**WYOMING GAME AND FISH DEPARTMENT**

**FISH DIVISION**

**ADMINISTRATIVE REPORT**

**Title:** Instream Flow Studies on Piney Creek, a Greybull River Tributary

**Project:** IF-CY-2GR-510

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## ABSTRACT

Instream flows necessary for maintaining Yellowstone cutthroat trout (YSC) habitat and populations were identified through studies conducted on Piney Creek during 2001. Instream flow water right recommendations in this report are based on those studies. A PHABSIM model was used to develop instream flow recommendations for maintaining YSC spawning habitat during spring runoff. The Habitat Quality Index model was used to assess the relationship between stream flow and habitat quality for adult trout in the summer. 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.

Instream flow recommendations were developed for a 2.3-mile stream segment extending from the confluence of an un-named tributary downstream to Wilderness boundary. The following instream flow recommendations were developed: 55 cfs to maintain hydraulic habitat for spawning during the spring season from May 1 to July 15, 7 cfs to maintain or improve adult trout habitat quality in the existing stream channel during the late summer period between July 16 and September 30, and 2.5 cfs to maintain habitat for all YSC life stages from October 1 to April 30. Flow recommendations for maintaining channel characteristics and the long-term fishery are provided.

# INTRODUCTION

In a recent book, the Instream Flow Council (IFC), an organization of state and provincial fishery and wildlife management agencies, describes key attributes of effective instream flow studies and programs (Annear et al. 2002). The group asserts that adequate instream flows must address eight ecosystem components including three policy components (legal, institutional, and public involvement) and five riverine components (hydrology, geomorphology, biology, water quality and connectivity). In conducting and reporting instream flow studies, the WGFD has adopted the recommendations set forth in Annear et al. (2002) by explicitly addressing all eight components. Legal and institutional issues are discussed. Public involvement occurs by virtue of public information meetings, hearings and comments solicited during public presentations and open houses. Meetings with individual landowners, community groups and special interest groups also provide opportunity for public involvement. Hydrology is specifically covered in this report. The geomorphology component is addressed under *Channel Maintenance* headings below and in the results section. Biology is covered explicitly under the subheading *Fish Flows* and implicitly under the *Channel Maintenance* section Water quality is not addressed in a unique section because aspects of water quality that directly impinge on fish health (e.g. water temperature) are implicitly covered by the methods used in the *Fish Flows* sections (e.g. HQI method). Finally, the connectivity component is addressed under the *Instream Flow Recommendations* section of this report where the instream flow segments are defined relative to the network of water drainage in the Piney Creek watershed.

## Legal and Institutional Background

The Wyoming Game and Fish Department (WGFD) is empowered in Title 23 of Wyoming statutes to manage the fishery and wildlife resources of the state for the benefit of its citizens. The WGFD was created and placed under the direction and supervision of a 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 WGFD is the only entity of state government directly charged with managing Wyoming's wildlife resources and conserving them for future generations. The WGFD mission statement is: "Conserving Wildlife - Serving People" while the Fish Division mission statement details a stewardship role toward aquatic resources and the people who enjoy them.

Water for protecting and managing fishery and wildlife resources can be provided by a variety of administrative mechanisms such as memorandums of agreement and special use permits for water development projects. The instream flow law, Wyoming Statute 41-3-1001, was passed in 1986 and 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...". The statute directs that the Game and Fish Commission is responsible for determining streamflows that will "maintain or improve" fisheries identified as important. The Game and Fish Department fulfills this function under the general policy oversight of the Commission. An application for an instream flow water right is signed and held by the Wyoming Water Development Commission (WWDC) on behalf of the state should the water right be approved by the State Engineer. The priority date for the instream flow water right is the day the application is received by the State Engineer.

Through December 31, 2003, the WGFD has submitted 89 instream flow water right applications, of which the state engineer permitted 33 and the Board of Control has adjudicated 4. Initially, important fisheries were interpreted as WGFD class 1 and 2 waters, which are highly productive fisheries and provide popular recreational opportunities. Recent efforts have focused on small headwater streams supporting native cutthroat trout. From 1998 through 2001, studies were conducted on eight Greybull River tributary stream segments, including Piney Creek, containing populations of Yellowstone cutthroat trout (YSC; *Oncorhynchus clarki bouvieri*). Future plans include studies and instream flow filings on additional tributaries in the Wood River drainage.

## Interpretation and Application of the Instream Flow Law Toward Fishery Maintenance

To fishery managers, others who helped craft this legislation and sponsors of the initiative that led to passage, the instream flow statute was supported 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 communications). The following discussion provides our interpretation of some key terms in this statute.

Perhaps the most critical term in the statute is “fishery”. Since passage of the instream flow law, the WGFD 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 definition of *fishery* necessitates a broad view when defining flows. The WGFD perspective in the past was more narrow and involved identifying flows only for fish. This tactic was consistent with the perspective of many natural resource management agencies at the time. A considerable body of knowledge now indicates protecting 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 geomorphologic 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.

The term “existing” fishery warrants clarification. Biologically, “existing” cannot refer to a constant number of fish. Stream fish populations fluctuate in abundance annually and seasonally in response to a variety of environmental factors (Dey and Annear 2001a, House 1995, Nehring and Anderson 1993). In a study of six relatively pristine streams across Wyoming, Dey and Annear (2001a) documented coefficients of variation in annual trout abundance ranging from 29 to 115%. Similarly, in a western Oregon stream studied for 11 years, cutthroat trout fry density varied from 8 to 38 per 100 $m^2$ and juvenile density 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. Thus the goal of maintaining existing fisheries involves allowing a fishery to increase and decrease within natural historical bounds.

The amount of water needed to maintain the existing fishery also warrants interpretation. Under 41-3-1001(d), amount is defined as: “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 means 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. 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, "minimum" cannot be interpreted as the least amount of water in which fish can live. For agricultural beneficial use, the minimum amount of water is defined by W.S. 41-4-317 as 1 cfs for each 70 acres of land irrigated. The closest the instream flow law gets to a definition is under W.S. 41-3-1003 (b) where the term minimum is used again "…and a detailed description of the minimum amount of water necessary to provide **adequate** instream flows"(emphasis added). The "minimum", as used in this report, is thus an amount of water that the WGFD has determined adequate for maintaining a fishery.

## Channel Maintenance Flows

Our increased awareness of the state's responsibility for developing instream flow recommendations that maintain *fisheries*, as broadly defined (above), necessitates that we consider flow requirements for maintaining floodplains, their associated diverse fish habitats, and the riverine processes of sediment flux and riparian vegetation development that sustain a fishery over the long term. Addressing these issues is necessary to fully comply with Wyoming's instream flow statute. To maintain the existing dynamic character of the entire fishery, instream flows must maintain the stream channel and its functional linkages to the riparian corridor and floodplain to perpetuate habitat structure and ecological function.

The State Engineer has concluded that channel maintenance flows are not included in the legislative intent of the instream flow statute. Therefore, until the institutional climate and interpretation of state water law changes, channel maintenance flow recommendations are not included on instream flow applications. Channel maintenance flow requirements are presented in this report should it become feasible in the future to apply for an instream flow water right for this component of the hydrograph.

## Yellowstone Cutthroat Background

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), Kruse et al. (1997), Dufek et al. (1999), and May et al. (2003). 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 (Dufek et al. 1999). 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 relatively pure YSC. Future filings are anticipated in other drainages like the Shoshone River drainage and Bighorn Mountain tributaries to maintain 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. With the exception of Piney Creek, 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 was judged to provide an adequate level of protection. Piney Creek is an exception to this approach because the entire segment and study site occur in the Washakie Wilderness. This segment was judged to be relatively accessible to future development, despite the Wilderness status, and an instream flow segment was proposed to protect a healthy Yellowstone cutthroat trout fishery.

The Yellowstone cutthroat trout was petitioned for listing under the Endangered Species Act in 1998. In February 2001 the Fish and Wildlife Service (FWS) completed a 90-day petition review finding that listing is not warranted at this time. In January 2004, a suit was brought against the FWS alleging that this finding did not follow the tenets of the Endangered Species Act. Against this backdrop of ongoing dispute, the 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 base flow conditions against future consumptive and diversionary demands. Additional water rights for channel maintenance are still needed to ensure long-term habitat and fishery persistence.

## Objectives

The objectives addressed by this report are to 1) quantify year-round instream flow levels needed to maintain adequate base-level hydraulic habitat for Yellowstone cutthroat trout, 2) provide the basis for filing an instream flow water right application that will maintain Yellowstone cutthroat trout hydraulic habitat, and 3) identify channel maintenance flows that maintain long-term trout habitat and related physical and biological processes.

# METHODS

## Study Area

The Greybull River and its tributaries like Piney Creek 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.

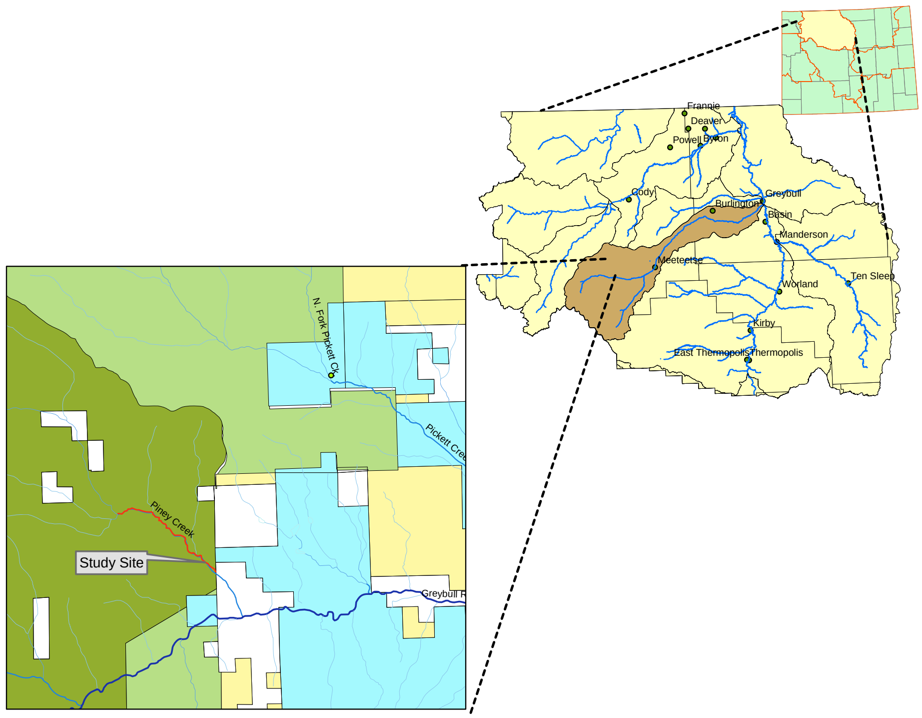


Figure 1. Piney Creek instream flow segment and study site location.

Snowfall on Carter Mountain at elevations up to and over 11,000 feet melts to form the upper reaches of Piney Creek. The stream flows in a southeasterly direction for approximately 7 miles before reaching the Greybull River (Figure 1). A steep channel and low quality adult habitat limits fish distribution in Piney Creek to about 4.6 stream miles from the mouth. The upstream limit of fish presence according to 1994 survey is in the southeast quarter of Section 6, T48N, R104W (Kruse 1995). An instream flow stream segment 2.3 miles long from the confluence of an unnamed tributary entering from the west (SW ¼ Section 8, T.48N., R.104W.) downstream to the Absoraka Wilderness boundary (SW ¼ Section 15, T.48N., R.104W.) was selected (Figure 1). The segment does not have any major tributary inflows (>33% of main stem) and channel slope and substrate are relatively uniform throughout the segment. Land ownership along the segment is Shoshone National Forest.

Channel features were measured with a Rosgen level 2 survey. Water surface slope was 6.3%. Other key features include a bankfull width of 19.1 feet, a mean bankfull depth of 0.91 feet, a maximum bankfull depth of 1.60 feet, a flood prone width of 25.6 feet, a d50 of 70 mm, and a sinuosity of 1.18. Under the Rosgen and Silvey (1998) channel rating scheme, these features conform to a "B3" rating reflecting a high slope and predominant cobble substrate.

Piney Creek's riparian zone alternates between reaches with conifers and willows to reaches nearly devoid of vegetation where the confined channel cuts through canyons (Figure 2). Cattle grazing, horse packing, and historic mining activity are the main land uses in the Piney Creek basin.

Figure 2. *Upper photo:* Piney Creek watershed. *Lower photo:* Piney Creek study site June 26, 2001 at 21cfs.

The instream flow segment was studied with a 324-foot-long study site located on National Forest land in the SE ¼ of Section 16, T.48N., R.104W. This site was selected 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 accessible and 3) a representative mix of riffles, runs, pools, spawning gravel, and stream-margin fry habitat were present (Figure 2). Data were collected on the dates and at the discharges listed in Table 1.

Table 1. Dates and discharge levels for Piney Creek instream flow studies.

| Date | Discharge (cfs) |
|---|---|
| June 6, 2001 | 8.5 – 12 |
| June 26, 2001 | 21 - 40 |
| July 19, 2001 | 7.3 |
| September 11, 2001 | 3.1 |
| September 25, 2003 | 3.5 |

## Hydrology

An independent contract was awarded to estimate mean annual flow, annual flow duration, monthly flow duration, and flood frequency intervals for the Piney Creek segment and other Greybull River tributaries (HabiTech 2001). A gage station was operated seasonally on the Greybull River at the Pitchfork Bridge in 2001-2003. These data are reported in three WGFD Administrative reports by Dey and Annear (2003a, 2003b, and 2001c).

## Fish Flows

### Fish Community Description

The fish community in the Greybull River basin above the Wood River confluence conforms to a simple 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 Piney Creek. 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.

### Instream Flow Model Description

Throughout this document, the term "habitat" is used frequently. In most cases, the term is used in reference to the physical conditions of depth, 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. The "physical" habitat modeled and discussed in this report covers the important dimensions of trout habitat that vary predictably as function of flow. It is assumed that these aspects of trout habitat are important to the health and long-term persistence of the modeled trout populations.

*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 at up to 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 no suitability. The PHABSIM default method of combining suitabilities was used for the Piney Creek 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 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. PHABSIM for Windows Version 1.2 was used for all analyses.

We apply PHABSIM selectively at study sites depending on the characteristics of the study site and judgment as to how a particular stream segment is used by different trout life stages. If spawning habitat exists, transects are usually placed to model this important habitat feature. A complete PHABSIM study in which transects are placed in the range of habitats used by all life stages offers the advantage of identifying flow-physical habitat tradeoffs for all life stages. Instream flow recommendations developed from Habitat Retention and HQI models (described below) can then be compared to the PHABSIM results.

### *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 (Table 2) in stream riffles. Maintaining criteria in riffles at all times of year 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 3).

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.

*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 Wyoming 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. Each attribute is assigned a rating that can vary from 0 to 4 with higher ratings representing better trout habitat. Attribute ratings are combined in the model with results 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 16 and September 30 (Table 3).

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 an 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). Piney Creek habitat attributes were measured on the same dates PHABSIM data were collected (Table 1). Some attribute ratings were mathematically derived to establish the relationship between discharge and trout habitat at discharges other than those measured.

## Instream Flow Model Application

*Physical Habitat Simulation*

A series of 8 transects were established over a stream length of 83.4 feet to model riffles, runs, plunge pools, and pocket pools. The transects were calibrated together in a single project using the stage-discharge and MANSQ approaches for defining water surface elevations. The velocity set collected at 21 cfs or 39 cfs served as the calibration velocity set for distributing roughness among the cells. Physical habitat was simulated over the range 1.3 cfs to 110 cfs based on calibration criteria in Milhous et al. (1984). Increments of 1.0 cfs were simulated over the range 1-20 cfs and increments of 5.0 cfs were used to simulate from 20 to 110 cfs. The HABTAE submodel was used in generating a WUA index for the reach. The peak of this index was used to set instream flow recommendations for the spawning life stage of YSC.

Habitat was delineated September 11, 2001 following the classification scheme of Hawkins et al (1993). Under this approach, channel units such as pools, riffles, and runs are identified by the relative channel gradient and surface turbulence. We classified habitat over a 1355-foot-reach that included the instream flow study site to determine the relative abundance of habitat types. Since PHABSIM transects were distributed over these representative habitats, we could weight each of the 8 transects in the

PHABSIM analysis to reflect the abundance of the habitat type. For example, riffles were found to comprise 71% of the stream habitat, so riffle transects were weighted to represent 71% of the total WUA. Curves of WUA versus flow were generated for spawning, fry, juvenile and adult Yellowstone cutthroat trout. The peak of the combined spawning WUA index was used to set instream flow recommendations while the WUA relationships for the other life stage patterns are presented for reference.

*Habitat Retention*

Three riffle transects modeled with PHABSIM were examined to identify flow levels necessary to maintain hydraulic criteria. The wetted perimeter criteria for a stream of this size is 50% of the wetted perimeter that occurs on the transect at bankfull stage (Nehring 1979, Annear and Conder 1984). In a departure from previous practice, bankfull wetted perimeter across each of the riffle transects was measured in July 2003. Prior practice was to use the bankfull discharge estimated from the 1.5 year return flow (here equal to 110 cfs from HabiTech 2001) and then use PHABSIM to simulate the wetted perimeter that occurs at that flow level. Using field measurements by a trained observer provides a more direct method of inferring bankfull discharge. Both methods were tested and the field measurements resulted in the same recommendation that would have resulted from using the bankfull discharge estimate.

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. Average daily flow was estimated at 11 cfs (HabiTech 2001) and at this flow average wetted width is less than 14 feet so the 0.20-foot criterion was used.

*Habitat Quality Index*

Average daily flow (ADF; 11 cfs) and peak flow (110 cfs) estimates for determining critical period stream flow and annual stream flow variation are from HabiTech (2001). Maximum water temperature was determined with an Optic StowAway® temperature recorder set to monitor water temperature at 1-hour intervals between June 6 and September 11, 2001. Nitrate levels were determined from a water sample collected September 14, 2001 and analyzed by the Analytical Services section of the Wyoming Department of Agriculture, Laramie, Wyoming. The HQI "substrate" attribute, a measure of invertebrates per square foot of streambed, was measured by collecting three Surber samples and counting invertebrate numbers streamside.

## Channel Maintenance Flow Development

The term "channel maintenance flows ", as used in this report, refers to flows that maintain existing channel morphology, riparian vegetation and floodplain function (US Forest Service 1997, Schmidt and Potyondy 2001). The basis and approach discussed in this report for providing channel maintenance flows applies only to gravel and cobble-bed (alluvial) 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 (Andrews 1984, Hill et al. 1991, Leopold 1994).

A flow regime that provides channel maintenance results in stream channels that are in approximate sediment equilibrium where sediment export equals sediment import on average over a period of years (Leopold 1994, Carling 1995, US Forest Service 1997). Thus, stream channel characteristics over space and time are a function of sediment input and flow (US Forest Service 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.

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 (Gordon 1995; US Forest Service 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 could occur if flows were artificially reduced at all times.

Channel maintenance flows must be sufficient to move the entire volume and all sizes of material supplied to the channel from the watershed over a long-term period (US Forest Service 1997, Carling 1995). A range of flows, under the dynamic hydrograph paradigm, provides this function. Infrequent high flows move large bed elements while the majority of the total volume of material is moved by more frequent but lower flows (Wolman and Miller 1960, Leopold 1994). In streams with a wide range of sediment sizes on the channel boundary, a range of flows may best represent the dominant discharge because different flow velocities are needed to mobilize different sizes of bed load and sediment. Kuhnle et al. (1999) note "A system designed with one steady flow to transport the supplied mass of sediment would in all likelihood become unstable as the channel aggraded and could no longer convey the sediment and water supplied to it. A system designed with one steady flow to transport the supplied sediment size distribution would in all likelihood become unstable as the bed degraded and caused instability of the banks."

A total bedload transport curve (Figure 3) 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.

The initiation of particle transport 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. 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, loss of habitat diversity, and alteration of fishery characteristics (Hill et al. 1991, Carling 1995, Annear et al. 2002).

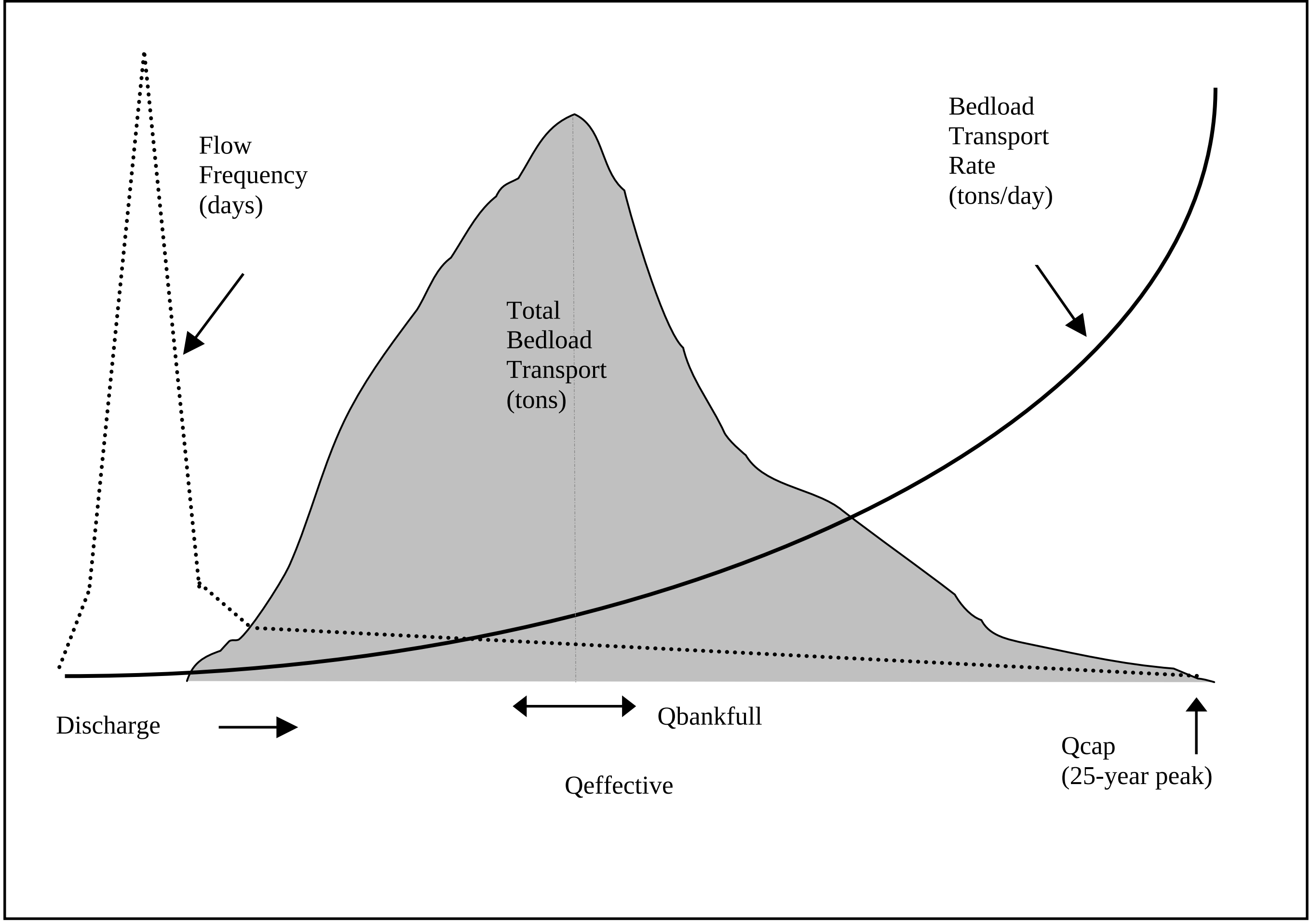


Figure 3. A general model of long-term total bedload transport as a function of flow frequency and bedload transport rate (from USFS 1997).

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

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

Where: $Q_s$ = 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 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 and thus better meets the statutory standard of “minimum needed”.

Application of the equation results in incrementally higher percentages of flow applied toward channel maintenance as flow approaches bankfull (Figure 4). Flows less than half of bankfull are available for other uses unless needed for direct fish habitat. At flows greater than bankfull but less than the 25-year flow level, the channel maintenance instream flow recommendation is equal to the actual flow. Flows greater that the 25-year recurrence flow are not necessary for channel maintenance and are available for other uses.

Under the dynamic hydrograph 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.

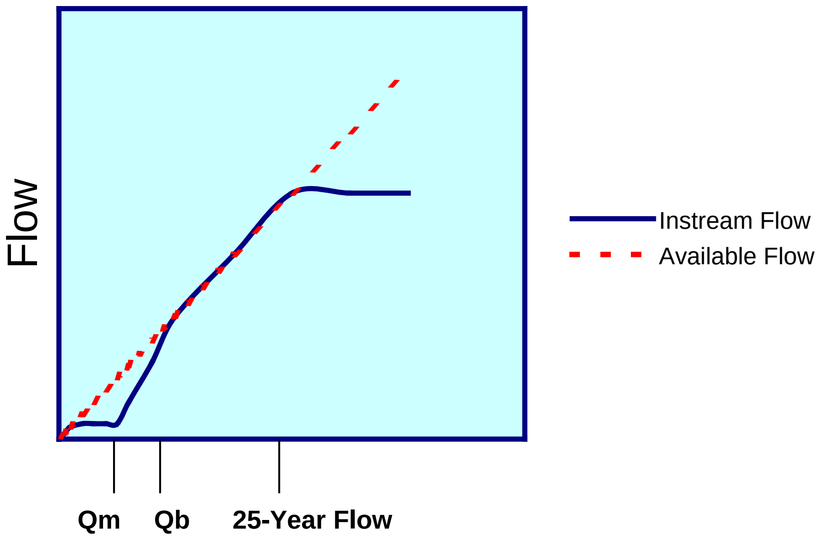


Figure 4. General function of a dynamic hydrograph instream flow for fishery maintenance. $Q_m$ is substrate mobilization flow and $Q_b$ is bankfull flow.

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 (Figure 4). This manner of flow regulation is complex and could prove burdensome to water managers. To facilitate flow administration while still ensuring reasonable flows for channel maintenance, we modified this aspect of the approach to claim instream flows for 4 evenly partitioned blocks or increments of flow between the sediment mobilization flow and bankfull (see Table 6).

## Seasonal Application of Methods

Adequate and continuous flow at all times of year is critically important to maintaining trout populations, connectivity among habitats throughout a drainage, and the stream channels that provide a fishery's foundation. The fishery functions and associated time periods summarized in Table 3 show how each of the models and approaches described above are applied on a seasonal basis. The instream flow recommendation for any month where two or more recommendations apply is based on the recommendation that yields the higher flow.

The PHABSIM approach was used to estimate flows that will maintain spawning habitat. Spawning activity was observed in the basin throughout May and into June when we actively sought spawning fish for development of habitat suitability criteria (WGFD 1999). Our spawning flow recommendations for Timber, Francs Fork, Jack Creek and lower Pickett Creek reflected these data and were applied to the period May 1 through June 30 (e.g. Dey and Annear 2001b). During data collection for the Pickett Creek study, a spawning trout was observed July 7th in Pickett Creek at an elevation of about 8200 feet. At higher elevations where water temperatures are likely to remain colder and both spawning and egg incubation may occur later in the summer, the spawning period should be recognized as occurring from May 1 until July 15 (Table 3). While the May 1 through June 30 spawning period is appropriate for segments with the majority of the stream channel length occurring below approximately 8000 feet elevation, a May 1 through July 15 period for higher elevation instream flow segments like Piney Creek will ensure that adequate spawning water is protected when it is needed.

Table 3. Yellowstone cutthroat trout life stages and months considered in the Piney Creek instream flow recommendations. Numbers indicate the method used to determine flow requirements.

| *Fishery Function* | JAN | FEB | MAR | APR | MAY | JUN | JUL 1 - 15 | Jul 16 - 31 | AUG | SEP | OCT | NOV | DEC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Spawning habitat | | | | | 1 | 1 | 1 | | | | | | |
| Survival, movement | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| Growth | | | | | | | 3 | 3 | 3 | 3 | | | |
| Channel maintenance | | | | | 4 | 4 | 4 | | | | | | |

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

The Habitat Retention approach - meant to identify flows for fish movement, survival, and the productive capacity of riffles - provides a year-round base flow (Table 3). Higher flows are often necessary for spawning, growth, and channel maintenance but when these functions do not take precedence the channel maintenance flow applies. The HQI model was developed and tested specifically for the late-summer period of July through September. The channel maintenance flows perform their function during runoff. The majority of runoff in most years in the Greybull basin comes in May and June (Dey and Annear 2003) but significant runoff can also occur in early July.

# 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, Piney Creek bankfull discharge at the downstream end of the segment is 110 cfs (Table 4). Average daily flow was estimated at 11 cfs (HabiTech 2001). Estimated monthly flow levels are listed in Appendix 2.

Table 4. Estimated flood frequency series for the Piney Creek instream flow segment (HabiTech 2001).

| Return Period (years) | Estimated Flow (cfs) |
|---|---|
| 1.01 | 49 |
| 1.05 | 60 |
| 1.11 | 69 |
| 1.25 | 82 |
| 1.5 | 110* |
| 2 | 122 |
| 5 | 197 |
| 10 | 262 |
| 25 | 363 |

* Bankfull discharge.

## Fish Flows

### *Physical Habitat Simulation*

The WUA index of spawning habitat in the 8 transect study reach peaked at 55 cfs (Figure 5). The index shows spawning habitat declines gradually at lower or higher flows. The peak at 55 cfs occurs because depth and velocity become suitable at this flow in the few small locations where the appropriate size spawning gravel exists. Shallow depths limit spawning habitat at low flows while high velocities limit spawning habitat at high flow levels.

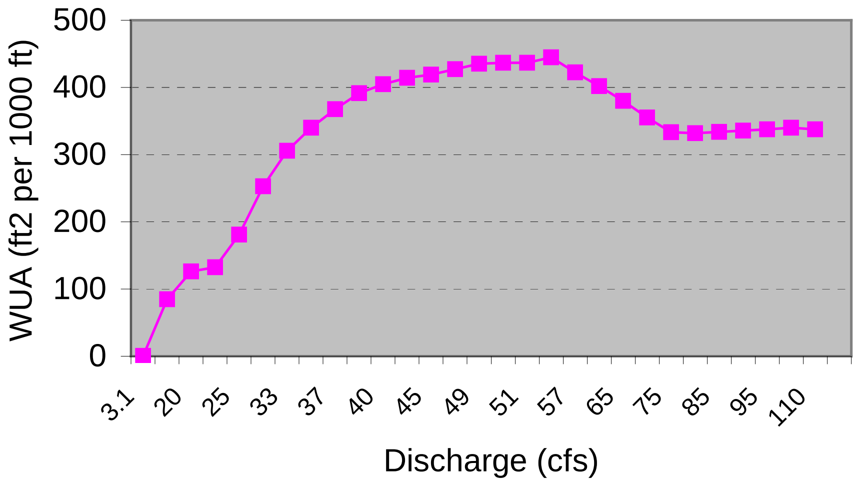


Figure 5. Yellowstone cutthroat trout spawning habitat (square feet per 1000 feet of stream).

Based on simulated spawning habitat (Figure 5), an instream flow of 55 cfs is recommended for the May through July 15 season to maintain YSC spawning habitat. Though the full 55 cfs may not always be present during this entire period, protection of flows up to that level, when available in priority, will prevent impacts to spawning success and therefore maintain the existing fishery.

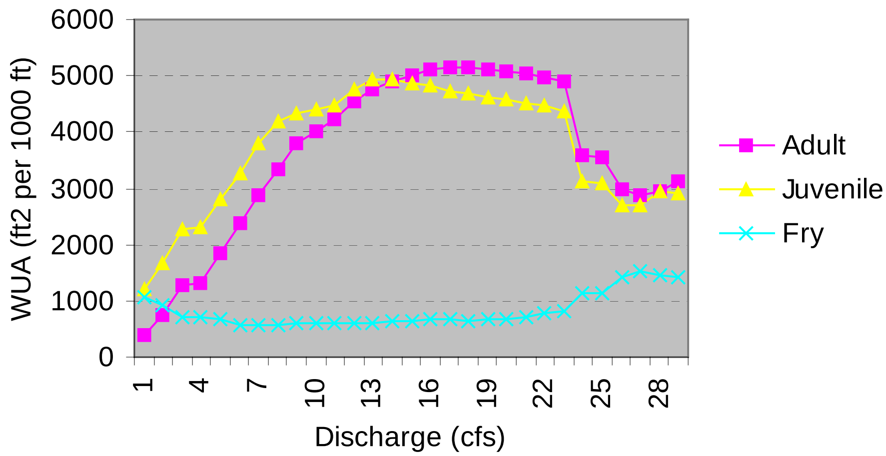


Figure 6. Yellowstone cutthroat trout weighted useable area for adult, juvenile, and fry life stages (square feet per 1000 feet of stream).

The indices of physical habitat for juvenile and adult Yellowstone Cutthroat trout show rapid gains as flow increases with peak levels at 11 cfs (juveniles) and 16 cfs (adults). Rapid declines occur at flows over 21 cfs as velocities become too fast (Figure 6). Fry habitat is low and stable with some increase at higher flows as stream margins increasingly become inundated and provide the slow, backwater conditions required by this life stage.

*Habitat Retention*

Average depth, average velocity, and wetted perimeter across three riffle transects as a function of flow are listed in Table 5. At riffle 1, wetted perimeter is the first hydraulic criteria "met" as flow declines from its bankfull level. The wetted perimeter criterion is met at 9 cfs. Next, the average velocity criterion is met at 2.5 cfs. Finally, for riffle 1, the depth criterion is reached at a flow of 1.6 cfs. Thus, two of three hydraulic criteria (mean velocity and depth) are retained by a flow of 2.5 cfs across riffle 1 (Table 5). In a similar fashion, somewhat lower flows retain the criteria on riffles 2 and 3. Therefore, the flow that retains two of three criteria for all of the studied riffles is 2.5 cfs. Based on the Habitat Retention model, a flow of 2.5 cfs is recommended to maintain trout survival over the fall and winter season (October 1 to April 30).

Table 5. Simulated hydraulic criteria for three Piney Creek riffles. Bold indicates that the hydraulic criterion was met. Flows meeting 2 of 3 criteria for each riffle are shaded.

| | Mean Velocity (ft/s) | Mean Depth (ft) | Wetted Perimeter (ft) | Discharge (cfs) |
|---|---|---|---|---|
| Riffle 1 – transect 1 | 3.88 | 1.18 | 27.4 | 110 |
| | 3.63 | 0.89 | 26.2 | 80 |
| | 2.80 | 0.72 | 20.7 | 39 |
| | 2.15 | 0.59 | 16.1 | 19 |
| | 1.59 | 0.46 | **13.1** | 9 |
| | 1.43 | 0.43 | 12.1 | 7 |
| | **0.99** | 0.27 | 9.8 | **2.5** |
| | 0.88 | **0.20** | 9.5 | 1.6 |
| | 0.86 | 0.17 | 9.4 | 1.3 |
| Riffle 2 – transect 3 | 5.14 | 0.94 | 28.5 | 130 |
| | 4.81 | 0.91 | 26.8 | 110 |
| | 3.32 | 0.62 | 20.3 | 39 |
| | 2.67 | 0.55 | **14.25** | 19 |
| | 1.97 | 0.38 | 10.4 | 7 |
| | 1.64 | 0.22 | 7.6 | 2.5 |
| | 1.64 | **0.20** | 7.3 | **2.2** |
| | 1.99 | 0.12 | 5.9 | 1.3 |
| | <**1.99** | <.12 | <5.9 | <1.3 |
| Riffle 3 – transect 6 | 5.56 | 0.96 | 21.4 | 110 |
| | 3.83 | 0.82 | 19.8 | 60 |
| | 2.90 | 0.74 | 18.8 | 39 |
| | 1.81 | 0.63 | 17.2 | 19 |
| | **0.99** | 0.55 | 13.4 | 7 |
| | 0.50 | 0.41 | 12.6 | 2.5 |
| | 0.46 | 0.40 | 12.3 | 2.2 |
| | 0.33 | 0.36 | 11.3 | 1.3 |
| | <0.33 | **<0.36** | **<11.3** | **<1.3** |

a - Discharge at which 2 of 3 hydraulic criteria are met for all riffles.

The 1.5 cfs from Habitat Retention provides limited adult habitat (Figure 6). Under ice-free conditions, the 1.5 cfs allows trout movement between pools while greater flow levels would provide additional adult habitat. By maintaining flowing water across riffles and through the boulder-strewn rapids, a flow level of 1.5 cfs serves chiefly to maintain survival of juvenile and fry life stages burrowed beneath the numerous boulders and cobbles.

*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, nitrate concentration, invertebrate numbers, and eroding banks. A maximum water temperature of 67° F was recorded August 6, 2001. This temperature falls in the 66 - 70º F band for a rating of "3" under Binns (1982) and reflects good but less than optimal thermal conditions in which maximum water temperatures can limit trout populations. Nitrate concentrations were low at <0.01 mg/l. The attribute rating for this level of nitrate is "0". For simulating Habitat Units over a range of flows, the nitrate rating was held constant at "1" so that the calculations would reflect the dynamics of the other habitat attributes. Eroding banks, at 59%, rated a "1". The average of three Surber samples was 86 invertebrates per square foot for a rating of "1". Percent cover was measured at 10.3%, 10.5% and 7.4% at 3.1, 8.5 and 32 cfs, respectively. The cover rating changes from "1" to "0" when cover is less than 10% of the wetted channel. By linear interpolation, the cover rating declines to less than 10% at 2.9 cfs.

Peak habitat units occur between 7.0 and 11 cfs (Figure 7). Water velocity was a key attribute with optimal mean channel velocities occurring from 4.7 to 11 cfs. At flow levels less than 4.7 and greater than 11 cfs, the velocity attribute declines to a lower rating. The annual stream flow variation attribute was also influential with optimal values for this attribute occurring at flows greater than or equal to 7 cfs.

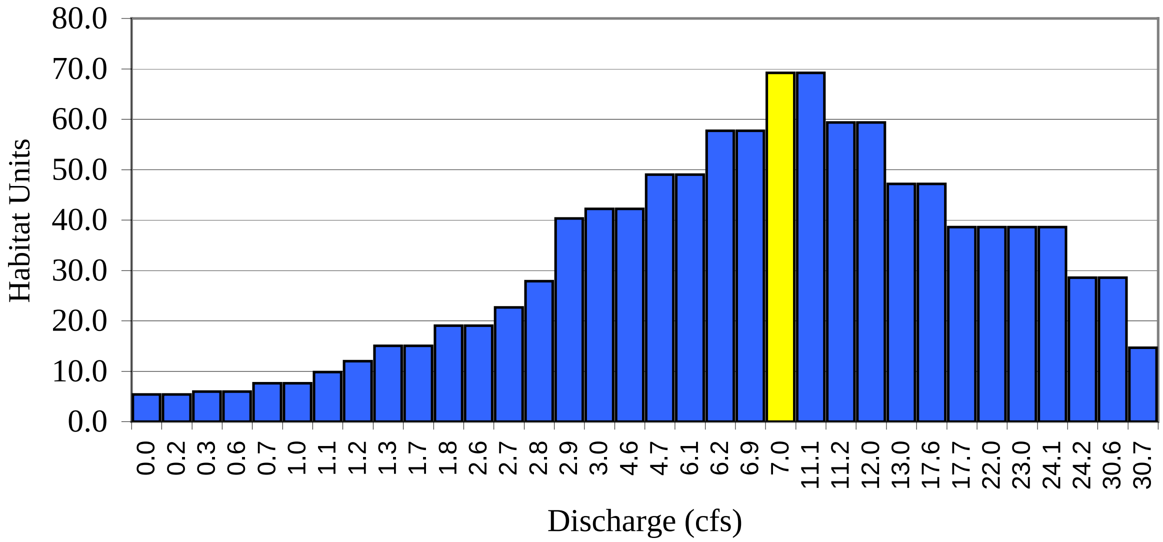


Figure 7. Habitat Quality Index at the Piney Creek study site for a range of flow levels. X-axis flows are scaled to show where changes in Habitat Units occur. The recommended flow is indicated by the light shaded bar.

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. Three flow measurements in the July through September period are 7.3 cfs (July 19, 2001), 3.1 cfs (September 11, 2001) and 3.5 cfs (September 25, 2003). Estimated monthly streamflows that occur 50% of the time are: 25 cfs, 8.7 cfs, and 5.3 cfs for July, August and September, respectively (Appendix 2, HabiTech 2001). The estimated August value of 8.7cfs 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 69 habitat units under existing conditions (Figure 7). The lowest flow that will maintain 69 habitat units is 7.0 cfs. The instream flow recommendation to maintain adult Yellowstone cutthroat trout habitat during the late summer period is 7.0 cfs.

## Channel Maintenance Flows

Like all properly functioning rivers, the Piney Creek 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 provided the instream flow recommendations in Table 6. The base or fish flow used in the analysis was the 55 cfs identified for maintaining spawning habitat. This flow also happens to be equivalent to the substrate mobilization flow of ½ bankfull (110 cfs). For naturally available flow levels up to 55 cfs, the channel maintenance instream flow recommendation is equal to natural flow. When naturally available flows range from 56 cfs to the bankfull flow of 110 cfs, application of the Leopold formula results in incrementally greater amounts of water applied toward instream flow (Table 6). At flows between bankfull and the 25-year flood flow (363 cfs), all of the streamflow is needed to perform channel maintenance functions. 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 4).

Table 6. Instream flow recommendations to maintain existing channel forming processes and long-term aquatic habitat characteristics in the Piney Creek instream flow segment. Recommendations apply to the run-off period from May 1 through July 15th.

| Description | Available Flow (cfs) | Instream Flow (cfs) |
|---|---|---|
| | <55 | Equal to available flow |
| Spawning Flow | 55 | 55 |
| Substrate Mobilization Flow | 55 | 55 |
| | 56 – 69 | 56 |
| | 70 – 83 | 68 |
| | 84 – 96 | 82 |
| | 97 - 109 | 96 |
| Bankfull | 110 | 110 |
| | 110 - 363 | Equal to available flow |
| 25-Year Flood | 363 | 363 |
| | >363 | 363 |

## INSTREAM FLOW RECOMMENDATIONS

Based on the analyses and results outlined above, the instream flow recommendations in Table 7 will maintain the short-term habitat requirements for Yellowstone cutthroat trout in a Piney Creek instream flow segment. Long-term channel maintenance flows to preserve the ecological functions that support the fishery are listed in Table 6. Flow recommendations apply to a stream segment extending 2.3 miles downstream from the confluence of an un-named tributary in the SW ¼ of Section 8, T.48N., R.104W. downstream to the Washakie Wilderness boundary in the SW ¼ of Section 15, T.48N., R.104W. UTM coordinates (NAD27) for the upper and lower boundaries of the segment are 630228E, 4888568N, Z12 and 632837E, 4886951N, Z12, respectively.

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 9. Instream flow recommendations to maintain or improve existing trout habitat in a Piney Creek segment.

| Season | Month | Instream Flow* Recommendation (cfs) |
|---|---|---|
| Fall/Winter | October | 2.5 |
| Fall/Winter | November | 2.5 |
| Fall/Winter | December | 2.5 |
| Fall/Winter | January | 2.5 |
| Fall/Winter | February | 2.5 |
| Fall/Winter | March | 2.5 |
| Fall/Winter | April | 2.5 |
| Spring | May | 55 |
| Spring | June | 55 |
| Spring | July 1 – 15 | 55 |
| Summer | July 16 - 31 | 7 |
| Summer | August | 7 |
| Summer | September | 7 |

* Channel maintenance flow recommendations for the spring runoff period are defined in Table 6.

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Appendix 2. Habitat suitability criteria. Substrate codes are 1=vegetation, 2=mud, 3=silt, 4=sand, 5=gravel, 6=cobble, 7=boulder, 8=bedrock. Decimals indicate the percent of the next higher class code (e.g. 4.4 = 60% sand, 40% gravel).

| Velocity (ft/s) | Weight | Depth (ft) | Weight | Substrate Code | Weight |
|---|---|---|---|---|---|
| Spawning | | | | | |
| 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 0.30 | 0.20 | 0.25 | 0.00 | 4.40 | 0.00 |
| 0.90 | 0.50 | 0.32 | 0.20 | 4.50 | 1.00 |
| 1.45 | 1.00 | 0.39 | 0.50 | 5.80 | 1.00 |
| 2.00 | 1.00 | 0.46 | 1.00 | 5.90 | 0.00 |
| 2.60 | 0.50 | 0.60 | 1.00 | | |
| 3.20 | 0.00 | 0.67 | 0.50 | | |
| | | 0.74 | 0.00 | | |
| Adults | | | | | |
| 0.00 | 0.20 | 0.00 | 0.00 | 1-8 | 1.00 |
| 0.23 | 0.20 | 0.40 | 0.00 | | |
| 0.24 | 0.50 | 0.45 | 0.10 | | |
| 0.42 | 0.50 | 0.49 | 0.10 | | |
| 0.43 | 1.00 | 0.50 | 0.20 | | |
| 1.66 | 1.00 | 0.59 | 0.20 | | |
| 1.67 | 0.50 | 0.60 | 0.50 | | |
| 2.28 | 0.50 | 0.79 | 0.50 | | |
| 2.29 | 0.20 | 0.80 | 1.00 | | |
| 2.82 | 0.20 | 2.30+ | 1.00 | | |
| 2.83 | 0.10 | | | | |
| 3.48 | 0.10 | | | | |
| 3.49 | 0.00 | | | | |
| Juvenile | | | | | |
| 0.00 | 0.50 | 0.00 | 0.00 | 1-8 | 1.00 |
| 0.50 | 0.50 | 0.75 | 0.50 | | |
| 0.60 | 1.00 | 0.80 | 1.00 | | |
| 1.50 | 1.00 | 2.30+ | 1.00 | | |
| 1.60 | 0.50 | | | | |
| 1.90 | 0.50 | | | | |
| 2.00 | 0.20 | | | | |
| 2.40 | 0.20 | | | | |
| 2.50 | 0.10 | | | | |
| 2.90 | 0.10 | | | | |
| 3.00 | 0.00 | | | | |
| Fry | | | | | |
| 0.00 | 0.60 | 0.00 | 0.00 | 1-8 | 1.00 |
| 0.03 | 1.00 | 0.03 | 0.10 | | |
| 0.07 | 0.90 | 0.07 | 0.20 | | |
| 0.10 | 0.60 | 0.10 | 0.20 | | |
| 0.13 | 0.60 | 0.13 | 0.40 | | |
| 0.16 | 0.50 | 0.16 | 0.60 | | |
| 0.20 | 0.30 | 0.20 | 0.60 | | |
| 0.23 | 0.30 | 0.23 | 0.70 | | |
| 0.27 | 0.20 | 0.26 | 0.80 | | |
| 0.30 | 0.10 | 0.30 | 0.90 | | |
| 0.52 | 0.10 | 0.36 | 0.90 | | |

| | | | | | |
|---|---|---|---|---|---|
| 0.56 | 0.00 | 0.39+ | 1.00 | | |

Appendix 2. Estimated monthly flow duration series for the Piney Creek segment (HabiTech 2001).

| Duration Class (% time≥) | **Piney Creek** Estimated Streamflow (cfs) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sept |
| 95 | 2.2 | 1.6 | 1.3 | 1.2 | 1.3 | 1.5 | 1.8 | 3.9 | 18 | 7.6 | 4.2 | 3.1 |
| 90 | 2.4 | 1.8 | 1.5 | 1.5 | 1.4 | 1.6 | 1.9 | 5.0 | 20 | 9.8 | 4.8 | 3.4 |
| 75 | 2.9 | 2.2 | 1.8 | 1.6 | 1.6 | 1.7 | 2.3 | 8.1 | 28 | 16 | 6.0 | 4.2 |
| 50 | 3.6 | 2.7 | 2.1 | 1.8 | 1.8 | 2.1 | 3.1 | 16 | 41 | 25 | 8.7 | 5.3 |
| 25 | 4.4 | 3.3 | 2.4 | 2.1 | 2.0 | 2.5 | 5.0 | 27 | 59 | 41 | 13 | 6.6 |
| 10 | 5.4 | 3.9 | 2.8 | 2.4 | 2.4 | 3.1 | 8.4 | 42 | 79 | 55 | 18 | 8.3 |
| 5 | 6.0 | 4.3 | 3.3 | 2.6 | 2.7 | 4.1 | 12 | 49 | 90 | 65 | 21 | 9.7 |