WYOMING GAME AND FISH DEPARTMENT

FISH DIVISION

ADMINISTRATIVE REPORT

Title: Greybull River Instream Flow Studies

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ABSTRACT

Instream flows necessary for maintaining Yellowstone cutthroat trout (YSC) habitat and populations were identified through studies conducted on the Greybull River 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 4.3-mile stream segment extending from the mouth of Anderson Creek downstream to the east boundary of State-owned land tract number 67. The following instream flow recommendations were developed: 65 cfs to maintain hydraulic habitat for spawning during the spring season from May 1 to June 30, 34 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 25 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 Greybull River watershed.

Legal and Institutional Background

The Wyoming Game and Fish Department 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 the Greybull River on the Shoshone National Forest, 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 (Dey and Annear 2004), 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 flow protection.

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 drainage features high-elevation mountain streams with high channel slopes, unstable substrates, and large annual fluctuations in discharge. The geologically young Absoraka Mountain Range provides the template for these conditions and 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.

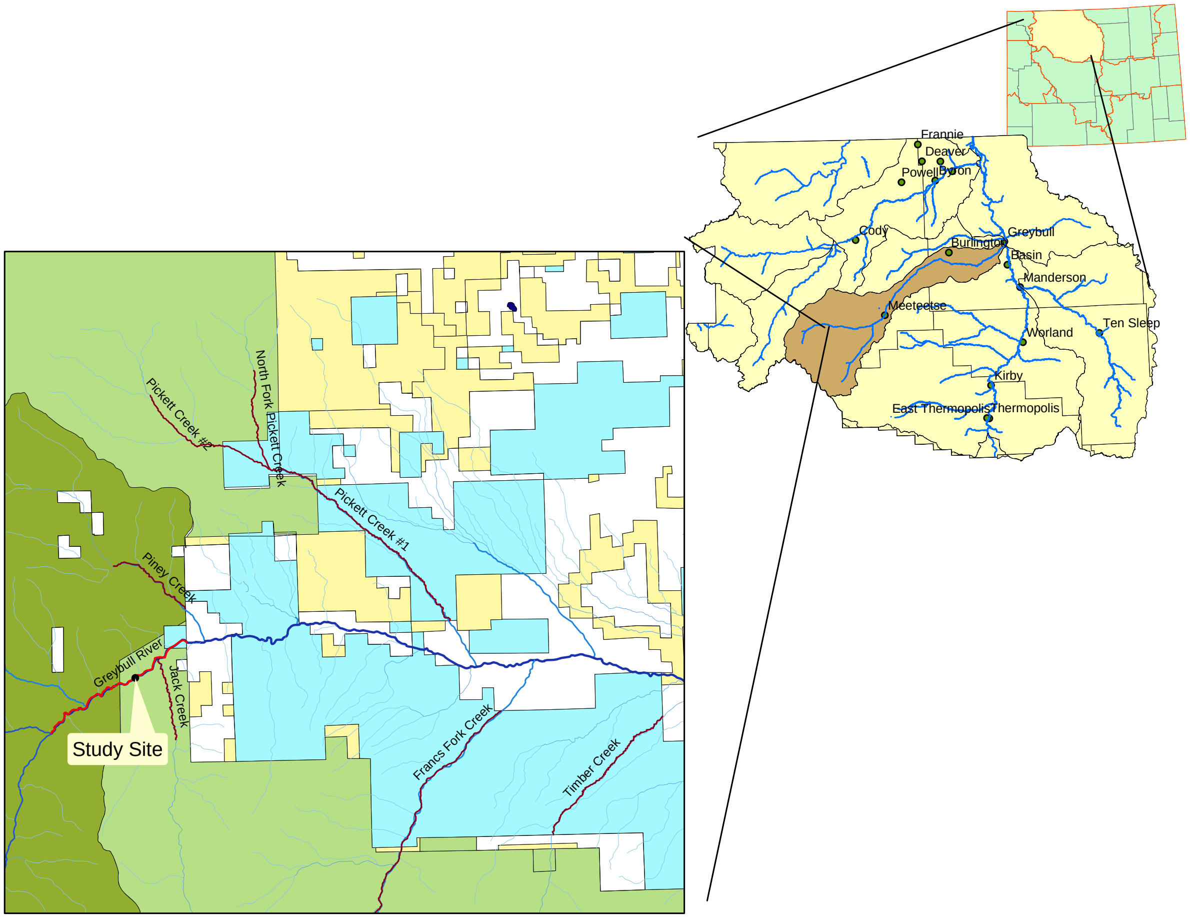

Figure 1. Greybull River instream flow segment and study site location.

Snowfall at elevations up to and over 13,000 feet in the Greybull River basin melts to form the upper reaches of the Greybull River. The headwaters in the Washakie Wilderness circumvent a broad, looping path, starting with a north-northwest oriented valley that gradually becomes east-west oriented (Figure 1). The headwaters alternate between open valleys containing multi-thread channels and narrow canyons with a steep, boulder-strewn channel. The upstream limit of trout distribution, according to a 1994 survey, is a point downstream from Pyramid Creek at an elevation of about 9400 feet (Kruse 1995). While shallow depths limit habitat at this point, a fish passage barrier about 4 miles upstream provides a definitive limit to potential trout distribution.

During a reconnaissance trip in August 2000, Greybull River trout habitat was surveyed visually to a point upstream of Venus Creek to estimate the number and locations of potential instream flow segments and study sites (WGFD 2001). An instream flow stream segment 4.3 miles long was selected and defined from the confluence with Anderson Creek (NE ¼ Section 36, T. 48N., R.105W.) downstream to the east boundary of State-owned land tract number 67 (T.49N., R.104W.; Figure 1). The reach was selected because it is relatively susceptible to development compared to upstream Wilderness Area waters and because habitat and flow conditions are fairly homogenous throughout. The downstream 0.5-mile of the segment is downstream of Jack Creek. Land ownership along the segment is Shoshone National Forest and State.

Channel features were measured with a Rosgen level 2 Survey performed September 11, 2003. Water surface slope was 1.9%. Other key features include a bankfull width of 53 feet, a mean bankfull depth of 1.8 feet, a maximum bankfull depth of 2.65 feet, a flood prone width of 66.6 feet, a d50 of 88 mm, and a sinuosity of 1.12. Under the Rosgen and Silvey (1998) channel-rating scheme, these features conform to a "B3c" rating reflecting a high slope and predominant cobble substrate.

The Greybull River riparian zone is vegetated by mixed conifers, shrubs and willows (Figure 2). Cattle grazing, horse packing, and historic mining activity are the main land uses in the upper portions of the basin.

Figure 2. Greybull River study site August 14, 2001 at 40 cfs. Looking upstream at riffle – run – pool modeled with 5 transects.

The instream flow segment was studied at three sites located on Shoshone National Forest land in the NE ¼ of Section 29, T.48N., R.104W, a short distance upstream from the trailhead. These sites were selected to sample a representative mix of riffles, runs, pools, spawning gravel, and stream-margin fry habitat (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 Greybull River instream flow studies. Additional flow measurements are listed in Appendix 1.

Date	Discharge (cfs)
June 7, 2001	109 -112
June 27, 2001	221-242
*August 14 - 15, 2001	28 – 38
August 16, 2001	38
September 12, 2001	29
*September 13, 2001	--
September 14, 2001	--
September 11, 2003	45

* upper study site mapped for River 2D analysis.

Hydrology

An independent contract was awarded to estimate mean annual flow, annual flow duration, monthly flow duration, and flood frequency intervals for the Greybull River and other tributaries (HabiTech 2001). Greybull River estimates are provided for a point at the downstream end of the instream flow segment, which includes Jack Creek flows. In estimating flow statistics at the study site (e.g. for HQI and Habitat Retention analysis) located upstream of the mouth of Jack Creek, Jack Creek flow estimates were subtracted from the Greybull River statistics.

Additional hydrologic data in the form of flow measurements collected during and following the instream flow studies are reported in Appendix 1. 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 5 species are native. These species are: Yellowstone cutthroat trout, mountain whitefish (*Prosopium williamsoni*), mountain sucker (*Catostomus platyrhynchus*), longnose sucker (*Catostomus catostomus)* and longnose dace (*Rhinichthys cataractae*). Yellowstone cutthroat trout and mountain whitefish are the most common species in the Greybull River instream flow segment. 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 Greybull River 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 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). Greybull River 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

Transects were established in the following manner: a single riffle transect near the trailhead, a series of three transects about ¼ mile upstream across a riffle-run-pool sequence, and a series of five transects starting about 600 feet further upstream. The upstream 5 transects spanned a stream distance of 83 feet and modeled riffle, pocket water, run, and pool (2 transects) habitat (shown in Figure 2). The three sets of transects were calibrated separately using the stage-discharge approach for defining water surface elevations. The velocity sets collected at 38 cfs and 109 – 112 cfs served as the calibration sets for distributing roughness among the cells. Physical habitat was simulated over the range 10 cfs to 500 cfs based on calibration criteria in Milhous et al. (1984). Increments of 5 cfs were simulated over the range 10-100 cfs and increments of 20 cfs were used to simulate above 100 cfs. Finer flow increments (1 cfs) were used in subsequent analyses to precisely identify flows where WUA peaks occurred. The HABTAE submodel was used in generating the WUA index for each set of transects.

Habitat was delineated September 14, 2001 following the classification scheme of Hawkins et al (1993). Under this approach, channel units such as pools, riffles, and runs are identified by relative channel gradient and surface turbulence. We classified habitat over a 3027-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 9 transects in the PHABSIM analysis to reflect habitat abundance. For example, riffles were found to comprise 65% of the stream habitat, so riffle transects were weighted to represent 65% of the total WUA. The weightings were done so that WUA output from each of the three sets of transects could be summed at each flow for the fry, juvenile, and adult life stages. Spawning WUA output from individual transect sets is presented and considered in developing instream flow recommendations.

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 studies conducted prior to 2001, bankfull discharge was estimated from the 1.5-year return flow (here estimated at 1295 cfs from HabiTech 2001) and then PHABSIM was used to simulate the wetted perimeter that occurs at that flow level. In recent studies, for example Piney Creek and North Fork Pickett Creek, bankfull wetted perimeter across each of the riffle transects was directly measured in July 2003. Using field measurements by a trained observer provides a more direct method of inferring bankfull discharge. In the Greybull River, headpins marking riffle transect end points were removed by high flows in 2003 impeding direct measurement of bankfull wetted width on the study transects. Thus the 1.5-year return flow was used to approximate bankfull conditions for application of the wetted perimeter criterion.

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 130 cfs (145-15 cfs from Jack Creek) and at this flow average wetted width is 45 feet so the average depth criterion is 45 * 0.01 = 0.45 feet.

Habitat Quality Index

Average daily flow (ADF; 130 cfs) and peak flow (1295 cfs) estimates at the study site for determining critical period stream flow and annual stream flow variation were estimated from HabiTech (2001). Maximum water temperature was determined with an Optic StowAway® temperature recorder 12 miles downstream at the Pitchfork Bridge set to monitor water temperature at 4-hour intervals between June 5 and November 26, 2002. A spot measurement at the study site on September 12, 2002 was 5° F cooler than recorded at the same time at the Pitchfork Bridge site, indicating an approximate 5° F difference between the sites. 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).

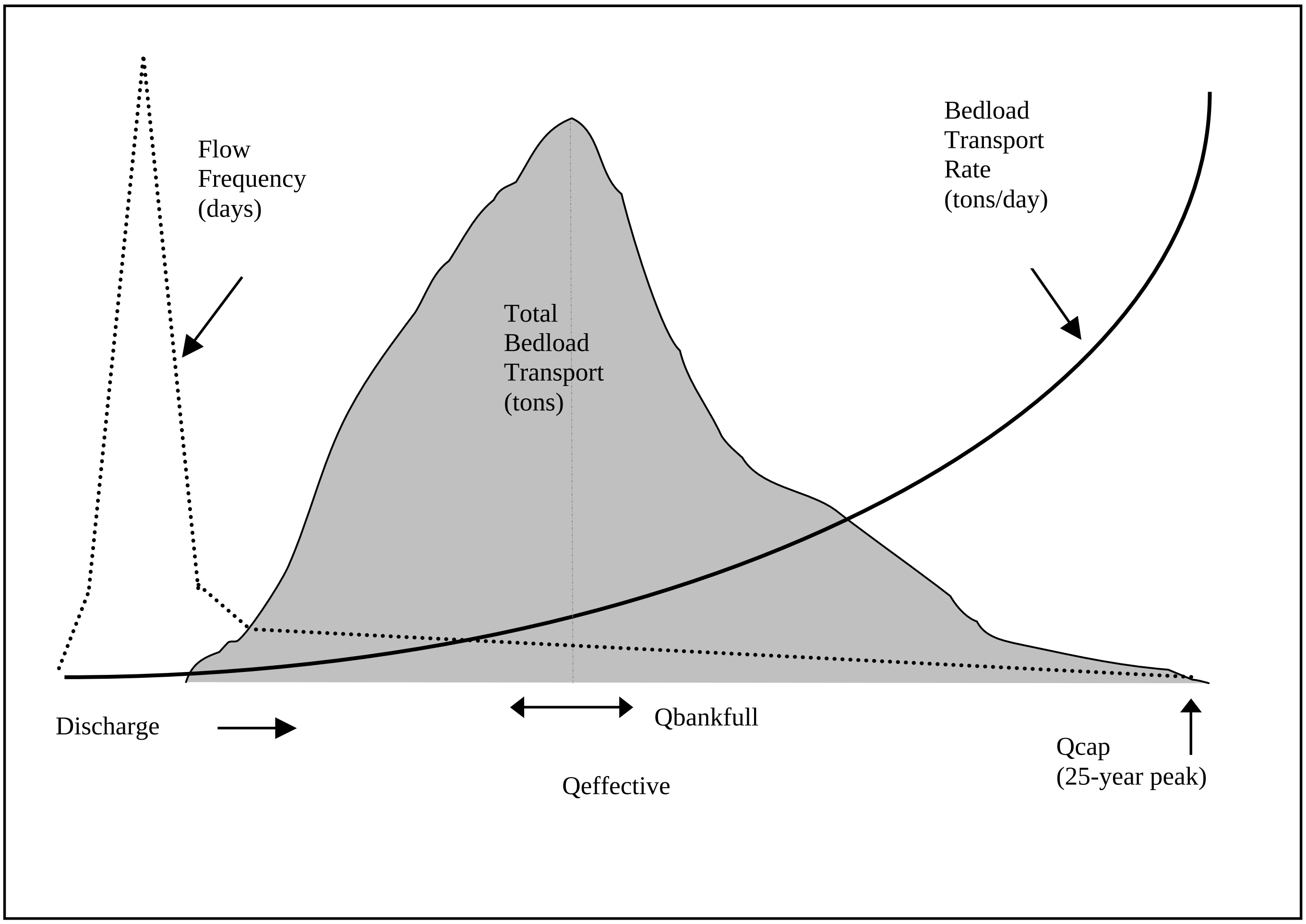

Figure 3. A general model of long-term total bedload transport as a function of flow frequency and bedload transport rate (from USFS 1997).

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.

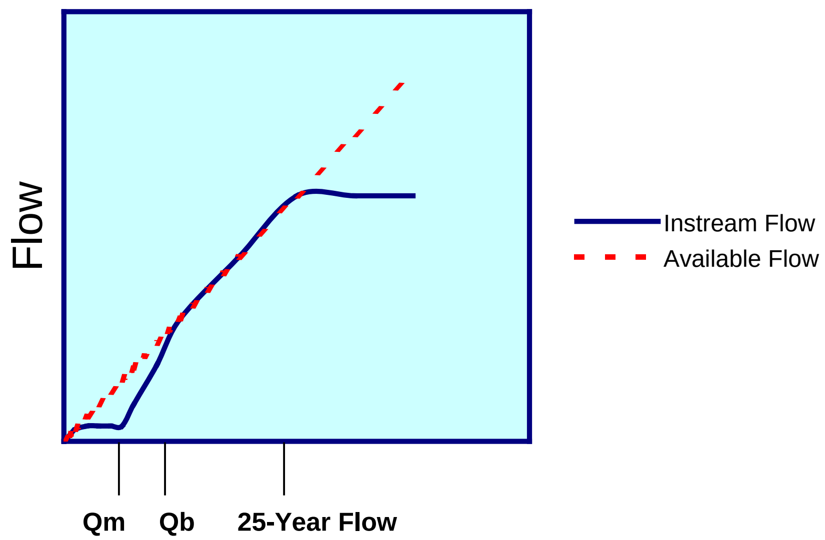

Figure 4. General function of a dynamic hydrograph instream flow for fishery maintenance. Q_m is substrate mobilization flow and Q_b is bankfull flow.

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

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, 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). In upper Pickett Creek, North Fork Pickett Creek, and Piney Creek, the spawning season instream flow recommendations were extended until July 15 to represent later spawning in these higher elevation (above ~8000 feet) stream segments. The Greybull River segment occurs below 8000 feet elevation so the May 1 through June 30 period is appropriate.

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

Fishery Function	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**Jul**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
Spawning habitat					1	1						
Survival, movement	2	2	2	2	2	2	2	2	2	2	2	2
Growth							3	3	3			
Channel maintenance					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, Greybull River bankfull discharge at the downstream end of the segment is 1448 cfs (Table 4). Average daily flow was estimated at 145 cfs (HabiTech 2001). Estimated monthly flow levels are listed in Appendix 3.

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

Return Period (years)	Estimated Flow (cfs)
1.01	646
1.05	796
1.11	906
1.25	1081
1.5*	1448
2	1609
5	2603
10	3451
25	4790

* Bankfull discharge.

Fish Flows

Physical Habitat Simulation

The WUA index of spawning habitat exhibited variable patterns for each of the study transect sets (Figure 5). The stand-alone riffle transect had relatively high quantities of spawning habitat and the peak occurred at a relatively low 17 cfs. The three transects a short distance upstream had low spawning habitat at flows less than about 60 cfs and the index did not peak until 170 cfs. Here, another peak occurs at flows above 460 cfs. Yet a third pattern occurs with the 5 transect set (Figure 5). In this riffle-run-pool sequence the spawning habitat index peaks at 65 cfs. Such variability among riffles is expected and highlights the range of spawning opportunities available to Yellowstone cutthroat trout depending on runoff conditions. Given this variability, the combined curve in Figure 5 indicates the composite relationship between the WUA spawning habitat index and flow. This curve is fairly flat over a broad flow range with a peak at 35 cfs.

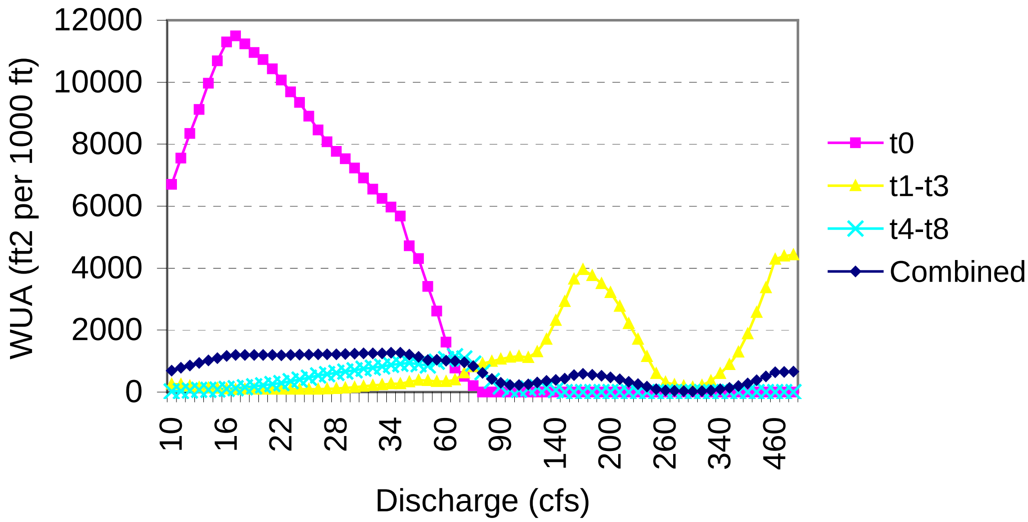

Figure 5. Yellowstone cutthroat trout spawning habitat (square feet per 1000 feet of stream).

To identify a flow to maintain or improve spawning habitat for Yellowstone Cutthroat trout, a number of approaches based on the collected data are possible. The peak of the composite curve, 35 cfs, could be selected. This approach, selecting the peak of the composite curve, was adopted for most other instream flow studies in the Greybull basin including Piney Creek, North Fork Pickett Creek, lower Pickett Creek, Francs Fork, Timber Creek, and Jack Creek. However, when a wide range of patterns occurs among study transects, as in Figure 5, a composite curve may not best reflect conditions needed to maintain spawning for the trout population. For example, on upper Pickett Creek, a flow less than the peak of the average curve was selected to provide greater diversity of spawning opportunity on more riffles (Dey and Annear 2003). In that case and in the Greybull data here, using the composite curve is not appropriate because a single transect exerts a disproportionate influence on the composite curve. As was the case with upper Pickett Creek, it is necessary to consider additional biological merits of the various transects in order to identify a spawning flow.

A flow of 65 cfs, the peak of the transect 4 – 8 curve, better maintains spawning habitat because it is more representative of the flow relationships from the 8 study transects (transects 1 through 8) that were established to model a diversity of habitat for all life stages. The stand-alone transect that greatly influences the combined WUA curve in Figure 5, while containing significant spawning habitat at low flow levels, does not contain a gravel bar. Rather, localized gravel and cobble deposited behind boulders provide potential spawning opportunity. The stream segments modeled with transects 1 through 3 and 5 through 8 contain gravel bars, however, and these larger expanses of spawning habitat better represent traditional spawning habitat.

A flow of 65 cfs will maintain moderate spawning habitat in transects 1 through 3. Alternatively, a flow of 170 cfs, the peak of the transect 1 – 3 curve, would maintain more total habitat but it comes at the expense of habitat in transects 1 through 3. A flow recommendation of 65 cfs is better than 170 cfs because it recognizes and maintains at least some spawning opportunity on more riffles. A flow recommendation of 65 cfs provides 79% of the spawning habitat maintained by the peak of the composite curve while a flow recommendation of 170 cfs would maintain only 46%.

Based on simulated spawning habitat (Figure 5), an instream flow of 65 cfs is recommended for the May through June 30 season to maintain YSC spawning habitat. Though the full 65 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.

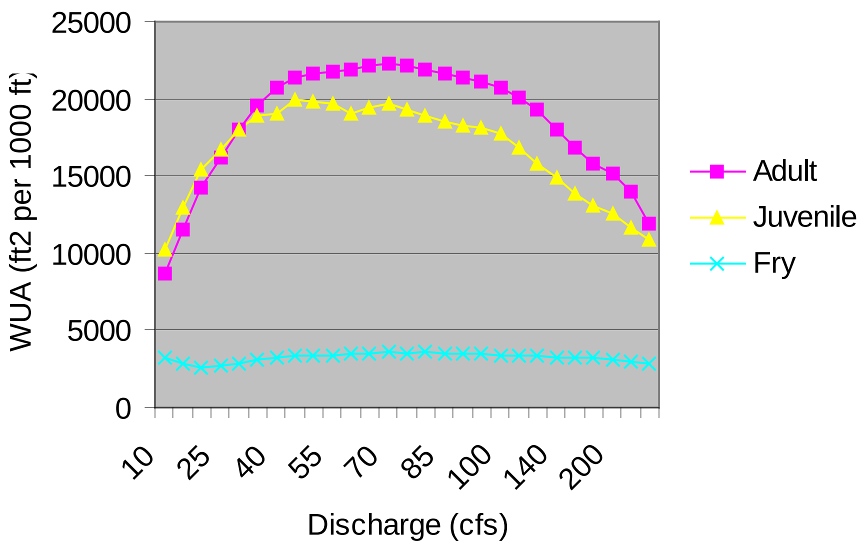

Figure 6. Yellowstone cutthroat trout WUA (ft^2 per 1000 feet of stream) for adult, juvenile and fry life stages in the Greybull River.

The availability of fry habitat varied little over the flow range examined according to the WUA index (Figure 6). Adult and juvenile physical habitat displayed a bell-shaped curve, rising rapidly to peak over a discharge range of about 50 to 100 cfs. These patterns suggest that any increase in flow up to about 50 cfs is beneficial for these larger trout life stages.

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, mean depth is the first hydraulic criteria “met” as flow declines from its bankfull level. The mean depth reached 0.45 feet (0.1 * 45 feet, the wetted width under average flow conditions) at a flow of 26 cfs. The average velocity criterion of 1.0 ft/s was attained when flow declined to 11 cfs. Finally, the wetted perimeter criterion was met at a flow less than 10 cfs (the exact flow could not be determined, nor was it necessary for this analysis). Thus, two of three hydraulic criteria (wetted perimeter and velocity) are retained by a flow of 11 cfs across riffle 1 (Table 5). In a similar fashion, flows of 25 cfs and 17 cfs are necessary to retain the criteria on riffles 2 and 3. Therefore, the flow that retains two of three criteria for all of the studied riffles is 25 cfs. Based on the Habitat Retention model, a flow of 25 cfs is recommended to maintain trout survival over the fall and winter season (October 1 to April 30).

At 25 cfs, adult and juvenile habitat is about 75% of maximum according to the WUA index (Figure 6). Any decreases in flow from this level result in rapid declines in habitat while higher flows offer improved physical habitat.

Table 5. Simulated hydraulic criteria for three Greybull River 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	7.20	3.05	68.5	1295
	2.23	0.89	55.3	109
	1.52	0.57	45.8	40
	1.31	**0.45**	44.0	26
	1.20	0.41	40.8	20
	1.01	0.28	39.1	**11**
	0.99	0.27	37.9	10
	<0.99	<0.27	**<37.9**	<10
Riffle 2 – transect 2	7.87	2.56	66.7	1295
	3.20	1.34	57.3	240
	2.17	1.08	47.7	109
	1.26	0.92	**33.4**	38
	1.10	0.89	31.1	30
	0.99	0.89	28.9	**25**
	0.97	0.88	28.6	24
	0.58	0.67	26.1	10
	<0.58	**<0.67**	<26.1	<10
Riffle 3 – transect 5	6.72	3.22	62.9	1295
	2.74	1.71	55.2	250
	1.83	1.20	51.4	109
	1.18	0.70	47.8	38.2
	1.04	0.55	45.4	25
	1.00	0.52	43.7	22
	0.94	**0.45**	41.8	**17**
	0.86	0.35	34.7	10
	<0.86	<0.35	**<34.7**	**<10**

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 65° F was estimated by examining maximum water temperatures from a recorder placed well downstream at the Pitchfork Bridge. There, a maximum of 69º F was measured July 31, 2002 suggesting the maximum in the study area is lower because of the higher elevations and greater shade. The estimated 65º F optimizes the temperature attribute under the HQI analysis. An error in the maximum water temperature estimate is inconsequential to the instream flow analysis because the pattern of habitat units versus flow does not depend on the water temperature attribute - only the relative level of predicted habitat units is affected.

Nitrate concentrations were measured at 0.01 mg/l which receives an attribute rating of "1". Eroding banks, at 25%, rated a "3". The average of three invertebrate samples was 175 invertebrates per square foot for a rating of "2". All four cover measurements fell within the "1" rating where 10 – 25% of the wetted channel area provides adult trout cover. The cover percentages were: 22% at 29 cfs, 14% at 38 cfs, 20% at 109 cfs, and 11% at 231 cfs. Since the cover rating did not change under the range of measured flow conditions, there is no basis to estimate the low or high flow level at which the rating declines from "1" to "0". Therefore, the cover rating was held constant at "1" for the flow versus Habitat Unit analysis.

Peak habitat units occur between 34 and 39 cfs (Figure 7). Water velocity was a key attribute with optimal mean channel velocities occurring from 19 to 39 cfs. The critical period stream flow attribute was also influential with a rating of "3" attained at flows between 34 and 72 cfs.

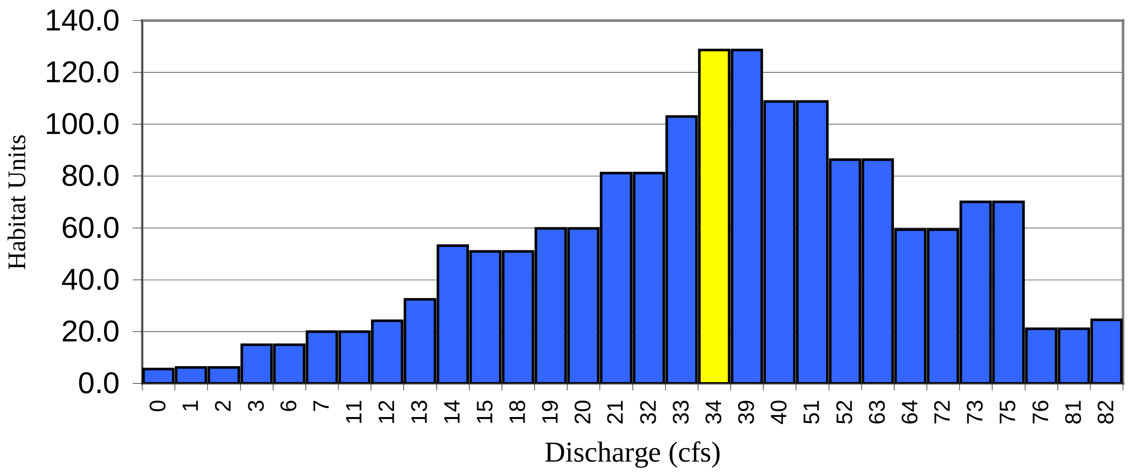

Figure 7. Habitat Quality Index at the Greybull River study site for a range of flow levels. X-axis flows are scaled to show where changes in Habitat Units occur. The recommended flow is indicated by the light shaded bar.

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. Few flow records are available to define normal July through September flows but six flow measurements have been collected by WGFD: 76 cfs (July 19, 2001), 28 cfs (August 14, 2001), 38 cfs (August 16, 2001), 28 cfs (September 10, 2001), 29 cfs (September 12, 2001) and 45 cfs (September 11, 2003). Estimated monthly streamflows that occur 50% of the time at the bottom of the instream flow segment are: 333 cfs, 114 cfs, and 70 cfs for July, August and September, respectively (Appendix 3, HabiTech 2001). Subtracting Jack Creek flow contributions, these monthly flow estimates would translate to approximately 298, 102, and 63 cfs, respectively, at the instream flow study site.

In applying the HQI in Greybull basin streams we have selected August flow estimates as indicative of the late-summer period flow. Then, we have looked for a flow that maintains the level of Habitat Units that occur at that August value (e.g. Dey and Annear 2001b). In the Greybull River study, the August estimated 102 cfs provides only 25 habitat units while lower flow levels provide over 120 habitat units (Figure 7). The 25 habitat units would be provided by flows all the way down to 13 cfs.

A flow of 34 to 39 cfs would maximize habitat units and improve the fishery from the current condition where late summer flows are higher than 39 cfs and limit adult trout productivity. Our instream flow water right recommendation based on the HQI analysis is 34 cfs for adult trout productivity during the July through September period. This recommendation will protect sufficient water to maintain or improve the fishery.

Channel Maintenance Flows

Like all properly functioning rivers, the Greybull River 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 65 cfs identified for maintaining spawning habitat. The channel maintenance instream flow recommendation is 65 cfs for periods when naturally available flows range from 65 cfs to 724 cfs. When naturally available flows range from 725 cfs to the bankfull flow of 1448 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 (4790 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 Greybull River instream flow segment. Recommendations apply to the run-off period from May 1 through June 30th.

Description	Available Flow (cfs)	Instream Flow (cfs)
	<65	Equal to available flow
Spawning Flow	65	65
	66 – 723	65
Substrate Mobilization Flow	724	65
	725 – 905	407
	906 – 1086	798
	1087 – 1267	1019
	1268 - 1447	1234
Bankfull	1448	1448
	1449 - 4789	Equal to available flow
25-Year Flood	4790	4790
	>4790	4790

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 the Greybull River 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 4.3 miles downstream from the confluence with Anderson Creek (NE ¼ Section 36, T. 48N., R.105W.) downstream to the east boundary of State-owned land tract number 67 (NE ¼ Section 21, T.49N., R.104W.; Figure 1). UTM coordinates (NAD27) for the upper and lower boundaries of the segment are 627957E, 4882567N, Z12 and 632856E, 4885820N, 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 7. Instream flow recommendations to maintain or improve existing trout habitat in a Greybull River segment.

Season	Month	Instream Flow* Recommendation (cfs)
Fall/Winter	October	25
Fall/Winter	November	25
Fall/Winter	December	25
Fall/Winter	January	25
Fall/Winter	February	25
Fall/Winter	March	25
Fall/Winter	April	25
Spring	May	65
Spring	June	65
Spring	July	34
Summer	August	34
Summer	September	34

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

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. 2001c. Statewide flow monitoring results: WY 2001-2002. Wyoming Game and Fish Administrative Report.

Dey, P.D. and T.C. Annear. 2003a. Instream flow water right status and statewide flow monitoring results for calendar year 2003.

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

Dey, P.D. and T.C. Annear. 2004. Instream flow studies on Piney Creek, a Greybull River tributary. Wyoming Game and Fish Department 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.

Hawkins, C.P., J.L.Kershner, P.A. Bisson, M.D. Bryant, LM. Decker, S.V.Gregory, D.A.McCullough, C.K. Overton, G.H.Reeves, R.J. Steedman, and M.K. Young. A hierarchical approach to classifying stream habitat features. Fisheries 18:6.

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. Pages 542-544. Wyoming Game and Fish Department, Cheyenne, WY.

WGFD. 2001. Annual Fisheries Progress Report on the 2000 Work Schedule. Pages 471-486. Wyoming Game and Fish Department, Cheyenne, WY.

Appendix 1. Flow measurements collected at the Greybull River instream flow segment.

Elevation (ft):	7594
Legal Description:	R104W; T48N, Sec 21, SW Quad
UTM Coordinates:	UTM coordinates from GPS: Zone 12, Northing: 4884889, Easting: 631587
Site Description	Upstream of Jack Creek confluence and horse trail crossing. Large rocky cliff on left.

DATE	DISCHARGE (cfs)	MEASURED
4/25/2001	47	Paul Dey, Steve Yekel
4/26/2001	79	Paul Dey, Steve Yekel
7/19/2001	76	Steve Wolff
8/16/2001	38.2	Paul Dey, Ron Renaldi
9/10/2001	28.3	Paul Dey, Tom Annear
10/9/2001	25.7	Paul Dey, Ron Renaldi
11/22/2002	20.2	Paul Dey, Jason Burckhardt

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 Greybull River segment (HabiTech 2001).

Duration Class (% time≥)	**Greybull River** Estimated Streamflow (cfs)											
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept
95	29	21	17	16	18	19	23	51	232	100	55	41
90	32	24	20	19	19	21	25	66	267	130	63	45
75	38	29	24	22	21	23	31	106	373	204	79	55
50	48	35	27	24	24	27	41	213	543	333	114	70
25	58	44	31	28	27	32	66	360	781	541	168	87
10	72	52	37	32	31	41	111	548	1041	729	232	109
5	79	57	43	34	36	54	156	647	1183	853	279	128