WYOMING GAME AND FISH DEPARTMENT

FISH DIVISION

ADMINISTRATIVE REPORT

Title: Instream Flow Studies on Pickett Creek, 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 at two sites on Pickett Creek during 1999. 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 two separate stream segments. One segment, labeled "segment #1," went from the mouth of North Fork Pickett Creek downstream about 5 miles to a section border. The following instream flow recommendations were developed: 19 cfs to maintain hydraulic habitat for spawning during the spring season from May 1 to June 30, 11.2 cfs to maintain or improve adult trout habitat quality in the existing stream channel during the late summer period between July 1 and September 30, and 8.6 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 should it become feasible in the future to protect these flows with instream flow water rights.

An upstream instream flow segment (segment #2) was defined from the North Fork Pickett Creek confluence to a point approximately 4 miles upstream. The following instream flow recommendations were developed: 25 cfs to maintain hydraulic habitat for spawning during the spring season from May 1 to July 15, 5.0 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 4.4 cfs to maintain habitat for all YSC life stages from October 1 to April 30. Again, flow recommendations for maintaining channel characteristics and the long-term fishery are provided.

INTRODUCTION

The Instream Flow Council (IFC), an organization of state and provincial fishery and wildlife management agencies, recently produced a text on the subject of instream flows (Annear et al. 2002). The document 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. The outline of this report is patterned after the eight components. Legal and institutional issues are discussed. Public involvement occurs by virtue of the instream flow application process wherein a public information meeting and a public hearing are held to solicit input on proposed instream flow water right filings. 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 and diversion in the Pickett 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 early 2003, the WGFD has submitted 84 instream flow water right applications, of which the state engineer has approved 26 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 shifted toward small headwater streams supporting native cutthroat trout. From 1998 through 2001, studies were conducted on eight Greybull River tributary stream segments, including two on Pickett 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.

This perspective on 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" 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 intent behind the instream flow statute. Therefore, until the institutional climate and interpretation of state water law changes, channel maintenance flow recommendations will not be included on instream flow applications. Channel maintenance flow requirements are developed within 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) and Dufek et al. (1999). 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. 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.

The Yellowstone cutthroat trout was petitioned for listing under the Endangered Species Act in 1998. In February 2001 the Fish and Wildlife Service completed a 90-day petition review finding that listing is not warranted at this time. 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 base flow conditions against unknown and unforeseeable future 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 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 Pickett 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.

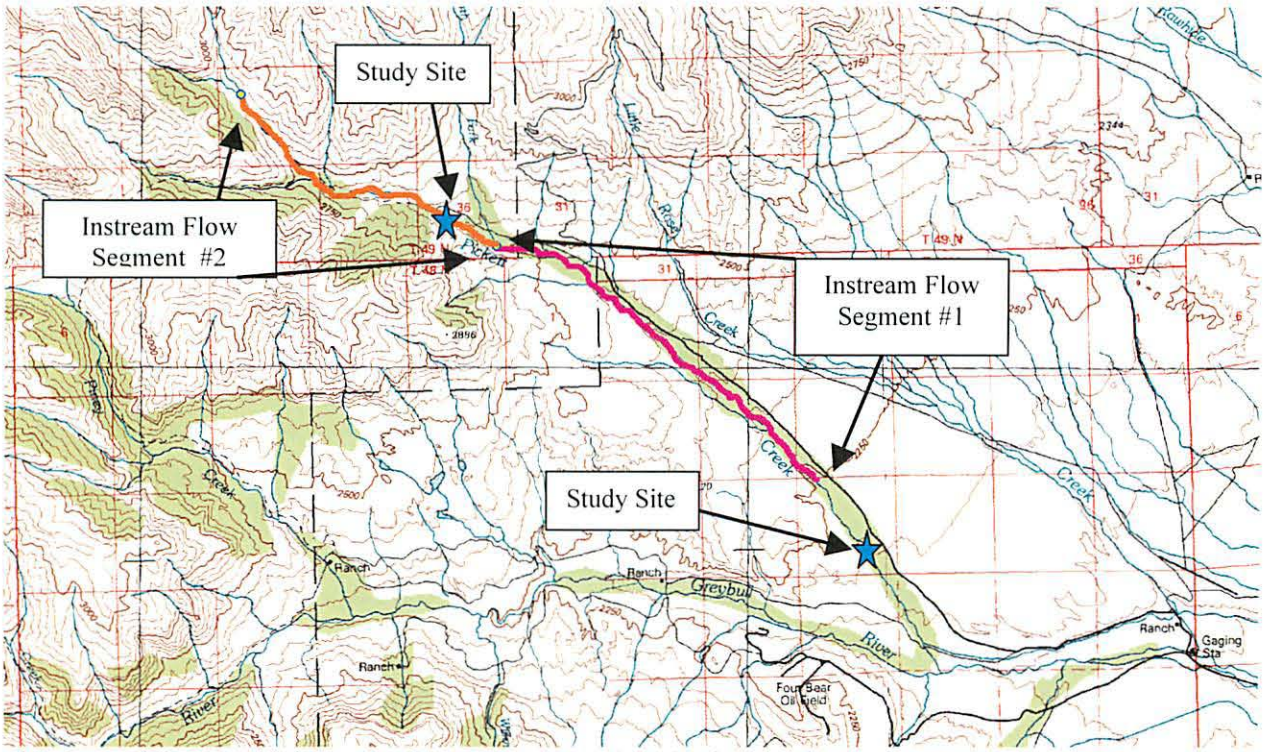

Figure 1. Pickett Creek instream flow segments and study site locations.

Snowfall on Carter Mountain at elevations up to and over 11,000 feet melts to form the upper reaches of Pickett Creek. The stream flows roughly southeast for approximately 13.5 miles before reaching the Greybull River (Figure 1). Passage barriers (Kruse 1995) and low quality adult fish habitat limit upstream fish distribution in Pickett Creek to a point in the northwest quarter of Section 27, T49N, R104W where two tributaries combine. A stream segment approximately 4 miles long from this point downstream to the confluence with North Fork Pickett Creek (SE1/4 Section 36, T49N, R104W) is hydrologically and morphologically relatively uniform and was defined as instream flow segment number 2 (Figure 1). Land ownership along the segment is mostly Shoshone National Forest with a state section at the downstream end.

The additional flow provided by North Fork Pickett Creek and different habitat characteristics in Pickett Creek downstream from the North Fork Pickett Creek confluence necessitate recognizing a separate instream flow segment. A downstream instream flow segment approximately 5 miles long was designated instream flow segment number 1 and was defined with a lower boundary where the stream crosses between State land sections 9 and 16 in the NW1/4 of Section 16, Township 48N, Range 103W and an upper boundary at the confluence with North Fork Pickett Creek (figure 1). The downstream boundary is about 2.8 miles upstream from the confluence of Pickett Creek with the Greybull River and about 0.2 miles upstream from a Pitchfork Ranch irrigation diversion. Although a longer segment extending an additional 3 miles (approximately) to the Greybull River would protect important stream habitat, the segment's lower end was defined to avoid interference with an active diversion ditch and to assure that WWDC's feasibility assessment would be based on the full volume of virgin flow. Land ownership along the instream flow segment is primarily state with a small section of Shoshone National Forest and a small deeded parcel near the upstream end of the segment.

Channel gradient in the lower segment ranges from 2% to 3% measured with a clinometer and from measuring stream distance with All Topo© between 5-40' contour intervals at 1:24,000. Channel type under Rosgen and Silvey (1998) conforms to a "B3" rating reflecting a moderately high slope and predominant cobble-boulder substrate. The channel in the upstream segment (upstream of North Fork Pickett Creek) was rated "A3" because the channel gradient is higher (4.5% from AllTopo©).

Pickett Creek's riparian zone is marked by a narrow green band of cottonwood and willow in the lower segment (Figure 2). In the upper segment, cottonwood are replaced by coniferous trees and willow becomes locally abundant (Figure 3). Cattle grazing, oil and gas extraction, horse packing, and historic mining activity are the main land uses in the Pickett Creek basin.

Figure 2. Lower Pickett Creek study site July 8, 1999 at 36 cfs. Tape crosses stream at transect 1.

Stream channel, riparian, and upland features along Pickett Creek were documented using the Wyoming Habitat Assessment Methodology (WHAM). This method is in development by the Wyoming Game and Fish Department and will serve to inventory natural resources and identify basins for which habitat enhancement or improvement options may be feasible. Data are contained in an ACCESS database on the internal WGFD network and describe general features like channel width, gradient, relative abundance of aquatic vegetation, percentages of riparian vegetation types, upland soil condition, etc. Although important for documenting resources and initially delineating the instream flow segments, these data do not further inform the process of identifying instream flow levels and will not be referenced further in this report

The lower instream flow segment was studied with a 595-foot-long study site located on State land in Section 16, T48N, R104W. 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. Additional days when flow measurements (but no additional instream flow data) were collected are listed in Appendix 1.

Table 1. Dates and discharge levels for Pickett Creek instream flow studies. Additional flow measurements are listed in Appendix 1.

Date	Discharge (cfs)
Lower Segment	
July 8, 1999	36
July 28, 1999	15
September 16, 1999	5.2
Upper Segment	
June 17, 1999	74
June 22, 1999	83
July 7, 1999	27-35
July 28, 1999	11
September 15, 1999	4.3
November 22, 2002	0.52

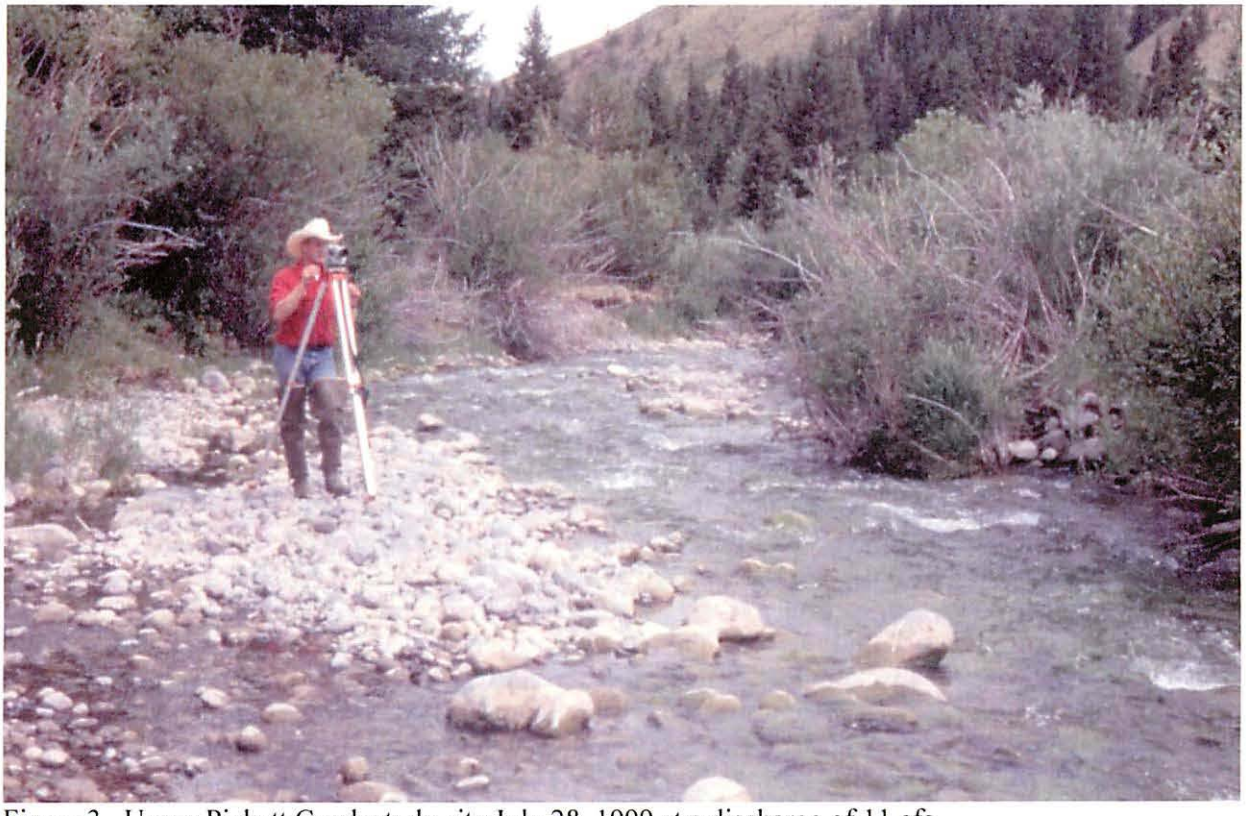

Figure 3. Upper Pickett Creek study site July 28, 1999 at a discharge of 11 cfs.

A study site on National Forest approximately 300 yards upstream of the confluence with North Fork Pickett Creek was selected to represent habitat conditions in the upper instream flow segment (Figure 3). The study site selected contained a diversity of habitat types including pools, spawning riffles, a backwater fry-rearing habitat, and runs. The study site was also near the downstream end of the instream flow segment so that flow recommendations developed for this site are likely to maintain habitat throughout the segment.

Hydrology

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

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 Pickett 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 Pickett 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 1.1 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. This approach was used at the lower Pickett Creek study site. 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. This approach was used at the upper Pickett Creek site.

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 1 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). Pickett 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 Applications at the Downstream Study Site

Physical Habitat Simulation

Three "stand-alone" transects were placed across separate riffles to model spawning habitat. The transects were calibrated separately using the stage-discharge approach for defining water surface elevations. The velocity set collected at 36 cfs served as the calibration velocity set for distributing roughness among the cells. Physical habitat was simulated over the range 5 cfs to 95 cfs based on calibration criteria in Milhous et al. (1984). Increments of 1.0 cfs were simulated over the range 10-20 cfs and increments of 5.0 cfs were used to simulate from 20 to 95 cfs. The HABTAE submodel was used to generate weighted useable area (WUA) for each of transect. The WUA values from each of the transects were averaged across each increment of simulated discharge to depict an index of average spawning habitat. The peak of this index was used to set instream flow recommendations for the spawning life stage of YSC.

Habitat Retention

The 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). The bankfull wetted perimeter across the three transects used in the Habitat Retention method was simulated using an estimated bankfull discharge of 204 cfs (HabiTech 2001). The 204 cfs identified by HabiTech (2001) is the 1.5 year flood flow, often recognized as the bankfull flow in alluvial streams (Dunne and Leopold 1978).

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 20 cfs

(HabiTech 2001) and at this flow average wetted width is about 22 feet. Therefore the depth criterion for applying the Habitat Retention method at this site is 0.22 feet.

Habitat Quality Index

Average daily flow (ADF; 20 cfs) and peak flow (204 cfs) estimates for determining critical period stream flow and annual stream flow variation are from HabiTech (2001). Maximum water temperature was determined with a Ryan temperature recorder set to monitor water temperature at 1-hour intervals between July 29 and September 16, 1999. Nitrate levels were determined from a water sample collected September 16, 1999 and analyzed by the Analytical Services section of the Wyoming Department of Agriculture, Laramie, Wyoming. Collecting three Surber samples and counting invertebrate numbers streamside in each of the samples rated the "substrate" attribute, which is the HQI term for number of invertebrates per square foot of substrate.

Rather than perform the HQI simulation holding the cover rating constant at "0" when cover is less than 10% at all flow levels, cover was treated as a continuous variable. The lowest percent cover was set to a rating of "1" and higher percentages of cover then resulted in ratings up to 1.46 so that the relative change in cover that was measured at different flow levels was reflected in the HQI simulation.

Instream Flow Model Applications at the Upstream Study Site

Physical Habitat Simulation

A series of nine transects were established in three distinct groups to model the range of habitat available at this site. Near the downstream end of the study site, three transects placed across a fast run with pocket pools comprised the first group. The second group was a single transect (transect 4) across a hydraulic control on a riffle with spawning habitat. This transect was about 200 feet upstream from the first group of transects. The third group of 5 transects (transects 5 through 9) were further upstream and modeled spawning habitat on an extensive gravel bar, a backwater fry-rearing area, and pockets of adult and juvenile habitat. The entire reach from transect 1 to transect 9 spanned a stream length of over 300 feet and comprised the HQI station described below.

The stage-discharge approach for defining water surface elevations was used for all transects. The velocity set collected at 27 cfs served as the calibration velocity set for distributing roughness among the cells for nearly all the transects and simulated flow levels. Velocities collected at 35 cfs were used for calibration of roughness for transects 7-9. Habitat was simulated over the range 2 cfs to 84 cfs based on calibration criteria in Milhous et al. (1984). Increments of 1.0 cfs were simulated over the range 2-20 cfs and increments of 5.0 cfs were used to simulate from 20 to 85 cfs. The HABTAE submodel was used to generate weighted useable area (WUA) for each of transect or group of transects.

Spawning WUA was simulated separately for the first transect in each group (transect 1, 4, and 5). Average spawning WUA over the range of simulated flows was also calculated. Unlike the approach used at the lower site, the peak in the average spawning curve was not the basis for a flow recommendation. Rather, a flow was selected to maintain spawning opportunity on all three transects (see RESULTS for a detailed discussion). Habitat for fry, juvenile, and adults was also simulated with PHABSIM for each of the three groups of transects. This information informed the decision making process in developing all of the flow recommendations.

Habitat Retention

Transect numbers 1, 4, and 5 were the hydraulic control riffle transects used in the Habitat Retention approach. The wetted perimeter criterion applied was 50% of the wetted perimeter that occurs on each transect at bankfull flow (89 cfs from HabiTech (2001)). The depth criterion that was applied was the default 0.20 feet average depth for streams with an average width less than 20 feet under average daily flow conditions (8.9 cfs from HabiTech 2001)).

Habitat Quality Index

Average daily flow (8.9 cfs) and peak flow (89 cfs) estimates for determining critical period stream flow and annual stream flow variation are from HabiTech (2001). Maximum water temperature was determined with a Ryan temperature recorder set to monitor water temperature at 1-hour intervals between July 28 and September 16, 1999. Nitrate levels were determined from a water sample collected September 16, 1999 and analyzed by the Analytical Services section of the Wyoming Department of Agriculture, Laramie, Wyoming. Invertebrate numbers for rating substrate were counted streamside in three Surber samples in September.

The HQI datasheets for all but the June 17th visit were lost. Because some HQI data were recorded in a separate field book, enough data were assembled to perform a HQI analysis. The biggest effect of the data loss was an inability to estimate cover percentage as a function of flow. To avoid bias, the cover rating was held constant at "1" as a function of flow. The cover measured on June 17th was very low at 1.3% due to high velocities. Cover was certainly higher at lower flows but we cannot define the exact relationship without collecting additional data. Our experience at the lower site and other small mountain streams like Pickett Creek suggests that cover, even at its highest, would not likely have climbed higher than 10%. Therefore, the effect of holding cover constant in this case is likely minimal.

Velocity data from measurements of dye travel were available for four visits and could be generated for the other two visits by using average velocity data on the PHABSIM transects. The average velocity on the nine transects was converted to dye velocity by using the equation:

dye velocity = (average velocity – 0.13) / 0.64 from Wesche et al. (1983).

Dye velocities were calculated using this equation for all dates, including those dates when dye velocity was measured. Velocities calculated by the Wesche equation averaged 0.25 ft/s low (range 0.21 to 0.29 ft/s) compared to actual measurements so 0.25 ft/s was added to the estimated velocities for the two dates when dye velocities were not measured. Linear equations between adjacent discharge/velocity pairs were then used to calculate the discharges at which HQI velocity ratings change.

Wetted width was calculated from PHABSIM for each of the nine transects on the four dates that PHABSIM data were collected. Width calculated in this manner was within 4.1% of the average width from ten random measurements of stream width collected on June 17th. Linear equations between adjacent discharge/width pairs were then used to calculate the discharges at which HQI width ratings change.

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 4) 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).

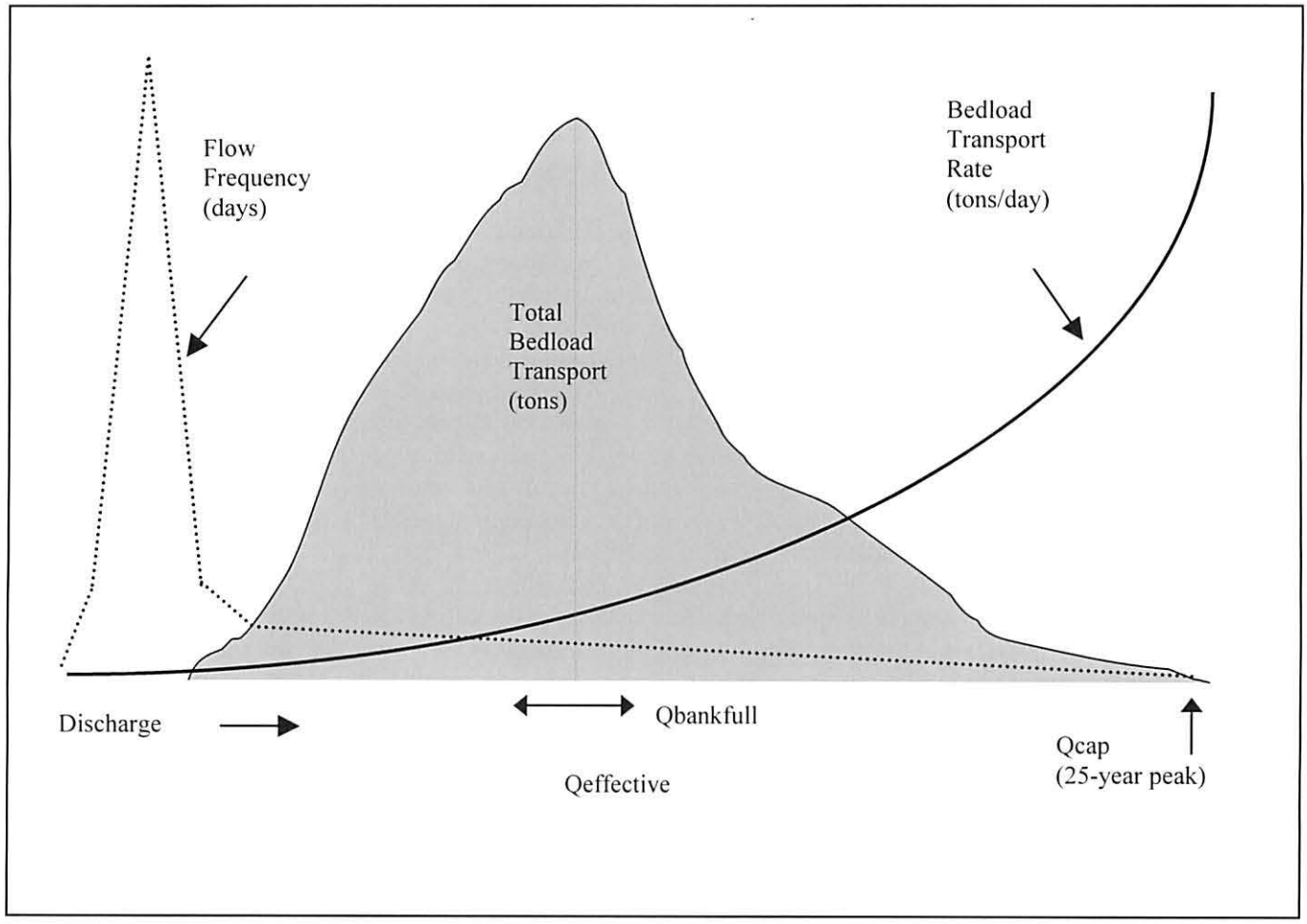

Figure 4. A general model of long-term total bedload transport as a function of flow frequency and bedload transport rate (from USFS 1997).

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

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

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 5). 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.

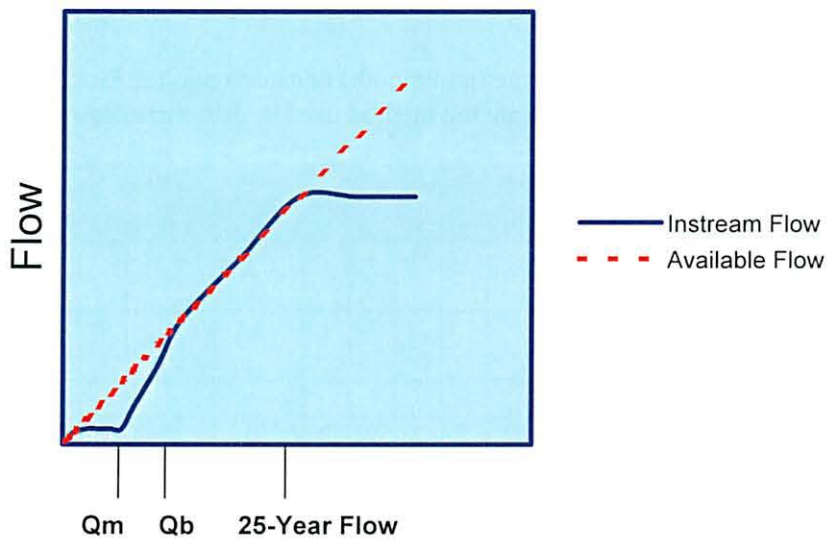

Figure 5. General function of a dynamic hydrograph instream flow for fishery maintenance. Q_m is substrate mobilization flow and Q_b is bankfull flow.

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 5). 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.

Seasonal Application of Methods

Maintaining adequate, continuous flow at all times of year is critically important to maintaining the population integrity of all trout life stages, to maintaining connectivity among habitats throughout a drainage, and to maintaining 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 and Jack Creeks reflected these data and were applied to the period May 1 through June 30 (e.g. Dey and Annear 2001b). During data collection for this study, a spawning trout was observed July 7th within 10 feet of transect 4 in the upper segment 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 Pickett Creek #2 will ensure that adequate spawning water is protected when it is needed.

Table 3. Yellowstone cutthroat trout life stages and months considered in the Pickett 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 – *segment 1*					1	1							
Spawning habitat – *segment 2*					1	1	1						
Both Segments													
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

Downstream Segment

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, Pickett Creek bankfull discharge at the downstream end of the lower segment (#1) is 204 cfs (Table 4). Average daily flow was estimated at 20 cfs (HabiTech 2001). Estimated monthly flow levels are listed in Appendix 3.

Table 4. Estimated flood frequency series for two Pickett Creek instream flow segments (HabiTech 2001).

Return Period (years)	Lower Segment Estimated Flow (cfs)	Upper Segment Estimated Flow (cfs)
1.01	91	40
1.05	112	49
1.11	128	56
1.25	152	67
1.5	204*	89*
2	227	99
5	367	161
10	486	213
25	675	295

* Bankfull discharge.

Upstream Segment

Under a return interval of 1.5 years, bankfull discharge at the upper segment was estimated at 89 cfs (Table 4). Average daily flow was estimated at 8.9 cfs (HabiTech 2001). Estimated monthly flow levels are listed in Appendix 4.

Fish Flow Models

Downstream Segment

Physical Habitat Simulation

Peak spawning habitat, averaged across three transects, occurred at 19 cfs (Figure 6). Spawning habitat declines rapidly when flow levels drop below 13 cfs and less rapidly as flows increase up to 30 cfs. Shallow depths limit spawning habitat at low flows while high velocities limit spawning habitat at high flow levels.

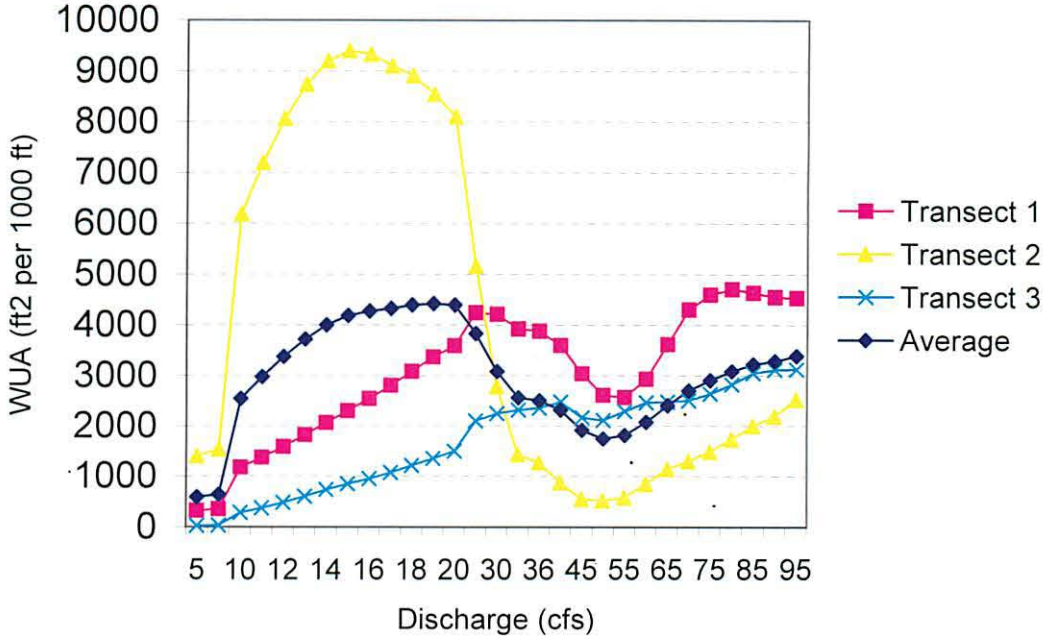

Figure 6. Yellowstone cutthroat trout spawning habitat (square feet per 1000 feet of stream).

Based on simulated spawning habitat (Figure 6), an instream flow of 19 cfs is recommended for the May through June season to maintain YSC spawning habitat. Though the full 19 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.

Habitat Retention

All three riffles displayed similar hydraulic patterns as a function of simulated flow (Table 5). As flow decreases, wetted perimeter decreases to 50% of its bankfull value. Next, as flow continues to decline, average velocity across the transects declines to 1.0 foot per second meeting the second hydraulic criteria. At very low flow levels, lower than could be simulated on two of the riffles, average depth declines to 0.22. For riffle 1, two of three hydraulic criteria (depth and velocity) are met at a flow of 8.6 cfs (Table 6). For riffle 2, a flow of 6.8 cfs satisfies two of three criteria and for riffle 3 a discharge of 8.4 cfs meets two of three hydraulic criteria. Therefore, a discharge of 8.6 cfs meets two out of three criteria for all riffles in the study site. Based on the Habitat Retention model, a flow of 8.6 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 lower Pickett Creek riffles. Bold indicates that the hydraulic criterion was met. Flows meeting 2 of 3 criteria for each riffle are shaded.

	Mean Depth (ft)	Mean Velocity (ft/s)	Wetted Perimeter (ft)	Discharge (cfs)
Riffle 1 – transect 1	0.89	5.93	39.4	204 (bankfull)
	0.66	2.67	28.9	50
	0.61	2.36	28.3	40
	0.55	1.82	25.7	25
	0.49	1.16	**19.9**	11
	0.49	**1.00**	18.3	8.6[a]
	0.48	0.99	18.3	8.5
	0.41	0.72	17.7	5.0
	<0.30	<0.42	<16.5	<2.0
Riffle 2 – transect 2	0.87	5.01	48.7	204 (bankfull)
	0.57	2.83	32.1	50
	0.63	2.54	26.3	40
	0.52	1.90	**24.4**	23
	0.40	1.29	22.1	11
	0.37	1.16	20.9	9.0
	0.34	1.01	21.1	7.0
	0.34	**1.00**	21.0	6.8
	0.22	0.51	18.4	2.0
Riffle 3 – transect 3	0.69	4.27	69.8	204 (bankfull)
	0.43	2.77	42.5	50
	0.46	2.57	**35.0**	41
	0.57	1.96	22.5	25
	0.46	1.11	19.7	10
	0.44	1.00	19.3	8.5
	0.44	**1.00**	19.3	8.4
	0.42	0.89	19.0	7.0
	<0.31	<0.39	<16.8	2.0

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

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 73° F was recorded August 26, 1999 at 1600. This temperature falls in the 71 - 75° F band for a rating of "2" under Binns (1982) and reflects 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 49%, rated a "2". The average of three Surber samples was 118 invertebrates per square foot for a rating of "2".

Percent cover was measured at 6.6%, 7.0%, and 4.8% at 5.2, 15 and 36 cfs, respectively. All these cover percentages are rated a "0" under the HQI scheme which requires at least 10% cover to rate a "1". Rather than perform the HQI simulation holding the cover rating constant at "0", cover was treated as a continuous variable between the measured values and the lowest percent cover at 36 cfs (4.8%) was set to a "1". The 7.0% cover at 15 cfs then gained a rating of 1.46, or 46% higher than at 36 cfs. Cover ratings under this approach did not vary greatly (from 0.88 at 0.1 cfs, to 1.46 at 15 cfs, to 0.89 at 41 cfs) but reflected the relative change in cover that was measured at different flow levels.

Peak habitat units occur between 11.2 and 15.0 cfs (Figure 7). Water velocity was a key attribute with optimal mean channel velocities occurring from 7.3 to 20 cfs. The critical period stream flow attribute was also influential with optimal values for this attribute occurring at flows greater than or equal to 11.2 cfs. The width attribute rating declines at flows greater than 15 cfs. Peak habitat units occur between 11.2 and 15 mainly due to the maximization of these three attributes. At flow levels less than 11.2 cfs, the "CPSF" attribute declines to a lower rating. The small increase in habitat units up to 15 cfs results from minor additional cover provided by higher flows.

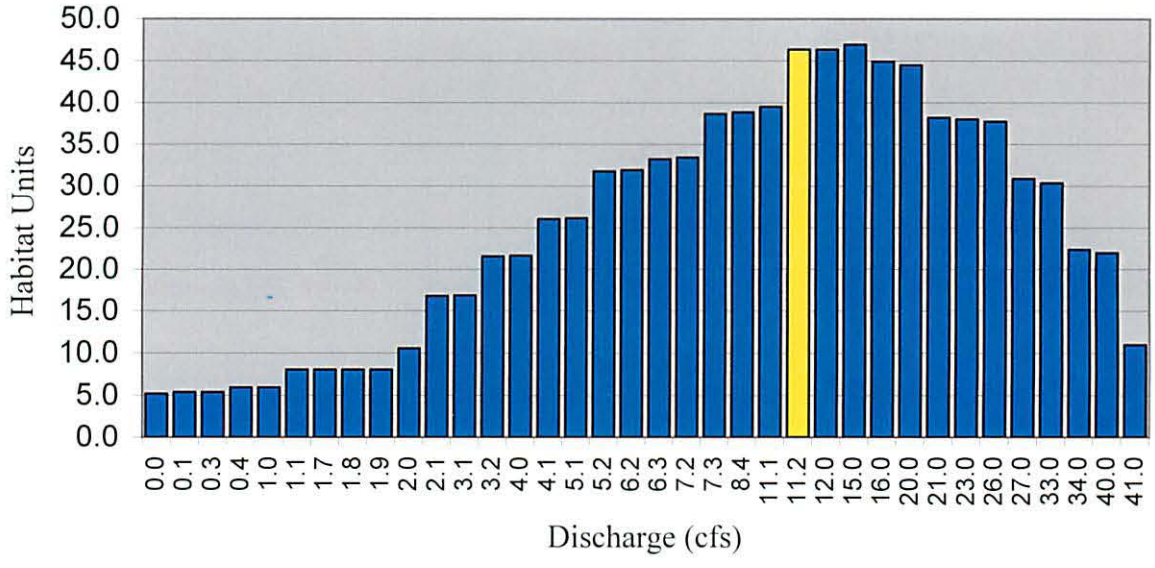

Figure 7. Habitat Quality Index at the lower Pickett Creek study site for a range of flow levels. X-axis flows are scaled to show where changes in Habitat Units occur. The recommended flow is indicated by the light shaded bar.

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. Flow monitoring during the late summer period documented flows ranging from 4.3 cfs to 36 cfs (Appendix 1). Estimated monthly streamflows that occur 50% of the time are 47 cfs, 16 cfs, and 9.8 cfs for July, August and September, respectively (Appendix 3, HabiTech 2001). The estimated August value of 16 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 45 habitat units under existing conditions (Figure 7). The lowest flow that will maintain 45 habitat units is 11.2 cfs

(which actually maintains 47 habitat units). The instream flow recommendation to maintain adult Yellowstone cutthroat trout habitat during the late summer period is 11.2 cfs.

Upstream Segment

Physical Habitat Simulation

Identifying a single flow level that will maintain Yellowstone Cutthroat trout spawning habitat and, by extension, YSC populations is a challenge. The challenge stems from both biology and sampling theory. Biologically, trout spawning occurs over a range of flow levels as individual trout select those stream channel sites with appropriate gravel sizes and flow characteristics during the May through June snowmelt runoff period when water temperatures cue spawning behavior. The spawning process of nest building, deposition and fertilization of eggs, and covering of the nest with fine gravel may occur over a time period of less than a day to several days for an individual pair of fish. The fish population as a whole spawns over a broader time period partly due to ripening variability and sensitivity to environmental cues. During these broad time periods when spawning occurs, flow levels are fluctuating on a diel basis as well as ascending toward or descending from a spring peak. In order for streams like Pickett Creek to maintain wild cutthroat trout populations that are persistent from year to year, it follows that Yellowstone Cutthroat trout must be relatively flexible in their ability to find adequate spawning habitat within and among years. Trout must move upstream or downstream to seek appropriate spawning habitat depending on flow conditions. These movements may be as short as tens of feet to the next riffle or gravel bar or they may move several miles.

The described plastic nature of spawning might lead some to the conclusion that any spring flow regime is sufficient because trout will always move around and find someplace to spawn. We believe this to be an incorrect conclusion because it ignores the population perspective in which it is understood that long-term trout population persistence depends on the periodic availability of excess habitat in addition to time periods when habitat quality and quantity is sparse. While some trout may find spawning habitat during a drought year, for example, it is unlikely that the level of recruitment from that spawning will carry the entire population over the long-term. Alternatively, trout that recruit during some years may carry the population through years in which little spawning habitat is available.

Because we sample spawning and other habitats by using transects rather than measuring everything in the entire segment, we can only approximate the general relationship between flow and area of the streambed suitable for spawning. Since our representation of the "true" segment-wide relationship is strongly dependent on the particular transects selected, it is conservative from a fish conservation perspective to select a flow that provides the greatest area for spawning among our limited set of transects. Hence, we commonly average output from three transects and recommend the flow that provides the peak level of spawning habitat. This approach was used on the lower Pickett Creek study.

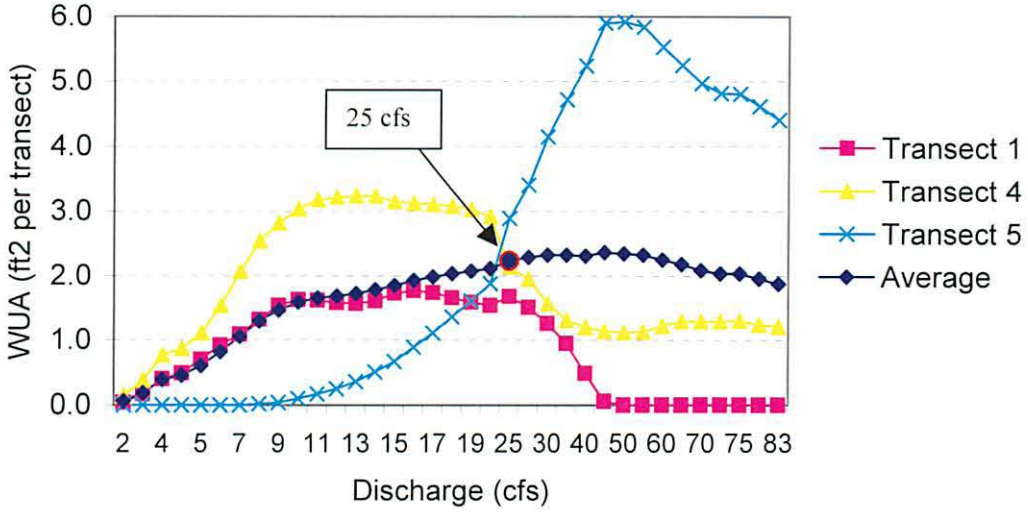

Figure 8. Yellowstone cutthroat trout spawning habitat on three transects at the upper Pickett Creek study site.

The three transects modeled in the upper Pickett Creek study provided an opportunity to apply a different approach. Here, our spawning flow recommendation is 25 cfs. The peak of the average curve occurs at a flow of 45 cfs (Figure 8). However, a 45 cfs flow would leave relatively little spawning habitat on two out of the three modeled transects. Spawning habitat on transects 1 and 4 decreases at flows higher than 25 cfs while it increases on transect 5. The high peak on transect 5 is driving the average. A slightly lower flow provides a greater diversity of spawning opportunity because more riffles are likely to have conditions conducive for spawning at 25 cfs than at 45 cfs.

By selecting 25 cfs instead of 45 cfs, the loss in average spawning habitat is minimal – average spawning habitat at 25 cfs is 94% of that which occurs at 45 cfs. A flow lower than 25 cfs, although conducive for spawning on two out of three transects all the way down to 10 cfs, is coincident with a dramatic decline in spawning habitat on transect 5 and therefore would be less likely to maintain spawning opportunity throughout the stream segment. Fry habitat quantity also continues to decline at lower flows so fry produced at lower flow levels like 10 cfs would find substantially fewer locations with the shallow depths and slow water velocities necessary for survival (Figure 9). Therefore, 25 cfs was identified as the minimum flow needed to maintain spawning habitat.

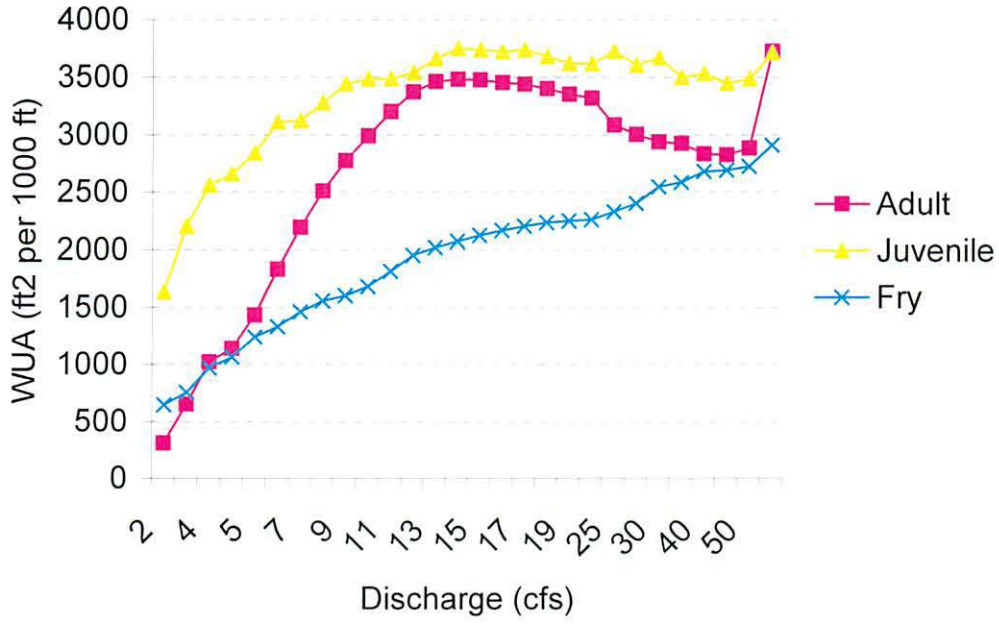

Figure 9. Cutthroat trout adult, juvenile and fry habitat (ft^2/1000 feet) averaged across two groups of transects at the upper Pickett Creek study site.

Habitat Retention

Riffles 1 and 3 displayed similar hydraulic patterns as a function of simulated flow and met two of three hydraulic criteria at discharges of 4.0 and 4.4 cfs, respectively (Table 6). Riffle 2, modeled with transect number 4, was quite flat in profile so flow could decrease to a very low value (<1.7 cfs) before depth and wetted perimeter decreased to critical levels. Therefore, a discharge of 4.4 cfs is required to meet two out of three criteria for all riffles examined in the study site. Based on the Habitat Retention model, a flow of 4.4 cfs is recommended to maintain trout survival over the fall and winter season (October 1 to April 30).

Table 6. Simulated hydraulic criteria for three upper Pickett Creek riffles. Bold indicates that the hydraulic criterion was met. Flows meeting 2 of 3 criteria for each riffle are shaded.

	Mean Depth (ft)	Mean Velocity (ft/s)	Wetted Perimeter (ft)	Discharge (cfs)
Riffle 1 – transect 1	1.06	3.53	25.3	89 (Bankfull)
	0.69	2.22	18.7	27
	0.51	1.63	15.8	12
	0.45	1.37	13.9	8.0
	0.45	1.26	**12.5**	6.6
	0.40	1.11	12.1	5.0
	0.37	**1.00**	11.8	4.0
	0.28	0.71	10.2	2.0
	<0.28	<0.66	<10.0	<1.7
Riffle 2 – transect 4	0.99	3.82	24.6	89 (Bankfull)
	0.69	1.91	21.6	27
	0.52	1.21	20.0	12
	0.45	**1.00**	19.5	8.3
	0.43	0.91	18.9	7.0
	0.37	0.77	18.4	5.0
	0.33	0.69	18.2	4.0
	0.24	0.51	16.9	2.0
	<0.22	<0.47	**<16.7**	<1.7
Riffle 3 – transect 5	0.81	3.27	35.4	89 (Bankfull)
	0.47	1.99	30.4	27
	0.37	1.52	22.3	12
	0.40	1.38	**17.9**	9.3
	0.39	1.22	15.5	7.0
	0.35	1.05	14.3	5.0
	0.34	**1.00**	13.8	4.4[a]
	0.31	0.71	9.7	2.0
	<0.31	<0.66	<8.9	<1.7

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

Habitat Quality Index

In performing the HQI simulation of Habitat Units over a range of discharges, the following attributes are held constant as a function of discharge: temperature, nitrate concentration, invertebrate numbers, and eroding banks. A maximum water temperature of 64° F was recorded August 18, 1999 at 1600. This temperature falls in the optimal 55 - 65° F band for a rating of "4" under Binns (1982). 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 less than 10%, rated a "4". The average of three Surber samples was 75 invertebrates per square foot for a rating of "1".

As described in the "Methods" section, the cover attribute rating was held constant at "1". Average channel velocities rated highest (4) between 4.2 and 14.2 cfs. Wetted channel width rated highest (4) between flows of 9.6 and 21.9 cfs. The critical period stream flow attribute achieves it highest rating at flows of 5.0 cfs or higher. Finally, the annual stream flow variability rating achieves its peak of

"2" at a flow of 1.0 cfs. Calculated habitat units under the HQI model achieved a maximum between flows of 9.6 and 14 cfs (Figure 10) and the wetted width attribute was responsible for the increase in habitat units at 9.6 cfs.

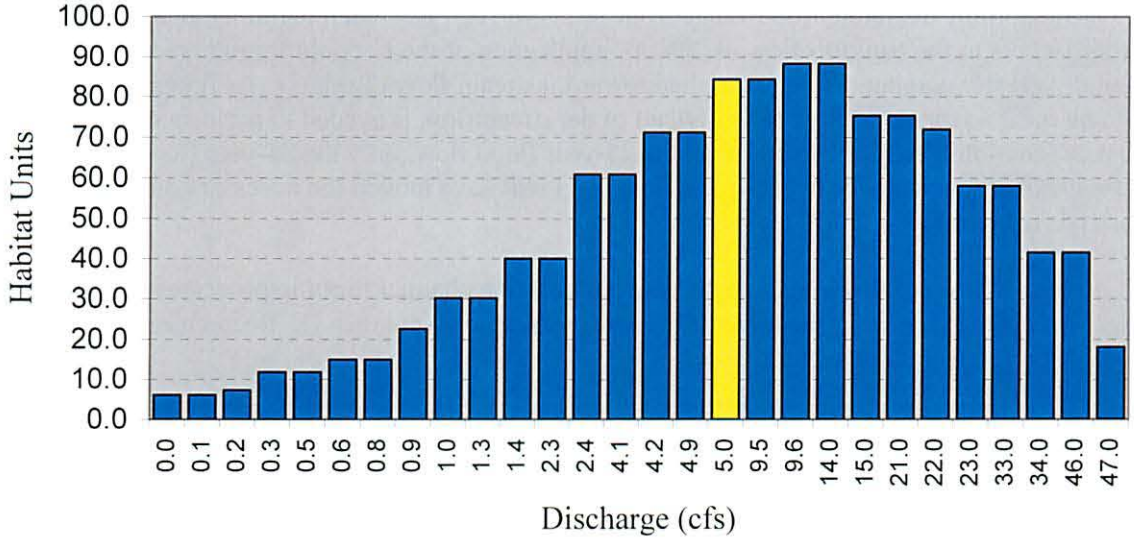

Figure 10. Habitat Quality Index at the upper Pickett Creek study site for a range of flow levels. X-axis flows are scaled to show where changes in Habitat Units occur. The recommended flow is indicated by the lightly shaded bar.

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 3.7 cfs to 29 cfs (Appendix 1). Estimated monthly streamflows that occur 50% of the time are: 21cfs, 7.0 cfs, and 4.3 cfs for July, August and September, respectively (Appendix 4, HabiTech 2001). Lacking an estimate for the entire period, the estimated August value of 7.0 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 84 habitat units under existing conditions (Figure 10). The lowest flow that will maintain 84 habitat units is 5.0 cfs. Therefore, the instream flow recommendation for the late-summer period of July through September is 5.0 cfs.

Channel Maintenance Flows

Like all properly functioning rivers, the Pickett 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 for the lower and upper segments in Tables 7 and 8, respectively. The base or fish flow used in the analysis was the 19 cfs and 25 cfs identified for maintaining spawning habitat in the lower and upper segments, respectively. In the lower segment (number 1), the channel maintenance instream flow recommendation is 19 cfs for periods when naturally available flows range from 19 cfs to 102 cfs. When naturally available flows range from 102 cfs to the bankfull flow of 204 cfs, application of the Leopold formula results in incrementally greater amounts of water applied toward instream flow (Table 7). At flows between bankfull and the 25-year flood flow (675 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 5).

Table 7. Instream flow recommendations to maintain existing channel forming processes and long-term aquatic habitat characteristics in the lower instream flow segment (number 1). Recommendations apply to the run-off period from May 1 through July 15th.

Description	Available Flow (cfs)	Instream Flow (cfs)
	< 19	Equal to available flow
Spawning Flow	19	19
	19-101	19
Substrate Mobilization Flow	102	19
	102 – 127	72
	128 – 153	114
	154 – 179	145
	180 – 203	176
Bankfull	204	204
	204 – 674	Equal to available flow
25-Year Flood	675	675
	All flows > 675	675

In segment 2, the channel maintenance instream flow recommendation is 25 cfs for periods when naturally available flows range from 25 cfs to 45 cfs (Table 8). From 45 cfs to the bankfull flow of 89 cfs, the Leopold equation apportions incrementally greater amounts of water for channel maintenance (Table 8). At flows between bankfull and the 25-year flood flow (295 cfs), all streamflow 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 5).

Table 8. Instream flow recommendations to maintain existing channel forming processes and long-term aquatic habitat characteristics in the upper instream flow segment (#2). Recommendations apply to the run-off period from May 1 through July 15th.

Description	Available Flow (cfs)	Instream Flow (cfs)
	< 25	Equal to available flow
Spawning Flow	25	25
	25 - 44	25
Substrate Mobilization Flow	45	25
	46 – 56	39
	57 – 67	53
	68 – 78	65
	79 – 88	77
Bankfull	89	89
	89 - 294	Equal to available flow
25-Year Flood	295	295
	All flows > 295	295

INSTREAM FLOW RECOMMENDATIONS

Based on the analyses and results outlined above, the instream flow recommendations in Table 9 will maintain the short-term habitat requirements for Yellowstone cutthroat trout in each of two Pickett Creek segments. Long-term channel maintenance flows to preserve the ecological functions that support the fishery are listed in Tables in 7 and 8. Flow recommendations apply to two segments defined as follows:

Segment 1 - the lower of the two segments, this segment is about 5 miles in length and is defined at the downstream end where the stream crosses between State land sections 9 and 16 in the NW1/4 of Section 16, Township 48N, Range 103W and has an upper boundary at the confluence with North Fork Pickett Creek (SE1/4 Section 36, T49N, R104W). UTM coordinates (NAD27) for the lower and upper boundaries of segment 1are 641018 E, 4888231N, Z 12 and 635790 E, 4892011 N, Z 12, respectively. The downstream boundary is about 2.8 miles upstream from the confluence of Pickett Creek with the Greybull River and about 0.2 miles upstream from a Pitchfork Ranch irrigation diversion.

Segment 2 – the upper of the two segments, extends from the North Fork Pickett Creek confluence (SE1/4 Section 36, T49N, R104W) upstream approximately 4 miles to the confluence of two tributaries (NW1/4 Section 27, T49N, R104W). UTM coordinates (NAD27) for the lower and upper boundaries of segment 2 are 635790 E, 4892011 N, Z 12 and 631602 E, 4894487 N, Z 12, 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 two Pickett Creek segments.

Time Period	Segment #1 (lower) Instream Flow Recommendation (cfs)	Segment #2 (upper) Instream Flow Recommendation (cfs)
October 1 to April 30	8.6	4.4
May 1 to June 30*	19	na
May 1 to July 15*	na	25
July 1 to September 30	11.2	na
July 16 to September 30	na	5.0

* Channel maintenance flow recommendations for the spring runoff period are defined in Tables 7 and 8.

LITERATURE CITED

Andrews, E. D. 1984. Bed-material entrainment and hydraulic geometry of gravel-bed rivers in Colorado. Geological Society of America Bulletin, 95:371-378.

Annear, T.C. and A.L. Conder. 1984. Relative bias of several fisheries instream flow methods. North American Journal of Fisheries Management 4:531-539.

Annear, T.C. and P. D. Dey. 2001. Instream Flow Program Five-Year Plan (2001-2005). Wyoming Game and Fish Department Administrative Report.

Annear, T., I. Chisholm, H. Beecher, A. Locke and 12 other authors. 2002. Instream flows for riverine resource stewardship. Published by the Instream Flow Council, Cheyenne, WY.

Behnke, R. J. 1992. Native trout of western North America. American Fisheries Society Monograph 6, Bethesda, Maryland.

Binns, N.A. 1982. Habitat Quality Index Procedures Manual. WDFG Publication

Binns, N.A. and F. Eiserman. 1979. Quantification of fluvial trout habitat in Wyoming. Transactions of the American Fisheries Society 108:215-228.

Bohn, C. C. and J. G. King. 2001. Stream channel responses to streamflow diversion on small streams in Idaho. Stream Notes. Stream Systems Technology Center, U. S. Forest Service, Fort Collins, CO. pp 6-7.

Bovee, K. and R. Milhous. 1978. Hydraulic simulation in instream flow studies: theory and technique. Instream Flow Information Paper 5, FWS/OBS-78/33, Cooperative Instream Flow Service Group, U.S. Fish and Wildlife Service. Fort Collins, Colorado.

Bovee, K.D, B.L. Lamb, J.M. Bartholow, C.B. Stalnaker, J. Taylor, and J. Henriksen. 1998. Stream habitat analysis using the instream flow incremental methodology. U.S. Geological Survey, Biological Resources Division Information and Technology Report USGS/BRD-1998-0004. viii + 131 pp.

Bozek, M.A. and F.J. Rahel. 1992. Generality of microhabitat suitability models of young Colorado River cutthroat trout (*Oncorhynchus clarki pleuriticus*) across site and among years in Wyoming streams. Canadian Journal of Fisheries and Aquatic Science 49:552-564.

Carling, P. 1995. Implications of sediment transport for instream flow modeling of aquatic habitat. *In* The Ecological Basis for River Management, Edited by D.M. Harper and A.J.D. Ferguson. John Wiley and Sons, Ltd.

Conder, A.L. and T.C. Annear. 1987. Test of weighted usable area estimates derived from a PHABSIM model for instream flow studies on trout streams. North American Journal of Fisheries Management 7:339-350.

Dey, P.D. and T.C. Annear. 2001a. Inter-annual trout population dynamics among six Wyoming streams. Wyoming Game and Fish Administrative Report.

Dey, P.D. and T.C. Annear. 2001b. Instream flow studies on Francs Fork, a Greybull River tributary. Wyoming Game and Fish Administrative Report.

Dey, P.D. and T.C. Annear. 2003. Instream flow water right status and statewide flow monitoring results for water years 2002 and 2003. Wyoming Game and Fish Administrative Report.

Ditton, B. 1997. Choosing our words more carefully. Fisheries. American Fisheries Society, Bethesda, MD. Vol 22, No. 10.

Dufek, D., K. Johnson, J. Kiefling, R. McDowell, R. McKnight, S. Roth, and S. Yekel. 1999. Status and management of Yellowstone cutthroat trout *Oncorhynchus clarki bouvieri*. Wyoming Game and Fish Administrative Report.

Dunne, T. and L. B. Leopold. 1978. Water in Environmental Planning. W. H. Freeman, New York. 796p.

Emmett, W. W. 1975. The channels and waters of the upper Salmon River area, Idaho. U.S. Geological Survey, Professional Paper 870-A. 116 p.

Gordon, N. 1995. Summary of technical testimony in the Colorado Water Division 1 Trial. USDA Forest Service, General Technical Report RM-GTR-270. 140 p.

HabiTech, Inc. 2001. Flow duration and flood frequency analysis for selected streams in the Greybull River Basin, Wyoming. Prepared by HabiTech, Inc., Laramie, Wyoming.

Hill, M. T., W. S. Platts and R. L. Beschta. 1991. Ecological and geo-morphological concepts for instream and out-of-channel flow requirements. Rivers, Volume 2, Number 3, 198-210.

House, R. 1995. Temporal variation in abundance of an isolated population of cutthroat trout in western Oregon, 1981-1991. North American Journal of Fisheries Management 15:33-41.

Kruse, C.G. 1995. Genetic purity, habitat, and population characteristics of Yellowstone cutthroat trout in the Greybull River drainage, Wyoming. University of Wyoming, Masters thesis. Laramie, Wyoming.

Kruse, C.G., W.A. Hubert, and F.J. Rahel. 1997. Geomorphic influences on the distribution of Yellowstone cutthroat trout in the Absoroka Mountains, Wyoming. Transactions of the American Fisheries Society 126:418-427.

Kruse, C.G., W.A. Hubert, and F.J. Rahel. 2000. Status of Yellowstone cutthroat trout in Wyoming Waters. North American Journal of Fisheries Management 20:693-705.

Kuhnle, R. A., A. Simon, and R. L. Bingner. 1999. Dominant discharge of the incised channels of Goodwin Creek. Published in the Proceedings 1999 Water Resources Conference, American Society of Civil Engineers. Seattle, WA.

Lageson, D.R. and D.R. Spearing. 1988. Roadside Geology of Wyoming. Mountain Press Publishing Company, Missoula, Montana. 271 pp.

Leopold, L. B. 1994. A View of the River. Harvard University Press, Cambridge, MA, 298 p.

May, B.E. 1996. Yellowstone cutthroat trout. Chapter 2 *in* Conservation assessment for inland cutthroat trout status and distribution. Donald A. Duff, editor. U.S. Department of Agriculture, Forest Service, Intermountain Region, Ogden, Utah.

Milhous, R.T., D.L. Wegner, and T. Waddle. 1984. User's guide to the physical habitat simulation system. Instream Flow Paper 11, FWS/OBS-81/43, U.S. Fish and Wildlife Service, Fort Collins, Colorado.

Milhous, R.T., M.A. Updike, and D.M. Schneider. 1989. Physical habitat simulation system reference manual - version II. Instream Flow Information Paper No. 26. U.S. Fish and Wildlife Service, Biol. Rep. 89(16).

Nehring, R. 1979. Evaluation of instream flow methods and determination of water quantity needs for streams in the state of Colorado. Colorado Division of Wildlife, Fort Collins.

Nehring, B.R. and R.M. Anderson. 1993. Determination of population-limiting critical salmonid habitats in Colorado streams using the Physical Habitat Simulation System. Rivers 4:1-19.

Nielsen, L. A. 1993. History of Inland Fisheries Management in North America. *in* Inland fisheries management in North America. C. Kohler and W. Hubert editors. American Fisheries Society, Bethesda, Md. 594 pp.

Rosgen, D. 1996. Applied River Morphology. Wildland Hydrology, Pagosa Springs, CO.

Rosgen, D. and L. Silvey. 1998. Field guide for stream classification. Wildland Hydrology, Pagosa Springs, CO.

Ryan, S.E. 1996. Bedload transport patterns in coarse-grained channels under varying conditions of flow. In: Proceedings of the 6th Inter-agency sedimentation conference, Las Vegas, Nevada, March 10-14. p VI-22 to VI-27b.

Schmidt, L.D. and J.P. Potyondy. 2001. Flow regimes needed to maintain channels in gravel-bed rivers. Poster paper presented at Seventh Federal Interagency Sedimentation Conference, March 25 to 29, 2001. Reno, Nevada.

Trush B. and S. McBain. 2000. Alluvial river ecosystem attributes. Stream Notes. January 2000. Stream systems technology Center, USDA Forest Service. PP 1-3.

U. S. Forest Service. 1994. Instream flow water right application for the Clarks Fork River to Wyoming State Engineer

U. S. Forest Service. 1997. An approach for quantifying channel maintenance instream flows in gravel-bed streams. Draft manuscript. Boise Adjudication Team, Boise, ID. 98 pp.

Wesche, T.A., W.T. Hill and V.R. Hasfurther. 1983. Two approaches for estimation of Manning's n in mountain streams. Wyoming Water Research Center. 41 pp.

Wolman M. G. and J. P. Miller. 1960. Magnitude and frequency of forces in geomorphic processes. Journal of Geology, 68: 54-74.

WGFD. 1998. Annual Fisheries Progress Report on the 1997 Work Schedule. Pages 490-491. Wyoming Game and Fish Department, Cheyenne, WY.

WGFD. 1999. Annual Fisheries Progress Report on the 1998 Work Schedule. Page 542-544. Wyoming Game and Fish Department, Cheyenne, WY.

Appendix 1. Flow measurements collected at two Pickett Creek instream flow segments.

Pickett Creek #1 (lower segment)

Elevation (ft): 7150

Legal: R103W; T48N, Sec 16, SE Quad

UTM: UTM coordinates from GPS = Zone 12 , Northing: 4886697, Easting: 642131

Site Description Lower site, on State land. Park at cattle guard on fence line, head west toward stream. IF site downstream end is approx. where 1st encounter stream

DATE	DISCHARGE (cfs)	MEASURED
6/22/1999	81	Schuyler Sampson
7/8/1999	36	Paul Dey
7/28/1999	15	Paul Dey
7/29/1999	19	Rating Curve - Paul Dey
9/16/1999	5.2	Paul Dey
7/19/2001	4.3	PD, LS
11/22/2002	1.2	Paul Dey

Instream Flow Segment #2 (upper)

Elevation (ft): 8280

Legal: R104W; T49N, Sec 36, SE Quad

UTM: UTM coordinates from GPS = Zone 12 , Northing: 4892121, Easting: 635642

Site Description: Approx. 300 yds upstream from N.Fk. Pickett Ck. confluence.

DATE	DISCHARGE (cfs)	MEASURED
6/17/1999	74	P. Dey, S. Sampson
6/22/1999	83	Schuyler Sampson
7/7/1999	29	Paul Dey
7/9/1999	27	Rating Curve - Paul Dey
7/27/1999	14	Rating Curve - Paul Dey
7/28/1999	11	Paul Dey
7/29/1999	13	Rating Curve - Paul Dey
9/15/1999	3.7	Paul Dey
7/19/2001	4	Travis Cundy
11/22/2002	0.52	Paul Dey

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 3. Estimated monthly flow duration series for the Lower Pickett Creek segment (HabiTech 2001).

Duration Class (% time≥)	**Lower Pickett Creek** Estimated Streamflow (cfs)											
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept
95	4.1	3.0	2.4	2.3	2.5	2.7	3.3	7.2	33	14	7.8	5.8
90	4.5	3.4	2.8	2.7	2.7	2.9	3.6	9.3	37	18	8.9	6.4
75	5.3	4.1	3.3	3.0	3.0	3.2	4.3	15	52	29	11	7.8
50	6.7	4.9	3.8	3.4	3.4	3.8	5.7	30	76	47	16	9.8
25	8.2	6.2	4.4	3.9	3.8	4.6	9.3	51	110	76	24	12
10	10	7.3	5.2	4.5	4.4	5.7	16	77	147	103	33	15
5	11	8.0	6.0	4.8	5.1	7.6	22	91	167	120	39	18

Appendix 4. Estimated monthly flow duration series for the Upper Pickett Creek segment (HabiTech 2001).

Duration Class (% time≥)	**Upper Pickett Creek** Estimated Streamflow (cfs)											
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept
95	1.8	1.3	1.1	1.0	1.1	1.2	1.4	3.1	14	6.1	3.4	2.5
90	2.0	1.5	1.2	1.2	1.2	1.3	1.6	4.1	16	8.0	3.9	2.8
75	2.3	1.8	1.4	1.3	1.3	1.4	1.9	6.5	23	13	4.9	3.4
50	2.9	2.2	1.7	1.5	1.5	1.7	2.5	13	33	21	7.0	4.3
25	3.6	2.7	1.9	1.7	1.7	2.0	4.1	22	48	33	10	5.3
10	4.4	3.2	2.3	2.0	1.9	2.5	6.8	34	64	45	14	6.7
5	4.8	3.5	2.6	2.1	2.2	3.3	9.6	40	73	52	17	7.9