Instream flow studies on West Fork Long Creek

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ABSTRACT

West Fork Long Creek has been identified as important habitat for Yellowstone cutthroat trout (YSC; *Oncorhynchus clarkii bouvieri*), a game fish and species of greatest conservation need in Wyoming. Though YSC were historically widespread throughout the Upper Wind River drainage, only a few populations remain. To help ensure the persistence of this population, the Wyoming Game and Fish Department has selected West Fork Long Creek for instream flow water right filing consideration. Securing an instream flow water right in West Fork Long Creek will help ensure that YSC remain in the creek by protecting existing base flow conditions against potential future consumptive water demands.

An instream flow investigation was conducted on West Fork Long Creek in 2015 and the resulting flow recommendations are reported here. One 4.15-mile long stream segment was selected for the study. The segment was chosen considering land ownership, hydrology, and stream channel characteristics to maintain or improve the important YSC population.

Several techniques were employed within the study segment to evaluate YSC habitat availability and develop flow recommendations. Modeling techniques included Physical Habitat Simulation (PHABSIM), the Habitat Retention Method, and the Habitat Quality Index (HQI). PHABSIM was used to calculate habitat availability for all life stages of YSC over a range of flow conditions. The Habitat Retention Method was used to examine riffle hydraulic characteristics needed to maintain fish passage (longitudinal connectivity) between habitat types and provide sufficient depth, velocity, and wetted area to ensure year-round survival of all life stages of YSC and fish prey items (benthic invertebrates). 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. For winter months, October through April, Habitat Retention Method results and natural flows represented by the 20% monthly exceedance values were evaluated for maintaining all life stages. Finally, a dynamic hydrograph model was used to quantify flow needs for maintenance of channel geomorphology.

Results of the instream flow investigation on West Fork Long Creek indicate that flows of 1.9 cubic feet per second (cfs) during winter, 4.0 cfs during spring, and 2.7 cfs during summer are needed to maintain YSC short-term habitat in the segment. If this instream flow application advances to permit status, approximately 4.2 miles of stream habitat in West Fork Long Creek will be protected directly by allowing for YSC spawning, passage, and year-round survival.

INTRODUCTION

Rivers and streams, and their associated fisheries, are important to the residents of Wyoming, as evidenced by the passage of the Wyoming Statute 41-3-1001-1014 allowing protection of stream flows for fisheries through instream flow water rights. The Wyoming Game and Fish Department (WGFD) works to protect fisheries throughout the state using various tools and strategies, including proposing instream flow water rights where it is appropriate and beneficial. Detailed background information on instream flows in Wyoming is presented in Appendix A. Guidance for selecting streams to evaluate for instream flow water rights consideration is provided by WGFD's Water Management Plan (Robertson and Annear 2011).

Some of the highest current priorities for new instream flow projects are streams containing Yellowstone cutthroat trout (YSC; *Oncorhynchus clarkii bouvieri*). Among the streams that contain populations of YSC, many have modified habitat conditions that restrict the YSC populations to isolated reaches relative to the watershed-wide distributions that the species once exhibited. These remaining isolated reaches are important 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.

Securing an instream flow water right will help facilitate successful preservation and maintenance of YSC after being re-introduced into this historical portion of their range. This creek occurs within an "enhancement" habitat area as identified in the WGFD Strategic Habitat Plan (SHP) (WGFD 2009); enhancement habitat areas "are important wildlife areas that can or should be actively enhanced or improved by WGFD and partners".

This report details the results of the West Fork Long Creek instream flow study conducted in June through September 2015. Flow recommendations are based upon consideration of the five primary riverine components that influence the characteristics of a stream or river: hydrology, biology, geomorphology, water quality, and connectivity (Annear et al. 2004). Maintaining sufficient water of good quality is essential for sustaining fish productivity in streams and rivers. When 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. The five riverine components were evaluated using various models and data sources to generate the recommendations for how much flow (when naturally available) should remain in West Fork Long Creek to provide sufficient habitat during important time periods in the life stages of YSC.

The objective of this study was to quantify instream flow levels needed to maintain YSC habitat in West Fork Long Creek during important seasonal periods. In addition, a channel maintenance flow regime was modeled that will maintain long-term trout habitat and related physical and biological processes (Appendix B). The information can be used as supporting material for an instream flow water right application. The audience for this report includes the Wyoming State Engineer and staff, the Wyoming Water Development Office, aquatic habitat and fishery managers, and non-governmental organizations and individuals interested in instream flow water rights.

METHODS

Study Area

West Fork Long Creek, located in Fremont County, Wyoming, is a tributary of Long Creek, which is a tributary of the Wind River in the Upper Wind River watershed (Figure 1). The stream is located within the Lander region of the WGFD. The West Fork Long Creek watershed (HUC12 100800010204) encompasses approximately 23.0 square miles. Land ownership in the watershed includes 77% U.S. Forest Service (USFS) land, 4% Bureau of Land

Management (BLM) land, and 19% private land. All private lands are downstream of the proposed instream flow segment.

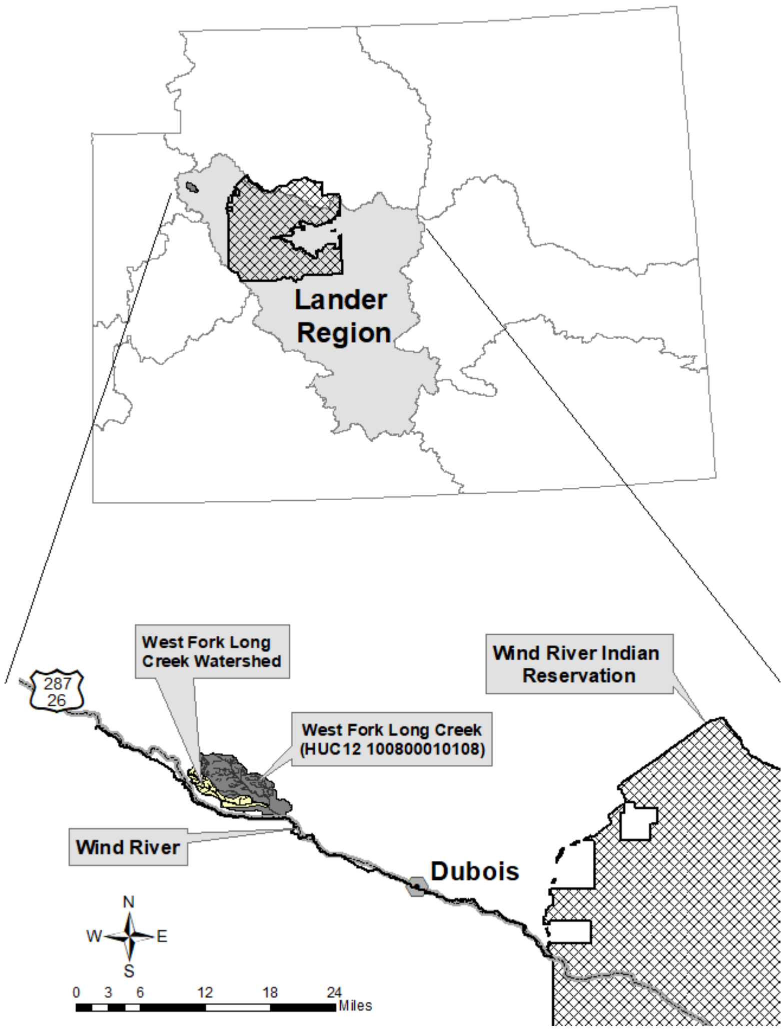


FIGURE 1. Location of West Fork Long Creek, WY (HUC100800010108).

The highest point in the West Fork Long Creek watershed is approximately 10,130 ft and the lowest point is approximately 7,800 ft. Annual precipitation averaged 19.3 inches in the area of the stream over the period 1895–2012 according to data retrieved from the Wyoming Water Resources Data System (WRDS 2016).

The fish community in West Fork Long Creek includes YSC, Snake River cutthroat trout (*Oncorhynchus clarkii behnkei*; SRC), and brook trout (*Salvelinus fontinalis;* BKT) within the proposed instream flow segment. The current management objective is to maintain a wild population of YSC in West Fork Long Creek. Evaluation of flow conditions that are necessary to maintain or improve this fishery was conducted using the habitat and hydrological modeling efforts described below.

Instream Flow Segment and Study Site Selection

One stream segment is proposed for an instream flow water right filing in West Fork Long Creek (Table 1; Figure 2). The boundaries for the segment were identified after considering land ownership, hydrology, and stream channel characteristics. The proposed instream flow segment extends upstream approximately 4.15 miles from the irrigation diversion (just upstream of Forest Road 513) to the upper extent of the YSC conservation population. The drainage area at the downstream end of the segment is 5.66 square miles. The instream flow segment selected on West Fork Long Creek is located entirely on public land.

TABLE 1. Location, drainage area, length, and elevation at the downstream end of the proposed instream flow segment on West Fork Long Creek.

Segment	**Description**	**Drainage Area (mi^2)**	**Length (mi)**	**Elevation (ft)**
West Fork Long Creek	Begins at the irrigation diversion just upstream of Forest Road 513 and extends upstream to the extent of the YSC conservation population.	5.66	4.15	7,950

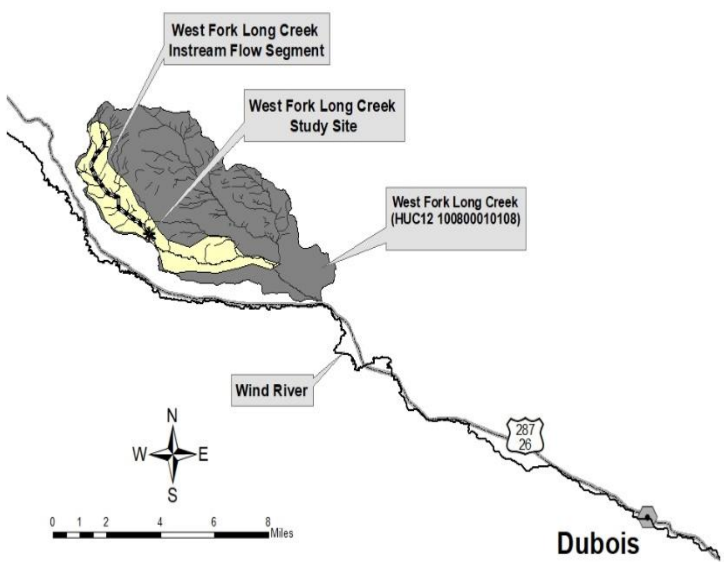


FIGURE 2. Location of West Fork Long Creek instream flow segment and study site.

Within the instream flow segment, one study site of approximately 260 ft of stream was selected to represent habitat conditions in the segment. Because the bankfull width in this reach was approximately 6.6 ft, the study site length was equal to approximately 40 times the channel width; this is longer than the reach length recommended by Bovee (1982; 10-14 times the channel width).

The study site included three distinct sections (riffle-run or riffle-run-pool-glide) characterized by a total of 10 cross-sections divided among them (Figure 3). The 10 transects included three riffles, three runs, two pools, and two glides. The transects were placed such that a riffle transect created the downstream boundary of each of the three short sections. Additional transects were placed in appropriate upstream locations to represent the range of conditions in each section. The complexity of this study site is representative of the range of habitat conditions available throughout the instream flow segment. All data collection was conducted in this study site. Habitat availability and flow results were extrapolated to the entire proposed instream flow segment.

FIGURE 3. A transect at the West Fork Long 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 or stream so flow conditions were estimated from a regional reference gage (see Appendix C for details). The USGS gage on the Wind River near Dubois (06218500) was selected as the reference gage for these analyses (Figures 4, 5); the period of record used for analysis was water years 1946-1992 and 2002-2018. This gage was active during the study period and, based on proximity, it is assumed that precipitation and runoff patterns are similar between the reference gage and the study site.

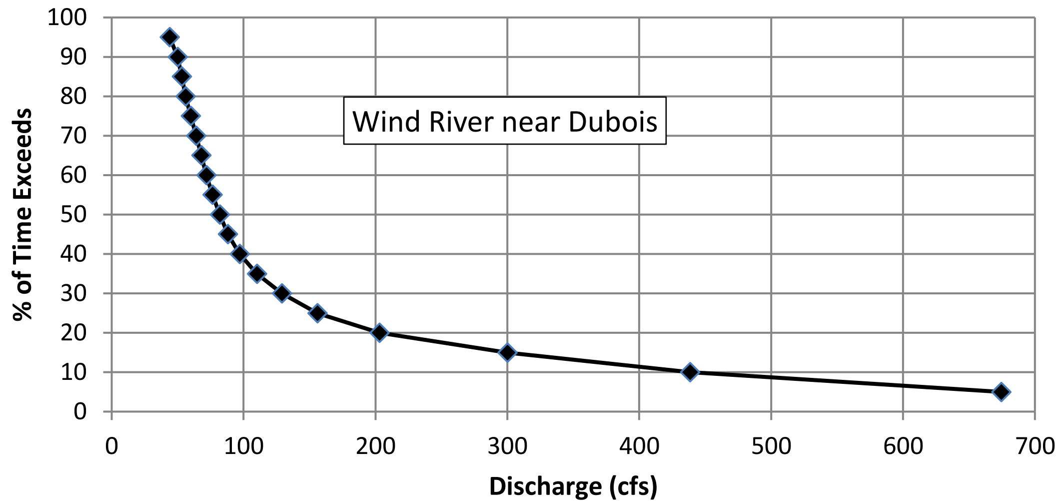


FIGURE 4. Flow exceedance curve for the Wind River near Dubois (USGS Gage 06218500) over a 64 year period of record (water years 1946-1992 and 2002-2018).

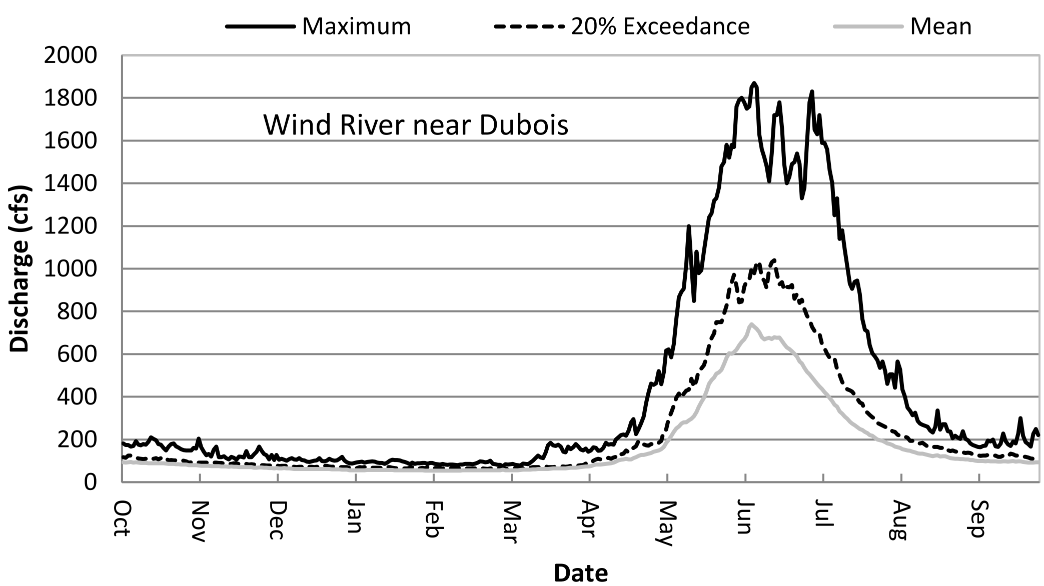


FIGURE 5. Hydrograph showing the maximum, 20% exceedance, and mean daily discharge for each day over a 64 year period of record (water years 1946-1992 and 2002-2018) at the Wind River near Dubois reference stream gage station (USGS Gage 06218500).

The 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 Method models (described below). The 1.5-year return interval of the flood frequency series was used to estimate bankfull flow (Rosgen 1996) for use in the Habitat Retention Method and for developing channel maintenance flow recommendations (Appendix B). Channel maintenance flow calculations required the 25-year peak flow estimate from the flood frequency analysis. In addition, monthly flow duration data were used in evaluating winter flow needs. Flow duration curves indicate the percent of time that a given flow is equaled or exceeded. The monthly 20% exceedance flows identified for this analysis refer to the flow levels that would be available approximately one year out of every five consecutive years.

In addition to estimates of local hydrology based on the regional reference gage data, a temporary stream gage station was installed in the study site between June 28, 2015 and September 25, 2015. The temporary gage data provide a detailed look at the flow variability during the study period and assist in selecting the appropriate regional reference gage. The gage was located upstream of a stable hydraulic control and a staff plate with 0.01 ft increments was placed in the stream in a location with minimal surface turbulence. The pressure transducer used for water level monitoring at 15-minute intervals was placed in a perforated PVC pipe that served as the stilling well. The pipe was anchored to a metal T-post and mounted vertically within the water column. Discharge measurements in the stream reach were collected over a wide range of flow conditions including high flows shortly after runoff and base flows near the end of the study period. The discharge measurements and corresponding readings on the staff plate were used to develop a local rating curve. The rating curve was used to convert the water level readings from the pressure transducer to discharge estimates during the study period.

Biology – Fish Habitat Modeling

Habitat preferences of target fish species, including each of their life stages, are important in instream flow studies because 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 (HSCs) that are in turn used in habitat models.

Availability of fish habitat in the study site was evaluated using several different habitat models. "Habitat" in this report refers to the combination of physical conditions (width, 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 compose trout habitat. Habitat for trout also includes other environmental elements such as water temperature, dissolved oxygen, and turbidity. Although such other elements are important for maintaining trout populations, they are not included in models used for these analyses because they do not fluctuate with changes in the quantity of flow as predictably as physical habitat parameters. Interpretation of model results based on 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 YSC 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 YSC, these ranges were 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 YSC 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.

During spawning, YSC use different habitat conditions than during other life history stages. 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). Dey and Annear (2006) observed too few spawning YSC (n=4) to develop habitat suitability curves for spawning YSC in Wyoming. Spawning YSC 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/s and depth preference highest from 0.52 to 0.82 ft. Information from that study was used to indicate habitat selectivity of YSC in West Fork Long Creek.

YSC spawning (believed to be triggered around 41°F; Kiefling 1978, Varley and Gresswell 1988, De Rito 2005) occurs between March and July throughout their range, depending on local hydrology and water temperatures. Spawning activity for YSC in Wyoming has been observed during May and June in watersheds in 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 YSC spawning, with stream reaches 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 River watershed occurred into July in streams above approximately 8,000 ft in elevation and, therefore, extended recommendations for spawning flows through July 15 in such high elevation sites. The downstream end of the West Fork Long Creek instream flow segment is about 8,000 ft in elevation, so it is likely that YSC spawning occurs into July in the segment.

Physical Habitat Simulation Model

The Physical Habitat Simulation (PHABSIM) model (Bovee et al. 1998) was used to estimate how much suitable habitat is available for individual life stages of YSC at different stream flow levels. The results of the model were evaluated to determine how much stream flow is needed to maintain sufficient habitat for these life stages during critical time periods.

The PHABSIM model calculated a relative suitability index for YSC based on depth, velocity, and substrate. Model calibration data were collected on all transects. Along each transect, depth and velocity were measured at multiple locations (cells); spacing was determined based on substrate characteristics and the cross-section depth profile. Measurements were taken in the same cells at three different discharge levels (2.5 cfs, 1.0 cfs, and 0.48 cfs). Calibrating the model involved hydraulic parameter adjustments to provide the best estimation of observed conditions at the different flows measured in the field (Bovee et al. 1998).

Simulations were conducted using a calibrated PHABSIM model over the flow range of 0.1 cfs to 20 cfs. Using the depth and velocity measurements in the cells along each transect at the calibration flow levels, the PHABSIM model predicted depth and velocity values in those cells for each simulated discharge level (Bovee and Milhous 1978, Milhous et al. 1984, Milhous et al. 1989). The predicted depths and velocities, along with substrate or cover information, were compared to HSCs of the target species to determine how much suitable habitat is present in the study site at each simulated discharge.

The amount of suitable habitat, or weighted usable area (WUA), for each stream flow and life stage combination was calculated using the HSCs for depth, velocity, substrate, and cover which range between "0" (no suitability) and "1" (maximum suitability) for each life stage. A suitability value was assigned to each cell for each HSC based on the simulation results for a given discharge. A combined suitability value was generated and multiplied by the surface area of each cell. The sum value of all cells yielded the WUA for the simulated discharge level. Data from the seven transects were grouped into three sections; each section was given equal weighting toward the total estimate of WUA for each flow.

Results were displayed by graphing WUA for a particular fish life stage versus a range of simulated discharges (Bovee et al. 1998). The values were normalized to a percent of the maximum WUA value as recommended by Payne (2003).

Habitat Retention Method

The Habitat Retention Method (Nehring 1979, Annear and Conder 1984) was used to evaluate hydraulic characteristics that affect the survival and movement of all life stages over a range of discharges in the West Fork Long Creek instream flow segment. The model was used to identify the lowest flow that maintains specified hydraulic criteria in riffles (Table 2). These criteria represent conditions needed to maintain fish passage, or longitudinal connectivity, among habitat types and ensure sufficient depths, velocities, and wetted areas year-round survival YSC and benthic invertebrates, many of which serve as fish prey (Nehring 1979). Flow recommendations derived from the Habitat Retention Method address portions of the connectivity and biology riverine components. The threshold flow identified by the Habitat Retention Method is important year round, although greater flows are necessary to meet other behavioral or physiological requirements of the target fish species.

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 was used to simulate cross section depth, wetted perimeter, and velocity for a range of flows. The flow that maintains two out of three criteria for all modeled transects is then identified as the threshold to maintain sufficient flow to meet the needs of the fishery. Because of the critical importance of depth for maintaining fish passage, the 0.2 ft threshold was required to be one of the criteria met for each transect (Table 2).

TABLE 2. Hydraulic criteria for determining maintenance flow with the Habitat Retention Method (Annear and Conder 1984).

Category	Criterion
Mean Depth (ft)	≥0.20[1]
Mean Velocity (ft/s)	≥1.00
Wetted Perimeter[2] (%)	≥50

[1] When transect bankfull width >20 ft, then 0.01 * mean bankfull width.

[2] Percent of bankfull wetted perimeter, calculated by transect.

Habitat Quality Index Model

The HQI model (Binns and Eiserman 1979, Binns 1982) was used to determine production potential of adult and juvenile YSC in the study site during summer (July through September) flow conditions. Most trout production (growth) in Wyoming streams occurs during summer, following peak runoff, when longer days and warmer water temperatures facilitate growth. Developed by the WGFD, the HQI model uses nine biological, chemical, and physical trout habitat attributes to estimate relative habitat suitability in a stream.

For this study, the HQI was used to estimate the number of YSC habitat units in the study site. Each habitat unit is expected to support about 1 pound of trout. Data were collected for HQI calculations at 2.5 cfs, 1.0 cfs, and 0.48 cfs cfs between July 1 and September 30. HQI attribute ratings were interpolated between these measurements to characterize the relationship between discharge and trout habitat conditions at discharges other than those measured (Conder and Annear 1987).

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." To maintain a viable trout fishery, it is critical to maintain normal late summer flows, which are represented by the September 20% monthly exceedance flow. The HQI results were used to identify the number of habitat units that occur at this flow and the lowest flow that maintains that quantity of habitat.

Natural Winter Flow Analysis

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 winter a stressful time period for fish in Rocky Mountain headwater streams (Locke and Paul 2011). Even relatively small flow reductions 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 that often harbor a substantial proportion of the total trout population (Lindstrom and Hubert 2004).

The PHABSIM and HQI habitat modeling approaches described above may not be well suited to determine flow requirements during ice-prone times of year. These methods were 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). However, the Habitat Retention Method can be appropriate for winter flow recommendations.

For comparison with the Habitat Retention Method recommendation for a winter flow necessary to maintain the YSC fishery in West Fork Long Creek, the 20% monthly exceedance values for winter months (October through April) were averaged. Whereas lower flow exceedance values may be sufficient to support the fishery at other times of the year, the 20% monthly exceedance flow is most appropriate in winter. 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. The 20% exceedance approach ensures 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 preventing loss of fish habitat over time throughout that stream. Reductions in flow quantity can affect the sediment load balance such that a stream's sediment transport capacity is diminished and excess fine sediments aggrade in the channel (Bovee et al. 1998). This usually reduces habitat suitability for fish communities. Other physical changes in the stream caused by road building, culvert addition, riparian habitat reduction, and other activities also affect sediment transport dynamics. In streams compromised by excess sediment inputs from streambank instability, poor land management practices in the watershed, and road construction and maintenance activities, any reduction in natural flow levels makes it even more difficult for the stream to move sediment sufficiently to prevent aggradation.

The geomorphology conditions of the proposed instream flow segment were evaluated by visual observation. Observations on channel form characteristics including Rosgen channel type, sinuosity, and riparian habitat conditions were noted. In addition, roads, culverts, and other changes to the watershed were identified along with areas of excessive erosion and any imbalances in sediment load conditions. This visual assessment also included observations on the influence of substrate sizes and large woody debris on pool development and habitat conditions for the fish community.

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 because 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. However, should opportunities arise in the future to secure instream flow water rights for long-term maintenance of stream habitat conditions, this information will provide a valuable reference.

Water Quality

Water quality in late summer and fall has been found to be a limiting factor for many trout populations and these data are critical to consider in development of an instream flow recommendation. The evaluation of water quality in the proposed instream flow segment included collecting water temperature data in the study reach between June 28 and September 25, 2015 with a logger that recorded water temperature every 15 minutes. These water temperature data were compared with NorWeST model results generated by the USFS Rocky Mountain Research station (http://www.fs.fed.us/rm/boise/AWAE/projects/NorWeST.html). That model is based on data collected at various points throughout the Yellowstone River HUC6 watershed (100800), including the Big Horn catchment, and estimates water temperature in all streams and tributaries throughout the watershed.

In addition, a Nitrate + Nitrite-N sample was collected and analyzed by the Wyoming Department of Agriculture Analytical Services Laboratory. Finally, the Wyoming Department of Environmental Quality classification was noted and any sampling conducted by that agency or any other entities (using the EPA STORET database) to determine existing water quality conditions and the potential for deterioration with reduced water flow was considered as part of the evaluation.

Connectivity

River system connectivity functions along four dimensions: longitudinal, lateral, vertical, and temporal (Ward 1989). The ability of fish and many other aquatic organisms to move and migrate longitudinally within a stream is important to their survival and ability to meet spawning, feeding, and temperature needs. Lateral connectivity is critical to the functioning of floodplain-based stream ecosystems due to the transport of nutrients and organic matter from the floodplain to and from the stream during floods. This process is important in population dynamics of aquatic insects and ultimately affects fish productivity in streams. The seasonal flooding of unregulated streams creates and maintains diverse species of riparian vegetation (Nilsson et al. 1989), which increases stream channel stability and fosters diverse animal communities both within and adjacent to the stream channel. Vertical connectivity, the connections between ground water and stream flow, is important for maintaining water table levels, stream flows, and water temperatures. Temporal connectivity refers to the seasonal timing of stream flow and biological interactions that fish and other aquatic organisms have evolved with and depend upon.

In developing instream flow recommendations for the West Fork Long Creek segment, the presence of barriers to connectivity were considered for physical, chemical, and 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, and a combination of methods was used to address the seasonal patterns of stream flow needs. However, no detailed assessment was conducted to quantify flows needed to maintain lateral or vertical connectivity because of the difficulty in evaluating these connections. Although the ability of the stream to transport of nutrients, energy, and sediments was beyond the scope of this study, this process also is important in a properly functioning stream environment.

Instream Flow Recommendations

Results from all methods used in evaluation of all five riverine components (hydrology, biology, geomorphology, water quality, and connectivity) were considered in determining flow needs of YSC in West Fork Long Creek. However, Wyoming statute 41-3-1001-1014, which declares that instream flows may be appropriated for maintaining or improving fisheries, has been interpreted by Wyoming state engineers to include only hydrology and fisheries components of streams. This interpretation limits the ability to include the other riverine components (geomorphology, water quality, and connectivity) as a basis for quantifying flow regime needs for maintaining fisheries. Though not specifically included in the flow recommendations, information on these other important riverine components on West Fork Long Creek is presented in this report including a detailed discussion of channel maintenance flows in Appendix B.

The recommendations below are expected to maintain short-term habitat for YSC in West Fork Long Creek. However, the recommendations do not address changes in natural geomorphic characteristics and stream habitat forming processes expected to occur over time intervals of decades or longer. Consequently, the flow recommendations do not include channel maintenance flows and may not fulfill the statutory opportunity to maintain or improve the existing fishery on a long-term basis (perpetuity).

Instream flow recommendations were generated for three seasonal periods that are critical to the various life stages of YSC in West Fork Long Creek. The timing and duration of each seasonal period is based on YSC biology and hydrology information from the reference gage (Table 3; Figure 6). Over-winter survival of adult and juvenile YSC from October 1 – April 30 is addressed with the results of the Habitat Retention Method and natural winter flow analysis. The estimated hydrograph (Figure 5) indicates that, on average, relatively low base flow conditions in winter persist through late-April. Spawning and incubation habitat for YSC during the period from May 1 to July 15 is quantified using PHABSIM habitat modeling results. Summer habitat for growth, production, and movement of adult and juvenile YSC from (July 16–September 30) is evaluated with results of the Habitat Quality Index, Habitat Retention Method, and PHABSIM modeling results.

TABLE 3. Yellowstone cutthroat trout life stages and seasons considered in developing instream flow recommendations. Abbreviations 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. (NWF=Natural Winter Flow; HRM=Habitat Retention Method, PHABSIM=Physical Habitat Simulation; HQI=Habitat Quality Index, CM=Channel Maintenance).

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	NWF or HRM[1]		
Connectivity between habitats	HRM	HRM	HRM
Adult and juvenile habitat availability	PHABSIM	PHABSIM	PHABSIM
Spawning habitat availability		PHABSIM	
Adult and juvenile growth			HQI
Habitat maintenance for all life stages		CM[2]	

[1] Whichever is greater.
[2] Channel maintenance flow recommendations are presented in Appendix B.

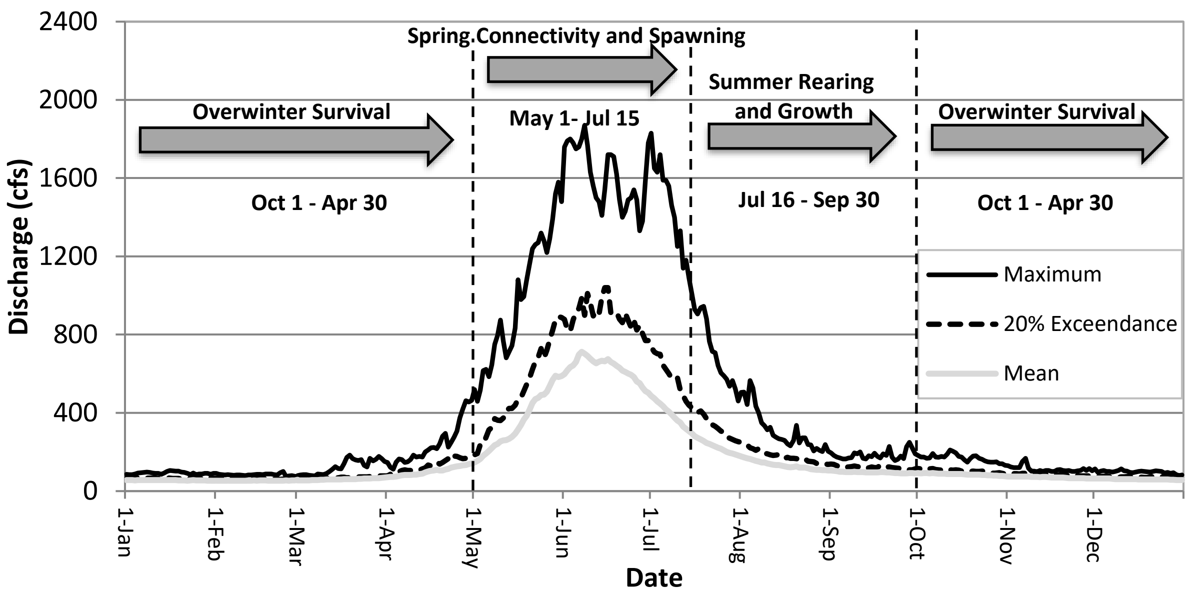


FIGURE 6. Maximum, 20% exceedance, and mean daily historical discharge values over the period of record at the reference gage with critical time periods for YSC distinguished. Discharge data are from the USGS stream gage on the Wind River near Dubois (06218500).

The models used for developing the recommendation for a given season were selected based on their appropriateness for the characteristics and flow needs at the study site (Table 3). Some models (e.g., Habitat Quality Index) are more suited to certain life stages and time periods so each was used during the season that was most appropriate. In some cases, the ecological characteristics and issues at the study site were unique and models used for developing flow recommendations in other studies were not necessarily appropriate in this situation. When two or more methods were appropriate for developing a flow recommendation, the one that yielded the higher flow requirement usually was chosen. Estimated monthly exceedance flows were considered in comparing the appropriateness of methods.

RESULTS

Hydrology

Stream flow at the Wind River near Dubois reference gage was high in 2015. At 201 cfs, mean discharge for the year was 17% higher than the mean discharge over the period of record (172 cfs). West Fork Long Creek flows were high early in the study period and delayed the onset of the field study. Base flows in the fall also may not have been as low as in other years. Nonetheless, all necessary data were collected to complete the study.

Using drainage area of 5.66 square miles and the Miselis et al. (1999) Wind River Mountains model based on drainage area, mean annual flow was estimated to be 3.8 cfs in the West Fork Long Creek instream flow segment (Table 4; Appendix B). Flood frequency analysis indicates that the 1.5-year peak flow is 23 cfs and the 25-year peak flow is 43 cfs. Monthly 50% and 20% exceedance values are displayed in Table 5. Discharge data collected during the study are presented in Table 6. In addition, a hydrograph was prepared that shows the mean, 20% exceedance, and maximum daily discharge estimates for the segment over the reference gage period of record (Figure 7).

TABLE 4. Estimated hydrologic characteristics for the West Fork Long Creek instream flow segment.

Flow Parameter	Estimated Flow (cfs)
Mean Annual	3.8
1.5-year peak	23
25-year peak	43

TABLE 5. Estimated monthly exceedance values for the West Fork Long Creek instream flow segment.

Month	50% Exceedance (cfs)	20% Exceedance (cfs)
October	1.8	2.3
November	1.5	1.9
December	1.3	1.6
January	1.2	1.5
February	1.2	1.4
March	1.3	1.5
April	1.9	2.9
May	6.6	12
June	13	20
July	5.4	10
August	2.7	4.0
September	2.0	2.7

TABLE 6. Dates of collection and discharge measurements in the West Fork Long Creek instream flow segment in 2015.

Date	Discharge (cfs)
6/28/15	2.5
8/1/15	1.0
9/25/15	0.48

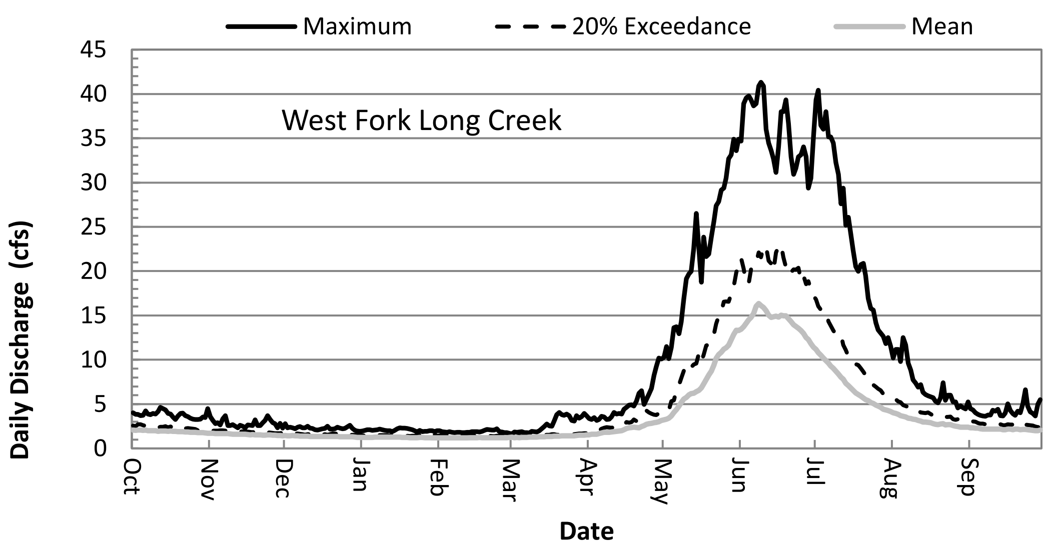
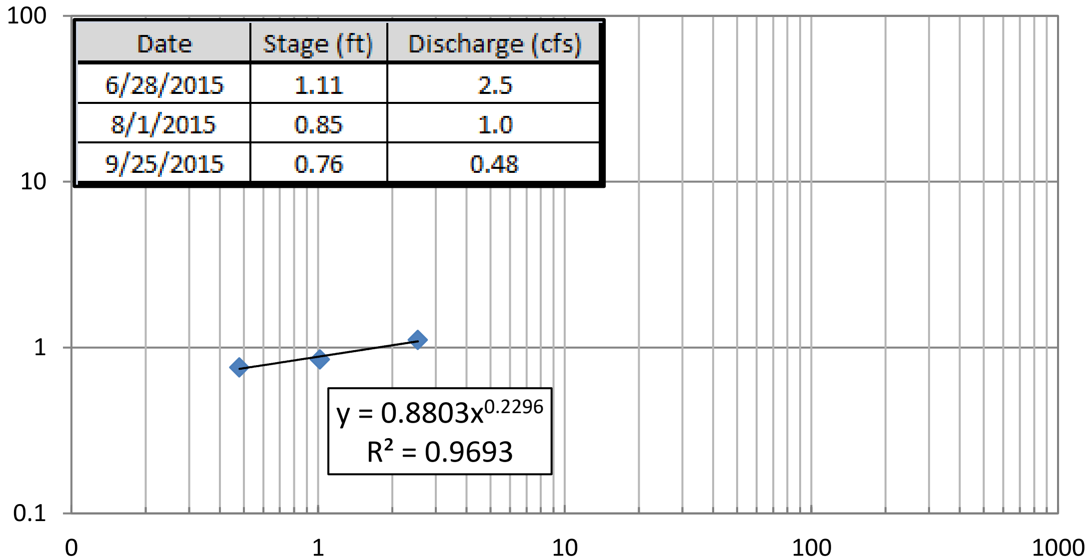


FIGURE 7. Hydrograph showing the maximum, 20% exceedance, and mean daily discharge estimates for the West Fork Long Creek study site.

The temporary stream gage in the West Fork Long Creek study site allowed estimates of daily discharge during the study period. Three stage and discharge pairs at 2.5 cfs, 1.0 cfs, and 0.48 cfs were collected to create the rating curve (Figure 8). This rating curve ($y = 0.8803x^{0.2296}$) was applied to the water level data recorded from the pressure transducer to generate an estimate of instantaneous and daily discharge values (Figure 9).



Date	Stage (ft)	Discharge (cfs)
6/28/2015	1.11	2.5
8/1/2015	0.85	1.0
9/25/2015	0.76	0.48

FIGURE 8. Rating curve data for the temporary gage established at the West Fork Long Creek study site during 2015.

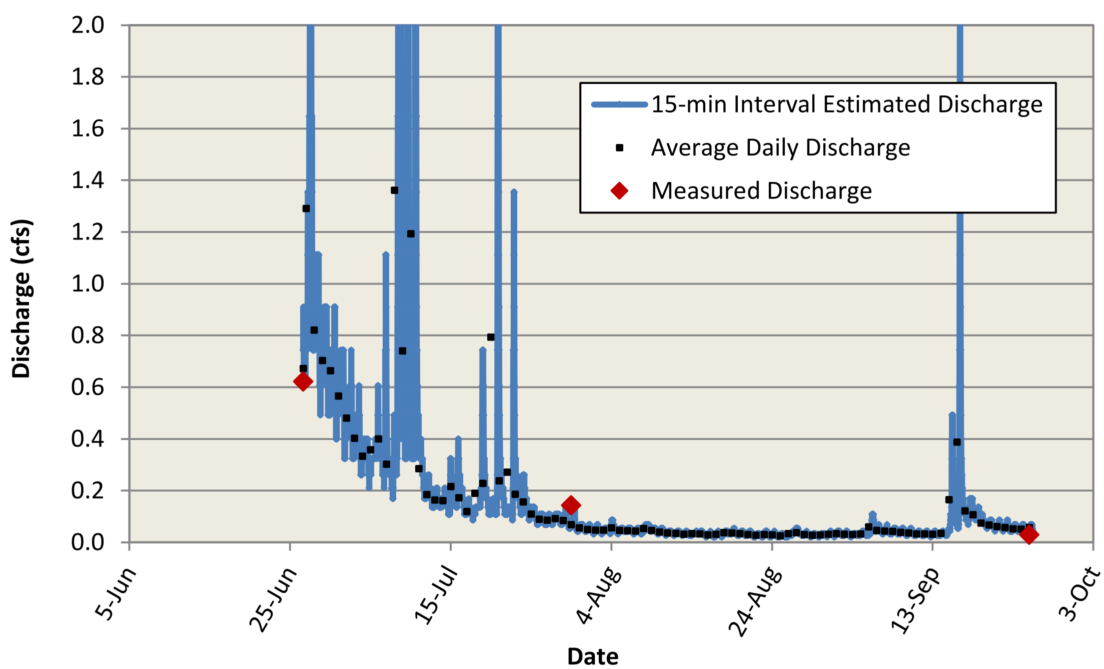


FIGURE 9. Estimated hydrograph for West Fork Long Creek study site during 2015.

Biology – Fish Habitat Modeling

Physical Habitat Simulation Model

The PHABSIM model was used to estimate weighted usable area (WUA) of habitat for adult, juvenile, and spawning life stages of YSC. The model results indicated that for the adult life stage, WUA increases with increasing flow up to 6.0 cfs and remains high up to about 10 cfs before decreasing slowly with additional increases in flow (Figure 10). The juvenile life stage WUA shows a similar increase up to 5.0 cfs and then decreases substantially at flows higher than 6 cfs. The lowest flow that maintained 95% or more of the WUA for both adult and juvenile life stages was 4.0 cfs. For the spawning life stage, WUA is essentially zero at flows up to 0.40 cfs, increases rapidly up to 3.0 cfs, and then declines with increasing flow; 4.0 cfs provides over 90% of the WUA for the spawning life stage.

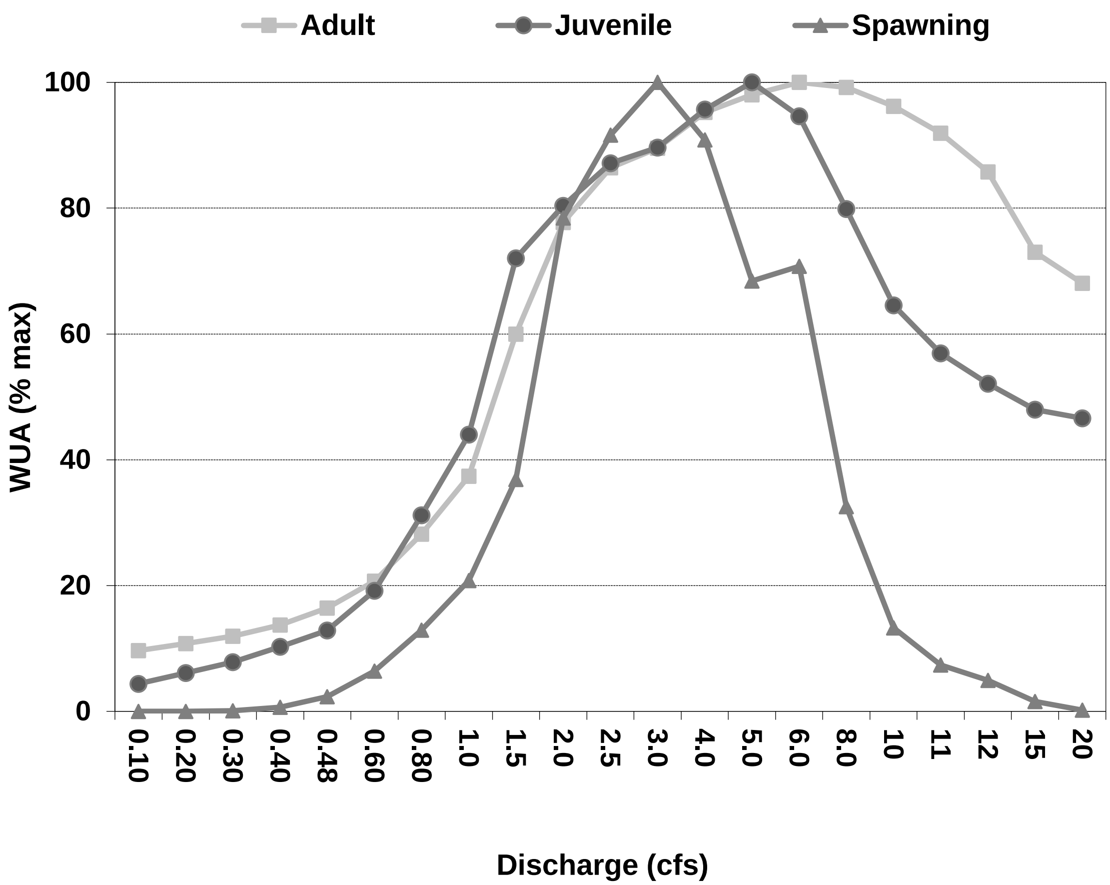


FIGURE 10. Relationship between WUA and discharge for YSC adult, juvenile, and spawning life stages in the West Fork Long Creek study site. X-axis values are not to scale; the values were chosen to highlight important habitat conditions.

Habitat Retention Method

The Habitat Retention Method was used to evaluate hydraulic characteristics that affect the survival and movement of all life stages, through all seasons, over a range of discharges in the West Fork Long Creek instream flow segment (Table 7). Three riffle cross-sections were modeled and the resulting discharge needed to maintain the necessary hydraulic criteria in all three riffles was 1.1 cfs. This threshold flow should maintain base level conditions for fish passage and provide overwinter survival habitat for fish and habitat for benthic invertebrate populations on riffles with similar characteristics as the riffle cross-sections, though higher flows at some times of year may be needed for other fishery purposes.

TABLE 7. Estimated hydraulic conditions for three riffles at selected modeled discharges in the West Fork Long Creek instream flow segment. Bold indicates that the hydraulic criterion (shown in Table 2) was met for an individual attribute at a selected discharge; the grayed-out value is the lowest discharge that meets two of the hydraulic criteria.

Riffle Transect Number	Discharge (cfs)	Mean Velocity (ft/s)	Mean Depth (ft)	Wetted Perimeter (% of bankfull)
1	20	5.48	0.62	83
	2.5	2.05	0.35	**50**
	0.75	1.12	**0.20**	45
	0.6	**1.00**	0.18	44
	0.1	0.50	0.07	38
2	20	2.68	0.73	162
	2.0	2.01	0.31	**50**
	1.1	1.77	**0.20**	46
	0.6	1.59	0.14	39
	0.1	**1.28**	0.04	30
3	20	3.54	0.77	105
	2.0	1.68	0.34	**50**
	0.67	1.07	**0.20**	43
	0.55	**1.00**	0.18	42
	0.1	0.68	0.05	35

Habitat Quality Index Model

The HQI model was used to determine production potential of adult and juvenile YSC in the study segment during summer (July 15 through September 30) flow conditions. The 20% exceedance flow value for September (2.7 cfs; Table 5) was used as an estimate of existing late summer flow levels for this model. At 2.7 cfs, the West Fork Long Creek site provides 188.8 HQI Habitat Units. The HQI model instream flow recommendation of 2.7 cfs is the lowest stream flow that provides as many Habitat Units as the 20% exceedance value (Figure 11). The model indicates that long-term reductions of late summer flow to levels less than 2.7 cfs would reduce the productivity of the existing fishery by over 20%.

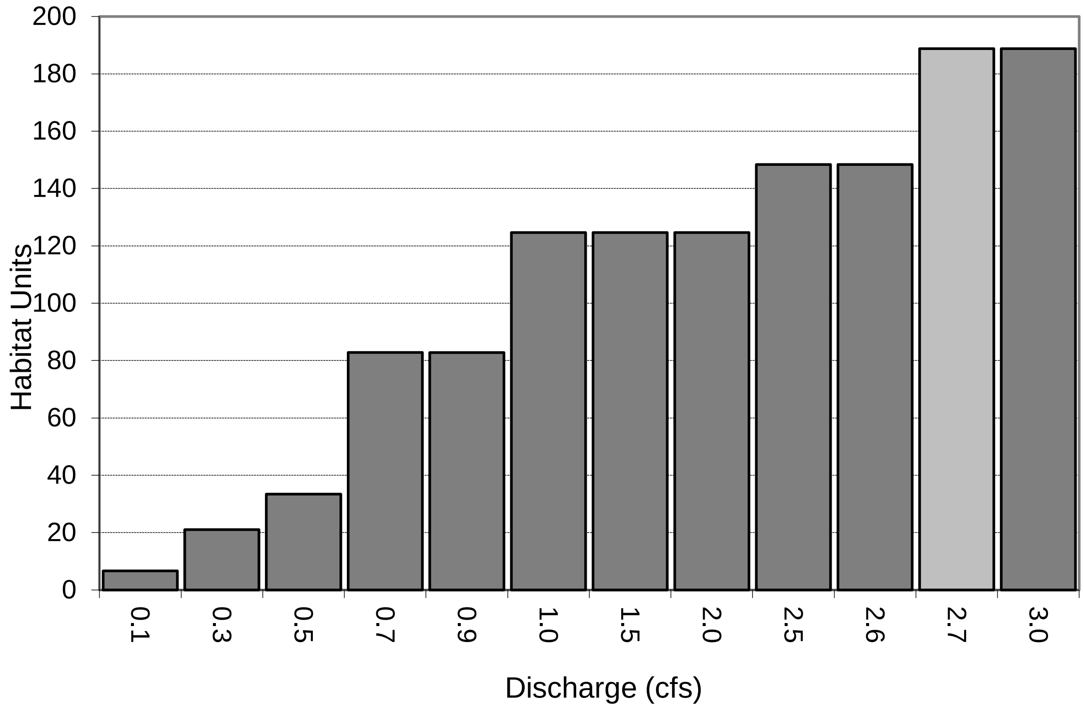


FIGURE 11. Habitat Quality Index vs. discharge in the West Fork Long Creek instream flow segment. X-axis values are not to scale; the values were chosen to indicate where changes in Habitat Units occur. The recommended flow (2.7 cfs) is needed to maintain the existing fishery and is indicated by the light shaded bar.

Natural Winter Flow Analysis

Between October through April, the estimated monthly 20% exceedance values in the proposed instream flow segment ranged from 1.4 cfs to 2.9 cfs (Table 5). According to this method, natural winter flows of up to 1.9 cfs, the mean of the 20% monthly exceedance discharges for the winter time period, are needed to maintain over-winter survival of all life stages of YSC at existing levels.

Geomorphology

The proposed instream flow segment in West Fork Long Creek is a mixture of Rosgen E-type channel, with a narrow and deep channel that has a low slope and high sinuosity, and B-type channel with steeper slopes and steep walls along the floodplain. The stream seems to be stable throughout the segment, with dense riparian cover stabilizing the banks in many areas and gravel substrates providing diverse habitat conditions for fish. Large wood contributions from the riparian habitats contribute to pool development.

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

West Fork Long Creek is a high elevation stream located on USFS lands and has little development within its catchment. As such, water quality conditions in West Fork Long Creek were assumed to be favorable for supporting the fishery at most times of year and in most years. Water quality could potentially deteriorate with any substantial reduction in flow or alteration of watershed form or function.

The Wyoming Department of Environmental Quality rates West Fork Long Creek as a "Class 2AB" water (WYDEQ 2013). 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. Class 2AB waters include all permanent and seasonal game fisheries and can be either 'cold water' or 'warm water' depending upon the predominance of cold water or warm water species present. All Class 2AB waters are designated as cold water game fisheries unless identified as a warm water game fishery by a 'ww' notation in the 'Wyoming Surface Water Classification List'. 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."

The maximum recorded water temperature in West Fork Long Creek was 62.2° F during the study period, with temperatures exceeding 55° F approximately 9.3% of the time between June 28 and September 25, 2015. The mean August temperature recorded in 2015 was 49.3° F. The NorWeST model generated by the Rocky Mountain Research Station estimates the mean August temperature to be 49.4° F at the downstream end of the West Fork Long Creek instream flow segment; the data collected in our study are very close to the historical (1993-2011) average estimated in the NorWeST model. The NorWeST model also considers future changes in stream temperatures and predicts a mean August temperature of 51.0 F in 2040 in this reach. Isaak and Hubert (2004) found that cutthroat trout abundance peaked in Wyoming streams around 53.6° F and Carlander (1969) indicates that YSC are commonly found in streams with a temperature range between 40° F and 60° F. Dwyer and Kramer (1975) found that metabolic activity peaks around 59° F. The water temperatures in West Fork Long Creek seem to favor YSC currently and will continue to be within suitable ranges with even a moderate increase; however, if flow were reduced substantially, water temperatures might increase to a point that YSC would be negatively affected. An additional concern for the effect of elevated temperatures on YSC is that some studies have indicated that water temperatures above 60° F provide non-native BKT a competitive advantage that would negatively affect the sympatric YSC population (De Staso and Rahel 1994; Dunham et al. 1999; Novinger 2000).

A review of the EPA STORET database did not show any water quality monitoring data from West Fork Long Creek. There are several sampling locations within the Upper Wind River watershed; however, the nearest sampling station is in a drainage to the east, Du Noir Creek. That location was sampled in August 2005. Dissolved oxygen was about 8.6 mg/L and pH was slightly basic at 7.8; these values were well within the WYDEQ thresholds for each parameter. Turbidity was much lower than the WYDEQ threshold of 10 NTU for cold water fisheries and/or drinking water supplies with a measurement of 1.29 NTU. These results indicate that water quality conditions are good in Du Noir Creek. While this does not directly correlate with conditions in the Long Creek watershed, there were also several samples from more distant streams within Upper Wind River watershed that indicated good water quality conditions. These data suggest water quality in West Fork Long Creek, with similar land use in its watershed, is probably good quality as well. The only water quality data that were collected at the study site included a single Nitrate + Nitrite – N sample, which was analyzed by the Wyoming Department of Agriculture Analytical Services Laboratory; the result was 0.012 mg/L, which is also a very low value and further supports the findings that water quality is good in this segment.

Flow recommendations in this report are expected to help maintain water quality within natural bounds and it is assumed that existing water quality features will remain 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 is an old diversion structure at the downstream end of the instream flow segment that does not seem to be used currently. There is one road crossing in the lower portion of the watershed that is downstream of the instream flow segment. The culvert at the road crossing has been reconfigured recently with an open-bottomed arch that alleviates any connectivity issues for resident fishes and improves flow conditions. The stream seems to have access to the narrow floodplain throughout the watershed except for a short reach, immediately upstream of the culvert, that has steep slopes on both sides and no floodplain development.

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.

Instream Flow Recommendations

The recommendations for specific seasonal fishery needs for the West Fork Long Creek instream flow segment are (Table 8; Figure 12):

- Winter (October 1 – April 30) – Natural winter flows of up to 1.9 cfs are needed to maintain over-winter survival of all life stages of YSC at existing levels. This flow value is the result of the natural winter flow analysis.
- Spring (May 1 – July 15) – Natural flow up to 4.0 cfs is needed to provide sufficient habitat for spawning YSC as well as adult and juvenile YSC (PHABSIM results).
- Summer (July 16 – September 30) – Natural flow up to 2.7 cfs is needed, based on HQI results, to provide sufficient habitat conditions for growth and production of juvenile and adult YSC.

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

Study Segment	Winter Oct 1 – Apr 30	Spring May 1 – Jul 15[1]	Summer Jul 16 – Sep 30
West Fork Long Creek	1.9	4.0	2.7

[1] Channel maintenance flow recommendations for the spring runoff period are defined in Appendix B.

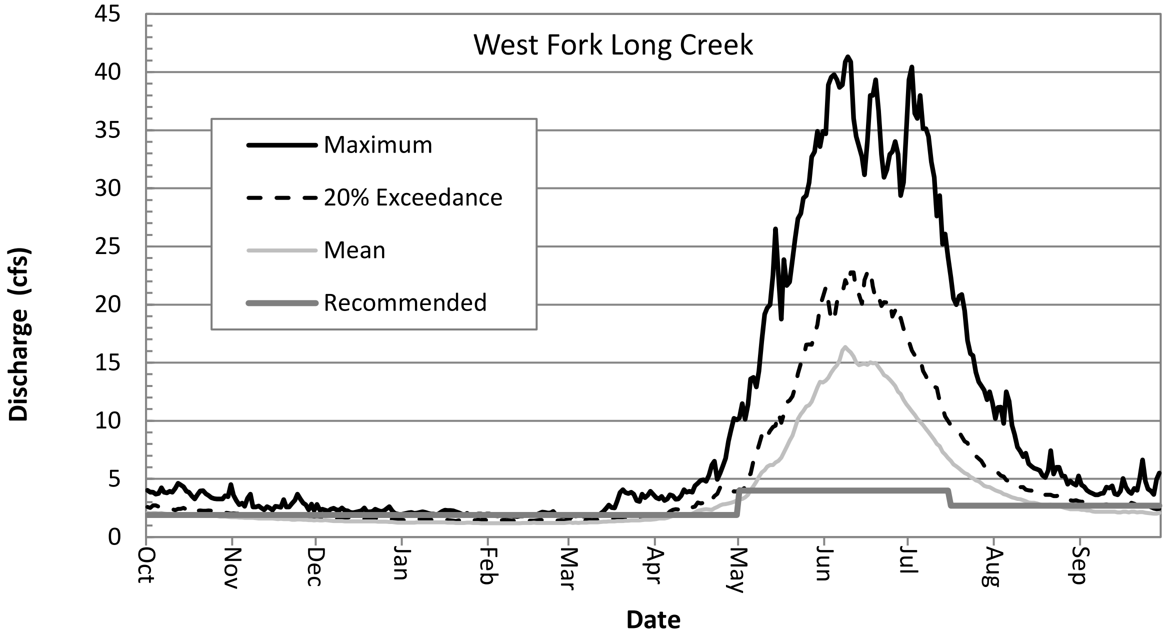


FIGURE 12. Recommended instream flow water right segment (when flow is naturally available) in the proposed relative to maximum, 20% exceedance, and mean daily discharge estimates.

DISCUSSION

West Fork Long Creek is within the historical range of YSC habitat and this stream is important in the long-term management plan for the species. Protecting stream flows that provide this habitat and support the population of trout will help ensure the long-term persistence of the species in the Upper Wind River watershed 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. If approved by the State Engineer, the proposed instream flow water right filing on West Fork Long Creek will maintain existing base flow conditions, when naturally available, against potential future out-of-channel uses up to the permitted amount. As a result, approximately 4.2 miles of YSC stream habitat will be maintained in West Fork Long Creek. If drastic, long-term changes to watershed form or function occur, then flow recommendations would need to be reviewed to achieve the statutorily provided opportunity of maintaining or improving the existing fishery.

ACKNOWLEDGEMENTS

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Appendix A. Instream Flows in Wyoming

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 (WGFC) 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 WGFC. The WGFD conducts biological studies to determine the quantity of flow needed to maintain or improve fisheries. The Wyoming Water Development Office conducts a feasibility study to determine the availability of flow to meet the recommendations and submits the instream flow water right applications. If approved by the State Engineer, instream flow water rights are held by the Wyoming Water Development Office 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. As with all other water rights in Wyoming, the doctrine of prior appropriation applies and instream flow water rights are junior to all pre-existing water rights in the stream. Permitted instream flow water rights will not affect the lawful use of water for senior rights.

BIOLOGICAL STUDIES

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. A comprehensive instream flow study is designed to consider all five riverine ecosystem components (hydrology, biology, geomorphology, water quality and connectivity) and all aspects of each component (e.g., long-term habitat processes; Annear et al. 2004); however, 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 when making instream flow recommendations (though information is provided in biological study reports, where available).

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 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. Until the interpretation of state water law changes to include a full range of flows of a dynamic fishery, channel maintenance flow recommendations are not included on instream flow applications, but are presented in an appendix of the biological studies report.

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. 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). By using the eight components described by the IFC as a guide, WGFD strives 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.

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 WGFD Water Management Unit's work plan (Robertson and Annear 2011).

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.

Instream flow segments are nearly always located on public land; however, landowners adjacent to a proposed segment have the opportunity to request that the state 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. Instream flow segments are not located on private lands without such a request.

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Appendix B. Channel Maintenance Flows

BACKGROUND

Maintaining a dynamic flow regime within the natural range of variability and including occasional high flows, is important in streams for maintaining diverse in-channel habitat for fisheries and riparian and floodplain vegetation (Kuhnle et al. 1999). A managed flow regime should mimic natural dynamic hydrographs within and between years (Gordon 1995, Trush and McBain 2000, Schmidt and Potyondy 2004) and include these higher flows that maintain the channel form and habitat conditions for fish over the long term (decades). High flows are needed in some years to scour the stream channel, prevent encroachment of stream banks, and deposit sediments on the floodplain to maintain a dynamic alternate bar morphology and a riparian community with diverse successional states (Carling 1995, Annear et al. 2004, Locke et al. 2008). Low flow years allow establishment of riparian seedlings on bars deposited in immediately preceding wet years (Trush and McBain 2000). Any time water is extracted from a stream the natural dynamic patterns change; larger quantities of extraction have a greater effect on habitat conditions and the organisms associated with those habitats. If naturally occurring high flows were reduced substantially on a regular basis, it would have negative effects 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 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 and "identifies the minimum essential regime of stream flows necessary for the channel and its floodplain to remain fully functioning with respect to sediment and flow conveyance." These are streams whose beds are dominated by loose material with median sizes larger than 0.08 inches 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 includes sufficient flow for 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, streambed elevation, streamside vegetation, water-carrying capacity, and changes in bed material composition.

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}) is the upper limit of the required channel maintenance flow regime, because 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. Because 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 of 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). Therefore, flows up to the Q_{25} flow are required to maintain existing channel form and critical habitat features for local fish populations.

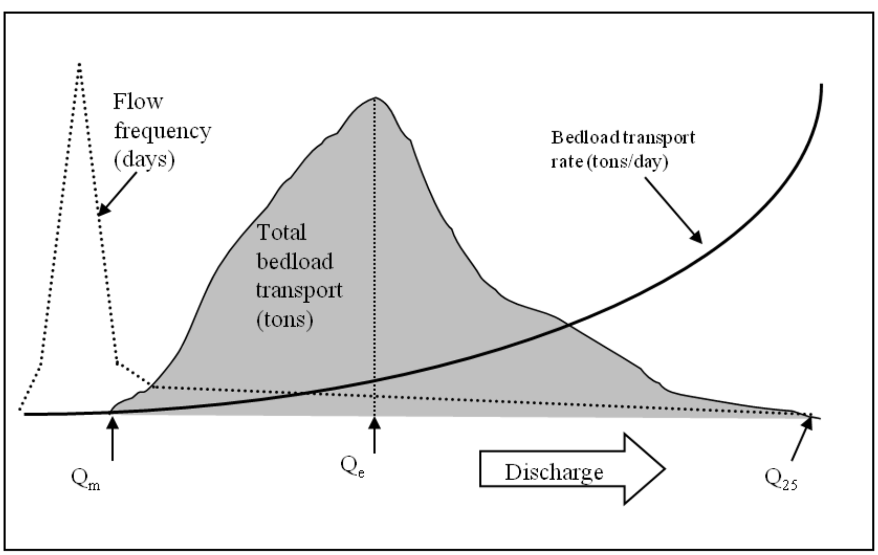

FIGURE B-1. Total bedload transport as a function of bedload transport rate and flow frequency (adapted from Schmidt and Potyondy 2004).

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}:

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

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 can 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 (Figure B-2).

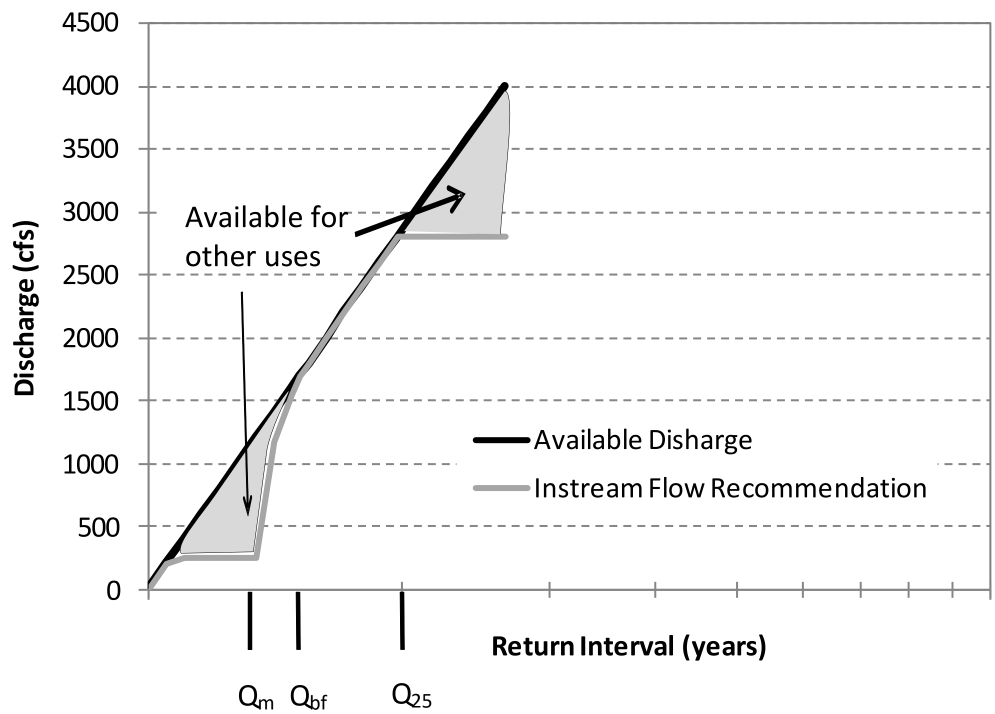

FIGURE B-2. Generalized dynamic hydrograph indicating recommended instream flow for fishery maintenance. Q_m is substrate mobilization flow, Q_{bf} is bankfull flow, and Q_{25} is the discharge with a 25-year return interval.

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. 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.

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.

WEST FORK LONG CREEK

Like all properly functioning rivers, West Fork Long 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 forms. 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, with modification to include a single recommendation for each of the four quartiles from Q_m to Q_{bf}, was used to develop channel maintenance recommendations for the West Fork Long Creek instream flow segment (Table B-1). The fish flow used in the analysis was the spring spawning flow (4.0 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 less than Q_m (18 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} (23 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} (43 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 West Fork Long Creek instream flow segment.

Flow Description	**Available Flow (cfs)**	**Recommended Flow (cfs)**
<Spawning Flow	<4	All available flow
Spawning Flow to Q_m	4-18	4
Q_m to Q_{bf} – Quartile 1	19-20	17
Q_m to Q_{bf} – Quartile 2	21	19
Q_m to Q_{bf} – Quartile 3	22	21
Q_m to Q_{bf} – Quartile 4	23	23
Q_{bf} to Q_{25}	23-43	All available flow
> Q_{25}	≥ 43	43

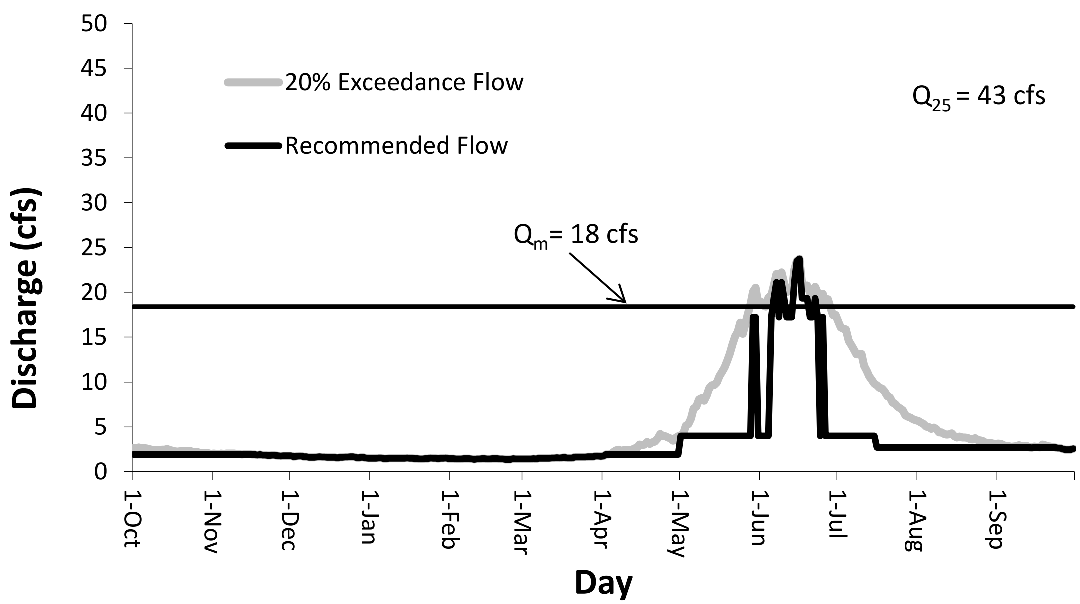

FIGURE B-3. Channel maintenance flow recommendations and hydrographs for the West Fork Long Creek instream flow segment if the flow were at the 20% exceedance flow all year.

Implementing these channel maintenance flow recommendations would have to include moderating the abrupt changes that occur at threshold flows with a ramping scheme that includes more gradual changes similar 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. In addition, spawning redds may be disturbed and fish recruitment negatively affected without an appropriate ramping rate. The Index of Hydrologic Alteration (IHA; Richter et al. 1996) or other hydrologic summary models 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.

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Appendix C. Hydrology Estimates for the Ungaged Study Segment

There are multiple methods for generating daily discharge estimates in ungaged stream segments; the one chosen for these estimates is based on watershed characteristics that can be calculated from maps and climatology data from the study area. These watershed characteristics models were developed using stream gage data both regionally and statewide. The results of these calculations and flow estimates for the study segment are compared with field data collected during the instream flow study. These results could be paired with a field hydrologic study (e.g., following the study design of 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 using a watershed characteristics model, a reference stream gage is first selected to provide baseline discharge data. The qualities of a good reference gage are: 1) that it be located close to the study segment (within the same eight-digit HUC drainage is 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 watershed 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 segments. Once a reference gage is selected, the recorded flow estimates from that gage are adjusted to correct for differences 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 segment.

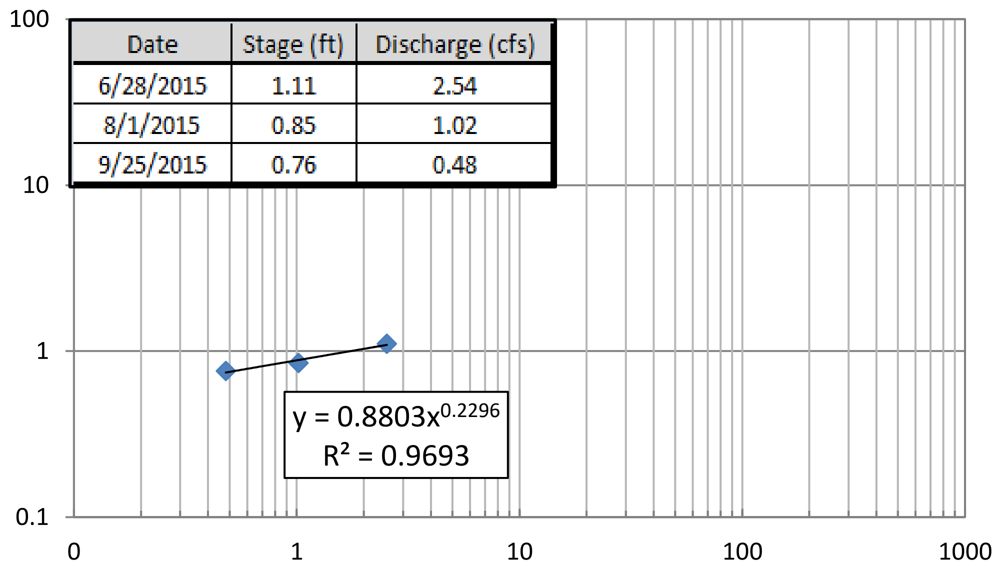
In the area near the West Fork Long Creek study segment, there are three active and one inactive USGS stream gaging sites that have more than 20 years of data and were considered as potential reference gages (Table C-1). Because there are good reference gage options that are active, the one inactive gage was excluded from consideration. All USGS gages were within the same HUC8 watershed (10080001- Upper Wind). The range of drainage basins among these gages was 88-1,073 square miles and all five of the 2015 study segments, including West Fork Long Creek, were much smaller with a range of 0.3-17.7 square miles. From this perspective, none of the gages is particularly well suited as a reference, but the one with the largest drainage area (1,073 square miles) is substantially larger than the study segments and least desirable for this characteristic. Among the three active gages, the one with the smallest drainage area, Dinwoody Creek, was the most distant from the study segment, whereas the Wind River near Dubois (06218500) was closest. Based on this observation, and the fact that the Wind River near Dubois gage had the longest period of record, it was selected as the reference gage for this study.

TABLE C-1. Potential USGS reference gages.

Gage Name	Gage Number	Period of Record	Drainage Area	Elevation (ft)
Wind River above Red Ck, WY	06220800	1990-2018	1,073	6,400
Wind River near Dubois, WY	06218500	1945-2018	232	7,188
Dinwoody Ck abv lakes, near Burris, WY	06221400	1957-2018	88.2	6,500
East Fork Wind River near Dubois, WY	06220500	1950-1997	427	6,450

TEMPORARY STREAM GAGE DATA

A temporary stream gage station was established upstream of the West Fork Long Creek study site between June 28, 2015 and September 25, 2015. Discharge measurements collected during the study period were used with stage readings from the staff plate during the same day to establish a rating curve (Figure C-1). This rating curve was used to estimate discharge from water level readings at the study site (Figure C-2) and then those data were compared to daily discharge values at the Wind River near Dubois reference gage (Figure C-3). The discharge estimates at the study site were closely correlated with discharge estimates at the reference gage; there was some divergence at higher flows where a high flow event in one location did not correspond closely to a high flow event in the other location.



Date	Stage (ft)	Discharge (cfs)
6/28/2015	1.11	2.54
8/1/2015	0.85	1.02
9/25/2015	0.76	0.48

FIGURE C-1. Rating curve data for the temporary gage established at the West Fork Long Creek study site during 2015.

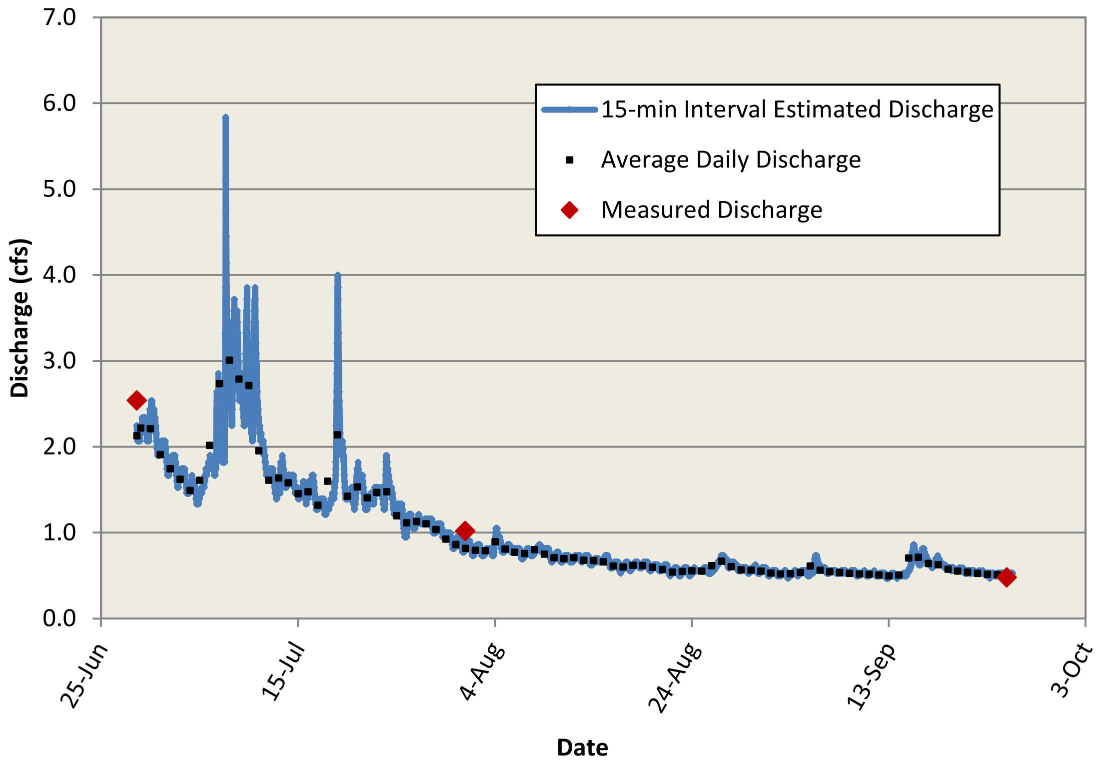


FIGURE C-2. Estimated hydrograph for West Fork Long Creek study site during 2015.

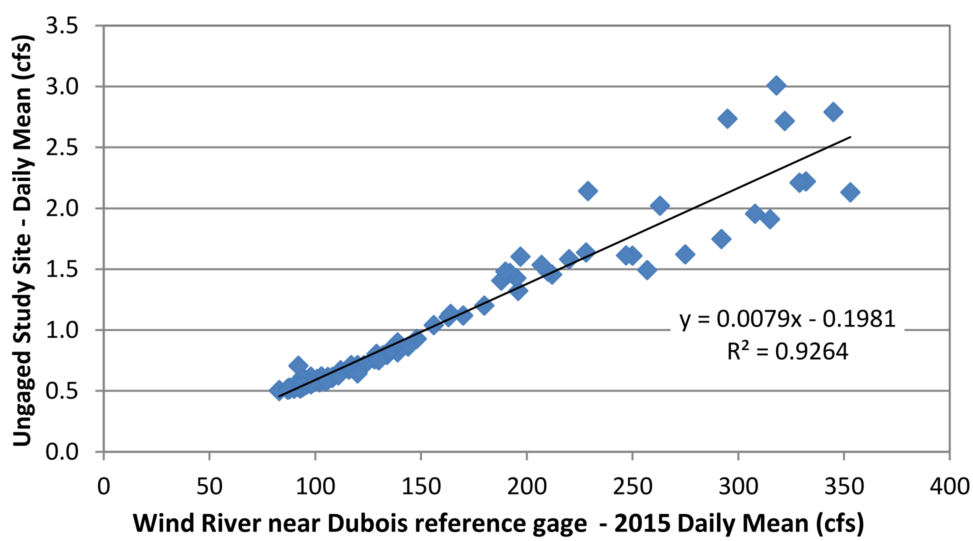


FIGURE C-3. Correlation between daily discharge estimates at the West Fork Long Creek study site in 2015 and the daily discharge estimates at the Wind River near Dubois (USGS Gage 06218500) reference gage.

WATERSHED MODEL SELECTION

After selecting a reference gage, models using various watershed characteristics were evaluated to determine which model is best suited to the study area. Potential models that use variables that include 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 are based on streams found in mountainous areas statewide. Miselis et al. (1999) 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 segment, though sometimes a detailed evaluation may provide support for an alternate model. Local discharge measurements or temporary stream gaging data at the study segment provide additional data sources, when available, to help guide model selection.

The Q_{AA} for the Wind River near Dubois reference gage (06218500) was 172 cfs for period of record water years 1946-1992 and 2002-2018. Table C-2 shows how closely each of several possible models comes to estimating the actual Q_{AA} for this location. The closest model was the Miselis model using drainage area for the Wind River mountains which estimated flow at the gage should be 173 cfs.

TABLE C-2. Watershed model estimates of mean annual discharge (Q_{AA}) for the Wind River near Dubois (USGS Gage 06218500) reference gage. The best model is shown in bold.

Model Description	Model[1]	Wind River Q_{AA} (cfs)
Miselis et al (1999): Mountainous for WY, Drainage Area	$1.20976\ DA^{0.894}$	158
Miselis et al (1999): Wind River Mountains, Mean Elevation	$1.00^{e-22}\ BE^{6.01}$	55
Miselis et al (1999): Wind River Mountains, Drainage Area	**$0.63504\ DA^{1.03}$**	**173**
Miselis et al (1999): Wind River Mountains, Precipitation	$0.00025\ P^{4.24}$	82
Miselis et al (1999): Wind River Mountains, Stream Length	$2.32809\ SL^{1.12}$	92
Miselis et al (1999): Wind River Mountains, Bankfull Width	$0.05664\ Wbf^{1.84}$	127
Lowham (1988): Drainage area and Mean Elevation	$0.0015DA^{1.01}(Elev/1000)^{2.88}$	200.6
Lowham (1988): Drainage area and Precipitation	$0.013DA^{0.93}P^{1.43}$	149.4
Lowham (1988): Bankfull Width	$0.087\ Wbf^{1.79}$	158
Wind River near Dubois, Water Years 1946-1992 and 2002-2018		172

[1] Basin characteristics include: DA – drainage area (232.0 square miles); P – annual precipitation (20 inches); SL – stream length (26.7 miles); Elev – mean basin elevation (8,920 feet); Wbf – Bankfull channel width (66.2 feet).

DIMENSIONLESS ANALYSIS

Once the watershed characteristics model was selected, a dimensionless analysis approach was used to develop estimates of daily flow, annual and monthly flow duration curves, and flood frequency for the proposed instream flow segment. The procedure uses the difference in the scale of the known Q_{AA} at the reference gage and the estimated Q_{AA} at the ungaged study segments to shift data from the reference gage up or down by the appropriate correction factor to estimates for the ungaged study segment. 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 reference gage location. The watershed model provides the Q_{AA} estimate at the ungaged study segment so the formula is rearranged to solve for Q_2 (daily discharge at the ungaged location).

FLOW ESTIMATES FOR THE WEST FORK LONG CREEK STUDY SEGMENT

Using the watershed characteristics model of Miselis (1999) based on drainage area ($0.63504\ DA^{1.03}$), Q_{AA} at the West Fork Long Creek study segment (drainage area of 5.66 square miles) was estimated to be 3.8 cfs. Daily flows were estimated for the study segment over the same period of record as the reference gage (water years 1946-1992 and 2002-2018) and a graph of mean, 20% exceedance, and maximum daily discharge was prepared (Figure C-4). A flood frequency series (Table C-3) was calculated using the Log-Pearson Type III method, and annual (Table C-4) and monthly (Table C-5) flow duration series were also calculated.

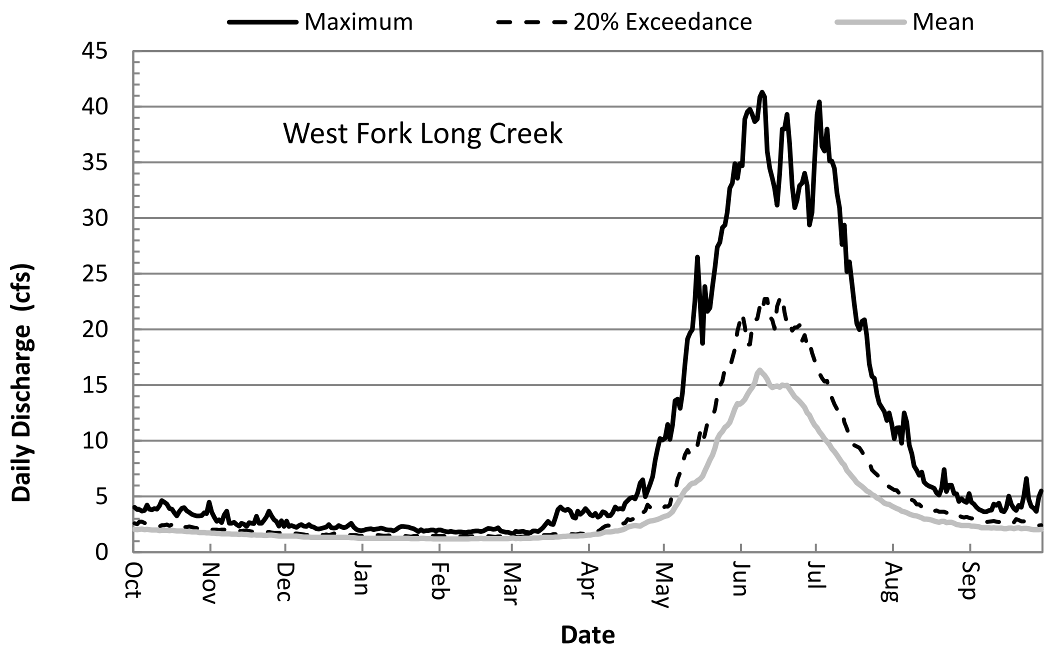


FIGURE C-4. Hydrograph showing the maximum, 20% exceedance, and mean daily discharge estimates for the West Fork Long Creek study segment.

TABLE C-3. Flood frequency data for the Wind River near Dubois (USGS Gage 06218500) reference gage and estimated values at the West Fork Long Creek study segment.

Return Period (years)	**Wind River (water years 1946-1992 and 2002-2018)**	**Dimensionless (Q/QAA using gage data)**	**West Fork Long Creek**
1.01	529	3.0734	12
1.05	679	3.9472	15
1.11	779	4.5262	17
1.25	907	5.2737	20
1.5	1038	6.0344	23
2	1187	6.9040	26
5	1517	8.8208	34
10	1709	9.9341	38
25	1926	11.1996	43

TABLE C-4. Annual exceedance flow for the Wind River near Dubois (USGS Gage 06218500) reference gage and estimated values at the West Fork Long Creek study segment.

Duration Class (% time flow equaled or exceeded)	**Annual Exceedance Flow Wind River (water years 1946-1992 and 2002-2018)**	**Dimensionless (Q/QAA using gage data)**	**Predicted Annual Exceedance Flow West Fork Long Creek**
95	44	0.2558	1.0
90	50	0.2907	1.1
85	53	0.3081	1.2
80	56	0.3256	1.3
75	60	0.3488	1.4
70	64	0.3721	1.4
65	68	0.3953	1.5
60	72	0.4186	1.6
55	76	0.4419	1.7
50	82	0.4767	1.8
45	88	0.5116	2.0
40	97	0.5640	2.1
35	110	0.6395	2.4
30	129	0.7500	2.8
25	156	0.9070	3.5
20	203	1.1802	4.5
15	300	1.7442	6.6
10	439	2.5523	9.7
5	675	3.9244	15

TABLE C-5. Monthly exceedance flow estimates for West Fork Long Creek study segment.

Duration Class (% time flow equaled or exceeded)	Stream Flow (cfs)											
	Oct	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**July**	**Aug**	**Sep**
95	1.2	1.0	0.9	0.8	0.8	0.9	1.2	1.9	4.8	1.9	1.4	1.3
90	1.3	1.1	1.0	0.9	0.9	1.0	1.3	2.3	6.2	2.4	1.6	1.4
85	1.4	1.1	1.0	0.9	1.0	1.1	1.4	2.8	7.1	2.8	1.7	1.5
80	1.5	1.2	1.1	1.0	1.0	1.1	1.4	3.1	7.7	3.1	1.8	1.6
75	1.5	1.3	1.1	1.0	1.0	1.1	1.5	3.5	8.5	3.4	2.0	1.7
70	1.6	1.4	1.1	1.1	1.1	1.2	1.5	3.9	9.3	3.7	2.1	1.7
65	1.6	1.4	1.2	1.1	1.1	1.2	1.6	4.4	10	4.1	2.2	1.8
60	1.7	1.5	1.2	1.1	1.1	1.2	1.7	5.2	11	4.5	2.3	1.9
55	1.8	1.5	1.3	1.2	1.1	1.3	1.8	5.9	12	4.9	2.5	1.9
50	1.8	1.5	1.3	1.2	1.2	1.3	1.9	6.6	13	5.4	2.7	2.0
45	1.9	1.6	1.4	1.2	1.2	1.3	2.0	7.3	14	5.9	2.8	2.1
40	1.9	1.7	1.4	1.3	1.2	1.4	2.2	8.1	15	6.5	3.0	2.2
35	2.0	1.7	1.5	1.3	1.3	1.4	2.3	8.9	16	7.2	3.1	2.3
30	2.1	1.8	1.5	1.4	1.3	1.5	2.5	9.9	18	8.0	3.3	2.4
25	2.2	1.8	1.5	1.4	1.4	1.5	2.7	11	19	8.9	3.6	2.6
20	2.3	1.9	1.6	1.5	1.4	1.5	2.9	12	20	10	4.0	2.7
15	2.5	2.0	1.7	1.5	1.5	1.6	3.2	14	22	11	4.3	2.9
10	2.7	2.0	1.8	1.7	1.5	1.7	3.7	17	25	13	4.7	3.1
5	3.0	2.2	2.0	1.8	1.7	1.9	4.5	20	29	16	5.6	3.5

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