WYOMING GAME AND FISH DEPARTMENT

FISH DIVISION

ADMINISTRATIVE REPORT

Title: Instream Flow Studies on Dry Fork Little Bighorn River, Sheridan County, Wyoming

Project: IF-SN-8LH-511

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ABSTRACT

Studies were conducted from 1991 to 1993 on the Dry Fork of the Little Bighorn River to identify instream flow needs and mitigation requirements for a proposed hydroelectric project. The instream flow water right recommendations contained in this report are based on those studies. The Habitat Quality Index model was used to assess the relationship between stream flow and habitat quality for adult trout in the summer. A physical habitat simulation model was used to develop instream flow recommendations for adult, juvenile and spawning rainbow trout habitat. A dynamic hydrograph model was used to quantify instream flow needs for channel maintenance. The lowest summer flow that will maintain adult trout habitat quality at its present level between July 1 and September 30 is 25 cfs. The instream flow needed to maintain physical habitat for adult and juvenile rainbow trout from October 1 to March 31 is 20 cfs. Physical habitat for spawning is maximized at 25 cfs from April 1 to June 30. A range of instream flows for maintaining channel characteristics and habitat is provided for the period of April 1 to June 30.

INTRODUCTION

The Wyoming Game and Fish Department (WGFD) conducted fisheries studies on the Dry Fork Little Bighorn (Dry Fork) between 1991 and 1993 to identify potential fishery impacts and mitigation needs for a proposed hydroelectric project (Dey and Annear 1993, Zafft and Annear 1991). The scope and detail of those studies was sufficient for preparing an instream flow water right application as per W.S. 41-3-1003 (b) and are the basis for the recommendations provided in this report.

The Dry Fork is the largest tributary to the Little Bighorn River in Wyoming (Figure 1) and is classified by the WGFD as a Class 3 trout stream. Class 3 trout streams are generally considered important sport fisheries on a regional level in the state. The section of the Dry Fork downstream from the mouth of Lick Creek is also under consideration for designation as a federally recognized Wild and Scenic River. The entire segment exhibits unique, pristine wilderness characteristics. The stream and its tributaries are isolated such that the entire stream system is relatively un-impacted by human developments (logging, roads, grazing, water diversion, etc.).

The Dry Fork supports self-sustaining populations of rainbow and brook trout. The downstream portions of the stream are dominated by rainbow trout whereas the headwaters contain primarily brook trout. The lack of vehicular access to large portions of the stream limits angler use but provides one of the few situations in the state and Rocky Mountain region where anglers can find a wilderness-type setting outside of a formally designated wilderness area.

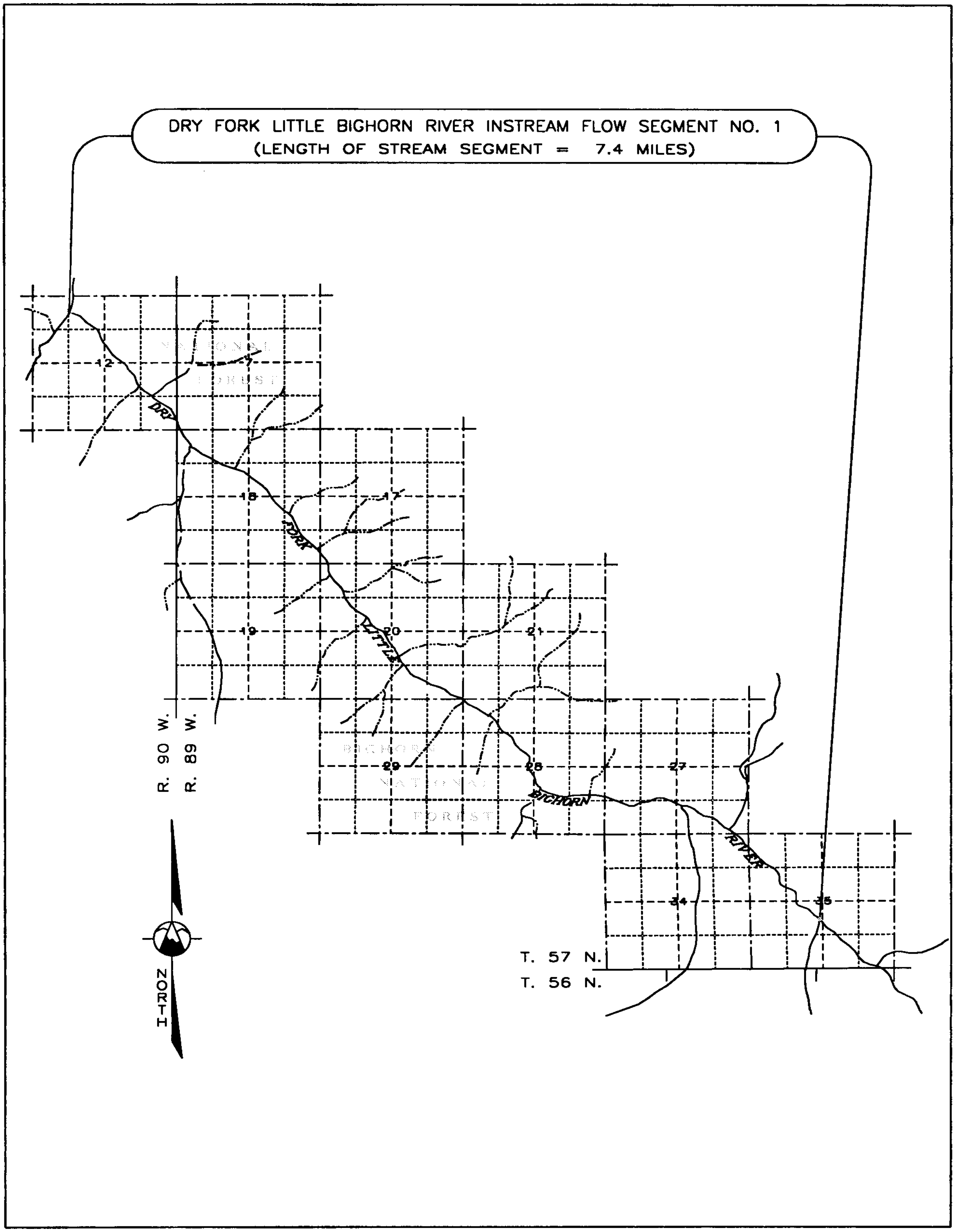

Figure 1. Location of Dry Fork Little Bighorn instream flow segment.

Over its length the Dry Fork transitions from a relatively low gradient gravel-bed stream to high gradient boulder-bed stream and then back to a lower gradient stream near its mouth. The stream flows through a fairly confined valley with dense conifers along its entire course. Most of the bedload (gravel and sediment) originates in the headwaters so connectivity of the tributaries and adequate stream flow are important attributes for maintaining the structure and function of the stream throughout its length.

To maintain or improve the unique existing fishery resources of the Dry Fork as well as its wild and scenic characteristics, adequate and continuous instream flows are critically important. The purpose of this report is to 1) quantify year-round instream flow levels needed to maintain or improve habitat for existing rainbow trout populations, 2) quantify instream flows needed to maintain long-term trout habitat and related physical and biological processes and 3) provide the basis for filing an application for an instream flow water right to maintain these beneficial uses. Results from these studies apply to the entire segment of the Dry Fork from its confluence with Garland Gulch Creek in T57N, R89W, S35 downstream to its mouth in T57N, R90W, S12. This segment is approximately 7.4 stream miles long (Figure 1).

BASIS FOR QUANTIFYING FISHERY INSTREAM FLOWS

Statutory Concepts

Preserving stream fisheries is a state obligation under the public trust doctrine. In 1986, the Wyoming legislature acted to affirm this responsibility by enacting legislation that provided a specific mechanism for fulfilling this responsibility. Wyoming Statute 41-3-1001(a) 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..." To fishery managers who helped craft this legislation, the intent of the statute was to do more than simply protect enough flow to keep fish alive in streams at all times. Rather, the statute was supported to provide fishery managers the opportunity to legally protect adequate flows to maintain existing habitat, fish community characteristics and public enjoyment opportunities (Mike Stone, WGFD, Cheyenne; personal communication). The following discussion provides our interpretation of the terms used in this statute.

Perhaps the most critical term referenced in the statute is the word "fishery". Since passage of the instream flow law, the Wyoming Game and Fish Department has identified instream flows to protect habitat for various species and life stages of fish. However, a fishery is in fact the interaction of aquatic organisms, aquatic environments and their human users to produce sustained benefits (Nielsen 1993, Ditton 1997). In other words, a fishery is a product of physical, biological and chemical processes as well as societal expectations and uses. Each component is important, each affects the other and each presents opportunities for affecting the character of a fishery resource. Fish populations are merely one attribute of a fishery.

The term "existing" fishery also warrants clarification. In this application, "existing" does not refer to a constant number of fish. In fact, fish populations commonly fluctuate annually, seasonally and daily in streams in response to a variety of environmental factors (House 1995, Nehring and Anderson 1993). In a western Oregon stream studied for 11 years, the density of cutthroat trout fry varied from 8 to 38 per 100 m^2 and the density of cutthroat trout juveniles ranged from 16 to 34 per 100 m^2 (House 1995). In this example, population fluctuations occurred despite the fact that summer habitat conditions were not degraded and appeared to be relatively stable.

The natural variability of flow, geology, climate and vegetation influence stream-forming processes which form and control fish habitat which in turn influences the spawning success, survival and growth of fish. Factors like movement, migration, and predation can also affect fish numbers over time and space. Though many fishery management decisions are based on a presumption that fish populations are at or near an equilibrium level, Van Den Avyle (1993) notes that populations that fluctuate randomly or cyclically around a long-term equilibrium level should be considered stable. Thus "existing fishery" is not a single, constant number of fish to be maintained by a defined target flow; but is a process in both time and space.

The WGFD instream flow strategy recognizes the inherent variability of trout populations in response to a range of environmental variables and defines the "existing fishery" as a dynamic equilibrium of habitat, fish, water quality and societal factors. Instream flow recommendations are based on a goal of maintaining flow-based habitat conditions that provide the opportunity for trout populations to fluctuate within existing, natural levels.

The amount of water needed to maintain the existing fishery also warrants interpretation. Section (d) of the above statute establishes that "waters used for the purpose of providing instream flows shall be the minimum flow necessary to maintain or improve existing fisheries". The law does not specifically define the term minimum; however it seems likely this term suggests the amount used for this purpose should be only as much water as is needed to achieve the objective of maintaining existing fisheries without exceeding that amount. It certainly cannot mean the least amount of water in which fish can live since fish are only one component of a fishery and other flow-related characteristics like habitat structure and water quality must also be addressed to maintain existing fisheries.

The statute likewise provides no indication that "minimum needed" refers to anything other than quantity. Certainly duration of flow is not a criterion of beneficial use that is commonly applied to any other water right. In fact, W.S. 41-3-101 establishes "Beneficial use shall be the basis, the measure *and limit* of the right to use water at all times, not exceeding the statutory limit except as provided by W.S. 41-4-317." Likewise, W.S. 41-4-317 defines "surplus" and "excess" water as "those waters belonging to the state in excess of the total amount required to furnish to all existing appropriations from the stream system *at any time*". Further, the Board of Control holds that water rights may remain in good standing if the permitted amount is put to the specified beneficial use at least once when it is available during any five-year period. Thus, the minimum needed for any purpose, including fisheries maintenance, does not mean the lowest flow that is available at all times.

The limit of water provided for some beneficial uses is established by statute. For agricultural uses it is defined by W.S. 41-4-317 as 1 cfs for each 70 acres of land irrigated. The limit of beneficial use for instream flow is likewise defined by statute (W.S. 41-3-1003 (b)) as an amount of water necessary to provide adequate instream flows as determined by the Game and Fish Commission. In consideration of these factors, the instream flow recommendations in this report are the minimum needed to achieve beneficial use for maintaining or improving the identified stream fishery. Beneficial use for fisheries maintenance is realized at any flow up to the recommended amount(s) regardless of the frequency or duration of the flow.

Fishery Maintenance Concepts

The science of quantifying instream flows for fisheries is a relatively young one. It was not until the first major instream flow conference in Boise, Idaho in May 1976 that it was recognized as its own multi-disciplinary field (Osborn and Allman 1976). Quantitative instream flow models were initially applied in 1979 when the U.S. Fish and Wildlife Service produced the first version of the now widely accepted Physical Habitat Simulation Methodology.

Methods for quantifying instream flow needs have evolved considerably since this time and continue to evolve today. Likewise, administrative policies for interpreting the results of studies and securing adequate flows to protect and enhance important public fishery resources have undergone similar development.

Since passage of Wyoming's instream flow law in 1986, the Wyoming Game and Fish Department approached quantification of instream flows for fisheries from a relatively narrow perspective of identifying flows only for fish. This tactic was consistent with the perspective of many natural resource management agencies at the time that placed a priority on protecting fish populations. A considerable body of knowledge has now been developed that indicates instream flows for fish alone will not achieve their intended objective over the long term. In fact, establishing instream flows only on the basis of fish needs may result in the alteration of geo-morphological process, reduction or alteration of riparian vegetation and changes in flood plain function if high flows are subsequently removed or reduced (Trush and McBain 2000). The removal of significant amounts of flow from some rivers may result in habitat change and a reduction or alteration in fish populations and diversity (Carling 1995, Hill et al. 1991). Quantification of instream flows for only fish thus may be inconsistent with legislation directing protection of existing fisheries.

Continuous, seasonally appropriate instream flows are essential for maintaining diverse habitats and viable, self-sustaining fish communities. The basis of maintaining existing fisheries (fisheries management) is facilitating the dynamic interaction of flowing water, sediment movement and riparian vegetation development to maintain good habitat and populations of fish and other aquatic organisms. To fully comply with Wyoming's instream flow statute, instream flows must address the instantaneous habitat needs for the target species and life stages of fish and other aquatic organisms during all seasons of the year. However, instream flows must also maintain the existing dynamic character of the entire fishery, which means they must maintain functional linkages between the stream channel, riparian corridor and floodplain to perpetuate essential habitat structure and ecological function.

Properly functioning stream channels are in approximate sediment equilibrium where sediment export equals sediment import on average over a period of years (USDA Forest Service 1997, Carling 1995). When sediment-moving flows are removed or reduced over a period of years, some gravel-bed channels respond by reducing their size (width and depth), rate of lateral migration, stream-bed elevation, bed material composition, structural character, stream side vegetation and water-carrying capacity. Consequently, to provide proper channel function while also providing adequate instantaneous habitat for fish, instream flows for fisheries maintenance must include both fish flows as well as channel maintenance flows.

METHODS

Instream Flows for Fish

Instream flows for fish propagation, or fish flows, are generally regarded as base flows needed to perpetuate survival and growth of target species and life stages (Trush and McBain 2000). Any of several methods that reasonably describe the relationship between flow and instantaneous habitat characteristics serve this function. These methodologies are typically based on existing channel characteristics and the assumptions that the present channel form will be maintained in perpetuity and the target fish population or community is relatively stable. Three different methods were used for this study.

Habitat Modeling

Study Site

After visually surveying the stream from the mouth of Garland Gulch Creek to about one-half mile below the mouth of Lick Creek, a study area was established on the Dry Fork about one-quarter mile downstream from its confluence with Lick Creek at T57N, R89W, S28 SW 1/4. Habitat at this site consisted mostly of pocket pool habitat behind boulders in the main channel and lateral scour pools along the stream banks. This site contained habitat for all motile life stages of rainbow trout as well as spawning habitat.

Physical Habitat Simulation

Physical Habitat Simulation (PHABSIM) methodology was used to quantify physical habitat (depth and velocity) availability for rainbow trout spawning as well as for adult and juvenile life stages over a range of discharges. This methodology was developed by the Instream Flow Service Group of the U.S. Fish and Wildlife Service (Bovee and Milhous 1978) and is widely used for assessing instream flow relationships between fish and existing physical habitat (Reiser et al. 1989).

The PHABSIM method uses empirical relationships between physical variables (depth, velocity, and substrate) and suitability for fish to derive weighted usable area (WUA; suitable ft^2 per 1000 ft of stream length) at various flows. Depth, velocity, and substrate were measured along transects (*sensu* Bovee and Milhous 1978) on the dates in Table 1. Hydraulic calibration techniques and modeling options in Milhous et al. (1984) and

Milhous et al. (1989) were employed to incrementally estimate physical habitat between 14 and 165 cfs. The modeled range accommodates typical flows in the Dry Fork for the seasons of interest.

Table 1. Dates and discharges when data were collected on the Dry Fork Little Bighorn River in 1991.

Date	Discharge (cfs)
July 9	67
August 22	35

Curves describing depth, velocity and substrate suitability for trout life stages are a necessary component of the PHABSIM modeling process. Suitability curves for rainbow trout were obtained from the U.S. Geological Survey, Biological Research Division (Raleigh, et al. 1986).

Rainbow trout in the Dry Fork typically spawn between April 1 and May 31 depending on runoff and stream water temperature patterns. The eggs remain buried in the gravels until hatching within 40 to 60 days (depending on water temperature). Recommendations for spawning were therefore developed for the period of April 1 to June 30. Adult and juvenile trout are present in the stream at all times of year. Instream flow recommendations based on this method for these life stages were provided for the period of October 1 to March 31, because the physical habitat elements included in the model (depth, velocity and substrate) are the primary ones affecting the amount of habitat. The Habitat Quality Index model (below) was used to quantify instream flow needs when biotic elements were also important (summer).

Habitat Quality Index

The Habitat Quality Index (HQI; Binns and Eisermann 1979) was used to estimate trout production over a range of late summer flow conditions. This model was developed by the WGFD and received extensive testing and refinement. It has been reliably used in Wyoming for trout habitat gain or loss assessment associated with instream flow regime changes. The HQI model includes nine attributes addressing biological, chemical, and physical aspects of trout habitat. Results are expressed in trout Habitat Units (HUs), where one HU is defined as habitat that will support about 1 pound of trout. HQI results were used to identify the flow needed to maintain or improve existing levels of trout habitat quality between July 1 and September 30.

In the HQI analysis, habitat attributes measured at various flow events are assumed to be typical of normal late summer flow conditions. Under this assumption, HU estimates are extrapolated through a range of potential late summer flows (Conder and Annear 1987). Habitat attributes in the Dry Fork were measured on the dates shown in Table 1. Some attributes were mathematically derived to establish the relationship between discharge and trout production at discharges other than those measured.

Instream Flows for Channel Maintenance

As noted previously, fisheries are comprised of the aquatic organisms found in streams as well as the physical habitat in which they live. In fact, the organisms found in streams are a direct expression of the quality and quantity of habitat and habitat processes over time and space (Hill et al. 1991). Both fisheries biologists and hydraulic geo-morphologists realize that maintenance of channel characteristics, which comprise aquatic habitat requires periodic channel maintenance flows (USDA Forest Service 1997, Carling, 1995, Leopold 1994, Hill et al. 1991).

Channel maintenance flow, as used in this report, refers broadly to instream flows that maintain existing channel morphology, riparian vegetation and floodplain function (USDA Forest Service 1997). The concepts discussed here apply primarily to gravel-bed streams. By definition, these are streams whose beds are dominated by loose material with median sizes larger than 2 mm and may have 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 (Hill et al. 1991).

Properly functioning stream channels maintain the basic stream structure (pools, riffles, depth, width and meander) necessary to sustain the natural aquatic community structure. They also pass the entire bed load that originates from tributaries on average over time. In doing so, they maintain the quality of habitat for fish and other aquatic organisms by transporting fine sediments and depositing gravels in a manner that enables those organisms to complete all important parts of their life cycles. For example adult trout can spawn successfully in clean riffles and young fish can burrow into silt-free cobble substrates in winter. By transporting all incoming bedload, properly functioning stream channels maintain their flow carrying capacity, which helps attenuate the magnitude and frequency of flooding. Properly functioning stream channels likewise exhibit variable lateral migration across the floodplain, which encourages development of staggered age classes and functions of riparian vegetation that benefit organisms in the stream.

Floodplains are extensions of the channel during both high and low flow periods. In high flow periods, they help cycle nutrients, store sediments, recharge groundwater and wetlands, distribute flow and attenuate flooding downstream. In low flow periods, floodplain groundwater seeps back into the channel and helps sustain continuous flow. Streamside vegetation is a common and necessary component of floodplains that affect aquatic organisms in streams. These vegetation communities filter pollutants, capture sediment, modify stream temperature by shading, provide woody debris for both cover and nutrient cycling and regulate the exchange of water between the groundwater and stream. Floodplain structure and function is an integral part of maintaining fisheries by affecting in-channel habitat for fish and other aquatic organisms.

Maintenance of channel features cannot be obtained by a single threshold flow. Rather, a dynamic hydrograph within and between years is needed for continuation of processes that maintain stream channel and habitat characteristics (Gordon 1995; USDA Forest Service 1997; Trush and McBain 2000). High flows are needed to scour the stream channel, prevent encroachment of stream banks and deposit sediments to maintain a dynamic alternate bar morphology and successionally diverse riparian community. Low flow years are as valuable as high flow years on some streams to allow establishment of riparian seedlings on bars deposited in immediately preceding wet years (Trush and McBain 2000). The natural interaction of high and low flow years maintains riparian development and aquatic habitat by preventing annual scour that might occur from continuous high flow (allowing some riparian development) while at the same time preventing encroachment by riparian vegetation that would occur if flows were artificially reduced at all times.

Stream channel characteristics over space and time are a function of sediment input and flow (USDA Forest Service 1997). Bankfull flow is generally regarded as the flow that moves most sediment, forms and removes bars, bends and meanders, and results in the average morphologic characteristics of channels over time (Dunne and Leopold 1978, Andrews 1984). As a rule, bankfull flows are confined enough to mobilize and transport bed material. When flow increases above bankfull, flow depths and velocities increase less rapidly. At higher flow, water spreads out onto the floodplain and decreases the potential for catastrophic channel damage.

To maintain channel form and processes, flows must be sufficient to move both the entire volume and all sizes of material supplied to the channel from the watershed over a long-term period (USDA Forest Service 1997). A range of flows is needed (as opposed to a single specified high flow) because, though higher discharges move more sediment, they occur less frequently so that over the long-term, they move less bedload than more frequent, lesser discharges (Wolman and Miller 1960). Thus instream flows for channel maintenance will vary both within a year and between years. The total bedload transport curve (Figure 2) shows the amount of bedload sediment moved by stream discharge over the long-term as a product of flow frequency and bedload transport rate. As this figure indicates, any artificial limit on peak flow for channel maintenance that prevents movement of the entire bedload through a stream over time creates sediment disequilibrium that would result in gradual bedload accumulation. The net effect would be an alteration of existing channel forming processes and habitat. For this reason, the 25-year peak flow is the minimum needed to maintain existing channel form.

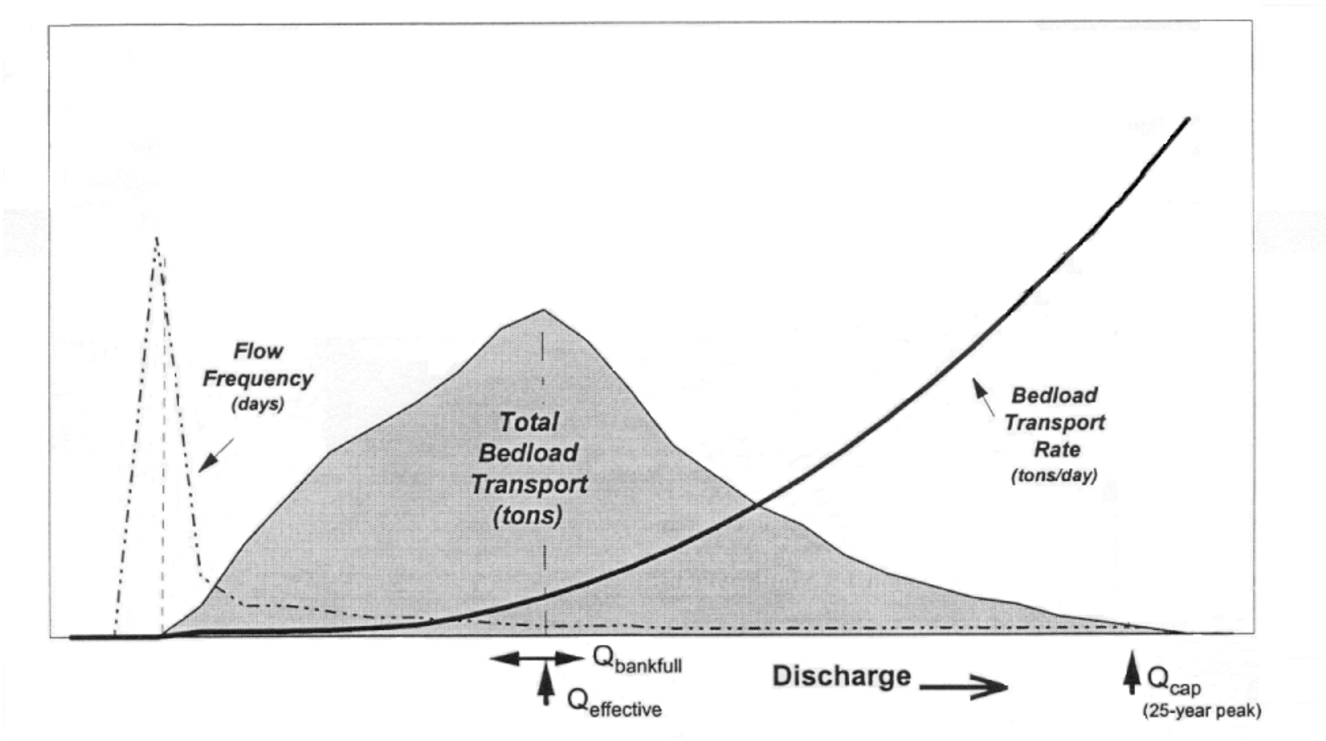

Figure 2. A general model of sediment transport processes for channel maintenance (U.S. Forest Service 1997).

The movement of substrate from the bottom of Rocky Mountain streams begins at flows somewhat greater than average annual flows but lower than bankfull flows (John Potyondy, Stream Systems Technology Center, USFS Rocky Mountain Research Center, Fort Collins, CO; personal communication). Ryan (1996) and Emmett (1975) found the flows that generally initiated transport were between 0.3 and 0.5 of bankfull flow. Regular movement of small particles is important to clean cobble and riffle areas of fine materials. This process and level of flow is commonly referred to as a flushing flow. Movement of coarser particles begins at flows of about 0.5 to 0.8 of bankfull (Carling 1995, Leopold 1994). This phase of transport is significant because of its potential to maintain channel form. Without mobilization of larger bed elements, only the fine materials will be flushed from the system, which over time causes the bed to armor and allows vegetation to permanently colonize gravel bars. This process ultimately enables stream banks to encroach on the natural channel (Carling 1995, Hill et al. 1991). Providing only higher flushing flows allows fine sediments to accumulate in years when target flows do not occur naturally and reduces the net transport of bedload materials. The loss of both of these processes eventually changes the ecological function of the stream and habitat suitability for existing aquatic organisms. Table 2 provides a description of the primary characteristics of stream ecosystem structure and function (Trush and McBain 2000).

Based on these principles, the following model was developed by Dr. Luna Leopold and is used in this report. The model is identical to the one presented in Gordon (1995) and U.S. Forest Service (1994) with one variation. The model presented in those documents used the average annual flow (Q_a, normally about 0.2 times bankfull flow) as the flow at which substrate movement begins. This term was re-defined here

Table 2. General attributes of alluvial, gravel-bed river ecosystems (Trush and McBain 2000).

<u>Spatially complex channel morphology</u>: No single segment of channel-bed provides habitat for all species, but the sum of channel segments provides high-quality habitat for native species. A wide range of structurally complex physical environments supports diverse and productive biological communities.

<u>Flows and water quality are predictably variable</u>: Inter-annual and seasonal flow regimes are broadly predictable, but specific flow magnitudes, timing, durations, and frequencies are unpredictable due to runoff patterns produced by storms and droughts. Seasonal water quality characteristics, especially water temperature, turbidity, and suspended sediment concentration, are similar to regional unregulated rivers and fluctuate seasonally. This temporal "predictable unpredictability" is the foundation for river ecosystem integrity.

<u>Frequently mobilized channel bed surface</u>: Channel bed framework particles of coarse alluvial surfaces are mobilized by the bankfull discharge, which on average occurs every 1-2 years.

<u>Periodic channel bed scour and fill</u>: Alternate bars are scoured deeper than their coarse surface layers by floods exceeding 3- to 5-year annual maximum flood recurrences. This scour is typically accompanied by re-deposition, such that net change in channel bed topography following a scouring flood usually is minimal.

<u>Balanced fine and coarse sediment budgets</u>: River reaches export fine and coarse sediment at rates approximately equal to sediment inputs. The amount and mode of sediment storage within a given river reach fluctuate, but also sustain channel morphology in dynamic quasi-equilibrium when averaged over many years. A balanced coarse sediment budget implies bedload continuity; most particle sizes of the channel bed must be transported through the river reach.

<u>Periodic channel migration</u>: The channel migrates at variable rates and establishes meander wavelengths consistent with regional rivers having similar flow regimes, valley slopes, confinement, sediment supply, and sediment caliber.

<u>A functional floodplain</u>: On average, floodplains are inundated once annually by high flows equaling or exceeding bankfull stage. Lower terraces are inundated by less frequent floods, with their expected inundation frequencies dependent on norms exhibited by similar, but unregulated river channels. These floods also deposit finer sediment onto the floodplain and low terrace.

<u>Infrequent channel resetting floods</u>: Single large floods (e.g., exceeding 10-yr to 20-yr recurrences) cause channel avulsions, rejuvenation of mature riparian stands to early-successional stages, side channel formation and maintenance, and create off-channel wetlands (e.g., oxbows). Resetting floods are as critical for creating and maintaining channel complexity as lesser magnitude floods.

<u>Self-sustaining diverse riparian plant communities</u>: Natural woody riparian plant establishment and mortality, based on species life history strategies, culminate in early- and late-successional stand structures and species diversities (canopy and understory) characteristics of self-sustaining riparian communities common to regional unregulated river corridors.

<u>Naturally fluctuating ground water table:</u> Inter-annual and seasonal groundwater fluctuations in floodplains, terraces, sloughs and adjacent wetlands occur similarly to regional unregulated river corridors.

as the substrate mobilization flow (Q_m) and assigned a value of 0.5 times bankfull flow based on the above studies by Ryan (1996) and Emmett (1975). Setting Q_m at a higher flow level leaves more water available for other uses by not initiating the call for channel maintenance flows until this higher flow is realized and thus meets the statutory standard of "minimum needed".

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

Q_s = available stream flow
Q_l = base flow (fish flow)
Q_m = substrate mobilization flow
Q_b = bankfull flow

The equation is based on the concept that channel maintenance flows are needed when stream flow begins to mobilize bed load materials. Incrementally higher percentages of flow are needed as flow approaches bankfull because the river does most of its work in transporting materials and maintaining fish habitat as flows approach bankfull. At flows greater than bankfull the instream flow is then equal to the actual flow to maintain floodplain function as well as stream channel form. The upper limit of flow specified by Leopold is the 25-year recurrence flow as this is the flow that assures transport of all bed material over time. Maintaining the opportunity for this level of flow in a natural setting minimizes the potential for causing flood-related property damage while providing sufficient depth for riparian vegetation and wetland maintenance and groundwater recharge. Figure 3 provides an illustration of instream flow needs relative to available stream flow.

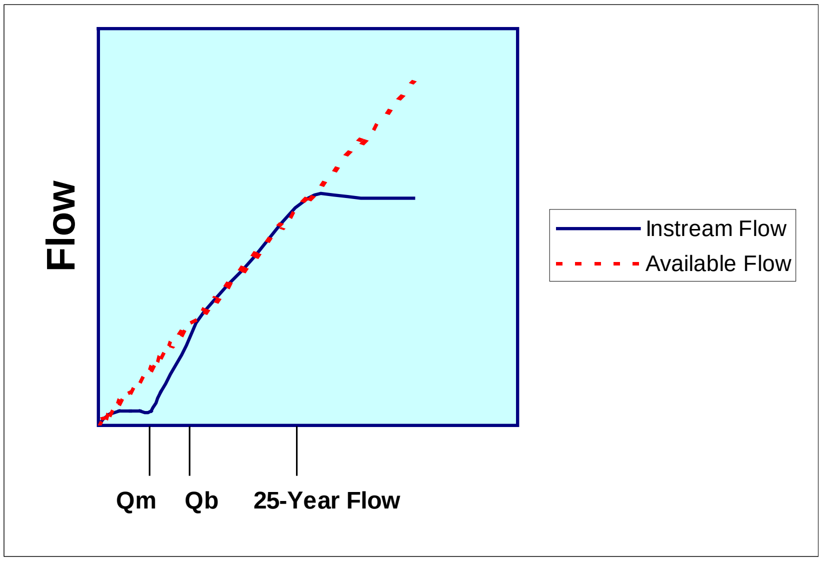

Figure 3. General function of a dynamic hydrograph instream flow for fishery maintenance. (Q_m = substrate mobilization flow, Q_b = bankfull flow)

The Leopold equation yields a continuous range of instream flow recommendations at flows between the sediment mobilization flow and bankfull for each cubic foot per second increase in flow. This manner of flow regulation could prove burdensome to water managers should a reservoir ever be built on the Dry Fork or its tributaries. To facilitate flow administration while still ensuring reasonable flows for channel maintenance, we modified this aspect of the approach to claim instream flows at each increased increment of 25 cfs between the sediment mobilization flow and bankfull.

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

Hydrology

Quantification of channel maintenance flows necessitated definition of existing flow characteristics. Key hydrologic statistics for the channel maintenance flow model are the 25-year flood flow and bankfull flow.

Hydrologic characteristics for the Dry Fork were developed by Little Horn Energy Wyoming, Inc. as part of the permit application for their proposed pump-storage project (LHEW 1993). Their hydrologic analysis was based on a correlation between data gathered at a project gage on the Dry Fork at its confluence with Lick Creek (gage number 62887) and the USGS gage downstream on the Little Bighorn River (gage number 662890). The gage below Lick Creek was operated for part or all of water years between 1982 to 1987 and 1992 to 1997.

Determination of bankfull flow has proven difficult and contentious for some hydrologists. Though some hydrologists make this determination directly with field measurements, others argue that transect placement can bias results. Bankfull is generally regarded as a flow that recurs in the stream every 1 to 2 years (Trush and McBain 2000). To minimize the bias associated with field data collection and provide a repeatable quantification level, we defined bankfull flow as the 1.5-year flood frequency (Larry J. Schmidt, Program Manager, Stream Systems Technology Center, USFS Rocky Mountain Research Center, Fort Collins, CO; Tom Wesche, Habitech, Laramie, WY; personal communication).

The gage records for both sites are considered "Good" by the U.S. Geological Service (USGS). By definition, this means that 95% of the daily discharges are within 10 percent of their true values. Thus, results of this hydrologic analysis and the conclusions based thereon must be viewed accordingly.

Seasonal Application of Results

Maintaining adequate, continuous flow at all times of year is critically important to maintain the population integrity of all life stages of trout. Both spawning and fry life stages may be constrained by habitat "bottlenecks" (Nehring and Anderson 1993); however, all life stages may face similar critical periods. Identifying critical life stages and periods is thus necessary to focus flow recommendations. Our general approach includes ensuring that adequate flows are provided to maintain spawning habitat in the spring as well as adult and juvenile habitat at all other times of the year (Table 3). The instream flow recommendation for any month where two or more recommendations apply is based on the recommendation that yields the higher flow.

Table 3. Rainbow trout life stages and months considered in the Dry Fork instream flow recommendations. Numbers indicate the method used to determine flow requirements.

Fishery Function	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Rainbow Trout Spawning Habitat				1	1	1						
Adult and Juvenile Trout Physical Habitat	2	2	2							2	2	2
Trout Growth							3	3	3			
Channel Maintenance				4	4	4						

1 and 2 - PHABSIM
3 - Habitat Quality Index
4 – Channel Maintenance

RESULTS AND DISCUSSION

Hydrology Analysis

The correlation between measured flow at the Dry Fork gage and the USGS gage showed a strong relationship ($R^2 = 0.957$, Appendix A). Average monthly flows are shown in Appendix A as well. The monthly flow duration figures for each month are shown in Appendix B. The 25-year flood flow estimate is 475 cfs (Table 4). Bankfull flow is 200 cfs. The minimum flow (quantity) at which sediment is mobilized was 100 cfs (0.5 * bankfull).

Table 4. Flood frequency estimates for the Dry Fork (LHEW 1993).

Return Period (Years)	Dry Fork (cfs)
1.5	200
2	247
5	341
10	404
25	475
50	542
100	600

Fish Habitat

Adult and Juvenile Rainbow Trout Physical Habitat

Based on the results of physical habitat simulation modeling, usable area for adult rainbow trout is maximized at 25 cfs (Figure 4). Physical habitat for juvenile rainbow trout is maximized at 20 cfs. Physical habitat for both life stages remains relatively high (greater than 90%) at flows between 20 and 30 cfs. Thus, the flow that will maintain both adult and juvenile physical habitat for rainbow trout is 20 cfs. These recommendations apply to the period from October 1 through March 31.

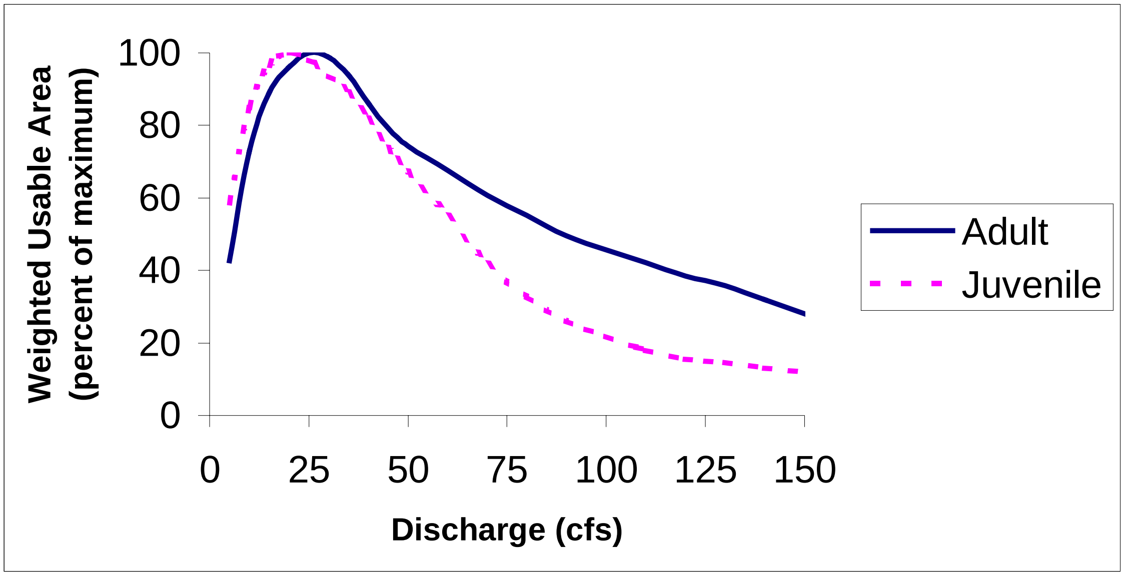

Figure 4. Weighted usable area (percent of maximum) for adult and juvenile rainbow trout life stages over a range of discharges in the Dry Fork Little Bighorn River.

Trout populations in northern latitudes are often limited by winter habitat conditions (Needham et al. 1945, Reimers 1957, Butler 1979, Kurtz 1980, Cunjak 1988, Cunjak 1996). Formation of frazil ice (suspended ice crystals formed from super-chilled water) can cause trout mortality through gill abrasion and subsequent suffocation. Frazil ice may also increase trout mortality as resultant anchor ice limits habitat, causes localized de-watering, and results in excessive metabolic demands on fish forced to seek ice-free habitats (Brown et. al 1994, Simpkins et al. 2000). Pools downstream from high gradient frazil ice-forming areas can accumulate anchor ice when woody debris or surface ice provides anchor points for frazil crystals (Brown et. al 1994, Cunjak and Caissie 1994). Such accumulations may result in mortalities if low winter flows or ice dams block emigration.

Super-cooled water (<0 C), of which frazil ice is an indicator, can also cause physiological stress on fish. At temperatures less than 7 C, fish gradually lose the ability for ion exchange and normal metabolic processes shut down. At water temperatures near 0 C, fish have very limited ability to assimilate oxygen or rid cells of carbon dioxide and other waste products. If fish are forced into an active mode under these thermal conditions (such as to avoid the negative physical effects of frazil ice or if changing hydraulic conditions force them to find areas of more suitable depth or velocity) direct mortalities can occur. The extent of impacts is dependent on the magnitude, frequency and duration of frazil events and the availability (proximity) of alternate escape habitats (Jakober et. al, 1998). Juvenile and fry life stages are typically impacted more than larger fish because younger fish inhabit shallower habitats and stream margins where frazil ice tends to concentrate (because it floats to the surface). Larger fish that inhabit deeper pools may endure frazil events with little effect if they are not displaced.

In contrast, refuge from frazil ice may occur in streams with groundwater influx (perennial springs), pools that develop cap ice (not close to frazil sources) and segments where heavy snow cover causes stream bridging (Brown et al. 1994).

The winter instream flows recommended for the fall and winter (October 1 to March 31) may not always be present. However, the existing fish community is adapted to natural flow patterns, including occasional periods when natural flow is less than recommended amounts. The fact that these periods occur does not mean permanently reduced flow levels can maintain the existing fishery; nor do they suggest a need for additional storage. Instead, they illustrate the need to maintain all natural winter stream flows, up to the recommended amount, to maintain existing trout survival patterns.

Rainbow Trout Physical Habitat for Spawning

Rainbow trout spawn in the spring. Spawning is triggered by a combination of physical cues that include temperature, photoperiod length and stream flow. These conditions typically initiate spawning behavior in the Dry Fork between early April and late May. The PHABSIM analysis showed that physical habitat for rainbow trout spawning was maximized at a flow of 25 cfs (Figure 5). Maintenance of flow at this level or higher from June 1 to June 30 is also needed to ensure that eggs deposited in gravels remain wet and survive as they hatch throughout the months of May and June. Average flow in the Dry Fork during spawning activities is typically this high or higher depending on snow pack and snow melt conditions (Appendix A) which suggests that high flow may occasionally limit physical habitat suitability. While this may occur in some years, high flows also provide a benefit to the rainbow trout fishery by helping adult fish migrate upstream to suitable spawning areas. They also help transport fry and juvenile trout throughout the system as part of their natural tendency to drift downstream to suitable habitats. Though the entire 25 cfs may not always be present during this period, protection of flows up to that level, when available in priority, will prevent additional impacts to spawning success and therefore maintain the existing fishery.

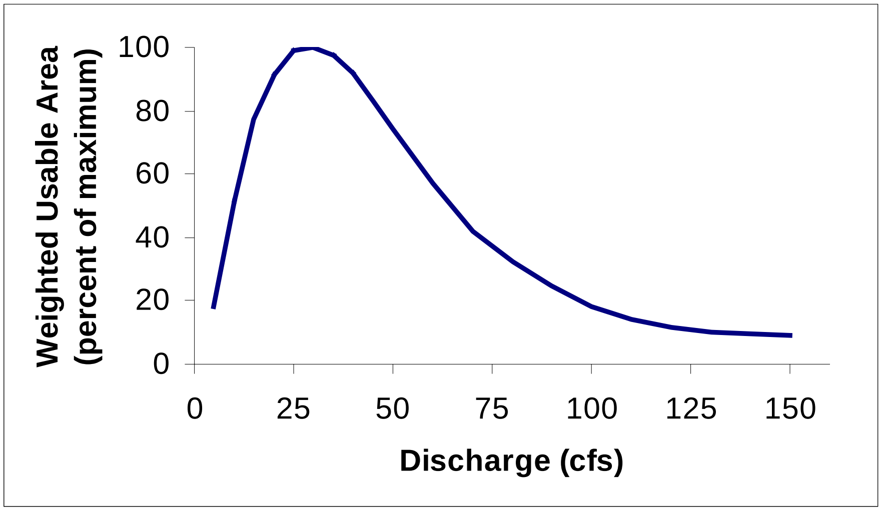

Figure 5. Weighted usable area (percent of maximum usable area) for rainbow trout spawning physical habitat over a range of discharges in the Dry Fork Little Bighorn River.

Habitat Quality Index

Article 10, Section d of the Instream Flow Act states that waters used for providing instream flows "shall be the minimum flow necessary to maintain or improve existing fisheries". One way to define "existing fishery" is by the number of habitat units that occur under normal July through September flow conditions. In the two years of data collection, flows between July and September were never below 35 cfs. At this flow, the stream provides 46 habitat units under existing conditions (Figure 6). The lowest flow that will maintain or provide the greatest level of improvement of the existing level of habitat units is 25 cfs.

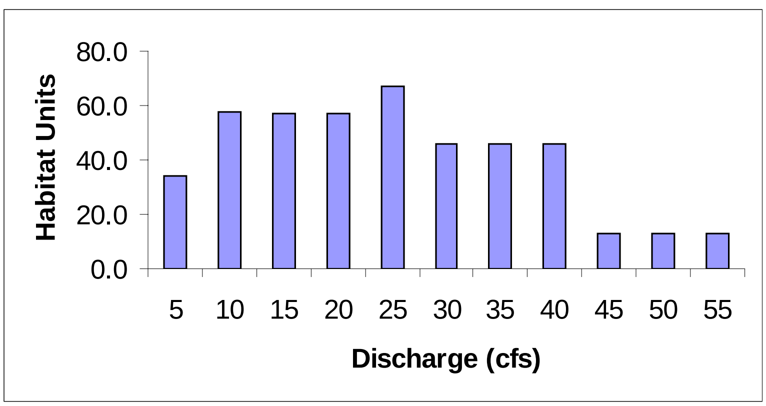

Figure 6. Trout habitat units at several late summer flow levels in the Dry Fork.

<u>Channel Maintenance</u>

The Dry Fork fishery is characterized and maintained by a hydraulically connected watershed, floodplain, riparian zone and stream channel. Bankfull and overbank flow are essential hydrologic characteristics for maintaining the habitat in and along this river system in its existing dynamic form. These high flows flush sediments from the gravels on an annual or more often basis and maintain channel form (depth, width, pool and riffle configuration) by periodically scouring encroaching vegetation. Overbank flow maintains recruitment of riparian vegetation, encourages lateral movement of the channel, and recharges ground water tables. Instream flows that maintain the connectivity of these processes over time and space are needed to maintain the existing fishery.

The channel maintenance model used for this analysis provided the instream flow recommendations shown in Table 5. Based on this model, natural flow up to the base flow of 25 cfs is needed at all times from April 1 to June 30. This same flow level (25 cfs) is also needed at all times when available flow is greater than 25 cfs up 0.5 times bankfull (100 cfs). At flows greater than 100 cfs up to bankfull (200 cfs), incrementally greater amounts of water are needed to mobilize bedload materials and maintain existing habitat characteristics and stream channel function. At flows between bankfull and the 25-year flood flow (475 cfs), all water originating in the drainage is needed. At flow greater than the 25-year flood flow, only the 25-year flood flow is needed for channel maintenance because this flow level will have moved the necessary amount of bed load materials (Figure 2).

INSTREAM FLOW RECOMMENDATIONS

Based on the analyses and results outlined above, the instream flow recommendations in Tables 5 and 6 will maintain the existing rainbow trout fishery in the Dry Fork of the Little Bighorn River as well as its unique and important wild and scenic characteristics and ecological functions. Results from these studies apply to the entire segment of the Dry Fork from its confluence with Garland Gulch Creek in T57N, R89W, S35 downstream to its mouth in T57N, R90W, S12. This segment is approximately 7.4 stream miles long. Because data were collected from representative habitats and simulated over a wide flow range, additional data collection under different flow conditions would not significantly change these recommendations. Development of new water storage facilities to provide the above recommended amounts on a more regular basis than at present is not needed to maintain the existing fishery characteristics.

Table 5. Instream flow recommendations to maintain existing channel forming processes and long-term aquatic habitat characteristics as related to available flow. Recommendations apply to the period from April 1 through June 30.

	Available Flow (cfs)	Instream Flow (cfs)
	5	5
	10	10
	15	15
	20	20
Fish (Base) Flow	25	25
	26 to 99	25
Substrate mobilization flow	100	25
	101 – 124	73
	125 – 149	112
	150 – 174	142
	175 - 199	171
Bankfull	200	200
	250	250
	300	300
	350	350
	400	400
25-Year Flood	475	475
	All flows > 475	475

Table 6. Instream flow recommendations to maintain or improve existing trout habitat in the Dry Fork Little Bighorn River.

Time Period	Instream Flow Recommendation (cfs)
October 1 to March 31	20
April 1 to June 30	25 or higher*
July 1 to September 30	25

*See Table 5

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Appendix A

Linear regression of flow quantities from the Dry Fork gage number 62887 and the Little Bighorn River gage number 62890 (LHEW 1993).

Regression	Output
Number of observations	1,826
Standard error of coefficient	0.001391
Standard error of Y estimate	9.557842
R Squared	0.9567

Dry Fork Flow = 5.312 + (0.279) * (Flow in Little Bighorn)

Average monthly and annual flow in the Dry Fork below the mouth of Lick Creek (LHEW 1993).

Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
30	27	25	23	23	23	29	96	156	69	40	33	48

Appendix B.

Monthly flow duration of Dry Fork below the mouth of Lick Creek (LHEW 1993).

Percent Exceedence	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
5	39	34	31	29	27	27	53	218	318	129	59	45
10	37	33	30	27	27	27	40	180	279	109	53	43
15	35	32	29	27	26	26	35	140	251	97	50	41
20	34	31	28	26	25	25	32	143	228	87	48	39
25	33	30	27	25	25	25	30	130	205	79	46	38
30	33	29	27	25	24	24	29	118	184	74	45	37
35	32	29	26	24	24	24	28	107	169	70	43	35
40	31	28	26	24	24	23	27	97	157	66	42	34
45	30	27	25	24	23	23	26	89	145	63	41	33
50	30	26	24	23	23	23	26	80	136	60	39	33
55	29	26	24	23	23	22	25	74	126	57	38	32
60	28	25	24	22	22	22	25	67	118	54	36	31
65	27	25	23	22	22	22	24	60	110	51	35	30
70	27	24	23	22	22	21	24	55	101	48	34	29
75	26	24	22	21	21	21	23	48	94	46	33	28
80	25	23	22	20	21	20	23	44	86	44	32	28
85	25	23	21	19	20	20	22	40	77	41	31	27
90	24	22	20	18	19	19	22	35	66	39	29	26
95	23	20	18	16	18	18	20	30	57	35	27	25
100	19	14	12	12	12	14	15	22	39	24	22	22