

WYOMING GAME AND FISH DEPARTMENT

FISH DIVISION

ADMINISTRATIVE REPORT

Title: Instream flow studies on Bear Creek.

Project: AW-LR-6WE-511

Author: Mike S. Robertson and Paul D. Dey

Date: April 2009



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EXECUTIVE SUMMARY

Three streams in the East Fork Wind River drainage near Dubois, WY were selected for instream flow water rights filing consideration (the East Fork Wind River, Bear Creek, and the Wiggins Fork). Yellowstone cutthroat trout (YSC) are common in the watershed and the watershed is managed as a wild YSC fishery. A total of 10 instream flow segments were selected for potential instream flow water rights to maintain or improve the YSC fishery and other important, though less abundant fisheries in the watershed (mountain whitefish, brown trout, and rainbow trout). Three segments were identified on Bear Creek due to the geomorphic changes and land ownership changes that occur. This report provides flow recommendations developed from studies conducted in 1991-1992 and 2005-2006. The Physical Habitat Simulation (PHABSIM) modeling technique was employed to develop instream flow recommendations for maintaining YSC spawning habitat during spring runoff. Riffle hydraulic characteristics were examined using the Habitat Retention approach to ensure that flow recommendations from other methods did not impede fish movement. The Habitat Quality Index (HQI) model was used to assess stream flow versus juvenile and adult trout habitat quality relationships in the summer. During the winter months, November through April, natural winter flows were recommended to maintain all life stages. The 20% monthly exceedance, based on hydrologic estimates from HabiTech (2007), was selected to represent natural winter flow. Finally, a dynamic hydrograph model was used to quantify flow needs for maintenance of channel geomorphology.

Approximately 13.2 miles of stream habitat will be directly protected if these instream flow applications advance to permit status. Recommended flows range from a low of 9.0 cfs during the winter in the upper reaches of Bear Creek to 35 cfs in the lower and middle segments during April (Table 1). Additional channel maintenance flow recommendations for long-term habitat maintenance are presented in Appendix 1. Wyoming’s instream flow statute has been interpreted to mean that this level and purpose of flow is not allowed for incorporation into an instream flow water right so this information is presented for informational purposes only.

Table 1. Instream flow recommendations to maintain trout habitat in the Bear Creek instream flow segments.

	Winter Survival Nov 16 – Mar 31	Early Spring Connectivity Apr 1-30*	Spring Spawning May 1 – Jun 30*	Summer Production Jul 1 – Sep 30	Fall Spawning Oct 1 – Nov 15
Bear Creek Lower	11	35	25	29	15
Bear Creek Middle	10	35	20	29	14
Bear Creek Upper	9	32	20	24	13

* Channel maintenance flow recommendations for the spring runoff period are defined in Appendix 1.

INTRODUCTION

Guiding Principles for Instream Flow Recommendations

The analyses and interpretation of data collected for this report considered important components of an aquatic ecosystem and their relationship to stream flow. Stream ecosystems are complex. Many instream flow studies conducted in the 1970s and 1980s overlooked the full breadth of this complexity by focusing solely on sport fish species and maintenance-level instream flow recommendations. This report describes recommendations developed using an ecosystem approach that is consistent with contemporary understanding of stream complexity and effective resource management. The recommendations of the Instream Flow Council (IFC), an organization of state and provincial fishery and wildlife management agencies, provide comprehensive guidance on conducting instream flow studies. The approach described by that organization includes consideration of three policy components (legal, institutional, and public involvement) and five riverine components (hydrology, geomorphology, biology, water quality and connectivity; Annear et al. 2004). Sections of this report were selected to reflect appropriate components of that template as closely as possible. By using the eight components as a guide, we strive to develop instream flow recommendations that work within Wyoming's legal and institutional environment to maintain or improve important aquatic resources for public benefit while also employing a generally recognized flow quantification protocol.

Legal and Institutional Background

The Wyoming Game and Fish Department (WGFD) manages fish and wildlife resources under Title 23 of Wyoming statutes (W.S.). The WGFD was created and placed under the direction and supervision of the Wyoming Game and Fish Commission (Commission) in W.S. 23-1-401 and the responsibilities of the Commission and the WGFD are defined in W.S. 23-1-103. In these and associated statutes, the WGFD is charged with providing “. . . an adequate and flexible system for the control, propagation, management, protection and regulation of all Wyoming wildlife.” 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. In a 2005 policy statement, the Commission formally assigned responsibilities for implementing instream flow water rights to the WGFD and specified procedures for notifying the Commission of instream flow filing activities.

The instream flow law, W.S. 41-3-1001-1014, 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 Commission is responsible for determining stream flows that will “maintain or improve” important fisheries. The WGFD fulfills this function under the general policy oversight of the Commission. Applications for instream flow water rights are 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.

One of the critical terms associated with the present instream flow statute relates to the concept of a “fishery.” From a natural resource perspective, a fishery includes the habitat that is required to support fish populations, which consists of the stream channel, riparian zone and floodplain as well as the processes of sediment flux and riparian vegetation development that sustain those habitats (Annear et al. 2004). To maintain the existing dynamic character of an 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 such channel maintenance flows are not consistent with the legislative intent of the instream flow statute. Therefore, until the

interpretation of state water law changes, channel maintenance flow recommendations are not included on instream flow applications. Channel maintenance flow requirements are presented in Appendix 1 of this report and may be useful should opportunities arise in the future to secure instream flow water rights for this important fishery management purpose.

Through February 2009, the WGFD has forwarded 100 instream flow water right applications to the WWDC for submission. Of these, the State Engineer has permitted 74 and the Board of Control has adjudicated four.

Purpose for Upper Wind River Instream Flow Studies and Water Rights

Guidance for selecting instream flow study sites is provided by the WGFD Water Management Unit's five-year plan for 2006-2010 (Annear and Dey 2006). This plan prioritizes high quality habitats for instream flow studies and identifies Yellowstone cutthroat trout (YSC; *Oncorhynchus clarki bouvieri*) as the greatest priority species on which to focus efforts during this planning period. The East Fork Wind River and its two major tributaries, the Wiggins Fork and Bear Creek, were identified as high priority streams for instream flow studies because of the number of stream miles with YSC populations of high genetic purity and because the Commission has a significant ownership stake in much of the land through which those streams pass.

The YSC is a native fish species in Wyoming that was petitioned for federal 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 the petitioners failed to present adequate information indicating that listing may be warranted. In January 2004, a suit was brought against the FWS alleging that this finding did not follow the tenets of the review process. In December 2004, the 9th Circuit Court overturned the FWS 90-day ruling on the basis that proper procedures were not followed and ordered the FWS to conduct a 12-month review which resulted in a finding that the species does not warrant endangered species protection (Federal Register 2006). The WGFD is pursuing significant, targeted management efforts to protect and expand YSC populations to prevent the need for such federal protections (WGFD 2005).

Yellowstone cutthroat trout historically occupied Wyoming waters in the Snake River and Yellowstone River drainages, including the tributary Wind/Bighorn and Tongue River drainages (Behnke 1992, May et al. 2003). More recent distribution information is summarized in May (1996), Kruse et al. (1997), Dufek et al. (1999), and May et al. (2003). In 2001, fisheries experts from Wyoming, Montana, and Idaho compiled information on YSC populations, including genetic status and population demographics (May et al. 2003). This project identified conservation populations and assessed the relative extinction risk among populations. 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) and hence were targeted first for instream flow studies during 1997 through 2003. The watershed with the next highest number of stream miles with high genetic purity is the upper Wind River, which includes the East Fork Wind River, the Wiggins Fork, and Bear Creek.

Cutthroat trout are native in the East Fork Wind River but were also stocked extensively (both YSC and Snake River cutthroat [SRC] through 1971 on Bear Creek, 1992 on the Wiggins Fork, and 1995 on the East Fork Wind River) (Binns 1996). In addition to YSC, the three major streams of the upper Wind River watershed also have high numbers of mountain whitefish (MWF) and support recreational fisheries for introduced brown (BNT) and rainbow (RBT) trout (though the latter are rare). Instream flow recommendations were developed for each of these species and their individual life stages with the priority on native YSC and MWF. Securing instream flow water rights on these stream segments will help ensure the future of YSC and other important fish species in Wyoming by protecting existing base

flow conditions in priority against potential but presently unidentified future consumptive and diversionary demands. These water rights apply directly to the instream flow segments, but there may also be some level of indirect protection by virtue of the fact that any new water development upstream of the instream flow segment must ensure enough water reaches the upstream end of each instream flow segment when an instream flow right is in priority.

Public Participation

The public has several opportunities to be involved in the process of identifying instream flow segments or commenting on instream flow applications. First, people can inform WGFD of their interest in protecting specific fisheries with instream flow filings. In addition, planning and selection of future instream flow study sites are detailed in the Water Management Unit's annual work schedules and five-year plans, which are available for public review and comment (either upon request or by visiting the WGFD web site at <http://gf.state.wy.us/downloads/pdf/Fish/5yearplan2006.pdf>). The public is also able to comment on instream flow water rights that have been filed with the State Engineer through statutorily required public hearings that are conducted by the State Engineer's Office for each proposed instream flow water right. The State Engineer uses these public hearings to gather information for consideration before issuing a decision on the instream flow water right application. To help the public better understand the details of instream flow filings and the public hearing process, WGFD personnel typically conduct an informal information meeting a week or two prior to each public hearing. Additional presentations to community or special interest groups at other times of year also provide opportunity for discussion and learning more about instream flow issues and processes.

Meeting with landowners adjacent to or immediately downstream from instream flow segments is vital for sharing information about aquatic resources and proposed instream flow studies, and can sometimes be important for securing access to collect field data for the instream flow study. While most instream flow segments are located on public land where unappropriated water remains, nearby or adjacent landowners are given the opportunity to consider extending an instream flow segment on streams crossing their property. Two of the ten instream flow segments selected in the East Fork Wind River are located above and below several small parcels with multiple property owners. All landowners were informed of the Commission's intention to submit filings for instream flow protections up- and downstream of their property and asked whether they would be interested in extending a segment through their property.

Objectives

The objectives of this study were to 1) maintain YSC habitat (highest priority) as well as habitat for MWF, BNT, and RBT, 2) quantify year-round instream flow levels needed to meet objective 1, and 3) identify channel maintenance flows needed to maintain long-term trout habitat and related physical and biological processes. The audience for this report is broad and includes the State Engineer and staff, the Water Development Commission and staff, aquatic habitat and fishery managers, and non-governmental organizations and individuals interested in instream flow water rights and YSC management in general or in the upper Wind River watershed in particular.

STUDY AREA

East Fork Wind River Basin Description

The East Fork Wind River basin (hydrologic unit code 1008000104) area is 434 square miles and is about 17% of the Upper Wind River basin area (measured upstream from Boysen Reservoir; Figure 1). The East Fork Wind River basin is a priority area for habitat enhancement in the Lander Region (WGFD 2009). Land ownership in the watershed includes 1.5% private land and 98.5% public land. The public land includes 76% Forest Service land, 16% owned and managed by Wyoming Game and Fish Commission, 3% State Land, and 3% Bureau of Land Management land. This watershed includes Inberg/Roy and the Spence/Moriarity Wildlife Habitat Management Areas. Recreational uses in the drainage include fishing, camping, hunting, and horseback riding and packing.

The East Fork Wind River enters the Wind River approximately 12 miles downstream of Dubois, Wyoming (Figure 1). Basin elevation ranges from 6,400 feet at the mouth of the East Fork Wind River to 12,635 feet at the head of Burwell Creek in the Wiggins Fork drainage. Much of the valley shape in the East Fork basin is U-shaped and conforms to valley type II from Rosgen's (1996) level I geomorphic classification. In the lower elevations, the broad valley is more like a type VIII. Stream channels throughout the East Fork Wind River basin would be primarily classified as "B" and "C" from inspection of 1:24,000 scale topographic maps (there are also some braided "D" channels in sections), which is consistent with observations at study sites. The basin's primary aspect is southwest facing. Annual precipitation at nearby Dubois averaged 9.0 inches over the period 1948 – 2006, but precipitation is substantially greater at higher elevations in the East Fork Wind River basin.

Geology

The East Fork Wind River and its tributaries are high-elevation Absaroka Mountain streams with steep channel slopes and unstable substrates. These characteristics derive from the geologically young nature of the Absaroka Mountain Range, which are remnants of a broad volcanic plateau that continues to erode as regional uplift occurs (Lageson and Spearing 1988). The Eocene Wind River formation underlies much of the East Fork Wind River basin. This stream-deposited claystone is made up of various colors and rusty brown feldspar-rich sandstone (Lageson and Spearing 1988). Annual precipitation is primarily snow, which leads to large fluctuations in annual discharge, including torrential spring flows during snowmelt runoff (Curtis and Grimes 2004). High snowmelt runoff easily moves erodible volcanic material resulting in stream channels that shift regularly, transport a lot of sediment and offer limited fish habitat. Earthen slumps are common and influence stream channel patterns by sometimes directly blocking or altering stream flow and providing large sediment supplies for eventual transport. Valley vegetation communities respond to mass wasting events with colonizing species, often aspen, establishing on denuded hill slopes.

Upland and Riparian Resources

Upland vegetation in the East Fork Wind River basin ranges from shrub-grassland steppe at lower elevations through montane coniferous forests to high elevation alpine moss-lichen-forb communities. Intermixed barren rock outcrops, cliffs and talus slopes are found interspersed in much of the montane forests. Spruce-fir forests occupy much of the mid-elevation regions of the East Fork Wind River basin; these forests also contain many pines and junipers. Some of these higher-elevation conifers have also begun to encroach on riparian areas and replace aspens throughout the drainage due to fire suppression. A severe outbreak of fir beetles during drought in the late 1990s and early 2000s resulted in high mortality of conifers throughout the East Fork Wind River basin, particularly Lodgepole pine. In addition, several years of drought have caused sagebrush to die in large numbers.

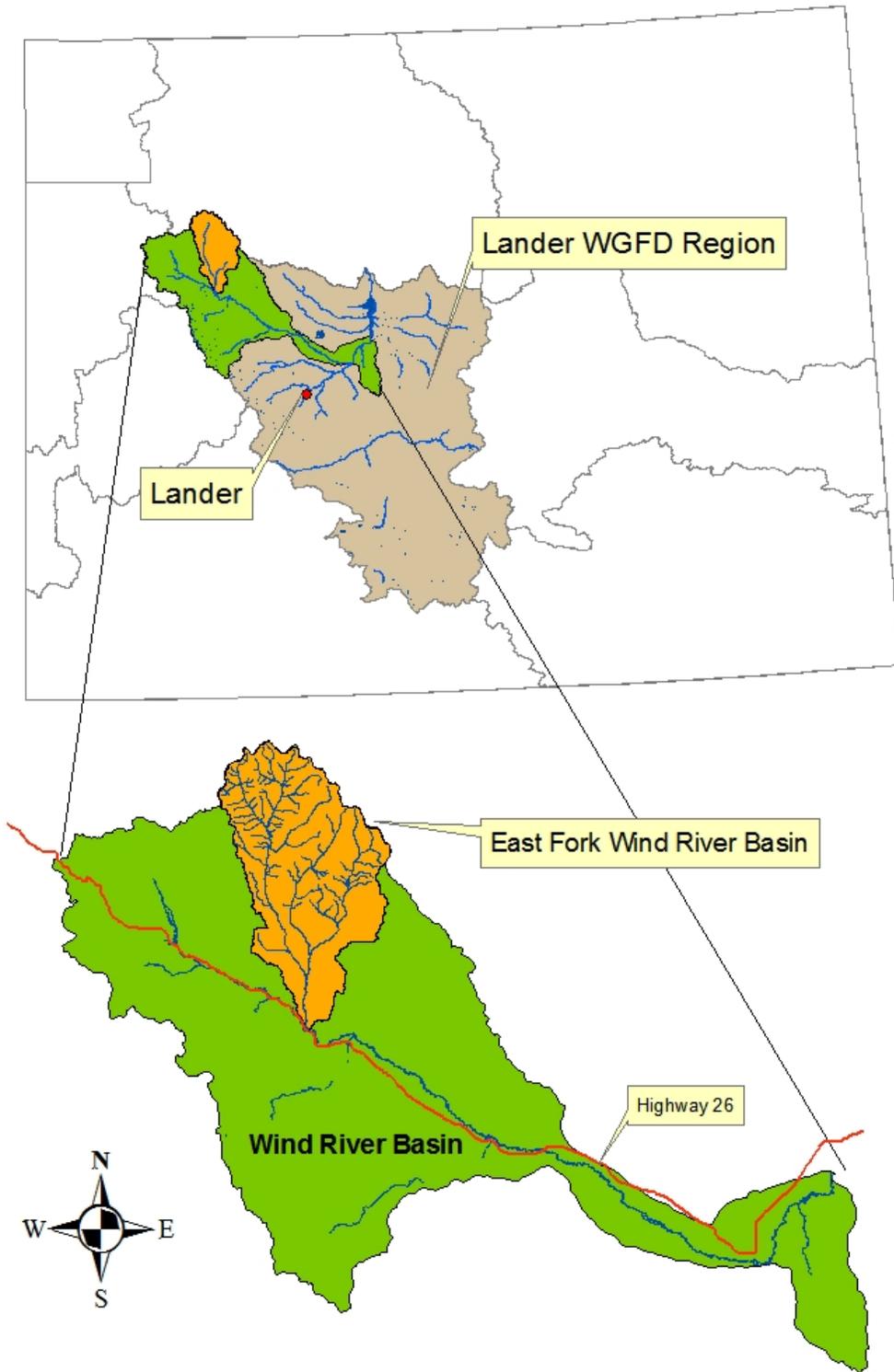


Figure 1. Location of East Fork Wind River basin, WY (hydrologic unit code 1008000104).

Riparian irrigated meadows and cottonwood stands occur on the Wildlife Habitat Management Areas and private land in the lower portions of the watershed. Beaver are active, in small numbers, in Bear Creek and the East Fork, but are rare in the Wiggins Fork. Grazing by wildlife and livestock is a common disturbance in riparian areas in the watershed and may be contributing to high soil erosion in some areas and invasion of Russian olive in many areas. The riparian zone in most places contains a mix of shrubs (mostly willow and water birch, but some alder and dogwood as well), multiple-age cottonwood stands (though little recruitment of small trees was observed), occasional conifers, and moderate herbaceous growth. The riparian zone extends from about 20 to 50 feet on each side of the streams in this watershed, growing narrower in an upstream direction.

East Fork Wind River Basin Hydrology

There was one USGS gage in the lower reaches of the East Fork Wind River (06220500) operated from 1950-1997. Two other gages in the region, both in the Wind River (06220800 and 06218500) were evaluated as potential reference gages for the instream flow segments, but the East Fork Wind River gage proved to be the best reference gage for all segments in the watershed. Stream flow at the East Fork Wind River gage is typical of snowmelt runoff streams with short periods of high (runoff) flow and a substantial portion of the annual flow as a low (base) flow (Figure 2). Flow peaks occurred between May 28 and June 28 over the period of record (median date was June 10). Base flow recession occurs throughout summer with near base flow levels attained by October. Annual flow minima occurred in winter, usually December, January, or February (Figure 3).

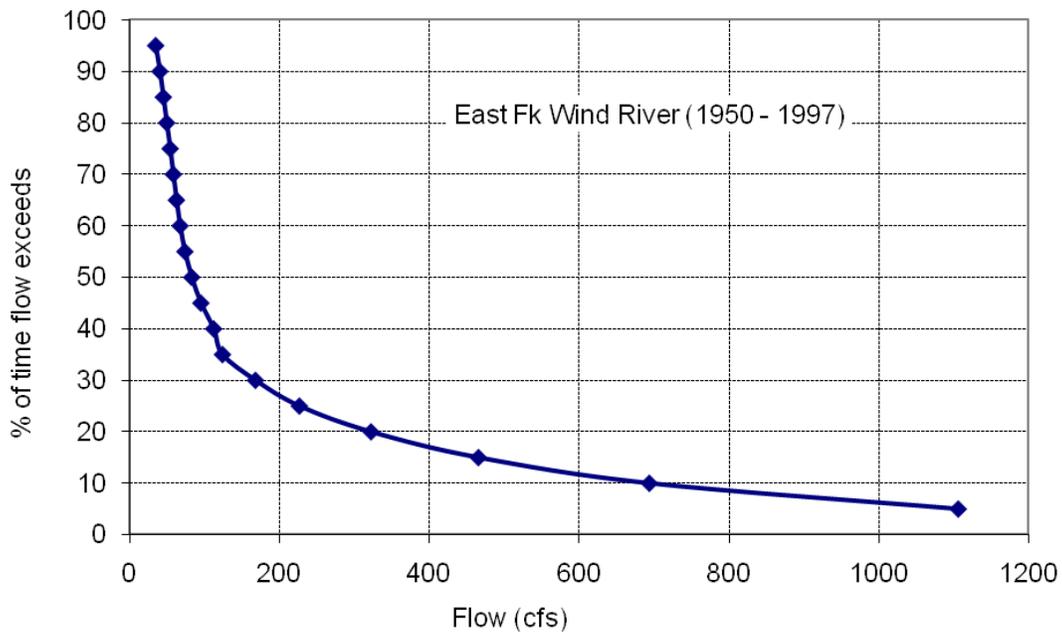


Figure 2. Flow exceedance curves for the East Fork Wind River USGS stream gage station (06220500) over the period of record (1950-1997; developed from Table 3 in HabiTech 2007).

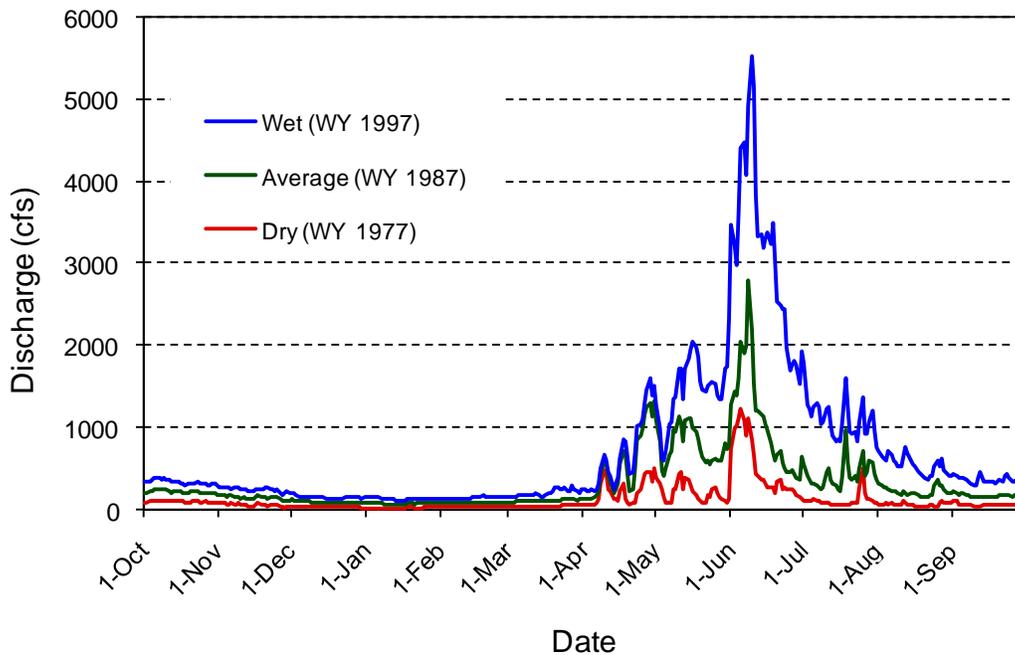


Figure 3. Hydrographs for representative wet, average, and dry water years (WY) from the East Fork Wind River USGS stream gage station (06220500). A representative year was randomly selected from within each of three flow exceedence classes (wet 0-10%, average 10-90%, and dry 90-100%; HabiTech 2007).

Annual stream flow variability (ASFV) and critical period stream flow (CPSF) as defined in Binns (1979) are two measures that characterize local hydrology (Table 2). Annual stream flow variability is the ratio of the instantaneous annual peak flow to the annual low flow, and averages 75.3 at the East Fork Wind River gage. Suitability for trout, expressed in a habitat index score, would be lower if the ASFV ratio were above 100 (less stable flow; Binns 1982). Conversely, habitat suitability would be considered higher if the ASFV ratio were below 40 (more stable flow). The CPSF is the average August 1 through September 15 flow expressed as a percent of average daily flow and averages 66.1%. This CPSF value is indicative of relatively high flow levels in late summer and indicates trout habitat suitability is likely to be relatively higher compared to streams with lower summer flows.

Table 2. Hydrologic statistics from the East Fork Wind River stream gage station (06220500).

	Annual Stream Flow Variability (ASFV; annual peak flow / lowest daily flow)	Critical Period Stream Flow (CPSF; Aug 1 – Sep 15 average flow / average annual flow)
Mean	Ratio = 75.3	66.1 %
Range	23 – 139	18.0 – 149.9 %
n (years)	30	30

Adjudicated irrigation diversions total 28.97 cfs in the East Fork Wind River watershed with priority dates ranging from 1903 to 1984. It appears that the diversions have disrupted some of the natural movement of sediment in the stream channel. There is a great deal of sediment movement through this watershed and frequent failures of structures used to divert flow for irrigation have contributed large pulses of stored sediment to the East Fork Wind River. These high sediment contribution events affect water quality in the short term and require subsequent high flows to naturally move the sediment down through the watershed. In this case, channel maintenance flows are particularly important to maintain or improve important aquatic resources of the East Fork Wind River watershed for public benefit.

Fishery Resources

The fish community in the East Fork Wind River basin includes native YSC (Figure 4), MWF (*Prosopium williamsoni*), mountain sucker (MTS; *Catostomus platyrhynchus*), longnose dace (LND; *Rhinichthys cataractae*), and longnose sucker (LNS; *Catostomus catostomus*). Introduced species include RBT, brook trout (BKT; *Salvelinus fontinalis*), and BNT (*Salmo trutta*). The most abundant species is YSC, but BKT, BNT, and MWF also occur in relatively high numbers at lower elevations; RBT are rare and MTS and LND are also uncommon in WGFD records. Amphibians include Tiger salamander (*Ambystoma tigrinum*), boreal chorus frog (*Pseudocris triseriata maculata*), Columbia spotted frog (*Rana luteiventris*) and boreal toad (*Bufo boreas*).

In the past, the fishery management focus in the Wind River basin was on providing diverse angling opportunities by supplementing natural populations with stocked fish. Cutthroat trout (both YSC and SRC), BKT and BNT were stocked throughout the East Fork Wind River drainage from the early 1900s until 1995. The East Fork Wind River drainage is currently managed as a wild trout fishery with native YSC a vital component of that fishery.



Figure 4. Yellowstone cutthroat trout (photo by WGFD).

One challenge for the fishery in the East Fork Wind River is fish loss to irrigation ditches. There are several diversions throughout the watershed. In 2006-2007, six diversions were evaluated for fish loss during irrigation, including all four diversions on Bear Creek and one each on the Wiggins Fork and East Fork (WGFD 2007). Fish trapping continued in 2008 and all efforts indicated that few fish were lost on the upper two diversions on Bear Creek (Elk Trap and Dennison) but the lower two diversions had significant fish loss. At the Fire House diversion, over 100 YSC were lost in 600 hours of sampling during irrigation season including some large (8 inches and larger) YSC. The lowest irrigation ditch on

Bear Creek (Lower Bear Creek diversion) had losses of 100s of suckers and dace, but only 3 YSC. The Spence Diversion on the East Fork had fish losses in two days of sampling that exceeded all sampling on the Bear Creek diversion throughout the irrigation season. As a result of these sampling results, proposals were developed to modify the two lowest diversions on Bear Creek and the Spence diversion on the East Fork Wind River. These high fish losses in some locations highlight the critical importance of protecting as much water as possible to sustain existing wild YSC populations.

Instream Flow Segments

Stream segments proposed for protection with instream flow water rights are described in Table 3 and displayed in Figure 5. The boundaries for individual segments were identified after considering land ownership, hydrology, and stream channel characteristics. To assure that fish habitat relationships at study sites apply to the majority of the instream flow segment, stream channel characteristics in a defined reach are relatively uniform without major breaks in slope, sediment and substrate size, and channel pattern.

Three instream flow segments were identified on Bear Creek.

- The “Bear Creek Lower” segment begins just upstream from private land approximately 0.4 miles upstream from the confluence of Bear Creek with the East Fork Wind River. This segment includes approximately 2.6 miles of stream and terminates at Lower Bear Creek Diversion.
- The “Bear Creek Middle” segment begins immediately above this diversion and runs upstream approximately 3.5 miles to the Dennison diversion.
- The “Bear Creek Upper” segment begins at the Dennison diversion and terminates 7.1 miles upstream at the Washakie Wilderness boundary.

The Lower and Middle segments are entirely bounded by Commission-deeded land and the upper segment crosses Forest Service land with just a small portion crossing Commission deeded land.

Table 3. Location and length of the proposed instream flow segments in Bear Creek. Coordinates are provided for the downstream end of segments and are UTM Zone 12, NAD27.

Segment	Description	Length (miles)	Easting	Northing	Elevation (feet)	
					Lower	Upper
Lower	Diversion ditch downstream to Commission-deeded property boundary near mouth.	2.6	624697	4826534	6,954	7,108
Middle	Diversion ditch downstream to diversion ditch	3.5	623606	4829739	7,108	7,402
Upper	Confluence of un-named tributaries in Bear Basin downstream to diversion	7.1	620985	4833850	7,402	8,405

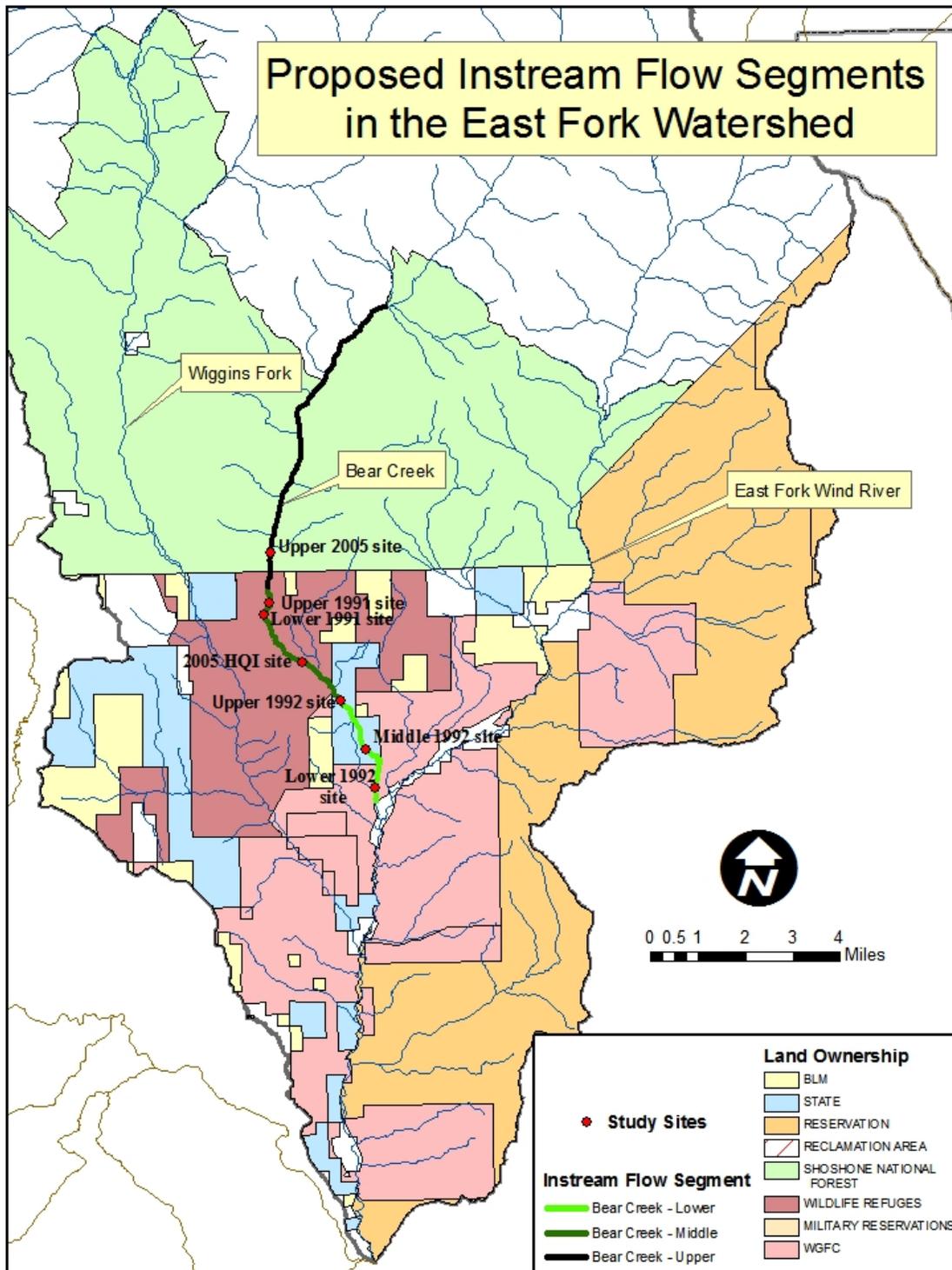


Figure 5. Three potential instream flow segments were identified on Bear Creek and data were collected at six study sites to evaluate fish habitat.

Physical characteristics in the proposed instream flow segments are described in Table 4. A level 2 Rosgen classification was conducted in the upper segment and revealed that the stream type is a B3 in the study site (Table 4). A B3 channel is very stable in pattern and profile (Rosgen 1996). Sediment is transported through but relatively little net removal or deposition occurs. Also, periodic pulses of high flow approximating a natural hydrograph remove fine organic sediment accumulations that might otherwise change ecosystem function under a reduced flow regime. For example, accumulated organic sediment might impair oxygenation of trout eggs and ultimately reduce or limit trout abundance. Periodic bankfull and higher flows to maintain floodplain features are developed in Appendix 1.

Table 4. Stream channel characteristics in the Bear Creek instream flow segments.

Channel Feature	Lower	Middle	Upper
Mean riffle bankfull width (ft)	48.7	34.3	37.0
Mean depth (ft)	1.39	1.75	1.45
Cross section area (ft ²)	67.8	59.7	56.7
Entrenchment ratio	–	–	1.4
*D50 (in)	–	–	3.2
Slope (ft/ft)	–	–	0.028
Sinuosity	–	–	1.11
Stream Type	–	–	B3

* D50 is the median particle size on a cumulative frequency plot. Missing data for the Lower and Middle segments were not collected.

METHODS

Overall Approach

A combination of several different methods was used to develop instream flow recommendations to maintain or improve the fishery in the East Fork Wind River watershed. When possible, data were collected to run each of several habitat models for a study site (including the PHABSIM or River 2D habitat model, the Habitat Retention model, and the Habitat Quality Index model); however, the ecological characteristics and issues at each site were sometimes unique to that site only. As a consequence, though data may have been collected for all models at each site, the ones used for developing a recommendation are selected based on their appropriateness for the characteristics and flow needs at each site. These models provide an evaluation of physical habitat for trout and flow recommendations based on these analyses were chosen to maintain sufficient habitat, which is defined as water depth, velocity, and cover necessary for each fish species and life stage of interest. Recommended flows were designed to protect habitat during portions of the year that are most critical to a given species and life stage. Recommendations were also evaluated relative to natural flow conditions, but because none of the instream flow segments had stream gage data, estimates of stream flow were developed for these comparisons.

With several species and life stages, interpretation of the data is complicated by the number of different peaks in habitat availability and the sometimes conflicting results (i.e., higher flows benefit one species or life stage to the detriment of another). To reduce this complexity, habitat availability was reviewed by individual time periods for which instream flow recommendations were made and focused on the species and life stages for which the flow conditions are most important. There are five time

periods (seasonal blocks) for which instream flow recommendations were made. These include: October 1 to November 15 to maximize habitat available for BNT and MWF spawning; November 16 to March 31 for winter survival; an early spring period (April 1 to 30) that is important for habitat connectivity in anticipation of YSC spawning; the YSC spawning period (May 1 to June 30); and the summer months (July 1 – September 30) when growth of juvenile and adult salmonids is critical due to the short growing period in high elevation watersheds. Habitat availability for MWF fry (present during April-May) is also considered in some of the lower instream flow segments (the species is not typically found higher in the watershed). Similarly, RBT spawning habitat (also April-May) is considered in the East Fork Lower instream flow segment (the only segment in which RBT have been observed). For all habitat evaluations and flow recommendations, YSC habitat requirements were given preference due to the management focus on this species in the East Fork Wind River watershed.

One limitation of these recommendations is that they assume physical geomorphic habitat conditions are stable over time and reflect only changes in the availability and suitability of hydraulic habitat within this existing channel form over a range of different potential stream flows. These analyses do not take into account the dynamic nature of channel-forming processes over long periods of time (e.g., lack of higher flows may result in fine sediment buildup and reduction in spawning habitat suitability). Channel maintenance flows are critical in long-term habitat availability for stream fish. These flows sustain the river channel conditions by permitting a connection to the floodplain, preventing buildup of fine sediments, and facilitating a variety of other important ecological processes (Carling 1995, Annear et al. 2004, Locke et al. 2008). Recommendations for flows sufficient to allow channel maintenance and provide a more complete flow pattern that fully maintains fishery habitat are presented in Appendix 1. Should opportunities arise in the future to secure instream flow water rights for long-term maintenance of the East Fork Wind River aquatic environments; Appendix 1 will provide a valuable reference.

Hydrology

None of the three proposed instream flow segments on Bear Creek had localized stream gage data available. The closest USGS stream gage to all segments was located near the mouth of the East Fork Wind River, which provided a 29-year period of record and served as a good reference gage for generating estimates of flow for each segment. To generate these local flow estimates, an independent hydrologist (HabiTech, Inc., Laramie, WY) was contracted. HabiTech estimated mean annual flow (also called “average daily flow” or ADF), annual flow duration, monthly flow duration, and flood frequency for each of the ten East Fork Wind River instream flow segments (HabiTech 2007). HabiTech calculated average daily flows from the contributing basin area models of Miselis et al. (1999) and Lowham (1988) and determined that the former more accurately predicted flows at the reference gage. The Miselis et al. (1999) model includes basin-specific stream gage data for eight regions in Wyoming as opposed to the more general Lowham (1988) model that was developed from statewide data. The basin area at the downstream end of each instream flow reach was used. A dimensional analysis approach was used to develop both annual and monthly flow duration information. Dimensionless duration tables were created for the East Fork Wind River near Dubois gage by dividing each duration class by the mean annual flow (i.e., Q_w / Q_{AA}). The dimensionless flow value for each annual and monthly percentile was then multiplied by the estimated average annual flow to develop flow duration values. A similar approach was used to develop the flood frequency series. For further details, see HabiTech (2007).

Average daily flow estimates from the HabiTech report were used in applying the Habitat Quality Index and Habitat Retention models (described below). The 1.5-year return interval on the flood frequency series was used to estimate bankfull flow (Rosgen 1996) for use in the Habitat Retention model and for developing channel maintenance flow recommendations (Appendix 1). Channel maintenance calculations also used the 25-year peak flow estimate from HabiTech (2007). The monthly flow duration series was used in developing winter flow recommendations. Throughout this report, the term

“exceedance” is used, as in “20% exceedance flow.” The 20% exceedance flow refers to the flow level that would be exceeded 20% of the time or that would be available approximately one year out of every five consecutive years.

Flow measurements collected by WGFD during instream flow habitat studies are included in the HabiTech (2007; Table 15) report. These flow measurements were used to help calibrate the models and enhance the accuracy of the hydrological estimates by HabiTech (2007).

Fish Habitat

The term “habitat” is used frequently in this report. In most applications, “habitat” refers to the relatively narrow concept of hydraulic habitat that reflects a composite suitability factor based on physical conditions such as depth, velocity, substrate and cover that are used by a particular fish species and life stage. These physical variables are those that change when discharge changes, however they do not represent a complete account of all variables that comprise trout habitat. Habitat for trout also includes water temperature, dissolved oxygen, distribution and abundance of prey and competitor species, movement timing and extent, and other variables. These other variables are important, but are not included in models used for these analyses because they do not fluctuate with changes in the quantity of flow as predictably as the “physical” habitat parameters. Interpretation of model results based on these physical habitat parameters assumes that this subset of trout habitat is important and provides a reasonable indication of habitat availability at each flow and an indirect expression of the ability of trout to persist on a short-term basis.

Models

Physical Habitat Simulation

The Physical Habitat Simulation (PHABSIM) system of computer models calculates a relative suitability index for target species like YSC based on depth, velocity, and substrate or cover (Bovee et al. 1998). 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 across the stream at each of several locations (transects) and involve measuring depth and velocity at multiple locations (cells) along each transect. Measurements are repeated at three or more different discharge levels. By using depths and velocities measured at one flow level, the user calibrates a PHABSIM model to accurately predict the depths and velocities measured at the other 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 user-specified discharges. These predicted depths and velocities, along with substrate or cover information, are compared to habitat suitability criteria (HSC). The relative value to fish of predicted depths, velocities, substrates, and cover elements are defined by HSC which range between “0” (no suitability) and “1” (maximum suitability). At any particular discharge, a combined suitability for every cell is generated. That suitability is multiplied by the surface area of the cell and summed across all cells to yield weighted useable area for the discharge level. Results are often depicted by graphing WUA for a particular fish life stage versus a range of simulated discharges (Bovee et al. 1998). Relationships are best interpreted as a relative suitability index rather than a definitive prediction of physical area (Payne 2003).

The HSCs used for these analyses were acquired from several sources. For adult (6 inches or greater total length) and juvenile (3 to 6 inches) YSC, HSCs were developed by WGFD by measuring depth, velocity, substrate, and cover at locations occupied by individual trout in Trout Creek in 2004 (Dey and Annear 2006). Yellowstone cutthroat trout spawning HSCs were developed by Thurow and King

(1994) who collected measurements at 66 YSC spawning locations in Idaho on a Snake River tributary. Fry HSC were developed from measurements reported in Bozek and Rahel (1992). Adult and juvenile HSCs for RBT and BNT and all four life stages for MWF were obtained from a workshop on HSC development for the Saskatchewan River Basin in Alberta, Canada. This workshop included several fish habitat experts and used existing data from several watersheds to develop curves that can be used broadly for PHABSIM studies (Addley et al. 2003). Spawning HSCs for BNT and RBT were obtained from Bovee (1978) and fry HSCs for both species from Nehring and Anderson (1993).

The PHABSIM approach was used to estimate flows that will maintain habitat for individual life stages during critical time periods. Physical habitat for adults and juveniles of each species were modeled for each month over the entire year. Spawning activity for YSC has been documented throughout May and June in other watersheds within the Big Horn River Basin in north central Wyoming (Greybull River, Shoshone River and their tributaries; Dey and Annear 2002, Dey and Annear 2006) and is consistent with observations in the East Fork Wind River (J. Deromedi, WGFD regional fisheries biologist, pers. comm.). Elevation does have some influence on the timing of spawning in YSC with stream segments located at higher elevations more likely to remain colder and cause both spawning and egg incubation to occur later in the summer. Dey and Annear (2003) found that spawning occurred into July in streams above approximately 8000 ft in elevation (in the Greybull watershed) and extended recommendations for spawning flows through July 15 in such high elevation sites. The upper portions of each of the three major streams in the East Fork Wind River are above 8000 ft in elevation and it is likely that where YSC spawning occurs, it extends into July. However, each instream flow segment (or the majority of each) is below this elevation, so without more local information on the spawning period for each segment it was assumed to occur between May 1 and June 30 for all segments. Fry habitat for YSC is important from July through October. MWF spawn between September and November and their fry are present from March to May (Baxter and Stone 1995). RBT spawn in most Wyoming streams between February and May (Baxter and Stone 1995) and fry habitat is important in June through September. BNT spawn in the fall (October and November) and fry are present during April through June.

Habitat Retention

The Habitat Retention Method (Nehring 1979; Annear and Conder 1984) was used to identify the flow that maintains specified hydraulic criteria (Table 5) in riffles. Maintaining depth, velocity and wetted perimeter criteria in riffles is based on an assumption that other habitat types like runs or pools remain viable when adequate flows are provided in shallow riffles that serve as hydraulic controls (Nehring 1979). Flow recommendations derived from the Habitat Retention Method are intended to identify instream flows needed to maintain fish passage between habitat types and benthic invertebrate survival at any time of year when the recommended flow is naturally available. The flow identified by the Habitat Retention Method is important year round, except when higher instream flows are required to meet other fishery management purposes.

Table 5. Hydraulic criteria for determining maintenance flow with the Habitat Retention method. These criteria vary with larger streams; for streams with a mean bankfull width greater than 20 feet the mean depth criteria is the product of 0.01 * mean bankfull width.

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 translate depth and velocity information into conclusions about incremental changes in the amount of physical space suitable for trout life stages. The habitat retention method focuses on riffle hydraulic characteristics so that fish passage and invertebrate production is maintained. 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 (Table 5) for all three transects is then identified; however, because of the critical importance of depth for maintaining fish passage, the 0.2 ft threshold is treated as an absolute minimum allowable.

Habitat Quality Index

The Habitat Quality Index (HQI; Binns and Eiserman 1979; Binns 1982) was used to determine relative trout habitat suitability or production potential over a range of late summer (July through September) 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 facilitate growth. The HQI was developed by the WGFD to estimate trout production in terms of nine biological, chemical, and physical trout habitat attributes. Each attribute is assigned a rating from 0 to 4 with higher ratings representing better trout habitat features. 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, though the precise relationship can vary between streams. HQI results were used to identify the flow between July 1 and September 30 needed to maintain existing levels of adult and juvenile Yellowstone cutthroat trout production and is based on an assumption that flow needs for other life stages are adequate at all other times of year.

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 that flow level were a base flow occurring in September. Under this assumption, HU estimates are extrapolated through a range of potential late summer flows (Conder and Annear 1987). Some attribute ratings were mathematically derived to establish the relationship between discharge and trout habitat at discharges other than those measured. In calculating Habitat Units over a range of discharges, temperature, nitrate concentration, invertebrate numbers, and eroding banks were held constant.

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”. The HQI is used to identify a flow to maintain the existing fishery in the following manner: the number of habitat units that occur under normal July through September flow conditions is quantified and then the flow that maintains that level of habitat is identified. The August 50% monthly exceedance flow was used as the

reference standard of normal late summer flow levels and is consistent with how the HQI was developed (Binns and Eiserman 1979).

Natural Winter Flow

The three modeling approaches described in the Methods section were used to generate fish-based instream flow water right recommendations for seasonal periods from April through October, but these tools are not as well suited to determine flow requirements during ice-prone times of year (November through March) for the fish species found in the East Fork Wind River and tributary segments. These methods were all developed for and apply primarily to open-water periods. Ice development during winter months can change the hydraulic properties of water flowing through some stream channels and compromise the utility of models developed for open water conditions. There are no widely accepted aquatic habitat models for quantifying instream flow needs for fish in under-ice. As a result, a different approach was used to develop recommendations for this time period.

Scientific understanding of winter trout habitat and the interaction between trout behavior, physiology, and survival during periods when ice is present has increased considerably over the last 60 years (Needham et al. 1945, Reimers 1957, Butler 1979, Cunjak 1988, Cunjak 1996, Prowse 2001a and 2001b, Annear et al. 2002). Prowse (2001a and 2001b) provides an extensive review of the wide range of effects ice processes have on the hydrologic, biologic, geomorphic, water quality and connectivity characteristics of riverine resources and fisheries. Ice formation and break-up processes in particular are extremely critical periods that affect trout survival. For example during open water periods in the fall and winter, suspended ice crystals (frazil ice) form when the river becomes super-chilled but an ice cover has not formed. During these times increased trout mortality can occur directly through gill abrasion and subsequent suffocation or indirectly by limiting available habitat, causing localized de-watering and excessive metabolic demands on fish forced to seek ice-free habitats (Brown et. al 1994, Simpkins et al. 2000, Annear et al. 2002, Lindstrom and Hubert 2004, Barrineau et al. 2005). Pools downstream from high gradient frazil ice-forming areas can accumulate anchor ice when woody debris or surface ice provides anchor points for frazil crystals (Brown et. al 1994, Cunjak and Caissie 1994). Such accumulations may result in mortalities if low winter flows or ice dams block emigration.

Mortalities can occur if fish are forced to move when water temperatures are near freezing, such as to avoid the physical effects of frazil ice or if changing hydraulic conditions force them to find areas of more suitable depth or velocity. The extent of impacts is dependent on the magnitude, frequency and duration of frazil events and the availability of alternate escape habitats (Jakober et. al, 1998, Simpkins et al. 2000). Juvenile and fry life stages are typically impacted more than larger fish because younger fish inhabit shallower habitats and stream margins where frazil ice tends to concentrate. Larger fish that inhabit deeper pools may endure frazil events with little effect if they are not displaced. Recent studies in Wyoming document complex interactions in localized areas with groundwater influx, ice formation, and trout habitat suitability (Barrineau et al. 2005).

The complexities of variable icing patterns make modeling of winter trout habitat over a range of flows difficult if not impossible. For example, frazil and surface ice may form and break up on multiple occasions over the winter over widely ranging spatial and temporal scales. Even cases that can be modeled, for example a stable ice cap over a simple pool, may not yield a result worthy of the considerable time and expense necessary to calibrate an ice model. The book Instream Flows for Riverine Resource Stewardship (Annear et al. 2004, Pp. 106) recognizes the challenges of developing winter flow prescriptions with the following statement:

Unfortunately, the tools to quantify the relation between flow and favorable ice conditions, and habitat, are limited at this time. In the face of this uncertainty,

managers should take a conservative approach when their actions or those of others will result in modification of winter flow regimes, either by additions or depletions.

For Wyoming Rocky Mountain headwater streams, a conservative approach to meeting the instream flow law's requirement of developing flow recommendations to maintain existing fisheries is to maintain the existing natural winter flow level. That approach was adopted for the ten instream flow segments in this report. The scientific literature indicates that already harsh winter habitat conditions would become more limiting if winter water depletions were to occur. Even relatively minor flow reduction at this time of year can force trout to move more frequently, change the frequency and severity of ice formation, distribution and retention, and reduce the holding capacity of the few large pools often harboring a substantial proportion of the total trout population (Lindstrom and Hubert 2004).

Indirect methods, such as the Habitat Retention approach employed by the WGFD, are an alternative way of indexing changes in trout habitat under winter flow levels and this approach was used in the past to set winter flow recommendations for many instream flow segments. Habitat Retention analyses are still conducted to ensure that riffle hydraulics are maintained under ice-free conditions. When natural winter flows in mountain streams are greater than those from Habitat Retention, the natural winter flow is the preferred expression of instream flow needed to maintain the existing fishery.

Another indirect method is developing hydrologic standards for universal application across Wyoming. This approach was found deficient by Hubert et al. (1997) due to the variable nature of winter trout habitat among streams and poor gage records often associated with the winter season. For this reason, the 50% monthly exceedance does not provide an appropriate estimate of naturally occurring winter flow. It is more conservative and appropriate from the standpoint of maintaining fisheries to recommend the higher flows of a 20% monthly exceedance. Such an approach assures that even in cases where flow availability is underestimated due to poor gage records or other estimation errors, flow approximating the natural winter condition will be recommended.

Site-Specific Data Collection and Analysis

Bear Creek – Lower Segment

Modeling tools used to develop recommendations for this instream flow segment include PHABSIM, Habitat Retention, and HQI. Data for PHABSIM and Habitat Retention were collected in 1992 while data for HQI were collected in 2005.

Twelve transects were established in two sites on Commission-deeded land in 1992, one site near the lower end of this 2.6 mile long instream flow segment and the other site at approximately the mid-point of the segment. Each of the two sites included 3 riffle and 3 pool transects that were used in PHABSIM analysis. All three riffle transects in each site were used in Habitat Retention analysis. Coordinates (UTM, NAD27, Zone 12) for the lower site are: 624660 E, 4827006 N; coordinates for the middle site are: 624351E, 4828319N.

The study sites were visited on three dates in 1992 and three dates in 2005 to measure stage, discharge, and habitat features under a range of flow conditions (Table 6, Table 7). Velocity measurements used in calculating discharge estimates were collected using a Marsh-McBirney Model 2000 flow meter set to integrate readings over a 25 second interval. Discharge estimation followed Rantz (1982). These measurements provided a stage-discharge relationship for hydraulic modeling and also provided calibration data for the Habitat Retention model.

Table 6. Dates of collection and discharge measurements collected in the Bear Creek Lower instream flow segment in 1992.

Date	Discharge (cfs)
May 30	50
June 19	87
August 19	12

Table 7. Dates of collection and discharge measurements collected in the Bear Creek Lower instream flow segment in 2005.

Date	Discharge (cfs)
June 24	66
July 22	10.7
August 18	4.9

Bear Creek – Middle Segment

Modeling tools used to develop recommendations for this instream flow segment include PHABSIM, Habitat Retention, and HQI. Data for PHABSIM were collected in 1991 and 1992, data for Habitat Retention analyses were collected in 1992, and data for HQI were collected in 2005.

Ten transects were established in two sites on Commission-deeded land in 1991 near the upper end of the 3.5-mile instream flow segment that runs from the “Dennison” diversion down to the “Fire House” diversion. An additional seven transects were established in 1992 at the lower end of the segment and HQI data were collected at approximately the mid-point of the segment in 2005. All 17 transects established in 1991-1992 were used to generate PHABSIM analyses for each of the three sites. Habitat Retention modeling was only feasible on three riffle transects in the 1992 study site. Coordinates (UTM, NAD27, Zone 12) for the two 1991 sites were: 620881 E, 4832896 N; 621070 E, 4833291 N, and for the 1992 site: 623495 E, 4829965 N, and for the 2005 site: 622186 E, 4832896 N.

The study sites were visited on two dates in 1991, three in 1992, and three in 2005 to measure stage, discharge, and habitat features under a range of flow conditions (Table 8, Table 9, and Table 10). Velocity measurements used in calculating discharge estimates were collected using a Marsh-McBirney Model 2000 flow meter set to integrate readings over a 25 second interval. Discharge estimation followed Rantz (1982). These measurements provided a stage-discharge relationship for hydraulic modeling and also provided calibration data for the Habitat Retention model.

Table 8. Dates of collection and discharge measurements collected in the Bear Creek Middle instream flow segment in 1991.

Date	Discharge (cfs)
July 1	42.9
July 20	18.2

Table 9. Dates of collection and discharge measurements collected in the Bear Creek Middle instream flow segment in 1992.

Date	Discharge (cfs)
May 29	60
June 19	141
August 19	12

Table 10. Dates of collection and discharge measurements collected in the Bear Creek Middle instream flow segment in 2005.

Date	Discharge (cfs)
July 20	9.9
September 16	5.7
October 13	4.5

Bear Creek – Upper Segment

Modeling tools used to develop recommendations for this instream flow segment include PHABSIM, Habitat Retention, and HQI. All data were collected in 2005.

Fifteen transects were established in 2005 on Forest Service property near the downstream end of the 7.1-mile instream flow segment that runs from the Washakie Wilderness boundary down to the “Dennison” diversion. Of the fifteen transects used for PHABSIM analysis, three represent control riffles that were used for Habitat Retention. Approximate coordinates (UTM, NAD27, Zone 12) for the site are: 621078 E, 4835025 N.

The study site was visited on three dates in 2005 to measure stage, discharge, and habitat features under a range of flow conditions (Table 11). Velocity measurements used in calculating discharge estimates were collected using a Marsh-McBirney Model 2000 flow meter set to integrate readings over a 25 second interval. Discharge estimation followed Rantz (1982). These measurements provided a stage-discharge relationship for hydraulic modeling and also provided calibration data for the Habitat Retention model.

Table 11. Dates of collection and discharge measurements collected in the Bear Creek Upper instream flow segment in 2005.

Date	Discharge (cfs)
June 23	71
July 20	13.7
September 13	7.9

Flows for Other Important Ecosystem Components

The hydraulic analyses used to generate instream flow recommendations in Bear Creek focus primarily on narrowly defined methods for maintaining short-term fish habitat. Additional biological issues include maintaining diverse riparian and floodplain vegetation and the community of animals that use these habitats. Channel maintenance flow recommendations (as described in Appendix 1) would promote a healthy riparian assemblage of plants and animals resembling that of today (Stromberg and Patten 1990; Rood et al. 1995; Mahoney and Rood 1998).

Existing water quality conditions in the East Fork Wind River watershed are excellent in and upstream of the instream flow segments. That is, water temperature, turbidity, and various organic and inorganic constituents are believed to be at normal levels for a fairly pristine Absaroka Mountain stream and no anthropogenic pollution is apparent (Kent 1984). Flow recommendations in this report are expected to maintain water quality within natural bounds and assume that existing water quality features remain within existing limits of natural variability. If factors affecting this assumption change in the future, water quality issues might bear reexamination of instream flow needs.

RESULTS AND DISCUSSION

Bear Creek – Lower Segment

Hydrology

The mean daily discharges that occurred in the East Fork Wind River basin during July, August, and September in study years (1991, 1992, 2005, and 2006) were generally lower than the long-term averages for those months (54 year period of record). Mean daily flows at the East Fork Wind River stream gage station (06220500) during July were 81, 41, 58, and 44 % of average during 1991, 1992, 2005, and 2006, respectively. In August, mean daily flows were 98, 47, 71, and 61% of average during those years and in September; these percentages were 105, 65, 77, and 74%. Despite the relatively low flows during these study periods and potential negative consequences for the fishery, there were no limitations on our ability to study the effects of a range of flows on fish habitat conditions.

Table 12 lists estimated mean annual flow and select flood frequency and monthly flow duration estimates for the Bear Creek Lower instream flow segment (HabiTech 2007). HabiTech (2007) noted that WGFD discharge measurements collected in the segment were within expectations of their estimates and concluded that their approach yielded reasonable results. The first of three discharge measurements conducted by WGFD in May 1992 (Table 6) was close to the estimated 50% monthly exceedance value (Table 12) but the other two in 1992 (June and August) and all three of those collected in 2005 (Table 7)

were lower than the 50% exceedance level. Again, this situation did not limit our ability to model the effect of flow conditions on habitat over a range of flows.

Table 12. Estimated hydrologic characteristics for the Bear Creek Lower instream flow segment (HabiTech 2007).

Flow Parameter		Estimated Flow (cfs)
Mean Annual		49
1.5-year peak		518
25-year peak		1079
Spring Month	Estimated 50% Exceedence (cfs)	Estimated 20% Exceedence (cfs)
April	18.9	37.6
May	77.0	147.9
June	166.9	291.7
Summer Month	Estimated 50% Exceedence (cfs)	Estimated 20% Exceedence (cfs)
July	84.8	156.9
August	30.6	47.9
September	19.1	28.5
Winter Month	Estimated 50% Exceedence (cfs)	Estimated 20% Exceedence (cfs)
October	15.9	22.1
November	11.0	14.6
December	9.3	11.4
January	8.3	10.9
February	9.1	10.5
March	10.7	12.5

In addition to monthly exceedence values as an indicator of flow conditions in the segment, HabiTech (2007) also produced daily flow estimates for three individual years (the 29-year period of record was first divided to represent wet, dry, and average conditions, then a representative year randomly selected from each group). Stream gage data from the same randomly selected three years were used to prepare daily flow estimates for all segments. Because of this and the fact that estimates for all segments are based on data from the same gage (near the mouth of the East Fork Wind River), the three representative hydrographs follow the same pattern for each segment with the difference being that the curve migrates up or down on the y-axis in proportion to the contributing basin area upstream of each segment (Figure 6). These hydrographs provide an indication of the range of discharge conditions that may occur in each instream flow segment. However, there is considerable variation in the timing and pattern of flow within a given year and between different years that is not fully described by three individual hydrographs simulated by HabiTech (2007). As a consequence these should be viewed only as a general template of runoff patterns.

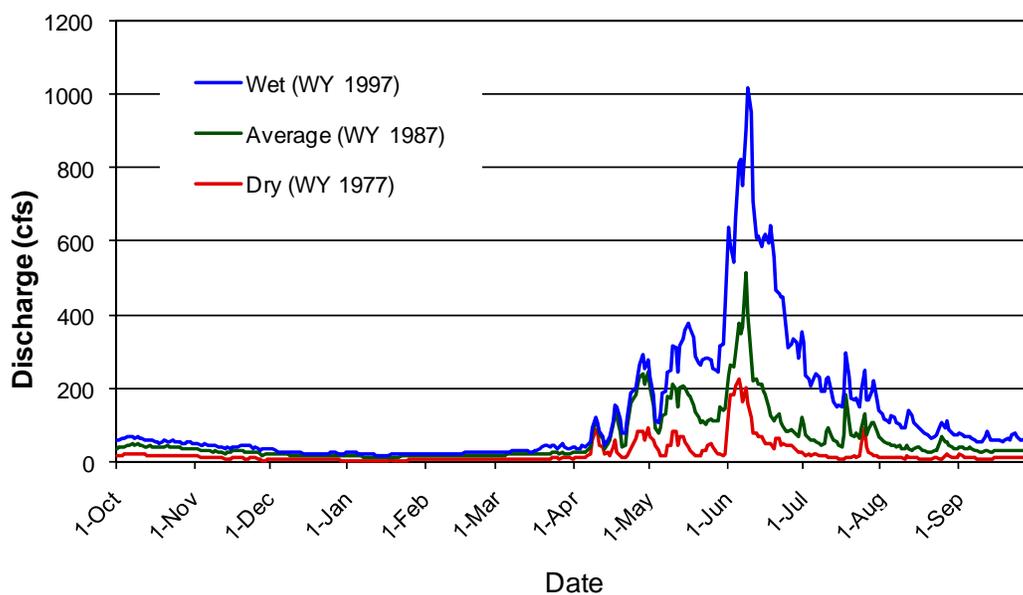


Figure 6. Simulated annual hydrographs for wet, dry, and average conditions in the Bear Creek Lower instream flow segment (HabiTech 2007).

Physical Habitat Simulation Model

There were two study sites in this instream flow segment (the 1992 lower and 1992 middle sites) and PHABSIM models were generated for both to help develop flow recommendations (Figure 7, Figure 8). Habitat availability was evaluated for all three salmonid species (YSC, BNT, and MWF) that are present in this instream flow segment. Simulations were conducted through both study sites using a calibrated PHABSIM model over the flow range 2 cfs to 400 cfs. The model for each site was run at each flow increment using data from each of six transects (3 riffles and 3 pools).

Transect data were collected individually and not part of a combined project; thus, separate models were developed for each transect and weighted appropriately to generate a sum total of available habitat. When a calibrated model was run for a given species / life stage at a given discharge, the resulting weighted usable area (WUA) for that transect was weighted by the abundance of the habitat type represented by that transect in the instream flow segment. Habitat mapping, conducted in 2005, determined that the habitat weighting factor should be 37.1% for pools, 0% for rapids, 55.2% for riffles, and 7.7% for runs. Because no transects were included in either model for runs, the weighting factor for that habitat type was split evenly between the two habitat types for which there were transects, riffles and pools. The weighting factor of an individual transect was determined by dividing the total value for a given habitat type by the number of transects of that type. The sum of the WUA from all weighted individual transect results was used as the final model output to represent habitat availability for a given species / life stage at the modeled discharge. It was these WUA data that were used to determine “peak” habitat availability for critical species / life stages in each of the five time periods described in the Methods section.

Using output from the models at both study sites, it appears that a discharge of 35 cfs provides the greatest amount of useable area (>87% of maximum) for juvenile and adult YSC over the range of flows for which the model was run. This flow also provided a relatively high amount of useable area (>85% of

maximum) for adults and juveniles of BNT. The higher velocities that MWF prefer (compared to all of the trout species) make it difficult to maximize habitat for that species while also ensuring favorable habitat conditions for trout, but with 35 cfs, over 70% of the maximum WUA (over the range of flows for which the model was run) is maintained. During the spring YSC spawning period (May 1 – June 30) the model indicated that 25 cfs would maximize spawning habitat for YSC over the range of flows for which the model was run. To maximize spawning habitat for BNT and MWF from October 1 to November 15, the model indicated that relatively high flows were needed. For spawning MWF, peak habitat availability occurs at 90-125 cfs, while the peak BNT spawning habitat occurs between 30-40 cfs. An intermediate flow that benefits both species is 60 cfs. Habitat for MWF fry (present April 1 – May 31) is maximized at 35 cfs (over the range of flows for which the model was run) at both study sites.

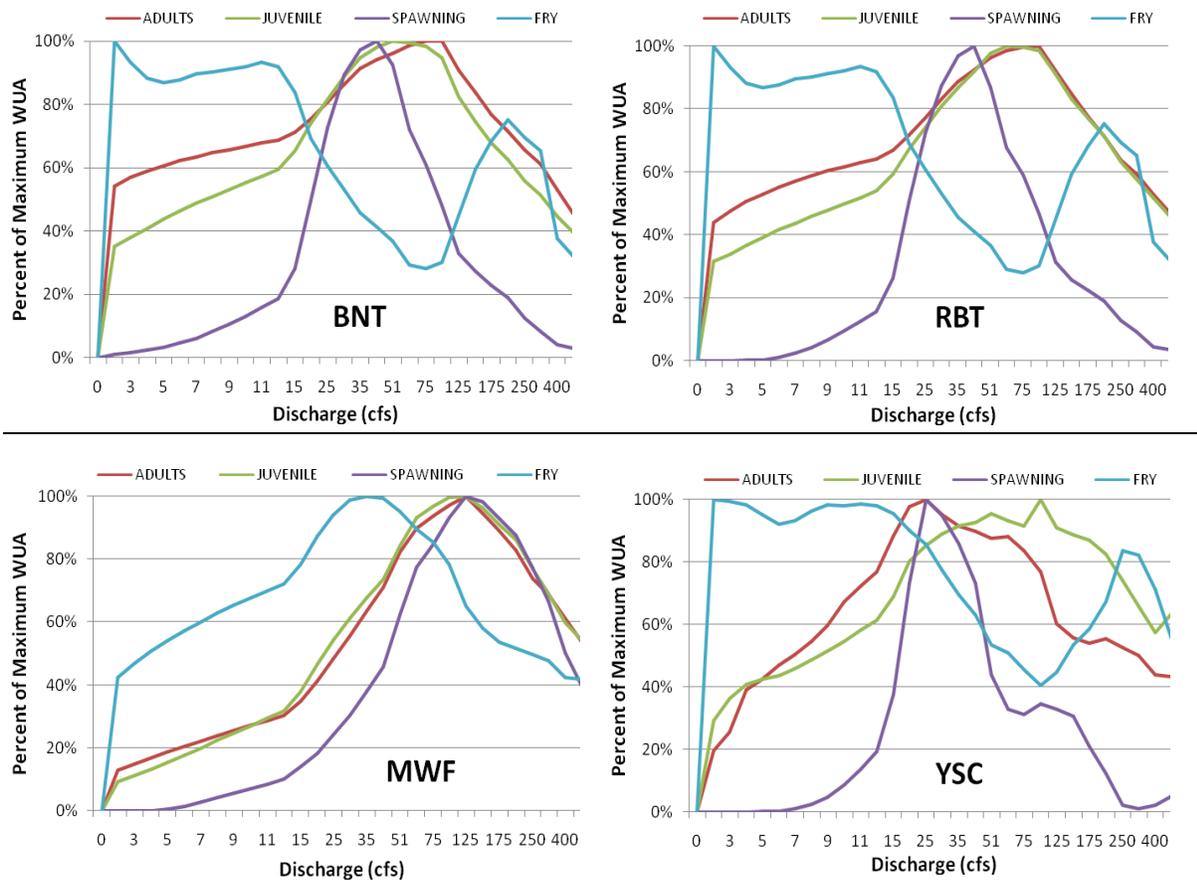


Figure 7. Percent of maximum weighted useable area (WUA) for the four study species using the PHABSIM model on data from the 1992 lower study site within the Bear Creek Lower instream flow segment.

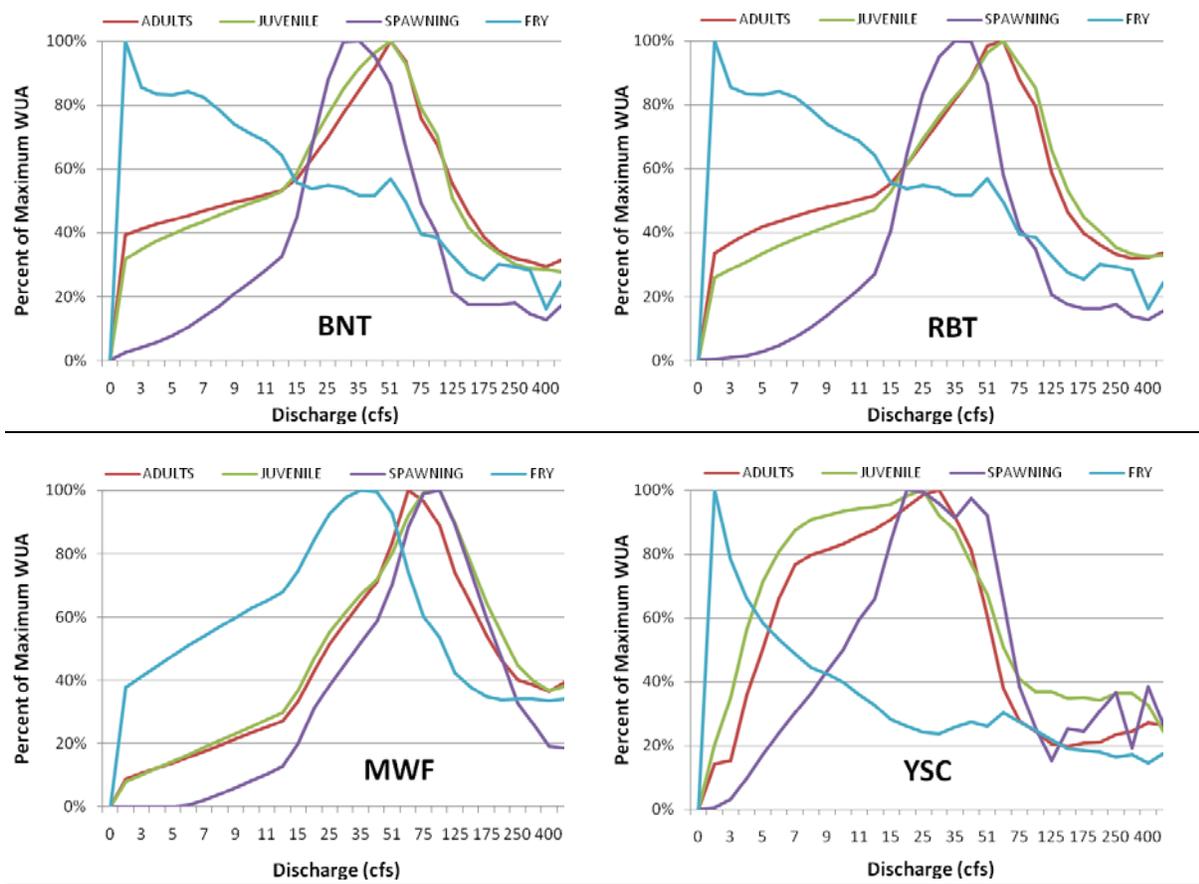


Figure 8. Percent of maximum weighted useable area (WUA) for the four study species using the PHABSIM model on data from the 1992 middle study site within the Bear Creek Lower instream flow segment.

Habitat Retention Model Calibration and Simulation

Habitat Retention data were available for both study sites (lower and middle 1992 sites). In the lower study site, average depth, average velocity, and wetted perimeter at a range of modeled discharges were evaluated on three riffle transects (Table 13). At riffle 1, depth is the first hydraulic criterion met as flow declines from its bankfull level to 31 cfs. As flow continues to decline, the minimum value allowed for depth (0.2 feet) is reached at 6.5 cfs before either the velocity or wetted width criteria are met. In this case, the depth criterion alone is used to determine the flow required (6.5 cfs) to maintain habitat across the riffle. For riffles 2 and 3 the minimum depth is not reached before 2 of 3 hydraulic criteria are met. The required flows for riffles 2 and 3 are natural flows up to 9 and 13 cfs.

In the middle 1992 study site, average depth, average velocity, and wetted perimeter at a range of modeled discharges were evaluated on three riffle transects (Table 14). At riffle 1, depth is the first hydraulic criterion met as flow declines from its bankfull level to 13 cfs. Next, the wetted perimeter criterion is met at a flow of 4.5 cfs. Thus, natural flow up to 4.5 cfs is the recommended flow required to maintain habitat across riffle 1. For riffles 2 and 3, the minimum depth criterion is met before a second hydraulic criterion and occurs at 8.5 and 7.5 cfs, respectively.

The flow that retains two of three criteria for all of the studied riffles in the lower and middle 1992 study sites is 13 cfs and based on the Habitat Retention model, this flow is necessary year round to maintain trout survival, movement and invertebrate production throughout the instream flow study segment.

Table 13. Estimated hydraulic conditions for three riffles over a range of modeled discharges in lower 1992 study site within the Bear Creek Lower instream flow segment. Bold indicates that the hydraulic criterion was met for an individual attribute. Bankfull flow was 518 cfs. Average width of the segment at this flow was 48.7 so the mean depth criterion was 0.49 feet. The flow meeting 2 of 3 criteria for each riffle are shaded.

	Discharge (cfs)	Mean Velocity (ft/sec)	Mean Depth (ft)	Wetted Perimeter (% of bankfull)
Riffle Transect 1	518.0	6.52	1.60	1.000
	200.0	4.40	1.14	0.797
	92.0	3.13	0.82	0.716
	51.0	2.42	0.62	0.680
	31.0	1.96	0.49	0.75
	12.0	1.38	0.28	0.618
	10.0	1.30	0.25	0.608
	8.0	1.21	0.22	0.591
	6.5	1.14	0.20	0.577
	4.0	1.00	0.15	<0.55
Riffle Transect 2	518.0	7.30	1.34	1.00
	200.0	4.63	0.94	0.86
	92.0	3.22	0.71	0.76
	51.0	2.47	0.54	0.72
	41.0	2.25	0.49	0.71
	25.0	1.88	0.36	0.70
	10.0	1.54	0.24	0.51
	9.0	1.50	0.23	0.49
	7.0	1.39	0.22	0.44
	5.0	1.26	0.20	0.38
4.0	<1.19	0.18	0.36	
Riffle Transect 3	518.0	9.79	1.23	1.00
	200.0	5.29	0.94	0.93
	92.0	3.23	0.72	0.91
	51.0	2.24	0.58	0.90
	30.0	1.63	0.49	0.89
	20.0	1.29	0.40	0.88
	13.0	1.01	0.34	0.87
	10.0	0.88	0.30	0.87
	8.0	0.79	0.27	0.85
	6.0	0.68	0.24	0.83
4.0	0.56	0.20	<0.79	

Table 14. Estimated hydraulic conditions for three riffles over a range of modeled discharges in middle 1992 study site within the Bear Creek Lower instream flow segment. Bold indicates that the hydraulic criterion was met for an individual attribute. Bankfull flow was 518 cfs. Average width of the segment at this flow was 34.3 so the mean depth criterion was 0.34 feet. The flow meeting 2 of 3 criteria for each riffle are shaded.

	Discharge (cfs)	Mean Velocity (ft/sec)	Mean Depth (ft)	Wetted Perimeter (% of bankfull)
Riffle Transect 1	518.0	8.57	1.85	1.00
	200.0	5.00	1.31	0.92
	81.0	3.08	0.89	0.88
	49.0	2.40	0.70	0.86
	13.0	1.42	0.34	0.78
	10.0	1.32	0.30	0.75
	6.0	1.18	0.27	0.56
	4.5	1.08	0.25	0.49
	4.0	<1.04	0.24	0.46
Riffle Transect 2	518.0	8.32	1.86	1.00
	200.0	5.07	1.26	0.92
	81.0	3.26	0.81	0.89
	49.0	2.60	0.62	0.87
	18.0	1.79	0.34	0.84
	10.0	1.57	0.22	0.82
	8.5	1.54	0.20	0.80
	6.0	1.51	0.18	0.64
	4.0	<1.46	0.14	<0.57
Riffle Transect 3	518.0	9.16	1.54	1.00
	200.0	5.33	1.11	0.92
	81.0	3.25	0.78	0.87
	49.0	2.51	0.62	0.85
	16.0	1.52	0.34	0.82
	10.0	1.31	0.25	0.80
	8.0	1.24	0.22	0.80
	7.5	1.23	0.20	0.80
	6.0	1.19	0.17	0.79
4.0	<1.21	0.12	<0.72	

Habitat Quality Index Model

The HQI model data (Figure 9) was important in evaluating late summer habitat availability for this instream flow segment. Data for the HQI model were collected in the lower portion of this instream flow segment in 2005. The estimated monthly streamflows that occur 50% of the time are: 85, 31, and 19 cfs for the months of July, August, and September respectively (Table 12). The 31 cfs August value provides a reasonable estimate of normal late summer flow levels. At this flow, the stream provides 10.5 Habitat Units. The lowest flow that will maintain 10.5 Habitat Units is 29 cfs; therefore, the instream flow recommendation to maintain adult YSC habitat during the late summer period is 29 cfs.

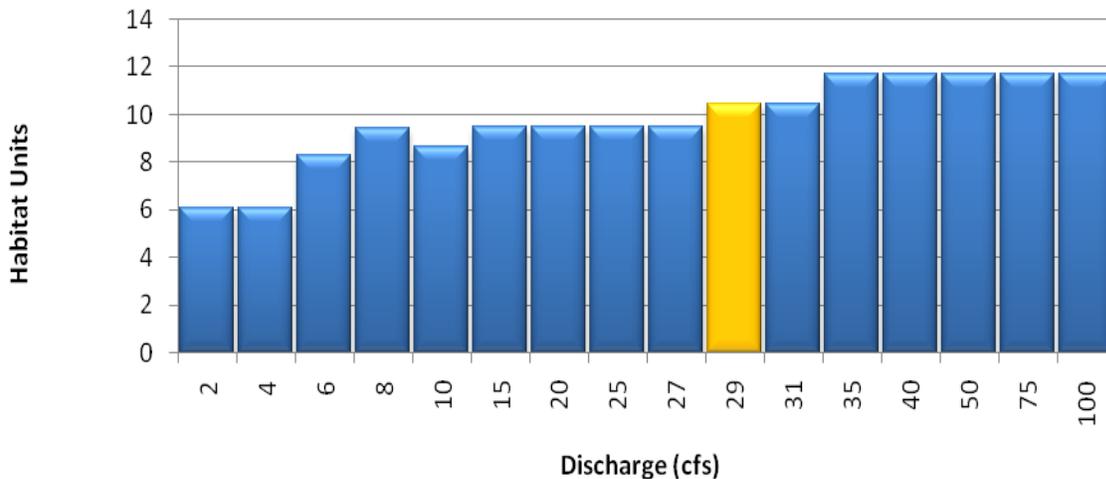


Figure 9. Habitat Quality Index for a range of flow levels in the Bear Creek Lower instream flow segment. X-axis flows are scaled to show where changes in Habitat Units occur. The recommended flow is indicated by the light shaded bar.

Instream Flow Recommendations

A table with instream flow recommendations for all segments (Table 19) is included in the section titled “Summary of Instream Flow Recommendations.” Recommendations are provided for specific seasonal fishery needs for the Bear Creek Lower instream flow segment:

- To maximize habitat for the two species that spawn in the fall (BNT and MWF; October 1 – November 15) requires 60 cfs according to the PHABSIM results. However, that flow may occur infrequently according to discharge estimates (HabitTech 2007); therefore, the recommendation is for the lowest 20% exceedence flow (natural flow up to 15 cfs) during this time period.
- Natural winter flows up to 11 cfs are recommended for November 16 – March 31. This is the lowest estimated value for the 20% monthly exceedence discharge during that time period.
- During the early spring period (April 1 – 30) natural flow up to 35 cfs is recommended (based on PHABSIM results) to maximize YSC juvenile and adult habitat while also providing near maximum habitat for MWF fry.
- The spring spawning flow period (May 1 – June 30) recommendation of natural flows up to 25 cfs is based on peak spawning habitat available to spawning YSC.
- The summer (July 1 – September 30) recommendation of natural flows up to 29 cfs was based on HQI data.

Bear Creek – Middle Segment

Hydrology

As discussed in the section on the Bear Creek Lower instream flow segment, the discharges that occurred in the East Fork Wind River basin during the course of this study were generally lower than the long-term monthly averages. Table 15 lists estimated mean annual flow and select flood frequency and monthly flow duration estimates for the Bear Creek Middle instream flow segment (HabiTech 2007). HabiTech (2007) noted that WGFD discharge measurements collected in the segment were within expectations of their estimates and concluded that their approach yielded reasonable results. Many of the flows measured by WGFD in 1991, 1992, and 2005 (Table 8, Table 9, and Table 10) were lower than the estimated 50% exceedance level (Table 15), but this did not limit our ability to model the effect of flow conditions on habitat over a range of flows.

Table 15. Estimated hydrologic characteristics for the Bear Creek Middle instream flow segment (HabiTech 2007).

Flow Parameter		Estimated Flow (cfs)	
Mean Annual		47	
1.5-year peak		497	
25-year peak		1035	
Spring Month	Estimated 50% Exceedence (cfs)	Estimated 20% Exceedence (cfs)	
April	18.1	36.1	
May	73.8	141.9	
June	160.1	279.8	
Summer Month	Estimated 50% Exceedence (cfs)	Estimated 20% Exceedence (cfs)	
July	81.3	150.5	
August	29.4	45.9	
September	18.3	27.3	
Winter Month	Estimated 50% Exceedence (cfs)	Estimated 20% Exceedence (cfs)	
October	15.3	21.2	
November	10.6	14.0	
December	8.9	10.9	
January	8.0	10.4	
February	8.7	10.1	
March	10.3	12.0	

In addition to monthly exceedence values as an indicator of flow conditions in the segment, HabiTech (2007) also produced daily flow estimates for three individual years (the 29-year period of record was first divided to represent wet, dry, and average conditions, then a representative year randomly selected from each group). Stream gage data from the same randomly selected three years were used to prepare daily flow estimates for all segments. Because of this and the fact that estimates for all segments are based on data from the same gage (near the mouth of the East Fork Wind River), the three representative hydrographs follow the same pattern for each segment with the difference being that the

curve migrates up or down on the y-axis in proportion to the contributing basin area upstream of each segment (Figure 10). These hydrographs provide an indication of the range of discharge conditions that may occur in each instream flow segment. However, there is considerable variation in the timing and pattern of flow within a given year and between different years that is not fully described by three individual hydrographs simulated by HabiTech (2007). As a consequence these should be viewed only as a general template of runoff patterns.

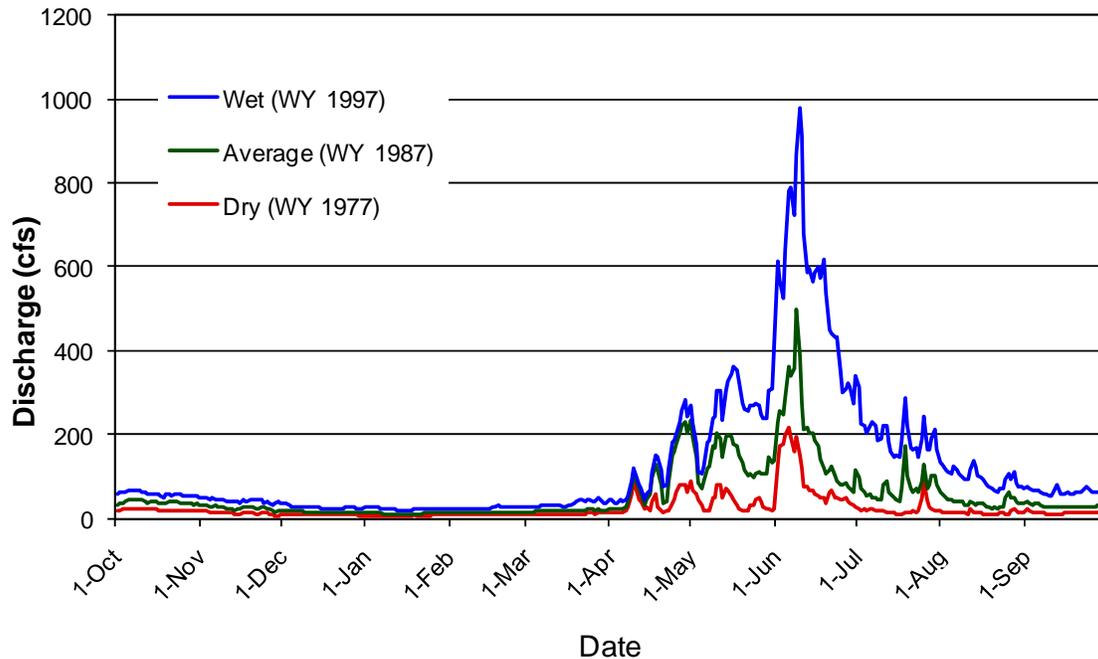


Figure 10. Simulated annual hydrographs for wet, dry, and average conditions in the Bear Creek Middle instream flow segment (HabiTech 2007).

Physical Habitat Simulation Model

The PHABSIM model was used to model habitat for all life stages of YSC in this instream flow segment. This is the primary species in this segment and management in the watershed is focused on maintaining a wild YSC population. There were three study sites in this instream flow segment (the 1991 lower, 1991 upper and 1992 upper sites) and PHABSIM models were generated for each to help develop flow recommendations (Figure 11, Figure 12, and Figure 13).

Simulations were conducted through the two 1991 study sites using a calibrated PHABSIM model over the flow range 2 cfs to 50 cfs and from 2 cfs to 200 cfs. The two 1991 models were run at each flow increment using data from a total of 10 transects (six transects in the lower site and 4 in the upper one). Transects were weighted individually within each project based on the abundance of the habitat type represented by that transect in the instream flow segment data. The transect data from the 1992 study site were collected individually and not part of a combined project; thus, separate models were developed for each transect and weighted appropriately to generate a sum total of available habitat. When a calibrated model was run for a given species / life stage at a given discharge, the resulting weighted usable area (WUA) for that transect was weighted by the abundance of the habitat type represented by that transect in the instream flow segment. Habitat mapping, conducted in 2005, determined that the

habitat weighting factor for this segment should be 22.5% for pools, 8.5% for rapids, 63.4% for riffles, and 5.6% for runs. Because no transects were included in the model for rapids or runs, the weighting factor for rapids was assigned to the most similar habitat type, riffles and the weighting factor for runs was divided evenly between riffles and pools. The weighting factor of an individual transect was determined for the 1992 data by dividing the total value for a given habitat type by the number of transects of that type. The sum of the WUA from all weighted individual transect results was used as the final model output to represent habitat availability for a given species / life stage at the modeled discharge. It was these WUA data that were used to determine “peak” habitat availability for critical species / life stages in each of the five time periods described in the Methods section.

Using output from the models at all three study sites, it appears that a discharge of 35 cfs would maximize habitat for juvenile and adult YSC over the range of flows for which the model was run. During the spring YSC spawning period (May 1 – June 30), the model indicated that 20 cfs would maximize spawning habitat for YSC over the range of flows for which the model was run. Both BNT and MWF are absent or uncommon in this portion of Bear Creek so no flow recommendations for spawning habitat (October 1 – November 15) were generated for these species. Similarly, habitat for MWF fry is not needed in this segment.

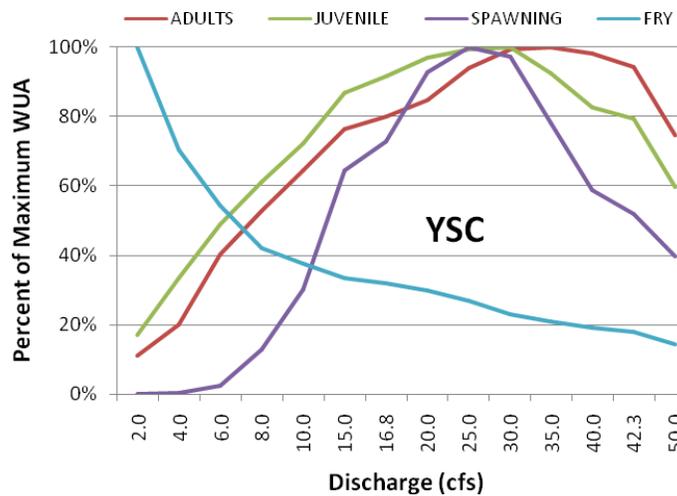


Figure 11. Percent of maximum weighted useable area (WUA) for YSC using the PHABSIM model on data from the 1991 lower study site within the Bear Creek Middle instream flow segment.

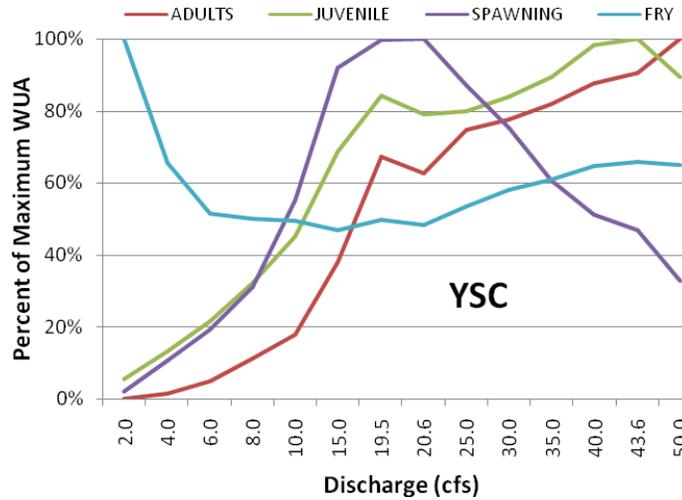


Figure 12. Percent of maximum weighted useable area (WUA) for YSC using the PHABSIM model on data from the 1991 upper study site within the Bear Creek Middle instream flow segment.

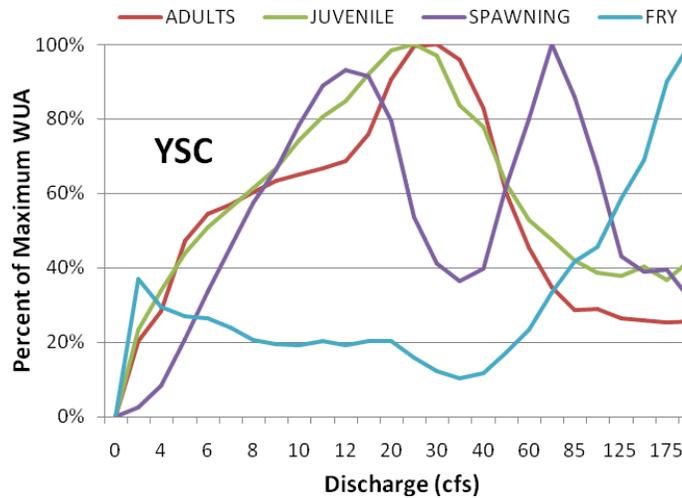


Figure 13. Percent of maximum weighted useable area (WUA) for YSC using the PHABSIM model on data from the 1992 upper study site within the Bear Creek Middle instream flow segment.

Habitat Retention Model Calibration and Simulation

The Habitat Retention model (Table 16) was an important component of the data analysis process for this instream flow segment. With this model, the hydraulic conditions of at least three riffle transects are calculated to determine the discharge required to maintain fish passage between habitat types and sufficient habitat to ensure survival of benthic invertebrates. The three criteria used to evaluate habitat suitability are mean velocity, mean depth, and the wetted perimeter (as a percentage of bankfull width). The discharge at which two of the three criteria are met at all three riffles is the recommended discharge to maintain habitat throughout the instream flow segment.

Average depth, average velocity, and wetted perimeter at a range of modeled discharges were evaluated in three riffle transects (Table 16). At riffle 1, the hydraulic criteria for both depth and wetted perimeter are met as flow declines from its bankfull level to 30 cfs. For riffles 2 and 3, 17 and 9 cfs (respectively) retain two of three criteria. Therefore, the flow that retains two of three criteria for all of the studied riffles is 30 cfs and based on the Habitat Retention model, this flow is necessary year round to maintain trout survival, movement and invertebrate production.

Table 16. Estimated hydraulic conditions for three riffles over a range of modeled discharges in the Bear Creek Middle instream flow segment. Bold indicates that the hydraulic criterion was met for an individual attribute. Bankfull flow was 497 cfs. Average width of the study segment at this flow was 48.8 so the mean depth criterion was 0.49 feet. The flow meeting 2 of 3 criteria for each riffle are shaded.

	Discharge (cfs)	Mean Velocity (ft/sec)	Mean Depth (ft)	Wetted Perimeter (% of bankfull)
Riffle Transect 1	497	9.59	1.04	1.00
	200	6.13	0.91	0.72
	100	4.35	0.70	0.65
	30	2.53	0.49	0.50
	12	1.73	0.33	0.42
	10	1.62	0.30	0.41
	8	1.50	0.27	0.39
	6	1.37	0.24	0.36
	4	<1.23	0.21	0.31
Riffle Transect 2	497	8.56	1.15	1.00
	200	5.52	1.03	0.70
	100	3.85	0.78	0.66
	26	2.00	0.49	0.53
	17	1.66	0.40	0.50
	7	1.13	0.30	0.40
	5	1.00	0.27	0.37
	4	0.90	0.25	0.35
Riffle Transect 3	497	9.65	1.12	1.00
	200	6.21	1.01	0.70
	100	4.19	0.82	0.64
	26	2.00	0.49	0.58
	10	1.30	0.30	0.55
	9	1.24	0.31	0.50
	8	1.18	0.30	0.49
	6	1.04	0.27	0.46
	5	1.00	0.29	0.42
	4	0.86	0.27	0.37

Habitat Quality Index Model

The HQI model data (Figure 14) was important in evaluating late summer habitat availability for this instream flow segment. Data for the HQI model were collected in the lower portion of this instream flow segment in 2005. The estimated monthly streamflows that occur 50% of the time are: 81, 29, and 18

cfs for the months of July, August, and September (Table 15). The 29 cfs August value provides a reasonable estimate of normal late summer flow levels. At this flow, the stream provides 11.7 Habitat Units. The lowest flow that will maintain 11.7 Habitat Units is 29 cfs; therefore, the instream flow recommendation to maintain adult YSC habitat during the late summer period is 29 cfs.

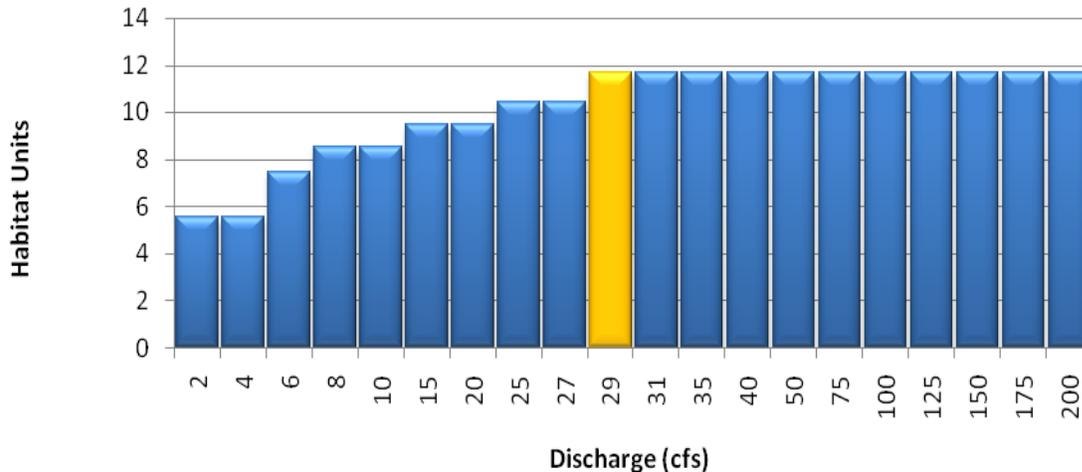


Figure 14. Habitat Quality Index for a range of flow levels in the Bear Creek Middle instream flow segment. X-axis flows are scaled to show where changes in Habitat Units occur. The recommended flow is indicated by the light shaded bar.

Instream Flow Recommendations

A table with instream flow recommendations for all segments (Table 19) is included in the section titled “Summary of Instream Flow Recommendations.” Recommendations are provided for specific seasonal fishery needs for the Bear Creek Middle instream flow segment:

- Because BNT and MWF are absent or uncommon in this segment the fall flow recommendation (October 1 – November 15) is based on maximizing habitat for YSC rather than spawning habitat for BNT and MWF. PHABSIM results indicate that YSC habitat is maximized at 35 cfs (over the range of flows for which the model was run), but that flow may occur infrequently according to discharge estimates (HabitTech 2007); therefore, the recommendation is for the lowest 20% exceedence flow (natural flow up to 14 cfs) during this time period.
- Natural winter flows up to 10 cfs are recommended for November 16 – March 31. This is the lowest estimated value for the 20% monthly exceedence discharge during that time period.
- During the early spring period (April 1 – 30) a discharge of 35 cfs is recommended to maximize YSC juvenile and adult habitat over the range of flows for which the PHABSIM model was run.
- The spring spawning flow recommendation (May 1 – June 30) of 20 cfs is based on the peak spawning habitat available to spawning YSC over the range of flows for which the PHABSIM model was run.
- The summer (July 1 – September 30) recommendation of 29 cfs was based on HQI data.

Bear Creek – Upper Segment

Hydrology

As discussed in the section on the Bear Creek Lower instream flow segment, the discharges that occurred in the East Fork Wind River basin during the course of this study were generally lower than the long-term monthly averages. Table 17 lists estimated mean annual flow and select flood frequency and monthly flow duration estimates for the Bear Creek Lower instream flow segment (HabiTech 2007). HabiTech (2007) noted that WGFD discharge measurements collected in the segment were within expectations of their estimates and concluded that their approach yielded reasonable results. All three flows measured by WGFD in 2005 (Table 11) were lower than the estimated 50% exceedance level (Table 17), but this did not limit our ability to model the effect of flow conditions on habitat over a range of flows.

Table 17. Estimated hydrologic characteristics for the Bear Creek Upper instream flow segment (HabiTech 2007).

Flow Parameter		Estimated Flow (cfs)
Mean Annual		42
1.5-year peak		444
25-year peak		925
Spring Month	Estimated 50% Exceedence (cfs)	Estimated 20% Exceedence (cfs)
April	16.2	36.1
May	66.0	141.9
June	143.1	279.8
Summer Month	Estimated 50% Exceedence (cfs)	Estimated 20% Exceedence (cfs)
July	72.7	150.5
August	26.3	45.9
September	16.4	27.3
Winter Month	Estimated 50% Exceedence (cfs)	Estimated 20% Exceedence (cfs)
October	15.3	21.2
November	10.6	14.0
December	8.9	10.9
January	8.0	10.4
February	8.7	10.1
March	10.3	12.0

In addition to monthly exceedence values as an indicator of flow conditions in the segment, HabiTech (2007) also produced daily flow estimates for three individual years (the 29-year period of record was first divided to represent wet, dry, and average conditions, then a representative year randomly selected from each group). Stream gage data from the same randomly selected three years were used to prepare daily flow estimates for all segments. Because of this and the fact that estimates for all segments are based on data from the same gage (near the mouth of the East Fork Wind River), the three representative hydrographs follow the same pattern for each segment with the difference being that the

curve migrates up or down on the y-axis in proportion to the contributing basin area upstream of each segment (Figure 15). These hydrographs provide an indication of the range of discharge conditions that may occur in each instream flow segment. However, there is considerable variation in the timing and pattern of flow within a given year and between different years that is not fully described by three individual hydrographs simulated by HabiTech (2007). As a consequence these should be viewed only as a general template of runoff patterns.

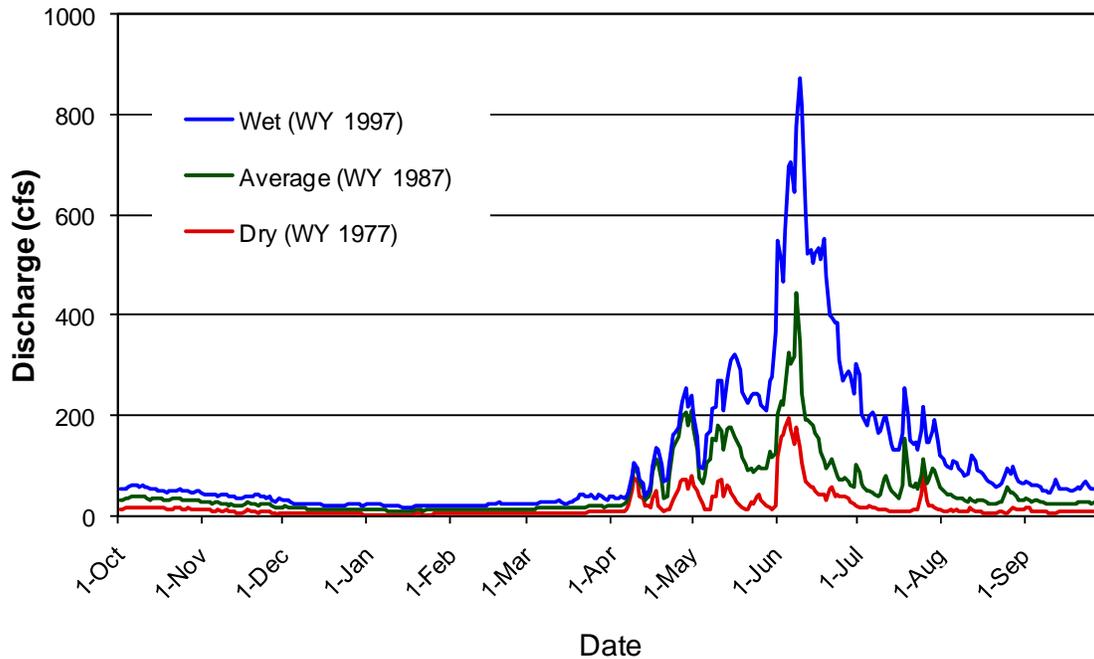


Figure 15. Simulated annual hydrographs for wet, dry, and average conditions in the Bear Creek Upper instream flow segment (HabiTech 2007).

Physical Habitat Simulation Model

The PHABSIM model was used to model habitat for all life stages of YSC in this instream flow segment (Figure 16). This is the primary species in this segment and management in the watershed is focused on maintaining a wild YSC population.

Simulations were conducted through the study site using a calibrated PHABSIM model over the flow range 5 cfs to 200 cfs. The model was run at each flow increment using data from all 15 transects combined. Transects were weighted individually within the project based on the abundance of the habitat type represented by that transect in the instream flow segment data. The habitat mapping results for this instream flow segment determined that the weighting factor should be 10.2% for pools, 42.8% for rapids, 45.1% for riffles, and 1.9% for runs. The weighting factor of an individual transect was determined by dividing the total value for a given habitat type by the number of transects of that type. When the calibrated model was run for a given species / life stage at a given discharge, the resulting weighted usable area (WUA) was the final output used for interpretation. It was these WUA data that were used to determine “peak” habitat availability for critical species / life stages in each of the five time periods described in the Methods section.

The model output revealed that a discharge of 71 cfs maximizes habitat for juvenile YSC (over the range of flows for which the model was run) and also provides good habitat for adult YSC. During the YSC spawning period (May 1 – June 30) the model indicated that 20 cfs would maximize spawning habitat for YSC over the range of flows for which the model was run. Both BNT and MWF are absent or uncommon in this portion of Bear Creek so no flow recommendations for spawning habitat (October 1 – November 15) were generated for these species. Similarly, habitat for MWF fry is not needed in this segment.

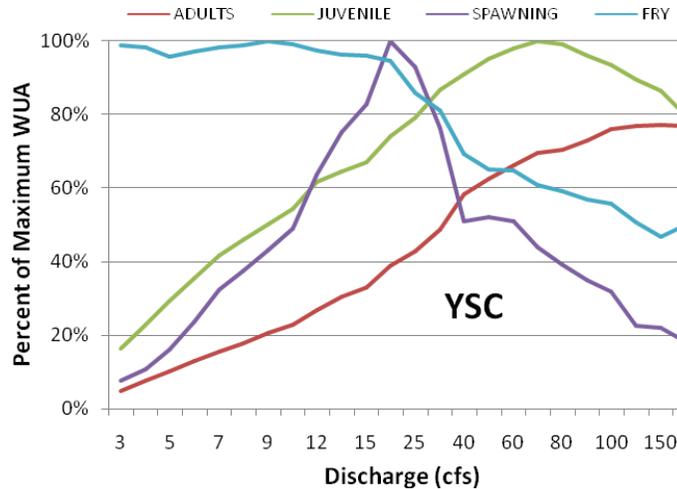


Figure 16. Percent of maximum weighted useable area (WUA) for YSC using the PHABSIM model on data from the 2005 study site within the Bear Creek Upper instream flow segment.

Habitat Retention Model Calibration and Simulation

The Habitat Retention model (Table 18) was an important component of the data analysis process for this instream flow segment. With this model, the hydraulic conditions of at least three riffle transects are calculated to determine the discharge required to maintain fish passage between habitat types and sufficient habitat to ensure survival of benthic invertebrates. The three criteria used to evaluate habitat suitability are mean velocity, mean depth, and the wetted perimeter (as a percentage of bankfull width). The discharge at which two of the three criteria are met at all three riffles is the recommended discharge to maintain habitat throughout the instream flow segment.

Average depth, average velocity, and wetted perimeter at a range of modeled discharges were evaluated in three riffle transects (Table 18). At riffle 1, the hydraulic criterion for depth is met as flow declines from its bankfull level to 15 cfs. The second hydraulic criterion (velocity) is met at 7cfs. For riffles 2 and 3, 5 and 9 cfs (respectively) retain two of three criteria. Therefore, the flow that retains two of three criteria for all of the studied riffles is 9 cfs and based on the Habitat Retention model, this flow is necessary year round to maintain trout survival, movement and invertebrate production.

Table 18. Estimated hydraulic conditions for three riffles over a range of modeled discharges in the Bear Creek Upper instream flow segment. Bold indicates that the hydraulic criterion was met for an individual attribute. Bankfull flow was 444 cfs. Average width of the segment at this flow was 37.0 feet so the mean depth criterion was 0.37 feet. The flow meeting 2 of 3 criteria for each riffle are shaded.

	Discharge (cfs)	Mean Velocity (ft/sec)	Mean Depth (ft)	Wetted Perimeter (% of bankfull)
Riffle Transect 1	444.0	7.95	1.53	1.00
	150.0	4.09	1.05	0.94
	71.0	2.68	0.78	0.91
	20.0	1.44	0.44	0.84
	15.0	1.29	0.37	0.82
	13.7	1.25	0.36	0.82
	10.0	1.13	0.33	0.71
	7.9	1.04	0.32	0.64
	7.0	1.00	0.30	0.62
	6.0	0.95	0.28	0.59
4.0	0.84	0.23	<0.54	
Riffle Transect 2	444.0	6.03	1.66	1.00
	150.0	3.73	1.05	0.86
	71.0	2.78	0.87	0.66
	26.0	1.84	0.63	0.50
	13.7	1.44	0.48	0.44
	10.0	1.28	0.46	0.38
	7.9	1.17	0.43	0.35
	6.0	1.06	0.40	0.32
	5.0	1.00	0.37	0.30
	4.0	0.92	0.33	0.30
Riffle Transect 3	444.0	10.97	1.17	1.00
	150.0	5.53	0.92	0.85
	71.0	3.43	0.74	0.81
	20.0	1.58	0.46	0.78
	13.7	1.28	0.39	0.78
	12.0	1.19	0.37	0.78
	10.0	1.08	0.35	0.76
	9.0	1.00	0.33	0.76
	7.9	0.95	0.32	0.75
	4.0	0.67	0.28	<0.62

Habitat Quality Index Model

The HQI model data (Figure 17) was important in evaluating late summer habitat productivity potential for this instream flow segment. Data for the HQI model were collected in the lower portion of this instream flow segment in 2005. The estimated monthly streamflows that occur 50% of the time are: 73, 26, and 16 cfs for the months of July, August, and September (Table 17). The 26 cfs August value provides a reasonable estimate of normal late summer flow levels. At this flow, the stream provides 16.4 Habitat Units. The lowest flow that will maintain 16.4 Habitat Units is 24 cfs; therefore, the instream flow recommendation to maintain adult YSC habitat during the late summer period is 24 cfs.

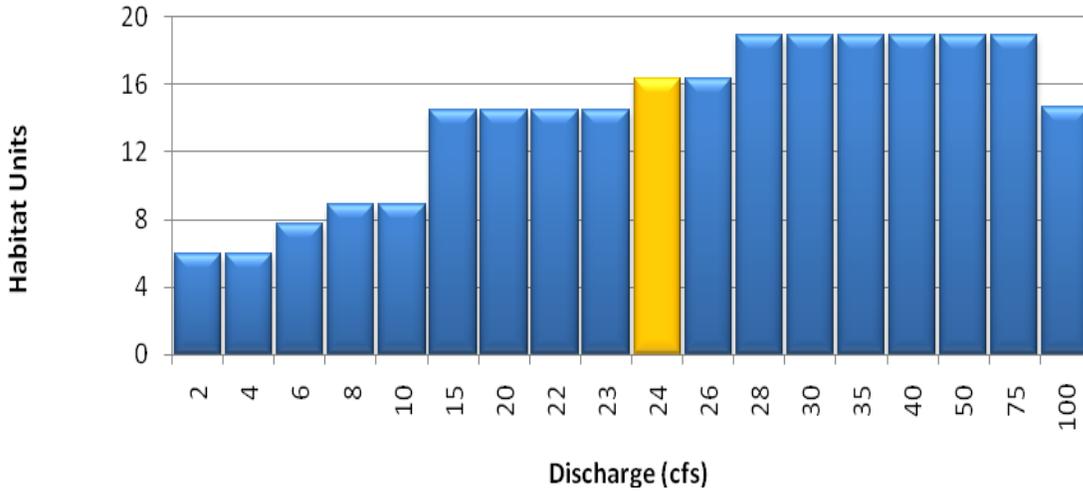


Figure 17. Habitat Quality Index for a range of flow levels in the Bear Creek Upper instream flow segment. X-axis flows are scaled to show where changes in Habitat Units occur. The recommended flow is indicated by the light shaded bar.

Instream Flow Recommendations

A table with instream flow recommendations for all segments (Table 19) is included in the section titled “Summary of Instream Flow Recommendations.” Recommendations are provided for specific seasonal fishery needs for the Bear Creek Upper instream flow segment:

- Because BNT and MWF are absent or uncommon in this segment the fall flow recommendation (October 1 – November 15) is based on maximizing habitat for YSC adults and juveniles. PHABSIM results indicate that habitat is maximized at 71 cfs, but that discharge is uncommon in this segment (HabiTech 2007) so the recommendation is for the lowest 20% exceedence flow during this time period (natural flow up to 13 cfs).
- Natural winter flows up to 9.0 cfs are recommended for November 16 – March 31. This is the lowest estimated value for the 20% monthly exceedence discharge during that time period.
- For the early spring period (April 1 – 30) PHABSIM results indicate that a discharge of 71 cfs maximizes juvenile YSC habitat over the range of flows for which the model was run (the adult habitat peak was much higher). This flow is uncommon during that time period (HabiTech 2007) so the recommendation is for the 20% exceedence flow (natural flow up to 32 cfs).
- The spring spawning flow recommendation (May 1 – June 30) of 20 cfs is based on peak habitat available to spawning YSC over the range of flow for which the PHABSIM model was run.
- The summer (July 1 – September 30) recommendation of 24 cfs was based on HQI data.

SUMMARY OF INSTREAM FLOW RECOMMENDATIONS

Bear Creek has important YSC habitat and a wild YSC fishery is currently the management focus for this watershed. Multiple instream flow filings for specific segments are necessary to provide hydrologically appropriate flow management to maintain or improve the existing fishery in Bear Creek. In addition, the filings will allow management of water rights, when they are in priority, to benefit native MWF and a small but popular fishery for BNT.

If approved by the State Engineer, the three proposed instream flow water right filings in Bear Creek will protect existing base flow conditions when they are naturally available against presently unknown future out of channel uses up to the limit of recommended water rights for each segment described in this report. Approximately 13.2 miles of stream habitat will be directly protected if these instream flow applications advance to permit status. Existing (senior) water rights will be unaffected if the proposed water rights are approved because the proposed instream flow rights will have a current day (junior) priority date and water for all senior water rights will be honored in their entirety when water is available.

The Bear Creek instream flow recommendations to maintain short-term habitat for YSC, BNT, and MWF are summarized in Table 19. Five seasonal time periods were identified for instream flow recommendations. These distinct seasons include the fall spawning period for BNT and MWF (October 1 – November 15), winter fish survival (November 16 – March 31), an early spring period that is important for habitat connectivity in anticipation of YSC spawning (April 1 – 30), the spring YSC spawning period (May 1 – June 30), and the summer months that facilitate trout productivity (July 1 – September 30).

The fall spawning period was only relevant for segments that have BNT and / or MWF. These segments were located lower in the watershed. For those segments, recommendations were based on data from the PHABSIM and / or Habitat Retention models. When BNT and MWF were uncommon or absent, fall recommendations were based on habitat availability for juvenile and adult YSC. Winter flow recommendations were based on a combination of Habitat Retention results and the lowest 20% monthly exceedence value during the winter period for each segment. Early spring recommendations were based on adult and juvenile habitat requirements (determined using PHABSIM). Recommendations for the spring spawning period were based on peak YSC spawning habitat availability determined using the PHABSIM model. Summer flow recommendations were based on habitat requirements to maintain adult and juvenile trout production. Late summer trout production was usually determined with the HQI model while the PHABSIM model was used to ensure sufficient habitat for other life stages during this season. In many cases, habitat models indicated that most favorable conditions were maximized for target species / life stages at discharges that are considerably higher than what naturally occurs in that segment. In those instances the 20% exceedence flow (the lowest monthly value estimated for the given time period) was recommended.

Table 19. Flow recommendations (cfs) for each of the three proposed instream flow segments in Bear Creek.

	Winter Survival Nov 16 – Mar 31	Early Spring Connectivity Apr 1-30	Spring Spawning May 1 – Jun 30	Summer Production Jul 1 – Sep 30	Fall Spawning Oct 1 – Nov 15
Bear Creek Lower	11	35	25	29	15
Bear Creek Middle	10	35	20	29	14
Bear Creek Upper	9	32	20	24	13

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APPENDIX 1. CHANNEL MAINTENANCE FLOWS

Overall Approach

The term “channel maintenance flows” refers to flows that maintain existing channel morphology, riparian vegetation and floodplain function (US Forest Service 1997, Schmidt and Potyondy 2004). The basis and approach used below for defining channel maintenance flows applies only to snowmelt-dominated gravel and cobble-bed (alluvial) streams. By definition, these are streams whose beds are dominated by loose material with median sizes larger than 0.08 in (2 mm) and with 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, Schmidt and Potyondy 2004). 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 (Kuhnle et al. 1999). Rather, a dynamic hydrograph within and between years is needed (Gordon 1995; Trush and McBain 2000, Schmidt and Potyondy 2004). 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 successional 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 (Carling 1995, Schmidt and Potyondy 2004). 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 1-1) 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 schematic shows that any artificial limit on peak flow prevents movement of the entire bedload through a stream over time and would result in gradual bedload accumulation. The net effect would be an alteration

of existing channel forming processes and habitat (Bohn and King 2001). For this reason, the 25-year peak flow is the minimum needed to maintain existing channel form.

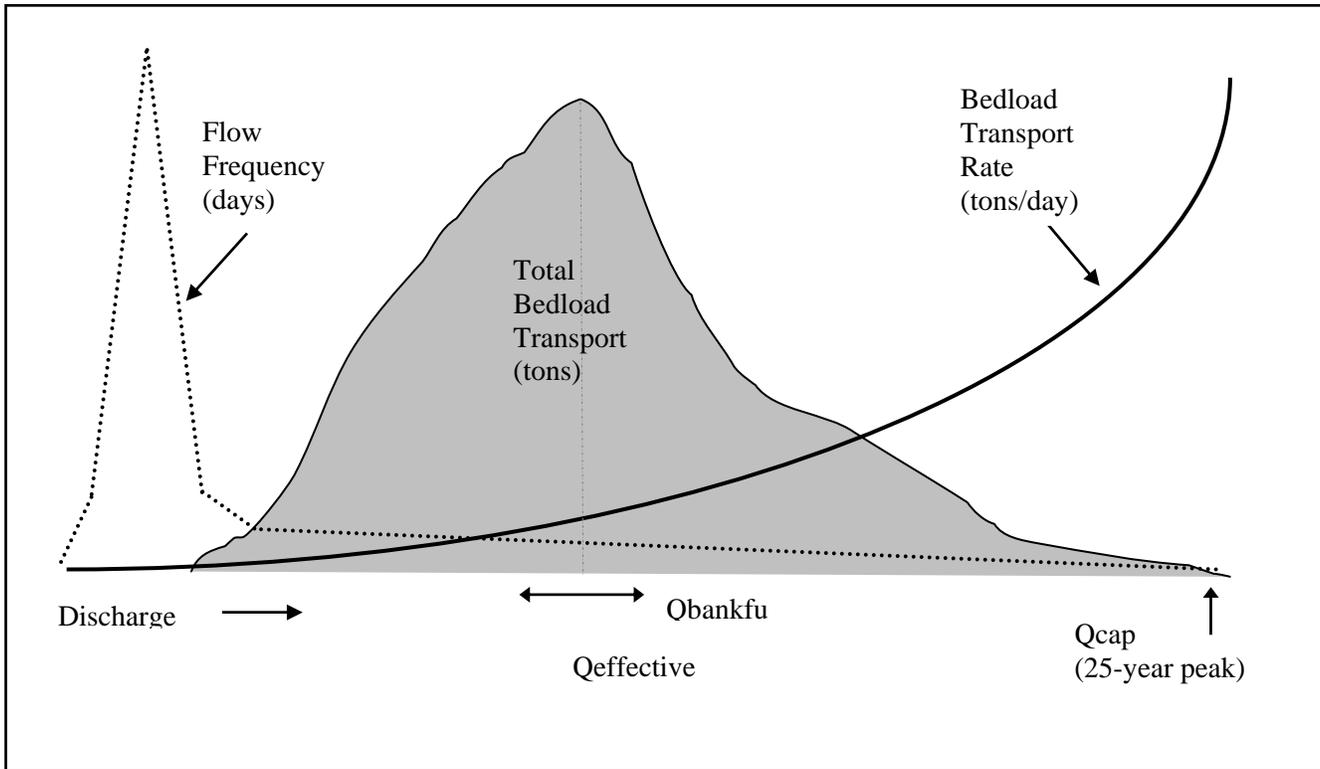


Figure 1-1. Total bedload transport as a function of bedload transport rate and flow frequency (adapted from Schmidt and Potyondy 2004).

The initiation of particle transport begins at flows somewhat greater than average annual flows but lower than bankfull flows (Schmidt and Potyondy 2004). 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). Schmidt and Potyondy (2004) discuss phases of bedload movement and suggest that a flow trigger of 80% of the 1.5-year discharge “provides a good first approximation for general application” in defining flows needed to maintain channels. They suggest that although lower flows will initiate fine sediment movement, “delaying the initiation point of the channel maintenance hydrograph (to $0.8 * Q_b$), is desirable because it minimizes the long-term volume of water needed for channel maintenance.”

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 (required to maintain fish habitat)
 Q_m = substrate mobilization flow = $0.8 * Q_b$
 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 0.8 times bankfull flow based on the report by Schmidt and Potyondy (2004). 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 1-2). 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 than 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.

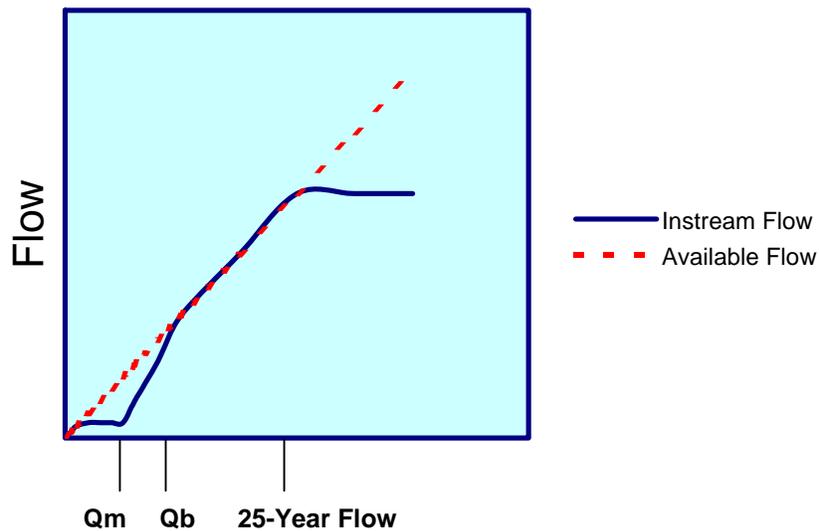


Figure 1-2. General function of a dynamic hydrograph instream flow for fishery maintenance. Q_m is substrate mobilization flow and Q_b is bankfull flow.

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 1-2). 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 four evenly partitioned blocks or increments of flow between the sediment mobilization flow and bankfull.

Bear Creek –Lower Segment

Applying the Leopold equation and approach yielded channel maintenance recommendations for the Bear Creek Lower instream flow segment (Table 1-1). The base or fish flow used in the analysis was the 25 cfs spawning flow. For naturally available flow levels less than the spawning flow, the channel maintenance instream flow recommendation is equal to natural flow. The spawning flow level is considerably less than the substrate mobilization flow (414 cfs). For the flow range between the spawning flow and the substrate mobilization flow, the channel maintenance flow recommendation is equal to the spawning flow (Table 1-1). When naturally available flows range from the substrate mobilization flow to the bankfull flow level, application of the Leopold formula results in incrementally greater amounts of water applied toward instream flow (Table 1-1). At flows between bankfull and the 25-year flood flow, all of the streamflow is needed to perform channel maintenance functions. At flows 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 and reconnected the channel with the floodplain (Figure 1-3).

Table 1-1. Channel maintenance instream flow recommendations (May 1 – June 30) to maintain existing channel forming processes and long-term aquatic habitat characteristics in the Bear Creek Lower instream flow segment.

Flow Level Description	Available Flow (cfs)	Recommended Flow (cfs)
<Spawning Flow*	<25	<25
Spawning Flow	25	25
<Substrate Mobilization Flow	26-413	25
Substrate Mobilization Flow	414	25
Mobilization to Bankfull	415-440	270
Mobilization to Bankfull	441-466	389
Mobilization to Bankfull	467-492	438
Mobilization to Bankfull	493-517	480
Bankfull Flow	518	518
Bankfull Flow to 25-Year Flood [#]	518-1079	518-1079
25-Year Flood	1079	1079
> 25-Year Flood	≥ 1079	1079

*At stream flows less than the spawning flow, the flow recommendation is all available flow.

Between bankfull and the 25-year flow, the flow recommendation is all available flow.

Figure 1-3 shows examples of channel maintenance flow recommendations implemented in randomly selected average and wet years. Dry years are not shown because flows would not exceed the 414 cfs substrate mobilization threshold to initiate channel maintenance flows. In the representative average year, 1987, flow did not exceed 414 cfs. In the representative wet year, 1997, channel maintenance flow recommendations would apply for 10 days in May and June (Figure 1-3).

If water storage were developed (though it is not recommended for this fishery) it would be necessary to further specify the rate at which releases could be increased or decreased to the channel

maintenance or spawning levels. The sharp flow increases and decreases evident in Figure 1-3 (e.g. 25 cfs to 614 cfs in one day) would cause habitat loss through excessive scour and potential trout mortality due to stranding. More gradual changes akin to a natural hydrograph would be recommended. In that case, the Index of Hydrologic Alteration (IHA; Richter et al. 1996) could provide a valuable reference. Daily increases and decreases during runoff measured at the East Fork Wind River gage could serve as a guide for developing such ramping rate recommendations using the IHA.

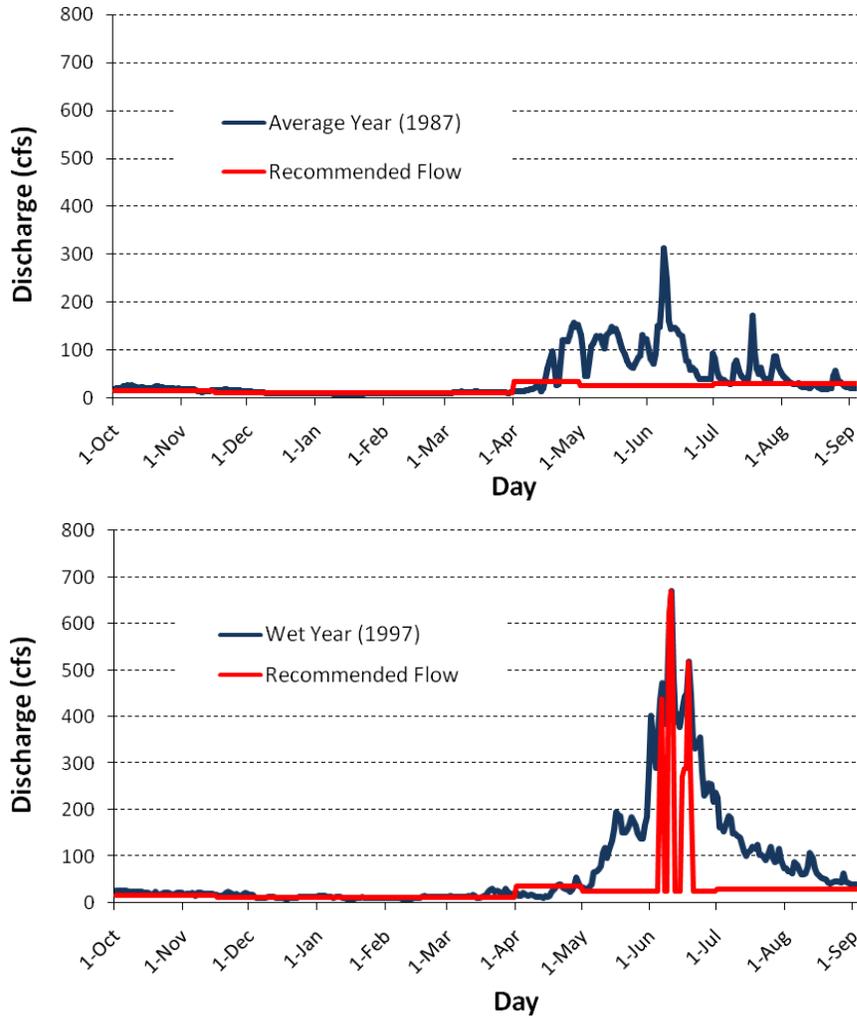


Figure 1-3. Channel maintenance flow recommendations and hydrographs for the Bear Creek Lower instream flow segment in an average (1987) and a wet (1997) water year.

Bear Creek –Middle Segment

Applying the Leopold equation and approach yielded channel maintenance recommendations for the Bear Creek Middle instream flow segment (Table 1-2). The base or fish flow used in the analysis was the 20 cfs spawning flow. For naturally available flow levels less than the spawning flow, the channel maintenance instream flow recommendation is equal to natural flow. The spawning flow level is considerably less than the substrate mobilization flow (398 cfs). For the flow range between the spawning flow and the substrate mobilization flow, the channel maintenance flow recommendation is equal to the spawning flow (Table 1-2). When naturally available flows range from the substrate mobilization flow to the bankfull flow level, application of the Leopold formula results in incrementally greater amounts of water applied toward instream flow (Table 1-2). At flows between bankfull and the 25-year flood flow, all of the streamflow is needed to perform channel maintenance functions. At flows 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 and reconnected the channel with the floodplain (Figure 1-4).

Table 1-2. Channel maintenance instream flow recommendations (May 1 – June 30) to maintain existing channel forming processes and long-term aquatic habitat characteristics in the Bear Creek Middle instream flow segment.

Flow Level Description	Available Flow (cfs)	Recommended Flow (cfs)
<Spawning Flow*	<20	<20
Spawning Flow	20	20
<Substrate Mobilization Flow	21-413	20
Substrate Mobilization Flow	398	20
Mobilization to Bankfull	399-422	259
Mobilization to Bankfull	423-447	373
Mobilization to Bankfull	448-472	420
Mobilization to Bankfull	473-496	461
Bankfull Flow	497	497
Bankfull Flow to 25-Year Flood [#]	497-1035	497-1035
25-Year Flood	1035	1035
> 25-Year Flood	≥ 1035	1035

*At stream flows less than the spawning flow, the flow recommendation is all available flow.

Between bankfull and the 25-year flow, the flow recommendation is all available flow.

Figure 1-4 shows examples of channel maintenance flow recommendations implemented in randomly selected average and wet years. Dry years are not shown because flows would not exceed the 398 cfs substrate mobilization threshold to initiate channel maintenance flows. In the representative average year, 1987, flow did not exceed 398 cfs. In the representative wet year, 1997, channel maintenance flow recommendations would apply for 10 days in May and June (Figure 1-4).

If water storage were developed (though it is not recommended for this fishery) it would be necessary to further specify the rate at which releases could be increased or decreased to the channel

maintenance or spawning levels. The sharp flow increases and decreases evident in Figure 1-4 (e.g. 20 cfs to 588 cfs in one day) would cause habitat loss through excessive scour and potential trout mortality due to stranding. More gradual changes akin to a natural hydrograph would be recommended. In that case, the Index of Hydrologic Alteration (IHA; Richter et al. 1996) could provide a valuable reference. Daily increases and decreases during runoff measured at the East Fork Wind River gage could serve as a guide for developing such ramping rate recommendations using the IHA.

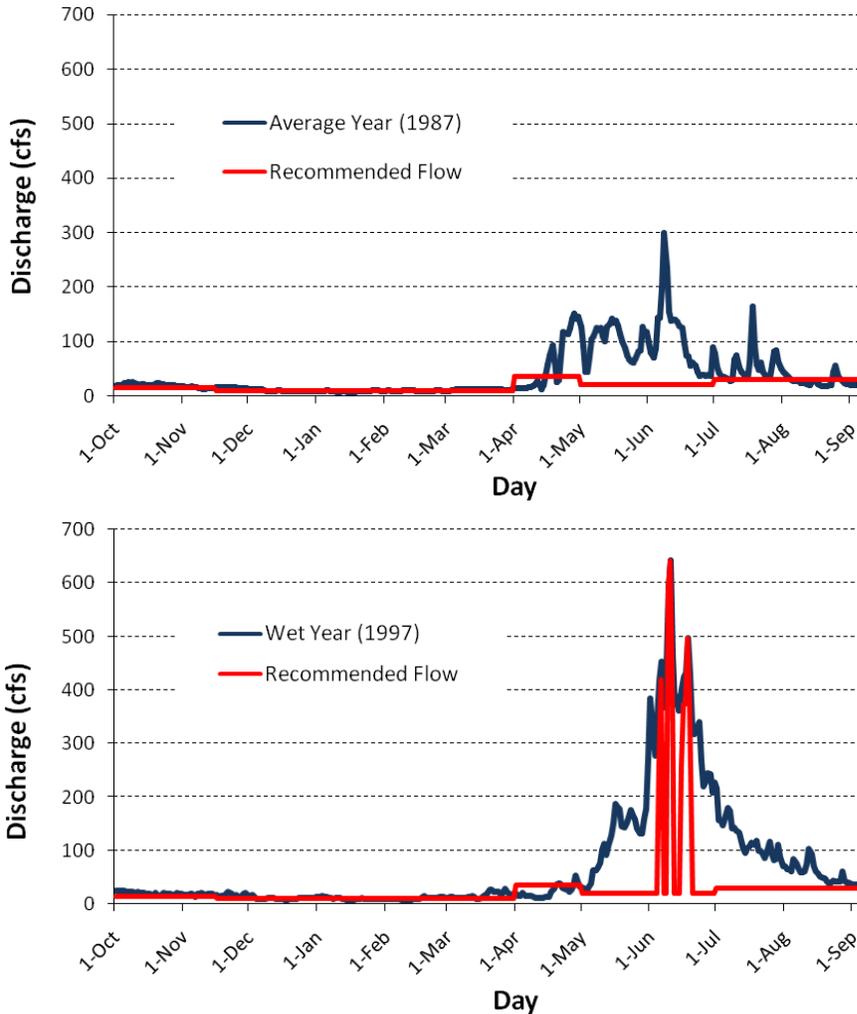


Figure 1-4. Channel maintenance flow recommendations and hydrographs for the Bear Creek Middle instream flow segment in an average (1987) and a wet (1997) water year.

Bear Creek –Upper Segment

Applying the Leopold equation and approach yielded channel maintenance recommendations for the Bear Creek Upper instream flow segment (Table 1-3). The base or fish flow used in the analysis was the 20 cfs spawning flow. For naturally available flow levels less than the spawning flow, the channel maintenance instream flow recommendation is equal to natural flow. The spawning flow level is considerably less than the substrate mobilization flow (355 cfs). For the flow range between the spawning flow and the substrate mobilization flow, the channel maintenance flow recommendation is equal to the spawning flow (Table 1-3). When naturally available flows range from the substrate mobilization flow to the bankfull flow level, application of the Leopold formula results in incrementally greater amounts of water applied toward instream flow (Table 1-3). At flows between bankfull and the 25-year flood flow, all of the streamflow is needed to perform channel maintenance functions. At flows 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 and reconnected the channel with the floodplain (Figure 1-5).

Table 1-3. Channel maintenance instream flow recommendations (May 1 – June 30) to maintain existing channel forming processes and long-term aquatic habitat characteristics in the Bear Creek Upper instream flow segment.

Flow Level Description	Available Flow (cfs)	Recommended Flow (cfs)
<Spawning Flow*	<20	<20
Spawning Flow	20	20
<Substrate Mobilization Flow	21-354	20
Substrate Mobilization Flow	355	20
Mobilization to Bankfull	356-377	235
Mobilization to Bankfull	378-400	333
Mobilization to Bankfull	401-422	376
Mobilization to Bankfull	423-443	412
Bankfull Flow	444	444
Bankfull Flow to 25-Year Flood [#]	444-925	444-925
25-Year Flood	925	925
> 25-Year Flood	≥ 925	925

*At stream flows less than the spawning flow, the flow recommendation is all available flow.

Between bankfull and the 25-year flow, the flow recommendation is all available flow.

Figure 1-5 shows examples of channel maintenance flow recommendations implemented in randomly selected average and wet years. Dry years are not shown because flows would not exceed the 355 cfs substrate mobilization threshold to initiate channel maintenance flows. In the representative average year, 1987, flow did not exceed 355 cfs. In the representative wet year, 1997, channel maintenance flow recommendations would apply for 10 days in May and June (Figure 1-5).

If water storage were developed (though it is not recommended for this fishery) it would be necessary to further specify the rate at which releases could be increased or decreased to the channel

maintenance or spawning levels. The sharp flow increases and decreases evident in Figure 1-5 (e.g. 20 cfs to 526 cfs in one day) would cause habitat loss through excessive scour and potential trout mortality due to stranding. More gradual changes akin to a natural hydrograph would be recommended. In that case, the Index of Hydrologic Alteration (IHA; Richter et al. 1996) could provide a valuable reference. Daily increases and decreases during runoff measured at the East Fork Wind River gage could serve as a guide for developing such ramping rate recommendations using the IHA.

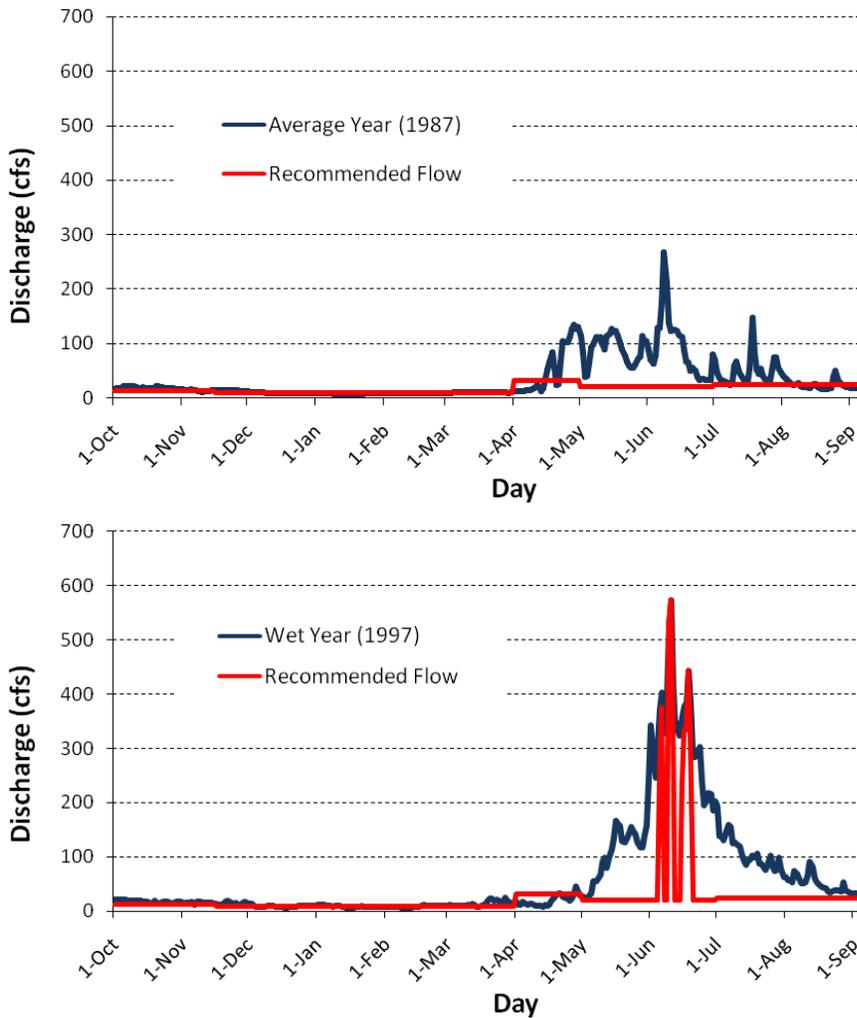


Figure 1-5. Channel maintenance flow recommendations and hydrographs for the Bear Creek Upper instream flow segment in an average (1987) and a wet (1997) water year.