WYOMING GAME AND FISH DEPARTMENT

FISH DIVISION

ADMINISTRATIVE REPORT

Title: Instream Flow Studies on Wagonhound Creek, Carbon County, Wyoming

Project: IF-LE-5UM-511

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Date: August 2000

ABSTRACT

Studies were conducted during 1998 and 1999 on Wagonhound Creek to determine the relationship between stream flow and the quantity and quality of trout habitat. The Habitat Quality Index model was used to relate stream flow to adult trout habitat quality in the summer. A hydraulic habitat simulation model was used to identify the relationship between stream flow and brown trout spawning physical habitat. The habitat retention method was used to identify a flow to maintain hydraulic characteristics that are important for year round trout habitat. The lowest summer flow that will maintain adult trout habitat quality at its present level between July 1 and September 30 is 2.2 cfs. The instream flow recommendation to maintain or improve physical habitat for brown trout spawning and incubation between October 1 and March 31 is 2.2 cfs. Recommendations for instream flows to maintain channel forming processes and aquatic habitat between April 1 and June 30are provided.

INTRODUCTION

Wagonhound Creek is a small, third order stream that originates in the Medicine Bow Mountains near Arlington, Wyoming. The stream flows northerly passing from high elevation conifer dominated-forest to willow and sagebrush lowlands before joining with the Medicine Bow River. In the early 1960's the Wyoming Game and Fish Department (WGFD) purchased 8,969 acres immediately downstream from the Forest Service boundary and established the Wick Brothers Wildlife Habitat Management Area (Wick WHMA). The WGFD manages this property primarily for big game winter habitat and public recreation.

Anecdotal information suggests that fish species historically present in Wagonhound Creek included speckled dace and longnose suckers (Don Miller, WGFD, Personal Communication). Trout were probably not native to the stream and were either introduced or migrated to the study area from other streams in the drainage. Within the study segment, the fishery now is comprised primarily of the above native fishes in addition to brown and brook trout. Brown trout are more abundant at lower elevations and brook trout are more common at higher elevations. Rainbow trout are also present in low numbers in upstream sections of the stream as well as in beaver ponds and reservoirs within the drainage.

In 1998, the Wyoming Game and Fish Commission directed that actions be taken to secure an instream flow water right to maintain important public fishery and wildlife values on the WHMA. An instream flow water right will provide legal protection for water and water-related public resources on the Wick WHMA. To accomplish this goal, studies were done to 1) quantify year-round instream flow levels needed to maintain or improve existing brown trout populations, 2) quantify instream flows needed to maintain long-term brown 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 and recommendations from these studies apply to the entire segment of Wagonhound Creek contained within the Wick WHMA. This segment is approximately 8.5 stream miles extending downstream from where the stream crosses the Forest Service boundary in section 31 in Township 19 North, Range 79 West to where the stream crosses the northern boundary of section 6 in Township 19 North, Range 79 West (Figure 1).

BASIS FOR QUANTIFYING INSTREAM FLOWS FOR FISHERIES MAINTENANCE

Statutory and Scientific Concepts

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). 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 for people (Nielsen 1993, Ditton 1997). In other words, a fishery is a product of physical, biological and chemical processes. Each component is important, each affects the other and each presents opportunities for impacting or enhancing the nature or 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 (mean) should be considered stable. Thus “existing fishery” is not an absolute standard or constant number to be maintained by a single 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 human 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.

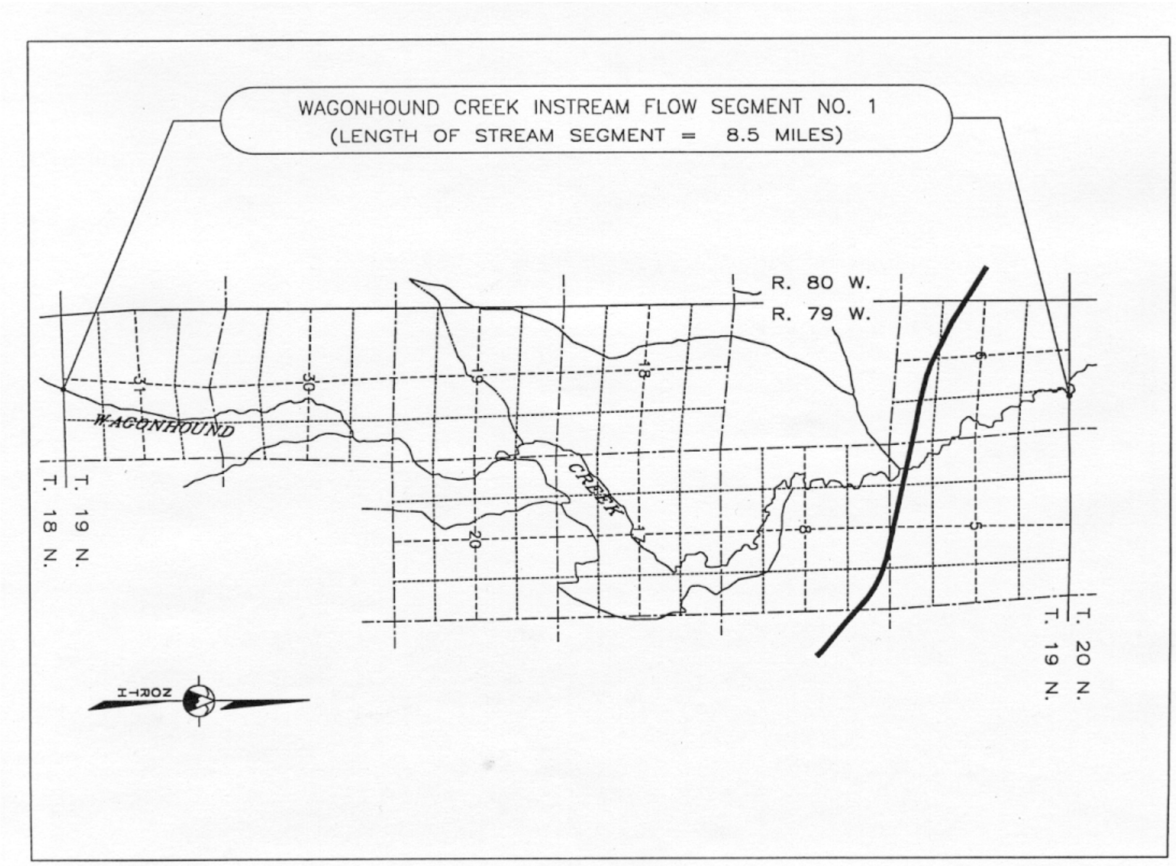

Figure 1. Location of Wagonhound Creek instream flow segment.

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 being excessive. 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 provides no indication that "minimum needed" refers to anything other than quantity. Duration of flow is not suggested nor is there any indication that "minimum" means the lowest flow available at all times. Certainly, duration of flow is not a criterion of beneficial use that is commonly applied to any other kinds of water rights. 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, regardless of the duration of use. As a consequence, constraints or reductions of instream flow water right applications based on the frequency or duration of availability would be inconsistent with administrative actions for other kinds of water rights. The Wyoming Constitution provides strong support for administering instream flow water rights in a like manner to other water rights. Article 1, section 41 directs that "*Water being essential to industrial prosperity, of limited amount, and easy of diversion, its control must be in the state, which, in providing for its use, shall equally guard all the various interests involved*." This passage clearly establishes that all beneficial uses of water are equal, except as otherwise conditioned by statute.

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 first 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 characteristic 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 either stable or in dynamic quasi-equilibrium. Three separate methods were used for this study.

Habitat Modeling

Study Sites

After visually surveying the stream from about one-half mile below Interstate-80 to near the Forest Service boundary, two study areas were selected. One 425-foot long study site was established starting about 500 feet downstream from Interstate-80 in section 5, Range 79 West, Township 19 North. Habitat at this site consisted mostly of main channel and lateral scour pools. Beaver activity was absent from this segment over the entire time when data were collected. Results from this site were used to quantify adult trout instream flow requirements.

Another study site was established about two miles upstream (South) from Interstate-80 in section 19, Range 79 West, Township 19 North. Beaver activity was less abundant in this stream section than it was downstream and longer lengths of stream were free flowing. This area contained several riffles with habitat suitable for brown trout spawning. Several of the riffles where data were collected to analyze spawning habitat were also suitable for developing maintenance flow recommendations. Seven transects were established for these purposes.

Habitat Retention Method

A Habitat Retention method (Nehring 1979, Annear and Conder 1984) was used to identify a maintenance flow by analyzing data from hydraulic control riffle transects. A maintenance flow is defined as the continuous flow required to maintain specific hydraulic criteria in stream riffles. Maintenance of these criteria in riffles ensures that habitat is also maintained in other habitat types such as runs or pools (Nehring 1979). In addition, maintenance of identified flow levels ensures passage between habitat types for all trout life stages and maintains adequate benthic invertebrate survival.

Simulation tools and calibration techniques used for hydraulic simulation in PHABSIM (Physical Habitat Simulation) are also used with this technique (see next section). The habitat retention method involves analysis of hydraulic characteristics at control riffles. The AVPERM model within the PHABSIM methodology is used to simulate cross section depth, wetted perimeter and velocity for a range of flows. A maintenance flow is defined as the discharge for which any two of the three criteria in Table 1 are met for all riffle transects in a study area. The instream flow recommendations from the Habitat Retention method are applicable year-round except when higher instream flows are required to meet other fishery management purposes. Dates when data were collected for analysis are shown in Table 2

Table 1. Hydraulic criteria for determining maintenance flow with the Habitat Retention method.

Category	Criteria
Mean Depth (feet)	0.20
Mean Velocity (feet/second)	1.00
Percent Wetted Perimeter[a]	50

a - Percent of bank full wetted perimeter

Table 2. Dates and discharges when data were collected for Habitat Retention and PHABSIM analysis on Wagonhound Creek in 1998.

Date	Discharge (cfs)
June 18	38
June 3	3.8
August 13	2.5

Physical Habitat Simulation

Physical Habitat Simulation (PHABSIM) methodology was used to quantify depth and velocity availability for brown trout spawning 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 feet^2 per 1000 feet of stream length) at various flows. Depth, velocity, and substrate were measured along transects (*sensu* Bovee and Milhous 1978) on the dates in Table 2. Hydraulic calibration techniques and modeling options in Milhous et al. (1984) and Milhous et al. (1989) were employed to incrementally estimate physical habitat between 0.5 and 95 cfs. Precision declines outside this range; however, the modeled range accommodates typical spawning season flows in Wagonhound Creek.

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

Brown trout in Wagonhound Creek typically spawn between October 1 and November 30. Their eggs remain in the gravel where they incubate until hatching in early spring (March). Maintaining natural flows up to the identified levels throughout the fall, winter and spring (from October 1 through March 31) will benefit trout egg incubation by preventing dewatering, facilitating fry emergence and providing habitat for fry after they leave spawning redds.

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 brown 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 calculated over a range of potential late summer flows (Conder and Annear 1987). Wagonhound Creek habitat attributes were measured on the dates shown in Table 3. Some attributes were mathematically derived to establish the relationship between discharge and trout production at discharges other than those measured.

Table 3. Dates and discharges when Habitat Quality Index data were collected on Wagonhound Creek in 1999.

Date	Discharge (cfs)
June 17	29
July 2	8.5
August 16	2.5

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 physical channel characteristics (aquatic habitat) requires periodic availability of channel maintenance flows (Hill et al. 1991, USDA Forest Service 1997).

“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 unconsolidated 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 (see below).

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, flood plain groundwater seeps back into the channel and helps sustain continuous flow. Streamside vegetation is a common and necessary component of floodplains that contribute to the character of aquatic organisms in the stream. 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. Their 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 of variable flows 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 successful establishment of riparian seedlings on bars deposited in immediately preceding wet years (Trush and McBain 2000). The natural interaction of high and low flows maintains riparian development and aquatic habitat by allowing some riparian development in most years (preventing annual scour that might occur from continuous high flow) 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 the result of predictable processes as 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. 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).

The movement of substrate from the bottom of Rocky Mountain streams begins at flows somewhat greater than average annual 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). The combination of these processes eventually changes the ecological function of the stream and habitat suitability for existing aquatic organisms. Table 4 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 ($Q_{a)}$ as the flow at which substrate movement begins. This term was re-defined here as the substrate mobilization flow ($Q_{m)}$ and assigned a value of 0.5 times bankfull flow based on the above studies by Ryan (1996) and Emmett (1975). Setting Qm 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 is the minimum standard of need.

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

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. 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 2 provides an illustration of instream flow needs relative to available stream 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 Wagonhound Creek 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.

Table 4. General attributes of alluvial, gravel-bed river ecosystems (Trush and McBain 2000).

Spatially complex channel morphology: 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.

Flows and water quality are predictably variable: 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.

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

Periodic channel bed scour and fill: 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.

Balanced fine and coarse sediment budgets: 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.

Periodic channel migration: 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.

A functional floodplain: 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.

Infrequent channel resetting floods: 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.

Self-sustaining diverse riparian plant communities: 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.

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

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.

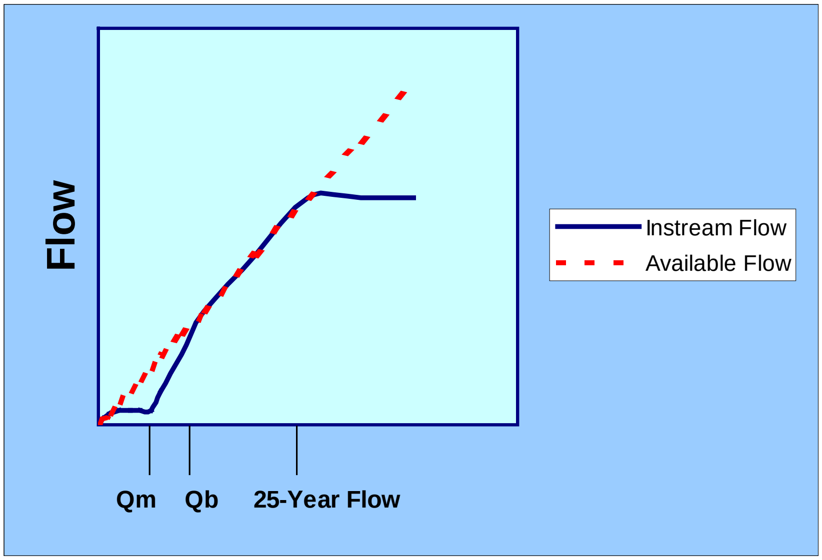

Figure 2. General function of a dynamic hydrograph instream flow for fishery maintenance.

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.

States West Water Resources Corporation, Cheyenne, Wyoming, determined hydrologic characteristics for Wagonhound Creek under contract with WGFD for this project. They analyzed the utility of gage data on both Pass Creek (gage 06628900) and Rock Creek (gage 06632400) by correlating instantaneous daily flows at those gages with data collected by WGFD on 16 days on Wagonhound Creek between April 1998 and September 1999 (Appendix A). This analysis showed that records from Pass Creek were more appropriate to use.

The correlation between flow in Wagonhound Creek and Pass Creek was used to generate flow duration tables for each month. Flood flows for Wagonhound Creek were calculated using equations derived for mountainous regions by Lowham (1988). 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 year or every other year (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 (personal communication, Larry J. Schmidt, Program

Manager, Stream Systems Technology Center, USFS Rocky Mountain Research Center, Fort Collins, CO; Tom Wesche, Habitech, Laramie, WY).

It should be noted that the Pass Creek gage records are considered "Poor" by the U.S. Geological Service (USGS). 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 identifies three discrete seasons when instream flows are needed to maintain important fishery features (Table 4). Adequate flows are needed for brown trout spawning and incubation. This season extends from October 1 through March 31. Instream flows are needed during the summer season to maintain opportunity for juvenile and adult trout growth. This season extends from July 1 through September 30. Channel maintenance flows are also needed. This season extends from April 1 through June 30, which is the time of year when high flows are often available to perform the work needed to maintain channel function and long-term fish habitat. The recommendations for each of these three seasons are determined specifically but must equal or exceed the flow that maintains basic fish survival and passage functions (maintenance flow). Providing adequate flow for all of these features is a necessary approach for maintaining the existing fishery.

Table 4. Brown trout life stages and months considered in Wagonhound Creek instream flow recommendations. Numbers indicate method used to determine flow requirements.

Fishery Function	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
All Trout Life Stages	1	1	1	1	1	1	1	1	1	1	1	1
Brown Trout Spawning	2	2	2							2	2	2
Brown Trout Adult							3	3	3			
Channel Maintenance				4	4	4						

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

RESULTS AND DISCUSSION

Habitat Retention Analysis

Habitat retention analysis indicates that 2.2 cfs is required to meet hydraulic criteria at all riffles (Table 5). Maintenance of flows up to this level, when they are available, will maintain passage between habitats for trout, enable reasonable winter survival of all trout life stages and provide adequate habitat for aquatic macroinvertebrates at the same frequency that now occurs. Flow levels higher than 2.2 cfs are needed at some times of year for other fishery maintenance needs (Table 4) and are addressed in the results below.

Trout populations in northern latitudes are often limited by winter habitat conditions (Needham et al. 1945, Reimers 1957, Butler 1979, Kurtz 1980, Cunjak

Table 5. Hydraulic criteria for riffles in Wagonhound Creek.

	Mean Depth (ft)	Mean Velocity (ft/s)	Wetted Perimeter (ft)	Discharge (cfs)
Riffle 1	0.13	0.41	**16.2**[a]	1.0
	0.20[a]	0.50	18.2	**2.2**[b]
	0.29	0.56	18.6	3.0
	0.37	0.66	19.0	4.5
	0.43	0.74	19.3	6
	0.49	0.84	19.7	8
	0.55	0.93	20.1	10
	0.60	**1.01**[a]	20.3	12
	0.76	1.28	21.2	20
	1.17	2.17	24.3	60
Riffle 2	0.18	0.14	**20.1**[a]	0.5
	0.24[a]	0.25	21.3	**1.1**[b]
	0.36	0.39	21.6	3.0
	0.41	0.51	21.7	4.5
	0.45	0.62	22.1	6
	0.48	0.74	22.7	8
	0.53	**0.97**[a]	23.7	12
	0.60	1.36	25.1	20
	0.80	2.80	26.9	60
Riffle 3	**0.14**[a]	0.48	7.6	0.5
	0.17	0.56	**9.1**[a]	**0.9**[b]
	0.26	0.73	11.0	2.0
	0.39	**1.01**[a]	12.0	4.5
	0.44	1.15	12.5	6
	0.54	1.46	13.4	10
	0.69	2.03	15.0	20
	1.01	3.45	18.2	60

a - Hydraulic criteria met
b - Discharge at which 2 of 3 hydraulic criteria are met

1988, Cunjak 1996). Formation of frazil ice (suspended ice crystals formed from super-chilled water) in high gradient stream reaches 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, or 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 metabolism decreases (Cunjak and Power 1986). At water temperatures near 0 C, fish have decreased 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 accumulates because it floats to the surface as it forms. Larger fish, that inhabit deeper pools, may endure frazil events with little effect if they are not displaced. In contrast, refuge from frazil ice may occur in streams with groundwater influx, pools that develop cap ice and segments where heavy snow cover causes stream bridging (Brown et al. 1994).

The deep, slow water found in the beaver pond complex on Wagonhound Creek provides suitable winter habitat for adult trout and it is likely that most adult trout are found in those habitats during the winter. Small life stages of trout, however, are vulnerable to predation by adult fish in those environments. As a consequence, they select shallow water habitats with cobble substrates, like riffle and run habitats. Wagonhound Creek typically develops a cap of ice or bridges with snow in riffles and runs at existing winter flow levels. Long-term artificial reduction of flow levels could reduce the suitability of these habitats and force small life stages of trout into less suitable areas where their survival rates would decrease.

The 2.2 cfs identified by the Habitat Retention Method may not always be present during the winter. However, the existing fish community is adapted to natural flow patterns, including occasional periods when natural flow is less than 2.2 cfs. 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 2.2 cfs, to maintain existing trout survival patterns. Maintaining this fishery component simply means maintaining natural stream flow up to the recommended amount when it is available.

PHABSIM Analyses

The presence of nearly continuous beaver ponds throughout much of the lower reaches of Wagonhound Creek affects brown trout spawning in several ways. Though many of the ponds are annually washed out by high spring flows, most are rebuilt in such high density by fall, when brown trout spawn, that very few sections of the stream flow over a long enough distance to provide adequate spawning habitat. Perhaps an even greater limitation to brown trout spawning is the fact that beaver dams in the upper reaches of the stream tend to trap spawning-size gravels and reduce the frequency at which those materials are distributed to the lower river. This phenomenon provides added importance to the need for high flows for channel maintenance, described below, which periodically breach beaver dams and transport those materials to the lower river. In most years, this pattern of substrate transport results in most of the trout spawning occurring in the upper sections of the stream. Thus, it is likely the majority of trout found in the stream is spawned in upstream sections and young fish then disperse throughout the lower section.

Physical habitat for brown trout spawning is extremely limited at flows below about 5 cfs on all of the riffles studied (Figure 2). Physical habitat for spawning is negligible on riffle 2 at 1.5 cfs. At flows of 1.0 cfs and less, no physical habitat is present on any of the riffles modeled. Physical habitat for spawning at the riffle area described by riffle 3 was unavailable at all flows less than 14 cfs. Given the hydrologic characteristics of the stream, it is unlikely brown trout use this particular riffle for spawning.

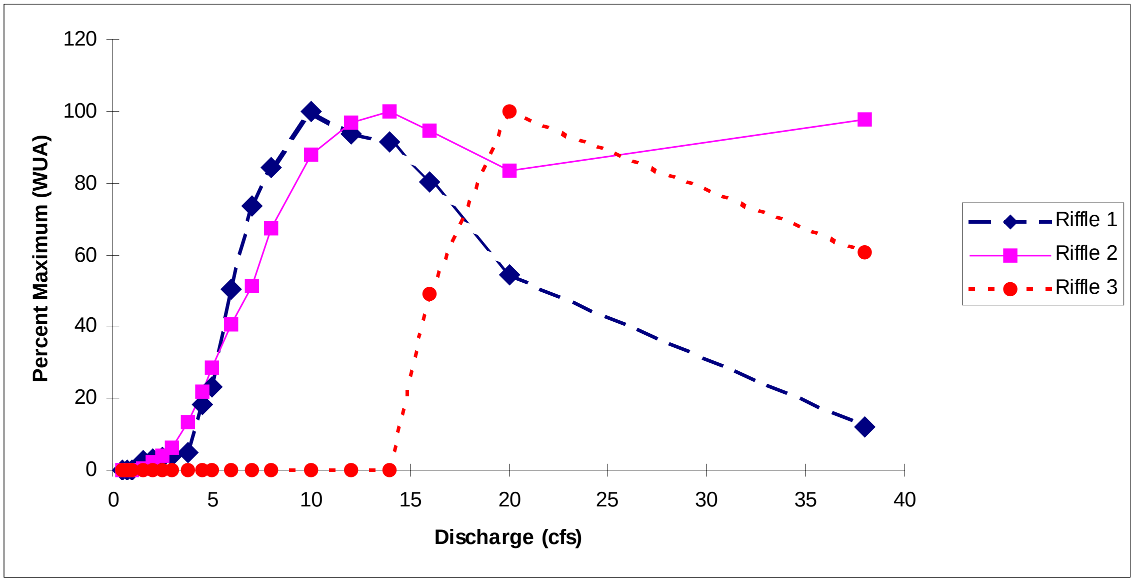

Figure 2. Weighted usable area (percent of maximum weighted usable area) for brown trout life stages over a range of discharges.

Brown trout spawn in the fall when flows in Wagonhound Creek are typically less than 4 cfs (Appendix B). Between 4 cfs and 1 cfs, available physical habitat for spawning declines rapidly with small incremental flow reductions (Table 6). This limitation in availability of spawning habitat at low flows suggests spawning success and recruitment is variable and strong year classes may not occur regularly. More specifically, these data suggest that any permanent reduction of existing natural flow between October 1 and March 31 may cause serious harm to brown trout recruitment and fishery maintenance. To maintain existing opportunities for the fishery to benefit from periodic good flow years on the same frequency as have historically occurred, a flow equal to the maintenance flow recommendation of 2.2 cfs is recommended. This recommendation applies to the brown trout spawning and egg incubation period, which is from October 1 to March 31. Though the entire 2.2 cfs may not always be present during this period, protection of flows up to that level, when available, will prevent additional impacts to spawning success and therefore maintain the existing fishery.

Table 6. Square feet of physical habitat for brown trout spawning per 1,000 feet of stream at two riffle areas in Wagonhound Creek.

Discharge (cfs)	Riffle 1	Riffle 2
1	0	0
1.5	56	14
2	67	111
2.5	77	204
3	86	304
3.5	94	528
4	179	788
4.5	378	1,101
5	472	1,426
6	1,032	2,032

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 typically were between 2 and 7 cfs (Appendix A). As a consequence, the stream provides about 9 habitat units under existing conditions (Figure 3).

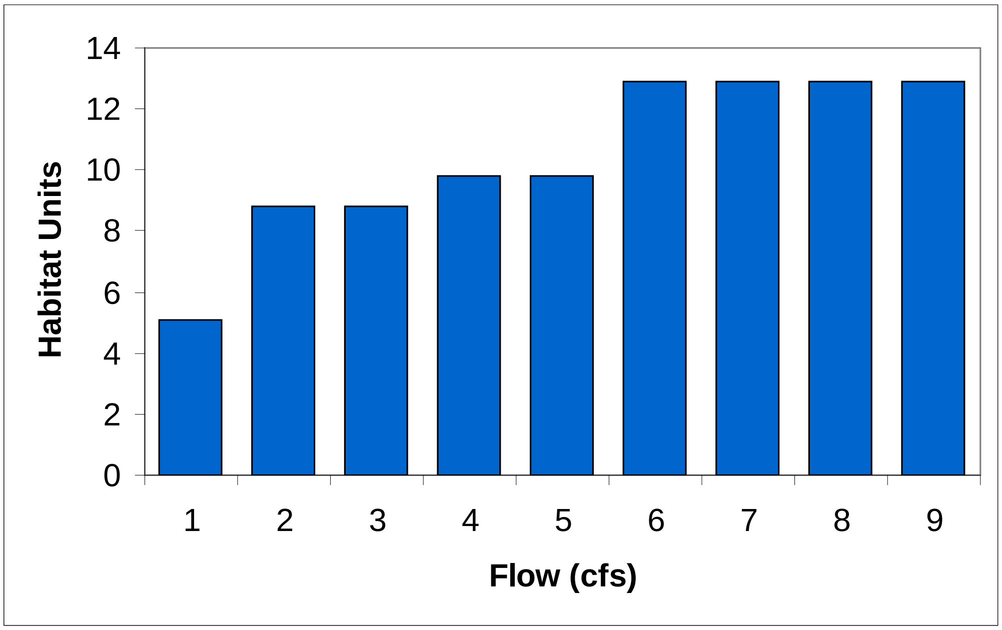

Figure 3. Trout habitat units at several late summer flow levels in Wagonhound Creek.

The lowest flow that will maintain the existing level of habitat units is 2.0 cfs. Because this flow is less than the 2.2 cfs derived from the Habitat Retention method, the instream flow recommendation for the summer season is 2.2 cfs.

Hydrologic Characteristics

The correlation between measured flow in Wagonhound Creek and daily flows in Pass Creek showed a strong relationship ($R^2 = 0.9952$, Appendix B). Even though the USGS rating for this gage was poor, it provided a better indication of monthly flow patterns than the Rock Creek gage. The monthly flow duration figures for each month are shown in Appendix B.

The 25-year flood flow estimate based on Lowham's equation was 545 cfs (Table 7). Bankfull flow was determined by plotting the 2 and 5-year events on probability paper and manually graphing the flow equal to the 1.5-year flood event. This resulted in a bankfull flow of 170 cfs. By definition, the minimum flow at which sediment is first mobilized was 0.5 times bankfull, which was 85 cfs.

Table 7. Flood frequency (peak flow) estimates for Wagonhound Creek.

Return Period (Years)	**Wagonhound Creek (cfs)**
1.5	170
2	223
5	352
10	427
25	545
50	640
100	739

Channel Maintenance

The Wagonhound Creek 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 this dynamic system. 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 and breaching beaver dams. Overbank flow maintains recruitment of riparian vegetation, encourages lateral channel movement, and recharges groundwater. 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 9. Based on this model, natural flow up to the base flow of 2.2 cfs is needed at all times from April 1 to July 30. This same flow level (2.2 cfs) is also needed at all times when flow is greater than 2.2 cfs up to 85 cfs (0.5 times bankfull). At flows greater than 85 cfs up to bankfull (170 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 (545 cfs), all available water originating in the drainage is needed. At flow greater than the 25-year flood flow, only the 25-year flood flow is needed.

INSTREAM FLOW RECOMMENDATIONS

Based on the analyses and results outlined above, the instream flow recommendations in Tables 8 and 9 will maintain the existing brown trout fishery in Wagonhound Creek. Results apply to the entire stream segment contained within the Wick WHMA, which is approximately 8.5 stream miles long.

The segment extends downstream from where the stream crosses the Forest Service boundary in section 31 in T 19 N, R 79 W to where the stream crosses the northern boundary of section 6 in T 19 N, R 79 W. 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 of Wagonhound Creek. Enhancement of stream flow that could result from deliveries of (new) stored water would improve the existing fishery but that action is beyond the present fishery management objective. Further, it is unlikely the potential fishery benefits would be commensurate with the cost of building new storage solely for fishery purposes.

Table 8. Instream flow recommendations to maintain existing channel forming processes and long-term aquatic habitat characteristics. Recommendations apply to the period from April 1 through June 30.

	Available Flow (cfs)	**Instream Flow (cfs)**
	1.0	1.0
	2.0	2.0
Base Flow	2.2	2.2
	3.0	2.2
	4.0	2.2
	5.0	2.2
	6.0	2.2
	7.0	2.2
	8.0	2.2
	9.0	2.2
	10	2.2
Average Annual Flow	12	2.2
	15	2.2
	20	2.2
	30	2.2
	40	2.2
	50	2.2
	55	2.2
	60	2.2
	70	2.2
	75	2.2
Substrate Mobilization Flow (Qm)	85	2.2
	86	56
	110	98
	135	128
	160	158
Bankfull Flow (Qb)	170	170
	200	200
	400	400
	500	500
25-Year Recurrence Flow	545	545
	All flows > 545	545

Table 9. Instream flow recommendations to maintain or improve the existing Wagonhound Creek fishery for the fall/winter spawning and incubation season and the summer growth season.

Time Period	**Instream Flow Recommendation (cfs)**
October 1 through March 31	2.2
July 1 through September 30	2.2

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Appendix A

Dates and discharges when stream flow data were collected on Wagonhound Creek that were used to correlate with flows from gages on Rock and Pass Creeks.

Date	Discharge (cfs)
April 22, 1998	7.7
June 3, 1998	14.3
June 5, 1998	18.8
June 18, 1998	52
July 10, 1998	4.7
July 30, 1998	3.4
August 13, 1998	2.9
October 14, 1998	2.7
June 1, 1999	94
June 10, 1999	62
June 17, 1999	29
June 25, 1999	16.6
June 30, 1999	8.7
July 2, 1999	6.4
August 16, 1999	2.5
September 30, 1999	2.6
October 12, 1999	2.7

APPENDIX B

Hydrologic analyses by States West Water Resources Corporation

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RECEIVED
MAY 1 - 2000
FISH DIVISION

April 28, 2000

Mr. Tom Annear
Instream Flow Supervisor
Wyoming Game and Fish Department
5400 Bishop Blvd.
Cheyenne WY 82006

Re: Wagonhound Creek Flow Duration Study - Revised

Dear Tom:

My, what a difference some data can make! I was able to review the provisional data from the USGS for water year 1999 at the Pass Creek gage, and the results were an "awakening." When I plotted the Game and Fish data against *all* the available USGS data for Pass Creek, a fairly strong relationship was beginning to form. I then further revised the work by removing your data for June 18, 1998, which was the only entry of yours which mentioned the possibility of an anomalous reading due to rain (it was an obvious outlier). The resulting relationship is shown on the attached chart. With this evidence, it doesn't make sense to use "rule of thumb" relationships for flow synthesis.

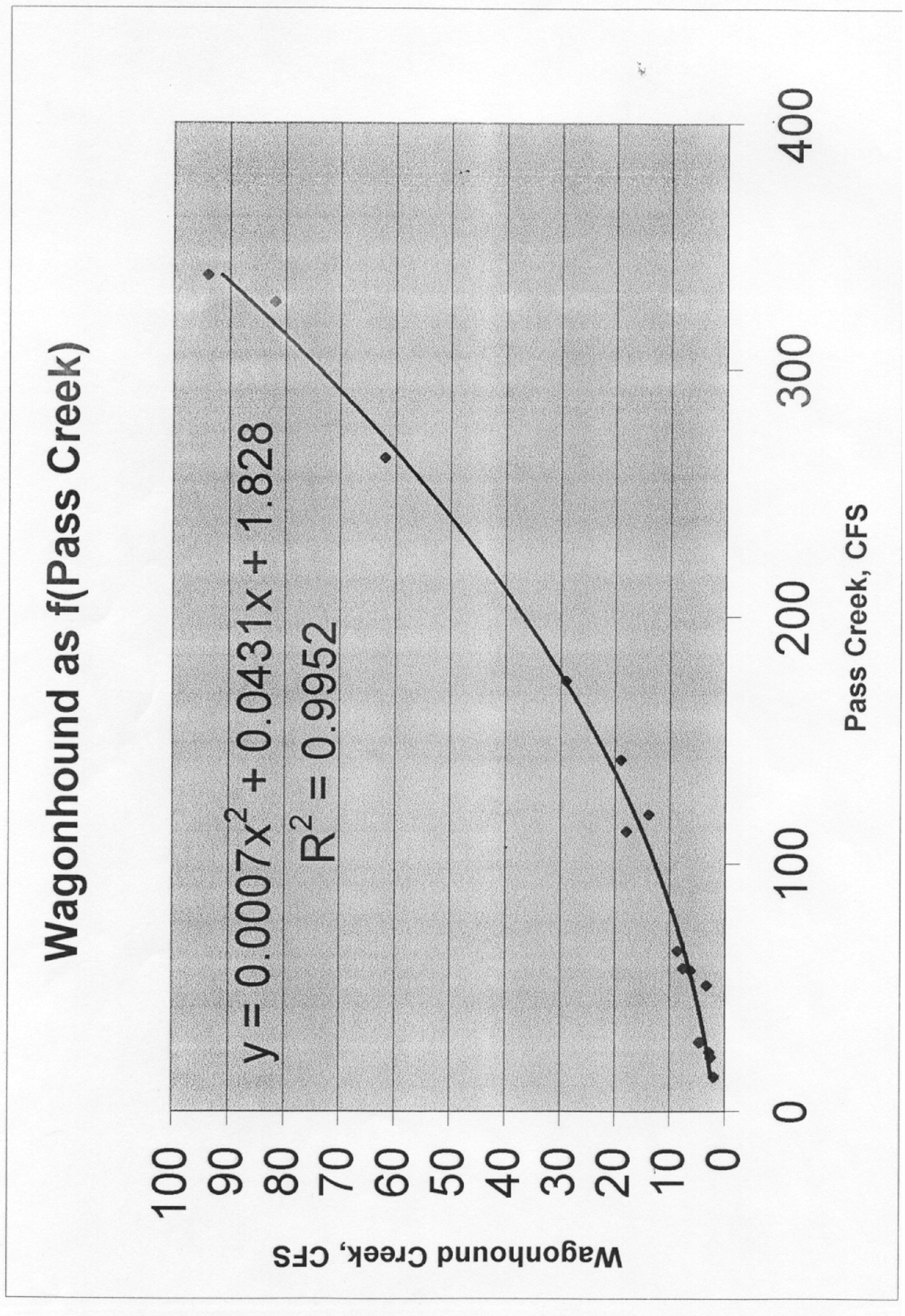
Low flows on Wagonhound do not exhibit the variability seen at Pass Creek, evidenced by the data and in the revised flow duration analysis. A new Table 3 is provided, and in the low flow months you will see less variation than shown in my first attempt. This is characteristic of the data and the relatively "flat" curve at low flows, indicating Wagonhound Creek may have a relatively stable base flow regime, attenuated even more than we originally thought by the willows and beaver dams upstream.

In checking this relationship for use in flood frequency analysis, I find it does not work well. The quadratic form of the equation causes the flood estimates for Wagonhound to exceed those for Pass Creek at flows greater than the 10-year event, a result that is not correct. Therefore, continue to use the flood frequency estimates I gave you earlier.

Please call if I can answer any questions. Because I believe I should have used the provisional data in my first report, no additional hours have been charged to our contract.

Sincerely,

Patrick T. Tyrrell, P.E.
Project Manager



Wagonhound as f(Pass Creek)
y = 0.0007x2 + 0.0431x + 1.828
R2 = 0.9952
Wagonhound Creek, CFS
100
90
80
70
60
50
40
30
20
10
0
0
100
200
300
400
Pass Creek, CFS

Table 3. Flow Duration Data, Wagonhound Creek at I-80

STATION Wagonhound at I-80
DA = 26.5 Mi.2

FLOW DURATION

% of time exceeded	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL
95	2.0	2.1	2.1	2.1	2.1	2.2	2.5	5.7	3.4	2.1	2.0	2.0	2.1
90	2.1	2.2	2.2	2.1	2.1	2.2	2.8	7.4	4.1	2.2	2.0	2.0	2.1
85	2.1	2.2	2.2	2.2	2.2	2.3	3.0	8.6	4.7	2.3	2.0	2.0	2.2
80	2.2	2.2	2.2	2.2	2.2	2.3	3.3	10	5.4	2.5	2.1	2.0	2.2
75	2.2	2.2	2.2	2.2	2.2	2.3	3.6	12	6.3	2.6	2.1	2.0	2.3
70	2.2	2.3	2.2	2.2	2.2	2.3	3.9	14	7.3	2.8	2.1	2.1	2.3
65	2.3	2.3	2.2	2.2	2.2	2.4	4.3	15	8.4	2.9	2.2	2.1	2.4
60	2.3	2.3	2.3	2.3	2.2	2.4	4.7	17	9.8	3.1	2.2	2.2	2.4
55	2.3	2.4	2.3	2.3	2.3	2.5	5.1	20	12	3.3	2.3	2.2	2.5
50	2.4	2.4	2.3	2.3	2.3	2.5	5.6	23	14	3.5	2.4	2.2	2.5
45	2.5	2.4	2.3	2.3	2.4	2.6	6.3	26	17	3.6	2.5	2.3	2.8
40	2.5	2.5	2.4	2.3	2.4	2.6	6.9	30	20	3.8	2.6	2.4	3.1
35	2.6	2.5	2.4	2.4	2.4	2.7	7.7	36	24	4.0	2.7	2.4	3.4
30	2.7	2.6	2.4	2.4	2.4	2.7	8.8	43	28	4.4	2.8	2.5	3.8
25	2.8	2.6	2.4	2.4	2.5	2.9	10	49	33	4.8	2.9	2.5	4.1
20	2.8	2.7	2.5	2.4	2.5	3.0	12	58	41	5.3	3.0	2.6	7.1
15	2.9	2.7	2.6	2.5	2.5	3.3	15	72	52	6.0	3.1	2.7	11
10	3.0	2.8	2.6	2.5	2.6	3.8	20	94	69	6.8	3.4	2.9	16
5	3.2	3.0	2.7	2.6	2.7	5.5	30	150	100	9.2	3.9	3.3	35

Wagonhound value = $0.0007x^2 + 0.0431x + 1.828$, where x represents the matching flow duration value for Pass Creek.

Values rounded to two significant figures.

Revised 4/28/2000

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June 27, 2000

Mr. Tom Annear
Instream Flow Supervisor
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Re: Wagonhound Creek Flood Study - Revised

Dear Tom:

I have revisited the flood frequency information developed earlier for your Wagonhound Creek project. As we discussed, the flood estimates calculated earlier seemed high to me as well. So, to test the reasonableness of the numbers previously generated, I took two additional approaches.

First, I contacted the Wyoming Department of Transportation (WyDOT) to see what flood magnitudes they were using for the Wagonhound underpass at I-80. Typically, WyDOT is a good reference for flood flows, because they do so many of them around the state. In talking with Mr. Bill Bailey, I learned that their approach (should the Wagonhound Creek crossing be in need of redesign today) would be to use published USGS regional techniques. Along with comparison to floods developed using gage data in adjacent basins, as I did previously for Wagonhound, they would arrive at a solution deemed most appropriate.

Therefore, I recalculated the flood events for Wagonhound using USGS Water Resources Investigations Report 88-4045, *Streamflows in Wyoming,* by H. W. Lowham. This procedure produced the floods in the attached table. A copy of the page describing peak flow relationships for mountainous regions in Wyoming is also attached.

The next approach was to estimate floods using a direct Wagonhound to Pass Creek drainage area ratio multiplied by flood flows at the Pass Creek gage previously used (gage no. 6628900). For instance, using a drainage area ratio of 26.5/91.5 = 0.29 multiplied by the 25 year event of 1,930 cfs for the Pass Creek gage, gives 560 cfs as an estimate of the 25-year peak at Wagonhound. This is quite close to the value estimated by Lowham's method (546 cfs).

All things considered, my gut feeling that the original flood peaks were over-conservative seems justified. In this case, there is more corroboration for the smaller numbers using the Lowham and direct drainage area approaches. My recommendation is to use the numbers from Lowham in the attached table.

Please call with questions.

Sincerely,

Patrick T. Tyrrell, P.E.
Project Manager

Table 1. Wagonhound Creek Floods Estimated Using Lowham (1988)

Wagonhound Creek Drainage Area: 26.5 Mi^2

Wagonhound Creek Mean Basin Elevation: 8,480 Ft.

Return Period, f Years	C	e1	e2	Flood Peak, P CFS	Avg Std Error, %	Correlation Coefficient
2	0.012	0.88	3.25	**223**	55	0.93
5	0.13	0.84	2.41	**352**	46	0.95
10	0.45	0.82	1.95	**427**	44	0.95
25	1.75	0.8	1.46	**546**	44	0.94
50	4.29	0.79	1.13	**640**	47	0.94
100	9.63	0.77	0.85	**739**	50	0.93
200	25.9	0.75	0.47	**826**	54	0.91

From *Streamflows in Wyoming*, USGS WRI Report 88-4045 (Lowham, 1988), the equation for peak flows in Mountainous Regions is as follows:

$P_f = C \times DA^{e1} \times (Elev/1000)^{e2}$, where:

f = Return Period of Flood peak, in Years
C = a constant
e1 = an exponent
e2 = an exponent
DA = Drainage Area in square miles
Elev = Mean Basin Elevation in feet

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May 1, 2000

Mr. Tom Annear
Instream Flow Supervisor
Wyoming Game and Fish Department
5400 Bishop Blvd.
Cheyenne WY 82006

Re: Pass Creek Irrigation

Dear Tom:

I looked into the amount of irrigation above the Pass Creek Gage (06628900), and the possible related effects on hydrologic calculations using the gage data. Here are my findings:

- According to the State Engineer's Office field personnel, a reasonable "on the ground" estimate is about 4,000 irrigated acres above the gage. The 6,300 acres reported in the USGS record is only an estimate, so I believe the smaller number is more reliable.
- The consumptive irrigation requirements (CIR) for 4,000 acres of grass hay, compared to the average annual gage flows (AAF) on Pass Creek, are as follows:

	Apr	May	Jun	Jul	Aug	Sep	**Seasonal**
CIR (AF)	43	890	1,520	1,813	1,440	733	**6,446**
AAF (AF)	3,840	11,100	7,960	1,920	798	606	**26,237**
%	1.1	8.0	19.1	94.4	180	121	**25**

- The numbers above reflect relatively little effect of irrigation on gage flows early in the season and the potential for noticeable effect mid- and late-summer. In July, about half the creek's water is consumed for irrigation above the gage. In August and September the CIR numbers are misleading and abnormally high because they do not reflect normal stoppage of irrigation for harvest.
- In all, while irrigation does consume significant mid- and late-season water, I believe the effects on the relationship with Wagonhound Creek flows can be neglected. My reasons are that 1) Wagonhound Creek is similarly affected with riparian consumption and flooding above the interstate, 2) the strong relationship already developed included the effects of irrigation from every month of the irrigation season,

and 3) late season irrigation, when effects could be strongest, is not as significant as you might think considering that irrigation is likely stopped for cutting and Wagonhound is not serving diversions anyway.

Finally, when you look at recorded flows at the Pass Creek gage, 1998 was about an average year at 97 percent of normal at the gage. In 1999 the gage recorded a wet year at about 160 percent of normal. Therefore no dry year data, which possibly could have negatively influenced the relationship, were used in developing the correlation.

Sincerely,

Patrick T. Tyrrell, P.E.
Project Manager