WYOMING GAME AND FISH DEPARTMENT

FISH DIVISION

ADMINISTRATIVE REPORT

Title: Instream Flow Studies on Francs Fork, a Greybull River Tributary

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ABSTRACT

Instream flows necessary for maintaining Yellowstone cutthroat trout (YSC) habitat and populations were identified through studies conducted on Francs Fork Creek during 1998. Instream flow water right recommendations in this report are based on those studies. The Habitat Quality Index model was used to assess the relationship between stream flow and habitat quality for adult trout in the summer. A physical habitat simulation model was used to develop instream flow recommendations for maintaining spawning YSC habitat during spring runoff. A Habitat Retention model was used to identify a maintenance flow level for all life stages for the late fall through winter season. A dynamic hydrograph model was used to quantify instream flow needs for maintenance of channel geomorphology and macro-habitat characteristics.

The lowest instream flow that will maintain or improve adult trout habitat quality in the existing stream channel during the late summer period between July 1 and September 30 is 17 cfs. An instream flow of 160 cfs is recommended to maintain hydraulic habitat for spawning from May 1 to June 30. The instream flow needed to maintain physical habitat for all YSC life stages from October 1 to April 30 is 8 cfs. A range of instream flows for maintaining channel characteristics and habitat is provided for the period of May 1 to June 30. These instream flow recommendations apply to a 6.5 mile stream segment that is entirely upstream of Pitchfork Ranch's irrigation diversion point in Township 48N, Range 103W, Section 34, NE1/4.

INTRODUCTION

Since the instream flow law was passed in 1986, through early 2002, Wyoming Game & Fish Department (WGFD) has submitted 82 instream flow water right applications, of which the state engineer has approved 16 and the Board of Control has adjudicated 2. Initially, efforts focused on WGFD class 1 and 2 waters, which are highly productive fisheries and provide popular recreational opportunities. Recent efforts have shifted toward small headwater streams supporting native cutthroat trout. From 1998 through 2001, studies were conducted on seven Greybull River tributaries, including Francs Fork, containing populations of Yellowstone cutthroat trout (YSC; *Oncorhynchus clarki bouvieri*). Future plans include studies and instream flow filings in 2002 and 2003 on an additional seven tributaries in the Wood River drainage.

Yellowstone cutthroat trout historically occupied Wyoming waters in the Snake River and Yellowstone River drainages, including the tributary Bighorn and Tongue River drainages (Behnke

1992). More recent distributional information is summarized in May (1996) and Kruse et al. (1997). Of the extant populations, those in the Greybull River and tributary Wood River contain genetically pure populations that span a large geographic area (Kruse et al. 2000). Several strategies are being pursued by the WGFD to maintain and improve populations and habitat for this species. Securing adequate instream flow water rights is a necessary and prominent component of these strategies. Instream flow protection is being pursued foremost in these drainages under a strategy of targeting broad systems of interconnected waters containing pure YSC. Future filings are anticipated in other regions like the Shoshone River drainage and Bighorn Mountain tributaries to maintain or improve fisheries throughout the species' historic range.

Within the Greybull River drainage, instream flow protection strategy focuses on stream segments on State and Federally administered public lands. Instream flow studies were not conducted in the Washakie Wilderness, even though a substantial portion of the species range occurs there, because the wilderness designation provides an adequate level of protection at present.

The Yellowstone cutthroat trout was petitioned for listing under the Endangered Species Act in 1998. Recently, the Fish and Wildlife Service completed a 90-day petition review finding that listing is not warranted at this time (Federal Register, February 23, 2001). However, WGFD continues management efforts to protect and expand YSC populations. Instream flow protection will help ensure the future of YSC in Wyoming by protecting existing flow conditions against unknown and unforeseeable future demands.

Adequate and continuous instream flows are important to maintain or improve the existing fishery resources of Francs Fork. The purpose of this report is to 1) quantify year-round instream flow levels needed to maintain or improve existing hydraulic habitat for Yellowstone cutthroat trout populations, 2) quantify instream flows needed to maintain long-term trout habitat and related physical and biological processes and 3) provide the basis for filing an application for an instream flow water right to maintain these beneficial uses.

BASIS FOR QUANTIFYING FISHERY INSTREAM FLOWS

In response to discord around the country about essential characteristics of instream flow applications and administrations, the Instream Flow Council (IFC) recently produced a text in which they provided guidance based on scientific literature on the subject of instream flows as well as the extensive experience of the 16 authors (Annear et al. 2002). The IFC is an organization of state and provincial fishery and wildlife management agencies that are represented by the senior instream flow administrator for those agencies. Among the perspectives advanced in that document is the assertion that adequate instream flows must address eight ecosystem components that include three policy components (legal, institutional, and public involvement) and five riverine components (hydrology, geomorphology, biology, water quality and connectivity). This perspective is based on the authors' understanding that fisheries and aquatic ecosystems include the complex of community and its environment functioning together as an ecological unit in nature. Consequently, the IFC holds that "... to maintain or restore the integrity of flowing water ecosystems, instream flow practitioners must recognize the importance of both inter- and intra-annual stream flow patterns for maintaining natural processes in streams. Where possible, managers should base decisions on the concept of natural flow variability and the need to balance sediment input with transport capability. Thus, a true minimum flow to maintain riverine processes is a *quantity* of water – rather than a single, continuous *rate* of flow – distributed over time in varying amounts to maintain natural stream processes."

In this report we directly address all of these eight ecosystem components except water quality and connectivity. These two components are indirectly addressed, however, as we assume that instream flows levels that address hydrology, geomorphology and biology will adequately address water quality and connectivity in this stream.

Legal and Institutional Components

Instream flow water rights may be provided according to one or more of several legal or administrative tools. The WGFD is statutorily empowered to manage the fishery and wildlife resources of the state for the benefit of its citizens. The statutes that created the WGFD also convey the sole responsibility for managing fisheries, and water to support fisheries, to the department. Specifically, the Wyoming Game and Fish Commission is created and empowered in Title 23 of the Wyoming Statutes. The department was created and placed under the direction and supervision of the commission in W.S. 23-1-401 and the responsibilities of the commission and the department are defined in W.S. 23-1-103. In these and associated statutes, the department is charged with providing ". . .an adequate and flexible system for the control, propagation, management, protection and regulation of all Wyoming wildlife." The department is the only entity of state government directly charged with managing Wyoming's wildlife resources and conserving them for future generations. The department's mission statement is: "Conserving Wildlife - Serving People."

Historically, water for protecting and managing fishery and wildlife resources has been provided by a variety of administrative mechanisms such as memorandums of agreement and special use permits for water development projects for many years. The most obvious legal tool is the state instream flow water law that was passed in 1986. Wyoming Statute 41-3-1001establishes that "unappropriated water flowing in any stream or drainage in Wyoming may be appropriated for instream flows to maintain or improve existing fisheries and declared a beneficial use...". To fishery managers, others who helped craft this legislation and sponsors of the initiative that led to passage, the statute's intent was to do more than simply protect enough flow to keep fish alive in streams at all times. Rather, the statute was supported to provide fishery managers the opportunity to legally protect adequate flow regimes to maintain existing habitat, fish community characteristics and public enjoyment opportunities (Mike Stone, WGFD, Cheyenne; Tom Dougherty, Wyoming Wildlife Federation, Boulder, CO, personal communication). The following discussion provides our interpretation of the terms used in this statute.

Preserving stream fisheries is a state obligation under the public trust doctrine. In 1986, the Wyoming legislature enacted legislation that provided a specific mechanism for fulfilling this responsibility. Wyoming Statute 41-3-1001(a) establishes that "unappropriated water flowing in any stream or drainage in Wyoming may be appropriated for instream flows to maintain or improve existing fisheries and declared a beneficial use...". To fishery managers, others who helped craft this legislation and sponsors of the initiative that led to passage, the statute's intent was to do more than simply protect enough flow to keep fish alive in streams at all times. Rather, the statute was supported to provide fishery managers the opportunity to legally protect adequate flow regimes to maintain existing habitat, fish community characteristics and public enjoyment opportunities (Mike Stone, WGFD, Cheyenne; Tom Dougherty, Wyoming Wildlife Federation, Boulder, CO, personal communication). The following discussion provides our interpretation of the terms used in this statute.

Perhaps the most critical term in the statute is the word "fishery". Since passage of the instream flow law, the Wyoming Game and Fish Department has identified instream flows to protect habitat for various fish species and life stages. However, a *fishery* is in fact defined as the interaction of aquatic organisms, aquatic environments and their human users to produce sustained benefits (Nielsen 1993, Ditton 1997). In other words, a fishery is a product of physical, biological and chemical processes as well as societal expectations and uses. Each component is important, each affects the other and each presents opportunities for affecting the character of a fishery resource. Fish populations are merely one attribute of a fishery.

The term "existing" fishery also warrants clarification. In this application, "existing" does not refer to a constant number of fish. Fish populations fluctuate in abundance annually and seasonally in streams in response to a variety of environmental factors (Dey and Annear 2001, House 1995, Nehring and Anderson 1993). In a study of six relatively pristine streams across Wyoming, Dey and Annear (2001) documented coefficients of variation in annual trout abundance ranging from 29 to 115%. Similarly, in a western Oregon stream studied for 11 years, the density of cutthroat trout fry varied from 8 to 38 per 100 m^2 and the density of cutthroat trout juveniles ranged from 16 to 34 per 100 m^2 (House 1995). In this example, population fluctuations occurred despite the fact that summer habitat conditions were not degraded and appeared to be relatively stable.

Naturally variable flow, geology, climate and vegetation provide the template of processes which form and control fish habitat. Fish habitat, in turn, influences the spawning success, survival and growth of fish. Additional biological factors like movement, migration, and predation also affect fish numbers over time and space. Van Den Avyle (1993) notes that populations that fluctuate randomly or cyclically around a long-term equilibrium level should be considered stable. Thus "existing fishery" is not a single, constant number of fish to be maintained by a defined target flow; but is a naturally fluctuating product of many processes. The WGFD instream flow strategy recognizes this inherent trout population variability and defines the "existing fishery" as a dynamic equilibrium of habitat, fish, water quality and societal factors. Instream flow recommendations are based on a goal of maintaining flow-based habitat conditions that provide the opportunity for trout populations to fluctuate within existing, natural levels.

The amount of water needed to maintain the existing fishery also warrants interpretation. Section (d) of the instream flow statute establishes that "waters used for the purpose of providing instream flows shall be the minimum flow necessary to maintain or improve existing fisheries". The law does not specifically define the term "minimum"; however it seems likely this term suggests the amount used for this purpose should be only as much water as is needed to achieve the objective of maintaining existing fisheries without exceeding that amount. From the discussion above, "minimum" certainly cannot mean the least amount of water in which fish can live since fish are only one component of a fishery and other flow-related characteristics like habitat structure must also be addressed to maintain existing fisheries.

The minimum amount of water provided for some other beneficial uses is established by statute. For agricultural uses it is defined by W.S. 41-4-317 as 1 cfs for each 70 acres of land irrigated. The limit of beneficial use for instream flow is likewise defined by statute (W.S. 41-3-1003 (b)) as an amount of water necessary to provide adequate instream flows as determined by the Game and Fish Commission. Therefore, the instream flow recommendations in this report are the minimum needed to achieve beneficial use for maintaining or improving the identified stream fishery. Beneficial use for fisheries maintenance is realized at any flow up to the recommended amount(s) regardless of the frequency or duration of the flow.

Fishery Maintenance Concepts

The science of quantifying instream flows for fisheries is relatively young. It was not until the first major instream flow conference in Boise, Idaho in May 1976 that it was recognized as its own multi-disciplinary field (Osborn and Allman 1976). Quantitative instream flow models were initially applied in 1979 when the U.S. Fish and Wildlife Service produced the first version of the now widely accepted Physical Habitat Simulation Methodology (Reiser et al. 1989). Methods for quantifying instream flow needs have changed considerably since this time and continue to change today. Likewise, administrative policies for interpreting the results of studies and securing adequate flows to protect and enhance important public fishery resources have undergone similar development. As noted previously, state and provincial instream flow experts from around the U.S. and Canada have recently undertaken efforts to help facilitate this evolution of thought and science (Annear et al. 2002).

Since passage of Wyoming's instream flow law in 1986, the Wyoming Game and Fish Department approached quantification of instream flows for fisheries from a relatively narrow perspective of identifying flows only for fish. This tactic was consistent with the perspective of many natural resource management agencies at the time that placed a priority on protecting fish populations. A considerable body of knowledge now indicates instream flows for fish alone will not achieve their intended objective over the long term (Annear et al. 2002). In fact, establishing instream flows only on the basis of fish needs may result in the alteration of geomorphological process, reduction or alteration of riparian vegetation and changes in flood plain function if high flows are subsequently removed or reduced (Trush and McBain 2000). The removal of significant amounts of flow from some rivers may result in habitat change and a reduction or alteration in fish populations and diversity (Hill et al. 1991, Carling 1995, Bohn and King 2001). Quantification of instream flows for only fish thus may be inconsistent with legislation directing protection of existing fisheries.

Continuous, seasonally appropriate instream flows are essential for maintaining diverse habitats and viable, self-sustaining fish communities. The basis of maintaining riverine processes (and existing fisheries) is facilitating the dynamic interaction of flowing water, moving sediment and riparian vegetation development to maintain habitat and populations of fish and other aquatic organisms (Annear et al. 2002). To fully comply with Wyoming's instream flow statute, instream flows must address the instantaneous habitat needs for the target species and life stages of fish and other aquatic organisms during all seasons of the year. However, to maintain the existing dynamic character of the entire fishery, instream flows must maintain functional linkages between the stream channel, riparian corridor and floodplain to perpetuate habitat structure and ecological function.

Properly functioning stream channels are in approximate sediment equilibrium where sediment export equals sediment import on average over a period of years (Leopold 1994, Carling 1995, USFS 1997). When sediment-moving flows are removed or reduced over a period of years, some gravel-bed channels respond by reducing their width and depth, rate of lateral migration, stream-bed elevation, bed material composition, stream side vegetation and water-carrying capacity. Consequently, to provide proper channel function while also providing adequate instantaneous habitat for fish, development of instream flow recommendations for fisheries maintenance must include both "fish" flows as well as channel maintenance flows. Subsections of the Methods and Results sections of this report are organized to address these aspects of flow recommendation development.

METHODS

Study Area

The Greybull River and its tributaries like Francs Fork are high-elevation mountain streams with high channel slopes, unstable substrates, and large annual fluctuations in discharge. These characteristics are related to the geologically young nature of the watershed. The Absoraka Mountain Range represents the remnants of a broad volcanic plateau that has eroded and continues to erode as regional uplift occurs (Lageson and Spearing 1988). The steep uplifted peaks and deep valleys result in steep longitudinal profiles along watercourses. High snowmelt runoff easily moves erodible volcanic material resulting in stream channels that shift regularly, are often poorly defined and offer limited fish habitat.

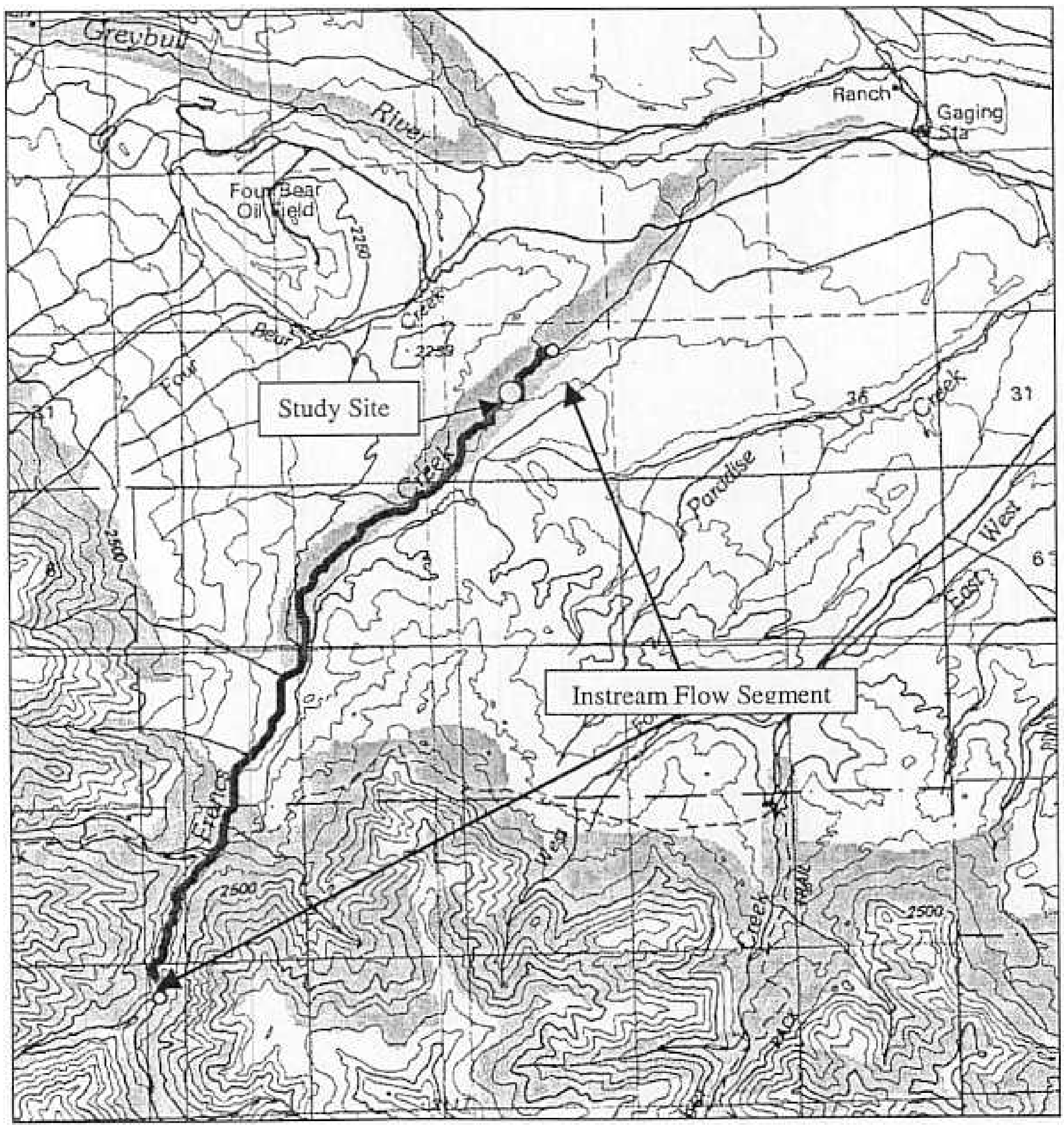

Figure 1. Francs Fork instream flow segment and study site location.

Francs Fork originates on the north side of Francs Peak and flows generally northward for about 12.8 miles before its confluence with the Greybull River (Figure 1). The lower 1.5 stream miles are on Pitchfork Ranch deeded land and are not included in the instream flow segment. The upper 4.8 miles do not contain fish according to survey work by Kruse (1995) and distances measured from 1:24000 maps in Arcview 3.2. The upper boundary of the proposed instream flow segment is the confluence with an unnamed tributary that enters from the west at UTM 639730E, 4876339N, Z12 in Township 47N, Range 103W, Section 20, NW1/4. This point is near the uppermost distribution of YSC in Francs Fork. The segment covers approximately 6.5 miles downstream to UTM 643636E, 4883059N, Z12 located about 300 feet upstream from an irrigation diversion point in Township 48N, Range 103W, Section 34, NE1/4. Land ownership is State for the lower 3.8 miles, Bureau of Land Management for 0.1 mile, and Shoshone National Forest for the upper 2.6 miles.

Channel gradient in the upper end of the segment is 3.0% (determined from measuring stream distance with All Topo© between 4-40' contour intervals at 1:24,000). Channel gradient near the lower end of the segment is 1.2%.. Stream type under Rosgen and Silvey (1998) conforms to B3 in upstream areas. Downstream reaches of the instream flow segment with multiple channels fit the D3 classification while remaining reaches are best described as C3.

Old-age cottonwood gallery forests occur along the floodplain at lower elevations along the instream flow segment. Willows are common along the stream bank. The stream channel is often located in a broad expanse of alluvium, isolated well away from riparian vegetation. In areas where the channel meanders near riparian vegetation, woody material, rootwads and willow plants provide high quality though rare adult trout habitat.

Riverine Components

Hydrology

An independent contract was awarded to estimate mean annual flow, annual flow duration, monthly flow duration, and flood frequency intervals for Francs Fork and other Greybull River tributaries (HabiTech 2001). Additional hydrologic data in the form of flow measurements collected during and following the instream flow study are reported in Appendix 1.

Biology

Fish Populations

The fish community in the Greybull River basin above the Wood River confluence conforms to a typical depauperate high mountain pattern; only 4 species are native. These species are: Yellowstone cutthroat trout, mountain whitefish (*Prosopium williamsoni*), mountain sucker (*Catastomus platyrhynchus*), and longnose dace (*Rhinichthys cataractae*). Only YSC have been sampled in Francs Fork. Rainbow trout and unknown cutthroat trout strains were stocked in the drainage through 1971. Snake River cutthroat trout were stocked in 1972 and 1975. In a status assessment of Yellowstone cutthroat trout, Kruse et al. (2000) found genetically pure Yellowstone cutthroat in all 15 upper Greybull River streams containing trout.

A 3-pass removal population estimate was conducted September 16, 1998 at the study site (*see location description below*). The 429-foot long reach was blocked at the lower end while fast current and shallow depths limited movement into or out of the reach at the upstream end. A Coffelt Mark X backpack unit set to 200 volts and 60 pulses per second generated about 1.0 amp of electrical current. All collected fish were measured to the nearest 0.1 inch and weighed to 0.02 pounds. A modified Zippen (1958) population estimate for multiple removal was used (Armour et al. 1983).

Instream Flows for Fish

Study Site

A study site was selected on State land in T48N, R103W, S34, NE quarter because, 1) it is near the downstream end of the instream flow segment so that instream flows sufficient to meet requirements here are also likely to maintain habitat requirements in upstream reaches, 2) this area of the stream is easily accessible and 3) a representative mix of riffles, runs, pools, spawning gravel, and stream-margin fry habitat were present. A combination of three approaches was used to relate stream flow level to fish habitat: Physical Habitat Simulation (PHABSIM), Habitat Retention, and the Habitat Quality Index (HQI). These methods and their application are discussed in more detail in subsequent sections of this report. Data for these approaches were collected on the dates and at the discharges listed in table 1.

Table 1. Dates and discharge levels for Francs Fork instream flow studies.

Date	Discharge (cfs)
July 16, 1998	97
August 9, 1998	48
August 24, 1998	31

Physical Habitat Simulation

The Physical Habitat Simulation (PHABSIM) system of computer models calculates the stream area suitable for each life stage (fry, spawning, juvenile, and adult) of a target species like YSC (Bovee et al. 1998). These calculations are repeated at user-specified discharges to develop a relationship between suitable area (termed weighted useable area or WUA) and discharge. Model calibration data are collected by stringing a tape perpendicular across the stream at each of several locations (transects) and measuring depth and velocity at multiple locations (cells) along the tape. These measurements are repeated, ideally, at three different and broadly ranging discharge levels. By using depths and velocities measured at one flow level, the user employs various calibration techniques to develop a PHABSIM model that accurately predicts depths and velocities measured at the other two discharge levels (Bovee and Milhous 1978, Milhous et al. 1984, Milhous et al. 1989). Following calibration, the user simulates depths and velocities over a range of discharges.

The next step in PHABSIM involves comparing the predicted depths and velocities, along with substrate or cover information, to habitat suitability criteria (HSC) that define the relative value to the fish of those predicted depths, velocities, substrates, and cover elements. Habitat suitability criteria for each parameter (e.g. depth) are defined with a "1" indicating maximum suitability and a "0" indicating none suitability. The PHABSIM default method of combining suitabilities was used for the Francs Fork analysis where combined suitability equals the product of depth suitability, velocity suitability and substrate suitability. At any particular given discharge, a combined suitability for every cell is generated. That suitability is multiplied by the surface area of each cell and summed across all cells to achieve a weighted useable area for the discharge level. Finally, a graph of WUA across a range of discharges depicts the relative amounts of physical habitat available at different flows (Bovee et al. 1998).

Habitat suitability criteria were developed for the adult, juvenile and spawning YSC life stages by measuring depth, velocity, substrate, and cover at trout locations in Francs Fork Creek and Timber Creek in 1997 and 1998 (*WGFD 1998 and 1999*). Fry HSC were developed from measurements reported in Bozek and Rahel (1992). The HSC are listed in Appendix 2.

A representative transect approach was used to model physical habitat. Over a mile of stream was initially walked to identify the range of habitat types (*sensu* Hawkins et al. 1993) in the instream flow segment. Relative abundance of habitat types was determined by measuring the length of each habitat type over a stream distance of 2737 feet. Nine transects were placed to model the predominant habitat types in the instream flow segment: rapid, riffle, and pool. Transects 1 through 3 and 6 through 7 were located in rapids. Transects 4 through 5 modeled riffle habitat and transects 8 through 9 modeled a lateral scour pool associated with an undercut bank. These four different sets of transects were calibrated separately and WUA results were combined by weighting each set according to the abundance of the habitat in the instream flow segment.

PHABSIM for Windows Version 1.1 was used for all analyses. Physical habitat was simulated over the range 10 cfs to 220 cfs based on calibration criteria in Milhous et al. (1984). After combining transect WUA results for each life stage, final graphs were smoothed with a 3-point running filter. PHABSIM results were used to set instream flow recommendations for the spawning life stage of YSC. Results for the other life stages were used to independently evaluate instream flow recommendations developed with the Habitat Retention and Habitat Quality Index approaches outlined below.

Habitat Retention

A Habitat Retention method (Nehring 1979; Annear and Conder 1984) was used to identify a maintenance flow by analyzing data from hydraulic control riffle transects. A maintenance flow is defined as the continuous flow required to maintain specific hydraulic criteria in stream riffles. Maintaining criteria in riffles at all times of year when flows are available in priority ensures that habitat is also maintained in other habitat types such as runs or pools (Nehring 1979). In addition, maintenance of identified flow levels may facilitate passage between habitat types for all trout life stages and maintain adequate benthic invertebrate survival. The instream flow recommendations from the Habitat Retention method are applicable year round except when higher instream flows are required to meet other fishery management purposes (Table 4).

Table 2. Hydraulic criteria for determining maintenance flow with the Habitat Retention method.

Category	Criteria
Mean Depth (ft)	0.20
Mean Velocity (ft/s)	1.00
Wetted Perimeter[a] (%)	50

a - Percent of bankfull wetted perimeter

Simulation tools and calibration techniques used for hydraulic simulation in PHABSIM are also used with the Habitat Retention approach. The difference is that Habitat Retention does not attempt to translate depth and velocity information into direct conclusions about the amount of physical space suitable for trout life stages. The habitat retention method focuses on hydraulic characteristics of riffles with an eye toward ensuring that fish can pass through the riffles and enough water is maintained to continue invertebrate production. The AVPERM model within the PHABSIM methodology is used to simulate cross section depth, wetted perimeter and velocity for a range of flows. The flow that maintains 2 out of 3 criteria in Table 2 for all three transects is then identified. Transects 1, 4 and 8 were placed across riffles and were used in applying the Habitat Retention method.

Habitat Quality Index

The Habitat Quality Index (HQI; Binns and Eiserman 1979; Binns 1982) was used to determine trout habitat levels over a range of late summer flow conditions. Most of the annual trout production in mountain streams occurs during the late summer, following peak runoff, when longer days and warmer water temperatures stimulate growth. The HQI was developed by the WGFD to measure trout production in terms of habitat. It has been reliably used in Wyoming for habitat gain or loss assessment associated with instream flow regime changes. The HQI model includes nine attributes addressing biological, chemical, and physical aspects of trout habitat. Results are expressed in trout Habitat Units (HU's), where one HU is defined as the amount of habitat quality that will support about 1 pound of trout. HQI results were used to identify the flow needed to maintain existing levels of Yellowstone cutthroat trout production between July 1 and September 30 (Table 4).

In the HQI analysis, habitat attributes measured at various flow events are assumed to be typical of late summer flow conditions. For example, stream widths measured in June under high flow conditions are considered a fair estimate of stream width that would occur if the same flow level occurred in September. Under this assumption, HU estimates are extrapolated through a range of potential late summer flows (Conder and Annear 1987). Francs Fork habitat attributes were measured on the same dates PHABSIM data were collected (Table 1). Some attributes were mathematically derived to establish the relationship between discharge and trout habitat at discharges other than those measured.

Average daily flow (ADF; 29 cfs) and peak flow (289 cfs) estimates for determining critical period stream flow and annual stream flow variation were based on estimates performed by HabiTech (2001). Maximum water temperature was determined with a Ryan temperature recorder set to monitor water temperature at 4-hour intervals between July 15 and September 16, 1998. Nitrate levels were determined from a water sample collected September 16, 1998 and analyzed by the Analytical Services section of the Wyoming Department of Agriculture, Laramie, Wyoming. Substrate was rated subjectively *sensu* Binns (1982).

Geomorphology

Channel maintenance flow, as used in this report, refers broadly to instream flows that maintain existing channel morphology, riparian vegetation and floodplain function (USDA Forest Service 1997, Schmidt and Potyondy 2001). The concepts discussed here apply primarily to gravel and cobble-bed streams. By definition, these are streams whose beds are dominated by loose material with median sizes larger than 2 mm and may have a pavement or armor layer of coarser materials overlaying the channel bed. In these streams, bedload transport processes determine the size and shape of the channel and the character of habitat for aquatic organisms (Hill et al. 1991, Leopold 1994).

Properly functioning stream channels maintain the basic stream structure (pools, riffles, depth, width and meander) necessary to sustain the natural aquatic community over time and space. On average and over the long term, they also pass the entire bed load originating from upstream tributaries. That process maintains habitat for fish and other aquatic organisms by transporting fine sediments and depositing gravels in a manner that enables those organisms to complete all parts of their life cycles. For example adult trout can spawn successfully in clean riffles and young fish can burrow into silt-free cobble substrates in winter. By transporting incoming bedload, properly functioning stream channels maintain their flow carrying capacity, which helps attenuate the magnitude and frequency of flooding. Properly functioning stream channels likewise exhibit variable lateral migration across the floodplain, which encourages development of staggered age classes and functions of riparian vegetation that ultimately benefit stream organisms.

Floodplains are lateral channel extensions during both high and low flow periods. In high flow periods, they help cycle nutrients, store sediments, recharge groundwater and wetlands, distribute flow and attenuate flooding downstream. In low flow periods, floodplain groundwater seeps back into the channel and helps sustain continuous flow.

Streamside plant communities have important influences on stream aquatic organisms like fish. Plant communities filter pollutants, capture sediment, modify stream temperature by shading, provide woody debris for both cover and nutrient cycling and regulate the exchange of water between the groundwater and stream. Floodplain structure and function play an integral role in maintaining fisheries by affecting in-channel habitat for fish and other aquatic organisms.

Maintenance of channel features and floodplain function cannot be obtained by a single threshold flow (Annear et al. 2002). Rather, a dynamic hydrograph within and between years is needed for continuation of processes that maintain stream channel and habitat characteristics (Gordon 1995; USFS 1997; Trush and McBain 2000). High flows are needed in some years to scour the stream channel, prevent encroachment of stream banks and deposit sediments to maintain a dynamic alternate bar morphology and successionally diverse riparian community. Low flow years are as valuable as high flow years on some streams to allow establishment of riparian seedlings on bars deposited in immediately preceding wet years (Trush and McBain 2000). The natural interaction of high and low flow years maintains riparian development and aquatic habitat by preventing annual scour that might occur from continuous high flow (allowing some riparian development) while at the same time preventing encroachment by riparian vegetation that would occur if flows were artificially reduced at all times. Important attributes of an alluvial, properly functioning stream ecosystem are listed in Table 3 (Trush and McBain 2000).

Table 3. General attributes of alluvial, gravel-bed river ecosystems (Trush and McBain 2000).

Spatially complex channel morphology: No single segment of channel-bed provides habitat for all species, but the sum of channel segments provides high-quality habitat for native species. A wide range of structurally complex physical environments supports diverse and productive biological communities.
Flows and water quality are predictably variable: Inter-annual and seasonal flow regimes are broadly predictable, but specific flow magnitudes, timing, durations, and frequencies are unpredictable due to runoff patterns produced by storms and droughts. Seasonal water quality characteristics, especially water temperature, turbidity, and suspended sediment concentration, are similar to regional unregulated rivers and fluctuate seasonally. This temporal "predictable unpredictability" is the foundation for river ecosystem integrity.
Frequently mobilized channel bed surface: Channel bed framework particles of coarse alluvial surfaces are mobilized by the bankfull discharge, which on average occurs every 1-2 years.
Periodic channel bed scour and fill: Alternate bars are scoured deeper than their coarse surface layers by floods exceeding 3- to 5-year annual maximum flood recurrences. This scour is typically accompanied by re-deposition, such that net change in channel bed topography following a scouring flood usually is minimal.
Balanced fine and coarse sediment budgets: River reaches export fine and coarse sediment at rates approximately equal to sediment inputs. The amount and mode of sediment storage within a given river reach fluctuate, but also sustain channel morphology in dynamic quasi-equilibrium when averaged over many years. A balanced coarse sediment budget implies bedload continuity; most particle sizes of the channel bed must be transported through the river reach.
Periodic channel migration: The channel migrates at variable rates and establishes meander wavelengths consistent with regional rivers having similar flow regimes, valley slopes, confinement, sediment supply, and sediment caliber.
A functional floodplain: On average, floodplains are inundated once annually by high flows equaling or exceeding bankfull stage. Lower terraces are inundated by less frequent floods, with their expected inundation frequencies dependent on norms exhibited by similar, but unregulated river channels. These floods also deposit finer sediment onto the floodplain and low terrace.
Infrequent channel resetting floods: Single large floods (e.g., exceeding 10-yr to 20-yr recurrences) cause channel avulsions, rejuvenation of mature riparian stands to early-successional stages, side channel formation and maintenance, and create off-channel wetlands (e.g., oxbows). Resetting floods are as critical for creating and maintaining channel complexity as lesser magnitude floods.
Self-sustaining diverse riparian plant communities: Natural woody riparian plant establishment and mortality, based on species life history strategies, culminate in early- and late-successional stand structures and species diversities (canopy and understory) characteristics of self-sustaining riparian communities common to regional unregulated river corridors.
Naturally fluctuating ground water table: Inter-annual and seasonal groundwater fluctuations in floodplains, terraces, sloughs and adjacent wetlands occur similarly to regional unregulated river corridors.

Stream channel characteristics over space and time are a function of sediment input and flow (USDA Forest Service 1997). Bankfull flow is generally regarded as the flow that, over the long term, moves the most sediment, forms and removes bars, bends and meanders, and results in the average morphologic characteristics of alluvial channels (Dunne and Leopold 1978, Andrews 1984). As a rule, bankfull flows are confined enough to mobilize and transport bed material. When flow increases above bankfull, flow depths and velocities increase less rapidly. At higher flow, water spreads out onto the floodplain and decreases the potential for catastrophic channel damage.

To maintain channel form and processes, flows must be sufficient to move both the entire volume and all sizes of material supplied to the channel from the watershed over a long-term period (USDA Forest Service 1997, Carling 1995). A range of flows is needed (as opposed to a single specified high flow) because, though higher discharges move more sediment, they occur less frequently so that over the long-term, they move less bedload than more frequent, lesser discharges (Wolman and Miller 1960). Thus instream flow prescription for channel maintenance will vary both within a year and between years depending on natural flow availability. A total bedload transport curve (Figure 2) shows the amount of bedload sediment moved by stream discharge over the long-term as a product of flow frequency and bedload transport rate. This figure indicates that any artificial limit on peak flow prevents movement of the entire bedload through a stream over time and would result in gradual bedload accumulation. The net effect would be an alteration of existing channel forming processes and habitat (Bohn and King 2001). For this reason, the 25-year peak flow is the minimum needed to maintain existing channel form.

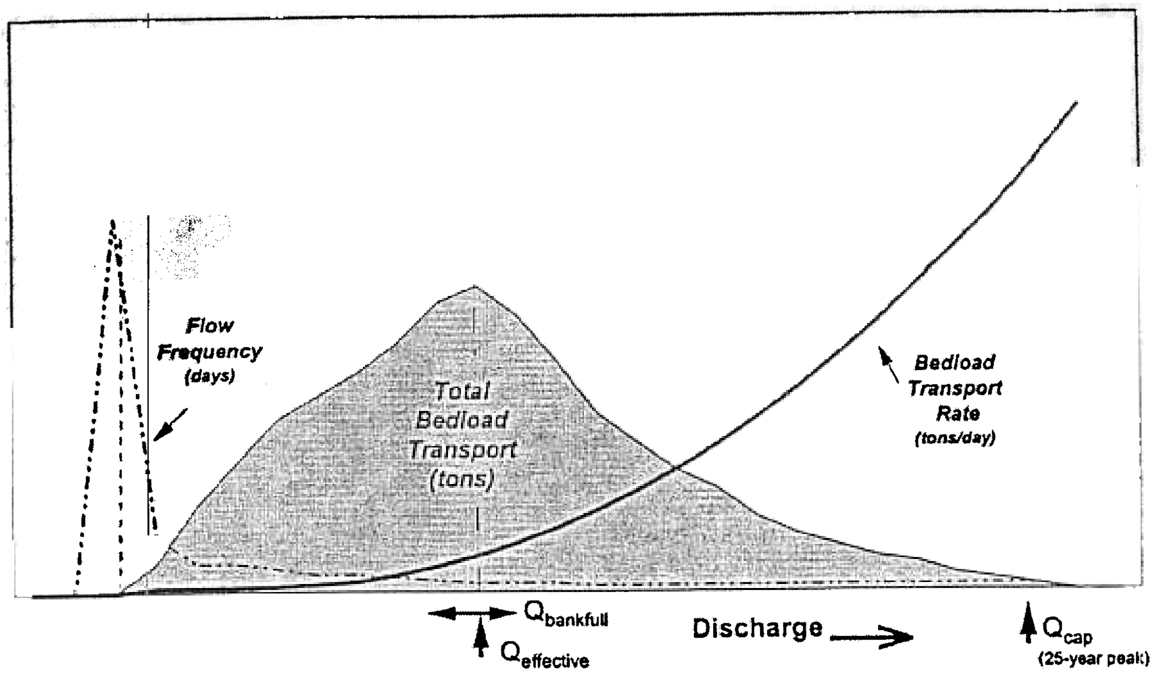

Figure 2. A general model of long-term total bedload transport as a function of flow frequency and bedload transport rate (from USFS 1997).

The movement of substrate from the bottom of Rocky Mountain streams begins at flows somewhat greater than average annual flows but lower than bankfull flows (John Potyondy, Stream Systems Technology Center, USFS Rocky Mountain Research Center, Fort Collins, CO; personal communication). Ryan (1996) and Emmett (1975) found the flows that generally initiated transport were between 0.3 and 0.5 of bankfull flow. Regular movement of small particles is important to clean cobble and riffle areas of fine materials. This process and level of flow is commonly referred to as a flushing flow. Movement of coarser particles begins at flows of about 0.5 to 0.8 of bankfull (Carling 1995, Leopold 1994). This phase of transport is significant because of its potential to maintain channel form. Without mobilization of larger bed elements, only the fine materials will be flushed from the system resulting in armoring and allowing vegetation to permanently colonize gravel bars. Ultimately, channel narrowing may occur with concomitant changes in aquatic ecosystem structure and function and potentially loss of habitat diversity (Carling 1995, Hill et al. 1991).

Based on these principles, the following model was developed by Dr. Luna Leopold and is used in this report:

$$Q\ \text{Recommendation} = Q_f + \{(Q_s - Q_f) * [(Q_s - Q_m) / (Q_b - Q_m)]^{0.1}\}$$

Q_s = actual stream flow
Q_f = fish flow
Q_m = substrate mobilization flow = 0.5 * Q_b
Q_b = bankfull flow

The model is identical to the one presented in Gordon (1995) and U.S. Forest Service (1994) with one variation. The model presented in those documents used the average annual flow (Q_a, normally about 0.2 times bankfull flow) as the flow at which substrate movement begins. This term was re-defined here as the substrate mobilization flow (Q_m) and assigned a value of 0.5 times bankfull flow based on the above studies by Ryan (1996) and Emmett (1975). Setting Q_m at a higher flow level leaves more water available for other uses by not initiating the call for channel maintenance flows until this higher flow is realized and thus meets the statutory standard of "minimum needed".

The equation is based on the principle that channel maintenance flows must mobilize bed load materials. Incrementally higher percentages of flow are needed as flow approaches bankfull because the river does most of its work in transporting materials and maintaining fish habitat as flows approach bankfull. At flows greater than bankfull the instream flow is then equal to the actual flow to maintain floodplain function as well as stream channel form. The upper limit of flow specified by Leopold is the 25-year recurrence flow as this is the flow that assures transport of all bed material over time. Maintaining the opportunity for this level of flow in a natural setting minimizes the potential for causing flood-related property damage while providing sufficient depth for riparian vegetation and wetland maintenance and groundwater recharge. Figure 3 provides an illustration of instream flow needs relative to available stream flow.

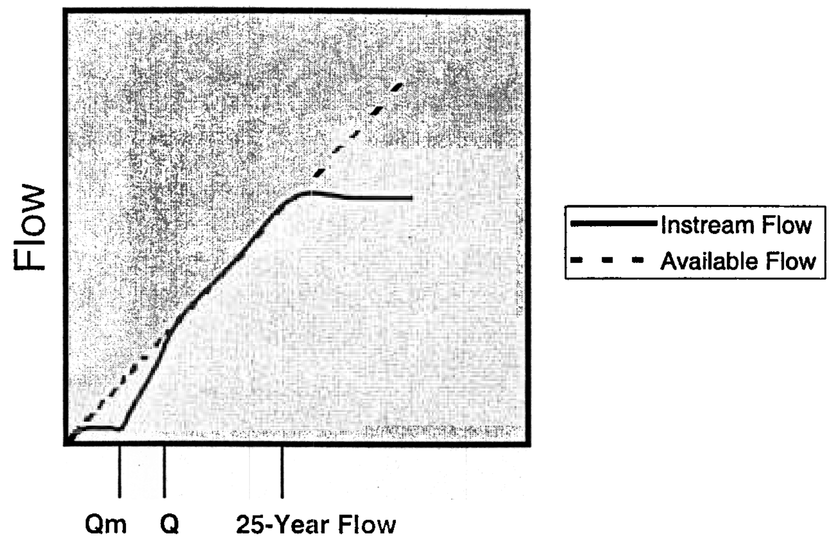

Figure 3. General function of a dynamic hydrograph instream flow for fishery maintenance. Q_m is substrate mobilization flow and Q_b is bankfull flow.

The Leopold equation yields a continuous range of instream flow recommendations at flows between the sediment mobilization flow and bankfull for each cubic foot per second increase in flow. This manner of flow regulation could prove burdensome to water managers should a reservoir ever be built on Francs Fork or its tributaries that would be required to release flows for channel maintenance purposes. To facilitate flow administration while still ensuring reasonable flows for channel maintenance, we modified this aspect of the approach to claim instream flows at each increased increment of 25 cfs between the sediment mobilization flow and bankfull.

With this approach, the volume of water required for channel maintenance is variable from year to year. During low flow years, less water is required for channel maintenance because flows may not reach the defined channel maintenance level. In those years, most water in excess of base fish flows is available for other uses. The majority of flow for channel maintenance occurs during wet years. One benefit of a dynamic hydrograph quantification approach is that the recommended flow is needed only when it is available in the channel and does not assert a claim for water that is not there as often happens with threshold approaches.

Seasonal Application of Results

Maintaining adequate, continuous flow at all times of year is critically important to maintain the population integrity of all life stages of trout. Both spawning and fry life stages may be constrained by habitat "bottlenecks" (Nehring and Anderson 1993); however, all life stages may face similar critical periods. Identifying critical life stages and periods is thus necessary to focus flow recommendations. Our general approach includes ensuring that adequate flows are provided to maintain spawning habitat in the spring as well as adult and juvenile habitat at all other times of the year (Table 4). The instream flow recommendation for any month where two or more recommendations apply is based on the recommendation that yields the higher flow.

Spawning activity was observed throughout May and into early June (WGFD 1999). Because spawning onset and duration varies between years due to differences in flow quantity and water temperature, spawning flow recommendations should extend from May 1 to June 30 (Table 4). Even if spawning is completed before the end of this period, maintaining flows at a selected level throughout June will benefit trout egg incubation by preventing dewatering when the water right is in priority.

Table 4. Yellowstone cutthroat trout life stages and months considered in the Francs Fork instream flow recommendations. Numbers indicate the method used to determine flow requirements.

Fishery Function	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Spawning habitat					1	1						
Survival, movement	2	2	2	2						2	2	2
Growth							3	3	3			
Channel maintenance				4	4	4						

1 - PHABSIM
2 – Habitat Retention and PHABSIM
3 - Habitat Quality Index
4 – Channel Maintenance

RESULTS AND DISCUSSION

Hydrology

Rosgen (1996) reviewed his studies and those of other geomorphologists and concluded that the return interval for bankfull discharge in alluvial streams is 1.4 to 1.6 years. Using a return interval of 1.5 years, Francs Fork bankfull discharge is 289 cfs (Table 5). Average daily flow was estimated at 29 cfs (HabiTech 2001). Estimated monthly flow levels are listed in Appendix 3.

Table 5. Estimated flood frequency series for Francs Fork (HabiTech 2001).

Return Period (years)	Estimated Flow (cfs)
1.01	129
1.05	159
1.11	181
1.25	216
1.5	289*
2	321
5	520
10	689
25	956

* Bankfull discharge.

Biology

Fish Populations

A total of 233 YSC were collected during three removal passes for a population estimate of 404 fish per mile (37.5 lbs/acre). Long-term data are not available for this stream so it is unknown how this estimate relates to the overall dynamic character of the population size. Eighteen trout were greater than 6 inches in length and fish ranged from 3 to 13 inches long. Based on observations during the population estimate and earlier snorkel surveys, trout habitat was limited by low availability of slow velocity areas.

Trout were located along the bank in velocity shelters formed from rare large woody debris. Trout were also present in the few slow pool habitats encountered.

Instream Flows for Fish

Physical Habitat Simulation

The relatively high gradient in the study reach results in abundant fast-water habitat types and uncommon pool habitats. Rapids accounted for 67% of the habitat, riffles 20% and pools 7% (Figures 4-6). The other 6% was even faster water habitat not occupied by trout. The prevalence of fast water habitats is reflected in low overall levels of physical habitat (Figure 7). The adult peak of about 5000 ft^2/1000 feet at 36 cfs would only occupy about 170 feet out of 1000 feet, assuming a 30 foot-wide channel.

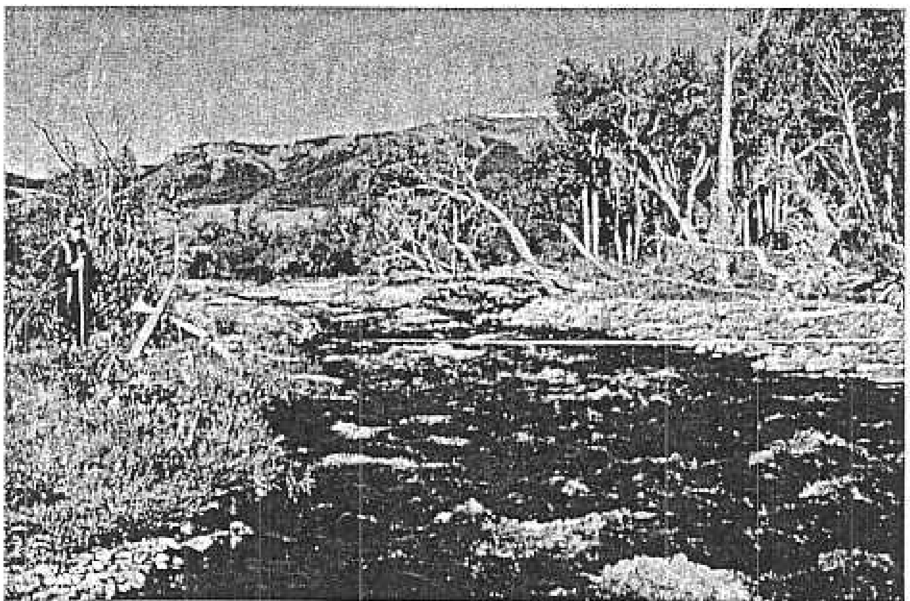

Figure 4. Rapid habitat on transects one through three (tape on two) at a discharge of 97 cfs.

Figure 7 depicts relative quantities of physical habitat and compares patterns among life stages. Figure 8 more clearly depicts flow levels at which peak physical habitat occur and is used for making instream flow recommendations. Maximum adult physical habitat occurs at 36 cfs (Figure 8). Physical habitat decreases rapidly at lower flow levels and declines more slowly for discharges greater than 36 cfs. Juvenile physical habitat follows a common pattern for PHABSIM analyses in high gradient streams: highest levels occur at the lowest flow levels with a gradual decline as discharge increases. This pattern reflects preference for low velocities and tolerance of shallow depths. Fry physical habitat peaks at high discharges (180 cfs) as stream margins become inundated and provide the preferred very slow velocity habitat.

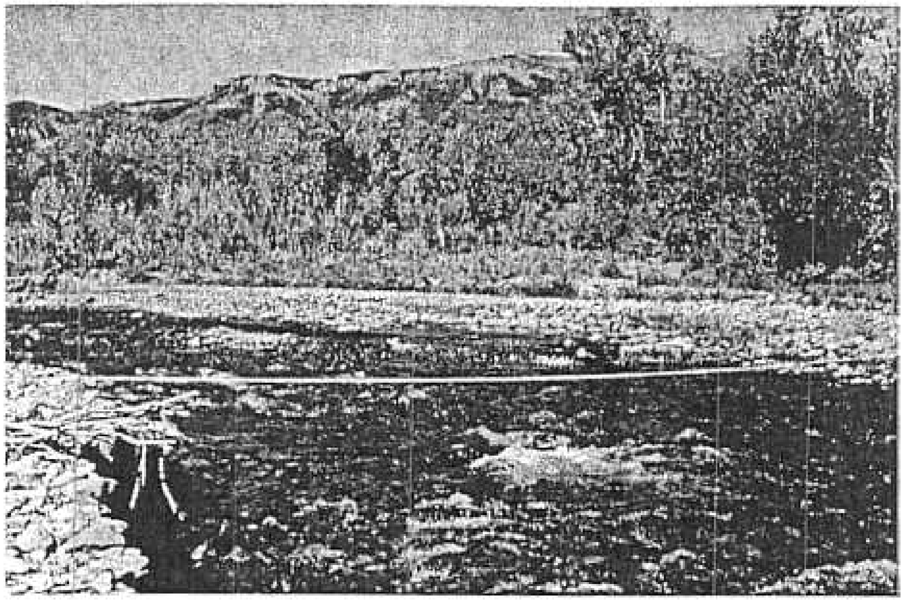

Figure 5. Riffle habitat on transect four at 97 cfs.

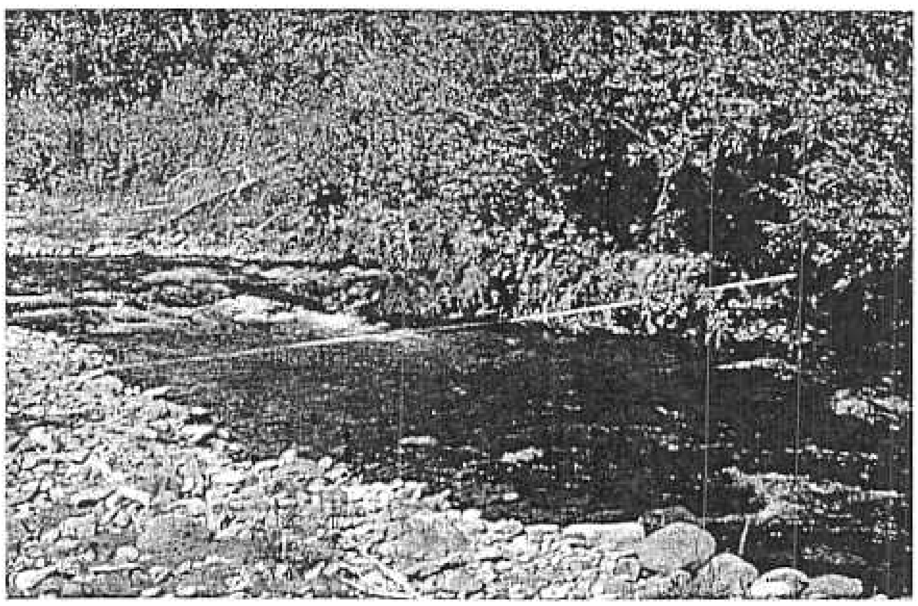

Figure 6. Pool habitat on transects eight and nine (tape on eight) at 97 cfs.

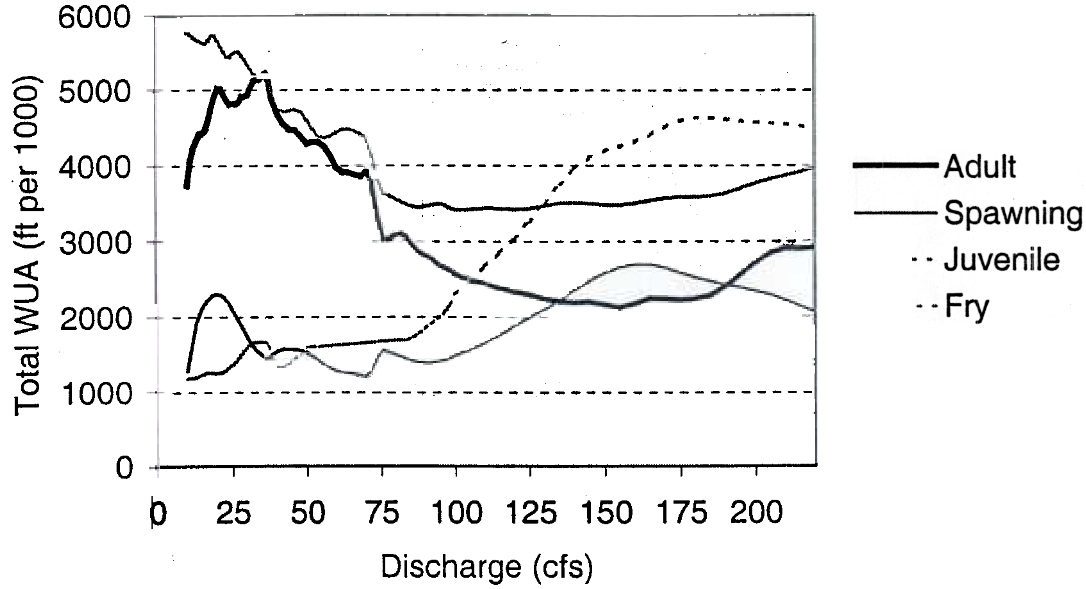

Figure 7. Total WUA (ft^2 per 1000 ft) for four YSC life stages in Francs Fork.

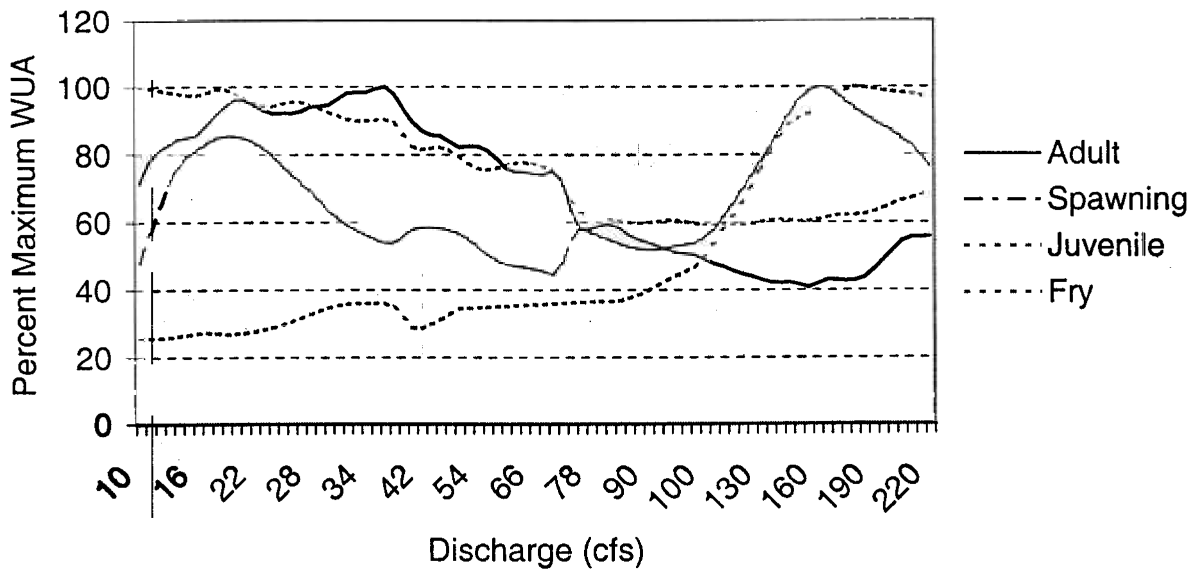

Figure 8. Percent of maximum weighted useable area for four YSC life stages in Francs Fork.

Spawning habitat shows a bimodal pattern with a peak at 19 cfs and another higher peak at 160 cfs (Figure 8). The lower peak is primarily from physical habitat modeled with transects 6-7 while the peak at a higher discharge results from physical habitat modeled with transects 4-5 (Figure 9). Very little spawning habitat occurred on the other 5 transects. The higher flow level is more appropriate for maintaining Francs Fork YSC spawning habitat because: 1) the riffle habitat of transects 4 and 5 is the habitat in which spawning normally occurs. Spawning in the "rapid" habitat of transects 6-7 as simulated is only occurring because the rapid habitat was turned into a riffle by low flow levels. Suitability criteria were developed from observations of YSC primarily spawning in riffles (WGFD 1998), 2) higher levels of spawning physical habitat occur at the higher flow level, and 3) higher spawning flow levels correspond to much higher levels of fry habitat which would improve the likelihood that fry will survive and recruit in numbers sufficient to maintain current YSC populations.

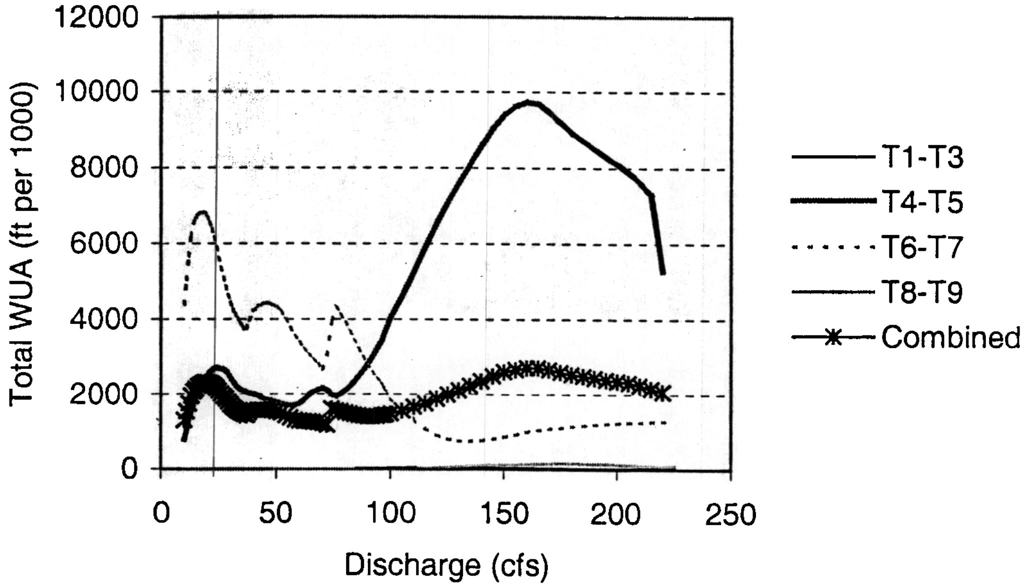

Figure 9. Yellowstone cutthroat trout spawning physical habitat on each of the different sets of transects.

An instream flow of 160 cfs is recommended for the May through June season to maintain YSC spawning habitat. Though the entire 160 cfs may not always be present during this period, protection of flows up to that level, when available in priority, will prevent impacts to spawning success and therefore maintain the existing fishery.

Habitat Retention

The depth criteria for applying the Habitat Retention approach is defined as 0.01 * stream width at average daily flow or 0.20, whichever is greater (Table 2). Average daily flow was estimated at 29 cfs (HabiTech 2001). Simulated stream widths at the nine transects at 29 cfs were: 19.1, 15.7, 30.9, 35.3, 23.9, 24.6, 24.0, 23.3, and 22.8 feet for an average width of 22 feet. Therefore the depth criterion is 0.22 feet.

The wetted perimeter criteria for a stream of this size is 50% of the wetted perimeter that occurs on the transect at bankfull stage. The bankfull width across the three transects used in the Habitat Retention method was simulated using an estimated bankfull discharge of 289 cfs (HabiTech 2001).

For riffle 1, two of three hydraulic criteria are met at a flow of 3 cfs (Table 6). For riffle 2, a flow of 8 cfs satisfies two of three criteria. For riffle 3, a discharge of 6 cfs meets two of three hydraulic criteria. Therefore, a discharge of 8 cfs meets two out three criteria for all riffles in the study site.

Table 6. Simulated hydraulic criteria for three Francs Fork riffles. Average daily flow was estimated at 29 cfs and bankfull discharge was estimated at 289 cfs, the 1.5 year return period flood peak. Bold indicates that the hydraulic criterion was met.

	Mean Depth (ft)	Mean Velocity (ft/s)	Wetted Perimeter (ft)	Discharge (cfs)
Riffle 1 – transect 1	1.20	8.01	31.3	289 (bankfull)
	1.10	6.89	30.7	225
	0.84	4.26	28.6	100
	0.69	2.86	26.1	50
	0.59	2.13	24.5	30
	0.37	1.19	23.3	10
	0.32	**1.01**	22.2	7
	0.22	0.70	19.6	**3**[a]
	0.19	0.60	**17.5**	2
	0.19	0.46	11.3	1
Riffle 2 – transect 4	0.99	6.05	49.2	289 (bankfull)
	0.95	4.98	47.3	220
	0.63	3.52	45.8	100
	0.57	2.67	33.2	50
	0.59	2.09	**24.5**	30
	0.47	1.15	18.9	10
	0.43	**1.02**	18.4	**8**[a]
	0.41	0.95	18.2	7
	0.34	0.60	14.8	3
	0.23	0.34	13.1	1
Riffle 3 – transect 8	1.33	6.90	32.5	289 (bankfull)
	1.35	6.10	28.4	225
	0.88	2.74	21.3	50
	0.75	2.09	19.6	30
	0.47	1.22	17.5	10
	0.43	1.10	17.0	8
	0.41	**1.04**	16.7	7
	0.38	0.97	**16.3**	**6**[a]
	0.24	0.63	13.1	2
	0.21	0.49	10.0	1

a - Discharge at which 2 of 3 hydraulic criteria are met

The Habitat Retention method is applied to the late fall and winter seasons, a period when trout populations in northern latitudes often experience natural habitat limitations (Needham et al. 1945, Reimers 1957, Butler 1979, Kurtz 1980, Cunjak 1988, Cunjak 1996). Prowse (2001a and 2001b) provides an extensive review of the wide range of effects ice process can have on the hydrologic, biologic, geomorphic, water quality and connectivity characteristics of riverine resources and fisheries. Ice processes in particular may limit habitat. For example, suspended ice crystals (frazil ice) can cause direct trout mortality through gill abrasion and subsequent suffocation or indirectly increase mortality by limiting available habitat, causing localized de-watering, and causing excessive metabolic demands on fish forced to seek ice-free habitats (Brown et. al 1994, Simpkins et al. 2000). Pools downstream from high gradient frazil ice-forming areas can accumulate anchor ice when woody debris or surface ice provides anchor points for frazil crystals (Brown et. al 1994, Cunjak and Caissie 1994). Such accumulations may result in mortalities if low winter flows or ice dams block emigration.

If fish are forced to move when water temperatures are near freezing, such as to avoid the physical effects of frazil ice or if changing hydraulic conditions force them to find areas of more suitable depth or velocity, mortalities can occur. The extent of impacts is dependent on the magnitude, frequency and duration of frazil events and the availability of alternate escape habitats (Jakober et. al, 1998). Juvenile and fry life stages are typically impacted more than larger fish because younger fish inhabit shallower habitats and stream margins where frazil ice tends to concentrate. Larger fish that inhabit deeper pools may endure frazil events with little effect if they are not displaced. In contrast, refuge from frazil ice may occur in streams with groundwater influx, pools that develop cap ice and segments where heavy snow cover causes stream bridging (Brown et al. 1994).

This review of ice impacts on trout highlights the importance of maintaining natural winter habitat levels and not introducing additional flow variability to this season or changing streamflows to a level where additional ice impacts may occur. Naturally available flow levels, up to the 8 cfs identified with the Habitat Retention Method, should remain in the stream channel during the fall/winter season (October 1 to April 30) to maintain the Francs Fork fishery. The recommended winter season instream flows may not always be present. However, the existing fish community is adapted to natural flow patterns, including occasional periods when natural flow is less than recommended amounts. The fact that these periods occur does not mean permanently reduced flow levels can maintain the existing fishery; nor do they suggest a need for additional storage. Instead, they illustrate the need to maintain all natural winter stream flows, up to the recommended amount, to maintain existing trout survival patterns.

Habitat Quality Index

In performing the HQI simulation of Habitat Units over a range of discharges, it was assumed the following attributes remained constant as a function of discharge: temperature, nitrates, percent cover, invertebrate numbers, and eroding banks. Cover normally changes at different flow levels but the percent cover was so low in Francs Fork (<5%) at all flow levels that this attribute did not influence the simulations. A maximum water temperature of 67° F was recorded August 13, 1998.

High water velocity limited trout habitat and water velocity was an influential HQI attribute in terms of defining the range of flows with peak levels of habitat (Figure 10). Habitat Units peaked over a flow range of 17 to 21 cfs. As flows rise to 17 cfs, the "Critical Period Stream Flow" attribute goes to its highest level (>55% of average daily flow). This attribute then remains high throughout all higher simulated flow levels. As discharge increases above 21 cfs, water velocity rises above the peak range and the attribute rating declines.

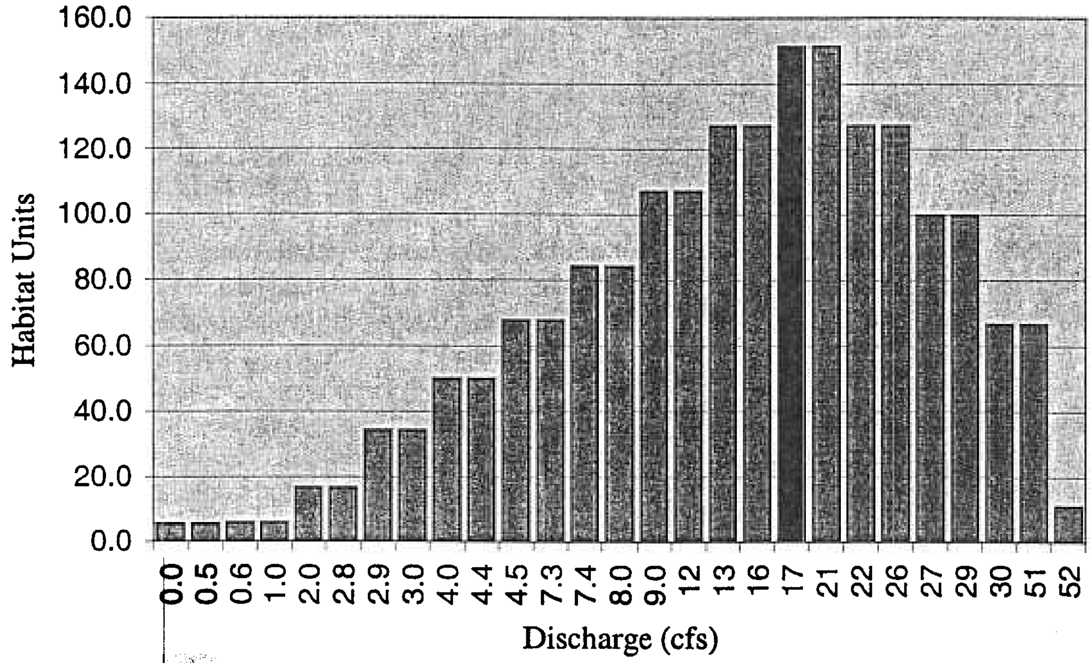

Figure 10. Habitat Quality Index for a range of flow levels. X-axis flows are scaled to show where changes in Habitat Units occur.

Article 10, Section d of the Instream Flow statute states that waters used for providing instream flows "shall be the minimum flow necessary to maintain or improve existing fisheries". One way to define the fish component of the "existing fishery" is by the number of habitat units that occur under normal July through September flow conditions. Flow monitoring during the late summer period documented flows ranging from 18 cfs to 119 cfs (Appendix 1). We do not have an estimate for normal flow conditions for the entire late summer period but do have monthly estimates. Estimated monthly streamflows that occur 50% of the time are 66 cfs, 23 cfs, and 14 cfs for July, August and September, respectively (Appendix 3, HydroTech 2001). Lacking an estimate for the entire period, the estimated August value of 23 cfs provides a reasonable estimate of normal late summer flow levels and is consistent with how the HQI was developed (Binns and Eiserman 1979). At this flow, the stream provides 123 habitat units under existing conditions (Figure 10). A lower flow of 17 cfs will improve late summer habitat to over 150 HU's. Therefore, the lowest flow that will maintain or improve late-summer habitat for YSC in Francs Fork is 17 cfs (Figure 10).

Based on the HQI analysis, natural flows up to 17 cfs between July 1 and September 30 would maintain or improve existing trout habitat quality. This flow represents the lowest stream flow that will accomplish this objective if all other habitat attributes remain unchanged. The existing fishery is naturally dynamic as a function of stream flow availability. In years when stream flow is naturally less than 17 cfs in late summer the number of fish may decline. Likewise, in years when late summer flow is 17 cfs or more, fish populations may expand. As noted above, maintaining this existing fishery simply means maintaining existing natural stream flows up to the recommended amount in order to maintain the existing natural habitat and fish population fluctuations.

Geomorphology

Like all properly functioning rivers, the Francs Fork fishery is characterized and maintained by a hydraulically connected watershed, floodplain, riparian zone and stream channel. Bankfull and overbank flow are essential hydrologic characteristics for maintaining the habitat in and along this river system in its existing dynamic form. These high flows flush sediments from the gravels on an annual or more often basis and maintain channel form (depth, width, pool and riffle configuration) by periodically scouring encroaching vegetation. Overbank flow maintains recruitment of riparian vegetation, encourages lateral movement of the channel, and recharges ground water tables. Instream flows that maintain the connectivity of these processes over time and space are needed to maintain the existing fishery (Annear et al. 2002).

The channel maintenance model used for this analysis provided the instream flow recommendations shown in Table 7. The base or fish flow used in the analysis was the 160 cfs identified for maintaining spawning physical habitat. Since 160 cfs is higher than the substrate mobilization flow (140 cfs), the spawning flow is the instream flow recommendation from May 1 to June 30 for all available natural flow levels up to 160 cfs. From 160 cfs to the bankfull discharge of 289 cfs, incrementally greater amounts of water are needed to mobilize bedload materials and maintain existing habitat characteristics and stream channel function. At flows between bankfull and the 25-year flood flow (956 cfs), all water originating in the drainage is needed. At flow greater than the 25-year flood flow, only the 25-year flood flow is needed for channel maintenance because this flow level will have moved the necessary amount of bed load materials (Figure 3).

INSTREAM FLOW RECOMMENDATIONS

Based on the analyses and results outlined above, the instream flow recommendations in Tables 7 and 8 will maintain Yellowstone cutthroat trout in the Francs Fork as well as the ecological functions that contribute to the fishery. Results from these studies apply to the entire segment of Francs Fork extending downstream from an un-named tributary at UTM 639730E, 4876339N, Z12 in Township 47N, Range 103W, Section 20, NW1/4 to a point about 300 yards upstream of a Pitchfork Ranch at 643636E, 4883059N, Z12 in Township 48N, Range 103W, Section 34, NE1/4. This segment is approximately 6.5 stream miles long. Because data were collected from representative habitats and simulated over a wide flow range, additional data collection under different flow conditions would not significantly change these recommendations. Development of new water storage facilities to provide the above recommended amounts on a more regular basis than at present is not needed to maintain the existing fishery characteristics.

Table 7. Instream flow recommendations to maintain existing channel forming processes and long-term aquatic habitat characteristics. Recommendations apply to the run-off period from May 1 through June 30.

Description	Available Flow (cfs)	Instream Flow (cfs)
	0.0 - 159	Equal to available flow
Substrate Mobilization Flow	145	145
	150	150
Spawning Flow	160	160
	161 – 175	161
	176 - 200	174
	201 - 225	197
	226 - 250	222
	251 - 275	248
	276 - 288	275
Bankfull	289	289
	290-956	Equal to available flow
25-Year Flood	956	956
	All flows > 956	956

Table 8. Instream flow recommendations to maintain or improve existing trout habitat in Francs Fork.

Time Period	Instream Flow Recommendation (cfs)
October 1 to April 30	8
May 1 to June 30	160
May 1 to June 30	Channel Maintenance – see Table 7
July 1 to September 30	17

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Appendix 1. Flow measurements collected in Francs Fork.

Elevation (ft): 7080
Legal: R103W; T48N, Sec 34, NW Quad
UTM: UTM coordinates from BLM Map = Zone 12, Northing: 4883500, Easting: 644200
Site: IF study site; State Land Section upstream less than 1/4 mile from Pitchfork diversion.

DATE	DISCHARGE (cfs)	MEASURED
5/28/1998	49	Paul Dey
7/16/1998	97	Paul Dey
8/9/1998	48	Paul Dey
8/24/1998	31	Paul Dey
9/16/1998	29	Paul Dey
6/23/1999	193	Jason Burckhardt
7/8/1999	119	P. Dey, J. Burckhardt
7/29/1999	44	Paul Dey
9/16/1999	20	Paul Dey
7/19/2001	18	Dennis Oberlie
10/9/2001	3.7	PD, RR

Appendix 3. Estimated monthly flow duration series for the Francs Fork study site (HabiTech 2001).

Duration Class (% time≥)	Francs Fork Estimated Streamflow (cfs)											
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept
95	5.8	4.2	3.5	3.3	3.5	3.8	4.6	10	46	20	11	8.2
90	6.4	4.8	3.9	3.8	3.8	4.1	5.1	13	53	26	13	9.0
75	7.5	5.8	4.7	4.3	4.3	4.6	6.1	21	74	41	16	11
50	9.5	7.0	5.4	4.8	4.8	5.4	8.1	43	108	66	23	14
25	12	8.7	6.2	5.5	5.4	6.5	13	72	156	108	34	17
10	14	10	7.4	6.4	6.3	8.1	22	109	208	146	46	22
5	16	11	8.6	6.8	7.2	11	31	129	236	170	56	26