WYOMING GAME AND FISH DEPARTMENT

FISH DIVISION

ADMINISTRATIVE REPORT

Title: Wood River Drainage Instream Flow Studies: Development of Instream Flow Water Right Recommendations for 4 Wood River Segments and Dick Creek.

Project: AW-CY-IF1-511, AW-CY-IF2-511, AW-CY-IF3-511, AW-CY-2GR-511

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Date: May 2005

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ABSTRACT

Five stream segments on the Shoshone National Forest in the upper Wood River basin were targeted for instream flow water rights because they contain genetically viable populations of Yellowstone cutthroat trout (YSC) and provide an interconnected stream system over a broad geographic region. This report provides flow recommendations developed from studies conducted during 2002 and 2003. Physical Habitat Simulation (PHABSIM) was used to develop instream flow recommendations for maintaining YSC spawning habitat during spring runoff. Riffle hydraulic characteristics under the Habitat Retention approach were examined 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 adult trout habitat quality relationships in the summer. During the winter months, October through April, natural winter flows were recommended to maintain all life stages. The 20% monthly exceedance, based on hydrologic estimates from HabiTech (2002), was selected to represent natural winter flow. Finally, a dynamic hydrograph model was used to quantify flow needs for maintenance of channel geomorphology.

Nearly 16 miles of important YSC habitat will be protected if the instream flow segments and recommendations identified in this report advance to permit status. Recommended flows range from 2.6 cfs in February in Dick Creek to 51 cfs in October in the Wood River downstream from the Middle Fork Wood River (Table 1). Additional channel maintenance flow recommendations to maintain long-term habitat requirements are presented in Appendix 1.

Table 1. Instream flow recommendations to maintain existing trout habitat in 5 Wood River basin instream flow segments.

Stream	Monthly Flow Recommendations (cfs)											
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May*	Jun*	Jul	Aug	Sep
Wood R. above Middle Fork	31	23	18	15	14	16	29	22	22	18	18	18
Middle Fork Wood River	20	15	11	10	9.5	11	19	19	19	14	14	14
South Fork Wood River	33	24	19	16	15	17	31	25	25	22	22	22
Wood River below Middle Fork	51	38	29	25	24	27	48	41	41	32	32	32
Dick Creek	5.7	4.2	3.2	2.8	2.6	2.9	5.2	11.5	11.5	4.2	4.2	4.2

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

INTRODUCTION

Legal and Institutional Background

The Wyoming Game and Fish Department (WGFD) has management authority over the fish and wildlife resources of the state under Title 23 of Wyoming statutes. The WGFD was created and placed under the direction and supervision of a commission in W.S. 23-1-401 and the responsibilities of the Commission and the Department are defined in W.S. 23-1-103. In these and associated statutes, the Department is charged with providing " . . .an adequate and flexible system for the control, propagation, management, protection and regulation of all Wyoming wildlife." The WGFD 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.

The instream flow law, Wyoming Statute 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 Game and Fish Commission is responsible for determining streamflows that will "maintain or improve" important fisheries. The Game and Fish Department fulfills this function under the general policy oversight of the Commission. An application for an instream flow water right is signed and held by the Wyoming Water Development Commission (WWDC) on behalf of the state should the water right be approved by the State Engineer. The priority date for the instream flow water right is the day the application is received by the State Engineer.

Through January 2005, the WGFD has submitted 97 instream flow water right applications, the state engineer has permitted 41, and the Board of Control has adjudicated 4. "Important" fisheries have been interpreted as productive fisheries and those that provide popular recreational opportunities. Recent efforts have focused on small headwater streams supporting native cutthroat trout. For example, studies were conducted from 1998 to 2001 on eight Greybull River tributary stream segments containing populations of Yellowstone cutthroat trout (YSC; *Oncorhynchus clarki bouvieri*). This document reports on studies and instream flow recommendations for five additional tributaries in the Wood River drainage.

Channel Maintenance Flows

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

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

Yellowstone Cutthroat Trout

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 distributional 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). Several strategies are being pursued by the WGFD to maintain and improve populations and habitat for this species (Dufek et al. 1999). Securing adequate instream flow water rights is a necessary and prominent component of these strategies. Instream flow protection is being pursued foremost in these drainages under a strategy of targeting broad systems of interconnected waters containing relatively pure YSC. A five year plan (Annear and Dey 2001) broadly outlines anticipated WGFD activities in filing for instream flow water rights on Yellowstone cutthroat trout streams through 2005. This plan will be updated for the 2006 to 2010 period and include prioritized descriptions of potential waters for instream flow studies (Dey and Annear, *in preparation*).

The Yellowstone cutthroat trout was petitioned for listing under the Endangered Species Act in 1998. In February 2001 the Fish and Wildlife Service (FWS) completed a 90-day petition review finding that 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. Against this backdrop, the WGFD continues management efforts to protect and expand YSC populations. Instream flow protection will help ensure the future of YSC in Wyoming by protecting existing base flow conditions against future consumptive and diversionary demands. Additional water rights for channel maintenance are still needed to ensure long-term habitat and fishery persistence.

Objectives

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

METHODS

Overall Approach

The Instream Flow Council (IFC), an organization of state and provincial fishery and wildlife management agencies, describes key attributes of effective instream flow studies and programs (Annear et al. 2004). The organization asserts that adequate instream flows must address eight ecosystem components including three policy components (legal, institutional, and public involvement) and five riverine components (hydrology, geomorphology, biology, water quality and connectivity). In conducting and reporting instream flow studies, the WGFD has adopted the recommendations set forth in Annear et al. (2004) by explicitly addressing all eight components. For example, legal and institutional issues are discussed in the *Introduction*. Public involvement occurs by virtue of public information meetings, hearings and comments solicited during public presentations and open houses. Meetings with individual landowners, community and special interest groups also provide opportunity for public involvement. Hydrology is specifically covered in this report. The geomorphology component is addressed in Appendix 1 where channel maintenance flow needs are developed. Biology is covered explicitly under the subheading *Development of Fish Flow Recommendations.* Water quality is not addressed in a unique section; water quality aspects that directly impinge on fish health (e.g. water temperature) are addressed with the HQI method in the *Development of Fish Flow Recommendations* sections. It is assumed that other water quality aspects in these high mountain streams are not limiting trout populations. Finally, the connectivity component is addressed under the *Instream Flow Recommendations* section of this report and throughout the report.

Study Area

The Wood River and its tributaries are high-elevation mountain streams with high channel slopes, unstable substrates, and large annual fluctuations in discharge (Hansen and Glover 1973). These characteristics are related to the geologically young nature of the watershed. The Absoraka Mountain Range represents the remnants of a broad volcanic plateau that has eroded and continues to erode as regional uplift occurs (Lageson and Spearing 1988). The steep uplifted peaks and deep valleys result in steep longitudinal profiles along watercourses. High snowmelt runoff easily moves erodible volcanic material resulting in stream channels that shift regularly, are often poorly defined and offer limited fish habitat. Earthen slumps are not uncommon and influence stream channel patterns by sometimes directly blocking or altering streamflow 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.

Spruce-fir forests blanket mid-elevation regions of the Wood River drainage, especially on north facing slopes. South slopes and ridge tops often contain open grass or shrub communities and whitebark pine occurs occasionally. Selective timber harvest, especially at lower elevations on the National Forest, occurs occasionally along with cattle grazing. The upper reaches of the Wood River at Kirwin supported a thriving, but short-lived, gold and silver mining community around the turn of the century.

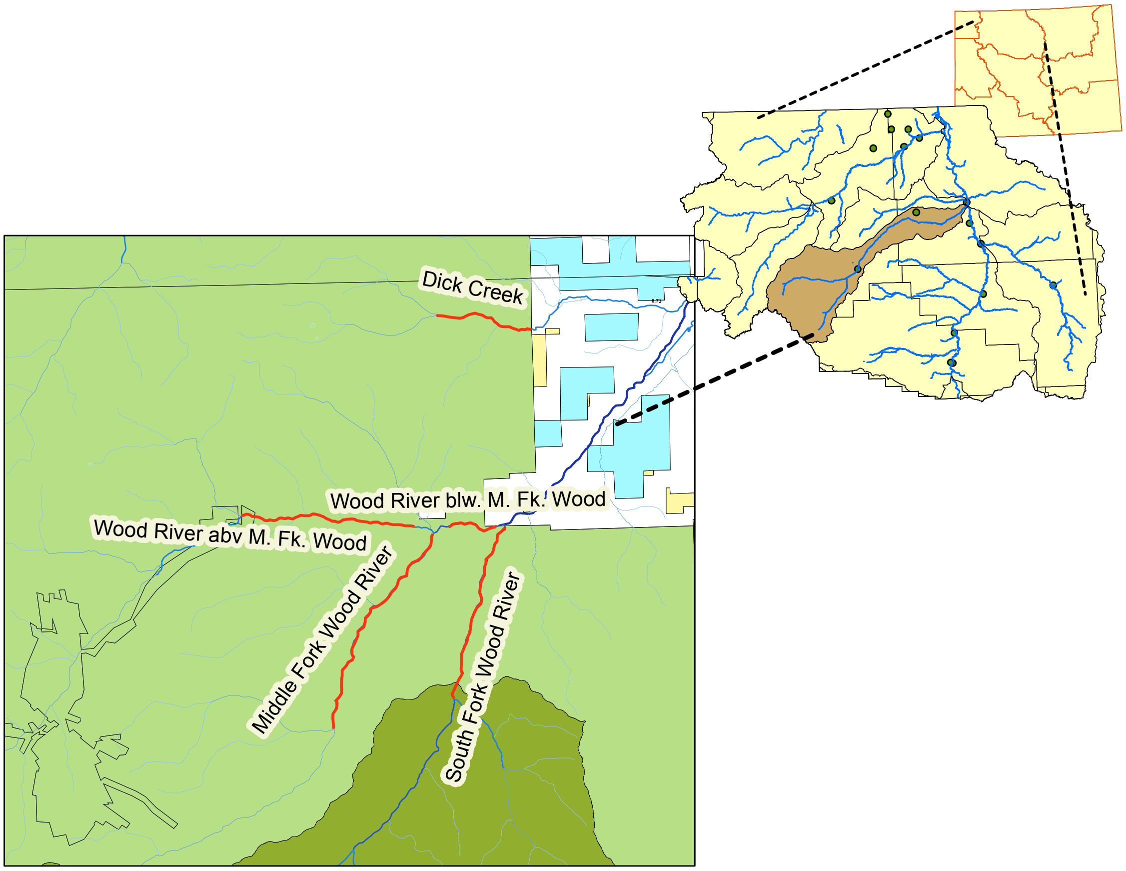

Figure 1. Wood River and Dick Creek instream flow segments.

Instream flow segments (Figure 1, Table 2) were delineated under multiple considerations: the segments should support viable YSC populations, segments should occur mostly or all on public land unless deed holders agree to a segment crossing their land, the segments should offer protection from future development, and the segments should have relatively uniform flow throughout their length. Relatively uniform flow throughout the reach assures that flow recommendations applied at the downstream end of the segment adequately maintains habitat near the upstream end. Except for a small portion of South Fork Wood River, instream flow segments were not established in the Washakie Wilderness because the wilderness designation was judged to provide adequate legal protection.

Instream flow segments were not pursued for some streams in the Wood River basin that harbor Yellowstone cutthroat trout. For example, Deer Creek and Brown Creek were relatively low priorities because of their small size and deeded land near their mouths. See Dey and Annear (in preparation) for a description of prioritization considerations.

Table 2. Wood River instream flow segments. Coordinates and lengths from AllTopo®.

Stream	Length (mi)	Approximate UTM (Z12, NAD27)		Segment Description
		Upper	Lower	
South Fork Wood River	3.9	650,146 E, 4,860,435 N	651,708 E, 4,865,757 N	Chimney Ck downstream to FS boundary
Middle Fork Wood River	4.9	646,412 E, 4,859,502 N	649,541.1 E, 4,865,498 N	Dundee Creek downstream to Wood River
Wood R. above Middle Fork	3.8	643,583 E, 4,866,070 N	649,082 E, 4,865,714 N	Jojo Creek downstream to FS boundary
Wood River below Middle Fork	1.0	649,919 E, 4,865,743 N	651,281.0 E, 4,865,764 N	Deeded/FS boundary downstream to FS boundary
Dick Creek	2.2	649,644 E, 4,872,279 N	652,587 E, 4,871,839 N	Confluence with Gwinn Fork downstream to FS boundary

Hydrology

The Wood River instream flow segments identified in Table 2 exhibit snow melt runoff hydrographs characterized by peak flow in May and June followed by base flow recession the remainder of the year. The magnitude and duration of peak flows are directly related to snow pack and snowmelt. Daily flows during runoff can cycle dramatically when warm air temperatures translate into melting and cold nighttime temperatures slow melting. Annual flow minima occur in January or February. The relative contributions of the South Fork and Middle Fork Wood River to the total Wood River flow also varies between years depending on snowfall and snow melt patterns (Dey and Annear 2003a). The Wood River above the Middle Fork contributes the greatest percentage of the total base flow, about 50-60% in September (Dey and Annear 2003a). The South and Middle Forks each contribute about 20-25%.

An independent contract was awarded to estimate mean annual flow (also called “average daily flow” or ADF), annual flow duration, monthly flow duration, and flood frequency intervals for the four Wood River and single Dick Creek instream flow segments (HabiTech 2002). HabiTech calculated average daily flows from the contributing basin area model of Miselis et al. (1999). This model was developed from gages in Absaroka Mountain streams and is similar to the approach of Lowham (1988). The basin area at the downstream end of the instream flow reaches was used. A dimensional analysis approach was used to develop both annual and monthly flow duration information for the instream segments. Dimensionless duration tables were created for the Wood River at Sunshine 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 for each of the instream flow segments to develop their respective flow duration values. A similar approach was used to develop the flood frequency series for each of the instream flow segments. For further details, see HabiTech (2002).

Alternative approaches for estimating hydrology of the Wood River tributaries include applying the Lowham (1988) basin characteristic approach or the recently refined basin characteristic approach described in Lowham et al. (2003). The basin area approach used by HabiTech (2002) is based on Absorka Mountain gage data to more accurately reflect local conditions. By comparison, the other 2 methods result in higher flow estimates. For example, HabiTech (2002) calculated an average daily flow of 41 cfs for the Wood River upstream of Middle Fork compared to 64 cfs using Lowham (1988). In another example, applying Lowham (2003) in October for the Wood River upstream of Middle Fork Wood River yields an estimated monthly flow of 27.1 cfs. The Miselis et al. equation used by HabiTech (2002) yields 21.1 cfs. Differences on this order are consistent for all months and tributaries. Therefore hydrology estimates used in this report are likely conservative and, if in error, are most likely lower than actually occur in the streams.

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 (2002). 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. As such, it is a higher flow level than the 50% or 80% exceedance flow.

Flow measurements collected during habitat studies are included in this report. HabiTech (2002) used these field measurements to evaluate their hydrological results. Additional flow data were collected from two gage stations operated seasonally by the WGFD on the Wood River during 2002 and 2003. One gage was located downstream from the four Wood River segments and the other gage was located near the lower end of the upper Wood River segment. Detailed methods and descriptions of these gages and flow recordings are reported in WGFD Administrative reports by Dey and Annear (2003a and 2003b). Additional flow measurements were collected at all of the instream flow segments over short time intervals to establish the relative contribution of each of the tributaries.

Flow measurements and habitat studies were collected during years in which the Wood River drainage (and entire State) was experiencing a prolonged drought (Figure 2). Precipitation was less than long-term averages for most months from 2001 through 2003. Drought conditions do not affect our ability to quantify the relationship between trout habitat and flow or recommendations. Measured flows, however, should be interpreted as indicative of drought conditions rather than approximations of normal or average flow.

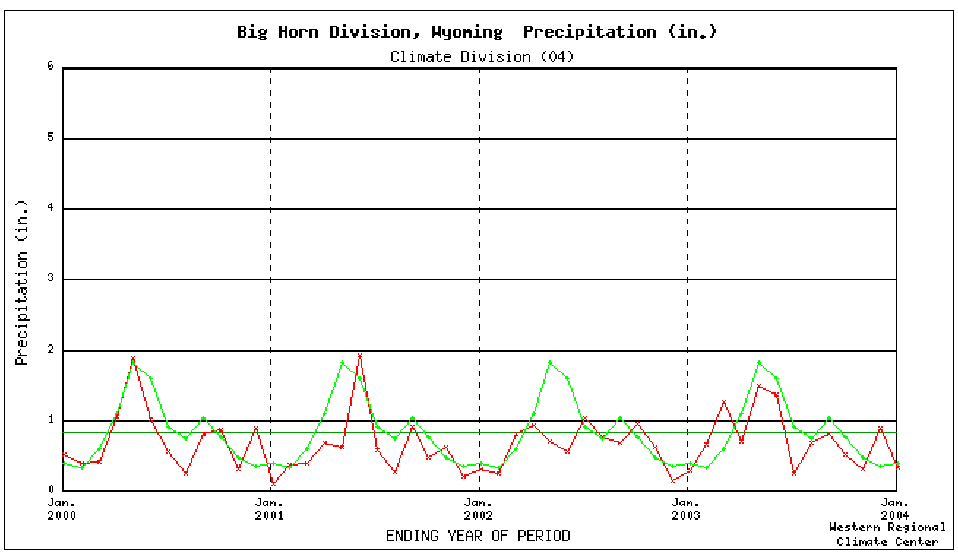

Figure 2. Precipitation in the Bighorn Division (graphic from the western regional climate center wrcc@dri.edu). Green is the long-term average monthly precipitation and red shows 2000 through 2004.

Development of Fish Flow Recommendations

Fish Community

The fish community in the Wood River basin above the Greybull River confluence conforms to a simple high mountain pattern; only 5 species are native. These species are: Yellowstone cutthroat trout, mountain whitefish (*Prosopium williamsoni*), mountain sucker (*Catostomus platyrhynchus*), longnose sucker (*Catostomus catostomus)* and longnose dace (*Rhinichthys cataractae*). Rainbow trout (*Oncorhynchus mykiss*), brook trout (*Salvelinus fontinalis*) and unknown cutthroat trout strains were stocked in the drainage through 1971. Snake River cutthroat trout, a fine-spotted variant of the Yellowstone cutthroat trout, were stocked in 1972 and 1975. Brook trout and Snake River cutthroat trout have been sampled at low to moderate densities in recent surveys of Wood River tributaries. Brook trout are moderately abundant in Dick Creek. Surveys conducted by Kruse (1995) failed to find Yellowstone cutthroat trout in the Wood River upstream of a waterfall near the upper end of the Wood River above Middle Fork segment. In 2004, Yellowstone cutthroat trout were reintroduced to this segment.

In a status assessment of Yellowstone cutthroat trout, Kruse et al. (2000) found genetically pure Yellowstone cutthroat in all sampled streams in the Greybull River watershed, including the Wood River. Yellowstone cutthroat trout in the Wood River drainage were judged to be at greater extinction risk than those in the upper Greybull basin due to the presence of brook trout in some of the streams and the downstream presence of rainbow trout. However, rainbow have not been found to persist in the drainage.

Instream Flow Models

The term "habitat" is used frequently in this report. In most cases, the term refers to the physical conditions of depth, velocity, substrate and cover – variables that change when discharge changes. A full description of trout habitat also includes temperature, dissolved oxygen, distribution and abundance of prey and competitor species, movement timing and extent, and other variables. The "physical" habitat modeled and discussed in this report covers the important dimensions of trout habitat that vary predictably as a function of flow. It is assumed that these aspects of trout habitat are important to the health and short-term persistence of trout populations.

Three modeling approaches described below are used in this report to arrive at monthly fish-based instream flow water right recommendations for May through September. Development of fish flow recommendations for the winter, October through April, is described in a separate section. Channel maintenance flow requirements are described in Appendix 1.

Physical Habitat Simulation

The Physical Habitat Simulation (PHABSIM) system of computer models calculates the stream area considered suitable for life stages (e.g. spawning, fry, juvenile, and adult) of a target species like YSC (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 by stringing a tape perpendicular across the stream at each of several locations (transects) and measuring depth and velocity at multiple locations (cells) along the tape. 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 discharges.

Next, the predicted depths and velocities, along with substrate or cover information, are compared to habitat suitability criteria (HSC). The relative value to a 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 given 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 over a range of discharges (Bovee et al. 1998).

Habitat suitability criteria were developed for adult (greater than or equal to 6 inches total length), juvenile (3 to 6 inches) and spawning YSC by measuring depth, velocity, substrate, and cover at trout locations in Francs Fork Creek and Timber Creek in 1997 and 1998 (WGFD 1998 and 1999). These two streams offered a wide range of habitat conditions and numerous fish for characterizing YSC habitat use. Fry HSC were developed from measurements reported in Bozek and Rahel (1992). The HSC are listed in Appendix 2. PHABSIM for Windows Version 1.2 was used for all analyses and the HABTAE submodel was used for generating WUA.

PHABSIM was applied at Wood River tributary study sites by establishing transects across pool, riffle, run, and rapid habitats. These habitats were selected to span the range of habitats most frequently used by the various life stages.

Habitat Retention

The Habitat Retention Method (Nehring 1979; Annear and Conder 1984) was used to identify the flow that maintains hydraulic criteria (Table 3) in riffles. Maintaining depth, velocity and wetted perimeter criteria in riffles ensures that other habitat types like runs or pools remain viable (Nehring 1979). Fish passage between habitat types and benthic invertebrate survival are considered adequate at the flow level identified by the Habitat Retention Method. 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 3. Hydraulic criteria for determining maintenance flow with the Habitat Retention method.

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

a - Percent of bankfull wetted perimeter

Simulation tools and calibration techniques used for hydraulic simulation in PHABSIM are also used with the Habitat Retention approach. The difference is that Habitat Retention does not attempt to translate depth and velocity information into conclusions about 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 in Table 3 for all three transects is then identified.

Habitat Quality Index

The Habitat Quality Index (HQI; Binns and Eiserman 1979; Binns 1982) was used to determine trout habitat levels over a range of late summer (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 stimulate growth. The HQI was developed by the WGFD to measure 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. Attribute ratings are combined in the model with results expressed in trout Habitat Units (HU's), where one HU is defined as the amount of habitat quality that will support about 1 pound of trout. HQI results were used to identify the flow between July 1 and September 30 needed to maintain existing levels of Yellowstone cutthroat trout production (Table 4).

In the HQI analysis, habitat attributes measured at various flow events are assumed to be typical of late summer flow conditions. For example, stream widths measured in June under high flow conditions are considered 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. To define July through September flow conditions, we review both measured flows and estimated 50% monthly exceedance flows for the July through September period. The August 50% monthly exceedance flow was used as a reasonable estimate of normal late summer flow levels and is consistent with how the HQI was developed (Binns and Eiserman 1979).

Winter Flow Recommendations

Natural winter (October through April) flow levels are recommended to maintain the Yellowstone cutthroat trout populations in the Wood River and Dick Creek segments. The following discussion provides the basis for this recommendation:

Scientific understanding of winter trout habitat and the interaction between trout behavior, their habitat and ice and snow has increased considerably over the last 60 years (Needham et al. 1945, Reimers 1957, Butler 1979, Kurtz 1980, Cunjak 1988, Cunjak 1996, Prowse 2001a and 2001b). 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 processes in particular may limit habitat. For example, suspended ice crystals (frazil ice) can cause direct trout mortality through gill abrasion and subsequent suffocation or indirectly increase mortality by limiting available habitat, causing localized de-watering, and causing excessive metabolic demands on fish forced to seek ice-free habitats (Brown et. al 1994, Simpkins et al. 2000, Annear et al. 2002, Barrineau et al. *In Press*, Lindstrom et al. 2004). 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). Juvenile and fry life stages are typically impacted more than larger fish because younger fish inhabit shallower habitats and stream margins where frazil ice tends to concentrate. Larger fish that inhabit deeper pools may endure frazil events with little effect if they are not displaced. In contrast, refuge from frazil ice may occur in streams with groundwater influx, pools that develop cap ice and segments where heavy snow cover causes stream bridging (Brown et al. 1994). Recent studies in Wyoming document complex interactions between localized ice conditions and trout habitat suitability (Barrineau et al., *In Press*).

The complexities of variable icing patterns (for example, frazil and surface ice often appear and disappear over widely ranging spatial and temporal scales) make direct modeling of winter trout habitat highly difficult if not impossible. 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 (Instream Flow Council 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 simply recommend the existing natural winter flow level. That approach was adopted for the 5 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 and 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.

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 will become the instream flow recommendation.

Another indirect method is developing hydrologic standards for universal application across Wyoming. Hubert et al. (1997) found this approach deficient due to the variable nature of winter trout habitat among streams and poor gage records often associated with the winter season. For this reason, we do not believe the 50% monthly exceedance provides an appropriate estimate of naturally occurring winter flow. It is more conservative 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.

Combining Methods to arrive at Instream Flow Recommendations

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

Table 4. Yellowstone cutthroat trout life stages and months considered in developing instream flow recommendations. Numbers indicate the method used to determine flow requirements and shaded cells indicate primary methods for flow recommendations.

Life Stage and Fishery Function	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Survival and movement of all life stages	1	1	1	1	2	2	2	2	2	1	1	1
Spawning habitat					3	3						
Fry habitat								3	3	3		
Juvenile habitat	3	3	3	3	3	3	3	3	3	3	3	3
Adult habitat	3	3	3	3	3	3	3	3	3	3	3	3
Adult growth							4	4	4			
All life stages habitat					5	5	5					

1=Natural winter flow, 2=Habitat Retention, 3=Physical Habitat Simulation, 4=Habitat Quality Index, 5=Channel Maintenance.

Maintenance of natural flows during the October through April winter months is recommended for high mountain streams like the Wood River tributaries (Table 4). The Habitat Retention approach provides a base flow but is not used for instream flow recommendations when other aspects of fishery maintenance require higher flows. Spawning physical habitat results from PHABSIM provide flow recommendations during May and June when the majority of spawning activity occurs at the elevations spanned by the Wood River instream flow segments. Additionally, physical habitat for adults, juveniles, fry and other life stages is examined to ensure adequacy of flow recommendations from other methods during the remainder of the year. The HQI applies to adult trout growth during the months of July, August and September and is the default method for those months. Channel maintenance flows perform their function during runoff in May, June and early July but are not used for flow recommendations as described in the *Introduction.*

Study Sites

The location of study sites was determined after walking most or all of each instream flow segment. During these reconnaissance inspections, the distribution of trout habitat, location and relative magnitude of tributary water sources, and other features were noted. A single study site was established within each segment at a location offering the range of features judged to be representative of the entire reach. Representative study sites were established near the downstream ends of the instream flow segments to allow modeling and measurement of all water accumulated throughout the reach.

Each study site was visited on multiple dates to measure habitat features under a range of flow conditions. In addition to collecting measurements for the HQI, PHABSIM and Habitat Retention models, a Rosgen Level 2 channel survey was conducted at each site (Rosgen 1996). Under this scheme, geomorphic measures of channel pattern, profile, dimension, and sediment size are characterized. This information serves to differentiate among stream types and provides a base for addressing questions of sediment supply, stream sensitivity to disturbance, channel response to flow regime changes and fish habitat potential. The data are also important for developing channel maintenance flow requirements. Channel measurements collected include measurements of at least 100 substrate particles, cross sectional area, longitudinal profile, and multiple bankfull width measurements. Channel pattern measurements of sinuosity, belt width, and meander length were obtained from digital ortho quarter quadrangles (DOQQ's) using ArcGis software. These measurements were collected in the field at the upper Wood River and Dick Creek sites because digital imagery was poor.

The relative percentages of "macrohabitats" (pools, riffles, runs, etc.) were determined for each study site under the classification scheme of Hawkins et al. (1993). Under this approach, channel units such as pools, riffles, and runs are identified by relative channel gradient, water velocity, surface turbulence, and depth. Channel unit lengths were determined by recording the paced length (about 3 feet per pace) of each channel unit encountered over a stream distance of at least 20X the bankfull width. Percentages of each macrohabitat were used to weight transects in PHABSIM modeling.

Wood River upstream of Middle Fork Wood River

The Wood River upstream of the Middle Fork Wood River is highly accessible to campers, hunters, horse riders, and anglers as it flows nearby and parallel to Forest Road 200. The Brown Mountain Campground is within the instream flow segment. The stream drains 52 square miles and flows primarily from west to east with open south-facing basin slopes dominated by a sagebrush steppe plant community while Engelmann Spruce and Douglas Fir dominate the north facing slopes (Figure 3). Riparian vegetation is moderately thick willow with forbs and grass browsed by wildlife and cattle. The channel is relatively wide and shallow and transports bedload from the geologically young upper basin as well as gully wash material from lateral benches. Additional channel features are described in the results section.

Figure 3. Wood River upstream from Middle Fork Wood River on July 2, 2002 at 56 cfs.

A 456-foot-long study site was established June 4, 2002 about 1 mile downstream from the Brown Mountain Campground at 647,296 m Easting; 4,865,917 m Northing (Zone 12, NAD27). This site was selected because riffles, runs, pools, spawning gravel, and stream-margin fry habitat were present (Figure 3). Data were collected on the dates and at the discharges listed in Table 5. Twelve transects were located in pools, runs, riffles, and rapids. A gully washed out following a July rainfall event and deposited a large fan of alluvial material across the channel near the bottom end of the study site. The debris flow covered the lowest three transects and backed water up about 100 feet through transect 7, rendering the lower part of the study site and previous data collected there unusable. An additional transect, numbered “13”, was added about 100 feet upstream of the previous transect number 12 and marked the new upper end of the HQI reach. PHABSIM modeling then used 6 transects.

Table 5. Dates and discharges when measurements were collected at the Wood River above Middle Fork Wood River study site. Additional flow measurements are reported in the Hydrology section.

Date	Discharge (cfs)	Data Collected
June 4, 2002	18 – 25	PHABSIM, HQI, Habitat Retention
July 2, 2002	56 – 69	PHABSIM, HQI, Habitat Retention
July 31, 2002	45	PHABSIM, HQI, Habitat Retention, channel features
September 11, 2002	26	PHABSIM, HQI, Habitat Retention
October 9, 2002	21	PHABSIM, HQI, Habitat Retention, macrohabitat %

Two PHABSIM projects were created. The new upper transect was modeled in a separate project from the five remaining original transects. Water surface elevations for the lower project were simulated using a stage-discharge relationship while a Manning’s Equation approach (MANSQ) was used for the upper transect. These approaches were selected to minimize error in water surface predictions. The velocity set collected at 58 cfs served as the calibration velocity set for distributing roughness among the cells. Physical habitat was simulated over the range 1.3 cfs to 110 cfs based on calibration criteria in Milhous et al. (1984). Increments of 1.0 cfs were simulated over the range 1-20 cfs and increments of 10 cfs were used to simulate from 20 to 100 cfs. Additional simulations at 1 cfs increments were run to identify peaks in spawning weighted useable area. Weighted useable area versus flow curves were generated for spawning, fry, juvenile and adult Yellowstone cutthroat trout.

Three riffle transects modeled with PHABSIM were used in the Habitat Retention analysis. Bankfull wetted width across each of the riffle transects was measured July 31, 2002 using bankfull indicators to identify the bankfull stage (Rosgen 1996). The flow required to attain the field measured bankfull stage (320 cfs) matched well with HabiTech’s (2002) 1.5-year recurrence peak flow (323 cfs), a common estimate of bankfull discharge. The correspondence between the two methods provides confidence that both estimates are reasonable. Measured bankfull wetted perimeter was used in the Habitat Retention analysis. An alternative approach would be to use the wetted perimeter that occurs at the HabiTech (2002) calculated bankfull flow of 323 cfs. Using measured bankfull width is a more direct approach. For applying the Habitat Retention depth criteria, an average daily flow of 41 cfs was used (HabiTech 2002). Average wetted width at 41 cfs was measured at 28 feet; therefore, 0.28 feet was the depth criteria.

For HQI analysis, the critical period stream flow and annual stream flow variation attributes were calculated using average daily flow (41 cfs) and peak flow (323 cfs) estimates from HabiTech (2002). Maximum water temperature was determined with an Optic StowAway® temperature recorder set to monitor water temperature at 4-hour intervals between June 3 and November 7, 2002. Nitrate levels were determined from a water sample collected September 11, 2002 and analyzed by the Analytical Services section of the Wyoming Department of Agriculture, Laramie, Wyoming. The HQI “substrate” attribute, a measure of invertebrates per square foot of streambed, was measured by collecting three Surber samples and counting invertebrate numbers streamside.

Middle Fork Wood River

The Middle Fork Wood River drains a 37 square mile basin, flowing primarily north to combine with the Wood River a short distance upstream from the Wood River Campground. East and west facing valley slopes have dense conifers dotted with small aspen patches (Figure 4). The channel transports large volumes of bed material naturally eroding from the steep terrain resulting in some braided channel reaches. A narrow band of grass, sedge and mature conifers mark the riparian zone. A horse-packing trail follows the stream corridor. Additional channel features are described in the Results section.

Figure 4. Middle Fork Wood River looking upstream from study site on September 26, 2003 at 14 cfs.

A 427-foot study site was established April 29, 2003 about 0.7 mile upstream from the mouth at 649,076 m Easting, 4,864,654 m Northing (Zone 12, NAD27). This site was selected because it was at a point where the valley began to narrow and a single channel existed. While multi thread channels were common in reaches both upstream and downstream, adult habitat is minimal in those areas and PHABSIM performs poorly under those conditions. The study site contained a diverse array of habitat for all trout life stages. Woody debris from fallen trees was an important formative agent in many pools and provided cover for adult and juvenile trout.

Data were collected on the dates listed in Table 6. Nine transects were distributed among riffle, run, pool, and rapid habitats. The 6 downstream transects spanned 62 feet of channel and were linked together in a PHABSIM project. The remaining three rapid and riffle transects were modeled individually under separate PHABSIM project folders. Best water surface elevation calibrations were achieved using PHABSIM's stage-discharge function for three of the projects. For the uppermost transect, MANSQ provided the best water surface elevation calibration. The velocity set collected at 39 cfs was used in calibrating velocities. Physical habitat was simulated using the HABTAE submodel over the range 5 cfs to 100 cfs based on calibration criteria in Milhous et al. (1984). Increments of 1.0 cfs were simulated over the range 5-50 cfs and increments of 10 cfs were used to simulate from 50 to 100 cfs. Weighted useable area versus flow curves were generated for spawning, fry, juvenile and adult Yellowstone cutthroat trout. Output from the various transects was combined by weighting each transect to correspond to the abundance of the habitat type covered by the transect as measured during the macrohabitat survey.

Table 6. Dates and discharges when measurements were collected at the Middle Fork Wood River study site. Additional flow measurements are reported in the hydrology section.

Date	Discharge (cfs)	Data Collected
April 29, 2003	14	Reconnaissance, study site picked
June 17, 2003	73	Flow measured, study site refined
July 9, 2003	39	PHABSIM, HQI, Habitat Retention
August 6, 2003	18	PHABSIM, HQI, Habitat Retention, channel features, macrohabitat %
September 26, 2003	14	PHABSIM, HQI, Habitat Retention

Three riffle transects modeled with PHABSIM were used in the Habitat Retention analysis. Bankfull wetted width across each of the riffle transects was measured August 6, 2003 using bankfull indicators to identify the bankfull stage (Rosgen 1996). The flow required to attain the field measured bankfull stage (272 cfs) matched reasonably well with HabiTech's (2002) 1.5-year recurrence peak flow (215 cfs), a common estimate of bankfull discharge. The correspondence between the two methods provides confidence that both estimates are reasonable. Measured bankfull wetted perimeter was used in the Habitat Retention analysis. An alternative approach would be to use the wetted perimeter that occurs at the HabiTech (2002) calculated bankfull flow of 215 cfs. Using measured bankfull width is a more direct approach. For applying the Habitat Retention depth criteria, an average daily flow of 27 cfs was used (HabiTech 2002). Average wetted width at 27 cfs was at 22 feet; therefore, 0.22 feet was the depth criteria.

For HQI analysis, the critical period stream flow and annual stream flow variation attributes were calculated using average daily flow (27 cfs) and peak flow (215 cfs) estimates from HabiTech (2002). Maximum water temperature was determined from a measurement on August 6, 2003 and by comparison to recorded water temperatures on the Wood River upstream of the Middle Fork Wood River. Nitrate levels were determined from a water sample collected September 26, 2003 and analyzed by the Analytical Services section of the Wyoming Department of Agriculture, Laramie, Wyoming. The HQI "substrate" attribute, a measure of invertebrates per square foot of streambed, was from counting invertebrate numbers collected in three Surber samples.

South Fork Wood River

The South Fork Wood River drains a 55 square mile basin, flowing primarily north to combine with the Wood River a short distance downstream from the Wood River Campground. This basin parallels the Middle Fork Wood River basin and has similar geomorphic, upland, and channel features (Figure 5). East and west facing valley slopes have dense conifers dotted with small aspen patches, scree slopes, and small meadows. The channel transports large volumes of bed material naturally eroding from the steep terrain resulting in some braided channel reaches. A narrow band of grass, sedge, shrubs and mature conifers mark the riparian zone. A horse-packing trail follows the stream corridor. Additional channel features are described in the Results section.

Figure 5. South Fork Wood River on September 23, 2003 at 11 cfs. Looking upstream at lower end of study site.

A 476-foot study site was established April 30, 2003 about 0.5 mile upstream from the mouth at 651,323 m Easting, 4,865,353 m Northing (Zone 12, NAD27). This site was selected partly because it had a single channel whereas multi thread channels were common in some upstream reaches. Adult habitat is minimal in those areas and PHABSIM performs poorly under multi channel conditions. The study site contained habitat for all trout life stages. Woody debris was less abundant than in the Middle Fork Wood River but the occasional fallen tree provided cover for adult and juvenile trout.

Data were collected on the dates listed in Table 7. Nine transects were distributed among riffle, run, pool, and rapid habitats. The most downstream transect was modeled individually as a PHABSIM project. The 8 remaining transects spanned 62 feet of channel and were linked together in a PHABSIM project. Best water surface elevation calibrations were achieved using PHABSIM's stage-discharge function for the single transect. For the remaining 8 transects, MANSQ provided the best water surface elevation calibration. The velocity set collected at 41 cfs was used to calibrate velocities. Physical habitat was simulated over the range 5 cfs to 200 cfs based on calibration criteria in Milhous et al. (1984). Increments of 1.0 cfs were simulated over the range 5-45 cfs and larger increments were used to simulate from 50 to 200 cfs. Weighted useable area versus flow curves were generated for spawning, fry, juvenile and adult Yellowstone cutthroat trout. The transects were combined by weighting each transect to correspond to the abundance of the habitat type represented by each transect.

Table 7. Dates and discharges when measurements were collected at the South Fork Wood River study site. Additional flow measurements are reported in the hydrology section.

Date	Discharge (cfs)	Data Collected
April 30, 2003	18	Reconnaissance, study site picked
July 8, 2003	41	PHABSIM, HQI, Habitat Retention
August 5, 2003	14	PHABSIM, HQI, Habitat Retention, channel profile, macrohabitat %
September 10, 2003	23	PHABSIM, Habitat Retention, channel area
September 23, 2003	11	PHABSIM, HQI, Habitat Retention

Three riffle transects modeled with PHABSIM were used in the Habitat Retention analysis. Bankfull wetted widths across each riffle transect was measured September 10, 2003 using bankfull indicators to identify the bankfull stage (Rosgen 1996). The flow required to attain the field measured bankfull stage (275-330 cfs) matched reasonably well with HabiTech's (2002) 1.5-year recurrence peak flow (344 cfs), a common estimate of bankfull discharge. The correspondence between the two methods provides confidence that both estimates are reasonable. Measured bankfull wetted perimeter was used in the Habitat Retention analysis. An alternative approach would be to use the wetted perimeter that occurs at the HabiTech (2002) calculated bankfull flow of 344 cfs. Using measured bankfull width is a more direct approach. For applying the Habitat Retention depth criteria, an average daily flow of 44 cfs was used (HabiTech 2002). Average wetted width at 44 cfs was 28 feet; therefore the depth criterion was 0.28 feet.

For HQI analysis, the critical period stream flow and annual stream flow variation attributes were calculated using average daily flow (44 cfs) and peak flow (344 cfs) estimates from HabiTech (2002). Maximum water temperature was determined with an Optic StowAway® temperature recorder set to monitor water temperature at 1-hour intervals between April 30, 2003 and September 10, 2003. Nitrate levels were determined from a water sample collected September 26, 2003 and analyzed by the Analytical Services section of the Wyoming Department of Agriculture, Laramie, Wyoming. The HQI "substrate" attribute, a measure of invertebrates per square foot of streambed, was from counting invertebrate numbers collected in three Surber samples on September 23, 2003.

Wood River downstream of Middle Fork Wood River

This one-mile stream segment parallels Forest Road 200 and includes the Wood River Campground. Since study sites in two nearby segments upstream provide detailed analyses of fish habitat tradeoffs at different flow levels, a study site was not established for this segment. Instream flow recommendations were developed by summing recommendations from the upper sites. With relatively deep pools and well-defined riffles and rapids, it offers excellent adult trout habitat. Limited gravel, boulders and backwater areas provide habitat for spawning, fry and juvenile trout but the deep pools indicate the reach is most important for adult trout. Deep pools are relatively insensitive to flow quantity so the summed flows recommendations from the shallower upstream segments will maintain adequate depth for adult trout.

Providing upstream-downstream connectivity is an important function of this segment. Adequate year round flows are needed to allow upstream adult fish passage in the spring for spawning, downstream fall movement for adults seeking winter cover, and incidental year round movement for juvenile and adult trout seeking unoccupied territory and feeding opportunities. Since flow recommendations at upstream study sites were developed in part to provide fish passage, the sum of those values is believed sufficient to maintain fish movement opportunities in the lower Wood River segment.

Dick Creek

Dick Creek drains an 11.8 square mile basin upstream of the Forest Service boundary and flows primarily from west to east (Figure 6). Downstream of the instream flow segment, the stream flows about 4.5 miles across private land to its confluence with the Wood River. South facing valley slopes have sagebrush and shrub steppe plant communities and include occasional whitebark pine, limber pine, and juniper. North facing slopes have thick spruce, lodgepole, and Douglas fir stands. Small aspen patches and open grassy ridge tops occur throughout the basin. Upland conifers are mostly mature or decadent and have little age class diversity. A spruce beetle epidemic combined with drought conditions during the late 1990's through 2004 has resulted in many dead or dying conifers. Prescribed fire treatments have been conducted in recent years along the Gwynn Fork of Dick Creek, upstream of the instream flow segment. The drainage receives moderate cattle use during summer and early fall.

Riparian plants include willow and occasionally other shrubs, herbaceous forbs and sedges. Conifers and localized cottonwood trees are present in the riparian zone. A perched wetland upstream from South Fork Dick Creek contains abundant willow. Canopy cover is moderate and varies from a few short reaches with near complete cover to, more commonly, reaches with less than 50% of the stream surface shaded. Forest roads 202 and 223 parallel the stream channel. Additional channel features are described in the Results section.

A 334-foot study site was established June 18, 2003 at 652,170 m Easting, 4,872,087 m Northing (Zone 12, NAD27), less than ¼ mile upstream from the Forest boundary. This site was selected because it is low in the watershed and offered a range of habitats used by all Yellowstone cutthroat trout life stages.

Data were collected on the dates listed in Table 8. Nine transects were distributed among riffle, run, pool, and rapid habitats. The most downstream 2 transects were seven feet apart and modeled together in a PHABSIM project. The remaining seven transects spanned 91 feet of channel and were linked together in a separate PHABSIM project. Best water surface elevation calibrations were achieved using PHABSIM's MANSQ function for the lower 2 transects. For the remaining 7 transects, stage-discharge provided the best water surface elevation calibration. The velocity set collected at 7.5 cfs was used to calibrate velocities. Physical habitat was simulated over the range 0.4 to 18 cfs based on calibration criteria in Milhous et al. (1984). Increments of 0.1 cfs were simulated over the range 0.4 to 3 cfs and 0.5 cfs increments were used to simulate above 3 cfs. Weighted useable area versus flow curves were generated for spawning, fry, juvenile and adult Yellowstone cutthroat trout. Transects were combined by weighting each transect to correspond to the abundance of the habitat type.

Table 8. Dates and discharges when habitat measurements were collected at the Dick Creek study site. Additional flow measurements are reported in the hydrology section.

Date	Discharge (cfs)	Data Collected
June 18, 2003	7.5	PHABSIM, HQI, Habitat Retention
July 10, 2003	3.5	PHABSIM, HQI, Habitat Retention, channel features, macrohabitat %
August 7, 2003	2.1	PHABSIM, HQI, Habitat Retention

Figure 6. Dick Creek on June 18, 2003 at 7.5 cfs. Looking upstream at upper end of study site.

Three riffle transects modeled with PHABSIM were used in the Habitat Retention analysis. Bankfull wetted widths across each riffle transect was measured June 18, 2003 using bankfull indicators to identify the bankfull stage (Rosgen 1996). The flow required to attain the field measured bankfull stage (average of 46 cfs) matched reasonably well with HabiTech's (2002) 1.5-year recurrence peak flow (58 cfs), a common estimate of bankfull discharge. The correspondence between the two methods provides confidence that both estimates are reasonable. Measured bankfull wetted perimeter was used in the Habitat Retention analysis. An alternative approach would be to use the wetted perimeter that occurs at the HabiTech (2002) calculated bankfull flow of 58 cfs. Using measured bankfull width is a more direct approach. For applying the Habitat Retention depth criteria, an average daily flow of 7.4 cfs was used (HabiTech 2002). Average wetted width at 7.4 cfs was less than 20 feet therefore the depth criterion was 0.20 feet.

For HQI analysis, the critical period stream flow and annual stream flow variation attributes were calculated using average daily flow (7.4 cfs) and peak flow (58 cfs) estimates from HabiTech (2002). Maximum water temperature was determined using an Optic StowAway® temperature recorder set to monitor water temperature at 1-hour intervals between June 18, 2003 and September 26, 2003. Nitrate levels were determined from a water sample collected September 26, 2003 and analyzed by the Analytical Services section of the Wyoming Department of Agriculture, Laramie, Wyoming. The HQI "substrate" attribute, a measure of invertebrates per square foot of streambed, was estimated visually.

RESULTS AND DISCUSSION

Wood River upstream of Middle Fork Wood River

Channel Features

This Wood River segment conforms to a Rosgen C4 channel type (Table 9). Rated as a gravel bed stream, the median substrate size of 62 mm is very close to the cobble category defined at 64 mm (Rosgen 1996). Low entrenchment and moderate slope and width to depth ratios mark this stream type. A well-developed flood plain and meandering channel with defined riffle to pool sequences further characterize this stream type. For a C-channel, sinuosity is low and slope is fairly high indicating that this channel is close to a transition zone toward the B-channel type, typically more common at higher elevations.

Table 9. Level 2 survey measurements at the Wood River upstream of Middle Fork Wood River study site.

Channel Feature	Value
Mean riffle bankfull width (ft)	42.2
Mean depth (ft)	1.44
Cross section area (ft2)	58.2
Entrenchment ratio	3.46
*D50 (mm)	62
Slope (ft./ft.)	0.018
Sinuosity	1.10
Stream Type	C4

* D50 is the median particle size on a cumulative frequency plot.

Hydrology

Table 10 lists key flow parameters from HabiTech (2002) and flow measurements collected by WGFD. HabiTech estimates are generally within the range of measured values, even considering measurements were collected during a drought period (Table 10). Peak average daily flows in 2002 and 2003 were 131 cfs and 221 cfs, respectively (Figure 7). These small peaks have return periods of about 1.05 years and 1.20 years according to the HabiTech (2002) analysis and provide further evidence of the drought conditions. Further tabulation of flow measurements during 2002 and 2003 are in Dey and Annear (2003a). Two measurements not included in that report were collected in 2004: 32 cfs was measured September 29 and 32 cfs was measured again October 13.

Table 10. Flow characteristics for the Wood River upstream of Middle Fork Wood River instream flow segment (HabiTech 2002). Measured flow ranges during May through September are average daily flows from a gage operated seasonally by the Wyoming Game and Fish (Dey and Annear 2003a). Measured flows were collected in 2002 – 2004.

Flow parameter or month	Estimated Flow (cfs)	
Mean Annual	41	
1.5 year peak	323	
25 year peak	1190	
	HabiTech 50% Exceedance (cfs)	WGFD measured flow range (cfs)
May	62	10 – 221
June	131	15 – 156
July	59	38 – 92
August	33	25 – 69
September	25	20 – 41
	HabiTech 20% Exceedance (cfs)	WGFD measured flow (cfs)
October	31	19, 32
November	23	--
December	18	--
January	15	--
February	14	--
March	16	--
April	29	8.8, 9.6

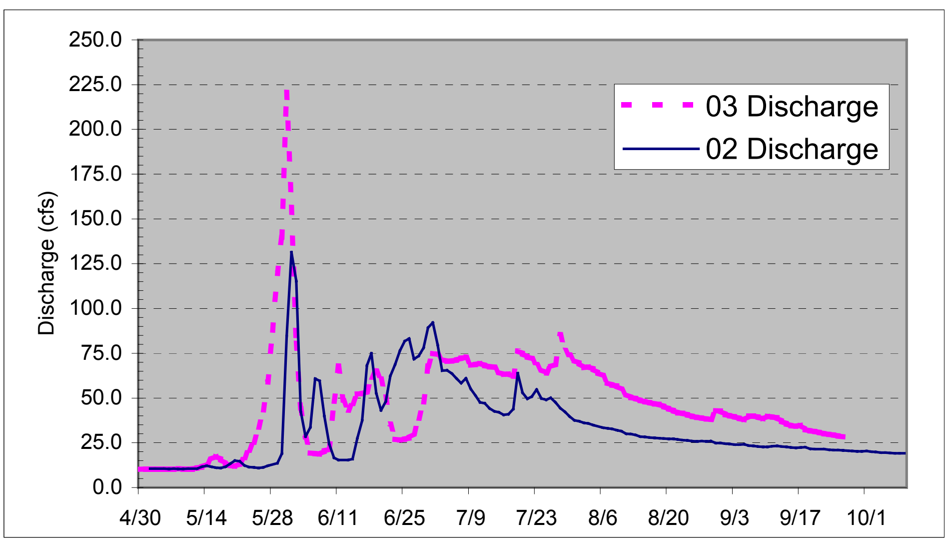

Figure 7. Daily flows recorded at a gage operated on the Wood River above Middle Fork Wood River (see Dey and Annear 2003a).

Development of Fish Flow Recommendations

Physical Habitat Simulation

The macrohabitat survey covered 1011 paces of stream channel including the study site and tallied 87% fast-water channel units and 13% slow-water units (pools). Rapids were the most frequent fast water category (52%) followed by riffles (20%). Chutes and runs each comprised less than 10% of the total. Small pools behind boulders or large cobble (9%), backwater pools (3%) and lateral scour pools (1%) were the most frequently identified pool types.

The WUA index of spawning habitat peaked at 19 cfs for the group of 5 transects and the peak was at 25 cfs for the single riffle transect (Figure 8). The average curve peaks at 22 cfs. The indices show spawning habitat declining gradually at lower flows and dropping rapidly at higher flows. At higher flow levels, velocity is the primary basis for reduced suitability, while declining depths at low flows are the primary limiting factor.

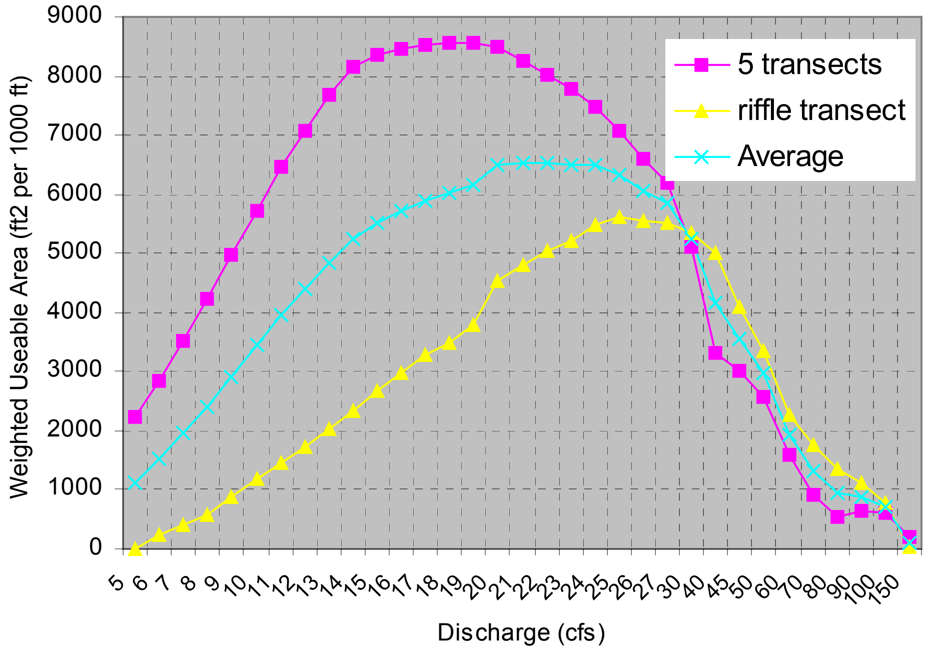

Figure 8. Yellowstone cutthroat trout spawning habitat at the Wood River above Middle Fork Wood River study site (square feet per 1000 feet of stream). Note x-axis values are scaled to show simulated flows.

To maintain spawning habitat (Figure 8), an instream flow of 22 cfs is recommended for May through June. Though the full 22 cfs may not always be present during this entire period, protection of flows up to 22 cfs will maintain adequate spawning habitat and therefore maintain the existing fishery.

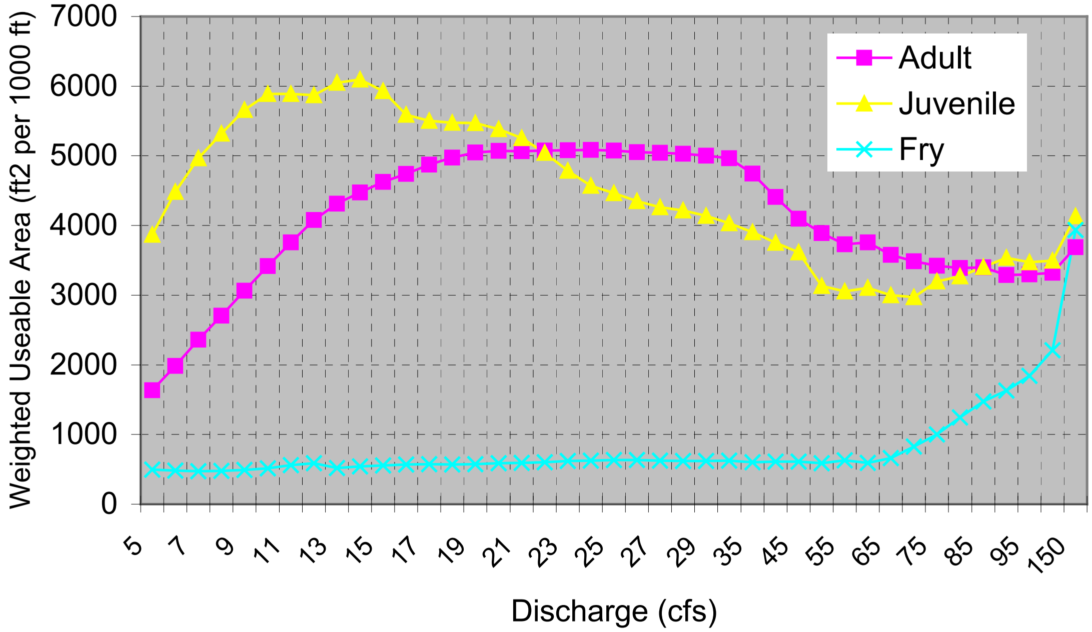

Figure 9. Yellowstone cutthroat trout weighted useable area for adult, juvenile, and fry life stages at the Wood River above Middle Fork Wood River site (square feet per 1000 feet of stream). Note x-axis values are scaled to show simulated flows.

The indices of physical habitat for juvenile and adult Yellowstone Cutthroat trout show rapid gains as flow increases with peak levels at 13 cfs (juveniles) and 20 cfs (adults; Figure 9). A broad plateau in adult WUA indicates favorable depth and velocity conditions up to at least 40 cfs (Figure 9). Fry habitat is low and stable with some increase at higher flows as stream margins increasingly become inundated and provide the slow, backwater conditions required by this life stage.

Habitat Retention

Average depth, average velocity, and wetted perimeter across three riffle transects as a function of flow are listed in Table 11. At riffle 1, velocity is the first hydraulic criteria "met" as flow declines from its bankfull level to 7.3 cfs. Next, the wetted perimeter criterion is met at 5.0 cfs. Finally, for riffle 1, the depth criterion is reached at a flow of less than 5 cfs (criteria could not be reliably simulated at flows less than 5 cfs). Thus, two of three hydraulic criteria (mean depth and wetted perimeter) are retained by a flow of 5.0 cfs across riffle 1 (Table 11). In a similar fashion, 7.6 cfs retains two of three criteria on riffle 2 and less than 5 cfs is required to meet criteria on riffle 3. Therefore, the flow that retains two of three criteria for <u>all</u> of the studied riffles is 7.6 cfs. Based on the Habitat Retention model, a flow of 7.6 cfs is necessary year round to maintain trout survival, movement and invertebrate production.

The 7.6 cfs from Habitat Retention provides limited adult habitat (Figure 9). Under ice-free conditions, trout can move between pools while greater flow levels would provide additional adult habitat. The HQI model results in the following section further define adult trout summer habitat needs. The need for natural winter flows, greater than 7.6 cfs, is discussed in a later section.

Table 11. Simulated hydraulic criteria for three Wood River riffles. Bold indicates that the hydraulic criterion was met. Flows meeting 2 of 3 criteria for each riffle are shaded.

	Mean Velocity (ft/s)	Mean Depth (ft)	Wetted Perimeter (ft)	Discharge (cfs)
Riffle 1 – transect 2	6.00	1.35	41.6	323
	4.20	0.91	40.5	150
	2.43	0.67	28.1	45
	2.33	0.64	27.9	41
	1.16	0.39	22.5	10
	1.00	0.34	21.7	7.3
	0.84	0.29	**20.8**	**5.0**
	<0.84	**0.28**	<20.8	<5
Riffle 2 – transect 3	7.83	1.25	33.5	323
	7.51	1.22	33.2	300
	2.62	0.70	24.9	45
	2.49	0.67	24.7	41
	1.15	0.49	17.9	10
	1.00	0.47	16.7	7.8
	0.99	0.47	**16.6**	**7.6**[a]
	0.96	0.47	16.4	7.3
	<0.77	**0.28**	<15.6	<5
Riffle 3 – transect 6	6.15	1.18	45.1	323
	6.17	1.18	44.3	320
	6.21	1.19	42.9	315
	2.95	0.51	29.9	45
	2.76	0.50	29.8	41
	1.00	0.38	28.1	10.5
	0.82	0.35	27.7	8
	0.74	0.34	27.5	7
	<0.59	**0.28**	**<26.0**	**<5**

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

Habitat Quality Index

A maximum water temperature of 60° F was recorded June 30, 2002. This temperature falls in the 55 - 65° F band for a rating of "4" under Binns (1982) and reflects optimal thermal conditions. Nitrate concentrations were ideal for trout production at 0.18 mg/l. Eroding banks, at 0%, rated a "4". The average of three Surber samples was 106 invertebrates per square foot for a rating of "2". Percent cover ranged between 6% and 15% with the peak measured at 21 cfs. The cover rating changes from "1" to "0" when cover is less than 10% of the wetted channel. By linear interpolation, the cover rating declines to less than 10% at flows less than 17 cfs and greater than 35 cfs.

Peak habitat units occur between 24 and 30 cfs (Figure 10). A combination of adequate base flow, minimal annual stream flow variation when baseflow is at least 24 cfs, and greater than 10% cover contribute to the peak habitat. When flows drop below 18 cfs, cover declines to less than 10% and habitat units decline (Figure 10).

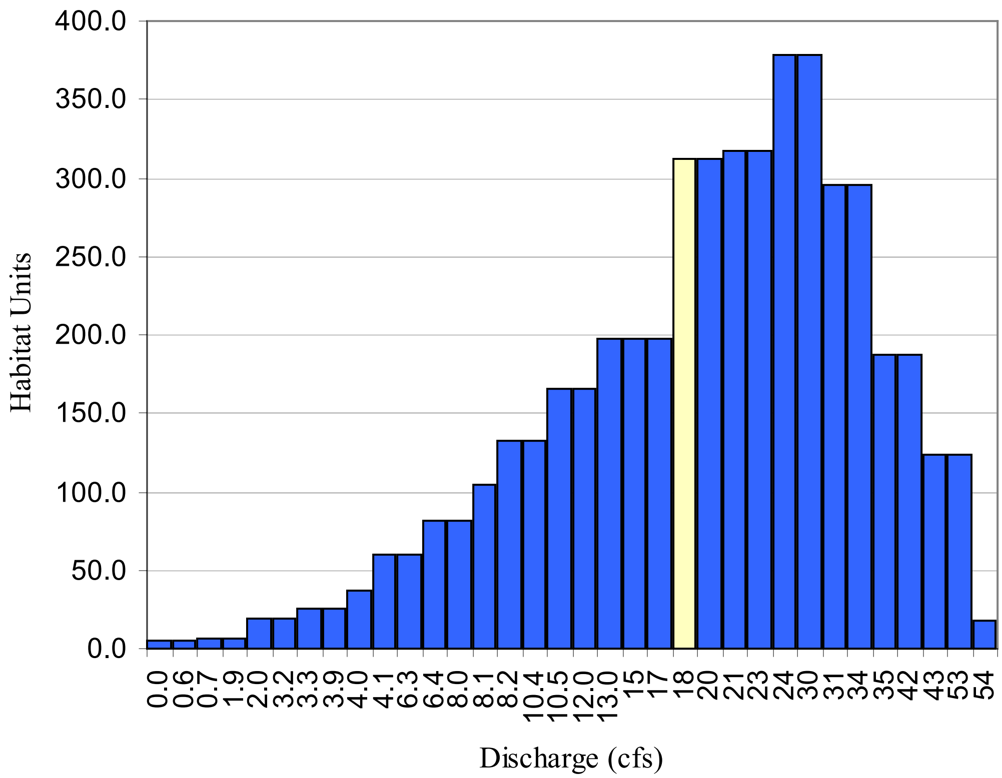

Figure 10. Habitat Quality Index at the Wood River above Middle Fork study site for a range of flow levels. X-axis flows are scaled to show where changes in Habitat Units occur. The recommended flow is indicated by the light shaded bar.

Measured flows in the July through September period range from 20 to 92 cfs (Table 10). Estimated monthly streamflows that occur 50% of the time are: 59 cfs, 33 cfs, and 25 cfs for July, August and September, respectively (Table 10). The 33 cfs August value provides a reasonable estimate of normal late summer flow levels. At this flow, the stream provides 295 habitat units (Figure 10). The lowest flow that will maintain 295 habitat units is 18 cfs. The instream flow recommendation to maintain adult Yellowstone cutthroat trout habitat during the late summer period is 18 cfs.

Winter Flows and Habitat

October through April 20% monthly exceedance flows listed in Table 10 are recommended to maintain winter trout habitat. As a conservative estimate of natural winter flow levels, these flow quantities will maintain winter habitat and icing constraints on trout survival at natural levels.

All of the recommended monthly flows are greater than the 7.4 cfs from Habitat Retention (Tables 10 and 11). At 7.4 cfs, fish passage and invertebrate production are maintained under ice-free conditions but there is no assurance hydraulic conditions will be similar when cap, edge and frazil ice are formed in winter. Rather, there is a reasonable likelihood that reduction of flows to such a level could harm trout survival. In wide and shallow channels such as the Wood River, there is great potential for winter ice to greatly change the depth and distribution of water flow through riffles under low flow conditions like 7.4 cfs. For example, accumulated anchor ice may limit passage and pose a significant threat of riffles freezing solid, forming ice jams that divert most or all flow out of the channel, and dewatering long stretches of stream. From PHABSIM, adult and juvenile physical habitat is much higher at the recommended winter flow levels than they would be at 7.4 cfs (Figure 9). PHABSIM results apply to ice-free conditions so extrapolation to winter is limited to ice-free areas and pools beneath a stable ice cover.

Middle Fork Wood River

Channel Features

The Middle Fork Wood River segment is a Rosgen C4 channel type (Table 12). The median substrate size of 58 mm qualifies as a very course gravel bed (Rosgen 1996). Low entrenchment and moderate slope and width-to-depth ratios mark this stream type. This stream type is characterized by a well-developed flood plain and meandering channel with defined riffle to pool sequences. For a C-channel, sinuosity in the instream flow reach is relatively low and slope is fairly high indicating that this channel is in a transition zone toward the B-channel type, typically more common at higher elevations.

Table 12. Level 2 survey measurements at the Middle Fork Wood River study site.

Channel Feature	Value
Mean riffle bankfull width (ft)	32.5
Mean depth (ft)	0.86
Cross section area (ft2)	29.0
Entrenchment ratio	2.74
D50 (mm)	58
Slope (ft./ft.)	0.0185
Sinuosity	1.10
Stream Type	C4

Hydrology

Table 13 lists key flow parameters from HabiTech (2002) and flow measurements collected by WGFD. HabiTech estimates are consistent with measured values considering measurements were collected during a drought period. Further tabulation of flow measurements during 2002 and 2003 are in Dey and Annear (2003a). An additional measurement not included in that report was 13.2 cfs on September 29, 2004.

Table 13. Flow characteristics for the Middle Fork Wood River instream flow segment (HabiTech 2002). Measured flows were collected in 2002 – 2004.

Flow parameter or month	Estimated Flow (cfs)	
Mean Annual	27	
1.5 year peak	215	
25 year peak	790	
	HabiTech 50% Exceedance (cfs)	WGFD measured flow (cfs)
May	41	--
June	87	38-73
July	39	10-39
August	22	18
September	17	8.9-24
	HabiTech 20% Exceedance (cfs)	WGFD measured flow (cfs)
October	20	6.3
November	15	--
December	11	--
January	10	--
February	9.5	--
March	11	--
April	19	14

Development of Fish Flow Recommendations

Physical Habitat Simulation

The macrohabitat survey covered 701 paces of stream channel including the study site and tallied 92% fast-water channel units and 8% slow-water units (pools). Riffles were the most frequent fast water category (45%) followed by rapids (38%). Cascades and runs each comprised less than 10% of the total. Pools were lateral scour pools (7%), small pools behind boulders or large cobble (0.5%) and backwater pools.

The WUA index of spawning habitat peaked at 19 cfs for the weighted combined transects (Figure 11). The spawning habitat index declines gradually at higher flows as velocities become too fast. As flow drops below 19 cfs, the spawning index drops rapidly because of shallow depths. To maintain spawning habitat (Figure 11), an instream flow of 19 cfs is recommended for May through June. Though the full 19 cfs may not always be present during this entire period, protection of flows up to 19 cfs will maintain adequate spawning habitat and therefore maintain the existing fishery.

The physical habitat index for adult Yellowstone Cutthroat trout shows a slow rise peaking at about 20 cfs and maintained over a broad flow range until slowly declining at flows over 40 cfs (Figure 11). Juvenile fish find more favorable velocities at relatively low discharges while no noteworthy patterns exist for fry (Figure 11).

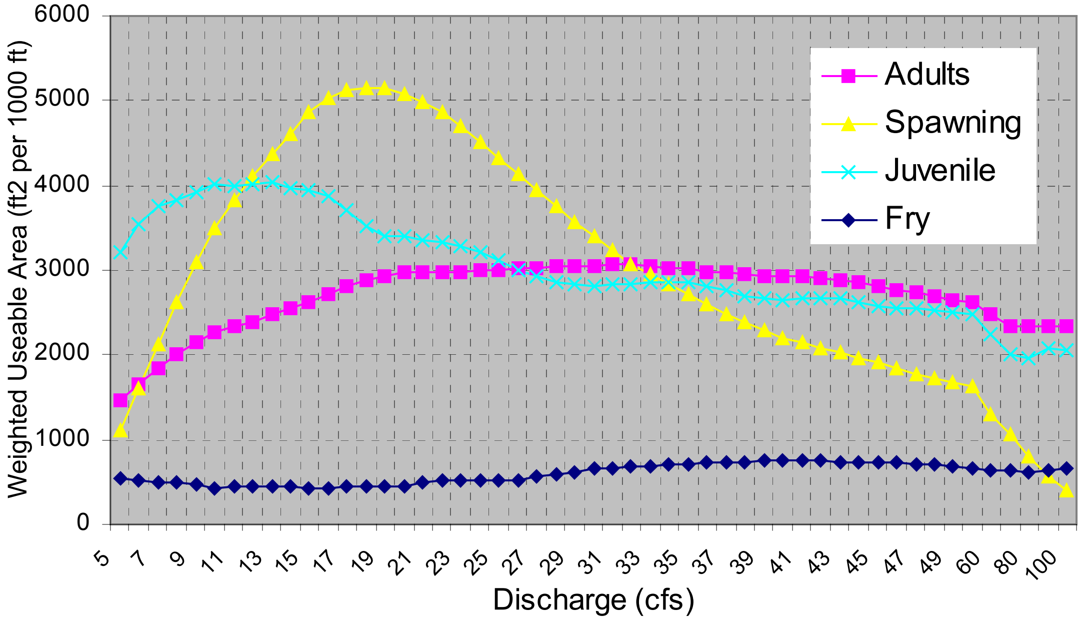

Figure 11. Yellowstone cutthroat trout weighted useable area for adult, spawning, juvenile, and fry life stages at the Middle Fork Wood River site (square feet per 1000 feet of stream). Note x-axis values are scaled to show simulated flows.

Habitat Retention

Average depth, average velocity, and wetted perimeter across three riffle transects as a function of flow are listed in Table 14. At riffle 1, mean depth is the first hydraulic criteria "met" as flow declines from its bankfull level to 7.0 cfs. Next, the wetted perimeter criterion is met at 3.4 cfs. Finally, for riffle 1, the velocity criterion is reached at 2.7 cfs. Thus, two of three hydraulic criteria (mean velocity and wetted perimeter) are retained by a flow of 3.4 cfs across riffle 1 (Table 14). In a similar fashion, 4.1 cfs retains two of three criteria on riffle 2 and 2.9 cfs is required to meet criteria on riffle 3. Therefore, the flow that retains two of three criteria for all of the studied riffles is 4.1 cfs. Based on the Habitat Retention model, a flow of 4.1 cfs is necessary year round to maintain trout survival, movement and invertebrate production.

The 4.1 cfs from Habitat Retention provides limited adult habitat (Figure 11). Under ice-free conditions, trout can move between pools while greater flow levels would provide additional adult habitat. The HQI model results below further define the benefit of higher summer flows. The need for natural winter flows, greater than 4.1 cfs, is discussed in a later section.

Table 14. Simulated hydraulic criteria for three Middle Fork Wood River riffles. Bold indicates that the hydraulic criterion was met. Flows meeting 2 of 3 criteria for each riffle are shaded.

	Mean Velocity (ft/s)	Mean Depth (ft)	Wetted Perimeter (ft)	Discharge (cfs)
Riffle 1 – transect1	9.6	1.19	35.7	400
	6.8	0.95	34.0	215
	2.33	0.45	25.8	27
	1.92	0.37	25.4	18
	1.66	0.31	25.0	13
	1.32	**0.22**	23.8	7.0
	1.09	0.17	**18.1**	3.4
	1.00	0.17	15.7	2.7
Riffle 2 – transect 3	5.67	0.97	39.9	215
	5.13	1.04	33.6	175
	2.09	0.52	25.3	27
	1.73	0.44	24.1	18
	1.51	0.39	22.5	13
	1.06	0.24	19.9	5.0
	1.01	**0.22**	19.6	4.3
	1.00	0.21	19.4	4.1[a]
	<0.89	<0.16	**16.8**	<2.5
Riffle 3 – transect 9	5.10	1.33	32.8	215
	3.55	0.99	29.3	100
	1.81	0.54	27.8	27
	1.49	0.46	26.4	18
	1.27	0.41	25.4	13
	1.00	0.33	23.8	7.9
	0.79	0.27	23.5	5.0
	0.61	**0.22**	21.5	2.9
	<0.61	<0.22	**14.7**	<2.9

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

Habitat Quality Index

A maximum water temperature of 68° F was measured August 6, 2003. This temperature falls in the 66 - 70º F band for a "3" rating under Binns (1982) and reflects higher than optimal thermal conditions. The north – south exposure, shallow and wide channel, and open valley upstream of the study site contribute to warmer maximum temperatures. Nitrate concentrations were 0.10 mg/l which earns a rating of "3". Eroding banks, at 0%, rated a "4". The average of three Surber samples was 95 invertebrates per square foot for a relatively low rating of "1". Percent cover was less than 10% (4.7% - 8%) at all flows. Since the cover rating changes from "1" to "0" when cover is less than 10% of the wetted channel, the cover attribute was held to a "0" rating for all simulated flow levels.

Peak habitat units occur at 16 cfs (Figure 12). A combination of adequate base flow, minimal annual stream flow variation and ideal velocities contribute to the peak habitat. When flows drop below 16 cfs, the critical period stream flow attribute rating declines to a "3" and habitat units decline (Figure 12). At a late summer flow less than 14 cfs, a decline in the annual stream flow variability attribute is reflected in lower Habitat Units.

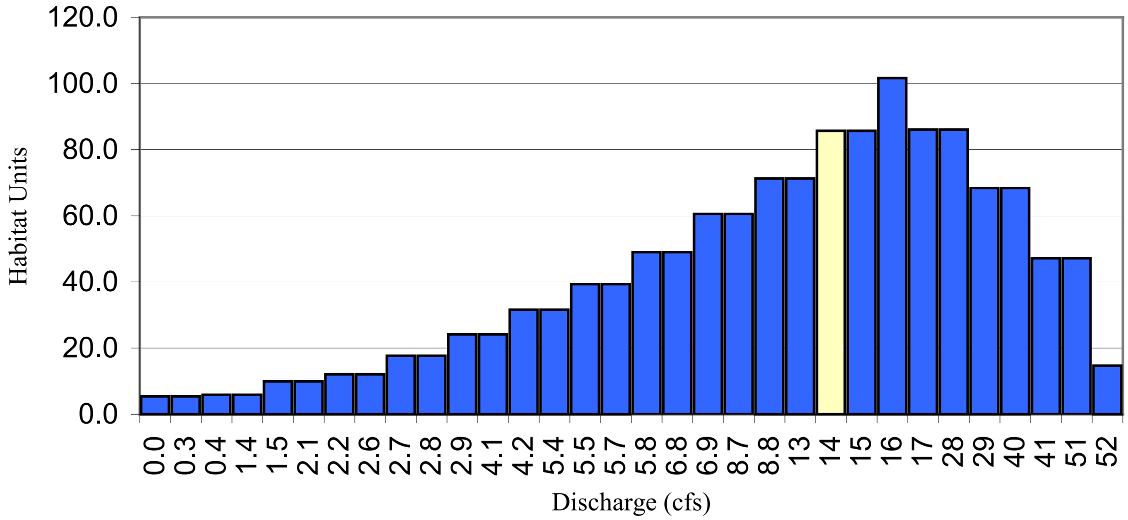

Figure 12. Habitat Quality Index at the Middle Fork study site for a range of flow levels. X-axis flows are scaled to show where changes in Habitat Units occur. The recommended flow is indicated by the light shaded bar.

Measured flows in the July through September period ranged from 10 to 39 cfs (Table 13). Estimated monthly streamflows that occur 50% of the time are: 39 cfs, 22 cfs, and 17 cfs for July, August and September, respectively (Table 13). The 22 cfs August value provides a reasonable estimate of normal late summer flow levels. At this flow, the stream provides 86 habitat units (Figure 12). The lowest flow that will maintain 86 habitat units is 14 cfs. The instream flow recommendation to maintain adult Yellowstone cutthroat trout habitat during the late summer period is 14 cfs.

Winter Flows and Habitat

October through April 20% monthly exceedance flows listed in Table 13 are recommended to maintain winter trout habitat. As a conservative estimate of natural winter flow levels, these flow quantities will maintain winter icing constraints on habitat at natural levels.

All of the recommended winter monthly flows are greater than the 4.1 cfs from Habitat Retention (Tables 13 and 14). At 4.1 cfs, fish passage and invertebrate production are maintained under ice-free conditions but there is no assurance hydraulic conditions will be similar when cap, edge and frazil ice are formed in winter. Rather, there is a reasonable likelihood that reduction of flows to such a level could harm trout survival. In wide and shallow channels such as the Middle Fork Wood River, there is great potential for winter ice to greatly change the depth and distribution of water flow through riffles under low flow conditions like 4.1 cfs. For example, accumulated anchor ice may limit passage. In some cases low flows in winter can pose a significant threat of riffles freezing solid, forming ice jams that divert most or all flow out of the channel, and dewatering long stretches of stream. From PHABSIM, adult and juvenile physical habitat is much higher at the recommended winter flow levels than at 4.1 cfs (Figure 11). PHABSIM results apply to ice-free conditions so extrapolation to winter is limited to ice-free areas and pools beneath a stable ice cover.

South Fork Wood River

Channel Features

The South Fork Wood River segment has the attributes of a Rosgen C4 channel type (Table 15). The median substrate size of 41 mm qualifies as a very course gravel bed (Rosgen 1996). Low entrenchment and moderate slope and width to depth ratios mark this stream type. This stream type is characterized by a well-developed flood plain and meandering channel with defined riffle to pool sequences.

Table 15. Level 2 survey measurements at the South Fork Wood River study site.

Channel Feature	Value
Mean riffle bankfull width (ft)	34.9
Mean depth (ft)	1.64
Cross section area (ft2)	70.5
Entrenchment ratio	6.55
D50 (mm)	41
Slope (ft./ft.)	0.0174
Sinuosity	1.22
Stream Type	C4

Hydrology

Table 16 lists key flow parameters from HabiTech (2002) and flow measurements collected by WGFD. HabiTech estimates are consistent with measured values considering measurements were collected during a drought period. Further tabulation of flow measurements during 2002 and 2003 are in Dey and Annear (2003a). Additional measurements not included in that report are 13.4 cfs on September 29, 2004 and 13.0 cfs on October 13, 2004.

Table 16. South Fork Wood River instream flow segment flow characteristics (HabiTech 2002). Measured flows were collected in 2002 – 2004.

Flow parameter or month	Estimated Flow (cfs)	
Mean Annual	44	
1.5 year peak	344	
25 year peak	1,268	
	HabiTech 50% Exceedance (cfs)	WGFD measured flow (cfs)
May	66	--
June	139	28-82
July	63	6.7-41
August	35	14
September	27	4.9-23
	HabiTech 20% Exceedance (cfs)	WGFD measured flow (cfs)
October	33	4.0-13
November	24	--
December	19	--
January	16	--
February	15	--
March	17	--
April	31	18

Development of Fish Flow Recommendations

Physical Habitat Simulation

The macrohabitat survey covered 586 paces of stream channel including the study site and tallied 82% fast-water channel units and 18% slow-water units (pools). Rapids were the most frequent fast water category (40%) followed by riffles (30%) and runs (12%). Pools types were backwater (7%), lateral scour (6%), and small pools behind boulders or large cobble (4%).

The WUA index of spawning habitat peaked at 25 cfs for the weighted combined transects (Figure 13). The spawning habitat index declines gradually at higher flows as velocities become too fast. As flow drops below 25 cfs, the spawning index drops rapidly because of shallow depths. To maintain spawning habitat (Figure 13), an instream flow of 25 cfs is recommended for May through June. Though the full 25 cfs may not always be present during this entire period, protection of flows up to 25 cfs will prevent impacts to spawning success and help maintain this component of the existing fishery.

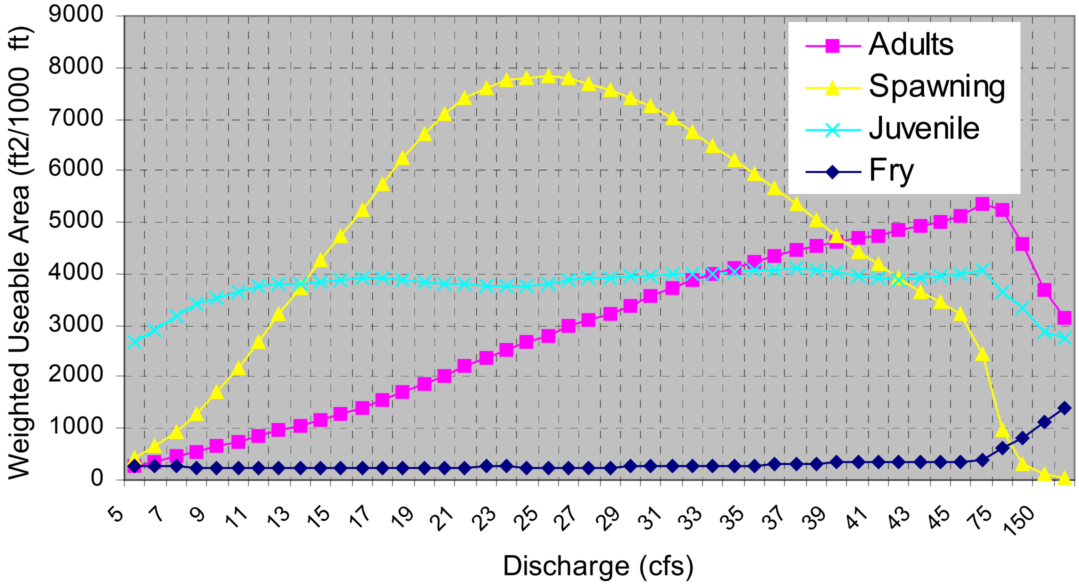

Figure 13. Yellowstone cutthroat trout weighted useable area for adult, spawning, juvenile, and fry life stages at the South Fork Wood River site (square feet per 1000 feet of stream). Note x-axis values are scaled to show simulated flows.

The physical habitat index for adult Yellowstone Cutthroat trout rises steadily to peak at about 50 cfs and then rapidly declines at higher flows (Figure 13). Juvenile and fry trout show little pattern across the modeled discharge range (Figure 13).

Habitat Retention

Average depth, average velocity, and wetted perimeter across three riffle transects as a function of flow are listed in Table 17. At riffle 1, mean depth is the first hydraulic criteria "met" as flow declines from its bankfull level to 10.6 cfs. Next, the average velocity criterion is met at 5.1 cfs. Finally, for riffle 1, the wetted perimeter criterion is reached at 2.1 cfs. Thus, two of three hydraulic criteria (mean velocity and wetted perimeter) are retained by a flow of 5.1 cfs across riffle 1 (Table 17). In a similar fashion, 5.1 cfs retains two of three criteria on riffle 2 and 5.8 cfs is required to meet criteria on riffle 3. Therefore, the flow that retains two of three criteria for all of the studied riffles is 5.8 cfs. Based on the Habitat Retention model, at least 5.8 cfs is necessary year round to maintain trout survival, movement and invertebrate production.

The 5.8 cfs from Habitat Retention provides very limited habitat for all life stages of trout (Figure 13). Under ice-free conditions, trout can move between pools while greater flow levels would provide additional adult habitat. The HQI model results below further define the benefit of higher summer flows. The need for natural winter flows, greater than 5.8 cfs, is discussed in a later section.

Table 17. Simulated hydraulic criteria for three South Fork Wood River riffles. Bold indicates that the hydraulic criterion was met. Flows meeting 2 of 3 criteria for each riffle are shaded.

	Mean Velocity (ft/s)	Mean Depth (ft)	Wetted Perimeter (ft)	Discharge (cfs)
Riffle 1 – transect1	6.77	1.35	38.6	344
	6.62	1.33	38.5	330
	3.54	.81	35.5	100
	2.37	.56	33.8	44
	1.31	.29	30.1	11.3
	1.28	**.28**	30.0	10.6
	1.00	.21	24.6	5.1
	0.73	.15	**19.2**	2.1
Riffle 2 – transect 4	6.44	1.59	35.0	344
	5.82	1.47	33.4	275
	3.54	0.96	30.2	100
	2.32	0.67	29.0	44
	1.18	0.37	26.0	11.3
	1.00	0.33	25.1	8.1
	0.87	0.29	23.9	6.0
	0.81	**0.28**	22.8	5.1
	<0.5	<0.18	**16.7**	<2.0
Riffle 3 – transect 9	6.35	1.65	34.2	344
	5.76	1.49	33.3	275
	3.66	0.94	30.0	100
	2.5	0.64	28.2	44
	1.34	0.34	25.4	11.3
	1.16	0.29	24.3	8.1
	1.11	**0.28**	24.1	7.4
	1.00	0.25	23.5	5.8[a]
	<0.64	<0.16	**16.7**	<2.0

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

Habitat Quality Index

A maximum water temperature of 73.5° F was recorded August 14, 2003. This temperature falls in the 71 - 75º F band for a "2" rating under Binns (1982) and reflects higher than optimal thermal conditions. The north – south exposure, shallow and wide channel, and open valley upstream of the study site contribute to warmer maximum temperatures. Nitrate concentrations were < 0.10 mg/l for a rating of "0". Eroding banks, at 11%, rated a "3". The average of three Surber samples was 54 invertebrates per square foot for a relatively low rating of "1". Percent cover climbed from 10.7% at 11.3 cfs to a peak of 30% before declining to 20% at 41 cfs. Cover was calculated to decline below 10% at flows less than 11.2 cfs.

Peak habitat units occur at 24 to 25 cfs (Figure 14). A combination of adequate base flow, minimal annual stream flow variation and peak cover contribute to the peak habitat. When flows drop below 24 cfs, the critical period stream flow attribute declines to a rating of "3". At a late summer flow less than 22 cfs, a decline in the annual stream flow variability attribute is reflected in lower Habitat Units.

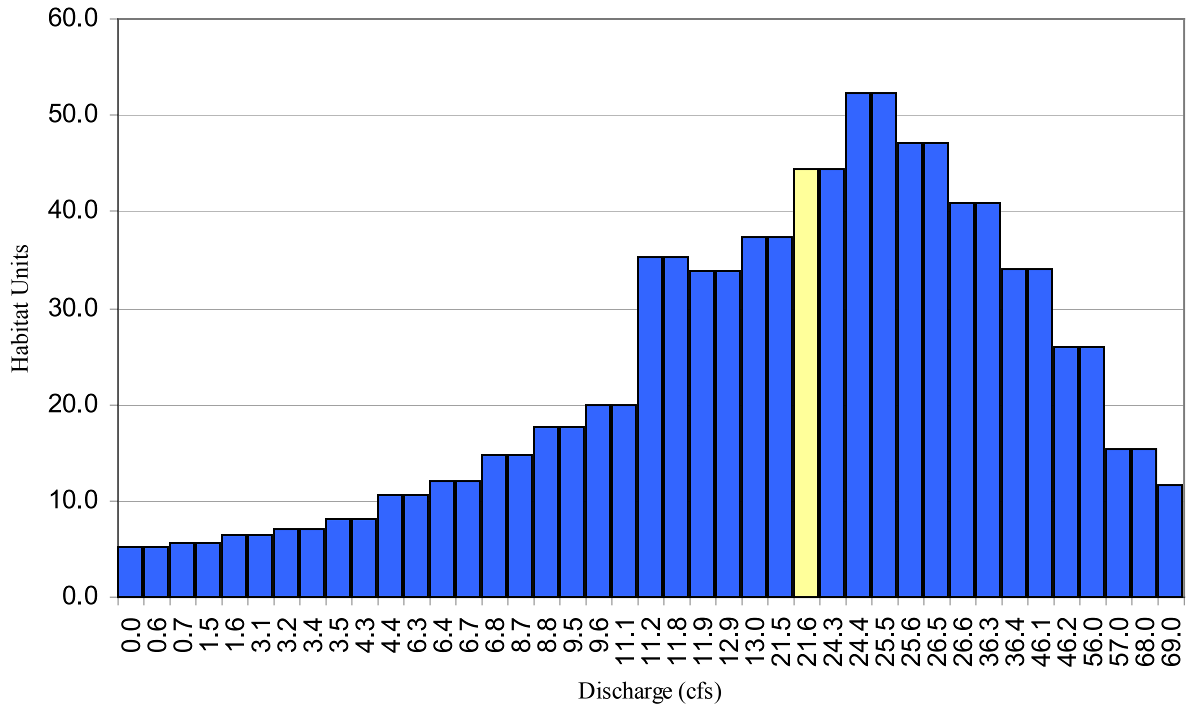

Figure 14. South Fork Wood River Habitat Quality Index over a range of flow levels. X-axis flows are scaled to show where changes in Habitat Units occur. The recommended flow is indicated by the light shaded bar.

July through September measured flows range from 4.9 to 41 cfs (Table 16). Estimated monthly streamflows that occur 50% of the time are: 63 cfs, 35 cfs, and 27 cfs for July, August and September, respectively (Table 16). The 35 cfs August value provides a reasonable estimate of normal late summer flow levels. At this flow, the stream provides 41 habitat units (Figure 14). The lowest flow that will maintain 41 habitat units is 22 cfs. The instream flow recommendation to maintain adult Yellowstone cutthroat trout habitat during the late summer period is 22 cfs.

Winter Flows and Habitat

October through April 20% monthly exceedance flows listed in Table 16 are recommended to maintain winter trout habitat. As a conservative estimate of natural winter flow levels, these flow quantities will maintain winter icing constraints on habitat at natural levels.

All of the recommended winter monthly flows are greater than the 5.8 cfs from Habitat Retention (Tables 16 and 17). At 5.8 cfs, fish passage and invertebrate production are maintained under ice-free conditions but there is no assurance hydraulic conditions will be similar when cap, edge and frazil ice are formed in winter. Rather, there is a reasonable likelihood that reduction of flows to such a level could harm trout survival. In wide and shallow channels such as the South Fork Wood River, there is great potential for winter ice to greatly change the depth and distribution of water flow through riffles under low flow conditions like 5.8 cfs. For example, accumulated anchor ice may limit passage. From PHABSIM, adult and juvenile physical habitat is much higher at the recommended winter flow levels than they would be at 5.8 cfs (Figure 13). PHABSIM results apply to ice-free conditions so extrapolation to winter is limited to ice-free areas and pools beneath a stable ice cover.

Wood River Downstream of Middle Fork Wood River

Hydrology

Table 18 lists key flow statistics from HabiTech (2002). Because flow measurements were conducted in nearby contributing segments, no flow measurements were collected in this segment. Deer Creek contributes less than 3 cfs during base flow to the segment (Dey and Annear 2003a).

Table 18. Flow characteristics for the Wood River downstream of Middle Fork Wood River instream flow segment flow (HabiTech 2002).

Flow parameter or month	Estimated Flow (cfs)
Mean Annual	77
1.5 year peak	604
25 year peak	2223
	HabiTech 50% Exceedance (cfs)
May	115
June	244
July	111
August	62
September	47
	HabiTech 20% Exceedance (cfs)
October	59
November	44
December	34
January	29
February	27
March	31
April	56

Development of Fish Flow Recommendations

Monthly flow recommendations (Table 19) to maintain Yellowstone cutthroat trout habitat were developed by summing recommendations from the Middle Fork Wood River and the Wood River above Middle Fork Wood River immediately upstream. Winter recommendations are slightly lower than the 20% monthly exceedance flows for this segment (Table 18) because Deer Creek contributes a small amount of water to the segment (Dey and Annear 2003a).

Table 19. Flow recommendations for the Wood River downstream of Middle Fork Wood River instream flow segment.

Month	Recommended Flow (cfs)
October	51
November	38
December	29
January	25
February	24
March	27
April	48
May	41
June	41
July	32
August	32
September	32

Dick Creek

Channel Features

The Dick Creek instream flow segment was rated a Rosgen B4 channel type (Table 20). The median substrate size of 45 mm qualifies as a very course gravel bed (Rosgen 1996). The moderately entrenched channel, in which water rarely flows out into a defined floodplain, distinguishes this stream type. Higher slope also distinguishes this channel type from the "C" channel type though there is overlap. "B" channels are considered relatively stable in that streambank erosion rates are generally low and lateral channel movements minimal.

Table 20. Level 2 survey measurements at the Dick Creek study site.

Channel Feature	Value
Mean riffle bankfull width (ft)	15.3
Mean depth (ft)	0.55
Cross section area (ft2)	9.2
Entrenchment ratio	1.44
D50 (mm)	45
Slope (ft./ft.)	0.0248
Sinuosity	1.50
Stream Type	B4

Hydrology

Table 21 lists key flow parameters from HabiTech (2002) and flow measurements collected by WGFD. Estimated flows appear higher than the few spot measurements collected, likely attributable to the ongoing drought. Accumulated fine sediment and silt in the channel indicated that high flows were lacking in the years immediately preceding instream flow habitat studies. Scoured banks and deposited woody debris indicated that higher flows occurred in past years.

Table 21. Dick Creek instream flow segment flow characteristics (HabiTech 2002). Measured flows were collected in 2003 – 2004.

Flow parameter or month	Estimated Flow (cfs)	
Mean Annual	7.4	
1.5 year peak	58	
25 year peak	214	
	HabiTech 50% Exceedance (cfs)	WGFD measured flow (cfs)
May	11	--
June	23	7.5
July	11	3.5
August	6.0	2.1
September	4.5	1.5
	HabiTech 20% Exceedance (cfs)	WGFD measured flow (cfs)
October	5.7	1.6
November	4.2	--
December	3.2	--
January	2.8	--
February	2.6	--
March	2.9	--
April	5.2	--

Development of Fish Flow Recommendations

Physical Habitat Simulation

The macrohabitat survey covered 350 paces of stream channel including the study site and tallied 80% fast-water channel units and 20% slow-water units (pools). Rapids were the most frequent fast water category (33%) followed by riffles (29%) and runs (14%). Lateral scour pools predominated (13%) and a few backwater and pocket pools were also tallied.

The WUA index of spawning habitat peaked at 11.5 cfs for the weighted combined transects (Figure 15). The spawning habitat index is very low for flows less than about 5 cfs due to insufficient depth. At flows greater than about 15 cfs, velocities become unfavorably high for spawning. To maintain spawning habitat (Figure 15), an instream flow of 11.5 cfs is recommended for May through June. Though the full 11.5 cfs may not always be present during this entire period, protection of flows up to 11.5 cfs will prevent impacts to spawning success and maintain the existing fishery.

The WUA index for adult Yellowstone Cutthroat trout rises rapidly at flows greater than 3.5 cfs and peaks at 9.5 cfs (Figure 15). Juvenile WUA peaks at 6 cfs. Fry have an inverted bell relationship where slow shallow water at extremely low flows provide habitat and flooded stream margins at high discharges also provide physical habitat (Figure 15).

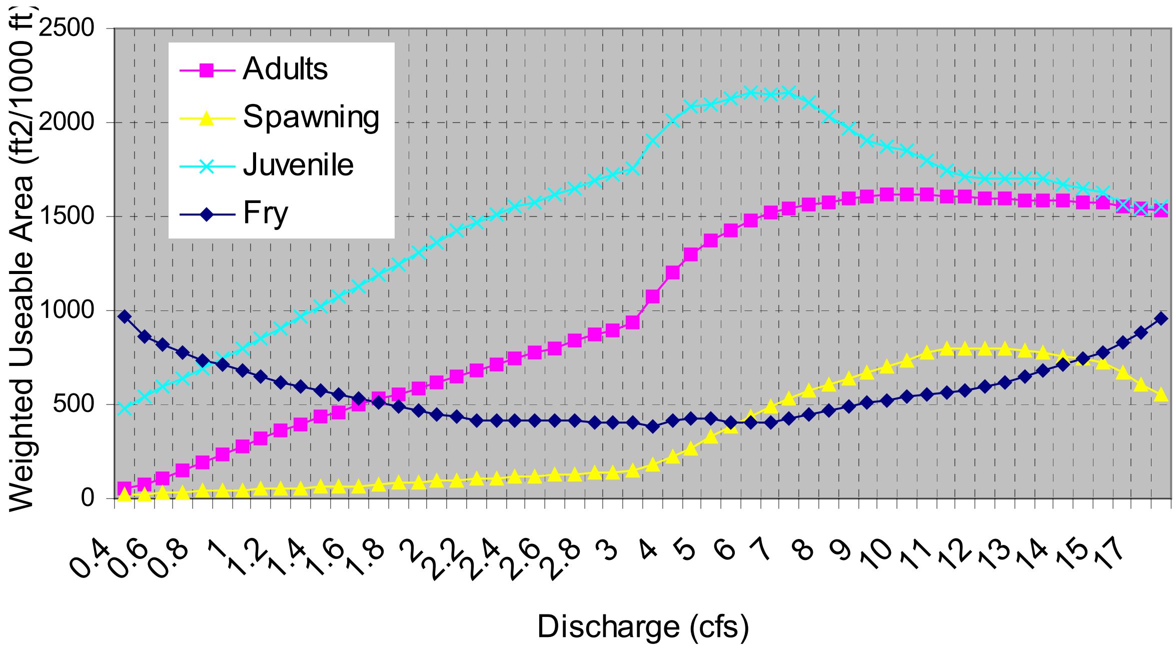

Figure 15. Yellowstone cutthroat trout weighted useable area for adult, spawning, juvenile, and fry life stages at the Dick Creek study site (square feet per 1000 feet of stream). Note x-axis values are scaled to show simulated flows.

Habitat Retention

Average depth, average velocity, and wetted perimeter across three riffle transects as a function of flow are listed in Table 22. At riffle 1, mean velocity is the first hydraulic criteria "met" as flow declines from its bankfull level to 4.4 cfs. Next, both the average depth criterion and wetted perimeter criteria are met at 0.4 cfs. Thus, two of three hydraulic criteria (average depth and wetted perimeter) are retained by a flow of 0.4 cfs across riffle 1 (Table 22). In a similar fashion, 2.1 cfs retains two of three criteria on riffle 2 and 1.2 cfs is required to meet criteria on riffle 3. Therefore, the flow that retains two of three criteria for all of the studied riffles is 2.1 cfs. Based on the Habitat Retention model, at least 2.1 cfs is necessary year round to maintain trout survival, movement and invertebrate production.

The 2.1 cfs from Habitat Retention provides limited adult and moderate juvenile habitat (Figure 15). Under ice-free conditions, trout can move between pools while greater flow levels would provide additional adult habitat. The HQI model results below further define the benefit of higher summer flows. The need for natural winter flows, greater than 2.1 cfs, is discussed in a later section.

Table 22. Simulated hydraulic criteria for three Dick Creek riffles. Bold indicates that the hydraulic criterion was met. Flows meeting 2 of 3 criteria for each riffle are shaded.

	Mean Velocity (ft/s)	Mean Depth (ft)	Wetted Perimeter (ft)	Discharge (cfs)
Riffle 1 – transect1	4.6	0.66	19.9	58
	1.56	0.38	17.1	10
	1.09	0.35	13.3	5.0
	1.00	0.34	13.1	4.4
	0.64	0.28	12.0	2.1
	0.40	0.23	10.9	1.0
	0.27	0.21	9.1	0.5
	0.24	**0.20**	**8.6**	0.4
Riffle 2 – transect 3	5.25	1.00	16.3	80
	4.52	0.87	15.6	58
	2.24	0.37	11.4	9.0
	1.83	0.29	9.8	5.0
	1.56	0.24	8.2	3.0
	1.51	0.23	**8.1**	2.7
	1.44	0.21	8.0	2.3
	1.41	**0.20**	7.9	2.1[a]
	1.00	0.16	5.1	0.78
Riffle 3 – transect 5	3.85	1.04	15.6	58
	3.53	0.96	15.0	47
	1.76	0.51	10.5	9.0
	1.36	0.39	9.8	5.0
	1.05	0.29	9.1	2.7
	1.00	0.28	8.9	2.4
	0.95	0.26	8.8	2.1
	0.76	**0.20**	8.0	1.2
	0.65	0.17	**7.5**	0.8

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

Habitat Quality Index

A maximum water temperature of 70.5° F was recorded July 23, 2003. This temperature falls in the 71 - 75° F band for a "2" rating under Binns (1982) and reflects higher than optimal thermal conditions. The shallow and wide channel contributes to warmer maximum temperatures. Nitrate concentrations were < 0.10 mg/l for a rating of "0". Eroding banks, at 32%, rated a "2". Invertebrate abundance was fairly low and rated a "2". Percent cover ranged from 6.4% at 2.1 cfs to a peak of 17.7% at 7.5 cfs. Cover was calculated to decline below 10% at flows less than 3.4 cfs.

Peak habitat units occur from 4.2 to 7.3 cfs (Figure 16). A combination of adequate base flow and ideal velocities contribute to the peak habitat. When flows drop below 4.2 cfs, the critical period stream flow attribute declines to a rating of "3". At a late summer flow greater than 7.3 cfs, velocities are higher than ideal resulting in lower Habitat Units.

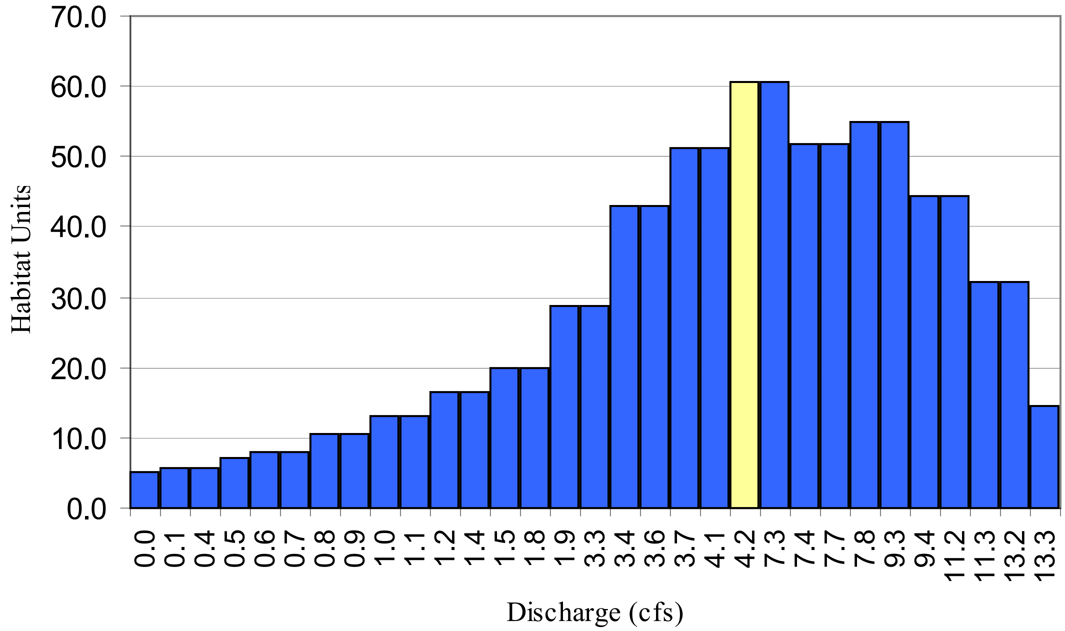

Figure 16. Dick Creek Habitat Quality Index over a range of flow levels. X-axis flows are scaled to show where changes in Habitat Units occur. The recommended flow is indicated by the light shaded bar.

July through September measured flows range from 1.5 to 7.5 cfs (Table 21). Estimated monthly streamflows that occur 50% of the time are: 11 cfs, 6 cfs, and 4.5 cfs for July, August and September, respectively (Table 21). The 6 cfs August value provides a reasonable estimate of normal late summer flow levels. At this flow, the stream provides 60 habitat units (Figure 16). The lowest flow that will maintain 60 habitat units is 4.2 cfs. The instream flow recommendation to maintain adult Yellowstone cutthroat trout habitat during the late summer period is 4.2 cfs.

Winter Flows and Habitat

October through April 20% monthly exceedance flows listed in Table 21 are recommended to maintain winter trout habitat. As a conservative estimate of natural winter flow levels, these flow quantities will maintain winter icing constraints on habitat at natural levels.

All of the recommended winter monthly flows are greater than the 2.1 cfs from Habitat Retention (Tables 21 and 22). At 2.1 cfs, fish passage and invertebrate production are maintained under ice-free conditions but there is no assurance hydraulic conditions will be similar when cap, edge and frazil ice are formed in winter. Rather, there is a reasonable likelihood that reduction of flows to such a level could harm trout survival. In wide and shallow channels such Dick Creek, there is great potential for winter ice to greatly change the depth and distribution of water flow through riffles under low flow conditions like 2.1 cfs. For example, accumulated anchor ice may limit passage. From PHABSIM, adult and juvenile physical habitat is higher at the recommended winter flow levels than at 2.1 cfs (Figure 15). PHABSIM results apply to ice-free conditions so extrapolation to winter is limited to ice-free areas.

INSTREAM FLOW RECOMMENDATIONS

A Yellowstone cutthroat trout risk assessment showed that the present-day distribution of YSC represents a fraction of the historical distribution (May et al. 2003). The Wood River drainage, in particular the five stream segments identified in this report, represents an important portion of YSC habitat containing viable populations of genetically pure trout. Instream flow filings on these segments will help ensure the future of YSC in Wyoming by protecting existing base flow conditions against future consumptive and diversionary demands. Nearly 16 miles of stream habitat will be protected if these instream flow applications advance to permit status.

Spring (May and June) instream flow recommendations to maintain Yellowstone cutthroat trout spawning habitat were developed using PHABSIM. Summer recommendations (July through September) to maintain Yellowstone cutthroat trout adult production were developed using the HQI model while ensuring sufficient habitat for all life stages using PHABSIM. The Habitat Retention Model was used to ensure that any other approach used to develop recommendations provided sufficient riffle hydraulic conditions for fish passage. Finally, natural winter flow levels were recommended for winter (October through April). The 20% monthly exceedance flow was selected to represent natural winter flow. Based on the analyses and results in this report, the instream flow recommendations in Table 23 will maintain short-term Yellowstone cutthroat trout habitat requirements. Channel maintenance flows to preserve the long-term habitat and ecological functions that support the existing fishery are described in Appendix 1. Flow recommendations apply to stream segments defined in Table 1.

Because data were collected from representative habitats and simulated over a wide flow range, additional data collection under different flow conditions would not significantly change these recommendations. New water storage facilities to provide the recommended amounts on a more regular basis than at present are not needed to maintain the existing fishery characteristics and would likely lead to significant changes to the existing habitat and fish community, some of which might not be desirable.

Table 23. Instream flow recommendations to maintain existing trout habitat in 5 Wood River basin instream flow segments.

Stream	Monthly Flow Recommendations (cfs)											
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May*	Jun*	Jul	Aug	Sep
Wood R. above Middle Fork	31	23	18	15	14	16	29	22	22	18	18	18
Middle Fork Wood River	20	15	11	10	9.5	11	19	19	19	14	14	14
South Fork Wood River	33	24	19	16	15	17	31	25	25	22	22	22
^Wood River below Middle Fork	51	38	29	25	24	27	48	41	41	32	32	32
Dick Creek	5.7	4.2	3.2	2.8	2.6	2.9	5.2	11.5	11.5	4.2	4.2	4.2

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

^ Winter recommendations for this segment are slightly lower than 20% exceedance values in Table 18 because recommendations were developed from summing upstream recommendations while HabiTech (2002) hydrology estimates in Table 18 included additional Deer Creek basin area

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APPENDIX 1. CHANNEL MAINTENANCE FLOWS

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 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 (Annear et al. 2004). 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 successionally diverse riparian community. Low flow years are as valuable as high flow years on some streams to allow establishment of riparian seedlings on bars deposited in immediately preceding wet years (Trush and McBain 2000). The natural interaction of high and low flow years maintains riparian development and aquatic habitat by preventing annual scour that might occur from continuous high flow (allowing some riparian development) while at the same time preventing encroachment by riparian vegetation that could occur if flows were artificially reduced at all times.

Channel maintenance flows must be sufficient to move the entire volume and all sizes of material supplied to the channel from the watershed over a long-term period (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.

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_{bf}), 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
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".

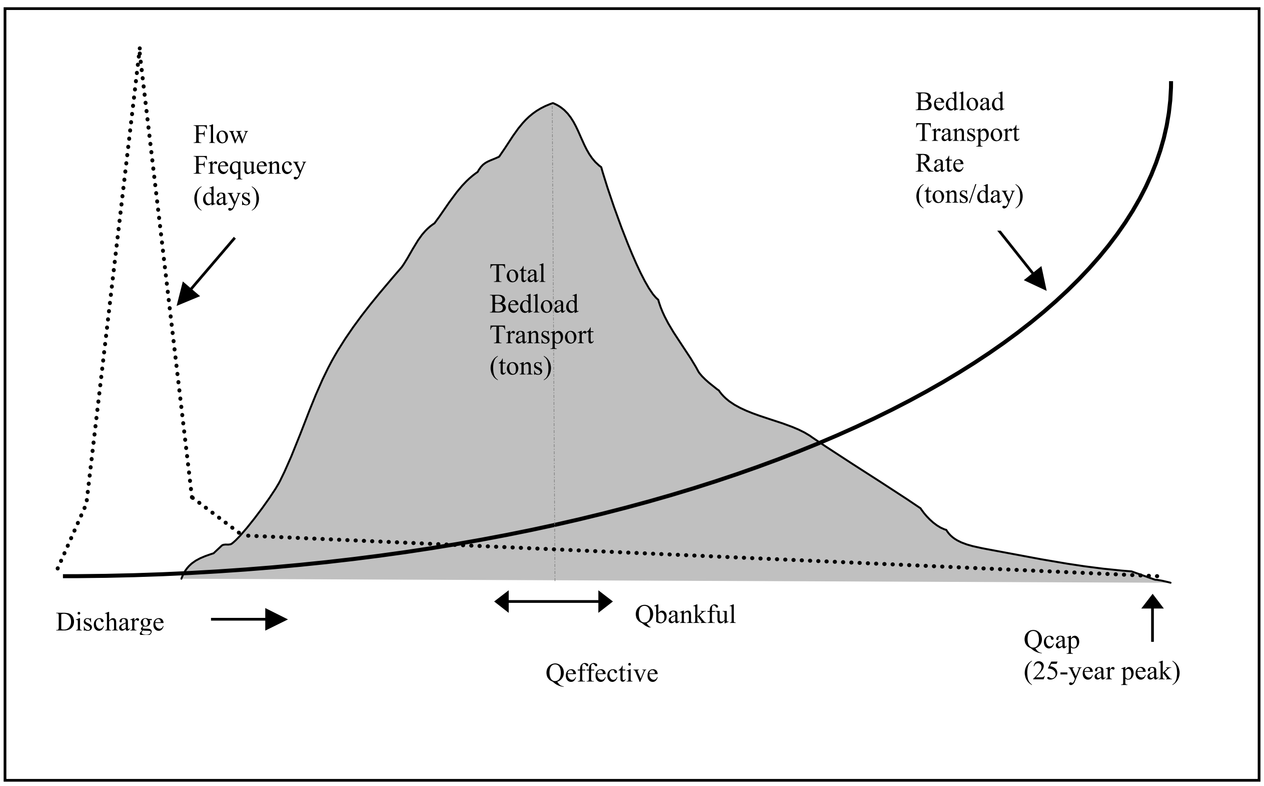

Figure 1-1. Total bedload transport as a function of bedload transport rate and flow frequency (adapted from Schmidt and Potyondy 2004)

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 that the 25-year recurrence flow are not necessary for channel maintenance and are available for other uses.

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

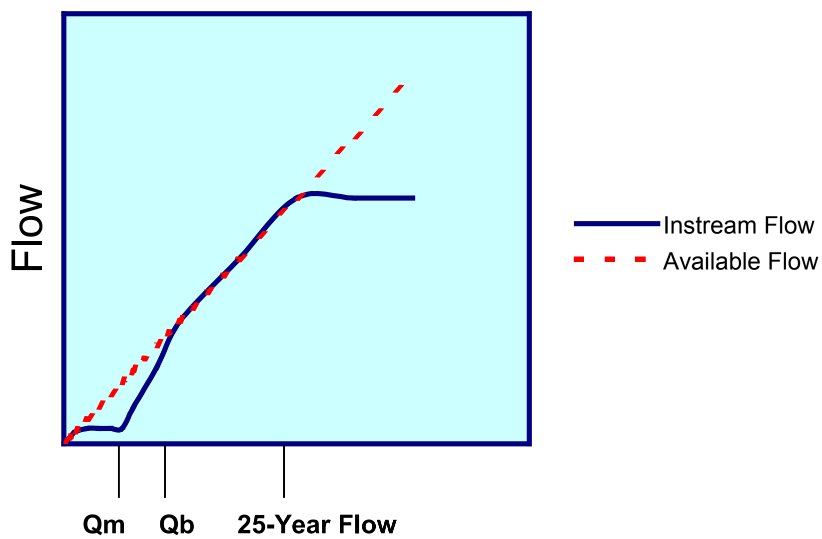

Figure 1-2. General function of a dynamic hydrograph instream flow for fishery maintenance. Q_m is substrate mobilization flow and Q_b is bankfull flow.

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 4 evenly partitioned blocks or increments of flow between the sediment mobilization flow and bankfull (see Table 1-1).

Like all properly functioning rivers, the Wood River and Dick Creek instream flow segments are characterized and maintained by a hydraulically connected watershed, floodplain, riparian zone and stream channel. Bankfull and overbank flow are essential hydrologic characteristics for maintaining the habitat in and along these river segments in their existing dynamic form. These high flows flush sediments from the gravels on an annual or more often basis and maintain channel form (depth, width, pool and riffle configuration) by periodically scouring encroaching vegetation. Overbank flow maintains recruitment of riparian vegetation, encourages lateral movement of the channel, and recharges ground water tables. Instream flows that maintain the connectivity of these processes over time and space are needed to maintain the existing fishery (Annear et al. 2004).

Applying the Leopold equation and approach described yielded the channel maintenance instream flow recommendations in Table 1-1. The base or fish flow used in the analysis were the spawning flows identified for each segment. For naturally available flow levels less than the spawning flow, the channel maintenance instream flow recommendation is equal to natural flow. All of the identified spawning flow levels were considerably less than the substrate mobilization flow. 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 flow greater than the 25-year flood flow, only the 25-year flood flow is needed for channel maintenance because this flow level will have moved the necessary amount of bed load materials and reconnected the channel with the floodplain (Figure 1-2).

Table 1-1. Channel maintenance instream flow recommendations (shaded columns) to maintain existing channel forming processes and long-term aquatic habitat characteristics in the Wood River and Dick Creek instream flow segments. Recommendations apply to the run-off period from May 1 through June 30th.

Flow Level Description	Wood River (upstream of M.Fk. Wood R.)		Middle Fork Wood River		South Fork Wood River		Wood River (downstream of M. Fk. Wood River)		Dick Creek	
	Flow (cfs)		Flow (cfs)		Flow (cfs)		Flow (cfs)		Flow (cfs)	
	Available	Channel	Available	Channel	Available	Channel	Available	Channel	Available	Channel
<Spawning Flow*	<22	<22	<19	<19	<25	<25	<41	<41	<11.5	<11.5
Spawning Flow	22	22	19	19	25	25	41	41	11.5	11.5
<Substrate Mobilization	23-257	22	20-171	19	26-274	25	42-482	41	12-45	11.5
Substrate Mobilization	258	22	172	19	275	25	483	41	46	11.5
Mobilization to Bankfull	259-274	170	173-182	125	276-292	186	484-513	309	47-49	38
Mobilization to Bankfull	275-290	243	183-193	162	293-309	259	514-543	454	50-52	46
Mobilization to Bankfull	291-306	273	194-203	183	310-326	291	544-573	511	53-55	51
Mobilization to Bankfull	307-322	299	204-214	199	327-343	319	574-603	559	56-57	55
Bankfull	323	323	215	215	344	344	604	604	58	58
Bankfull to 25-Year Flood#	324-1189	324-1189	216-789	216-789	345-1267	345-1267	605-2222	605-2222	59-213	59-213
25-Year Flood	1190	1190	790	790	1268	1268	2223	2223	214	214
> 25-Year Flood	≥1191	1190	≥791	790	≥1269	1268	≥2224	2223	≥215	214

*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

APPENDIX 2. HABITAT SUITABILITY CRITERIA

Substrate codes are 1=vegetation, 2=mud, 3=silt, 4=sand, 5=gravel, 6=cobble, 7=boulder, 8=bedrock. Decimals indicate the percent of the next higher class code (e.g. 4.4 = 60% sand, 40% gravel). See WGFD 1998 and WGFD 1997 for details on curve development.

Velocity (ft/s)	Weight	Depth (ft)	Weight	Substrate Code	Weight
Spawning					
0.00	0.00	0.00	0.00	0.00	0.00
0.30	0.20	0.25	0.00	4.40	0.00
0.90	0.50	0.32	0.20	4.50	1.00
1.45	1.00	0.39	0.50	5.80	1.00
2.00	1.00	0.46	1.00	5.90	0.00
2.60	0.50	0.60	1.00		
3.20	0.00	0.67	0.50		
		0.74	0.00		
Adults					
0.00	0.20	0.00	0.00	1-8	1.00
0.23	0.20	0.40	0.00		
0.24	0.50	0.45	0.10		
0.42	0.50	0.49	0.10		
0.43	1.00	0.50	0.20		
1.66	1.00	0.59	0.20		
1.67	0.50	0.60	0.50		
2.28	0.50	0.79	0.50		
2.29	0.20	0.80	1.00		
2.82	0.20	2.30+	1.00		
2.83	0.10				
3.48	0.10				
3.49	0.00				
Juvenile					
0.00	0.50	0.00	0.00	1-8	1.00
0.50	0.50	0.75	0.50		
0.60	1.00	0.80	1.00		
1.50	1.00	2.30+	1.00		
1.60	0.50				
1.90	0.50				
2.00	0.20				
2.40	0.20				
2.50	0.10				
2.90	0.10				
3.00	0.00				
Fry					
0.00	0.60	0.00	0.00	1-8	1.00
0.03	1.00	0.03	0.10		
0.07	0.90	0.07	0.20		
0.10	0.60	0.10	0.20		
0.13	0.60	0.13	0.40		
0.16	0.50	0.16	0.60		
0.20	0.30	0.20	0.60		
0.23	0.30	0.23	0.70		
0.27	0.20	0.26	0.80		
0.30	0.10	0.30	0.90		
0.52	0.10	0.36	0.90		
0.56	0.00	0.39+	1.00		