WINTER FLOW RECOMMENDATIONS FOR THE SHOSHONE RIVER BELOW BUFFALO BILL DAM

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EXECUTIVE SUMMARY

The Shoshone River is an exceptional "blue ribbon" fishery. Less than 3% of Wyoming's streams are in this class defined by a high mass of sport fish per mile (Annear et al. 1999). Anglers annually spend over 11,000 days pursuing trout on the river, putting this fishery on par with other top Wyoming trout fisheries like the "Miracle Mile" and upper North Platte River. Anglers spent over $609 million in Wyoming in 2001 (Wyoming Game and Fish Department 2002) and over 5% of all 2001 fishing license sales were in Park County. Economic estimates for aquatic recreation expenditures in Cody and Park County are between $19 million and $35 million. These estimates highlight the importance and role of the Shoshone River tailwater fishery.

Winter Shoshone River flow releases downstream from Buffalo Bill Reservoir depend on the amount of water stored in Buffalo Bill Reservoir and an operating agreement signed in March 1994 by Wyoming's Governor and the Bureau of Reclamation (BOR), U.S. Fish and Wildlife Service, Wyoming Water Development Commission (WWDC), State Engineer, and Wyoming Game and Fish Department (WGFD). This agreement (Appendix B) outlined winter instream flow releases that were to be provided under defined reservoir inflow conditions for a ten-year period. During the 10-year period, further studies were to be conducted by the WGFD to define winter flow needs; this document provides the results of those studies and is meant to help the state of Wyoming and the federal government develop a water marketing plan and reservoir operating plan that meets the needs of the State by supporting valuable fisheries resources as well as providing for irrigation, municipal and industrial water uses.

Shoshone River flow recommendations for the winter period (October 1 to March 31) were developed after examining multiple factors for relationships to flow quantity. The evaluation of winter Shoshone River flow needs followed guidance provided by the Instream Flow Council (Annear et al. 2002a) by examining the influence of hydrology, biology, geomorphology, water quality, and connectivity on the fishery. Subsections of this report describe hydrology for both the Shoshone River below Buffalo Bill Reservoir and for the reservoir, assess winter flow-related patterns in water temperature and hydrogen sulfide concentration, assess relationships between winter flow and trout populations, define trout

habitat availability and use, simulate trout habitat availability over a range of potential winter flows, define invertebrate prey availability, and describe relationships between angler use and flow. This report also contains a general assessment of economic values associated with water uses.

The Shoshone River tailwater studies on hydrology, geomorphology, water quality, and biology in combination with public preferences reinforced one another and converged at a flow recommendation of 440 cfs at USGS gage #06282000. This equates to a release of approximately 380 cfs at the Buffalo Bill Power Plant release point. Based on PHABSIM results, 440 cfs would maintain high habitat indices for both brown and cutthroat trout. Lower flows would maintain an index of cutthroat trout habitat down to 340 cfs but brown trout habitat would decline. Higher flows would maintain relatively high levels of habitat but are not necessary.

The recommended 440 cfs would provide wading anglers with the opportunity to access much of the river while higher flows would limit wading access. Lower flows would provide greater wading access but decrease trout habitat quantity and quality and encourage trout over-harvest. Lower flows would also limit kayaking and float fishing, important to the local guiding business.

Hydrogen sulfide concentration and dissipation in the Shoshone River is independent of stream flow. Water temperature is an important consideration and the lower the stream flow the higher the water temperatures and the greater the stress on trout. At 440 cfs, water temperatures are about 42-44ºF and may be high enough to cause loss of body condition. Temperature data collected during winter 1997-1999 show water temperature rises rapidly as flows decrease. Therefore, any flow less than 440 cfs would negatively affect trout body condition. Higher flows would result in cooler water temperatures and allow trout to maintain greater body condition. The physiological advantage provided by flows higher than 440 cfs is not as distinct as the disadvantage of flows lower than 440 cfs.

Brown trout spawning area is high at 440 cfs. A higher flow of 480 cfs would maximize brown trout spawning habitat in the region near the mouth of Sulphur Creek. Higher flows increase spawning habitat in the main river channel but such higher flows may not be necessary given that the historic flow regime has largely maintained wild brown trout reproduction and flows are normally at least 400 cfs during the October and November spawning period. Population data suggest that brown trout numbers are higher following years with October flows higher than 440 cfs. Flows less than the recommended 440 cfs would result in rapid declines in brown trout spawning habitat.

Flow stability is perhaps the most important issue for brown trout reproductive success. Once the winter flow level is set in early October, it must be maintained without significant changes to ensure that trout eggs and larvae remain viable. The data show that if the coefficient of variation among daily flows during October can be maintained below 20%, brown trout populations benefit.

The proportion of pool, riffle and run habitats is insensitive to flow level. At 440 cfs, runs comprise about 80% of the wetted area, pools 7% and riffles 13%. While the relative proportions do not change substantially, the area of each decreases as flow drops. Riffles are a particularly important source of invertebrate prey items ("food") for trout. From Dare (2001), over half of the area classified as riffle at 447 cfs was lost when flows were reduced to 226 cfs. Riffle area losses should be avoided because Shoshone River trout already experience a high metabolic cost from warm water temperatures. Reducing available food by reducing riffle area at flows less than 440 cfs would further compromise trout condition.

For flow management purposes, the river can be divided into 2 reaches: an approximately one-mile long reach from the base of the dam where the Shoshone Power Plant discharges water downstream to the Buffalo Bill Power Plant discharge point. The second reach is from the Buffalo Bill Power Plant discharge point downstream to Corbett Dam, a distance of about 17.5 miles. The fishery upstream of the Buffalo Bill Power Plant discharge point is important as some anglers enjoy the relative seclusion and angling opportunities of this river reach (Steve Yekel, Pers. Obs.). This fishery should be maintained through continuation of the delivery of at least 100 cfs from the Shoshone Power Plant stipulated in the Annual Operating Agreement (AOA) and evaluated by Vogt and Annear (1991).

Vogt and Annear (1991) determined that 350 cfs at the Buffalo Bill Power Plant, as stipulated in the AOA, would maintain the Shoshone River tailwater blue ribbon fishery. Due to accrual from DeMaris Springs, 350 cfs at Buffalo Bill Power Plant translates to about 410 cfs at the USGS gage assuming 60 cfs of spring contribution (Vogt and Annear 1991). Therefore, the 440 cfs recommendation resulting from our intensive work is only 30 cfs (7.3%) higher than the results from the original instream flow analysis. To achieve 440 cfs at USGS gage #06282000, we estimate the BOR would need to provide a total flow of 380 cfs from the Buffalo Bill Power Plant release point.

Average discharge at USGS gage #06282000 between October 1 and March 31 over the 30-year period 1973 to 2002 is 444 cfs. The average minimum daily winter flow over this period is 277 cfs. A flow of 414 cfs is exceeded 50% of the time based on the 30-year period of winter flows. The recommended 440 cfs is exceeded 44% of the time during the winter months of the 30-year period.

Hydrology simulations by the BOR for release scenarios ranging from 100 to 400 cfs indicate that under releases of 100 and 200 cfs, the reservoir stores water in nearly all years and may increase in elevation 10 or more feet. Given a release of 50 cfs from the Shoshone storage account and the remainder from the State storage account, the BOR simulations reveal that the state account cannot support a release of 300 cfs under the climatic and use conditions that occurred in water years 1989 and 1990. Given the same assumptions, the state account cannot support a release of 400 cfs under the climatic and use conditions that occurred in water years 1978, 1986, 1988-1990 and 1994.

Elevation reductions under any of the studied releases are not likely to have negative effects on lake trout recruitment. Reservoir operating criteria and flow recommendations need to be developed for low inflow periods like 1988 to 1990 when a flow release of 380 cfs could probably not be sustained.

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INTRODUCTION

Buffalo Bill Reservoir and the waters of the Shoshone River have been important resources for the people of Park County and Wyoming since the project was completed in 1910. When first constructed, the reservoir could store 456,600 acre-feet but siltation decreased that substantially over the years. Renovation and expansion completed in 1993 raised the dam 25 additional feet resulting in a present day total storage capacity of 646,565 acre-feet with 604,817 acre-feet of active capacity. Initially, the primary benefit was availability of a reliable source of late season water for irrigation and development of the local economy. Commensurate with this benefit was the development of high quality fisheries in the reservoir and downstream river. Over time, the importance of aquatic wildlife resources to the local economy has grown to the point that residents from across the U.S. and beyond find angling opportunities in the Shoshone River and Buffalo Bill Reservoir a popular destination point (Dean Runyan Associates, 2001).

The enlargement of Buffalo Bill Reservoir in the early 1990s created 189,965 acre-feet of available storage space for the State. This space provides a reliable annual supply of about 74,000 acre-feet of "new" water for marketing at the mouth of the Bighorn River according to the final EIS for the project (Department of Interior 1981). Plans for the dam were initiated in the early 1970s in response to anticipated new energy development in the Yellowstone River drainage. The need for more water to accommodate that development seemed imminent. Enlarging Buffalo Bill Reservoir was one of the best and most economical alternatives to meet that need. However, by the time the dam was completed in 1993, the anticipated energy boom had diminished and the need for additional municipal and industrial (M and I) water had waned. As a consequence, the state was left with a large quantity of storage water to use for municipal and industrial purposes in the town of Cody and Park County in general.

Construction of this latest enlargement, like most reservoir construction projects, was not a simple process absent considerable public debate. The issue of quantity and certainty of instream flow releases from the dam was (and continue to be) at the forefront of discussion and debate. For various reasons, this project did not include features to mitigate the loss of inundated river fisheries in parts of the North and South Forks of the Shoshone River. The National Wildlife Federation (NWF), in a 1990 letter to Governor Mike Sullivan, argued that the 1981 Final Environmental Impact Statement (FEIS) did not adequately protect instream flow in the Shoshone River below the dam. The NWF proposed an amendment to the federal funding authorization bill that would provide additional assurance for instream flow. Rather than support "heavy-handed federal directives such as represented by the amendment to control Wyoming's waters"(quoted in Casper Star Tribune, March 4, 1990), Governor Sullivan provided assurances to federal leaders that the state would adequately address this issue under state water law and implement appropriate flows (Appendix A).

In response to this commitment, the Wyoming Game and Fish Department (WGFD), Wyoming Water Development Commission (WWDC), State Engineers Office (SEO), Bureau of Reclamation (BOR) and U.S. Fish and Wildlife Service (USFWS) produced a revised annual operation agreement (AOA) for the reservoir that was signed March 1, 1994 (Appendix B). The agreement was different from previous annual operating agreements in place since 1982 in that it outlined instream flow releases that were to be provided under defined reservoir inflow conditions for a ten-year period through March 1, 2004. The terms of a contractual repayment agreement between Wyoming and the United States allow the state to defer payment during the 10-year period. The state could have elected to market water to downstream users during this period but would have suffered an economic penalty in the form of an obligation to repay a proportionate share of the money the state borrowed from the United States to acquire the contract right to market water in the 190,000 acre-foot space. Wyoming would also have been obligated to pay a proportionate share of the annual operating and maintenance expenses of the project. The AOA stipulated that the WGFD would conduct additional studies during the 10-year interim period to refine their earlier instream flow assessment (Vogt and Annear 1991). Results from those additional studies by WGFD were to be incorporated into a state water marketing plan at the termination of the interim 10-year period.

The purpose of this report is to comply with the terms and requirements of the 1994 AOA and the promise of former Governor Sullivan and provide a more detailed analysis of winter instream flow needs in the Shoshone River that will fairly protect the state's fishery interests in the river and in Buffalo Bill Reservoir. To accomplish that purpose, this report begins by providing a detailed explanation of instream flow concepts and guidelines recently developed by the Instream Flow Council – a group of state and provincial fish and wildlife agency instream flow experts from the U.S. and Canada. The report also provides a detailed analysis of the relationship between various flows in the river below the dam and water quality, fish behavior, and fish habitat. Additionally, the report discusses the trade-offs between different reservoir releases and the effect on reservoir storage, fisheries and recreational opportunities. Lastly, the report contains a cursory assessment of economic opportunities associated with fisheries in Buffalo Bill Reservoir and the Shoshone River. Results from this report will be one of several factors considered in the state's water marketing plan that will be developed for the storage water provided by the most recent enlargement of Buffalo Bill Dam.

INSTREAM FLOW CONCEPTS

The Instream Flow Council (IFC), a group comprised of state and provincial fish and wildlife agency instream flow experts, advise that instream flow studies to maintain fishery values should clearly identify the purpose of instream flow prescriptions and acknowledge the role of 5 riverine components when developing flow recommendations (Annear et al. 2002a). The five riverine components are hydrology, biology, geomorphology, water quality, and connectivity. The IFC also advises that it is important to gather public input to understand and meet their expectations to the extent possible according to biological limits and ecological constraints. The issues associated with each of the five riverine components can be simple or complex depending on the unique characteristics of a particular instream flow needs assessment. See Annear et al. 2002a for a full treatment of these components.

Fisheries scientists define a fishery as "the interaction of aquatic organisms and aquatic environments and their human users to produce sustained benefits for people" and "a dynamic product of physical, biological, and chemical processes. Each component (process) is important, affects the other, and presents opportunities for impacting or enhancing the nature or character of fishery resources" (Annear et al. 2002a). Hydrology is the driving element affecting a fishery; however, the structure and function of a fishery is also intimately linked with four other riverine components: biology, geomorphology, water quality, and connectivity.

The term "hydrology" can be generally defined as the movement of water over and under the land surface and includes the variety of geomorphic, geochemical, and biological processes that depend upon the storage and movement of water (from Dunne and Leopold 1978). The timing, seasonality and rate of change of stream flows are especially important aspects of hydrology (Stanford et al. 1996, Poff et al. 1997). Another hydrological consideration according to the IFC is ground water and how it interacts with surface water. The influence of DeMaris Springs on Shoshone River streamflows provides an example in the context of this report. Finally, releases of stored water from reservoirs to provide instream flows can affect reservoir fisheries by reducing the quantity of water available in the reservoir at times of the year.

Geomorphology pertains to the form and function of the stream channel. Hydraulic habitat for fish and other riverine organisms is provided by the shape and structure of the channel (width, depth, number of pools, etc.) and the water that flows through it. Geomorphic processes are a direct function of the quantity of water flowing through a stream system and sediment and bedload types and quantities.

Streams that transport all the bed materials that enter them over time are said to be in a condition of sediment equilibrium. When either the water or sediment supply is changed, stream channels may either aggrade or degrade depending on the manner and extent of alteration (Dunne and Leopold 1978). Instream flow studies that focus on habitat-discharge relations also need to address the dynamic nature of channels.

Water quality relationships to flow level are also an essential component of determining instream flows. Of the various physical and chemical characteristics that determine the river's biological productivity, dissolved oxygen, sediment and water temperature are usually the primary constituents of concern in natural systems. The combination of these and other chemical characteristics of rivers influences fish migration, distribution, spawning, timing and success of incubation, maturation and growth, inter- and intra-specific competition, proliferation of disease and parasites, and other lethal factors and synergisms (Fry 1947, Armour 1991). Artificial stream flow changes can alter ambient water temperatures. In the summer, reduced flows can result in elevated water temperature that can significantly affect species survival and growth. In winter, super-cooled water (<0° C), of which frazil ice is an indicator, can cause physical as well as physiological stress and mortality to some fish species and life stages.

Biology is often the primary focus of instream flow assessments. The timing, quantity, and quality of water flowing in streams affect the growth and survival of all riverine organisms including fish. Instream flow studies identify which aquatic species receive primary consideration (e.g. game fish species or non-game fish species, or other organisms like aquatic macroinvertebrates or even aquatic macrophytes). Studies may also be designed to address effects on groups of organisms. Biological studies can range from simple quantification of available habitat at a range of flows to a more complex consideration of, for example, the response of aquatic organisms to changes in stream flow or water quality in terms of behavior, recruitment success, or growth and survival (Annear et al. 2002a).

Connectivity refers to the pathways that move or link organisms, nutrients, and organic and inorganic matter throughout a river basin. As with hydrology, river system connectivity is manifested along four dimensions: longitudinal, lateral, vertical, and temporal (Ward 1989). The inter-related components of watershed, hydrology, biology, geomorphology, and water quality, together with climate, determine the flow and distribution of energy and material in river ecosystems. When developing instream flow prescriptions, studies should account for the presence of physical (including hydrologic barriers caused by low flow), chemical, and even biological barriers to connectivity and document to the extent possible the effects of those disconnections on the fishery as a function of stream flow.

<u>Public Involvement</u>

Fisheries management includes the public and their expectations and uses of riverine resources. This fact is rooted in Title 23 of Wyoming statutes that convey a responsibility to the Game and Fish Department to manage wildlife resources for the benefit of the state's citizens. The public's interest in water resources of the state are also noted in the Wyoming Constitution, in particular Article 1, Section 41 that says "Water being essential to industrial prosperity, of limited amount, and easy of diversion, its control must be in the state, which, in providing for its use, shall equally guard all the various interests involved". As a consequence instream flow studies could consider human uses, expectations and values of the aquatic ecosystem that are consistent with maintaining the ecological integrity of the system. Questions to answer might include: how do people use the river and level(s) of flow is/are needed to afford that level of use? What level of flow do they expect to see when frequenting the riverine environment? What are their values associated with the river (monetary, esthetic)? Answers to these questions may change seasonally.

METHODS

Research Summary

Primary investigations contributing to the winter (October through March) instream flow recommendations in this report are listed in Table 1. These investigations were conducted by or funded through the WGFD to better understand relationships between flow and fishery response. Specific methods and results are described briefly but see the original reports for detailed methods.

Table 1. Research supporting development of winter Shoshone River instream flow recommendations.

Report	Information
Vogt and Annear (1991)	Original instream flow report identifies tradeoffs between flow and habitat and evaluates operating agreement impact to reservoir and Shoshone River.
Pedlar (1985)	Measured hydrogen sulfide concentrations in the Shoshone River at multiple locations and flows.
Dare (2001) – Chapter One	Described hydrogen sulfide concentrations relative to discharge, locations and movements of cutthroat trout and brown trout during two winters.
Dare (2001) – Chapter Two	Described brown trout and cutthroat trout mesohabitat and microhabitat use.
Dare (2001) – Chapter Three	Described water temperatures, habitat availability, use, and movement by brown and cutthroat trout under alternate winter discharge regimes.
Hebdon (1999)	Defined drifting invertebrate prey availability, and trout diet and body condition during the fall and winter of 1997-1998.
Yekel (2003)	Conducted annual fall trout population estimates and relation to previous winter flows.
Dey and Annear (this report)	PHABSIM modeling of habitat availability as a function of flow. Various results synthesized and winter flow recommendations developed.

Study Area

River distances between key Shoshone River features were measured at 1:24,000 scale using AllTopo©. Distances were measured twice by two individuals and the average of the 4 measurements are reported in Table 2. The distances are different from those reported in the earlier draft report and in other sources but more accurately represent true stream distances. The Shoshone River flows for approximately 18.5 miles from Buffalo Bill dam downstream to the Corbett Diversion Dam (Figure 1, Table 2). This river section is classified by the WGFD as a blue ribbon trout fishery. This designation is based on the number of adult trout per mile as described in a Department report by Annear et al. (1999). Blue ribbon fisheries are rare in the state, comprising less than 3% of all miles of trout streams. Blue ribbon fisheries are recognized nationally as premium quality streams making them and surrounding communities a destination point for nonresidents. Maintenance of these high quality fisheries is a high priority to the department.

Four non-peaking hydropower plants operate below Buffalo Bill Dam: Shoshone Power Plant at the base of the dam, Buffalo Bill Power and Spirit Mountain Power Plants about 1-mile from the dam, and Heart Mountain Power Plant about 3.5 miles from the dam. The latter three facilities are supplied water via a large conduit from the reservoir to the Heart Mountain Irrigation District canal. Pressurized water is diverted to the Buffalo Bill Power Plant year round while the Spirit Mountain and Heart Mountain Power Plants only generate electricity during the irrigation season. While the pressurized conduit is normally watered up year round, in low flow years operational practice has been to release water only through the Shoshone Power Plant (or through dam outlets when maintenance is being performed on the Shoshone Power Plant) and the only water delivered through the conduit is to the

Shoshone Municipal Pipeline. Therefore, winter flows in the Shoshone River through Cody depend on releases at the Shoshone and Buffalo Bill Power Plants and the relative amounts of those releases in recent years have depended on water conditions.

Table 2. River distances (miles) between Shoshone River features.

Buffalo Bill Dam to:	**Miles**
Buffalo Bill Power Release	~1.0
DeMaris Springs	4.3
USGS Gage 06282000	6.3
Sulphur Creek	7.5
Highway 120 Bridge	9.4
Corbett Dam	18.5
Derived Reach Distances:	
USGS Gage to Corbett Dam	12.2
Sulphur Creek to Corbett Dam	11.0

Winter Shoshone River flows through Cody also depend in part on groundwater, particularly DeMaris Springs (Figure 1), located about 4 miles downstream from Buffalo Bill Dam. Though the flow from these springs has been known to vary, these hot springs contribute approximately 60 cfs to the total stream flow measured 2 miles further downstream at USGS gage number #06282000 (Vogt and Annear 1991). From the gage to Corbett Dam, additional winter accrual from surface and groundwater averages 116 cfs but reaches a minimum in January (Vogt and Annear 1991).

The Shoshone River downstream of USGS gage #06282000 is readily accessible for float fishing. Upstream, the Shoshone River is confined to a narrow canyon with limited boat and foot access. Trout are absent from approximately 3 miles of the Shoshone River between DeMaris Springs and the downstream terminus of a hydrogen sulfide plume extending from the Springs to about Sulphur Creek. Therefore, the highest-value public fishery begins 7.5 miles downstream from the dam, approximately where Sulphur Creek combines with the Shoshone River, and extends downstream to Corbett Dam. Potential effects on the river fishery downstream from Corbett Dam are not a part of this report.

The investigations summarized in this report (Table 1) occurred within a study reach extending from approximately DeMaris Springs downstream to a point a short distance below the Highway 120 Bridge (Figure 1). Specific boundaries of individual investigations are defined within the original reports.

Winter instream flow recommendations developed in this report refer to flows measured at USGS gage #06282000. As a consequence, all uncontrolled inflows to the Shoshone River between the dam and this gage, such as those arising from DeMaris Springs must be accounted for to determine the amount of water to release from Buffalo Bill Dam to meet recommended flows.

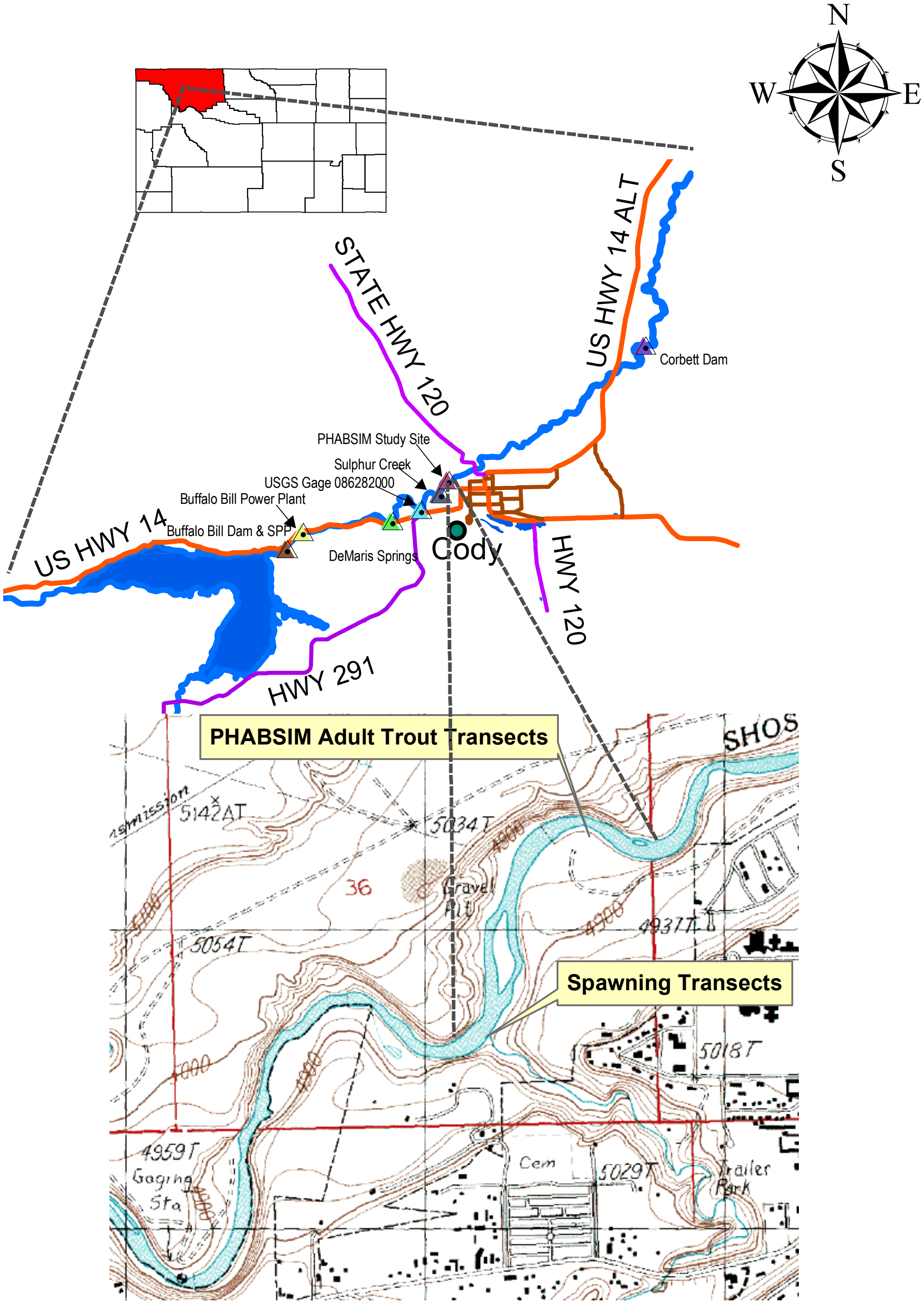


Figure 1. Shoshone River from Buffalo Bill Dam to Corbett Dam and location of PHABSIM study transects.

Hydrology

Buffalo Bill Reservoir – BOR Model Simulations

The BOR, Mills, Wyoming office, provided model output from their Buffalo Bill Reservoir annual operation plan model (BBRAOP) to simulate reservoir storage elevations and energy production under 4 requested flow release scenarios. The four scenarios modeled were releases of 100, 200, 300, and 400 cfs for the October 10 to March 31 non-irrigation season using historic inflow conditions for the 31 year period 1971-2001. The BOR's methods and assumptions in performing the modeling runs are included under Appendix C. Water released for non-irrigation season flow simulations was withdrawn in the following manner: the first 50 cfs from the Shoshone account and the remainder from the State account.

The WGFD requested the flow scenarios ranging from 100 cfs to 400 cfs to bracket the range of winter flows that most likely will be provided in the Shoshone River below Buffalo Bill Dam. It is important to note that these are not necessarily the only flow scenarios that will or should be considered and they are for preliminary planning only. We anticipate that this information will be used to further refine water management strategies and that those strategies may involve various reservoir elevation and natural inflow triggers to provide one or more different release scenarios depending on hydrologic conditions.

Shoshone River Below Buffalo Bill Reservoir

Stream flow data were used to document and discuss present and historical release patterns, characterize winter flows during instream flow studies, identify relationships between flow characteristics and fish population changes, and evaluate the effects of potential future winter release patterns. Monthly mean, maximum and minimum discharges for the Shoshone River below Buffalo Bill gage 06282000 were extracted from published USGS Water Resources Data (Swanson et al. 2002) for three periods of water years: 1943-2002, 1973-2002, and 1991-2002. The start date in water year (WY) 1943 reflects the period after diversion began to the Heart Mountain Canal over 2 miles upstream from the study area. The 1943-2002 period provides a representation of long-term water availability and usage patterns. The 1973-2002 period is a relatively long-term period that is reflective of present-day usage and availability patterns. This 30-year period will provide the baseline for discussing general aspects of Shoshone River winter hydrology. Finally, hydrology during the 1991-2002 period is provided and discussed separately because the bulk of the studies referenced in this report were conducted during those years. Hydrology statistics were especially important for the 1991-2002 period to help understand relationships to trout populations sampled during this period.

Duration frequency was calculated using the program SWSTAT available from the USGS. Flow durations for the three periods described above were calculated using winter daily flows. To characterize winter flow variability during the 1991-2002 period, 7-day maximum and minimum flows were calculated for each winter by averaging the 7 highest (or lowest) consecutive daily average flows. This metric is less sensitive than maximum or minimum daily flow to short-term fluctuations. Calculating the coefficient of variation (CV) around mean winter flows for each water year provided further characterization of winter flow variability. Mean October and November flows and CV's were calculated and used in comparisons to fish population metrics.

Flow recommendations in this report refer to flows measured at USGS gage #06282000. Groundwater contributes approximately 60 cfs of flow into the Shoshone River upstream of the gage and downstream of the Shoshone Power Plant and Buffalo Bill Power Plant (BBPP) flow release points (Vogt and Annear 1991). Therefore, to calculate flow releases necessary to achieve target flows at the gage, 60 cfs of groundwater flows must be subtracted from the target flow recommendations. Also, simulated releases in the BOR report do not include the 60 cfs of groundwater. Since actual groundwater contribution may vary from the estimated 60 cfs on a seasonal and annual basis, achieving target flows at USGS gage 06282000 may require continued monitoring and slight adjustment of releases over the winter period.

Geomorphology

Scientists have recognized the value of considering geomorphic characteristics of the stream channel such as meander pattern, slope, bankfull width and depth, and particle size distribution, in developing stream flow prescriptions below dams, (Trush and McBain 2000). Management toward a semblance of a natural and dynamic channel contributes toward a diversity of aquatic and riparian habitats and biological communities. Such management below dams may include, if below-dam sediment sources are available, peak flow prescriptions meant to mobilize sediment on a prescribed basis (Kondolf 1998). Flow prescriptions may also target overbank flooding with specific timing and rate of flow recession for encouraging cottonwood or other riparian vegetation formation (Rood et al. 1999, Polzin and Rood 2000). Often, a geomorphic goal of flow prescriptions is to achieve a long-term balance between sediment import and export through the reach of interest below the dam (Kondolf 1998, Osmundson 2001).

Maintaining channel patterns and processes was judged to be a relatively minor consideration in developing flow recommendations for the Shoshone River below Buffalo Bill Dam. The upper several miles of the reach is tightly canyon-bound with little perceived need or possibility of channel maintenance. Downstream, the channel remains constrained by its canyon but the canyon is wider and additional features such as point bars, a few islands/side channel complexes, and small floodplains are evident. Cursory visual inspection of these features during instream flow studies did not indicate that significant geomorphic changes are occurring under the present flow regime. With some uncertainty, it is plausible to hypothesize that sediment supply downstream of Buffalo Bill reservoir may be limited for prescribing channel maintenance flow recommendations. Such geomorphic recommendations would fall outside the scope (no geomorphic data were collected) and purview (studies pertain only to winter) of this report.

Another aspect of geomorphology considered below dams is the need for flushing flows. Flushing flows are defined as short-term flows of a magnitude and duration sufficient to flush fine sediment from the surface of gravel and cobble in riffles (Reiser et al. 1989). These flows are often specifically tailored for improving fish habitat by improving the suitability of gravel and cobble for spawning and rearing young fish life stages and aquatic insects. The Bureau of Reclamation has implemented flushing flow prescriptions for the North Platte River below Alcova Reservoir and also for the Bighorn River below Boysen Reservoir. The primary goal of those flushing flows is to improve wild rainbow trout reproduction though releases can provide benefits to fall spawning fish like brown trout (Wenzel 1993). Managing releases to provide flushing flows for wild rainbow and brown trout recruitment in the Shoshone River is not now a fishery management goal in the Shoshone River. Therefore, flushing flows were not considered in developing winter flow recommendations for the Shoshone River below Buffalo Bill Dam. If fishery management objectives change in the future, then flushing flow studies followed by specific recommendations may become a water management option for consideration.

Water Quality

Water quality during the winter in the Shoshone River downstream of Buffalo Bill Reservoir was specifically addressed in developing flow recommendations. The traditional suite of water quality parameters that may change as a function of flow include sediment, temperature, dissolved gases, and the concentrations of various chemical constituents. Of these, two water quality parameters were judged to warrant examination and documentation in closer detail: hydrogen sulfide (H_2S) and water temperature.

Hydrogen Sulfide

As noted earlier in this report, DeMaris Springs is a cluster of geothermal springs that on average contribute approximately 60 cfs of H_2S-enriched water to the Shoshone River (Figure 1). Pedlar (1985) reported that at Shoshone River discharges between 100 and 1600 cfs, H_2S concentrations immediately downstream of DeMaris Springs greatly exceeded the lethal concentration for trout. Cody regional fishery managers have long noted the absence of trout in a short reach below the springs but a sudden presence of trout further downstream, below a large riffle. Hypothetically, the H_2S plume may extend downstream further at lower discharges as the H_2S-enriched water constitutes a larger percentage of the total discharge. This could cause direct trout mortality, fish displacement, and indirect mortality. To assess the relationship between the extent of H_2S influence and discharge, a study was funded by the WGFD through the University of Wyoming Cooperative Research Unit during the winters of 1997-1998 and 1998-1999 (Dare 2001). Methods for this study involved monitoring H_2S at several locations and discharges. Radio-tagged trout movements were also monitored during the same period. For a detailed description of methods, consult Dare (2001).

Water Temperatures

Water temperatures have been recorded in the Shoshone River at various locations, seasons, and flows. The most comprehensive data suited for defining relationships between flow level and water temperature in the Shoshone River downstream from USGS gage 06282000 were collected by Dare (2001). Seven continuously recording thermographs were placed at intervals throughout the Shoshone River study reach and operated from October through February of winters 1997-1998 and 1998-1999. Water temperatures were recorded hourly. Concurrent air temperatures in Cody were obtained by Dare (2001) from the National Weather Service. Discharge in 1997-1998 was held relatively constant at 500-525 cfs while discharge during winter 1998-1999 was manipulated to maintain flow stages of 706, 637, 447, 322, and 226 cfs. Additional methods are in Dare (2001).

Biology

Buffalo Bill Reservoir Fishery

Vogt and Annear (1991) assessed potential impacts to Buffalo Bill Reservoir lake trout (*Salvelinus namaycush*) spawning success associated with the 1991 reservoir operating agreement. A similar analysis of anticipated reservoir water surface elevations under various release scenarios, and the fishery maintenance implications of those elevations, is conducted in this report.

Shoshone River Below Buffalo Bill Reservoir Fishery

The native Shoshone River fish community in the study reach and tributaries consists of Yellowstone cutthroat trout (*Oncorhynchus clarki bouvieri*), mountain whitefish (*Prosopium williamsoni*), longnose sucker (*Catostomus catostomus*), mountain sucker (*C. platyrhynchus*), white sucker (*C. commersoni*), longnose dace (*Rhinichthys cataractae*), flathead chub (*Platygobio gracilis*), fathead minnow (*Pimephales promelas*), and the plains minnow (*Hybognathus placitus*). Additional nonnative species include rainbow trout (*Oncorhynchus mykiss*), brown trout (*Salmo trutta*), Snake River cutthroat trout (*O. clarki sp.*), and the rare lake trout, rainbow/cutthroat hybrid, sand shiner (*Notropis stramineus*), and yellow perch (*Perca flavescens*).

The managed fishery emphasis is on wild brown trout (BNT), rainbow trout (RBT) and Snake River Cutthroat trout (SRC) which are annually stocked at lengths less than 7.0 inches (Yekel 2002). Rainbow trout are not stocked and do not appear to reproduce in significant numbers in the reach but may periodically recruit during spill events from Buffalo Bill Dam (Yekel 2003). Brown trout have not been stocked since 1953 but maintain a population through natural recruitment.

Trout Populations and Winter Flow

Yekel (2003) reports trout population monitoring results for the Shoshone River between 1992 and 2002. Population estimates were conducted in October of each year by electrofishing with a raft-mounted fixed electrode system. Two rafts, one on each side of the river, were used in multiple passes. Additional methods are detailed in Yekel (2003).

Meso and Micro-Habitat Availability

Throughout this document, the term “habitat” is used frequently. In most cases, the term refers to the physical conditions provided by water depth, water velocity, substrate and cover – variables that change as a function of discharge. A full understanding of trout “habitat” also includes temperature, dissolved oxygen, distribution and abundance of prey and competitor species, movement timing and extent, and other variables and throughout this report we attempt to understand these variables as they influence the relationship between winter flow and the fishery. Habitat modeled with PHABSIM (described below) is more correctly understood to be “physical” habitat and includes the important dimensions of trout habitat that vary predictably as function of flow. The term “mesohabitat” refers to pools, riffles and runs. The term “microhabitat” refers to the depth, velocity, substrate and cover at a single point.

A WGFD funded study by the University of Wyoming Cooperative Research Unit project during the winters of 1997-98 and 1998-99 gathered information on habitat availability under different flow conditions (Dare 2001). Discharge during the 1997-98 data collection period was stable at about 500-525 cfs. In the 1998-99 effort, habitat availability information was collected at 4 discharges: 637-710, 447, 322, and 226 cfs (these discharges were calculated by the primary author from USGS records and differ slightly from discharges calculated by Dare (2001) using Hydromet discharges). Data collected at the highest discharge (637-710) were not reported by Dare (2001) because flow level changed before all transects were sampled. A 3.1-mile-long (5 km) study reach was established with an upstream terminus near the USGS gage (6282000) below Trail Creek and ending downstream of Cody. This reach was divided into 50 segments each 100-m in length and a transect was randomly placed at 0, 25, 50, or 75 m down from the upstream end of each segment. Habitat availability measurements were made within a series of 4-m diameter circles evenly spaced along each transect. The 4-m diameter circle area was selected based on an error of 2-m in locating a fish’s location (Simpkins and Hubert 1998).

Minimum and maximum depth, minimum and maximum water velocity, substrate composition, and cover area were measured within each sampling area. Cover was defined as any area where water depth was at least 1.3 feet and water velocity was less than 0.33 ft/s. Cover types recognized were: 1) boulder, 2) vegetation, and 3) slow water. Slow water cover was any area meeting the cover definition that did not have boulders or vegetation within or adjacent to the sampling area. The sampling areas were also classified as being in one of three mesohabitat types: pool, run, or riffle. Pools were areas having 4.9 ft maximum depth or greater than 2.5 ft maximum depth and less than 1.0 ft/s maximum velocity. Runs were intermediate areas having 1.0 – 4.9 ft maximum depth, intermediate velocities, and no surface turbulence. Riffles were stream areas having less than 1.0 ft maximum depth or less than 2.5 ft maximum depth and greater than 2.1 ft/s minimum water velocity.

Habitat Use

Twenty each brown trout and cutthroat trout (9-12 in TL) were captured by angling and electrofishing between 13 and 17 November 1997 and implanted with radio transmitters (Dare 2001). Fish were located every 2-4 days between November 22, 1997 and February 28, 1998 and fish locations were determined to the nearest 2-m using two-point triangulation (Simpkins and Hubert 1998). Mesohabitat type and microhabitat characteristics of fish locations were measured as described above and in Dare (2001).

During the winter of 1998-99, 38 cutthroat trout and 24 brown trout (8-12 in TL) were implanted with transmitters and habitat use information was collected from December 8, 1998 through February 17, 1999. By December 24 only 9 cutthroat remained within the study section so 14 additional cutthroat were radio-tagged on January 2, 1999.

Fish movement distance between consecutive observations was measured with a tape if less than 328 feet or estimated from 1:24000 maps for movements greater than 328 feet. Map resolution was sufficient to resolve distance measurements to 16 ft. Mean, median, and range of movement distance from pool and run mesohabitat types was calculated.

Simulated Habitat Availability

Data collected by Dare and Hubert (2000) during 1998-99 indicated that run habitat was more abundant than pools and riffles and heavily used during the winter months by both cutthroat and brown trout. Therefore, in November 1999 we selected a run mesohabitat for modeling the relationship between discharge and useable area. A run on the "Stock Property" was selected (Figures 1 and 2) because it contained a diversity of boulder, deep-water, and vegetative cover and because this particular run had abundant fish (Dare, personal communication). The run also featured a cobble-strewn bench on the left side of the channel (looking upstream) that we wanted to evaluate for suitability over a range of discharges. Four transects were established to capture the range of conditions along the run: the most downstream transect (number one) crossed the run where the bench was wide while at the upper-most transect (number 4) the bench was relatively narrow and a deep, fast chute existed on the right. Boulders were strewn throughout the run and they provided variable cover on each transect.

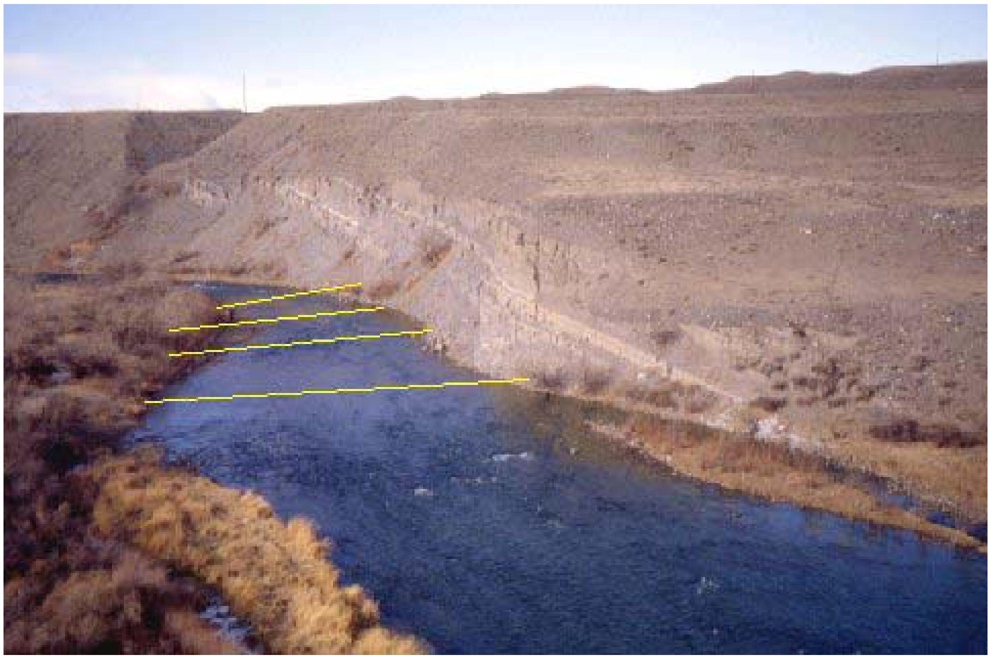


Figure 2. Shoshone River study site focused on run-type habitat. Orientation is looking upstream. Lines indicate approximate location of PHABSIM transects and were numbered from downstream to upstream.

Physical Habitat Simulation Models (PHABSIM) simulate depths, velocities and cover availabilities over a range of flows and combine that information with species and life-stage-specific requirements to predict useable area as a function of flow level (Bovee and Milhous 1978, Milhous et al. 1989). Depths, velocities, and cover type were measured at locations (cells) spaced 1 to 4 feet apart across each transect on the dates and discharges listed in Table 3. Wading completely across the channel was not possible at the high flow level so only water surface elevations were collected. Depth was measured to the nearest 0.1 foot and velocity was measured to the nearest 0.01 ft/s using a Marsh-McBirney Model 2000 flow meter. Cover was defined according to the criteria established by Dare (2001): Pool (areas within a habitat type such as a run that were greater than 1.5 feet deep and had a bottom velocity ≤ 0.30 ft/second), boulder (a boulder within 6 feet on or upstream of the location, depth ≥ 1.5 feet, and bottom velocity ≤ 0.30 ft/s), aquatic macrophytes present, and no cover.

Table 3. Dates and discharges PHABSIM data were collected.

Date	Discharge
November 14, 1999	252
November 15, 1999	436
November 16, 1999	650

Habitat Suitability Criteria (HSC) describe the relationship between depth, velocity, and cover and the perceived value of those parameters to the trout. Observations of cutthroat and brown trout habitat use collected by Dare and Hubert (2000) during winter 1997-1998 were used to develop HSC. Depth, mean column velocity, nose velocity, and cover type were measured at 358 brown trout locations (multiple observations of 14 fish) and 342 Snake River cutthroat trout locations (multiple observations of 16 fish) in run habitat. Frequency of use histograms were created for depth, mean column velocity and nose velocity and the interval (bin) size encompassed by each histogram block was determined from the equation (Cheslak and Garcia 1988, Sturges 1926):

$$C = R / (1 + 3.322 * \log_{10} N)$$

Where:

C = interval size
R = measured range of variable
N = number of observations

The non-parametric tolerance interval method (Bovee 1986, Slauson 1988) was used to develop HSC at a confidence limit of 90%. Suitability was defined on a scale of 0.0 to 1.0 where 1.0 indicates optimal suitability. Suitability scores of 1.0, 0.5, 0.2, and 0.1 were assigned to the central 50%, 75%, 90%, and 95%, respectively, of parameter range. Cover HSC were defined from measurements of percent cover use. Boulder cover was used predominately by brown trout and thus was assigned a weight of "1". Pool cover was used by brown trout approximately 20% as often as boulder cover so pool cover received a weight of 0.2. In practice, any cell without boulders was potentially pool cover. For cutthroat, boulder cover was also used most frequently and received a weight of "1". However, cutthroat used pool cover more frequently than brown trout at a level approximately 50% as often as boulder cover so pool cover was weighted 0.5. During the winter in which these data were collected, relatively little aquatic vegetation was available. Though vegetation may be important cover when it occurs, no data were collected to quantify its potential importance. Therefore, vegetation was not weighted in HSC and the cover code for the few cells in which vegetation was noted on transects was changed to indicate potential pool cover (if simulated depth and velocity was suitable).

The subroutine HABTAV in PHABSIM was used to simulate in 20 cfs increments over a range of flows from 100 to 800 cfs. The VLIM option (**V**elocity **LIM**it) under this program was used to assign a relative value to a location based on the occurrence of nearby fast water. During description of trout locations (focal points), the maximum and minimum mean column velocity within 6.6 feet of the focal point was measured (Dare and Hubert 2000). These data indicated that trout used slow locations near faster water. The VLIM option was set to equal the average of the maximum mean column velocities for each species and the distance was set to 6.6 feet. For example, for brown trout the model looked out a distance of 6.6 feet for a velocity greater than or equal to 2.18 ft/s. If that velocity was found, the location's weighted usable area (WUA) was multiplied by "1". If not found, the model looked again for a second value of 1.54 ft/s (the minimum of the maximum mean column velocities measured within 6.6 feet of a brown trout location). If the lower velocity was found this second time, the WUA was multiplied by a number less than "1" such that the further the found number was from 2.18, the smaller the weight.

A preliminary modeling run was performed for the downstream transect to compare WUA using mean column velocity, nose velocity, and the VLIM option. The VLIM approach produced more defined curves for each species and was adopted for the modeling runs.

Brown trout spawning habitat was modeled using two additional partial transects established about ¼ mile upstream immediately below the mouth of Sulfur Creek (Figures 1 and 3). This location is one of the few areas where small gravel suitable for trout spawning occurs and trout spawning activity (redds) has been observed (Steve Yekel, WGFD, personal communication). The HABTAE sub-routine of PHABSIM was used along with brown trout HSC from Bovee to simulate weighted useable area.

Figure 3. Shoshone River looking upstream at Sulphur Creek confluence. Lines indicate the approximate location of two partial PHABSIM transects for evaluating spawning habitat.

Invertebrate Prey Availability

During the winter of 1997 – 1998, a University of Wyoming Master's student performed aquatic insect drift availability studies during winter on three Wyoming tail-waters including the Shoshone River (Hebdon 1999). This WGFD supported study and a composite report of other department and University studies dealing with trout winter bioenergetics by Annear et al. (2002b) were used to assess the relationship between different flow management patterns, macroinvertebrate availability and trout body condition and survival.

Hebdon (1999) collected drift and trout stomach content samples monthly to characterize the abundance, biomass and species composition of prey items and identify relationships between food availability and trout body condition. Data were collected from the same reach near Cody examined by Dare (2001) and others (Figure 1). Although discharge was constant during Hebdon's study, his results are used in this report to infer food availability at other discharges based on changes in wetted riffle areas measured during Dare's research (Dare and Hubert 2000).

Public Involvement

Formal public involvement was relatively limited. Two presentations were given to the local Trout Unlimited Chapter in response to their expressed interest in the status of biological studies. Input was sought from this group and local angling outfitter Tim Wade as to flows that were preferred or limiting to bank anglers, boat fishermen and kayakers on the river in the winter. Though their input was not technical or scientifically based, their opinions were considered valuable indicators of recreational interests and values in the Cody community. Following review of this draft report by AOA signatories (Governor, BOR, WWDC, SEO, FWS), additional public input and comments will be solicited and incorporated into a final report in 2003.

Economic Analyses

The 1994 Annual Operating Agreement directed the WGFD to conduct economic analyses of instream flow releases. Because instream flow conditions offer significant values to some sectors of the public that are non-monetary, we chose to limit the scope of this task to a fairly simplistic approach. In addition, though some studies exist that document the importance of tourism and aquatic recreation to the community, it is difficult, if not impossible to quantify the precise fishery and recreational economic benefits that can be attributed solely to a winter instream flow in the Shoshone River. As such, the economic benefits we present should be considered only a partial and relatively general assessment of the environmental or fishery values of instream flow.

To assess the relative benefits of a winter instream flow for fisheries purposes, we approached the issue by providing the approximate benefits of a winter instream that would maintain the full productive potential of the Shoshone River and Buffalo Bill Reservoir fisheries. It was not practical to provide an incremental analysis of lesser flows that would maintain incrementally fewer fish and user days by anglers, boaters and others, other than to note that they may not meet public expectations of maintaining a blue ribbon fishery in the river or a high quality reservoir fishery.

RESULTS

Hydrology

Buffalo Bill Reservoir – BOR Model Simulations

By WGFD request, the BOR provided an analysis of reservoir storage conditions during the non-irrigation season under historic (1971-2001) inflow and use conditions (Appendix C). In performing the analysis, the state storage account could support a constant winter release of 300 cfs in all years except 1989 and 1990. The state account could support a release of 400 cfs in all years except 1978, 1986, 1988, 1989, 1990, and 1994. To perform the simulation, the releases in these years were reduced to 100 cfs with 50 cfs drawn from each of the accounts (Appendix C). Therefore, the effects illustrated during these years are not as dramatic as would occur if the 300 or 400 cfs had continued to be released. Average changes in reservoir elevation and the state storage account during the non-irrigation season are less than would have occurred had the 300 or 400 cfs releases continued.

Change in Buffalo Bill Reservoir water elevations following a winter of constant flow releases ranging from 100 to 400 cfs, under historic inflow conditions, is shown in figure 4. Under releases of 100 and 200 cfs, the reservoir stores water in nearly all years and may increase in elevation 10 or more feet. Flow releases of 300 cfs typically result in elevation decreases averaging 0.6 feet (range +5.4' to –5.4'). Winter releases of 400 cfs result in an average elevation decrease of 3.1' (range +11.7' to –8.9). The results from the 300 and 400 cfs release scenarios are tempered by the fact that these releases could not be sustained in all years (see Appendix C).

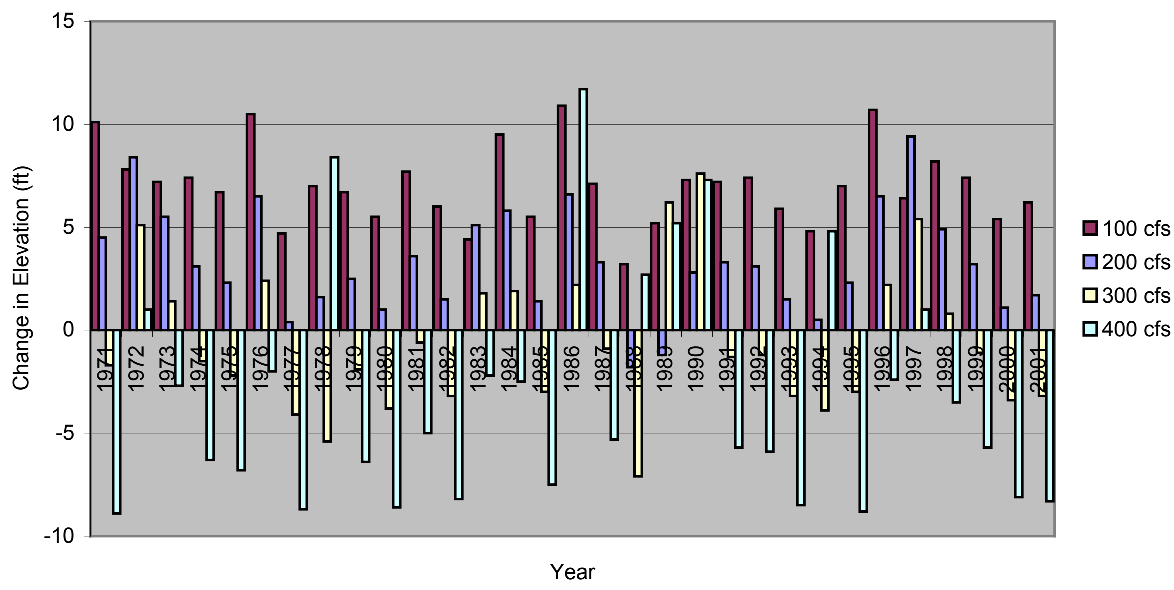


Figure 4. Change in Buffalo Bill Reservoir elevation between October 10 and March 31 for years 1971-2001 based on four flow releases modeled with the BOR's BBRAOP model. Data provided by BOR from BBRAOP model simulations.

The Wyoming State water account in Buffalo Bill Reservoir, 190,000 AF, averages 91% full by March 31 every year under a flow release of 100 cfs (Figure 5). Under a release of 200 cfs, the account averages 71% full and ranges between 14 and 100% at the end of March. In 1990, the storage account would have dipped to 14% of full. The account is filled to 73% or more of its capacity for 26 out of the 31 years modeled (84%). Flow releases of 300 cfs would deplete an average of 55% of the state account by the end of March (e.g. 55% full; range 0% to 92%). Under a flow release of 400 cfs, the account averages 42% full and in most years it is 37% or less of full with a range between 0% and 74% (Figure 5).

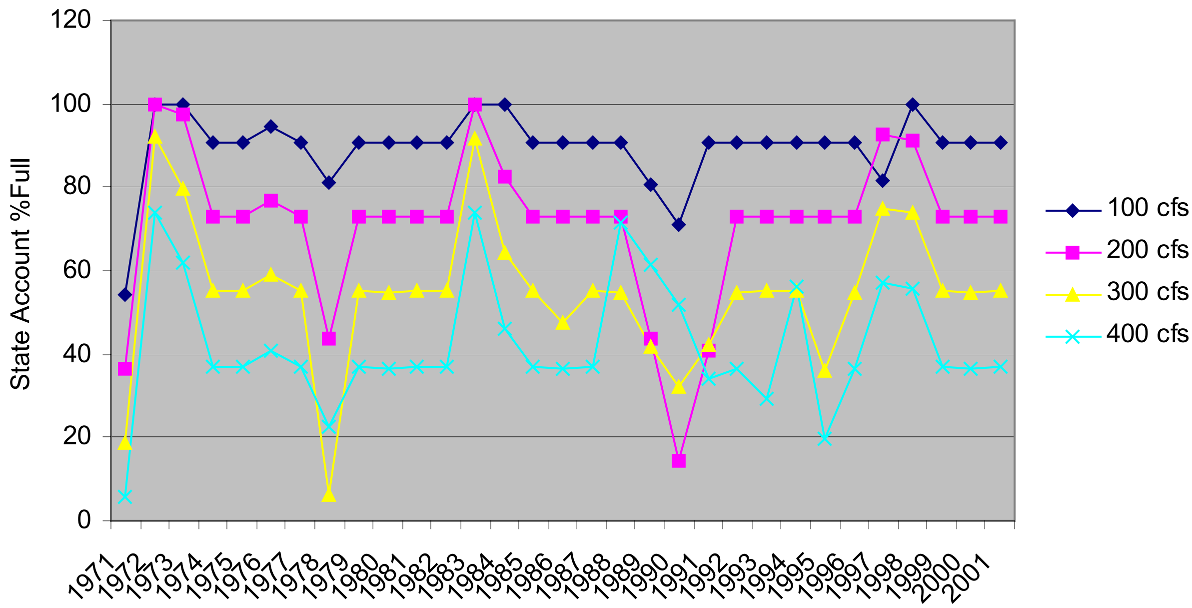


Figure 5. Buffalo Bill Reservoir State Account percent of full (190,000 AF) by March 31 under historic inflows and four flow release scenarios. Data provided by BOR from BBRAOP model simulations.

The BOR simulations of 4 different release scenarios show that water surface elevation and Buffalo Bill reservoir storage can be dramatically affected under certain combinations of historic water availability and flow release. The potential influence of reservoir elevation changes on the reservoir trout population is discussed later in the Results section.

Shoshone River Below Buffalo Bill Reservoir

The hydrologic simulations provided by the BOR achieved requested target flows using a combination of releases from the Shoshone Power Plant and BBPP. A significant amount of additional flow enters the river from springs immediately below BBPP including 60 cfs or more from DeMaris springs (Vogt and Annear 1991). Flow releases from Buffalo Bill Reservoir storage to meet flow recommendations for the study area downstream from the springs (to be detailed in subsequent sections) are thus approximately 60 cfs less than the flow recommendation. Another way of understanding this distinction is to realize that the BOR's simulated release of 300 cfs would correspond to approximately 360 cfs in the downstream study reach for which flow recommendations are being developed.

The annual hydrographs for three different periods show that relatively low flows are released during the winter months followed by increasing flows during the spring irrigation season peaking in June and July (Figure 6). The longer period of record going back to 1943 exhibits a wetter pattern with greater winter flows than the recent 30-year period from 1973 to 2002. The recent years in which studies were conducted had even lower releases during most months (Figure 6).

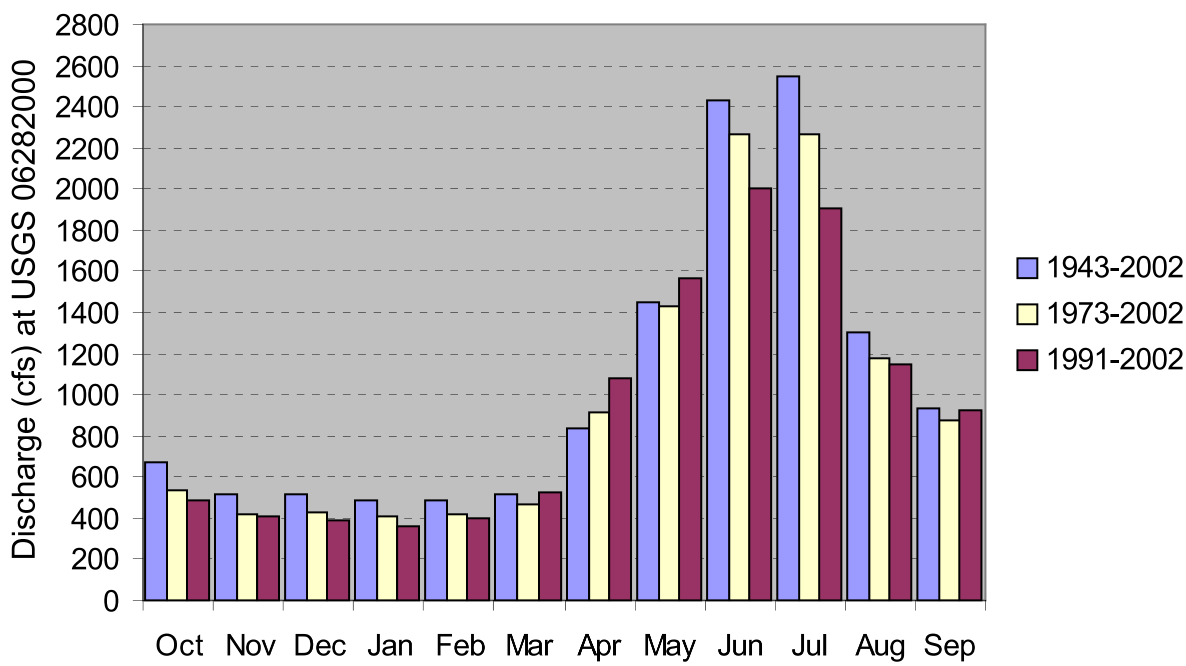


Figure 6. Historic (1943-2002), 30-year (1973-2002) and recent (1991-2002) Shoshone River mean monthly annual hydrograph at the Shoshone River below Buffalo Bill gage, USGS number 06282000.

Average discharge between October 1 and March 31 over the period 1943 to 2002 was 534 cfs; over the period 1973 to 2002 average winter discharge was 444 cfs. Over water years 1991 to 2002, winter discharge averaged 427 cfs. The value of 444 cfs calculated over water years 1973 to 2002 provides the most appropriate description of average winter flows because it encompasses a relatively long but recent period that reflects modern usage patterns. Minimum daily flows in the winter over this 30-year period ranged from 104 cfs (January 4, 1989) to 490 cfs (December 14, 1978) with an average minimum daily flow of 277 cfs. Maximum winter daily flows over the 1973 to 2002 period ranged from 465 cfs (March 29, 1986) to 2,710 cfs (March 31, 1997). The average maximum winter daily flow was 832 cfs.

Daily flow exceedance curves reflect the decrease in winter flows in recent years (Figure 7). A flow of 508 cfs was exceeded 50% of the time in the winter over the WY 1943 to 2002 period. Over the recent 12-year period of WY 1991 to 2002, the exceedance curve is shifted substantially lower and it takes a flow of only 399 cfs to be exceeded 50% of the time. The 30-year period of water years from 1973 to 2002 exhibited a 50% exceedance flow of 414 cfs (Figure 7). A flow of 440 cfs is exceeded 44% of the time during the winter season.

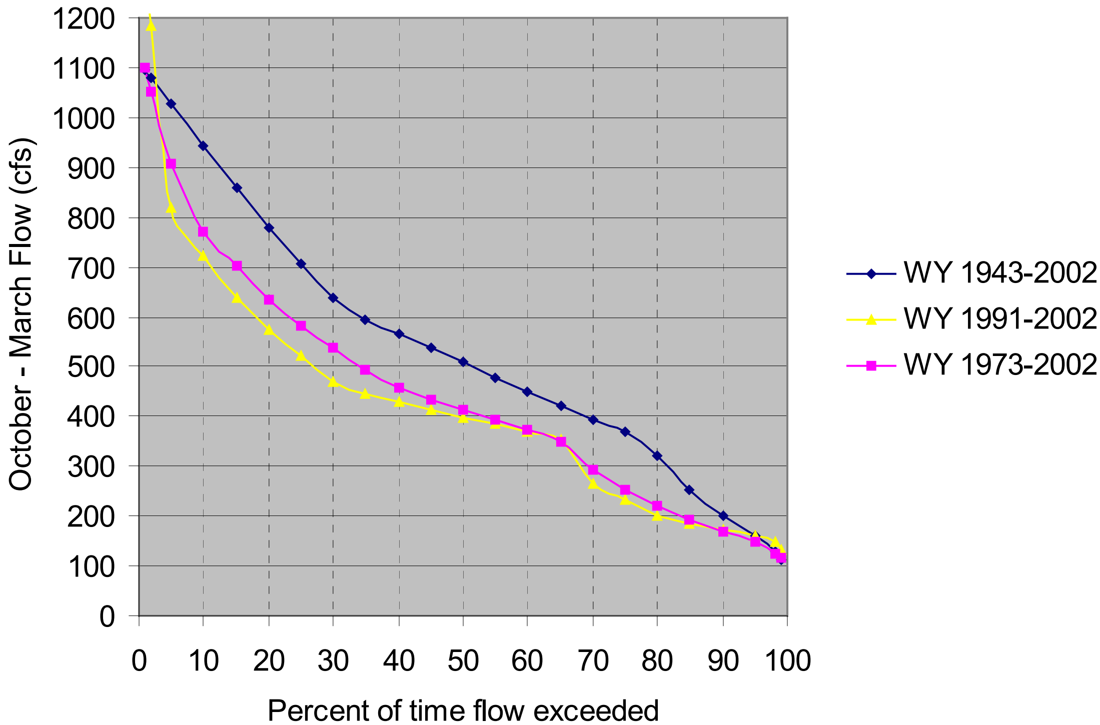


Figure 7. Daily flow exceedance curves for flows during October 1 to March 31 over selected water years.

A range of October through March hydrographs from the period water year 1991 to water year 2002 are presented in Figure 8 to illustrate flow conditions during studies. The average hydrograph, where daily flow values were averaged across years, shows that for most of the winter period, flow averaged about 400 cfs. Higher flows occur in early October as flows are ramped down from irrigation-season levels. Higher flows also occur in some years in March as water is released from the reservoir in anticipation of runoff. Water year 1995 represents a year with low winter flows – flows averaged about 200 cfs and were less than 200 cfs for the majority of the winter period. Water year 1993, not illustrated, also exhibited low flows during winter.

Water years 1998 and 1999, the years in which Dare (2001) performed extensive studies on trout habitat use, habitat availability, and H_2S patterns, are depicted in Figure 8. Discharge was held fairly stable at about 500 cfs during 1998, approximately 100 cfs higher than average winter flows during the last 10 years. In water year 1999, flow releases were stepped through levels averaging 710 cfs, 637 cfs, 447 cfs, 322 cfs, and 226 cfs for the periods December 7 to 18, December 19 to 31, January 3 to 14, January 16 to 31, and February 2 to 17, respectively. The average flow values for these steps differed somewhat from values reported by Dare (2001) who used uncorrected discharge values downloaded from the BOR's Hydromet website.

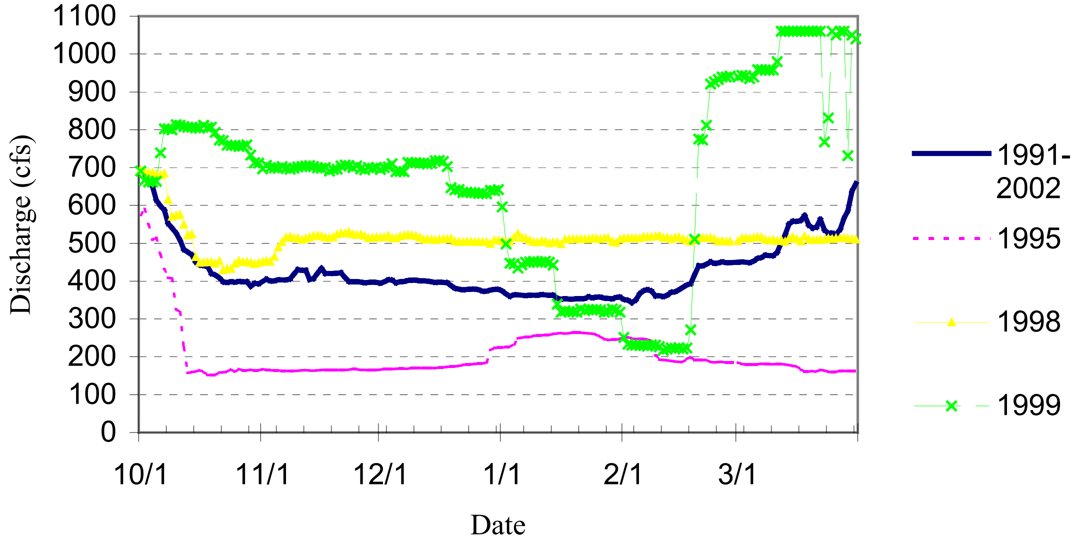


Figure 8. Shoshone River daily flow hydrographs for selected winters and averaged over water years 1991 – 2002.

Seven-day minimum flows over the 1991 to 2002 water years were at or below 200 cfs 5 out of the 12 years (Figure 9). Seven-day maximum flows were less than 759 cfs in all years except 1996, 1997, and 1999. Daily maximum and minimum flows were similar to the 7-day maximum and minimum flows, indicating that average daily flow level during winter was not highly variable (Table 4). By far the greatest range between maximum and minimum flows occurred in 1997 (Figure 9). Water years 1996 and 1999 also had relatively high flow ranges between maximum and minimum winter flows. These patterns in variability are reflected in the highest coefficient of variation (CV) in 1997 (Figure 10). Water years 1991-1993 also exhibited relatively high variability through the winter as reflected by the CV's (Figure 10).

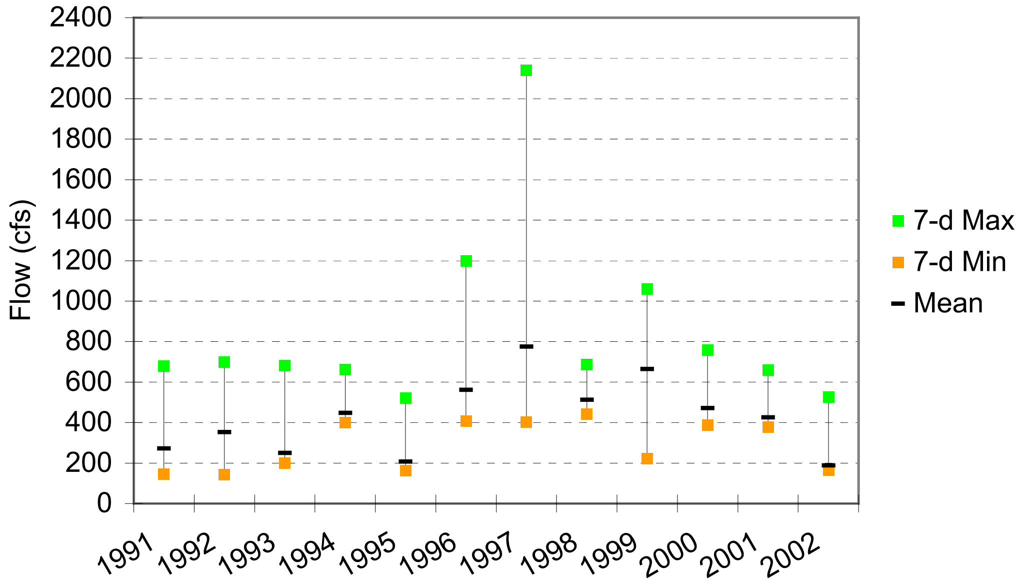


Figure 9. 7-day maximum, 7-day minimum and mean winter (October 1 to March 31) flows for water years 1991 through 2002.

Water year 2002 had an average winter flow of 189 cfs, the lowest winter period average flow calculated over the 1991 to 2002 water year period (and perhaps over the period of record but this calculation was not performed). Water years 1995 and 1993 ranked 2nd and 3rd lowest in average winter flow with averages of 207 and 250 cfs, respectively.

Table 4. Shoshone River flow statistics for October 1 through March 31 for water years 1991 through 2002.

Water Year	Minimum Daily (cfs)	Minimum Date	Maximum Daily (cfs)	Maximum Date	October Mean (cfs)	October %CV	November Mean	November %CV
1991	144	2/9	743	10/1	402	43	374	198
1992	143	3/18	712	10/1	566	20	410	0.4
1993	183	3/26	721	10/2	401	53	203	1.3
1994	395	2/24	672	11/12	458	18	525	22
1995	151	10/19	590	10/2	270	58	165	0.8
1996	390	10/8	1570	3/30	435	11	411	0.9
1997	303	10/29	2710	3/31	572	24	515	1.0
1998	429	10/22	693	10/1	527	19	508	4.5
1999	217	2/11	1060	3/22	762	7	700	0.5
2000	249	11/14	810	10/1	684	7	493	27
2001	374	3/5	737	10/2	481	23	442	3.9
2002	164	11/20	719	10/1	259	71	168	1.9

Winter maximum flows usually occur either in early October as flow releases are being decreased from irrigation season levels or late in March as flows are ramped up for irrigation or evacuation of reservoir space in anticipation of runoff (Table 4). Minimum flows have occurred in all months except

December or January. The minimum flow that occurred in November of water year 2000 (November 1999) was a test release requested for instream flow studies. November flows are lower and less variable than October flows since most reductions from irrigation season levels are completed by mid October (Table 4).

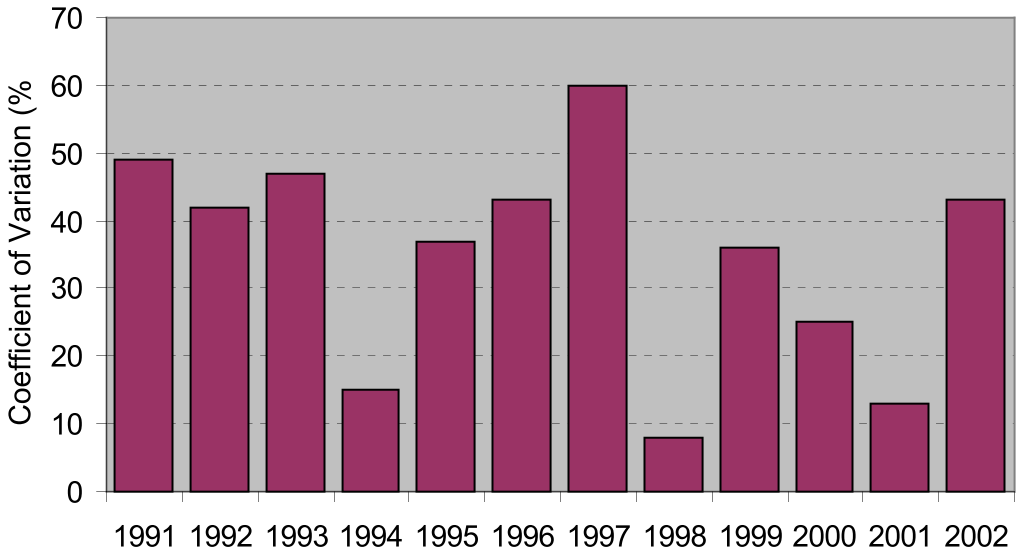


Figure 10. Coefficient of variation (%) of winter (October 1 to March 31) flows for water years 1991 through 2002.

<u>Water Quality</u>

Hydrogen Sulfide

Pedlar (1985) reported H_2S sampling results for multiple dates, flows and distances downstream from Buffalo Bill Dam. He documented toxic H_2S levels immediately below the Dam and again at DeMaris Springs. Hydrogen sulfide levels downstream from DeMaris Springs declined below the lethal threshold near the confluence with Sulphur Creek. Following his work, however, it remained uncertain how far downstream the H_2S plume might extend under a range of potential winter flows.

Dare (2001) conducted measurements of H_2S concentration on a finer spatial scale and also examined fish distribution relative to H_2S concentration. He found that the hydrogen sulfide plume downstream from DeMaris Springs extended for about 2.8 miles regardless of discharge level (Dare 2001) during winter 1998 and 1999. Again, the terminus of the plume remained near Sulphur Creek as noted by Pedlar (1985). A small increase in downstream extent of the plume (approximately 0.1 mile) when experimental flows were decreased from 637-710 cfs to 322-447 cfs was attributed to an increase in the proportion of total flow made up by H_2S -laden DeMaris Spring water. When flow was decreased further to 226 cfs, the plume migrated back upstream a short distance, about 0.2 mile. This movement was attributed to a concurrent increase in mean daily water temperature from about 46 ºF to 54 ºF, which decreased the solubility of H_2S gas and hastened its dissipation (Dare 2001).

Radio-tagged trout were observed within 0.6 miles of the downstream end of the H_2S plume but never moved upstream into the plume. Trout also did not change distribution relative to the plume as flows were manipulated during winter 1998-1999, further evidence that over the flow range examined, there is no significant interaction between flow level and extent of the Shoshone River influenced by excessive H_2S levels.

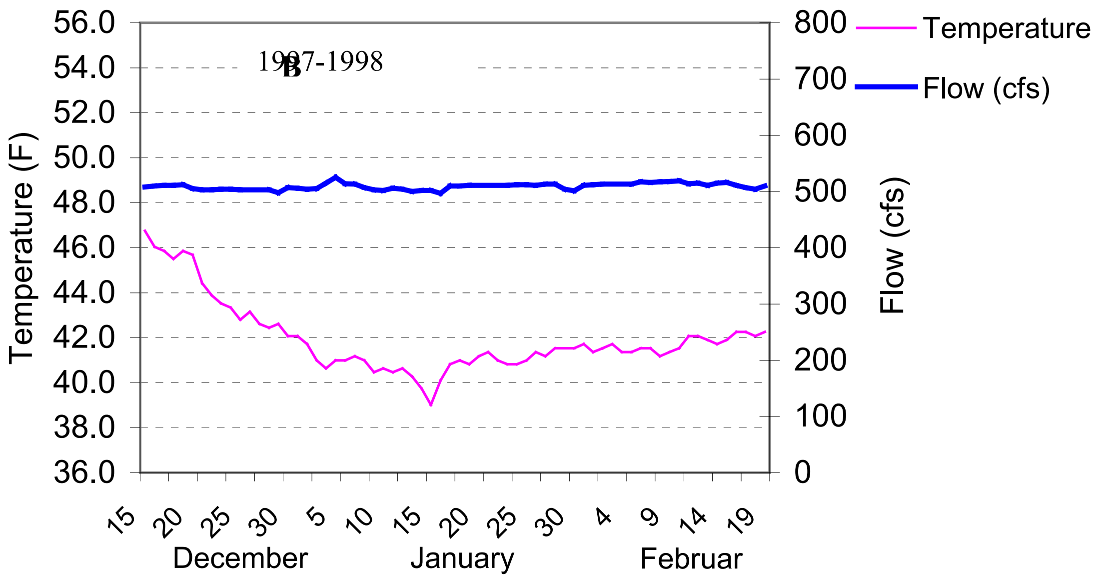
For the purpose of defining winter instream needs for the trout fishery below Buffalo Bill Reservoir, hydrogen sulfide concentration in the Shoshone River downstream from DeMaris Springs does not appear to depend on flow level. This conclusion remains somewhat tentative, however, based on unexplained anecdotal accounts of periods when fish were absent from a longer reach of the Shoshone River. During March 1996 and March 1999, Cody WGFD personnel were unable to locate trout with electrofishing over a 2-mile stretch of river that normally contains trout. During these occasions, a strong H_2S odor was evident along with a white precipitate on the substrate. These observations suggest periodic pulses of H_2S from DeMaris Springs or other unidentified sources. It remains unknown if there is a flow-related component; however, if future information better documents the occurrence of H_2S pulses and defines flow-related causative mechanisms, then winter flow prescriptions may require refining.

Water Temperatures

In winter 1997-1998, average daily water temperatures declined in the face of constant discharge (510 cfs) until a 40-42º F plateau was reached in early January 1998 (Figure 11). Since discharge remained constant throughout the winter, the decline to 40-42ºF represents the cooling influence of daily winter climate (short days and colder temperatures). Small variations like a temperature decrease in mid-January illustrate that even at 510 cfs the river is moderately sensitive to atmospheric conditions like a series of very cold days. The Shoshone River was also resilient in maintaining a constant temperature during the stable flow release of 1997-1998 because it rapidly returned to the 40-42º F level following a brief decrease to 39º in mid-January (Figure 11).

Water temperatures during 1997-1998 in the Shoshone River were higher than measured in two other Wyoming tailwaters (Hebdon 1999). The North Platte River downstream from Gray Reef Reservoir had average daily water temperatures near or below 34º during the same period Shoshone River water temperatures were 40-42º F. The Bighorn River downstream from Boysen Dam likewise was colder with water temperatures of 32-36º F. The warmer Shoshone River water temperatures are attributed to the influence of thermal spring input, especially DeMaris Springs.

At a relatively high flow level of 640 cfs during December 1998, water temperatures were approximately 41 to 42º F (Figure 11). This is colder than the 42-47º F of December 1997 when discharge averaged 510 cfs. The difference between years might be attributable to discharge level; higher discharges are influenced relatively less by warm hydrothermal input from DeMaris Springs and will therefore have colder water temperatures. Further evidence for this pattern is provided by the response of water temperature to decreased flow within winter 1998-1999. As flows declined during 1998-1999, water temperatures increased (Figure 11). At an average flow of 447 cfs in early January 1999, water temperature was about 44º F. When flows were decreased to about 322 cfs during later January, water temperature increased to 44-46ºF. When flow was dropped to 226 cfs in February 1999, water temperature increased dramatically to about 53º F (Figure 11).



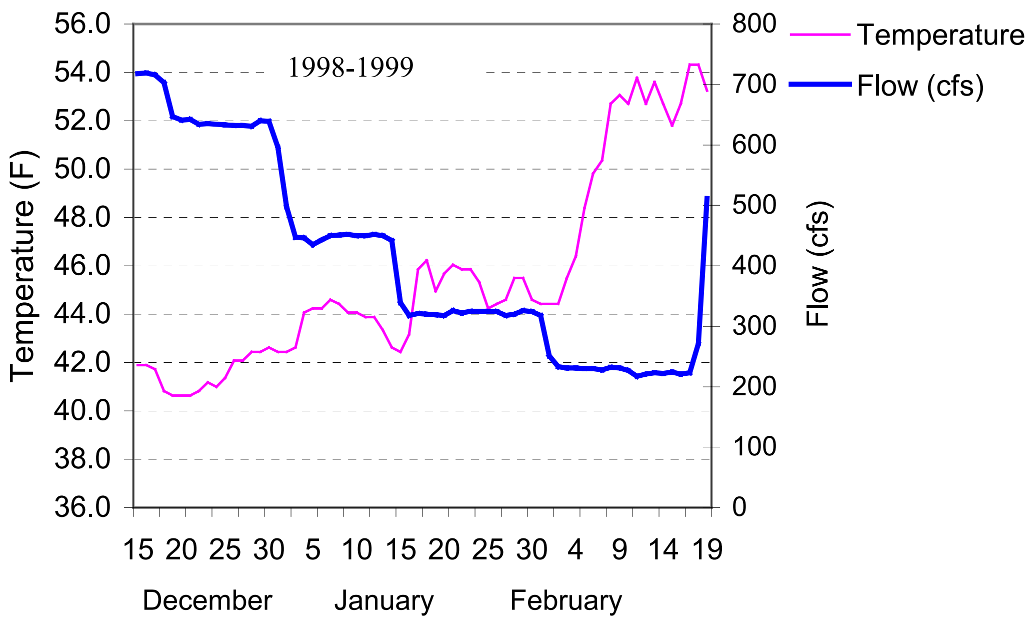


Figure 11. Water temperature and discharge in the Shoshone River during winter 1997-1998 and 1998-1999. From Dare (2001).

<u>Biology</u>

Buffalo Bill Reservoir

Vogt and Annear (1991) described the potential for harm to the Buffalo Bill Reservoir lake trout fishery under various elevation reduction scenarios. They concluded that the number of potential spawning areas in Buffalo Bill Reservoir made it unlikely that elevation reductions of up to 15 feet would impact lake trout spawning and hatching success. This conclusion was based on the assumption that recruitment lost from fish spawning at depths less than 15 feet would be balanced by recruitment from deeper spawning trout from throughout the large reservoir. The majority of spawning is believed to occur at depths greater than 15 feet. Under these assumptions, the BOR model runs suggest no impact is likely to occur to Buffalo Bill Reservoir lake trout spawning and hatching success under winter flow releases of 300 cfs or less. The maximum reservoir elevation change over winter under a 300 cfs release was simulated at 7.1 feet in 1988. However, under the simulation, releases were reduced in 1989 and 1990 otherwise more significant reservoir elevation changes would have occurred to meet the 300 cfs release.

With release of 400 cfs during winter, BOR model runs indicate that reservoir elevations decrease an average of 3.1 feet. Again, this underestimates decreases because the simulation was performed to reduce releases to 100 cfs in 6 years that would not have had enough water to sustain a continuous 400 cfs release throughout the non-irrigation season. Had releases continued at 400 cfs and if the reservoir then dropped approximately 15 feet or more, there would likely be impacts to lake trout spawning and hatching success as eggs deposited in October and November become exposed during the winter. The average winter decrease of 3.1 feet with release of 400 cfs would not likely impact lake trout recruitment. The potential deleterious effects to lake trout recruitment and populations from the occasional loss of a year class (no more frequently than perhaps once every 10 years) could be an acceptable fishery management risk but consecutive years of recruitment failure due to drastic draw downs would be undesirable.

Shoshone River Fishery

Trout Populations and Winter Flow

Data from eight years of fall population estimates suggest a polynomial relationship between trout abundance (all species combined) in the Shoshone River and flow level during the previous winter (Figure 12, Yekel 2003). Winters with low flows such as 1993, 1995 and 2002 were followed by the lowest abundance measurements. Highest trout abundances were measured following winters with intermediate flows in the range of about 400 to 600 cfs (R^2=0.90). This relationship is even stronger (R^2=0.94) if winter is defined more narrowly as November through February (i.e. the variable “shoulder” months are excluded in determining winter flow level) as done in Yekel (2003). Population estimates conducted in fall 2002 provide additional evidence that preceding low winter flows impact fish populations as total trout numbers dropped from 3,101fish/mile in 2001 to 1,967 fish/mile in 2002. November through March flows were 422 cfs (2000) and 173 cfs (2001).

The relationship in Figure 12, in addition to indicating low trout numbers follow winters with low flow, also shows that winter flows greater than about 550 to 600 cfs may result in depressed trout populations. For example, the fall population estimate in 1999 was low and followed a winter in which flows averaged 665 cfs. Possible mechanisms for this relationship between discharge and trout numbers are elaborated in the PHABSIM section of this report.

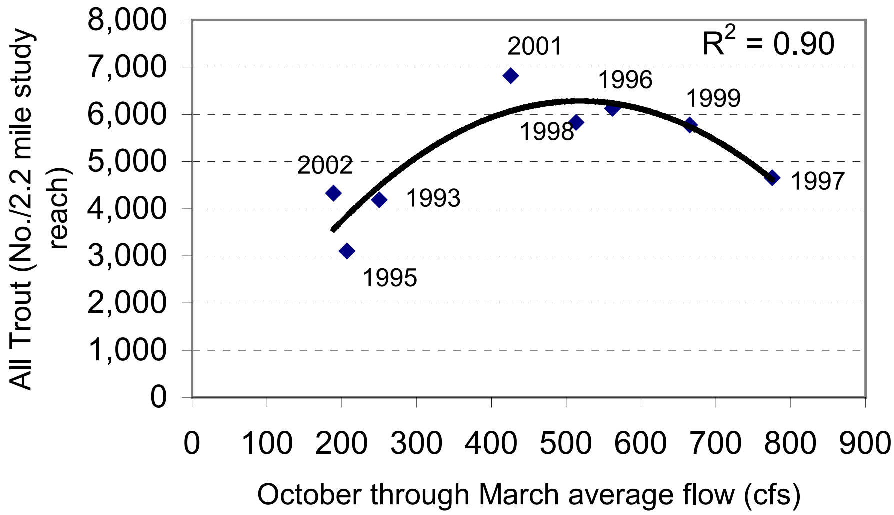


Figure 12. Shoshone River study reach trout numbers from October estimates and winter flow level the previous winter.

The hydrologic statistics reported in Figure 9 and Table 4 were compared to trout population density. Brown trout numbers were higher following years with higher and more stable October and November flows (Figure 13) suggesting that higher flows offer greater reproductive success, perhaps from additional area available for spawning and incubation. Less variable years may increase reproductive success by keeping relatively shallow sites wet and suitable throughout the incubation period, reducing energetic stress and the potential for stranding non- or semi-motile life stages.

The two years with the lowest 7-day maximum winter flows coincided with following years of low SRC numbers (Figure 14). Years in which higher winter maximum flows occurred were associated with greater SRC numbers. The significance of this result will be re-examined during analysis of habitat availability for the various trout species (below).

Meso and Micro-Habitat Availability

A significant portion Dare's (2001) research characterizes trout habitat in the Shoshone River at different flows. Runs were by far the most abundant macrohabitat type at all flows (Table 5). The amount of stream area classified as "pool", run" or "riffle" did not appear to change over flows ranging from 322 to 515 cfs (Table 4; Dare 2001). When flows declined from 322 to 226 cfs, pools increased with small decreases in runs and riffles (Table 4).

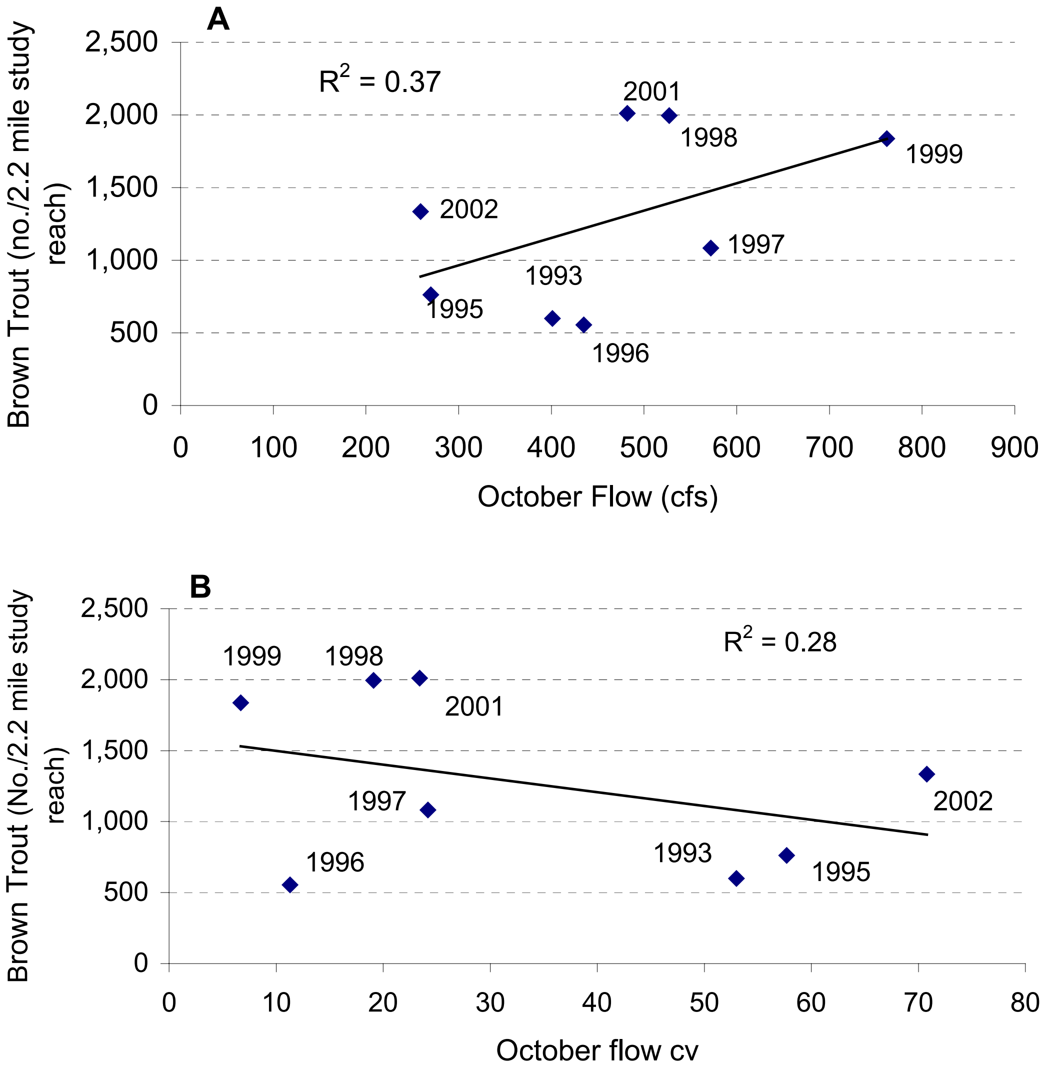


Figure 13. Relationships between brown trout numbers measured during fall population estimates and (A) average October flow the previous year and (B), coefficient of variation of October flow the previous year.

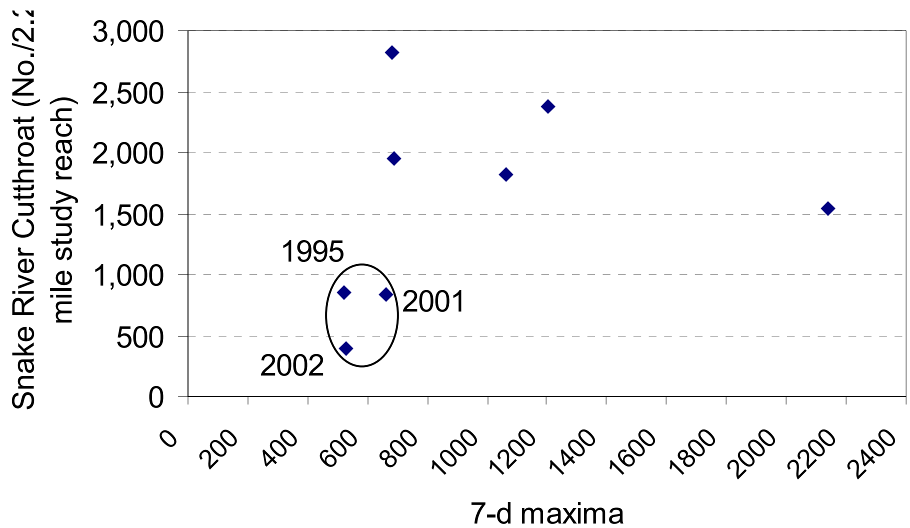


Figure 14. Numbers of SRC in the study reach (Yekel 2003) and 7-day maximum flows the previous winter. Three circled data points emphasize the low SRC numbers that followed years with low winter maximum flows.

Table 5. Percentage of sampling locations classified into each of three mesohabitat categories at 4 discharges (from Dare 2001). Flow was 515 cfs in winter 1997-1998 and the lower flows occurred in winter 1998-1999.

Discharge (cfs)	No. Sampled Locations	Pool (%)	Run (%)	Riffle (%)
515	400	7.5	83.5	9.0
447	427	7.6	79.8	12.6
322	381	7.5	83.3	9.2
226	361	12.2	81.3	6.5

Although the relative percentages of the three macrohabitats did not change dramatically as flow level declined, there were substantial changes in the total area of each (Dare 2001). During the discharge reduction of winter 1998-1999, over one-half (57%) of the area originally classified as riffle at 447 cfs was de-watered at a discharge of 226 cfs. Total wetted stream area declined by 16% as discharge declined from 447 to 226 cfs. Since runs were the most abundant macrohabitat, the greatest total decrease in stream area occurred in runs (Dare 2001).

Microhabitat information was compiled in Table 6 from chapters 2 and 3 of Dare (2001). The information at 515 cfs was collected during winter 1997-1998 and the remaining data were collected in winter 1998-1999. These data offer a few general insights into habitat changes at decreasing flows. First, the relative suitability of pools changes little as a function of discharge (Table 6). Maximum and minimum pool depths remain well above minimum trout requirements at the lowest flow level. Velocities in pools are also moderate throughout the measured discharge range. In runs, minimum depths drop below levels considered suitable for adult trout as flow decreases from 447 cfs to 322 cfs. Riffles appear to offer limited habitat for adult trout at all flows due to limited depth (Table 6). The decrease in maximum depth at higher flows in riffles, seemingly a counterintuitive result, is due to the fact that new measurements were collected in additional shallow riffles created under the high flow conditions (Table 6).

Table 6. Average microhabitat characteristics within mesohabitats measured along transects at 4 discharges (from Dare 2001). Flow was 515 cfs in winter 1997-1998 and the lower flows occurred in winter 1998-1999.

	Discharge (cfs)			
Microhabitat Variable	515	447	322	226
Pools				
Maximum depth (ft)	5.3	5.1	4.6	4.0
Minimum depth (ft)	3.7	3.3	3.2	2.3
Maximum velocity (ft/s)	1.57	1.11	0.82	0.59
Minimum velocity (ft/s)	0.88	0.46	0.46	0.26
Boulder Cover (%)	65	19	17	19
Deep-Water Cover (%)	27	69	86	95
Vegetation Cover (%)	0	84	100	2
Runs				
Maximum depth (ft)	2.5	2.4	2.2	2.0
Minimum depth (ft)	1.4	1.2	0.9	0.7
Maximum velocity (ft/s)	2.69	2.76	2.03	1.74
Minimum velocity (ft/s)	1.51	1.02	0.62	0.39
Boulder Cover (%)	63	43	42	42
Deep-Water Cover (%)	2	16	18	21
Vegetation Cover (%)	2	13	8	4
Riffles				
Maximum depth (ft)	0.76	1.04	1.12	1.06
Minimum depth (ft)	0.03	0.39	0.33	0.27
Maximum velocity (ft/s)	1.57	1.87	2.13	1.74
Minimum velocity (ft/s)	0.33	0.79	0.92	0.49
Boulder Cover (%)	6	8	3	9
Deep-Water Cover (%)	3	0	0	0
Vegetation Cover (%)	0	0	1	0

Flow-dependent changes in cover within the macrohabitat types are few. It appears that an inter-annual effect occurred; either a real change in cover or a difference in measurement technique or bias, because there are substantial differences between cover measured at 515 cfs in 1997-1998 and cover measured at the three lower flows in 1998-1999 (Table 6). Dare (2001) did not include 1997-1998 microhabitat and cover data with the 1998-1999 data in his presentation of flow-related changes, therefore the two data sets may not be entirely consistent and no comparisons will be made here between 515 cfs and 447 cfs. As flow declines from 447 cfs to 226 cfs, the percent of area classified as deep-water cover increased in pools and runs. Deep-water cover is an area at least 1.3 feet deep with a velocity less than 0.33 ft/s. The increase of deep-water cover as discharge decreases occurs because velocities decrease rapidly as a function of discharge while depth remains relatively high. The lower velocities are especially evident in pools so the relative increase in deep-water cover is highest in pools (Table 6).

Vegetation cover peaked at 322 cfs in pools then dropped significantly at the lower flow level of 226 cfs. Dare (2001) attributes this decrease primarily to senescence of aquatic vegetation with a minor amount due to de-watering of vegetation along the stream margin.

Habitat Use

Mesohabitat use, determined by locating fish with radio transmitters and measuring habitat variables at their locations, is summarized in Table 7. Trout use of pools and runs was nearly equal, with a slightly higher use of pools than runs. Given the much greater availability of run habitat in the study reach (Table 5), both trout species showed a preference for pool habitat. When discharge dropped to the lowest flow level, cutthroat trout pool use increased 10% (while relative abundance of pools increased 5%; Tables 5 and 7).

Table 7. Mesohabitat use at 4 discharges (from Dare 2001).

Discharge (cfs)	Number of Observations	Pool	Run
Cutthroat trout			
515	42	57%	43%
447	26	54%	46%
322	57	54%	46%
226	50	64%	36%
Brown Trout			
515	63	46%	54%
447	60	63%	37%
322	56	63%	37%
226	51	49%	51%

Trout Movement

Movement frequency decreased as discharge declined (Figure 15). At the first discharge level (710 cfs), trout were located at a new location 60-70% of the time. At the lowest discharge (226 cfs), trout were at new locations less than 50% of the time. Most movements by each species were less than 20 m in length and were consistent with an individual fish moving within a single pool. Movements during winter 1997-1998, when flow was held stable at 515 cfs, were less frequent (new locations only 30-40% of the time) than observed during 1998-1999.

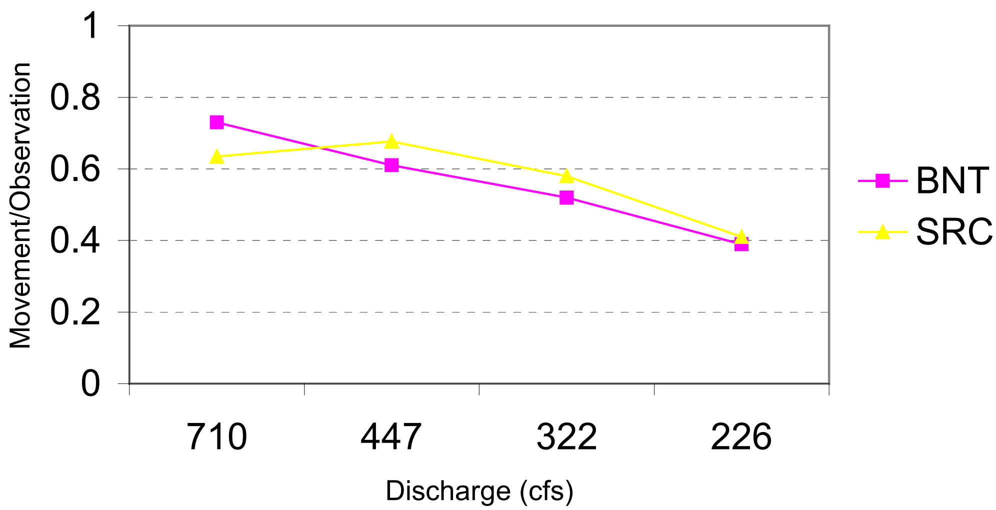


Figure 15. Movement frequency as a function of discharge during winter 1998-1999 (from Dare 2001).

Simulated Physical Habitat Availability

Habitat suitability criteria (HSC) developed for nose velocity were similar between the two species except nose velocities above 1.0 ft/s were not suitable for brown trout while nose velocities up to 2.0 ft/s had a low level of suitability for Snake River cutthroat (Figure 16). The HSC developed for mean column velocity were also similar for the two trout species with optimal suitability over the range of about 0.5 – 1.5 ft/s. Adult Snake River cutthroat trout depth HSC are wider than those for brown trout with deeper water more suitable for cutthroat (Figure 16).

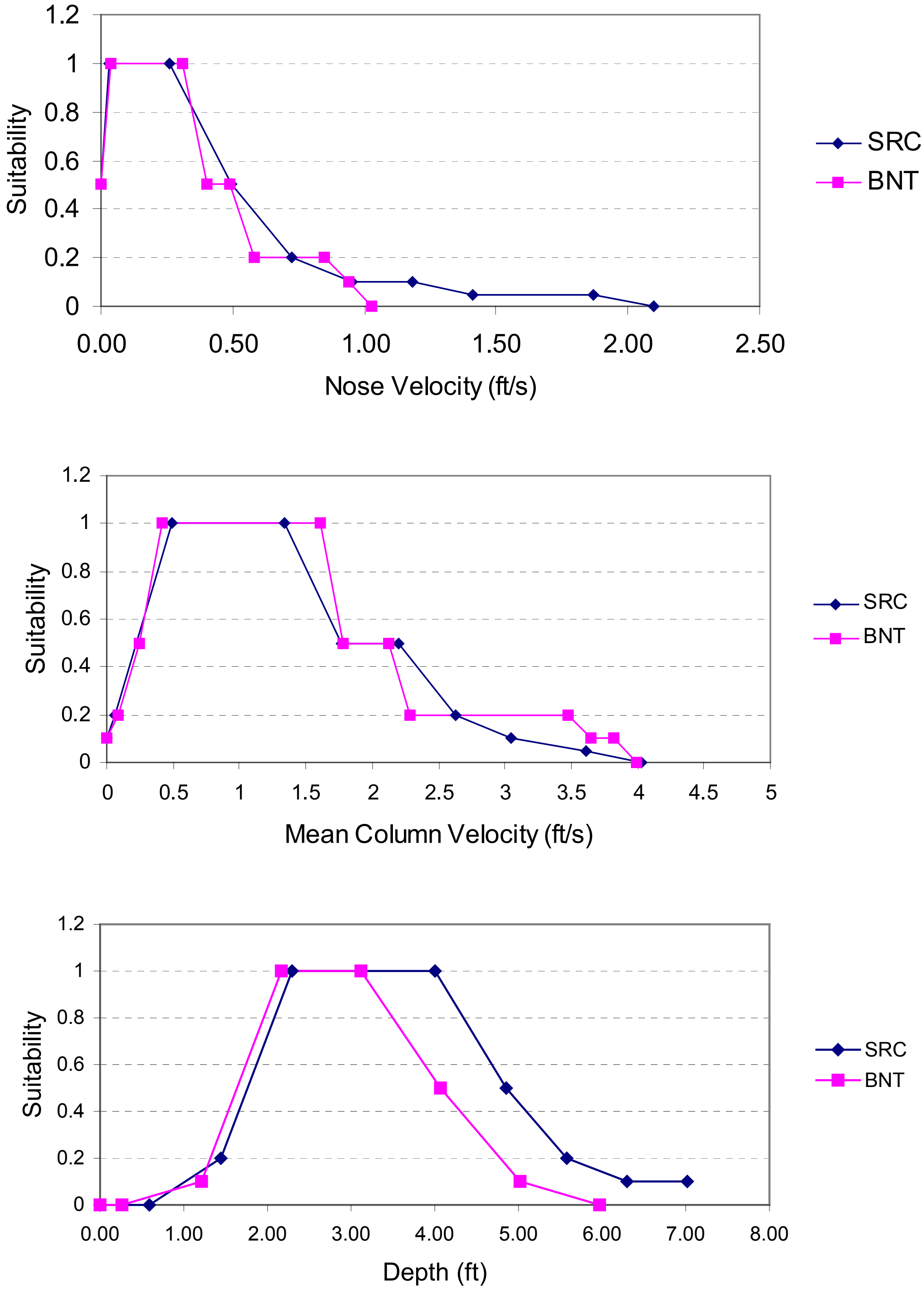


Figure 16. Mean column, nose and depth suitability criteria for Snake River cutthroat and brown trout in Shoshone River run-habitat during the winter (developed from data in Dare (2001)).

Weighted useable area for adult brown trout among transects decreased evenly in an upstream direction with transect 1 exhibiting the highest levels and transect 4 the lowest levels (Figures 2 and 17). Transect one has a relatively flat profile with a broad cobble bench on the left side of the channel. This bench narrows in the upstream direction toward transect 4 as the main channel becomes deeper and faster. The modeling results show that the deep and fast channel modeled at transect 4 provides less habitat throughout much of the flow range examined (Figure 17). There is little difference in brown trout habitat availability between transects 1 and 4 at 300 cfs or less. The greater relative increase in brown trout WUA at transect 1 at higher flows is due to an increase in the suitability of a few locations in the thalweg (deepest part of the main channel) and the flooding of the cobble shelf which increased the area with suitable habitat. On transect 4, the suitability of a few thalweg cells also increased as discharge increased (but not to the level attained on transect 1) but less area on the stream margins became suitable. This comparison illustrates that brown trout suitable habitat can be increased by maintaining flows above 300 cfs and the mechanism involves both increasing the suitability of locations in the main channel as well as providing additional stream margin habitat. The data for transects 1, 2 and 3 tend to support the trend noted in Figure 12 that suggests flows higher than about 550 cfs are less suitable for adult brown trout and may lead to lower populations.

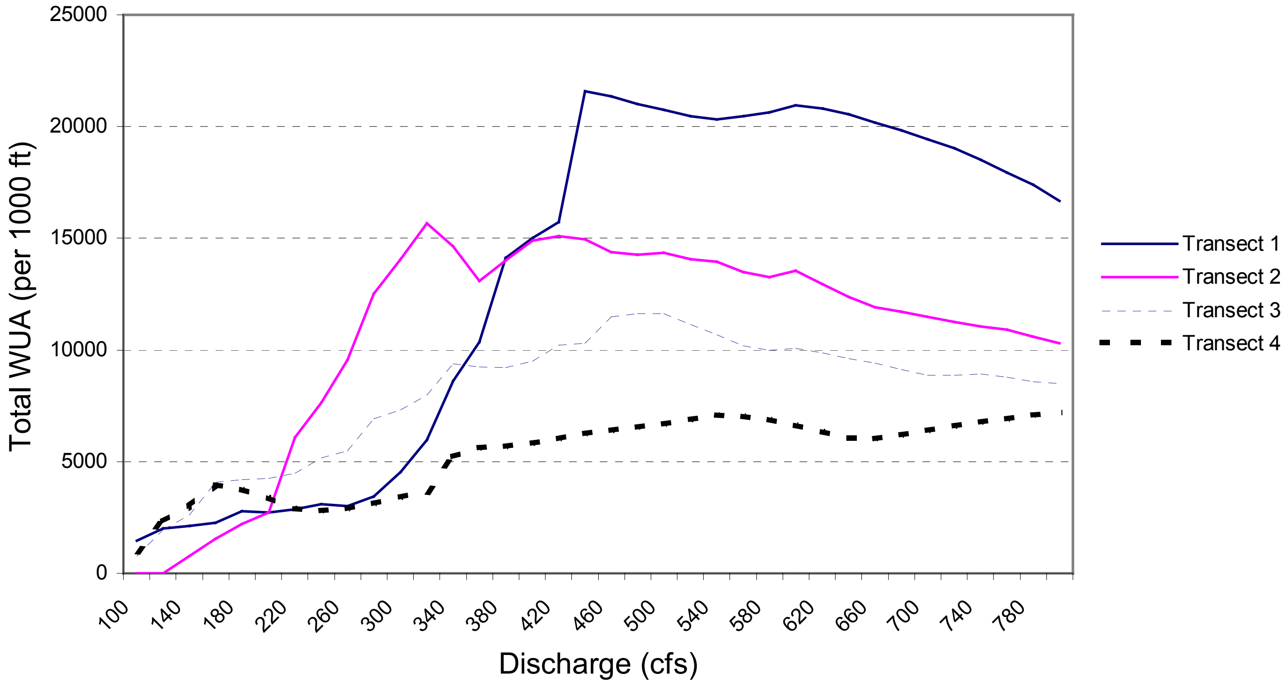


Figure 17. Brown trout weighted useable area on each of four run transects.

Comparing adult Snake River cutthroat trout habitat availability in transects 1 through 4 shows habitat was generally higher on transects 1 and 2 due largely to the greater width of the channel (Figure 18). The most suitable "cells" on all transects were located in or near the thalweg while additional cells located along the margins of all four transects often had low or zero suitability values.

To summarize this exercise of comparing transects, it is evident that the wider area of the run studied offered more habitat for both trout species. This higher level was not simply due to increased habitat on the broad cobble bench on the left side of the channel; rather, the suitability of habitat within the thalweg was higher and increased more dramatically as a function of discharge than in upstream locations where the entire channel is narrower. The narrower and swifter channel at the head of the run provided relatively low habitat regardless of discharge level.

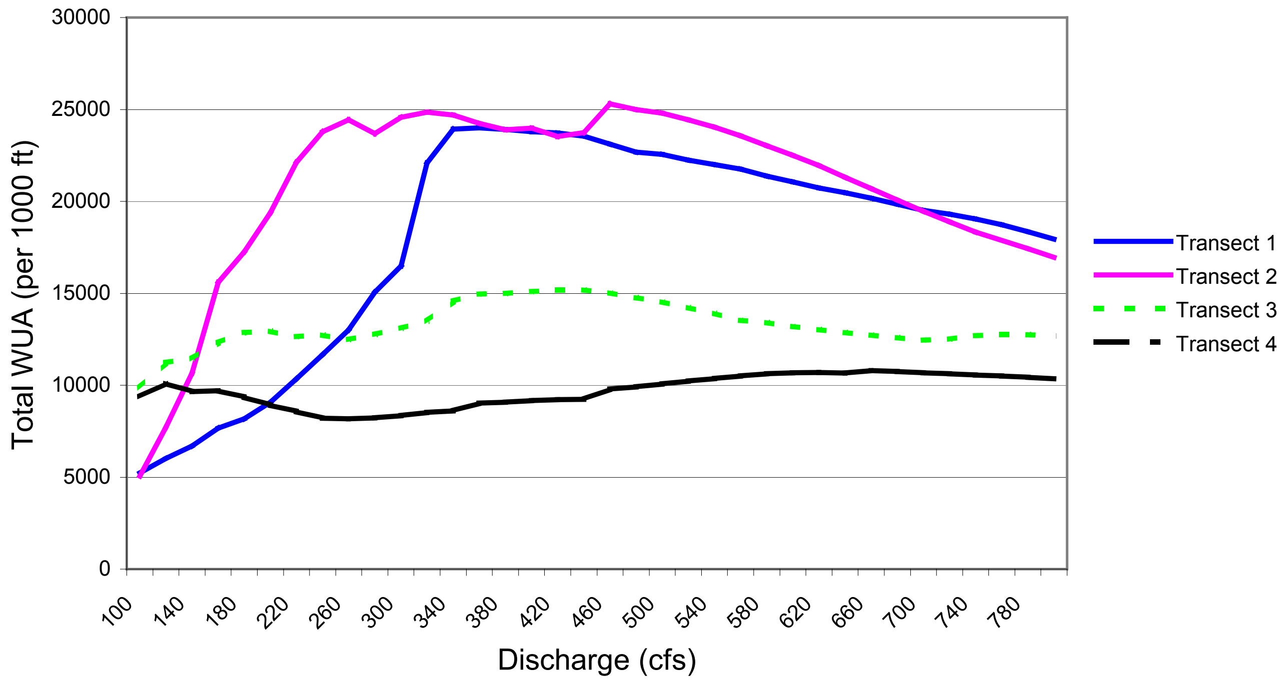


Figure 18. Snake River cutthroat trout weighted useable area on each of four run transects.

Since the run selected for PHABSIM analysis contains a diversity of habitat conditions, averaging WUA output across the four transects established in the run provides a good estimate of the general relation between discharge and winter habitat (Figure 19). Snake River cutthroat trout habitat increases steadily as discharge increases and essentially peaks at 340 cfs. Habitat maintains a plateau until about 540 cfs and then gradually decreases at higher discharges (Figure 19). As noted for brown trout, these data tend to support the trend noted in Figure 12 that suggests flows higher than about 550 cfs are less suitable for adult Snake River cutthroat trout and may lead to lower populations over time.

The shape of the brown trout WUA curve is similar due to similarity in the underlying HSC. Habitat levels are lower for brown trout, however, and peak at a discharge of 440 cfs. Habitat levels gradually decline at higher discharges (Figure 19).

A discharge of 440 cfs in the study area below the USGS gage would maintain the maximum level of physical habitat for both trout species. A winter discharge of 340 cfs would maintain the maximum level of SRC habitat but result in BNT habitat levels about 30% less than maximum. A winter discharge of 540 cfs would result in nearly maximum habitat for both species (Figure 19).

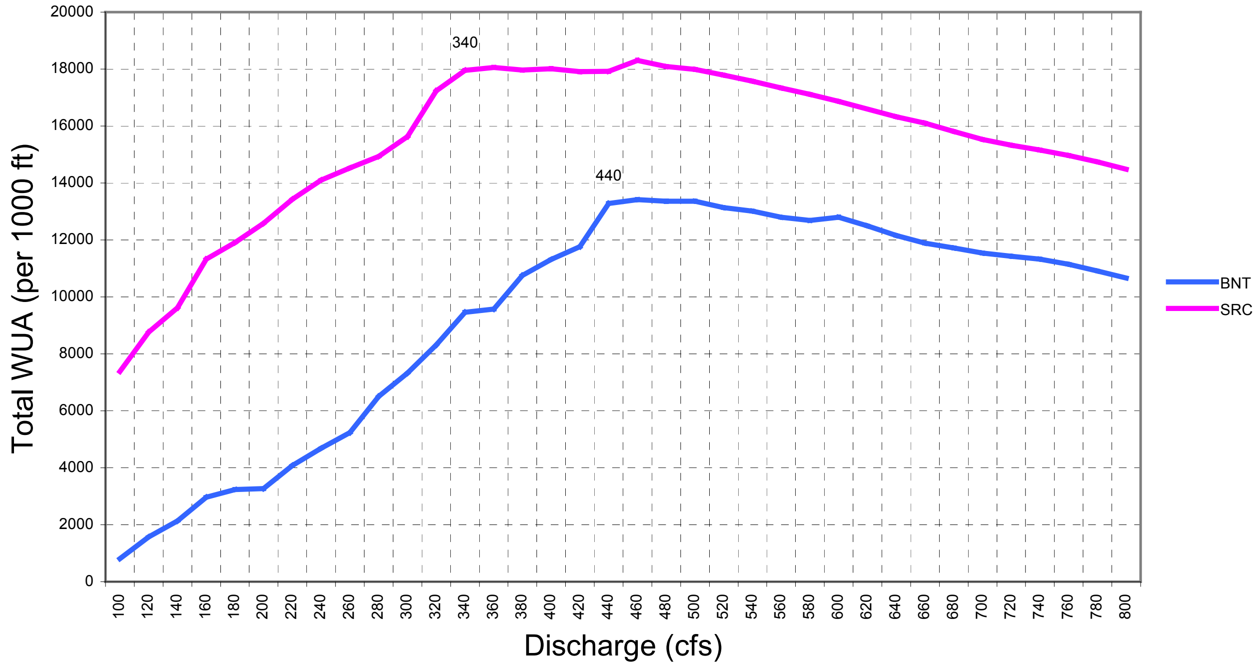


Figure 19. Combined weighted useable area for brown trout (BNT) and Snake River cutthroat trout (SRC) in Shoshone River run-habitat.

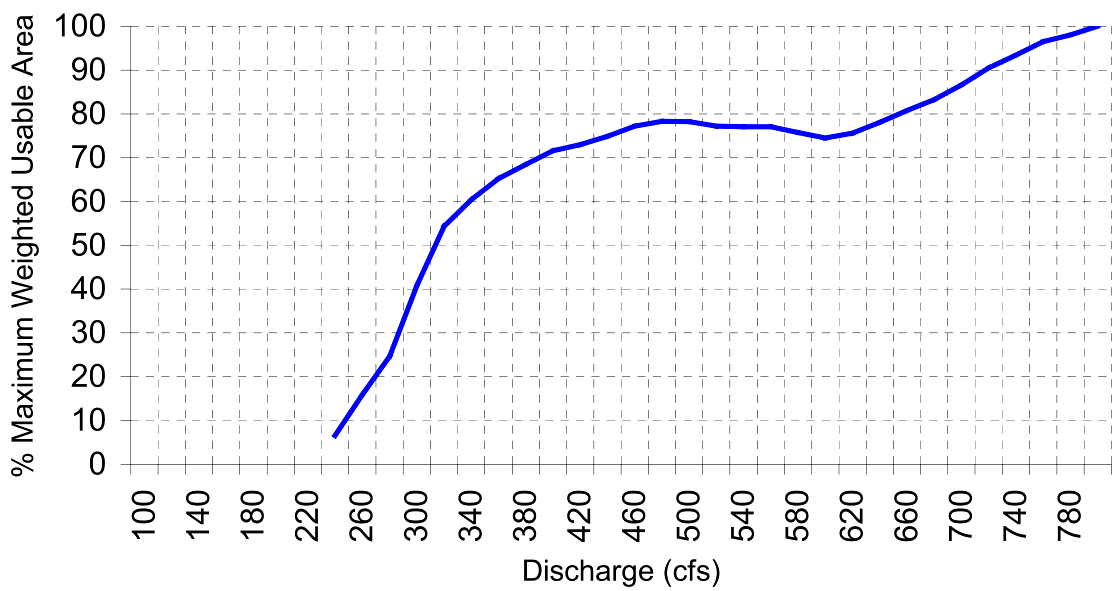


Figure 20. Brown trout spawning weighted useable area.

Habitat for brown trout spawning peaked at 480 cfs and then increased again at high discharges (Figure 20). The first peak is important because it represents the increase in spawning habitat associated with the flooding of the gravel bar at the mouth of Sulphur Creek where most of the appropriate-sized gravel and cobble occurs. The transects were established to model this area in which redds have been observed. Additional spawning area is created in the main channel at higher flows. Spawning habitat decreases rapidly at discharges below 340 cfs. The steep slope at flows less than 340 cfs explains why varied flows in the fall and winter that drop to or below these levels negatively impacts brown trout year class strength (Figure 12 B). When flows are below 340 cfs, a small change in flow has a large effect on the amount of spawning area.

Invertebrate Prey Availability and Trout Bioenergetics

Hebdon's (1999) research revealed that the total number of drifting insects was relatively high through the early winter months and actually increased from levels measured in October (Figure 21). However, after November, he noted that most of the invertebrate drift consisted of zooplankton and that numbers of macroinvertebrates declined significantly. Concurrent with this shift in drift composition was a marked decline in the number of invertebrates and total biomass of prey items he observed in the stomachs of trout (Figure 22). Zooplankton are considerably smaller than most aquatic macroinvertebrates to the extent that the gill rakers of most trout are unable to filter them from the water and convert them to food. Hebdon also observed that the size of macroinvertebrates in winter was smaller than during warmer summer months. This is a normal phenomenon of aquatic macroinvertebrate life cycles as the young insects of most species hatch from eggs in late summer and fall and grow to adulthood over the winter of one or more years.

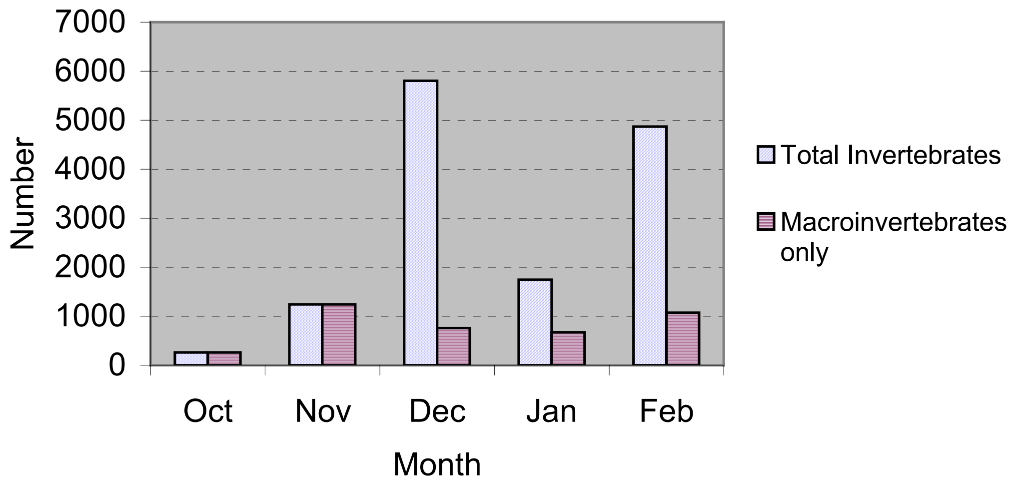


Figure 21. Total number of invertebrates and macroinvertebrates measured in Shoshone River drift samples (Hebdon 1999).

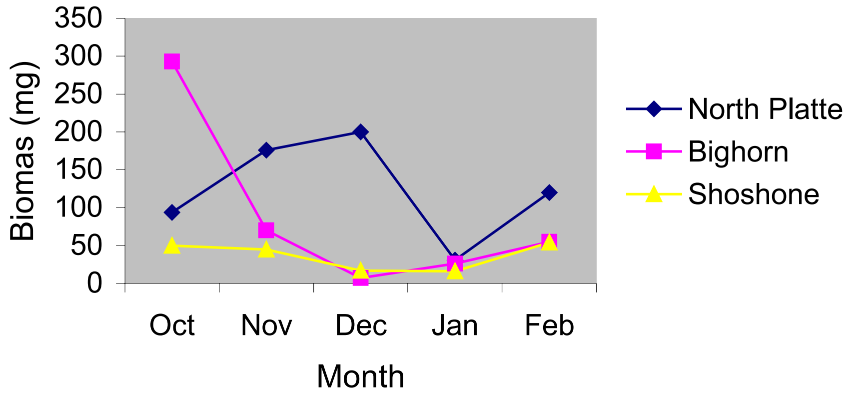


Figure 22. Biomass (mg) of food items in the stomachs of juvenile trout in three Wyoming rivers from Hebdon (1999).

Hebdon also noted that cutthroat trout body condition declined continuously through the winter in the Shoshone River (Figure 23). This trend was not observed in other streams he studied and he concluded that this decline was likely due to a combination of relatively low food availability and high activity associated with increased foraging by trout on the high numbers of invertebrates. Trout activity is enhanced by relatively warm water temperatures from thermal spring influences (Hebdon 1999). The ultimate consequence of this series of events and conditions is the gradual decrease in trout body condition that can ultimately lead to increased stress and mortality due to secondary causes (Annear et al. 2002b). Since invertebrates are largely produced in riffles, decreases in the area of riffles at lower flows can be expected to further limit the invertebrate food supply (Weisberg and Burton 1993). The 57% decline in riffle areas noted by Dare (2001) as flow declined from 447 to 226 cfs suggests that food supply could be limited at flows as low as 226 cfs.

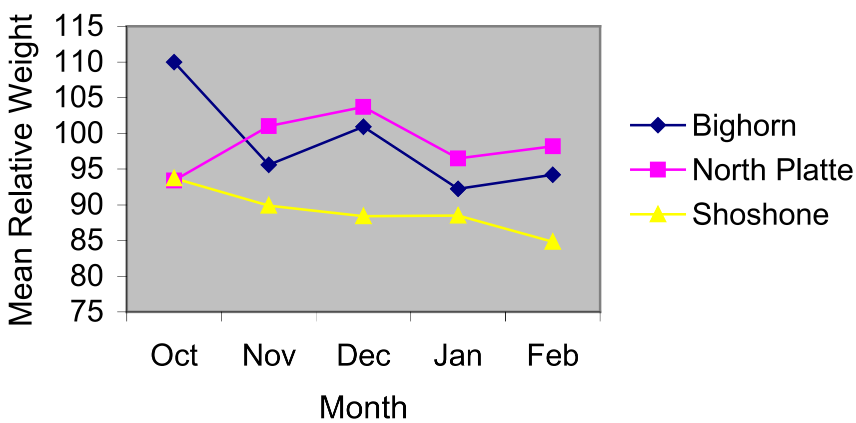


Figure 23. Mean relative weight of juvenile trout in three Wyoming rivers during winter 1997-1998.

The data are not available to incrementally identify changes in riffle area as a function of flow. In other words, we do not know if the 57% decline in riffle area reported by Dare (2001) occurred evenly throughout the 447 to 226 cfs range or whether relatively greater decreases in riffle area occurred at lower flows. The latter is more likely because of the cross-sectional shape of riffles. Regardless, it is apparent that invertebrate-producing riffle areas decrease as flow declines. In general, higher winter flows increase riffle areas and thereby increase the surface area suitable for invertebrate production – maintaining the food supply for trout.

Public Involvement

Public involvement should always be a critically important part of natural resource allocation decisions. Buffalo Bill Dam and the Shoshone River are no exception to this tenet. The water that flows through this system is the basis for settlement of much of Park County and has much to do with the vitality and diversity of the economy today and it is a fact that virtually all members of the communities along and adjacent to the river have a strong interest in how those waters are used.

Public involvement had much to do with the encouragement of legislative efforts that secured funding and authorization for the enlargement of the reservoir. At the time of authorization, most of those interests foresaw use of new storage waters downstream in the lower Powder River drainage for municipal and industrial purposes. As those uses became less feasible, other public interests increased to encourage consideration of applying the new waters for other uses including traditional irrigation, hydropower, reservoir recreation, municipal supply and instream flow for boating, fisheries, and esthetic purposes. Most of the input received pertaining to these new uses has been informal, but as the state develops a marketing plan for the new storage water, opportunities for formal public input are anticipated.

For preparation of this report, we solicited public input from local anglers and business people as to their perception of preferred or minimum flows needed for various river activities. The most detailed and useful information we received to date was from Mr. Tim Wade of North Fork Anglers in Cody. Mr. Wade has owned and operated one of the largest fishing outfitting businesses in Cody for many years and has an exceptional understanding of the relation of various flows in the river with angling and boating opportunities. In a telephone conversation on November 11, 2002, Mr. Wade provided the information contained in Table 8.

Table 8. Minimum and preferred flows for various river based activities on the Shoshone River below Buffalo Bill Dam as measured at USGS gage number 06282000.

Activity	Lowest Effective Flow	Optimum flow
Bank fishing	250 cfs	400 cfs or less
Boat fishing	250 cfs	400 cfs or more
Kayaking	350 cfs or more	NA

According to Mr. Wade, kayaking is not possible at flows less than about 350 cfs; but at this flow and higher, considerable use occurs. Likewise, boat fishing is unsafe at flows less than 250 cfs and the river receives essentially no use by boaters at flows of this level or lower. He notes that, even at these flows, he suspects that boats and rafts that do venture onto the river are dragged through many of the riffles in the river, disturbing or destroying important macroinvertebrate (trout food) organisms and habitat. At flows of 400 cfs, boat angling is considerably safer, more productive in terms of angling success and less detrimental to aquatic macroinvertebrate communities.

The ability to bank fish the Shoshone River is strongly dependent on flow level. At flows around 200 cfs anglers can wade nearly everywhere except the deeper runs and pools (Steve Yekel, WGFD, personal observation). During PHABSIM studies at 436 cfs, we were able to just barely cross the river in a wide run. At the 650 cfs flow our ability to wade was markedly reduced and limited to the channel margins. Wading through most of the riffles in the river becomes dangerous at flows greater than 400 cfs and Mr. Wade concurs with this assessment. He also noted that bank anglers who fish the river at flows less than 250 cfs find considerably fewer places in the river that hold fish and the slower water makes angling success considerably more difficult in some parts of the river. Flows of 250 cfs or more maximize angling opportunities for anglers.

Economic Analyses

The Shoshone River tailwater receives relatively heavy angler use during the fall, winter and spring months, receiving at least 11,000 angler days of activity (Steve Yekel, personal communication). This level is consistent with other top Wyoming fisheries like Grey Reef or the upper North Platte River. No studies were available or conducted that specifically targeted the importance of instream flows or Buffalo Bill Reservoir storage levels to the economies of Cody and Park County, however data were obtained from two reports that described the importance of tourism and aquatic based recreation in economic terms. A report conducted by Dean Runyan Associates (2001) showed that travel-related spending in Park County in 2000 was $177.2 million and noted that spending increased 5.5% on average from 1997 to 2000. This report also noted that travel related employment accounted for 3,870 jobs or 22.4% of all jobs and that travel related tax receipts were $7.14 million in 2000 in Park County.

According to a study conducted for the Jackson Hole Alliance for Responsible Planning by Phillips (1987), non-local anglers in Jackson County accounted for 11% of all tourism dollars spent. No comparable studies have been done for Park County and a direct application of this figure for Teton County to Park County is not entirely defensible without supporting evidence. However, there are some similarities between the economies of these two counties such that there may be some basis to infer that this portion of income in Teton County may approximate the same portion in Park County. From this purely speculative perspective, applying this figure to the amount of travel spending in Park County ($177.2 million) indicates that non-local anglers may have spent about $19.4 million in the community.

Longwoods International (2001) reported that 67% of all tourists visiting Wyoming expressed the belief that Wyoming offers excellent fishing; 72% indicated the state offered excellent opportunities for boating and water sports; 33% of all tourists noted they came here for outdoors related activities and 48% of all trips targeted Cody and the surrounding area as a destination for at least some of their time in the state. According to a census report, 293,000 anglers (both resident and nonresident) spent 2.5 million days fishing in Wyoming in 2001 and spent $212 million (U.S. Department of the Interior). The same report lists statewide nonresident angling expenditures at $55.8 million. If approximately 48% of those nonresident anglers spent time in the Cody vicinity as the Longwoods report suggests, then $26.8 million in expenditures would be a high estimate of Cody area economic activity.

Statewide, anglers spent over $609 million in Wyoming in 2001 and averaged over $488 million over the 5-year period 1997-2001 (Wyoming Game and Fish Department 2002). These figures do not consider other water-dependent recreation like boating or swimming. Statewide, anglers purchased 400,996 licenses in 2001 while the 5-year average is 466,739 licenses. In 2001, 5.05% of all fishing license sales were in Park County. If expenditures by anglers occurred by this same ratio of license sales, angling related activities in 2001 contributed about $30.7 million to the Park County economy (e.g. 5.05% of $609 million). Since most licenses were sold in Cody, the majority of expenditures were likely made in this community. In consideration of the potential non-local angler expenditures inferred from the above study in Teton County, it seems possible that aquatic recreation related expenditures in 2001 in Cody and Park County were probably between $19.4 million and $30.7 million. Though the majority of these benefits to the local community accrue during the summer tourist season, maintaining the quality of the Shoshone River fishery is highly dependent on adequate stream flows during the winter.

KEY RESULTS

1. BOR simulations show that Buffalo Bill Reservoir stores water in nearly all years with flow releases of 100 or 200 cfs and may increase in elevation 10 or more feet.
2. BOR simulations indicate that flow releases of 300 cfs result in elevation changes ranging from +5.4 feet to – 5.4 feet with decreases averaging 0.6 feet.
3. BOR simulations indicate that flow releases of 400 cfs over the winter result in an average elevation decrease of 3.1 feet and changes range from +11.7 feet to –8.9 feet.
4. Given a release of 50 cfs from the Shoshone storage account and the remainder from the State storage account, the BOR simulations reveal that the state account could support a release of 300 cfs under the climatic and use conditions that occurred in most water years except 1989 and 1990.
5. Given a release of 50 cfs from the Shoshone storage account and the remainder from the State storage account, the BOR simulations reveal that the state account could support a release of 400 cfs under the climatic and use conditions that occurred in most water years except 1978, 1986, 1988-1990 and 1994.
6. The State account would retain an average of 91% or more of its capacity at the end of March every year under a release of 100 cfs. Under a 200 cfs release, the account averages 71% full and ranges from 14-100% full. Under a 300 cfs release, the account averages 55% full and ranges from 0-100% full. Under a 400 cfs release, the account averages 42% full and in most years is 37% or less of full with a range between 0% and 74%.
7. Average discharge at USGS number 06282000 between October 1 and March 31 in water years 1943 to 2002 was 534 cfs.
8. In the period 1991 to 2002, when studies were conducted, winter discharge averaged 427 cfs
9. Average winter discharge over the period 1973-2002 was 444 cfs. Minimum daily flows averaged 277 cfs (104-490 cfs) while maximum daily flows averaged 832 cfs (465-2710 cfs).
10. Winter maximum flows usually occur either in early October as flow releases are being decreased from irrigation season levels or late in March as storage space is evacuated in Buffalo Bill Reservoir in anticipation of runoff.
11. Minimum daily flows in the 1991 to 2002 period occurred in October, November, February, and March and no minima occurred in December or January.
12. The hydrogen sulfide plume downstream from DeMaris Springs extends for about 3 miles to the mouth of Sulphur Creek independent of discharge level.
13. Periodic pulses of H_2S may emanate from DeMaris Springs or other sources and extend further downstream but their relationship to flow level remains unknown.
14. In December 1997, average daily water temperatures declined under a constant discharge of 510 cfs until a 40-42º F plateau was reached in early January 1998.
15. The water temperatures in the Shoshone River during winter 1997-1998 were substantially higher than measured over the same period in two other Wyoming tail waters: Bighorn River and North Platte River due to the inflow of heated water from DeMaris Springs.
16. Water temperatures measured during winter 1998-1999 increased as flow level decreased.
17. When flow was dropped to 226 cfs in February 1999, water temperature increased dramatically to about 53º F.
18. Eight years of fall population estimates show that trout abundance in the Shoshone River is highest when intermediate flows between about 400 and 600 cfs occurred the previous winter.

19. Brown trout numbers were higher following years with higher and more stable October flows.
20. The two years with the lowest 7-day maximum winter flows coincided with following years of low SRC numbers and years with higher winter maximum flows were followed by greater SRC numbers.
21. Run habitat was by far the most abundant macrohabitat type (>=80%) at all flows.
22. The amount of stream area classified as "pool", run" or "riffle" did not change over flows ranging from 322 to 515 cfs.
23. During the winter of 1998-1999 when discharge was reduced, over one-half (57%) of the area originally classified as riffle at 447 cfs was de-watered at a discharge of 226 cfs.
24. In runs, minimum depths drop below levels considered suitable for adult trout as flow decreases from 447 cfs to 322 cfs. Riffles have limited habitat for adult trout at all flows, but are important for producing aquatic insects.
25. Trout use of pools and runs was nearly equal and given the much greater availability of run habitat in the study reach, both trout species showed a preference for pool habitat.
26. Movement frequency decreased as discharge declined in 1998-1999 and movements during winter 1997-1998, when flow was held stable at 515 cfs, were less frequent than during winter 1998-1999.
27. Snake River cutthroat trout habitat increases steadily as discharge increases and peaks at 340 cfs. Habitat maintains a plateau until about 540 cfs and then gradually decreases at higher discharges.
28. Habitat for brown trout peaks at 440 cfs.
29. A discharge of 440 cfs would maintain the maximum level of habitat for both trout species.
30. A winter discharge of 340 cfs would maintain the maximum level of SRC habitat but result in BNT habitat levels about 30% less than maximum.
31. Habitat for brown trout spawning exhibited a bimodal pattern with a peak at 480 cfs followed by a sharp decrease at lower flows and then another increase at high discharges.
32. Hebdon's research showed declining cutthroat trout body condition through winter 1997-1998 when flows were 430 to 470 cfs. This decline was likely due to a combination of relatively low food availability and high activity induced by relatively warm water temperatures from thermal spring influences.
33. Winter flows lower than 430-470 cfs are likely to result in even more dramatic trout body condition declines than Hebdon observed because lower invertebrate food levels will be produced from the reduced riffle areas at the same time increased water temperatures extract a greater metabolic expense and level of stress.
34. Minimum winter flows for kayakers, boat fishermen and bank fishermen range from 250 to 300 cfs. Preferred winter stream flows for these users are between 350 and 400 cfs.
35. Aquatic based recreation and tourism may generate between $19 million and $35 million per year to the Cody and Park County economies.

FLOW RECOMMENDATIONS

The foregoing results and analyses provide a detailed examination of four river components (hydrology, geomorphology, water quality, and biology) identified by the Instream Flow Council as essential riverine components to consider when performing instream flow studies (Annear et al. 2002a). A fifth component, "connectivity", will be discussed below. Considering connectivity ensures that the spatial and temporal dimensions of instream flow prescriptions are fully considered.

Identifying a flow level that balances various riverine elements and issues can be a challenging task. In the Shoshone River tailwater, this task is simplified because the studies on hydrology, geomorphology, water quality, and biology in combination with input from the public regarding preferred flows reinforce one another. Our analyses indicate that a Shoshone River flow level of 440 cfs at USGS gage #06282000 (380 cfs release from the reservoir) during the winter months would maintain the blue ribbon fishery. Specifically, a flow of 440 cfs was identified through the PHABSIM incremental analysis and supported by analysis of the other important riverine components. Under PHABSIM, 440 cfs would maintain a peak level of both brown and cutthroat trout habitat indices. Lower flows would maintain a cutthroat trout habitat index down to 340 cfs but the brown trout habitat index would decline. Higher flows would maintain relatively high levels of habitat but are not necessary for maintaining habitat. Based on hydrologic analyses, 440 cfs is approximately the same as the average winter flow of 444 cfs during the 1973-2002 period. Therefore, 440 cfs seems a reasonable quantity that has been demonstrably achieved during recent years.

Hydrogen sulfide concentration in the Shoshone River and its dissipation is independent of stream flow. Water temperature, however, is a very important consideration and the lower the stream flow the higher the water temperatures and the greater the stress on the fishery. At a flow of 440 cfs, results indicate that water temperatures may be high enough to result in some loss of body condition. At this flow level, water temperatures can be expected to be about 42-44ºF with minor deviations depending on air temperature. From temperature data collected during winter 1997-1999, water temperature rises rapidly as flows decrease. Therefore, any flow less than 440 cfs would be expected to negatively affect trout body condition and survival. Higher flows would result in cooler water temperatures and allow trout to maintain greater body condition. However, the physiological advantage provided by a flow level higher than 440 cfs is not as distinct as the disadvantage of a flow level lower than 440 cfs.

Population estimates tracking trout abundance annually over the study period strongly support a flow recommendation of 400 to 500 cfs. Trout populations were highest following winters that averaged more than 400 cfs. Population data, in fact, would support a winter flow recommendation up to about 600 cfs. Flows greater than about 600 cfs may be detrimental based on the empirical population estimates. Likewise, lowest trout populations were found following winters with flows less than 400 cfs.

Brown trout spawning area is high at 440 cfs. A higher flow of 480 cfs would maximize brown trout habitat in the region near the mouth of Sulphur Creek. Higher flows would increase spawning habitat in the main river channel but such higher flows may not be necessary. Brown trout have been observed spawning near the stream margins, especially in and near the Sulphur Creek confluence. Also, the historic flow regime has largely maintained wild brown trout reproduction and flows are normally at least 400 cfs during the October and November spawning period. Population data suggest that brown trout numbers are higher following years with October flows higher than 440 cfs. Flows less than the recommended 440 cfs would result in rapid declines in brown trout spawning habitat.

Stability of flows at or above the recommended 440 cfs is perhaps the most important issue for brown trout reproductive success. Once the winter flow level is set in early October, it must be maintained without significant changes to ensure that established redds are maintained and trout eggs and larvae remain viable. The data show that if the coefficient of variation among daily flows during October can be maintained below 20%, brown trout populations are likely to benefit. This is an issue of temporal connectivity - maintaining adequate flows continuously over a defined time period (spawning and incubation season).

The proportion of pool, riffle and run habitats is insensitive to flow level. At a discharge of 440 cfs, runs comprise about 80% of the wetted area, pools 7% and riffles 13%. While the relative proportions do not change substantially as a function of flow, the area of each decreases as flow drops. Riffles are particularly important as a source of invertebrate prey items for trout. From Dare (2001), over half of the area classified as riffle at 447 cfs was lost when flows were reduced to 226 cfs. Any loss in riffle area should be avoided because the trout in the Shoshone River already appear to operate under energetically unfavorable conditions because of the high metabolic cost of warm water temperatures. Reducing available food by reducing riffle area at flows less than 440 cfs would further compromise trout condition. This is an issue of lateral connectivity – ensuring that important habitats along the margin of the river remain connected to the main channel.

Implementation of a winter instream flow prescription can address issues associated with "connectivity" by considering important temporal and spatial dimensions in the Shoshone River tailwater. The temporal scale is pre-determined by the fact that the focus for the studies and resultant instream flow recommendations was defined as the non-irrigation, or winter, period. Broadly, this period extends from October through March. Historic project operations require a short period in early October to adjust flows from irrigation delivery levels and higher releases in late March are sometimes necessary to handle runoff. Thus, the operational period to which these winter flow prescriptions apply is better defined as October 11 to March 20.

Another important temporal flow consideration related to connectivity is the day-to-day and winter season variability of flow releases. Winter flow releases should be maintained at a stable level with relatively minor, if any, change between maximum and minimum flows during any 24-hour period. Over the course of the winter, differences between maximum and minimum releases should be minimized to reduce negative effects to the fishery and habitat. We do not presently have specific, numeric ramping recommendations for the Shoshone River but instead urge that ramping rates be as gradual as possible to ensure that trout are not induced by fluctuating flows to move long distances decreasing their body condition and increasing mortality.

The spatial scale to which these flow recommendations apply is also somewhat pre-determined. At the upstream end the dam marks the furthest possible upstream extent the recommendations could apply. Corbett Dam marks the downstream end. But this reach is further truncated at the upper end by several features including hydro and diversion facilities, DeMaris Springs and the 3.1 miles of river unsuitable for fish below the hydrogen sulfide-laden discharge. The highest value fishery in terms of trout productivity, habitat and angler accessibility exists from the mouth of Sulphur Creek downstream to Corbett Dam. This is the reach for which a specific numeric flow recommendation was developed (440 cfs) and for which a USGS gage exists to directly monitor and implement the flow recommendation.

For flow management purposes, the river can be divided into 2 reaches: an approximately one-mile long reach from the base of the dam where the Shoshone Power Plant discharges water downstream to the discharge point from the Buffalo Bill Power Plant. The second reach is from the Buffalo Bill Power Plant release point downstream to Corbett Dam. The fishery upstream of the Buffalo Bill Power Plant discharge is important. A significant group of anglers enjoy the relative seclusion and angling opportunities. This fishery should be maintained through continuation of the delivery of at least 100 cfs from the Shoshone Power Plant stipulated under the AOA and evaluated by Vogt and Annear (1991).

Vogt and Annear (1991) determined that a flow of 350 cfs at the Buffalo Bill Power Plant, as stipulated under the Annual Operating Agreement in effect at the time, would maintain the blue ribbon fishery in the Shoshone River tailwater. Due to accrual from DeMaris Springs, 350 cfs at Buffalo Bill Power Plant translates to approximately 410 cfs at the USGS gage assuming 60 cfs of spring contribution (Vogt and Annear 1991). Therefore, the 440 cfs recommendation resulting from the intensive work documented in this report comes quite close to the results from the original instream flow analysis. To achieve 440 cfs at USGS gage 06282000, we estimate the BOR will need to release a combined 380 cfs at the Buffalo Bill Power Plant.

Relationships between angler use and winter flow level were not specifically studied but some general observations are relevant. First, as briefly discussed above, angler success may be higher at lower flows because fish become concentrated and hence more susceptible. For example, Steve Yekel, Cody Fisheries Supervisor, noted that anglers were having high success during winter 1995 when flows were low (average of about 200 cfs). At flows around 200 cfs anglers can wade nearly everywhere except the deeper runs and pools. During PHABSIM studies at 436 cfs, we were able to just barely cross the river in a wide run. At the 650 cfs flow our ability to wade was markedly reduced and limited to the channel margins. Therefore, the recommended flow level of 440 cfs will provide wading anglers with the opportunity to access much of the river while higher flows would limit wading access. Lower flows would provide greater wading access but decrease trout habitat quantity and quality, and not afford a measure of protection against trout over-harvest, as described in earlier sections of this report and would also limit portions of the river that could be used by other types of river recreationists like kayakers and anglers who float the river in the winter.

Wind erosion and the resulting blowing sand and dust from exposed beaches around Buffalo Bill Reservoir has been an ongoing issue for a number of years. Dikes have been installed to alleviate the problem and we assumed in this report that the dikes would continue to function at all potential reservoir elevations. Detailed analyses of wind erosion under various operational scenarios were judged to be beyond the purview of this report.

Hydrology simulations by the BOR for release scenarios ranging from 100 to 400 cfs indicate that while releases of 100 and 200 cfs have minimal impacts on the ability of the state to fill its storage account, releases of 300 and 400 cfs are not sustainable under some historic climate and use conditions. Therefore, reservoir operating criteria need to be developed for low inflow periods like 1989 when a flow release of 380 cfs cannot be sustained for the entire winter by the State storage account. The advantages of higher winter flows from a fishery perspective are clear and negotiations toward water management criteria should strive to find strategies that provide such higher flows when feasible. As a reference for negotiation, identifying triggers and developing flow management strategies, Table 9 was compiled from data provided by the BOR (except for water year 2002 in which USGS gage data for the North and South Fork Shoshone were used to calculate inflows) to illustrate annual and winter inflow into Buffalo Bill Reservoir.

Table 9. Annual inflow (kaf) into Buffalo Bill Reservoir and October through March mean flow for water years 1973-2002.

Water Year	Annual inflow (kaf)	October – March flow (cfs)
1973	743	388
1974	1216.3	300
1975	992.4	286
1976	1171.2	395
1977	441.2	249
1978	1093.3	257
1979	724.2	291
1980	829	250
1981	843.5	333
1982	1160.1	264
1983	916.3	406
1984	932	398
1985	597.8	278
1986	1101.6	380
1987	604.7	332
1988	497.7	197
1989	802.6	220
1990	775.4	290
1991	1019.1	322
1992	674.6	305
1993	778.7	272
1994	547.9	253
1995	992.9	288
1996	1352.5	382
1997	1429.1	456
1998	860.8	367
1999	1035.7	311
2000	664	257
2001	507.1	281
2002	333.7	225
Mean	854.6	308

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Appendix A.

STATE OF WYOMING
OFFICE OF THE GOVERNOR
CHEYENNE 82002

MIKE SULLIVAN
GOVERNOR

June 14, 1990

The Honorable George Miller
Chairman, Subcommittee on Water, Power
and Offshore Energy Resources
Committee on Interior and Insular Affairs
U. S. House of Representatives
Washington, D.C. 20515

Dear Mr. Chairman:

This letter is to confirm my previous conversation with your office regarding Wyoming's commitment to protecting the fishery on the Shoshone River below Buffalo Bill Dam. As you are aware, I oppose any amendment to the Buffalo Bill legislation which imposes federal minimum requirements to stream flow in areas where Wyoming law provides a legislatively authorized process. The State Game & Fish Dept. has already commenced biological studies to determine adequate and required stream flows below Buffalo Bill in preparation for an application under Wyoming Law. As well, the State has worked with the Bureau of Reclamation as to its operating plan which, as adopted, provides a 100 cfs. flow.

This is to advise and assure you that I will see that these processes continue and that steps are taken under our laws to assure the study results are thoroughly reviewed with the Bureau, the U. S. Fish & Wildlife Service and steps taken to implement the recommendations.

The Buffalo Bill Dam funding represents a superb federal-state cooperation effort. I appreciate your assistance in seeing that the funding proceeds to assure that the project is not suspended for a lack of funding which can only serve to increase costs and delay completion.

With best regards, I am

Very truly yours,

Mike Sullivan
Governor

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Appendix B. Annual Operating Agreement (AOA).

REVISED INSTREAM FLOW OPERATION AGREEMENT FOR BUFFALO BILL RESERVOIR ENLARGEMENT

THIS REVISED OPERATION AGREEMENT, entered into as of this 1st day of March, 1994 by and between the Bureau of Reclamation (Reclamation), the U.S. Fish and Wildlife Service (Service), and the State of Wyoming (State) serves to replace, in their entirety, the operation agreements dated May 24, 1982 and April 17, 1991.

WHEREAS, all parties agree to the need to provide an instream flow for fisheries in the Shoshone River in conjunction with other water needs.

NOW THEREFORE, the parties hereto do mutually agree as follows:

1. The Buffalo Bill Reservoir shall be operated to insure that, except for years directly following a critical low flow year or a critical low flow period, a minimum flow of 100 cubic feet per second (cfs) will be provided in the river at the Shoshone Powerplant and a minimum flow that will not exceed a combined total of 350 cfs will be provided in the river at the Buffalo Bill Powerplant for instream flow purposes.

2. An individual critical low flow year is a water year with an annual inflow to Buffalo Bill Reservoir of 650,000 acre-feet or less. A critical low flow period is a series of two or more consecutive water years with an average annual inflow of 750,000 acre-feet or less. Exhibit "A" to this agreement provides an example as to the determination of minimum flow releases in relation to critical low flow years and critical low flow periods. During years following a critical low flow year or a critical low flow period, a minimum flow of 100 cfs will be provided in the river at the Shoshone Powerplant and a minimum flow of 100 cfs will be provided in the river at the Buffalo Bill Powerplant. Once the average of the annual inflows for a critical low flow period has exceeded 750,000 acre feet, the determination of the next critical low flow period will not use any of the years used in the previous critical low flow period.

3. The Wyoming State Engineer (State Engineer) shall review the Bureau of Reclamation's Buffalo Bill Reservoir inflow records, together with other available information, such as reservoir ownership accounting, and make a determination whether the water year or period was a critical low flow year or low flow period as defined in Section 2 of this revised operation agreement. The State Engineer shall advise all other parties to this agreement, state water administration officials, and local irrigation district administrators of the preliminary determination by September 1 and the final determination by October 10 of the water year preceding the water year in which the reduced minimum flows will be provided.

At times when the State Engineer issues a preliminary determination of a critical low flow year or low flow period, all parties shall meet prior to September 15 to discuss water availability and the logical implications of various release scenarios. When available information indicates that releases for instream flow purposes can be made from the State's reservoir account and/or uncommitted storage reserves administered by Reclamation, without affecting existing water rights or existing contracts for storage, the parties to this agreement may authorize such releases in excess of 100 cfs, but not more than 350 cfs. The operation to release such stored water to provide an instream flow of up to 350 cfs has been evaluated through the National Environmental Policy Act (NEPA) process. A categorical exclusion checklist was used for this purpose. However, in the years when the State stored water is used to provide this release, Reclamation will also consider the possible need for additional site specific NEPA compliance.

4. The flows discussed in Sections 1, 2, and 3 of this revised operation agreement shall be provided only to the extent that they do not impact any existing project contract obligations as of the date of this agreement.

5. The Wyoming Game and Fish Department (WGFD) will conduct appropriate biological, hydrologic, and water quality studies to quantify the instream flow needs for fisheries. The WGFD will complete a report summarizing the results of this study and providing data relative to stream flow characteristics to include analyses of anticipated inflow from tributaries, springs, return flow and other sources; data relative to water quantity and water quality needs of the fishery; identifying various alternative measures of meeting those needs; and estimating the economic benefits of the proposed fishery.

   The WGFD will provide interim reports, as appropriate, discussing the status of the study, summarizing data obtained, and providing preliminary conclusions. The draft final report will be completed and submitted to Reclamation, the Service, and Wyoming Water Development Commission (WWDC) and the State Engineer for review and comment at least one year prior to the end of the term of this agreement. The final report will be completed prior to the end of the term of this agreement and will address the comments of the reviewing agencies. At the end of the term of this agreement, an instream flow for fisheries will be implemented based on the results of the WGFD study and the WWDC final marketing plan for the M&I water.

6. The term of this agreement shall commence on the date it is entered into as shown at the top of the agreement. The term of this agreement shall extend until the end of the 10-year deferment period described in Section C of Article 7 of the Agreement between the United States of America and the State of Wyoming covering Buffalo Bill Modifications dated March 29, 1985.

THE PARTIES to this revised operation agreement have executed this agreement as to the date first above written.

State of Wyoming	United States
Mike Sullivan Governor, State of Wyoming	Neil Stessman U.S. Bureau of Reclamation
Gordon W. Fassett State Engineer	Charles P. Davis U.S. Fish and Wildlife Service
Francis Petera Game and Fish Department	
Paul Hickey Water Development Commission	

Exhibit "A"
to the
Revised Operation Agreement
Buffalo Bill Reservoir

Water Year	Reservoir Inflow (KAF)	Minimum Winter Release (cfs)	Reason
1916	1120.1		
1917	1042.9	350	
1918	1334.9	350	
1919	525.3	350	
1920	1050.6	100	1919 inflow < 650 KAF
1921	964.2	350	
1922	851.3	350	
1923	906.8	350	
1924	901.2	350	
1925	1296.5	350	
1926	782.9	350	
1927	1179.2	350	
1928	1336.6	350	
1929	795.8	350	
1930	865.9	350	
1931	618.4	350	
1932	957.7	100	1931 inflow < 650 KAF
1933	855.5	350	
1934	590.6	350	
1935	958.6	100	1934 inflow < 650 KAF
1936	978.0	350	
1937	770.4	350	
1938	1043.1	350	
1939	831.2	350	
1940	694.3	350	
1941	906.6	350	
1942	905.7	350	
1943	1359.7	350	
1944	767.8	350	
1945	868.0	350	
1946	819.1	350	
1947	1004.5	350	
1948	911.7	350	
1949	797.7	350	
1950	979.5	350	
1951	1276.4	350	
1952	931.3	350	
1953	744.1	350	
1954	833.0	350	

4

Exhibit "A"
to the
Revised Operation Agreement
Buffalo Bill Reservoir
Continued

Water Year	Reservoir Inflow (KAF)	Minimum Winter Release (cfs)	Reason
1955	603.7	350	
1956	1115.9	100	1955 inflow < 650 KAF
1957	1104.3	350	
1958	797.1	350	
1959	844.5	350	
1960	620.9	350	
1961	672.1	100	1960 inflow < 650 KAF
1962	1044.1	100	1960 & 1961 average inflow = 645.5 < 750 KAF
1963	971.0	350	
1964	927.7	350	
1965	1258.8	350	
1966	713.4	350	
1967	1115.9	350	
1968	861.8	350	
1969	807.0	350	
1970	993.1	350	
1971	1240.6	350	
1972	1052.7	350	
1973	743.0	350	
1974	1216.2	350	
1975	992.4	350	
1976	1171.1	350	
1977	441.2	350	
1978	1093.4	100	1977 inflow < 650 KAF
1979	724.1	350	
1980	828.9	350	
1981	843.4	350	
1982	1160.2	350	
1983	916.3	350	
1984	931.9	350	
1985	597.8	350	
1986	1101.0	100	1985 inflow < 650 KAF
1987	604.8	350	
1988	497.8	100	1987 inflow < 650 KAF
1989	802.8	100	1988 inflow < 650 KAF and 1987 & 1988 average in-flow = 551.3 < 750 KAF

Appendix B. Annual Operating Agreement (AOA).

Exhibit "A"
to the
Revised Operation Agreement
Buffalo Bill Reservoir
Continued

Water Year	Reservoir Inflow (KAF)	Minimum Winter Release (cfs)	Reason
1990	776.0	100	1987-1989 average inflow = 635.1 < 750 KAF
1991	1019.1	100	1987-1990 average inflow = 670.4 < 750 KAF
1992	674.0	100	1987-1991 average inflow = 740.1 < 750 KAF
1993	778.8	100	1987-1992 average inflow = 729.1 < 750 KAF
1994	544.0	100	1987-1993 average inflow = 736.2 < 750 KAF

Regional Office CEC
Sheet 1 of 3

(1) C.E.C. No. GP-450-94-01

(2) Contract No. 4-AA-60-04180

(3) Cost Auth. No. ___________

CATEGORICAL EXCLUSION CHECKLIST (CEC)

(4) PROJECT: Shoshone - Buffalo Bill Dam, Shoshone River (5) DATE: January 18, 1994

(6) NATURE OF ACTION: This CEC addresses the Revised Instream Flow Operation Agreement for Buffalo Bill Reservoir Enlargement, an operational agreement between the Bureau of Reclamation, Fish and Wildlife Service, and the State of Wyoming, for the 10-year period between May 1993 and May 2003. This agreement replaces agreement RV031391/F dated April 17, 1991. The description of this action is the same as in CEC # GP-151-91-001 (copy attached) except for the following changes or additions:

1. The agreement limits the use of data from previous low flow periods in defining a low flow period if the average annual inflow exceeds 750,000 acre feet.

2. The provision limiting use of the State's stored water to 11,310 acre feet annually to supplement instream flows during critical low flow years and critical low flow periods for the 10 year period following completion of dam modifications has been discontinued. The revised agreement now provides for use of the State's uncommitted stored water to supplement the minimum release of 100 cfs and provide a flow of up to 350 cfs in the river at the Buffalo Bill Power Plant.

3. The new agreement provides for a meeting of all parties prior to September 15 whenever the State Engineer determines a low flow period or year exists.

4. Whenever a low flow period or year exists, parties to the agreement may authorize water releases in excess of 100 cfs but not more than 350 cfs. If the State's stored water is considered for use to make such releases, Reclamation will also consider the need for additional site specific NEPA compliance.

5. Completion of the draft final report on instream flow needs for fisheries will be completed about May 2002 (one year prior to expiration of the agreement) rather than by December 31, 1999.

(7) EXCLUSION CATEGORY : 516 DM 6, Appendix 9.4.B.1
Routine planning investigation activities where the impacts are expected to be localized, such as land classification surveys, topographic surveys, archeological surveys, wildlife studies, economic studies, social studies, and other study activity during any planning, preconstruction, construction, or operation and maintenance phases.

CATEGORICAL EXCLUSION
CHECKLIST
(CONTINUED)

EVALUATION OF CRITERIA FOR CATEGORICAL EXCLUSION

(8)	This action or group of actions would have a significant effect on the quality of the human environment.	No _X_ Uncertain ____ Yes ____
(9)	This action or group of actions would involve unresolved conflicts concerning alternative uses of available resources.	No _X_ Uncertain ____ Yes ____

EVALUATION OF EXCEPTIONS TO ACTIONS WITHIN CATEGORICAL EXCLUSION

(10)	This action would have significant adverse effects on public health or safety.	No _X_ Uncertain ____ Yes ____
(11)	This action would affect unique geographical features such as: wetlands, wild or scenic rivers, rivers in the nationwide inventory, refuges, flood plains, or prime and unique farmlands.	No _X_ Uncertain ____ Yes ____
(12)	The action will have highly controversial environmental effects.	No _X_ Uncertain ____ Yes ____
(13)	The action will have highly uncertain environmental effects or involve unique or unknown environmental risk.	No _X_ Uncertain ____ Yes ____
(14)	This action will establish a precedent for future actions.	No _X_ Uncertain ____ Yes ____
(15)	This action is related to other actions with individually insignificant but cumulatively significant effects.	No _X_ Uncertain ____ Yes ____

(16) This action will affect properties listed or eligible for listing in the National Register of Historic Places. (To be completed only by ~~project~~ Regional archeologist.) — No ___ Uncertain _____ Yes _____

(17) This action will affect a species listed or proposed to be listed as Endangered or Threatened. — No _X_ Uncertain _____ Yes _____

(18) This action threatens to violate Federal, State, local, or tribal law or requirements imposed for protection of the environment. — No _X_ Uncertain _____ Yes _____

(19) NEPA ACTION RECOMMENDED: CATEGORICAL EXCLUSION _X_______

EA _____________

EIS _____________

(20) NATURE OF ACTION (CONTINUED)

(21) ENVIRONMENTAL COMMITMENTS, EXPLANATION AND/OR REMARKS:
This agreement provides minimum instream flows for fishery maintenance in the Shoshone River below Buffalo Bill Dam, Wyoming. Flows will be evaluated and another instream flow agreement will be negotiated by the year 2003.

(22) PREPARER'S NAME AND TITLE: Auzie Blevins, Environmental Specialist

(23) RECOMMENDED: [signature] DATE: 1-19-94
Regional Division or Office Chief

(24) REGIONAL ARCHEOLOGIST'S CERTIFICATION OF ITEM 16: [signature] DATE: 1-19-94
Regional Archeologist

(25) APPROVED: [signature] (Acting) DATE: 1/19/94
Regional Environmental Affairs Officer

Revised October 1992

Appendix C. Bureau of Reclamation hydrologic analysis.

USBR -WYAO
May 16, 2003

Hydrologic Analysis for the Shoshone River below Buffalo Bill Dam

Hydrologic Analysis
This study was performed to provide information to Wyoming Game and Fish for their analysis of the effects of various reservoir releases on storage levels and fisheries in Buffalo Bill Reservoir. The Buffalo Bill Reservoir annual operation plan model (BBRAOP) was used to simulate operation of the enlarged reservoir with the historic inflow conditions of water years 1971 through 2001 as requested by Wyoming Game and Fish Department (WG&F). Four scenarios which WG&F requested to analyze the effect of a release from the Dam of 100, 200, 300, or 400 cubic feet per second (cfs) for the October 10 through March 31 period of each year have been prepared. In the non-irrigation season there were years when the reservoir filled prior to the end of March. In these years, increased releases were required during part of the non-irrigation period to prevent the reservoir from rising above the top of the active conservation pool.

It should be noted that non-irrigation season releases were set at the requested flows for purpose of the study. In actual operation non-irrigation season releases would be increased when necessary to delay the filling of the reservoir, maximize power generation and reduce the downstream releases during peak runoff. Also the study reveals that the state account cannot support a non-irrigation season release of either 300 cfs or 400 cfs for water years 1978, 1986, 1988, 1989, 1990, and 1994 in the 400 cfs run and water years 1989 and 1990 in the 300 cfs run. The releases for the years mentioned have been reduced to the minimum release of 50 cfs from each of the two accounts.

Historic inflow for the October 1970 through September 2001 period was entered into the model along with estimated irrigation requirements, municipal demand, and powerplant availability. All of the operation studies began with Buffalo Bill Reservoir at elevation 5338.30 feet, which was the elevation on September 30, 1970. The BBRAOP model utilizes the interim condition area-capacity table dated March 1992 to determine reservoir content for any given reservoir elevation. The BBRAOP model operates on monthly input and provides end of month elevation and content, and total monthly power generation. The October 10 elevation and content was determined by calculating daily elevation and content during October, assuming a uniform release for the month. Since irrigation releases were made during the first ten days of October the actual release is not uniform. The content and elevation was adjusted to reflect the elevation and content on the day of the month when the volume released during the first ten days occurred. Power generation displayed on the tables represents total generation for the October 10 through March 31 period. October generation for the non-irrigation portion of the month was estimated at 21 times the daily generation for November.

Water Accounting Hydrologic Analysis for the Districts and State Accounts
The first 50 cfs of the non-irrigation season releases are made from the Shoshone account with additional releases of up to 350 cfs being made from the State account.

Assumptions used in the Buffalo Bill / Shoshone River Hydrology Analysis for Wyoming Game and Fish Reservoir Operation

- Initial reservoir content for the study is based on the actual September 30, 1970 elevation of 5338.30 feet, which is 267,700 acre-feet using the interim condition area-capacity table used in the Buffalo Bill model.

- The only reservoir target is an end of July target to fill the reservoir.

- When releases above the irrigation demand were required, they were delayed to the extent that no monthly release averaged more than 4,500 cfs. In years when the reservoir was full by or before the end of March, the release was increased as inflow was passed to prevent the reservoir from exceeding the top of conservation capacity of 646,565 acre-feet.

- Monthly inflows are historic data from Basic Data.

- Heart Mountain Canal diversion is the 11 year average from Hydromet (1991 - 2001) as requested by Wyoming Game and Fish.

- Municipal Demand is 300 acre-feet per month for the entire period of the study.

- The minimum release from the Dam used in the analysis is 100 cfs.

- The minimum flow below Buffalo Bill Powerplant is 100 cfs. If the required winter release is greater than 100 cfs, 100 cfs will be released through Shoshone Powerplant or the outlet at the Dam if Shoshone Powerplant is unavailable. The remainder is released through Buffalo Bill Powerplant.

- The flows at the Cody gage used in the study were as follows unless it became necessary to release additional water due to the reservoir capacity being filled:

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
100	327	160	160	160	160	160	410	1270	1350	1370	1170	940
200	395	260	260	260	260	260	460	1270	1350	1370	1170	940
300	463	360	360	360	360	360	510	1270	1350	1370	1170	940
400	530	460	460	460	460	460	560	1270	1350	1370	1170	940

The October flow at the Cody gage includes a flow of 680 cfs to meet irrigation demands during the first 10 days of the month. The last 21 days are at the winter release rate. April through September flows are an estimate of what is required to meet downstream demands in a normal year.

- The contribution from springs between Buffalo Bill Powerplant and the Cody gage was used as a constant 60 cfs for the entire study period.

- Shoshone Powerplant was modeled as being unavailable for 14 days each December in order to perform annual maintenance. Every third year, extended maintenance is performed requiring an additional outage of 28 days in January. During periods when Shoshone Powerplant is unavailable, 100 cfs is released through the outlet at the Dam.

- Buffalo Bill Powerplant is available 100% of the time in the study. Non-irrigation season releases allow that at least one unit can be off-line for maintenance through the winter months.

- Spirit Mountain Powerplant is not available during October through March. During the April through September period, Spirit Mountain Powerplant is modeled as available 100% of the time.

- Heart Mountain Powerplant is not available from October 1 through April 15 in the model. From April 16 through September 30, Heart Mountain Powerplant is modeled as available 100% of the time.

- All inflows accrue to the Shoshone account until first fill.

Appendix C. Bureau of Reclamation hydrologic analysis.

USBR -WYAO
May 16, 2003

- On September 30, 1970 we assumed that the State account was at 130,000 acre-feet for the 400 cfs run and 120,000 for the rest of the runs (this kept their account from going negative in the first year). For the purpose of the model Polecat bench and the Private accounts were not distinguished from other Shoshone project accounts.

- Non-irrigation season releases were modeled as October 10 through April 15. The first 50 cfs was released from the Shoshone account and additional releases are made from the State account.

Appendix C. Bureau of Reclamation hydrologic analysis.

Shoshone River Hydrologic Analysis

Based on average consumptive use demand from 1991 to 2001

Continuous release for instream flow and hydro combined of 100 cfs (measured at USGS gage number 06282000)

Water Year	Water year inflow acre-feet	State account status on October 1 acre-feet	Total reservoir contents on October 10 acre-feet	Total reservoir elevation on October 10 acre-feet	Nonconsumptive winter releases total acre-feet from 10/10 to 3/31 *	Total reservoir contents on March 31 acre-feet	Total reservoir elevation on March 31 acre-feet	State account status on March 31 acre-feet	KW hours generated**
1971	1,240,500	120,000	269,000	5337.9	34,300	324,600	5348.0	102,900	5,865,000
1972	1,052,700	189,600	584,000	5385.7	72,000	**646,500**	**5393.5**	**189,600**	18,208,000
1973	743,000	189,600	588,400	5386.3	48,500	**646,500**	**5393.5**	**189,600**	10,091,000
1974	1,216,300	189,500	487,400	5372.8	34,300	542,200	5380.2	172,300	6,763,000
1975	992,400	189,600	523,000	5377.6	34,300	573,000	5384.3	172,500	6,900,000
1976	1,171,200	189,600	540,400	5380.0	34,500	621,300	5390.5	180,000	5,805,000
1977	441,200	189,600	535,300	5379.3	34,300	570,900	5384.0	172,400	6,924,000
1978	1,093,300	170,900	321,900	5347.5	34,300	364,000	5354.5	153,700	6,121,000
1979	724,200	189,600	556,700	5382.1	34,300	608,000	5388.8	172,500	5,769,000
1980	829,000	189,600	489,800	5373.1	34,500	530,100	5378.6	172,200	6,800,000
1981	843,500	189,600	550,500	5381.3	34,300	608,400	5388.8	172,400	7,020,000
1982	1,160,100	189,600	474,700	5371.0	34,300	518,200	5377.0	172,400	5,511,000
1983	916,300	189,600	610,200	5389.1	71,200	**646,500**	**5393.5**	**189,600**	18,119,000
1984	932,000	189,600	557,700	5382.3	34,500	631,900	5391.8	**189,600**	7,134,000
1985	597,800	189,600	544,600	5380.5	34,300	586,300	5386.0	172,400	5,728,000
1986	1,101,600	189,600	450,300	5367.6	34,300	529,000	5378.5	172,400	6,645,000
1987	604,700	189,600	551,800	5381.5	34,300	606,800	5388.6	172,500	7,027,000
1988	497,700	189,600	416,500	5362.6	34,500	437,900	5365.8	172,200	5,332,000
1989	802,600	170,700	265,200	5337.2	34,300	292,900	5342.4	153,500	5,748,000
1990	775,400	152,000	419,800	5363.1	34,300	469,800	5370.4	134,800	6,508,000
1991	1,019,100	189,600	521,500	5377.4	34,300	575,200	5384.6	172,500	5,688,000
1992	674,600	189,600	520,100	5377.3	34,500	576,500	5384.7	172,200	6,938,000
1993	778,700	189,600	467,100	5370.0	34,300	510,100	5375.9	172,400	6,673,000
1994	547,900	189,600	526,400	5378.1	34,300	562,600	5382.9	172,400	5,658,000
1995	992,900	189,600	401,400	5360.3	34,300	448,100	5367.3	172,500	6,412,000
1996	1,352,500	189,600	528,300	5378.3	34,500	609,400	5389.0	172,200	6,998,000
1997	1,429,100	189,600	547,500	5380.9	89,400	596,500	5387.3	155,200	19,994,000
1998	860,800	189,600	580,900	5385.3	36,700	**646,500**	**5393.5**	**189,600**	7,850,000
1999	1,035,700	189,600	530,300	5378.6	34,300	586,500	5386.0	172,400	6,930,000
2000	664,000	189,600	530,000	5378.6	34,500	571,300	5384.0	172,200	5,724,000
2001	507,100	189,600	428,900	5364.5	34,300	472,300	5370.7	172,400	6,528,000

Note: On September 30, 1970 we assumed that the State account was at 130,000 acre-feet for the 400 cfs run and 120,000 for the rest of the runs (this kept their account from going negative in the first year).
For the purpose of the model Polecat bench and the Private accounts were not distinguished from other Shoshone project accounts.
Non-irrigation release (Begin after October 10 and ending April 15) = The first 50 cfs from Shoshone account and additional releases are made from the State account.

* Assumes a constant release in cubic feet per second

** Assumes non-irrigation season 100 cfs release from Shoshone Power Plant and all releases greater than 100 cfs are made through the Buffalo Bill Power Plant

Appendix C. Bureau of Reclamation hydrologic analysis.

Shoshone River Hydrologic Analysis

Based on average consumptive use demand from 1991 to 2001

Continuous release for instream flow and hydro combined of 200 cfs (measured at USGS gage number 06282000)

Water Year	Water year inflow acre-feet	State account status on October 1 acre-feet	Total reservoir contents on October 10 acre-feet	Total reservoir elevation on October 10 acre-feet	Nonconsumptive winter releases total acre-feet from 10/10 to 3/31 *	Total reservoir contents on March 31 acre-feet	Total reservoir elevation on March 31 acre-feet	State account status on March 31 acre-feet	KW hours generated**
1971	1,240,500	120,000	266,900	5337.5	68,200	290,700	5342.0	69,100	14,199,000
1972	1,052,700	189,600	579,200	5385.1	72,000	646,500	5393.5	189,600	18,128,000
1973	743,000	189,600	584,200	5385.7	68,200	626,800	5391.2	185,500	15,728,000
1974	1,216,300	189,500	486,100	5372.6	68,200	508,300	5375.7	138,500	16,161,000
1975	992,400	189,600	521,800	5377.5	68,200	539,100	5379.8	138,700	16,404,000
1976	1,171,200	189,600	537,400	5379.6	68,600	587,200	5386.1	145,900	15,522,000
1977	441,200	189,600	533,800	5379.1	68,200	537,000	5379.5	138,600	16,451,000
1978	1,093,300	134,100	284,300	5340.8	68,200	293,200	5342.4	83,100	14,209,000
1979	724,200	189,600	555,400	5381.9	68,200	574,100	5384.4	138,700	15,410,000
1980	829,000	189,600	489,100	5373.0	68,600	496,000	5374.0	138,200	16,195,000
1981	843,500	189,600	547,400	5380.9	68,200	574,500	5384.5	138,600	16,632,000
1982	1,160,100	189,600	473,800	5370.9	68,200	484,300	5372.4	138,600	14,808,000
1983	916,300	189,600	604,900	5388.4	71,200	646,500	5393.5	189,600	18,034,000
1984	932,000	189,600	553,100	5381.7	68,600	597,800	5387.5	156,500	16,903,000
1985	597,800	189,600	542,200	5380.2	68,200	552,400	5381.6	138,600	15,313,000
1986	1,101,600	189,600	448,000	5367.3	68,200	495,100	5373.9	138,600	15,844,000
1987	604,700	189,600	548,200	5381.0	68,200	572,900	5384.3	138,700	16,669,000
1988	497,700	189,600	415,900	5362.5	68,600	403,800	5360.7	138,200	14,374,000
1989	802,600	133,700	227,200	5329.1	68,200	221,900	5327.9	82,700	13,482,000
1990	775,400	78,200	344,300	5351.3	68,200	361,900	5354.1	27,200	14,914,000
1991	1,019,100	128,000	438,100	5365.8	68,200	461,000	5369.1	77,100	14,638,000
1992	674,600	189,600	518,700	5377.1	68,600	542,400	5380.2	138,200	16,489,000
1993	778,700	189,600	465,400	5369.7	68,200	476,200	5371.2	138,600	15,924,000
1994	547,900	189,600	524,800	5377.9	68,200	528,700	5378.4	138,600	15,148,000
1995	992,900	189,600	386,600	5358.0	68,200	401,500	5360.3	138,700	15,257,000
1996	1,352,500	189,600	526,200	5378.1	68,600	575,300	5184.6	138,200	16,638,000
1997	1,429,100	189,600	544,900	5380.6	68,200	617,700	5390.0	176,400	15,478,000
1998	860,800	189,600	577,400	5384.8	68,200	615,000	5389.7	173,700	16,909,000
1999	1,035,700	189,600	528,500	5378.4	68,200	552,600	5381.6	138,700	16,467,000
2000	664,000	189,600	529,100	5378.4	68,600	537,200	5379.5	138,200	15,300,000
2001	507,100	189,600	426,700	5364.2	68,200	438,400	5365.9	138,600	15,614,000

Note: On September 30, 1970 we assumed that the State account was at 130,000 acre-feet for the 400 cfs run and 120,000 for the rest of the runs (this kept their account from going negative in the first year).
For the purpose of the model Polecat bench and the Private accounts were not distinguished from other Shoshone project accounts.
Non-irrigation release (Begin after October 10 and ending April 15) = The first 50 cfs from Shoshone account and additional releases are made from the State account.

* Assumes a constant release in cubic feet per second

** Assumes non-irrigation season 100 cfs release from Shoshone Power Plant and all releases greater than 100 cfs are made through the Buffalo Bill Power Plant

Appendix C. Bureau of Reclamation hydrologic analysis.

Shoshone River Hydrologic Analysis

Based on average consumptive use demand from 1991 to 2001
Continuous release for instream flow and hydro combined of 300 cfs (measured at USGS gage number 06282000)

Water Year	Water year inflow acre-feet	State account status on October 1 acre-feet	Total reservoir contents on October 10 acre-feet	Total reservoir elevation on October 10 acre-feet	Nonconsumptive winter releases total acre-feet from 10/10 to 3/31 *	reservoir contents on March 31 acre-feet	Total reservoir elevation on March 31 acre-feet	State account status on March 31 acre-feet	KW hours generated**
1971	1,240,500	120,000	265,500	5337.2	102,200	256,700	5335.5	35,100	22,304,000
1972	1,052,700	189,600	576,000	5384.7	102,700	615,800	5389.8	174,500	26,834,000
1973	743,000	189,600	581,500	5385.4	102,200	592,800	5386.8	151,500	25,397,000
1974	1,216,300	189,500	485,300	5372.5	102,200	474,300	5371.0	104,500	25,353,000
1975	992,400	189,600	521,000	5377.4	102,200	505,100	5375.2	104,700	25,747,000
1976	1,171,200	189,600	535,400	5379.3	102,700	553,100	5381.7	111,800	25,072,000
1977	441,200	189,600	532,900	5379.0	102,200	503,000	5374.9	104,600	25,818,000
1978	1,093,300	97,200	247,000	5333.4	102,200	222,300	5328.0	12,200	21,649,000
1979	724,200	189,600	554,500	5381.8	102,200	540,100	5379.9	104,700	24,893,000
1980	829,000	189,600	488,700	5373.0	102,700	461,900	5369.2	104,100	25,399,000
1981	843,500	189,600	545,400	5380.6	102,200	540,500	5380.0	104,600	26,128,000
1982	1,160,100	189,600	473,200	5370.8	102,200	450,300	5367.6	104,600	23,917,000
1983	916,300	189,600	601,400	5387.9	102,200	615,500	5389.7	174,200	26,896,000
1984	932,000	189,600	550,000	5381.2	102,700	563,700	5383.1	122,400	26,487,000
1985	597,800	189,600	540,700	5380.0	102,200	518,400	5377.0	104,600	24,740,000
1986	1,101,600	175,400	413,600	5362.2	102,200	428,200	5364.4	90,400	24,489,000
1987	604,700	189,600	545,900	5380.7	102,200	538,900	5379.8	104,700	26,155,000
1988	497,700	189,600	415,600	5362.5	102,700	369,700	5355.4	104,100	23,207,000
1989 ***	802,600	96,700	193,700	5321.0	34,300	218,800	5327.2	79,500	5,287,000
1990 ***	775,400	78,000	347,300	5351.8	34,300	395,700	5359.4	60,800	6,138,000
1991	1,019,100	164,800	472,800	5370.8	102,200	463,800	5369.5	79,900	24,034,000
1992	674,600	189,600	517,800	5376.9	102,700	508,300	5375.7	104,100	25,848,000
1993	778,700	189,600	464,400	5369.6	102,200	442,200	5366.4	104,600	25,008,000
1994	547,900	189,600	518,400	5377.0	102,200	489,400	5373.1	104,600	24,439,000
1995	992,900	153,400	343,000	5351.1	102,200	325,300	5348.1	68,500	23,367,000
1996	1,352,500	189,600	524,900	5377.9	102,700	541,200	5380.1	104,100	26,093,000
1997	1,429,100	189,600	543,200	5380.3	102,200	583,700	5385.7	142,400	25,050,000
1998	860,800	189,600	575,100	5384.5	102,200	581,000	5385.3	139,700	26,528,000
1999	1,035,700	189,600	527,400	5378.2	102,200	518,600	5377.1	104,700	25,841,000
2000	664,000	189,600	528,400	5378.4	102,700	503,100	5375.0	104,100	24,688,000
2001	507,100	189,600	425,300	5364.0	102,200	404,400	5360.8	104,600	24,523,000

Note: On September 30, 1970 we assumed that the State account was at 130,000 acre-feet for the 400 cfs run and 120,000 for the rest of the runs (this kept their account from going negative in the first year).
For the purpose of the model Polecat bench and the Private accounts were not distinguished from other Shoshone project accounts.
Non-irrigation release (Begin after October 10 and ending April 15) = The first 50 cfs from Shoshone account and additional releases are made from the State account.

* Assumes a constant release in cubic feet per second

** Assumes non-irrigation season 100 cfs release from Shoshone Power Plant and all releases greater than 100 cfs are made through the Buffalo Bill Power Plant

*** Non-irrigation season releases from the reservoir were decreased to 100 cfs to keep the accounts from going negative.

Appendix C. Bureau of Reclamation hydrologic analysis.

Shoshone River Hydrologic Analysis

Based on average consumptive use demand from 1991 to 2001
Continuous release for instream flow and hydro combined of 400 cfs (measured at USGS gage number 06282000)

Water Year	Water year inflow acre-feet	State account status on October 1 acre-feet	Total reservoir contents on October 10 acre-feet	Total reservoir elevation on October 10 acre-feet	Nonconsumptive winter releases total acre-feet from 10/10 to 3/31 *	Total reservoir contents on March 31 acre-feet	Total reservoir elevation on March 31 acre-feet	State account status on March 31 acre-feet	KW hours generated**
1971	1,240,500	130,000	264,600	5337.0	136,400	222,500	5328.1	10,800	30,201,000
1972	1,052,700	189,600	573,800	5384.4	137,200	581,300	5385.4	140,000	36,496,000
1973	743,000	189,600	579,600	5385.1	136,400	558,600	5382.4	117,300	34,973,000
1974	1,216,300	189,600	484,700	5372.4	136,400	440,100	5366.1	70,400	34,449,000
1975	992,400	189,600	520,500	5377.3	136,400	470,900	5370.5	70,500	34,979,000
1976	1,171,200	189,600	534,000	5379.1	137,200	518,600	5377.1	77,300	34,532,000
1977	441,200	189,600	532,200	5378.9	136,400	468,800	5370.2	70,400	35,080,000
1978 ***	1,093,300	60,000	214,800	5326.3	34,300	253,000	5334.7	42,800	5,443,000
1979	724,200	189,600	553,800	5381.7	136,400	505,900	5375.3	70,500	34,273,000
1980	829,000	189,600	488,400	5372.9	137,200	427,400	5364.3	69,600	34,540,000
1981	843,500	189,600	544,000	5380.4	136,400	506,300	5375.4	70,400	35,505,000
1982	1,160,100	189,600	472,700	5370.8	136,400	416,100	5362.6	70,400	32,945,000
1983	916,300	189,600	598,900	5387.6	136,400	581,300	5385.4	140,000	36,549,000
1984	932,000	189,600	547,900	5381.0	137,200	529,200	5378.5	87,900	36,023,000
1985	597,800	189,600	539,600	5379.9	136,400	484,200	5372.4	70,400	34,063,000
1986 ***	1,101,600	86,900	380,700	5357.1	34,300	458,900	5368.8	69,700	6,347,000
1987	604,700	189,600	544,200	5380.5	136,400	504,700	5375.2	70,400	35,535,000
1988 ***	497,700	152,900	383,900	5357.6	34,500	401,200	5360.3	135,500	5,182,000
1989 ***	802,600	134,000	231,800	5330.2	34,300	256,200	5335.4	116,800	5,420,000
1990 ***	775,400	115,300	385,200	5357.8	34,300	433,100	5365.1	98,100	6,216,000
1991	1,019,100	183,500	508,800	5375.7	136,400	467,000	5370.0	64,400	33,585,000
1992	674,600	189,600	517,100	5376.8	137,200	473,800	5370.9	69,600	35,133,000
1993	778,700	174,500	429,800	5364.6	136,400	374,200	5356.1	55,300	33,346,000
1994 ***	547,900	123,500	452,000	5367.8	34,300	486,300	5372.6	106,300	5,358,000
1995	992,900	156,200	344,900	5351.4	136,400	293,900	5342.6	37,000	31,666,000
1996	1,352,500	189,600	524,000	5377.8	137,200	506,700	5375.4	69,600	35,473,000
1997	1,429,100	189,600	542,000	5380.2	136,400	549,500	5381.2	108,200	34,498,000
1998	860,800	189,600	573,500	5384.3	136,400	546,800	5380.8	105,500	36,045,000
1999	1,035,700	189,600	526,500	5378.1	136,400	484,400	5372.4	70,500	35,090,000
2000	664,000	189,600	528,000	5378.3	137,200	468,600	5370.2	69,600	34,019,000
2001	507,100	189,600	424,300	5363.8	136,400	370,200	5355.5	70,400	33,294,000

Note: On September 30, 1970 we assumed that the State account was at 130,000 acre-feet for the 400 cfs run and 120,000 for the rest of the runs (this kept their account from going negative in the first year).
For the purpose of the model Polecat bench and the Private accounts were not distinguished from other Shoshone project accounts.
Non-irrigation release (Begin after October 10 and ending April 15) = The first 50 cfs from Shoshone account and additional releases are made from the State account.

* Assumes a constant release in cubic feet per second

** Assumes non-irrigation season 100 cfs release from Shoshone Power Plant and all releases greater than 100 cfs are made through the Buffalo Bill Power Plant

*** Non-irrigation season releases from the reservoir were decreased to 100 cfs to keep the accounts from going negative.