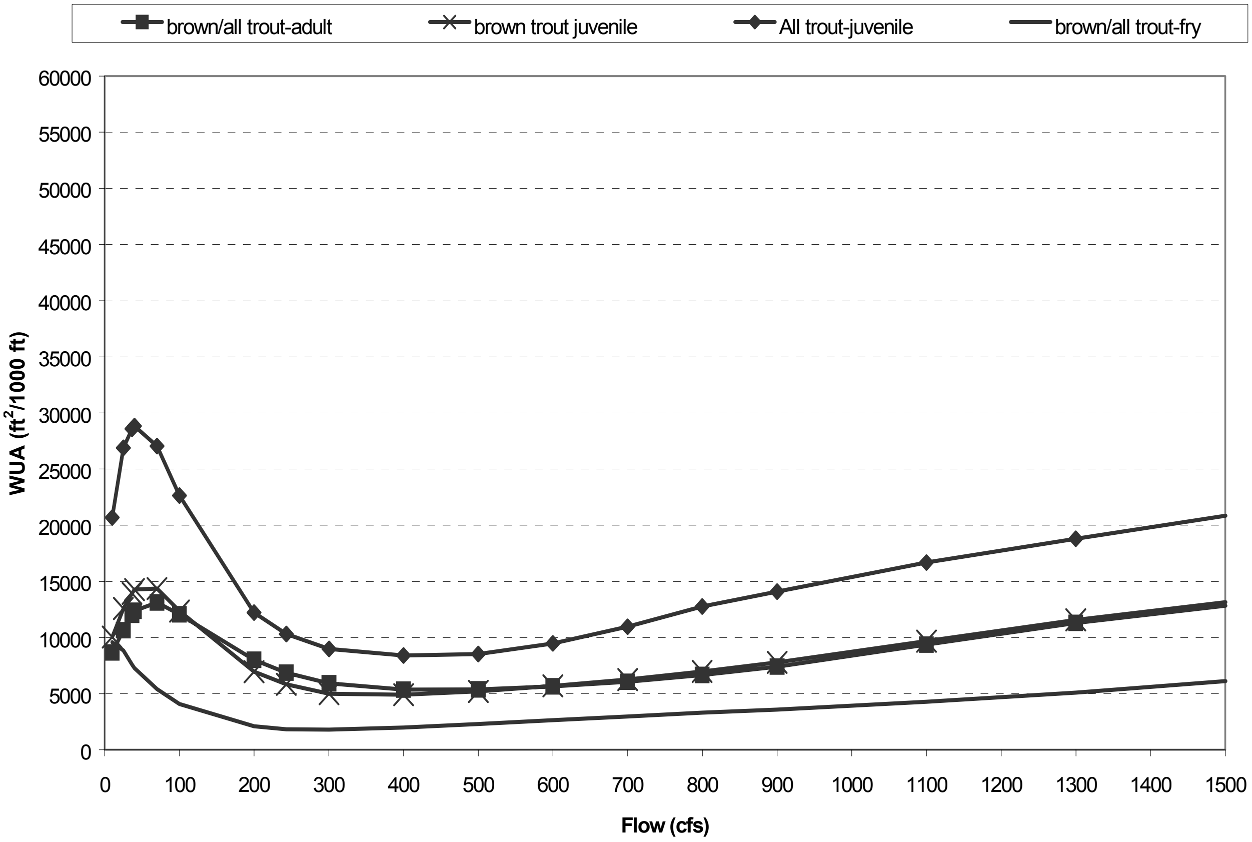


FIGURE 3.22. REACH 3: TROUT - WUA VS. FLOW.

As shown in Image 3.6 and presented in Figure 3.22, adult brown trout habitat at 100 cfs is available in this reach whereas increasing flows quickly reduce the amount of WUA within the main channel leaving the majority of WUA along the edge or overbank areas.

IMAGE 3.6. ADULT BROWN TROUT - WEIGHTED USABLE AREA (SITE 3). THE IMAGES BELOW VISUALLY DEPICT SUITABLE HABITAT AVAILABLE TO ADULT BROWN TROUT AT DISCHARGES OF 40, 100, 200, 500, 700, AND 900 CFS. THE BEST HABITAT IS REPRESENTED BY SUITABILITY OF 1.0 (BLUE) AND NO HABITAT IS REPRESENTED BY 0 (RED).

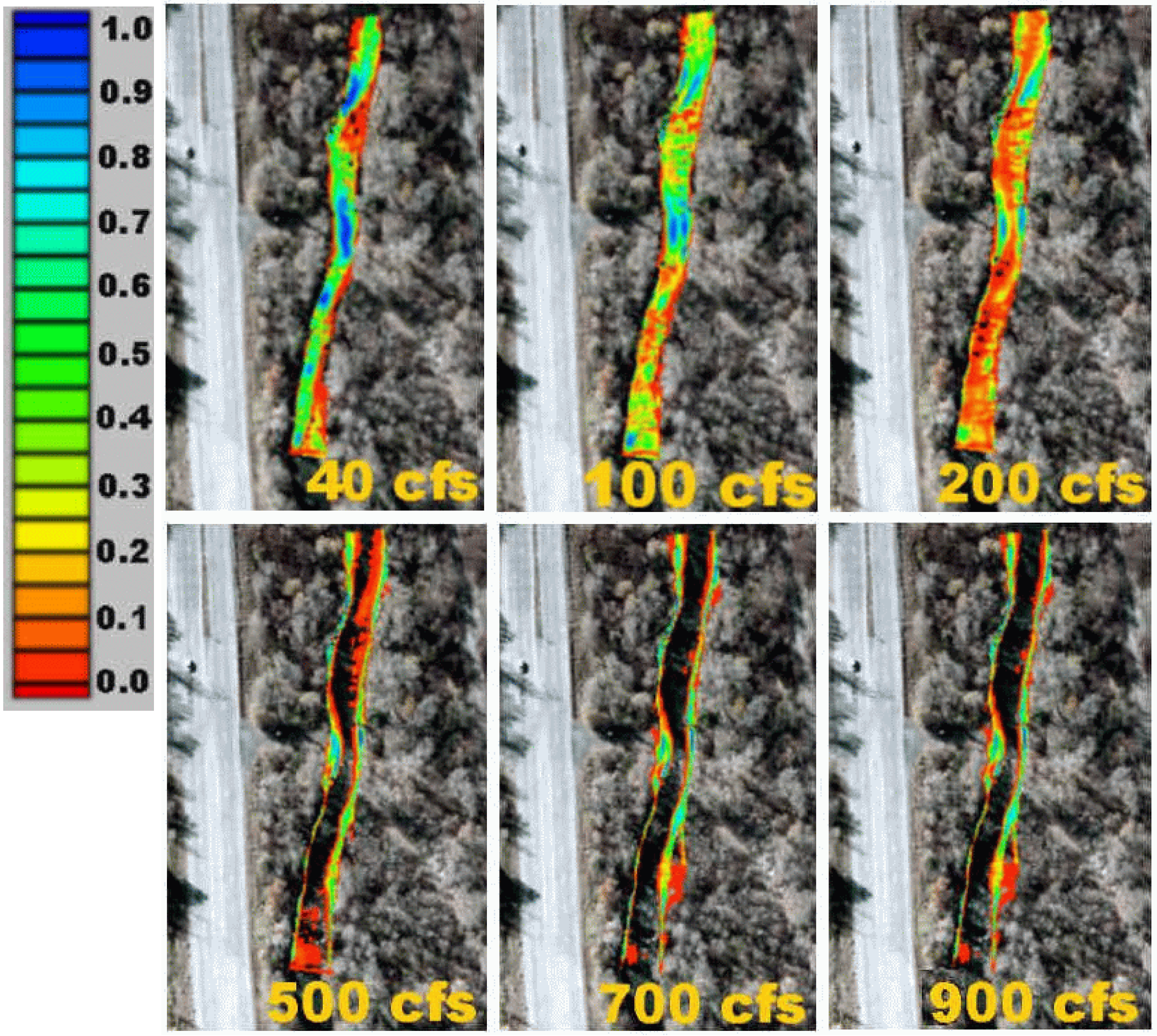


Figure 3.22 reveals that habitat for fry is nearly 10,000ft^2/1,000ft at 10 cfs then quickly declining to below 5,000ft^2/1,000ft around 100 cfs. Based on field observations and temperature data, Wiley and Thompson (1996) estimated that in 1996, brown trout eggs should have hatched the second week in April and emerged from the substrate approximately the third week in May. However, the high flows present during this time period in 1996 prohibited attempts to verify hatching, swimup or monitor survival (Wiley and Thompson 1996). Wiley and Thompson (1996) made the observation that high flows during late April and early May may be detrimental to emerging brown trout fry by perhaps flushing them downstream. This study documents that the optimal range for fry habitat in Reach 3 is approximately 10 to 70 cfs. As flow increases, trout fry habitat is reduced. This supports Wiley and Thompson's observations that fry habitat is lost during high flow spring conditions. However, the recruitment of brown trout throughout the Provo River remains strong which is counter to this detrimental effects hypothesis. As for cutthroat and rainbow trout, fry emergence is later in the spring/summer; however, continued increased flows may have impacts on their success as well.

An evaluation of the existing data on spawning criteria revealed that although the brown trout curves encompassed the depth and velocity criteria for rainbow and cutthroat trout, the depth and velocities required for the latter two species differed to a degree where an examination of individual curves versus the "all trout" curve was warranted. As substrate requirements were very similar, it turned out that the requirement for lesser depths and velocities for rainbow trout and lesser yet (depths and velocities) for cutthroat trout resulted in less spawning habitat available (Figure 3.23) There is approximately 27,000ft^2/1,000ft of brown trout spawning habitat at the peak of approximately 40 cfs but is maintained at greater than 15,000ft^2/1,000ft to approximately 200 cfs. Rainbow trout spawning habitat follows the same trend but demonstrates considerably less WUA (< 8,500ft^2/1,000ft at all flows). According to Wiley and Thompson (1996), brown trout spawning occurs in early to mid-November. As demonstrated by Wiley and Thompson (1996) and again by the results of this study, lower flows provide more WUA for brown trout spawning. Wiley and Thompson (1996) modeled sites below Olmsted Diversion and concluded that 26 cfs was the optimum flow for brown trout spawning in that reach. The results of this study suggest that flows ranging from approximately 15 to 200 cfs are optimal in Reach 3. Brown trout spawn in the fall when flows are significantly lower than during spring and early summer when rainbow and the native cutthroat trout spawn. Rainbow and cutthroat trout appear to require similar substrate conditions as brown trout, but more restrictive depth and velocity requirements to spawn; therefore, flows in this reach of the Provo River may be unsuitable for spawning during the late spring and early summer. As evident in Figure 3.23, WUA for spawning cutthroat trout is cut by nearly 80% from 25 cfs to 70 cfs and continues to stay below 3,500ft^2/1,000ft at all higher flows. Thus, the timing of spawning and less WUA for spawning at any flow level puts rainbow and native cutthroat trout at a substantial disadvantage to brown trout.

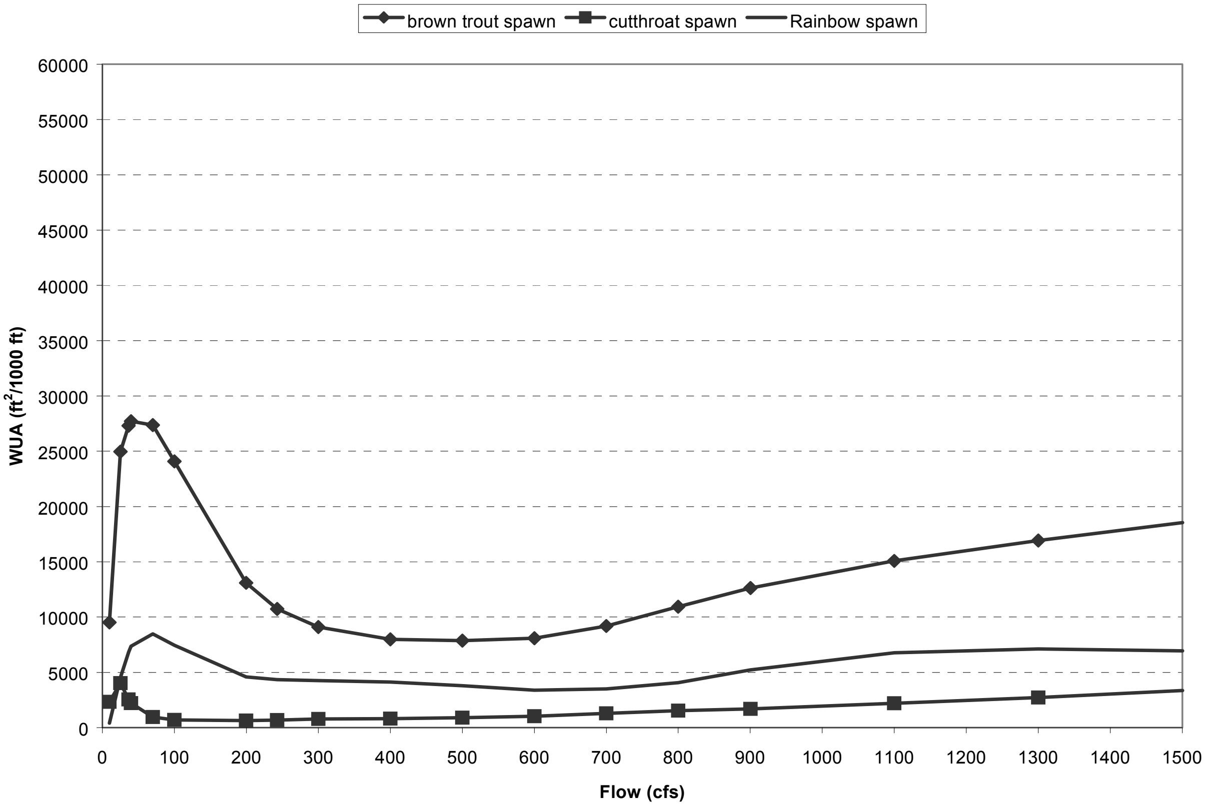


FIGURE 3.23. REACH 3: TROUT SPAWNING - WUA VS. FLOW.

3.4.2 WATER TEMPERATURE - SITE 3

For this study, a thermistor was placed at Site 3 between April 27 and August 16, 2002. The following mean temperatures were observed during the study period.

April (27 - 30)	8.5°C
May (excluding 22 - 23)*	9.0°C
June	11.7°C
July	14.0°C
August (1 - 16)	15.0°C

*- flows dropped to a level where the thermistor was exposed

The lack of a representative USGS flow gage near this site disallowed the comparison of temperature with flow. However, an evaluation of the temperature data reveals that, similar to the other sites, temperature remains fairly constant with higher flow releases and greater diurnal variation occurs during lower flow conditions. As in the other reaches, temperature changes and diurnal fluctuations may be very important in understanding the macroinvertebrate assemblages (see

Macroinvertebrate Case Studies in Section 4 of this report) and recruitment success of fishes in Reach 3 of the Provo River.

3.4.3 RECREATIONAL USABILITY - SITE 3

3.4.3.1 *WADING/FISHING*

The wading/fishing WUAs calculated for Reach 3 represent the total amount of suitable "habitat" (area) per 1,000 linear feet for the entire reach (Figure 3.24). At 40 cfs, approximately 37,000ft^2/1,000ft of fishing/wading area is provided for recreationists. At flows greater than 150 cfs, fishing/wading area within this reach is reduced to below 25,000ft^2/1,000ft.

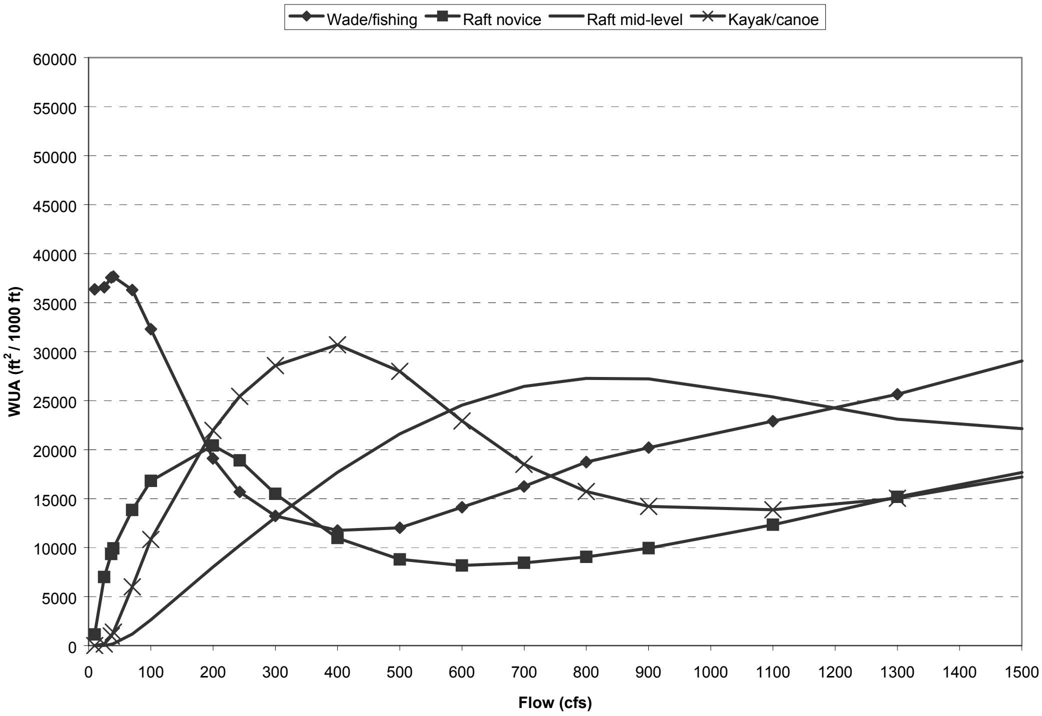


FIGURE 3.24. REACH 3: RECREATION - WUA VS. FLOW.

3.4.3.2 *BOATING*

Figure 3.24 displays the Reach 3 boating WUA (ft^2/1,000ft) for novice rafting, mid-level rafting, and canoeing/kayaking. The amount of WUA for canoeing/kayaking increases rapidly as flows increase (> 20,000ft^2/1,000ft increase from 100 to 500 cfs). The peak at approximately 30,000ft^2/1,000ft and subsequent tapering off effect at flows greater than 400 cfs is a result of a conservative classification that includes safety concerns for both canoes and kayaks. It is recognized that experienced kayakers would welcome the challenge of even higher flows. Reach 3 provides more than 15,000ft^2/1,000ft for novice rafters at a flow range of approximately 100 to 300 cfs, and for mid-level rafters greater than 15,000ft^2/1,000ft is provided at flows greater than 300 cfs.

3.4.4 SEDIMENT TRANSPORT - SITES 3 AND 4

3.4.4.1 SAMPLING RESULTS

The results of the bedload sampling at Bridges 3 and 4 are fairly similar to the results at Bridge 5-6 for flows less than 800 cfs (Figure 3.25, Plates 3.4 and 3.5). The material in transport was dominated by mostly sand-sized particles. Peak flows were much lower in Reaches 3 and 4 due to upstream water diversions at Olmsted. The size distribution of the material in transport at Bridges 4 and 3 did not change noticeably during the sampling period. It appears that bed material was simply "winnowing" fine particles around the stable larger particles and the "equal mobility" phase of bedload transport did not occur at these sites for the sampled flows.

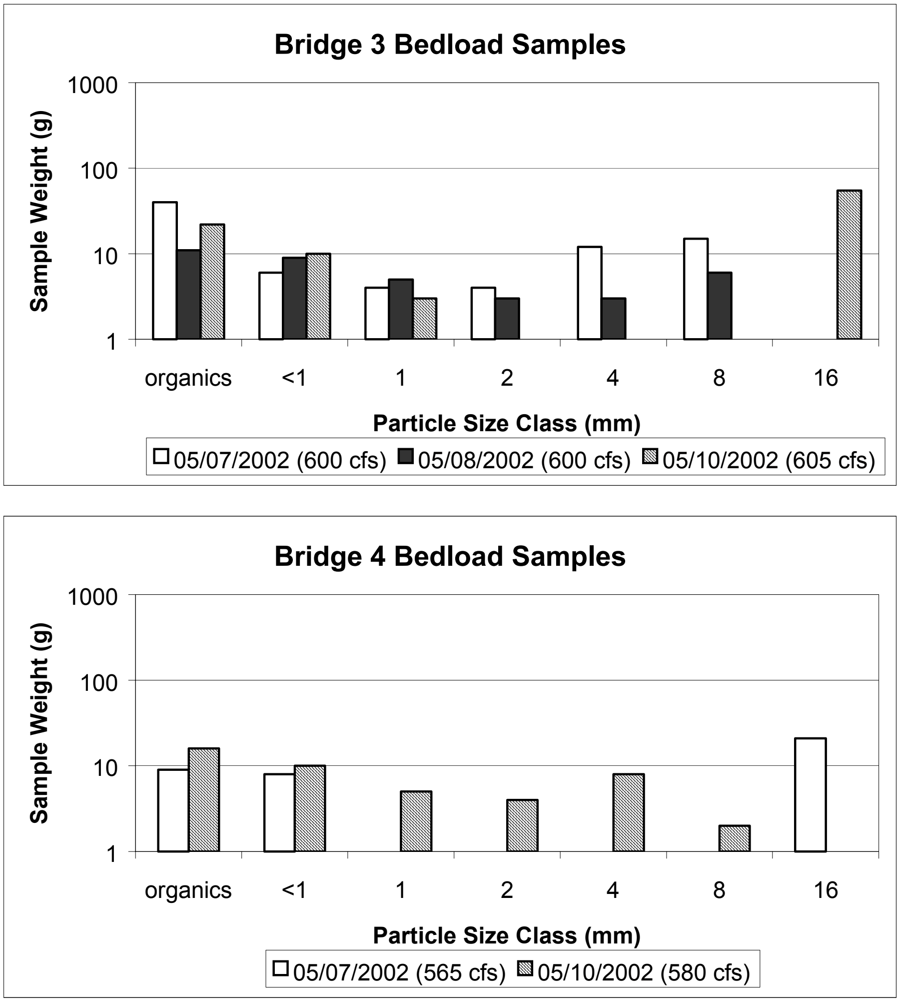


FIGURE 3.25. BEDLOAD SAMPLING RESULTS FOR BRIDGES 3 AND 4 BROKEN INTO SIZE CLASSES.

565 cfs

600 cfs

580 cfs

PLATE 3.4. PHOTOGRAPHS OF SITE 4 BEDLOAD SAMPLES COLLECTED DURING 2002 SPRING RUNOFF.

3.4.4.2 MODELING RESULTS

There are some fundamental geomorphic differences between Reaches 3 and 4 that were considered in modeling sediment transport. First, Reach 4 is much steeper than Reach 3. In addition, Reach 4 runs adjacent to steep side hills and is cluttered with large boulders resulting in a step-pool cascading profile. Despite these differences, the results of bedload sampling at Bridges 4 and 3 indicate that similar sized particles were in transport, at least during the winnowing stages. Because of this similarity, Sites 4 and 3 were combined for bedload modeling purposes. Figure 3.26 shows the particle size distribution of streambed material at the bedload modeling cross-section within each Study Site and Table 3.2 shows important fractions of the streambed particle size distribution compared to the largest particle captured during bedload sampling.

Site 3

600 cfs

600 cfs

605 cfs

Plate 3.5. Photographs of Site 3 Bedload Samples Collected During 2002 Spring Runoff.

Table 3.2. Important Fractions of Sites 3 and 4 Streambed Particle Size Distributions and largest particles Captured During Bedload Sampling at Bridges 3 and 4.[A]

Site	D16	D25	D50	D75	D84	Maximum Size in Transport
3	20	50	145	230	265	29
4	37	52	180	320	408	16

[A] The size of particles are measured in mm along the b-axis.

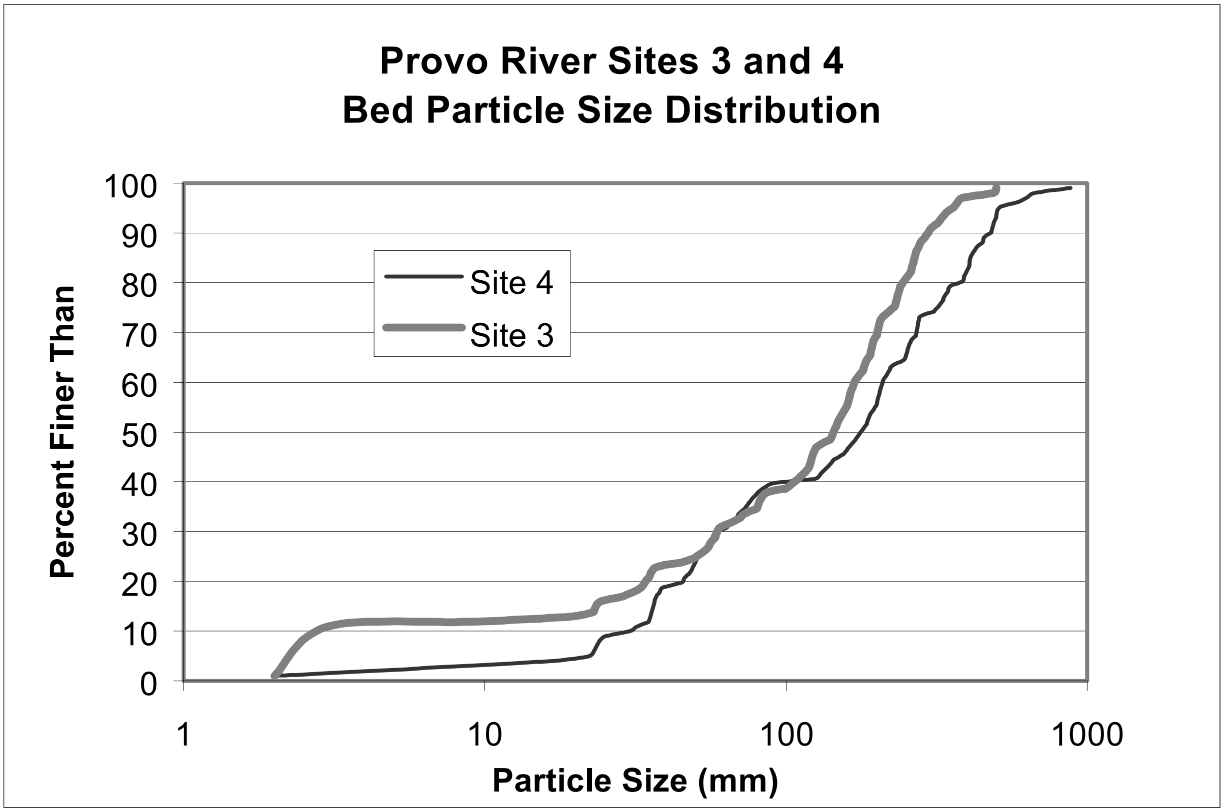


FIGURE 3.26. THE PARTICLE SIZE DISTRIBUTIONS OF BEDLOAD MODELING CROSS-SECTIONS AT SITES 3 AND 4.

Sites 3 and 4 are located below Olmsted Diversion which is a large structure that essentially traps all bedload sediment generated from the upstream reaches (Reaches 5 and 6). Streambed armoring is not as severe as might be expected in Sites 3 and 4 due to the fact that this is a narrow part of Provo Canyon with many local sediment sources such as adjacent side hills and small tributaries. The streambed of Provo River through Sites 3 and 4 is only moderately armored similar to Sites 5 and 6, which also have local sediment sources in the form of large tributaries and eroding side hills.

The D_{50} sized particles at Sites 3 and 4 (145 to 180 mm in size) are predicted to remain in-place at flows up to 2,000 cfs based on the Meyer-Peter Muller equation ($\tau^* = 0.047$). Immobility of the D_{50} is likely due to the somewhat armored conditions below Olmsted Diversion. Therefore, the Site 3 D_{25} (particle 50 mm in size) was used to model bedload transport at Sites 3 and 4.

The bedload rating curve for Sites 3 and 4 is shown in Figure 3.27. This graph shows that bedload begins to move at approximately 300 cfs, which is at lower flows than Sites 5 and 6. The channel

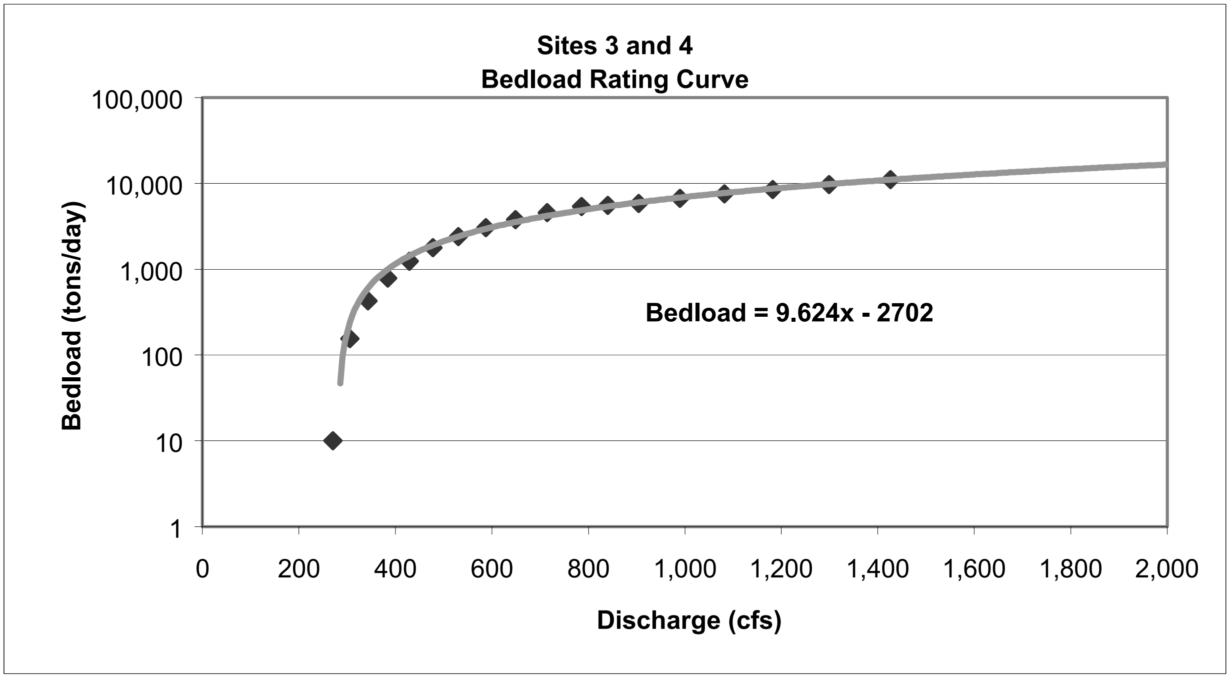


FIGURE 3.27. THE BEDLOAD RATING CURVE FOR SITES 3 AND 4 BASED ON THE D_{25} OF THE EXISTING STREAMBED (PARTICLE 50 MM IN DIAMETER). THIS GRAPH SHOWS THAT BEDLOAD STARTS MOVING AT APPROXIMATELY 300 CFS AND INCREASES AS FLOWS INCREASE.

is noticeably smaller/narrower below Olmsted Diversion, probably resulting from diversion withdrawals, and likely has a lower effective discharge than Sites 5 and 6. The channel is also steeper than above Olmsted, causing higher shear stress levels at lower discharges.

The empirically derived suspended sediment transport rates (Figure 3.9) are much lower than the modeled bedload rates within Sites 3 and 4, except at flows below 300 cfs when no bedload is in motion. Once bedload transport is initiated, bedload rates increase rapidly and surpass suspended sediment transport rates at all flows greater than 300 cfs. Figures 3.9 and 3.27, along with the bedload sampling results, demonstrate that sedimentation of fine grained particles may occur within riffles at Sites 3 and 4 if spring peaks only initiate fine grained sediment transport and do not last long enough to initiate the equal mobility phase.

A comparison of sediment transport, in terms of effective discharge, timing, magnitude, and duration could not be made at this time because of limited flow data available for these Sites. It is important to note that the bedload rating curve is steeper for Sites 3 and 4 than for Sites 5 and 6, indicating greater sediment loads than Sites 5 and 6 at the same flows. However, the flows will likely always be lower below Olmsted Diversion due to withdrawals. If adequate daily flow data were available, an analysis of alternative flow regimes would be made using the same techniques as at Sites 5 and 6.

3.4.5 RIPARIAN VEGETATION - SITE 3

As with the previous sites, riparian vegetation width at Site 3 is constrained by levees built to protect the highway on the south side of the stream and the Provo Canyon Trail on the north side. Although channel straightening and the presence of the levees has limited the ability of the channel to meander and develop bars and floodplain surfaces, the low-flow channel within Site 3 does meander slightly, and vegetated floodplain areas are present on the insides of the bends (Map 3.3). On the outer sides of these subtle bends, banks are typically vertical, and dense shrub vegetation grows on the top of these banks (Plate 3.6).

3.4.5.1 TRANSECT RESULTS

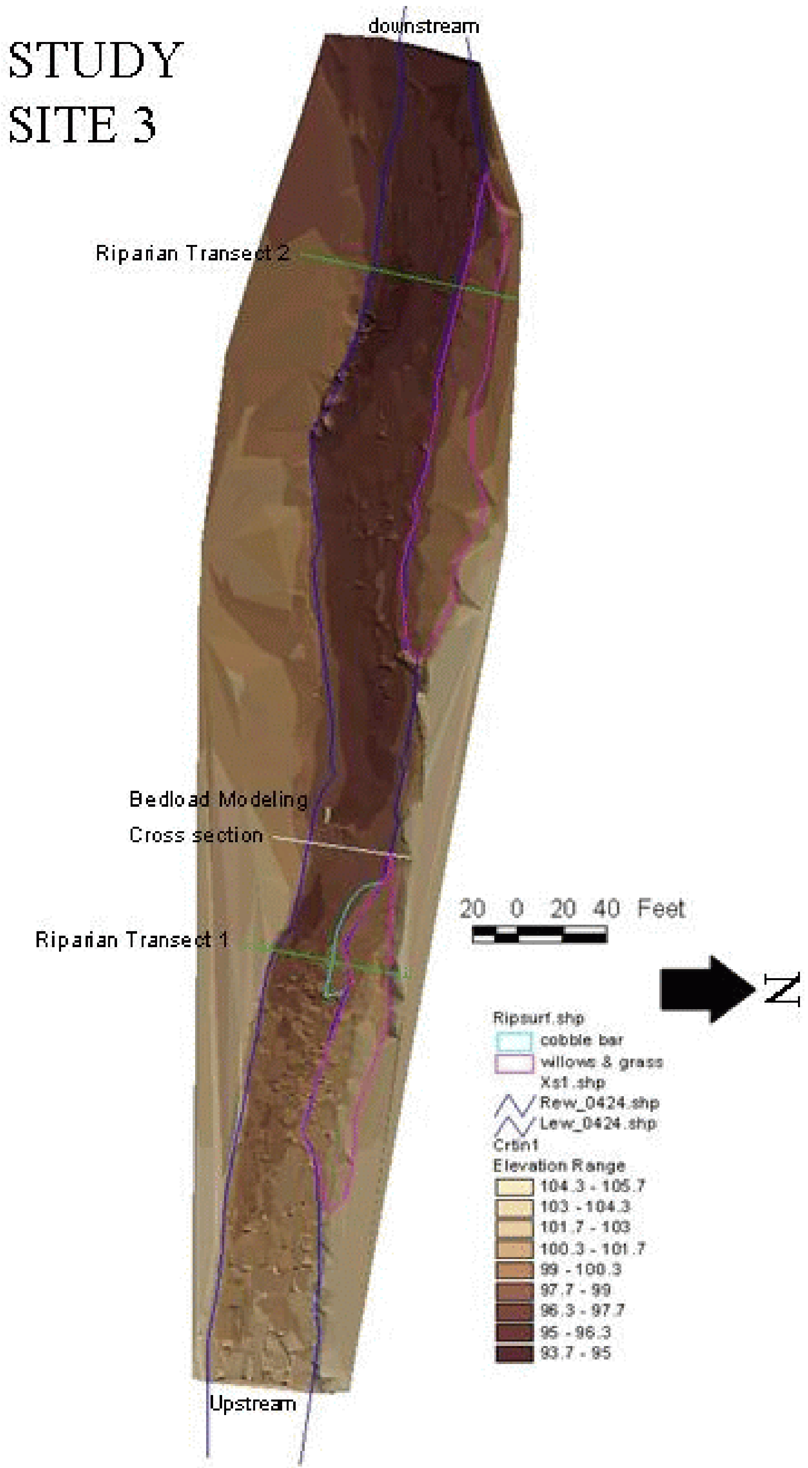
Within Site 3, two transects spanning riparian establishment surfaces were selected to evaluate the relationships between streamflow and riparian characteristics (Map 3.3). These transects are plotted in Figure 3.28 along with the range of flows that inundate the different establishment surfaces.

Transect 1 crosses a willow and grass-covered floodplain surface on river right (facing downstream, Plate 3.6, Figure 3.28). The left edge of this surface, which is dominated by grass vegetation, begins to be inundated by flows of 40 cfs and greater. The upper portion of the surface, which consists of willow and grass vegetation, is inundated by flows between about 200-400 cfs (Figure 3.28). Shrub and tree vegetation, including young cottonwoods, occupies the steep leveed right bank at Transect 1. Flows above 400 cfs begin to inundate this bank area.

Transect 2 crosses a similar willow and grass-covered floodplain surface on river right (Plate 3.6). This surface begins to be inundated by flows above about 243 cfs and is completely inundated by flows of 900 cfs (Figure 3.28). On both banks, mixed tree and shrub vegetation occupies areas above the 900 cfs inundation level.

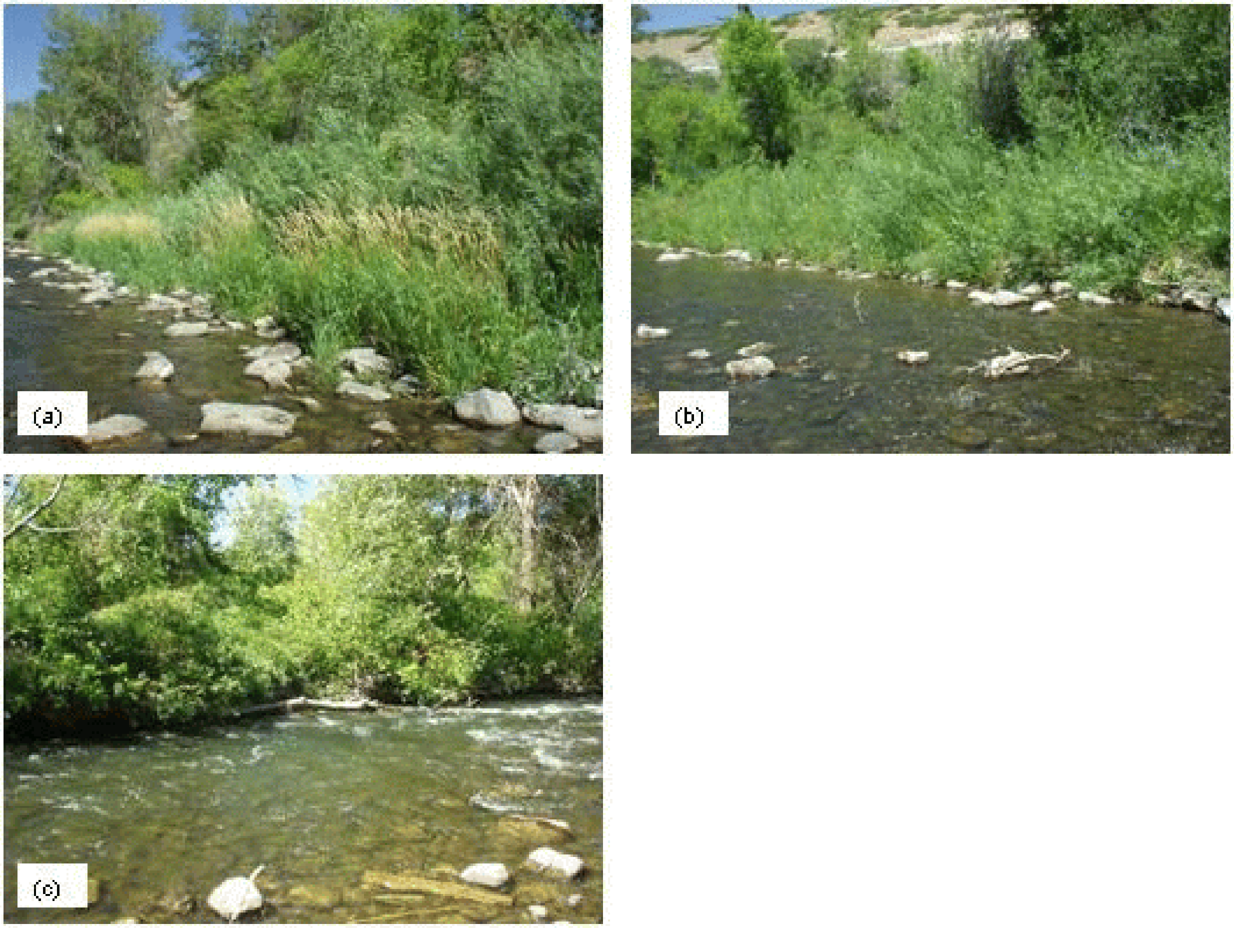
Because no USGS streamflow gage is located near Site 3, a complete hydrologic data set with which to develop flow duration and flood frequency information is not readily available. However, an incomplete set of average daily flows is available for the period 1998-2002, and these data are adequate to illustrate that the influence of Olmsted Diversion creates a hydrologic regime that is significantly different from the regime at Sites (and reaches) 5 and 6 (Appendix C). More specifically, because power plant delivery flows are diverted upstream from Site 3, summertime flows are much lower (typically 30-40 cfs) than in the reaches above Olmsted Diversion (typically 300-400 cfs). The other main difference is that flood peaks are lower below Olmsted.

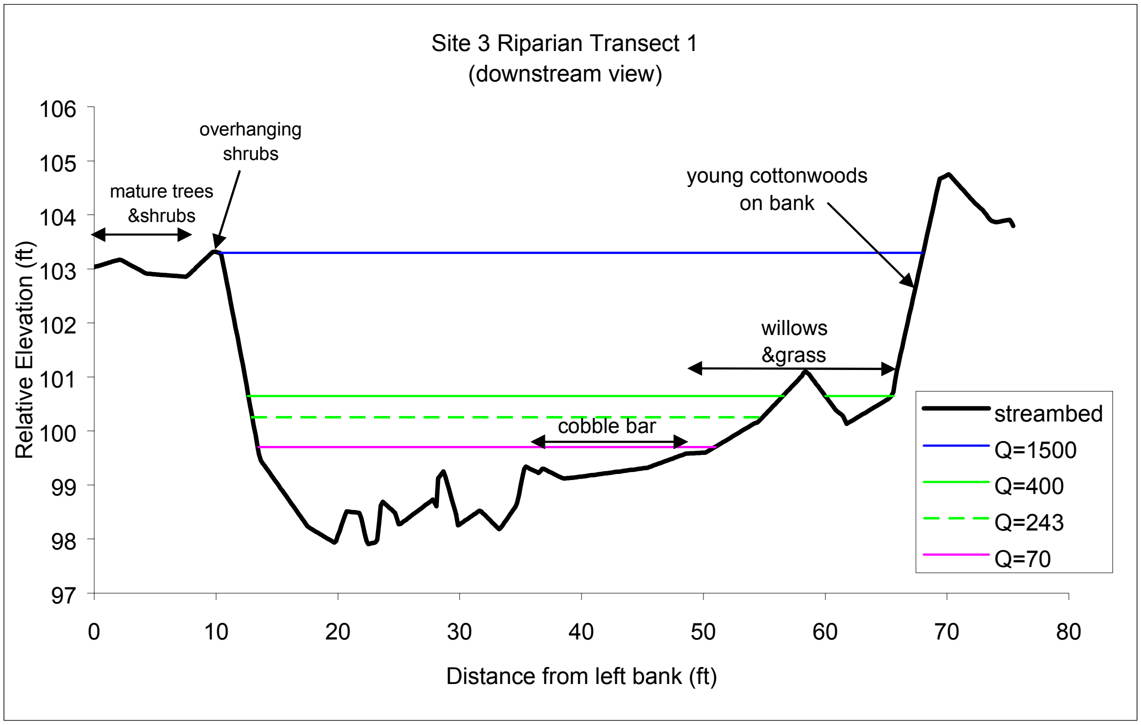
SITE 3



MAP 3.3. MAP OF STUDY SITE 3 SHOWING RIPARIAN TRANSECT AND BEDLOAD MODELING CROSS SECTION LOCATIONS. DARK BLUE LINES INDICATE WATER'S EDGE AT LOW FLOW.

PLATE 3.6. PHOTOS OF SITE 3 RIPARIAN SURFACES. (A) AND (B): WILLOW AND GRASS-DOMINATED FLOODPLAIN SURFACES PRESENT ON RIVER RIGHT AT TRANSECTS 1 AND 2, RESPECTIVELY. (C) OVERHANGING SHRUB VEGETATION GROWING ON VERTICAL LEFT BANK AT TRANSECT 1; LEFT BANK VEGETATION AT TRANSECT 2 IS SIMILAR.





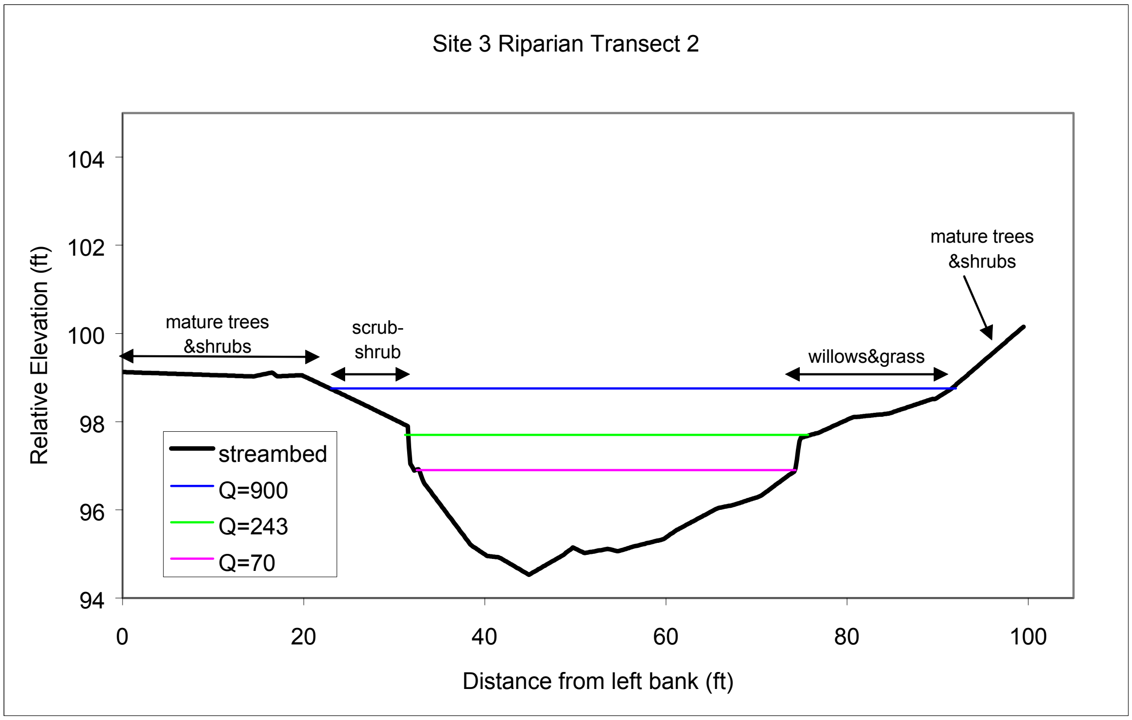


FIGURE 3.28. SITE 3 RIPARIAN TRANSECTS AND INUNDATION DISCHARGES (CFS).

These differences in hydrology result in differences in the streamflow-riparian surface relationships at the different sites. The lower, more natural flow levels that occur during the growing season at Site 3 allow for more extensive riparian vegetation growth on lower-elevation surfaces: at Site 3, vegetation extends down to the 40 cfs flow level, whereas at Sites 5 and 6, no vegetation grows below the 300-400 cfs flow level.

3.4.5.2 COTTONWOOD RECRUITMENT POTENTIAL

Unlike Sites 6 and 5, Site 3 does show evidence of recent cottonwood recruitment, although recruitment is not spatially extensive. Several small patches of young cottonwood trees and seedlings are evident within the site. Because the young cottonwoods are located on steep banks, it is difficult to identify the specific flow range associated with this vegetation type; however, based on Transect 1 results, it appears that recruitment is occurring at elevations above the 400 cfs flow level.

Although recruitment is occurring at Site 3, its extent is limited by some of the same factors that prohibit successful recruitment at the upstream Canyon sites. Cottonwoods generally have a lower inundation tolerance than willows, and therefore occupy higher positions relative to the channel (Amlin and Rood 2001). Because the levees at Site 3 artificially clip the horizontal extent of "high" floodplain surfaces, the total area of surfaces at appropriate elevations is limited. In addition, the levees have steep slopes, causing water levels to drop more rapidly with flow, increasing the risk of seedling dessication. And although the hydrologic regime at Site 3 does allow for some cottonwood recruitment and has more natural low flow characteristics than the regime at Sites 5 and 6, its flood flow characteristics are not ideal for recruitment. The frequency and magnitude of floods that would scour existing vegetation and create fresh sediment deposits has been significantly reduced, as has the duration of flood flows. At the Hailstone gage above Jordanelle Dam where flows are not dam-regulated, springtime flows commonly remain elevated above 600 cfs for 1.5 to 2 months or longer, whereas the duration of high spring flows at the sites below Deer Creek is typically 1 month or less (Figure 1.2, Appendix C). The rapid hydrograph recession rate makes seedlings more prone to dessication and reduces recruitment success.

Therefore, as with Sites 6 and 5, lowering high springtime flow releases more gradually would increase the probability of cottonwood recruitment success at Site 3. This may be possible in wet years when surplus water is available. In addition, mechanically re-configuring the upper levee bank at Site 3 to reduce its slope would enable water levels to decrease more slowly as flows recede. This may be possible in some locations along the north side of Site 3, where the paved Provo Canyon Trail is set back by several hundred yards and the existing steep levee bank does not protect any developed infrastructure.

3.5 SITE 2

3.5.1 AQUATIC HABITAT - SITE 2

3.5.1.1 HABITAT NICHE MODELING

A habitat niche approach was used along with individual species/life stage HSI for assessing suitable habitat for Site 2. To represent habitat in entire river reaches, Site 2 results from the channel reach-scale habitat mapping were extrapolated to all of Reach 2. As discussed in the methods, some interpretative caution should be used when viewing the results from either the intensive study sites alone or the extrapolated (reach) results. Due to the similarity in trends between the individual site (2) and the extrapolated reach, the results for the entire Reach 2 are discussed below.

Each WUA value calculated for Reach 2 represents the total amount of suitable habitat per 1,000 linear feet of stream. Figure 3.29 shows the WUA (ft^2/1,000ft) for each niche per respective flow. The backwater/edge habitat (niche 1) is used by a majority of native fish species and larval stages of many fish. At 10 cfs, greater than 5,000ft^2/1,000ft of Niche 1 habitat exists; it decreases rapidly (< 2,000ft^2/1,000ft) near 25 cfs and remains below that amount for the remainder of flows. Routine fisheries data from UDWR and BYU fisheries assessments confirm that only rarely are native fishes collected in confined reaches in the Provo River. The slow/shallow habitat (niche 2) supports many juvenile and YOY species. This niche maintains greater than 25,000ft^2/1,000ft at approximately 25 cfs but decreases rapidly (> 20,000ft^2/1,000ft decline) as flows exceed 150 cfs and stays below 5,000ft^2/1,000ft for all subsequent flows. Niches 2 (slow/shallow habitat) and 3 (moderate/shallow) overlap in supporting larval and juvenile life stages for certain species, but niche 3 is broader and includes certain adult species. Availability of niche 3 habitat is similar to niche 5 (moderate/mid-depth); both have peaks in WUA in the lower end of the flow range. Available niche 3 and niche 5 habitat increases until approximately 150 cfs (> 20,000ft^2/1,000ft) and 215 cfs (> 15,000ft^2/1,000ft), respectively, then both decrease until falling below 5,000ft^2/1,000ft at approximately 400 cfs and all subsequent flows. Niche 5 is the primary habitat type for the sportfish in the Provo River including all trout and mountain whitefish adults and juveniles. In this reach, flows ranging from approximately 70 to 350 cfs provide over 10,000ft^2/1,000ft of niche 5 habitat. The fast/shallow habitat (niche 4), which provides suitable habitat for mountain sucker adults and mottled sculpin adults and juveniles, peaks at slightly over 5,000ft^2/1,000ft at approximately 400 cfs and then declines. The only species/lifestage documented in niche 6 habitat (fast/mid-depth) is the adult mountain sucker. Niche 6 habitat increases dramatically (> 35,000ft^2/1,000ft increase from 100 to 500 cfs) with increasing flows and peaks at approximately 700 cfs. Essentially no moderate/deep (niche 7) habitat is available at any flow for Reach 2; this habitat is preferred by adult mountain whitefish and adult Utah sucker. Although the fast/deep habitat (niche 8) does not directly relate to any fish species, it is included to describe how the habitat changes as flows increase; niche 8 increases steadily above 600 cfs to nearly 15,000ft^2/1,000ft of WUA at 1,500 cfs.

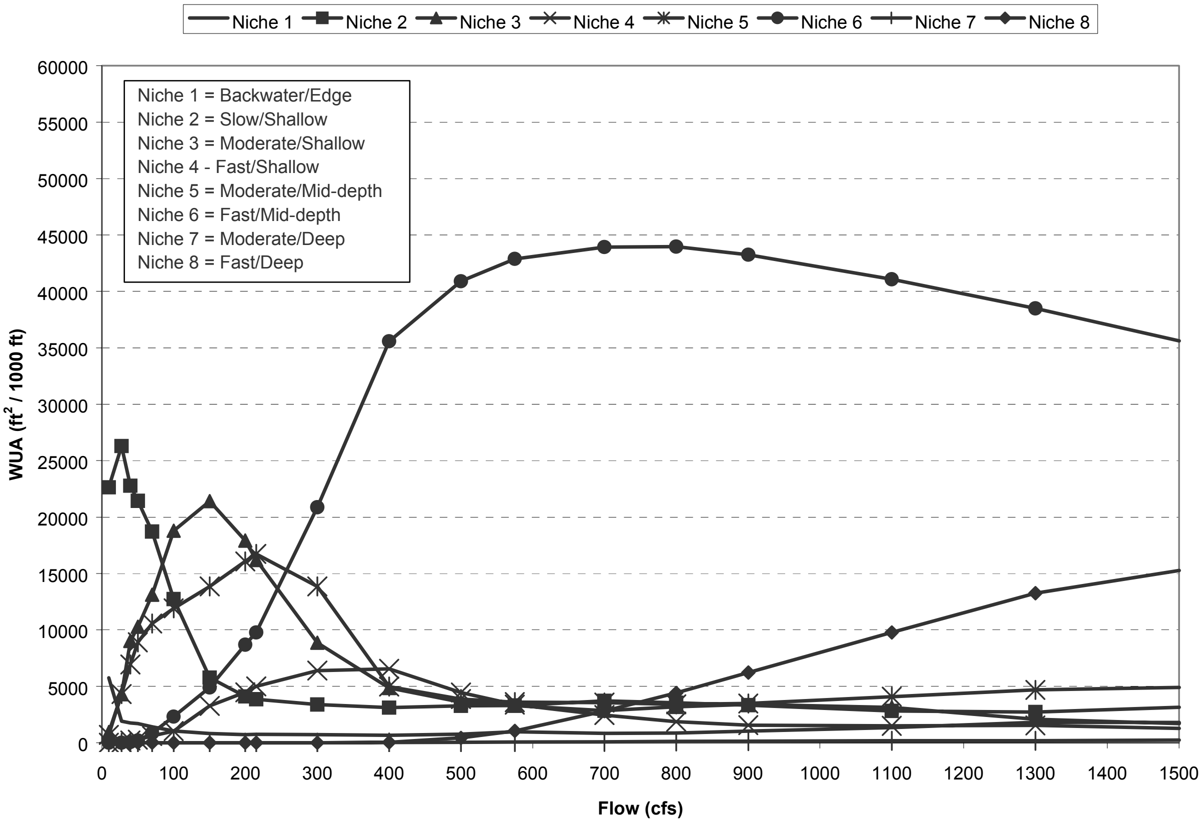


FIGURE 3.29. REACH 2: HABITAT NICHES - WUA VS. FLOW.

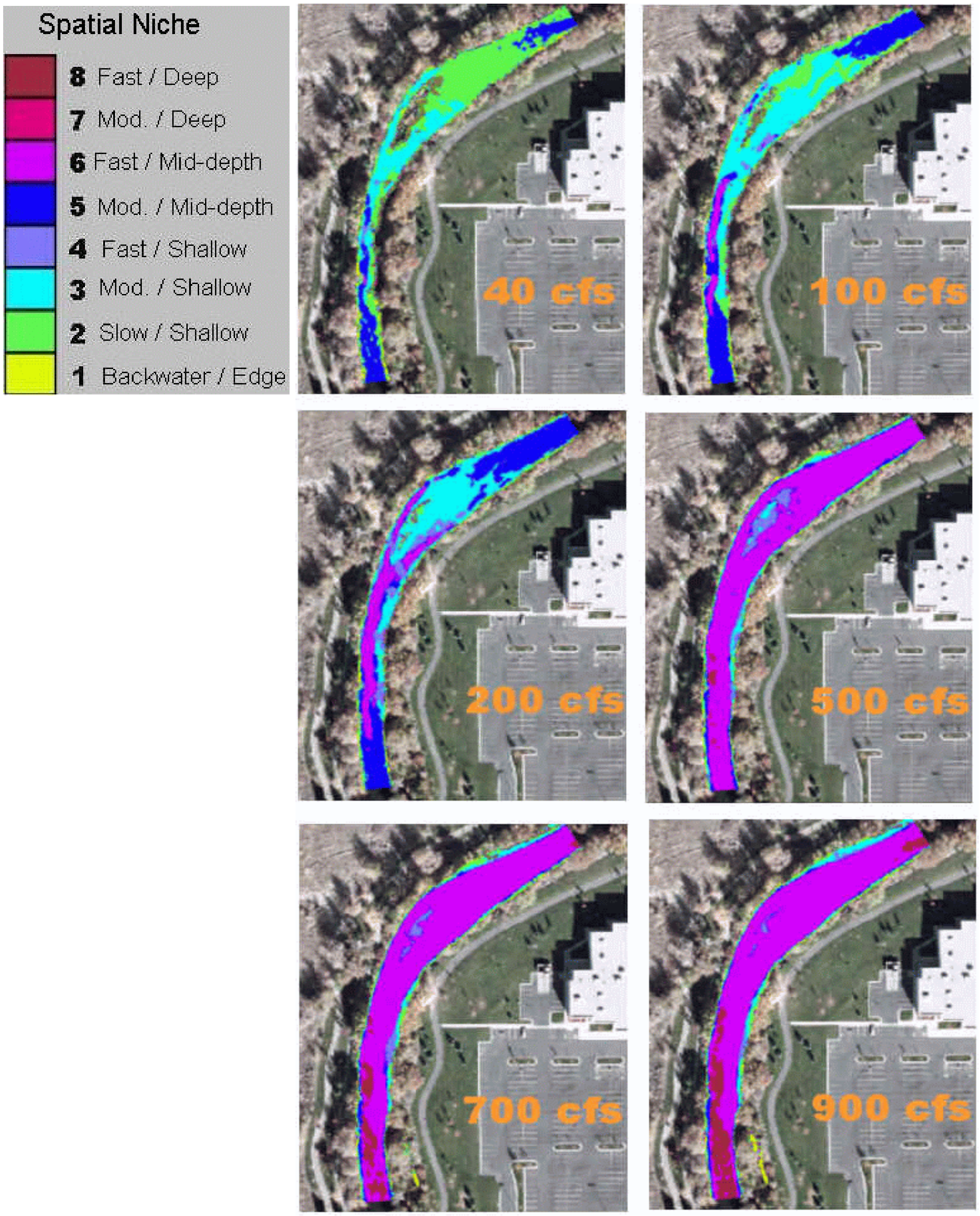
As evident in Image 3.7 and Figure 3.29, there is only approximately 1,000ft^2/1,000ft of niche 1 habitat at 100 cfs, while niche 2, 3, and 5 habitat each maintain over 10,000ft^2/1,000ft. In contrast, at 500 cfs, the majority of habitat in this site is niche 6 (approx. 40,000ft^2/1,000ft) with the WUA for niches 2, 3, and 5 becoming confined to the edges. Overall, the results of the habitat niche modeling at this site support the biological data that very few species other than trout and mottled sculpin have been collected in this reach. As in other confined reaches, the lack of backwater/edge habitat and rapid decrease of slow/shallow habitat with increasing flows probably limits the success of native fishes and juveniles of other species. The niche approach separates suitable habitat for brown trout from the backwater/edge habitat that is suitable for many native species and juveniles and YOY of most species; however, the abundance of brown trout and potential threat of predation may have an influence on the presence and/or abundance of some of those species in this reach.

3.5.1.2 HSI CURVE MODELING

An examination of the individual HSI curves for brown trout and "all trout" reveal similar trends with those observed above for niche 5. Figure 3.30 shows the WUA (ft^2/1,000ft) for each trout species/lifestage per respective flow. The brown trout adult curve was used to assess habitat availability for all trout species; over 15,000ft^2/1,000ft of adult trout WUA is present between

SITE 2

IMAGE 3.7. HABITAT NICHES - WEIGHTED USABLE AREA (SITE 2). THE IMAGES BELOW VISUALLY DEPICT HABITAT NICHES THAT ARE PRESENT AT DISCHARGES OF 40, 100, 200, 500, 700, AND 900 CFS. EACH HABITAT NICHE IS REPRESENTED BY THE COLOR IMMEDIATELY ADJACENT THE NUMBER/DESCRIPTION IN THE LEGEND. FOR EXAMPLE, NICHE 6 = MAGENTA, NICHE 5 = BLUE, NICHE 1 = LIGHT YELLOW, ETC.



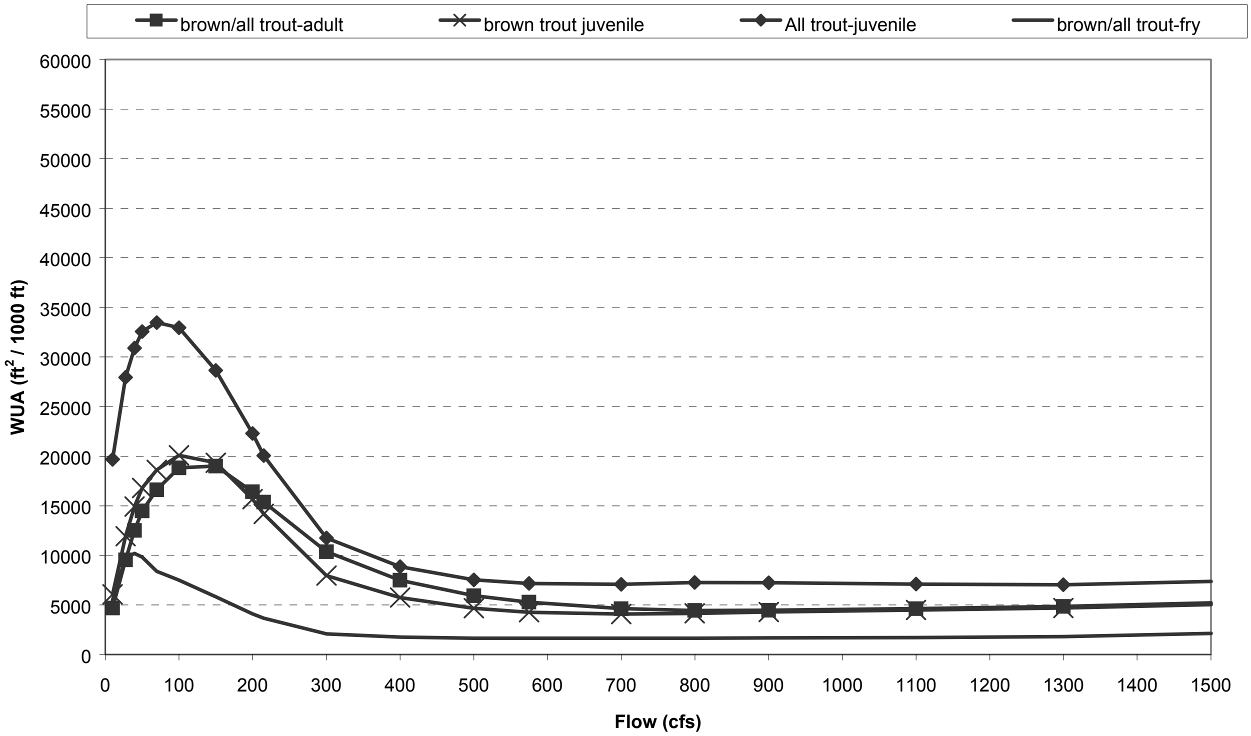


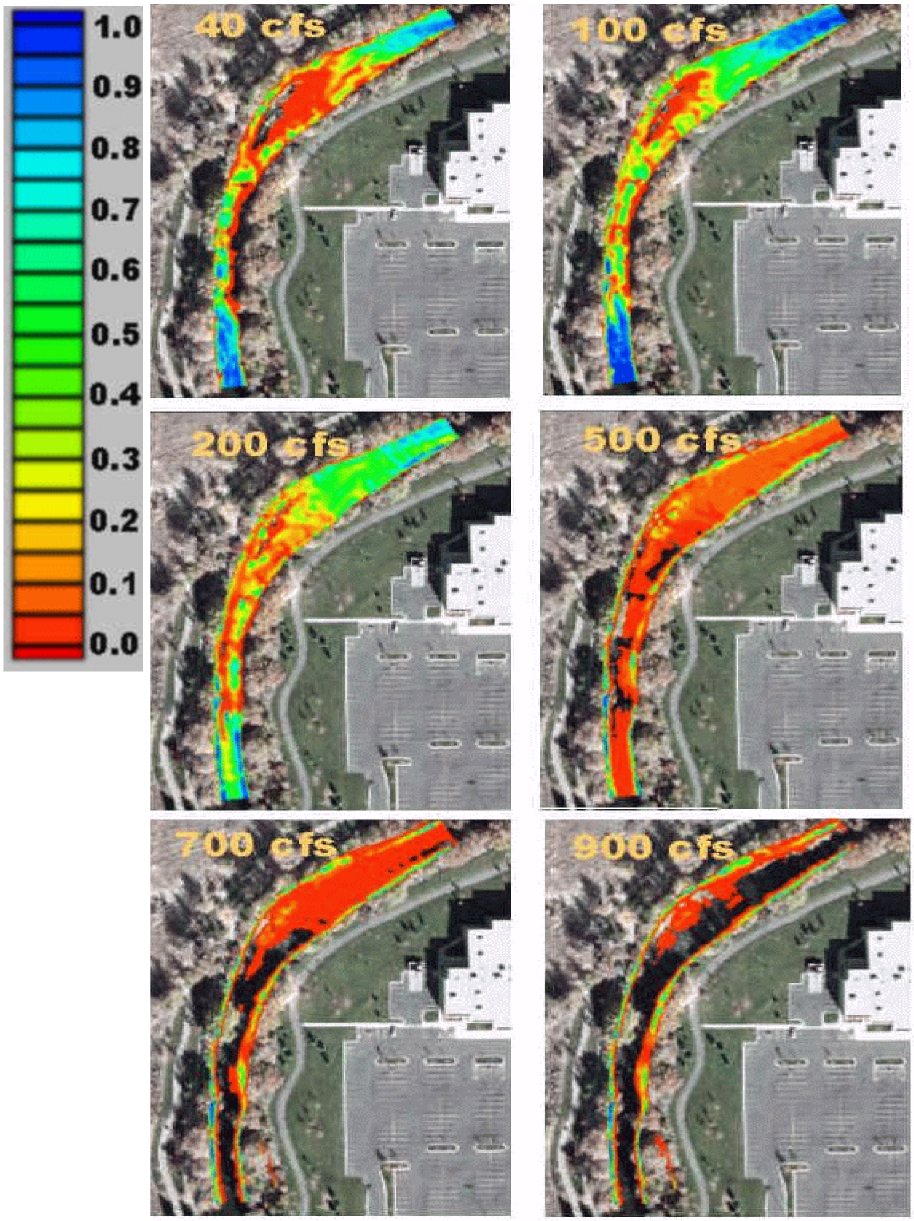
FIGURE 3.30. REACH 2: TROUT - WUA VS. FLOW.

approximately 70 and 200 cfs. The juvenile "all trout" and brown trout curves reveal a similar trend with the highest total between 70 and 200 cfs. As witnessed in all reaches, the results of the two juvenile categories differ slightly.

As displayed in Image 3.8, the upper- and lower-most sections of this site provide excellent (blue) adult brown trout habitat with an abundance (nearly 19,000ft^2/1,000ft) of WUA present throughout the site at 100 cfs. In contrast, the majority of the main channel is not suitable at 500 cfs with only 1/3 of WUA remaining.

Figure 3.30 reveals that greater than 10,000ft^2/1,000ft of habitat for fry is available at the peak of 40 cfs with greater than 5,000ft^2/1,000ft available until approximately 150 cfs. This study documents that the optimal range for fry habitat in Reach 2 is approximately 25 to 100 cfs. As flow increases above 100 cfs, trout fry habitat is reduced. Model runs demonstrate that there is no suitable habitat for trout spawning in Site 2; this is affected by substrate requirements (i.e. substrate mapping for Site 2 documented larger substrate than suitable for spawning). Therefore, the population of trout present in Site 2 may be composed of migrants from up- and downstream reaches.

IMAGE 3.8. ADULT BROWN TROUT - WEIGHTED USABLE AREA (SITE 2). THE IMAGES BELOW VISUALLY DEPICT SUITABLE HABITAT AVAILABLE TO ADULT BROWN TROUT AT DISCHARGES OF 40, 100, 200, 500, 700, AND 900 CFS. THE BEST HABITAT IS REPRESENTED BY SUITABILITY OF 1.0 (BLUE) AND NO HABITAT IS REPRESENTED BY 0 (RED).



Although physical barriers currently restrict the upstream migration of June suckers into Reach 2, this area was once within the range for the species. Therefore, the individual HSI spawning curve for the June sucker was applied for Site 2 based on depth and velocity criteria. As no WUA was determined via modeling, a further evaluation of the data revealed that there is limited substrate suitable for June sucker spawning in Site 2. However, this does not rule out the possibility for suitable substrate in other select areas within Reach 2, but extrapolation of data to the reach was not possible without additional substrate characterization in Reach 2.

3.5.2 WATER TEMPERATURE- SITE 2

For this study, a thermistor was placed at Site 2 between April 25 and August 16, 2002. The following mean temperatures were observed during the study period.

April (25 - 30)	8.6°C
May	8.8°C
June (excluding 28 - 30)*	10.9°C
July (excluding 1 - 21)*	15.5°C
August (1 - 16)	16.4°C

*- flows dropped to a level where the thermistor was exposed

The lack of a representative USGS flow gage near this site disallowed the comparison of temperature with flow. However, an evaluation of the temperature data reveals that, similar to the other sites, temperature remains fairly constant with higher flow releases and greater diurnal variation is experienced during lower flow conditions. As with the other reaches, temperature changes and diurnal fluctuations may be very important in understanding the macroinvertebrate assemblages (see Macroinvertebrate Case Studies in the Discussion section) and recruitment success of fishes in Reach 2 of the Provo River.

3.5.3 RECREATIONAL USABILITY-SITE 2

3.5.3.1 WADING/FISHING

The WUA's calculated for Reach 2 represent the total amount of suitable wading/fishing "habitat" (area) per 1,000 ft of stream for the entire reach. Figure 3.31 shows the WUA (ft^2/1,000 ft) for fishing/wading recreational activities. At 70 cfs, approximately 43,000ft^2/1,000ft of fishing/wading area is provided for recreationists. At flows greater than approximately 250 cfs, usable wading area within this site declines to below 25,000ft^2/1,000ft.

3.5.3.2 BOATING

Figure 3.31 displays the Reach 2 boating WUA (ft^2/1,000 ft) for novice rafting, mid-level rafting, and canoeing/kayaking. The amount of WUA for canoeing/kayaking increases rapidly as flows increase (> 35,000ft^2/1,000ft increase from 100 to 500 cfs). The peak at approximately 41,000ft^2/1,000ft and subsequent tapering off effect at flows greater than 550 cfs is a result of a conservative classification that includes safety concerns for both canoes and kayaks. It is recognized

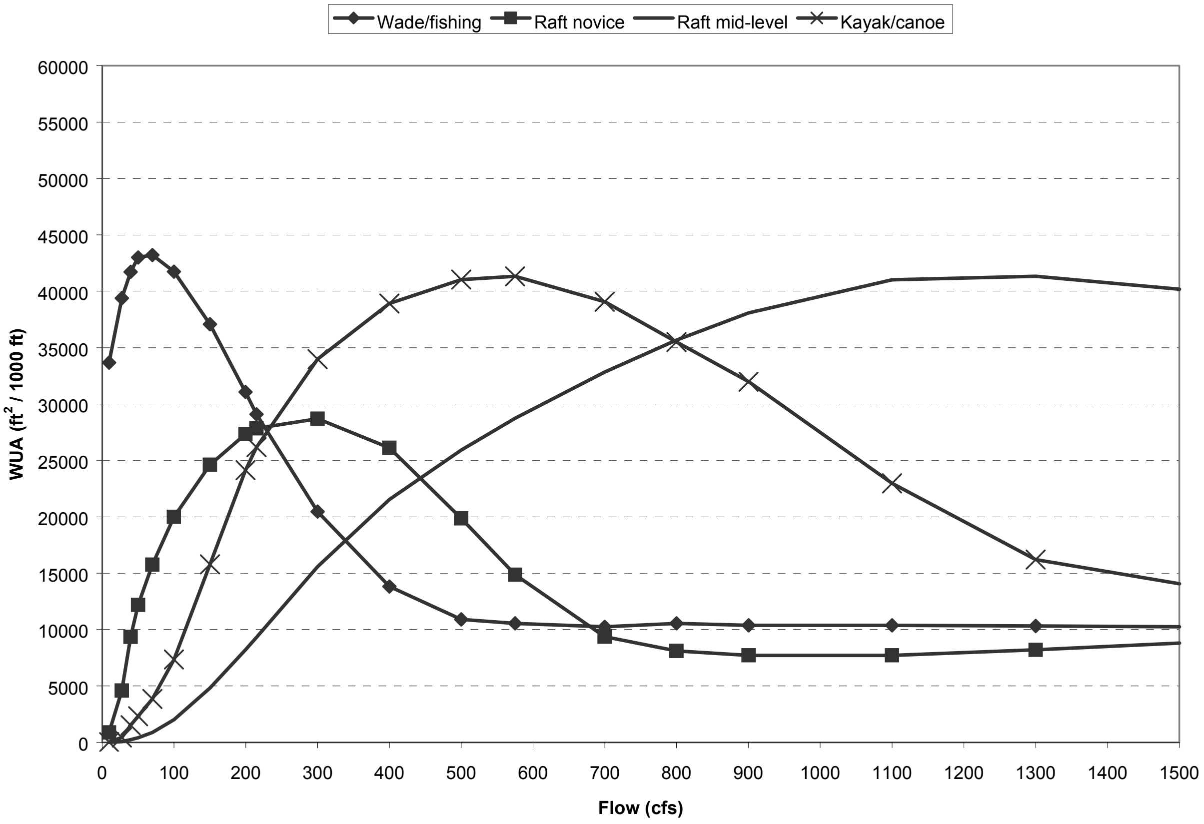


FIGURE 3.31. REACH 2: RECREATION - WUA VS. FLOW.

that experienced kayakers would welcome the challenge of even higher flows. Reach 2 provides more than 20,000ft^2/1,000ft for novice rafters at a flow range of approximately 100 to 500 cfs, and for mid-level rafters greater than 20,000ft^2/1,000ft is provided at flows greater than approximately 400 cfs.

3.5.4 SEDIMENT TRANSPORT - SITE 2

3.5.4.1 SAMPLING RESULTS

The results of the bedload sampling at Bridge 2 illustrate the lack of small grained particles in this reach of the Provo River. It appears that only a small amount of fine grained bed material was "winnowing" around the stable larger particles (Figure 3.32, Plate 3.7). Figure 3.33 shows the particle size distribution of streambed material at the Site 2 bedload modeling cross-section and Table 3.3 shows important fractions of the existing streambed particle size distribution compared to the largest particle captured during bedload sampling.

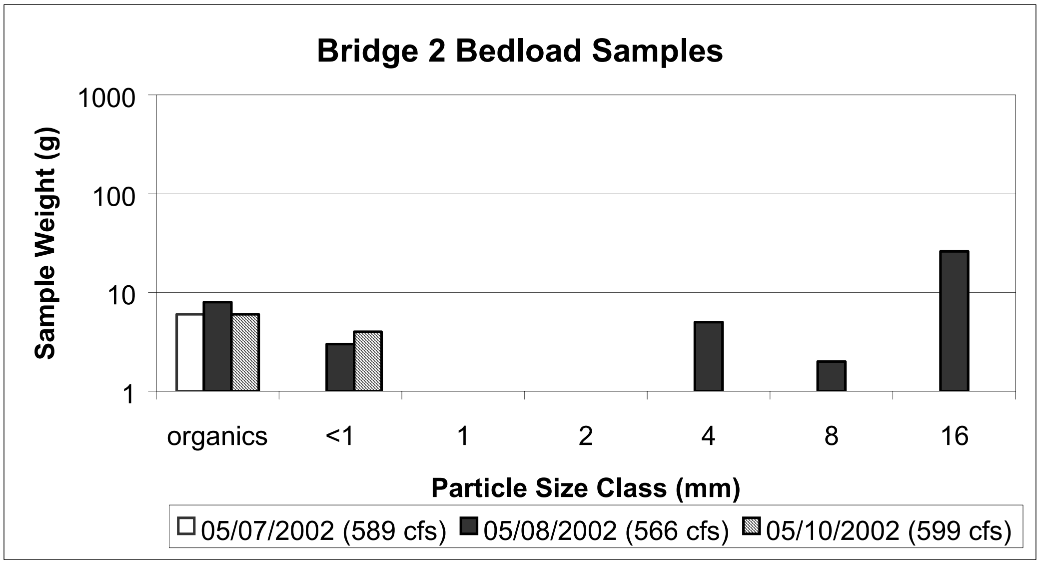


FIGURE 3.32. BEDLOAD SAMPLING RESULTS FOR BRIDGE 2 BROKEN INTO SIZE CLASSES.

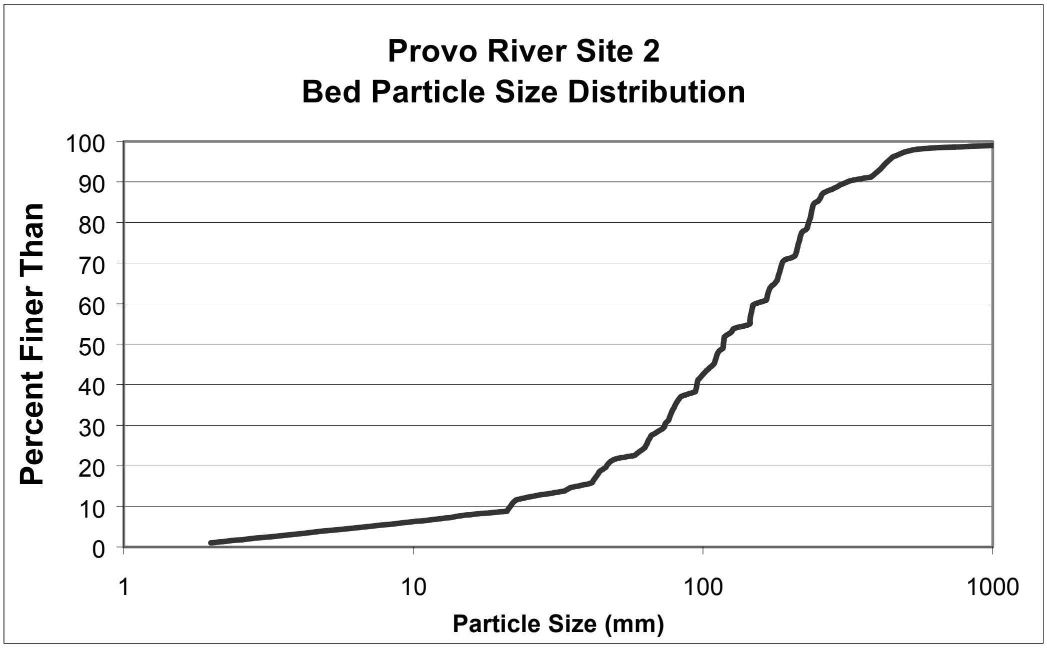


FIGURE 3.33. PARTICLE SIZE DISTRIBUTION OF THE BEDLOAD MODELING CROSS SECTION AT SITE 2. THE MAJORITY OF THE PARTICLES AT SITE 2 ARE 100-200 MM IN DIAMETER WITH RELATIVELY FEW LARGER OR SMALLER PARTICLES.

Bedload Sample Site 2 05/07/02 3:30 PM

589 cfs

Bedload Sample Site 2 05/08/02 1:03 PM

566 cfs

Bedload Sample Site 2 05/10/02 2:38 PM

599 cfs

PLATE 3.7. PHOTOGRAPHS OF SITE 2 BEDLOAD SAMPLES COLLECTED DURING 2002 SPRING RUNOFF.

TABLE 3.3. IMPORTANT FRACTIONS OF SITE 2 STREAMBED PARTICLE SIZE DISTRIBUTIONS AND LARGEST PARTICLE CAPTURED DURING BEDLOAD SAMPLING AT BRIDGE 2.[A]

SITE	D16	D25	D50	D75	D84	MAXIMUM SIZE IN TRANSPORT
2	42	63	118	214	255	29

A THE SIZE OF PARTICLES ARE MEASURED IN MM ALONG THE B-AXIS.

SITE 2

Site 2 is highly armored and is dominated by particles ranging from 100 to 200 mm in diameter. This site is located downstream of Murdock Diversion Dam and a number of other diversion structures that trap bedload sediment being generated in Provo Canyon. Site 2 is highly channelized with riprap banks, and is located within Utah Valley, away from any side hills or tributary sediment inputs. Therefore, there are very few sources of local sediment supplies available for bedload transport. Mining of the smaller size fractions has apparently disrupted any sense of sediment flux equilibrium at Site 2 (and Reach 2).

3.5.4.2 MODELING RESULTS

Due to the highly armored conditions, it was necessary to model the D_{16} (particle 42 mm in size) at Site 2 instead of the D_{25} or D_{50}. However, the actual size (42 mm) is the same as the D_{25} size modeled at Sites 5 and 6. It was necessary to model this smaller size fraction at Site 2 than was used at Sites 3-6 because the bed was found to be more armored than in the "Canyon" reaches. This is apparently because of the lack of local bedload sediment sources. In fact, the streambed is much more armored at Site 2 than any other site in Provo River below Deer Creek Dam.

The bedload rating curve for Site 2 is shown in Figure 3.34. As with Sites 3 and 4, bedload is predicted to begin moving at approximately 300 cfs but, unlike any of the other sites, the relationship with flow is much steeper (e.g. a greater increase in bedload transport as flows increase). The channel is steep and narrow through this site producing very high shear stress values. Shear stress and the resulting drag was so extreme, it was nearly impossible to hold the bedload sampler on the bed at the sampled flows. The bedload sampling and pebble count results indicate that there is a very limited supply of sand and gravel sized particles in Site 2 to become entrained. The shear stress calculations show that particles greater than the D_{50} do not move until flows exceed 1,300 cfs. It is important to note that the D_{25} is larger at Site 2 than any other Site within the Study Area.

Suspended sediment transport at Site 2 was evaluated using data from the DWQ monitoring site near Geneva Road (Map 1.3). Figure 3.35 shows the relationship between suspended sediment transport and flow at this monitoring site. As with the Murdock Diversion water quality monitoring data, caution must be exercised when interpreting the suspended sediment transport data at Geneva Road. The transport rating curve is based on TSS data that were collected for water quality assessment purposes, not for evaluating suspended sediment transport. The data were collected as water quality grab samples taken at a single point in the water column, not taken across an entire river transect in a depth- and cross sectionally-integrated manner. There were limited amounts of samples collected at the higher flows, with only 7 samples taken when flows were in excess of 1,000 cfs.

Sedimentation is not likely under any flow scenario at Site 2 because of the super-armored conditions and lack of fine-grained sediment supply. A comparison of sediment transport in terms of timing, magnitude, and duration could not be made at this time because of limited flow data available for Site 2. An analysis of alternative flow regimes could be made using the same techniques as at Sites 5 and 6 if data became available.

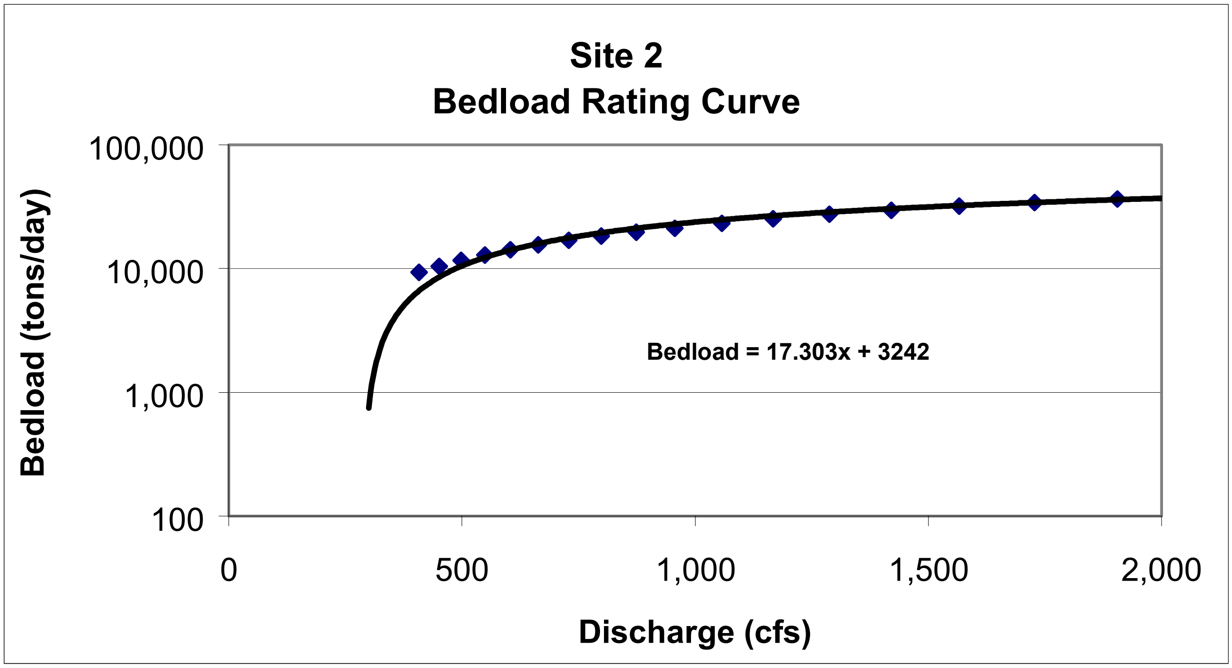


FIGURE 3.34. THE BEDLOAD RATING CURVE FOR SITE 2.

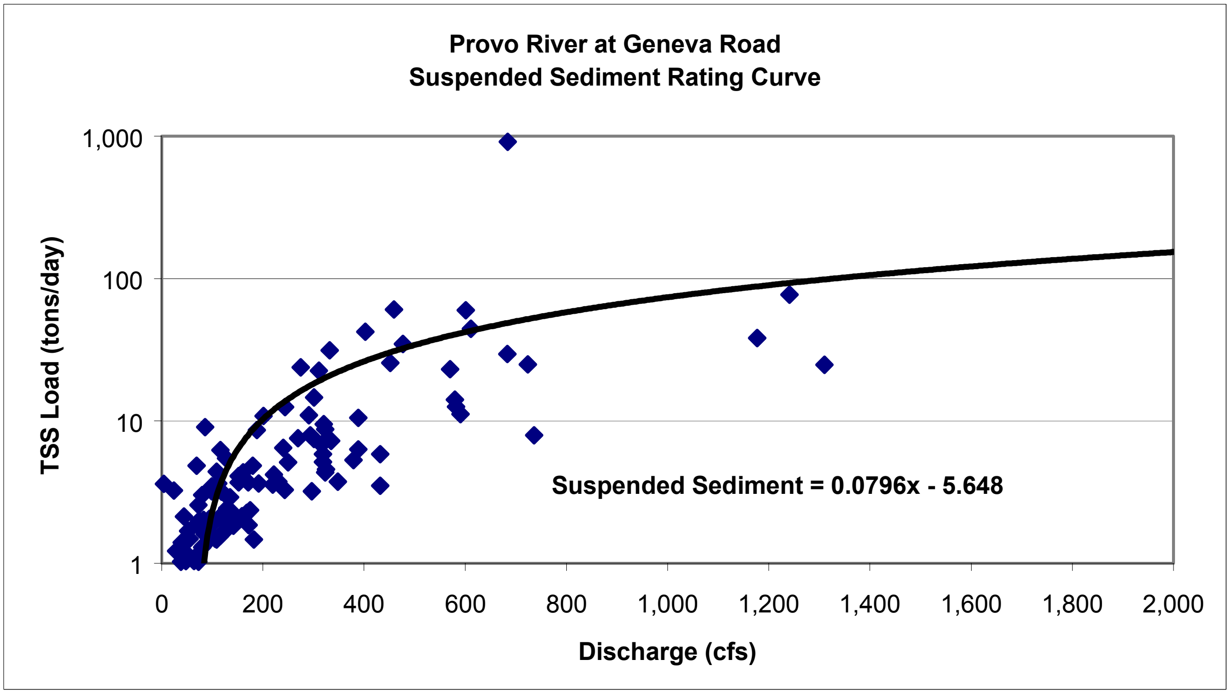


FIGURE 3-35. THE EMPIRICALLY DERIVED SUSPENDED SEDIMENT RATING CURVE DEVELOPED USING DATA COLLECTED AT THE GENEVA ROAD WATER QUALITY MONITORING SITE.

3.5.5 RIPARIAN VEGETATION - SITE 2

As with the previous sites, riparian vegetation width at Site 2 is constrained by levees built to protect development. At Site 2, sections of the paved Provo Canyon Trail are located on top of the levees on both sides of the river. Beyond the trail to the east is a parking lot and shopping mall; beyond the trail to the west is a parking lot and business development. Although channel straightening and the presence of the levees has limited the ability of the channel to meander and develop bars and floodplain surfaces, the low-flow channel within Site 2 does meander slightly, and vegetated floodplain areas are present on the insides of the bends on river right (facing downstream) at the upstream end of the site and on river left at the middle/downstream portion of the site (Map 3.4). On the outer sides of these subtle bends, banks are tall and steep, and rip rap has typically been placed to protect the streambank (Plate 3.8). On both sides of the stream the area beyond the top of the banks/levees is landscaped with grass, pruned shrubs, and scattered trees.

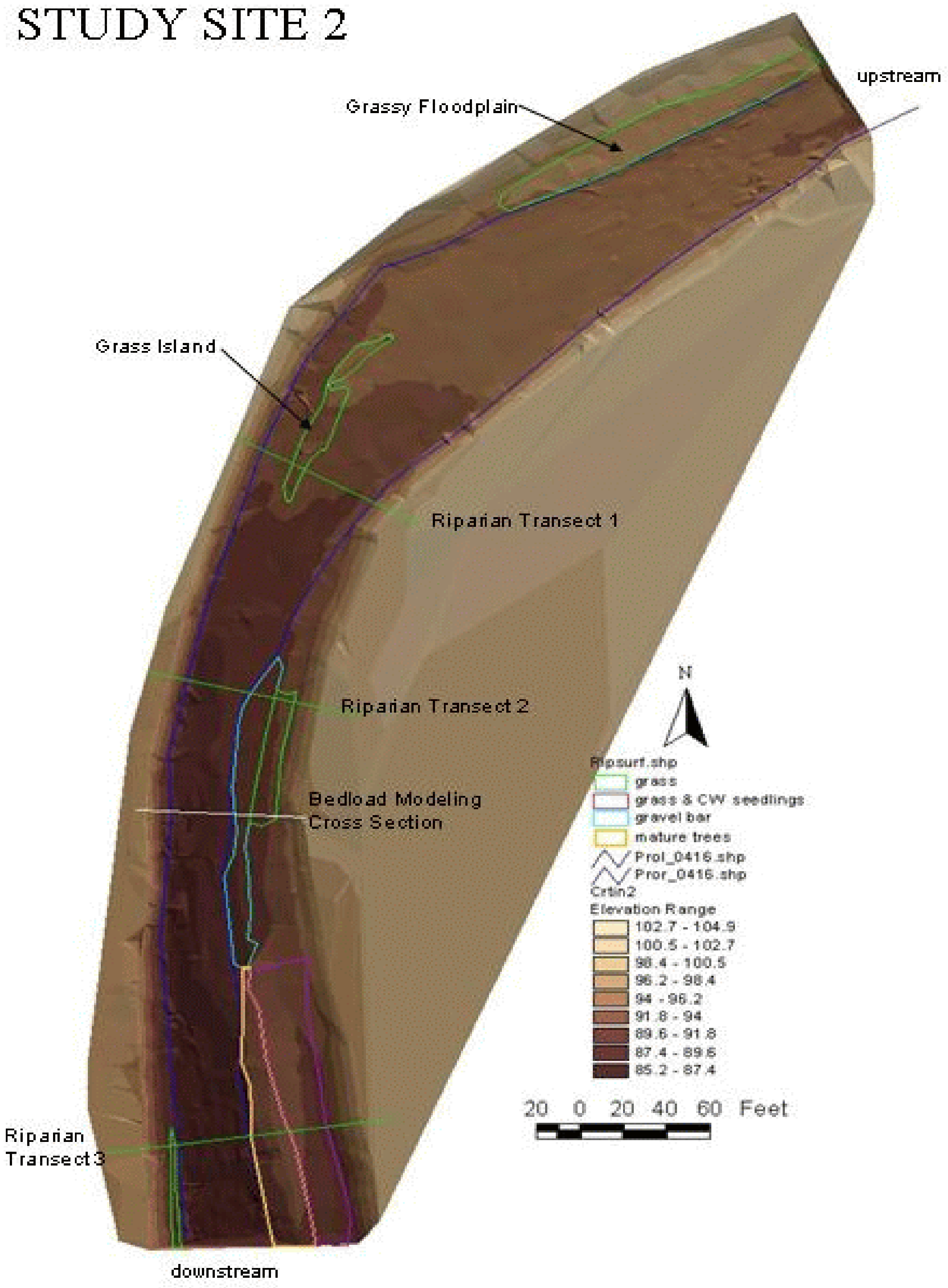
3.5.5.1 TRANSECT RESULTS

Within Site 2, three transects spanning riparian establishment surfaces were selected to evaluate the relationships between streamflow and riparian characteristics (Map 3.4). These transects are plotted in Figure 3.36 along with the range of flows that inundate the different establishment surfaces.

Transect 1 crosses a grass-covered mid-channel bar/island feature (Plate 3.8, Figure 3.36). This surface is inundated by flows of 500 cfs and greater (Figure 3.36). The steep leveed banks on both sides of the channel easily contain the highest modeled flow of 1,500 cfs.

Transect 2 crosses a gently-sloping gravel bar on river left; the bank on river right is steep and leveed (Plate 3.8). At the time of field survey (April 2002), the lower portion of this gravel bar was mostly bare but the presence of several small cottonwood seedlings was noted. This lower portion of the gravel bar surface begins to be inundated by flows above 70 cfs and is completely inundated by flows of 300 cfs (Figure 3.36). Beyond the bare gravel bar on river left, Transect 2 crosses a grass floodplain surface that is inundated by flows between 300 and 900 cfs. A similar grass-dominated floodplain area located on river right at the top of Site 2 is also inundated by flows between 300-900 cfs. This flow range is also similar to the flows that inundate the willow-grass floodplain on river right at Site 3 Transect 2. At Site 2 Transect 2, as with Transect 1, the highest modeled flow of 1,500 cfs is easily contained between the levees.

As with Transects 1 and 2, the bank on river right at Transect 3 is steep and leveed and does not provide any flat riparian establishment surfaces. On river left at Transect 3, the bank is a vertical cut bank occupied by mature trees (primarily cottonwood). The top of this cut bank is located at a flow level of approximately 800 cfs (Figure 3.36). Beyond the near-bank surface occupied by mature trees is a depression/swale area occupied by grass and cottonwood seedlings (Plate 3.8). This swale area is bounded on the left by a steep levee (Figure 3.36) Although the highest modeled flow of 1,500 cfs does not overtop the near-bank mature tree surface, water is nevertheless present



MAP 3.4. MAP STUDY SITE 2 SHOWING RIPARIAN TRANSECT AND BEDLOAD MODELING CROSS SECTION LOCATIONS. DARK BLUE LINES INDICATE WATER'S EDGE AT LOW FLOW.

PLATE 3.8. PHOTOS OF SITE 2 RIPARIAN SURFACES. (A) UPSTREAM VIEW OF GRASSY ISLAND CROSSED BY TRANSECT 1; (B) DOWNSTREAM VIEW OF GRAVEL BAR CROSSED BY TRANSECT 2 AND STEEP LEVEED RIGHT BANK; (C) AND (D) YOUNG COTTONWOODS ON RIVER LEFT CROSSED BY TRANSECT 3.

in the swale area at 1,500 cfs. This occurs because at high flows greater than about 1,100 cfs, water enters the swale at a low point upstream from Transect 3 (Map 3.4).

Because no USGS streamflow gage is located near Site 2, a complete hydrologic data set with which to develop flow duration and flood frequency information is not readily available. However, the general hydrologic regime at Site 2 is represented reasonably well by the data from the USGS gage located downstream at Provo (gage #10163000); flows at Site 2 during the irrigation season are typically 40 to 60 cfs greater than the flows at the Provo USGS gage due to the presence of several water diversions between Site 2 and the gage (BIO-WEST 2001 diversion study). As with Site 3, summertime flows at Site 2 are much lower (about 60-100 cfs) than in the reaches above Olmsted Diversion (typically 300-400 cfs). Flood peaks at Site 2 are also slightly lower than in the reaches above Olmsted. The 2 year flood at the Provo gage is 925 cfs (Appendix C); at Site 2 above several irrigation diversions this value is likely slightly higher, on the order of 990-1,000 cfs.

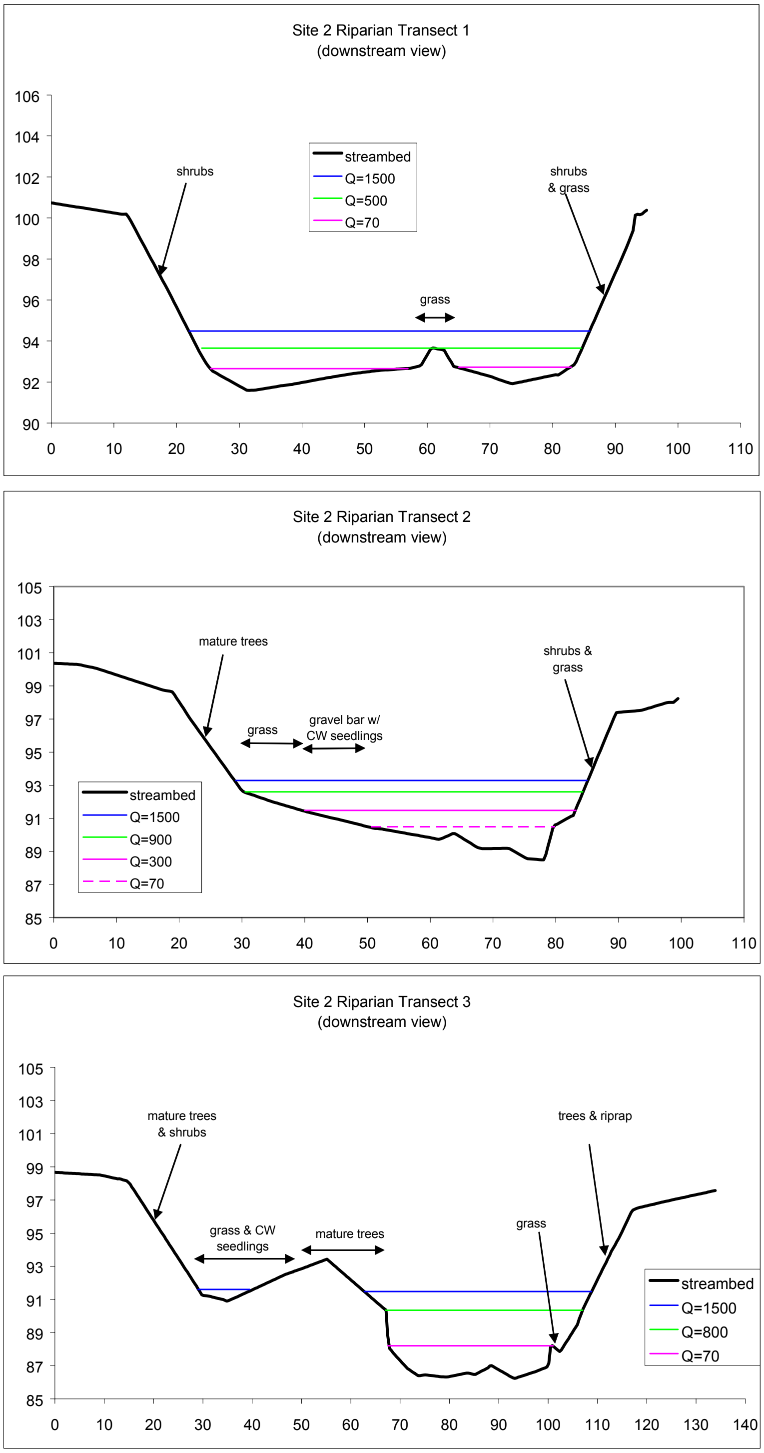


FIGURE 3.36. SITE 2 RIPARIAN TRANSECTS AND INUNDATION DISCHARGES (CFS).

These differences in hydrology result in differences in the streamflow-riparian surface relationships at the different sites. The lower, more natural flow levels that occur during the growing season at Site 2 allow for more extensive riparian vegetation growth on lower-elevation surfaces: at Site 2, vegetation extends down to about the 70 cfs flow level, whereas at Sites 5 and 6, no vegetation grows below the 300-400 cfs flow level.

3.5.5.2 COTTONWOOD RECRUITMENT POTENTIAL

Site 2 contains the greatest amount of cottonwood recruitment of any of the study sites, and also exhibits the greatest age-diversity of cottonwoods. There are several factors that may account for the relative success of cottonwood recruitment at Site 2. The swale area on river left that is crossed by Transect 3 provides a surface which is shallowly inundated by moderate-frequency floods and is conducive to sediment deposition due to its protection from the high-velocity flows in the main channel. The 5- and 10-year recurrence interval floods at the Provo gage are 1,308 cfs and 1,495 cfs, respectively, and modeling results indicate that floods of this magnitude would at least partially inundate the swale area. Thus, this surface meets recruitment requirement 1 (presence of a bare surface with freshly-deposited sediments at the time of seed dispersal) on a somewhat regular basis.

Another unique aspect of Site 2 is the presence of irrigated, manicured landscape areas in close proximity to the channel. Irrigation water from the nearby sprinkler systems likely infiltrates into the ground and flows downhill toward the swale and floodplain areas of the river, providing an alternative source of water to prevent seedling dessication associated with rapid declines in river flow levels. If this alternative water source were not present, cottonwood recruitment success would likely be reduced at Site 2, because flow regulation has also resulted in un-naturally rapid receding limb of the spring hydrograph.

Although recruitment is occurring at Site 2, its extent is limited by some of the same factors that prohibit successful recruitment at the upstream Canyon sites. Because the levees at Site 2 artificially clip the horizontal extent of floodplain surfaces, the total area of surfaces at suitable elevations is limited. However, it is not likely feasible to re-configure the levee banks to reduce their slope and widen the riparian corridor at Site 2 due to the proximity of development and infrastructure.

3.6 SITE 1

3.6.1 AQUATIC HABITAT - SITE 1

3.6.1.1 HABITAT NICHE MODELING

Based on the results of the channel reach mapping, Study Site 1 modeling results were extrapolated to represent habitat throughout Reach 1. Due to the similarity in WUA trends between the individual site (1) and the extrapolated reach, the results for the entire Reach 1 are discussed below.

Each WUA value calculated for Reach 1 represents the total amount of suitable habitat per 1,000 linear feet of stream. Figure 3.37 shows the WUA (ft^2/1,000ft) for each niche per respective flow. The backwater/edge habitat (niche 1) is used by a majority of the native fish species and larval stages of many fishes. Approximately 26,000ft^2/1,000ft of Niche 1 habitat is present at 10 cfs but decreases rapidly (> 20,000ft^2/1,000ft decline) near 40 cfs and remains below 5,000ft^2/1,000ft at all higher flows. Fisheries data from UDWR and BYU fisheries assessments only rarely document native fishes in confined reaches in the Provo River. The slow/shallow habitat (niche 2) supports juvenile and YOY life stages of many species. This niche maintains over 30,000ft^2/1,000ft at approximately 25 cfs but decreases rapidly (>25,000ft^2/1,000ft decline) by 150 cfs. Niche 2 (slow/shallow habitat) and 3 (moderate/shallow) overlap in supporting both larval and juvenile life stages for certain species, but niche 3 is broader and includes certain adult species. Availability of niche 3 habitat is similar to niche 5 (moderate/mid-depth); both have peaks in WUA in the lower end of the flow range. Available niche 3 and niche 5 habitat increases until approximately 100 cfs (> 20,000ft^2/1,000ft) and 200 cfs (> 30,000ft^2/1,000ft), respectively. Niche 5 is the primary habitat type for the sportfish in the Provo River including all trout and mountain whitefish adults and juveniles. In this reach, flows ranging from approximately 100 to 350 cfs provide over 20,000ft^2/1,000ft of niche 5 habitat. The fast/shallow habitat (niche 4), which provides suitable habitat for mountain sucker adults and mottled sculpin adults and juveniles peaks at approximately 200 cfs but is consistently less than 5,000ft^2/1,000ft at any flow. This is not surprising considering the lake/river interface represented by the sample site. The only species/lifestage documented in niche 6 habitat (fast/mid-depth) is the adult mountain sucker. Niche 6 habitat increases dramatically (> 40,000ft^2/1,000ft increase from 100 to 500 cfs) with increasing flows and peaks at approximately 700 cfs. Only a small amount (< 2,000ft^2/1,000ft) of moderate/deep habitat (niche 7) is available in Reach 1; this habitat is preferred by adult mountain whitefish and adult Utah sucker. Although the fast/deep habitat (niche 8) does not directly relate to any fish species, it is included to describe how the habitat changes as flows increase; niche 8 increases rapidly above approximately 700 cfs.

It is evident that even at 100 cfs the majority of the niche 1 (yellow) and niche 2 (green) habitat is already gone (Image 3.9). At 100 cfs, niche 3 and niche 5 make up the majority of the available habitat. In contrast, at 500 cfs, niche 6 and niche 8 make up the majority of the habitat with WUA for other niches now restricted to the channel margins. Overall, the results of the habitat niche modeling at this site support available biological data and reveal that several habitats and species (some only seasonal) are present in this lake/river interface reach. As with other reaches, the lack of backwater/edge habitat and rapid decrease of slow/shallow habitat with increasing flows probably limits the success of native fishes and juveniles of many species. The niche approach separates suitable habitat for brown trout from the backwater/edge habitat that is suitable for many native species and juveniles and YOY of most species. Therefore, the potential threat of predation from non-native species may have an influence on the presence and/or abundance of some of the native species in this reach. Another major consideration in Reach 1 is water quality, which may deteriorate and affect habitat suitability during “first flush” of spring runoff and low-flow summer conditions.

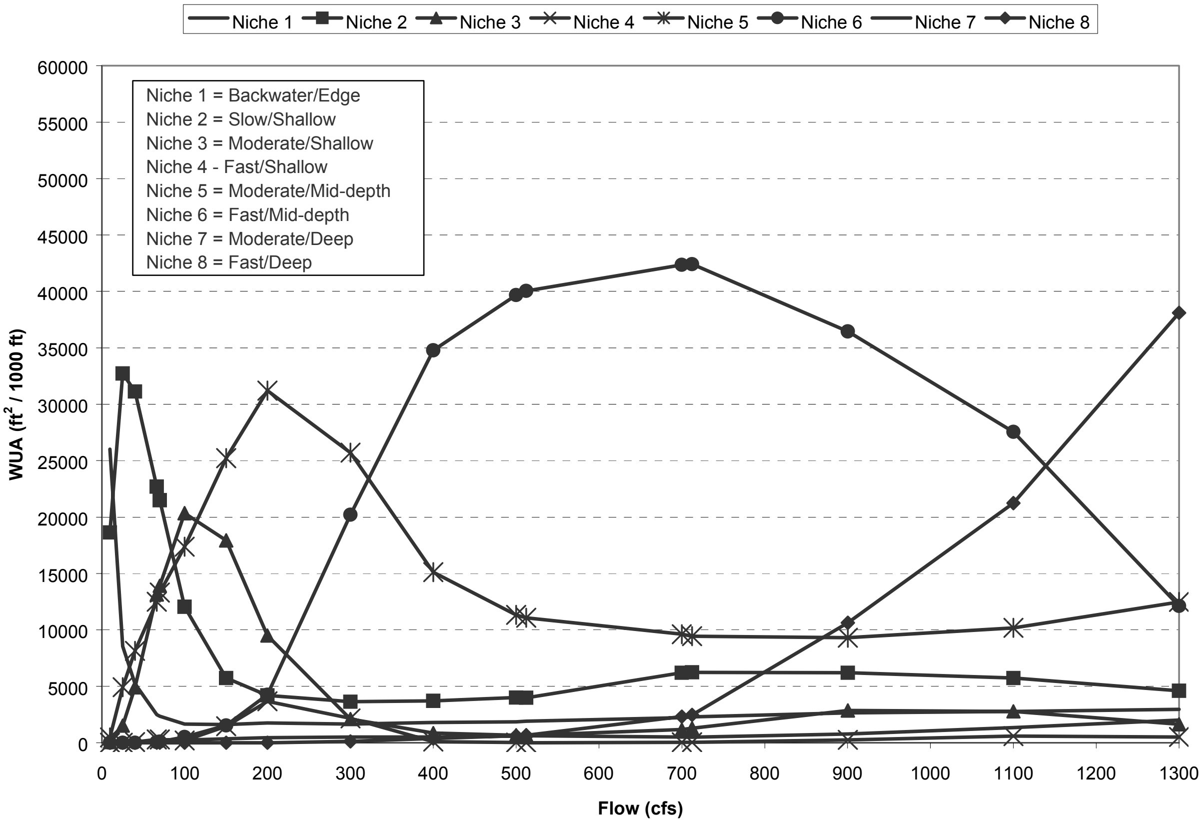


FIGURE 3.37. REACH 1: HABITAT NICHES - WUA VS. FLOW.

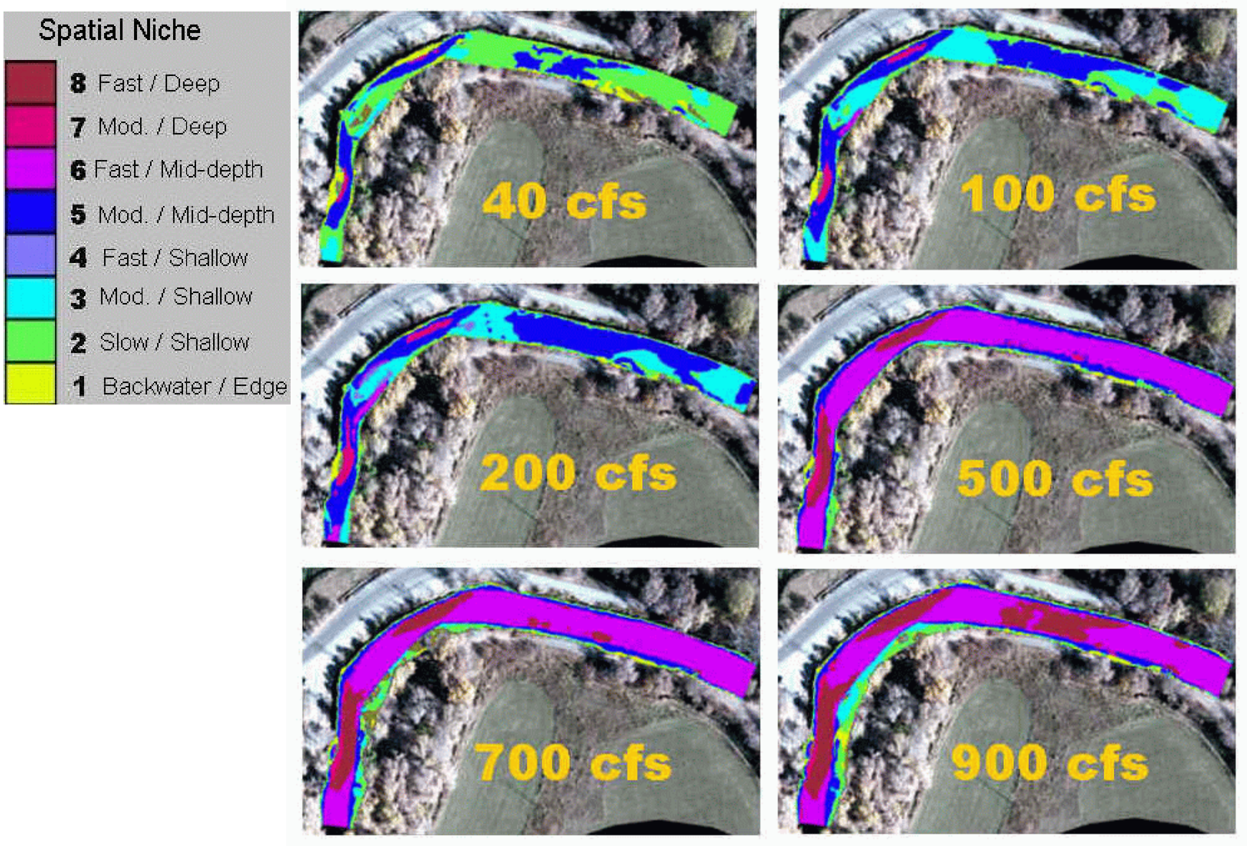
3.6.1.2 HSI CURVE MODELING

Using individual HSI curves for brown trout and "all" trout reveal similar trends to the niche 5 results from the habitat niche approach. Figure 3.38 shows the WUA (ft^2/1,000ft) for each trout species/lifestage per respective flow. To avoid overestimating trout habitat, an "all" trout classification scheme (described in Section 2 and Appendix A) was used to include cutthroat and rainbow trout habitat suitability with that of brown trout. Based on these HSI curves, the amount of WUA for each trout species and life stage varies at each flow level, but the greatest amount for adults and juveniles is between approximately 25 and 250 cfs. Although the overall trend is the same between the juvenile brown trout curve and juvenile "all trout" curve, the adjustment to accommodate shallower depths had an impact on estimates of available habitat.

As demonstrated in Figure 3.38 and displayed in Image 3.10, the majority of this site provides adult brown trout habitat (> 25,000ft^2/1,000ft) at 100 cfs. As with most of the confined sites, the majority of the main channel is not suitable for adult brown trout at 500 cfs with only limited edge habitat remaining.

SITE 1

IMAGE 3.9. HABITAT NICHES - WEIGHTED USABLE AREA (SITE 1). THE IMAGES BELOW VISUALLY DEPICT HABITAT NICHES THAT ARE PRESENT AT DISCHARGES OF 40, 100, 200, 500, 700, AND 900 CFS. EACH HABITAT NICHE IS REPRESENTED BY THE COLOR IMMEDIATELY ADJACENT THE NUMBER/DESCRIPTION IN THE LEGEND. FOR EXAMPLE, NICHE 6 = MAGENTA, NICHE 5 = BLUE, NICHE 1 = LIGHT YELLOW, ETC.



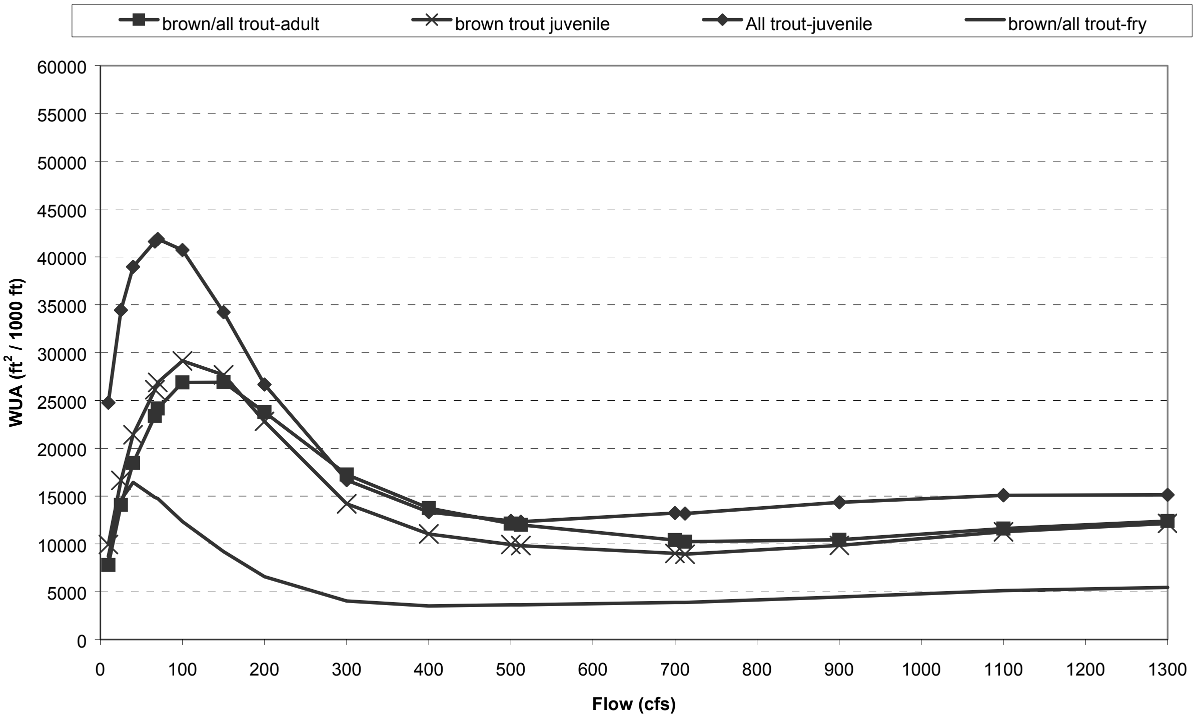
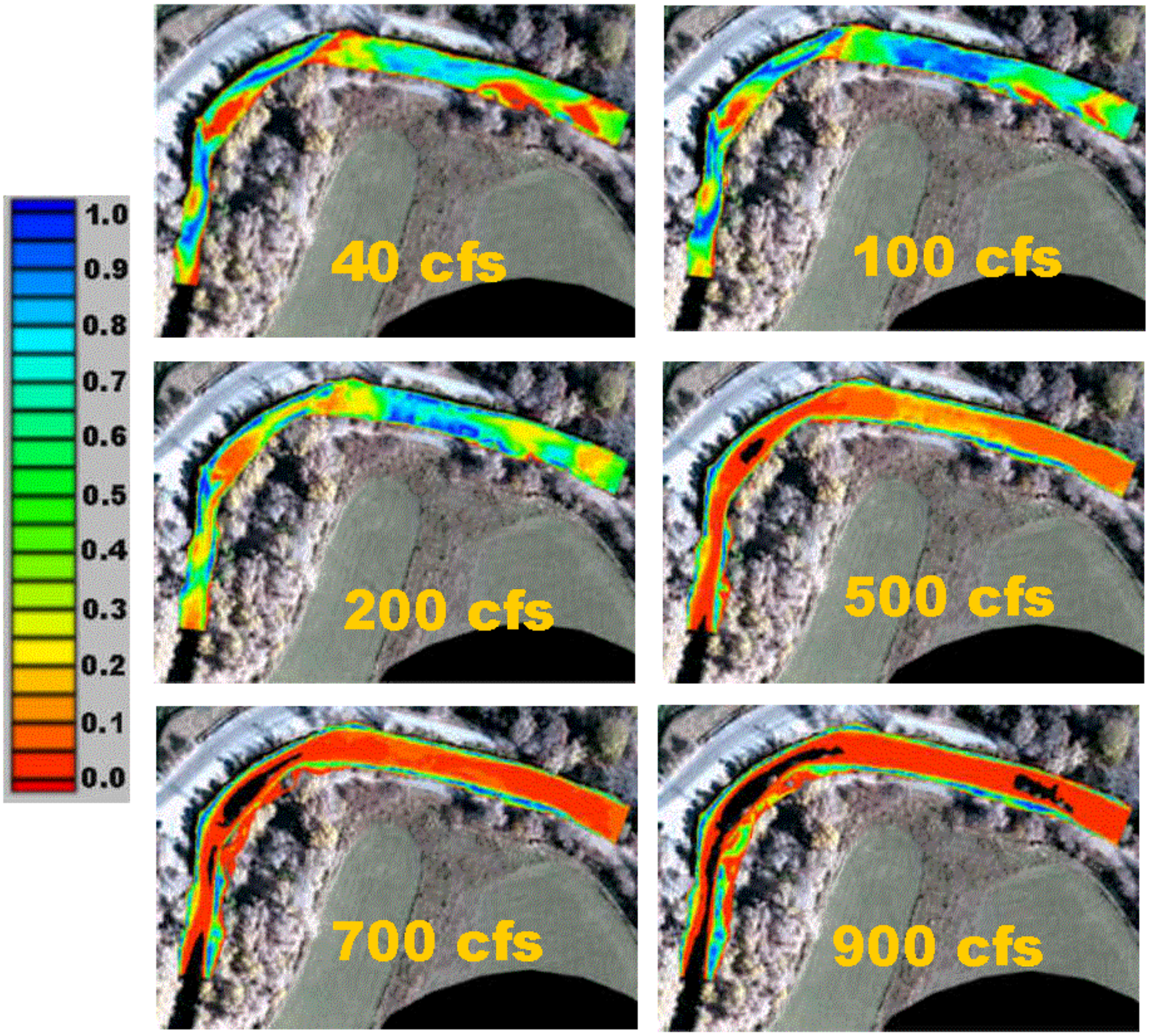


FIGURE 3.38. REACH 1: TROUT - WUA VS. FLOW.

Figure 3.38 reveals that over 15,000ft^2/1,000ft trout fry habitat is available at a peak of 40 cfs while greater than approximately 10,000ft^2/1,000ft is maintain to approximately 150 cfs. This study documents that the optimal range for fry habitat in Reach 1 is approximately 25 to 100 cfs.

An evaluation of the existing data on spawning criteria revealed that although the brown trout curves encompassed the depth and velocity criteria for rainbow and cutthroat trout, the depth and velocities required for the latter two species differed to a degree where an examination of individual curves versus the "all trout" curve was warranted. As substrate requirements were very similar, it turned out that the requirement for lesser depths and velocities for rainbow trout and lesser yet (depths and velocities) for cutthroat trout resulted in less spawning habitat available (Figure 3.39) There is approximately 37,000ft^2/1,000ft of brown trout spawning habitat at the peak of approximately 70 cfs but is maintained at greater than 15,000ft^2/1,000ft to nearly 300 cfs. Rainbow trout spawning habitat follows the same trend but demonstrates considerably less WUA (< 25,000ft^2/1,000ft at all flows). Brown trout spawn in the fall when flows are significantly lower than during spring and early summer when rainbow and the native cutthroat trout spawn. Rainbow and cutthroat trout appear to require similar substrate conditions as brown trout, but more restrictive depth and velocity requirements to spawn; therefore, flows in this reach of the Provo River may be unsuitable for spawning during the late spring and early summer. As evident in Figure 3.39, WUA for spawning cutthroat trout is cut by 10,000ft^2/1,000ft from 25 cfs to 100 cfs and continues to decline as flows increase. Thus, the timing of spawning and less WUA for spawning at any flow level puts rainbow and native cutthroat trout at a substantial disadvantage to brown trout.

IMAGE 3.10. ADULT BROWN TROUT - WEIGHTED USABLE AREA (SITE 1). THE IMAGES BELOW VISUALLY DEPICT SUITABLE HABITAT AVAILABLE TO ADULT BROWN TROUT AT DISCHARGES OF 40, 100, 200, 500, 700, AND 900 CFS. THE BEST HABITAT IS REPRESENTED BY SUITABILITY OF 1.0 (BLUE) AND NO HABITAT IS REPRESENTED BY 0 (RED).



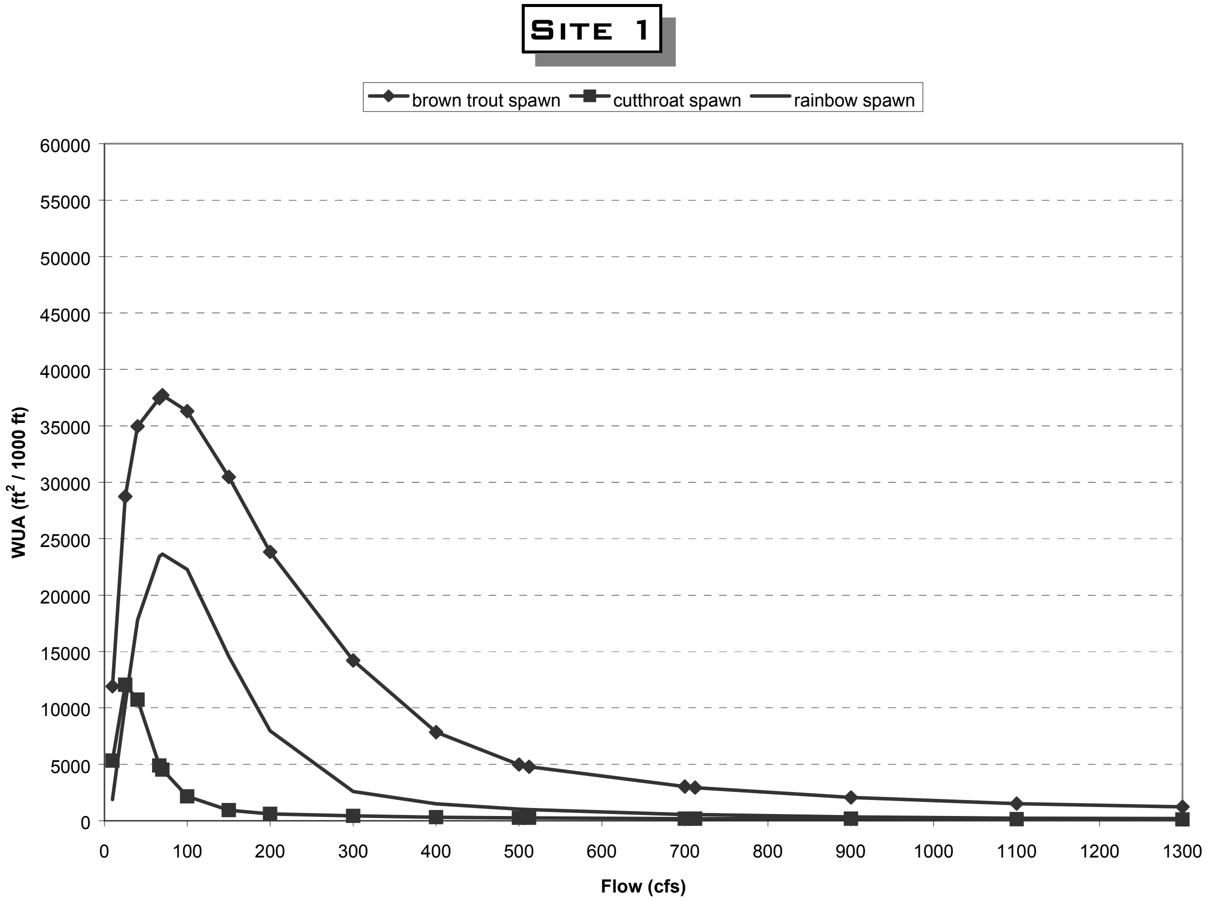


Figure 3.39. Reach 1: Trout Spawning - WUA vs. Flow.

An examination of the individual HSI spawning curve was also conducted for the June sucker in Reach 1. As discussed in Section 1 of this report, Reach 1 consists of the designated critical habitat for June sucker, a federally-listed endangered species. Figure 3.40 reveals that an initial increase in habitat occurs with flow peaking at approximately 150 to 200 cfs and a decline in habitat occurs at higher flows. This range of flows was also documented as optimal for 3 of the 4 sites (Site 1 had no suitable habitat) modeled during the 1987 June sucker instream flow analysis (Radent et al. 1987). The amount of spawning habitat available for this federally-listed endangered species is extremely important. As described in the recovery plan (U.S. Fish and Wildlife Service 1999) the June sucker uses this lower section of the Provo River in late April through early June and having appropriate flow conditions to support spawning and subsequent fry transport is vital to the continued survival of this species. Additionally, the higher water temperatures and/or potentially degraded water quality that is possible during periods of low spring and summer flow may have an impact on the recruitment success of the June sucker.

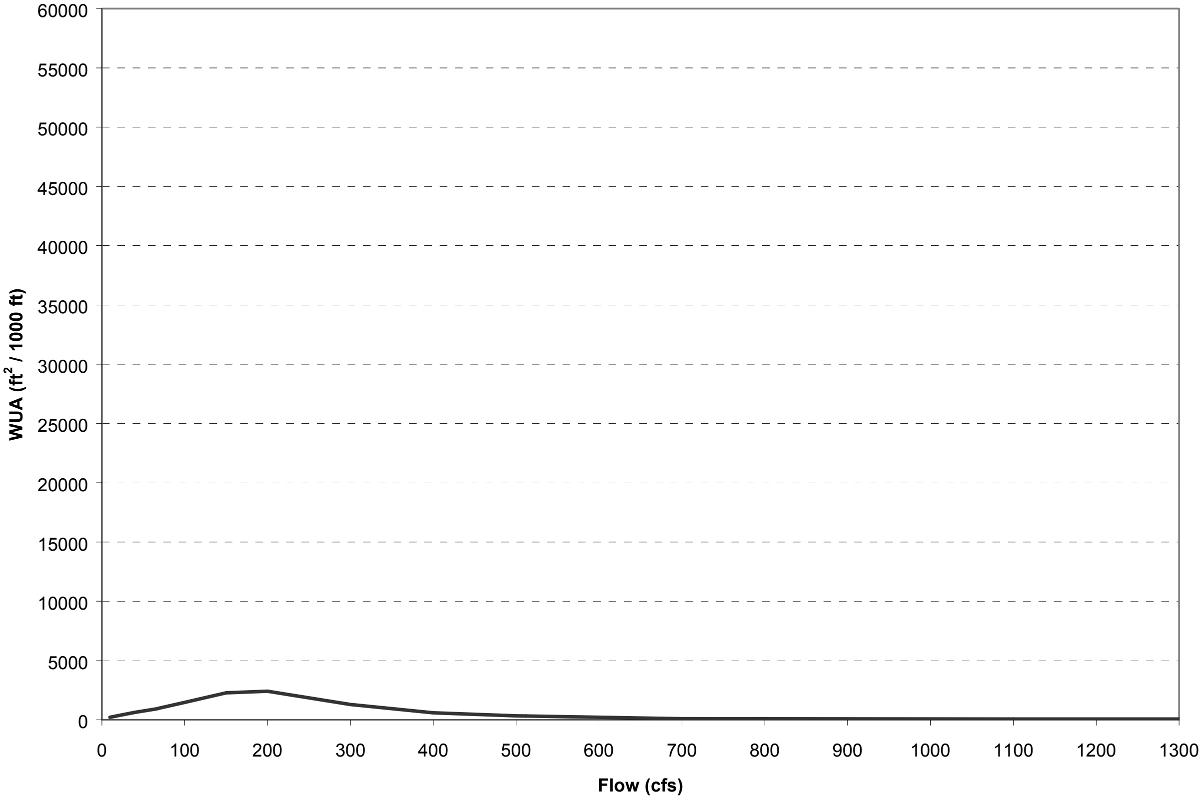


FIGURE 3.40. SITE 1 : JUNE SUCKER - WUA VS. FLOW.

3.6.2 WATER TEMPERATURE - SITE 1

During this study, a thermistor was placed at Site 1 between April 26 and August 16, 2002. The following mean temperatures were observed during the study period.

April (26 - 30)	11.0°C
May	10.7°C
June	14.6°C
July	21.6°C
August(1 -16)	20.3°C

The temperature data was compared to the flow data at USGS Station # 10163000 (Provo River at Provo) to assess thermal fluctuations relative to discharge variations in the Provo River. Figure 3.41 shows the temperatures and flows recorded over the study period.

SITE 1

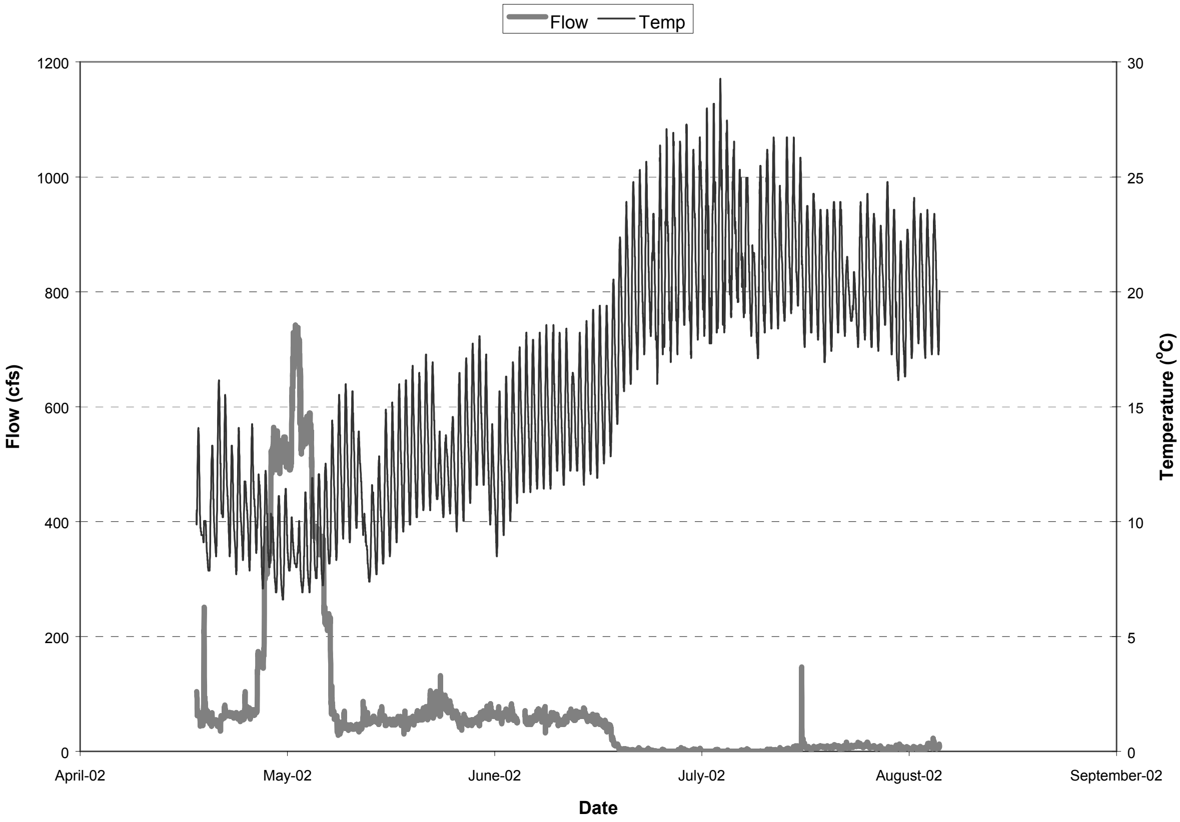


FIGURE 3.41. SITE 1: TEMPERATURE AND FLOW.

Site 1 is located approximately 2 miles upstream from the mouth of the Provo River at Utah Lake. Low-flow conditions are common in this reach. For example, flows of 50 cfs are typical in the springtime in low water years and flows often drop to near zero in mid to late summer. Diurnal temperature fluctuation averaged 4.93°C during the 50 cfs low flows from May 1 to May 6. Under increased flow conditions from May 6 to May 16, diurnal temperature fluctuation decreased to 3.86°C. From May 17 to May 24 the river returned to low-flow conditions and the daily temperature change averaged 5.33°C. Weather patterns are always important in daily temperature changes but under the low <50 cfs flows it seems to have a relatively greater impact on daily stream temperature trends than during higher flows. On May 21 a cold front resulted in minimal diurnal temperature fluctuation (0.93°C); on the 20th and 22nd diurnal fluctuation had been 4.21°C and 4.20°C, respectively.

The average stream temperature from May 1 to May 5 was 10.51°C. During the high flow period May 6 to May 16 the average stream temperature was 9.06°C. From May 17 through May 24 the average stream temperature was 11.78°C. Once the flows were stabilized, a typical warming trend with increasing daily temperatures was observed. The temperature changes and diurnal fluctuations may be very important in understanding the macroinvertebrate assemblages (see Macroinvertebrate

Case Studies in the Discussion section) and recruitment success of fishes in Reach 1 of the Provo River.

3.6.3 RECREATIONAL USABILITY -SITE 1

3.6.3.1 WADING/FISHING

The wading/fishing WUA's calculated for Reach 1 represent the total amount of suitable "habitat" (area) per 1,000 linear feet for the entire reach (Figure 3.42). At 50 cfs, approximately 49,000ft^2/1,000ft of fishing/wading area is provided for recreationalists. At flows greater than approximately 300 cfs, suitable fishing/wading area within this site is reduced to below 25,000ft^2/1,000ft.

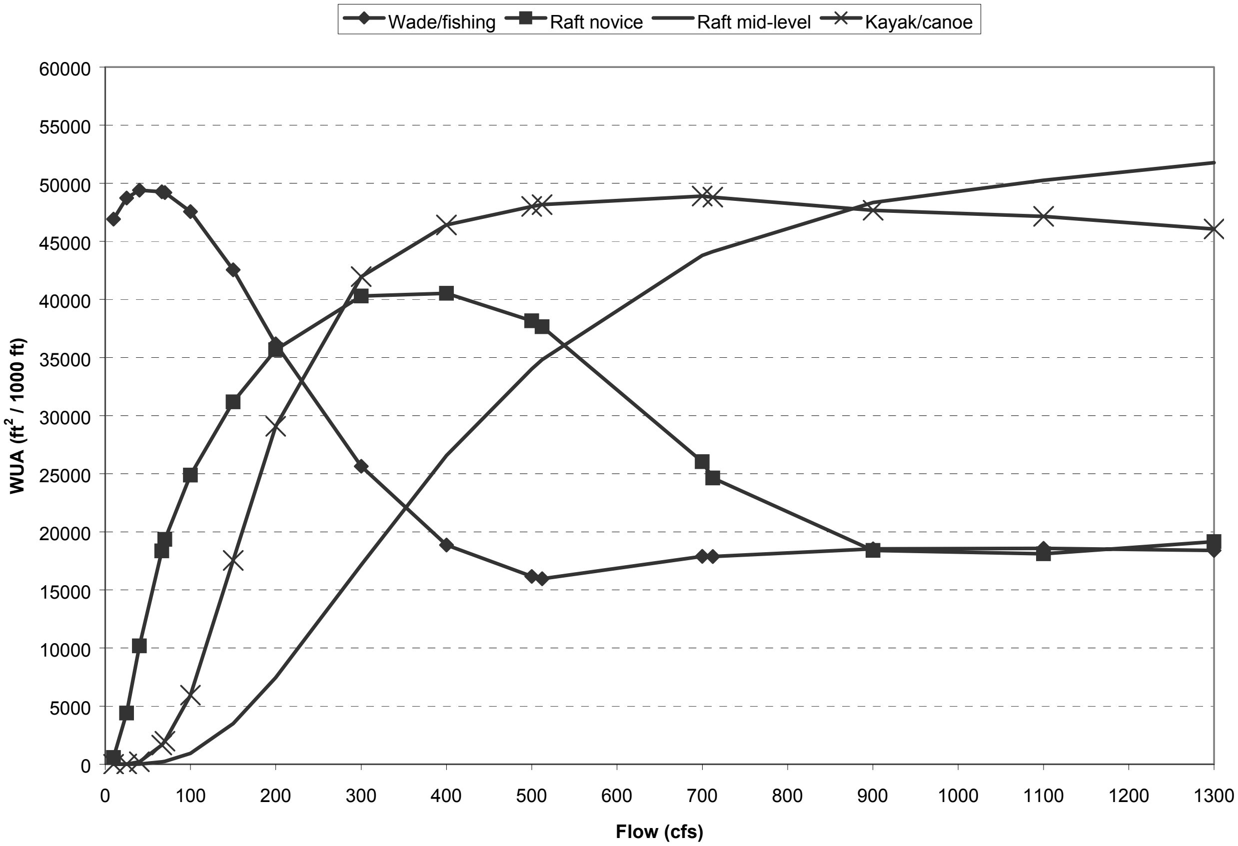


FIGURE 3.42. REACH 1: RECREATION - WUA VS. FLOW.

3.6.3.2 BOATING

Figure 3.42 displays the Reach 1 boating WUA (ft^2/1,000ft) for novice rafting, mid-level rafting, and canoeing/kayaking. The amount of suitable area for canoeing/kayaking increases rapidly as flows increase (> 40,000ft^2/1,000ft increase from 100 to 500 cfs). The peak at approximately 49,000ft^2/1,000ft and subsequent tapering off effect at flows greater than 800 cfs is a result of a conservative classification that includes safety concerns for both canoes and kayaks. It is recognized that experienced kayakers would welcome the challenge of even higher flows. Reach 1 provides more than 25,000ft^2/1,000ft for novice rafters at a flow range of between approximately 100 and 700 cfs, and for mid-level rafters greater than 25,000ft^2/1,000ft of area is available at flows greater than approximately 400 cfs.

3.6.4 SEDIMENT TRANSPORT - SITE 1

3.6.4.1 SAMPLING RESULTS

The results of the bedload sampling at Bridge 1 show that there were mainly fine grained particles in transport at the sampled flows and that flows would have to be higher to initiate the equal mobility phase of sediment transport (Figure 3.43, Plate 3.9).

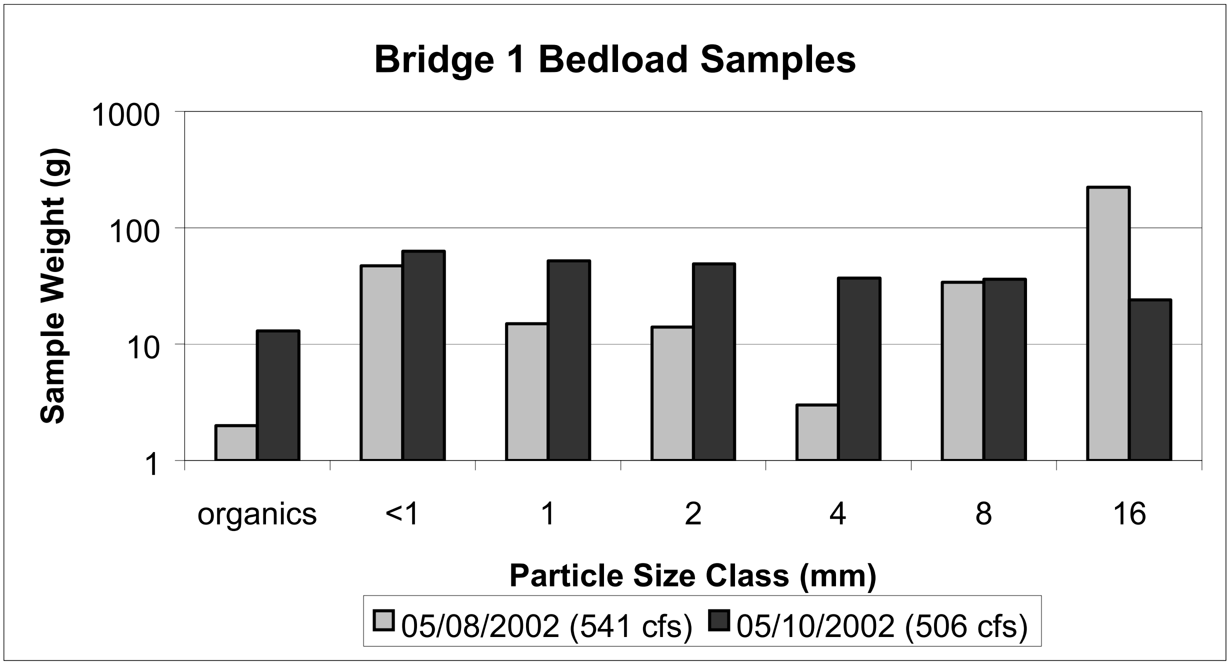


FIGURE 3.43. BEDLOAD SAMPLING RESULTS FOR BRIDGE 1 BROKEN INTO SIZE CLASSES.

541 cfs

506 cfs

PLATE 3.9. PHOTOGRAPHS OF SITE 1 BEDLOAD SAMPLES COLLECTED DURING 2002 SPRING RUNOFF.

Figure 3.44 shows the particle size distribution of the existing streambed at the bedload modeling cross section. Table 3.4 shows important fractions of the streambed particle size distribution compared to the largest particle captured during bedload sampling. Streambed materials are much smaller at Site 1 than any other location within the Study Area as a result of lower stream gradients. As shown in Figure 1.1, the channel flattens before it enters Utah Lake.

3.6.4.2 MODELING RESULTS

Site 1 is located in Utah Valley with limited local supplies of bedload sediments due to channelization and bank stabilization practices (i.e. riprap). There are two additional large diversion structures (Upper and Lower City Diversions) upstream of Site 1 which trap bedload sediments. Even though the channel has a lower slope (Figure 1.1) and smaller sized materials (Figure 3.44), the streambed remains relatively armored. The D_{50} is predicted to remain in-mobile at flows exceeding 2,000 cfs and the D_{25} is not predicted to move until flows exceed 1,200 cfs. Therefore, as with Site 2, the D_{16} (particle 15 mm in size) was used for bedload modeling. The bedload rating curve for Site 1 based on the D_{16} is shown in Figure 3.45. This graph shows that bedload does not begin to move until flows exceed 500 cfs, as with Sites 5 and 6, and once motion is initiated there is a positive relationship between discharge and bedload transport rates.

The bedload rating curve is much flatter at Site 1 than the other sites. Site 1 has much lower bedload transport rates at higher flows. Shear stress values are much lower at Site 1 than the upstream sites at the same discharge levels. This obviously allows for some bedload sediments to fall out of transport or aggrade before entering into Utah Lake. A large delta of accumulated bedload material would naturally form at Site 1 without channelization, upstream sediment traps, and flow regulation.

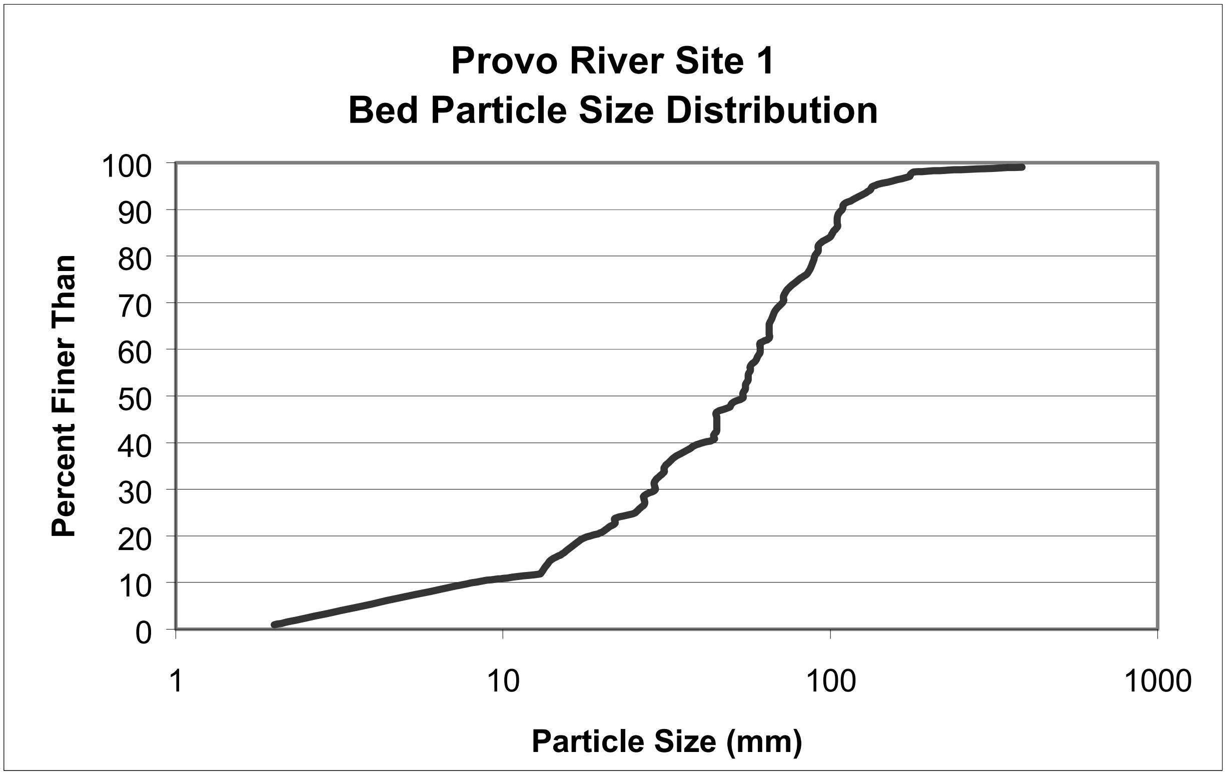


FIGURE 3.44. THE PARTICLE SIZE DISTRIBUTION FOR THE BEDLOAD MODELING CROSS SECTION AT SITE 1.

TABLE 3.4. IMPORTANT FRACTIONS OF THE SITE 1 STREAMBED PARTICLE SIZE DISTRIBUTION AND LARGEST PARTICLE CAPTURED AT BRIDGE 1 DURING BEDLOAD SAMPLING.[A]

SITE	D16	D25	D50	D75	D84	MAXIMUM SIZE AT SITE IN TRANSPORT
1	15	26	54	81	100	47

A THE SIZE OF PARTICLES ARE MEASURED IN MM ALONG THE B-AXIS.

The established DWQ water quality monitoring site located near Geneva Road (Map 1.3) was used for suspended sediment modeling at Site 1. Figure 3.35 shows the relationship between suspended sediment transport and flow at this site. As with the other sites, suspended sediment transport rates are only greater than bedload until flows exceed the bedload transport threshold, then bedload rates increase rapidly and surpass suspended sediment transport rates.

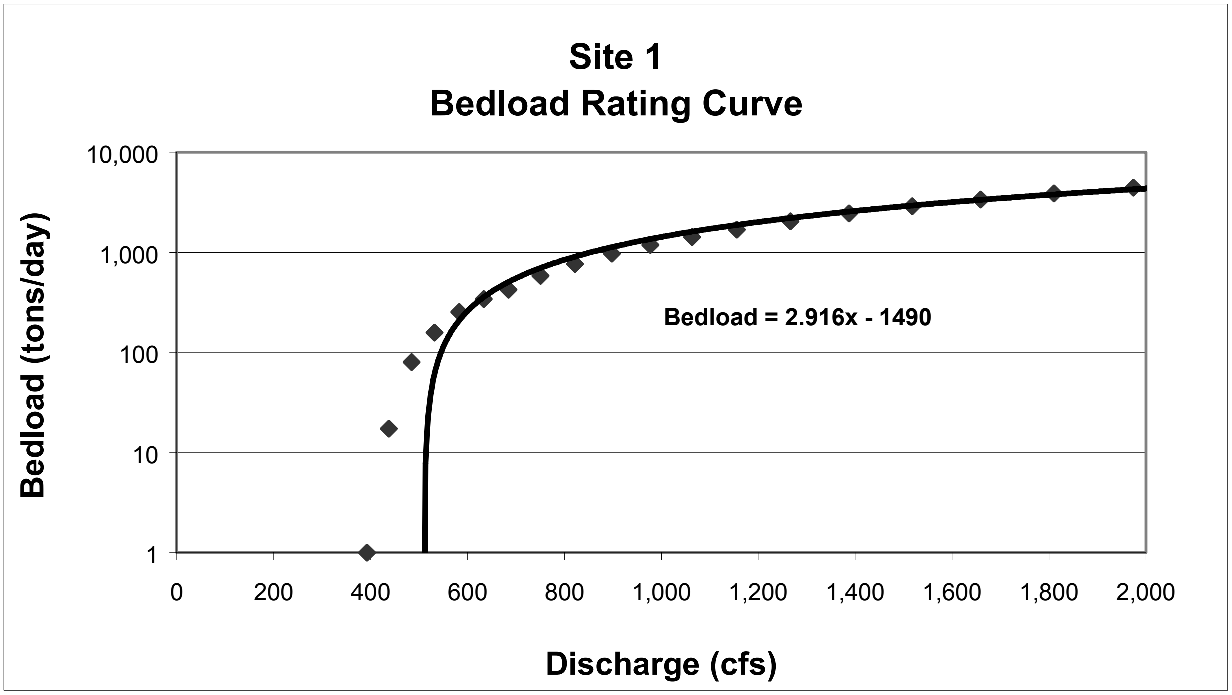


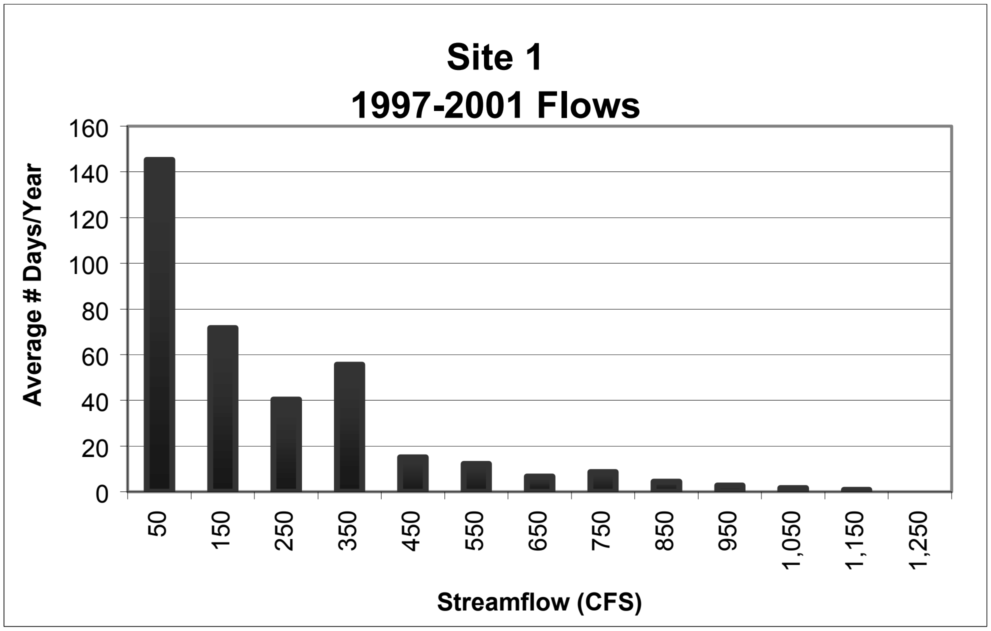
FIGURE 3.45. THE BEDLOAD RATING CURVE FOR SITE 1.

3.6.4.3 EFFECTIVE DISCHARGE RESULTS

Effective discharge calculations show a single peak (flow increment transporting the greatest sediment loads over the past five years) between 700-800 cfs (Figure 3.46). The majority of the year (90% of the time) is dominated by flows less than 500 cfs with no bedload transport. Flows between 700-800 cfs only occur approximately 9 days per year (2% of the time) but have transported the most bedload sediment over the past 5 years. Flows greater than 800 cfs occur less frequently at Site 1 and even though they have a higher daily transport rate, are less and less effective as their occurrences decline.

3.6.4.4 SEDIGRAPH RESULTS

A comparison of sediment transport in terms of timing, magnitude, and duration was made between two alternative flow regimes for Site1 (Figure 3.47). Equations shown in Figures 3.35 and 3.45 defining the bedload and suspended sediment rating curves were applied to average daily flows over the past five years (water years 1997 to 2001). This analysis was performed for the “unregulated” flow regime (based on adjusted Hailstone gage data) and the Site 1 flow regime (Provo River at Provo gage). See Appendix C for actual hydrographs. Unfortunately, average daily flows at Site 1 (averaged over the past five years) are not high enough to cause bedload transport. This is likely caused by multiple years of very low peak flows over the past five years. Low flows over the recent drought years have likely led to accumulation of fine-grained sediment and dense cover of aquatic vegetation on the streambed throughout Site 1.



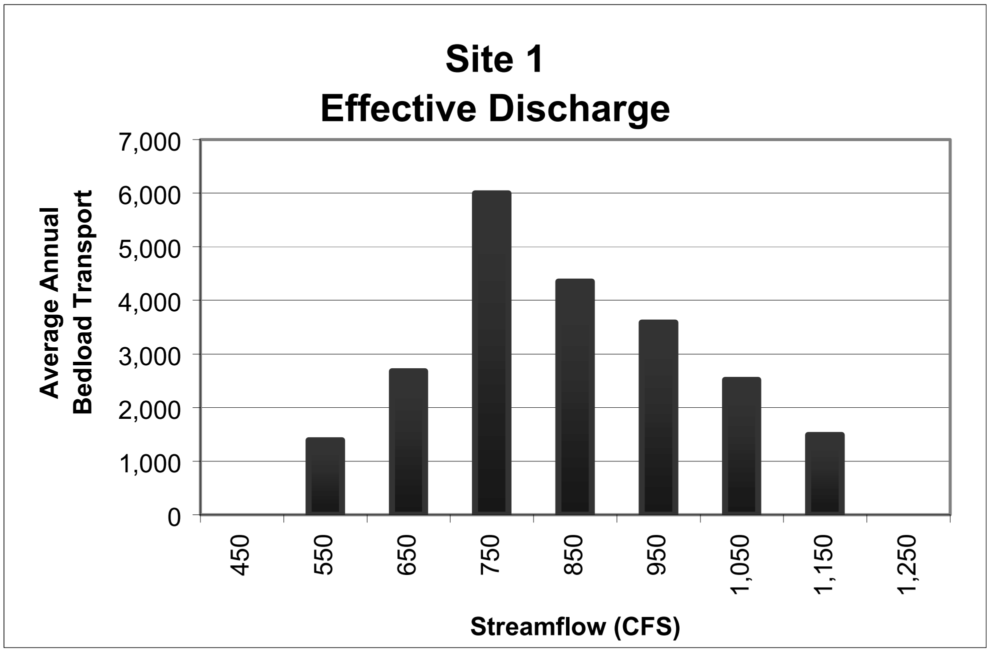


FIGURE 3.46. EFFECTIVE DISCHARGE RESULTS FOR SITE 1. THE UPPER GRAPH SHOWS THE AVERAGE NUMBER OF DAYS PER YEAR STREAMFLOW HAS BEEN WITHIN EACH 100 CFS INCREMENT (0-100, 200-300, ETC.). THE LOWER GRAPH APPLIES THE MODELED BEDLOAD TRANSPORT RATE MULTIPLIED BY THE NUMBER OF OCCURRENCES TO DETERMINE THE STREAMFLOW THAT TRANSPORTS THE MOST BEDLOAD SEDIMENT OVER THE PERIOD ANALYZED.

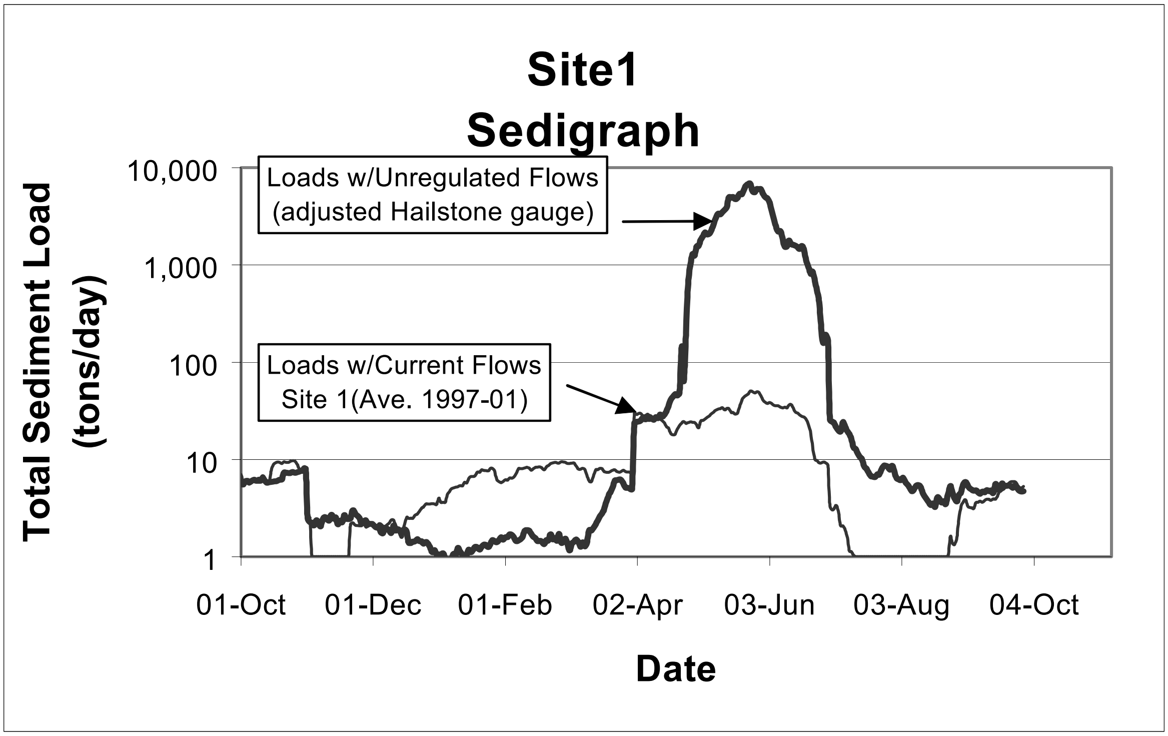


FIGURE 3.47. TIMING, MAGNITUDE, AND DURATION OF SEDIMENT TRANSPORT FOR AVERAGE FLOWS (WATER YEARS 1997-2001) AT SITE 1 BASED ON BEDLOAD AND SUSPENDED SEDIMENT RATING CURVES. THE HIGHER CURVE REPRESENTS THE PREDICTED ADJUSTMENT IN SEDIMENT TRANSPORT WITHOUT THE INFLUENCE OF FLOW REGULATION BY JORDANELLE AND DEER CREEK RESERVOIRS.

An alternative hydrograph (water year 1999) was therefore used as a typical runoff year for Site 1 and a new sedigraph was generated (Figure 3.48) for comparison. The results of this analysis produce bedload transport at Site 1 but illustrate significant differences in type, timing, magnitude, and duration of the sediment transport regime compared to the unregulated 1999 sedigraph. Overall, the magnitude, and duration of the sediment transport regime during spring runoff has a lower peak, starts later, and drops earlier at Site 1 under the “typical” flow regime. Suspended sediment transport remains higher at Site 1 throughout the winter months.

Again, the most noticeable difference in the two sediment transport regimes is the magnitude of bedload transport during spring runoff, causing suppressed flushing flows at Site 1. Flow duration curves were used to calculate total annual sediment loads. The total annual sediment load for Site 1 is 27,000 tons. However, the total annual sediment load based on the unregulated flow regime is approximately 223,000 tons (over 8 times greater than Site 1). Basically, Site 1 is not aggrading as quickly under the current flow regime as would occur under an unregulated flow regime.

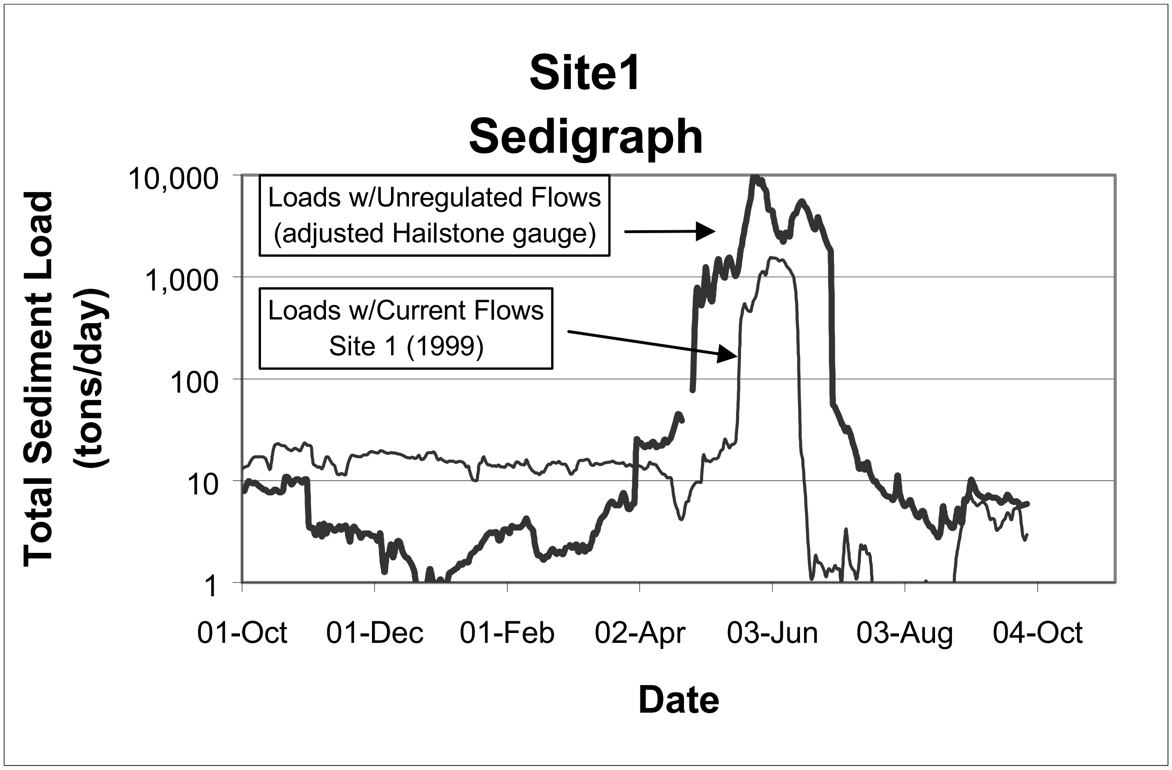
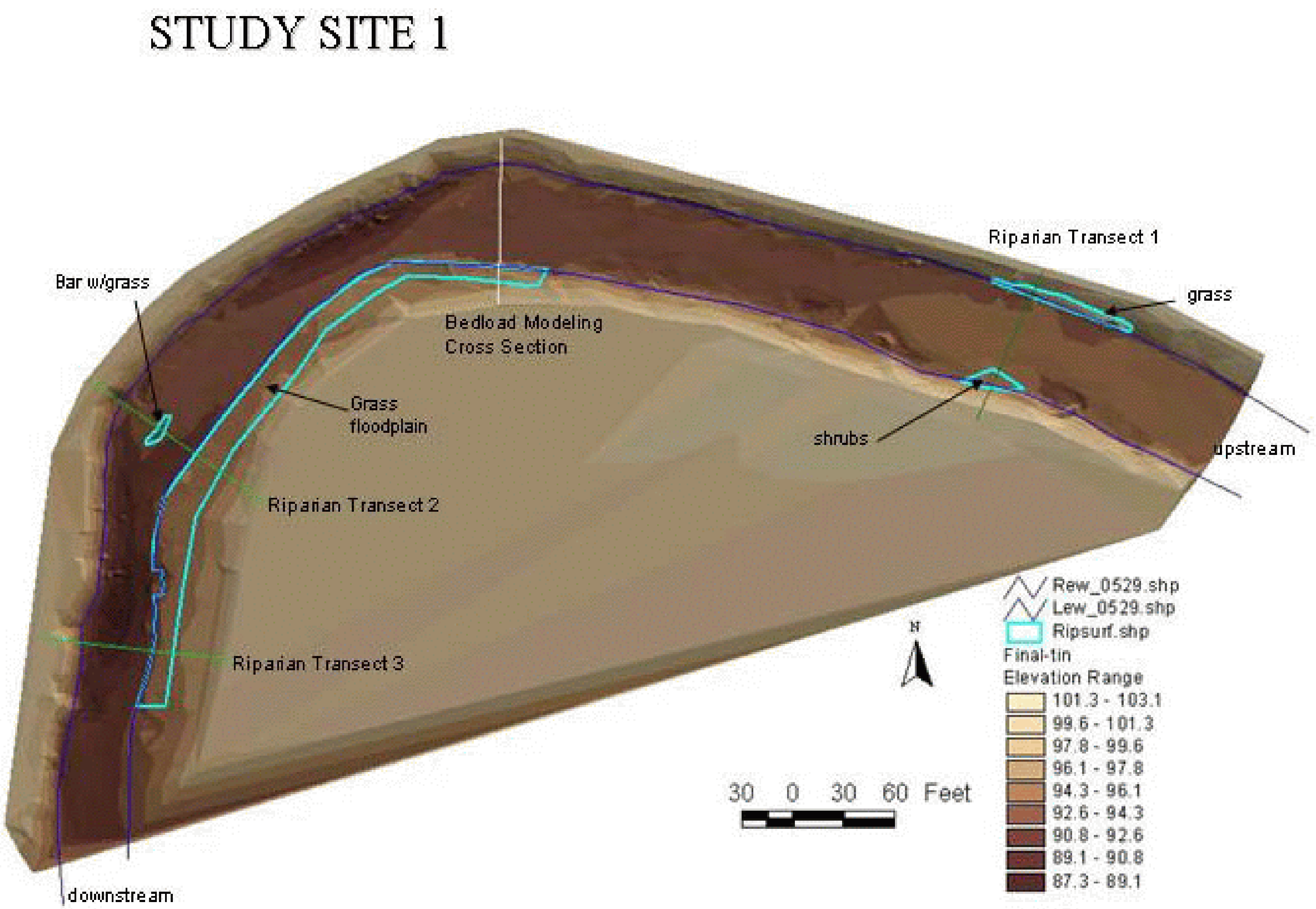


FIGURE 3.48. TIMING, MAGNITUDE, AND DURATION OF SEDIMENT TRANSPORT FOR WATER YEAR 1999 AT SITE 1 BASED ON BEDLOAD AND SUSPENDED SEDIMENT RATING CURVES. THE HIGHER CURVE REPRESENTS THE PREDICTED ADJUSTMENT IN SEDIMENT TRANSPORT WITHOUT THE INFLUENCE OF FLOW REGULATION BY JORDANELLE AND DEER CREEK RESERVOIRS.

3.6.5 RIPARIAN VEGETATION - SITE 1

As with the previous sites, riparian vegetation width at Site 1 is constrained by levees built to protect development. At Site 1, the paved Provo Canyon Trail is located on top of the levee on the north side of the river; agricultural development is present beyond the levee on the south side of the river. As seen in the air photo images for the site (Images 3.9 and 3.10), the width of the riparian buffer is greater on the south side of Site 1. Although channel straightening and the presence of the levees has limited the ability of the channel to meander and develop bars and floodplain surfaces, Site 1 does encompass one meander bend and a vegetated floodplain area is present along the inside of the bend on river left (facing downstream, Map 3.5). In nearly all other areas of Site 1, banks are tall and steep, and rip rap has typically been placed to protect the streambank (Plate 3.10).



Map 3.5. Map of Study Site 1 Showing Riparian Transect and Bedload Modeling Cross Section Locations. Dark Blue Lines Indicate Water's Edge at Low Flow.

Site 1

Plate 3.10. Photos of Site 1 Riparian Surfaces. (a) View of River Right at Transect 1; (b) Upstream View Showing Shrub Area on River Left Crossed by Transect 1; (c) Upstream View of Transect 2 Showing Mid-channel Bar and Grassy Floodplain on River left; (d) Downstream View of Transect 3.

3.6.5.1 Transect Results

Within Site 1, three transects spanning riparian establishment surfaces were selected to evaluate the relationships between streamflow and riparian characteristics (Map 3.5). These transects are plotted in Figure 3.49 along with the range of flows that inundate the different establishment surfaces.

Transect 1 crosses a low-elevation deposit occupied by shrub vegetation on river left and a narrow grass-covered floodplain area on river right (Plate 3.10, Figure 3.49). The grass floodplain area is inundated by flows of about 700 cfs, while the shrub -covered deposit is inundated at lower discharges. Flow duration analysis of data from the nearby USGS gage indicates that flows of 700 cfs or greater occur about 5% or the time at Site 1 (Appendix C). As with the other study sites, the

SITE 1

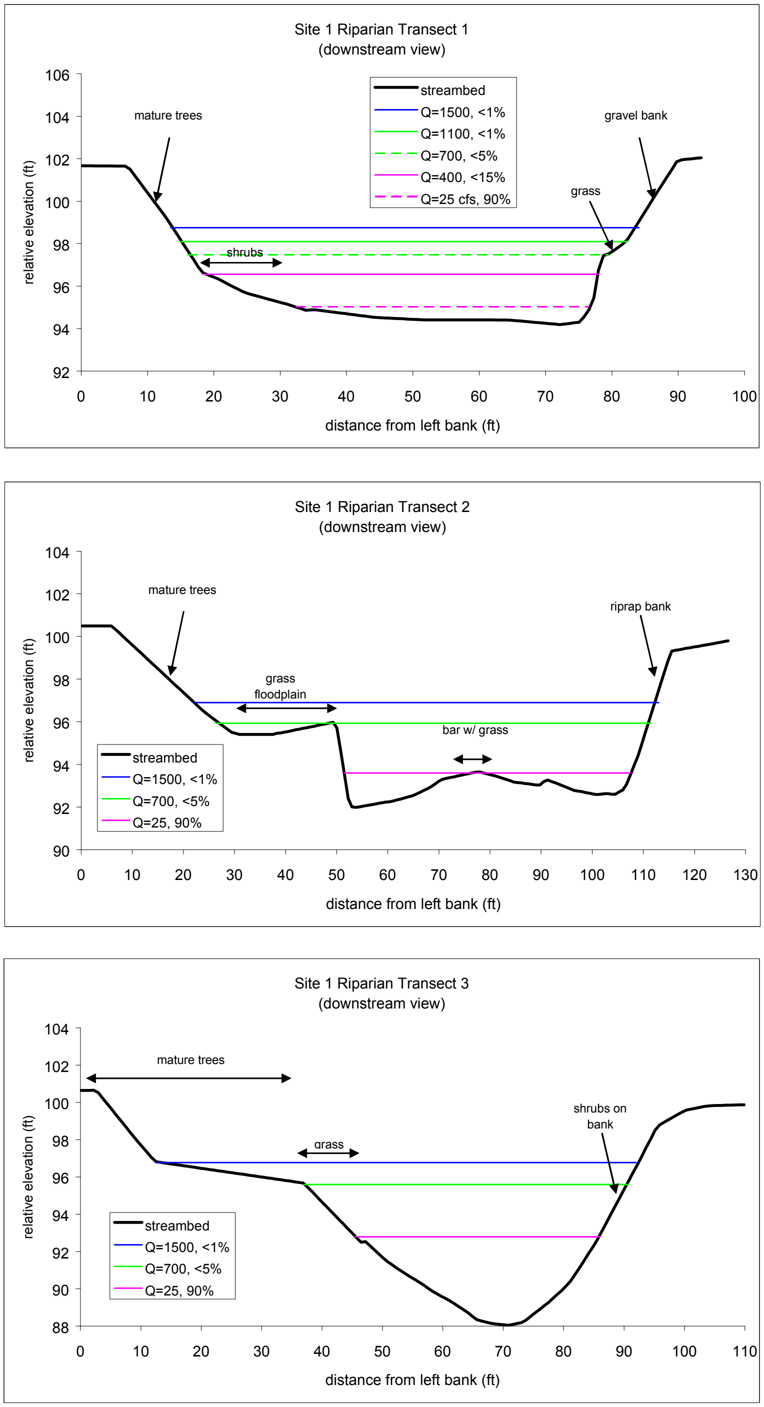


FIGURE 3.49. SITE 1 RIPARIAN TRANSECTS AND INUNDATION DISCHARGES (CFS). PERCENTAGES SHOWN IN LEGEND INDICATE THE PERCENT OF TIME A GIVEN DISCHARGE IS EQUALED OR EXCEEDED.

steep leveed banks on both sides of the channel at Transect 1 easily contain the highest modeled flow of 1,500 cfs, although this discharge level reaches relatively higher up the levees than at Site 2 (Figure 3.49).

Transect 2 crosses a relatively wide grass floodplain area on river left; the bank on river right is steep and rip-rapped (Plate 3.10). The river left floodplain area begins to be inundated by flows of about 700 cfs (Figure 3.49). The 2-year flood at Site 1 is 925 cfs (Appendix C), indicating that the floodplain elevation (i.e., the bankfull channel) matches flood levels slightly smaller than the 2-year flood. At Site 2, similar grass floodplain areas were not substantially inundated until flows reached about 900 cfs, suggesting that bankfull channel size is slightly larger at Site 2. This difference is most likely the result of flow diversions that occur between the sites. Transect 2 at Site 1 also crosses a mid-channel gravel bar vegetated with grass (Plate 3.10); this bar surface is almost completely inundated by low flows of 25 cfs (Figure 3.49). During the summer growing season (which is also the irrigation season), flows at Site 1 are typically very low: the long-term average July flow is only 6 cfs. This allows vegetation to grow on surfaces positioned very low within the channel, such as the bar crossed by Transect 2. Vegetation at the upstream study sites does not grow at elevations as low in the channel as at Site 1. At Transect 2, as with Transect 1, the highest modeled flow of 1,500 cfs is easily contained between the levees.

Transect 3 spans a deep pool (Figure 3.49). The bank on river right is steep and does not provide any flat riparian establishment surfaces. On river left, the bank is less steep, and Transect 3 crosses the downstream end of the grass floodplain area crossed by Transect 2 Map 3.5). As with Transect 2, this grass floodplain is inundated by flows of about 700 cfs. The flow level at 1,500 cfs matches the base elevation of the set-back levee on river left (Figure 3.49).

3.6.5.2 COTTONWOOD RECRUITMENT POTENTIAL

No recently-recruited cottonwood seedlings were noted at Study Site 1. This is most likely due to the unnaturally rapid hydrograph recession rate associated with Deer Creek Dam high flow release patterns, which could cause dessication of any seedlings, if established. Conditions at Site 1 most likely meet the other recruitment requirements, at least in some years. The grass floodplain area on river left is inundated by relatively-frequent flood flows and flood deposits would provide a bare surface for seed germination (requirement 1 discussed above). This surface is located at an elevation high enough that seedlings would be protected from post-germination flood scour (requirement 4 discussed above).

Although the river left floodplain area does provide a potential recruitment surface, the levees at Site 1 artificially clip the horizontal extent of the floodplain surfaces at the site and limit the total area of surfaces at appropriate elevations. However, proposed channel re-configuration activities to restore larval June sucker rearing habitat within the lower Provo River (Reach 1) may provide an opportunity to improve channel conditions to promote cottonwood recruitment. Proposed activities include significantly increasing the floodplain width between levees. However, adjusting flood flow release patterns to reduce flows more gradually would still be necessary in order to prevent seedling dessication. This may be possible in wet water years when surplus water is available. Cottonwood recruitment was observed in several locations within Reach 1 during the channel reach mapping conducted for this study, indicating that successful recruitment is possible in this portion of the Provo River.

4.0 DISCUSSION

4.1 AQUATIC HABITAT: STUDY AREA COMPARISON

4.1.1 REACH COMPARISON

Figures 4.1 through 4.8 display the WUA per flow for each of the respective habitat niches per each modeled study reach. At 10 cfs, niche 1 habitat is greater than 15,000ft^2/1,000ft for Reaches 1, 3, and 6, while Reaches 2 and 5 maintain near or less than 5,000ft^2/1,000ft at the same flow (Figure 4.1). However, as flows increase, Reaches 1 and 3 quickly fall to below 5,000ft^2/1,000ft joining the other confined reaches (2 and 5). Reach 6 (less confined sections of Provo River between Deer Creek and Olmsted Diversion) remains at over 10,000ft^2/1,000ft until nearly 250 cfs and above 6,000ft^2/1,000ft for the remainder of flows. The habitat complexity (beaver dams, log jams, islands, large gravel bars, etc.) in Reach 6 enables it to maintain these lower velocity habitats at higher flows. The other more confined reaches quickly lose low velocity habitat as flows increase. Figure 4.2 reveals that niche 2 habitat can be maintained at above 15,000ft^2/1,000ft for all reaches up to nearly 100 cfs. Reach 1 actually provides the greatest amount of niche 2 habitat modeled (approx. 32,000ft^2/1,000ft). Niche 2 habitat quickly declines in Reaches 1, 2, and 3 while Reach 5 and 6 maintain WUA at higher flows. Reach 5 provides over 10,000ft^2/1,000ft until nearly 300cfs while Reach 6 provides greater than 10,000ft^2/1,000ft until nearly 700cfs. Again, the habitat complexity of Reach 6 enables the creation of slower velocity habitats at greater flows. Niche 3 habitat follows a very similar trend to that of Niche 2 with Reaches 1, 2, and 3 being very similar, but producing as much or more WUA/1,000ft as Reaches 5 and 6 (Figure 4.3). Reach 5 maintains more WUA for niche 3 than does Reach 6 at flows up to nearly 600cfs.

Niche 5 is very important in that it supports the major sportfish in the Provo River. Figure 4.5 reveals that the confined reaches follow similar patterns with increasing habitat at flows between 25 and 250cfs with declines thereafter. Reach 1 displays the greatest amount of habitat with over 30,000ft^2/1,000ft at 200cfs, while Reach 3 maintains the least amount of habitat. Reaches 2 and 5 react very similar, and Reach 6 again exhibits its uniqueness by providing greater than 20,000ft^2/1,000ft at all flows greater than approximately 150cfs. Niches 4, 6, 7, and 8 (Figures 4.4, 4.6, 4.7, and 4.8) are similar with respect to each reach. Again, the habitat complexity of Reach 6 enables it to have less of a rapid increase in Niche 6 habitat as flows increase. Additionally, Reach 6 provides approximately 5,000ft^2/1,000ft more niche 7 WUA than all other reaches at flows greater than 200cfs.

Figures 4.9 through 4.12 show the reach comparison of WUA for the various life stages of brown trout. The trends for each life stage are very similar between reaches and simply vary in the amount of total WUA predicted. The same trends observed for niche 5 habitat are exhibited for the brown trout life stages with respect to confined versus complex reaches. Figure 4.12 shows the reach comparison for brown trout spawning. As mentioned in the results, Site 2/Reach 2 did not support trout spawning because substrate measured within the site was too large. Each reach (excepting Reach 3) supports greater than 20,000ft^2/1,000ft of spawning habitat up to approximately 250cfs. Reach 6 again maintains the most WUA at the higher flows excepting the overbank situation at Site 3/Reach 3 that may or may not actually produce quality spawning habitat. Figure 4.13 shows the fishing/wading WUA per reach at the modeled flows. Similar trends appear with respect to confined versus complex reaches with all reaches maintaining greater than 25,000ft^2/1,000ft until nearly 200cfs.

Overall, the habitat niche approach and individual species/recreation modeling demonstrate that confined reaches from Deer Creek Reservoir to Utah Lake behave in a similar fashion with limited slower velocity habitat maintained as flow increases and decreasing moderate velocity habitat as flows exceed several hundred cfs. Additionally, the modeled results demonstrate the ability of complex reaches (i.e. Reach 6) to maintain greater habitat diversity (more niches, more suitable habitat) at higher flows. Detailed comparisons of flows necessary to maximize ecological health of individual reaches is proposed for Phase 2 of the Provo River project.

4.1.2 COMBINED REACH ASSESSMENT

Figures 4.14 through 4.16 are included to show the combined WUA/1,000ft for all of the modeled reaches for habitat niches, trout, and recreation, respectively. It is understood that the Provo River with all the diversions and coinciding operational schedules does not operate in the true fashion of a contiguous river. However, to evaluate the magnitude that each of the reaches has on the overall river, the WUA/1,000ft values were combined. As evident in Figures 4.14 through 4.16, the trends more closely resemble those displayed by the confined reaches modeled. This is not surprising because of the overwhelming confined percentage of the Provo River from Deer Creek Reservoir to Utah Lake. A close examination of the figures does reveal that Reach 6, albeit small percentage wise, does play a role in extending greater amounts of habitat to higher flows. This overall assessment shows that as the distribution of unique/complex habitat and channelized features shift in one direction or the other, the potential for increased or decreased habitat with greater flows is possible.

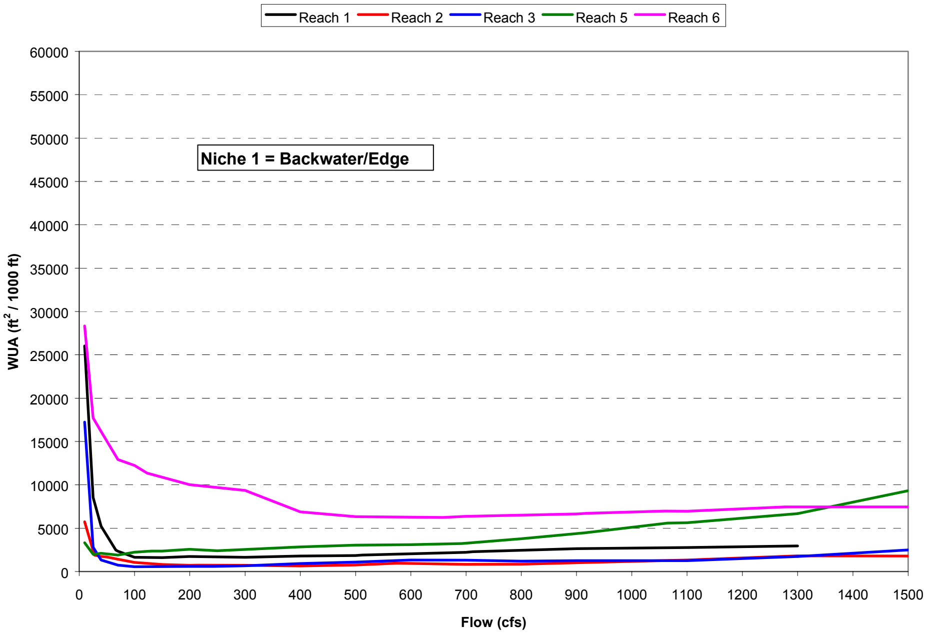


FIGURE4.1. REACH COMPARISON: HABITAT NICHE 1 - WUA VS. FLOW.

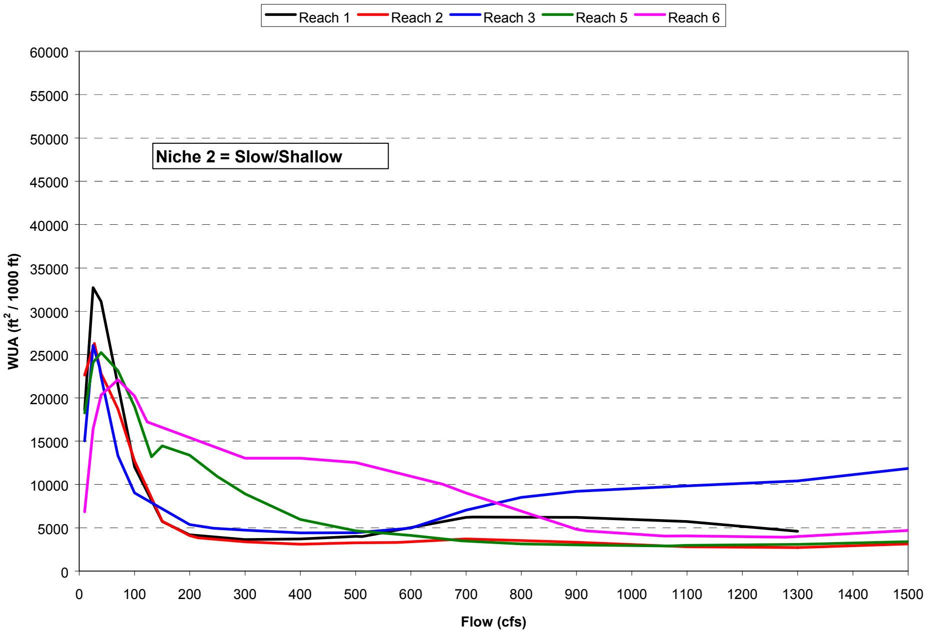


FIGURE 4.2. REACH COMPARISON: HABITAT NICHE 2 - WUA VS. FLOW.

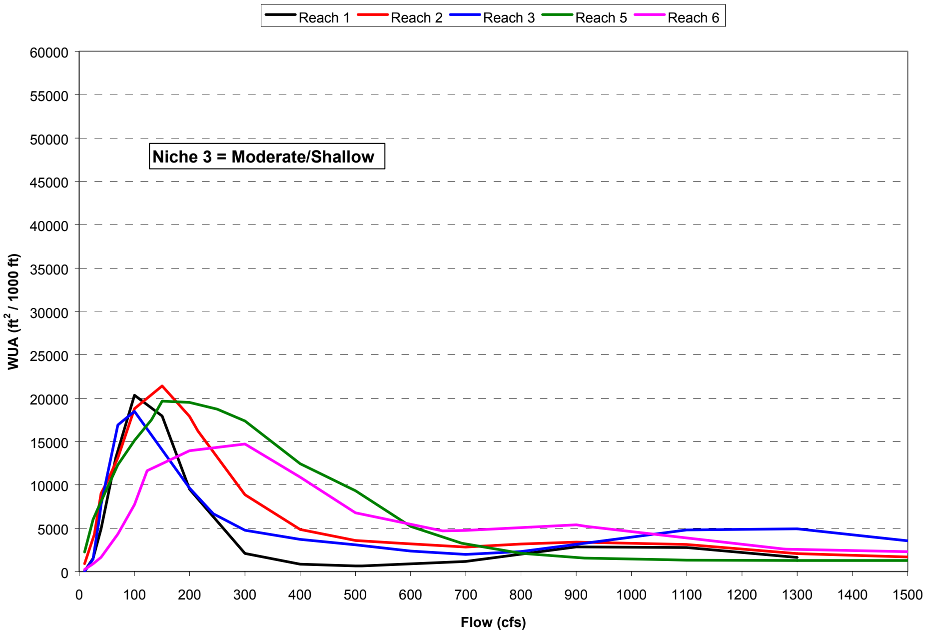


FIGURE 4.3. REACH COMPARISON: HABITAT NICHE 3 - WUA VS. FLOW.

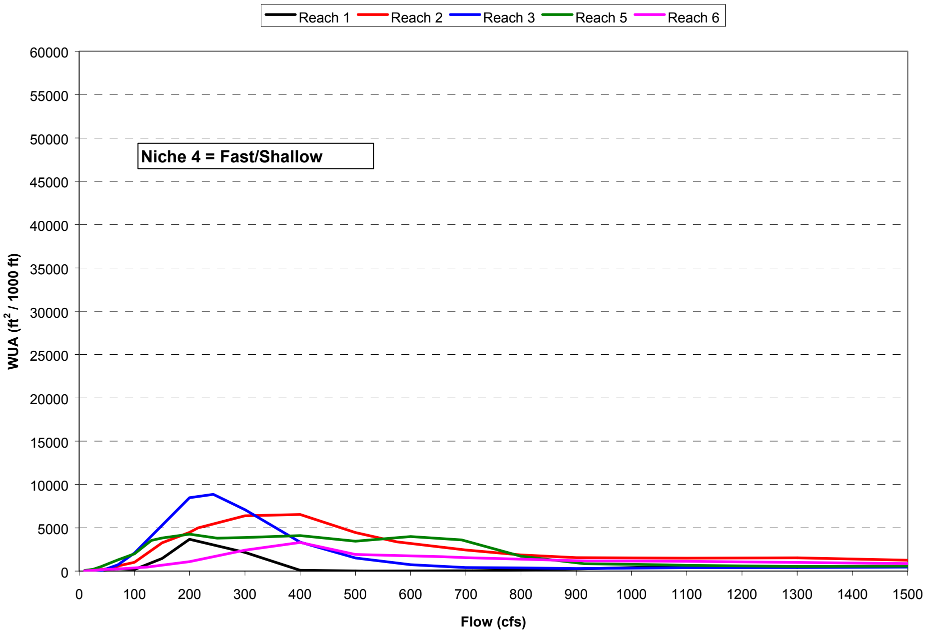


FIGURE 4.4. REACH COMPARISON: HABITAT NICHE 4 - WUA VS. FLOW.

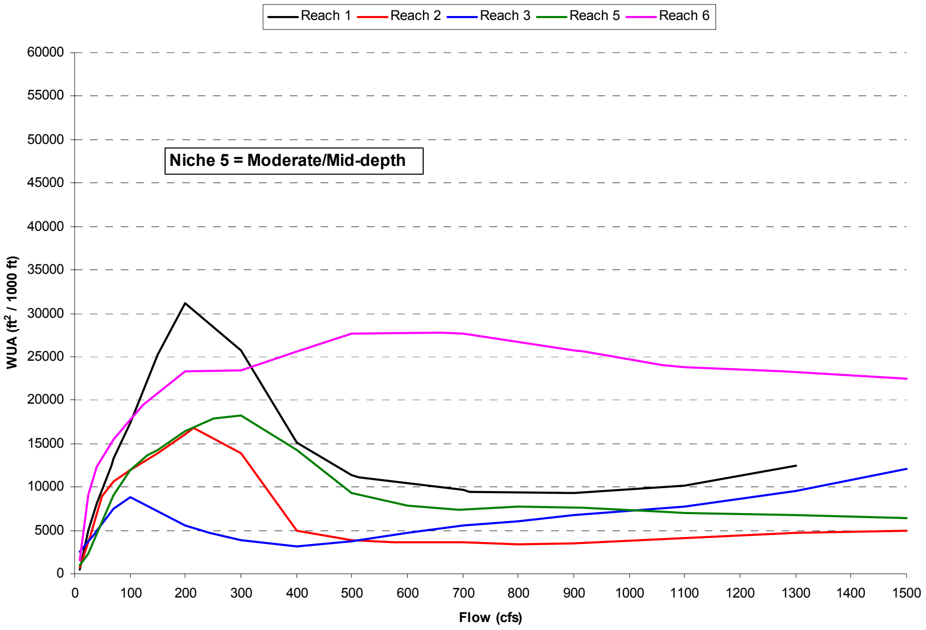


FIGURE 4.5. REACH COMPARISON: HABITAT NICHE 5 - WUA VS. FLOW.

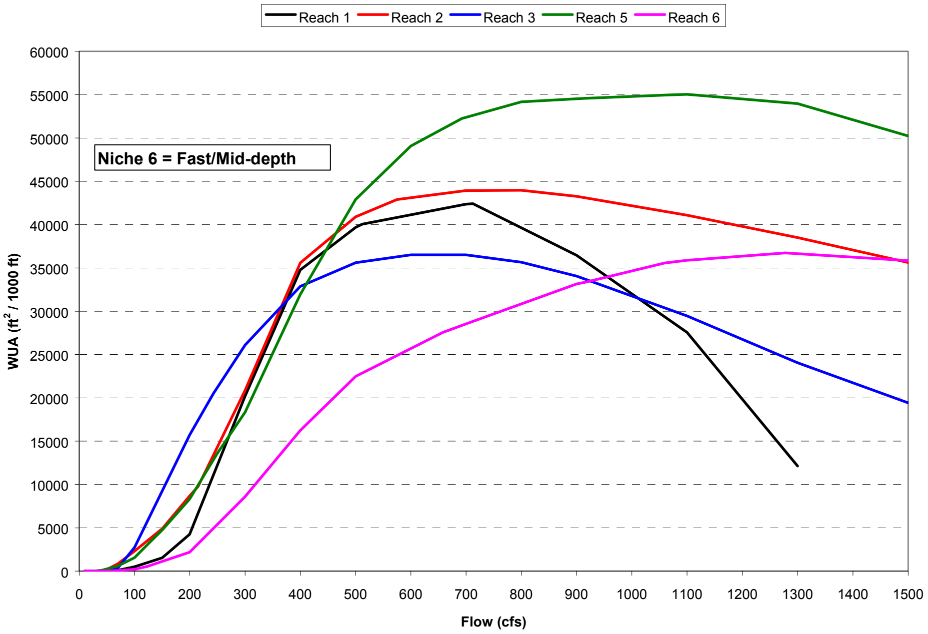


FIGURE 4.6. REACH COMPARISON: HABITAT NICHE 6 - WUA VS. FLOW.

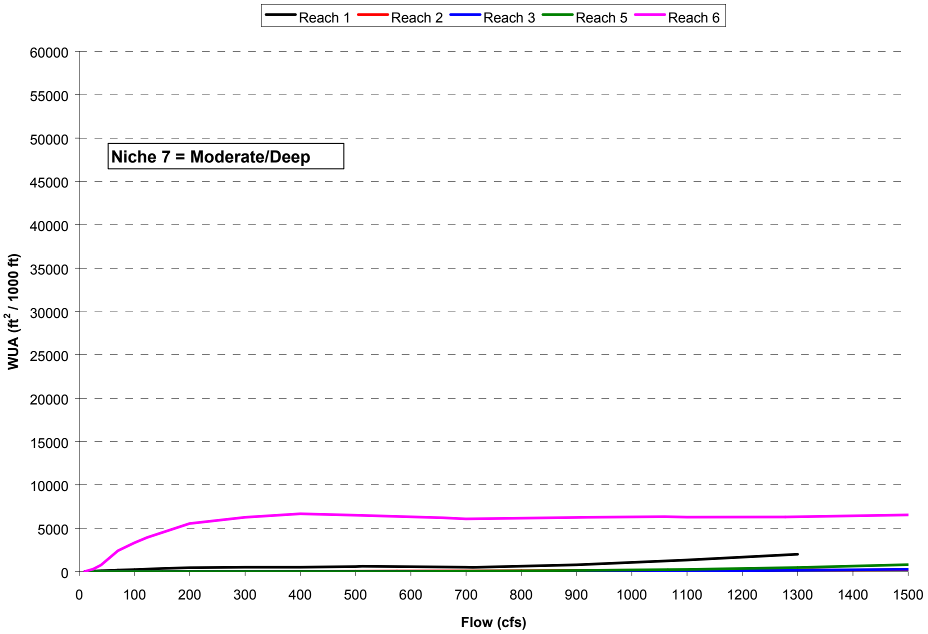


FIGURE 4.7. REACH COMPARISON: HABITAT NICHE 7 - WUA VS. FLOW.

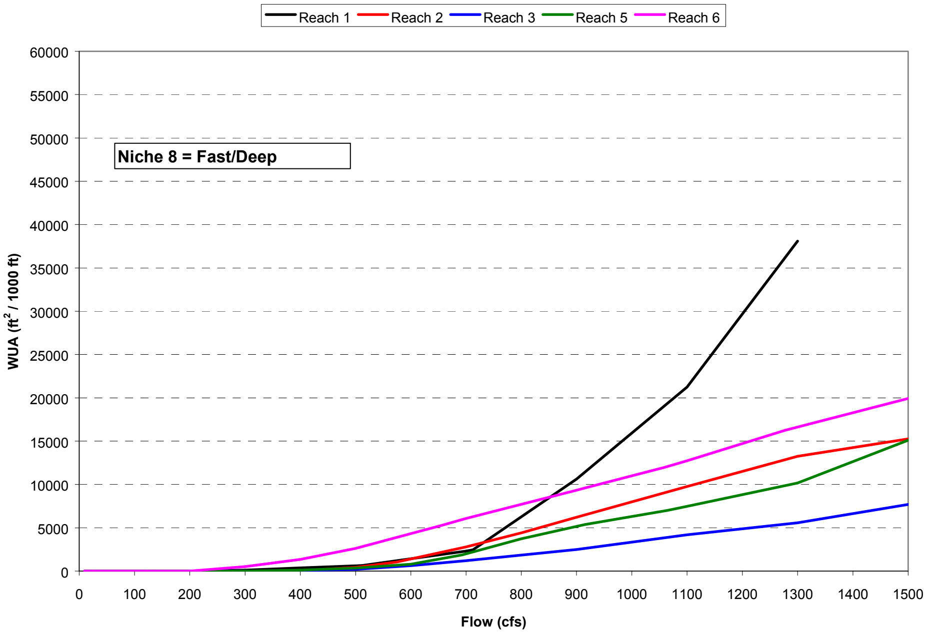


FIGURE 4.8. REACH COMPARISON: HABITAT NICHE 8 - WUA VS. FLOW.

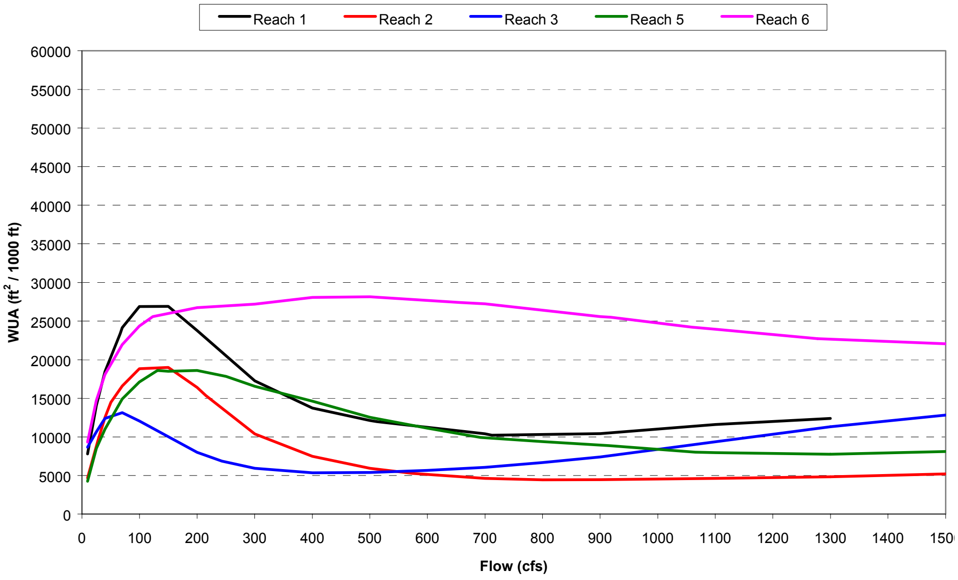


FIGURE 4.9. REACH COMPARISON: ADULT TROUT - WUA VS. FLOW.

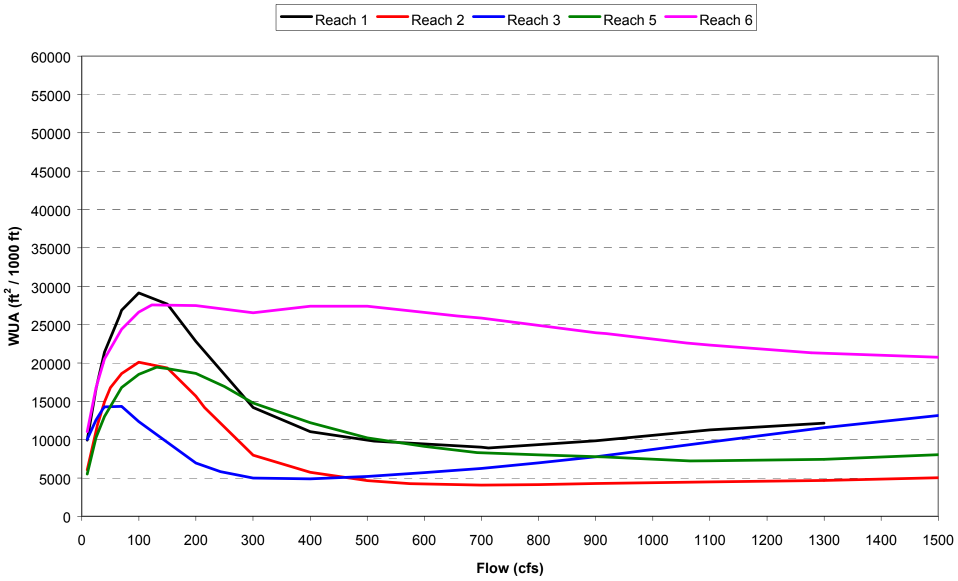


FIGURE 4.10. REACH COMPARISON: JUVENILE BROWN TROUT - WUA VS. FLOW.

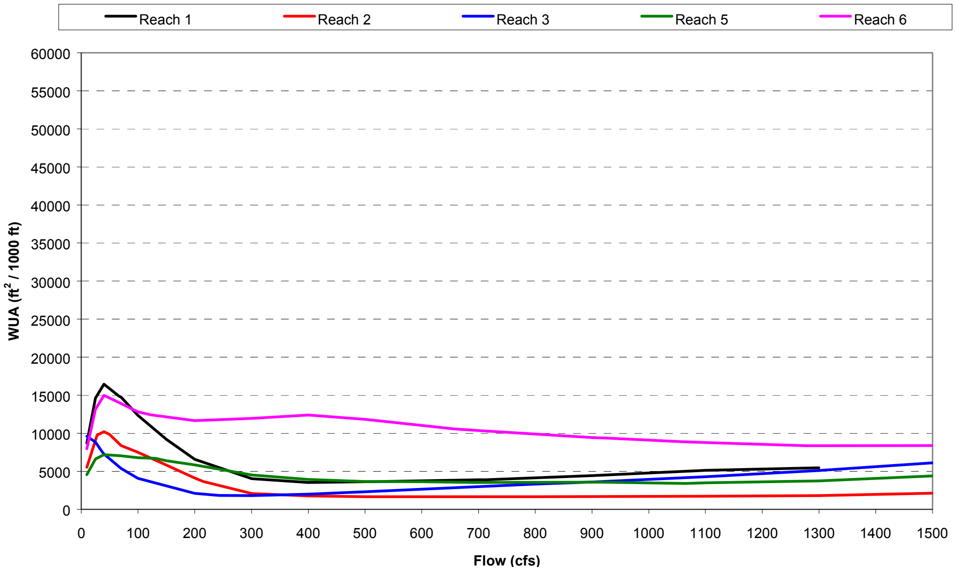


FIGURE 4.11. REACH COMPARISON: BROWN TROUT FRY - WUA VS. FLOW.

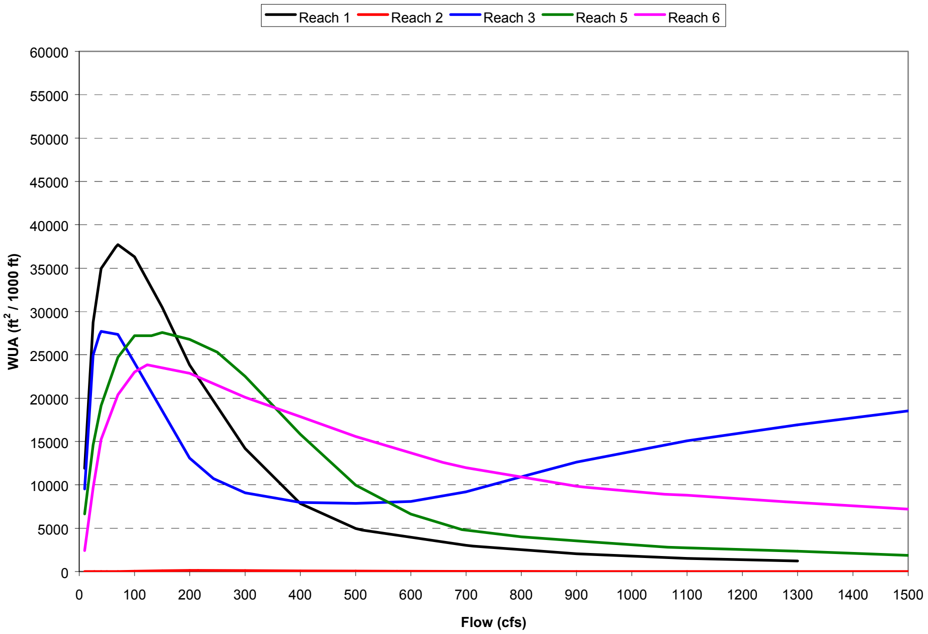


FIGURE 4.12. REACH COMPARISON: BROWN TROUT SPAWNING - WUA VS. FLOW.

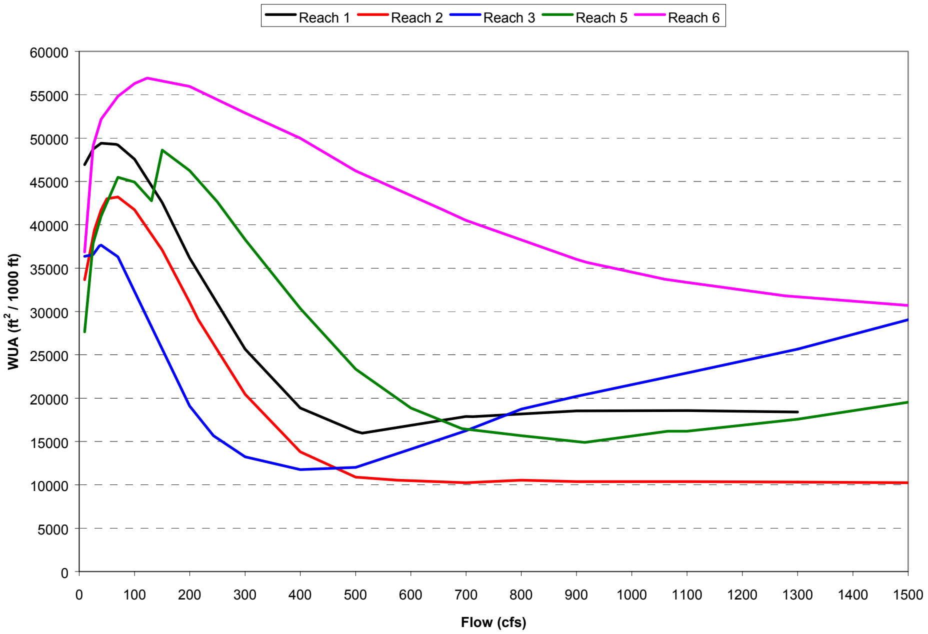


FIGURE 4.13. REACH COMPARISON: FISHING - WUA VS. FLOW.

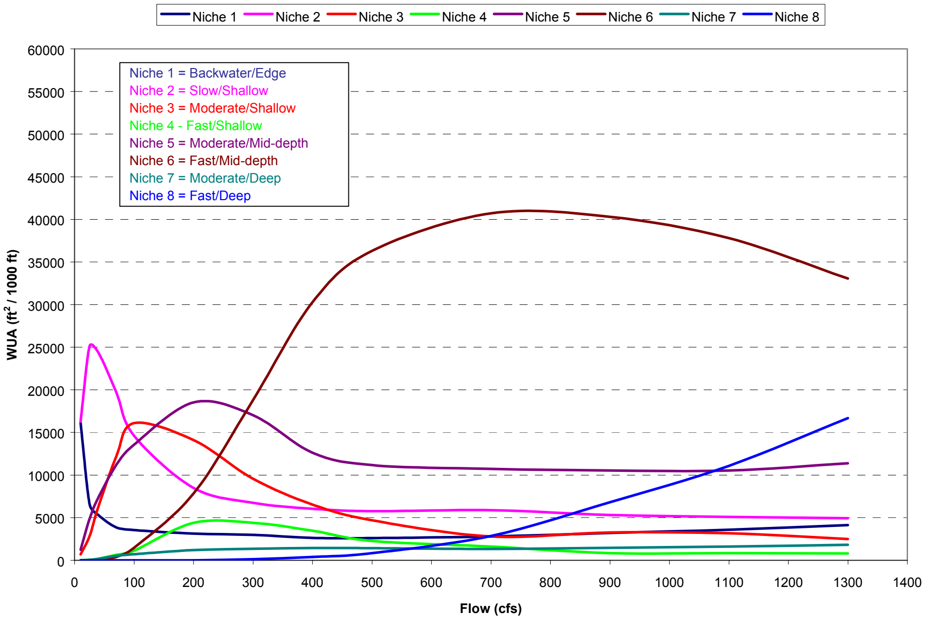


FIGURE 4.14. COMBINED REACHES: HABITAT NICHES - WUA VS. FLOW.

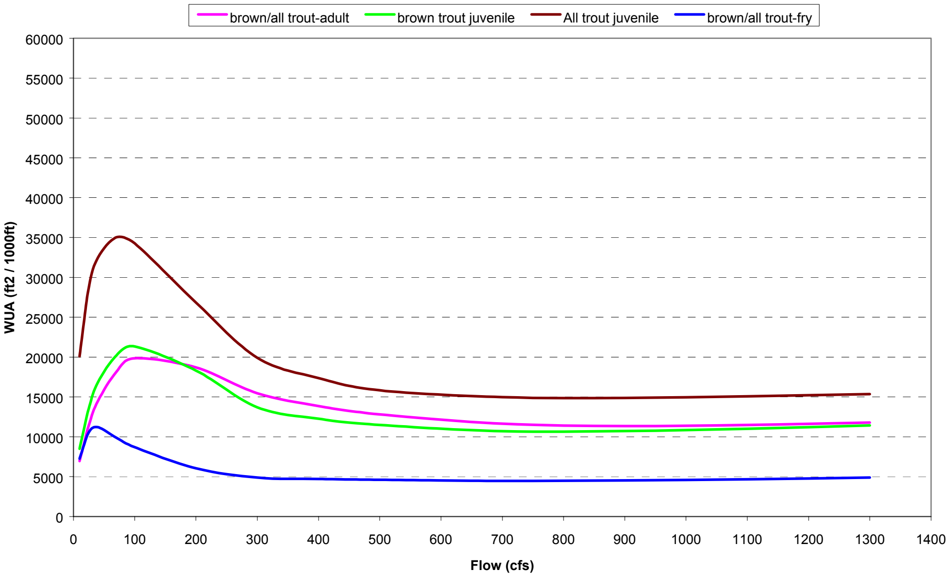


FIGURE 4.15. COMBINED REACHES: TROUT - WUA VS. FLOW.

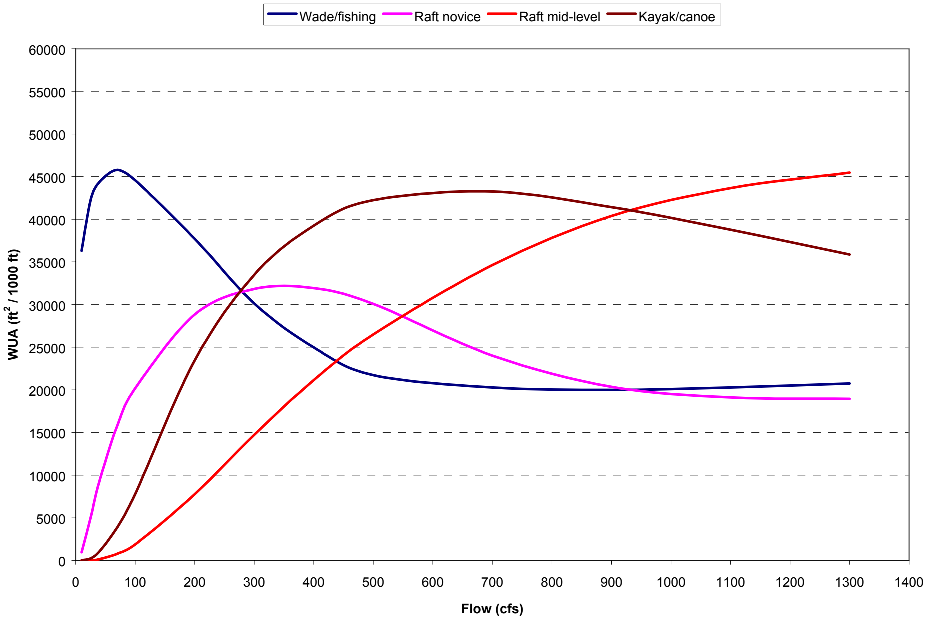


FIGURE 4.16. COMBINED REACHES: RECREATION - WUA VS. FLOW.

4.2 MACROINVERTEBRATE-STREAMFLOW RELATIONSHIPS

Alterations to streamflow regimes have the potential to affect the macroinvertebrate populations that serve as a food base for riverine fisheries. As discussed in the Section 2 of this report, the existing macroinvertebrate dataset on the Provo River is inadequate to allow development of a quantitative model for use in predicting flow-related impacts to macroinvertebrates. Therefore, a review of case studies on other rivers that have experienced flow alterations is provided.

Research on areas below deep release dams provides useful case studies of the impacts that altered flow regimes can have on invertebrate communities. Flow regulation can result in reductions in the seasonal and diurnal temperature fluctuations; interruptions in the cycling of nutrients, food and sediment; and, alterations of bedload movement that result in changes to channel form and substrate characteristics. Changes in the seasonal timing of the flow and temperature regimes of a system can impact the life history characteristics of individual species (Ward and Stanford 1979, Vannote and Sweeney 1980, Power et al. 1996). The changes in life history often result in reductions in species diversity (Ward 1974, Ward and Stanford 1979). Dipteran and worm populations generally see large increases in tailwater release areas, while mayfly, stonefly, and other benthic orders are generally significantly reduced.

The flow regimes below deep release dams are generally altered by lowering spring runoff and delivering higher flows during the summer months. This alteration of the normal flow regime changes the transport of nutrients and particulates, which can alter the amount and diversity of food items available. An alteration of the food base can change the bioenergetics of the system. Additionally, changes in water velocity can impact channel forming flows, which structure the bedform and substrate composition of the 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 habitat niches available. All of this works to limit the diversity of habitat available for macroinvertebrates. Since macroinvertebrates are good indicators of stream ecosystem health, as well as a valuable component of the food chain for fish populations, it is important to understand the potential ramifications of regulated flow changes on the macroinvertebrate community. Below we summarize information from two other river systems affected by altered flow regimes - the Green River and the San Juan River - to provide examples of the potential impacts of such changes on macroinvertebrate communities.

4.2.1 CASE STUDIES

4.2.1.1 GREEN RIVER BELOW FLAMING GORGE

Flaming Gorge Dam was completed on the Green River in 1962 for flood control and hydroelectric power generation. Prior to the completion of the dam, peak discharges exceeding 10,000 cfs (300 cms) were often seen in the spring, and flows as low as 350 cfs (10 cms) were seen in the winter (Vinson 2001). Water temperature ranged from 0-26° C, with mean summer temperatures around 18° C (Vinson 2001). After dam closure, maximum flows were decreased over 50%, while minimum flows were doubled (Vinson 2001). The flows fluctuated with power demand, resulting in a loss of the natural climate-driven seasonality of the flow regime. Additionally, the range of temperature dropped to 0-14° C and the warmest average temperatures occurred in November at about 9° C (Vinson 2001). In 1978, a multi-level water withdrawal structure was completed to increase mean summer water temperatures and to try to provide a thermal regime closer to pre-dam conditions. Mean summer water temperatures were increased from 6° C to 12° C, and peak temperatures occurred in July versus November (Vinson 2001). The changes in flow and temperature regime caused by the dam and its release schedule have resulted in changes to the macroinvertebrate community.

Vinson (2001) examined 50 years of macroinvertebrate data and 100 years of hydrologic data on the Green River in the vicinity of Flaming Gorge dam. He compared macroinvertebrate communities and flow conditions at areas around and below the dam before the dam was in place, after the dam was finished, and after modifications were made to the dam to increase summer water temperatures. Pre-dam collections ranged from 175 km above the present dam location to 18 km below the dam. Post-dam collections were grouped into collections made 0-18 km below the dam (above a large tributary), and 26-27 km below the dam. The pre-dam community was very diverse and housed at least 30 species of mayfly. Densities were relatively low at about 1,000/m2, and 60-80% of the community was comprised of mayfly taxa. Following the closure of the dam, the area 0-18 km below the dam saw a rapid increase in the density of macroinvertebrates, along with a drastic decrease in the diversity of insects. Midges and blackflies dominated the community, and the number of mayfly taxa was reduced to one common taxa and two rare taxa. Amphipods began to appear in the post-dam community after a number of years, as well. After the thermal restoration, amphipods and midges dominated the community 0-18 km below the dam. Density fell slightly and remained more consistent. Taxonomic richness remained as low or lower than in the years immediately following dam closure.

The area 26-27 km below the dam saw a more gradual change in the invertebrate community. Densities rose slowly, and reached levels comparable to the reaches closer to the dam after the thermal restoration. Midges and blackflies became more numerous, but mayflies still comprised 37% of the organisms collected. Amphipods are present, but only in low numbers.

Vinson (2001) determined that the change in the temperature regime immediately after dam completion played a large role in eliminating a large number of taxa from the system. The warmer winter and cooler summer temperatures resulting from the dam operation both played a role in reducing species diversity. Additionally, he felt that the limitations on downstream drift caused by the reservoir, and negative interactions with invertebrates that established themselves in high densities in the post-dam environment, prevented some invertebrates from recolonizing the area below the dam after the partial restoration of the thermal regime. He concluded that to reduce impacts to the diversity of the invertebrate community from dam systems, it is necessary to retain a hydrologic and thermal regime as similar as possible to the natural riverine condition.

4.2.1.2 San Juan River below Navajo

Navajo Reservoir began storage in June 1962 to provide water for the Navajo Irrigation Project, flood control, silt abatement, power generation, and recreation (Holden et al. 1980, Stone et al. 1983). The reservoir has altered the flow and temperature regime of the river below the dam. The pre-operation temperature regime varied between 0-25° C, with coolest temperatures in the winter and warmest temperatures in late summer and early fall (Dubey 1996). The post-operation temperature regime ranges from 3-14° C. Post-operation summer temperatures are colder and winter temperatures are warmer than the original temperature regime (Dubey 1996) . In 1992 the dam release schedule was altered in an attempt to more closely mimic the natural hydrograph for the benefit of native fish. However, the change in release schedule has not resulted in a significant change in the temperature regime (Dubey 1996). The following studies offer a look at how modified flow regimes have impacted the benthic communities of the San Juan River below Navajo Dam.

Holden et al. (1980) sampled the benthic and drift macroinvertebrate populations at 16 stations on the San Juan River below Navajo Dam. Their stations ranged from just below the dam to almost 183 miles downstream. Additionally, they used PHABSIM to develop habitat suitability curves for three species and determine the amount of available habitat for these species at three different flows scenarios: 300 cfs, 650 cfs, and 1200 cfs. They found that macroinvertebrate densities were highest at those stations closest to the dam. Densities remained fairly high for about 16 miles below the dam, and then generally decreased moving downstream. Conversely, taxonomic diversity was lowest at the stations closest to the dam. Mayflies, stoneflies, and caddisflies comprised little if any of the macroinvertebrate populations at their stations 1-4, which extended from the base of the dam to approximately 13 miles downstream. Conversely, a large proportion of the benthic community was comprised of mayflies, stoneflies, and caddisflies at their stations 12-20, which extend from approximately 53 miles downstream to 183 miles downstream. They noted that studies conducted before the dam's completion showed a benthic community in the vicinity of the dam very similar to what they found in the downstream areas.

Holden et al. (1980) also created habitat suitability curves for three species commonly found during their study, the mayfly *Ephemerella inermis*, the caddisfly *Hydropsyche* sp., and the blackfly *Simulium* sp. They concluded that based on the depth, velocities and substrate information collected at the different flow levels, that impacts on the macroinvertebrate community would be minimal as long as flows remained between 300-1200 cfs. Within this range of flows, habitat that was taken away for certain species by higher velocities was made available for other more rheophilic species. Additionally, as the total wetted area increased, slower habitat that was lost in the main channel, was regained along the margins. However, they cautioned that the PHABSIM analysis did not encompass other potentially important variables, such as temperature and turbidity that can also structure macroinvertebrate communities. Temperature data collected in this study showed that the warmer winter and cooler summer temperature regime, often seen below dams, extended downstream for at least 13 miles before air temperatures began to return the water to a more natural thermal regime. The area most influenced by this altered thermal regime had the most impaired invertebrate community, as well. Holden et al. (1980) also concluded that temperature was the water quality variable most directly linked to flows, and that the greater the magnitude of flow release, the greater the downstream distance of thermal impact.

Dubey (1996) also studied the San Juan River macroinvertebrate community below Navajo Dam from 1994-1996, including an examination of winter flow reductions in 1996. He sampled four sites below Navajo Dam at 10-week intervals, and also sampled a site above Navajo Reservoir less frequently. He found that the sites closest to the outlet of the reservoir had more dense, less diverse macroinvertebrate communities. The communities near the base of the dam were dominated by midges, blackflies, and worms. Two mayfly taxa, and no stonefly or caddisfly taxa were collected at the station closest to the dam.

Macroinvertebrate diversity seemed to improve on a gradient further downstream from the dam release. At the downstream-most site, 3 stonefly taxa, 3 mayfly taxa, and 4 caddisfly taxa were captured. However, the community diversity at all downstream stations was still lower than the station sampled upstream of the reservoir. Dubey (1996) found 8 stonefly taxa, 6 mayfly taxa, and 5 caddisfly taxa above the reservoir. Studies conducted in the area prior to dam construction also showed a much more diverse community. Dubey (1996) felt that the reduced temperature range, and cooler summer and warmer winter temperatures caused by the deep dam releases were the main factor responsible for the change in the macroinvertebrate community.

As revealed in the temperature data collected for the Provo River, large releases of water from Deer Creek reservoir dampen diurnal temperature fluctuation in the water column and reduce the mean daily temperatures. Prolonged increases in water release and subsequent temperature alterations in the Provo River have the potential to alter the macroinvertebrate communities. In particular, the seasonality of these releases (i.e., higher summer flow and lower temperatures) can negatively affect macroinvertebrate life cycles. As described in the case studies, areas immediately below dams, in this case Reach 6, have the greatest potential for macroinvertebrate community alteration. Additionally, the channelization along the Provo River limits the amount of slower habitat that can be created along the margins when higher flows are experienced. Samples collected in the vicinity of the North Fork confluence in the mid-1990's showed depressed macroinvertebrate diversity in that area, which could be an indication of the impacts of the altered flow regime (National Aquatic Monitoring Center, unpublished data). Quantification of such impacts would require a detailed study of the macroinvertebrate assemblages of the Provo River under altered flow regimes, and was outside of the scope of this project.

4.3 WATER QUALITY - STREAMFLOW RELATIONSHIPS

Many observed relationships between water quality and streamflow below large dams (such as Deer Creek Dam) apply to the Provo River with biological significance and therefore are discussed in the Macroinvertebrate section of this report. Deer Creek Reservoir certainly traps sediment and pollutants attached to particulates, but does allow for releases of dissolved nutrients into Reach 6 which are readily available for plant uptake such as nuisance aquatic vegetation. Dam operations at Deer Creek Reservoir are believed to influence nutrient concentrations, dissolved oxygen, and water temperature.

Water temperature data collected at each study site (shown in the Results section of this report) illustrate that water temperature remains colder and diurnal fluctuations are depressed more significantly immediately below Deer Creek Dam (Reach 6) than within the other reaches farther downstream from the dam. Nevertheless, cold water releases from Deer Creek Dam are shown to affect these two temperature attributes throughout the remaining reaches of the river (i.e., through Reach 1 near Utah Lake). Other independent factors such as day and night time temperatures play an important role in water temperature/ streamflow relationships in the Provo River, making the data collected for this study specific to spring and summertime conditions.

Other than water temperature, water quality data were not specifically collected for this study; however, existing information was used to provide a qualitative description of the relationships between water quality and streamflow along other important reaches in the Provo River.

4.3.1 EXISTING WATER QUALITY MONITORING DATA

Water quality has been monitored at select locations between Deer Creek and Utah Lake (Map 1.3) for the last several years. The sampling protocol has been to collect single grab samples near the water surface from each monitoring site at fairly routine temporal intervals (weekly- monthly). A full description of current water quality conditions based on available data can be found in the recently developed TMDL and watershed management plan for Provo Canyon (BIO-WEST, 2000). It is important to re-emphasize that data used to develop the TMDL primarily represents average conditions near the top of the water column and does not capture pollutant loads during critical events (storm water runoff/peak flow events). In addition, water quality data has not been analyzed within critical "urbanized" reaches of Provo River in Utah Valley. The only known samples taken to characterize water quality in Provo River during the critical events were recently taken by Dr. Larry Grey of Utah Valley State College. However, these data are unavailable for this report.

4.3.2 SOURCES OF IMPAIRMENT

The Provo River is a highly used and highly regulated river in a watershed where urbanization is the dominant land use affecting water quality. Thus, Provo River is subject to many water quality problems associated with stormwater runoff, particularly from the more developed areas around Utah Valley in Reach 1 and the lower portions of Reach 2. The associated problems and impairment from polluted stormwater runoff tends to be event-driven.

Some of the most common pollutants associated with stormwater runoff include:

- sediment
- nutrients
- salts (road de-icing)
- herbicides/pesticides
- heavy metals

- petroleum products
- bacteria/pathogens

Sediment sources can include construction areas and other areas with exposed soil. Fertilizers, septic systems, and on-site sewage treatment plants are all potential sources of nutrients. Runoff from home lawns may carry fertilizers which have phosphorous and nitrogen. Sewage may be another source of nutrients. Excess nutrients often leads to eutrophication which impacts fish health and can cause fish kill due to a drop in oxygen levels. Drinking water is also affected by excess nutrients and can lead to human health problems.

Salts are generated from road de-icing. Salts are put down to clear ice from roads and can build up over the winter. The salts are often flushed out with the first significant thawing and runoff. In addition to affecting total dissolved solids (TDS) levels, irrigation and drinking water uses are impacted as well.

Similar to fertilizers, herbicides and pesticides are often washed off residential lawns and landscaped areas. These can be toxic to aquatic life and may accumulate or be magnified in higher trophic levels including fish and birds.

Heavy metals are often associated with runoff from roads and parking lots. Automobiles are often the main source of heavy metals from roads. Industrial pollution may also add metals.
Metals may also act in a toxic manner to aquatic organisms and affect higher trophic levels through bio-accumulation or bio-magnification. Roads and cars are also the main sources of petroleum products. Oil, tar, grease and other petroleum products are also harmful to aquatic communities.

Bacteria and pathogens may enter the stream through discharge from a waste water treatment plant, overflow from sewage treatment ponds, and failing and/or leaking septic systems. Such pollutants can cause human health problems in addition to impacts on aquatic life.

4.3.3 WATER QUALITY IMPACTS TO BENEFICIAL USES

During periods of little or no flow, the above mentioned pollutants can build up either in the channel or at the source, creating conditions for a highly concentrated flush during stormwater runoff events. In the case of the lower Provo River, sediment and other pollutants likely build up in the channel during the low flow months and are flushed downstream during the spring release from Deer Creek Dam. A flush of poor quality water at the wrong time may be harmful to June sucker recruitment or recruitment of other spring spawners in the lower Provo River (USFWS, 1999). Current conditions with runoff and timing of the release from Deer Creek Dam leave June suckers spawning in potentially the dirtiest water of the entire year.

Unfortunately, water quality sampling is inconclusive and incomplete in Provo River, especially at Sites 1 and 2 where urbanization is greatest. Water quality samples would need to be taken at critical times and at strategic locations to fully evaluate streamflow/pollutant concentration relationships in the lower Provo River.

4.4 GEOMORPHOLOGY AND SUBSTRATE CHARACTERISTICS: STUDY AREA COMPARISON

Hydraulic geometry characteristics at various flow levels and existing streambed particle size distributions of bedload modeling cross sections are shown in Table 4.1, Table 4.2, and Figure 4.17 for all study sites.

TABLE 4.1. HYDRAULIC GEOMETRY CHARACTERISTICS OF BEDLOAD MODELING CROSS SECTIONS AT SITES 1-6.[A] BEDLOAD CROSS SECTION LOCATIONS ARE SHOWN ON MAPS 3.1-3.5.

MEASUREMENT	STREAMFLOW (CFS)	SITE 1	SITE 2	SITE 3	SITE 5	SITE 6
WETTED WIDTH (FT)	100 500 1,000 1,500	57 61 75 80	34 45 53 54	39 48 56 59	37 59 63 68	51 59 70 71
HYDRAULIC RADIUS (FT)	100 500 1,000 1,500	0.94 1.97 2.30 2.65	1.05 1.90 2.27 2.60	0.90 1.85 2.25 2.55	0.97 1.85 2.60 3.10	1.20 2.44 2.95 3.40
CHANNEL ROUGHNESS (MANNING'S "N")	100 500 1,000 1,500	0.034 0.027 0.023 0.021	0.063 0.045 0.036 0.031	0.047 0.037 0.031 0.027	0.039 0.037 0.035 0.033	0.091 0.069 0.056 0.049
AVERAGE VELOCITY (FT/S)	100 500 1,000 1,500	1.95 4.23 5.73 7.17	2.70 5.50 8.00 10.00	2.76 5.70 7.85 9.54	2.90 4.70 6.15 7.10	1.42 3.00 4.25 5.35
SHEAR STRESS (PSF)	100 500 1,000 1,500	0.12 0.27 0.36 0.44	0.76 1.41 1.70 1.93	0.50 1.02 1.24 1.40	0.36 0.66 0.93 1.13	0.45 0.91 1.10 1.28
WATER SURFACE SLOPE (%)	500	0.2	1.2	0.9	0.6	0.6

[A] SURVEY DATA NECESSARY TO DETERMINE HYDRAULIC GEOMETRY/FLOW RELATIONSHIPS WERE NOT AVAILABLE AT SITE 4.

TABLE 4.2. EXISTING STREAMBED PARTICLE SIZES (MM) FOR VARIOUS SIZE FRACTIONS (D_{16} THROUGH D_{84}) OF THE CUMULATIVE DISTRIBUTION CURVE AS SAMPLED ALONG THE BEDLOAD MODELING CROSS SECTIONS.

SITE	D_{16}	D_{25}	D_{50}	D_{75}	D_{84}
1	15	26	54	81	100
2	42	63	118	214	255
3	28	50	145	230	265
4	37	52	180	320	408
5	35	42	88	130	158
6	22	40	104	260	310

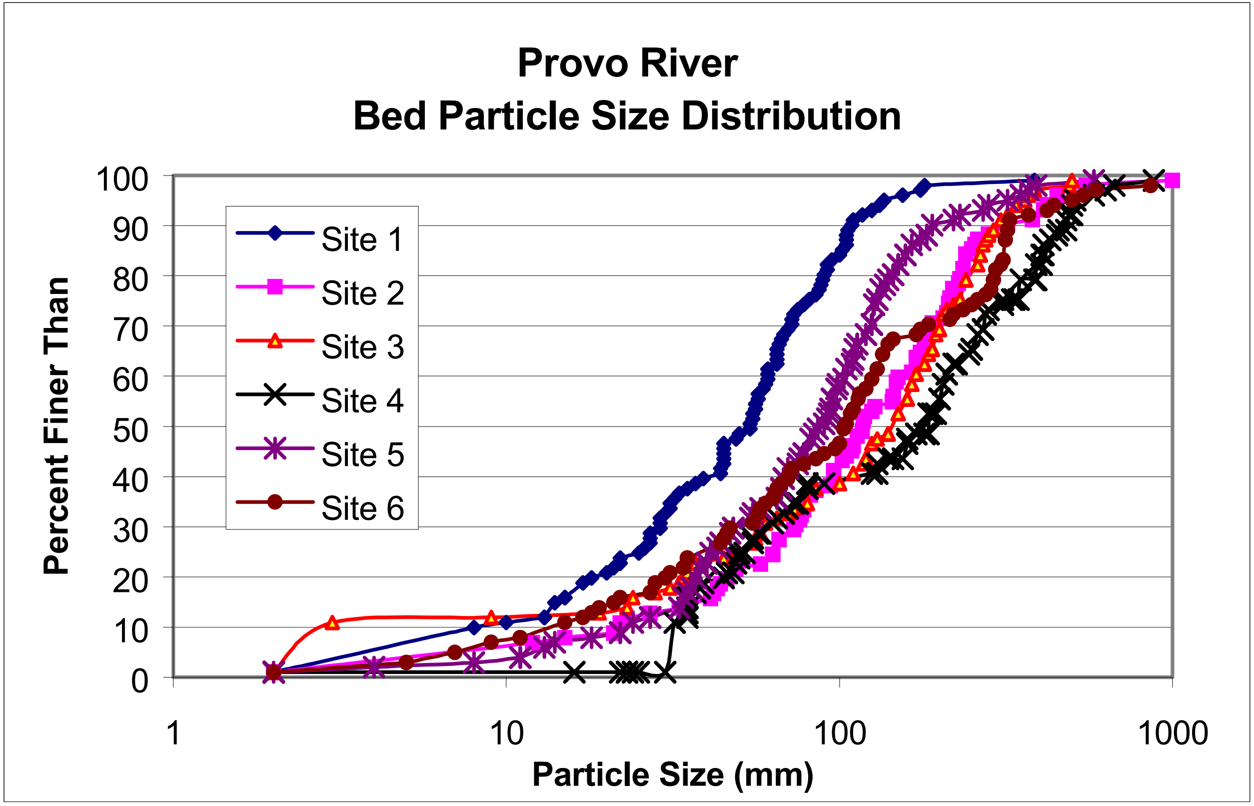


FIGURE 4.17. STREAMBED PARTICLE SIZE DISTRIBUTIONS FOR ALL SITES BETWEEN DEER CREEK RESERVOIR AND UTAH LAKE.

In general, the Provo River narrows (becomes more confined within various geomorphic constraints) in the downstream direction from Site 6 through Site 2, until the channel flattens (Figure 1.1) and broadens near Utah Lake at Site 1. The river is wider and more morphologically complex at Site 6 where at least one side/bank of the channel is free to adjust laterally to the ever-changing water and sediment flux. Site 2 currently has the narrowest wetted width at all modeled flows, likely caused by aggressive channelization practices, combined with severe peak discharge reductions and complete removal of upstream bedload sediment supplies.

There are no discernable patterns between the various reaches concerning hydraulic radius or channel depth. However, channel roughness (Manning's n) values are greatest at Sites 6 and 2, and lowest at Site 1. Manning's n values are high at Site 6 during all flows due to the presence of large boulders combined with "macro" roughness characteristics such as pronounced bed forms (pools, bars, and riffles) and accumulations of large organic debris. Manning's n values at Site 2 are only high during lower flows (likely caused by extreme surface coarsening), however Manning's n values at Site 2 drop quickly during the higher flows to levels similar to the other Sites. Site 2 also has the highest velocities and shear stress values, especially when flows exceed 500 cfs.

The channel becomes wider and smoother (lower Manning's n values) at Site 1. The wetted width of Site 1 is wider at all flows than the other sites. The channel flattens below Tanner Race (Lower City Dam) causing shear stress levels to drop well below levels at the upstream sites. Sediment trapping behind upstream dam structures have certainly slowed down the inevitable bed aggradation and delta development which would normally occur at Site 1.

Streambed particle size distributions are being influenced by several factors, including: local sources of boulders and other sizes of bedload material; channel slope; magnitude of peak flows; and supply limitations. Many of the larger particles in the Provo River are relics of larger historic peak flow events and are not predicted to move under the current flow regime. The cumulative distribution curves for Sites 2,3,5, and 6 are relatively similar, but also exhibit some distinct differences. For example, Site 2 has the largest sized particles in the smaller size fractions (D_{16} and D_{25}), yet has average or smaller sized particles in the medium and larger size fractions ($D_{50,}$ D_{75} and D_{84}). The medium and larger size fractions are again, relics of a previous flow regime, and are mostly immobile during the existing flows. However, the high shear stress values at Site 2 and lack of local bedload sediment supplies have mined most sand and gravel-sized particles out of Site 2, inflating the particle sizes in these size fractions. No data is known to exist that describes the historic streambed particle sizes to compare with. Shear stress and velocity levels are also high at Site 3, similar to Site 2. However, the local and upstream supply of sand and gravel-sized particles (see discussion below) seems to have dampened the coarsening effect at Site 3.

Site 4 has the greatest amount of coarse boulder-sized particles. The likely source of these boulders is from the adjacent steep side hills near Bridal Veil Falls. It is interesting that Site 4 has very few particles less than 30 mm, even though there are local sources throughout the reach, including tributary inputs. Site 4 is in the steepest reach in the Study Area and likely, because of its steepness, winnows the sand and gravel-sized materials down to Site 3 where the channel is somewhat flatter.

An accumulation of this material in Site 3 shows up on the lower end of the cumulative distribution curve (Figure 4.17). Site 3 and 4 have the same flow regime. Therefore, local geomorphic conditions apparently have a distinguished influence on the existing streambed particle size distribution in the Provo River even with equal streamflows.

The streambed at Site 1 consists primarily of smaller sized particles less than 100 mm and clearly has a “finer” distribution curve than the other sites.

The fluvial characteristics of Provo River have adjusted to reduced peak flows (in terms of magnitude, frequency and duration) and channelization practices most severely in the lowermost reaches. As a result, effective discharge is lower at Site 1 than Sites 5 and 6. It is anticipated that this longitudinal trend holds true for the remainder of the study sites.

4.5 RIPARIAN VEGETATION: STUDY AREA COMPARISON

4.5.1 COMMON PATTERNS AMONG SITES

While specific riparian vegetation characteristics and flow relationships vary among the different study sites, some common patterns emerge. In general, at all sites, herbaceous vegetation (primarily grass) occupies the lowest-elevation portions of the channel. Slightly higher-elevation surfaces such as vegetated islands and floodplains generally contain a mix of herbaceous and shrub species. Stands of mature trees or mixed tree/shrub communities occupy the highest-elevation riparian surfaces including high floodplain/terrace surfaces and steep levee banks. At all sites, flows significantly greater than the highest modeled flow (1,500 cfs) would be needed to inundate these high surfaces occupied by mature trees.

4.5.2 LONGITUDINAL TRENDS

Several aspects of study site and reach-scale riparian vegetation characteristics were observed to vary along a longitudinal gradient from upstream (Site/Reach 6) to downstream (Site/Reach 1).

4.5.2.1 SPECIES & AGE COMPOSITION

Although shrub vegetation is present at all the study sites, the species composition of the shrub community changes between Site 6 and Site 1. At Sites 6 and 5, red osier dogwood is a dominant shrub species along with willow. However, this species is much less common at Site 3, and was not observed at Sites 2 or 1. Red osier dogwood was not noted in Reaches 2 or 1 during the channel-reach scale riparian mapping either. This is most likely due to a climate-driven elevational threshold below which dogwood is unable to out-compete other species.

Although red osier dogwood becomes increasingly rare at the downstream study sites, overall diversity of riparian vegetation species generally increases in a downstream direction. Reach-scale mapping of riparian vegetation noted the presence of non-native species such as tamarisk, Russian olive, and common reed within Reaches 1 and 2, in addition to the willow, grass, and cottonwood species that are common to the entire Study Area. These non-native species are generally not present in Reaches 3-6, which may be due to the higher elevation and colder climate within Provo Canyon. Species diversity also increases in Reaches 2 and 1 due to the high degree of near-stream urban development and associated stream-side landscaping and irrigation.

As previously discussed, the degree to which cottonwood recruitment is occurring also varies among the sites. Recruitment is extremely limited upstream of Olmsted Diversion (Reaches/Sites 5 and 6), and the cottonwood populations are generally restricted to old, mature individuals located along high terrace or levee surfaces. This lack of recruitment appears to be a result of the combined effect of reduced flood peaks and artificially high summertime flow releases. Relict, higher-elevation floodplain surfaces are no longer inundated and no longer provide springtime seedling establishment sites, and elevated summer flows prevent vegetation growth on lower-elevation surfaces. Downstream from Olmsted Diversion (Sites/Reaches 3, 2, and 1), summertime flows are lower, and cottonwood recruitment is able to occur.

4.5.2.2 STREAMFLOW ASSOCIATIONS

The relationship between riparian vegetation and streamflow varies among the study sites in a longitudinal fashion (Table 4.3). At Sites 5 and 6, which are located upstream of Olmsted Diversion, no riparian vegetation grows below approximately the 400 cfs flow level. This is due to the fact that flow releases from Deer Creek Dam are typically kept between 300-500 cfs during the summer growing season (Appendix C). Riparian vegetation grows to much lower levels in the channel at the downstream sites, where summertime flows are reduced by irrigation withdrawals (Table 4.3). The vegetation level is lowest at Site 1, which is located downstream from all the diversions on the Provo River.

TABLE 4.3. STREAMFLOW ASSOCIATIONS WITH RIPARIAN VEGETATION AT DIFFERENT STUDY SITES.

STUDY SITE	APPROXIMATE FLOW ABOVE WHICH VEGETATION IS INUNDATED	APPROXIMATE FLOW THAT INUNDATES FLOODPLAIN	COTTONWOOD RECRUITMENT WITHIN SITE
SITE 6	400-700 CFS	1100 CFS	NO
SITE 5	400 CFS	1500 CFS	NO
SITE 3	70 CFS	800-900 CFS	YES
SITE 2	70 CFS	800-900 CFS	YES
SITE 1	25 CFS	700 CFS	NO, BUT RECRUITMENT IS EVIDENT IN OTHER PORTIONS OF REACH 1

Floodplain inundation flows also vary among the sites. Table 4.3 compares the approximate flow levels needed to inundate “low floodplain” surfaces at the different sites. At Sites 6 and 5, floodplain areas are predominantly relict “high floodplains” that would require flows well above 1,500 cfs to become completely inundated. At Site 6, the small island/bar located on river left (facing downstream) is fully inundated at 1,100 cfs, and can be considered a low “active” floodplain surface. At Site 5, the shrub area on river right near the downstream end of the site functions as a low floodplain, and is fully inundated at 1,500 cfs. These flow levels are close to the 2-year recurrence interval flood magnitude of 1,136 cfs (1,248 cfs using long-term data set; see Appendix C) at the gage below Deer Creek Dam. Floodplain-inundating flows are lower at the downstream sites (Sites 3, 2, and 1), corresponding to the smaller flood magnitudes that occur at these sites due to water diversions.

4.6 INTEGRATED RESOURCE DISCUSSION

It is apparent from the above discussions that the relationships between streamflow and the various ecological components of the Provo River are complex, non-linear, and variable. Flows of differing magnitudes and patterns are needed to maximize conditions for individual resources. For example, modeling results indicate that at most study sites, aquatic habitat is maximized at relatively low flows (250 cfs or less). On the other hand, large floods capable of transporting bedload sediment and inundating floodplain surfaces are needed for successful riparian vegetation recruitment. At most sites, suitable aquatic habitat for fish is extremely limited at flood flows between 1,000-1,500 cfs. However, short duration flows of this magnitude are necessary to preserve the morphological characteristics of the channel and provide recruitment areas for riparian vegetation. Consequently, even though flood flows appear somewhat detrimental to fish habitat over the short-term, they remain essential for habitat maintenance and other ecological components of the riverine system over the long-term. Because of these conflicting flow needs within and between resources, the results of isolated components of any single resource should not be considered in isolation.

Another important component of the Provo River is that the longitudinal gradient of the river is dissected by dams, water diversions, and disrupted ecological/fluvial processes, and does not function as a contiguous system. As a result, Reaches 5-6, 3-4, 2, and 1 function more independently than other analogous natural systems. Concepts in river continuum, stream ecology, and dynamic equilibrium in fluvial geomorphology become somewhat skewed and are reset to varying degrees in the Provo River below each structure. Ironically, it is possible that the longitudinal dissection of the Provo River may allow for conflicting management objectives to be accomplished in adjacent reaches. For example, flows in Reaches 5 and 6 could conceivably be managed to maintain conditions preferred by brown trout, whereas flows in Reach 2 (and possibly Reaches 3 and 4) could simultaneously be managed to create and then maintain conditions preferred by cutthroat trout given the distinctive habitat, water temperature tolerances, and spawning seasons between the two species.

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APPENDIX A: DEVELOPMENT OF HABITAT SUITABILITY INDEX CURVES

HABITAT SUITABILITY INDEX CURVES

Habitat Suitability Index or HSI curves were developed for depth, velocity, and substrate (for spawning life stages) for each species and life history stage (fry, YOY [young-of-year], juvenile, adult, spawning) in the Provo River, where possible. For the coldwater species found in the Provo River, depth and velocity are the primary factors that dictate habitat use. Substrate and cover are often important in habitat selection but are not considered primary factors affecting habitat selection in the Provo River. The exception is the spawning life stage for each species which generally require specific substrate types; the availability of appropriate substrate was considered for calculating habitat availability for that life stage. Substrate is probably of limited importance in other instances because it is predominantly uniform (cobble) throughout the Provo River. Although some mesohabitats have larger boulders or gravel/sand mixtures for substrate, these habitats are generally associated with velocities that differ from the mainstem and selection based on these substrate types would be accounted for by a velocity suitability curve.

Regarding cover, data gathered by Dr. Mark Belk on six central Utah streams (Olsen and Belk 2001) does not show any discernible relationships between habitat selection and cover for any species and snorkeling activities in the Provo River yielded similar conclusions (BIO-WEST unpublished data). As in other rivers, cover is generally important to brown trout in the Provo River, but less so when they are feeding. Brown trout often utilize cover, or remain fairly close to cover, but occupy more open areas when feeding. But because fish in the Provo River are feeding during most daylight hours in the summertime and because cover probably does not fluctuate dramatically with changes in discharge (much of the cover is large boulders and large woody debris that will generally remain in place under all but the most extreme high flows), adding a cover suitability curve for brown trout was unnecessary.

HSI CURVE DEVELOPMENT

For this study, a combination of data sources were used to develop HSI curves for use in the analyses. HSI curves developed for species/life history stages in other studies were examined and evaluated relative to biological data gathered in the Provo River. Where possible, data from other streams or rivers in Utah or from similar-sized rivers were used. Frequently, several curves were compared and a single HSI curve created based on degree of similarity of Provo River habitat to the study area used in curve development. To gather additional data for individual species or assemblages where data gaps existed, BIO-WEST also conducted fisheries sampling efforts (snorkel observations) in each study reach. In particular, a high-flow snorkeling effort (described below) was conducted to assess the use of higher velocity water by brown trout. These snorkeling efforts were conducted in each available habitat type and assisted in selection/modification of brown trout and mottled sculpin curves. A few other species were observed, but observations were too infrequent to assist in curve development.

HSI curves were developed for depth and velocity suitability of each species/life history stage where possible, but a lack of information on some species and life history stages limited curve development. Therefore, a habitat niche approach was used to incorporate all species found in the Provo River. For each species, the range of values that fell above the 50% suitability threshold on both depth and velocity HSI curves were used to define its habitat "niche." A cluster analysis conducted by Dr. Mark Belk on Provo River fishes (Belk and Elsworth 2000) greatly assisted in grouping fishes for which HSI curves could not be developed with those having similar habitat associations. Species with similar niches were grouped together and ultimately, eight representative habitat niches were selected. Each species was assigned to one (or more) of the following niches (Figure 2.1):

(1) Backwater / Edge
(2) Slow / Shallow
(3) Moderate / Shallow
(4) Fast / Shallow
(5) Moderate / Mid-Depth
(6) Fast / Mid-Depth
(7) Moderate / Deep
(8) Fast / Deep

Table 2.6 depicts the fishes/life stages represented by each habitat niche, while Table A1 provides a description of the habitat niche for each species.

In addition to being categorized into habitat niches, some species/life stages of particular interest were modeled using suitability criteria directly from HSI curves. This includes all life stages of brown trout and "all trout" throughout the Provo River, and June sucker spawning in Reaches 1 and 2 of the lower Provo River. The "all trout" classification includes a composite criteria for brown trout, rainbow trout, and cutthroat trout. The reasoning behind this composite classification is to avoid over-representation of trout habitat in the Provo River by modeling each of the three species individually and summing all habitat. The HSI curves for brown trout, "all trout", and June sucker-spawning are presented in Figures A1 - A7.

A sensitivity analysis was conducted on the habitat niche versus HSI approach. This was completed by modeling several species via individual HSI curves and also by habitat niche and comparing the flow versus habitat relationship for these species. The relationships (trends) for the tested species were very similar while the total amount of habitat varied as expected. The intent is to represent habitat types that encompass a diversity of species and to display relationships of habitat versus flow. The conclusion of the sensitivity analysis is that the niche approach does represent the habitat versus flow relationships of the Provo River species.

TABLE A-1. NICHE USE BY SPECIES/LIFESTAGES.

SPECIES	LIFESTAGE	NICHE
brown trout	adult, juvenile, fry	(5) Moderate / Mid-depth
brown trout	spawning	(2) Slow / Shallow
		(3) Moderate / Shallow
		(5) Moderate / Mid-depth
all trout	adult	(5) Moderate / Mid-depth
all trout	juvenile, fry, spawning	(2) Slow / Shallow
		(3) Moderate / Shallow
		(5) Moderate / Mid-depth
June sucker	spawning	(5) Moderate / Mid-depth
mountain whitefish	adult	(5) Moderate / Mid-depth
		(7) Moderate / Deep
mountain whitefish	juvenile, spawning	(5) Moderate / Mid-depth
mountain whitefish	fry	(1) Backwater / Edge
		(5) Moderate / Mid-depth
mountain sucker	adult	(2) Slow / Shallow
		(3) Moderate / Shallow
		(4) Fast / Shallow
		(5) Moderate / Mid-depth
		(6) Fast / Mid-Depth
mountain sucker	juvenile, YOY	(1) Backwater / Edge
Utah sucker	adult	(5) Moderate / Mid-depth
		(7) Moderate / Deep
Utah sucker	juvenile	(5) Moderate / Mid-depth
Utah sucker	YOY	(1) Backwater / Edge
mottled sculpin	adult, juvenile	(2) Slow / Shallow
		(3) Moderate / Shallow
		(4) Fast / Shallow
mottled sculpin	YOY	(2) Slow / Shallow
speckled dace	adult	(2) Slow / Shallow
		(3) Moderate / Shallow
speckled dace	juvenile	(2) Slow / Shallow
speckled dace	YOY	(1) Backwater / Edge
longnose dace	adult	(2) Slow / Shallow
		(3) Moderate / Shallow
		(5) Moderate / Mid-depth
longnose dace	juvenile	(2) Slow / Shallow
longnose dace	YOY	(1) Backwater / Edge
leatherside chub	adult, juvenile, YOY	(1) Backwater / Edge
redside shiner	adult, juvenile, YOY	(1) Backwater / Edge

FISH SAMPLING (SNORKELING)

Although data from previous studies in nearby/similar habitat were used predominantly to develop habitat suitability curves and habitat niches, some data were gathered on the Provo River to assist in model verification and provide insight where data gaps existed. Several methods were considered, but direct observation through snorkeling was chosen as the most accurate means of assessing true habitat usage. Unfortunately, this limited the range of the fish community that could readily be observed to trout species, mountain whitefish, and sculpin. Other species are generally small-bodied and, at least in the main river, difficult to approach to a distance where observation and recognition is possible without startling.

Snorkeling was conducted during two distinct periods during the annual discharge cycle in the Provo River: once during low flows in the spring, and again during the higher flows of mid-summer. The primary focus during each period was to determine habitat usage, specifically depth and velocity of occupied habitats, but the methodology used differed slightly in each effort. During the spring, entire study sites were snorkeled moving from downstream to the upstream boundaries of the site. This provided an examination of habitat used relative to total area, but did not provide a comparison of lower versus higher velocity habitat use or the range of available velocities. In the summer, specific ranges of velocity were chosen *a priori* and similar-sized habitats outlined before snorkeling began. This method allowed for a comparison of habitat use of each of several major velocity ranges to determine if fish use higher velocity habitat when that is what is predominantly available, or whether fish will seek out lower velocity habitats and congregate there. Also in the summer, with higher velocities, the snorkeling possibilities were more restricted and a much smaller area was available to sample.

Methodology differed slightly between the two snorkel efforts. In the spring, observers moved upstream and marked each observation with pin flags; species and estimated length were noted for each individual on a diver's slate. Following the underwater survey, measurements of depth and velocity were made and the location was marked on a survey map of the site. Entire sites were snorkeled in the spring including sites 1, 2, 3, 6, and 8. This resulted in a number of observations within a wide range of velocities, but did not assess the use of high and low velocities relative to the total amount of habitat available.

The follow-up snorkeling effort in the summer was designed to assess the use of higher velocity habitat by sampling a similar amount of habitat within different velocity ranges. Because the spring snorkeling revealed that depth suitability was high in the 1-4 foot depth range and low outside of this range, only habitats within that depth range were sampled. Velocity ranges were predetermined and included 0.05 - 0.25 m/sec, 0.25 - 0.4 m/sec, 0.4 - 0.6 m/sec, and 0.6 - 0.8 m/sec, which correspond to the major breaks in habitat suitability observed in other studies; these ranges were referred to as "BINs 1-4." In the field however, it was immediately apparent that most habitat fell within the upper BINs, including a significant amount above the highest BIN range. Thus "BIN 5" was added and included velocities of 0.8 - 1.0 m/sec. Within each site, areas were chosen that had representative habitat quality and quantity of each BIN relative to the entire site. Before snorkeling, BINs were delineated within the area by taking numerous velocity measurements with a Marsh-McBirney flowmeter.

Initially, effort was to be standardized across sample areas by time, but with the higher flows, some habitats required floating downstream to make observations, while in others, moving upstream remained the preferred method. This resulted in a shift from standardizing by overall time spent in each BIN to total area covered in each BIN (and assuming complete coverage of the area during each sample). Three samples were conducted in most areas (weather and limits on time restricted the number to two in some sites) to correspond with different times of the day to limit the influence of this parameter on observed differences between BIN habitats. The three samples were conducted in late morning (10am - 12pm), early afternoon (1pm - 3 pm) and late afternoon (3:30pm to 5:30 pm). These efforts were concentrated in Study Site 6 and an area below Study Site 5 (but above Vivian Park) because these two areas provided the greatest range of BIN velocities including some habitat in the lower BINs, which was very rare throughout the river during this higher discharge period. Individual observations were assigned to one of the BINs based on the area outlined prior to snorkeling; individual measurements of depth and velocity were not taken.

Appendix B. Measured versus modeled water surface and velocity values.

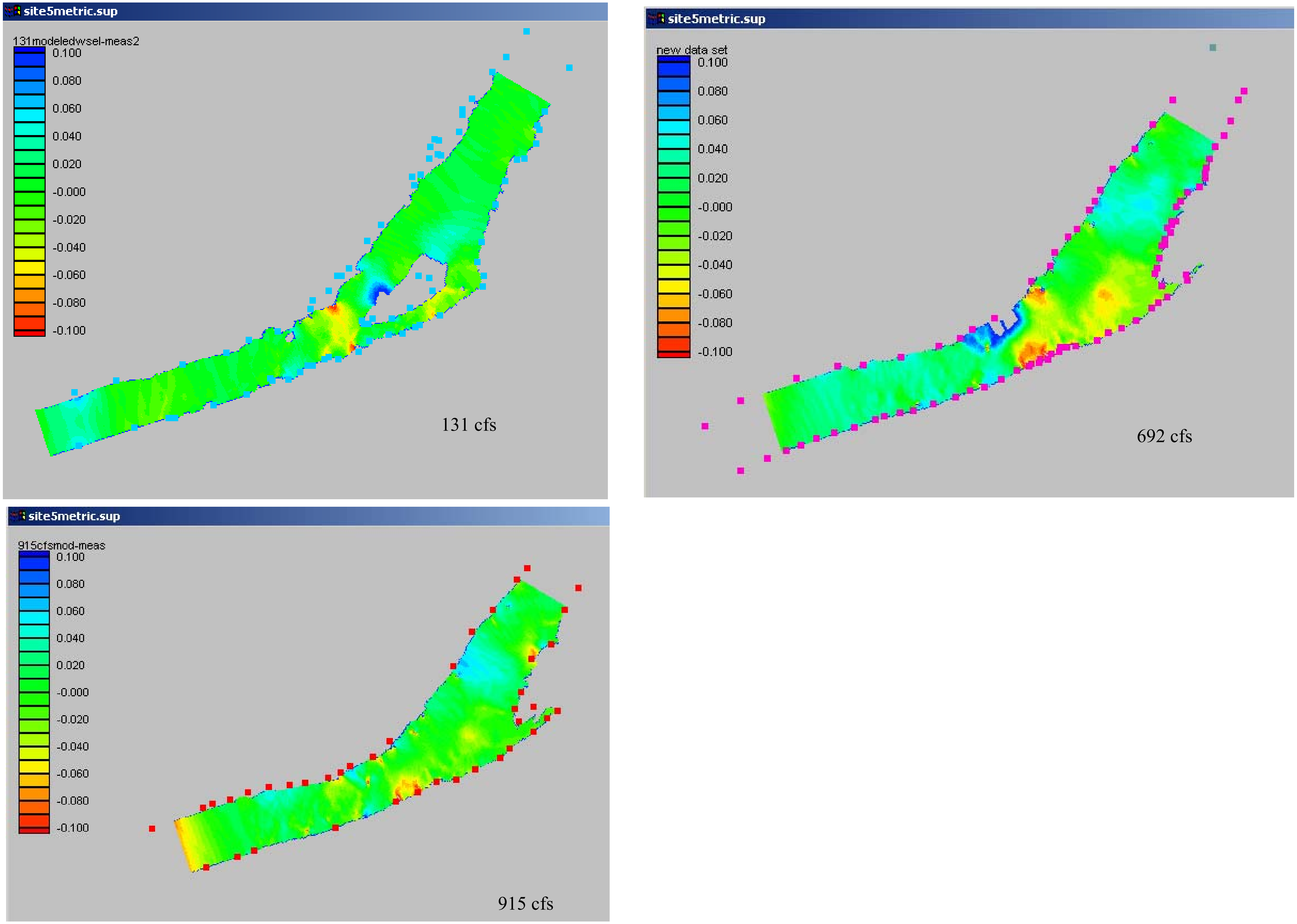

Figure B1. Comparison of modeled versus field-surveyed water surface elevations for three flow levels at Site 5.

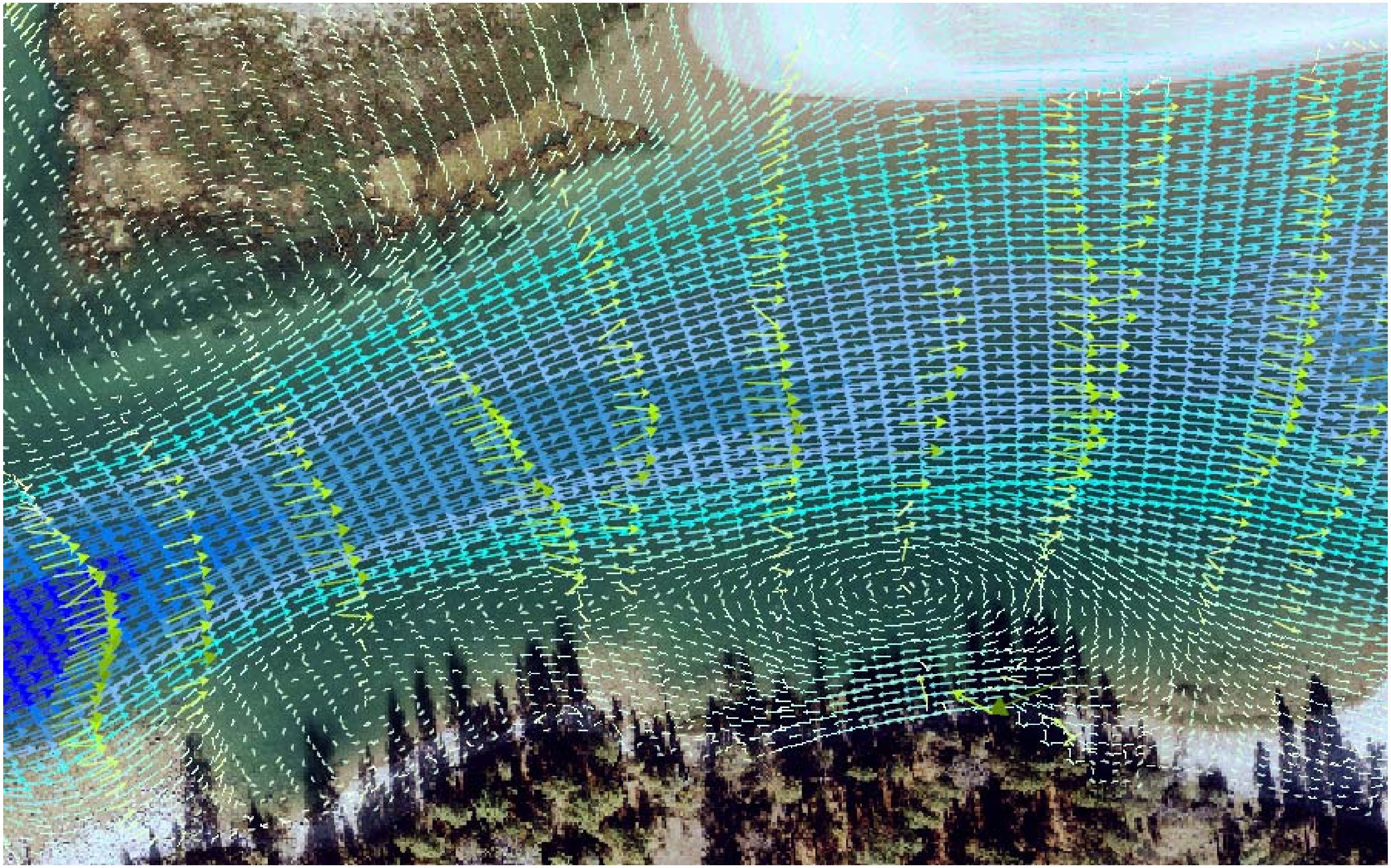

Figure B2. Comparison of measured versus modeled velocities on a Flathead River site.

APPENDIX C. HYDROLOGIC DATA AND ANALYSES

BACKGROUND

As discussed in Section 1 of this report, the hydrology of the Provo River has been substantially altered by a complex network of dams, water imports, and water diversions constructed for hydropower, irrigation, and water supply purposes. In order to understand how these alterations have affected flows on the Provo River and in order to describe existing hydrologic conditions, several analyses were performed using available hydrologic data.

DATA SOURCES

Average daily flow and instantaneous peak flow data were obtained from U.S. Geological Survey (USGS) records for the streamflow gages located on the Provo River (Map 1.3, Table C1) Supplemental data were obtained from the Utah Division of Water Rights (DWRT) Flow Records database (DWRT 2002).

TABLE C1. U.S. GEOLOGICAL SURVEY GAGE CHARACTERISTICS.

GAGE NAME	GAGE NUMBER	PERIOD OF RECORD	AVERAGE ANNUAL DISCHARGE FOR PERIOD OF RECORD
PROVO RIVER NEAR HAILSTONE	10155000	1949-2001	278.1
PROVO RIVER NEAR CHARLESTON	10155500	1938-1950; 1992-2001	217.2
PROVO RIVER BELOW DEER CREEK DAM	10159500	1953-2001	358.2
PROVO RIVER AT PROVO	10163000	1937-2001	200.0
DEER CREEK NEAR WILDWOOD	10160000	1938-1950 (USGS) 1975-1982 (DWRT)	13.3 17.4
NORTH FORK PROVO RIVER AT WILDWOOD	10160800	1964-1974	16.7
SOUTH FORK PROVO RIVER AT VIVIAN PARK	10161500	1912-1962	27.3

Average daily flow data for the specific study sites were calculated from the gage data as listed in Table C2. The calculation for Sites 4 and 3, which are not located near a USGS gage, was made by combining flows for "Provo Reservoir Canal" and "Past Murdock" (obtained from the DWRT database) and adding an additional 5 cfs to account for Bridal Veil tributary inputs (same calculation described in Table 2.3 of this report). These data were obtained for the time period May 1998- June 2002; however, data are incomplete and non-continuous within this time period, limiting the usefulness of the data set for analysis.

TABLE C2. HYDROLOGIC DATA SOURCES AND CALCULATION TECHNIQUES FOR STUDY SITES.

STUDY SITE	DATA SOURCE/ CALCULATION TECHNIQUE
SITE 6	USGS #10159500 (PROVO R. BELOW DEER CK. DAM) + TYPICAL DEER CREEK DAILY FLOW (USGS#10160000, WATER YEAR 1979)
SITE 5	USGS #10159500 (PROVO R. BELOW DEER CK. DAM) + TYPICAL DEER CREEK DAILY FLOW (DWRT WATER YEAR 1979) + TYPICAL NORTH FORK DAILY FLOW (USGS#10160800, WATER YEAR 1973)
SITES 4 AND 3	"PROVO RESERVOIR CANAL" + "PAST MURDOCK" + 5 CFS FOR BRIDAL VEIL INPUTS (DWRT 2002; INCOMPLETE/NONCONTINUOUS DATA)
SITE 2	NO DAILY FLOW DATA READILY AVAILABLE
SITE 1	USGS #10163000 (PROVO RIVER AT PROVO)
"UNREGULATED"	HAILSTONE FLOW * (SITE 5 MEAN ANNUAL FLOW*/HAILSTONE MEAN ANNUAL FLOW^A) OR USGS #10155000 * 1.43

^A MEAN ANNUAL FLOWS CALCULATED AS AVERAGE OF DAILY FLOW DATA FOR WATER YEARS 1997-2001.

In order to illustrate the difference between existing flow conditions and what flows would be without the influence of Jordanelle and Deer Creek Dams, a data set representing "unregulated" flows was developed. The "unregulated" data set is based on flows at the Hailstone USGS gage, which is located upstream from both dams. The Hailstone data were adjusted by a mean annual flow ratio to account for the increased watershed area and tributary inputs that occur between Hailstone and Sites 1 through 6 (Table C2). It is important to note that this synthetic "unregulated" data set does not represent "natural" flow conditions, because flows at the Hailstone gage are affected by water imports via the Duchesne Tunnel and Weber-Provo Canal. However, it does provide a useful approximation of the flow magnitudes and patterns that would occur on the Provo River without the effects of the dams and diversions that occur downstream from the Hailstone gage.

HYDROGRAPHS

Because water operations on the Provo River system have undergone recent changes with the completion of Jordanelle Dam and the establishment of target flow releases for June sucker, the data period of October 1996 to September 2001 (i.e., water years 1997-2001) was used to represent existing hydrologic conditions. Although this is a short data period, it does encompass a climatic range from relatively dry to relatively wet years. Hydrographs were plotted for water year 1999 to represent typical seasonal flow patterns during an average water year (Figure C1). Water year 1999 was selected because at the Hailstone gage, which is unaffected by dam operations, the mean annual flow for 1999 was closest to the long-term average mean annual flow at Hailstone. As a complimentary means of illustrating average flow conditions, average daily flows were also plotted for each site (Figure C2). Average daily flows were calculated by taking the 1997-2001 flows for a given date and averaging the values to come up with an average daily flow for that date. Because of the sparsity of available data, no average hydrograph was plotted for Sites 3 and 4.

FLOW DURATION ANALYSIS

Flow duration curves representing the percent of time a given flow is equaled or exceeded are plotted for the different sites in Figure C3, and flow duration data are presented in Table C3. Due to the sparsity of available data, no flow duration analysis was performed for Sites 3 and 4.

FLOOD FREQUENCY ANALYSIS

Instantaneous peak flow data were analyzed to determine the frequency and magnitude of flood flows on the Provo River. Instantaneous peak flows were available only at actual USGS gage sites; therefore, tributary inputs were not added to USGS gage flows to determine site-specific values as was done with average daily flow data. However, tributary inputs within Provo Canyon contribute only a minor portion of the peak flows on Provo River, so the data from gage #10159500 (Provo River below Deer Creek Dam) provide a good approximation of flood magnitude and frequency at Sites 6 and 5. No frequency analysis was performed for Sites 4,3, or 2 due to lack of data. Site 1 flood frequency is represented by data from the nearby Provo River at Provo gage. Flood frequency analysis of the gage data at Hailstone was completed for comparison purposes, but no adjustment to account for increased watershed area was made.

The magnitudes of the 1, 2, 5, 10, 25, 50, and 100-year recurrence interval floods were determined using log-Pearson Type III analysis (Table C4, Figure C4). The analysis was performed using for two distinct time periods at each gage: water years 1997-2001; and, the complete period of record for the individual gage. The period 1997-2001 was examined to illustrate existing conditions since completion of Jordanelle Dam and provision of target June sucker flow releases. However, this period of time is short and may not provide an accurate prediction of large, infrequent floods such as the 50 or 100-year event. Therefore, the full data sets available for each site were used to provide a second set of flood values that incorporate longer-term climatic variability into the analysis. The long-term values can also be compared with the recent (1997-2001) values to examine how flood frequencies have changed since completion of Jordanelle Dam and provision of target June sucker flow releases.

Table C3. Flow duration data for Provo River sites.

PERCENT EXCEEDENCE	DISCHARGE (cfs)				
	SITE 6	SITE 5	SITE 1	UNREGULATED	HAILSTONE
99	96	103	5	27	19
98	103	108	7	36	25
95	106	112	13	43	30
92	108	114	20	61	43
90	110	116	25	86	60
85	117	123	37	112	78
80	138	144	50	122	85
75	245	252	61	129	90
70	284	291	79	136	95
60	341	351	102	150	105
50	372	382	124	166	116
40	413	449	206	186	130
30	471	503	298	230	161
25	502	537	324	276	193
20	551	576	350	375	262
15	589	615	393	706	494
10	635	695	507	1139	797
8	702	749	562	1318	922
5	805	832	696	1834	1283
2	993	1073	858	2946	2060
1	1176	1240	955	3664	2563

Table C4. Flood frequency values for Provo River gages.

Recurrence Interval (years)	Provo River below Deer Creek Dam		Provo River at Provo		Provo River near Hailstone	
	recent 1997-2001 (cfs)	long-term 1953-2001 (cfs)	recent 1997-2001 (cfs)	long-term 1937-2001 (cfs)	recent 1997-2001 (cfs)	long-term 1950-2001 (cfs)
1	309	310	171	139	1414	684
2	1136	1248	925	921	3208	2613
5	1373	1774	1308	1385	3669	3298
10	1454	2070	1495	1632	3835	3573
25	1508	2393	1673	1880	3959	3795
50	1530	2600	1772	2026	4014	3901
100	1543	2782	1850	2145	4050	3974

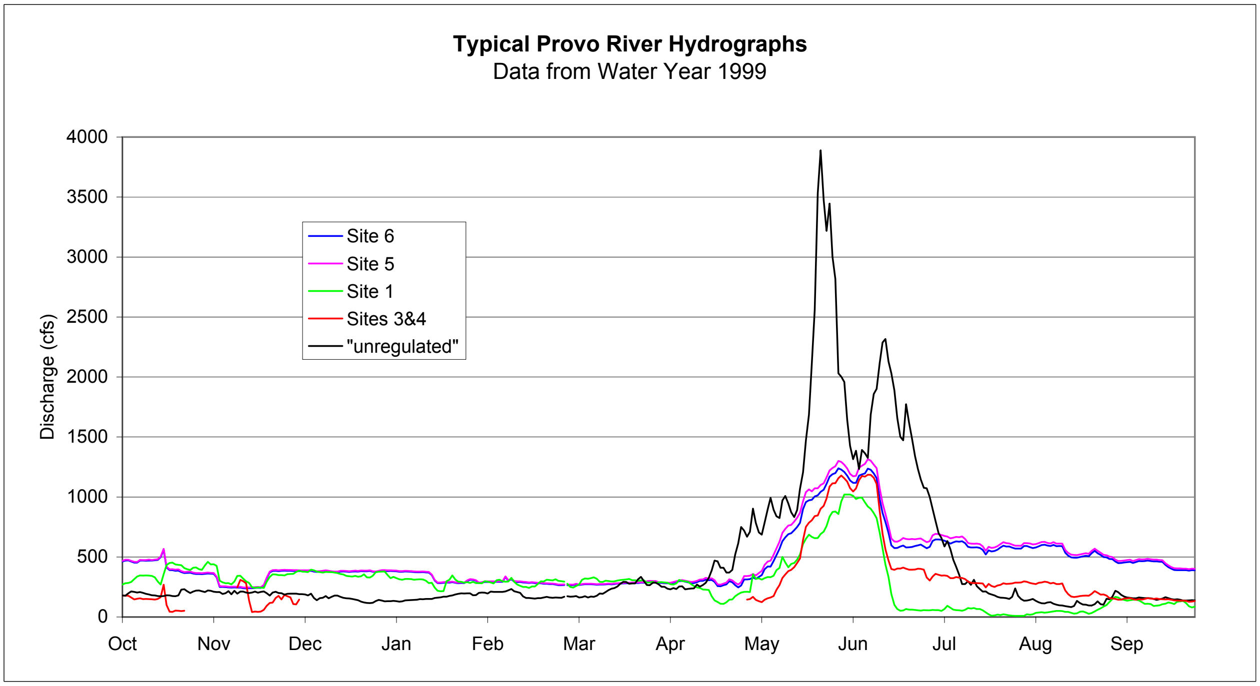

Figure C1. Typical hydrographs for Provo River sites. Data from water year 1999.

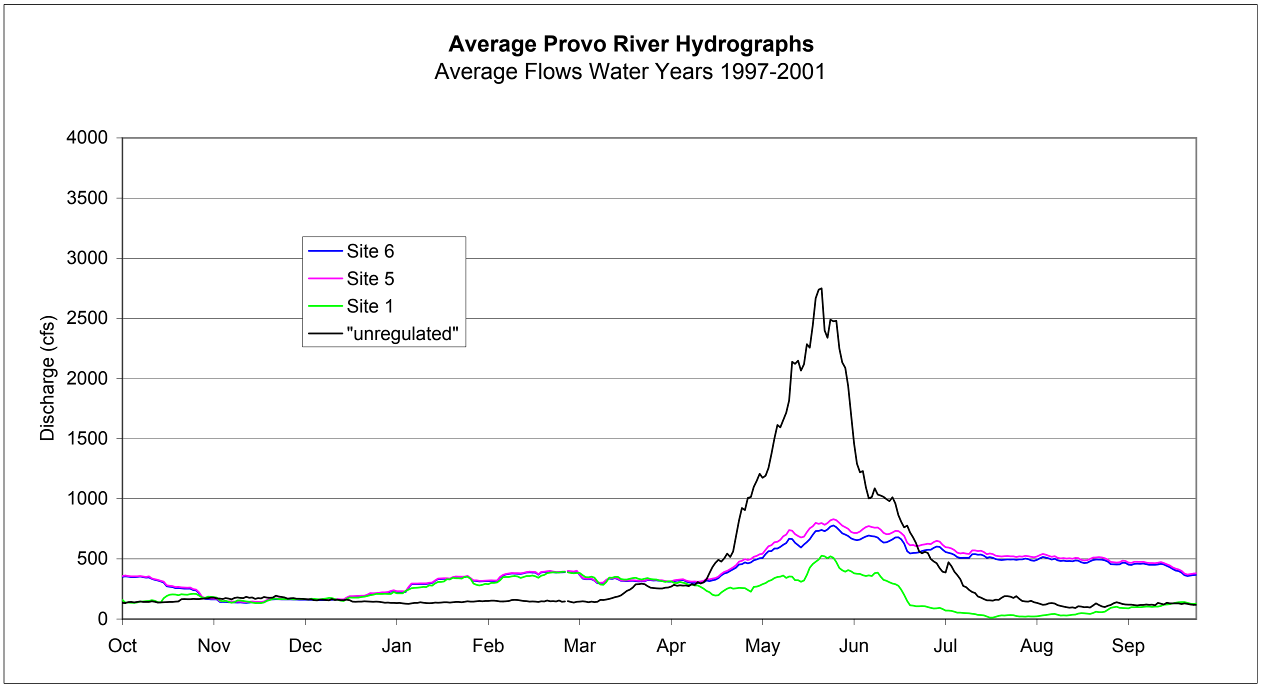

Figure C2. Average Provo River Hydrographs for Water Years 1997-2001.

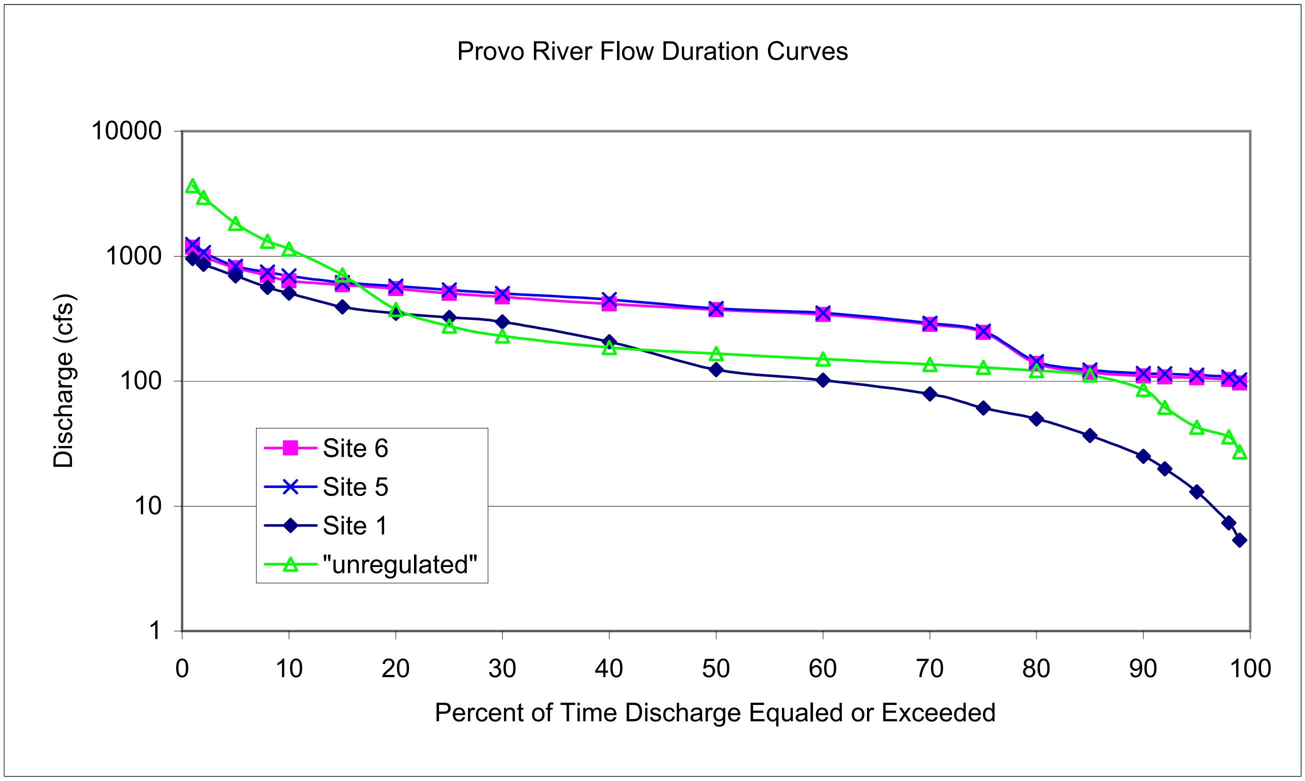

Figure C3. Provo River flow duration curves.

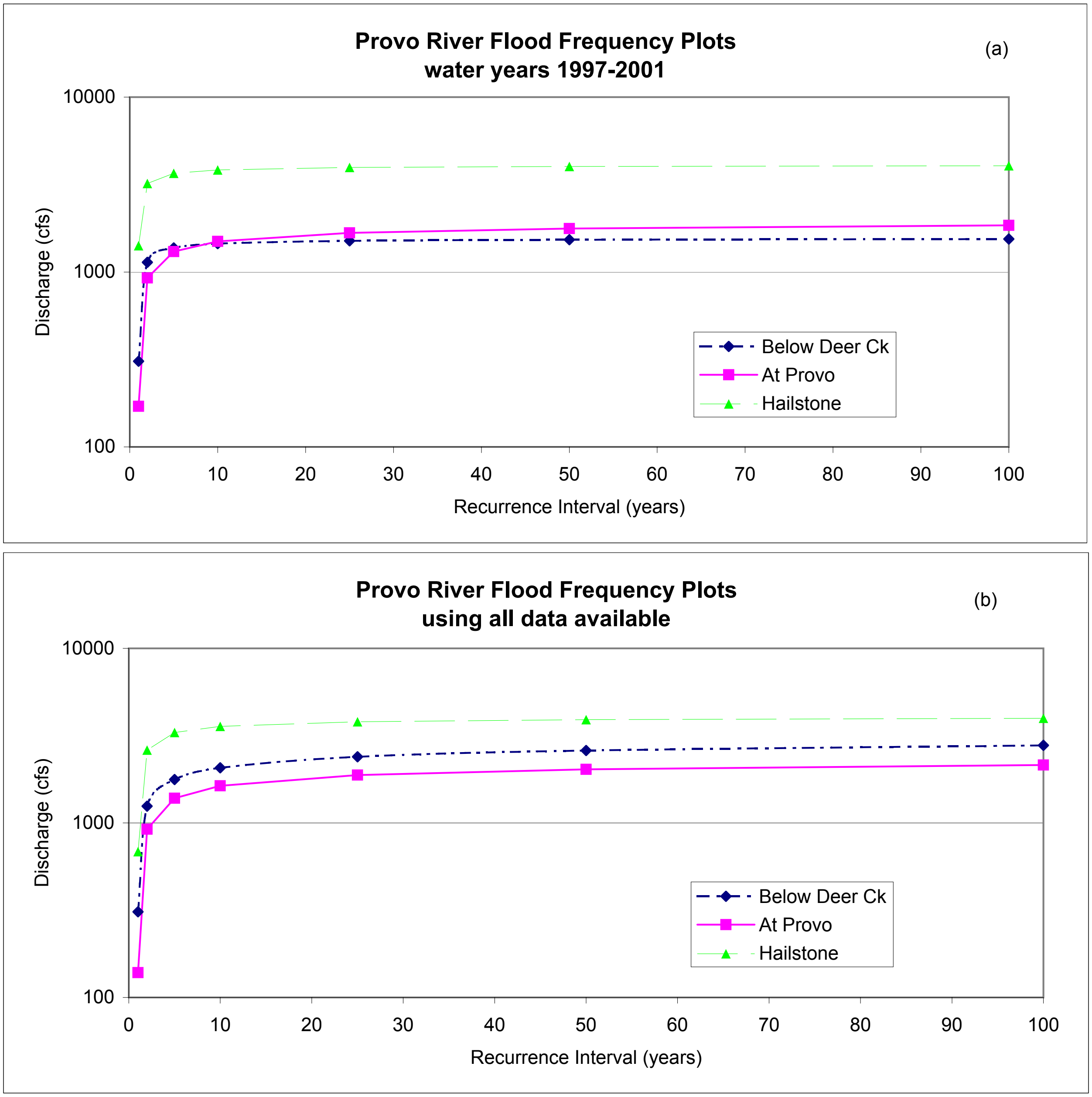

Figure C4. Flood frequency curves for Provo River gage sites.