Wyoming Game and Fish Department
Fish Division, Administrative Report 2014

Instream flow studies on Cedar Creek, tributary to Shell Creek

Mike Robertson, Fisheries Biologist, Wyoming Game and Fish Department, 5400 Bishop Blvd, Cheyenne, WY 82006

Abstract

One segment on Cedar Creek was selected for instream flow water rights filing consideration. The segment was selected considering land ownership, hydrology, and stream channel characteristics to maintain or improve the Yellowstone cutthroat trout (YCT; *Oncorhynchus clarki bouvieri*) fishery in this stream. The species is restricted to small, isolated populations in streams of the Bighorn River watershed that flow from the Bighorn Mountains, and is a species of greatest conservation need within its range in Wyoming. This report provides flow recommendations developed from studies conducted in 2012. Several modeling techniques were employed to develop instream flow recommendations for maintaining YCT spawning habitat during spring runoff, including Physical Habitat Simulation (PHABSIM) modeling for calculations of habitat suitability over a range of flow conditions. Riffle hydraulic characteristics were examined using the Habitat Retention Method to identify instream flows needed to maintain fish passage (longitudinal connectivity) between habitat types and provide sufficient depth, velocity, and wetted area to ensure survival of fish prey items (benthic invertebrates) when the recommended flow is naturally available. The Habitat Quality Index (HQI) model was used to assess the relationship between stream flow and juvenile and adult trout habitat quality in the summer. During winter months, October through April, natural flows were recommended to maintain all life stages. The 20% monthly exceedance flow was selected to represent natural winter flow. Finally, a dynamic hydrograph model was used to quantify flow needs for maintenance of channel geomorphology.

Approximately 4.3 miles of stream habitat will be directly protected if this instream flow application advances to permit status. Recommended flows in the segment range from a low of 7.1 cubic feet per second (cfs) during the winter to 13 cfs during spring.

Introduction

There are five primary riverine components that influence the characteristics of a stream or river: hydrology, biology, geomorphology, water quality and connectivity (Annear et al. 2004). These five components are inter-related in complex ways. As water resources are developed in Wyoming for out-of-stream, consumptive, uses there are corresponding changes in riverine components that alter the ability of a stream to support fisheries habitat. Maintaining sufficient water of good quality is essential for sustaining fish productivity in streams. Rivers and streams, and their associated fisheries, are important to the residents of Wyoming, as evidenced by the passage of W.S. 41-3-1001-1014 in 1986. This statute established instream flows as a beneficial use of water when used to maintain or improve existing fisheries. It directed that any unappropriated water flowing in any stream or drainage in Wyoming may be appropriated for instream flow water rights (see Appendix A for more information on instream flow water rights in Wyoming). All existing water rights in that stream remain unaffected by a permitted instream flow water right.

Purpose for Instream Flow Studies and Water Rights

Studies designed to evaluate instream flow needs for fisheries in Wyoming are initiated by the Wyoming Game and Fish Commission. Important stream fisheries are identified throughout the state and studies are conducted in each stream to determine how much flow is needed to maintain or improve these fisheries. Though a comprehensive instream flow study is designed to consider all five riverine ecosystem components and all aspects of each component (e.g., long-term habitat processes) (Annear et al. 2004), the instream flow statute has been interpreted by the Wyoming State Engineer's Office as applying only to direct fishery response to changes in flow. Other important components that influence stream conditions (and fish populations) such as geomorphology, water quality and connectivity are not considered in making instream flow recommendations (though information is provided in the report, where available).

Guidance for selecting streams to evaluate statewide was provided by the Wyoming Game and Fish Department's (WGFD) Water Management Plan (Robertson and Annear 2011). One of the highest current priorities for new instream flow projects are streams containing YCT. Among the streams that contain populations of YCT, several have modified habitat conditions that have restricted the YCT populations to isolated reaches relative to the watershed-wide distributions that the species once inhabited. These remaining isolated reaches are a high priority for conservation efforts, including maintaining sufficient stream flow to ensure long-term persistence to the extent allowed within the current interpretation of the instream flow statute.

Cedar Creek occurs within a "crucial" habitat area as identified in the WGFD Strategic Habitat Plan (WGFD 2009) and a "conservation area" in the WGFD State Wildlife Action Plan (2010). According to the SHP, "crucial habitats have the highest biological values, which should be protected and managed to maintain healthy, viable populations of terrestrial and aquatic wildlife. These include habitats that need to be maintained as well as habitats that have deteriorated and should be enhanced or restored." Securing an instream flow water right on this stream segment will help ensure the future of YCT here by protecting existing base flow conditions in priority against potential future consumptive water demands.

Objectives

The objectives of this study were to quantify year-round instream flow levels needed to maintain YCT habitat, and identify a channel maintenance flow regime that will maintain long-term trout habitat and related physical and biological processes (Appendix B). The audience for this report includes the State Engineer and staff, the Water Development Office, aquatic habitat and fishery managers, and non-governmental organizations and individuals interested in instream flow water rights, YCT management in general, or in the Lower Bighorn Basin in particular.

Study Area

Cedar Creek is a tributary of Shell Creek (Figure 1). The Cedar Creek HUC12 (100800100103) encompasses approximately 28.7 square miles. Land ownership in the Cedar Creek watershed includes 100% public land, which is all Forest Service land.

The elevation of the portion of the watershed that includes the Cedar Creek instream flow segment ranges from approximately 5,300 ft at the confluence with Shell Creek to over 9,800 ft at Cedar Mountain. Annual precipitation averaged 24.3 inches in the area of the stream over the period 1895–2012 according to data provided from the PRISM Climate Group, Oregon State University (http://www.prismclimate.org).

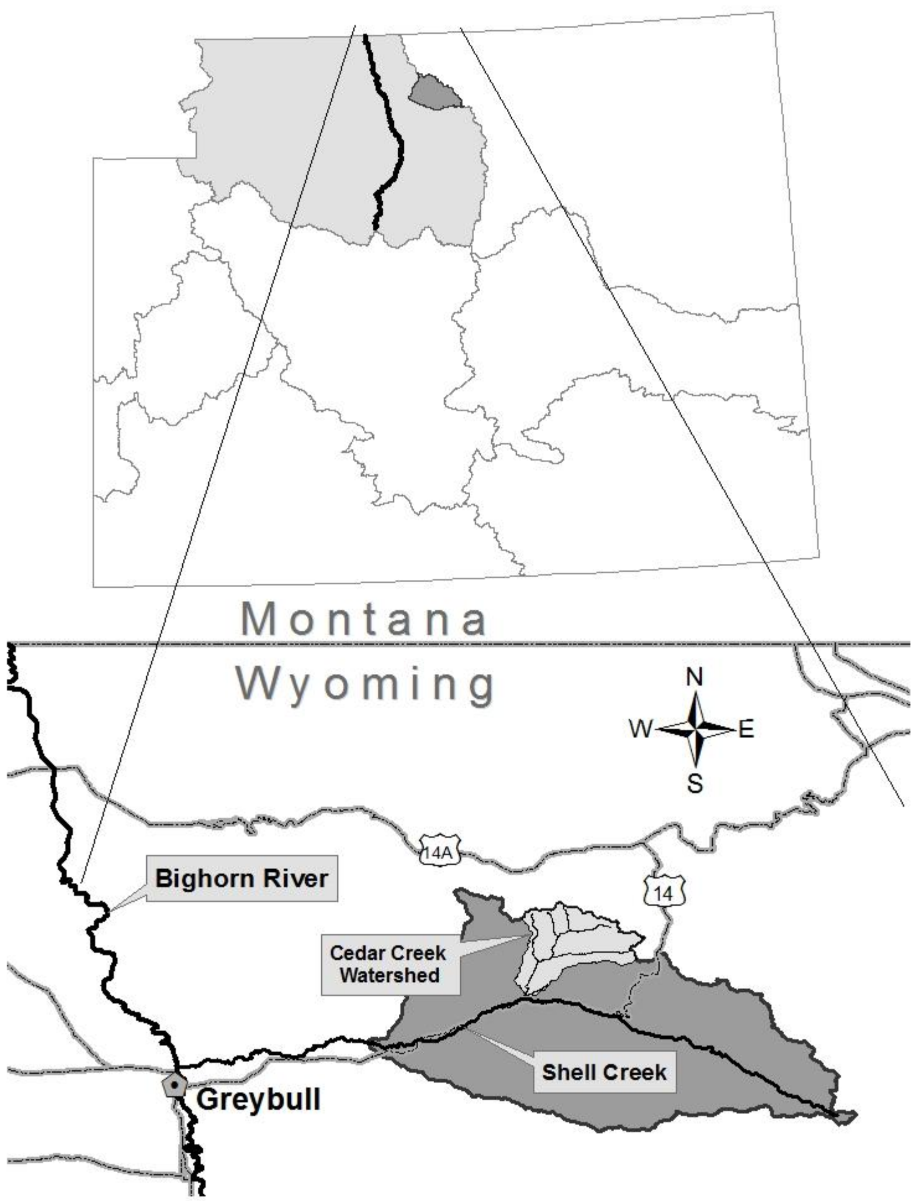

FIGURE 1. Location of Cedar Creek, WY (HUC 100800100103).

Methods

Instream Flow Segment and Study Site Selection

One stream segment is proposed for an instream flow water right filing in Cedar Creek (Table 1; Figure 2). The boundaries for the segment were identified after considering land ownership, hydrology, and stream channel characteristics. The downstream end of the segment is at the confluence with Shell Creek and the upstream boundary is the upper extent of the YCT population at a barrier just downstream from Willey Creek. The instream flow segment selected on Cedar Creek is located entirely on public land.

TABLE 1. Location, length, and elevation at the downstream end of the proposed instream flow segment on Cedar Creek.

Segment	Description	Length (mi)	Elevation (ft)
Cedar Creek	Begins at confluence with Shell Creek and extends upstream to a YCT barrier just downstream of Willey Creek.	4.3	5300

Within the instream flow segment, five transects were selected over a study site reach of approximately 500 feet to represent habitat conditions in the entire segment (Figure 3). The bankfull width in this reach was approximately 22 ft so the study site length was equal to approximately 23 times the channel width. This is longer than the reach length recommended by Bovee (1982; 10-14 times the channel width), but transects were not placed to represent one continuous reach of habitat. Instead, the five transects, including three riffles, a run, and a pool, were placed in individual habitat features that combined to provide a good representation of the range of habitat conditions observed in the segment and each was treated independent of the others.

The complexity of this site is representative of the range of habitat conditions available in the instream flow segment. All data collection was conducted in this study site and extrapolated to the entire proposed instream flow segment. These data were analyzed to determine the availability of suitable habitat for all life stages of YCT at various flow conditions.

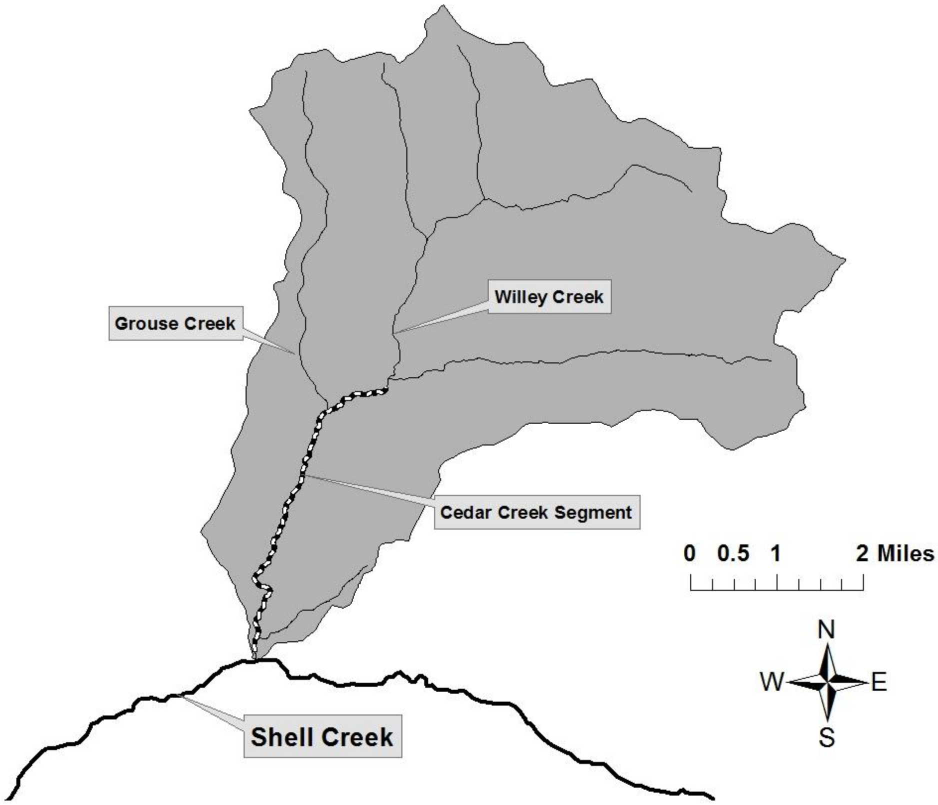

FIGURE 2. Data were collected to evaluate fish habitat at one potential instream flow segment on Cedar Creek.

FIGURE 3. Cedar Creek study site.

Hydrology

Development of flow recommendations for an instream flow study segment requires an understanding of hydrology within the study segment. There are no stream gage data available within the segment so the data was estimated from a regional reference gage (see Appendix C for details). The USGS gage on Shell Creek above the reservoir (06278300) was selected as the reference gage for these analyses (Figure 4, Figure 5).

Several models using contributing basin characteristics and channel geometry (bankfull width) by Lowham (1988) and Miselis et al. (1999) were evaluated to determine which generated the closest estimates of observed flow data at the reference gage. Using the model with the most accurate flow estimates and historical discharge data from the reference gage, a dimensionless analysis approach was used to develop estimates of mean annual flow (also called average daily flow or ADF), annual and monthly flow duration curves, and flood frequency for the proposed instream flow segment (see Appendix C for more detail on models and dimensionless analyses). Flow measurements collected by WGFD during instream flow field studies were used to help validate the models and enhance the accuracy of the hydrological estimates.

Dimensionless flow duration tables were created for the reference gage by dividing each duration class (5% increments between 5% and 95%) by the mean annual flow. The dimensionless flow value for each annual and monthly percentile was then multiplied by the estimated average annual flow for the instream flow segment to develop flow duration values for the segment. A similar approach was used to develop the flood frequency series.

These estimates of the hydrologic characteristics in the instream flow segment were used in several ways. Average daily flow estimates 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 B). Channel maintenance calculations also used the 25-year peak flow estimate from the flood frequency analysis. In addition, the monthly flow duration curve was used in developing winter flow recommendations. Flow duration curves indicate that percent of time that a given flow is equaled or exceeded. The 20% exceedance flow was identified for this analysis, which refers to the flow level that would be available approximately one year out of every five consecutive years.

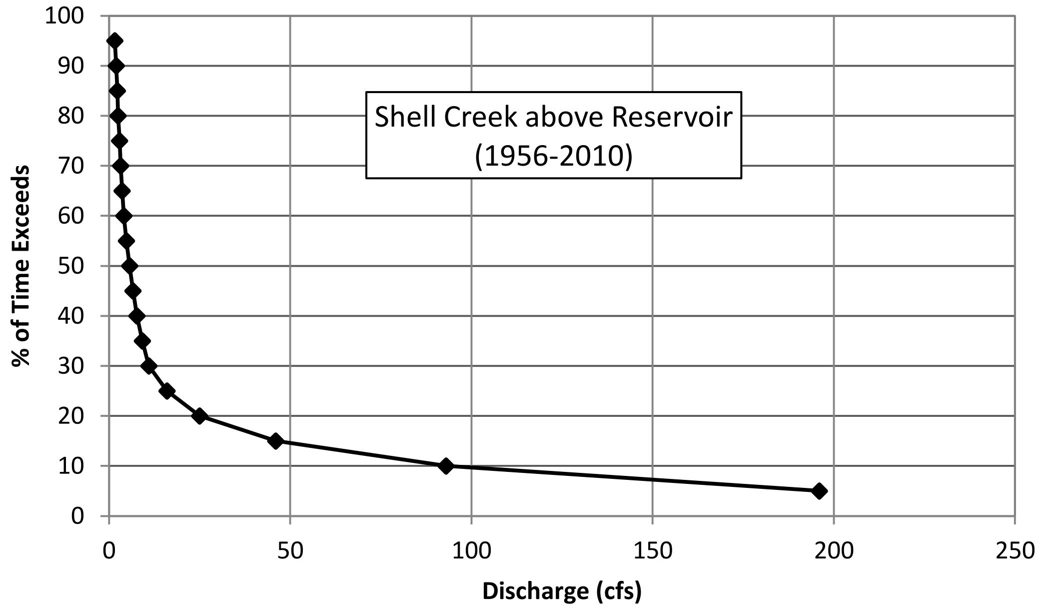

FIGURE 4. Flow exceedance curve for the Shell Creek USGS stream gage station (06278300) over the period of record (1956-2010).

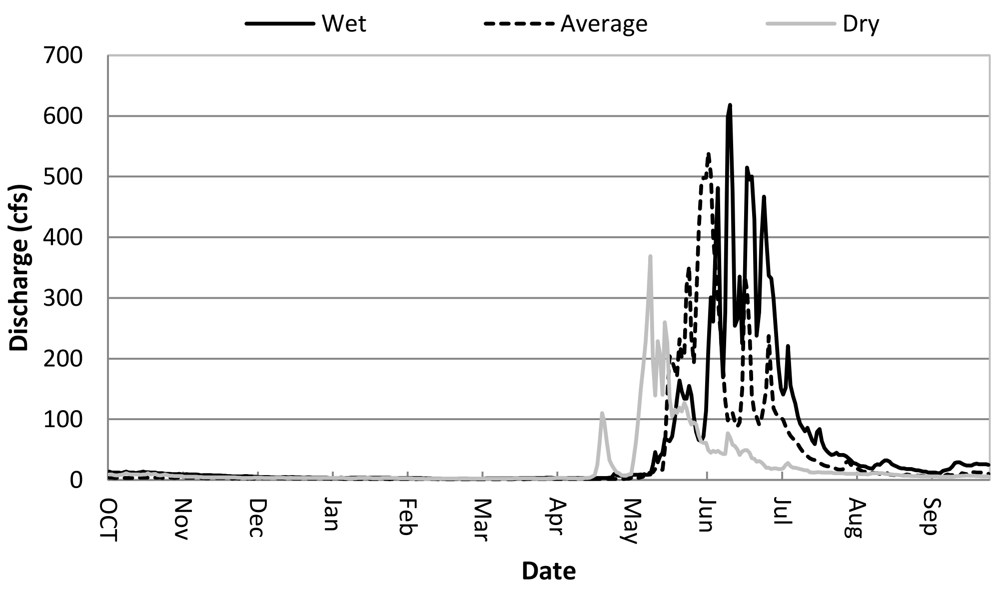

FIGURE 5. Hydrographs for representative wet (1978), average (1976), and dry (1994) water years from the Shell Creek USGS stream gage station (06278300). Representative years were randomly selected from within each of three flow exceedance classes (wet 0–10%, average 30–70%, and dry 90–100%).

Biology

The fish community in Cedar Creek includes only one species within the proposed instream flow segment, YCT. There are brown trout (BNT; *Salmo trutta*) and rainbow trout (RBT; *Oncorhynchus mykiss*) downstream in Shell Creek, but a steep gradient near the mouth of the creek appears to be limiting access of these species into Cedar Creek. The current management objective is to maintain a wild population of YCT. Evaluation of flow conditions that are necessary to maintain or improve this fishery was conducted using the habitat and hydrological modeling efforts described below.

<u>Fish Habitat Modeling</u>

Habitat preferences of target fish species, including each of their life stages, are important in instream flow studies since flow recommendations are based on maintaining sufficient habitat for target species to survive, grow, and reproduce. Species-specific habitat preferences are used to develop habitat suitability curves that are in turn used in habitat models (described below).

Availability of fish habitat is evaluated using several different habitat models for a study site. "Habitat" in this report refers to the combination of physical conditions (depth, velocity, substrate, and cover) for a given area. These physical conditions vary with discharge. It is important to note that these variables do not represent a complete account of all variables that comprise trout habitat. Habitat for trout also includes environmental elements such as water temperature, dissolved oxygen, and other variables. These other variables are important, but are not included in models used for these analyses because they do not fluctuate with changes in the quantity of flow as predictably as the physical habitat parameters. Interpretation of model results based on these physical habitat parameters assumes that this subset of trout habitat is important and provides a reasonable indication of habitat availability at each flow and an indirect expression of the ability of trout to persist on at least a short-term basis at those flow levels.

Dey and Annear (2006) found that adult YCT in Trout Creek (tributary of the North Fork Shoshone River) were most commonly found in areas with depths of 1.15–1.60 ft and average column velocities of 0.36–1.91 ft/s. For juvenile YCT, these ranges were slightly different with depths of 1.0–1.5 ft and average column velocities of 0.38–1.65 ft/s (Dey and Annear 2006). Growth rate of adult and juvenile YCT is greatest during the relatively short summer and early fall periods. Habitat for these life stages is also critical during winter to allow over-winter survival.

In addition to adults and juveniles, availability of suitable spawning habitat for YCT was evaluated over a range of flows. YCT spawn between March and July throughout their range, depending on local hydrology and water temperatures (believed to be triggered around 41°F; Kiefling 1978, Varley and Gresswell 1988, De Rito 2005). The stream gradient observed in spawning areas is usually less than 3% (Varley and Gresswell 1988), but non-migratory fluvial populations have been documented in streams with a mean gradient of 6% (Meyer et al. 2003). Spawning activity for YCT in Wyoming has been observed during May and June in watersheds within the Bighorn River Basin in north central Wyoming (Greybull River, Shoshone River and their tributaries; Kent 1984, Dey and Annear 2002, Dey and Annear 2006). Elevation has an influence on the timing of spawning in YCT with stream segments located at higher elevations more likely to remain colder and cause delayed spawning and slower egg incubation rates. Dey and Annear (2003) found that spawning in the Greybull watershed occurred into July in streams above approximately 8,000 ft in elevation and extended recommendations for spawning flows through July 15 in such high elevation sites. The upstream boundary of the instream flow segment is about 7,000 ft. It is possible that spawning may extend into July in the upper portions of the watershed (above the segment), but most activity in the segment likely occurs in June. Dey and Annear (2006) observed too few spawning YCT (n=4) to develop habitat suitability curves for spawning YCT in Wyoming. Spawning YCT habitat suitability data from a Snake River tributary in Idaho are presented in Thurow and King (1994); these researchers found that velocity preference was highest from 1.12 to 1.72 ft/sec and depth preference highest from 0.52 to 0.82 ft. Information from that study was used to indicate habitat selectivity of YCT in Cedar Creek.

Physical Habitat Simulation Model

The Physical Habitat Simulation (PHABSIM) model was used to estimate how much stream flow is needed to maintain habitat for individual life stages of YCT during critical time periods. The PHABSIM approach uses computer models to calculate a relative suitability index for target species based on depth, velocity, and substrate or cover (Bovee et al. 1998). Model calibration data are collected across the stream at each of several locations (transects) and involve measuring depth and velocity at multiple locations (cells) along each transect. Measurements are repeated at three or more different discharge levels. By using depths and velocities measured at one flow level, the user calibrates a PHABSIM model to accurately predict the depths and velocities measured at the other discharge levels (Bovee and Milhous 1978, Milhous et al. 1984, Milhous et al. 1989).

Following calibration, the user simulates depths and velocities over a range of user-specified discharges. These predicted depths and velocities, along with substrate or cover information, are compared to habitat suitability curves (HSCs) to determine areas with suitable habitat conditions for the target species. The relative value to fish of predicted depths, velocities, substrates, and cover elements are defined by HSCs 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 (WUA) for the discharge level. Results are often depicted by graphing WUA for a particular fish life stage versus a range of simulated discharges (Bovee et al. 1998). Relationships are best interpreted as a (unitless) relative suitability index rather than a quantitative calculation of physical area (Payne 2003).

Habitat Retention Model

The Habitat Retention Method (Nehring 1979, Annear and Conder 1984) was used to identify the flow that maintains specified hydraulic criteria (Table 2) in riffles. These recommendations identify instream flows needed to maintain fish passage (longitudinal connectivity) between habitat types and provides sufficient depth, velocity, and wetted area to ensure survival of fish prey items (benthic invertebrates) when the recommended flow is naturally available (Nehring 1979). Flow recommendations derived from the Habitat Retention Method addresses a portion of the connectivity riverine component as well as the biology riverine component. The flow identified by the Habitat Retention Method is important year round, except when higher instream flows are needed to meet other fishery management purposes.

Simulation tools and calibration techniques used for hydraulic simulation in PHABSIM are also used with the Habitat Retention Method. 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 two out of three criteria (Table 2) for all three transects is then identified; however, because of the critical importance of depth for maintaining fish passage, the 0.2 ft threshold must be one of the criteria met for each transect. On streams that are wider than 20 feet (bankfull width) the mean depth criterion becomes 0.01 times the mean bankfull width of each transect.

TABLE 2. Hydraulic criteria for determining maintenance flow with the Habitat Retention Method.

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

a – when transect bankfull width >20 ft, then 0.01 * mean bankfull width
b – Percent of bankfull wetted perimeter, calculated by transect

Habitat Quality Index Model

The Habitat Quality Index (HQI; Binns and Eiserman 1979, Binns 1982) was used to determine trout production potential over a range of late summer (July through September) flow conditions. Most of the annual trout production in Wyoming streams occurs during the late summer, following peak runoff, when longer days and warmer water temperatures facilitate growth. The HQI was developed by the WGFD to provide an index of relative habitat suitability referenced to trout production as a function of nine biological, chemical, and physical trout habitat attributes. Each attribute is assigned a rating from 0 to 4 with higher ratings representing better trout habitat features. Attribute ratings are combined in the model with results expressed in trout Habitat Units (HU's), where one HU is defined as the amount of habitat quality that will support about 1 pound of trout, though the precise relationship can vary between streams. HQI results were used to identify the flow needed between July 1 and September 30 to maintain existing levels of adult and juvenile trout production (habitat quality) and are based on an assumption that water quality and flow needs for other life stages are met or exceeded at all other times of year.

To evaluate changes in HU estimates over a range of potential late summer flows three or more HQI measurements were collected. Attribute ratings were interpolated between measurements to characterize the relationship between discharge and trout habitat conditions at discharges other than those measured (Conder and Annear 1987). In calculating HUs over a range of discharges, temperature, nitrate concentration, invertebrate numbers, and eroding banks were held constant.

Article 10, Section d of the Wyoming Instream Flow statute states that waters used for providing instream flow water rights “shall be the minimum flow necessary to maintain or improve existing fisheries.” The HQI is used to identify a flow to maintain the existing fishery in the following manner: the number of habitat units that occur under normal July through September flow conditions is quantified and then the flow that maintains that level of habitat is identified. The September 20% monthly exceedance flow was used as the reference standard of normal late summer flow levels and is consistent with how the HQI was developed (Binns and Eiserman 1979).

Natural Winter Flow – Hydrology Estimates

The habitat modeling approaches described above are not well suited to determine flow requirements during ice-prone times of year (October through early April). These methods were all developed for and apply primarily to open-water periods. Ice development during winter months can change the hydraulic properties of water flowing through some stream channels and compromise the utility of models developed for open water conditions. The complexities of variable icing patterns make direct modeling of winter trout habitat over a range of flows difficult if not impossible. For example, frazil and surface ice may form and break up on multiple occasions during the winter over widely ranging spatial and temporal scales. Even cases that can be modeled, for example a stable ice cap over a simple pool, may not yield a result worthy of the considerable time and expense necessary to calibrate an ice model. There are no widely accepted aquatic habitat models for quantifying instream flow needs for fish in under-ice conditions (Annear et al. 2004). As a result, a different approach was used to develop recommendations for winter flows.

For Wyoming Rocky Mountain headwater streams, a conservative approach is needed when addressing flow requirements during harsh winter conditions. The scientific literature indicates that the stressful winter conditions for fish would become more limiting if winter water depletions were to occur. Low water temperature, which reduces metabolic rates, reduced living space associated with naturally lower flow conditions during this season, and the lack of food are all factors that make the winter a stressful time period for fish (Locke and Paul 2011). Even relatively minor flow reduction at this time of year can change the frequency and severity of ice formation, force trout to move more frequently, affect distribution and retention of trout, and reduce the holding capacity of the few large pools often harboring a substantial proportion of the total trout population (Lindstrom and Hubert 2004). Hubert et al. (1997) observed that poor gage records often associated with the winter season requires use of a conservative value. Their studies showed that 50% monthly exceedance does not provide an appropriate estimate of naturally occurring winter flow. It is more appropriate from the standpoint of maintaining fisheries to secure 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 protected.

Geomorphology

Maintaining appropriate stream channel characteristics in a given stream reach is important for maintaining fish habitat throughout that stream. Channel form is a direct result of interactions among flow regimes (Schumm 1969), sediment loads (Komura and Simmons 1967), and riparian vegetation, which are in turn a direct function of the form and condition of the watershed (Leopold et al. 1964; Heede 1992; Leopold 1994). For many alluvial streams in their natural state, the channel exists in a state of dynamic equilibrium in which the sediment load is balanced with the stream's transport capacity over time (Bovee et al. 1998). When sediment load exceeds transport capacity, aggradation or other alteration of channel form will occur. When transport capacity exceeds sediment load, the channel may adjust through widening the channel or degrading the bed.

Physical changes in the stream caused by road building, culvert addition, riparian habitat reduction, and other impacts also affect the ability of the stream to sustain effective sediment transport and regenerate riparian plant communities. Additional streambank instability and sediment inputs result from land management practices (grazing and channel alterations) and road construction and maintenance activities in the watershed. The resulting streambank instability, channel widening and high sediment loads promote unstable stream channel dynamics that limit pool development and increase stream channels dominated by long series of runs and riffles. A lack of pool-forming large woody debris in many locations also contributes to a lack of pools. However, where large woody debris is abundant, pools are more common. Also, beaver activity enhances instream habitat complexity in some locations.

In addition to physical characteristics in the watershed affecting its geomorphological characteristics, a natural range of flows, including occasional high flow, is important in streams for maintaining diverse riparian and floodplain vegetation. This in turn, provides suitable conditions for the community of animals that use these habitats. An effective instream flow regime should include these higher flows that maintain the channel form and habitat conditions for fish over the long term (decades). These flows sustain the river channel conditions by permitting a connection to the floodplain, preventing buildup of fine sediments, and facilitating a variety of other important ecological processes (Carling 1995, Annear et al. 2004, Locke et al. 2008). Any time water is extracted from a stream this condition changes; larger quantities of extraction have a greater impact on habitat conditions and the organisms associated with those habitats. If naturally-occurring high flows were substantially reduced on a regular basis, it would have negative impacts on habitat, riparian assemblage of plants and animals, and ultimately the resident fishery (Stromberg and Patten 1990, Rood et al. 1995, Mahoney and Rood 1998).

The physical characteristics of the watershed that affect the geomorphology of the proposed instream flow segment were evaluated by visual observation. An evaluation of high flows that are important for channel maintenance and necessary to maintain existing fisheries on a long-term basis was not included in the main body of the report since the current interpretation of the instream flow statute does not allow issuance of water rights for high flows. Recommendations for flows sufficient to allow channel maintenance and to fully maintain fishery habitat in the segment are presented in Appendix B. Should opportunities arise in the future to secure instream flow water rights for long-term maintenance of fluvial geomorphic processes, this information will provide a valuable reference.

Water Quality

Water quality is a critical variable that affects any fishery. The evaluation of water quality in the proposed instream flow segment included a review of the Wyoming Department of Environmental Quality classification and any sampling conducted by that agency or any other entities (using the EPA STORET database) to determine existing water quality conditions. In addition, a water temperature logger was deployed to evaluate summer temperatures in the reach as part of the HQI evaluation.

Connectivity

Connectivity of a river system refers to the ability of fish and other organisms to navigate between habitats to complete each portion of their life cycles. However, connectivity of a stream system also incorporates the pathways that move energy and matter through these systems. River system connectivity is manifested along four dimensions: longitudinal, lateral, vertical, and time (Ward 1989). Lateral connectivity is critical to the functioning of floodplain-based stream ecosystems because of the transport of nutrients and organic matter from the floodplain to the stream during floods. This process often drives development of aquatic food elements that affects productivity of the fish. The seasonal flooding of unregulated streams creates and maintains diverse species of riparian vegetation (Nilsson et al. 1989), which adds stream channel stability and fosters diverse animal communities both within and adjacent to the stream channel.

In developing instream flow recommendations for the proposed segment, the presence of barriers to connectivity were considered for physical, chemical, and even biological conditions in all four dimensions. The Habitat Retention Method was used to quantify the flow needed to maintain longitudinal hydrologic connectivity within the stream channel. However, no detailed assessment was conducted to quantify flows needed to maintain lateral connectivity nor was an assessment done to evaluate the relationship between ground water and flow (vertical connectivity) because interpretation of instream flow legislation is such that requests for these flows are not legally allowed. Though the ability of the stream to transport of nutrients, energy and sediments was beyond the technical and legal scope of this study, this process is important in a properly functioning stream environment.

Instream Flow Recommendations

Instream flow recommendations were identified to protect habitat during portions of the year that are most critical to a given species and life stage in Cedar Creek. Recommendations were developed for three seasonal periods, which are based on YCT biology and hydrology information from the reference gage (Table 3; Figure 6). Over-winter survival of adult and juvenile YCT is addressed with natural winter flow from October 1 through April 30. The estimated hydrograph indicates that, on average, relatively low base flow conditions in winter persist through late-April during both the highest and lowest flows recorded. Spawning and incubation habitat for YCT is quantified using habitat modeling results for the spawning life stage using PHABSIM for the period May to July 15. Summer habitat for growth and production of adult and juvenile YCT is quantified with Habitat Quality Index results and modeling results from PHABSIM for the period July 16–September 30.

A combination of several different methods was used to develop instream flow recommendations to maintain or improve the fishery (biology riverine component) in Cedar Creek. When possible, data were collected to run each of several habitat models for a study site (including the PHABSIM model, the Habitat Retention Model, and the Habitat Quality Index model). However, the ecological characteristics and issues at a study site were sometimes unique and not necessarily appropriate for scaling up to the entire segment. As a consequence, the models used for developing a recommendation were selected based on their appropriateness for the characteristics and flow needs at the site. Recommended flows were designed to maintain habitat during portions of the year that are most critical to a given species and life stage. Recommendations were also evaluated relative to natural flow conditions, but because the instream flow segment did not have stream gage data, estimates of stream flow were developed for comparison.

When two or more methods could be used for a recommendation, the method chosen is the one that yields the higher flow needed for a particular fishery maintenance purpose.

TABLE 3. Yellowstone cutthroat trout life stages and seasons considered in developing instream flow recommendations. Numbers indicate the method used for each combination of season and life stage, and gray shading indicates the primary data used for flow recommendations in each season.

Life stage and Fishery Function	Over-Winter Oct 1 – Apr 30	Spring May 1 – Jul 15	Summer Jul 16 – Sep 30
Survival of all life stages	1		
Connectivity between habitats	2	2	2
Adult and juvenile habitat availability	3	3	3
Spawning habitat availability		3	
Adult and juvenile growth			4
Habitat maintenance for all life stages*		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 presented in Appendix B.

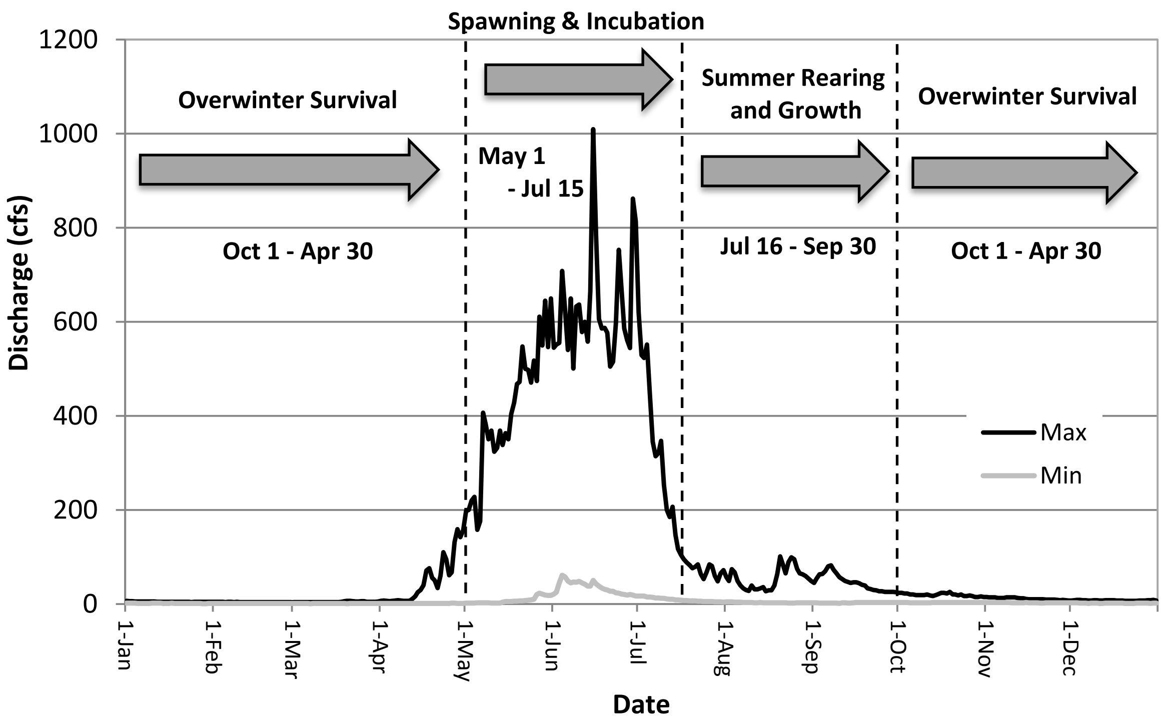

FIGURE 6. Lowest and highest daily historical discharge values in the reference gage for this study with critical time periods for YCT distinguished. Data is from the reference gage for this study, USGS gage 06278300 on Shell Creek above Shell Reservoir (1956-present).

Results

Hydrology

Streamflow at the reference gage was low in 2012. Mean discharge for the year (28.7 cfs) was in the lowest one third of annual flow values in the period of record (18th lowest of 57 years). The low flows had minimal affects on sampling efforts.

Using data from the reference gage and the Lowham (1988) watershed model (Appendix C), mean annual flow was estimated for the Cedar Creek instream flow segment along with monthly flow duration estimates and select flood frequency (Table 4, Table 5). Data collected during the study are also presented in Table 6.

TABLE 4. Estimated monthly exceedance values for the Cedar Creek instream flow segment.

Month	50% Exceedance (cfs)	20% Exceedance (cfs)
October	9.7	14
November	7.0	10
December	4.6	6.1
January	3.5	4.5
February	2.8	3.9
March	2.8	3.6
April	3.7	7.5
May	70	233
June	193	414
July	39	79
August	13	21
September	9.3	15

TABLE 5. Estimated hydrologic characteristics for the Cedar Creek instream flow segment.

Flow Parameter	Estimated Flow (cfs)
Mean Annual	42.8
1.5-year peak	583
25-year peak	1003

TABLE 6. Dates of collection and discharge measurements collected in the Cedar Creek instream flow segment in 2012.

Date	Discharge (cfs)
6/27/12	49
7/13/12	39
7/28/12	34
8/27/12	29

In addition to monthly flow duration estimates as an indicator of flow conditions in the segment, annual hydrographs for representative years were prepared for comparisons (Figure 7). Three representative years were selected from the period of record of the reference gage to produce the necessary daily flow estimates for these graphs. The three years were selected by first dividing the period of record to represent wet, average, and dry conditions, and then randomly choosing a representative year from each group. These representative annual hydrographs provide an indication of the range of discharge conditions that may occur in the instream flow segment; however, in reality there is considerable variation in the timing and pattern of flow within a given year and between different years that is not fully described by three individual, simulated hydrographs. These graphs should be interpreted only as general templates of runoff patterns; flow recommendations from the analyses do not vary as a function of water year characteristics.

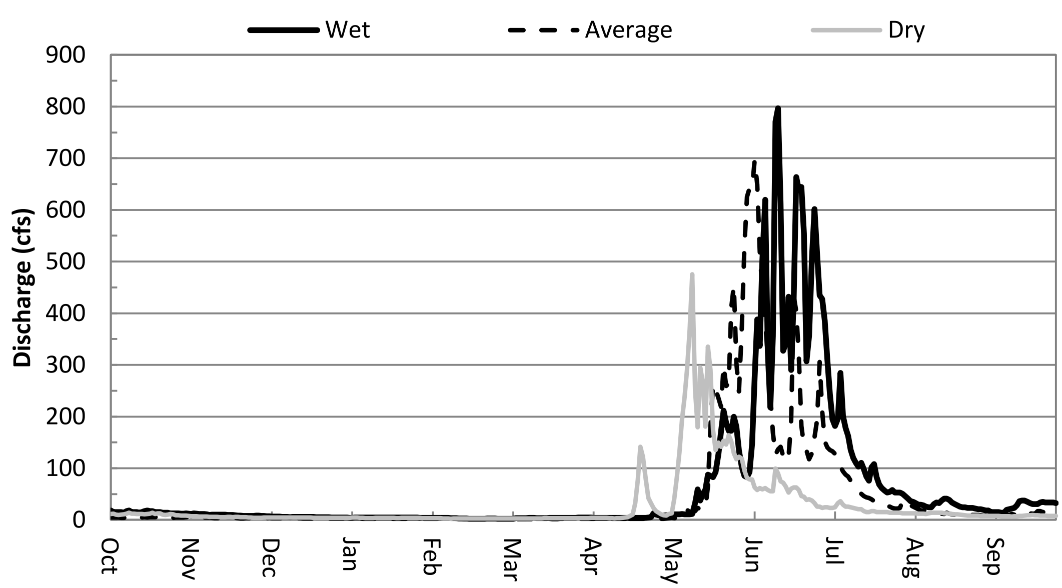

FIGURE 7. Simulated annual hydrographs for randomly selected wet (1978), average (1976), and dry (1994) water years for the Cedar Creek instream flow segment.

Biology

Physical Habitat Simulation Model

The PHABSIM model was used to estimate habitat for adult, juvenile and spawning life stages of YCT in the Cedar Creek study site. Simulations were conducted through the study site using a calibrated PHABSIM model over the flow range 5 cfs to 200 cfs. The model was run at each flow increment using data from 5 transects. The five transects for this location were located in three riffles, a small pool, and a run. When the calibrated model was run for a given species / life stage at a given discharge, the resulting weighted usable area (WUA) was the final output used for interpretation.

The model results indicated that for both adult and juvenile life stages, WUA increases rapidly with increasing flow up to about 30 cfs and then decreases slowly with additional increases in flow. For the spawning life stage, there is an even steeper increase in WUA up to 13 cfs and a sharp decline in habitat availability as flows increase beyond that point (Figure 8).

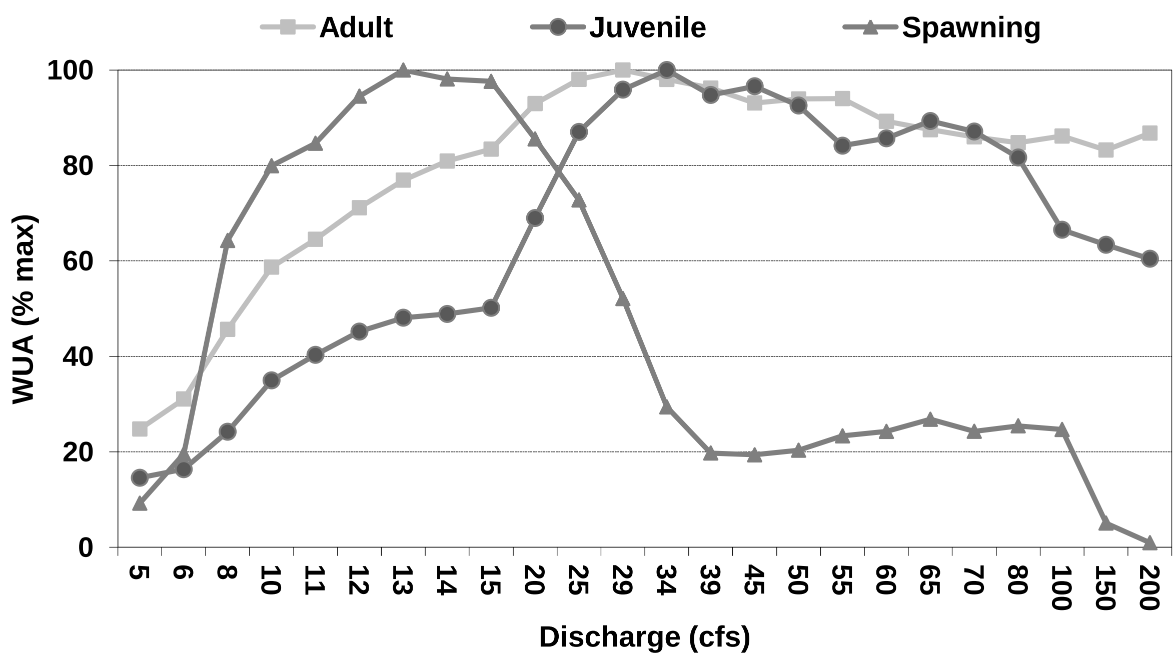

FIGURE 8. Relationship between weighted usable area and discharge for YCT adult, juvenile and spawning life stages in the Cedar Creek study site. X-axis values are not to scale; the values were chosen to highlight peak habitat conditions.

Habitat Retention Model

The Habitat Retention Model was used to evaluate hydraulic characteristics that affect the survival and movement of all life stages over a range of discharges in the Cedar Creek instream flow segment (Table 7). The result of this analysis is that 5.2 cfs is the threshold flow necessary for maintaining specified riffle hydraulic conditions. This flow will maintain base level conditions for fish passage and provide habitat for benthic invertebrate populations on these riffles, though higher flows at some times of year are needed for other fishery purposes. This flow is lower than the 50% exceedence for all months between May and November (Table 4).

TABLE 7. Estimated hydraulic conditions for three riffles over a range of modeled discharges in the Cedar Creek instream flow segment. Bold indicates that the hydraulic criterion was met for an individual attribute; the grayed-out discharge value meets the selection criteria. Bankfull width (ft) for transect 1 = 20.4, for transect 2 = 25.2, and for transect 3 = 21.0.

Riffle Transect Number	Discharge (cfs)	Mean Velocity (ft/sec)	Mean Depth (ft)	Wetted Perimeter (% of bankfull)
1	68*	2.55	1.22	1.00
	16	2.82	1.52	**0.50**
	10	2.81	0.38	0.42
	5.2	3.11	**0.20**	0.35
	4.0	3.39	0.17	0.29
	2.0	4.17	0.11	0.18
2	270*	8.32	1.31	1.00
	15	1.55	0.58	0.66
	8.0	**1.08**	0.49	0.59
	6.0	0.92	0.45	0.56
	3.0	0.62	0.37	**0.50**
	2.0	0.50	**0.32**	0.48
3	163*	5.37	1.44	1.00
	10	1.46	0.39	0.80
	3.0	1.10	0.23	0.55
	2.6	1.08	0.21	**0.52**
	2.4	1.07	0.20	0.50
	2.0	**1.04**	**0.19**	0.46

*= Bankfull flow

<u>Habitat Quality Index Model</u>

The HQI model data (Figure 9) was important in evaluating late summer habitat production potential for this instream flow segment. The 20% exceedance flow value for September (15.5 cfs; Table 4) is used as an estimate of normal late summer flow levels for this model. At this flow, the stream provides 166.1 Habitat Units; 11.0 cfs is the lowest flow that provides that number of habitat units. The model shows that long-term reductions of late summer flow to levels less than this amount would reduce the productivity of the existing fishery by over 20%.

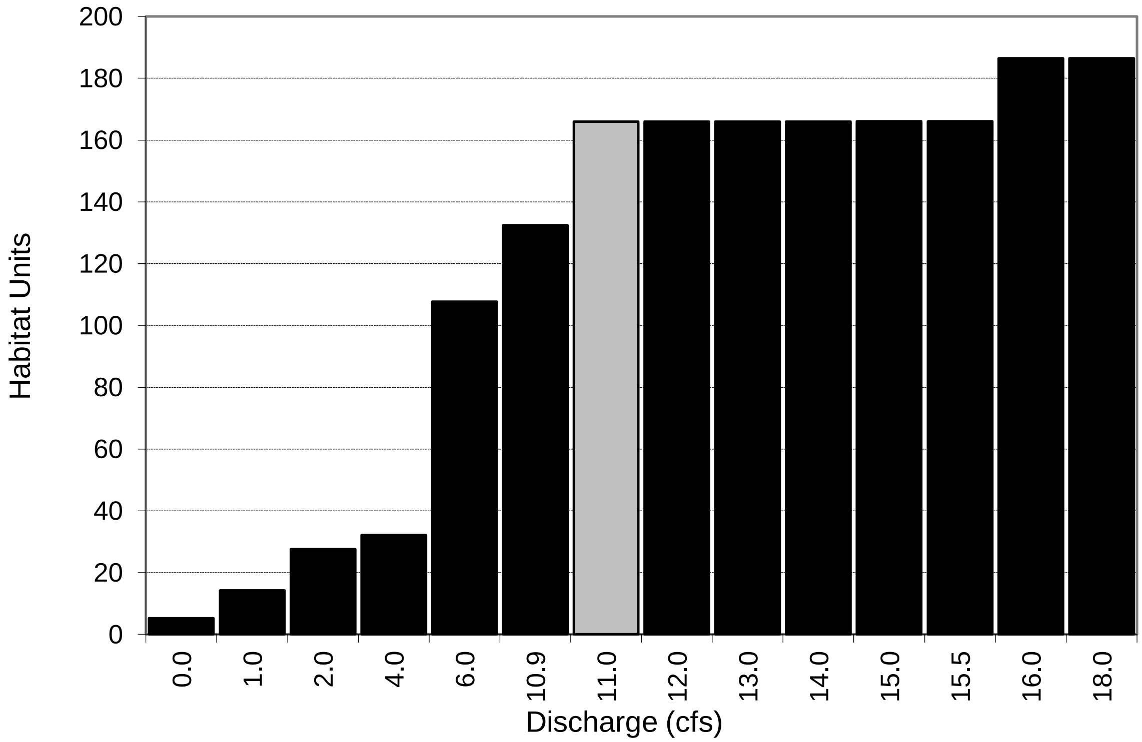

FIGURE 9. Habitat Quality Index vs. discharge in the Cedar Creek instream flow segment. X-axis values are not to scale; the values were chosen to indicate where changes in Habitat Units occur. The recommended flow is indicated by the light shaded bar.

<u>Natural Winter Flow</u>

Between October 1 and April 30, the estimated monthly 20% exceedance values in the proposed instream flow segment ranged from 3.6 cfs to 14 cfs (Table 4). The mean value for that time period, 7.1 cfs, is higher than the 5.2 cfs value that the Habitat Retention Model indicates is required for sufficient hydraulic conditions to permit fish passage. The flow estimates from the 20% exceedence calculations are more appropriate in this case for the winter season of October 1 through April 30.

Geomorphology

The proposed instream flow segment in Cedar Creek is a stable Rosgen B-type channel with a steep slope (e.g., 2-4%) and low sinuosity (e.g., 1.2). There were no distinct gravel riffles in the study reach and hydraulic controls were formed primarily by large cobbles. There were moderate amounts of gravel deposited along the stream margins. The stream also has fully intact riparian habitat in most places, which provides shading over much of its surface area and contributes a moderate amount of large woody debris to the stream and facilitates pool development. The steep canyon in the study reach was prohibitive to grazing.

A detailed description of recommended channel maintenance flows to sustain the channel form and fisheries habitat in the proposed instream flow segment over the long term is presented in Appendix B.

Water Quality

The Wyoming Department of Environmental Quality rates Cedar Creek as a "Class 2AB" water. According to their classification system, "Class 2AB waters are those known to support game fish populations or spawning and nursery areas at least seasonally and all their perennial tributaries and adjacent wetlands and where a game fishery and drinking water use is otherwise attainable. Unless it is shown otherwise, these waters are presumed to have sufficient water quality and quantity to support drinking water supplies and are protected for that use. Class 2AB waters are also protected for nongame fisheries, fish consumption, aquatic life other than fish, recreation, wildlife, industry, agriculture and scenic value uses."

A review of the EPA STORET database revealed no water quality monitoring data in the Cedar Creek watershed. Data collected at the study site included a single Nitrate + Nitrite – N sample was collected during the study and analyzed by the Wyoming Department of Agriculture Analytical Services Laboratory; the result was 0.26 mg/L. This value was higher than found in other instream flow segments in the region. There is no specific criterion for aquatic life by WYDEQ (2001), but the observed value is well below the drinking water standard of 110 mg/L. This value falls in the middle of the observed range of streams in the region (0.0-0.56 mg/L; USEPA 2000). A water temperature logger was installed on site between June 6, 2012 and September 6, 2012 and recorded temperatures ranging from 38.4 degrees Fahrenheit to 57.9 degrees Fahrenheit. Daily fluctuations ranged from 4-12 degrees Fahrenheit.

Flow recommendations in this report are expected to maintain water quality within natural bounds and within existing limits of natural variability. If drastic long-term changes to watershed form or function occur, then flow recommendations would need to be reviewed.

Connectivity

There are no road crossings or diversion structures within the proposed instream flow segment in Cedar Creek, so longitudinal connectivity remains excellent. There was a bridge crossing within the study reach, but it was located in a place where the channel appeared to be stable and not constricted by the structure. The stream appears to have access to the narrow floodplain in the few places that it is not severely constricted by steep canyon walls. Connectivity has been largely un-impacted in this portion of the watershed.

Flow recommendations in this report are expected to maintain good connectivity conditions within the instream flow segment. If drastic long-term changes to watershed form or function occur, then flow recommendations would need to be reviewed.

Discussion

Cedar Creek provides important YCT habitat. Protecting flows that provide this habitat and support the population of trout will help ensure the long-term persistence of the species in the Bighorn Mountains and throughout Wyoming. This action will also support the state's interests by adding to conservation actions needed to keep the species from being listed as threatened or endangered by the federal government. This population is managed as a wild YCT fishery within the recreationally important Bighorn National Forest. If approved by the State Engineer, the proposed instream flow water right filing in Cedar Creek will maintain existing base flow conditions when naturally available against potential but unidentified future out-of-channel uses up to the limit of recommended water rights. Approximately 4.3 miles of stream habitat will be directly maintained if these instream flow applications advance to permit status. Existing (senior) water rights will be unaffected if the proposed water rights are approved because the proposed instream flow rights will have a current day (junior) priority date and water for all senior water rights would be honored in their entirety when water is available according to state law.

Instream Flow Recommendations

Wyoming statute 41-3-1001-1014 declares that instream flows may be appropriated for maintaining or improving fisheries. This statute has been interpreted by Wyoming state engineers to include only hydrology and fisheries components of streams. This interpretation denies the opportunity to include other scientifically established components of a fishery including geomorphology, water quality, and connectivity that also serve as a basis for quantifying flow regime needs for maintaining fisheries. Information on these other important riverine components in Cedar Creek is presented above, but the recommendations are based on the habitat needs associated with maintaining physical habitat in the short-term for YCT. Over a longer temporal scale, a flow regime that does not provide sufficient flow at appropriate times of year to maintain all the necessary riverine components may not achieve the statutorily authorized beneficial use of maintaining the existing fishery in perpetuity. The analyses presented in this report indicate which flows provide suitable hydraulic habitat within this existing channel form, but the channel form may change over time.

The instream flow recommendations to maintain short-term habitat for YCT in Cedar Creek (Table 8; Figure 10) assume that natural geomorphic characteristics and habitat forming processes of the stream do not change measurably. Three seasonal time periods were identified for instream flow recommendations. These distinct seasons include winter (October 1–April 30), when sufficient stream flow is critical for survival of all life stages, the YCT spawning period in spring (May 1–July 15), and summer (July 16–September 30) which is important for trout growth.

The recommendations for specific seasonal fishery needs for the Cedar Creek instream flow segment are:

- Winter (October 1–April 30) – Natural winter flows of up to 7.1 cfs are needed to maintain over-winter survival of all life stages of YCT at existing levels. This value was the mean of the 20% monthly exceedance discharges for the winter time period (range of 3.6-14 cfs). The Habitat Retention Model estimated that 5.2 cfs is necessary to maintain appropriate riffle hydraulics.
- Spring (May 1 – July 15) – Natural flow up to 13 cfs is needed to provide sufficient habitat for spawning YCT (PHABSIM results). This level of flow will maintain existing habitat for this life history need and is consistent with conditions during which spawning activity was observed during field data collection.
- Summer (July 16 – September 30) – Natural flow up to 11 cfs is needed based on HQI results to provide sufficient habitat conditions for growth and production of juvenile and adult YCT.

TABLE 8. Instream flow water right recommendations (cfs) for the proposed instream flow segment in Cedar Creek.

Study Segment	**Winter Oct 1 – Apr 30**	**Spring May 1 – Jul 15***	**Summer Jul 16 – Sep 30**
Cedar Creek	7.1	13	11

∗ Channel maintenance flow recommendations for the spring runoff period are defined in Appendix B.

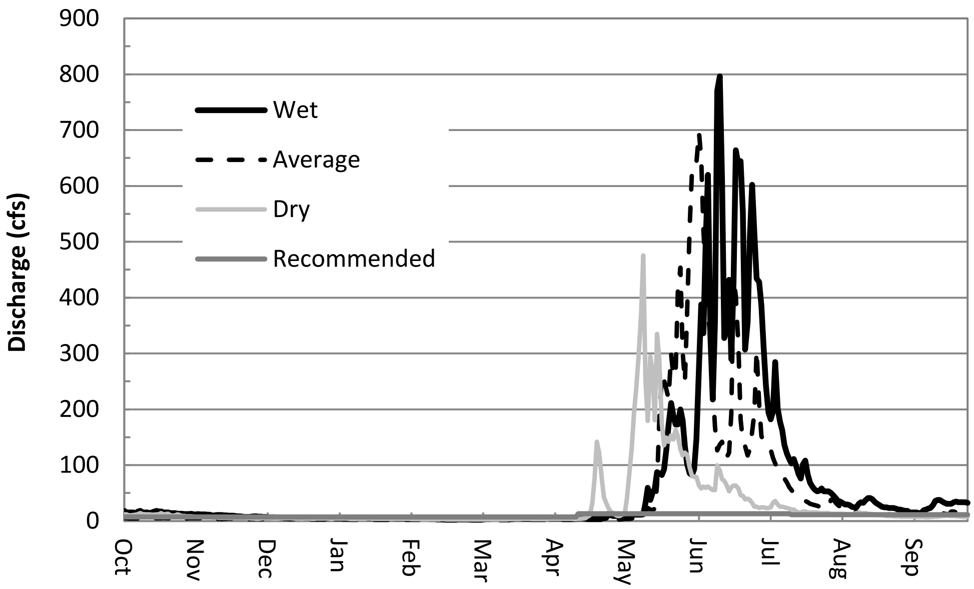

FIGURE 10. Recommended instream flow water right in the proposed segment (when naturally available) relative to wet, dry, and average flow years.

Acknowledgements

Data was collected with the help of Wyoming Game and Fish Department fisheries technician Kyle Berg. Paul Dey reviewed the manuscript and provided constructive comments that greatly improved the quality and clarity of the report.

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Appendix A. Instream Flows in Wyoming

Guiding Principles for Instream Flow Recommendations

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

Legal and Institutional Background

The 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 Wyoming Game and Fish Commission (Commission) is responsible for determining stream flows that will "maintain or improve" important fisheries. The Wyoming Game and Fish Department (WGFD) fulfills this function under the general policy oversight of the Commission. Applications for instream flow water rights are signed and held by the Wyoming Water Development Office on behalf of the state should the water right be approved by the State Engineer. The priority date for the instream flow water right is the day the application is received by the State Engineer.

One of the critical terms associated with the present instream flow statute is "fishery." From a natural resource perspective, a fishery includes the habitat and associated natural processes that are required to support fish populations. The primary components that comprise needed physical habitat include, but are not limited to, the stream channel, riparian zone and floodplain as well as the processes of sediment flux and riparian vegetation development that sustain those habitats (Annear et al. 2004). To maintain the existing dynamic character of an entire fishery, instream flow regimes 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 a full range of flows of a dynamic fishery (e.g., channel maintenance flows) is not consistent with the legislative intent of the instream flow statute. Therefore, until the interpretation of state water law changes, channel maintenance flow recommendations are not included on instream flow applications. Channel maintenance flow requirements are presented in Appendix B of this report in the event that an opportunity arises in the future to secure a broader, more appropriate range of instream flow water rights for this important fishery management purpose.

Public Participation

The general public has several opportunities to be involved in the process of identifying instream flow segments or commenting on instream flow applications. Individuals or groups can inform WGFD of their interest in protecting the fisheries in specific streams or stream segments with instream flow filings. In addition, planning and selection of future instream flow study sites are detailed in the Water Management Unit's annual work schedules and planning documents, which are available for public review and comment (either upon request or by visiting the WGFD web site at http://wgfd.wyo.gov).

The public is also able to comment on instream flow water rights that have been filed with the State Engineer through public hearings, which are required by statute and conducted by the State Engineer's Office for each proposed instream flow water right. The State Engineer uses these public hearings to gather information for consideration before issuing a decision on the instream flow water right application. To help the public better understand the details of instream flow filings and the public hearing process, WGFD personnel are available before and after each public hearing to provide information and answer questions. Additional presentations to community or special interest groups at other times of year also provide opportunity for discussion and learning more about instream flow issues and processes.

Instream flow segments are nearly always located on public land where unappropriated water remains, and the public has access to the fishery. However, in some instances landowners that are nearby or adjacent to a proposed segment are given the opportunity to request that the state to extend an instream flow segment on the portion or portions of those streams crossing their property. Any such requests must be made in writing to the department and are on a voluntary basis. Regardless of whether instream flow segments are placed entirely on public lands or include private segments, the instream flow water rights are junior to existing water rights holders in the stream and will not affect their lawful use of the water.

Appendix B. Channel Maintenance Flows

Background

The term "channel maintenance flows" refers to flows that maintain existing channel morphology, riparian vegetation and floodplain function (Schmidt and Potyondy 2004). The basis and approach used for defining channel maintenance flows applies to snowmelt-dominated gravel and cobble-bed (alluvial) streams. By definition, these are streams whose beds are dominated by loose material with median sizes larger than 0.08 in. 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 (Schmidt and Potyondy 2004). When sediment-moving flows are removed or reduced over a period of years, some gravel-bed channels respond with reductions in width and depth, rate of lateral migration, stream-bed elevation, stream side vegetation, water-carrying capacity, and changes in bed material composition.

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 a riparian community with diverse successional states. 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) noted "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."

Bedload Transport

A bedload transport model (Figure B-1) shows the total amount of bedload sediment transported over time (during which a full range of stream discharge [Q] values occur). Smaller discharges, such as the substrate mobilization flow (Q_m) occur more frequently, but not much sediment is moved during those times. The effective discharge (Q_e) mobilizes the greatest volume of sediment and also begins to transport some of the larger sediment particles (gravels and small cobbles). The bankfull discharge (Q_{bf}), in which flow begins to inundate the floodplain and which has a return interval of approximately 1.5 years on average, typically occurs near the Q_e. The discharge corresponding to the 25-year return interval (Q_{25}) represents the upper limit of the required channel maintenance flow regime, since the full range of mobile sediment materials move at flows up to this value, but these higher flows are infrequent. The more frequent discharges that occur between the Q_m and the Q_e move primarily smaller-sized particles (sand and small gravel) and prevent filling in of pools and other reduction in habitat complexity. Since these particles are deposited into the stream from the surrounding watershed with greater frequency, it is important to maintain a flow regime that provides sufficient conveyance properties (high frequency of moderate discharges) to move these particles through the system. However, alluvial streams, particularly those at higher elevations, also receive significant contributions of larger-sized particles from the surrounding watershed and restrictions to the flow regime that prevent or reduce the occurrence flows greater than Q_e (which are critical for moving these coarser materials) would result in gradual bedload accumulation of these larger particles. The net effect would be an alteration of existing channel forming processes and habitat (Bohn and King 2001). For this reason, flows up to the Q_{25} flow are required to maintain existing channel form and critical habitat features for local fish populations.

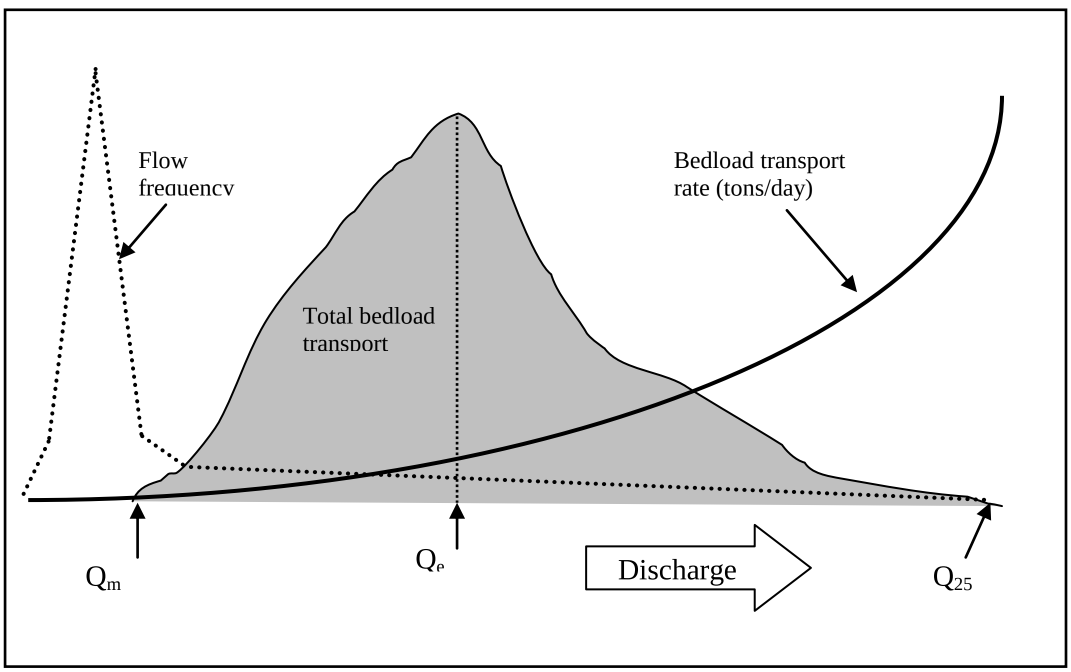

FIGURE B-1. Total bedload transport as a function of bedload transport rate and flow frequency (adapted from Schmidt and Potyondy 2004).

Channel Maintenance Flows Model

The model used to recommend flows to maintain the form and function of the stream channel is derived from bedload transport theory presented above. Based on these principles, the following channel maintenance flow model was developed by Dr. Luna Leopold and is used in this report to calculate the appropriate instream flows up to the Q_{25}:

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

Where: Q_s = actual stream flow
Q_f = fish flow (required to maintain fish spawning habitat)
Q_m= sediment mobilization flow = 0.8 * Q_{bf}
Q_{bf} = bankfull flow

The Leopold model calculations could be used to yield a continuous range of instream flow recommendations at flows between the Q_m and Q_{bf} for each cubic foot per second increase in discharge. However, this manner of flow regulation is complex and could prove burdensome to water managers. To facilitate flow administration while still ensuring sufficient flows for channel maintenance, we modified this aspect of the approach to recommend a single instream flow for each of four quartiles between the Q_m and Q_{bf}.

Channel maintenance flow recommendations developed with the Leopold model require that only a portion of the flow remain instream for maintenance efforts. When total discharge is less than Q_m, only fish flows are necessary; discharge between the fish habitat flows recommended in the main body of this report and Q_m is available for other uses (Figure B-2). Similarly, all discharge greater than the Q_{25} flow is less critical for channel maintenance purposes and available for other uses (these higher flows do allow a connection to the floodplain and it is valuable for infrequent inundation of riparian habitat to occur, but not for the physical maintenance of the stream channel). Between the Q_m and Q_{bf}, the model is used to determine what proportion of flow should remain in channel for maintenance activities. For those relatively infrequent flows that occur in the range between Q_{bf} and the Q_{25}, all flow is recommended to remain in the channel for these critical channel maintenance purposes.

Using this "dynamic hydrograph" approach, the volume of water required for channel maintenance is variable from year to year. During low-flow years, less water is recommended for channel maintenance because flows may not reach the defined channel maintenance level. In those years, most water in excess of fish habitat flows is available for other uses. The majority of flow for channel maintenance occurs during wet years. One benefit of this dynamic hydrograph 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 a threshold approach.

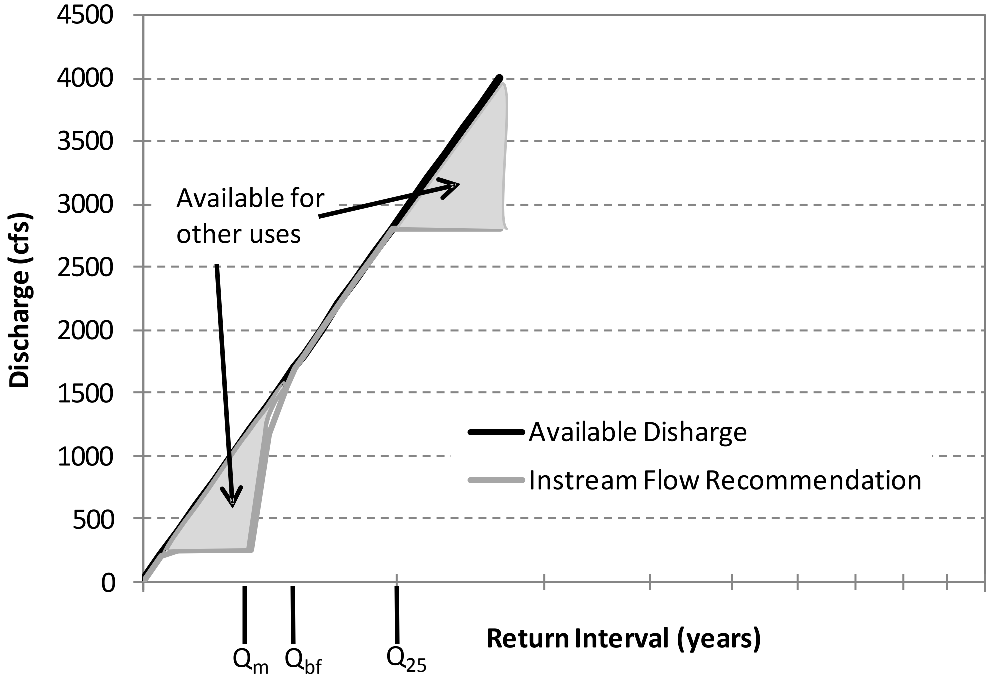

FIGURE B-2. Generalized dynamic hydrograph indicating recommended instream flow for fishery maintenance. Q_m is substrate mobilization flow, Q_{bf} is bankfull flow, and Q_{25} is the discharge with a 25-year return interval.

This channel maintenance flow model is the same as the one presented in Gordon (1995) and the Clark's Fork instream flow water right (C112.0F) filed by the U.S. Forest Service with the Wyoming State Engineer, with one exception. The model presented in those documents used the average annual flow to represent Q_m. Subsequent work by Schmidt and Potyondy (2004) identified Q_m as occurring at a discharge of 0.8 times Q_{bf}. Initial particle transport begins at flows somewhat greater than average annual flows but lower than Q_{bf} (Schmidt and Potyondy 2004). Ryan (1996) and Emmett (1975) found the flows that generally initiated transport were between 0.3 and 0.5 of Q_{bf}. Movement of coarser particles begins at flows of about 0.5 to 0.8 of Q_{bf} (Leopold 1994, Carling 1995). Schmidt and Potyondy (2004) discuss phases of bedload movement and suggest that a flow trigger of 0.8 of the Q_{bf} "provides a good first approximation for general application" in defining flows needed to maintain channels.

Cedar Creek

Like all properly functioning rivers, Cedar Creek 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).

The Leopold model was used to develop channel maintenance recommendations for the Cedar Creek instream flow segment (Table B-1). The fish flow used in the analysis was the spawning flow (30 cfs). For naturally available flow levels less than the spawning flow, the channel maintenance instream flow recommendation is equal to natural flow. The spawning flow level is substantially less than Q_m (466 cfs). For the flow range between the spawning flow and Q_m, the channel maintenance flow recommendation is equal to the spawning flow (Table B-1). When naturally available flows range from Q_m to Q_{bf} (583 cfs), the Leopold formula is applied and results in incrementally greater amounts of water applied toward instream flow (Table B-1). At flows between Q_{bf}, and Q_{25} (1003 cfs), all stream flow is retained in the channel to perform maintenance functions. At flows greater than Q_{25}, only the Q_{25} flow is recommended for channel maintenance (Figure B-3).

TABLE B-1. Channel maintenance instream flow recommendations (May 1–Jul 15) to maintain existing channel forming processes and long-term aquatic habitat characteristics in the Cedar Creek instream flow segment.

Flow Description	**Available Flow (cfs)**	**Recommended Flow (cfs)**
<Spawning Flow	<30	All available flow
Spawning Flow to Q_m	30-466	30
Q_m to Q_{bf} – Quartile 1	467-496	302
Q_m to Q_{bf} – Quartile 2	497-525	438
Q_m to Q_{bf} – Quartile 3	526-554	493
Q_m to Q_{bf} – Quartile 4	555-583	541
Q_{bf} to Q_{25}	583-1003	All available flow
> Q_{25}	≥ 1003	1003

Figure B-3 shows example annual hydrographs (randomly selected average and wet years) with channel maintenance flow recommendations implemented. Dry years are not shown because flows would not exceed the substrate mobilization threshold to initiate channel maintenance flows. In the representative average year, 1976, flow exceeded substrate mobilization flow on 7 days in June, which would trigger channel maintenance flow recommendations. In the representative wet year, 1978, these recommendations would apply for 12 days in June (Figure B-3).

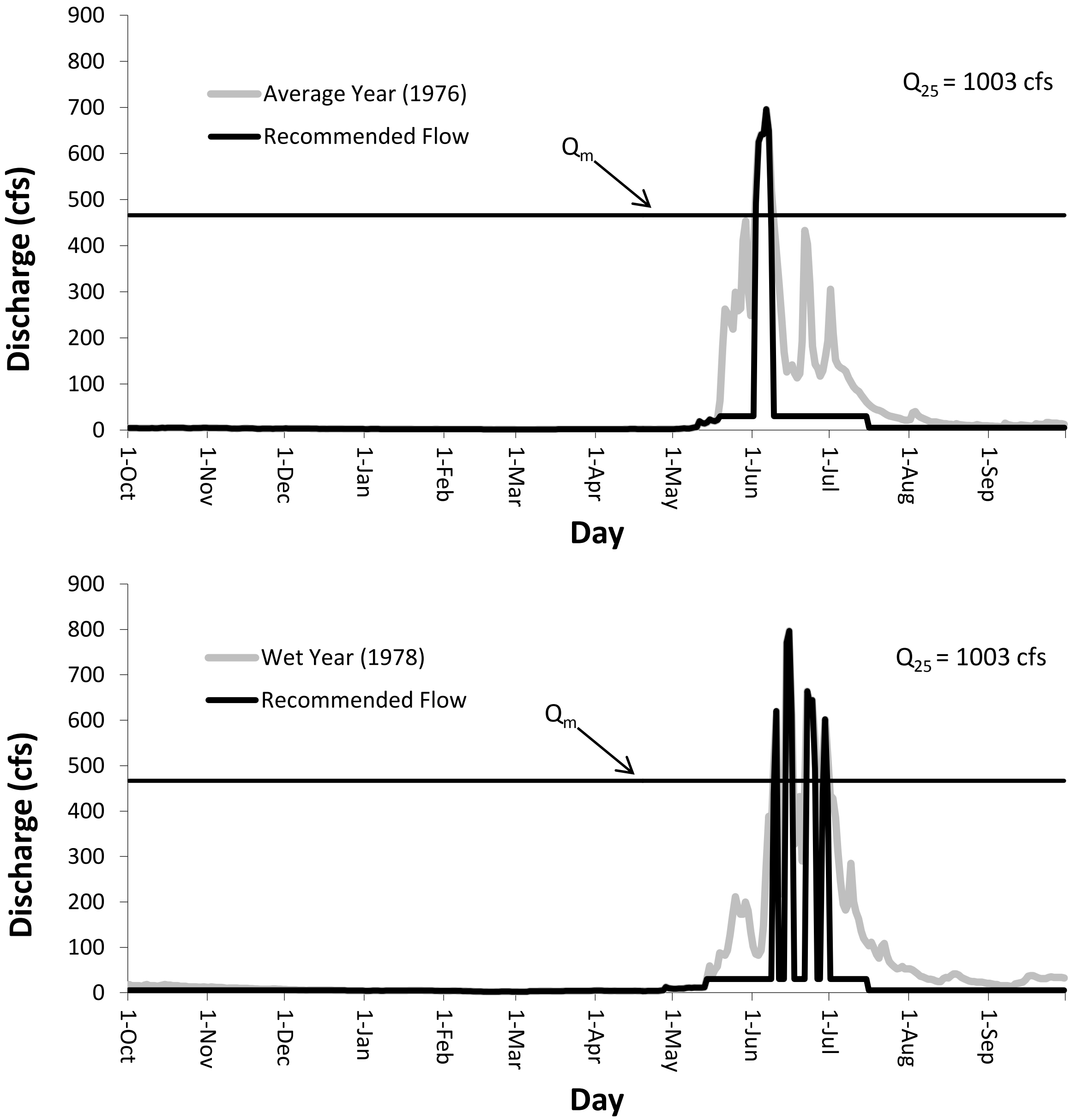

FIGURE B-3. Channel maintenance flow recommendations and hydrographs for the Cedar Creek instream flow segment in an average (1976) and a wet (1978) water year.

Implementing these flow recommendations would have to include moderating the abrupt changes that occur at threshold flows with a ramping scheme that includes more gradual changes akin to a natural hydrograph. Such sharp flow increases and decreases evident in Figure B-3 would cause habitat loss through excessive scour and potential trout mortality due to stranding. The Index of Hydrologic Alteration (IHA; Richter et al. 1996) could provide a valuable reference to find suitable rates of change. Daily increases and decreases during runoff measured at the reference gage could serve as a guide for developing such ramping rate recommendations using the IHA.

Appendix C. Hydrology Estimates for the Ungaged Study Segment

There are multiple methods for generating daily discharge estimates in ungaged stream segments, but the one chosen for these estimates is based on watershed characteristics that can primarily be calculated from maps. The data are supported by field observations, but the estimates are not based on measurements of flow in the study reach. These results do provide flow estimates with strong supporting documentation (e.g., the underlying formulas are based on extensive field investigations), but these results could be paired with a local study using extensive field data (e.g., Lowham 2009) to generate comprehensive flow estimates that have a higher probability of accuracy than either method used alone. An excellent example of how multiple flow estimation methods can be combined into a single set of daily discharge estimates is described in Parrett and Cartier (1990).

Reference gage selection

To estimate flows in an ungaged stream, a reference stream gage is first selected for making comparisons. The qualities of a good reference gage are: 1) that it be located close to the study site (within the same HUC4 drainage is strongly preferred, where possible), 2) that it have at least 10 years of continuous records (it is not necessary that it be in current operation, but this is preferable), and 3) that be in a stream with similar basin characteristics (mean elevation, drainage area, stream width, etc.). Due to the limited number of stream gages in Wyoming, this combination is difficult to find for many study sites. Once a reference gage is selected, the recorded flow estimates from that gage are adjusted to correct for differences in basin characteristics between it and the ungaged study stream. After this correction factor is applied, the period of record at the reference gage can be used to estimate flows over the same period (including generating monthly and annual summary statistics) at the study site.

In the area near the Cedar Creek study site, there are two USGS gages that are currently operating (considering only gages in Wyoming), both in Shell Creek. In addition, there was one historical gage that was located in the Nowood River near Tensleep (upstream of the confluence with Medicine Lodge/Paintrock Creek). One of the Shell Creek gages (06278300) is located above Shell Creek Reservoir and has been active from 1956 to the present. The other Shell Creek gage (06278500) is located near the town of Shell and has been active from 1940 to the present. The Nowood River gage (06270000) was active between 1938 and 1992 but it was inactive for much of that time (the total period of record includes 29 years with records). Among the three potential reference gages, the Shell Creek gage near the town of Shell is a poor fit due to the influence of the upstream reservoir. The gage located on the Nowood River was also a relatively poor fit, because it is located much lower in the watershed than each of the study sites with a greater moderating affect of multiple tributaries and higher flow conditions in the fall (September) that was not consistent with observations at the study site. Both of these sites were also low enough in the watershed to be influenced by water diversions. The potential reference gage that appears to provide the best representation of conditions at the study sites was the one above Shell Creek Reservoir (06278300) since this gage was upstream of any diversions and relatively high in the watershed, like the study site. Stream flow at this reference gage is typical of snowmelt runoff streams with short periods of high (runoff) flow and a substantial portion of the annual flow as a low (base) flow. Annual peak flow occurred between May 13 and July 1 over the period of record (median date was June 7). Base flow recession occurs throughout summer with base flow levels attained by late September. Annual flow minima occurred in winter (December, January, or February).

Watershed Models

The first step in estimating daily flow values at the ungaged study site is to determine which watershed model is best suited to the conditions in the study area. There are several potential models that use basin characteristics including mean elevation, drainage area, precipitation, stream length, and bankfull width to estimate mean annual flow (Q_{AA}). In Wyoming streams, models for making these estimates are found in two primary sources, Lowham (1988) and Miselis et al. (1999). The Lowham (1988) models were based on streams found in mountainous areas statewide and the Miselis et al. (1999) models created separate models for each of eight specific mountain ranges. Each model is used to estimate Q_{AA} at the reference gage and the result is compared to the known Q_{AA} value. The model that best predicts Q_{AA} at the reference gage is a good prospect for predicting Q_{AA} at the ungaged study site. However, sometimes this is not the best model. Local estimates of flow at the ungaged study site provide an opportunity to review the model results and consider alternatives when the resulting flow estimates do not match up well with observed flows.

Dimensionless analysis

The goal of this process is to generate daily flow estimates at the ungaged study sites, which are derived from daily flow estimates at the reference gage. Once the best watershed model is found and Q_{AA} is estimated at the study site, the difference in the scale of the known Q_{AA} at the reference gage and the estimated Q_{AA} at the ungaged study sites is used to shift the daily discharge from the reference gage up or down by the appropriate correction factor to generate daily flow estimates for the ungaged study site. The adjustment factor is a dimensionless value that uses average annual discharge (Q_{AA}) for scaling according to the formula:

$$\frac{Q_1}{Q_{AA1}} = \frac{Q_2}{Q_{AA2}}$$

Where:

Q_1 = Daily discharge at the gage location

Q_{AA1} = Average annual discharge at the gage location

Q_2 = Daily discharge at the ungaged study segment

Q_{AA2} = Average annual discharge at the ungaged study segment

Daily discharge and Q_{AA} are known at the gage location. The watershed model provides the Q_{AA} estimate at the ungaged study site so the formula is rearranged to solve for Q_2 (daily discharge at the ungaged location).

Model selection

The Q_{AA} for the upper Shell Creek reference gage (06278300) was 33 cfs for the 54 year period of record (1957-2010). Table C-1 shows how closely each of several possible models comes to estimating the actual Q_{AA} for this location. Among them, the Miselis et al. (1999)

model based on mean basin elevation predicts the actual Q_{AA} at the reference gage most closely. Unlike in other study sites where data were collected in 2012, Cedar Creek drains an area approximately similar in size to the reference gage. In other cases, this discrepancy resulted in QAA estimates for the study sites that were too high when compared with local observations of discharge. In this case, however, the best fit model for estimating QAA at the reference gage also appeared to provide a good estimate of QAA at the study site.

The result of these analyses was to select the Miselis (1999) model that used mean basin elevation as the best fit model to estimate Q_{AA} and subsequently, daily discharge values for the Cedar Creek study site.

TABLE C-1. Watershed models used to calculated QAA for the upper Shell Creek reference gage.

Model Description	**Model***	**Upper Shell Q_{AA} (cfs)**
Miselis et al. (1999): Mountainous for WY, Drainage Area	$1.20976\ DA^{0.894}$	20
Miselis et al. (1999): Bighorn Mountains, Mean Elevation	$254000\ Elev^{-0.97}$	33
Miselis et al. (1999): Bighorn Mountains, Drainage Area	$0.65418\ DA^{0.97}$	14
Miselis et al. (1999): Bighorn Mountains, Precipitation	$0.09290\ P^{1.93}$	25
Miselis et al. (1999): Bighorn Mountains, Stream Length	$2.23254\ SL^{1.17}$	26
Miselis et al. (1999): Bighorn Mountains, Bankfull Width	$0.01730\ W_{BF}^{2.20}$	55
Lowham (1988): Drainage area and Mean Elevation	$0.0015DA^{1.01}(Elev/1000)^{2.88}$	27
Lowham (1988): Drainage area and Precipitation	$0.013DA^{0.93}P^{1.43}$	15
Lowham (1988): Bankfull Width	$0.087\ W_{BF}^{1.79}$	61
Historic gage records (54 years of record)		**33**

*-Basin characteristics include: DA – drainage area (square miles); P – annual precipitation (inches); SL – stream length (miles); Elev – mean basin elevation (feet); Wbf – Bankfull channel width (feet).