WYOMING GAME AND FISH DEPARTMENT

FISH DIVISION

ADMINISTRATIVE REPORT

Title: Rock Creek, Tributary to Medicine Bow River, Instream Flow Studies

Project: AW-LE-5UM-511

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Date: September 2006

TABLE OF CONTENTS

TABLES

FIGURES

EXECUTIVE SUMMARY

A 3.9-mile segment of Rock Creek on national forest and state land near Arlington, WY was selected for an instream flow water right because it provides an important rainbow trout (RBT) fishery. This report provides flow recommendations developed from studies conducted in 1997. Physical Habitat Simulation (PHABSIM) was used to develop instream flow recommendations for maintaining adult and juvenile 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 was selected to represent natural winter flow. Finally, a dynamic hydrograph model was used to quantify flow needs for maintenance of channel geomorphology.

Important RBT habitat on Forest Service land will be directly protected if the instream flow segment and recommendations identified in this report advance to permit status. In addition to the 3.9-mile segment, over 75 headwater stream miles will be indirectly protected. Recommended flows range from a low of 13.0 cfs in January through March to 60 cfs in May and June (Table 1). Additional channel maintenance flows for long-term habitat maintenance are presented in Appendix 1 but are not included in the instream flow recommendations (Table 1).

Table 1. Instream flow recommendations to maintain rainbow trout habitat in the Rock Creek instream flow segment.

Monthly Flow Recommendations (cfs)											
Oct	Nov	Dec	Jan	Feb	Mar	Apr	May*	Jun*	Jul	Aug	Sep
21	17	15	13	13	13	30	60	60	21	21	21

* Different channel maintenance flows for the spring runoff period are developed in Appendix 1.

INTRODUCTION

Overall Approach

This report was compiled using a framework recognizing important components of an aquatic ecosystem and their relationship to stream flow. The results and analyses represent a continuing evolution from early Wyoming Game and Fish Department (WGFD) instream flow reports, which focused solely on sport fish species and maintenance-level instream flow recommendations, toward a focus consistent with contemporary understanding of stream ecosystems and fisheries management. In conducting and reporting instream flow studies, the WGFD develops recommendations based largely on concepts and strategies advocated by the Instream Flow Council (IFC), an organization of state and provincial fishery and wildlife management agencies (Annear et al. 2004). These recommendations include consideration of three policy components (legal, institutional, and public involvement) and five riverine components (hydrology, geomorphology, biology, water quality and connectivity; Annear et al. 2004). Sections and headings throughout this report were selected to generally reflect those components. By using the eight components as a guide, we develop instream flow recommendations that are consistent with Wyoming's legal and institutional environment to maintain or improve important fishery resources for public benefit.

Legal and Institutional Background

The Wyoming Game and Fish Department manages fish and wildlife resources under Title 23 of Wyoming statutes (W.S.). The WGFD was created and placed under the direction and supervision of the Wyoming Game and Fish Commission (Commission) in W.S. 23-1-401 and the responsibilities of the Commission and the 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. In a 2005 policy statement, the Commission formally assigned responsibilities for implementing instream flow water rights to the WGFD and specified procedures for notifying the Commission of instream flow filing activities.

The instream flow law, W.S. 41-3-1001-1014, was passed in 1986 and establishes that "unappropriated water flowing in any stream or drainage in Wyoming may be appropriated for instream flows to maintain or improve existing fisheries and declared a beneficial use..." The statute directs that the Game and Fish Commission is responsible for determining stream flows that will "maintain or improve" important fisheries. The WGFD fulfills this function under the general policy oversight of the Commission. An application for an instream flow water right is signed and submitted by the Wyoming Water Development Commission (WWDC) and, if approved by the State Engineer, the WWDC holds the permit on behalf of the state. The priority date for the instream flow water right is the day the application is received by the State Engineer.

The word "fishery", which is referenced throughout the instream flow legislation, is a key concept that affects the determination of how much water is needed for instream flow purposes. From a natural resource perspective, a fishery includes the diverse fish habitats of the stream channel, riparian zone and floodplain as well as the processes of sediment flux and riparian vegetation development that sustain those habitats (Annear et al. 2004). To maintain the existing dynamic character of 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 such 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 Appendix 1 of this report, should opportunities arise in the future to secure instream flow water rights for this important component of the hydrograph.

Through early May 2006, the WGFD has forwarded 97 instream flow water right applications to the WWDC for submission, while the State Engineer has permitted 59, and the Board of Control has adjudicated four. Recently, we have focused on small headwater streams supporting native cutthroat trout (Annear and Dey 2006). For example, studies were conducted from 1998 to 2003 on thirteen Greybull River tributary stream segments containing Yellowstone cutthroat trout (*Oncorhynchus clarki bouvieri;* see Dey and Annear 2004 for an example). This document reports results and flow recommendations from a 1997 study on an important sport fishery.

Importance of the Fishery

Rock Creek was selected for an instream flow segment because it provides a robust wild trout sport fishery in a remote, aesthetic setting. Under the WGFD's rating system for stream fisheries, Rock Creek is classified as a "Class 2" or red, indicating a very good trout water with relatively abundant fish populations. A Rock Creek instream flow segment is consistent with Wyoming Game and Fish Commission direction to select instream flow segments on class 1 or 2 waters with public access.

Public Participation

The public has several opportunities to be involved in the process of identifying instream flow segments or commenting on instream flow applications. First, people can make us aware at any time of important fisheries to consider for instream flow filings. We develop annual work schedules and five-year plans that are available for public review and comment. The State Engineer is required to conduct a public hearing on the proposed instream flow water right to gather information for consideration before issuing a decision on the instream flow water right application. Prior to this hearing, the WGFD often conducts an informal information meeting to distribute information about the instream flow study (i.e., this report) and answer questions. Additional presentations to community or special interest groups also provide opportunity for discussion.

Meeting with landowners adjacent to or immediately downstream from instream flow segments is vital for sharing information about aquatic resources and the instream flow study, and sometimes for securing access to conduct the instream flow study. While most instream flow segments are delineated on public land where unappropriated water remains, landowners are often given the opportunity to consider an instream flow segment on streams crossing their property.

Objectives

The objectives of this study were to 1) quantify year-round instream flow levels that maintain base-level rainbow trout *Oncorhynchus mykiss* habitat, 2) provide the basis for filing an instream flow water right application to maintain hydraulic conditions for RBT, and 3) identify channel maintenance flows that maintain stream channel form and function over the long-term. The audience for this report is broad and includes the State Engineer and staff, the WWDC and staff, aquatic habitat and fishery managers, interest groups like Trout Unlimited and anyone interested in instream flow water rights in general or an instream flow water right on Rock Creek, in particular.

STUDY AREA

Rock Creek Basin Description

Rock Creek headwaters are in the Snowy Range Mountains of the Laramie Range in Southeast Wyoming (Figure 1). Rock Creek drains roughly north to the Medicine Bow River, a North Platte River tributary. Basin (hydrologic unit code 101800040201) area is 62.9 square miles upstream from USGS gage 06632400, near Arlington (Figure 1) and elevation ranges from about 7790 feet at the USGS gage to over 11,000 feet in the headwaters. The basin's primary aspect is north facing. Annual precipitation at the Sand Lake Snotel site (number 06h23s) in the upper end of the drainage averaged 42 inches over the period 1971 - 2000.

Interstate Highway 80 crosses Rock Creek at Arlington, about 40-miles west of Laramie. A trailhead near the Medicine Bow National Forest boundary is less than two miles from I-80 and provides easy access to a hiking trail that parallels Rock Creek for much of its length. The Rock Creek watershed has been recommended for designation as Wilderness in the latest Medicine Bow National Forest Management Plan (USFS 2003). As such, the area will be managed to protect wilderness characteristics. Existing mechanized uses such as mountain biking, snowmobiles, chainsaws and motor vehicles may continue until formal congressional designation as Wilderness (USFS 2003). Other human uses in the drainage include fishing, camping, hunting, and horseback riding and packing.

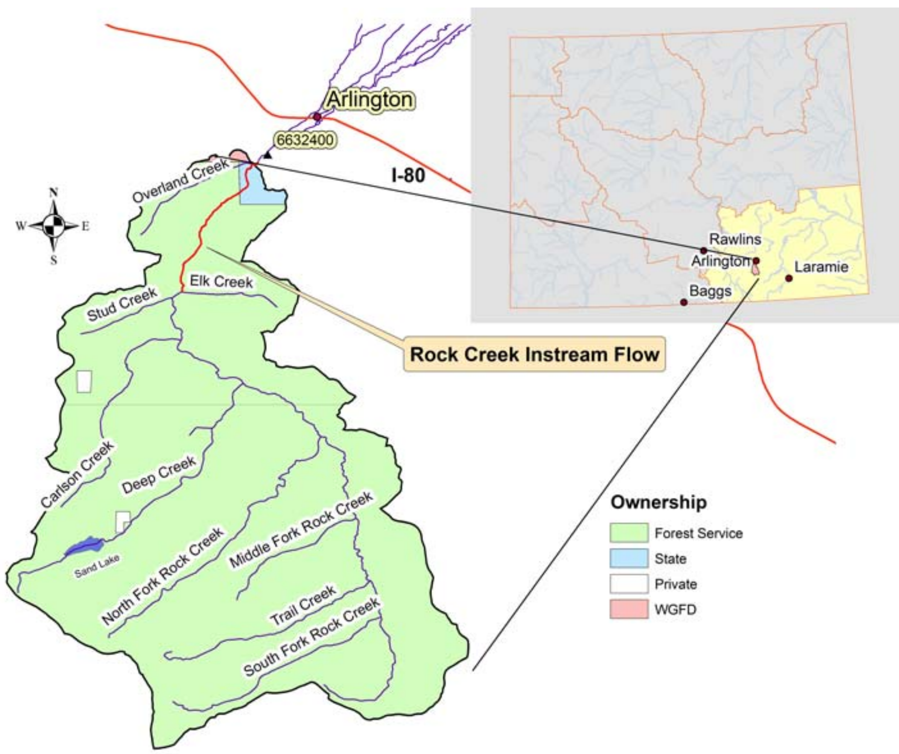

Figure 1. Location of Rock Creek basin, WY and instream flow segment (hydrologic unit code 101800040201).

Sand Lake, near the head of Deep Creek (Figure 1), is a natural lake enlarged with a dam to store irrigation water for the Wheatland Irrigation District. Water is delivered down Rock Creek to the Canon Ditch, downstream from the National Forest boundary. According to the site notes for USGS gage 06632400, there is minor flow regulation at Sand Lake and no diversion upstream from the gage station.

Historically, Rock Creek and its tributaries experienced tie drives wherein trees felled through the winter months were floated downstream during high runoff conditions. Even today, streams subject to tie drives over 100 years ago exhibit simplified channels that are straighter and contain less obstructions than natural channels. Current day fish habitat limitations resulting from historic tie drives may include a lack of wood debris accumulations, low habitat diversity, and wide shallow areas during low flow periods.

While the Rock Creek channel today may be somewhat simplified compared to 150 years ago, woody debris accumulations are evident and indicate natural recovery processes are occurring.

Geology

The Snowy Range Mountain range was formed during the Laramide orogeny when Precambrian metamorphic rocks were uplifted and shoved eastward along the Arlington thrust fault (Lageson and Spearing 1988). The Arlington fault line extends in a northwest to southeast trend along the northeast corner of the Snowy Range near Arlington (Bartos et al. 2006). During the Pleistocene, glaciers extended from the summits of the Snowy Range down many of the major drainages, including Rock Creek (Bartos et al. 2006). The bedrock geology in upper Rock Creek basin is largely Precambrian rock of the Deep Lake Group and glacial deposits. Further downstream in the basin but still on national forest, rocks classified as metasedimentary, metavolcanic and mafic intrusive provide the undermaterial (USGS 1994). The glacial deposits in headwater regions provide a source of sediment material for downstream transport and a region relatively susceptible to bank erosion. However, the relatively resistant metamorphic rocks in the lower basin likely prevent significant headward degradation of the Rock Creek stream channel.

The Rock Creek valley near the forest boundary is V-shaped and conforms to valley type II under Rosgen's (1986) rating scheme. This valley type has moderate relief and side slope gradients, floor slopes usually less than 4%, and soils derived from parent colluvium and alluvium. This valley type often has "B" – type streams, which are quite stable in pattern and profile (Rosgen 1996). Additional stream channel types in the Rock Creek basin are "A" and "C" as determined from inspection of 1:24,000 scale topographic maps. Steep side drainages would be "A" channels. The "C" channels would be more prevalent at higher elevations where a U-shaped glacial valley (valley type V) allows a meandering channel. The stream channel at the lower end of the instream flow segment (segment location is described in a later section) appears to conform to a B3 channel type, reflecting a large cobble bed and moderate entrenchment, slope and width-depth ratios. The floodplain is narrow, ranging from about 10 to 50 feet.

Channel measurements for Rosgen level II characterization (Rosgen 1986) of the Rock Creek instream flow segment are planned for 2006 and will be available in a separate WGFD publication. These measurements are part of a general investigation of stream geomorphology patterns and relationships to instream flow quantification tools. The stream channel measures may provide a useful reference for further development of channel maintenance flow recommendations. Interim bankfull and higher flows to maintain floodplain features are developed in Appendix 1.

Upland and Riparian Resources

Upland vegetation in the Rock Creek basin is primarily lodgepole pine and spruce-fir. Lower amounts of limber pine, aspen, grasses and shrubs complete the upland vegetative community. According to the Forest Plan (USFS 2003), 49% of the forested area is considered late-successional. Riparian species include cottonwood, willow, conifers and moderate herbaceous growth. The riparian zone extends about 10 to 50 feet on each side of the stream through lower Rock Creek where canyon-like conditions are common. The riparian zone is wider in lower-gradient upper reaches, sometimes consisting of wide wet meadows and beaver ponds.

Fishery Resources

The Rock Creek fish community upstream of Arlington is entirely made up of introduced trout species including rainbow trout, brown trout *Salmo trutta*, and brook trout *Salvelinus fontinalis*. Colorado River cutthroat trout *Oncorhynchus clarki pleuriticus* were stocked several times in Elk Creek and Stud Creek between 1985 and 1992 and a 2003 survey by Forest Service biologists documented continued persistence of the Stud Creek population. Amphibians expected to occur in the basin based on general distribution information include leopard frog *Rana pipiens*, boreal chorus frog *Pseudocris triseriata maculata*, wood frog *Rana sylvatica* and boreal toad *Bufo boreas*.

The fishery management focus in Rock Creek upstream from I-80 is on providing a wild rainbow trout fishery. While brown trout are more common downstream of the Forest Service boundary and brook trout are more common in the headwaters, the rapids and deep pools of the instream flow segment favor rainbow trout. Population estimates in 1997, 1998, and 2000 documented rainbow trout numbers of 1,400 to 2,700 per mile. Lower numbers of brown trout and brook trout were also recorded. Total trout biomass ranged up to 71 lbs/acre (284 lbs per mile) among the three sample dates. Fish ranged in length up to 11 inches and many juvenile rainbow trout were found among the large cobbles and boulders in fast water.

While pockets of gravel likely provide localized spawning opportunities for rainbow trout in the lower more canyon-like reaches of Rock Creek, the majority of rainbow trout spawning likely occurs a short distance downstream of the canyon and Forest Service boundary or in lower gradient upstream reaches. The abundance of juveniles and consistently high rainbow trout populations found during population estimates indicates spawning is occurring near, in or upstream of the instream flow segment. Adult rainbow trout use the lateral scour and boulder pocket pools where fast water occurs near deep water. Juvenile trout use slightly shallower and slower water and are often found in shallow rapids and near the tail of pools. This life stage over-winters by burrowing beneath loose boulders and cobbles in fast water. Fry habitat is limited to flooded bars, small backwater pockets along the bank and a narrow band of slow, shallow water along the banks and inside of bends.

Instream Flow Segment

A 3.9-mile long instream flow segment was identified from Elk Creek downstream to the State land/private land boundary (Figure 1, Table 2). The lower boundary was identified because it marks the beginning of public land. The upper boundary marks a hydrologic break where Rock Creek upstream of Elk Creek may have less water and a different relationship between habitat and water quantity.

The lower mile of the Rock Creek instream flow segment is on State owned land and the remaining headwaters occur on the Medicine Bow National Forest (Figure 1). From measurements on 1:24,000 scale maps in AllTopo V7 (iGage 2003), Rock Creek extends nearly 17 miles on National Forest. Including all the perennial tributaries on a 1:24,000 scale map, there are approximately 75 stream miles in the drainage network above the Forest Service boundary.

Table 2. Rock Creek instream flow segment. Coordinates and lengths from AllTopo® software.

Length (mi)	Approximate UTM (Z12, NAD83)		Segment Description
	Upper	Lower	
3.9	395,596E; 4,599,292N	397,844E; 4,604,169N	Elk Creek downstream to State land border with private land

This instream flow segment will indirectly protect about 73 stream miles in the upper Rock Creek basin. Indirect protection comes by virtue of the fact that any new water users in the headwaters must pass enough water to fulfill the downstream senior instream flow appropriation. The indirectly protected headwaters are home to brook trout and rainbow trout. The instream flow segment will directly protect 3.9 miles of Rock Creek that provide important habitat for rainbow, brown and brook trout. While instream flow protections focus on rainbow trout, brown trout and brook trout will also benefit.

METHODS FOR DEVELOPING FLOW RECOMMENDATIONS

This section presents methods used in developing fish flow recommendations for a Rock Creek instream flow water right application. However, if flows are limited to only the instream flow water right recommendations developed from these methods, the fishery will suffer over the long-term because annual patterns of floodplain inundation and sediment flux would not be functioning to maintain the stream channel and associated habitat. Channel maintenance flow recommendations are developed in Appendix 1 to address a broader interpretation of fishery maintenance. Should opportunities arise in the future to secure instream flow water rights for long-term maintenance of Rock Creek aquatic environments, Appendix 1 will provide a valuable reference.

Hydrology

Rock Creek is somewhat unique among instream flow studies in that a complete hydrology record is available from a long history of stream flow gage records. Gage stations have operated near the downstream end of the instream flow segment since October of 1954. The current gage, USGS 06632400, is located less than ½ mile downstream from the end of the instream flow segment and upstream from Canon Ditch. The gage provides an ideal flow history for the instream flow segment and covers the period from October 1965 to present (2006).

Flow statistics for water years 1966 through 2004 were compiled after downloading daily and monthly average flow and peak flow data from the USGS web site (http://nwis.waterdata.usgs.gov/wy/nwis/discharge). The USGS computer program PEAKFQ (Thomas et al. 1998) was used to determine peak flow frequency. The USGS program SWSTAT (Lumb et al. 1994) was used to compute duration frequencies from daily flow data.

Average daily flow was 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. Monthly flow duration series were 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 instream flow habitat studies are included in this report (Table 5). All flow measurements were collected to USGS standards using a Marsh-McBirney model 2000 flow meter.

Fish Habitat From Instream Flow Models

The term "habitat" is used frequently in this report to refer to the physical conditions of depth, velocity, substrate and cover – variables that change when discharge changes. A full trout habitat description 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 were used to generate 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 a relative suitability index for target species like RBT as a function of flow based on depth, velocity, and substrate or cover (Bovee et al. 1998). Calculations are repeated at user-specified discharges to develop a relationship between suitable area (termed "weighted useable area" or WUA) and discharge. Model calibration data are collected across the stream at each of several locations (transects) and involve measuring depth and velocity at multiple locations (cells) along each transect. Measurements are repeated at three or more different discharge levels. By using depths and velocities measured at one flow level, the user calibrates a PHABSIM model to accurately predict the depths and velocities measured at the other discharge levels (Bovee and Milhous 1978, Milhous et al. 1984, Milhous et al. 1989). Following calibration, the user simulates depths and velocities over a range of user-specified discharges.

Next, the predicted depths and velocities, along with substrate or cover information, are compared to habitat suitability criteria (HSC). The relative value to fish of predicted depths, velocities, substrates, and cover elements are defined by HSC which range between "0" (no suitability) and "1" (maximum suitability). At any particular discharge, a combined suitability for every cell is generated. That suitability is multiplied by the surface area of the cell and summed across all cells to yield weighted useable area for the discharge level. Results are often depicted using graphs of WUA for a particular fish life stage versus a range of simulated discharges (Bovee et al. 1998). Developed relationships are best interpreted as a relative suitability index rather than a definitive prediction of physical area (Payne 2003). Rainbow trout habitat suitability criteria for adult (6 inches or greater total length), juvenile (3 to 6 inches), fry (<3") and spawning life stages are Bovee (1978).

Habitat Retention

The Habitat Retention Method (Nehring 1979; Annear and Conder 1984) was used to identify the flow that maintains selected values of depth, velocity and wetted perimeter in riffles (Table 5). 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 (Annear and Conder 1984).

Category	Criteria
Mean Depth (ft)	The greater of 0.20 ft or 0.01 * avg. width
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 5 for all riffle 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 attributes: Critical Period Stream Flow (CPF), Annual Stream Flow Variation (ASFV), maximum temperature, nitrate concentration, percent cover, percent eroding banks, substrate or invertebrate numbers, water velocity, and stream width. Values for each attribute are 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 per acre.

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). Linear equations of velocity and cover at different flow levels were used to calculate ratings. In calculating Habitat Units over a range of discharges, temperature, nitrate concentration, invertebrate numbers, and eroding banks were held constant. HQI results were used to identify the flow between July 1 and September 30 needed to maintain existing trout production (Table 4).

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 late summer conditions is quantified and then the flow that maintains that level of habitat is identified. In streams without gages, an estimate of the August 50% monthly exceedance flow has been used as a reasonable estimate of normal late summer flow levels (e.g. Dey and Annear 2006). Since Rock Creek daily flow data are readily available, existing conditions can be defined as the critical period stream flow (August 1 through September 15).

Winter Fish Habitat

Natural winter (October through April) flow levels are recommended to maintain the Rock Creek RBT population. 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, Cunjak 1988, Cunjak 1996, Prowse 2001a and 2001b, Greenberg et al. 2005). 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. Frazil ice may also 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. 2005, 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 or 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. 2005).

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 IFC (Annear et al. 2004, Pp. 106) recognizes the challenges of developing winter flow prescriptions with the following statement:

> *Unfortunately, the tools to quantify the relation between flow and favorable ice conditions, and habitat, are limited at this time. In the face of this uncertainty, managers should take a conservative approach when their actions or those of others will result in modification of winter flow regimes, either by additions or depletions.*

For Wyoming Rocky Mountain headwater streams, a conservative approach to meeting the instream flow law's requirement of developing flow recommendations to maintain existing fisheries is to simply recommend the existing natural winter flow level. That approach was adopted for Rock Creek. 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 trout holding capacity of the few large pools.

Indirect methods, such as the Habitat Retention Method employed by the WGFD, are an alternative way of indexing winter trout habitat changes to flow 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. This assures that even in cases where flow is underestimated due to poor gage records or other estimation errors, flow levels approximating the natural winter condition will be protected.

Combining Methods to Arrive at Instream Flow Recommendations

The fishery functions and associated time periods summarized in Table 4 show how each of the models and approaches described above were applied to Rock Creek on a monthly basis. The instream flow recommendation for any month where two or more recommendations apply is based on the recommendation that yields the higher flow. Natural flows during the October through April winter months are recommended for high mountain streams like Rock Creek (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. The HQI applies to adult trout growth during the months of July, August and September and is the default methods for those months. Channel maintenance flows perform their function during runoff in May and June but are not used in the instream flow water right application as described in the *Introduction*.

Table 4. Rainbow trout life stages and months considered in developing instream flow recommendations. Numbers indicate the method used to determine flow requirements and green 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
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						

1=Natural winter flow or Habitat Retention, whichever is greater, 2=Habitat Retention, 3=Physical Habitat Simulation, 4=Habitat Quality Index, 5=Channel Maintenance.
* Channel maintenance flow recommendations are developed in Appendix 1.

Study Site

A 465-foot study site was selected after walking most of the identified instream flow segment on July 1, 1997. During this reconnaissance inspection, the distribution of trout habitat, location and relative magnitude of tributary water sources, and other features were noted. A study site was established near the downstream end of the instream flow segment at a location (Figure 1; UTM 397,522E; 4,603,386N; Z13; NAD83) offering the range of features judged to be representative of the entire reach. Riffles, runs, pools, and stream-margin fry habitat were present (Figure 2). Very little spawning-size gravel was observed. The study site was visited on multiple dates to measure habitat features under a range of flow conditions (Table 5).

Table 5. Dates and discharges for measurements at a Rock Creek study site.

Date	Discharge (cfs)	Data Collected
7/1 – 7/2/1997	184*	Reconnaissance and site selection
7/3/1997	163	PHABSIM, Habitat Retention, HQI
7/10/1997	119*	Snorkel fish observations
7/17/1997	90	PHABSIM, Habitat retention, HQI
9/9/1997	16	PHABSIM, Habitat Retention, HQI, fish population est.
9/2/1998	17	Fish population estimate
9/14/2000	8.4	Fish population estimate

* discharge from USGS gage record.

Figure 2. Rock Creek at 163 cfs (top), 90 cfs (middle), and 16 cfs (bottom). Transects 5 through 8 are in this riffle – run – pool sequence.

Nine transects for collecting PHABSIM data were distributed with four transects in each of two separate riffle-pool-run sequences and an additional riffle transect. Transects were numbered starting with "1" at the farthest downstream transect and ending with "9" for the upstream most transect. The 465–foot HQI reach extended from between transects 8 and 9 downstream to a riffle between transects 5 and 4.

PHABSIM for Windows Version 1.2 was used and three PHABSIM "projects" were created. Each of the two separate pool-riffle habitat sequences and the single riffle were modeled in separate projects. Water surface elevations for all transects were simulated using stage-discharge relationships. We assessed water surface predictions by looking for linearity of the log flow-log water surface elevation plot, low mean square error of regression, and parallel water surface profiles (Waddel 2001). The velocity set collected at 163 cfs served as the calibration source for distributing roughness among cells. Velocity calibration included comparison of predicted and measured velocities and examination of VAF plots (Waddel 2001). The HABTAE subprogram was used to generate weighted usable area for each of the 4-transect projects. Weighted usable area output from the two 4-transect projects was averaged for each flow and life stage. A simulation range from 5 cfs to 400 cfs was used based on solid stage-discharge relationships and general calibration criteria. Simulation increments of 1.0 cfs were used up to 30 cfs, 5 cfs increments were used from 30 cfs to 100 cfs, and 10 cfs increments were used above 100 cfs. Weighted useable area versus flow curves were generated for fry, juvenile and adult RBT.

Three riffle transects modeled with PHABSIM were intended for Habitat Retention analysis (numbered transects 1, 5 and 9). In calculating the wetted perimeter criterion (Table 3), bankfull discharge was estimated as the 1.5-year return interval flow of 1063 cfs (see Hydrology Results). For applying the depth criterion, an average daily flow of 81.5 cfs was used. Average wetted stream width on the 9 transects at 81.5 cfs was 37 feet (from PHABSIM simulations) so 0.37 feet (0.01 * width at ADF) was the depth criterion. Riffle transect 9 could not be calibrated to simulate above about 300 cfs because surveyed points were lacking on the right side of the channel. Therefore this transect was not used in the habitat retention analysis. If it had been useable, the wide and shallow nature of the cross section would have resulted in the same or a higher flow to maintain hydraulic criteria (compared to the other two riffle transects).

For HQI analysis, the critical period stream flow and annual stream flow variation attributes were calculated directly from the gage record for the period October 1965 through September 2004. Maximum water temperature was determined with a Taylor Max-Min thermometer placed in Rock Creek July 17, 1997 and retrieved September 9, 1997. The HQI "substrate" attribute, a measure of invertebrates per square foot of streambed, was rated visually.

Flows For Other Important Ecosystem Components

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

Existing Rock Creek water quality is excellent in and upstream of the instream flow segment. That is, water temperature, turbidity, and various organic and inorganic constituents are believed to be at normal levels for a fairly pristine Snowy Range stream and no pollution is apparent. Flow recommendations in this report are expected to maintain water quality within natural bounds. If new water development were to occur in the Rock Creek basin, water quality issues might bear re-examination.

RESULTS AND DISCUSSION

Hydrology

Rock Creek exhibits a snowmelt runoff pattern with the bulk of the annual flow occurring in May and June as snow melt (Figure 3). Nearly 50% of the total annual flow occurs in the month of June (from Appendix 1-11 in Miller 2003). Average June flows have ranged up to 1024 cfs (June 1971) and the 39-year mean June flow is 480 cfs (Figure 3). Flow recedes during August and September so that base flows are essentially reached by early fall. Annual flow minima occur in winter, usually January, February or March (Figure 3). Average February flows are 10 cfs and the lowest February flow of 6.6 cfs occurred in 2001. Many winter records at the gage site are considered "poor" by the USGS since they had to be estimated due to ice.

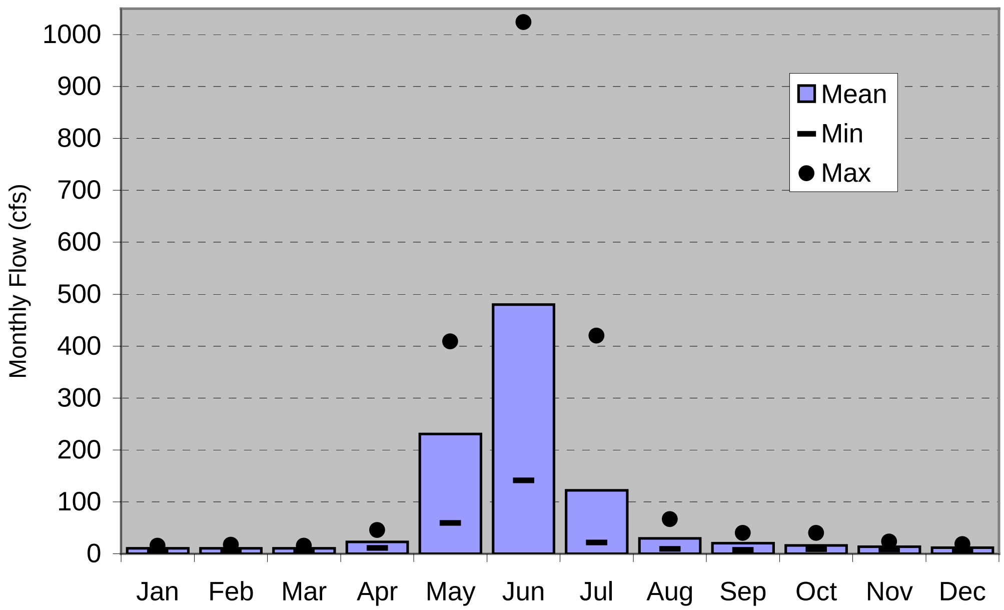

Figure 3. Mean, minimum and maximum of average monthly flows from October 1965 to September 2004.

The relative magnitude and frequency of daily flows are illustrated in the exceedance diagram of Figure 4. The shape of the relationship reflects a runoff pattern in which for most days of the year, flow is relatively low. That pattern is also apparent in Figure 3. The 90% exceedance flow is 8.0 cfs, 50% of the time flow exceeds 16 cfs and the 10% exceedance flow is 261 cfs (Figure 4). Average daily flow is 81.5 cfs (Table 6). Monthly 50% and 20% exceedance flows are listed in Table 6.

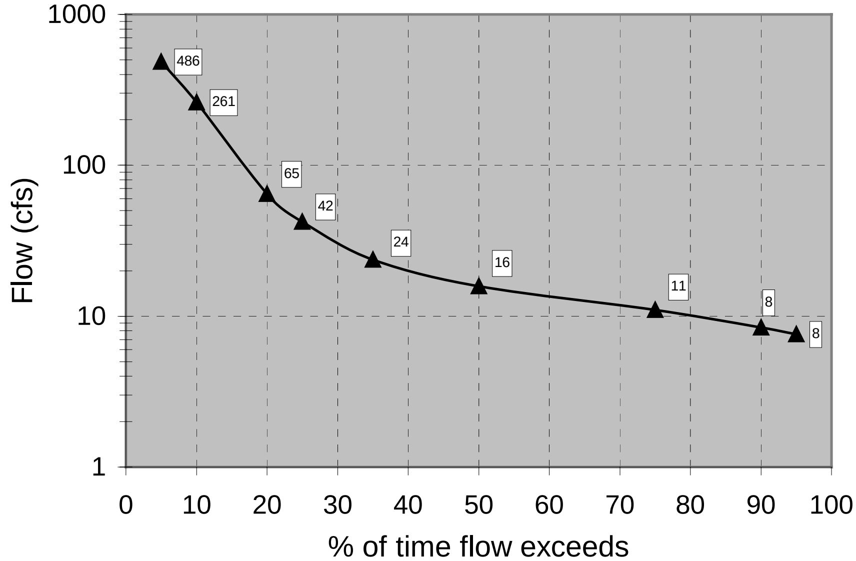

Figure 4. Daily flow exceedance, Rock Creek gage 06632400 October 1965 through September 2004.

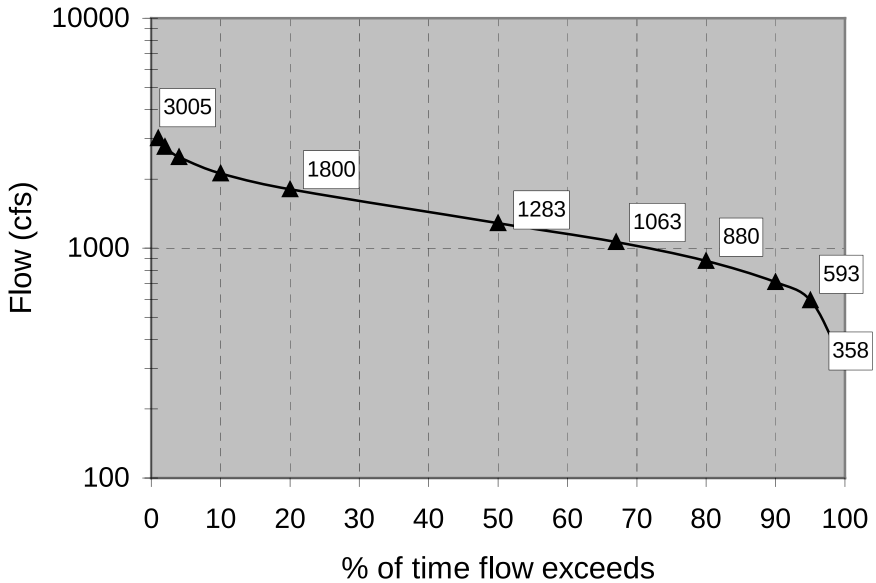

Figure 5. Peak flow exceedance, Rock Creek gage 06632400 October 1965 through September 2004.

Peak flow characteristics are illustrated in the exceedance diagram of Figure 5. The 1.5-year flood level (exceedance probability of 0.6667) is 1063 cfs and provides an estimate of bankfull discharge. The 25-year flood level is 2495 cfs. Over the period 1965 through 2004, peak flows occurred between May 16 and June 25 with a median date of June 6. Peak flow in 1997, prior to the instream flow study, was 1540 cfs and occurred on June 1. Therefore, data were collected immediately following a bankfull event.

Table 6. Rock Creek instream flow segment hydrologic characteristics from Rock Creek gage 06632400. Monthly exceedance is from a 32-39 year period between 1965 and 2004.

Flow parameter		Flow (cfs)
	Mean Annual	81.5
	1.5 year peak	1063
	25 year peak	2495
Spring Month	Monthly 50% Exceedance (cfs)	Monthly 20% Exceedance (cfs)
May	205	340
June	426	727
Summer Month		
July	95	187
August	24	42
September	16	27
Winter Month		
October	14	21
November	13	17
December	11	15
January	10	13
February	10	13
March	10	12
April	19	30

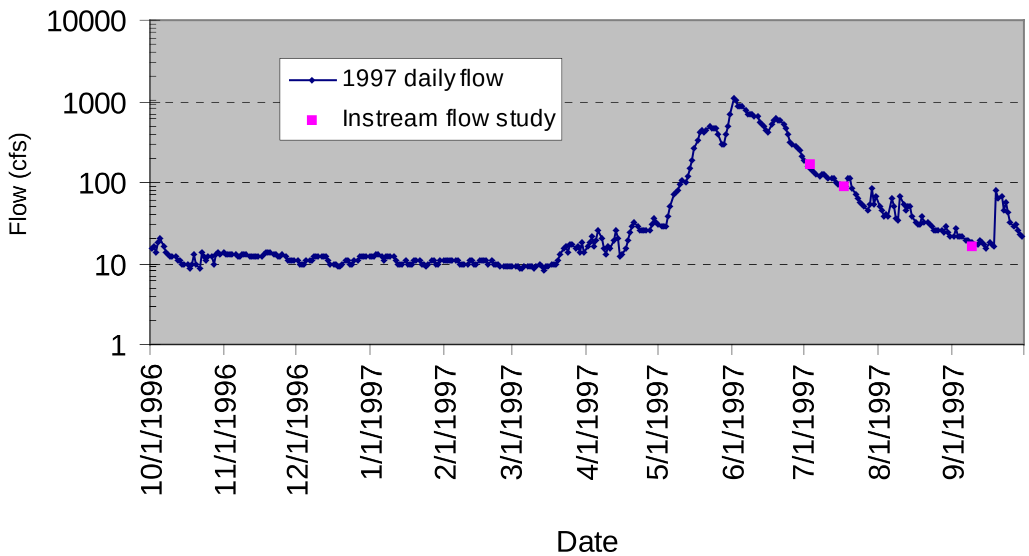

Figure 6. Daily Rock Creek flows in water year 1997 at USGS 06632400. Instream flow study sample dates and measured flows are illustrated.

The hydrologic conditions during 1997 when the instream flow study were near normal. Mean annual daily flow at the Rock Creek gage for water year 1997 was 90.5 cfs, slightly higher than the long-term average of 81.5 cfs. Average monthly flows for May through September were at the 60 to 75th percentile, indicating slightly above average flow conditions. Precipitation in the Sand Lake Snotel site for water year 1997 was 47 inches compared to a 42-inch average. The flow levels in 1997 were ideal for studying fish habitat versus flow relationships because they provided an opportunity for measurements under a broad range of conditions.

While a wide variety of statistics can describe hydrology, annual stream flow variability (ASFV) and critical period stream flow (CPSF) from Binns (1979) are listed in Table 7 because these parameters are used in the HQI model. Annual stream flow variability is the ratio of the instantaneous annual peak flow to the annual low flow and averages 195% (Table 7). This is rather pronounced annual fluctuation and earns a low rating of "1" under the HQI (Binns 1982). The rating increases to "2" for an ASFV ratio of 99% or less. With an average peak flow of 1357 cfs, the annual minimum flow would have to be at least 13.7 cfs to increase the ASFV rating to 2. The CPSF is the average August 1 through September 15 flow expressed as a percent of average daily flow and averages 33% (Table 7). This CPSF value corresponds to a "3" rating and indicates late summer trout habitat is moderate and flow may occasionally limit trout numbers. Values of CPSF less than 26% would result in a lower trout habitat score.

Table 7. Rock Creek hydrologic statistics for application of the Habitat Quality Index.

	Annual Stream Flow Variability (ASFV; annual peak flow / lowest daily flow	Critical Period Stream Flow (CPSF; Aug 1 – Sep 15 average flow / average annual flow
Mean peak (cfs)	1357	NA
Mean CPF	NA	27 cfs
Mean (%)	195	33
Range (%)	67 – 432	10 – 66
n (years)	39	40

Development of Fish Flow Recommendations

Physical Habitat Simulation

The physical habitat indices for fry, juvenile and adult RBT generally exhibit bell-shaped curves with lower habitat suitability at low and high flow levels (Figure 7). Fry have a broad plateau of relatively favorable conditions between about 11 cfs and 65 cfs. At low flows, the physical habitat index for fry rapidly declines rapidly as the wetted stream channel shrinks. At higher flow levels, fry would be expected to seek low velocity backwater and stream margin areas to avoid high velocities. Since rainbow trout are spring spawners, most fry would be expected to reach the juvenile stage by the following spring runoff period and thus have more tolerance for high flow levels (Figure 7). During August and into the fall when fry are emerging and growing, flows of 14 to 26 cfs normally occur (Table 6) and offer near optimal physical habitat.

Juvenile and adult trout exhibit similar flow responses, achieving their maximum physical habitat values at 60 cfs (Figure 7). Declines in the physical habitat indices at higher flow levels occur as high velocities begin to limit the amount of useable space. At lower flow levels, less than ideal depths limit physical habitat. It is clear from duration analysis (Figure 4) that a flow of at least 60 cfs is available about 21% of the time annually and these days occur during runoff (Table 6). When 60 cfs naturally occurs, RBT populations benefit. In fact, this analysis (and ignoring for the moment a range of other considerations) suggests that if flow were artificially held at a constant 60 cfs the RBT populations in Rock Creek would expand. They maintain their current lower population level, however, because that 60 cfs is available for only a short time span every year. Therefore, to maintain Rock Creek RBT populations, a flow of 60 cfs is recommended for the spring runoff months of May and June. We do not recommend storage to provide the 60 cfs on a more consistent basis than naturally available.

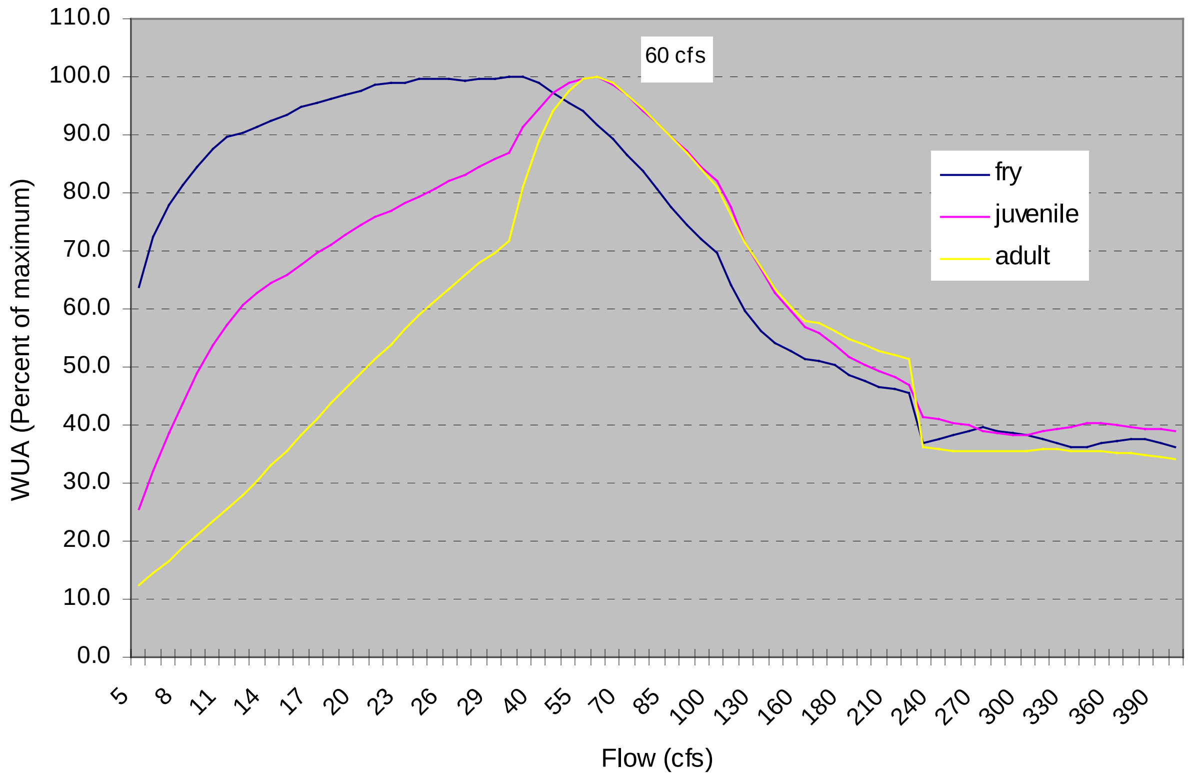

Figure 7. Rainbow trout weighted useable area for adult, juvenile, and fry life stages (percent of maximum value). Note x-axis values are scaled to show simulated flows.

Habitat Retention

Average depth, average velocity, and wetted perimeter for two riffle transects as a function of flow are listed in Table 8. At riffle 1, velocity is the first hydraulic criterion met as flow declines from its bankfull level to 28 cfs. Next, the wetted perimeter criterion is met at 9.2 cfs and the depth criterion is met at a flow less than 5.0 cfs (simulating lower flows was not reliable or necessary). Thus, two of three hydraulic criteria (wetted perimeter and mean depth) are retained by a flow of 9.2 cfs across riffle 1 (Table 8). In a similar fashion, 13 cfs retains two of three criteria on riffle 2. Therefore, the flow that retains two of three criteria for all of the studied riffles is 13 cfs. Based on Habitat Retention, a flow of 13 cfs is necessary year round to maintain trout survival, movement and invertebrate production.

Assessing 13 cfs in the context of adult and juvenile habitat, PHABSIM results show low suitability levels at lower flow levels and rapid gains in suitability at flow levels higher than 13 cfs (Figure 7). Under ice-free conditions, trout can move between pools at 13 cfs while greater flow levels would provide additional adult and juvenile habitat. The HQI model results in the following section further define adult trout summer habitat needs. The need for natural winter flows, sometimes higher than 13 cfs, is discussed in a later section.

Table 8. Simulated hydraulic criteria for three Rock Creek riffles. Bold indicates that the hydraulic criterion was met. Bankfull is 1063 cfs and the depth criterion is 0.37 feet. Flows meeting 2 of 3 criteria for each riffle are shaded.

	Mean Velocity (ft/s)	Mean Depth (ft)	Wetted Perimeter (ft)	Discharge (cfs)
Riffle 1 – transect 1	7.77	2.09	68.8	1063
	5.18	1.87	57.0	523
	2.58	1.27	51.1	160
	1.86	1.05	47.8	90
	0.99	0.66	43.5	28
	0.77	0.51	41.5	16
	0.61	0.44	**34.4**	9.2
	<0.43	**<0.47**	<25.5	<5.0
Riffle 2 – transect 5	6.64	2.11	78.1	1063
	4.47	1.56	76.6	523
	2.49	1.06	62.7	163
	1.82	0.93	54.6	90
	1.03	0.63	46.8	30
	0.75	0.55	39.9	16
	0.67	0.51	**38.8**	13[a]
	0.59	0.47	37.1	10
	0.41	**0.38**	32.1	5

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

Habitat Quality Index

A maximum water temperature of 63° F was recorded. This temperature falls in the 55 - 65º F band for a rating of "4" under Binns (1982) and reflects optimal thermal conditions. Nitrate level was low, <0.01 mg/l, and rates "0" under the HQI. To allow simulation of Habitat Units at different flows, the nitrate rating was held constant at "1" (the rating is multiplied against other ratings). Eroding banks, at 26%, were borderline between a "2" and "3" rating. The erosion appeared mostly natural so the higher rating was used and does not affect the simulation results. The substrate attribute was occularly estimated as "3" due to an estimated 200 – 250 aquatic invertebrates per square foot. Percent cover increased with flow and ranged between nearly 10% at 16 cfs and 12% at 163 cfs. The cover rating changes from "1" to "0" at less than 10% cover. Since measured cover at 16 cfs was very close to 10%, 16 cfs was defined as the threshold for the rating change; at flows less than 16 cfs the cover was rated "0" and for flows greater than or equal to 16 cfs cover was rated "1".

Peak Habitat Units occur between 46 and 55 cfs (Figure 8). Contributing to the peak is a combination of adequate base flow (CPSF rating peaks at 46 cfs) and ideal velocities. At flows greater than 55 cfs, higher velocities begin to limit the habitat quality.

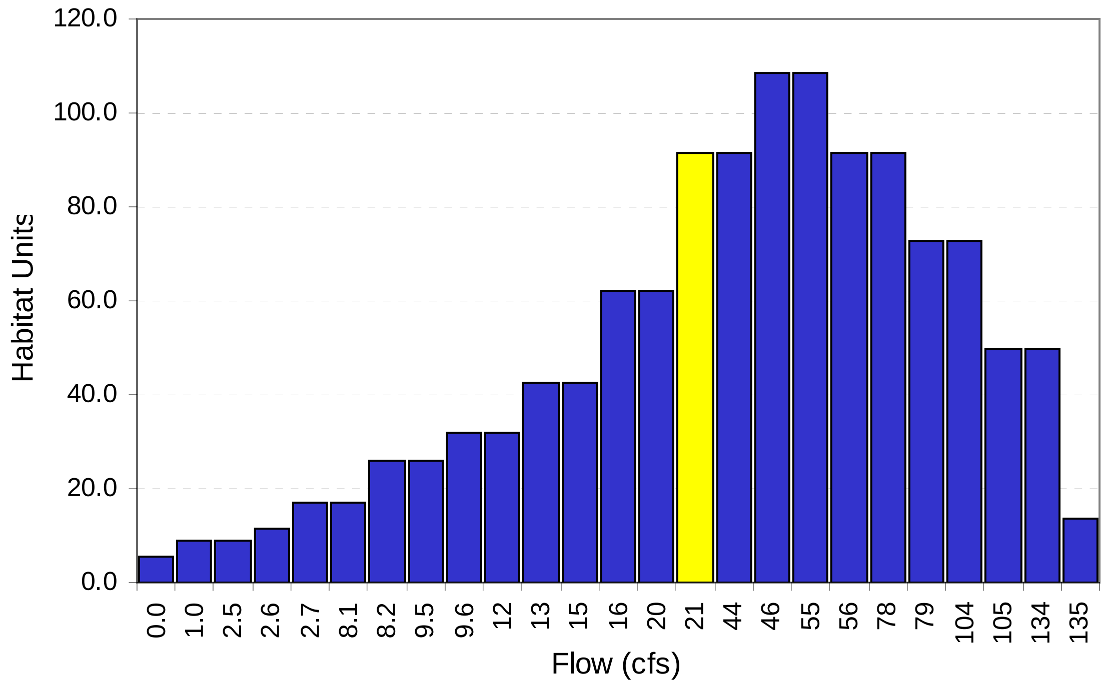

Figure 8. Habitat Quality Index for a range of flow levels. X-axis flows are scaled to show where changes in Habitat Units occur. The recommended flow is indicated by the light shaded bar.

The historic CPSF of 27 cfs (Table 7) provides a reasonable estimate of normal late summer flow levels. Another estimate is the 50% August exceedance flow of 24 cfs. At both of these flows, the stream provides 91 Habitat Units (Figure 8). The lowest flow that will maintain 91 Habitat Units is 21 cfs; therefore, the instream flow recommendation to maintain existing adult RBT habitat during the late summer period is 21 cfs. This flow will also maintain existing brown and brook trout production since the HQI model does not distinguish among trout species.

Winter Flows and Habitat

October through February and April 20% monthly exceedance flows (Table 6) are recommended to maintain existing winter trout habitat. In March, the estimated 20% exceedance flow of 12 cfs falls below the 13 cfs Habitat Retention flow. To maintain opportunities for fish passage and invertebrate production, the habitat retention flow of 13 cfs is recommended for March. Adult, juvenile and fry physical habitat drops sharply at flows less than 13 cfs (Figure 7). PHABSIM results apply to ice-free conditions so extrapolation to winter is limited to ice-free areas and pools beneath a stable ice cover.

INSTREAM FLOW WATER RIGHT RECOMMENDATIONS

Rock Creek has important RBT habitat in addition to habitat that supports lower numbers of brown trout and brook trout. An instream flow filing will protect existing base flow conditions against unknown future consumptive and diversionary demands. About 3.9 miles of stream habitat will be directly protected and about 75 miles of headwaters will be indirectly protected if this instream flow application advances to permit status.

Rock Creek instream flow recommendations to maintain short-term RBT habitat are summarized in Table 9. Spring (May and June) instream flow recommendations to maintain adult and juvenile physical habitat were developed using PHABSIM. Summer recommendations (July through September) to maintain RBT adult production were developed using the HQI model. Winter (October through April) flow recommendations were developed from a combination of Habitat Retention and natural winter flow estimates, defined as the 20% monthly exceedance. For March, estimated natural winter flow was less than the habitat retention flow. To maintain riffle hydraulic conditions, the habitat retention flow was recommended for this month.

Table 9. Rock Creek instream flow recommendations for short-term fishery maintenance.

Monthly Flow Recommendations (cfs)											
Oct	Nov	Dec	Jan	Feb	Mar	Apr	May*	Jun*	Jul	Aug	Sep
21	17	15	13	13	13	30	60	60	21	21	21

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

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 2.

Because data were collected from a range of habitats and simulated over a wide flow range, additional data collection under different flow conditions is not likely to 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.

Based on hydrology, the instream flow recommendations constitute a small portion of annual water yield in the Rock Creek basin, even in very dry years (Figure 9). Runoff flows in randomly selected dry, average and wet years are considerably higher than the 60 cfs fish maintenance recommendation. To maintain long-term fish habitat needs, flow recommendations more reflective of the natural hydrograph would be required (Appendix 1). The recommended 60 cfs instream flow maintains adult and juvenile RBT physical habitat in the Rock Creek channel as it exists today.

During a wet summer like 1983, flow is higher than the 21 cfs recommendation for most of July through September. In contrast, during a dry year like 2004, the recommended flow is available only for a couple weeks in July (Figure 9). The instream flow recommendations during the winter months are a couple cfs higher than the flows that occurred in the randomly selected dry and average years. In wet years like 1983, however, the winter instream flow recommendations are usually naturally available. Since gage records are often poor during winter months due to interference from ice, the recommended flow levels provide a slight safety margin in favor of the fish. For example, the goal is to recommend naturally available winter flow levels which some might argue would be better represented by the 50% monthly exceedance flow. However the historical record from which the monthly estimates of 50% exceedance were derived are riddled with poor records due to ice interference. A recommendation at the 20% exceedance level makes it highly likely that the natural winter flow level will be maintained for most years.

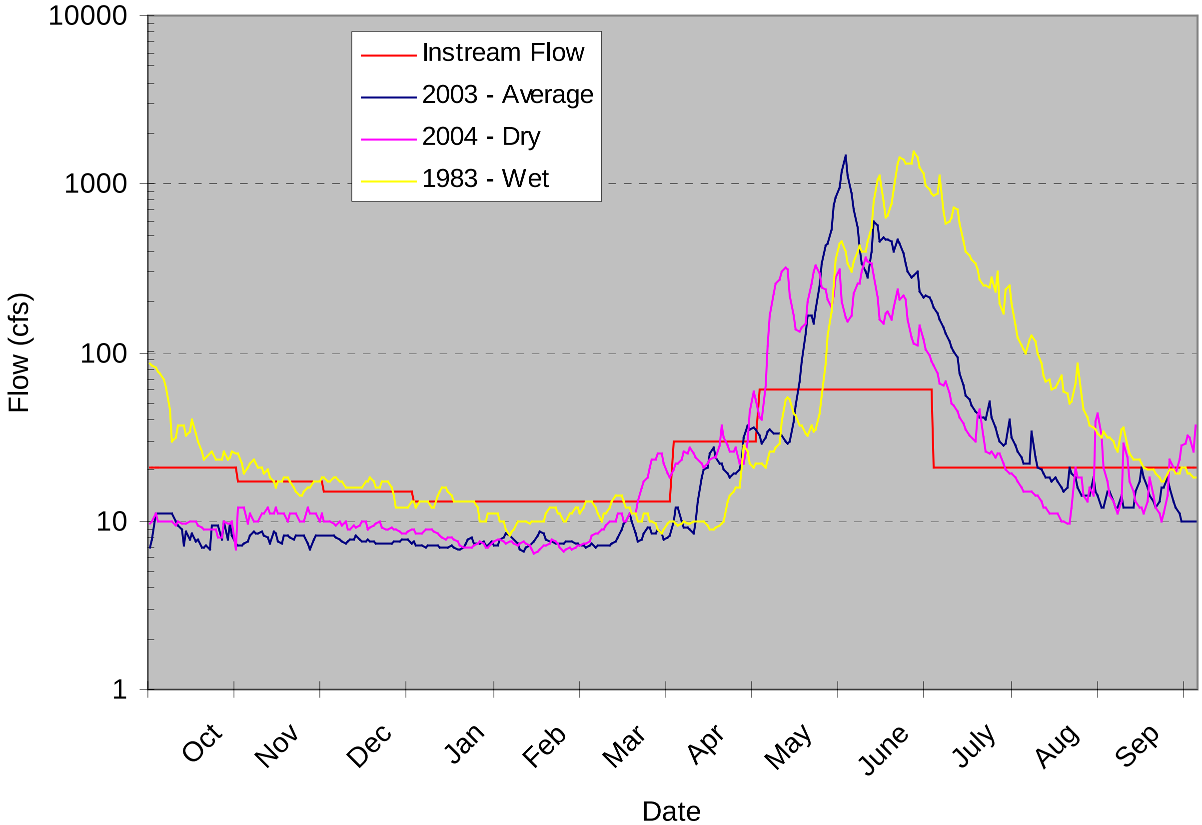

Figure 9. Rock Creek instream flow recommendations and hydrographs from water years in three exceedance classes: wet (0-10%), average (30-70%), and dry (90-100%).

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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 (USFS 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 (USFS 1997). When sediment-moving flows are removed or reduced over a period of years, some gravel-bed channels respond by reducing their width and depth, rate of lateral migration, stream-bed elevation, bed material composition, stream side vegetation and water-carrying capacity.

Maintenance of channel features and floodplain function cannot be obtained by a single threshold flow (Kuhnle et al. 1999). Rather, a dynamic hydrograph within and between years is needed (Gordon 1995; Trush and McBain 2000, Schmidt and Potyondy 2004). High flows are needed in some years to scour the stream channel, prevent encroachment of stream banks and deposit sediments to maintain a dynamic alternate bar morphology and 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.

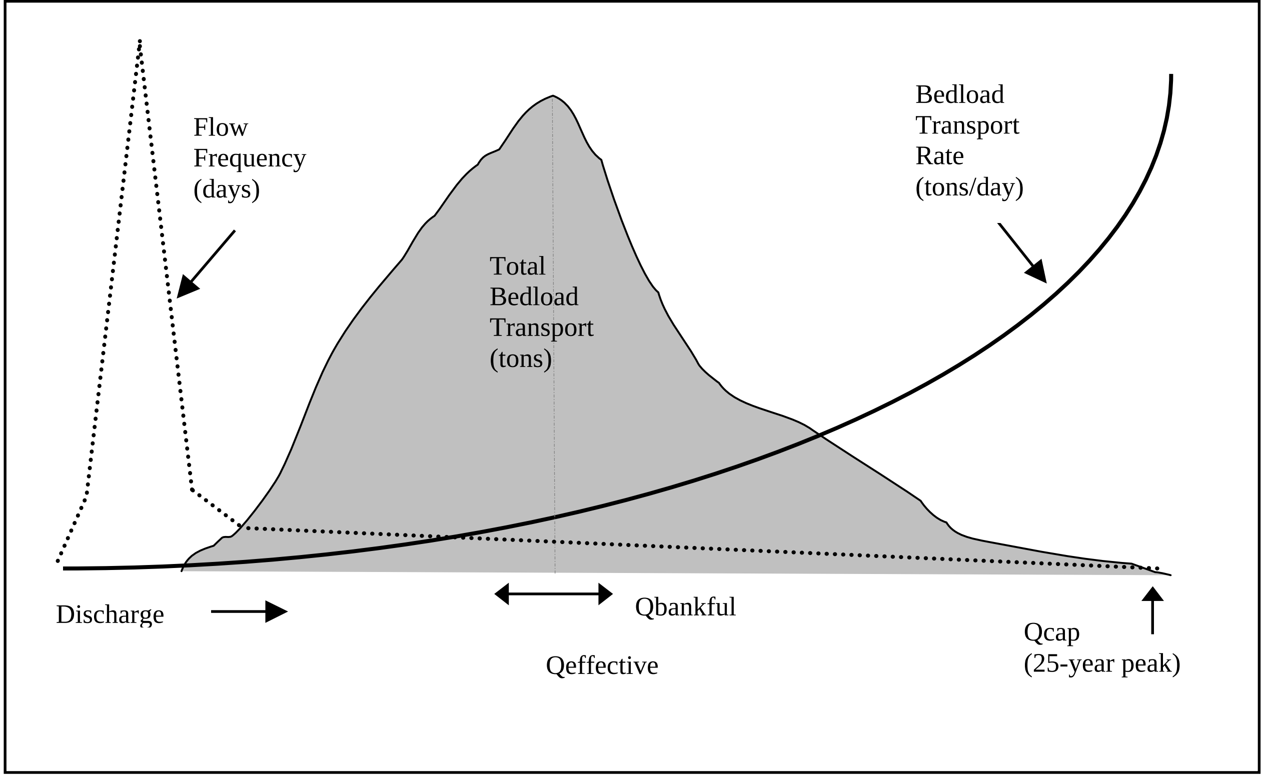


Figure 1-1. Total bedload transport as a function of bedload transport rate and flow frequency (adapted from Schmidt and Potyondy 2004).

The initiation of particle transport begins at flows somewhat greater than average annual flows but lower than bankfull flows (Schmidt and Potyondy 2004). Ryan (1996) and Emmett (1975) found the flows that generally initiated transport were between 0.3 and 0.5 of bankfull flow. Movement of coarser particles begins at flows of about 0.5 to 0.8 of bankfull (Carling 1995, Leopold 1994). Schmidt and Potyondy (2004) discuss phases of bedload movement and suggest that a flow trigger of 80% of the 1.5-year discharge "provides a good first approximation for general application" in defining flows needed to maintain channels. They suggest that although lower flows will initiate fine sediment movement, "delaying the initiation point of the channel maintenance hydrograph (to 0.8 * Q_b), is desirable because it minimizes the long-term volume of water needed for channel maintenance."

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

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

Where: Q_s = actual stream flow
Q_f = fish flow
Q_m = substrate mobilization flow = 0.8 * Q_b
Q_b = bankfull flow

The model is identical to the one presented in Gordon (1995) and U.S. Forest Service (1994) with one variation. The model presented in those documents used the average annual flow as the flow at which substrate movement begins. This term was re-defined here as the substrate mobilization flow (Q_m) and assigned a value of 0.8 times bankfull flow based on the report by Schmidt and Potyondy (2004). Setting Q_m at a higher flow level leaves more water available for other uses and thus better meets the statutory standard of "minimum needed".

Application of the equation results in incrementally higher percentages of flow applied toward channel maintenance as flow approaches bankfull (Figure 1-2). Flows less than half of bankfull are available for other uses unless needed for direct fish habitat. At flows greater than bankfull but less than the 25-year flow level, the channel maintenance instream flow recommendation is equal to the actual flow. Flows greater 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.

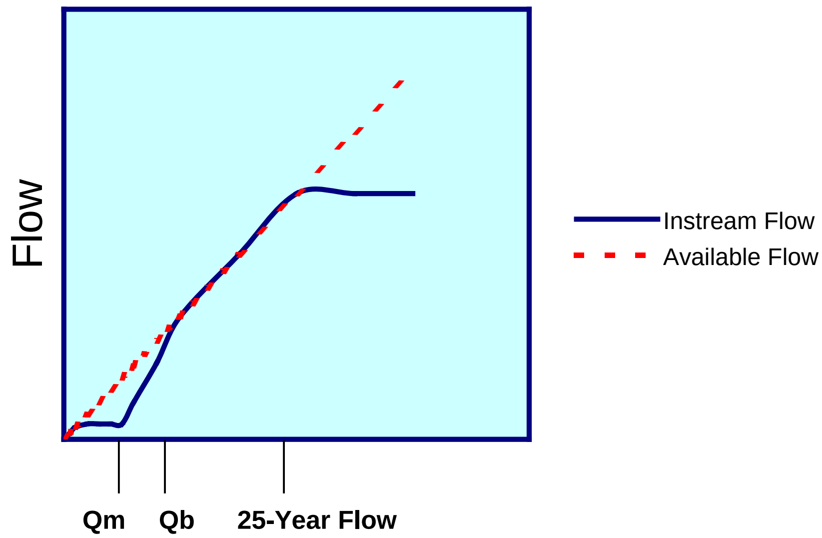


Figure 1-2. General function of a dynamic hydrograph instream flow for fishery maintenance. Q_m is substrate mobilization flow and Q_b is bankfull flow.

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

Like all properly functioning rivers, the Rock Creek instream flow segment has 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 and maintain channel form (i.e., depth, width, and 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 yielded the channel maintenance instream flow recommendations in Table 1-1. The base or fish flow used in the analysis was the 60 cfs recommended to maintain adult and juvenile habitat during May and June. For naturally available flow levels less than 60 cfs, the channel maintenance instream flow recommendation is equal to natural flow. The fish flow is considerably less than the substrate mobilization flow (850 cfs). For the flow range between the fish flow and the substrate mobilization flow, the channel maintenance flow recommendation is equal to the fish flow (Table 1-1). When naturally available flows range from the substrate mobilization flow to the bankfull flow level, application of the Leopold formula results in incrementally greater amounts of water applied toward instream flow (Table 1-1). At flows between bankfull and the 25-year flood flow, all of the streamflow is needed to perform channel maintenance functions. At flows greater than the 25-year flood flow, only the 25-year flood flow is needed for channel maintenance because this flow level will have moved the necessary amount of bed load materials and reconnected the channel with the floodplain (Figure 1-2).

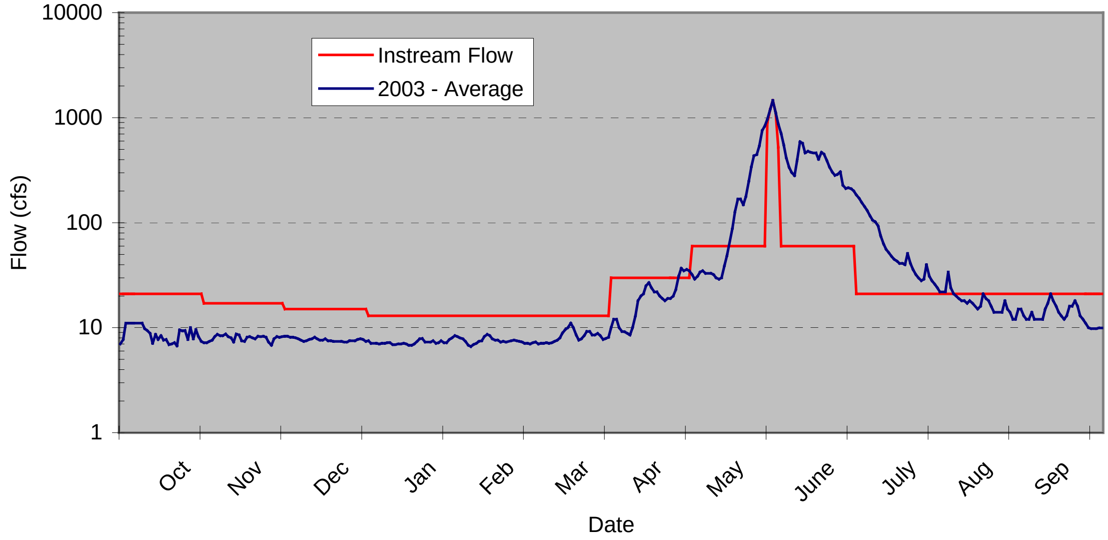
Table 1-1. Channel maintenance instream flow recommendations (shaded columns) to maintain existing channel forming processes and long-term aquatic habitat characteristics in the Rock Creek instream flow segment. Recommendations apply to the run-off period from May 1 through June 30.

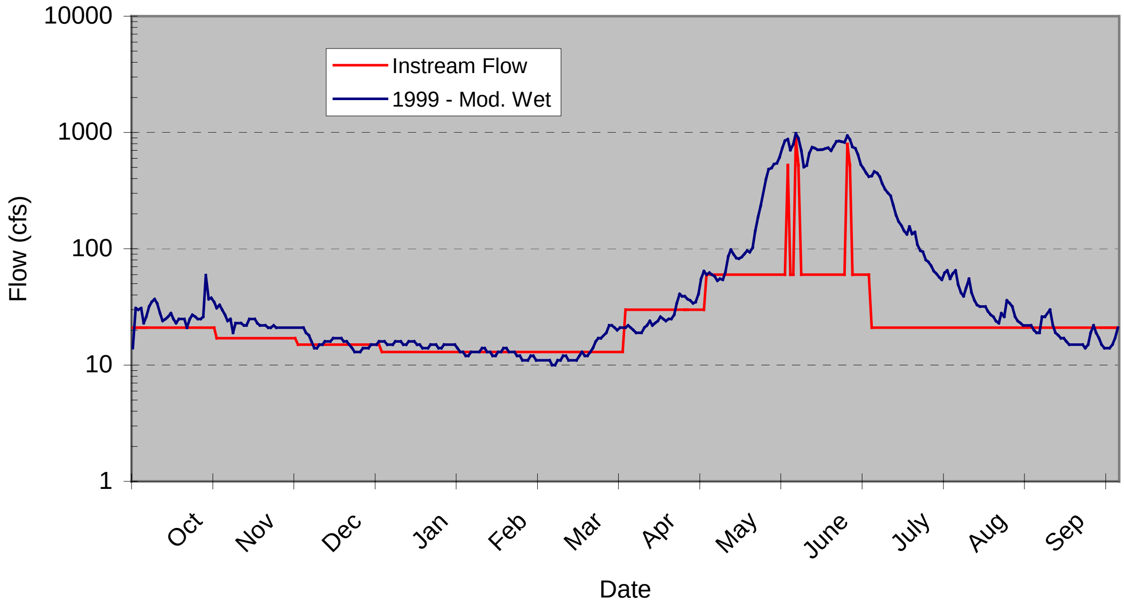
Flow Level Description	Flow (cfs)	
	Available	Channel
<Base (fish) Flow*	<60	<60
Base Flow	60	60
Base flow to Substrate Mobilization	61-849	60
Substrate Mobilization	850	60
Mobilization to Bankfull	851 – 903	523
Mobilization to Bankfull	904 - 956	796
Mobilization to Bankfull	957 – 1009	897
Mobilization to Bankfull	1010 - 1062	983
Bankfull	1063	1063
Bankfull to 25-Year Flood[#]	1063-2495	1063-2495
25-Year Flood	2495	2495
> 25-Year Flood	≥ 2495	2495

*At stream flows less than the base flow, the flow recommendation is all available flow.
Between bankfull and the 25-year flow, the flow recommendation is all available flow.

Figure 1-3 shows examples of channel maintenance flow recommendations implemented in a randomly selected average, moderately wet and wet year. Dry or moderately dry years are not shown because during most of these years flows would not exceed the 850 cfs substrate mobilization threshold to initiate channel maintenance flows. In the representative average year, 2003, flow exceeded 850 cfs for five consecutive days invoking channel maintenance flow recommendations (Table 1-1). For three of the five days, natural flow exceeded bankfull thus the channel maintenance flow would be equal to the natural flow on those days. In moderately wet 1999, the hydrograph was fairly flat and did not exceed bankfull flow but again exceeded 850 cfs for five days. This time, those days were separated resulting in multiple channel maintenance flow spikes (Figure 1-3). In the wet year example, flow exceeded the 850 cfs substrate mobilization level for 16 days and exceeded the bankfull discharge on 11 days.

If water storage were developed (though it is not recommended for this rainbow trout fishery) it would be necessary to further specify the rate at which releases could be increased or decreased to the channel maintenance or base levels. The sharp flow increases and decreases evident in Figure 1-3 (e.g. 60 cfs to 983 cfs in one day) would cause habitat loss through excessive scour and potential trout mortality due to stranding. More gradual changes akin to a natural hydrograph would be recommended. In that case, the Index of Hydrologic Alteration (IHA; Richter et al. 1996) could provide a valuable reference. Daily increases and decreases during runoff measured at the Rock Creek gage could serve as guide for developing such ramping rate recommendations using the IHA.





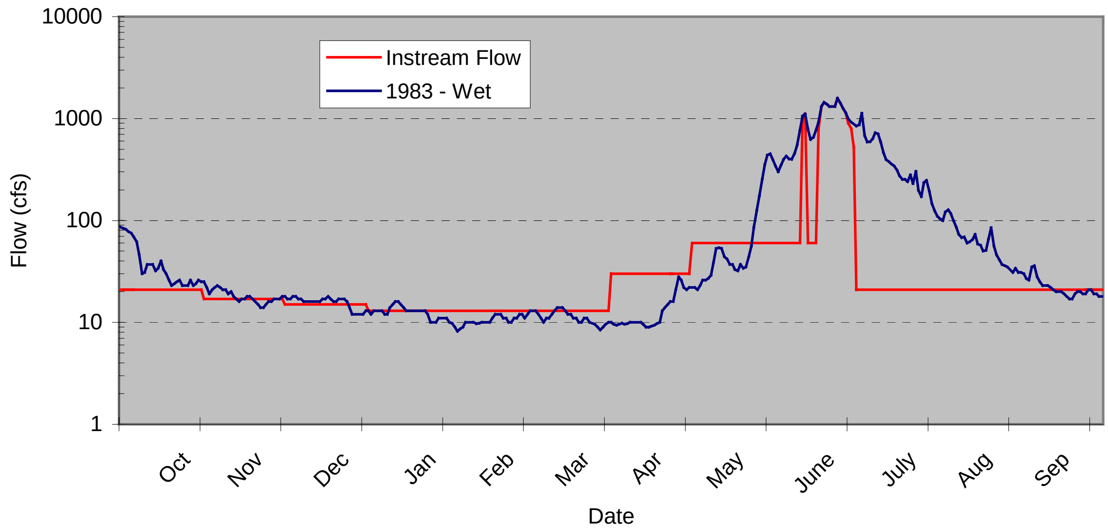


Figure 1-3. Rock Creek channel maintenance flow recommendations and hydrographs in an average (2003), moderately wet (1999) and wet (1983) water year.

APPENDIX 2. HABITAT SUITABILITY CRITERIA

Table 2-1. Rainbow trout habitat suitability criteria (Bovee 1978). Substrate codes are 1=vegetation, 2=mud, 3=silt, 4=sand, 5=gravel, 6=cobble, 7=boulder, 8=bedrock.

Velocity (ft/s)	Suitability	Depth (ft)	Suitability	Substrate Code	Suitability
Adults					
0.00	0.04	0.00	0.00	0.00	0.00
0.10	0.18	0.15	0.06	4.00	0.00
0.25	0.32	0.30	0.11	4.30	0.12
0.50	0.48	0.50	0.14	4.40	0.18
0.75	0.63	0.80	0.18	4.70	0.42
0.95	0.81	0.85	0.19	4.80	0.54
1.00	0.88	1.00	0.22	4.90	0.70
1.05	0.95	1.10	0.26	5.00	0.92
1.15	0.98	1.20	0.30	5.40	1.00
1.20	1.00	1.30	0.36	6.50	1.00
1.30	1.00	1.40	0.46	6.80	0.98
1.35	0.98	1.45	0.54	7.00	0.90
1.45	0.93	1.50	0.73	7.10	0.78
1.65	0.79	1.55	0.91	7.20	0.64
1.95	0.66	1.60	0.95	7.30	0.56
2.10	0.56	1.65	0.98	7.50	0.44
2.25	0.42	1.75	1.00	8.00	0.26
2.40	0.30	4.00	1.00	8.50	0.16
2.90	0.00	100.0	1.00	9.00	0.00
Juvenile					
0.10	0.00	0.40	0.00	4.50	0.00
0.20	0.11	0.60	0.27	4.60	0.70
0.30	0.40	0.70	0.55	4.70	0.90
0.40	0.95	0.80	0.98	5.00	1.00
0.50	0.97	0.90	1.00	5.30	0.94
0.70	1.00	1.05	1.00	5.40	0.84
1.30	1.00	1.10	0.98	5.50	0.72
1.50	0.98	1.30	0.68	5.60	0.62
1.60	0.94	1.50	0.52	5.70	0.54
1.70	0.86	1.60	0.45	5.80	0.46
1.80	0.73	1.80	0.37	6.00	0.36
1.90	0.70	1.90	0.34	6.10	0.32
2.20	0.49	2.00	0.30	6.20	0.28
2.40	0.38	2.10	0.28	6.30	0.24
2.50	0.14	2.20	0.26	6.40	0.22
2.60	0.10	2.40	0.23	7.00	0.10
2.70	0.07	2.60	0.21	7.10	0.08
3.00	0.03	3.00	0.20	7.50	0.04
4.00	0.00	3.20	0.18	8.00	0.00
		3.80	0.12		
		4.10	0.10		
		100.0	0.10		
Fry					
0.00	0.06	0.00	0.00	0.00	0.00
0.10	0.18	0.20	0.00	1.00	0.00
0.15	0.24	0.40	0.15	4.00	0.02
0.20	0.39	0.50	0.30	4.30	0.04
0.25	0.88	0.60	1.00	4.50	0.08
0.30	0.96	0.90	1.00	4.60	0.12
0.40	1.00	1.00	0.98	4.70	0.22
0.60	1.00	1.10	0.88	4.90	0.98
0.70	0.95	1.30	0.60	5.00	1.00
0.75	0.86	1.50	0.40	5.10	0.96
0.80	0.81	1.60	0.33	5.20	0.76
0.90	0.75	1.70	0.27	5.30	0.64
1.05	0.70	1.90	0.19	5.40	0.58
1.25	0.63	2.10	0.13	5.60	0.46
1.50	0.56	2.40	0.08	5.80	0.37
1.65	0.49	2.70	0.03	6.00	0.30
1.80	0.38	3.00	0.02	6.30	0.22
2.00	0.26	100.0	0.02	6.80	0.11
2.20	0.14			7.00	0.07
2.40	0.06			8.50	0.01
2.65	0.00			9.00	0.00