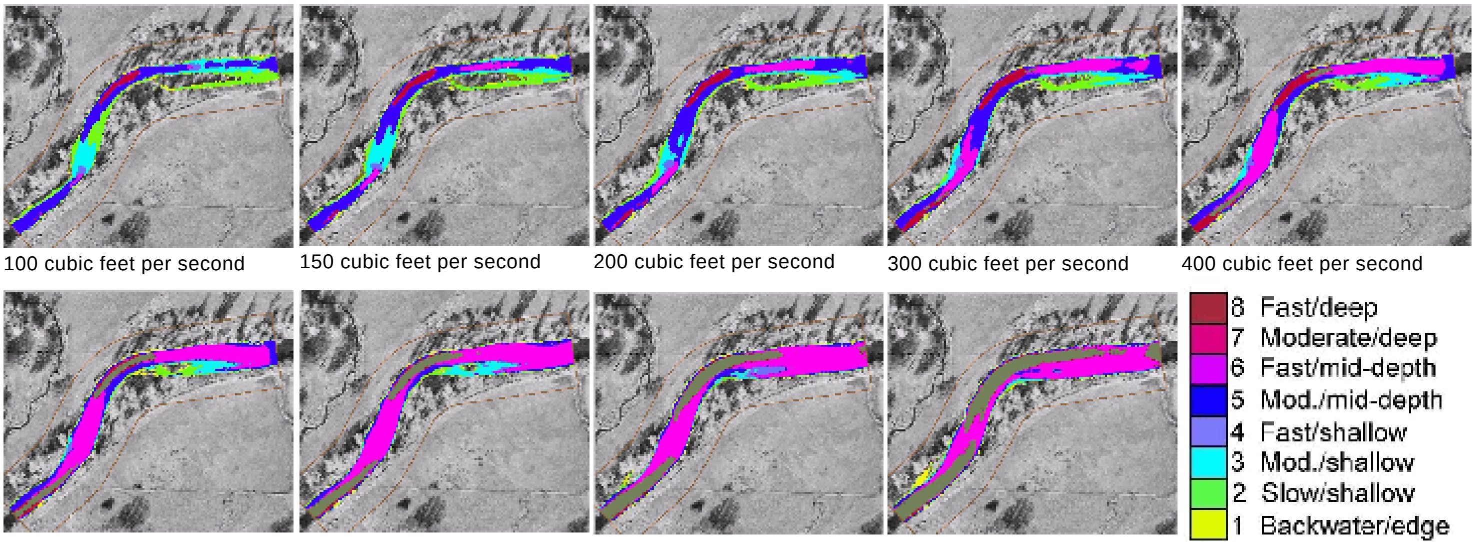
Jordanelle to Deer Creek

PROVO RIVER FLOW STUDY

Flow-habitat and Flow-ecological Relationships within the Riverine Ecosystem: Aquatic Habitat, Riparian Vegetation, Recreational Uses, Fluvial Processes

February 2004



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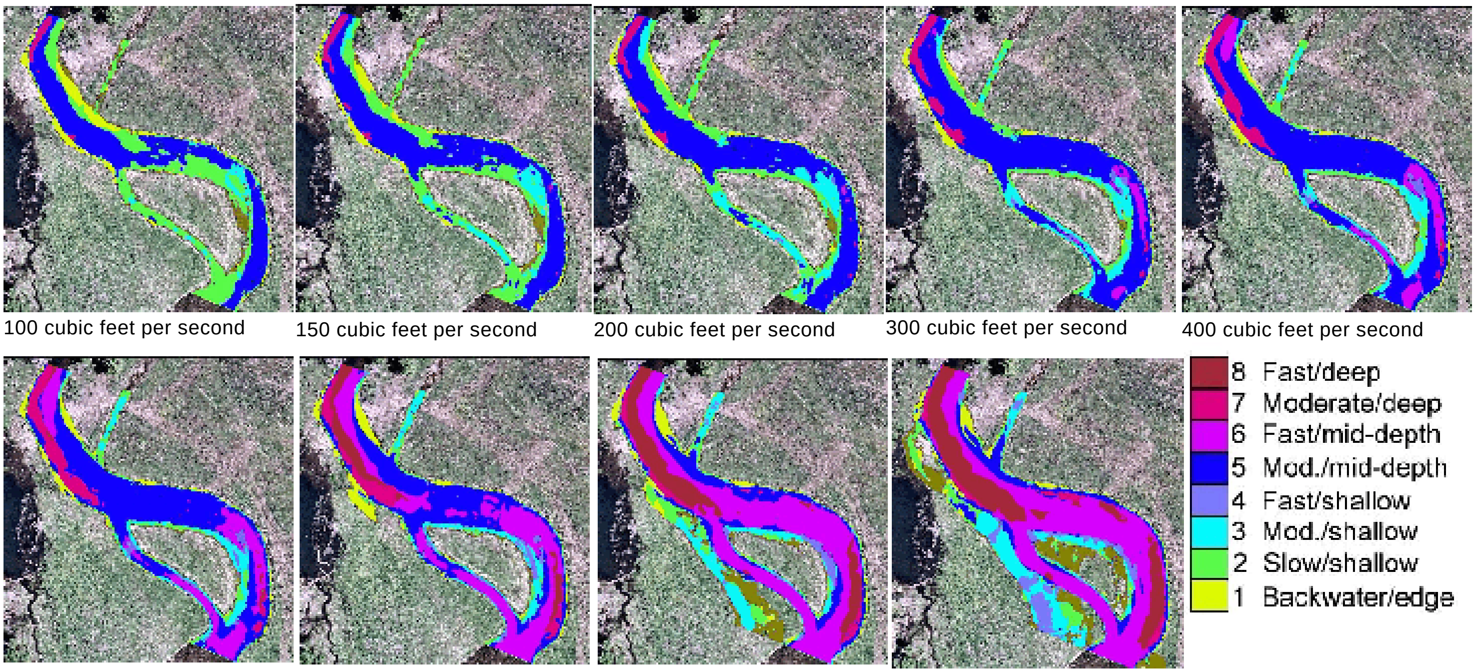
150 cubic feet per second
200 cubic feet per second
300 cubic feet per second
400 cubic feet per second
500 cubic feet per second
700 cubic feet per second
1,100 cubic feet per second
1,500 cubic feet per second

Site 7 (Channelized Reach)



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500 cubic feet per second
700 cubic feet per second
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1,500 cubic feet per second

Site 8 (Unchannelized Reach)

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1.0 INTRODUCTION

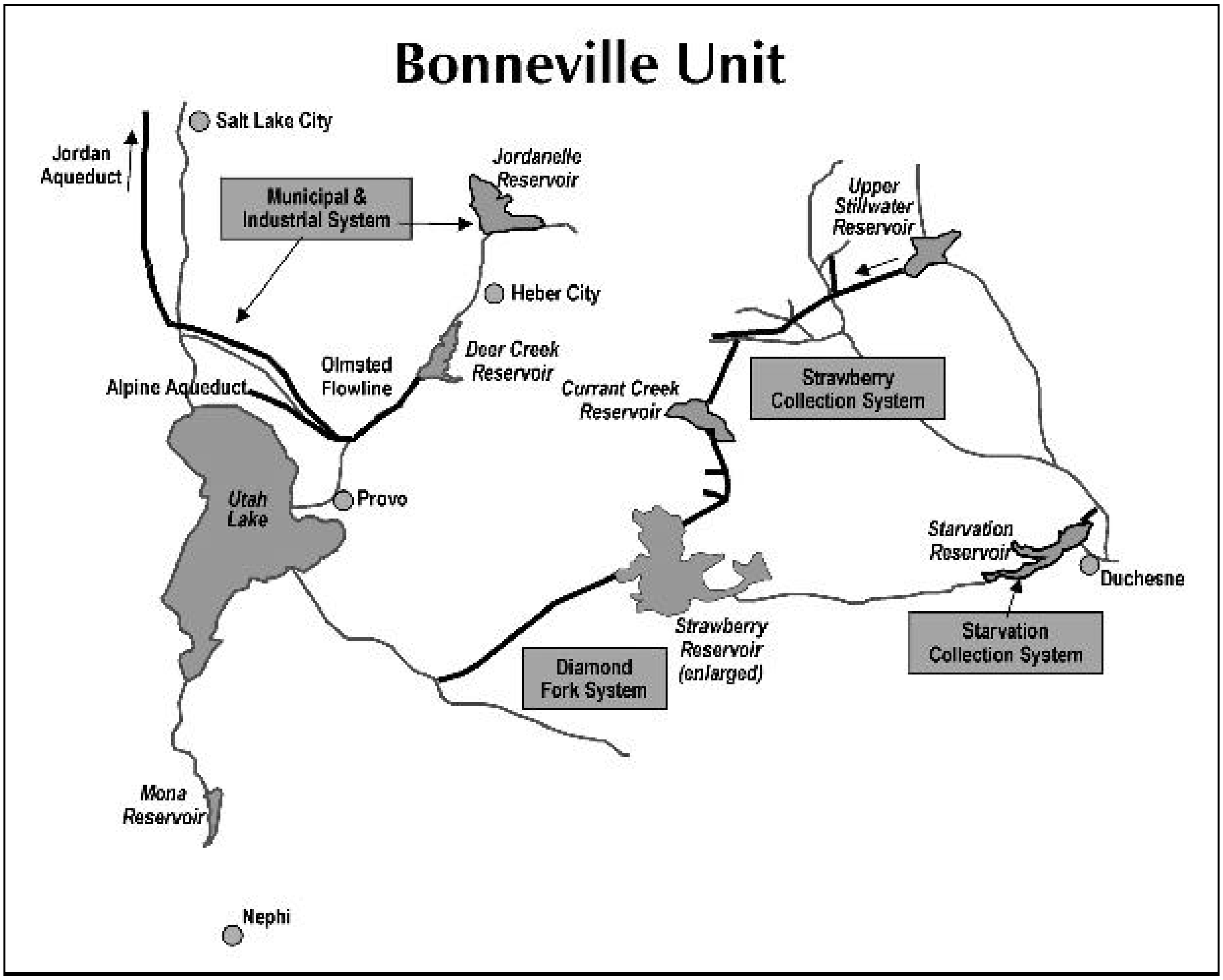
The Provo River is a highly significant water resource within the State of Utah. The river is a major source of drinking water for residents along the Wasatch Front, and is also heavily used for agricultural and recreational purposes. To put the importance of this water body in perspective, Provo River 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 that transport water from the Uinta Basin to the Bonneville Basin in Utah. The CUP is intended to develop a portion of Utah's share of water from the Upper Colorado River system, according to interstate compacts. The CUP was authorized by Congress in 1956 through enactment of the Colorado River Storage Project Act of 1956 (43 U.S.C. §§ 620 et seq.).

The Bonneville Unit is the largest unit of the CUP. The 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 Lake Aqueduct transferring water stored in Deer Creek Reservoir to the Salt Lake Valley, also completed in 1941, (3) the Duchesne Tunnel to transfer



Map 1.1. Features of the Bonneville Unit, Central Utah Project (*map provided by CUWCD*).

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.

In 1992, Congress enacted the Central Utah Project Completion Act ("CUPCA", Titles II through VI of Public Law 102-575). Among other things, CUPCA raised the Bonneville Unit appropriations ceiling; required local cost-sharing of project capital costs; authorized various water conservation and wildlife mitigation projects; and allowed local entities to construct certain project features under the direction of the 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 the 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 Environmental Commitment (EC) was included in the Record of Decision for the M&I System:

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

"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 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

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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."

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.

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.

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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).

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, active geomorphic processes that cause channel change over time, and trade-offs between resource components in evaluating alternative flow regimes.

This report covers channel reaches located between Jordanelle Dam and Deer Creek Reservoir (i.e., Middle Provo River); a separate companion report covers channel reaches located below Deer Creek Dam – areas known as “Provo Canyon and Lower Provo River.”

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), 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 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 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 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. If flows remain elevated for an adequate length of time, this supply of fine grained material becomes

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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.

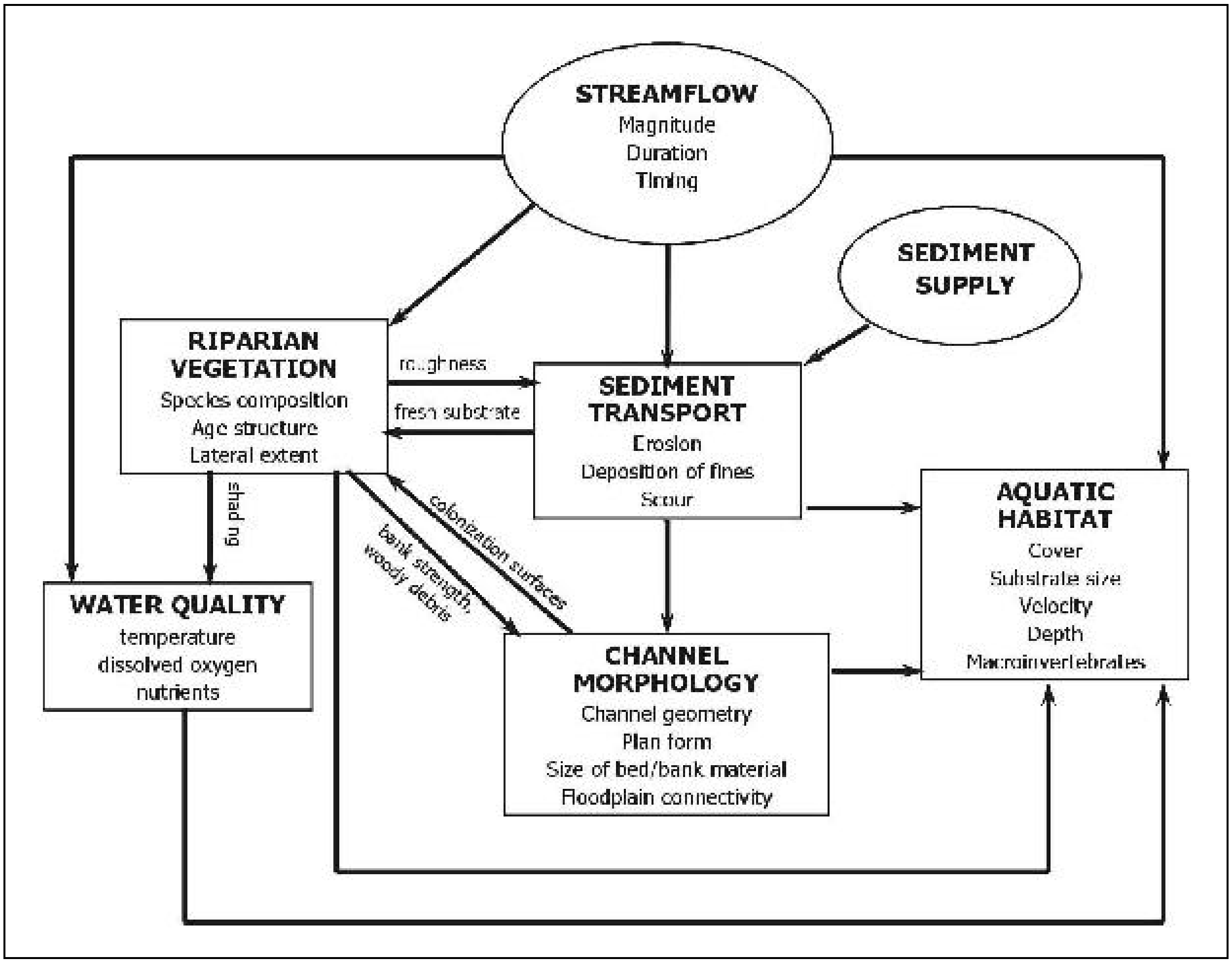


Diagram 1.1. Schematic illustration of major interactions among riverine resources and processes.

exhausted. If flows exceed the shear stress threshold to transport the 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 Provo River (Olsen et al. 1996), and the transition to the equal mobility phase has been 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 in the Lower Provo River (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. 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.

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 and floodplain development, 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. 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.

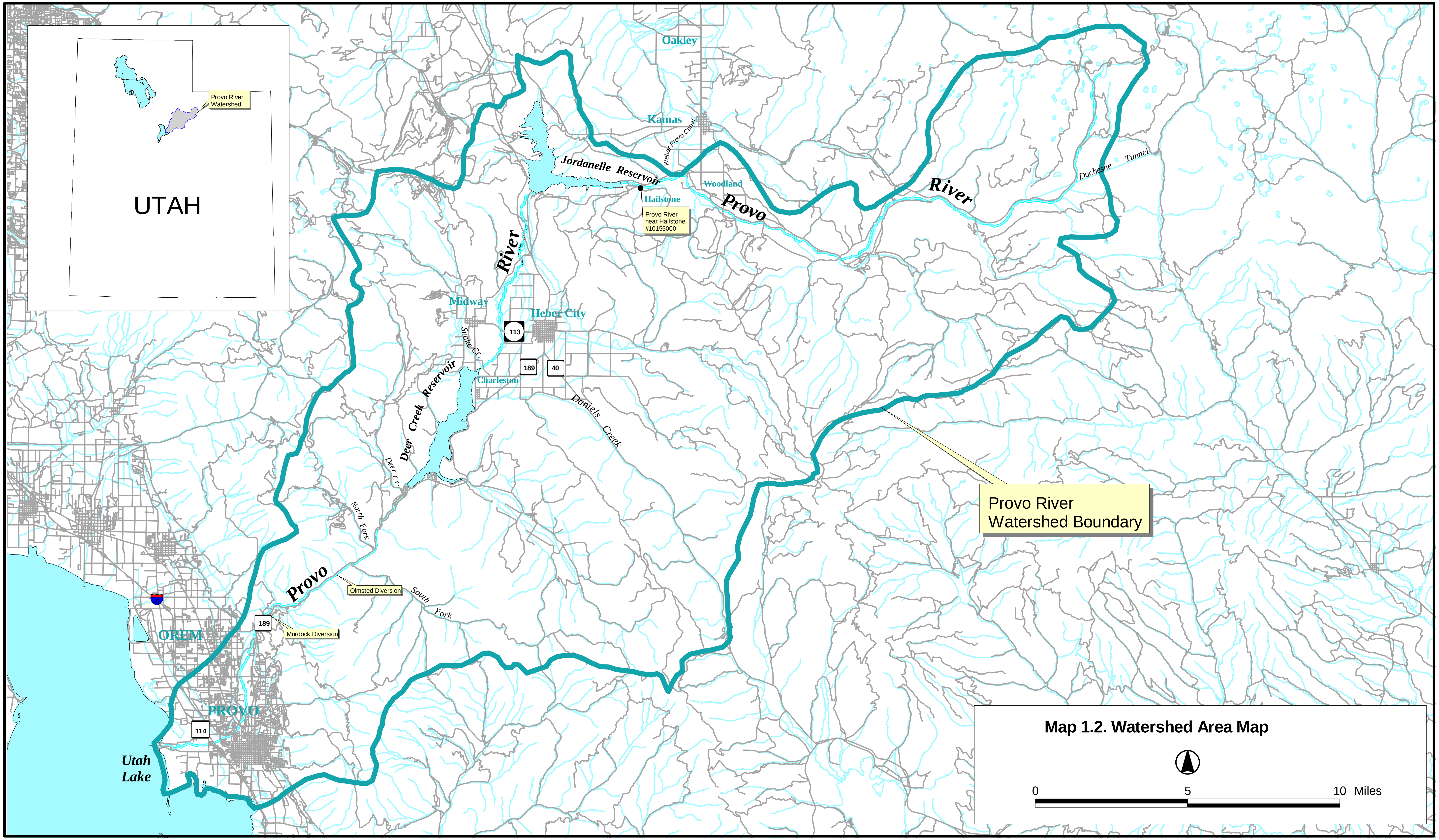
1.4.3 Amphibians and Riparian Obligate Species

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 relationships for amphibians and riparian obligate habitats 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.



Map 1.2. Watershed Area Map

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.

1.5.2 Description of study reaches

Within the Study Area, the main stem of 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. This report specifically covers the upper reaches between Jordanelle Dam and Deer Creek Reservoir (Reaches 7 and 8).

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 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.

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

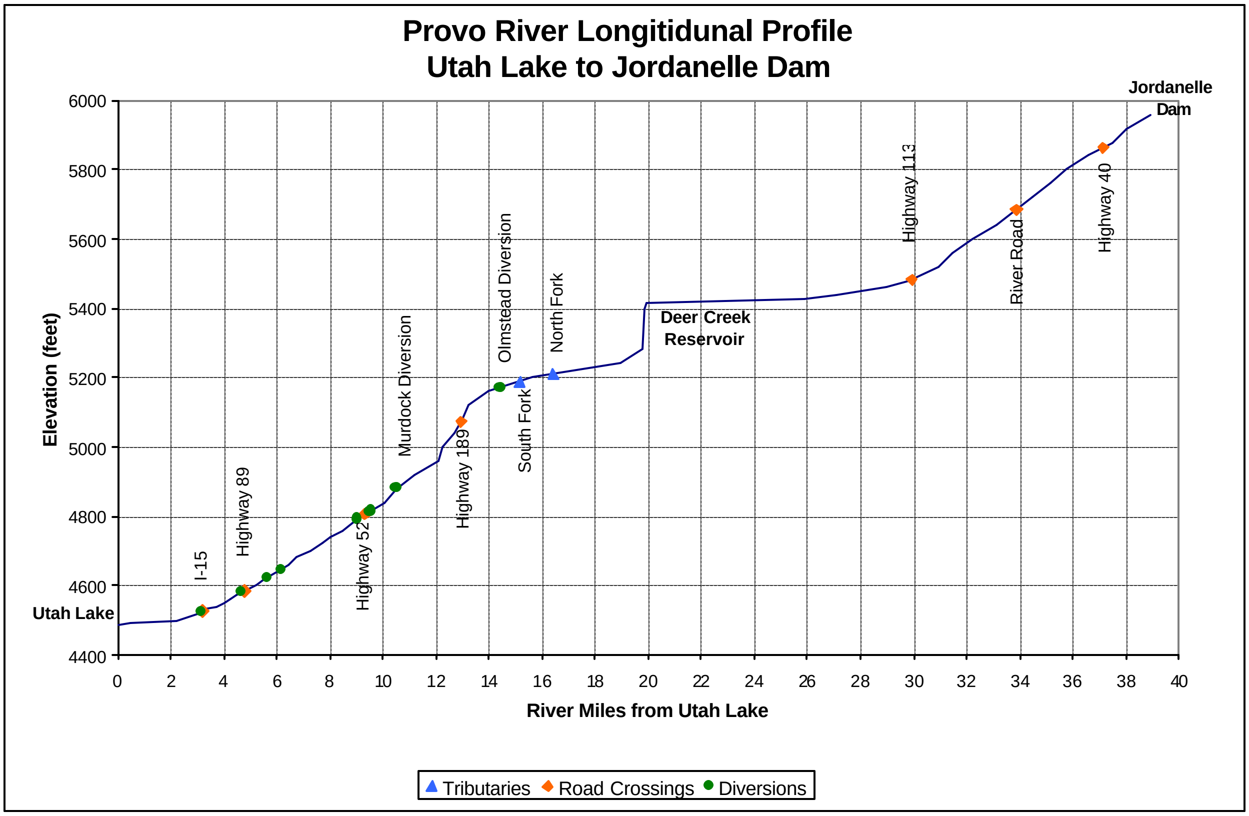


Figure 1.1 Generalized longitudinal profile of Provo River within the Study Area.

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.

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 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.

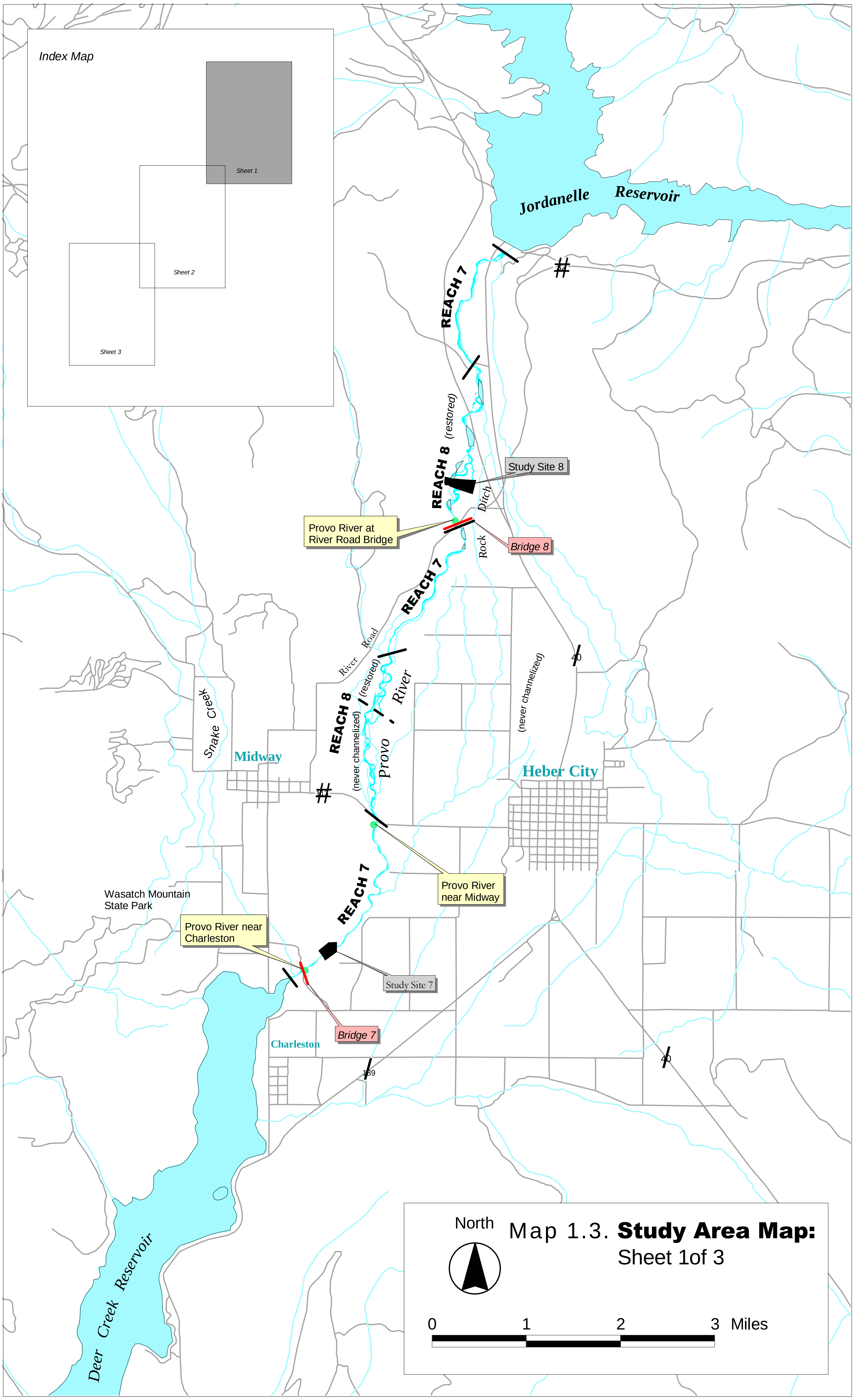
1.6 Existing Conditions: the Middle Provo River (Reaches 7 and 8)

As previously mentioned, this report covers study results for Reaches 7 and 8 only (Map 1.3). However, there are seven different study sites used to represent the many different elements expressed in these reaches. First, Reach 7 includes two study sites; Sites 7 and 7a. Site 7 represents the channelized portions of river whereas Site 7a represents the unique man-made cascades which are located below several diversion structures. These short cascades provide a unique habitat that would not otherwise exist in this portion of the Provo River without the physical presence of the diversion structures. There are no side-channels associated with Reach 7.

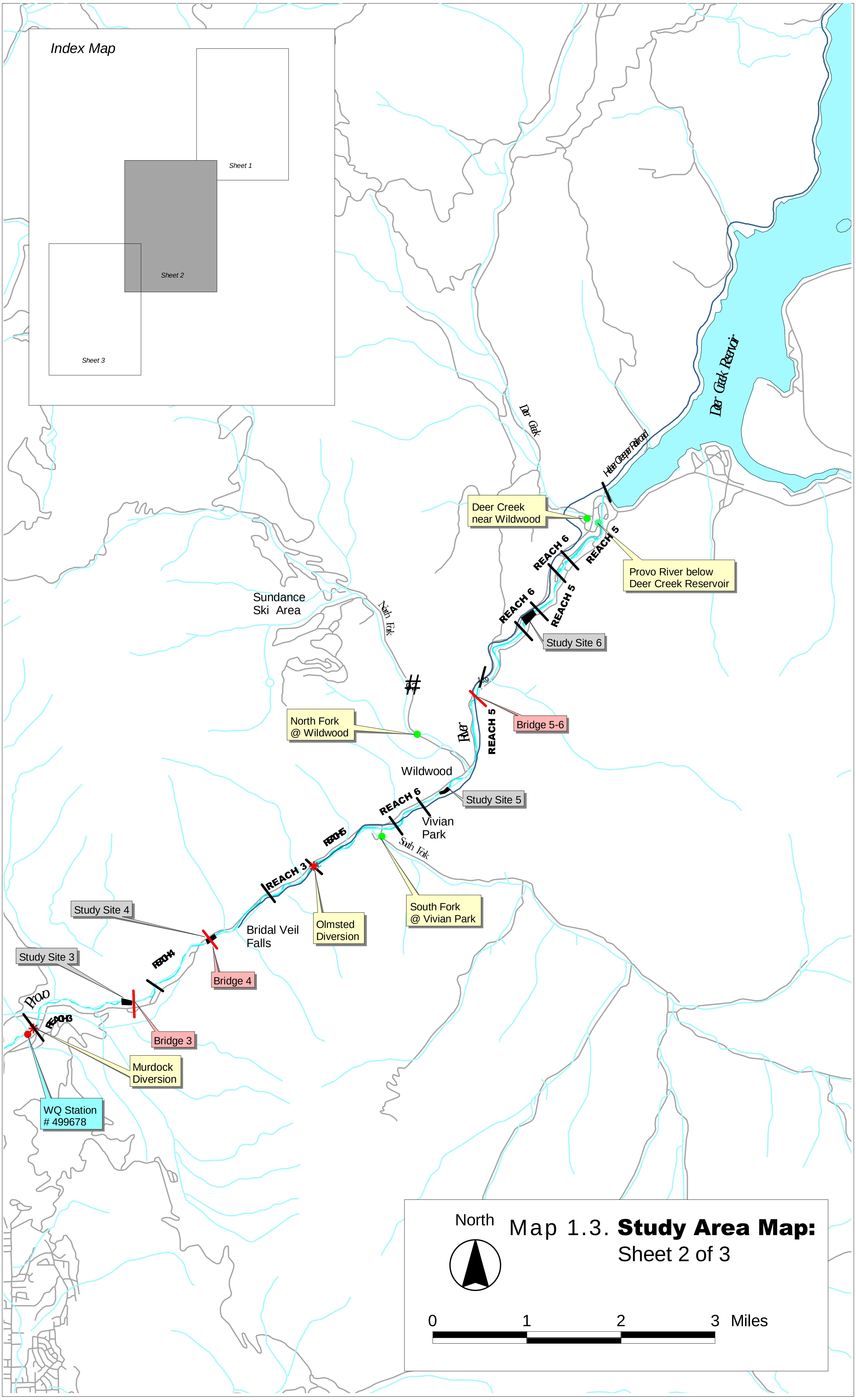
Second, Reach 8 includes five study sites; Sites 8, 8b, 8c, 8d, and 8e (Map 1.4). Site 8 represents the un-channelized portions of the main stem of the river. In general, the complexity of the river is much greater and side-channels exist in the river sections that have been restored or never channelized. Site 8b represents an historic ditch that exhibits some natural stream features that is currently being used to deliver return flow back to the Provo River from the Rock Ditch Diversion. Site 8c represents side-channels with moderate meanders and a relatively high width-to-depth ratio (similar to the "C" stream type based on the Rosgen (1996) classification system). Site 8d represents side-channels that have extensive beaver activities (i.e., a series of beaver dams). And finally, Site 8e represents side-channels with tight meanders and a relatively low width-to-depth ratio (similar to the "E" stream type based on the Rosgen (1996) classification system). Although side channel sites 8c, 8d, and 8e were evaluated separately for modeling purposes, it is important to note that they connect with the main stem of the Provo River near Site 8; therefore, habitats associated with the individual side channel study sites also contribute to the overall habitat diversity and availability associated with Site 8. Overall habitat in Reach 8 is best represented by the combination of Sites 8, 8c, 8d, and 8e. Site 8b represents a unique situation associated with a specific diversion system, and does not represent Reach 8 as a whole.

1.6.1 Hydrology

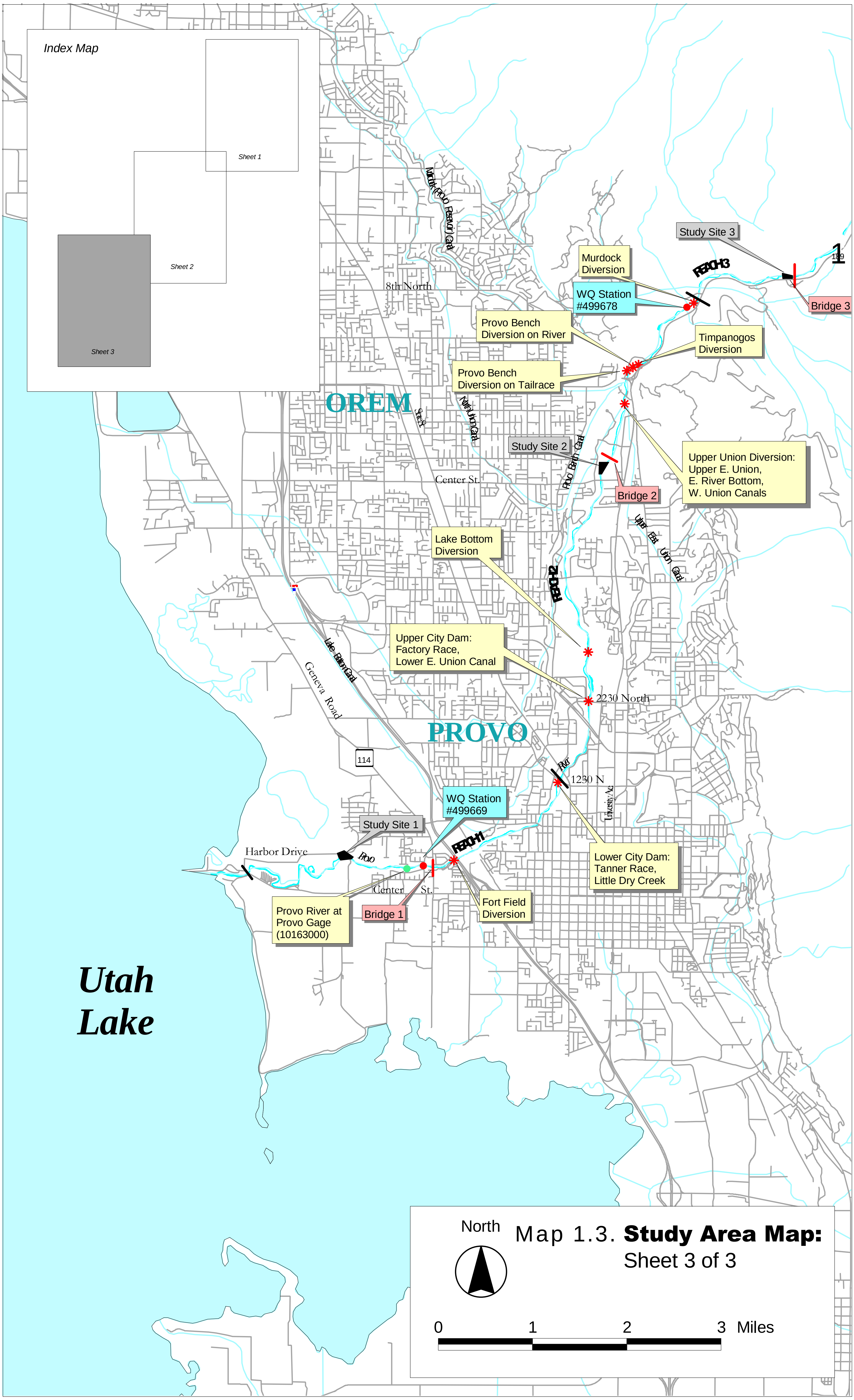
Currently, streamflows in the Middle Provo River (Reaches 7 and 8) are controlled by releases from Jordanelle Dam, and are further affected by several agricultural diversions in the Heber Valley. Hydrogeologically, this portion of the Provo River is a gaining stream reach, and groundwater inputs from 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. Although Jordanelle Dam has reduced peak flows and artificially elevated low flows, 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. Flows typically peak in the spring and recede to baseflow levels by mid-summer. The typical flow regime for the Middle Provo River is represented by water year



Map 1.3. **Study Area Map:**
Sheet 1of 3



Map 1.3. **Study Area Map:**
Sheet 2 of 3



Map 1.3. **Study Area Map:** Sheet 3 of 3

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, are also plotted in Figure 1.2 for comparison. Currently, a minimum instream flow of 125 cfs is legally required in Reaches 7 and 8.

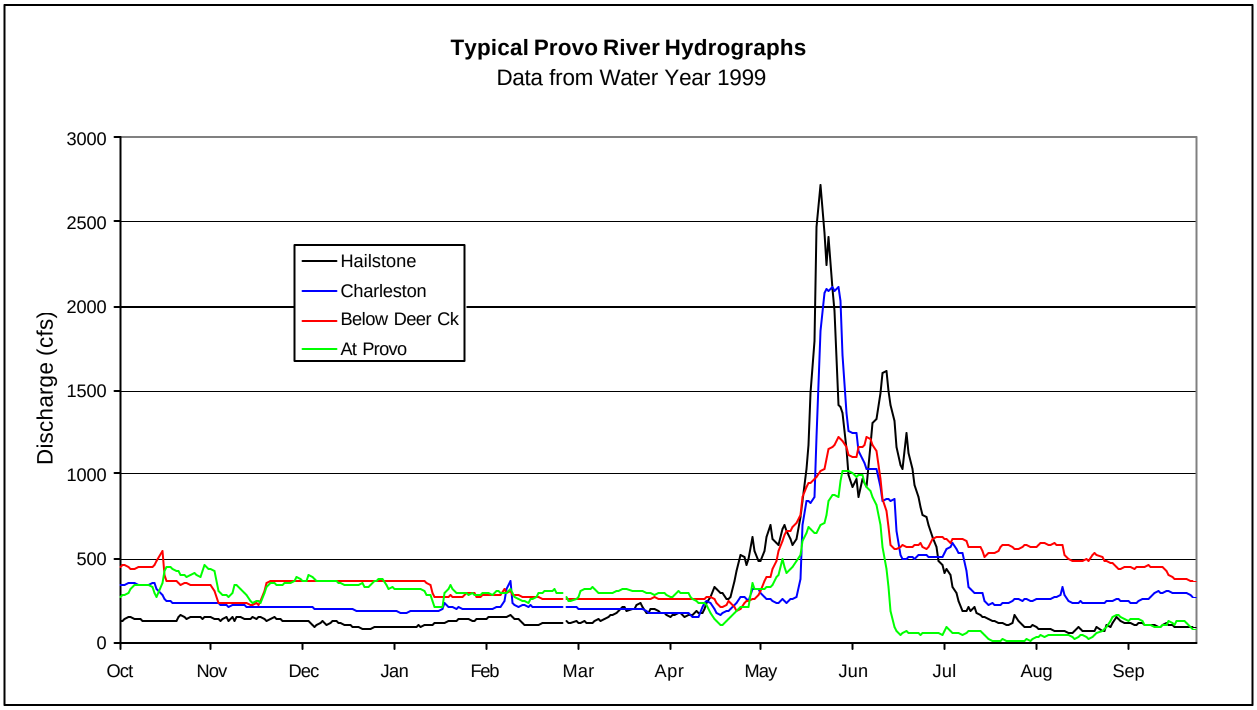


Figure 1.2. Typical Provo River hydrographs.

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, 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 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.

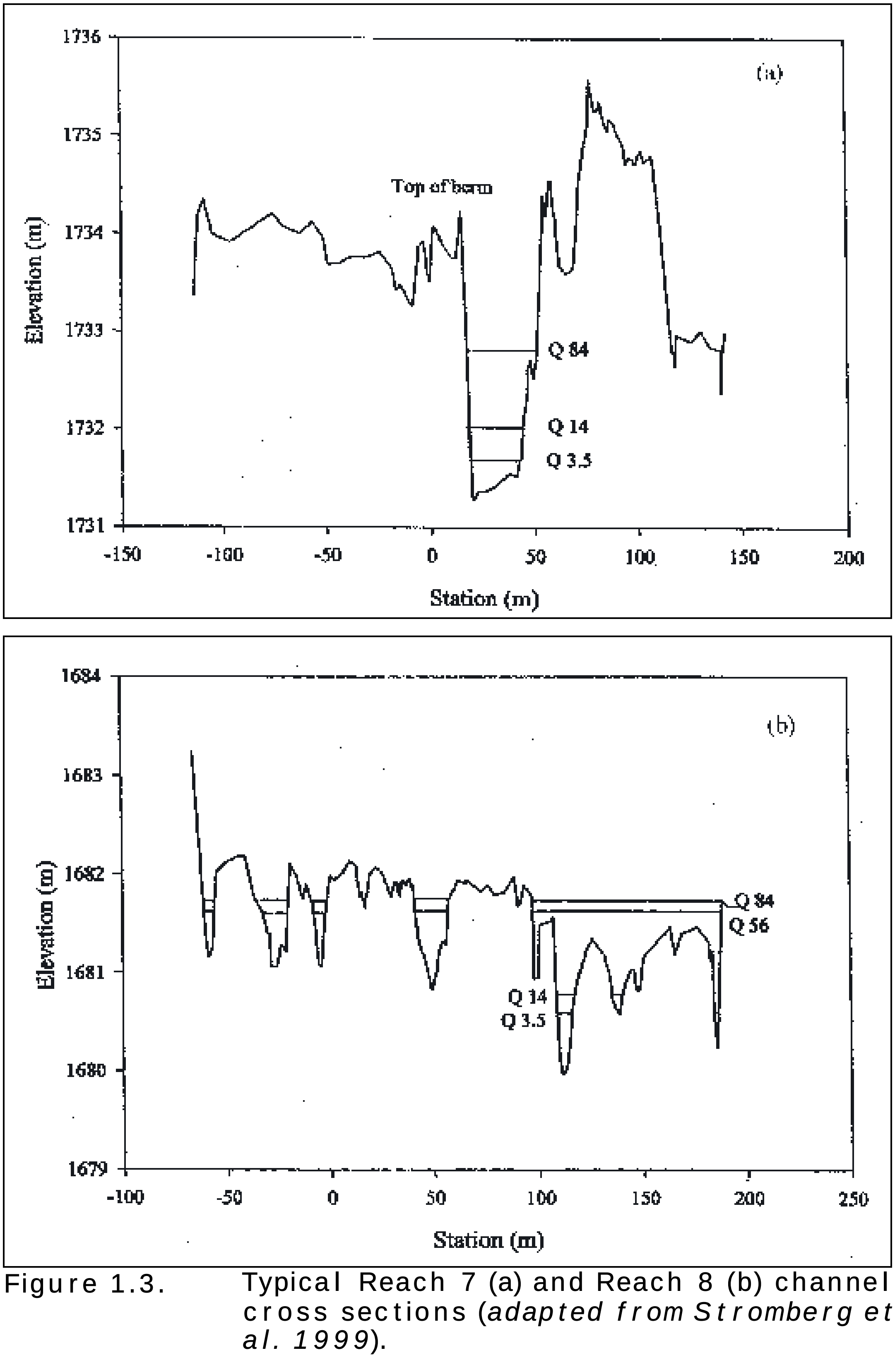


Figure 1.3. Typical Reach 7 (a) and Reach 8 (b) channel cross sections (*adapted from Stromberg et al. 1999*).

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, however the 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?

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 (Table 2.1) 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 7 represents Reach 7, 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. 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 flows.

2.2.2 Streamflow Determination

Actual streamflows encountered during sampling were determined using a combination of "real time" provisional data at USGS gauging stations combined with 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 7 and 7a	USGS Station #10155500 (Provo River near Charleston) 15 minute real-time data - 38 cfs (field measurement difference between Site 7/7a and the Charleston Gauge).
Study Site 8	USGS Station #10155200 (Provo River at River Road Bridge) 15 minute real-time data - 8c (field measurements in adjacent side-channel).
Study Site 8b-8e	Field measurements.

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 and 4) habitat modeling (details in Appendix A). Two-dimensional models were developed for Study Sites 7, 8, 8b, 8c and 8e, and these models were used to represent habitat in Reaches 7 and 8, respectively. Study Sites 7a and 8d were not suitable for hydraulic modeling due to either the steep cascading gradient at Site 7a and step-pool morphology at Site 8d; therefore, habitat-flow relationships at these sites 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 7-15 cfs in side-channels and 125-175 cfs in the main channel, depending on the site) when the entire channel was visible, and mapping for all 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. Water surface elevation at Site 8b was only surveyed at "low" and "medium" discharge levels because of the anticipated constant flow conditions in this regulated ditch.

Table 2.5. Discharge levels for water surface elevation measurements.

Study Site	Discharge (cfs) and Date Surveyed			
	Low	Medium	Medium-High	High
Site 7	169 April 26, 2002	339 May 20, 2002	897 May 21, 2002	1362 May 22, 2002
Site 8	122 May 16, 2002	378 May 20, 2002	729 May 21, 2002	1136 May 22, 2002
Site 8b	<1 May 10, 02	15 May 23, 02		
Site 8c	7 May 16, 2002	30 May 20, 2002	85 May 21, 2002	124 May 22, 2002
Site 8e	8 May 14, 2002	32 May 20, 2002	56 May 21, 2002	80 May 22, 2002

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.

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 three (or more) 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. 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

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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.

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

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.

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 and Weighted Usable Area (WUA) was calculated. 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 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.

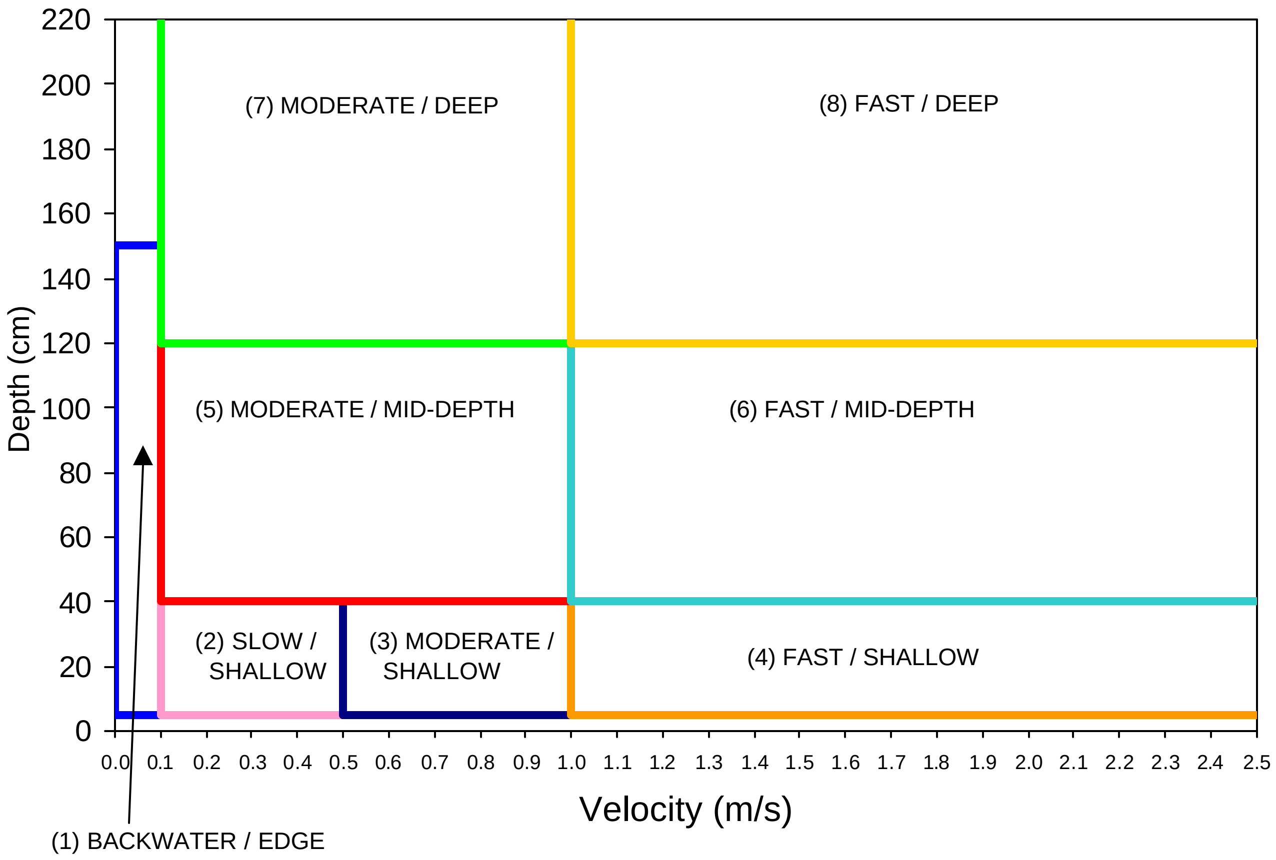

Figure 2.1. Provo River habitat niches.

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 (i.e., Reaches 7 and 8 respectively), 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.

Table 2.6. Species use of Provo River habitat niches.

Niche	Species	Life stage	Use[a]
(1) Backwater/ Edge	Mountain whitefish	Fry	Partial (1,5)
	Mountain sucker	Juvenile, YOY[b]	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)
	Specked 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) Moderate/ Mid-depth	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 (1,7)
	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" indicates best habitat suitability within niche; "partial" indicates best habitat suitability shared between niches.

[B] YOY - Young-of-year.

Table 2.7. Proportion of different aquatic habitat types in channel reaches on the Provo River.

Reach	Broad Habitat Type	Total Acreage	Percent
7	Bar	2.25	5
7	Island	4.54	9
7	Pool	2.85	6
7	Riffle	15.89	33
7	Run	23.14	48
7	**Total**	**48.67**	**100**
8	Bar	5.26	5
8	Island	58.27	53
8	Pool	4.56	4
8	Riffle	13.34	12
8	Run	28.29	26
8	**Total**	**109.72**	**100**

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 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 Sites 7a and 8d were selected to represent the unique high-gradient cascading portion of the river below diversion structures and step-pool side-channels created by beaver dams, respectively. The complexity of these sites made it infeasible for computer-based flow modeling. Therefore, transects were established and velocity and depth measurements were collected across each transect. 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 major anthropogenic channelization practices and the resultant sediment flux. 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). A relatively new yet important factor affecting sediment transport and channel morphology in the Middle Provo River is the presence of Jordanelle Dam which traps upstream sediment supplies and interrupts downstream transport. Sediment supplies become limited to local sources (i.e. bank erosion, tributaries, side hill inputs, and bed degradation) when upstream supplies are cut off. Transport equilibrium (influx equaling outflux) becomes skewed, resulting in “sediment mining” and in most cases channel degradation.

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 size and shape of pools and riffles, 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 Study Sites 7 and 8 by calculating bedload transport at even increments of flow from 0 to 2,000 cfs. Originally, bedoad calculations were performed using the Meyer-Peter and Muller (1948) equation. Additional bedload samples were collected in 2003 and it became apparent that the Parker (1990) equation more accurately predicts daily transport rates. Therefore, the Parker equation was used instead of the Meyer-Peter Muller for Study Sites 7 and 8. The Parker 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 it is important to note that 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 relationship (rating curve) between flow and transport is assumed correct (especially during the initial stages where recently collected bedload data is available), the actual quantities should be viewed in relative terms (relative to the other study sites).

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). Although this assumption holds true for the unchannelized reaches (Reach 8) of the Middle Provo River, the streambed has apparently become coarsened/armored in the channelized reaches (Reach 7). Bed coarsening is a common effect of channel straightening. Talbot and Lapointe (2002) found that the D_{50} size fraction more than doubled following extensive meander straightening in the Sainte-Marguerite River, Quebec, Canada from road construction that occurred in the 1960s. A similar pattern of channel degradation is evident in the channelized portions of the Middle Provo River however the actual historical D_{50} values at both sites are unknown. Because of bed coarsening, the D_{50} at Site 7 is predicted to be relatively immobile and therefore may under-predict transport rates.

At Site 8, the D_{50} (70 mm in diameter) was used initially for modeling. This site was recently constructed and the bed particle size distribution has not completely adjusted. It is anticipated that the bed will coarsen over time and the D_{50} will increase to 80-100 mm in diameter. Bedload rating curves are shown under various levels of bed armoring in the Discussion Section of this report. The actual bedload sampling data was plotted against the rating curves to determine the best-fit curve (D_{50} size) for modeling bedload at Site 8. Effective discharge calculations are provided for the best-fit in the Results Section of this report.

2.4.2 Bedload Sampling

Field samples of bedload were collected in 2002 and 2003 to calibrate the rating curve (model) and determine the sizes of bed material actually in transport during high flow. In 2002, bedload was sampled at 2 bridges near Sites 7 and 8 (Map 1.3) whereas in 2003 bedload was sampled at the same 2 bridges as 2002 plus 2 additional bridges (the "white bridge" immediately upstream of Highway 40 and the Midway bridge near the Provo River near Midway gauging station). Bedload was not sampled in the side-channels at Site 8. Sampling occurred 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.

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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.

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 where bedload movement was active. You can feel when material is in transport because it bumps against the sides of the orifice. The width of active bedload transport was noted so that total transport calculations could be performed. Total time for most samples was 30 minutes. 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.

Table 2.8. Bedload sampling dates and flows.

Bedload Bridge	Dates Sampled	Flows Sampled (Cubic Feet Per Second)
7 (2002)	05/20, 05/21, 05/22	357, 854, 1342
8 (2002)	05/20, 05/21, 05/22	408, 800, 1250
7 (2003)	06/17, 06/17, 06/17, 06/17 06/18, 06/18	1405, 1396, 1372, 1372 1404, 1346
Midway (2003)	06/17, 06/17, 06,17, 06/17 06/18, 06/18	1388, 1388, 1395, 1395 1409, 1409
8 (2003)	06/16, 06/16, 06/16, 06/16 06/16, 06/16, 06/16, 06/16 06/16, 06/16, 06/16, 06/16 06/17, 06/17, 06/17 06/17, 06/17, 06/17 06/18, 06/18, 06/18	537, 558, 568, 580 634, 719, 849, 920 1023, 1084, 1209, 1273 1388, 1405, 1388 1413, 1396, 1388 1422, 1422, 1396
Above Hwy 40 (2003)	06/17, 06/17, 06/17, 06,17 06/18, 06/18, 06/18, 06,18	1388, 1388, 1422, 1405 1430, 1273, 1355, 1355

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.

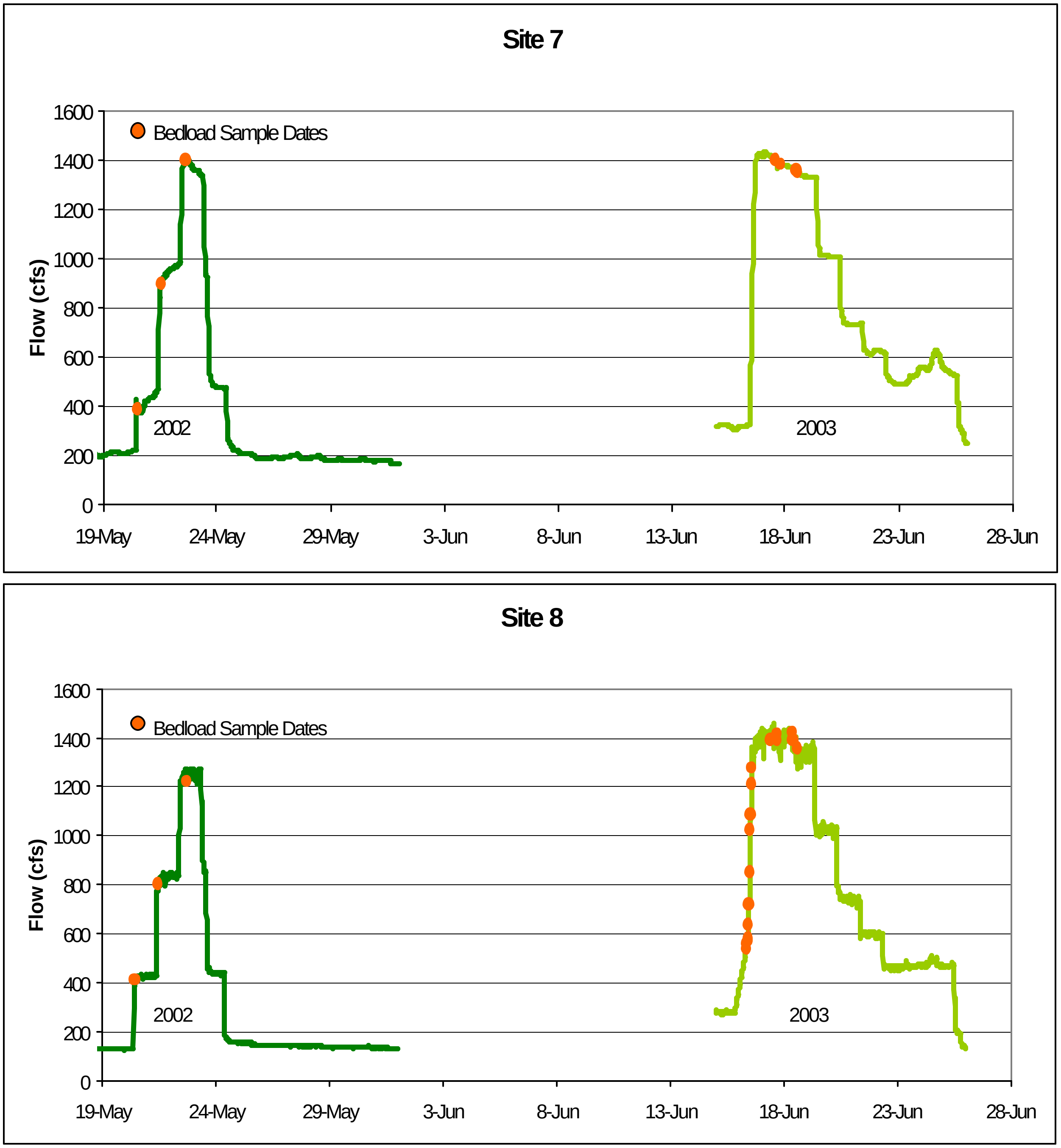


Figure 2.2. Bedload sampling dates positioned within the 2002 and 2003 spring runoff hydrographs for Bridges 7 and 8.

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.

2.4.5 Suspended Sediment Modeling

Flow and Total Suspended Solids (TSS) data were obtained from the EPA STORET database for the Midway water quality monitoring site (#499730) near the USGS gauging station. 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. 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 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 this data is the relative lack of samples collected at high flows.

TSS and flow data were plotted. For each sample, TSS concentrations and streamflow values 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 Dam) flow regimes for the Reaches 7 and 8 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 obtained and analyzed (see Appendix C for details). 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 200 cfs increments (0-200, 200-400, etc.). Bedload transport was calculated at the mid-point of each flow increment (100, 300, 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 200 cfs increment. The flow duration weighted sediment loads were then graphed to determine the increment of discharge that transports the most bedload sediment over the period of record and identify 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 spring runoff when the majority of sediment transport occurs. 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.

2.5.1 Riparian Transect Evaluations

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 various flows between 10 and 2,000 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.

2.5.2 Expanded Site 8 Recruitment Model

In addition to the transect-based evaluations described above, a more detailed model was developed to evaluated cottonwood recruitment potential under different hydrologic scenarios at Site 8. The original Site 8 study site was expanded to include a greater expanse of floodplain and to include the entire length of the side channel where study site 8c is located (Map 1.4). Additional topographic surveys were completed, and air photos of the expanded study site were flown in May, 2003. Additional topographic data points were added interactively using OrthoMax 3D visualization software with the aerial imagery, and the combined topographic data were used to develop a comprehensive terrain model (TIN) of the expanded study site.

A 2-dimensional hydrodynamics model (River2D) that includes a groundwater component was used to determine water depths at various discharge increments (more information on the River2D model can be found at http://www.river2d.ualberta.ca) . Water surface elevations were surveyed and field-mapped at a discharge of 1,400 cfs during peak flows in June, 2003, and these measured elevations were used for model calibration in conjunction with water surface measurements taken in May, 2002 at original Study Sites 8 and 8c. Calibration techniques were the same as those described above for the original study sites. Water surface elevations were modeled for flows between 150 cfs and 2,000 cfs.

Once the hydrodynamics model was complete, a cottonwood recruitment model was developed that interfaces with the hydrodynamics model outputs to determine the number of model nodes meeting recruitment criteria for a given input hydrograph. Each model node is a point in the terrain model "mesh", and each node represents a 1 square meter area. The riparian model tracks water depths (both positive and negative – i.e. groundwater – elevations) at each node for each daily flow level. Water depths for each daily discharge value defined in the input hydrograph are determined via linear interpolation between the modeled stage-discharge values. Input hydrographs and model runs were developed for the time period May 1-July 31, which encompasses the typical springtime peak flow period and the cottonwood seed dispersal window.

The following cottonwood recruitment criteria were used to determine success/failure at individual nodes:

1. the node must be wetted (i.e. water depth > 0) and then become exposed (water depth <0) within the cottonwood seed dispersal window, defined as May 30-July 19
2. within 10 days of being wetted, the soil surface at the model node remains moist and viable for seed germination (i.e. the groundwater level has not dropped below the capillary fringe, estimated at 20 cm)
3. the groundwater recession rate at the model node does not exceed 2.5 cm (1 inch) per day, calculated as a 5-day moving average
4. the final groundwater elevation at the node at the end of the model run (i.e. July 31) is not more than 1 meter (3.3 feet) below the ground surface
5. the node is not re-wetted (i.e. depth remains ≤ 0) after initial flow recession and after the seed dispersal window

These specific model criteria are based on values published in the literature. Criteria #4 is based on studies of cottonwood recruitment that have found that the maximum cottonwood root growth within the first growing season is about 1 meter (3.3 feet) (Scott et al. 1993, Mahoney and Rood 1998, Segelquist et al. 1993). Published drawdown rates range from 0.3 cm/day to 4 cm/day (Mahoney and Rood 1998, Stromberg et al. 1999, Scott et al. 1993, Segelquist et al. 1993); the 2.5 cm/day used in criteria #3 is a commonly used value in the middle of this range.

In order to calibrate the recruitment model, staff visited the expanded Site 8 area in August 2003 to identify areas where young seedlings were present and compare the specific locations where recruitment was successful with the overall area that had been inundated by the June 2003 peak flows of 1,400 cfs. Recruitment model parameters (capillary fringe size, maximum recession rate/ averaging period, seed dispersal window) were adjusted so that the results using spring 2003 flow inputs matched the recruitment patterns observed in the field.

The recruitment model was run using several different input hydrographs with different flood peak magnitudes and recession rates. Specifically, springtime hydrographs of daily flows at the Charleston

USGS gage for the years 1950, 1993, 1999, and 2000 were analyzed. The years 1950 and 1993 represent high water years prior to Jordanelle Dam, while the 1999 and 2000 hydrographs represent contrasting conditions under the current post-Jordanelle flow regime.

2.6 Water Quality Evaluation

2.6.1 Temperature

Thermisters (Onset optic stowaways) were placed in the two main channel study sites 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 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.

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 the Study Area, 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. These criteria were used to determine the amount of wading/fishing "habitat" at Study Sites 7 and 8 for the same range of flows at which fish habitat was modeled.

3.0 RESULTS

3.1 SITE 8

3.1.1 AQUATIC HABITAT - SITE 8

3.1.1.1 HABITAT NICHE MODELING - SITE 8

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 8, but individual trout life stage HSI curves were also used. To represent habitat in the entire river reaches, Site 8 results from the channel reach-scale mapping were extrapolated to all of Reach 8. 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 8 and the extrapolated reach, the results for Reach 8 are discussed below.

Each WUA value calculated for Reach 8 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>26,000 ft^2/1,000ft at 25 cfs. Although niche 1 habitat decreases with increasing flows, the channel complexity of this “restored” reach allows for a moderate amount of this habitat type (>3,900 ft^2/1,000ft) to be present at all modeled flows. The presence of this type of habitat in the Reach 8 would suggest the potential for native species to inhabit this area and previous surveys (Belk and Ellsworth 2000) have found several native fishes in these areas. The slow/shallow habitat (niche 2) supports many juvenile and young-of-year (YOY) species. This niche peaks at nearly 29,000 ft^2/1,000ft at 70 cfs; habitat decreases as flow increases, but never drops below 5,700 ft^2/1,000ft. 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) is minimal at low flows, increases to 10,000 ft^2/1,000ft at approximately 200-300 cfs, decreases slightly until 900 cfs, and then increases again steadily to over 17,500 ft^2/1,000ft at 2,000 cfs. The fast/shallow habitat (niche 4), which provides habitat for mountain sucker adults and mottled sculpin adults and juveniles increases steadily with increasing flows to 4,800 ft^2/1,000ft at 1,300 cfs and then increases rapidly as flows exceed 1,300 cfs. Niche 5 is the primary habitat type for the sportfish in the Provo River including all trout and mountain whitefish adults and juveniles. Niche 5 habitat (moderate/mid-depth) is abundant (>23,000 ft^2/1,000ft) between 70 and 700 cfs. Niche 5 habitat peaks at 700 cfs then declines steadily at higher flows.

The only species/lifestage documented in niche 6 habitat (fast/mid-depth) is the adult mountain sucker. Niche 6 habitat in Reach 8 increases steadily to a maximum near 48,000 ft^2/1,000ft at 1,500 cfs. Moderate/deep habitat (niche 7) is consistently above 3,000 ft^2/1,000ft at 300 cfs and higher; this habitat is preferred by adult mountain whitefish and adult Utah sucker. This was the only reach that adult Utah sucker were observed during snorkeling surveys. Although the fast/deep (niche 8) does not directly

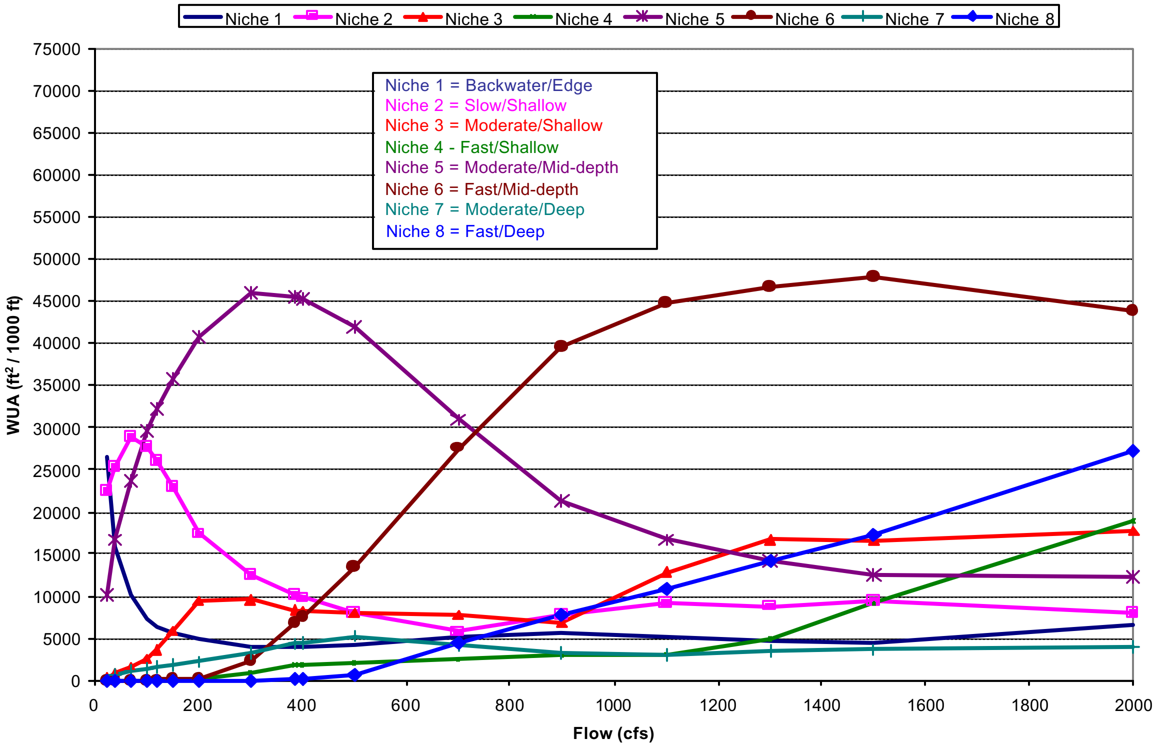


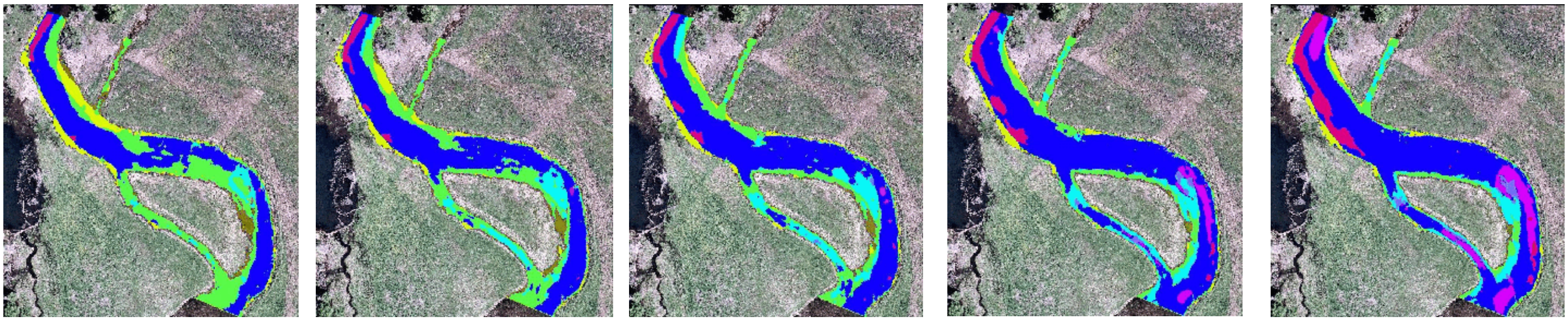
FIGURE 3.1. REACH 8: HABITAT NICHES - WUA VS. FLOW.

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 500 cfs.

As depicted in Image 3.1 and displayed in Figure 3.1, niche 1 maintains WUA greater than 10,000 ft^2 / 1,000ft to approximately 70 cfs, whereas niche 5 (sportfish niche) is maintained at greater than 25,000 ft^2 / 1,000ft for all modeled flows higher than 70 cfs. Niche 2 remained high (>10,000 ft^2/1,000ft) in this reach through 400 cfs. The diversity of habitats available in this reach with variable flows suggests the potential for maintaining a diverse fish community composed of natives and trout. The dominance of niche 5 conditions at most flows will provide substantial habitat for adult and juvenile trout. During this time, natives may be restricted to the side channels in this area (see sites 8b-e), but when flows are relatively low, conditions will provide abundant habitat in the main channel for natives. Biological interactions (e.g., predation) and timing of appropriate flows may limit the feasibility of supporting some species, but the diverse habitat will be beneficial to those species that persist in this reach.

Overall, the results of the habitat niche modeling for this reach supports the available biological data, which recognizes the presence of several native species. Niches 1 and 3 remain at moderate levels at all flows and niche 2 is abundant in this reach. However, most native species have been observed in low densities and this may be a consequence of niche 5 (sportfish) dominance at most flows.

IMAGE 3.1. HABITAT NICHES - WEIGHTED USABLE AREA (SITE 8). THE IMAGES BELOW DEPICT HABITAT NICHES THAT ARE PRESENT AT DISCHARGES OF 100, 150, 200, 300, 400, 500, 700, 1100, AND 1500 CUBIC FEET PER SECOND. HABITAT NICHES ARE REPRESENTED BY THE COLORS REPRESENTED THE LEGEND.



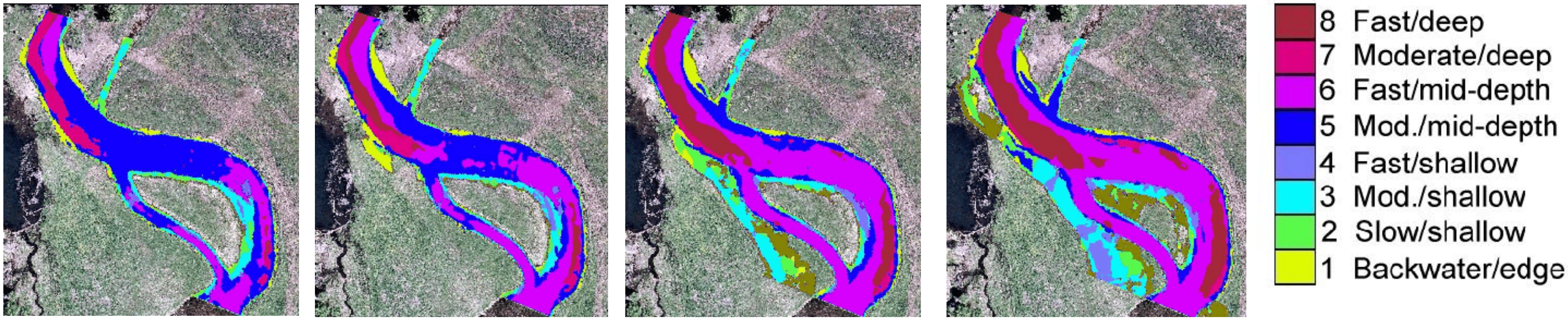
100 cubic feet per second

150 cubic feet per second

200 cubic feet per second

300 cubic feet per second

400 cubic feet per second



500 cubic feet per second

700 cubic feet per second

1,100 cubic feet per second

1,500 cubic feet per second

When suitable habitat for the sportfish (trout) is abundant, biological interactions probably limit native fish populations; small pockets of suitable habitat for natives may exist, but are often surrounded by trout habitat. Also, niche 1 habitat may be abundant in this reach at low flows, but discharge rarely falls to those levels (Figure 1.2) in the Middle Provo River.

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 and fry), 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 (> 20,000 ft^2 / 1,000ft) of habitat is available at flows greater between 25-900 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).

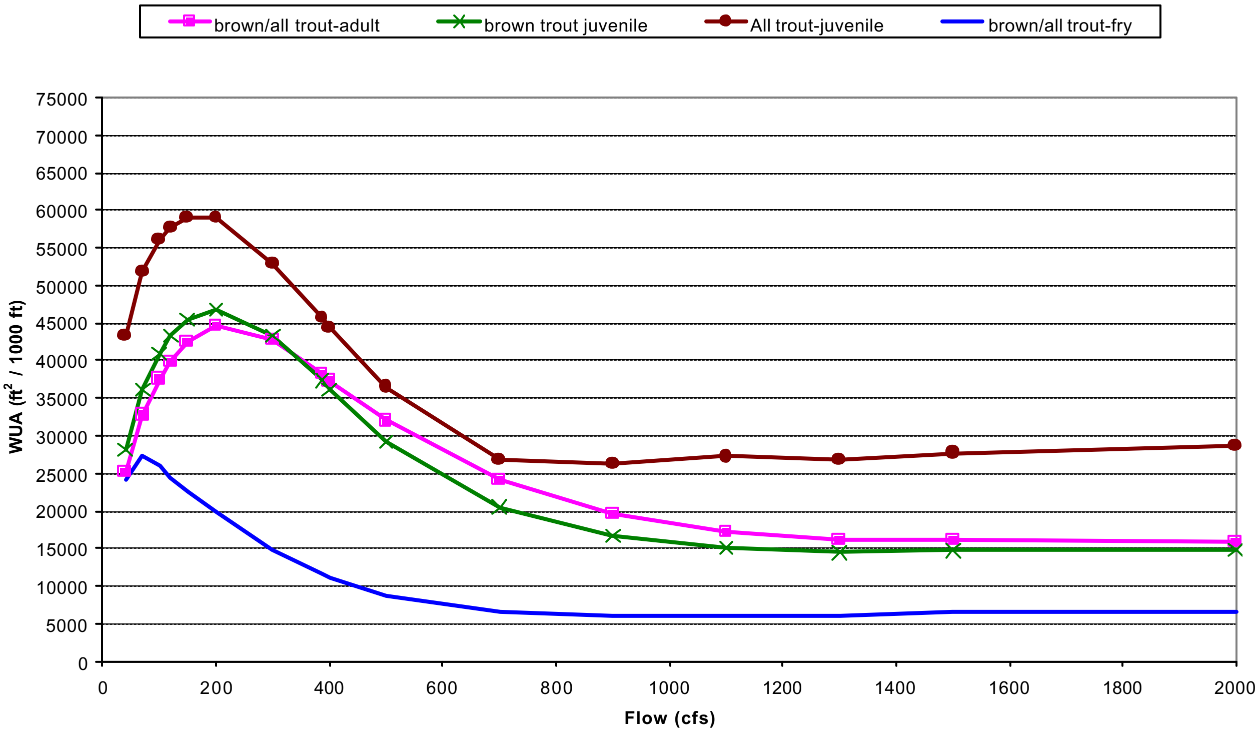


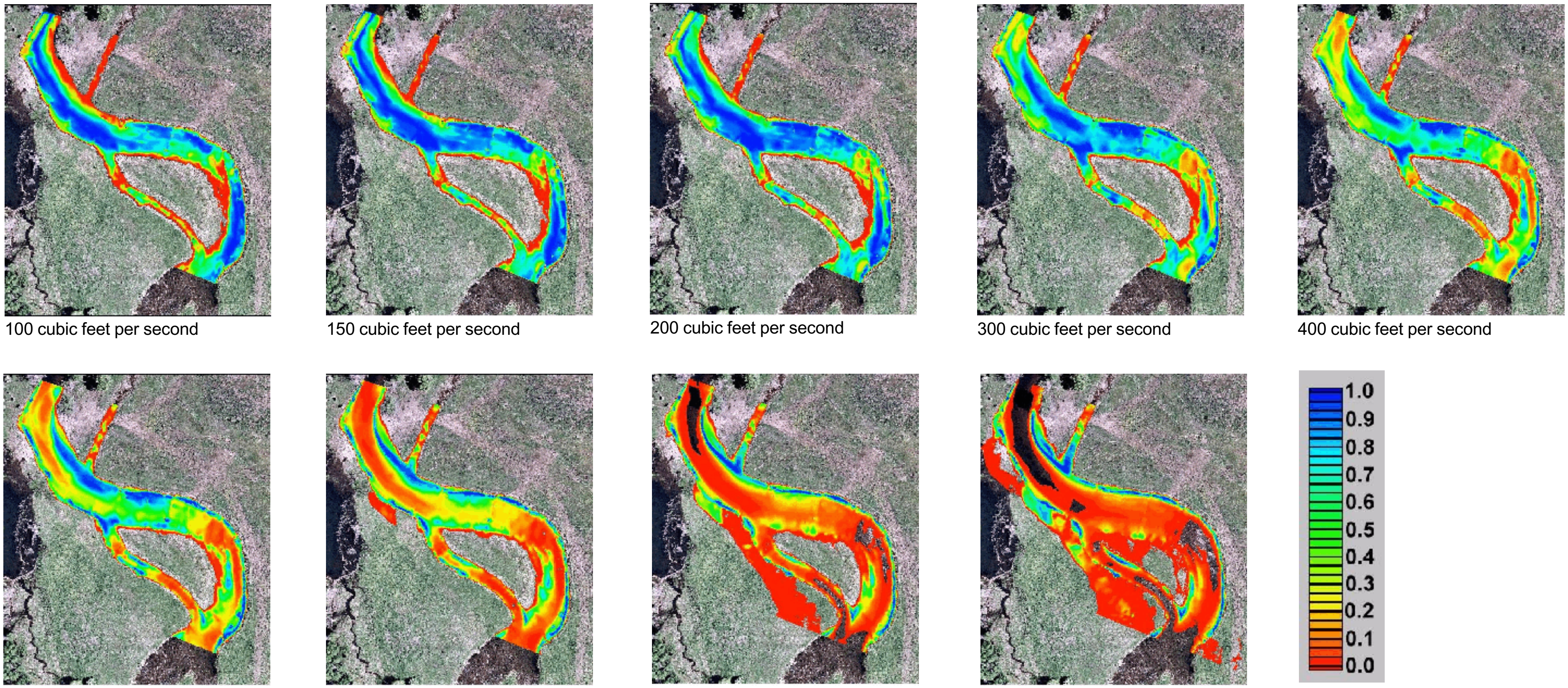
FIGURE 3.2. REACH 8: TROUT - WUA VS. FLOW.

As evident in Image 3.2a and Figure 3.2, Reach 8 has approximately 40,000 ft^2/1,000 ft adult brown trout habitat at 120 cfs, represented by green and blue areas and peaks at around 44,000 ft^2/1,000ft at 200 cfs. As flows increase, suitable habitat becomes restricted to edge habitat and decreases in total WUA.

Fry habitat is present in this reach throughout the range of modeled flows (Figure 3.2). This study documents that the peak for fry habitat is approximately 70 cfs in Reach 8; however, fry habitat (>6,000 ft^2/1,000 ft) remained during all flows. During the spring, flows are generally maintained in the Middle Provo at lower levels than below Deer Creek Reservoir, and thus, may help to explain how the recruitment of brown trout throughout the Provo River remains strong even with high spring flows below Deer Creek Reservoir. Emergence of cutthroat and rainbow trout fry occurs later in the summer. Although the susceptibility of fry of those species should be limited, should sustained high flows into late summer occur, impacts to their success in channelized reaches may occur and complex habitat like that found in Reach 8 may provide a substantial benefit by dampening these effects.

An evaluation of existing data on spawning criteria revealed that although the brown trout curves encompassed depth and velocity requirements 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. Because substrate requirements were similar, differences were due to lower water depth and velocity requirements for rainbow trout and lower yet (depths and velocities) for cutthroat trout resulted in less spawning habitat (Figure 3.3). There is approximately 16,000 ft^2/1,000ft of brown trout spawning habitat at the peak of approximately 200 cfs and the total remains above 10,000 ft^2/1,000ft between 70-400 cfs. Available rainbow trout spawning habitat was similar to brown trout up to 200 cfs, but was lower at higher flows. Cutthroat trout spawning habitat peaked at 70 cfs (12,500 ft^2/1,000ft) but quickly decreased to below 5,000 at 200 cfs and above. According to Wiley and Thompson (1996), brown trout spawning occurs in early to mid-November when flows are low. As demonstrated by Wiley and Thompson (1996) and again by the results of this study, lower flows provide more WUA for brown (and all other) 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 400 cfs are optimal in Reach 8. 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. As evident in Figure 3.3, WUA for spawning cutthroat trout is cut by more than 50% from 70-150 cfs and continues to decline as flows increase. Thus, the timing of spawning and less WUA for spawning at any flow level puts native cutthroat trout at a substantial disadvantage to brown trout in this reach.

Image 3.2a. Adult Brown Trout - Weighted Usable Area (Site 8). The images below depict habitat niches that are present at discharges of 100, 150, 200, 300, 400, 500, 700, 1100, and 1500 cubic feet per second. The best habitat is represented by suitability of 1.0 (blue) and no habitat is represented by 0 (red).



100 cubic feet per second

150 cubic feet per second

200 cubic feet per second

300 cubic feet per second

400 cubic feet per second

500 cubic feet per second

700 cubic feet per second

1,100 cubic feet per second

1,500 cubic feet per second

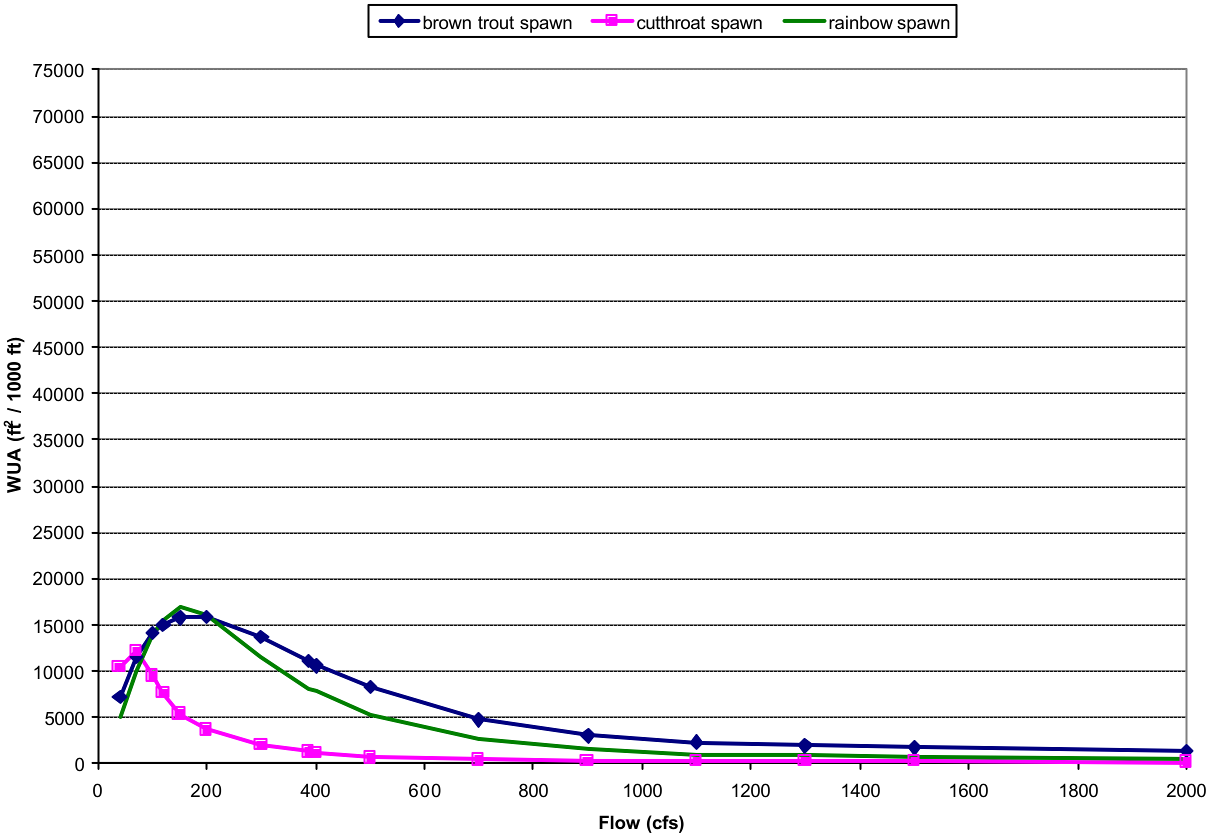


FIGURE 3.3. REACH 8: TROUT SPAWNING - WUA VS. FLOW.

3.1.2 WATER TEMPERATURE - SITE 8

For this study, a thermistor was placed at Site 8 between April 27 and August 16, 2002. The following mean temperatures were observed during the study period.

April (27 - 30)	6.7°C
May	9.0°C
June	12.2°C
July	12.2°C
August (1 - 16)	12.5°C

The temperature data was compared to the flow data at USGS Station # 10155200 (Provo River at River Road Bridge) 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.

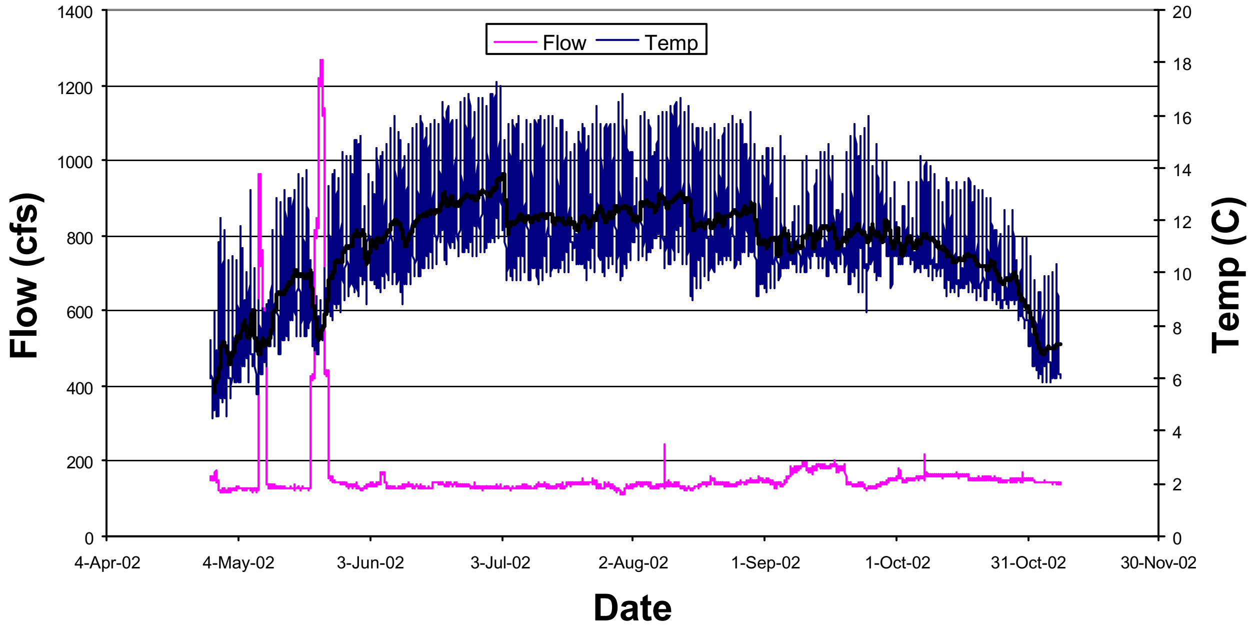


FIGURE 3.4. SITE 8: TEMPERATURE AND FLOW.

Two hydrographic spikes associated with releases for this study occurred in which the flow increased from about 130 cfs to 957 cfs in about 3.5 hours on May 8 and then rose gradually from 130 cfs to 1,270 cfs over a three-day period from 20-22 May. The descending limb of the hydrograph for both events lasted three days. Neither event had a substantial impact on mean water temperature, though it decreased slightly in both cases and the maximum temperature was 2-3°C lower during the high flows. Correspondingly, the daily temperature fluctuation decreased substantially for three days during each event.

Aside from the two spikes, flow fluctuated between about 125 cfs and 145 cfs throughout the study period with no discernable trends. There was a general trend of increasing maximum daily temperatures from the beginning of the study period to a peak in early July, after that, maximum daily temperatures remained fairly consistent through August. The daily water temperature fluctuation varied throughout the study period, but generally remained near the mean of 5.4°C; no trend of increasing or decreasing fluctuation was observed. The lowest water temperature measured during the period was 4.4°C on April 28; the maximum was 17.3°C, which occurred on July 1.

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 8 of the Provo River.

3.2.2 RECREATIONAL USABILITY-SITE 8

3.2.2.1 WADING (FISHING)

The WUA's calculated for Reach 8 represent the total amount of suitable wading/fishing "habitat" (area) per 1,000 ft of stream for the entire reach. Figure 3.5 shows the WUA (ft^2/1,000 ft) for fishing/wading recreational activities. At 100-200 cfs, >70,000 ft^2/1,000ft of fishing/wading area is provided for recreationists, far beyond estimates at any other reach. High levels (>38,000 ft^2/1,000ft) of suitable wading/fishing habitat are maintained at all modeled flows.

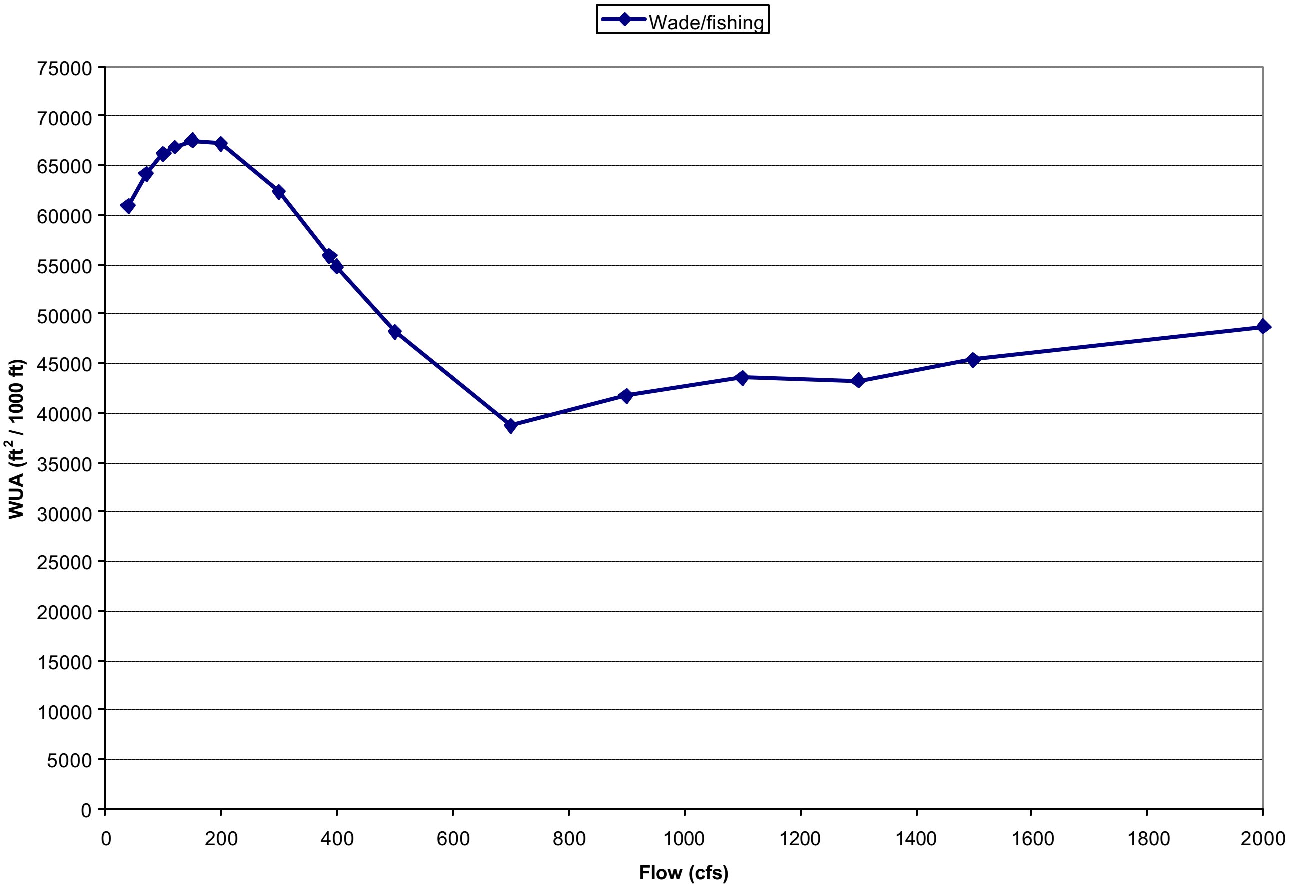


FIGURE 3.5. REACH 8: WADING/FISHING - WUA VS. FLOW.

3.1.4 SEDIMENT TRANSPORT - SITE 8

3.1.4.1 SAMPLING RESULTS

Bedload samples were collected during the 2002 and 2003 spring runoff. The results of the 2002 bedload sampling show that bedload movement was dominated by sand-sized material at all sampled flows (Figure 3.6a and Plate 3.1a), which is a common phenomenon in natural gravel-bed rivers. At 400 cfs, bedload was limited to fine-grained sand intermixed with organic material. At 800 cfs, small amounts of medium-sized gravel became entrained along with the sand. At 1,250 cfs, a greater amount of gravel was entrained along with the sand including large-sized gravel particles greater than 16 mm. In total, there was less sand in transport overall at 1,250 cfs than at 800 cfs, albeit the texture was noticeably coarser at 1,250 cfs. Total transport rates (collected in the bedload sampler) during the referenced flows were found to be less than 10 tons/day at the River Road bridge below Site 8. There was no obvious transition between phase I and phase II transport as occurred in the Canyon reaches (Olsen et al, 2002). We assume that the magnitude and duration of the peak flows as shown in Figure 2.2 were insufficient to initiate phase II transport in 2002.

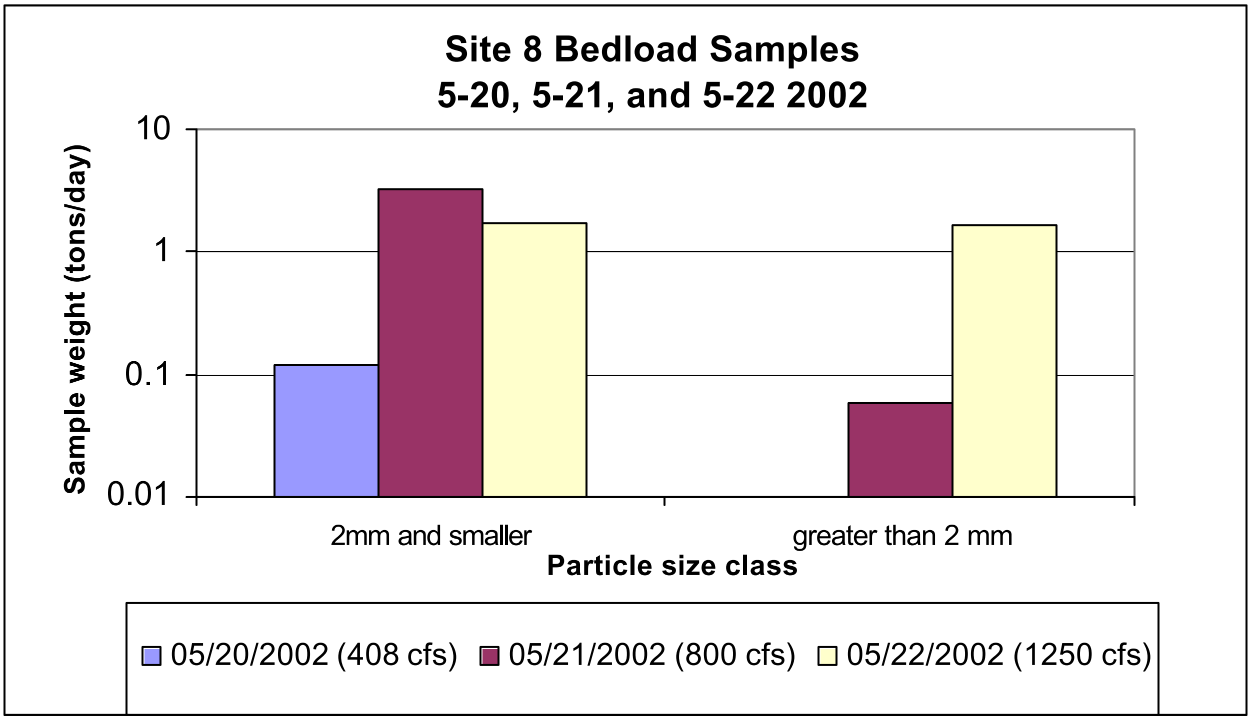


FIGURE 3.6A. BEDLOAD SAMPLING DATA BROKEN INTO SAND AND GRAVEL SIZED PARTICLES COLLECTED AT SITE 8 DURING THE 2002 SPRING HYDROGRAPH.

SITE 8

408 cubic feet per second

800 cubic feet per second

1250 cubic feet per second

PLATE 3.1A. PHOTOGRAPHS OF BEDLOAD SAMPLES COLLECTED AT BRIDGE 8 DURING 2002 SPRING RUNOFF.

High flows were limited in 2002 because of the drought conditions. We expected that it would have been necessary to sample bedload transport at Bridge 8 for a longer duration and possibly at higher flows to observe shifts in bedload composition that indicate phase shifts and/or supply limitations.

Fortunately we were able to resample bedload transport more thoroughly at Site 8 during the 2003 spring runoff. In 2003 we had slightly higher flows with a longer peak flow duration. The longer duration allowed us to sample at additional locations above and below Site 8 (the white bridge above I-40 and the lower Midway bridge near the USGS gauge station) to assess spatial variability in bedload data throughout the Middle Provo River. Sampling at multiple locations was especially important given the recent channel construction activities in the area and the likelihood of increased fine grained sediment transport in downstream reaches.

The 2003 spring hydrograph was significantly different than the 2002 spring hydrograph. The peak flows were approximately 12% greater in 2003 (1,400 cfs instead of 1,250 cfs). More importantly, the duration of peak flows were maintained 3 times longer in 2003 (3 days) compared to the sharp peak (1 day) and rapid receding limb in 2002 (Figure 2.2). The 2003 hydrograph shows a more gradual receding limb as per recommendations made by the Utah Reclamation Mitigation and Conservation Commission.

Bedload samples were collected over a 3-day period at Site 8. During day 1 samples were collected nearly continuously to capture the rising limb (June 16, 2003) as flows ascended from 500 cfs to 1,400 cfs. During day 2 and 3 samples were collected periodically (switching with the other monitoring sites) throughout the daylight hours. In general, bedload transport was dominated by sand-sized particles which began to move in small amounts (between 0.1 and 0.2 tons/day) as flows exceeded 500 cfs (Figure 3.6b). Although transport rates were not steady over day 1, they generally increased with flow. Total bedload transport was approximately 2 tons/day at 1,400 cfs at Site 8 (Figure 3.6c). There were no obvious trends of either increased or decreased transport rates over the 3-day peak runoff sampling period as flows were maintained at 1,400 cfs. Although transport of sand-sized particles peaked during day 2, it appears that the supply of sand-sized particles available for transport was not exceeded during the 2003 peak flows.

The results of the 2003 bedload sampling show that bedload movement was again dominated by sand-sized material at all sampled flows (Figure 3.6b-e, and Plates 3.1b-e). As with 2002, there was no obvious transition between phase I and phase II transport at Site 8, even with flows reaching 1,400 cfs for a 3-day period. There was a greater proportion of gravel transport compared to sand with increasing flows during the rising limb, but no obvious trends with increasing duration over the 3-day peak runoff sampling period.

Some interesting trends occurred at the bedload sampling sites above and below Site 8 (Figures 3.6c and 3.6d). There appeared to be a decreasing supply of sand-sized particles at the White Bridge (just above I-40) during the peak flow event with nearly no transport of gravel-sized particles (unlike any of the other sampling sites). Some sand deposition occurred between the White Bridge and River Road probably in backwater areas and on the floodplain at Site 8. Evidence of this deposition was seen during a site visit

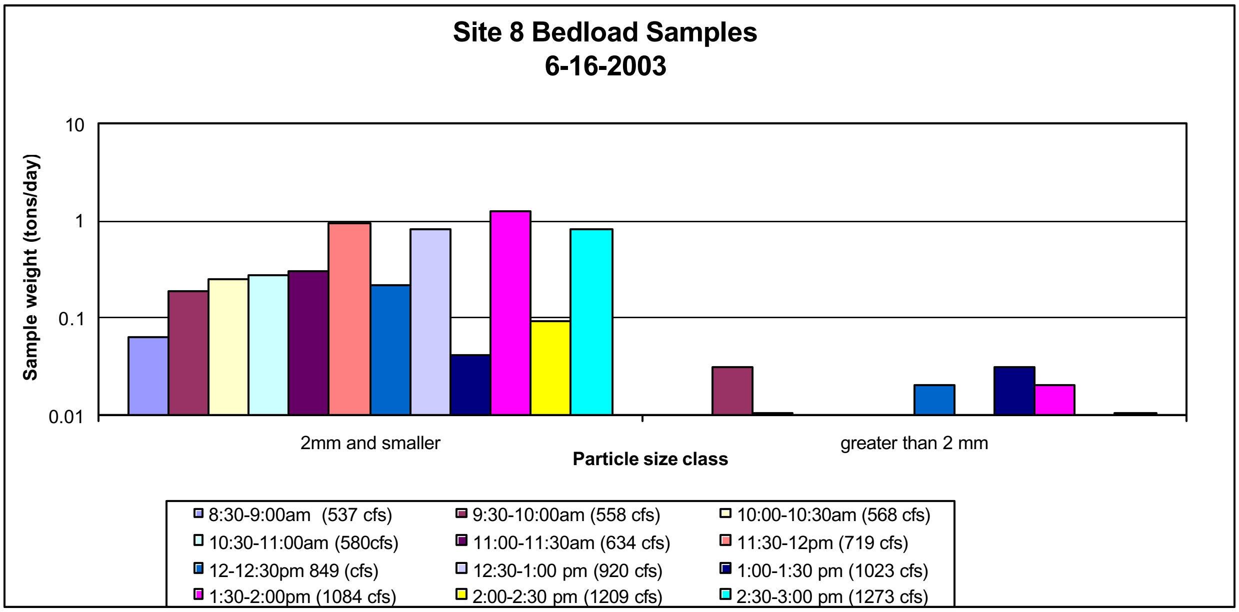


Figure 3.6b. Bedload sampling data broken into sand and gravel sized particles collected at Site 8 during the rising limb of the 2003 spring hydrograph.

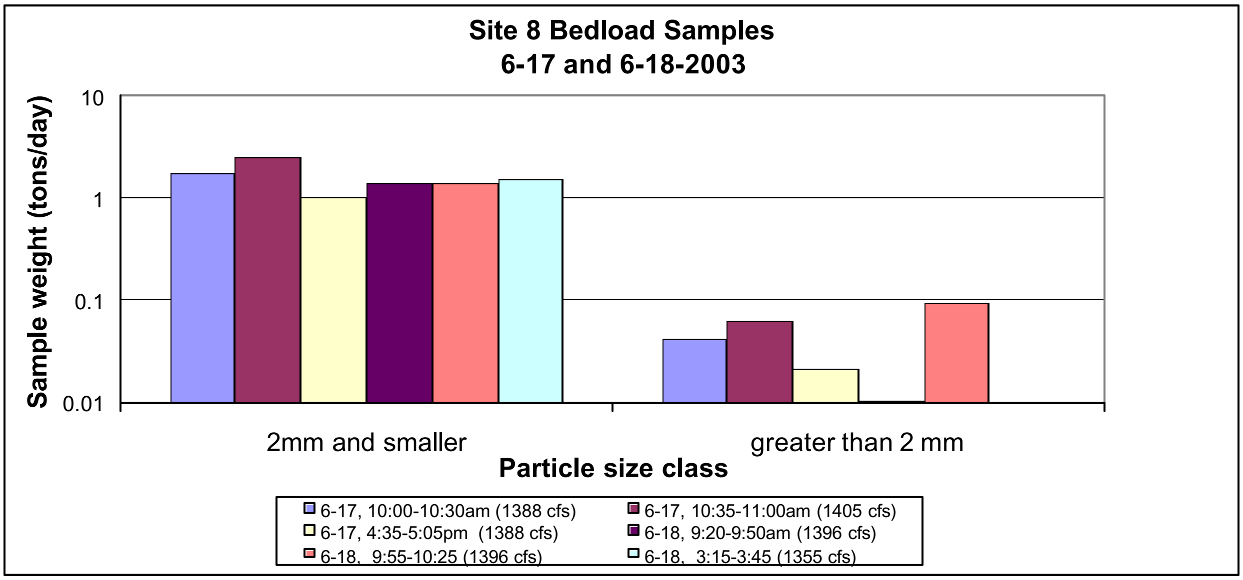


Figure 3.6c. Bedload sampling data broken into sand and gravel sized particles collected at Site 8 during the 2nd and 3rd days of 1,400 cfs peak flows in 2003.

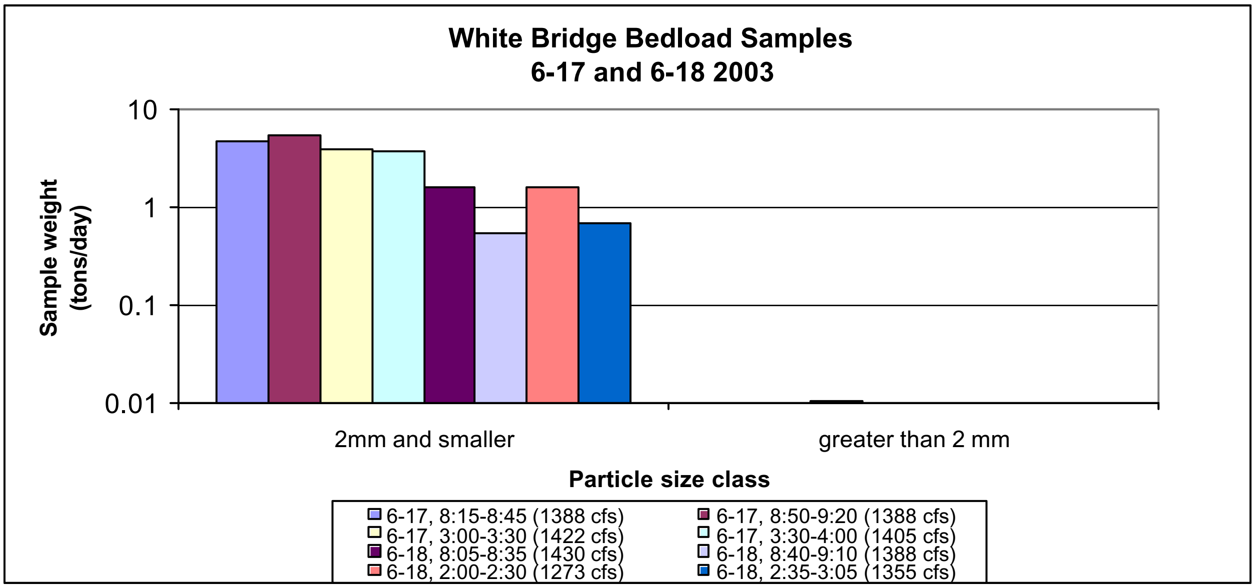


Figure 3.6d. Bedload sampling data broken into sand and gravel sized particles collected above Site 8 (at the white bridge above I-40) during the 2003 spring hydrograph.

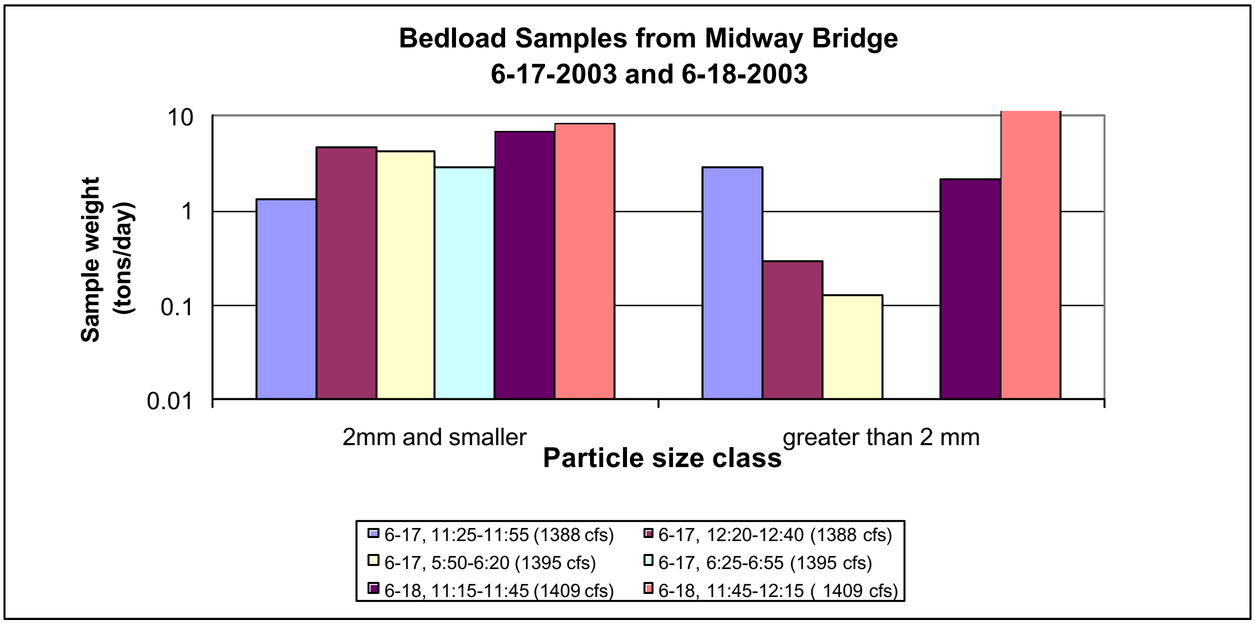
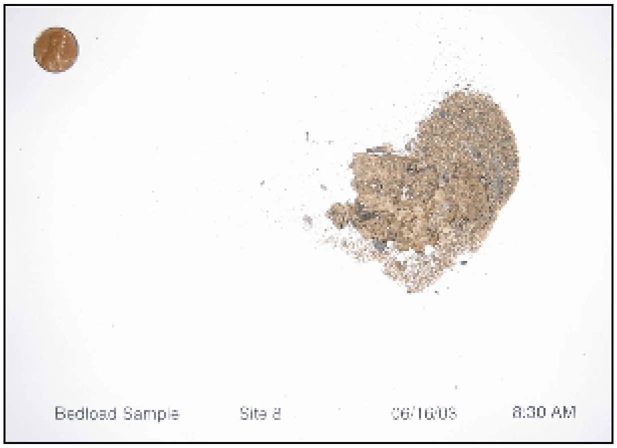
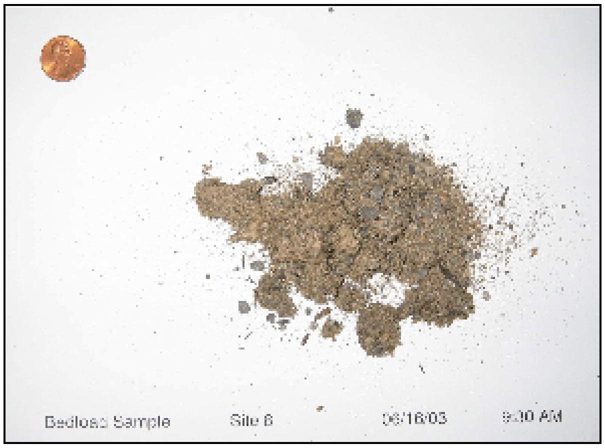


Figure 3.6e. Bedload sampling data broken into sand and gravel sized particles collected below Site 8 (Provo River at Midway USGS gauging station) during the 2003 spring hydrograph.

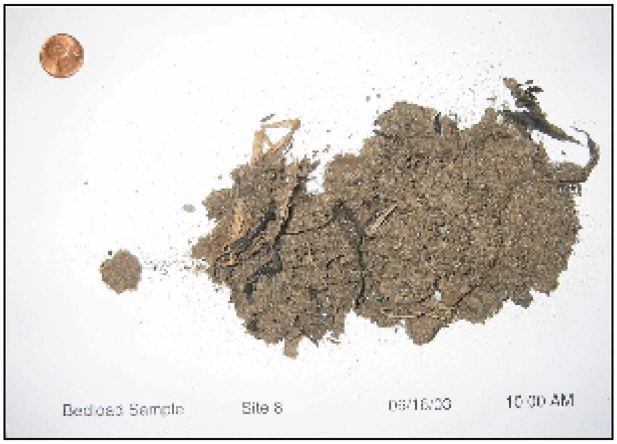
SITE 8



537 cubic feet per second



558 cubic feet per second



568 cubic feet per second

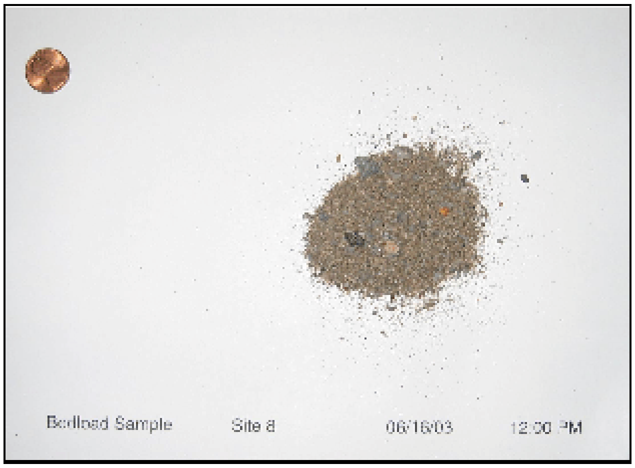
580 cubic feet per second

634 cubic feet per second

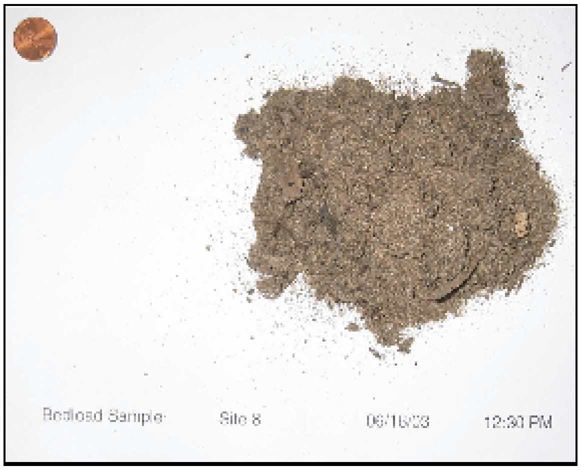
719 cubic feet per second

PLATE 3.1.B. PHOTOGRAPHS OF BEDLOAD SAMPLES COLLECTED AT BRIDGE 8 DURING THE RISING LIMB OF THE 2003 SPRING RUNOFF.

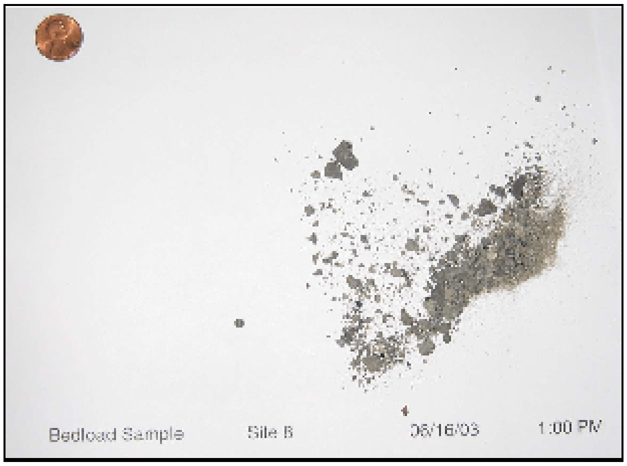
SITE 8



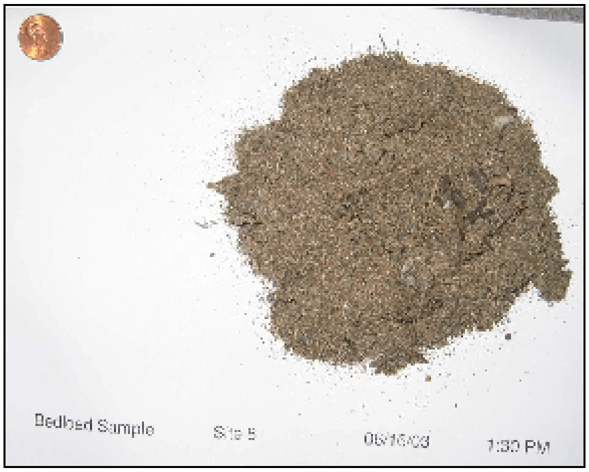
849 cubic feet per second



920 cubic feet per second



1023 cubic feet per second



1084 cubic feet per second

1209 cubic feet per second

1273 cubic feet per second

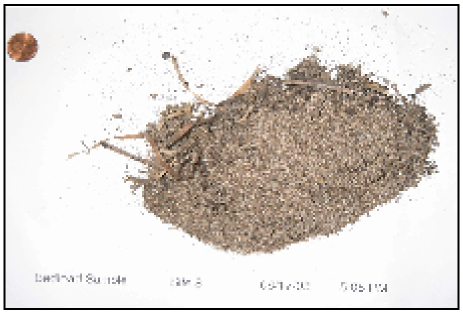
PLATE 3.1B. (CONT.).

SITE 8

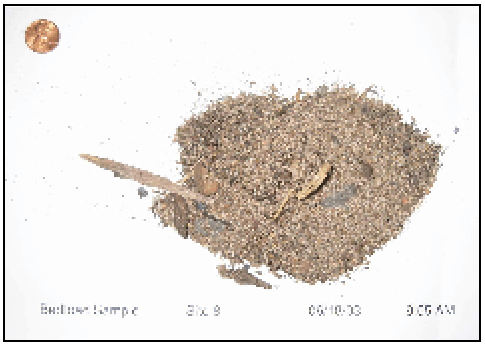

1388 cubic feet per second


1405 cubic feet per second


1388 cubic feet per second


1413 cubic feet per second


1422 cubic feet per second


1396 cubic feet per second

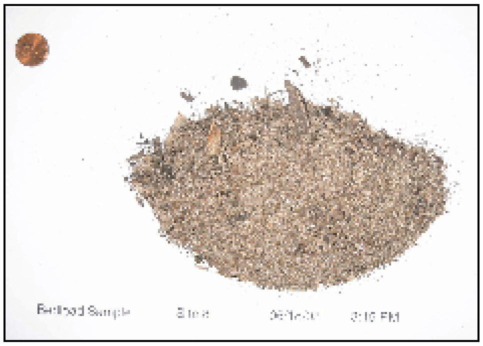
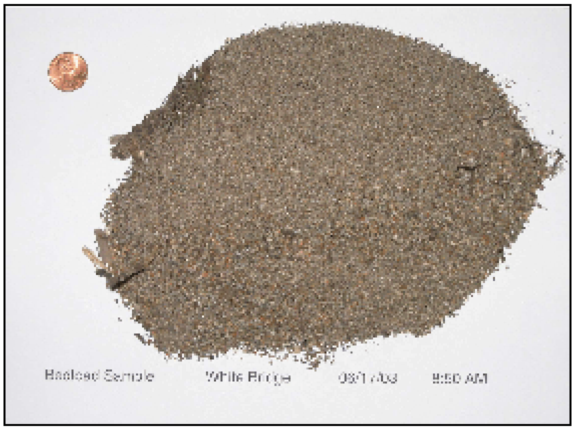

1355 cubic feet per second

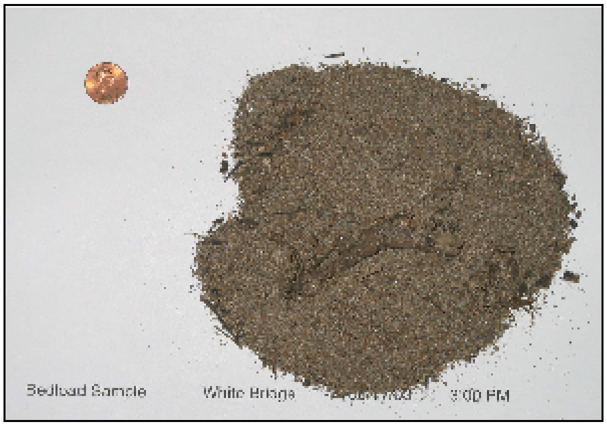
PLATE 3.1.c. PHOTOGRAPHS OF BEDLOAD SAMPLES COLLECTED AT BRIDGE 8 DURING THE 2ND AND 3RD DAYS OF 1,400 CFS DURING THE 2002 SPRING RUNOFF.

SITE 8

1388 cubic feet per second



1388 cubic feet per second



1422 cubic feet per second

1405 cubic feet per second

1430 cubic feet per second

1355 cubic feet per second

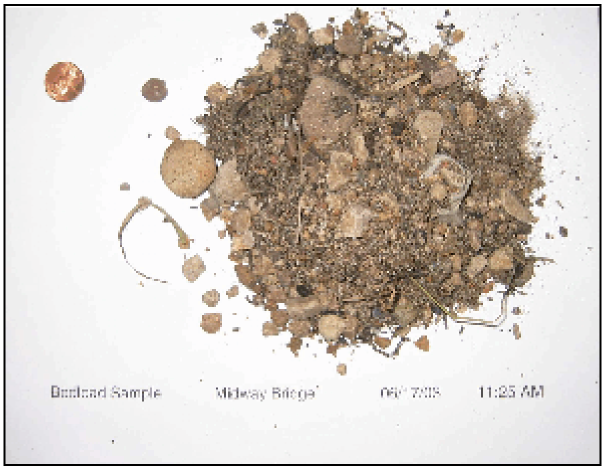
PLATE 3.1.D. PHOTOGRAPHS OF BEDLOAD SAMPLES COLLECTED ABOVE SITE 8 (AT THE WHITE BRIDGE UPSTREAM OF I-40) DURING 2003 SPRING RUNOFF.

1273 cubic feet per second

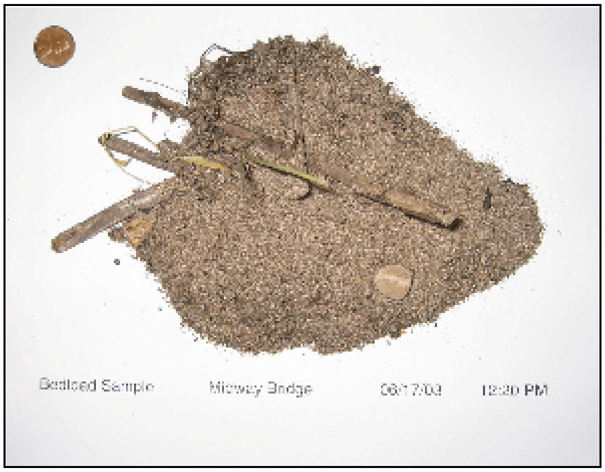
1355 cubic feet per second

PLATE 3.1.D. (CONT.).

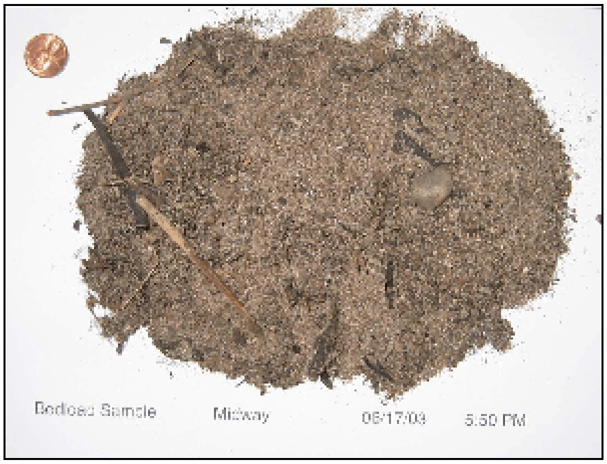
SITE 8



1395 cubic feet per second

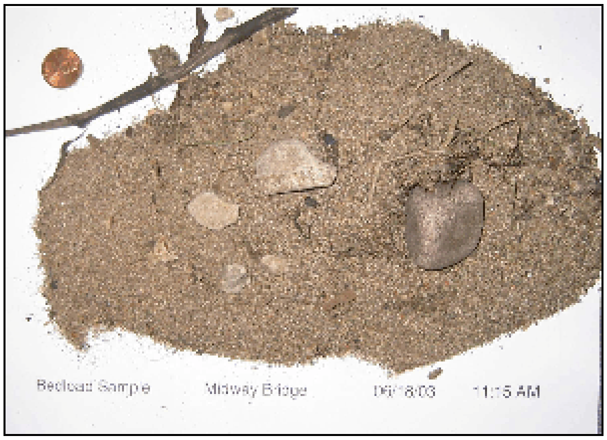


1395 cubic feet per second

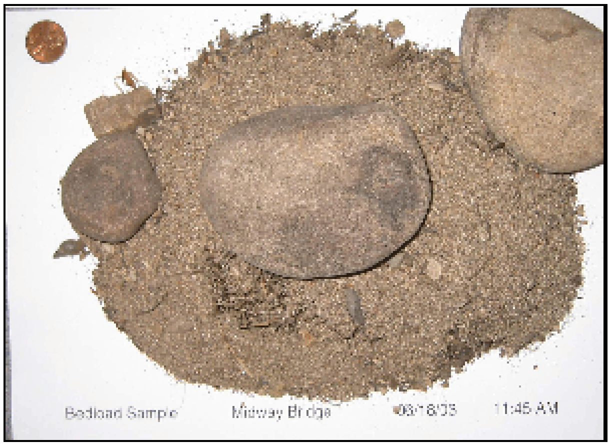


1395 cubic feet per second

1395 cubic feet per second



1409 cubic feet per second



1409 cubic feet per second

PLATE 3.1.E. PHOTOGRAPHS OF BEDLOAD SAMPLES COLLECTED BELOW SITE 8 (AT THE LOWER MIDWAY BRIDGE NEAR THE USGS GAUGING STATION) DURING 2003 SPRING RUNOFF.

following the peak flows. Additional supplies of sand and gravel must be available between Site 8 and Midway Bridge. There was a general increasing trend of sand- and gravel-sized bedload transport with time as flows were maintained near 1,400 cfs.

Using the data collected in 2003, some degree of bed armoring probably occurred above I-40 (approximately 2 miles downstream of Jordanelle Dam) and bed fining or equilibrium transport at and below the Midway Bridge. At this time (approximately 7 years after Jordanelle Reservoir was filled) bedload sampling results indicate very limited supplies of sand- and gravel-sized materials during bedload transport immediately downstream of Jordanelle Dam, and that additional supplies of sand- and gravel-sized particles currently exist somewhere above the Midway Bridge, probably in the "restored" and "never channelized" portions of the Provo River. The higher sand- and gravel-sized bedload transport at the Midway Bridge continues downstream through Site 7 (less than 2 miles downstream) as shown in subsequent sections of this report. Sand and gravel "mining" (outgoing loads exceeding incoming loads) and the succeeding bed armoring/channel entrenchment processes currently active immediately below Jordanelle Dam is expected to migrate downstream over time as bedload supplies become more and more depleted unless supplies are mitigated below this large structure.

3.1.4.2 MODELING RESULTS

The streambed particle sizes at Site 8 range from small-sized sand to large-sized cobbles (Table 3.1). There is nearly an equal number of particles in the various size classes with no apparent dominant size class (Figure 3.7). The riffle sampled at Site 8 is poorly sorted with fifty percent of the bed material between 40-150 mm in diameter, a broad range of particle sizes for the steepest portion of the distribution curve. Although it is apparent that this riffle has not coarsened over the past two years since the channel was constructed, this riffle is representative of the particle sizes in the general vicinity of the bedload cross section at Site 8. We noticed some coarser patches of cobbles within Site 8 away from the bedload cross section but they were not close enough to be controlled by the hydraulics at the bedload cross section.

TABLE 3.1. IMPORTANT FRACTIONS OF SITES 7 AND 8 STREAMBED PARTICLE SIZE DISTRIBUTIONS AND LARGEST PARTICLE CAPTURED AT BRIDGES 7 AND 8 DURING BEDLOAD SAMPLING.[A]

SITE	D16	D25	D50	D75	D84	MAXIMUM SIZE AT BRIDGES 7 AND 8 IN TRANSPORT
7	73	81	108	130	145	21
8	16	33	70	128	168	41

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

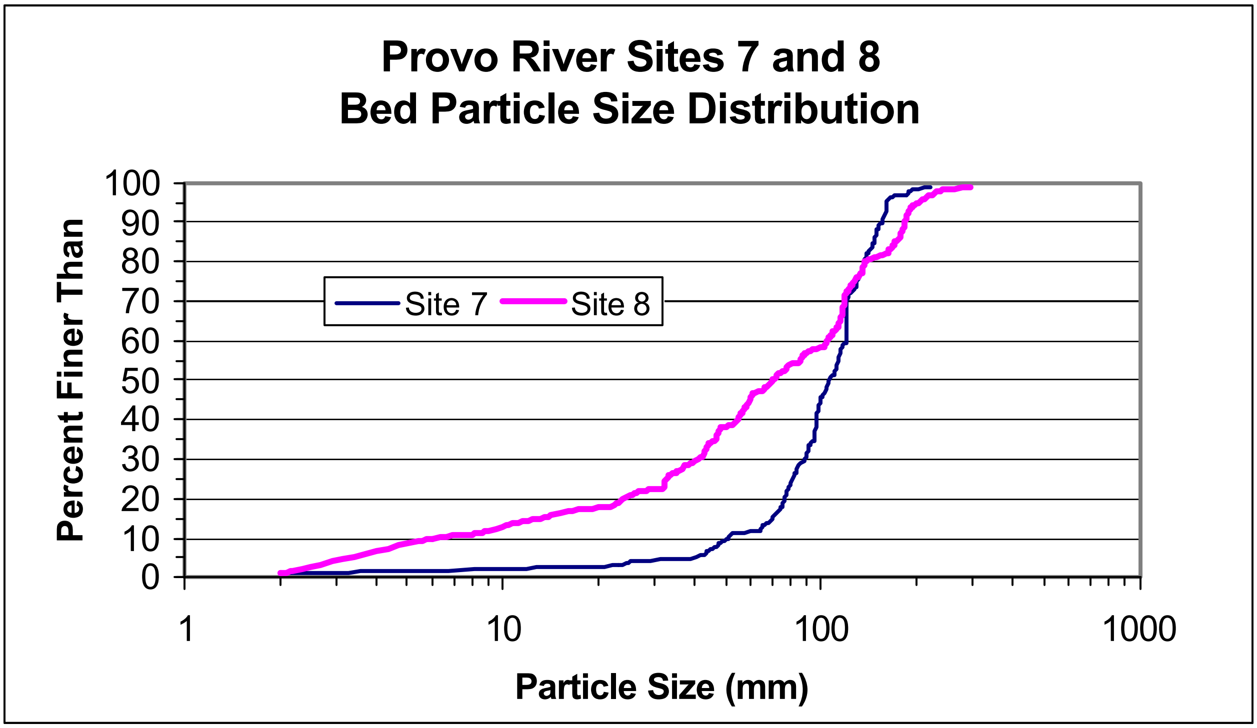


FIGURE 3.7. PARTICLE SIZE DISTRIBUTIONS OF SITES 7 AND 8.

The equal distribution of bed material at Site 8 is very much in contrast to the 100+ mm (cobble) dominated armored/coarsened bed at Site 7 (See Section 4 [Discussion] of this report for a more detailed comparison of the two Sites). It is likely that the bed materials at Site 8 (i.e., D_{50}) will become larger over time as a result of material sorting and/or armoring processes. Furthermore, the smaller particle sizes at Site 8 is an anomaly compared to reaches above and below this specific area.

The effects of armoring (increasing the size of the D_{50} over time) on bedload transport rates within this newly constructed channel was evaluated first; to use a “stable’ sized D_{50} in establishing a bedload rating curve for this reach, and second; to apply an appropriate rating curve to flow projections to evaluate future loads and the effects of alternative flow regimes on fluvial processes as quantified through effective discharge calculations. The current D_{50} (particle 70 mm in size) first was used to model bedload transport based on hydraulic conditions at 0.1 feet stage increments at Site 8's bedload cross section. A bedload transport rating curve was developed for both the Meyer-Peter Muller (1948) and Parker (1990) bedload transport equations (Figure 3.8a) using the reach average (1.0%) water surface slope. Bedload sampling results were then plotted on the same graph to illustrate the equation with the best fit through the actual data (Figure 3.8a).

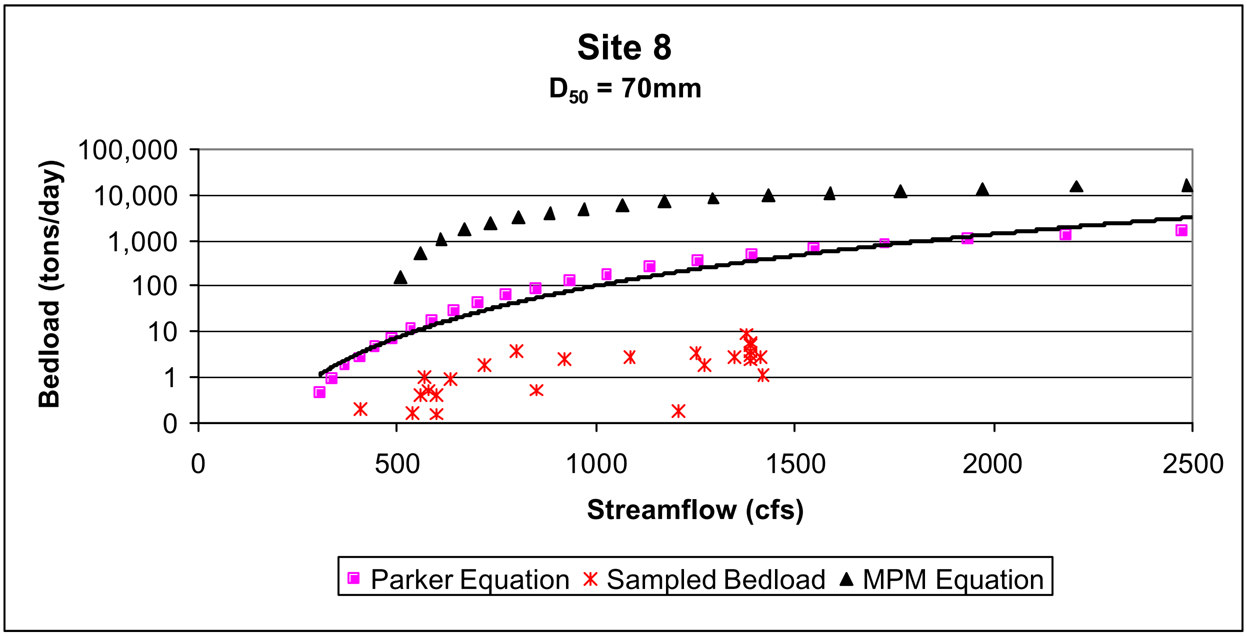


FIGURE 3.8A. PARKER (1990) AND MEYER-PETER MUELLER (1948) BEDLOAD RATING CURVES AT SITE 8 BASED ON A 70 MM SIZED D_{50}. ACTUAL BEDLOAD DATA IS SHOW TO COMPARE ACTUAL VERSES MODELED BEDLOAD TRANSPORT RATES.

Based on the bedload sampling data, the Parker (1990) equation performs better than the Meyer-Peter Mueller (1948) equation at Site 8. However, the Parker (1990) equation still over-predicts transport rates using the measured D_{50} in this newly constructed channel. Adjusting the D_{50} to 90 mm (assuming armoring of 20 mm) and using the Parker (1990) equation produces the best-fit-line through the actual sampling data (Figure 3.8b). Bedload transport rates under a range of future bed armoring are further evaluated in the Discussion (Section 4) of this report.

The suspended sediment rating curve for the Midway water quality monitoring site (Figure 3.9) illustrates very low suspended sediment loads (i.e., TSS concentrations) at flows less than 200 cfs, and is positively correlated with streamflow similar to the Murdock and Geneva Road water quality monitoring sites (Olsen et al, 2002). A comparison of Figures 3.8b and 3.9 indicate that suspended sediment constitutes 100 percent of the sediment load at flows less than 500 cfs, and more than 90 percent of the total sediment load at higher flows.

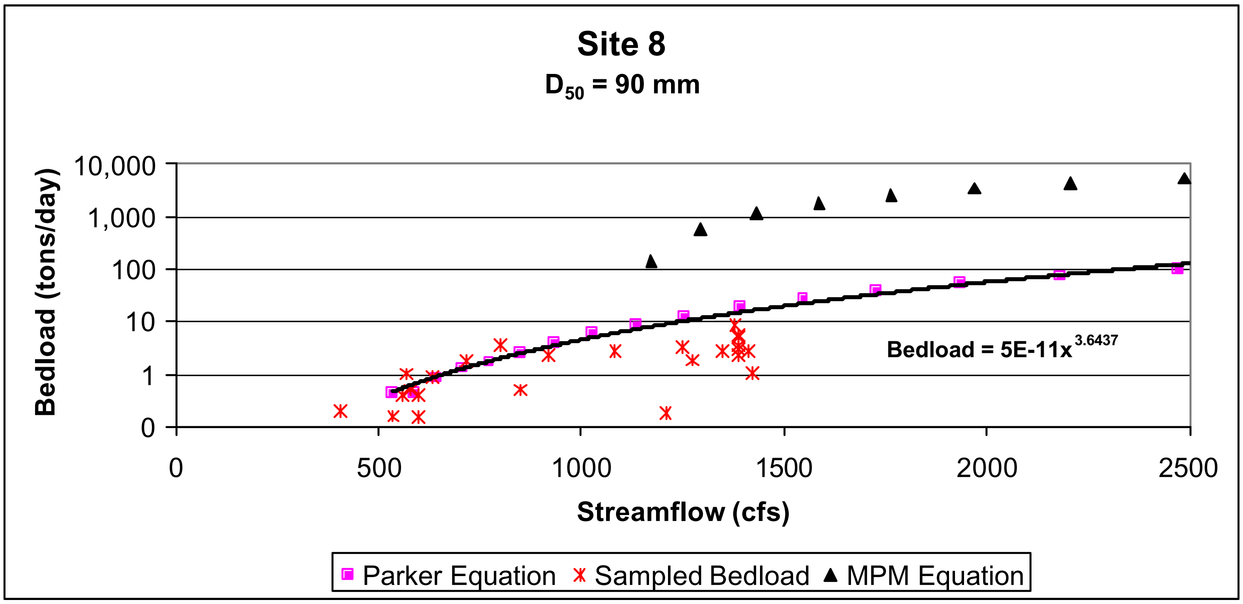


FIGURE 3.8B. PARKER (1990) AND MEYER-PETER MUELLER (1948) BEDLOAD RATING CURVES AT SITE 8 BASED ON A 90 MM SIZED D_{50}. BEDLOAD DATA COLLECTED AT RIVER ROAD BRIDGE IS SHOW TO COMPARE ACTUAL VERSES MODELED BEDLOAD TRANSPORT RATES AT THIS LOCATION. THE POWER EQUATION (I.E., TRENDLINE) IS SHOWN ON THIS GRAPH BECAUSE IT WAS USED FOR EFFECTIVE DISCHARGE CALCULATIONS.

3.1.4.3 EFFECTIVE DISCHARGE RESULTS

Daily streamflow values during the 1997-2001 water years are quite different between the Midway and Hailstone gauges (Figure 3.10 and Appendix C). There is a reversal in number of occurrences between the two gauges at 600 cfs (ironically just above the point when bedload transport begins). Flows below 600 cfs transport very little bedload sediment and are not considered “effective” in governing channel size and shape. Flows less than 600 cfs occur 30 more days per year at the Midway gauge, whereas flows greater than 600 cfs occur 2.5 times more often (50 compared to 20 days per year) at the Hailstone gauge. Furthermore, the magnitude and duration of high flow is much greater at Hailstone. On average, the Hailstone gauge has 16-days per year when flows exceed 1,400 cfs whereas the Midway gauge only averages two. The morphologic result of these flow differences is that effective discharge would have been much greater prior to operation of Jordanelle Dam and channel narrowing will likely occur over time in the unrestored reaches of the Middle Provo River (all of Reach 7 and the never channelized portions of Reach 8).

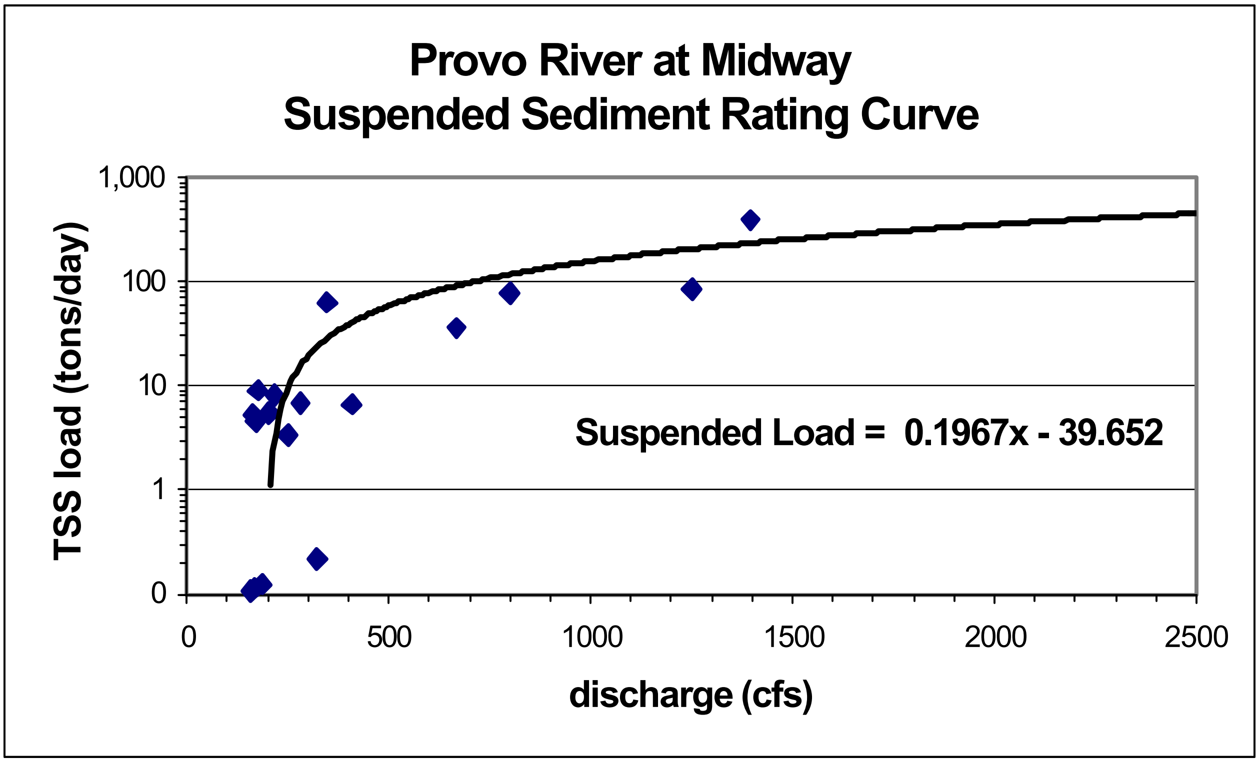
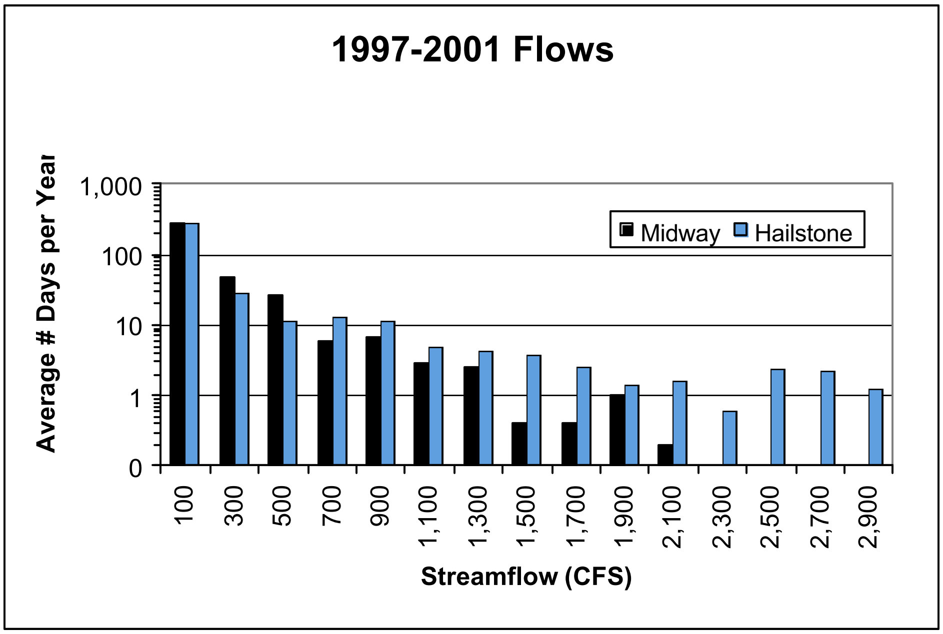


FIGURE 3.9. THE EMPIRICALLY DERIVED SUSPENDED SEDIMENT RATING CURVE DEVELOPED USING DATA COLLECTED IN PROVO RIVER AT MIDWAY CUTOFF ROAD CROSSING NORTH OF HEBER (UDWQ MONITORING SITE #499730).

An important consideration at Site 8 is that effective discharge calculations are for the "main channel" where the bedload rating curve was established. Flow does not remain in a single channel at Site 8 and the "out of bank" flow needs to be accounted for when applying the bedload rating curve and looking at the effective discharge values shown in Figure 3.10. A fairly large side channel (Site 8c) runs adjacent to Site 8 (Map 1.4) and contains over 100 cfs when total flow at the USGS gauge station exceeds 1,000 cfs (Table 2.5). An empirical relationship was developed between total flow (as measured at the USGS gauge station) and flow in the 8C side channel (as measured by BIO-WEST personnel during field studies). A linear equation (Flow in 8c Side Channel = 0.1213 x Total Flow in Provo River at USGS Gauge Station - 10.681) is used to quantify flows in the side channel relative to flows reported at the USGS gauge station. This relationship has an R^2 value of 0.99. For example, an effective discharge of 1,800 cfs at the USGS gauge station translates to approximately 1,600 cfs in the main channel at Site 8.



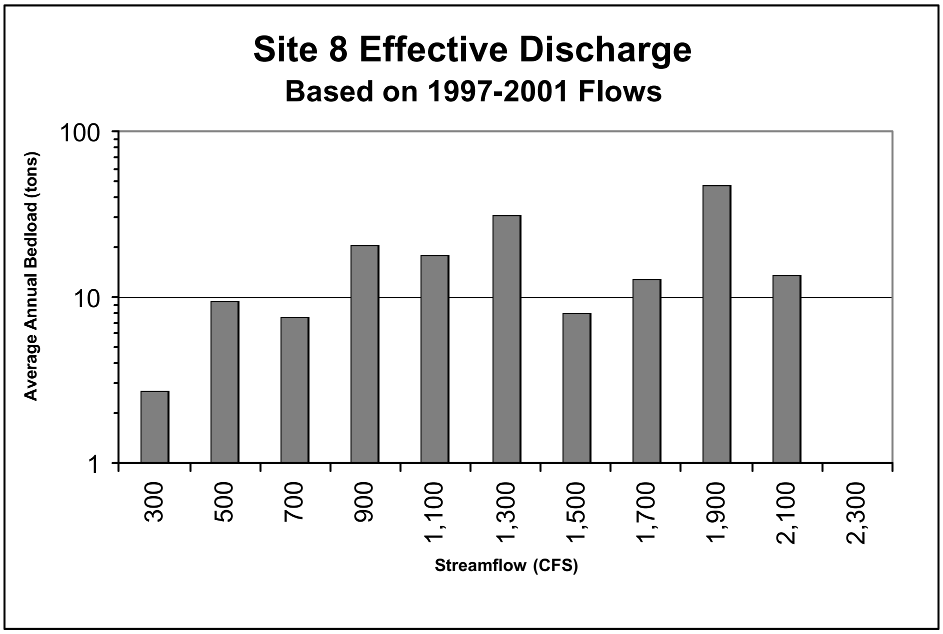


FIGURE 3.10. EFFECTIVE DISCHARGE RESULTS FOR SITE 8. THE UPPER GRAPH SHOWS THE AVERAGE NUMBER OF DAYS PER YEAR FROM 1997-2001 THAT STREAMFLOW HAS BEEN WITHIN ANY 200 CFS INCREMENT (0-200, 200-400, ETC.). THE LOWER GRAPH APPLIES THE MODELED BEDLOAD TRANSPORT RATE AT SITE 8 (BASED ON THE PARKER [1990] EQUATION USING A 90 MM D_{50}) MULTIPLIED BY THE NUMBER OF OCCURRENCES TO DETERMINE THE STREAMFLOW THAT TRANSPORTS THE MOST BEDLOAD SEDIMENT OVER THE PERIOD OF RECORD.

Our calculations show that effective discharge has been somewhat bimodal over the past 5 years (Figure 3.10). The multiple peaks are likely a result of the relatively wet and dry runoff conditions with no real "average" years during this period. The results show that a dominant range of flow between 1,800 and 2,000 cfs (as measured at the River Road USGS Gauging Station) has transported the greatest amount of bedload sediment at Site 8 since the construction of Jordanelle Dam (Figure 3.10). This translates to approximately 1,600-1,800 cfs in the main channel of Site 8. As a measure of its significance, this narrow yet dominant range of flow has transported more than 25 percent of the total sediment load since 1997. If flows in this range continue to remain dominant over a longer period of record, the channel will continue to adjust its size (channel shape and capacity) to accommodate the new hydraulic conditions resulting from the post-Jordanelle flow regime.

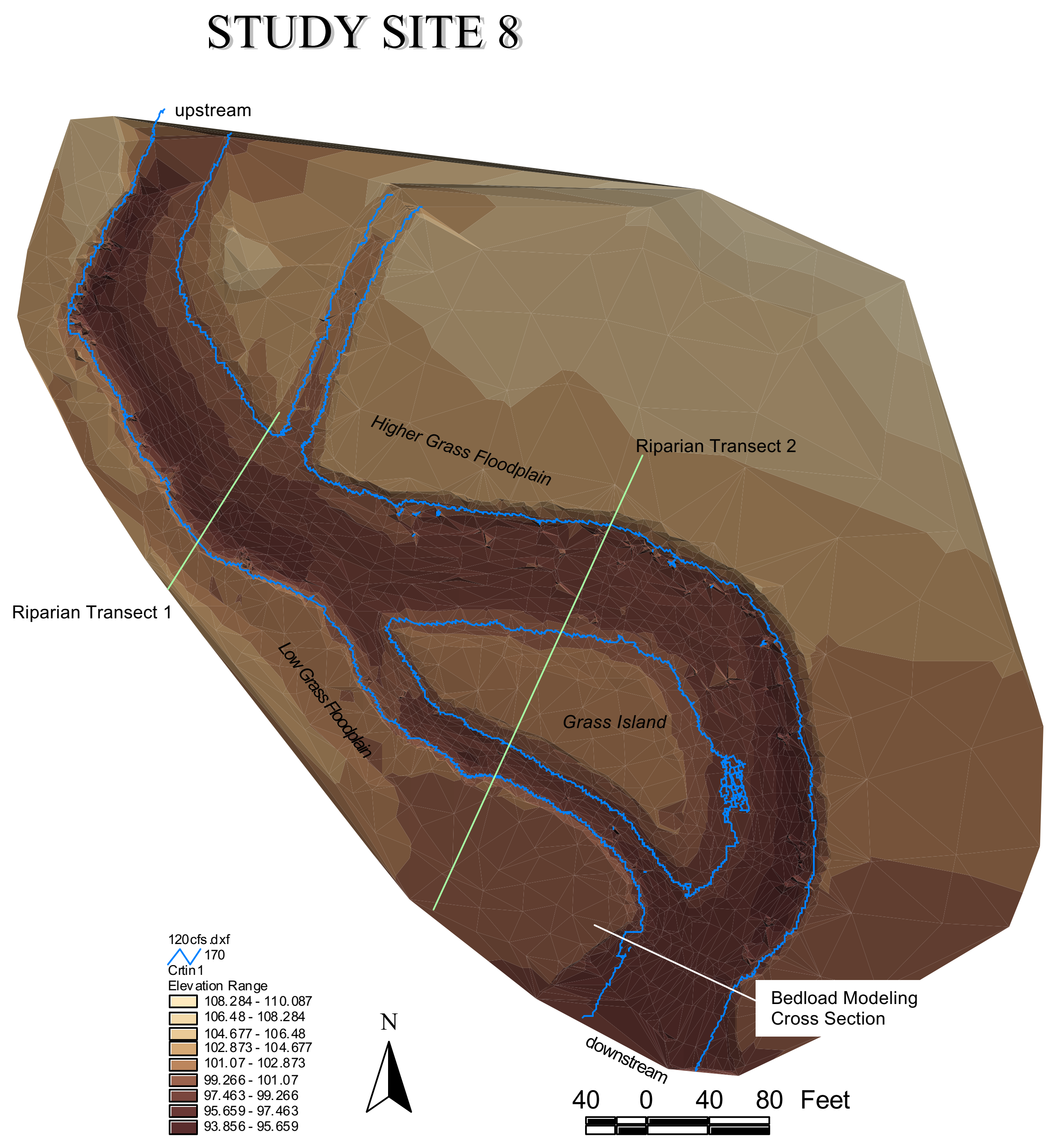
Another lesser peak exists between 1,200 and 1,400 cfs (Figure 3.10). This translates to approximately 1,060 to 1,240 cfs in the main channel of Site 8. According to the bedload cross section placement (Map 3.1) and hydraulic modeling using WinXSPRO, this portion of the restored channel was sized to overtop its banks at flows near 1,000 cfs, which happens to be the beginning of the first mode of high transport (Figure 3.10). The channel has a much greater capacity above and below Site 8, and water does not overtop the banks until flows exceed 1,600 cfs.

It is important to note that this type of analysis is sensitive to small changes in peak flows, which are sometimes accentuated over short time periods. Although some channel adjustments occur annually or even during shorter time periods (especially during extreme floods), we recommend using a minimum of a 25-years of daily flow records for more reliable effective discharge calculations. There were not very many days during the referenced period of record with flows between 1,400 and 1,800 cfs, yet there were enough days just below and just above this range to cause a dual peak. We expect that the true post Jordanelle effective discharge (current operations over a broader range of climatic conditions) would be between 1,400 and 2,000 cfs (as measured at the River Road USGS Gauging Station).

An evaluation of the effects of channel armoring (increasing the D_{50}) at Site 8 on effective discharge calculations is provided in the Discussion Section of this report.

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 Site 8 (Figure 3.11). Equations shown in Figures 3.8b and 3.9 defining the suspended sediment and bedload rating curves were applied to average daily flows over the past 5 years (water years 1997 to 2001) daily sediment loads for the "unregulated" (Hailstone) and regulated (Midway) gauges (see Appendix C for details). 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.



Map 3.1. Map of Study Site 8 showing riparian transect and bedload modeling cross section locations.

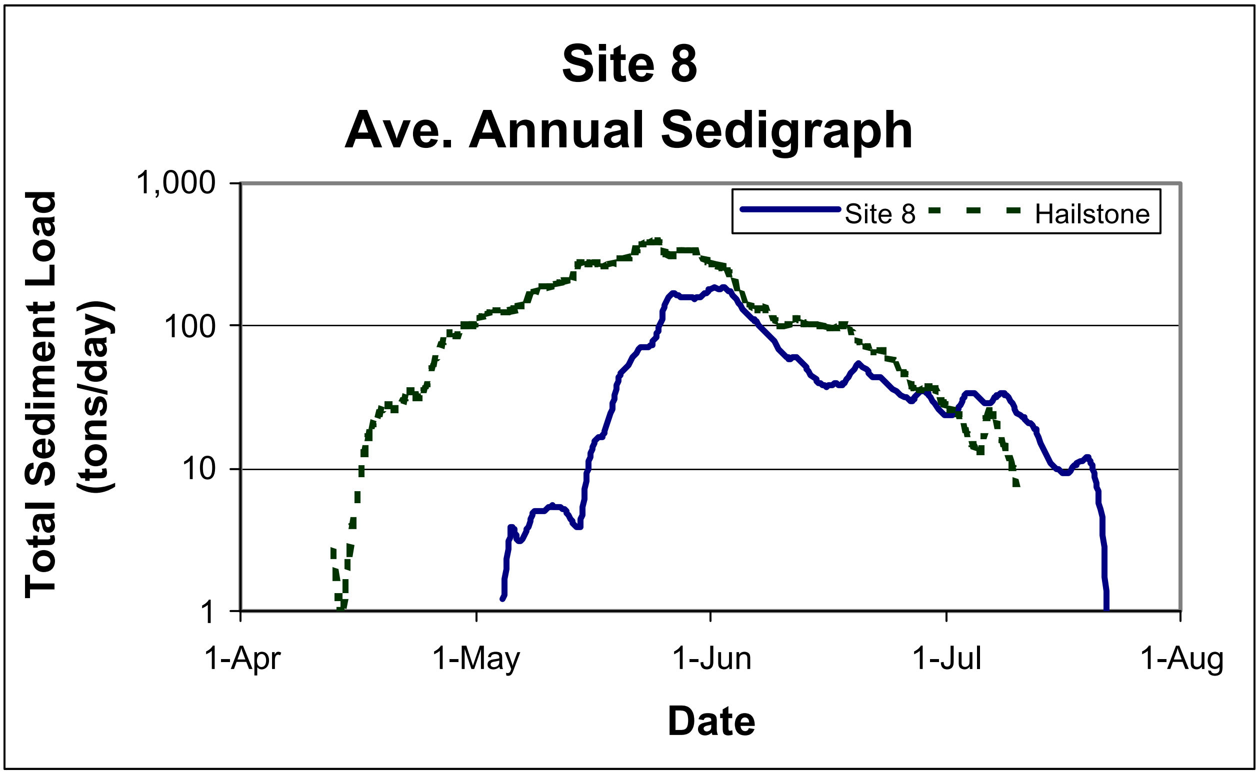


FIGURE 3.11. TIMING, MAGNITUDE AND DURATION OF SEDIMENT TRANSPORT FOR AVERAGE DAILY FLOWS OVER THE PAST 5 YEARS (1997-2001) AT SITE 8 (MIDWAY GAUGE) BASED ON THE 90 MM D_{50}. THE HIGHER CURVE REPRESENTS THE PREDICTED ADJUSTMENT IN SEDIMENT TRANSPORT USING SITE 8'S RATING CURVES WITHOUT THE INFLUENCE OF FLOW REGULATION BY JORDANELLE DAM (HAILSTONE GAUGE).

The rising and falling limbs of the annual regimes have identical angles (rates of change) but occur at different times, peak at unequal levels, and persist for varying lengths. Daily sediment transport rates are much lower at Site 8 during the majority of spring runoff. It is apparent that channel maintenance flows (high sediment transport rates) at Site 8 have been reduced significantly due to flow regulations. Peak daily sediment loads are approximately 50% lower below Jordanelle Dam and have been shortened in duration by approximately 20 days per year.

Flow duration curves (Figure 3.12) were used to calculate total annual sediment loads for Site 8 based on the regulated (Midway) and unregulated (Hailstone) flow regimes (and based on the 90 mm D_{50}). The total annual sediment load for Site 8 is 4,037 tons. However, the total annual sediment load using the unregulated flow data at Hailstone is approximately 11,659 tons (approximately 2.9 times greater than Sites 8). Therefore, sediment transport loads have been reduced by nearly 300% below Jordanelle since its construction.

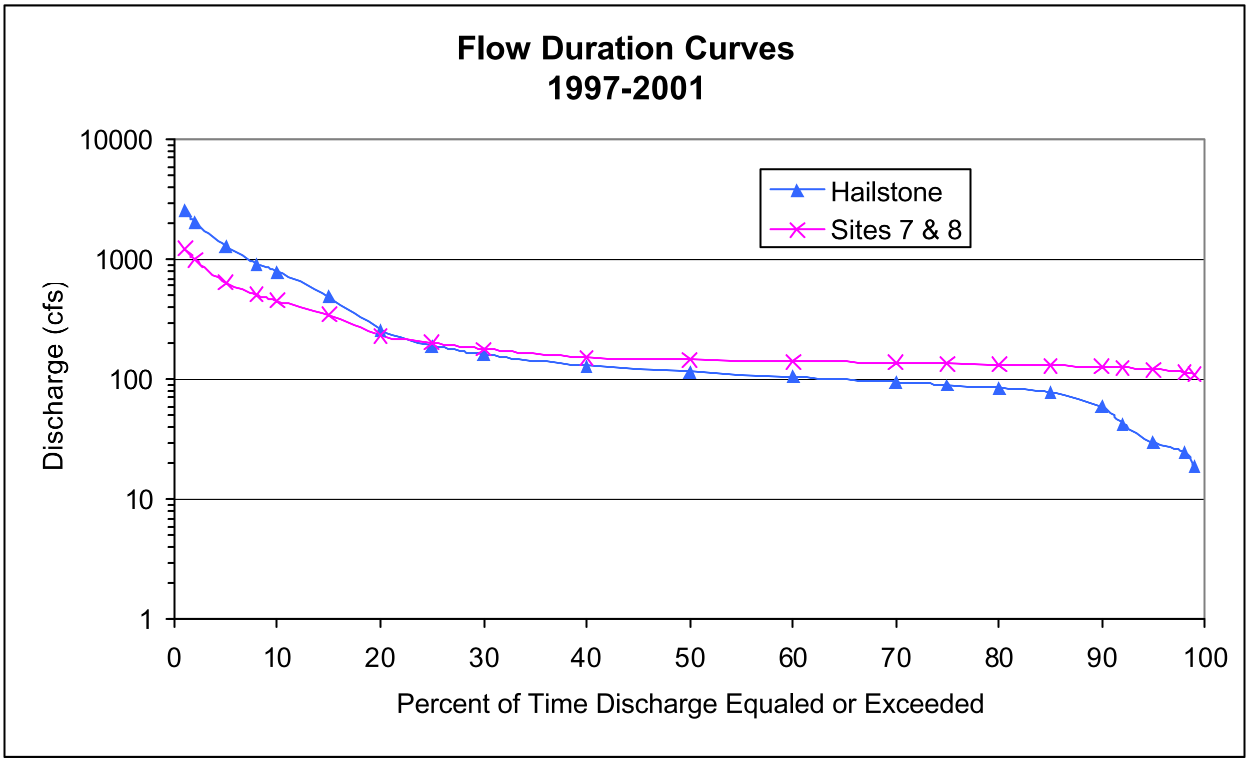


FIGURE 3.12. FLOW DURATION CURVES FOR WATER YEARS 1997-2001 FOR USGS-GAUGED SITES WITHIN THE STUDY AREA INCLUDING THE HAILSTONE GAUGE TO REPRESENT FLOWS WITHOUT THE INFLUENCE OF JORDANELLE DAM AND THE MIDWAY GAUGE TO REPRESENT FLOWS AT SITES 7 AND 8.

The composition of sediment in transport (proportion moving in suspension compared to bedload) was found to be dominated by suspended sediment (98% of the total annual sediment load). The proportion of the suspended load to bedload is much different using unregulated flows at Hailstone. Although the total sediment load is still dominated by suspended sediment, it only makes up 94% of the total annual load instead of 98% below Jordanelle.

Previous results using the Meyer-Peter Mueller equation were shown to over-predict bedload transport rates by an order of magnitude (Figure 3.8b) indicating a higher proportion of bedload. It is apparent that the Parker (1990) equation best represents actual measured bedload transport rates at Site 8 based on the recent bedload sampling results (Figure 3.8b). A further evaluation of total annual bedload transport under less/more armored conditions at Site 8 (larger D_{50}) is provided in the Discussion Section of this report.

3.1.5 RIPARIAN VEGETATION - SITE 8

Unlike all of the other Provo River study sites, riparian vegetation width at Site 8 is not constrained by levees on either side of the stream. Because the river is not constrained, a variety of fluvial surfaces including islands, broad floodplain areas, and gently sloping streambanks are present within the Site. However, because the channel was constructed so recently (in 2001), riparian vegetation has had limited time to become established. Currently, riparian vegetation within Site 8 consists primarily of grasses, small willow plantings, and volunteer willow/cottonwood seedlings (Plate 3.2). It is not yet possible to identify the vegetation patterns and flow relationships that will ultimately develop within the site. However, two transects were analyzed to determine inundation patterns for different fluvial surfaces that may serve as riparian recruitment sites.

3.1.5.1 TRANSECT RESULTS

Within Site 8, two 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 3.13a along with the range of flows that inundate the different establishment surfaces.

Transect 1 crosses grassy floodplain areas on both river right and river left (Figure 3.13a, Plate 3.2). On river right (facing downstream), the floodplain is at a slightly lower elevation and is bordered by a berm that grades into an upland area. On both streambanks, grass begins growing at approximately the 120 cfs flow level. Flows of 120 cfs are equaled or exceeded 95% of the time in the Middle Provo River (Appendix C), which eliminates the potential for vegetation growth on surfaces lower than this flow level.

The right floodplain surface becomes inundated at flows between 1,300 and 1,500 cfs, and is inundated to a width of about 50 feet at the 2,000 cfs discharge level (Figure 3.13a). Based on frequency analysis of gage data, this surface is overtopped by floods with a return interval between 2 and 5 years (Appendix C). The higher floodplain on river left remains dry at 2,000 cfs, which is the highest modeled flow. Even at 2,300 cfs (the maximum flow release from Jordanelle Dam), this left floodplain surface would most likely remain dry.

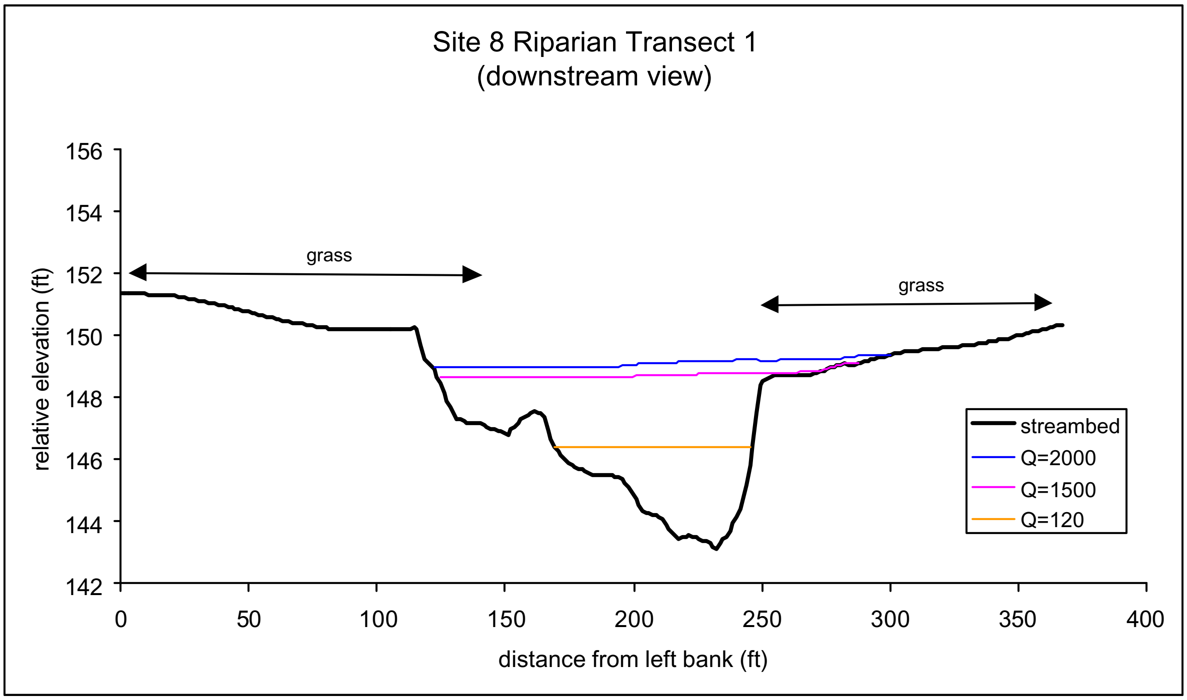
Transect 2 also spans the high floodplain surface on river left, and modeling results indicate that flows considerably greater than 2,000 cfs would be needed to inundate this surface (Figure 3.13a). As with Transect 1, the river right floodplain surface is at a lower relative elevation, and at Transect 2 the right bank is overtopped by discharges of 1,100 cfs and greater. The mid-channel island at Transect 2 becomes completely inundated by flows of 1,500 cfs and greater. As with Transect 1, vegetation (grass) at Transect 2 occupies surfaces higher than the 120 cfs flow level, but is not present on lower surfaces (Figure 3.13a).

SITE 8

PLATE 3.2. PHOTOS OF SITE 8 RIPARIAN SURFACES. (A) DOWNSTREAM VIEW OF SURFACES CROSSED BY TRANSECT 1; (B) UPSTREAM VIEW OF SURFACES CROSSED BY TRANSECT 1; (C) UPSTREAM VIEW OF ISLAND AND FLOODPLAIN SURFACES CROSSED BY TRANSECT 2. (D) DOWNSTREAM VIEW OF SURFACES CROSSED BY TRANSECT 2.

3.1.5.2 COTTONWOOD RECRUITMENT MODEL RESULTS

Since cottonwood seeds require a bare, moist surface for germination, overbank flooding and sediment deposition are an essential component of successful cottonwood recruitment. Modeled water depths at the expanded riparian Study Site 8 indicate that significant overbank flooding begins at this site at flows greater than 800 cfs (Image 3.2b). Large portions of the overall site, including important island and side-channel floodplain areas, are underwater at flows of 2,000 cfs (Image 3.2b).



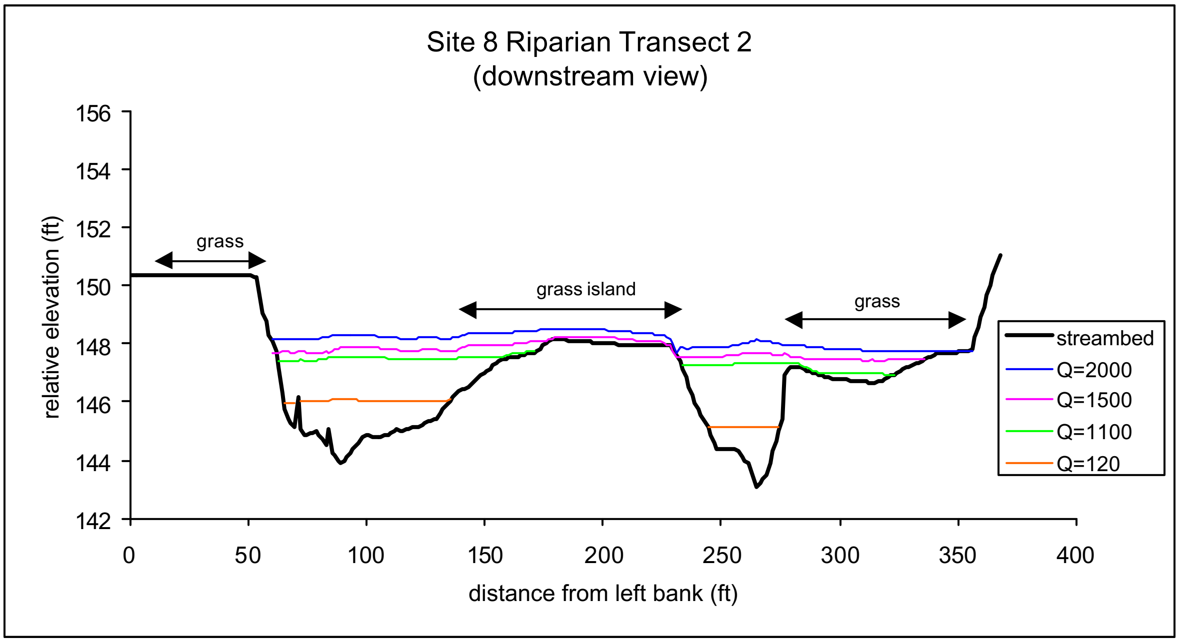
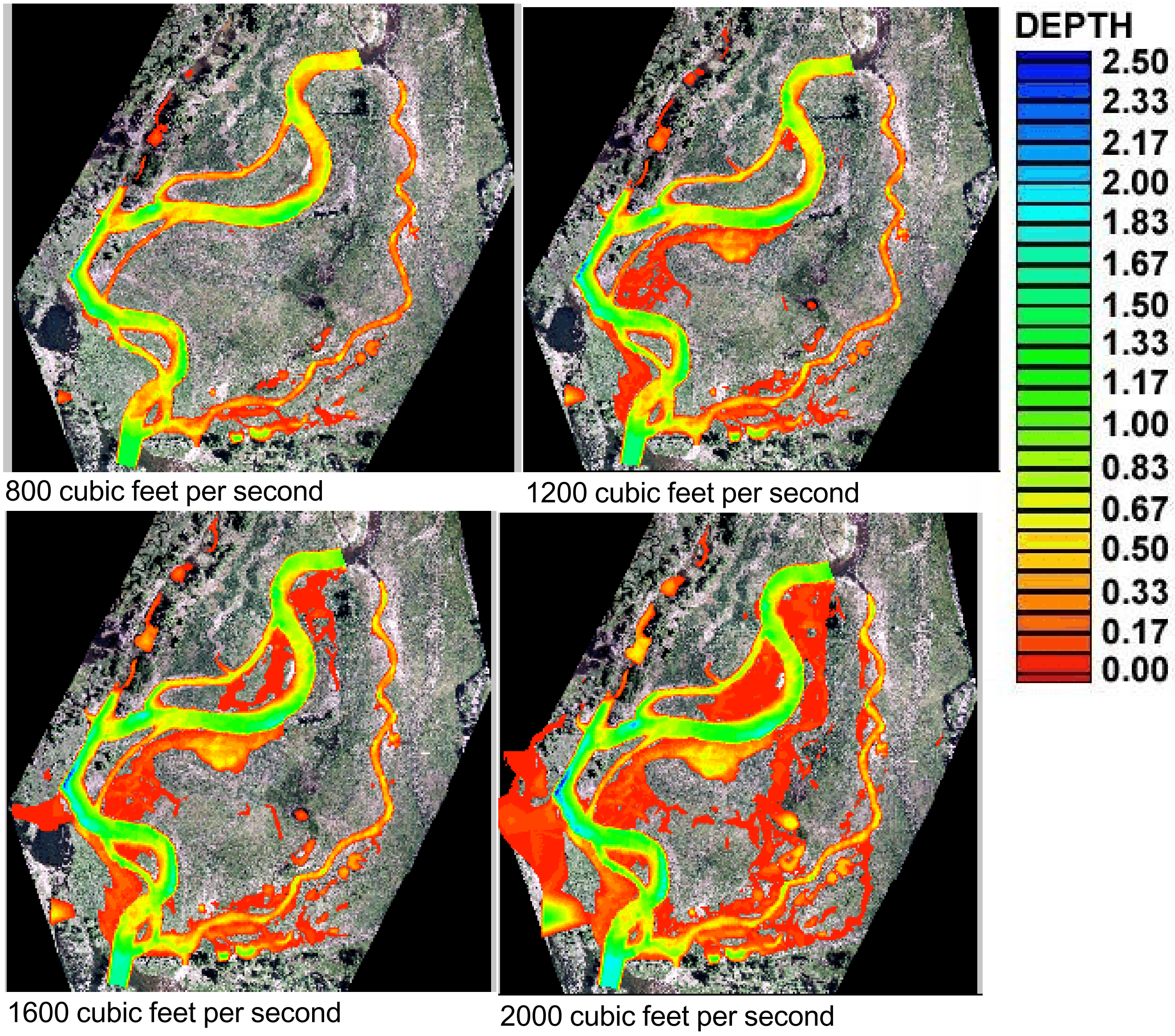


FIGURE 3.13A. SITE 8 RIPARIAN TRANSECTS AND INUNDATION DISCHARGES (CFS). PERCENTAGES SHOWN IN LEGEND INDICATE THE PERCENT OF TIME A GIVEN DISCHARGE IS EQUALED OR EXCEEDED. NOTE: UNEVEN WATER SURFACE ELEVATIONS ARE DUE TO COMPLEX HYDRAULICS THAT OCCUR AT HIGH FLOWS.

IMAGE 3.2B. MODELED FLOODPLAIN WATER DEPTHS AT DIFFERENT FLOWS FOR THE EXPANDED RIPARIAN STUDY SITE 8. DEPTHS ARE IN METERS.



800 cubic feet per second

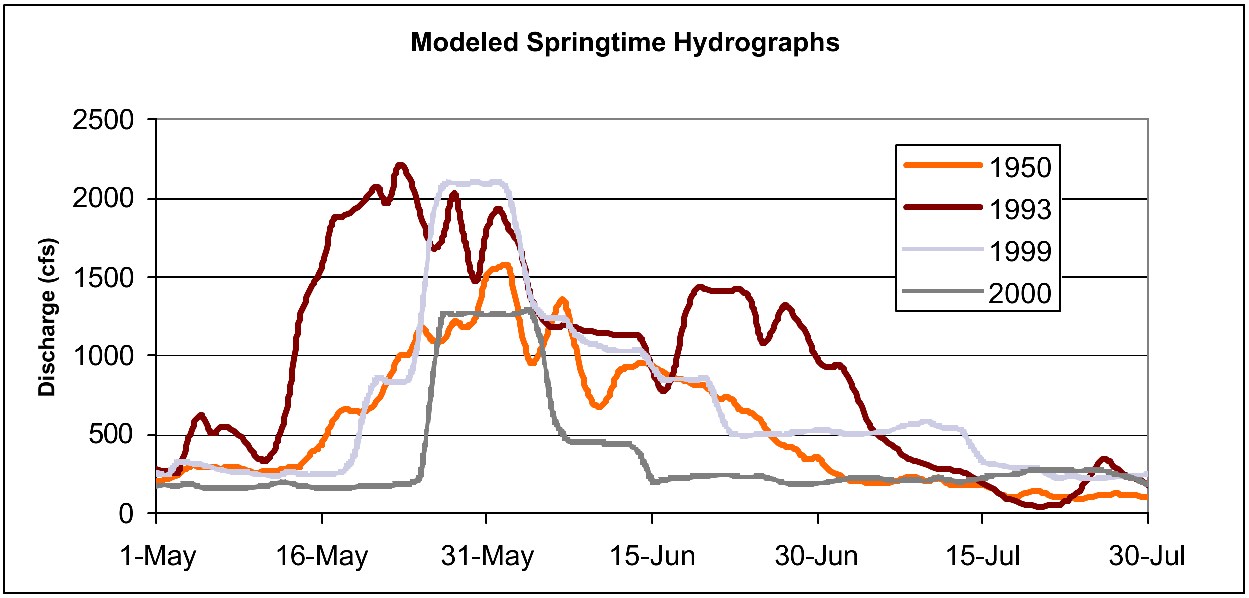
1200 cubic feet per second

1600 cubic feet per second

2000 cubic feet per second

The four modeled springtime hydrographs and recruitment area results are shown in Figure 3-13b. Of the four water years, the year with the greatest predicted area of successful recruitment is 1999, which had the highest peak flows during the seeding window (May 30-July 19). The year with the lowest predicted area of successful recruitment is 2000, which had the lowest peak flows. Because peak flows in 2000 only reached 1,280 cfs, a much smaller potential recruitment area was inundated relative to 1999, when peak flows reached 2,100 cfs. This difference is readily seen in Image 3.2c.

SITE 8



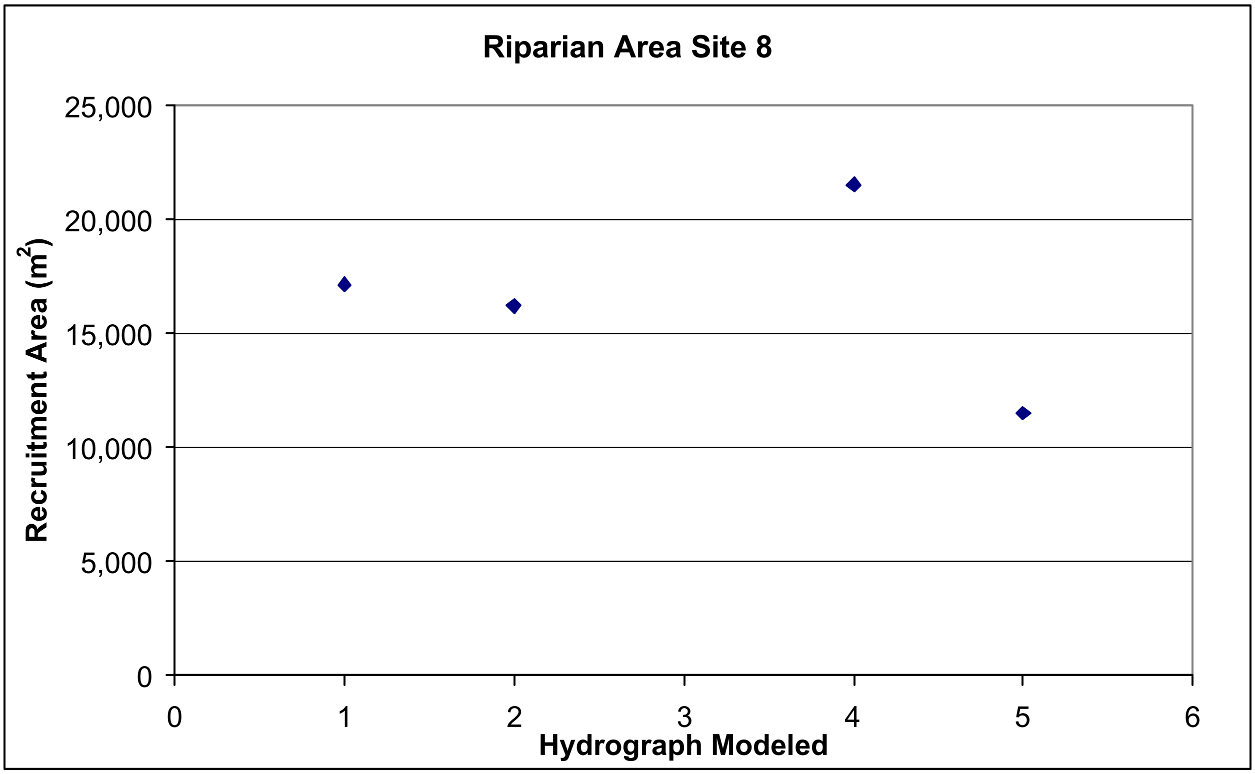
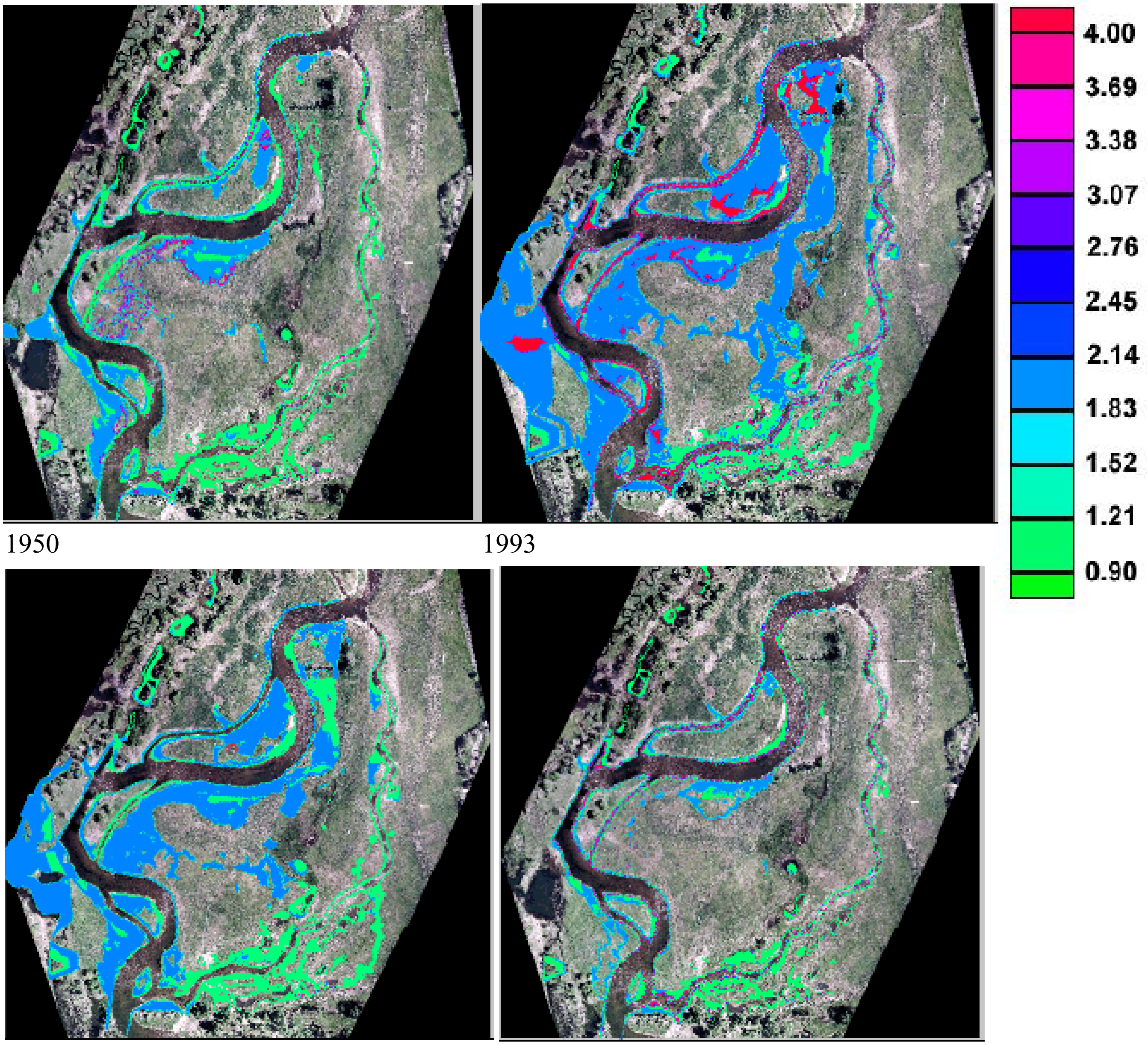


FIGURE 3.13B. PLOTS OF SPRINGTIME HYDROGRAPHS AND MODELED SUCCESSFUL RECRUITMENT AREA FOR DIFFERENT WATER YEARS.

IMAGE 3.2c. COTTONWOOD RECRUITMENT MODEL RESULTS FOR WATER YEARS 1950, 1993, 1999, AND 2000. AREAS THAT SUCCESSFULLY MEET ALL RECRUITMENT CRITERIA ARE SHOWN IN GREEN; AREAS WHERE THE GROUNDWATER RECESSION RATE WAS TOO RAPID ARE SHOWN IN BLUE; AREAS THAT WERE RE-WETTED/FLOODED ARE SHOWN IN RED.



1950

1993

1999

2000

Although the magnitude of the springtime peak flow is a very important variable in cottonwood recruitment, it is not the only factor that determines recruitment success. For example, the year 1950 had a slightly higher amount of successful recruitment area than 1993, despite the fact that 1993 peak flow (2,210 cfs) was considerably higher than the 1950 peak flow (1,570 cfs) (Figure 3-13b). This is partly due to the fact that flows in 1993 peaked early, prior to the cottonwood seeding window; the highest 1993 flow after May 30 was only 1,930 cfs. This illustrates the fact that the timing of peak flows, not just the magnitude, is an important variable in recruitment.

Although flows in 1993 inundated more of the floodplain than the 1950 flows, the 1950 hydrograph pattern enabled greater recruitment success along lower surfaces such as channel banks and point bar surfaces (Image 3.2c). The latter portion of the 1950 hydrograph receded slowly and steadily from 954 cfs on June 14 to 99 cfs on July 30 (Figure 3-13b). In contrast, flows in this range dropped relatively quickly in 1993 (from 982 cfs on June 30 to 103 cfs on July 17). In addition, in 1993, flows increased at the end of the modeling period (from 45 cfs on July 20 to 349 cfs on July 26), flooding any germinated seedlings on these lower surfaces. This flow increase accounts for the red zones along the lower banks seen in the 1993 model results (Image 3-2b). These same areas are green in the 1950 results, indicating recruitment success (Image 3-2c).

Although seedlings that grow on these lower surfaces are susceptible to scour during the following year's high flows and may not be as successful in the long-term as recruitment on higher, more protected surfaces, the different model results for 1950 and 1993 illustrate the importance of multiple flow variables (magnitude, timing, duration, pattern, and recession rate) in determining cottonwood recruitment success. Simple, integrated flow variables such as average annual flow or even monthly average flow are not adequate to predict complex resource processes such as cottonwood recruitment.

The four modeled hydrographs are simply examples of how the Site 8 cottonwood recruitment model can be used. Additional water years could be modeled and design hydrographs could be developed and modeled to help define criteria for Jordanelle Dam flow releases to maximize cottonwood recruitment success.

3.2 SITE 8B

3.2.1 AQUATIC HABITAT - SITE 8B

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 8b, but individual trout life stage HSI curves were also used. Site 8b consisted of the Rock Ditch return flow was modeled from 9 to 21 cfs.

As with other sites, each WUA value calculated for Site 8b represents the total amount of suitable habitat per 1,000 linear feet of stream. The total linear distance for this site was only 196 feet; therefore, the total WUA was extrapolated to 1,000 linear feet for comparison to other sites. Image 3.3 and Figure 3.14 shows the WUA (ft^2/1,000 ft) for each niche per respective flow. This site is dominated by Niche 2 habitat (slow/shallow) which remains just above 20,000 ft^2/1,000ft throughout the range of flows. The only other niche type with greater than 1,000 ft^2/1,000ft was niche3 (moderate/shallow) which increased to just over 5,000 ft^2/1,000ft at the highest modeled flow. These two niche types are important for native fish species. The niche most closely associated with trout, niche 5, increased with flow rate, but remained below 1,000 ft^2/1,000ft at the modeled flows. All other niches were essentially 0 ft^2/1,000ft at all flows.

Overall, the results of the habitat niche modeling at this site indicates native species should be dominant in this reach at the modeled flows. The dominance of slow/shallow habitat and gradual increase of moderate/shallow habitat provides ideal conditions for native species; however, the presence of some niche 5 habitat at higher flows suggests that a few trout may occupy the area during those times and may prevent native species from establishing sustaining populations. In general, this habitat will provide high quality habitat for fry and juveniles of many species, including trout, and will probably serve as a refugia area for native species during times when trout are restricted.

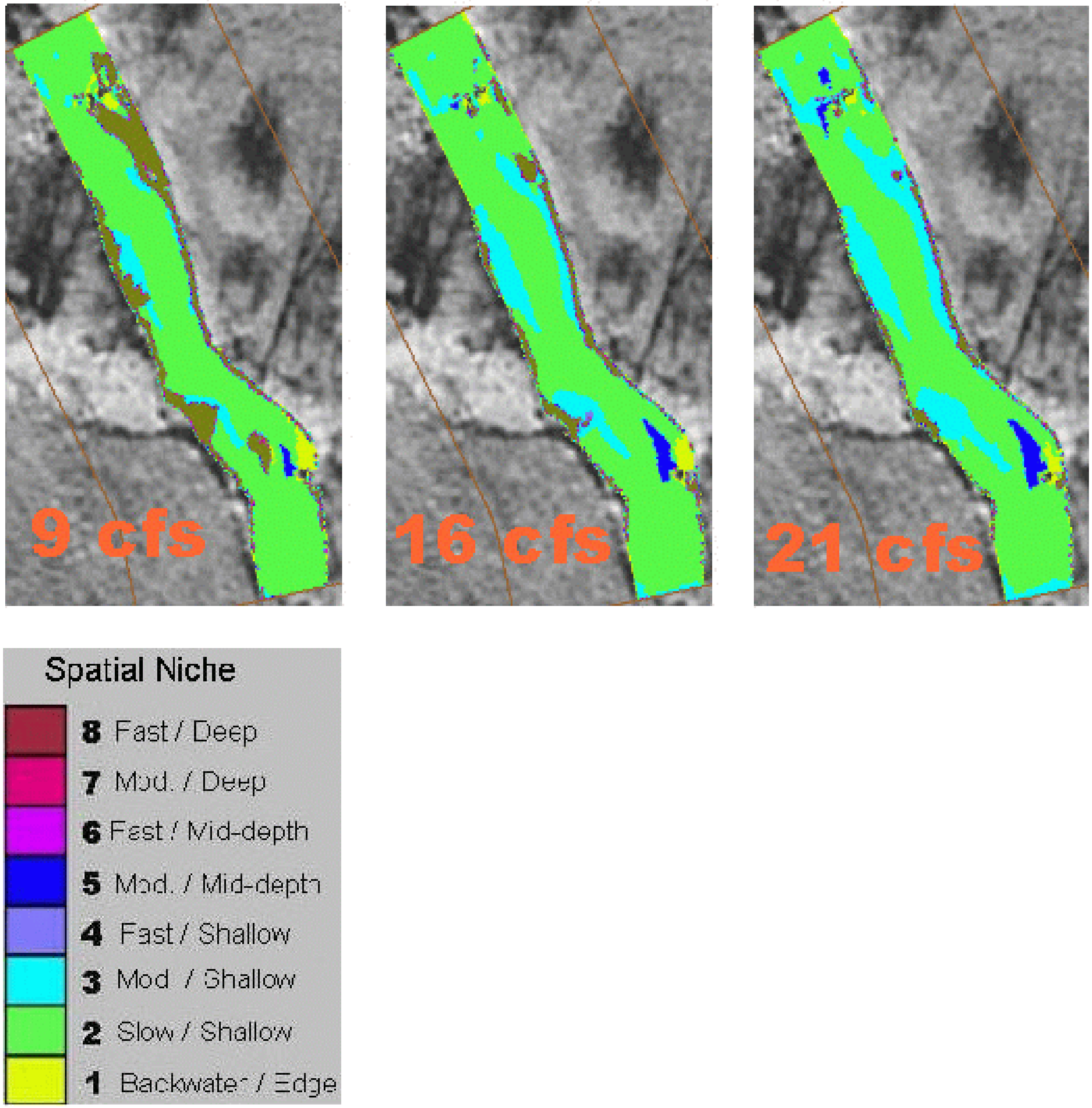
3.2.1.2 HSI CURVE MODELING

Figure 3.15 shows the WUA (ft^2/1,000 ft) for each trout species/lifestage per respective flow using individual HSI curves for brown trout and "all" trout. To avoid overestimating trout habitat, an "all" trout classification scheme (described in Methods) was used. The results show higher estimates of WUA than that indicated by the habitat niche approach. Niche 5 habitat was below 1,000 ft^2/1,000 ft under all flows, but the all-trout HSI curve increased from 2,300 ft^2/1,000 ft to nearly 7,000 ft^2/1,000 ft. Curves for juvenile brown trout and fry were similar. The all-trout juvenile curve had the highest WUA and increased from 16,300 ft^2/1,000 ft to 21,300 ft^2/1,000 ft at the highest flow. This corresponds closely to the niche 2 results.

Based on these HSI curves, the amount of habitat available to each trout species and life stage increases steadily with flow and the optimal for any species/life stage is at the highest flow (21 cfs). The adjustment applied to accommodate shallower depths in the all-trout juvenile curve relative to the brown trout juvenile curve revealed substantial differences in habitat availability in this instance and suggests that cutthroat and/or rainbow juveniles would be dominant in this habitat, which may result in the displacement of native species that do not generally inhabit areas with abundant juvenile trout (Figure 3.13).

Site 8b

Image 3.3. Habitat Niches - Weighted Usable Area (Site 8b). The images below visually depict habitat niches that are present at discharges of 9, 16 and 21 cfs for the site. Each habitat niche is represented by the color immediately adjacent the number/description in the legend. For example, Niche 5 = blue, Niche 1 = light yellow, etc.



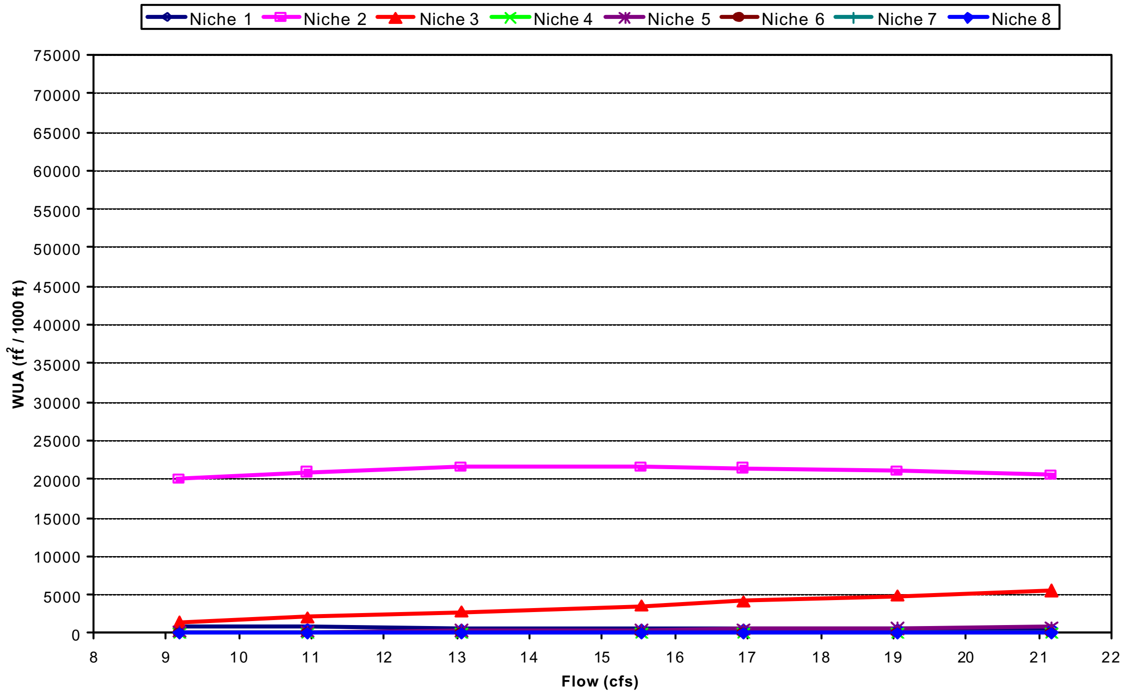


FIGURE 3.14. SITE 8B: HABITAT NICHES - WUA VS. FLOW.

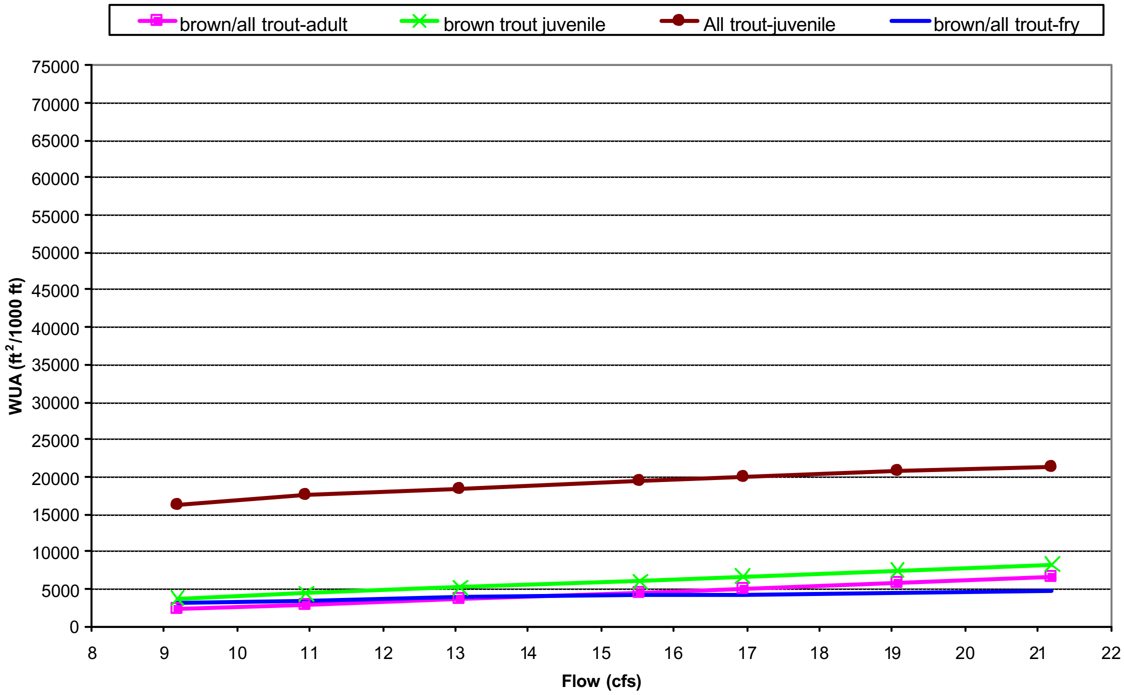


FIGURE 3.15. SITE 8B: TROUT - WUA VS. FLOW.

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 separation of individual curves for each species (versus the "all trout" curve) was warranted. Since substrate requirements were very similar among species, the variation in depth and velocity requirements for rainbow and cutthroat trout resulted in lower availability of spawning habitat (Figure 3.16). Brown trout habitat increased from about 7,800 ft^2/1,000 ft to over 9,200 ft^2/1,000 ft and rainbow trout spawning habitat increased more rapidly from 3,300 ft^2/1,000 ft to nearly 8,800 ft^2/1,000 ft. Cutthroat trout spawning habitat was approximately equal to rainbow trout at the lowest flow but decreased with increasing flows.

3.2.3 RECREATIONAL USABILITY-SITE 8B

3.2.3.3 WADING (FISHING)

The WUA's calculated for Reach 8b represent the total amount of suitable wading/fishing "habitat" (area) per 1,000 ft of stream. Figure 3.17 shows the WUA (ft^2/1,000 ft) for fishing/wading recreational activities. At the modeled flows (9-21 cfs), >25,000 ft^2/1,000ft of fishing/wading area is provided for recreationists.

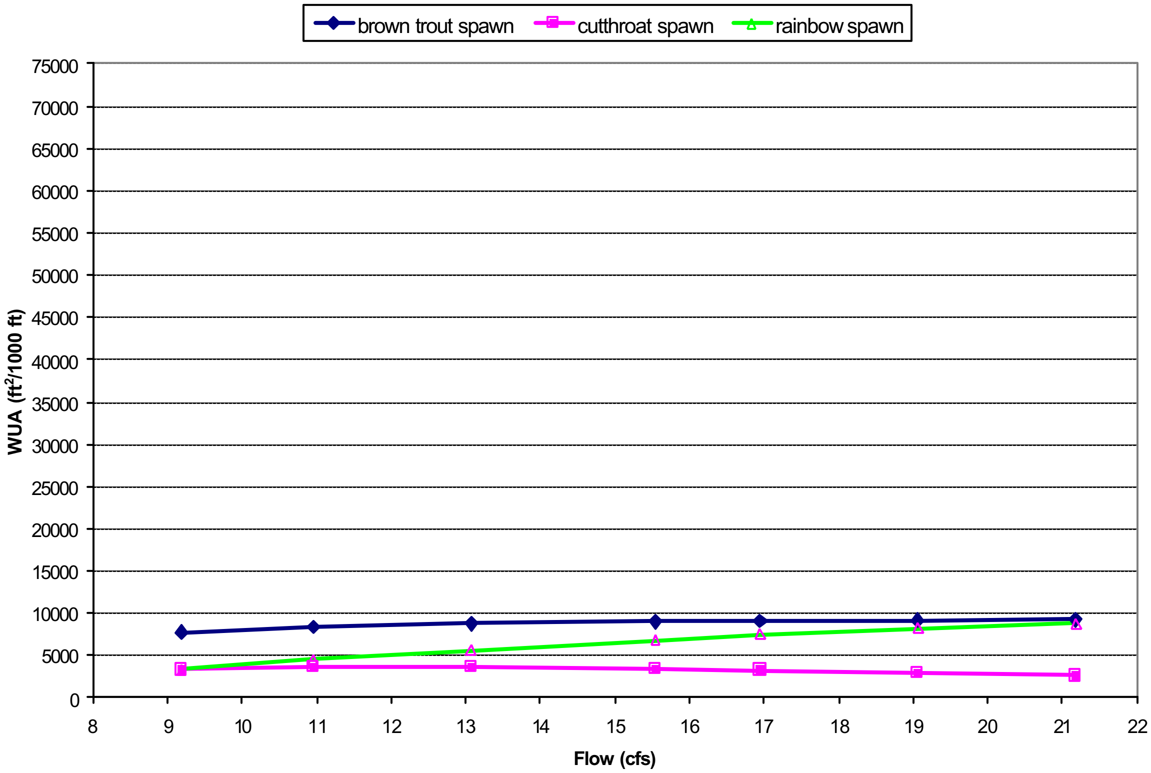


FIGURE 3.16. SITE 8B: TROUT SPAWNING - WUA VS. FLOW. FT^2/1,000 FT TO NEARLY 8,800 FT^2/1,000 FT. CUTTHROAT TROUT SPAWNING HABITAT WAS APPROXIMATELY EQUAL TO RAINBOW TROUT AT THE LOWEST FLOW, BUT DECREASED WITH INCREASING FLOWS.

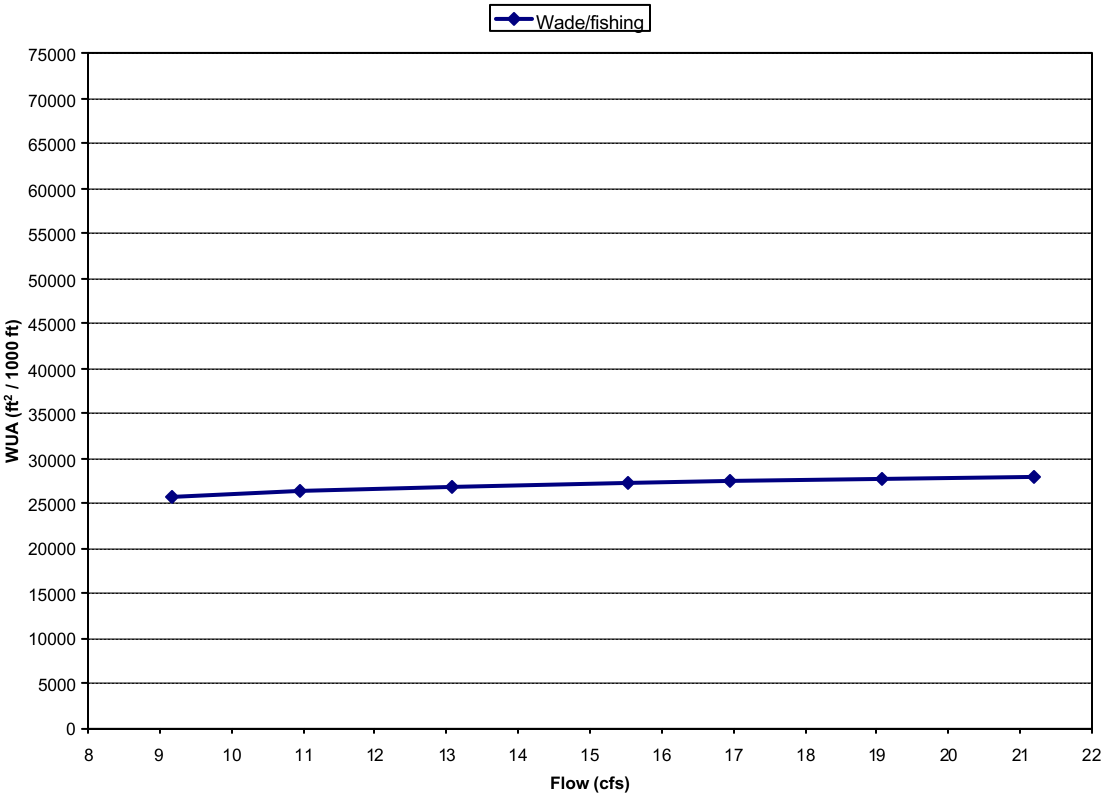


FIGURE 3.17. SITE 8B: FISHING - WUA VS. FLOW.

3.3 SITE 8C

3.3.1 AQUATIC HABITAT - SITE 8C

3.3.1.1 HABITAT NICHE MODELING

As discussed in Section 2 and Appendix A, a habitat niche approach was primarily used for assessing suitable habitat for Site 8c, but individual trout life stage HSI curves were also used. Site 8c consisted of a cutoff channel from the mainstem of the river and was modeled from 2 to 85 cfs.

Each WUA value calculated for site 8c represents the total amount of suitable habitat per 1,000 linear feet of stream. Figure 3.18 shows the WUA (ft^2/1,000 ft) for each niche per respective flow. Habitat variability was higher in site 8c than in site 8b. The backwater/edge habitat (niche 1), which is used by a majority of native fish species and larval stages of many fish was highest (8,800 ft^2/1,000 ft) at the lowest flow (2 cfs). This habitat decreases in WUA down to near 5,000 ft^2/1,000ft at approximately 10 cfs to 15 cfs, but between 15 cfs and the highest flow, 85 cfs the niche 1 habitat increases gradually to near the WUA value modeled at the lowest flow. The slow/shallow habitat (niche 2) supports many juvenile and YOY species (Image 3.4).

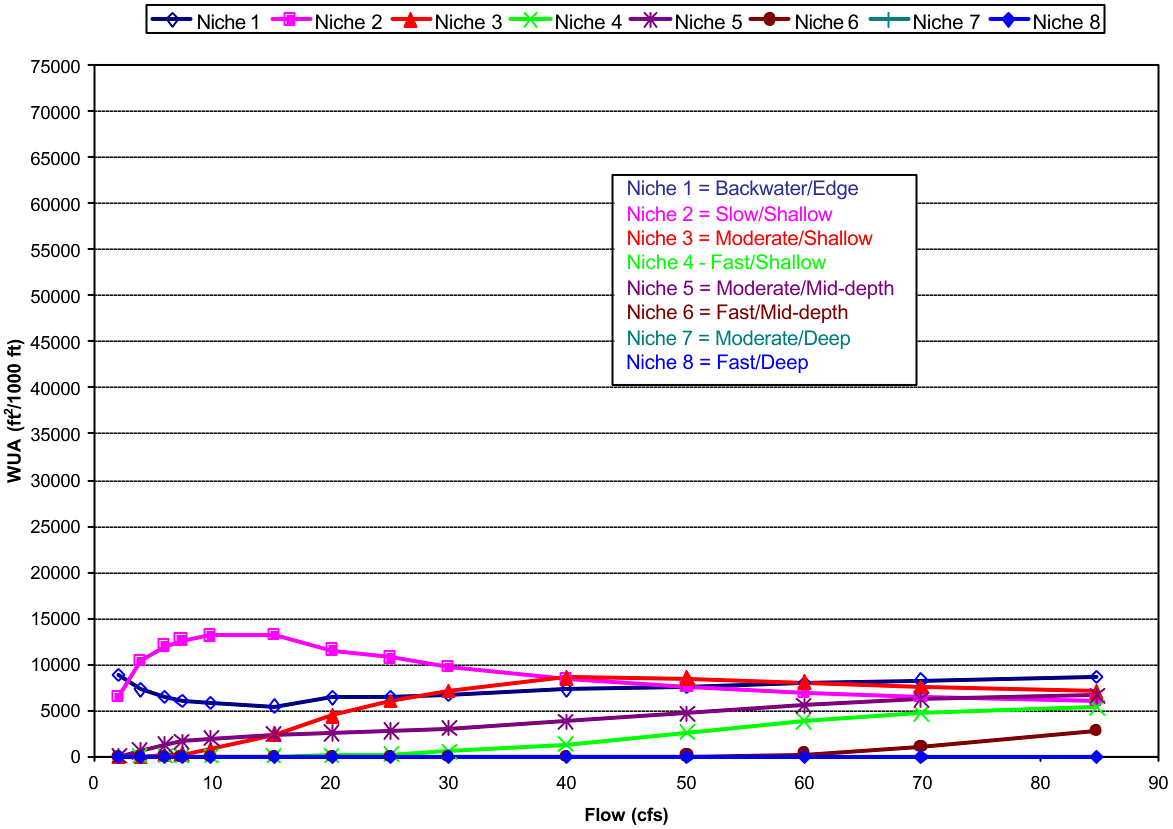
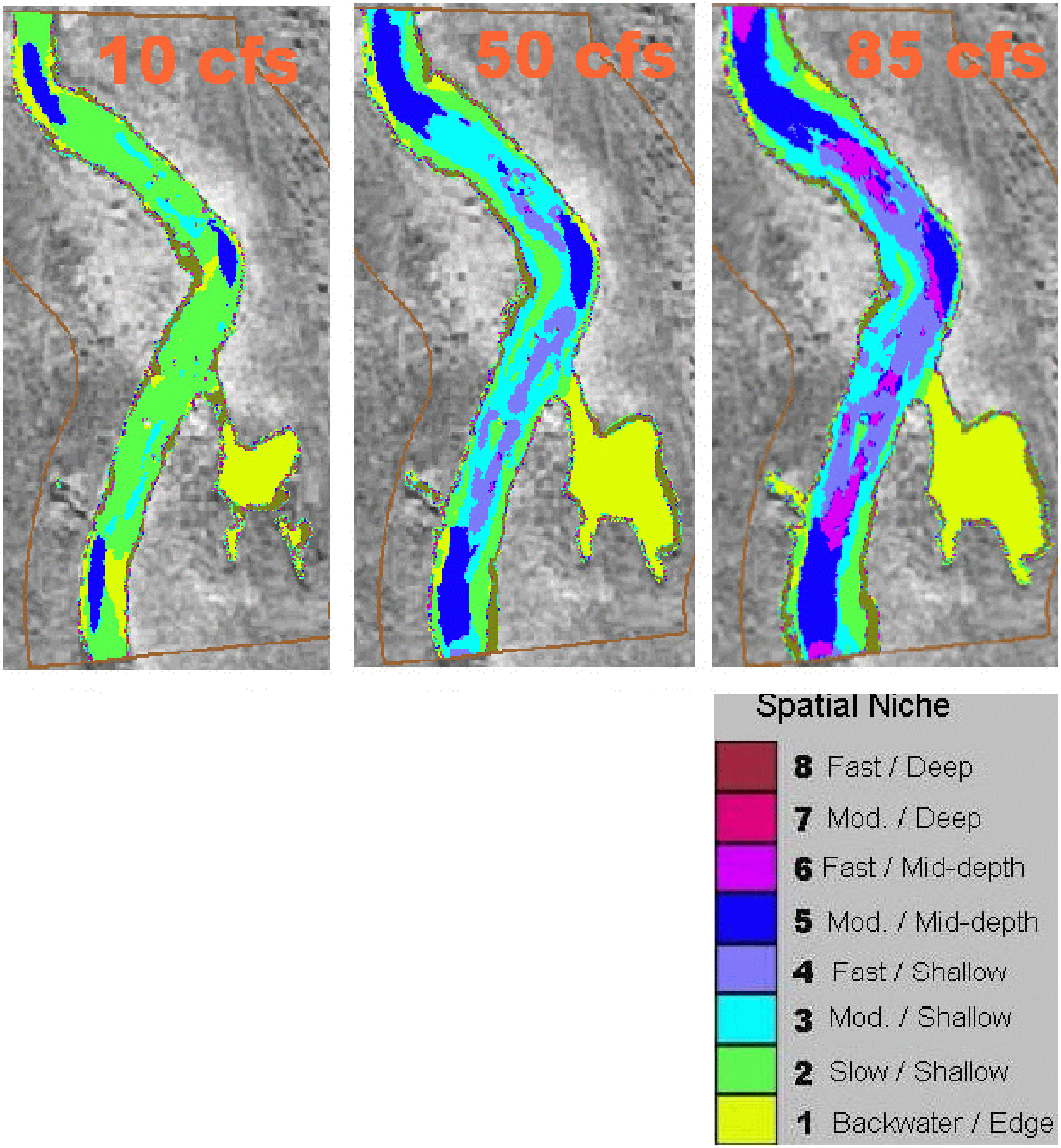


FIGURE 3.18. SITE 8C: HABITAT NICHES - WUA VS. FLOW.

SITE 8C

IMAGE 3.4. HABITAT NICHES - WEIGHTED USABLE AREA (SITE 8C).



This niche maintains the highest WUA at all flows between 2 cfs and 40 cfs (6,500 ft^2/1,000 ft - 13,000 ft^2/1,000 ft) and remains above 5,000 ft^2/1,000 ft at all flows. Niche 3 habitat increases from 0 ft^2/1,000 ft to over 8,500 ft^2/1,000 ft at 40 cfs and decreases slightly beyond that. 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. The fast/shallow habitat (niche 4), which provides suitable habitat for mountain sucker adults and mottled sculpin adults and juveniles, remains at 0 ft^2/1,000 ft up to 30 cfs then increases to 5,000 ft^2/1,000 ft at 85 cfs. Niche 5 is the primary habitat type for the sportfish in the Provo River including all trout and mountain whitefish adults and juveniles but it is also is relatively limited throughout the range of flows in site 8c and just barely tops 5,000 ft^2/1,000 ft at the highest flow. The only species/lifestage documented in niche 6 habitat (fast/mid-depth) is the adult mountain sucker and this niche is barely represented in site 8c; niches 7 and 8 are nonexistent at all flows.

Overall, the results of the habitat niche modeling at this site suggest that it provides high quality habitat for juveniles of several species and provides the habitat to support native fishes. However, the presence of some habitat for adult trout and probability of supporting populations of juvenile trout suggests that biological interactions would limit native fishes in this site. Backwater/edge habitat remains relatively abundant compared to other habitats in this reach at all times and may provide a shelter to those native fishes that primarily use this habitat type.

3.3.1.2 HSI CURVE MODELING

An examination of the individual HSI curves for brown trout and "all trout" reveal slightly higher estimates for habitat availability than that observed above for niche 5. Figure 3.19 and Image 3.5 show 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 5,000 ft^2/1,000 ft between approximately 10 and 85 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 85 cfs except that habitat for all-trout juveniles was substantially higher (>15,000 ft^2/1,000 ft between 10 and 85 cfs).

Figure 3.19 reveals that habitat for fry increases to nearly 5,000 ft^2/1,000ft at 10 cfs and then declines gradually to about 2,500ft ft^2/1,000 ft at the highest flow. This study documents that the optimal range for fry habitat in site 8c is approximately 5 to 30 cfs. As flow increases, trout fry habitat is reduced.

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 separation of individual curves for each species (versus the "all trout" curve) was warranted. Since substrate requirements were very similar among species, the variation in depth and velocity requirements for rainbow and cutthroat trout resulted in lower availability of spawning habitat (Figure 3.20). Brown trout habitat increased to nearly 12,000 ft^2/1,000 ft at 25 cfs and decreased beyond that; rainbow trout spawning habitat followed a similar curve, but available

Site 8c

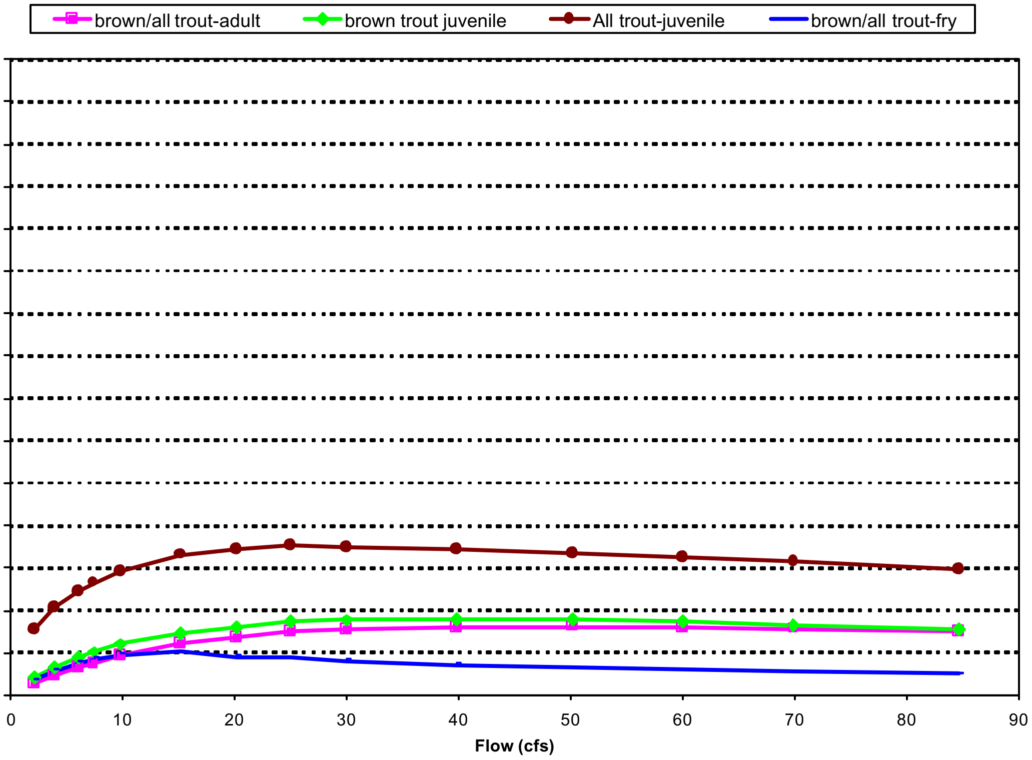
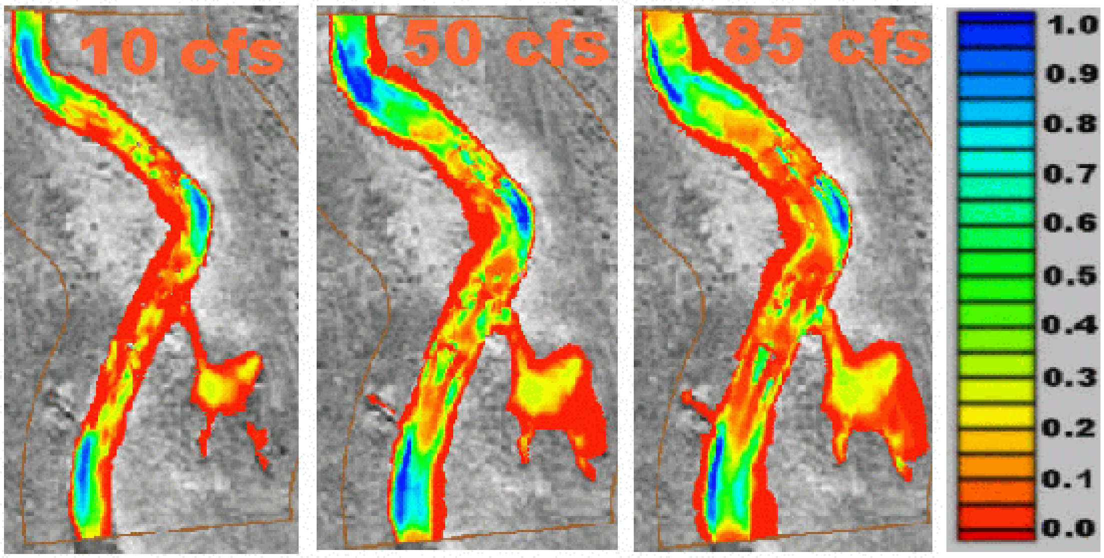


Figure 3.19. Site 8c: Trout - WUA vs. flow.

Image 3.5 Adult Brown Trout - Weighted Usable Area (Site 8c). The images below visually depict suitable habitat available to adult brown trout at discharges of 10, 50, and 85 cfs. The best habitat is represented by suitability of 1.0 (blue) and no habitat is represented by 0 (red).



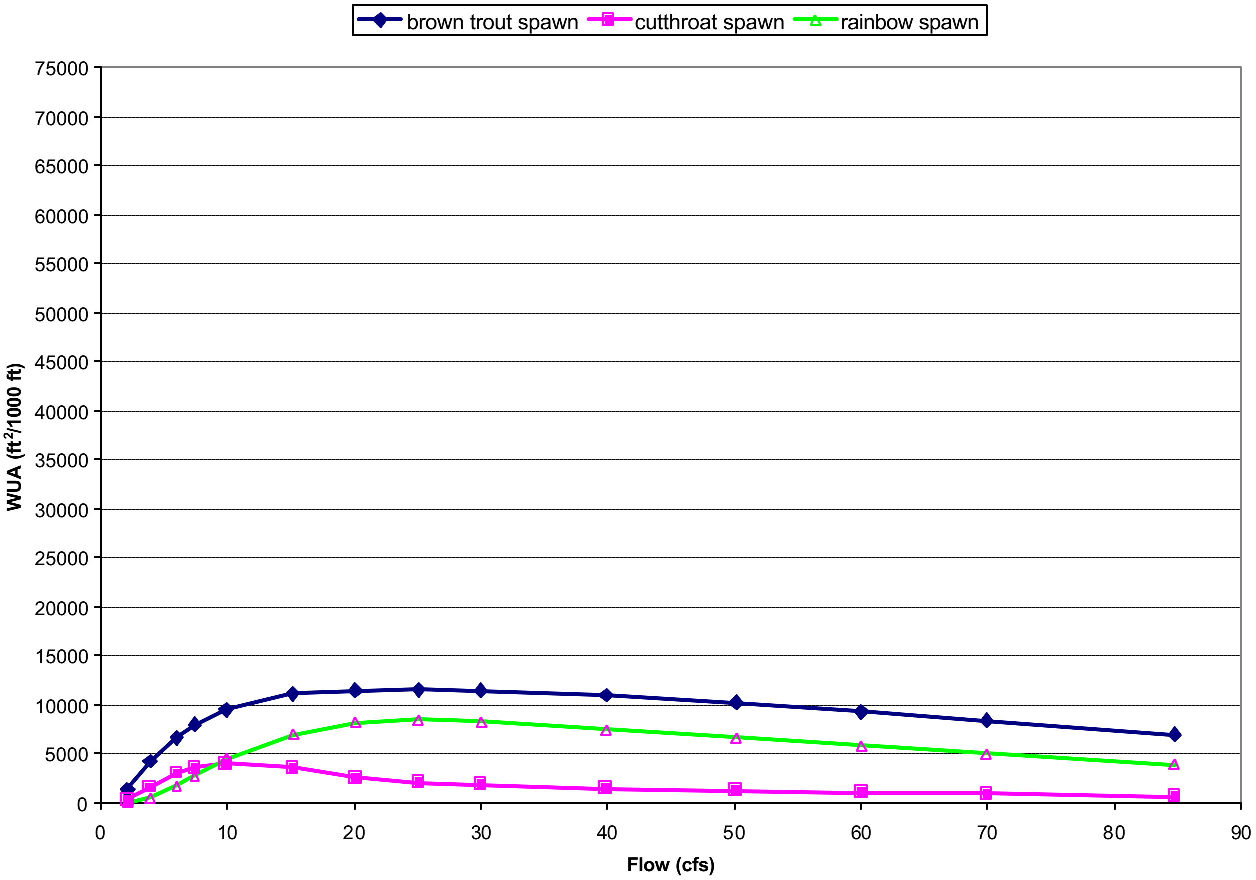


FIGURE 3.20. SITE 8C: TROUT SPAWNING - WUA VS. FLOW.

habitat was about 3,000 ft^2/1,000 ft less at all flows. Cutthroat trout spawning habitat was nearly identical to rainbow trout spawning habitat up to a peak at 10 cfs, but decreased substantially at higher flows and dropped to only 600 ft^2/1,000 ft at 85 cfs.

3.1.3.3 WADING (FISHING)

The WUA's calculated for Reach 8c represent the total amount of suitable wading/fishing "habitat" (area) per 1,000 ft of stream. Figure 3.21 shows the WUA (ft^2/1,000 ft) for fishing/wading recreational activities. At flows between 15 and 85 cfs, >25,000 ft^2/1,000ft of fishing/wading area is provided for recreationists.

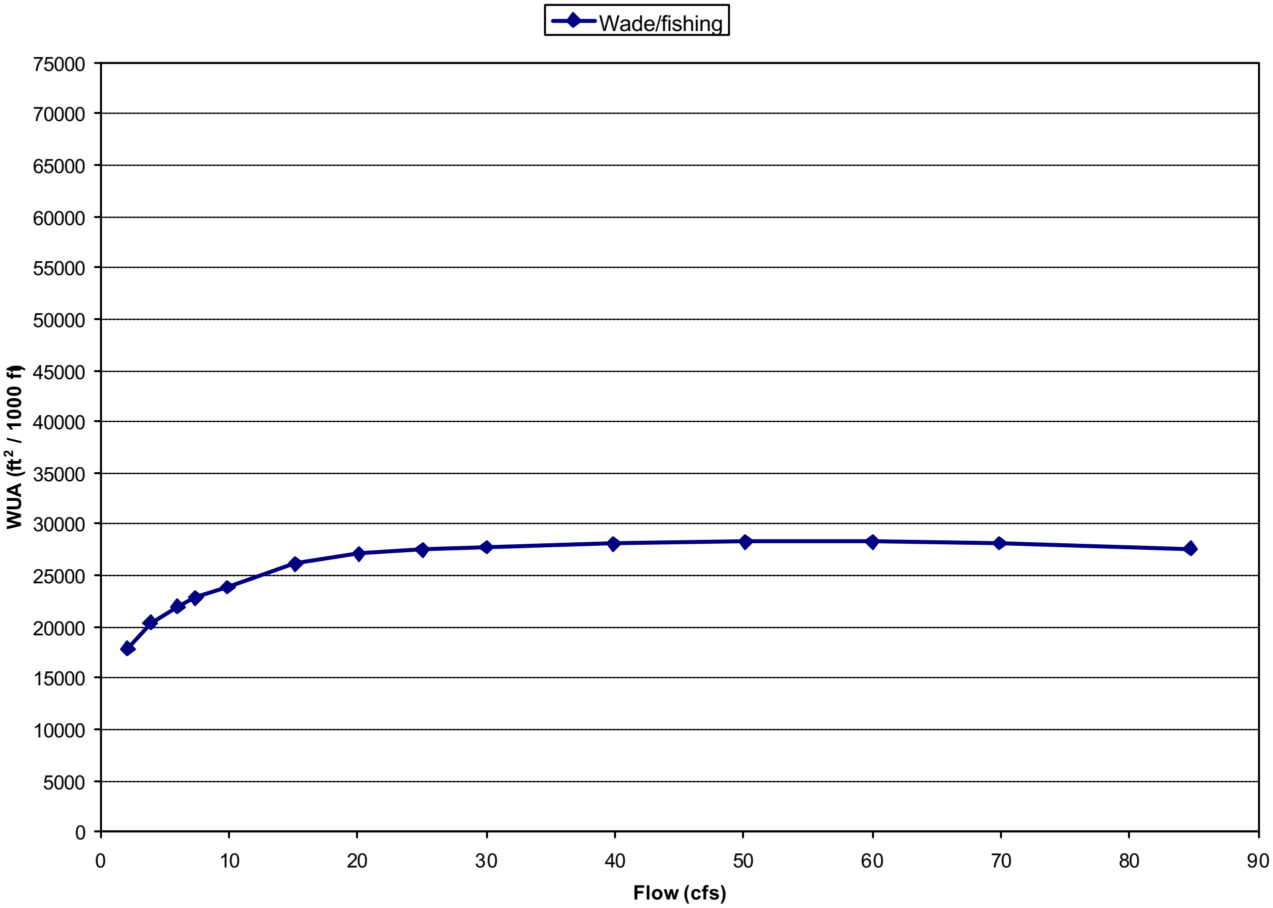


FIGURE 3.21. SITE 8C: FISHING - WUA VS. FLOW.

3.4 SITE 8D

3.4.1 AQUATIC HABITAT - SITE 8D

Site 8d represented a beaver dam complex in which changes in flow had minimal effects on wetted area and thus modeling was not warranted at this site. Two transects were placed within this site and point measurements were taken with depth and velocity recorded as described in Section 2. For both cross sections, the only niche represented was Niche 1 (backwater/edge). Niche 1 habitat represented 83% of the wetted area for the cross section above the second lowest dam (17% of the area was to shallow to classify as Niche 1) and 100% of the wetted area at the cross section above the lowest dam. The backwater/edge habitat (niche 1) is used by a majority of native fish species and larval stages of many fish.

When evaluating the available adult and juvenile brown trout habitat only habitat with a > 0.5 suitability - depth and velocity was used for each life stage. The following table shows the percentage of available habitat for each cross section.

	Site 8d above second lowest dam	Site 8d above lowest dam
brown trout adult	0%	43%
brown trout juvenile	17%	57%

The first cross section (above second lowest dam) provides only minimal habitat for brown trout juveniles and no habitat for adults as the velocities are too low. With slightly increased velocities at the lowest dam, the percentages of habitat increases for both adult and juvenile brown trout. As the backwater/edge habitat is the only available habitat, it may provide a shelter/refuge for native fishes. However, the presence of some habitat for juvenile trout at the upper cross sections and increased amounts of suitable habitat for juveniles and adult trout at the lower cross section suggests that biological interactions could limit native fishes in this site. The ability of brown trout to use habitats with shallow depths and lower flows potentially impedes the sustainability of native fishes even in habitat such as this, which under non-predatory conditions would be ideal for many native species.

3.5 SITE 8E

3.5.1 AQUATIC HABITAT - SITE 8E

3.5.1.1 HABITAT NICHE MODELING

As discussed in Section 2 and Appendix A, a habitat niche approach was primarily used for assessing suitable habitat for Site 8e, but individual trout life stage HSI curves were also used. Site 8e consisted of a meandering meadow stream that was modeled from 1 to 20 cfs. At flows higher than 20 cfs, the water breaks out of the bank creating sheet flow over the floodplain.

Each WUA value calculated for site 8e represents the total amount of suitable habitat per 1,000 linear feet of stream. Figure 3.22 shows the WUA (ft^2/1,000 ft) for each niche per respective flow. Habitat variability was minimal in site 8e (Image 3.6), all niches were limited to under 5,000 ft^2/1,000 ft. The backwater/edge habitat (niche 1), which is used by a majority of native fish species and larval stages of many fish was highest (4,500 ft^2/1,000 ft) at the lowest flow (1 cfs) and decreased steadily in WUA down to near 600 ft^2/1,000 ft at the highest flow (20 cfs). The slow/shallow habitat (niche 2), which supports many juvenile and YOY species, peaked at 3 cfs (3,400 ft^2/1,000 ft) and decreased to 1,000 ft^2/1,000 ft at the highest flow. Niche 3 habitat increases from 0 ft^2/1,000 ft to a peak of 2,200 ft^2/1,000 ft at 12 cfs and decreases slightly beyond that. 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. The fast/shallow habitat (niche 4), which provides suitable habitat for mountain sucker adults and mottled sculpin adults and juveniles, increased very gradually with higher flows to a peak of only 1,300 ft^2/1,000 ft at 20 cfs. Niche 5 is the primary habitat type for the sportfish in the Provo River including all trout and mountain whitefish adults and juveniles and increases steadily from 1 - 20 cfs with a peak of about 3,700 ft^2/1,000 ft. Niches 6 - 8 are nonexistent at all flows.

3.5.1.2 HSI CURVE MODELING

An examination of the individual HSI curves for brown trout and "all trout" reveal similar estimates for habitat availability compared to that observed above for niche 5. Figure 3.23 and Image 3.7 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 2,000 ft^2/1,000 ft at 3 cfs and above. Although exhibiting different habitat amounts, the juvenile "all trout" and brown trout curves reveal a similar trend except that habitat for all-trout juveniles was substantially higher (>4,000 ft^2/1,000 ft above 2 cfs).

Figure 3.24 reveals that habitat for fry increases to 2,500 ft^2/1,000ft at 5 cfs then declines gradually to about 1,700ft ft^2/1,000 ft at the highest flow. This study documents that the optimal range for fry habitat in site 8e is approximately 3 to 13 cfs, but even in this range, suitable habitat is limited.

SITE 8E

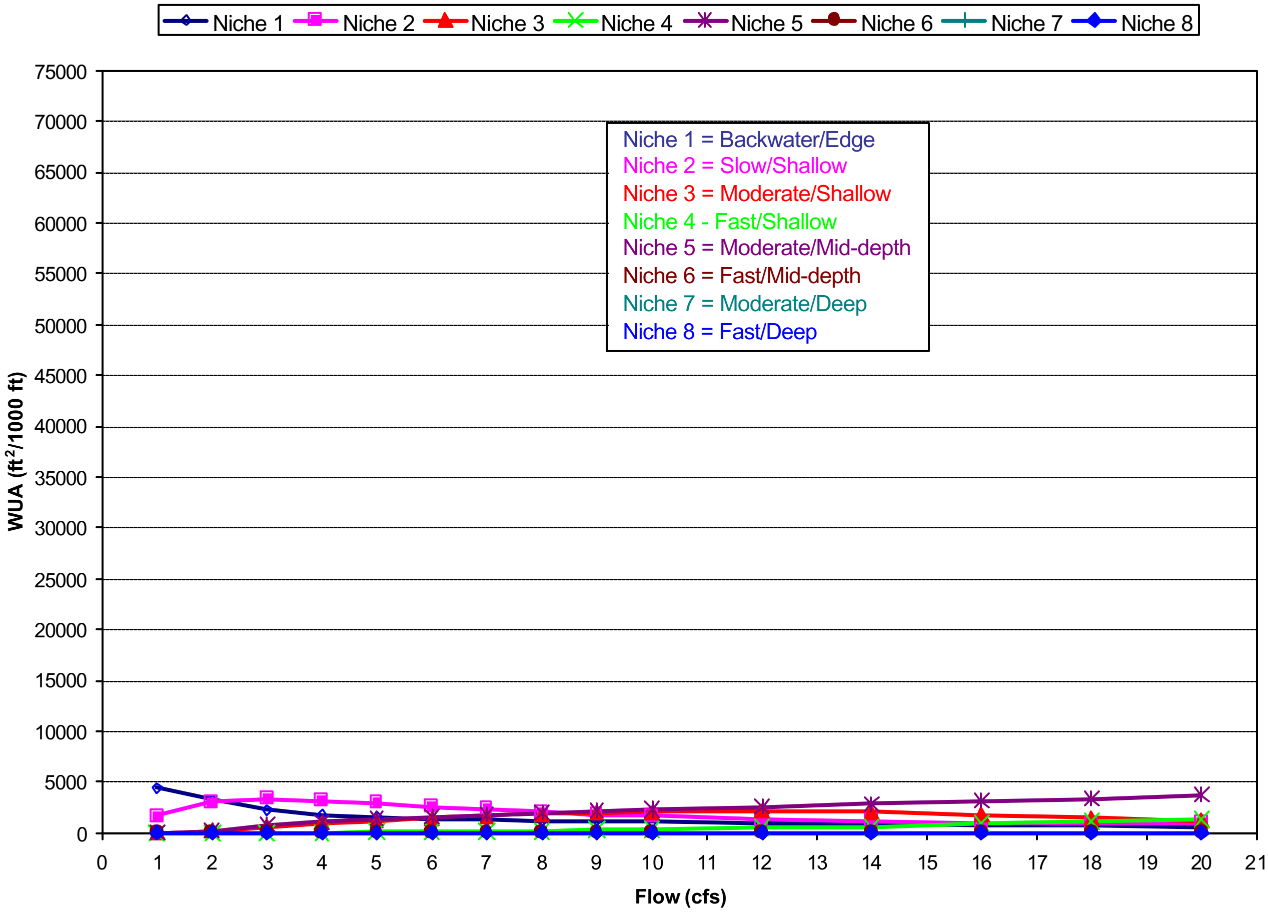
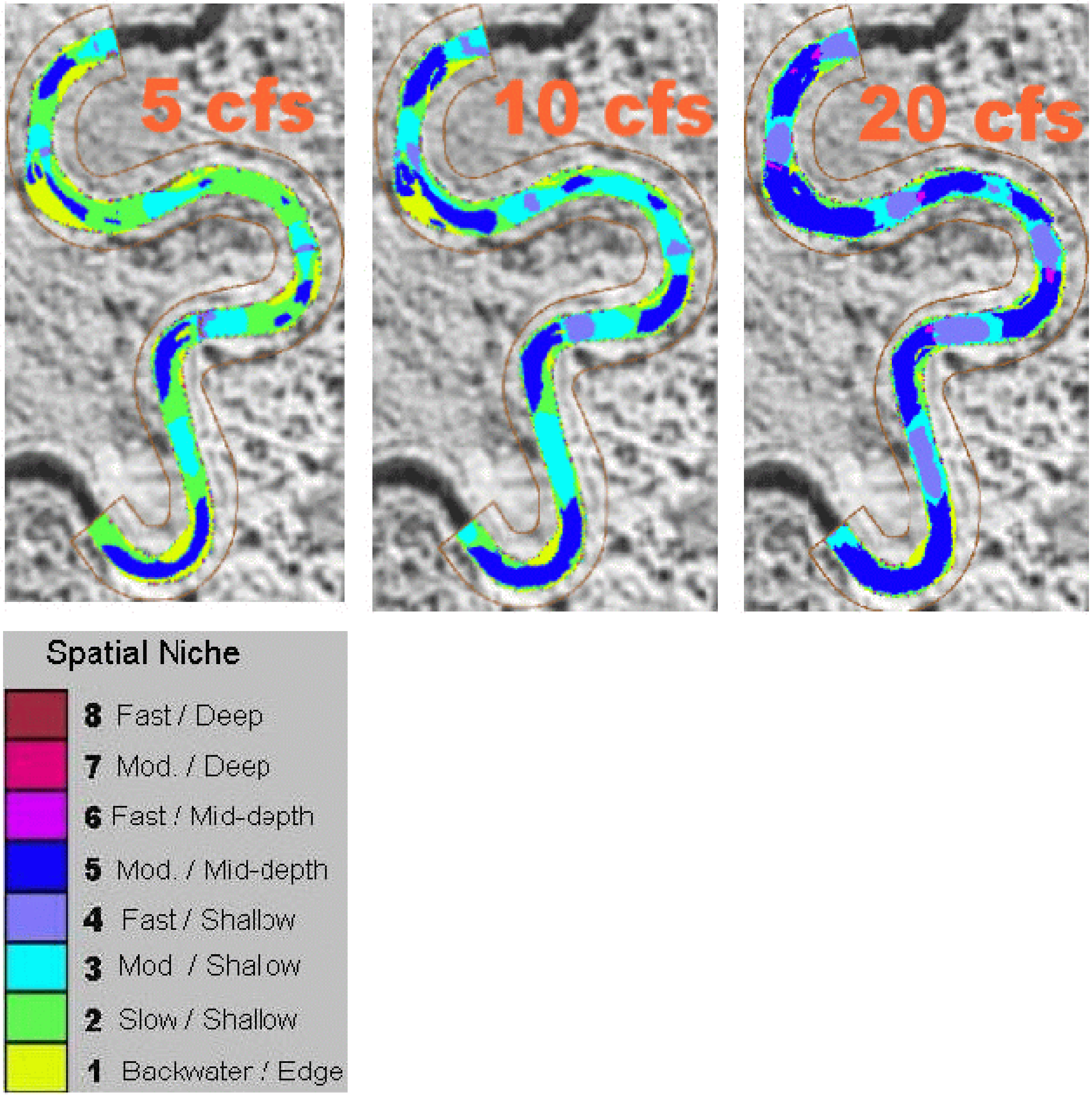


FIGURE 3.22. SITE 8E: HABITAT NICHES - WUA VS. FLOW.

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 separation of individual curves for each species (versus the "all trout" curve) was warranted. Although some differences exist in spawning habitat availability between species, it is minimal (<3,000 ft^2/1,000 ft) for all trout species at all flows in this site (Figure 3.24).

SITE 8E

IMAGE 3.6. HABITAT NICHES - WEIGHTED USABLE AREA (SITE 8E). THE IMAGES BELOW VISUALLY DEPICT HABITAT NICHES THAT ARE PRESENT AT DISCHARGES OF 5, 10, AND 20 CFS FOR SITE 8E. 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.



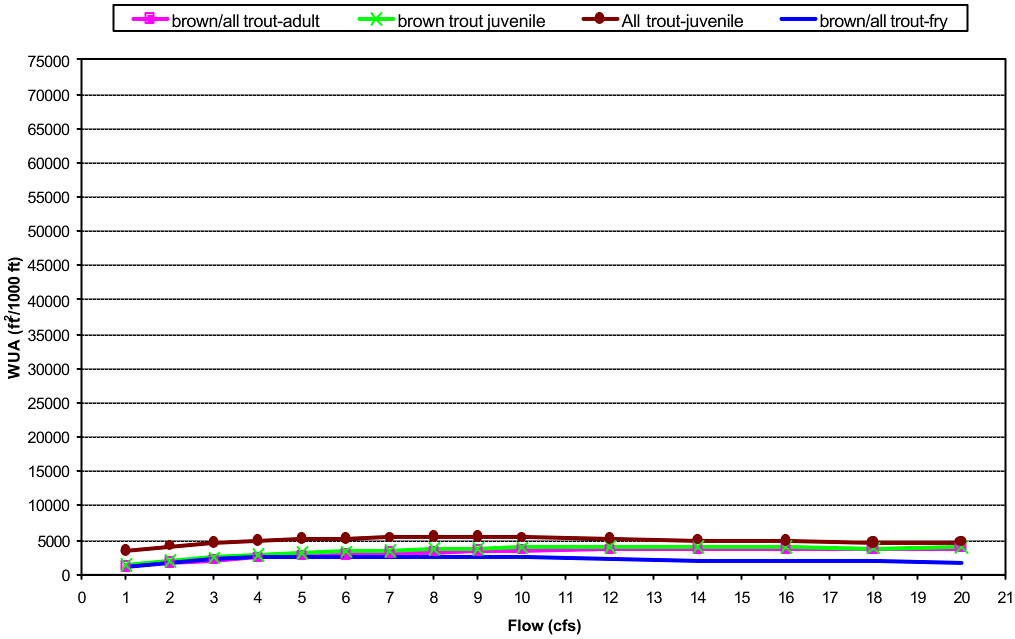


FIGURE 3.23. SITE 8E: TROUT - WUA VS. FLOW.

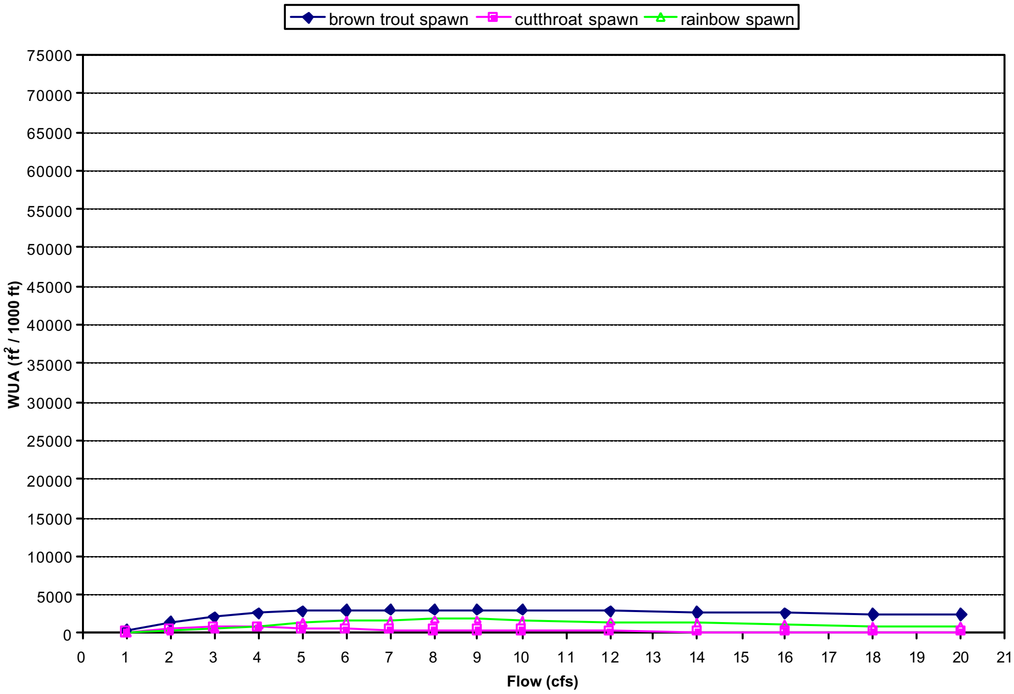
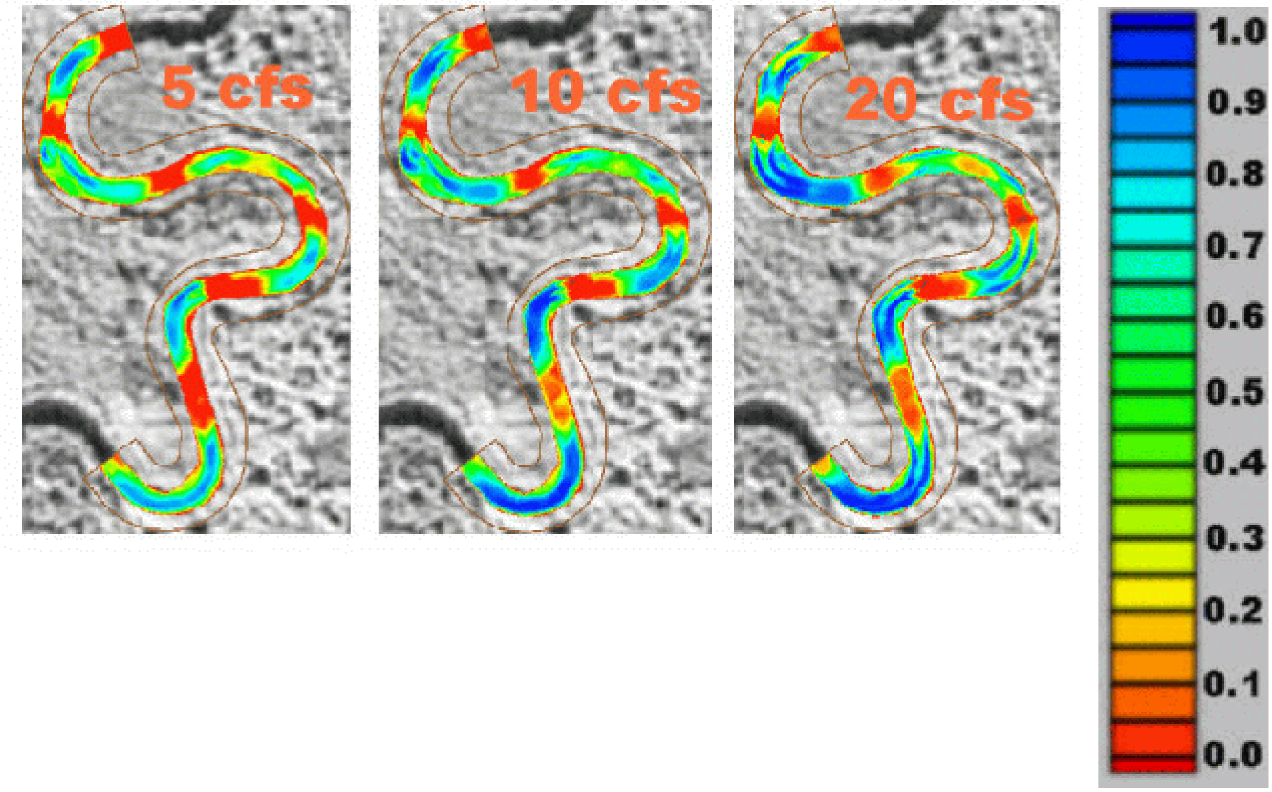


FIGURE 3.24. SITE 8E: TROUT SPAWNING - WUA VS. FLOW.

Site 8e

Image 3.7. Adult Brown Trout - Weighted Usable Area (Site 8e). The images below visually depict suitable habitat available to adult brown trout at discharges of 5, 10, and 20 cfs. The best habitat is represented by suitability of 1.0 (blue) and no habitat is represented by 0 (red).



3.1.3.3 WADING (FISHING)

The WUA's calculated for Reach 8e represent the total amount of suitable wading/fishing "habitat" (area) per 1,000 ft of stream. Figure 3.25 shows the WUA (ft2/1,000 ft) for fishing/wading recreational activities. t the modeled flows (1-20 cfs), >5,000 ft2/1,000ft of fishing/wading area is provided for recreationists.

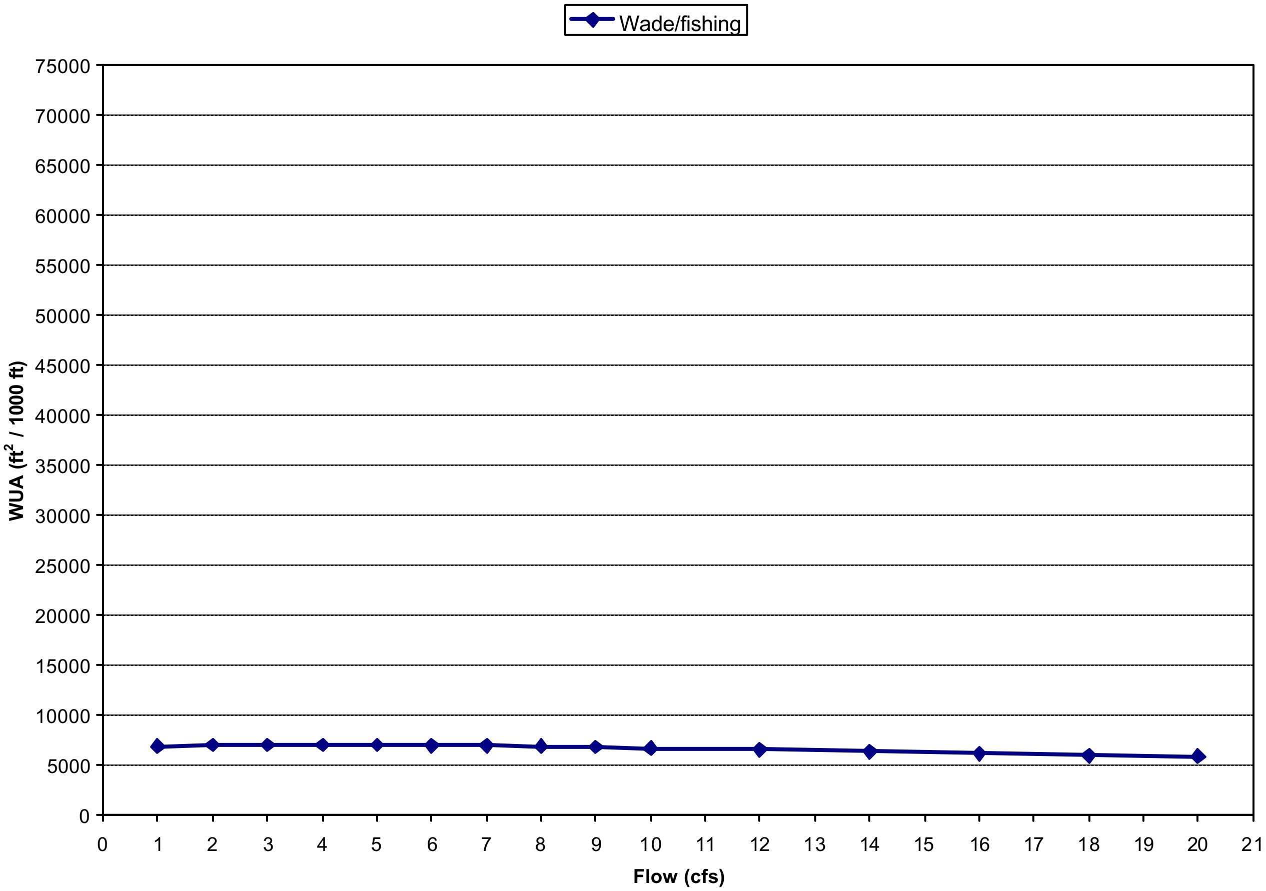


FIGURE 3.25. SITE 8E: FISHING - WUA VS. FLOW.

3.6 SITE 7

3.6.1 AQUATIC HABITAT - SITE 7

3.6.1.1 HABITAT NICHE MODELING

A habitat niche approach was used along with individual species/life stage HSI curves for assessing suitable habitat for Site 7. To represent habitat in entire river reaches, Site 7 results from the channel reach-scale habitat mapping were extrapolated to all of Reach 7. 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 (7) and the extrapolated reach, the results for the entire Reach 7 are discussed below.

Each WUA value calculated for Reach 7 represents the total amount of suitable habitat per 1,000 linear feet of stream. Figure 3.26 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 14,000ft^2/1,000ft of niche 1 habitat exists; it decreases rapidly (< 2,700ft^2/1,000ft) near 100 cfs. WUA for niche 1 remains below 2,500ft^2/1,000ft for all flows above 150cfs. 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. The WUA for this niche peaks at approximately 25 cfs with greater than 21,000ft^2/1,000ft and declines gradually at higher flows. Niches 2 (slow/shallow) 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. Unlike many of the downstream reaches, availability of niche 3 habitat in reach 7 does not closely mirror that of niche 5 (moderate/mid-depth); there is substantially more niche 5 habitat present at all discharges. The trend of niche availability is similar between the two categories, with a peak around 150 - 200 cfs and gradual decrease at higher flows, but the substantially higher values for niche 5 favors larger sportfish, including all trout and mountain whitefish adults and juveniles. Niche 3 provides suitable habitat for juvenile, fry, and spawning trout. In Reach 7, flows ranging from approximately 40 to 500 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, is relatively limited in Reach 7 with WUA increasing steadily with increasing flows to a peak of slightly over 2,300ft^2/1,000ft at approximately 900 cfs. The only species/lifestage documented in niche 6 habitat (fast/mid-depth) is the adult mountain sucker. As in most downstream sites, niche 6 habitat is the most abundant type, at higher discharges; niche 6 habitat increases dramatically to approximately 30,000ft^2/1,000ft at 500 cfs and a peak of >35,000ft^2/1,000ft. Niche 7 (moderate/deep) habitat is relatively abundant in Reach 7 (peak >4,000ft^2/1,000ft) compared with other reaches; 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 300 cfs to >28,000ft^2/1,000ft of WUA at 1,500 cfs.

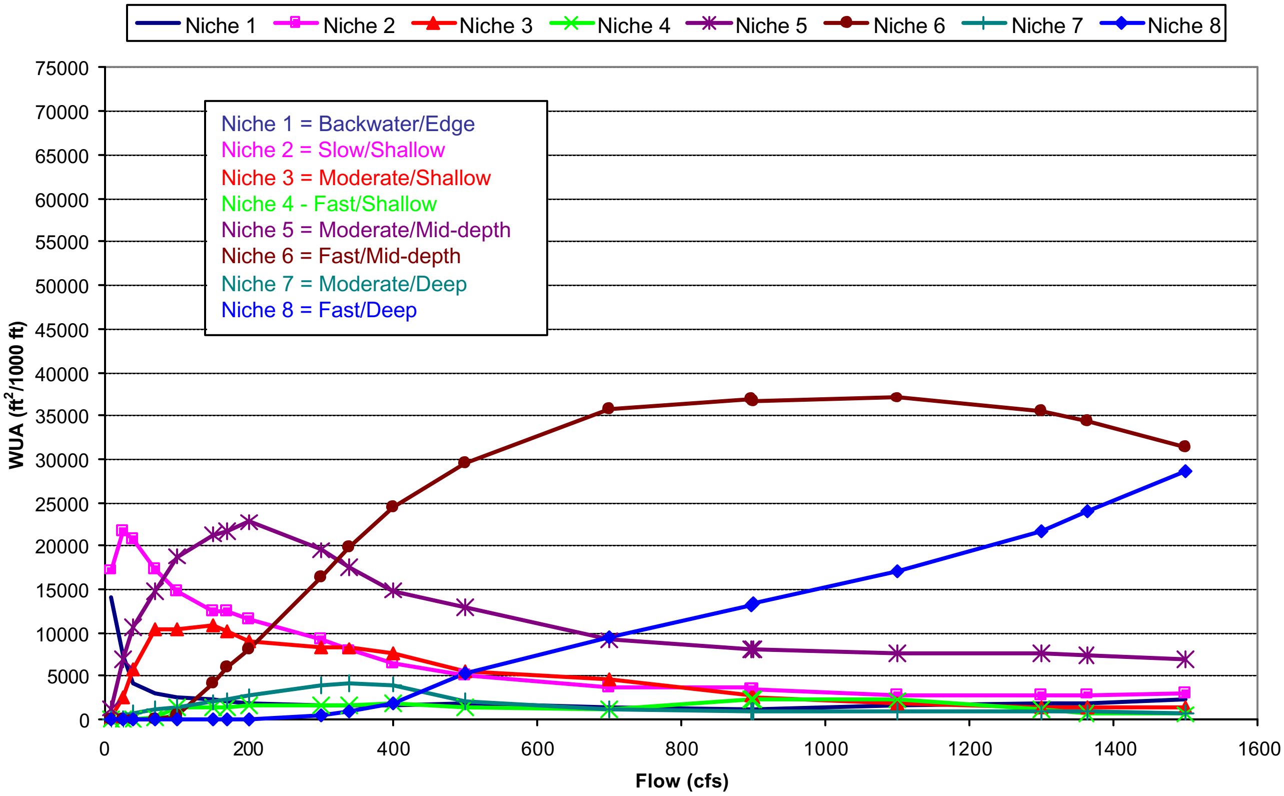
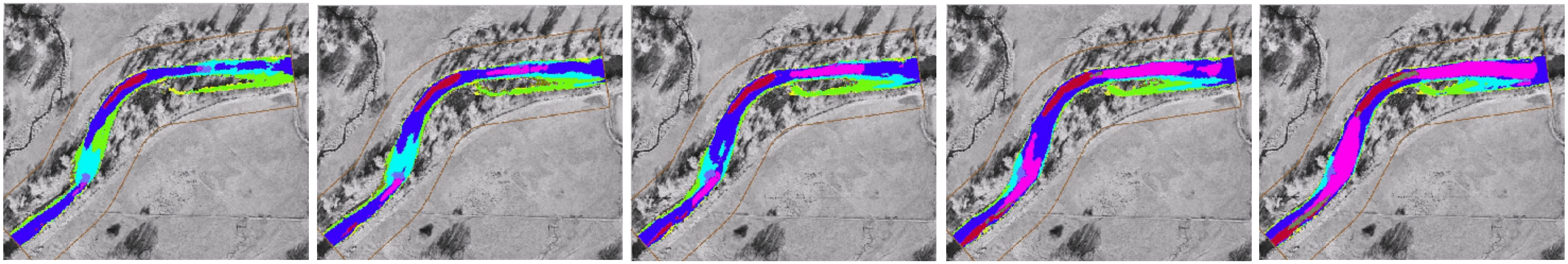


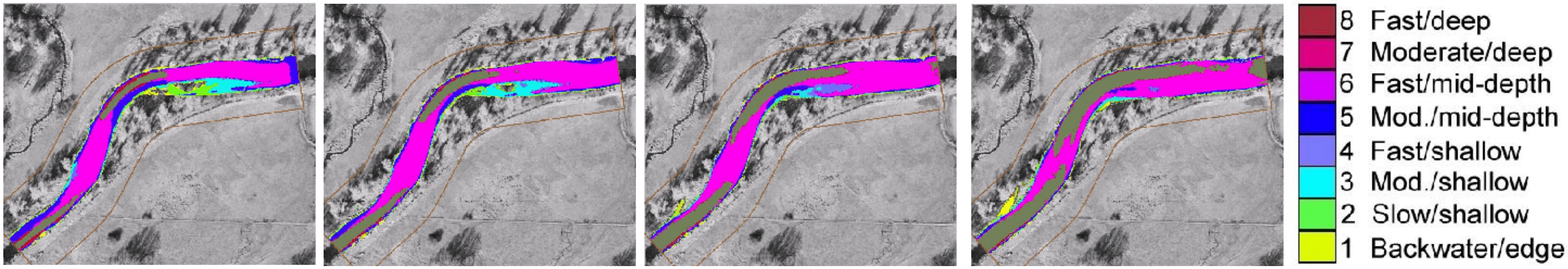
FIGURE 3.26. REACH 7: HABITAT NICHES - WUA VS. FLOW.

As evident in Image 3.8 and Figure 3.26, there is only approximately 2,600ft^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. At 500 cfs, niche 6 dominates (approx. 35,000ft^2/1,000ft); but a relatively even distribution exists among the other niche types (niche 5 is approx. 12,000ft^2/1,000ft; niches 2, 3, and 8 are approx. 5,000ft^2/1,000ft; and niches 1, 4, and 7 are near 2,000ft^2/1,000ft). Overall, the results of the habitat niche modeling at this site suggest that a relatively wide-range of habitat diversity is present in this reach (at flows below 400 cfs) despite channelization. At low flows (<40 cfs) a substantial amount of niches 1 and 2 exists, and while the niche 1 habitat decreases rapidly with increasing discharge, niche 2 habitat decreases more moderately. With this range of habitat diversity, a fish community that includes both natives and sportfish might be maintained; 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 3.8. Habitat Niches - Weighted Usable Area (Site 7). The images below depict habitat niches that are present at discharges of 100, 150, 200, 300, 400, 500, 700, 1100, and 1500 cubic feet per second. habitat niches are represented by the colors represented the legend.



100 cubic feet per second 150 cubic feet per second 200 cubic feet per second 300 cubic feet per second 400 cubic feet per second



500 cubic feet per second 700 cubic feet per second 1,100 cubic feet per second 1,500 cubic feet per second

3.6.1.2 HSI CURVE MODELING

Individual HSI curves for brown trout and "all trout" reveal similar trends compared with those for niche 5. Figure 3.27 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 approximately 25 and 400 cfs. The juvenile "all trout" and brown trout curves reveal a similar trend with the highest total between 25 and 400 cfs. As witnessed in all reaches, the results of the two juvenile categories differ slightly.

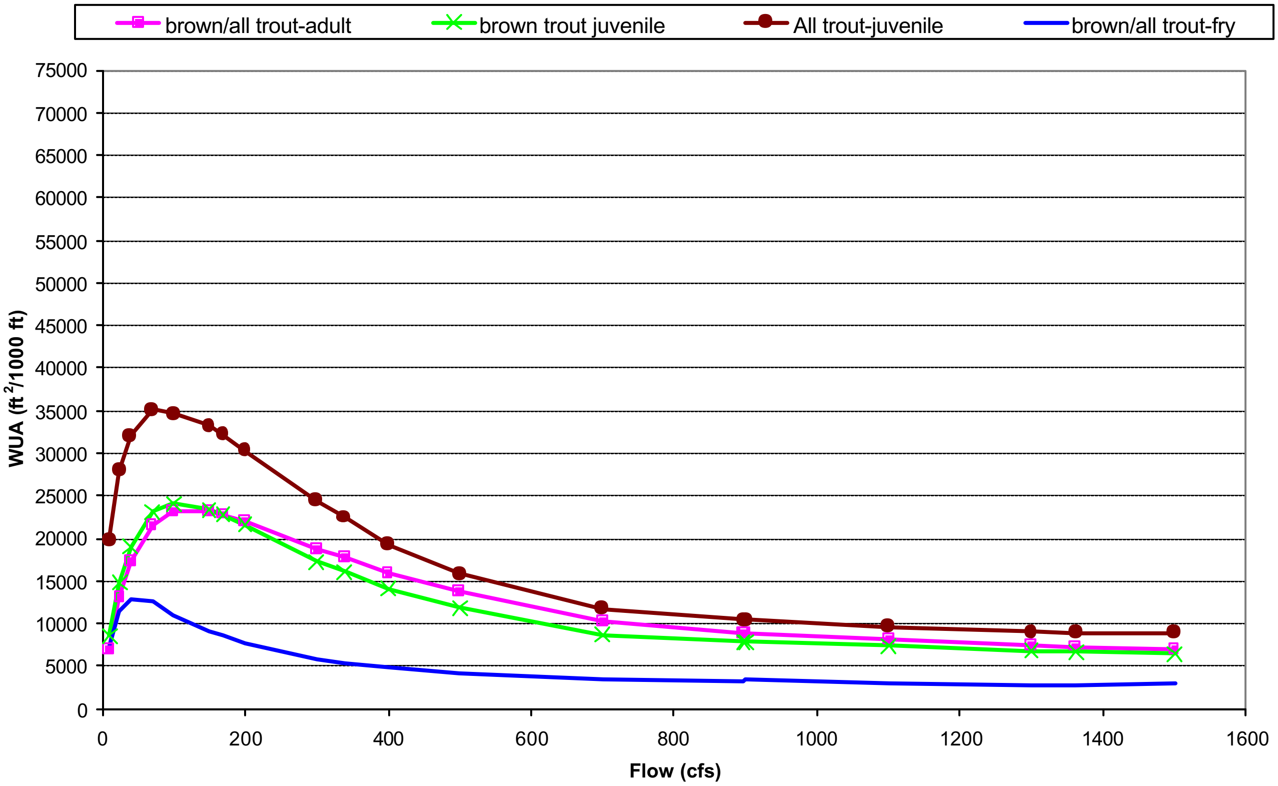
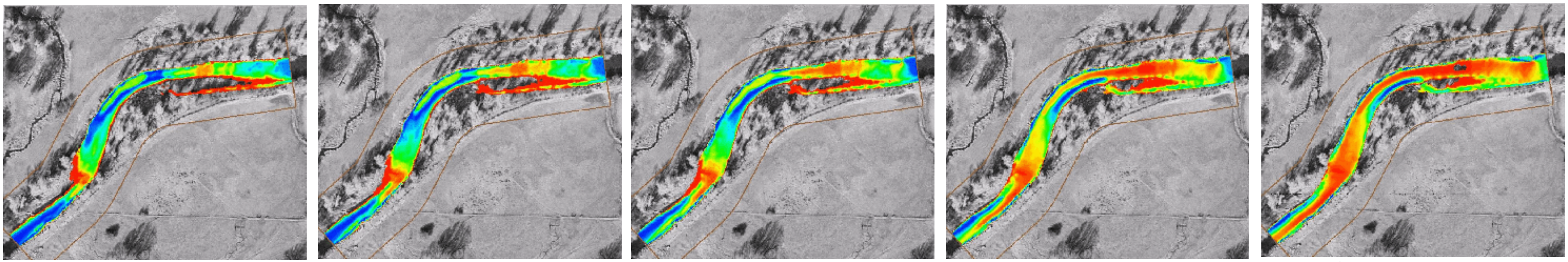


FIGURE 3.27. REACH 7: ADULT BROWN TROUT - WUA VS. FLOW.

As displayed in Image 3.9, 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. The majority of the main channel is not suitable at 500 cfs with WUA reduced by one half.

Image 3.9. Habitat Niches - Weighted Usable Area (Site 7). The images below depict habitat niches that are present at discharges of 100, 150, 200, 300, 400, 500, 700, 1100, and 1500 cubic feet per second. habitat niches are represented by the colors represented the legend.



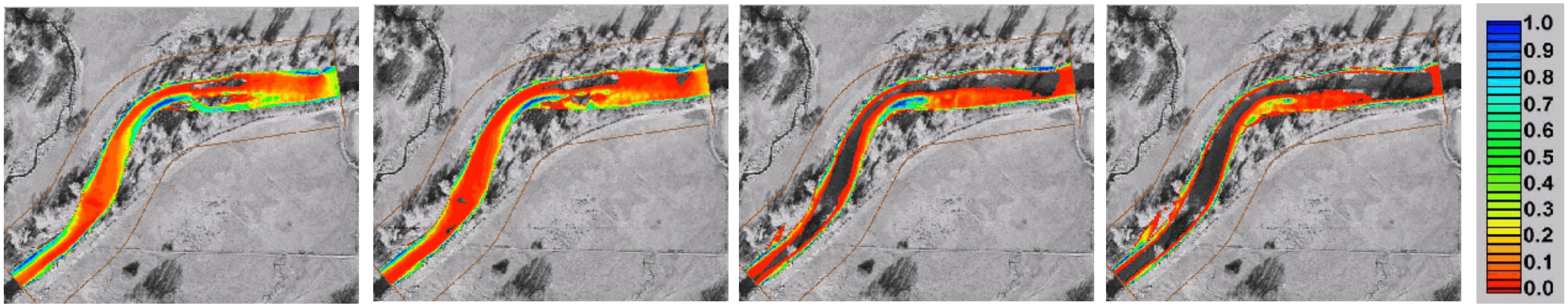
100 cubic feet per second

150 cubic feet per second

200 cubic feet per second

300 cubic feet per second

400 cubic feet per second



500 cubic feet per second

700 cubic feet per second

1,100 cubic feet per second

1,500 cubic feet per second

Figure 3.27 reveals that greater than 12,000ft^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 400 cfs. This study documents that the optimal range for fry habitat in Reach 7 is approximately 10 to 200 cfs. As flow increases above 100 cfs, trout fry habitat is reduced. Model runs demonstrate that there is minimal habitat available for brown and cutthroat trout spawning in Reach 7, but some habitat is available for rainbow trout (>5,000ft^2/1,000ft) between 70 and 300 cfs (Figure 3.28). The majority of trout in this reach were probably stocked directly or migrated from other reaches, but some potential exists for a sustaining rainbow trout population in this reach.

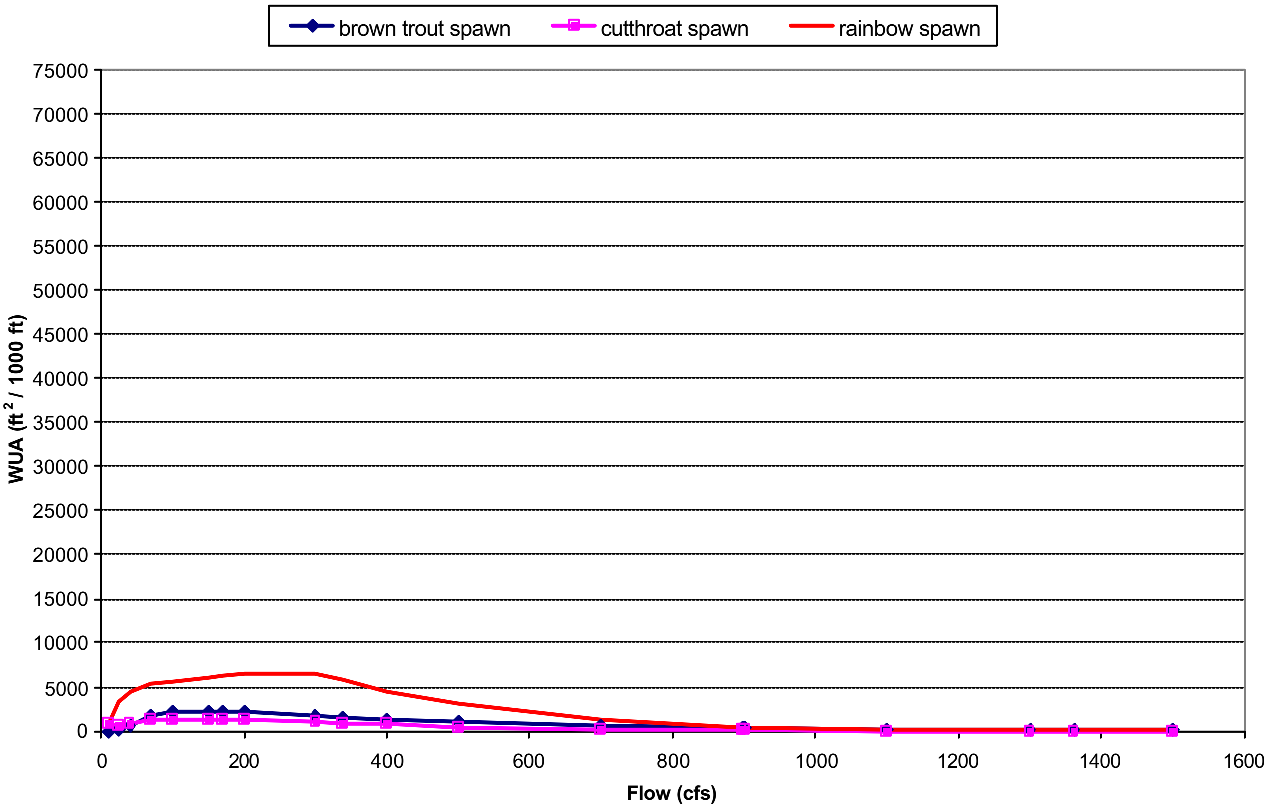


FIGURE 3.28. TROUT SPAWNING - WUA VS. FLOW

3.6.2 WATER TEMPERATURE- SITE 7

For this study, a thermistor was placed at Site 7 between April 25 and August 16, 2002. The following mean temperatures were observed during the study period.

April (25 - 30)	9.2°C
May	11.2°C
June	15.0°C
July	16.3°C
August (1 - 16)	15.4°C

The temperature data gathered from the thermistor was compared to flow data from USGS Station #10155500 (Provo River near Charleston) to assess thermal fluctuations relative to discharge variations in the Provo River. Figure 3.29 shows the temperatures and flows recorded over the study period.

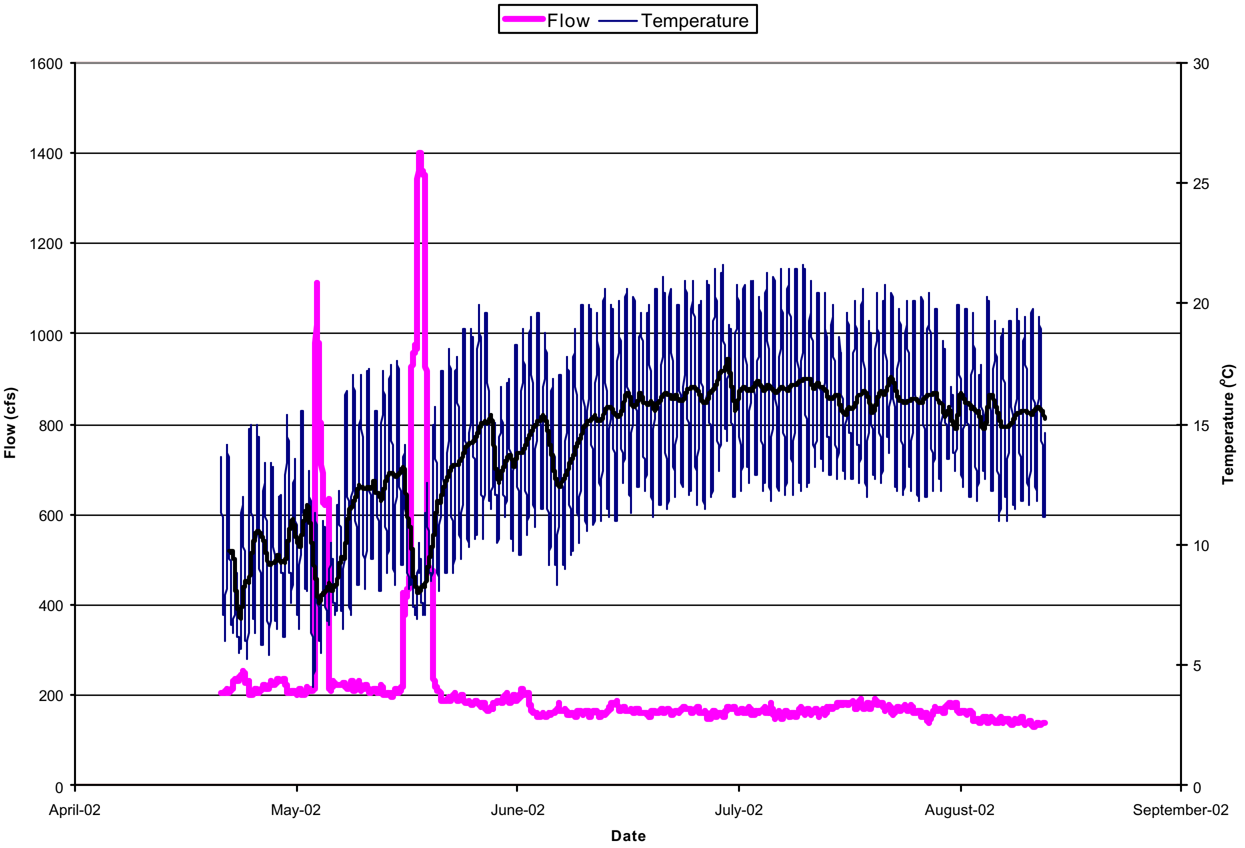


FIGURE 3.29. REACH 7: TEMPERATURE AND FLOW. THE DARK LINE RUNNING THROUGH THE CENTER OF THE INSTANTANEOUS 15-MINUTE TEMPERATURE VALUES IS THE 24-HOUR AVERAGE TEMPERATURE.

Two hydrographic spikes (associated with study releases) occurred during the study period in which the flow increased from just over 200 cfs to 1,100 cfs in about 3.5 hours on May 8 and then rose gradually from 220 cfs to 1,400 cfs over a three-day period from 20-22 May. The descending limb of the hydrograph for both events lasted three days. The first event dropped the mean water temperature from 10.5 to 7.7°C and the minimum temperature from 8.0 to 4.1°C. Similarly, the second spike in flow dropped mean water temperature from 11.5 to 8.6°C and minimum temperature from 9.1 to 7.4°C. In both instances, lower temperatures persisted for about three days. Daily water temperature fluctuation was also lower during both events but remained above 2.5°C at all times, compared to 7.8°C on average during the study. After the second event, flows were maintained near 200 cfs until June 6, then dropped to about 150 cfs and maintained around this level through the end of the study period. There was a general trend of increasing maximum daily water temperatures from the beginning of the study period to a peak in the middle of July, after that, maximum daily temperatures gradually decreased. The daily water temperature fluctuation varied throughout the study period, but generally remained near the mean; no trend of increasing or decreasing fluctuation was observed. The lowest water temperature measured during the period was 4.1°C - during the first flow increase - and the maximum was 21.6°C, which occurred on July 13.

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 7 of the Provo River.

3.6.3 RECREATIONAL USABILITY-SITE 7

3.6.3.1 WADING/FISHING

The WUAs calculated for Reach 7 represent the total amount of suitable wading/fishing "habitat" (area) per 1,000 ft of stream for the entire reach. Figure 3.30 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 400 cfs, usable wading area within this site declines to below 25,000ft^2/1,000ft.

3.6.4 SEDIMENT TRANSPORT - SITE 7

3.6.4.1 SAMPLING RESULTS

Bedload samples were collected during the 2002 and 2003 spring runoff. Very little bedload material moved during the 2002 spring runoff at Bridge 7 and the material in transport was dominated by sand-sized particles at all sampled flows (Plate 3.3a). At 357 cfs, bedload was limited to fine-grained sand intermixed with organic material (Figure 3.31a). At this flow, small and medium sized organic material became entrained, thus loosening or freeing a small amount of sand that had been stored behind this semi-anchored organic material. The same composition of sand intermixed with organic material was moving at 854 cfs. The quantity of sand and organic material in transport increased significantly at this higher flow even though there was still no gravel movement. Small gravel became mobile along with increased amounts of sand and organic material at 1,342 cfs.

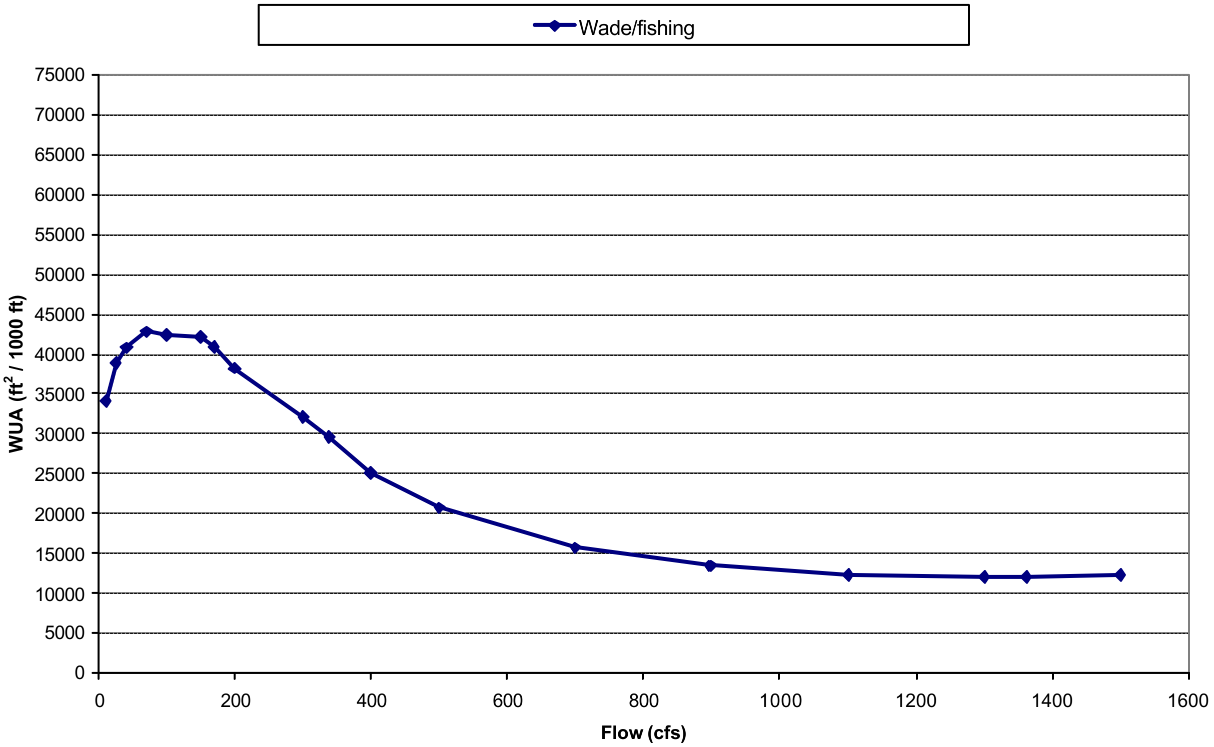


FIGURE 3.30. REACH 7: FISHING - WUA VS. FLOW.

As with Site 8, Site 7 showed no obvious transition between phase I and phase II transport. The magnitude and duration of high flows available for this study was limited in 2002 because of the drought conditions (Figure 2.2). It would be necessary to sample bedload at Bridge 7 for a longer duration and possibly at higher flows to observe shifts in bedload transport that indicate phase shifts and/or supply limitations.

As with Site 8, we were able to sample bedload transport at Site 7 during the 2003 spring runoff. We were fortunate enough to have slightly higher flows with a longer peak flow duration. The peak flows were approximately 12% greater in 2003 (1,400 cfs instead of 1,250 cfs). More importantly, the duration of peak flows were maintained 3 times longer in 2003 (3 days) compared to the sharp peak (1 day) and rapid receding limb in 2002 (Figure 2.2). The 2003 hydrograph shows a more gradual receding limb as per recommendations made by the Utah Reclamation Mitigation and Conservation Commission.

Bedload samples were collected at Site 7 during the 2nd and 3rd when flows were maintained near 1,400 cfs. As with 2002, the material in transport was dominated by sand-sized particles at the beginning of the high flows. However, there was a transition of bedload materials from sand-dominated particles into a mixture of sand- and gravel-sized particles which lasted until flows were dropped (Plate 3.3b and Figure 3.31b).

SITE 7

357 cfs

854 cfs

1,342 cfs

PLATE 3.3A. PHOTOGRAPHS OF BEDLOAD SAMPLES COLLECTED AT BRIDGE 7 DURING 2002 SPRING RUNOFF.

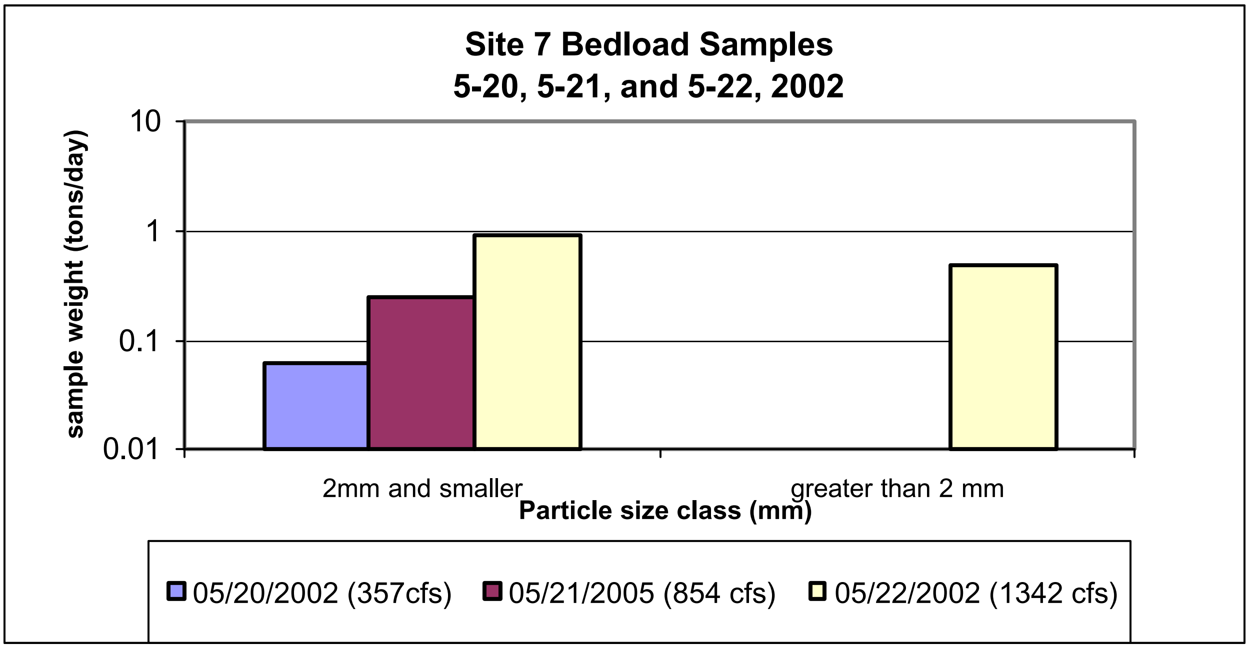


FIGURE 3.31A. BEDLOAD SAMPLING DATA BROKEN INTO SAND AND GRAVEL SIZED PARTICLES COLLECTED AT SITE 7 DURING THE 2003 SPRING RUNOFF.

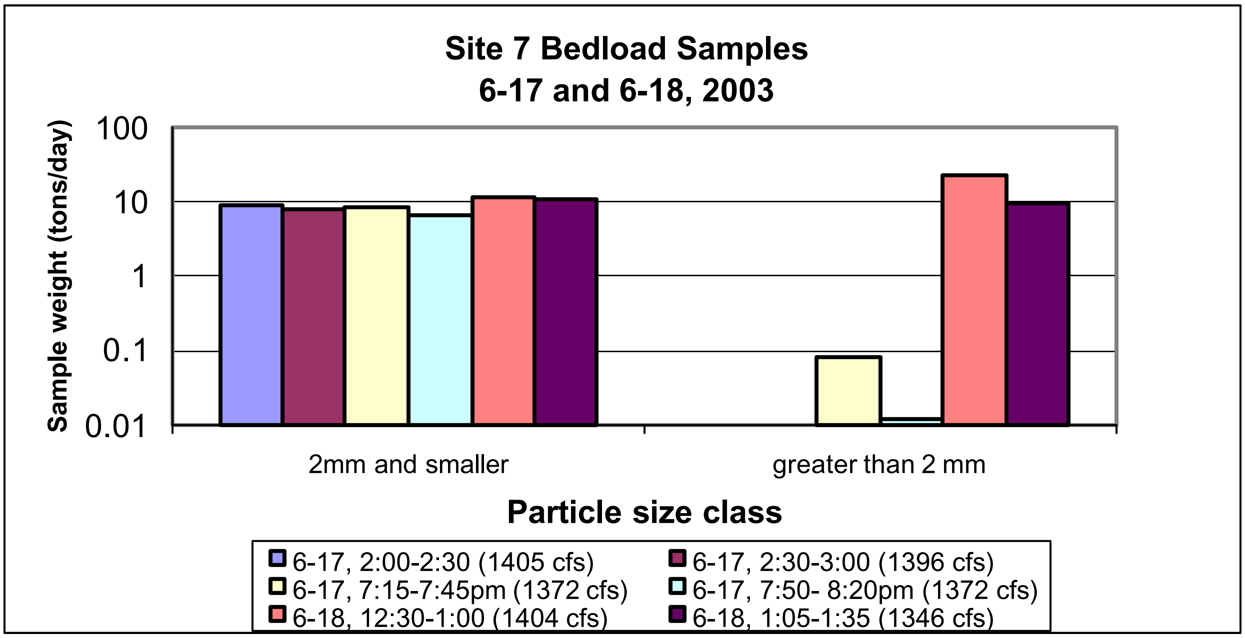
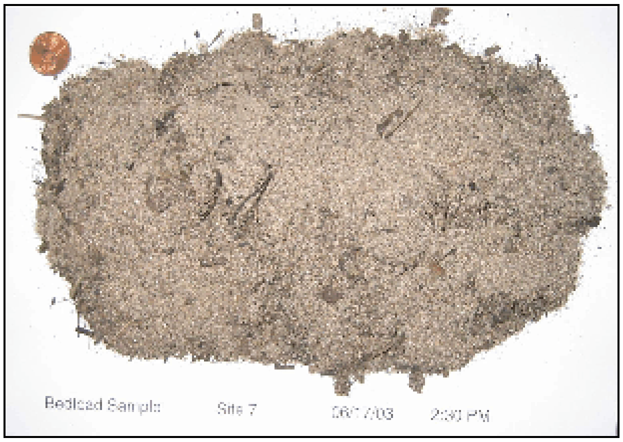


FIGURE 3.31B. BEDLOAD SAMPLING DATA BROKEN INTO SAND AND GRAVEL SIZED PARTICLES COLLECTED AT SITE 7 DURING THE 2ND AND 3RD DAYS OF 1,400 CFS PEAK FLOWS IN 2003.

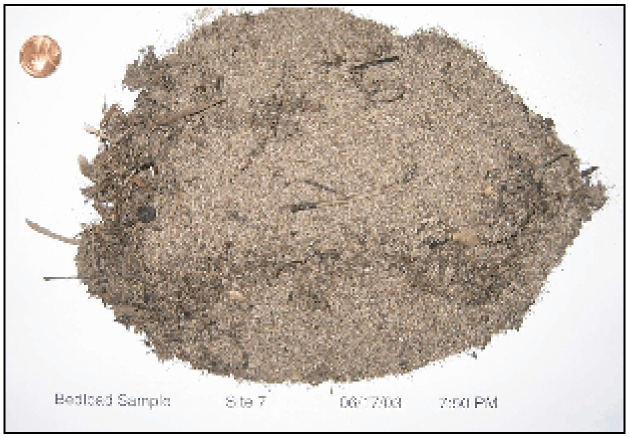
SITE 7

1400 cubic feet per second



1400 cubic feet per second

1384 cubic feet per second



1384 cubic feet per second

1362 cubic feet per second

1354 cubic feet per second

PLATE 3.3B. PHOTOGRAPHS OF BEDLOAD SAMPLES COLLECTED AT BRIDGE 7 DURING SPRING 2003 RUNOFF.

3.6.4.2 MODELING RESULTS

The streambed particle sizes at Site 7 are dominated by large-sized cobbles ranging from 64-256 mm in diameter (Table 3.1). Even though this is a relatively flat section of the river (0.7% slope), there are very few sand- and gravel-sized particles in the streambed at Site 7. In fact, less than 12% of the bed surface is covered in particles smaller than 64 mm (Figure 3.7). Site 7 is relatively straight, highly channelized with riprap banks. Mining of the smaller sized particles from the bed over the past 50 years (since channelization) has apparently disrupted any sense of sediment flux equilibrium at Site 7.

Previous bedload calculations using the Meyer-Peter Mueller (1948) equation at Site 7 predicted no bedload transport until flows exceeded 2,300 cfs based on the measured D_{50} (108 mm). A hypothetical smaller sized D_{50} (70 mm) was originally used to accommodate modeling objectives using the Meyer-Peter Mueller (1948) equation. As with Site 8, the Parker (1990) equation was found to be more accurate at Site 7, and was therefore used to model bedload transport. One interesting detail is that the Parker (1990) equation uses a lower dimensionless shear stress value in its computation, and therefore predicts bedload transport at Site 7 for the actual D_{50} at lower flows (shear stress) than the Meyer-Peter Mueller (1948) equation. As a result, the measured D_{50} was used to model bedload transport at Site 7.

The bedload rating curve for Site 7 is shown in Figure 3.31c. Due to relatively low channel slope and coarsened bed, particles 108 mm in diameter are not predicted to begin moving until approximately 1,440 cfs. The channel is narrow yet somewhat flat (low water surface slope) through this site producing relatively low shear stress values. These conditions keep the predicted transport rates low at Site 7. As shown in Figure 3.31c, the modeled results do not fit well with the bedload samples collected near Site 7. This discrepancy may be caused by some of the hydraulic dissimilarities between the two cross sections. Although the entire area around Site 7 has been channelized, the bedload samples were collected at an upstream bridge in a depositional zone above a diversion structure.

The suspended sediment rating curve for the Midway water quality monitoring site (Figure 3.9) was used to model suspended sediment transport at Site 7. A comparison of Figures 3.31c and 3.9 for Site 7 indicates that suspended sediment constitutes nearly 100 percent of the sediment load.

3.6.4.3 EFFECTIVE DISCHARGE RESULTS

Effective discharge calculations show a dominant range of flow between 1,800-2,000 cfs have transported the greatest amount of bedload sediments at Site 7 over the previous 5 years (Figure 3.31d). Total loads were predicted to be much smaller at Site 7 than Site 8 due to the relatively flat channel at Site 7. Flows rarely exceed 2,000 cfs under the new “post Jordanelle” flow regime (Appendix C). Overall, effective discharge calculations at Site 7 probably reflect channel size and substrate characteristics that formed prior to construction of Jordanelle Dam. Because the bed is mostly immobile at Site 7, the channel will likely adjust (narrow) slowly from the reduced peak flows under the post Jordanelle flow regime, and effective discharge will likely decrease over time.

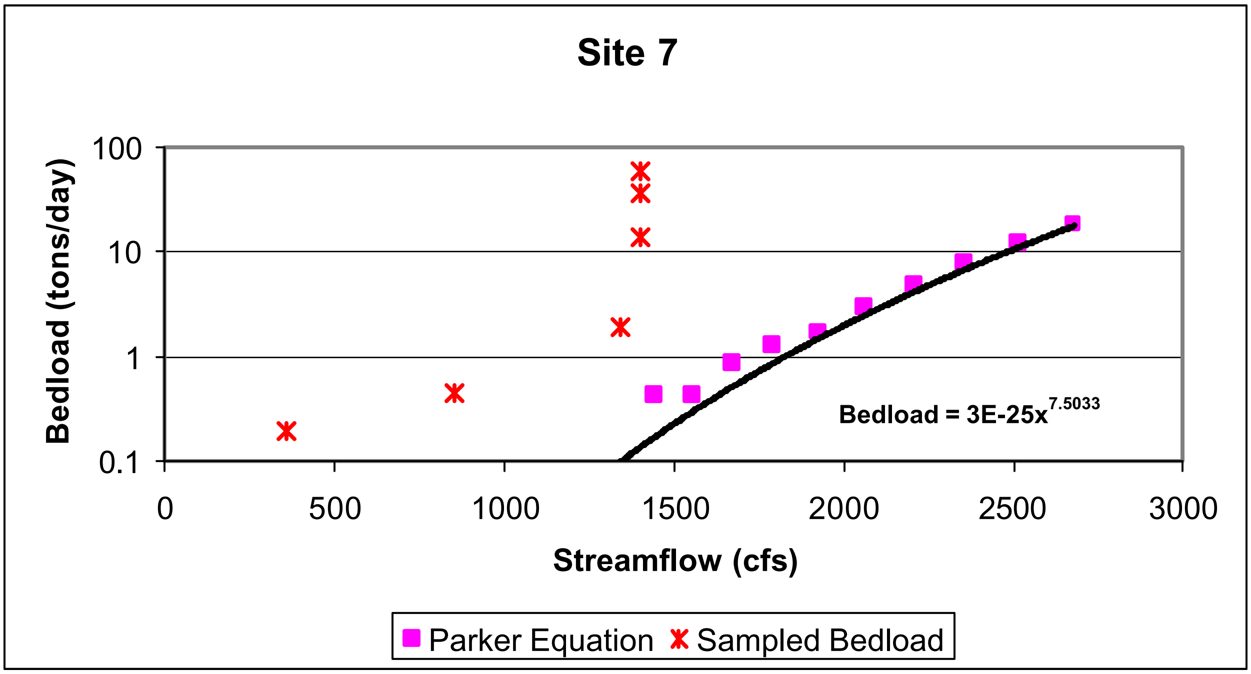
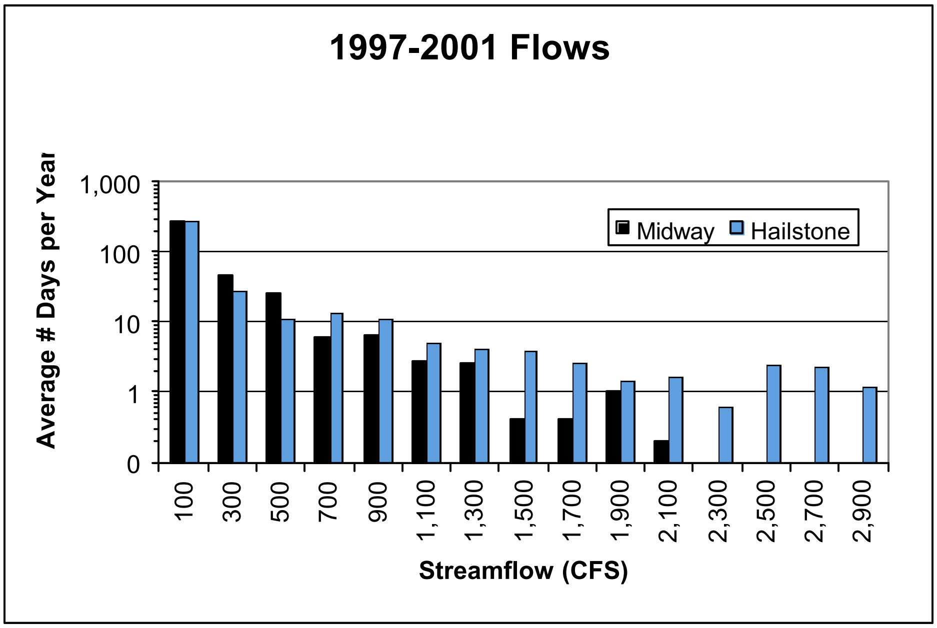


FIGURE 3.31C. PARKER (1990) BEDLOAD RATING CURVE AT SITE 7. THE POWER EQUATION (TRENDLINE) IS SHOWN ON THIS GRAPH BECAUSE IT WAS USED FOR EFFECTIVE DISCHARGE CALCULATIONS.

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 Site 7 (Figure 3.32). Equations shown in Figures 3.9 and 3.31c defining the suspended sediment and bedload rating curves, respectively, were applied to post Jordanelle average daily flows (water years 1997 to 2001) for the "unregulated" (Hailstone) and regulated (Midway) gauges (see Appendix C for details). The results of this analysis show that daily sediment loads have been dominated by suspended sediment at Site 7 with only small spikes of bedload transport during the peak of spring runoff. Further analysis show that bedload transport does not occur every year at Site 7, and on average only lasts for a single day.



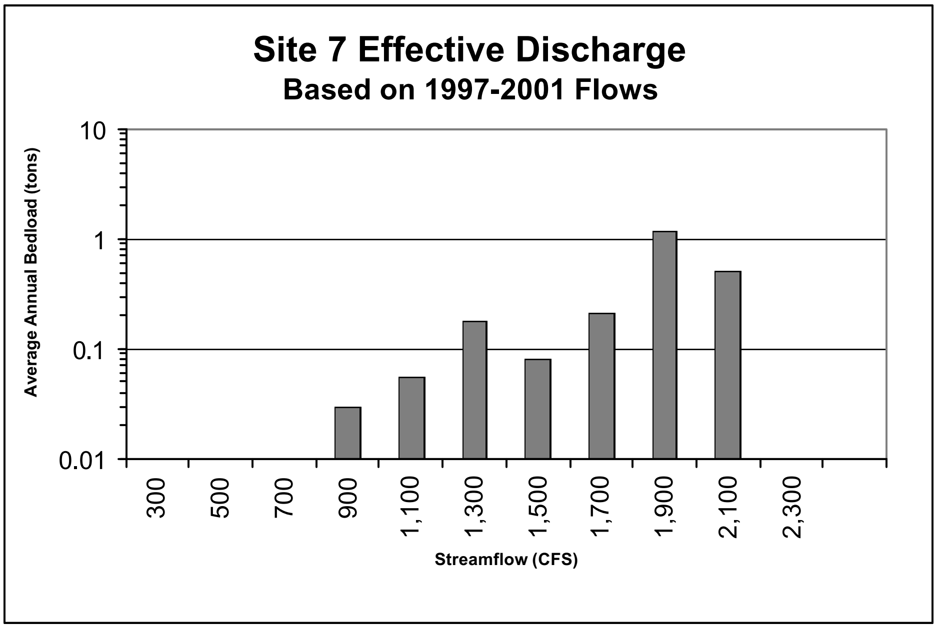


FIGURE 3.31D. EFFECTIVE DISCHARGE RESULTS FOR SITE 7. THE UPPER GRAPH SHOWS THE AVERAGE NUMBER OF DAYS PER YEAR FROM 1997-2001 THAT STREAMFLOW HAS BEEN WITHIN EACH 200 CFS INCREMENT (0-200, 200-400, ETC.). THE LOWER GRAPH APPLIES THE MODELED BEDLOAD TRANSPORT RATE AT SITE 7 (FIGURE 3.31C) MULTIPLIED BY THE NUMBER OF OCCURRENCES TO DETERMINE THE INCREMENT OF FLOW THAT TRANSPORTS THE MOST BEDLOAD SEDIMENT OVER THE PERIOD OF RECORD.

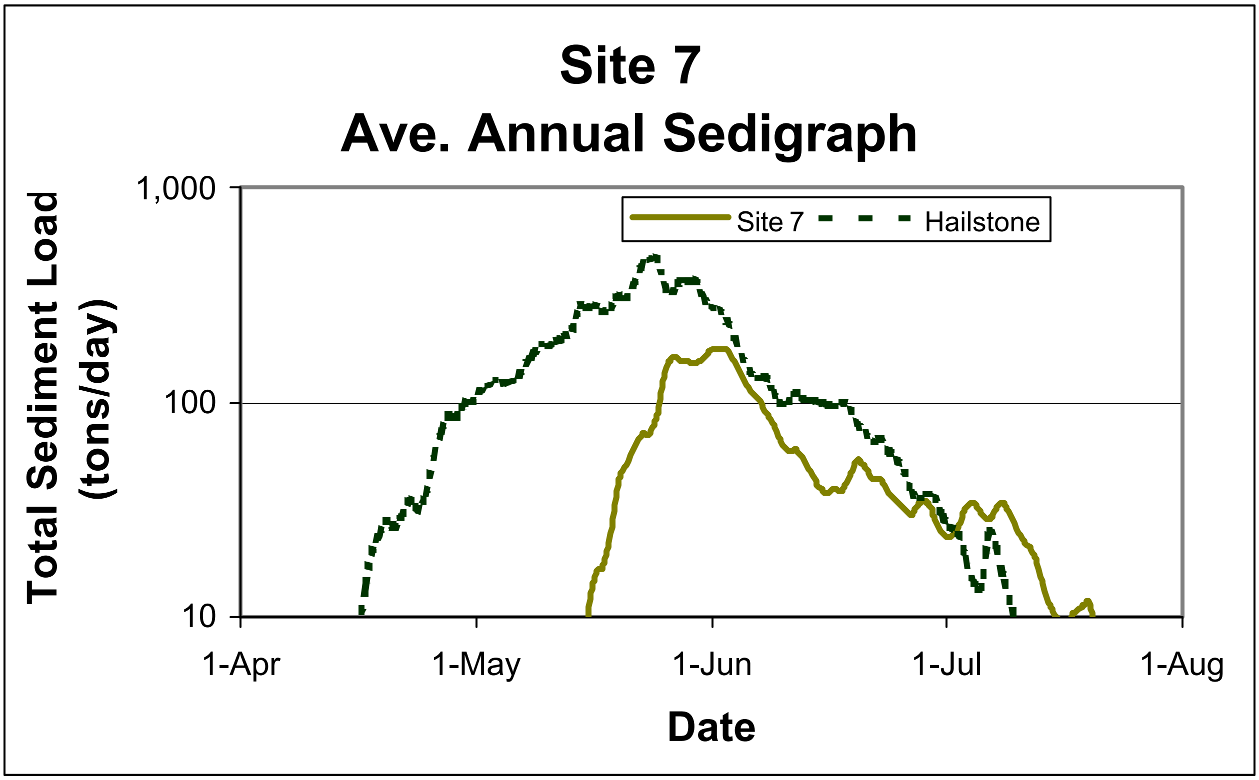


FIGURE 3.32. TIMING, MAGNITUDE AND DURATION OF SEDIMENT TRANSPORT FOR AVERAGE DAILY FLOWS OVER THE PAST 5 YEARS (1997-2001) AT SITE 7 (MIDWAY GAUGE). THE HIGHER CURVE REPRESENTS THE PREDICTED ADJUSTMENT IN SEDIMENT TRANSPORT USING SITE 7'S RATING CURVES WITHOUT THE INFLUENCE OF FLOW REGULATION BY JORDANELLE DAM (HAILSTONE GAUGE).

The rising limb of peak sediment transport occur much later at Site 7 than Hailstone. As with Site 8, daily sediment transport rates are much lower at Site 7 during the majority of spring runoff except the very tail end (July 1-15) when suspended sediment loads remain relatively high. It is apparent that channel maintenance flows (high sediment transport rates) at Site 7 have been reduced significantly, with peak daily sediment loads reduced from 465 tons/day to just 175 tons/day.

Flow duration curves (Figure 3.12) were used to calculate total annual sediment loads for Site 7 based on the regulated (Midway) and unregulated (Hailstone) flow regimes. The total annual sediment load for Site 7 is 3,976 tons. However, the total annual sediment load using the unregulated flow data is approximately 12,027 tons (over 3 times greater than Site 7). This differential reflects the recent drop in peak flows at Site 7 since the construction of Jordanelle Dam. It is fortunate that the channelized portions of the Middle

Provo River will be reconstructed and restored to establish a dynamic equilibrium with the new regulated flow regime.

The balance between bedload and suspended sediment varies significantly between the two flow regimes. Although suspended sediment makes up the majority of the annual sediment load under both regimes, the proportion of bedload compared to suspended sediment load is much higher using the unregulated flow regime (8.578%) than the regulated flow regime (0.003%). Peak flows simply do not get high enough below Jordanelle Dam since 1997.

3.6.5 RIPARIAN VEGETATION - SITE 7

A detailed riparian recruitment model was not developed for Site 7. Therefore, a more qualitative approach was used to assess the potential for cottonwood recruitment at Site 7 based on general criteria for recruitment success. 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):

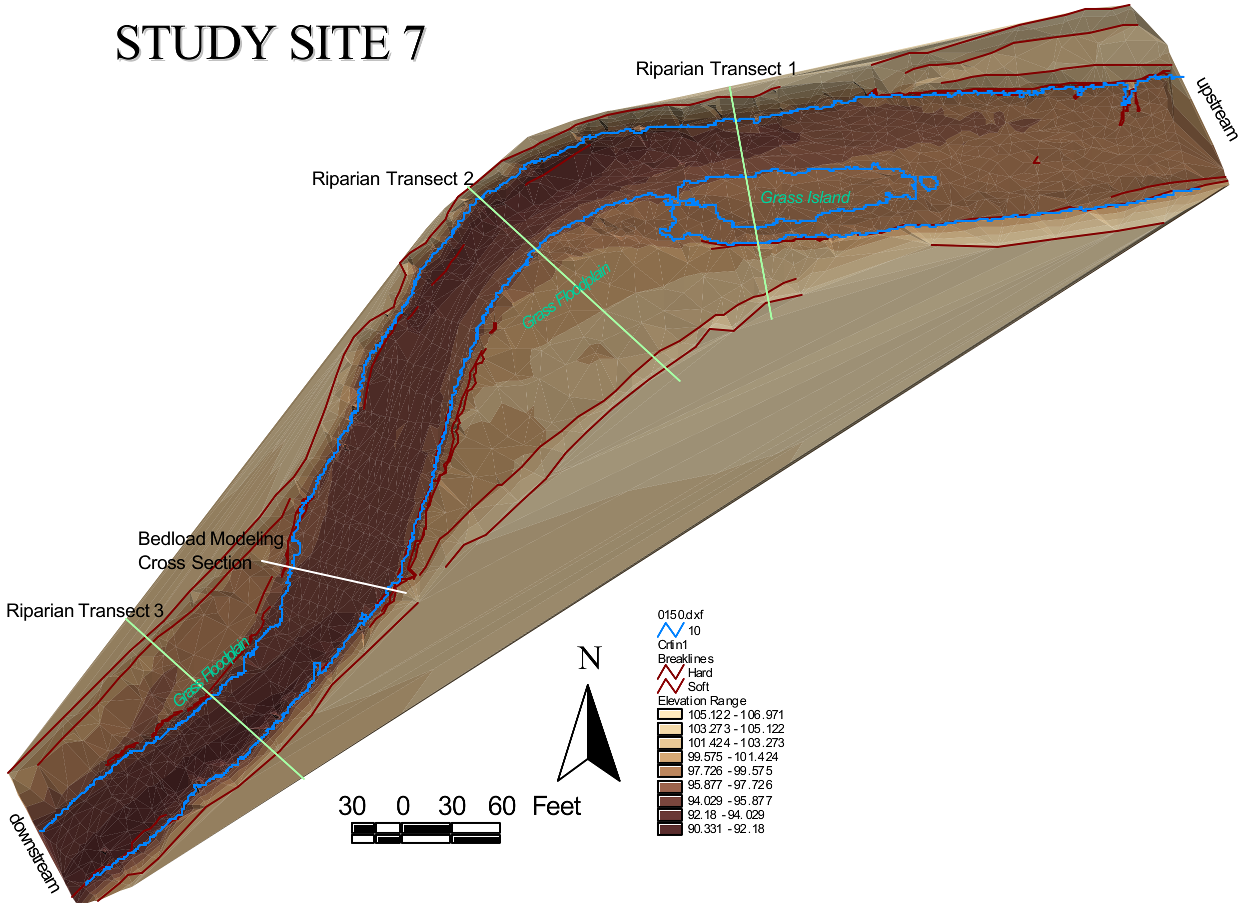
1. presence of a bare surface with freshly-deposited sediments at the time of seed dispersal
2. transport and deposition of seeds onto the surface
3. post-germination decline in water levels at a rate slow enough that seedlings do not dessicate
4. absence of post-germination floods that would scour seedlings

Unlike Site 8, Site 7 is constrained by levees built to protect farmland on both sides of the river. 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 7 does meander slightly, and vegetated floodplain areas are present on the insides of the bends on river right (facing downstream) at the downstream end of the site and on river left in the middle portion of the site (Map 3.2). On the outer sides of these bends, banks are tall and steep, and rip rap has typically been placed to protect the streambank (Plate 3.4). On both sides of the stream the area beyond the top of the banks/levees consists of pasture land.

3.6.5.1 TRANSECT RESULTS

Within Site 7, three transects spanning riparian establishment surfaces were selected to evaluate the relationships between streamflow and riparian characteristics (Map 3.2). These transects are plotted in Figure 3.33 along with the range of flows that inundate the different establishment surfaces.

MAP 3.2. MAP OF STUDY SITE 7 SHOWING RIPARIAN TRANSECT AND BEDLOAD MODELING CROSS SECTION LOCATIONS. BLUE LINES INDICATE WATER'S EDGE AT LOW FLOW.



SITE 7

PLATE 3.4. PHOTOS OF SITE 7 RIPARIAN SURFACES. (A) AND (B): UPSTREAM VIEWS OF SURFACES CROSSED BY TRANSECT 1; (C): VIEW OF FLOODPLAIN ON RIVER LEFT CROSSED BY TRANSECT 2; (D): DOWNSTREAM VIEW OF SURFACES CROSSED BY TRANSECT 3.

The left boundary of Transect 1 consists of a steep levee occupied by mature cottonwood trees and grass. Transect 1 then crosses a grass floodplain surface and grass-covered mid-channel bar/island feature (Plate 3.4, Figure 3.33). The steep right bank at Transect 1 is occupied by shrub vegetation (willows). Significant inundation of the mid-channel island surface occurs at flows of 900 cfs, and the island is completely inundated by flows of 1,100 cfs and greater. Water stage at the highest modeled flow of 1,500 cfs is not high enough to inundate the grass floodplain area present on river left (Figure 3.33); however, higher flows on the order of the 10-year flood (estimated at 2,086 cfs, see Appendix C) would most likely inundate the lower portions of the floodplain surface. The upper portion of the floodplain and the forested levee are unlikely to be inundated under the current hydrologic regime since the maximum potential Jordanelle Dam release is 2,500 cfs (70 cms) (Stromberg et al. 1999).

Transect 2 crosses the same forested levee and river-left floodplain surface as Transect 1, but at a wider location (Map 3.2, Plate 3.4). The right bank at Transect 2 is steep and leveed and consists of rip rap and sparse willows. As with Transect 1, no vegetation is present on surfaces lower than the 150 cfs flow level. Based on analysis of flow data at the Midway gage, flows of 150 cfs are equaled or exceeded 45% of the time. However, because Site 7 is downstream from the Midway gage (Map 1.3) and gains flow from groundwater and tributary inputs below the gage, the actual duration of the 150 cfs flow level may be somewhat higher.

A break in slope is evident at the 500 cfs flow level at Transect 2 (Figure 3.33). Based on the Midway gage data, flows of 500 cfs are equaled or exceeded 8% of the time. Based on peak flow analysis, the 1-year flood at the Midway gage is 589 cfs (Appendix C). Although no change in vegetation composition occurs at this flow level, the break in slope is geomorphically indicative of a frequent/ "ordinary" high flow level.

The highest modeled flow of 1,500 cfs partially inundates the river left floodplain surface at Transect 2 (Figure 3.33). As with Transect 1, it appears that even maximum Jordanelle flow releases of 2,500 cfs would not completely inundate the full width of the floodplain. Prior to dam construction, however, the full width of the floodplain was probably inundated on a relatively regular basis: the 2-year flood at the Hailstone gage, which is not affected by dams, is 3,208 cfs, and the 10 year flood is 3,835 cfs (Appendix C). Under the post-Jordanelle Dam hydrologic regime at Site 7, the upper portion of the floodplain surface now functions as an inactive terrace, and the lateral extent of the active floodplain has narrowed. The reduced magnitude of infrequent flood events may ultimately lead to changes in riparian vegetation patterns at Site 7.

Transect 3, located near the downstream end of Site 7, crosses a grass floodplain surface on river right (Plate 3.4). The right boundary of Transect 3 consists of a levee occupied by mature cottonwood trees and willows, and on river left the bank is steep, leveed, and rip-rapped. As with the other transects, vegetation at Transect 3 extends down to the 150 cfs flow level (Figure 3.33). As with Transect 2, a break in slope is evident at the 500 cfs flow level at Transect 3, suggesting that this is a common high flow level. Grass vegetation is present both above and below this break in slope.

A topographically low area within the river right floodplain is present just downstream from Transect 3 (Map 3.2). This area begins to be inundated by backwater from the main channel at flows of approximately 900 cfs and higher, and the backwater extends up to the area crossed by Transect 3 at flows of 1,100 cfs and greater (Figure 3.33). Therefore, although the floodplain at Transect 3 is not completely overtopped at the highest modeled flow of 1,500 cfs, much of the surface is inundated due to the downstream backwater. Flows on the order of the 10-year flood (2,086 cfs) would likely be sufficient to overtop the high point (at about 90 foot distance in Figure 3.33) of the river right floodplain surface at this location; however, these flows would probably not be high enough to extend all the way to the forested levee on far river right. Therefore, as with the river left floodplain crossed by Transects 1 and 2, the upper portion of the Transect 3 floodplain has become an inactive terrace under the post-Jordanelle Dam hydrologic regime.

3.6.5.2 COTTONWOOD RECRUITMENT POTENTIAL

Several fluvial surfaces are present within Site 7 that could serve as potential cottonwood recruitment sites; however, these sites are relatively limited in extent. At Transect 1, the grass-covered island is inundated by regularly-occurring high flows, and therefore deposition of fresh sediments that would provide germination substrate is possible. The presence of the left side channel, where water remains at a higher stage than in the main channel, would help prevent dessication of any seedlings that establish on the island. At a maximum recession rate of 0.016 ft/day, flows would need to recede gradually from 900 cfs (the flow level at which the island is almost entirely inundated) to 150 cfs over a period of 31 days. Although 2002 flows at the Midway gage dropped from 1,060 cfs to 128 cfs in only 18 days, 31 days would not be an unrealistically-long recession period, especially in wetter water years. Therefore, it appears that the island surface at Transect 1 would potentially meet recruitment requirements 1 through 3 (listed above in Section 3.1.5.2 of this report). However, it may be difficult to meet requirement 4 on this surface, because any seedlings that establish would be susceptible to scour by future floods. The 2-year flood event is 1,284 cfs (Appendix C), which is a flow level that inundates the island to a depth that may induce scour (Figure 3.33). This may account for the absence of newly-recruited cottonwoods on this surface.

The broad grassy floodplain surface on river left (crossed by both Transects 1 and 2) also provides a potential cottonwood recruitment surface. At Transect 2, a portion of this surface about 25 feet wide is inundated at the 1,500 cfs flow level (Figure 3.33), providing a potential location for sediment deposition/provision of germination substrate (meeting recruitment requirement 1). The existing mature cottonwoods present along the levees at Site 7 should provide an adequate seed supply for dispersal by wind and water (meeting recruitment requirement 2). However, any seedlings that were to establish on the floodplain would be subject to dessication. To meet the 0.016 ft/day threshold (requirement 3), flows at Transect 2 would have to gradually decline from 1,100 cfs to 150 cfs over 146 days. Under current dam operations, it is unlikely that flows would ever recede this slowly, except perhaps during an unusually wet year. A similarly long recession period would be needed to prevent dessication of any seedlings that were to establish on the river right floodplain surface in the vicinity of Transect 3.

3.7 SITE 7A

3.7.1 AQUATIC HABITAT - SITE 7A

Site 7a was a cascading stretch of the river that was not practical for modeling. Therefore this stretch was represented by four cross sections and point velocity and depth measurements were taken as described in Section 2.0. Measurements at all four cross sections were only feasible (due to extremely swift current and dangerous sampling conditions at higher flows) at the lowest measured flow (192 cfs). At 362 cfs, measurements were conducted at cross sections 3 and 4, and at 902 cfs only cross sections 1 and 2 were measured. The ability for the sampling crew to take measurements at only certain cross sections at certain flows helps illustrate the dynamic nature of this reach in which cascades and pools shift laterally as well as longitudinally as flows increase.

As only two cross sections were available for any given flow, conducting a graph comparing habitat changes relative to flow was not practical. Additionally, as the habitat niche calculations revealed a dominance of higher flow habitat as expected, an evaluation of the percentages of brown trout habitat was conducted across each transect relative to each flow in which measurements were recorded. The following percentages of suitable habitat across the cross section for adult and juvenile brown trout are presented below.

	Flow (cfs)			
	192	362	902	
Brown Trout (Adult)	**Percentage suitable habitat**			**Notes:**
XSect 1	21%		29%	more wetted area at higher flow
XSect 2	43%		30%	assume equal wetted area - too fast to complete cross section
XSect 3	15%	33%		same wetted area
XSect 4	8%	7%		more wetted area at higher flow
(Juvenile)				
XSect 1	26%		26%	more wetted area at higher flow
XSect 2	35%		27%	assume equal wetted area - too fast to complete cross section
XSect 3	20%	43%		same wetted area
XSect 4	11%	20%		more wetted area at higher flow

An evaluation of the trout habitat percentages and/or the niche results both confirm that habitat in this cascading reach shifts with respect to flow, and thus increases versus decreases in habitat are difficult to calculate. For the flow range examined it appears that between 7 and 43% of suitable brown trout habitat may occur any given flow.As the slower velocity habitat (niches 1, 2, and 3) virtually disappeared at the second measured flow, unless overbanking occurred and additional backwater areas were inundated, none of the these niches would be represented at higher flows. The moderate/mid-depth habitat niche and brown trout results 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 902 cfs as was present at approximately 192 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.

4.0 DISCUSSION

4.1 Aquatic Habitat: Study Area Comparison

4.1.1 Reach Comparison

Figures 4.1 through 4.3 display the WUA per flow for select habitat niches, adult trout, and recreation (fishing) per each modeled study reach. Habitat niches 1 (backwater/edge) and 5 (moderate/mid-depth) were most interesting because they represent the greatest disparity in reach results. Although each niche differed in the amount of available habitat, the Niche 1 results were very similar to Niche 2 (slow/shallow) and the Niche 5 results were very similar to Niche 3, thus niches 2 and 3 were not displayed. Niches 4 (fast/shallow), 6 (fast/mid-depth), 7 (moderate/deep) and 8 (fast/deep) displayed similar patterns between reaches in habitat availability with flow changes. Reach 8 represented the restored sections of the Middle Provo River and was modeled up to 2,000 cfs while Reach 7 represented the channelized portion of this stretch and was modeled to 1,500 cfs. The availability of certain habitat types in the restored site compared to the channelized site was evident with more Niche 1 habitat available at lower flows, maintenance of this habitat type with higher flows, and consistently higher availability throughout all modeled flows (Figure 4.1). As evident throughout the Provo River, confined reaches quickly lose low velocity/shallow habitat as flows increase; this type of habitat generally exists along channel margins and high-gradient slopes in confined reaches which prevents lateral movement of this habitat type. Niche 5 is very important habitat for the major sportfish in the Provo River. Niche 5 habitat is also more abundant in Reach 8, as greater habitat complexity results in a peak in habitat at a greater flow (300 versus 200 cfs, respectively) than in the channelized reach (Figure 4.1). At the respective peaks, reaches 8 and 7 maintain approximately 46,000 and 22,000ft^2/1,000ft. Reach 8 supports approximately 2 times (or more) of the available useable trout habitat within the main channel than Reach 7 under any given flow level. Additional habitat outside of the main channel is also available within the side channels of Reach 8. The additional habitat available in each side channel is further discussed in Section 4.1.2.

Because trends for each trout life stage are similar and generally vary only in the amount of total WUA predicted, only results for the adult trout habitat available is presented. As expected, a trend similar to Niche 5 is observed with a peak in habitat occurring at a greater flow and an overall greater amount of available habitat in Reach 8. Reach 7 provides similar amounts of trout habitat compared with confined reaches below Deer Creek Reservoir (see Olsen et al, 2002). Reach 8 provides a greater amount of trout habitat than even the diverse habitat at Site 6 below Deer Creek Reservoir. It appears that the restoration effort has effectively restored habitat for the fisheries in the Provo River. In addition, the amount of wadeable/fishing area is also considerably greater in Reach 8 (nearly 70,000ft^2/1,000ft) compared to Reach 7 (43,000ft^2/1,000ft) (Figure 4.3). Higher amounts of WUA for fishing are observed for all modeled flows.

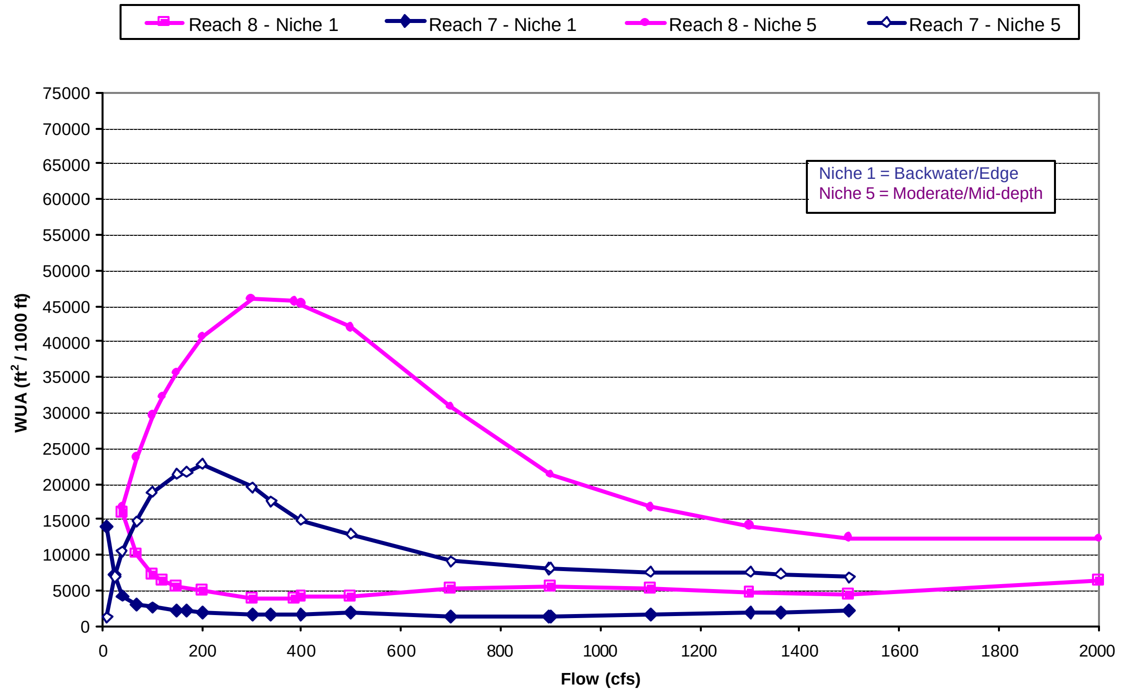


Figure 4.1. Reach Comparisons: Habitat Niches 1 and 5 - WUA vs. Flow.

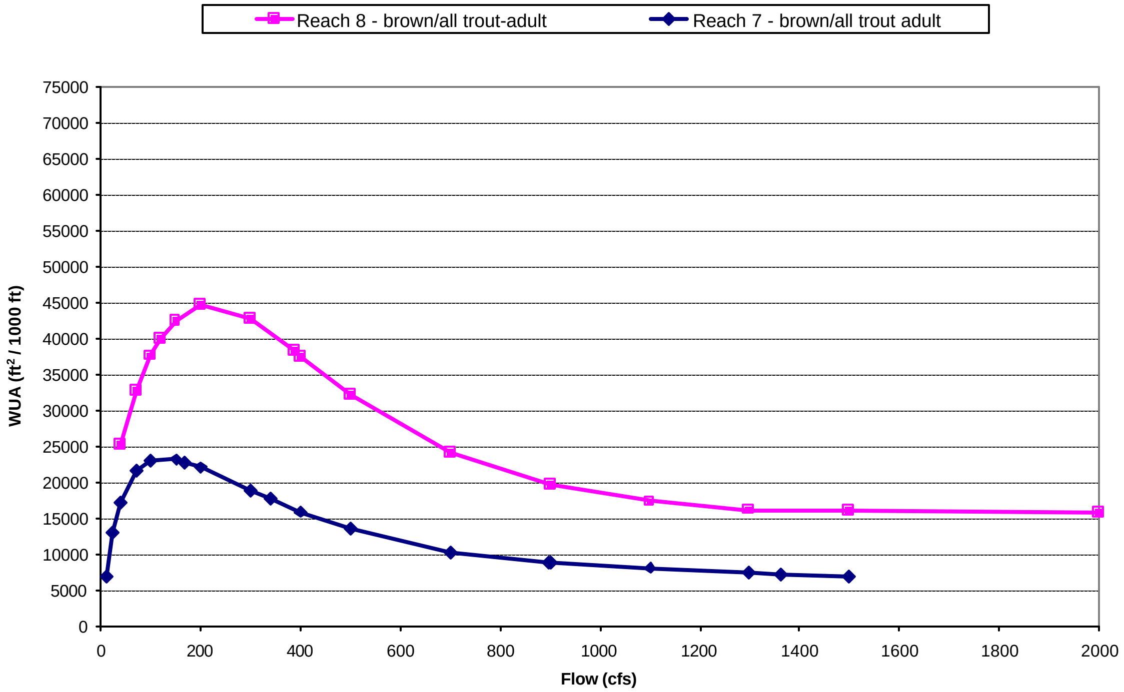


Figure 4.2. Reach Comparisons: Adult Trout - WUA vs. Flow.

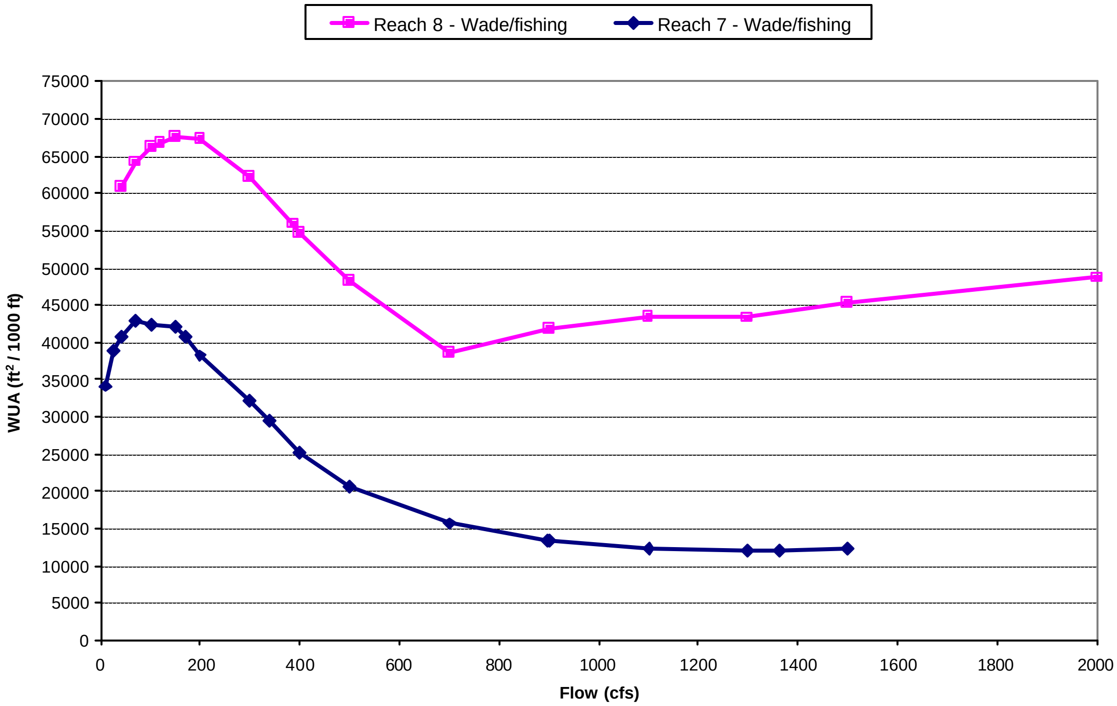


Figure 4.3. Reach Comparisons: Fishing - WUA vs. Flow.

In summary, the habitat niche approach and individual species/fishing modeling demonstrate that the confined reach from Jordanelle Reservoir to Deer Creek Reservoir maintains limited slower velocity habitat as flow increases and moderate velocity habitat decreases as flows exceed several hundred cfs. Additionally, the modeled results demonstrate the ability of a complex reach (i.e., Reach 8) to maintain greater habitat diversity (more niches, more suitable habitat, more fishing area) at all flows compared with a confined reach.

4.1.2 Sites 8b, 8c, and 8e (Side Channels) Assessment

Figures 4.4 through 4.6 display the WUA per flow for select habitat niches, adult trout, and recreation (fishing) for sites 8b, 8c, and 8e. For reference purposes, Site 8b is an intermittent rock ditch that was modeled from 9 to 21 cfs; Site 8c is a cutoff channel that was modeled from 2 to 85 cfs; and Site 8e is a narrow meandering channel that was modeled from 1-20 cfs. These sites generally have much less total habitat compared to main stem sites because of their size, but all WUA's were compared on a ft^2 per 1,000 linear ft of stream basis by extrapolating from the actual distance modeled up to 1,000 ft (e.g., 200ft modeled x 5 = 1,000ft). Habitat niches 2 (slow/shallow) and 5 (moderate/mid-depth) were most interesting because they represent the greatest disparity in site results. Although each niche differed in the amount of available habitat, the Niche 2 results were very similar to Niche 1 (backwater/edge) and the Niche 5 results were very similar to Niche 3, thus niches 1 and 3 were not displayed. Niches 4

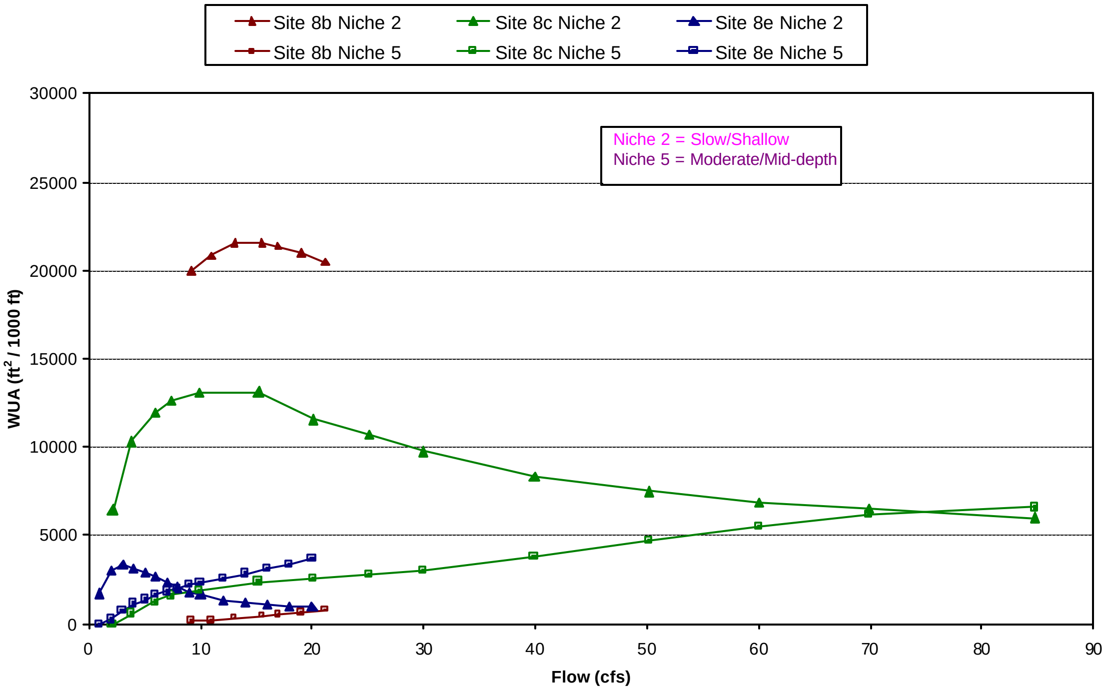


Figure 4.4 Sites 8b, 8c, and 8e: Habitat Niches 2 and 5 - WUA vs. Flow.

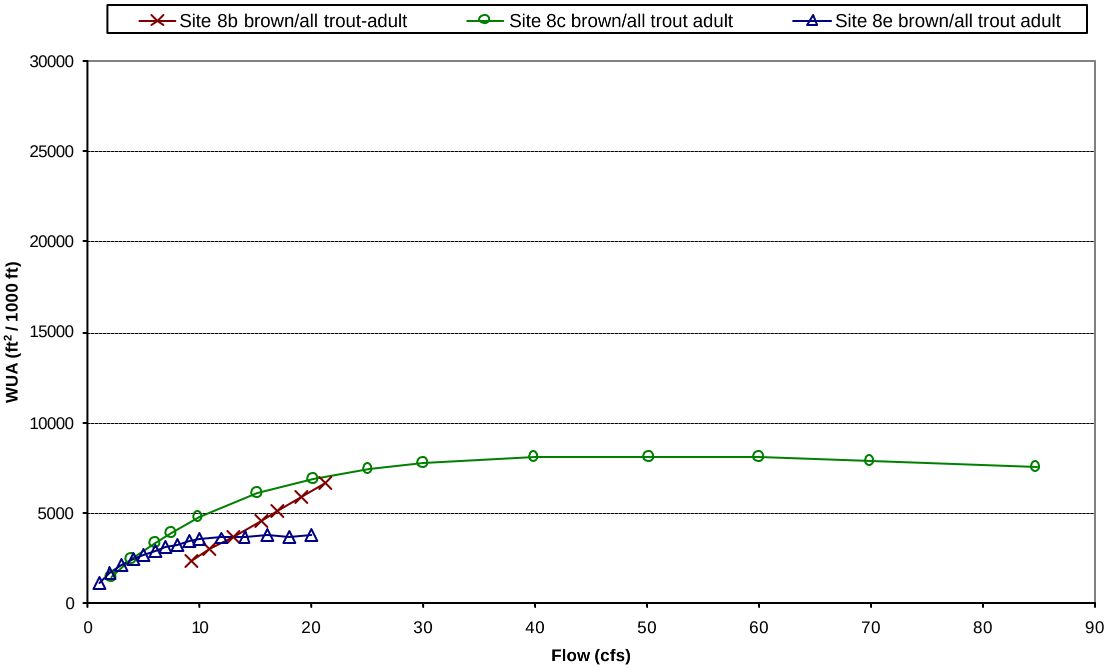


Figure 4.5. Sites 8b, 8c, and 8e: Adult Trout - WUA vs. Flow.

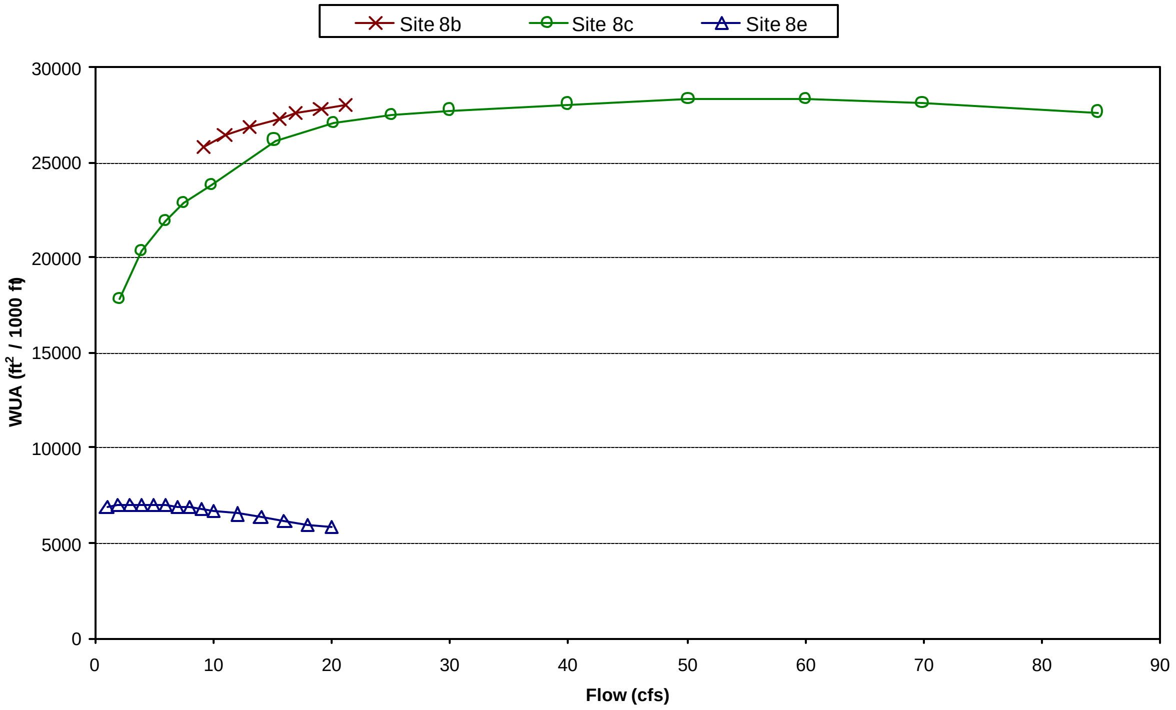


Figure 4.6. Sites 8b, 8c, and 8e: Fishing - WUA vs. Flow.

(fast/shallow), 6 (fast/mid-depth), 7 (moderate/deep) and 8 (fast/deep) displayed similar patterns between sites in habitat availability with flow changes.

As evident in Figure 4.4, Site 8b maintains the greatest amount of Niche 2 habitat and the least amount of Niche 5 habitat for the modeled flows, which increases the probability that this site will maintain native species. Site 8c maintains the second greatest amount of Niche 2 habitat with over 11,000ft^2/1,000ft between 7 and 20 cfs, but Niche 5 habitat gradually increases with flow at Site 8c and surpasses the amount of Niche 2 habitat at approximately 75 cfs. This is important because as adult trout habitat increases it reduces the likelihood that certain species/life stages will use the remaining Niche 2 habitat. Site 8e maintains very little Niche 2 and Niche 5 habitat at all flows but has slightly more Niche 2 at lower flows and slightly more Niche 5 at higher flows (Figure 4.4).

Because the trends for each trout life stage are similar and generally vary only in the amount of total WUA predicted, only results for adult trout habitat available is presented. As expected, a trend similar to Niche 5 is observed with adult trout habitat for all sites. Sites 8b and 8c both peak near 21cfs with approximately 6,800ft^2/1,000ft adult trout habitat; after which Site 8b is not modeled at higher flows and Site 8c stabilizes for the remaining modeled flows (Figure 4.5).

In streams/rivers where predatory species (in this case brown trout) are dominant, the tendency is for potential prey to occupy areas that are less favorable for the predatory species, but not necessarily optimal for the prey. In addition, small pockets of suitable habitat for the prey species may exist, but are often surrounded by trout habitat. Thus, modeling habitat availability may suggest that habitat is available in some areas, but biological interactions prevent its use. In the Provo River, the areas that provide the greatest potential for the survival of many native fishes (potential prey species) appears to be these small off channel or backwater areas away from the main channel where habitat for adult trout is limited most of the time. Because Site 8b maintains a fair amount of Niche 2 habitat with minimal Niche 5 or brown trout habitat at lower flows it is an excellent candidate for sustaining populations of native species. Maintaining 10 cfs in the rock ditch (Site 8b) might support this habitat as a refuge for prey species. The model results for Reach 8 suggest that a 10 cfs transfer from the main channel to augment Site 8b would have no impact on the reach at the current minimum flow requirements. Site 8c also appears to be a valuable resource at the lower flows (less than 15 cfs), but is overtaken by suitable brown trout habitat as flows increase. Site 8e may also provide some habitat for native species at the lower range of flows. The ability of juvenile brown trout to use habitats with shallow depths and lower flows potentially impedes the sustainability of native fishes even in habitat such as this, which under non-predatory conditions and/or without inter- species competition would be ideal for many native species. However, in the absence of brown trout extirpation, maintaining flows suitable for native fishes in these and other side channel areas, while limiting suitability for brown trout, may provide the best opportunity for the re-establishment or sustainability of native fishes.

Although the preference for fishing will likely be in the main channel reaches because of the abundance of sportfish habitat, Sites 8b and 8c provide greater than 25,000ft^2/1,000ft WUA for fishing at most flows. Site 8e shows limited fishing area, however the channel is narrow enough in places to cross over without wading.

4.1.3 Sites 8d and 7a Assessment

Sites 8d and 7a provide unique habitat features in this section of the Provo River. The backwater/edge habitat provided by the beaver dam complex at Site 8d may be extremely valuable for native fishes, since it is not suitable for adult brown trout at most flows and is limited for juvenile brown trout suitability. Site 7a is a cascading stretch of river that provides suitable trout habitat that shifts with flow. The shifting nature of pocketwater and cascades is evident by the results of the point velocity measurements described in Section 3.0. As both features are unique to this section of river, efforts should be made to maintain both. The final objectives for the restoration efforts of the Middle Provo River (i.e. whether it be to re-establish native fish populations, increase fishing opportunities, or some combination), will dictate the importance of habitat features such as the beaver dam complex at Site 8d or the cascading habitat present at Site 7a.

4.1.4 Aquatic Habitat Flow Assessment

The modeling results confirm that the restoration effort has effectively restored habitat in the Middle Provo River as the amount and diversity of habitat is greater compared with all other modeled reaches. The minimum flow requirement (125 cfs) for the Middle Provo River appears to provide a diversity of habitat within both the main stem and associated side channels. As flows increase in both the main stem and side channels, the amount of native fish habitat decreases while brown trout habitat increases up to approximately 200 cfs, when a decline in both are experienced. In contrast to the greater amount of native fish habitat at lower flows, the amount of fishing area (wadable area) peaks around 150-200 cfs which corresponds well with flows that optimize brown trout habitat throughout the Middle Provo River.

Habitat modeling results demonstrate the benefits provided to trout and native fishes by maintaining flow in the various side channels at all discharges, even during the 125 cfs minimum flow. For example, Figure 3.1 shows a Niche 5 habitat decrease of about 3,000 ft^2/1,000 ft when main channel flows are reduced from 125 cfs to 110 cfs. However, diverting this 15 cfs into side channels 8c and 8e (see Table 2.5 for side channel discharges at various flow levels) would produce more than 15,000 ft^2/1,000 ft of Niche 5 habitat as shown in Figures 3.18, and 3.22, more than compensating for the main channel losses. As with Niche 1 habitat, Figure 3.1 shows an increase of approximately 1,000 ft^2/1,000 ft when main channel flows are reduced from 125 cfs to 100 cfs. The 25 cfs diverted into side channels 8c and 8e, including 10 cfs diverted into the Rock Ditch return ditch (8b), would add an additional 10,000 ft^2/1,000 ft of Niche 1 habitat for native fishes. Maintaining year-round flow in the side channels of Reach 8 provides a win-win situation for both native and trout habitat.

Although the modeling effort demonstrates an abundance of native fish habitat with the current minimum flow distribution and has revealed some valuable contributions of the restoration effort, there are some areas that remain to be considered. The model suggests limited habitat availability for adult brown trout in the side channels at all flow levels and considerably less habitat for juvenile brown trout than for native fishes at low flow levels. This is theoretically a favorable situation for native fishes, but the fact that the model does show suitability for juvenile trout habitat in all of the above areas (main and side channels) under most flows may not provide conditions necessary for native species to re-establish due to predation. Biological data collected by Dr. Mark Belk (BYU) has documented that a large amount of good native fish habitat was present upon completion of the restoration effort and that there was a strong influx of native species. However, within two years, young-of-year and juvenile brown trout dominated population estimates in these areas (Belk pers. comm. 2003). The model corresponds well with these field observations; it suggests that providing flow to and/or creating additional side channel areas would provide native fishes a refuge from adult brown trout, however, leaves native fish habitat vulnerable by documenting some juvenile trout habitat. The high levels of recruitment for brown trout, or possibly the ability of juvenile brown trout to out compete native fishes in these side channel areas may outweigh model predictions of less juvenile brown trout habitat. According to Dr. Belk, the only areas that were relatively un-impacted by brown trout during his surveys were areas with limited access to the main channel (i.e. ponds, wetlands, etc.). Therefore, in addition to the creation of side channels for refuge from adult brown trout, it may also be necessary to create habitat that only has one or limited connection to the main stem of the river (i.e. small stream merging into a wetland/small pond). The reduced access to the main channel would likely limit the feasibility of preference for brown trout and potentially enhance the opportunities for native fishes. A complete evaluation of the restoration components should be conducted incorporating the modeling results presented herein and the final biological report by Dr. Belk.

One existing habitat type among the various ones modeled within Reach 8 may provide an opportunity to meet the above criteria by altering the flow regime. Site 8b (the rock ditch) could be provided with a continuous, stable flow of water. This would be beneficial because at the minimum flow level, approximately 15 cfs flows through side channels and the remaining 110 cfs in the main channel. Diverting an additional 10 cfs into this habitat type would enhance the benefits derived from a minimum flow requirement and restored channel conditions by providing an additional refuge to the native fish population from adult brown trout without impacting habitat diversity in the main channel. Under this scenario, the rock ditch would receive a continuous discharge of only 10 cfs and maintain habitat for natives at all times and be particularly important at higher flows when native habitat is substantially reduced in other areas. If Site 8b could be altered to provide only a limited connection with the main stem, the potential for decreasing inter-species competition with young-of-year and juvenile brown trout would also be possible, which in turn could be extremely beneficial to the native fishes.

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 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 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 4 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.

4.3 Water Quality - Streamflow Relationships

As revealed in the temperature data collected in the Middle Provo River (Figures 3.4 and 3.32 flow and temperature graphs for 7 and 8), large releases of water from Jordanelle Reservoir dampen diurnal temperature fluctuation in the water column and reduce the mean daily temperatures. Water temperature and diurnal fluctuations increase with distance below Jordanelle Reservoir. 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. 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. 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.

4.4 Channel Geometry 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 4.7 for all study sites.

It is easy to contrast the hydraulic and geomorphic differences between the channelized (Site 7) and unchannelized (Site 8) portions of the Middle Provo River. The riverine environment is much wider and more morphologically complex within Site 8 where the channel is free to adjust laterally to the ever-changing water and sediment flux. The main channel itself is also wider within Site 8. For example, the wetted width (width of flowing water) of Site 8 is 22-34 percent greater than Site 7, depending on flow level. In addition to the main channel, hydraulically connected side-channels are also abundant throughout Site 8, whereas all flow is contained within the main channel at Site 7. Flow in the Site 8 side-channels persist perennially as with 8c, 8d and 8e; and contains about 10 percent of the total flow during low flow (120 cfs), and about 20 percent of the total flow during high flow (1,100). The active floodplain at Site 8 also allows for seasonal overbank flows during spring runoff, including energy dispersal and deposition of sediment and riparian seeds (see Section 4.5).

The hydraulic radius (i.e. water depth) is much greater at Site 8 during low flow, yet becomes lower than Site 7 as flows approach 1,000 cfs (Table 4.1). Therefore, although water depths are more shallow at Site 7 during low flow, they become deeper than Site 8 during high flow. This reversal in hydraulic radius between Sites 7 and 8 is another result of the channelized vs unchannelized conditions of the Middle Provo River.

Table 4.1. Hydraulic geometry characteristics of bedload modeling cross sections for all sites between Jordanelle Reservoir and Utah Lake. Cross section locations for Sites 7 and 8 are shown on Maps 3.1 and 3.2.

Measurement	Streamflow (cfs)	Site 1	Site 2	Site 3	Site 5	Site 6	Site 7	Site 8
Wetted Width (ft)	100	57	34	39	37	51	59	72
	500	61	45	48	59	59	65	87
	1,000	75	53	56	63	70	67	90
	1,500	80	54	59	68	71	72	91*
	2,000						74	91*
Hydraulic Radius (ft)	100	0.94	1.05	0.90	0.97	1.20	0.53	0.79
	500	1.97	1.90	1.85	1.85	2.44	1.25	1.40
	1,000	2.30	2.27	2.25	2.60	2.95	1.97	1.75
	1,500	2.65	2.60	2.55	3.10	3.40	2.52	1.89*
	2,000						3.07	2.03*
Channel Roughness (Manning's "n")	100	0.034	0.063	0.047	0.039	0.091	0.022	0.081
	500	0.027	0.045	0.037	0.037	0.069	0.024	0.051
	1,000	0.023	0.036	0.031	0.035	0.056	0.027	0.037
	1,500	0.021	0.031	0.027	0.033	0.049	0.029	0.031*
	2,000						0.031	0.025*
Average Velocity (ft/s)	100	1.95	2.70	2.76	2.90	1.42	3.74	1.80
	500	4.23	5.50	5.70	4.70	3.00	6.00	4.10
	1,000	5.73	8.00	7.85	6.15	4.25	7.36	6.70
	1,500	7.17	10.00	9.54	7.10	5.35	8.00	8.40*
	2,000						8.50	10.25*
Shear Stress (psf)	100	0.12	0.76	0.50	0.36	0.45	0.23	0.64
	500	0.27	1.41	1.02	0.66	0.91	0.55	1.13
	1,000	0.36	1.70	1.24	0.93	1.10	0.86	1.40
	1,500	0.44	1.93	1.40	1.13	1.28	1.09	1.55*
	2,000						1.34	1.62*
Water Surface Slope (%)	500	0.2	1.2	0.9	0.6	0.6	0.7	1.3

* = main channel only. WinXSPRO results are specific to the main channel at the Bedload Modeling Cross Section (Map 3.1). A comparison of modeling results across the entire floodplain at other transects are provided in Section 4.5.

Channel roughness (Manning's n) is much higher at Site 8 during flows less than 2,000 cfs, probably because of the "macro" roughness characteristics such as pronounced bed forms (pools, bars, and riffles), higher sinuosity, and greater diversity of bed materials in this restored reach. Site 8 follows a common pattern of decreased roughness values as flows increase due to a diminished influence of skin friction. Riparian vegetation along the newly constructed channel has not yet matured, and therefore has a minimal influence at Site 8. The riparian vegetation and large organic debris will have a greater influence on high flow roughness values at Site 8 over the next 5-10 years. The flow/roughness relationship is reversed at Site 7, showing higher roughness values as flows increase. It appears that vegetation encroachment and the presence of large organic debris significantly influence channel roughness values at Site 7 as flows exceed 100 cfs.

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 for all sites between Jordanelle Reservoir and Utah Lake.

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
7	73	81	108	130	145
8	16	33	70	128	168

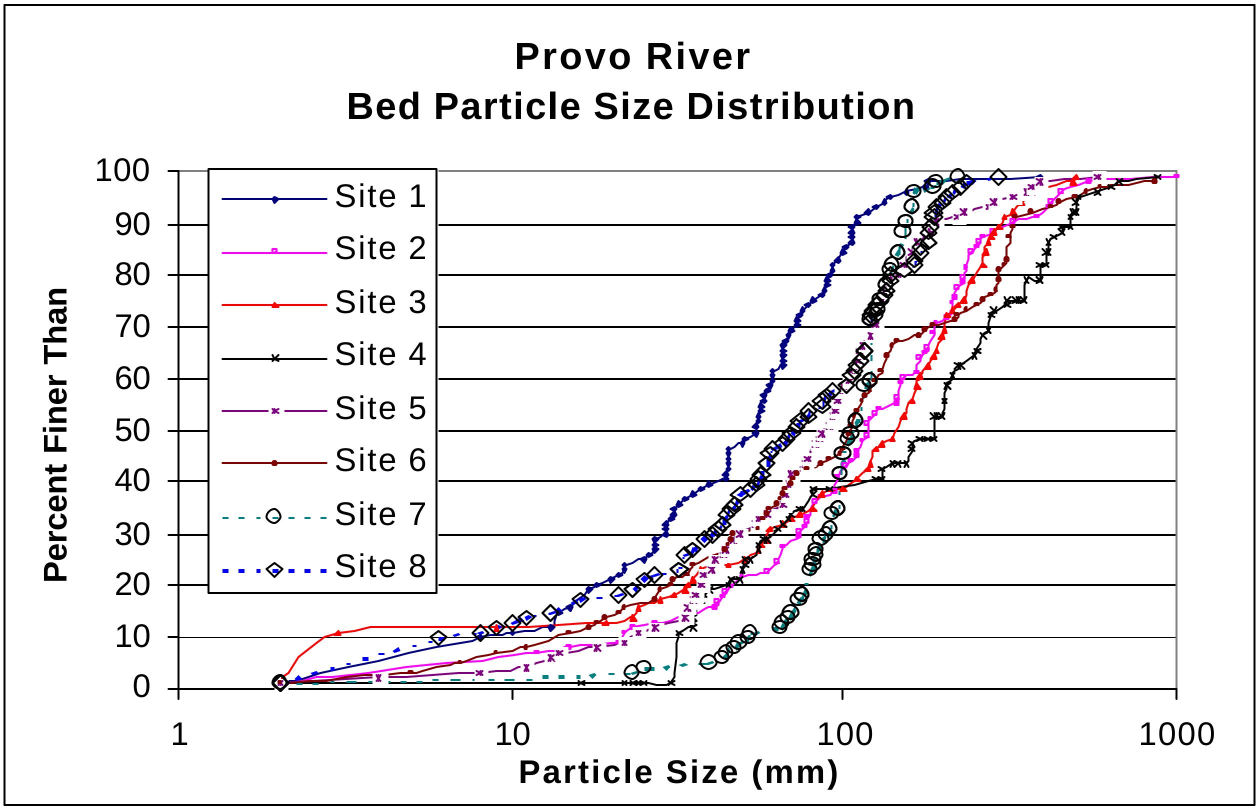


Figure 4.7. Streambed particle size distributions for all sites between Jordanelle Reservoir and Utah Lake.

The combined influence of channel roughness and hydraulic radius are illustrated in the average velocity and shear stress values, respectively, as shown in Table 4.1. First, average velocities are relatively high at Site 7 during low flow. The low roughness values during low flow at Site 7 allow for relatively fast moving water across the entire channel. As flow increases, Site 7 velocities increase at a relatively slow rate because of the increasing roughness values at higher flows. This dynamic contrasts with Site 8 where these relationships occur in the opposite direction.

Second, shear stress values remain relatively low at Site 7 until flows exceed 1,500-2,000 cfs. Notice the similarities between shear stress and hydraulic radius values at Site 7, showing dramatic increases only during the highest flows. These results would explain some of the physical conditions why the bed remains immobile and why effective discharge does not occur until much higher flow at Site 7 as compared with the mobile bed at Site 8.

Another physical condition affecting bedload transport and effective discharge values in the channelized and unchannelized reaches of the Middle Provo River is the streambed particle size distributions. The cumulative distribution curves for Sites 7 and 8 are distinctively different (Figure 4.7) producing contrasting distribution parameters (Table 3.1). Site 8 has relatively equal proportions of particles from all size fractions whereas Site 7 has nearly all cobble-sized particles. It is anticipated that bed coarsening and channel degradation will eventually occur in the restored reaches immediately downstream of Jordanelle Dam. Further longitudinally based analysis (i.e. size selective sediment budgets) would need to be performed to determine the degree and extent of "gravel mining" below Jordanelle Dam given alternative flow regimes. The potential for gravel mining, bed coarsening, and channel degradation to occur at Site 8 under the current flow regime is likely as long as outgoing loads exceed incoming supplies.

4.4.1 Site 8 Bedload Calculations Under Various Degrees of Channel Armoring

The field data used at Site 8 was collected only a couple years following channel construction. It is unknown whether or not the channel and bed materials have completely adjusted to the current flow regime. One foreseeable argument to the bedload transport results presented for Site 8 (Figure 3.8, 3.10 and 3.11) is that the bed material has not completely sorted, resulting in a relatively small D_{50} in this recently constructed riffle. The concern with using an undersized D_{50} (which is possible in an unsorted riffle) for bedload transport calculations is that it may overestimate transport rates.

Initial discussions with Tyler Allred and Mark Holden of the Utah Reclamation Mitigation and Conservation Commission prompted the need to further analyze bedload transport rates and effective discharge calculations at Site 8 based on hypothetical adjustments in the median particle size. Hypothetical bedload rating curves were produced at Site 8's bedload modeling cross section (Map 3.1) using larger sizes for the D_{50} (from 70 to 100 mm), representing increasing degrees of bed coarsening and armoring at this site (Figure 4.8). Hypothetical effective discharge calculations were also performed using the various degrees of bed armoring (Figure 4.9).

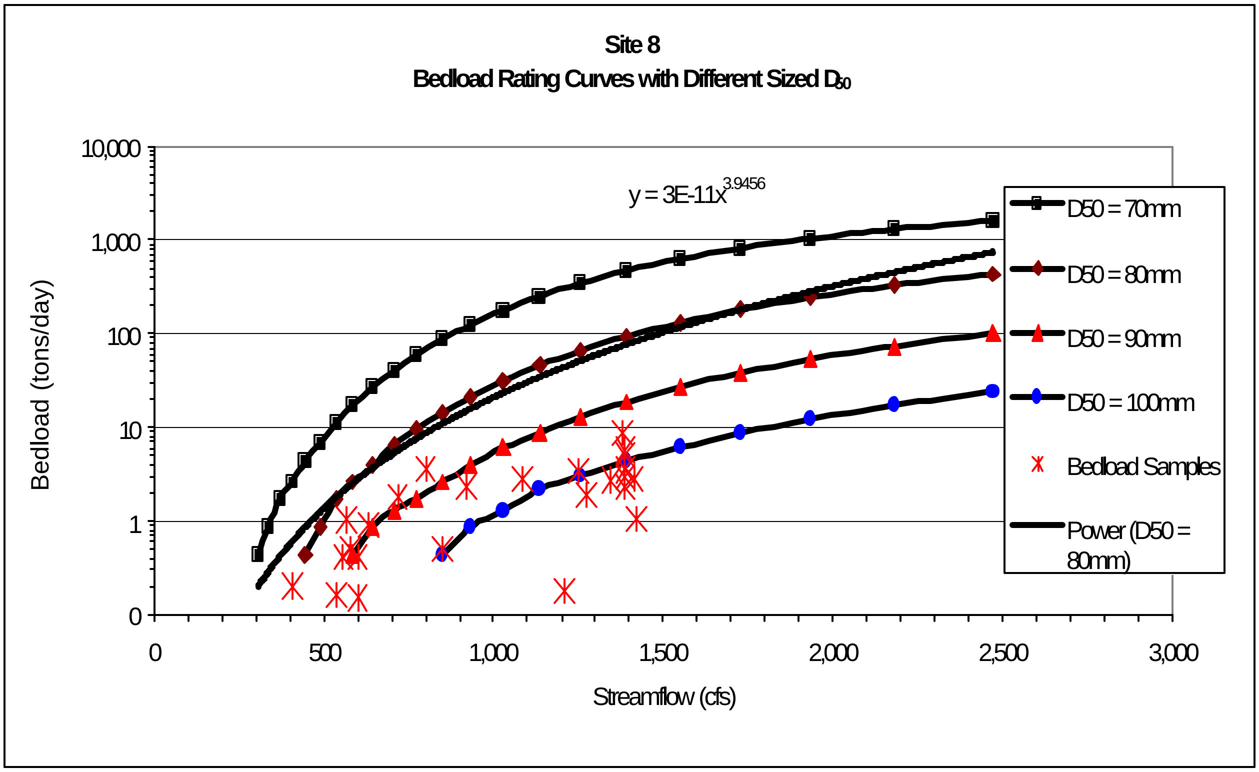


Figure 4.8. Hypothetical bedload rating curves for Site 8 based on various degrees of bed armoring at the bedload modeling cross section (Map 3.1). The top curve (D_{50} = 70 mm) is the actual measured D_{50} for this riffle. The bottom curve (D_{50} = 100 mm) represents the maximum degree of armoring anticipated at this site.

This exercise demonstrates just how sensitive bedload transport calculations are to slight changes in the D_{50}. Figure 4.8 shows a great disparity of transport rates at 2,000 cfs with different sized D_{50}. Total bedload transport shown in the effective discharge calculations is very sensitive to slight changes in the D_{50} (Figure 4.9 and Table 4.3). Although the increment of flow that transports the most bedload sediment over time is the same for the different sized D_{50}, annual loads vary significantly. As described in Section 3.4, there seems to be an abnormally low number of days during the 5 year period of record where flows were in the range of 1,400-1,800 cfs (Figure 3.10). We anticipate that this is an anomaly over the recent period of record and that this phenomenon will not occur over a longer time duration unless flow operations dictate its existence.

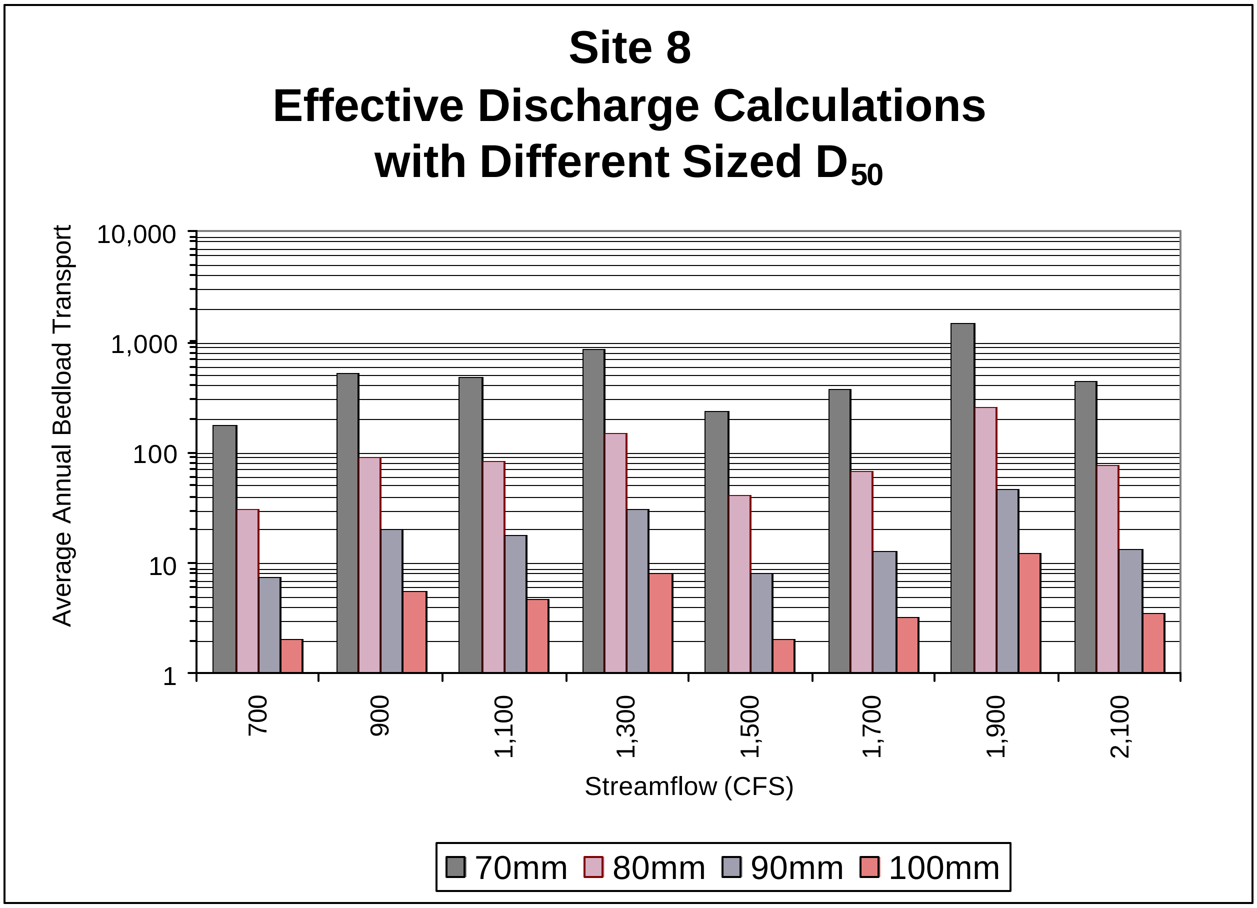


Figure 4.9. Hypothetical effective discharge calculations for Site 8 based on various degrees of bed armoring at the bedload modeling cross section (Map 3.1). The D_{50} = 90 mm bar is the same as shown in Figure 3.10. The D_{50} = 100 mm bar represents the maximum degree of armoring anticipated at this site.

Table 4.3. Total annual loads of bedload transport at Site 8 based on hypothetical adjustments to the D_{50} at the bedload modeling cross section (Map 3.1).

PARTICLE SIZE (mm)			
D_{50} = 70	**D_{50} = 80**	**D_{50} = 90**	**D_{50} = 100**
4,817 tons	834 tons	171 tons	44 tons

4.5 Riparian Vegetation: Study Area Comparison

Because the stream channel at Site 8 was recently constructed and vegetation patterns have not yet had time to develop, the ability to compare Sites 7 and 8 is somewhat limited. Nevertheless, several differences between the sites can be discerned.

As previously discussed, there is a slight difference in the flow level below which no vegetation growth occurs (Table 4.4). Specifically the "low flow" level at Site 8 is 120 cfs, while at Site 7 it is 150 cfs. This is most likely a function of the fact that flows are typically somewhat higher at Site 7 than at Site 8 due to tributary and groundwater inputs that occur between the sites. For example, on April 26, 2002, streamflow at Site 7 was field-measured at 169 cfs, while the average flow recorded at the River Road gage (located near Site 8 - see Map 1.3) for that date was only 145 cfs. This difference in base flow level during the growing season is reflected in the level to which vegetation is able to extend into the channel. However, the difference in hydrology between the sites is relatively minor, and flow data from the Midway gage (located between the sites) provide a reasonable representation of the flow regimes at both Site 7 and Site 8.

Table 4.4. Streamflow associations with riparian vegetation at different study sites.

Study Site	Approximate Flow above which Vegetation is Inundated	Approximate Flow that Inundates Channel Shelf or Floodplain	Maximum Wetted Width at 700 cfs	Maximum Wetted Width at 1100 cfs
Site 8	120 cfs	700 cfs	115 feet[a] / 130 feet[b]	>200 feet
Site 7	150 cfs	900 cfs	82 feet	88 feet

[a] main channel only
[b] left + right channels at Transect 2

Another difference between the sites is the flow level at which floodplain areas become inundated (Table 4.3). At Site 8, significant inundation of the low portion of the river right floodplain near Transect 1 occurs at 700 cfs. At Site 7, significant inundation of the island at Transect 1 and low portion of the river right floodplain below Transect 3 does not occur until 900 cfs. This difference means that out-of-bank flows occur more frequently at Site 8 than at Site 7.

In addition to the fact that out-of-bank flows occur more frequently at Site 8, the lateral extent of inundation when flows do get out of the channel is much greater at Site 8 than at Site 7. For example, at the 700 cfs flow level, maximum main-channel flow width at Site 8 is about 115 feet, and the combined flow width of the left and right channels at Transect 2 is 130 feet. In contrast, the maximum wetted width at 700 cfs at Site 7 is only 82 feet (Table 4.3). More significantly, when flows increase from 700 to 1,100 cfs, the maximum flow width at Site 7 only increases slightly, to 88 feet. This is despite the fact that at 1,100 cfs the island crossed by Transect 1 is fully inundated and the low portion of the river right floodplain near Transect 3 is inundated (Figure 3.39). Active floodplain areas at Site 7 are just not very wide due to levees and channelization.

At Site 8, in contrast, the maximum wetted width increases significantly between the 700 and 1,100 cfs flow levels (Table 4.3). Although aquatic habitat at flows above 725 cfs were not modeled at Site 8, field-surveys of the water surface at 1,100 cfs indicate that approximately 80 feet of the river right floodplain becomes inundated between 700 and 1,100 cfs, increasing the combined flow width of the left and right channels at Transect 2 to more than 200 feet. If the wetted width of the nearby Site 8c side channel were also considered, total flow width would further increase to more than 300 feet.

The difference in flow width between Site 7 and Site 8 is significant because it means that the maximum lateral extent of potential riparian recruitment surfaces is much smaller at Site 7. This difference is indicative of differences between channelized and unchannelized reaches of the Middle Provo River on a broader scale. The study by Stromberg et al. (1999) found that riparian vegetation width in the section of Reach 8 near Midway that has historically remained unchannelized was as great as 1300 feet (400 m), while riparian vegetation width in channelized portions of the river was only 200-400 feet.

In addition to causing a difference in maximum flow width, the differences in channel and floodplain geometry between Sites 7 and 8 also lead to a difference in the potential for successful cottonwood recruitment. Because more total surface area is inundated at a given flow at Site 8, the total area of sediment deposition and amount of potential germination substrate would be substantially greater than at Site 7. At Site 7, the floodplain surfaces are more sloping than the flat surfaces at Site 8 (Figures 3.12 and 3.39), such that germination and recruitment could only occur along a relatively narrow band at Site 7; at Site 8, recruitment could occur across an entire broad surface.

Cottonwood recruitment potential is also enhanced by the greater diversity of fluvial surfaces present at Site 8. For instance, the river right floodplain at Site 8 is inundated by relatively low-magnitude, frequent flood flows, while the river left floodplain is only inundated by high-magnitude events. The island at Site 8 is inundated by flood flows of intermediate frequency and magnitude. This variety increases the probability that conditions will be right for cottonwood recruitment somewhere within Site 8 in any given water year. The presence of nearby side channels (such as 8e and 8c) with distinct flow vs. inundation relationships further adds to fluvial diversity and enhances the likelihood of successful recruitment. At Site 7, the left and right floodplain surfaces have similar inundation stages, and the probability of successful recruitment in a given year would be similar in both locations.

4.6 Integrated Resource Discussion

Aquatic habitat relationships described for the various reaches of the Middle Provo River assume static conditions and are based strictly on depth and velocity criteria. Although necessary for modeling purposes, we acknowledge that this approach simplifies the dynamic nature of riverine ecosystems and merely provides a snapshot in time. It is important to note that the aquatic environment of the Middle Provo River will likely adjust and change over time especially in the newly restored reaches such as Site 8 as riparian vegetation matures and fluvial processes reach a more stable state of dynamic equilibrium. Side-channels such as Site 8c will soon be lined and/or covered with woody vegetation and the banks will likely steepen and become more built up with sediment accumulations. Channel narrowing and vegetation encroachment will likely also occur in the channelized reaches as they continue to adapt to the post Jordanelle flow regime.

As with the lower reaches below Deer Creek Dam (Olsen et al, 2002), it is apparent that the relationships between streamflow and the various ecological components of the Middle 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 main channel 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 greater than 1,000 cfs. However, 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 individual components of any single resource should not be considered in isolation.

One important consideration is that the physical and biological relationships with streamflow in the Middle Provo River are quite different between the channelized and unchannelized reaches. Although somewhat straightforward, many differences between the two reaches are compounded by dissimilar rates of change and nonparallel responses to varying flow conditions. The unchannelized reaches not only have a wider variety of velocities and depths at any given flow (i.e., better defined pool, riffle and run habitats), but also adjusts or fluctuates at an accelerated rate as flows change. For example, the fluctuation or range of velocities at flows between 100-2,000 cfs in riffles is nearly 2 times greater in the unchannelized reaches than occur in the channelized reaches (Table 4.1). The aquatic environment of the channelized reaches remain more spatially and temporally homogeneous over the range of flows considered in this study. Fluvial processes that create and maintain habitat conditions and promote recruitment of riparian vegetation occur more often and remains active for a longer duration each year in the unchannelized reaches. In general, the unchannelized reaches of the Middle Provo River currently maintains greater habitat diversity and supports a wider variety of ecological functions than the channelized reaches under the current flow regime; and with natural adjustments to the ever changing fluvial environment, the unchannelized reaches are predicted to continue supporting all beneficial uses including native fish habitat into the foreseeable future.

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APPENDIX A: DEVELOPMENT OF HABITAT SUITABILITY INDEX CURVES

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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

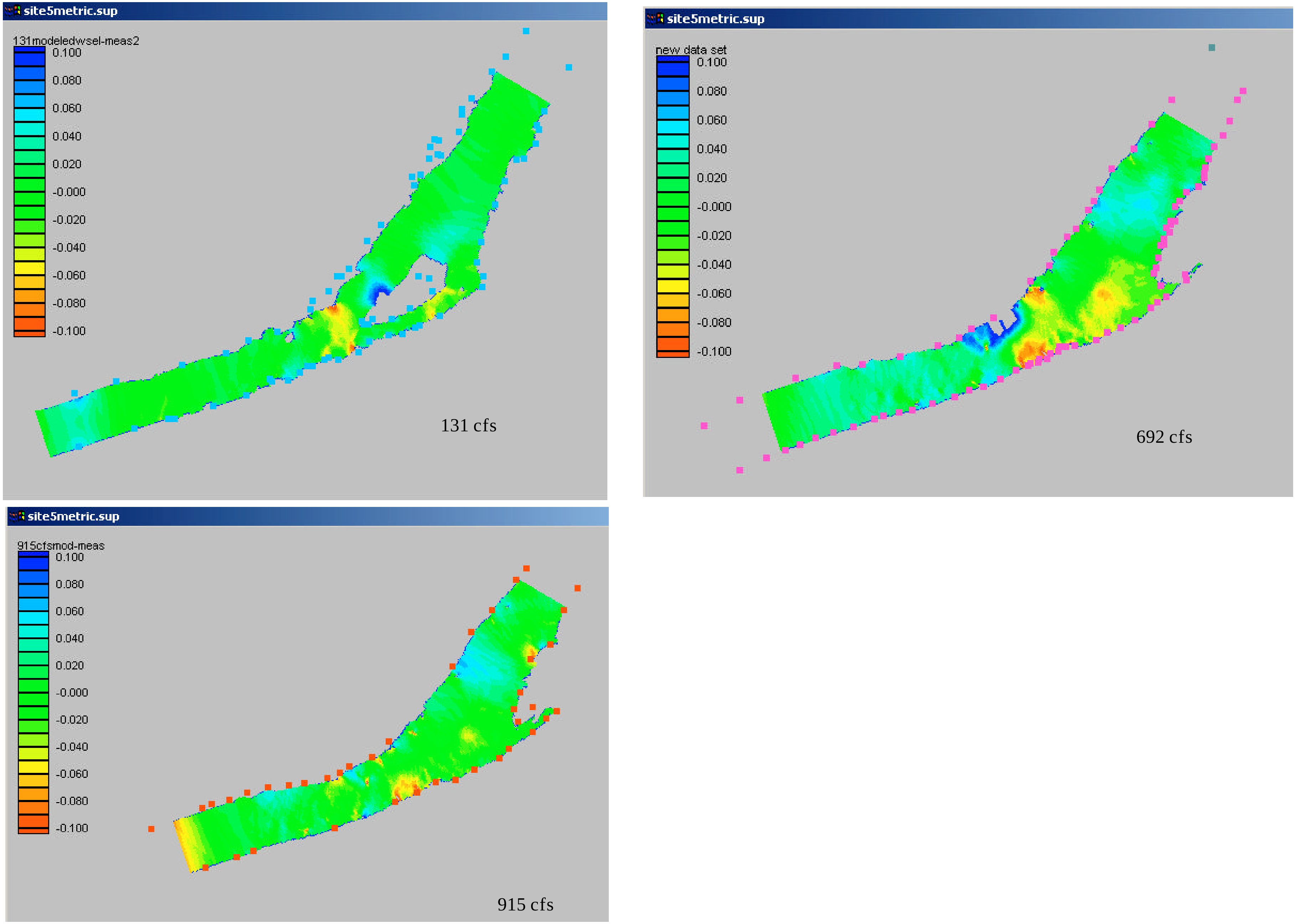


Figure B1. Comparison of modeled versus field-surveyed water surface elevations for three flow levels at Site 5.

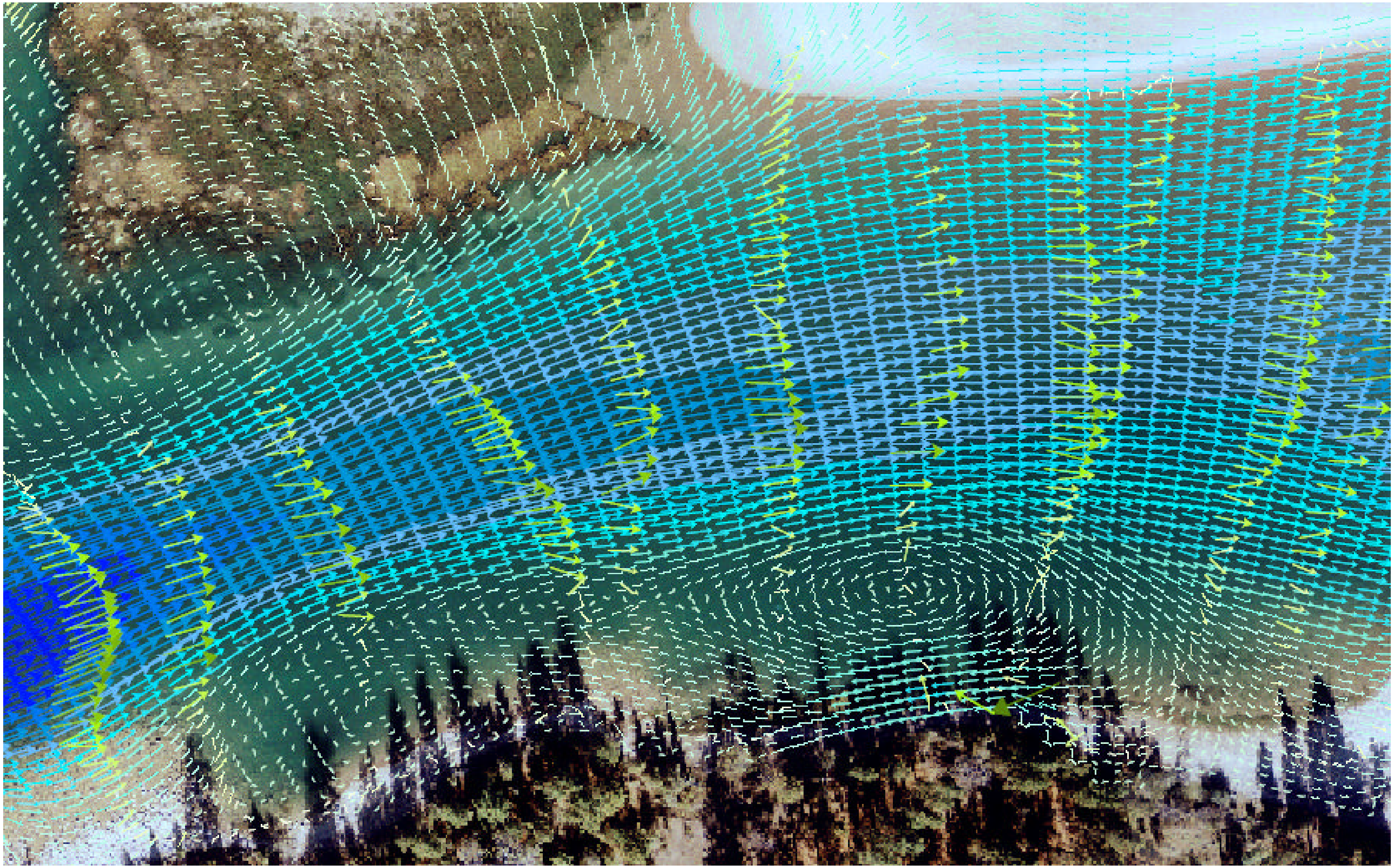


Figure B2. Comparison of measured versus modeled velocities on a Flathead River site.

APPENDIX C: HYDROLOGIC DATA AND ANALYSES

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).

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 near Midway	10155300	1995-2001	222.6

Average daily flow data for the specific study sites were calculated from the gage data as listed in Table C2. Based on a review of the available gage data and comparison with field-measured discharge values, it was determined that the Provo River near Midway gage best approximates flows at Sites 7 and 8.

Table C2. Hydrologic data sources and calculation techniques for study sites.

Study Site	Data Source/ Calculation Technique
Sites 7 and 8	USGS #10155300 (Provo River near Midway)
“unregulated”	USGS #10155000 (Provo River near Hailstone)

In order to illustrate the difference between existing flow conditions and what flows would be without the influence of Jordanelle Dam, the Hailstone gage data set was used to represent “unregulated” flows. The Hailstone USGS gage is located upstream from Jordanelle Dam (Map 1.3). Because there is no significant increase in mean annual flow volume associated with the increased drainage area between the Hailstone gage site and Sites 7 and 8, no adjustments were made to the Hailstone data. It is important to note that the Hailstone 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 Jordanelle Dam and other 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.

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.

Flood Frequency Analysis

Instantaneous peak flow data were analyzed to determine the frequency and magnitude of flood flows on the Provo River at Sites 7 and 8 (Midway gage) and for the “unregulated” Hailstone gage.

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 for two distinct time periods at the Hailstone gage: water years 1997-2001; and, the complete period of record for the gage (1950-2001). 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.

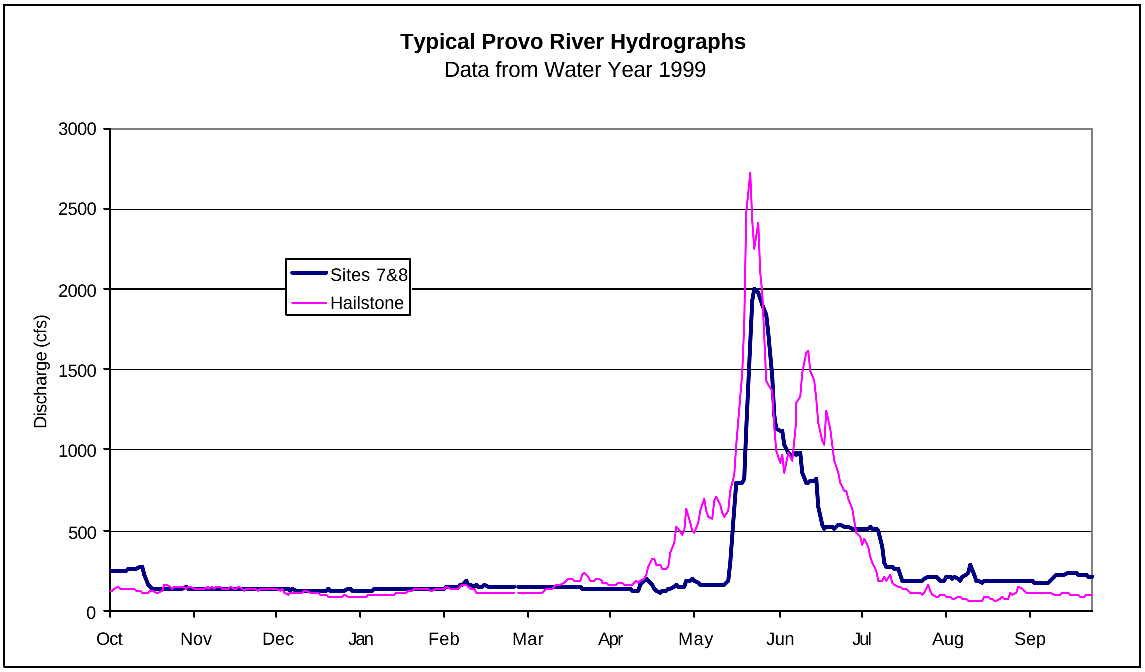


Figure C1. Typical hydrographs for Provo River sites. Data from water year 1999.

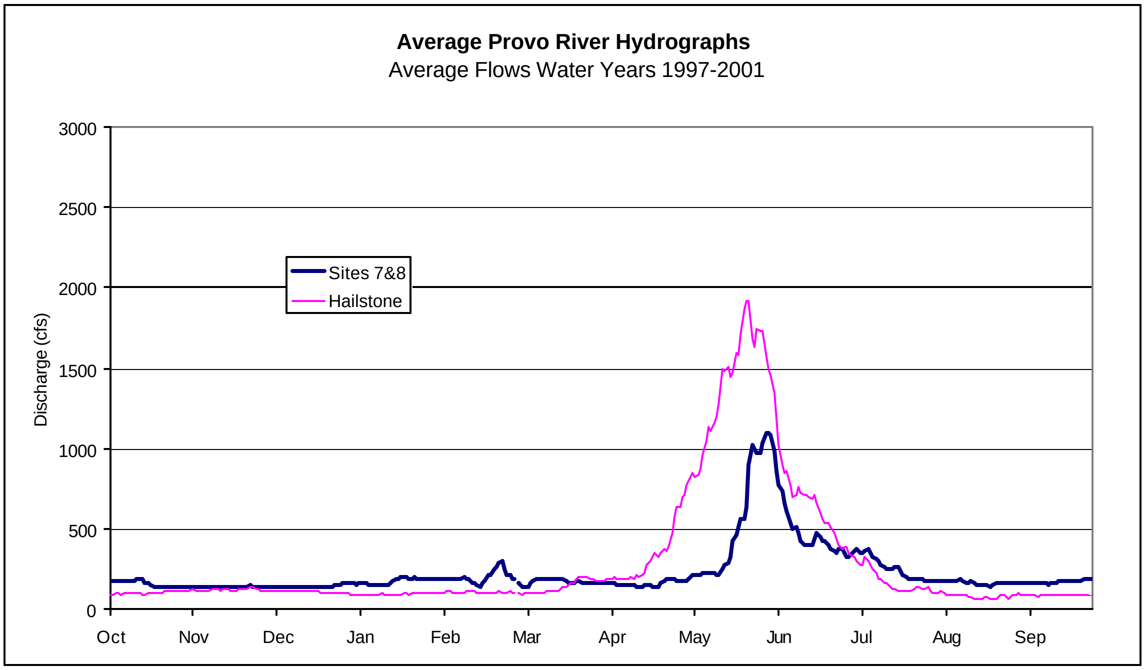


Figure C2. Average Provo River Hydrographs for Water Years 1997-2001.

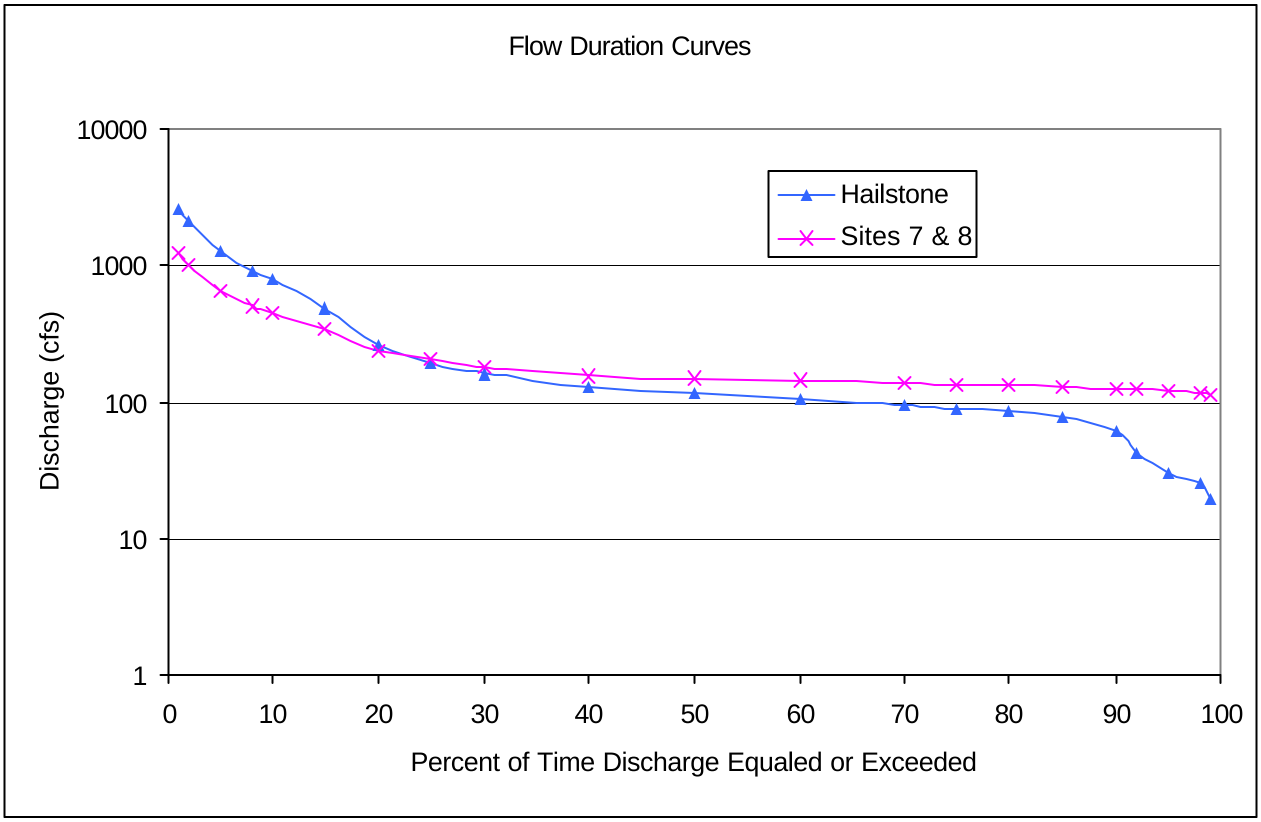


Figure C3. Provo River flow duration curves.

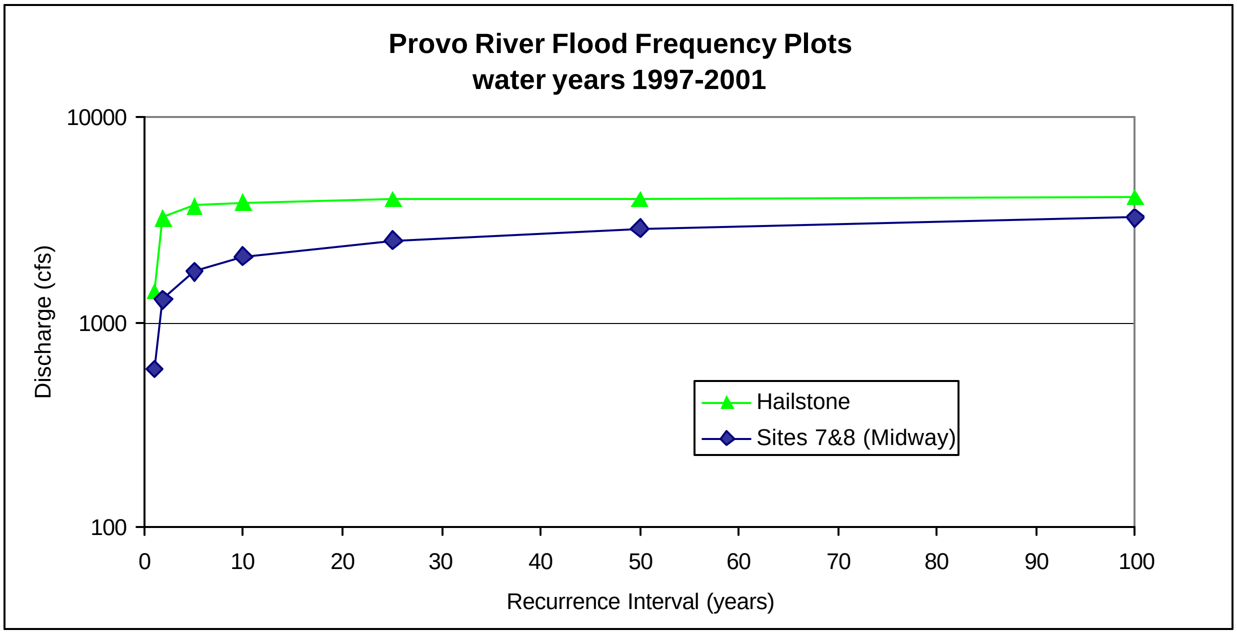
Therefore, the full data set available was used to provide a second set of flood values that incorporate longer-term climatic variability into the analysis. The data set for the Midway gage only includes water years 1996-2001; therefore, only the results of the 1997-2001 frequency analysis are presented. For completeness, long-term flood frequency values are also presented for the Charleston gage, which is located downstream from Site 7 (Map 1.3) and has a longer period of record. However, flows at the Charleston gage are typically higher than the flows at Sites 7 and 8 due to inputs from groundwater sources.

Table C3. Flow duration data for Provo River sites.

Percent Exceedence	DISCHARGE (cfs)	
	Sites 7 & 8	Hailstone
99	111	19
98	115	25
95	122	30
92	126	43
90	127	60
85	131	78
80	134	85
75	136	90
70	138	95
60	142	105
50	147	116
40	153	130
30	179	161
25	202	193
20	233	262
15	348	494
10	452	797
8	506	922
5	639	1283
2	996	2060
1	1240	2563

Table C4. Flood frequency values for Provo River gages.

Recurrence Interval (years)	Provo River near Midway	Provo River at near Charleston		Provo River near Hailstone	
	recent 1997-2001 (cfs)	recent 1997-2001 (cfs)	long-term 1938-1950; 1992-2001 (cfs)	recent 1997-2001 (cfs)	long-term 1950-2001 (cfs)
1	589	647	504	1414	684
2	1284	1383	1347	3208	2613
5	1758	1911	1773	3669	3298
10	2086	2286	2014	3835	3573
25	2518	2792	2281	3959	3795
50	2850	3192	2458	4014	3901
100	3193	3610	2618	4050	3974



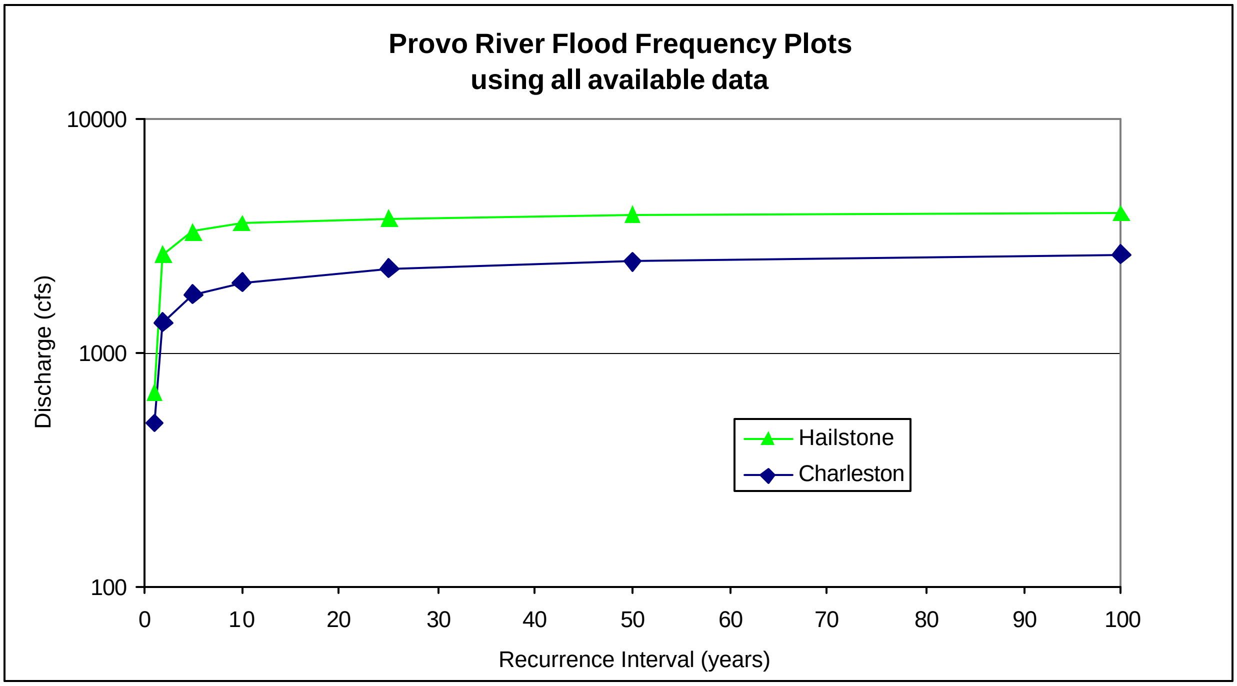


Figure C4. Flood frequency curves for Provo River gage sites.