Some Affects of Sustained Sub-Minimum Over-winter Flow Regimes on Wild Brown Trout Populations in the Upper Beaverhead River of Southwest Montana 2001 – 2008

By:

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ABSTRACT

Over-winter flow release regimes from Clark Canyon Reservoir were compared with recommended minimum instream flows for the tailwater fishery of the upper Beaverhead River in southwest Montana. October – March flow regimes were examined for the 1998 - 2007 period of study spanning abundant flow releases from ample storage pools to sub-minimum flow releases from record low reservoir storage resulting from consecutive years of extreme to exceptional drought. Over-winter flow regimes ranged from 118.5 % to 217.5% of the recommended minimum of 200 cfs under abundant reservoir storage pools to13.5% to 26.5% of the instream minimum under drought driven restrictions. The affects of over-winter flow regimes were investigated for select wild brown trout population dynamics including standing crop, condition factor, and densities of large mature fish within the populations of two study sections in the upper and middle tailwater reach. Highly significant positive correlations ($P<.01$) were observed for standing crop and densities of older, larger fish as a result of variation in over-winter flow regimes in both study sections. Correlations between brown trout condition and flow yielded a significant positive relationship ($P<.05$) only for the 20-inch and larger component of the upper study section. Linear and logarithmic regression analyses of all three population parameters established equations and graphic links between standing crop, condition and densities of older, larger fish as functions of over-winter flow regime. Relatively robust coefficients of determination ($R^2 = 0.62 – 0.91$) accompanied both forms of regression, however, it was determined that logarithmic analyses most closely fit scatter plot data and expected population dynamics. As a result, it was concluded that logarithmic equations represented the most accurate means of prediction of anticipated affects of over-winter flow management on brown trout populations. Analyses of the cumulative affects of consecutive years of sub-minimum flow regimes yielded a significant ($P<.05$) correlation with standing crop in the upper study section and highly significant ($P<.01$) correlations with densities of older, larger fish in both study sections. Analyses of standing crop and densities of mature fish tended to yield steep negative linear regressions as a function of cumulative years of sub-minimum over-winter flow regimes and exhibited relatively robust R^2 values, particularly for densities of large brown trout.

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The author wishes to express his sincere appreciation of those who assisted him during the course of the study. Scott Lula provided valuable and competent assistance in the field, in data management, and in the calculation of population estimates. Tim Mosolf, John Hoerning, and Sam Hochhalter provided especially dedicated and highly competent assistance in the field. Others who made valued contributions in the field include Chris Brozell, Greg Gibbons, Pete Lamothe, Austin McCullough, and Jamie Thompson. Bob McFarland and Tracy Simonson provided valuable assistance in data entry and statistical analysis. Pete Lamothe and Jim Magee graciously consented to review the draft manuscript. Emma Rens and Pete Lamothe provided assistance in the layout and formatting of the document. Finally, the author wishes to recognize the contributions and inspiration of Fred Nelson, a Montana pioneer in the role of instream flow in the determination of productive aquatic habitat.

CONTENTS

INTRODUCTION

The construction of bottom draw reservoirs on western rivers has often resulted in highly productive tailwater trout fisheries capable of sustaining standing crops well in excess of those observed in nearby free flowing streams or downstream reaches within the same river system. In these tailwater fisheries, enhanced productivity often is accompanied by enhanced growth rates, ultimate size, condition, and density of large individuals within the affected trout populations (Nelson 1977, Oswald 1986 and 2000). This enhanced productivity is generally derived through hypoliminion draw from the reservoir resulting in significant modification of the fluvial river continuum through a lacustrine influence. Factors contributing to a productive environment within the tailwater reach can include increases in concentrations of chemical nutrients, favorable alteration of ambient thermal regime, inclusion of zooplankton, phytoplankton and bacteria into the food web, interruption in sediment delivery, and favorable alteration of the hydrograph (Hynes 1970). While these factors have the potential to enhance trout populations under optimal storage and flow conditions, attenuated winter flow regimes can be one of the most significantly altered results of impoundment and dam management (Smith 1973). These sub-minimum over-winter flow regimes can result in detrimental affects within wild brown trout populations (Vincent 1971b, Nelson 1977 and 1980, Frazer 2003, Oswald 2003 and 2006).

With the construction of Clark Canyon Reservoir in 1964, the Beaverhead River of southwest Montana began to develop the characteristics of a highly productive tailwater fishery for wild populations of brown and rainbow trout. Berg (1974) described the limnology of Clark Canyon Reservoir and Smith (1973) defined the length and characteristics of the resultant tailwater plume in the Beaverhead River. In a general sense, depending upon patterns of storage in the reservoir and volume of discharge from the dam, the tailwater reach of the upper Beaverhead River extends from Clark Canyon Dam to Barretts Diversion 16 miles downstream (Smith 1973). At Barretts Diversion, major canals divert a significant quantity of irrigation release and Grasshopper Creek, 12.5 miles downstream from the dam, impresses significant influence on lower, nonirrigation season releases from the dam. As is the case in all tailwaters, the effect of the hypolimnion is decreased in a longitudinal fashion with distance from the dam and dilution from tributary inflow and groundwater accretions (Hynes 1970).

Prior to impoundment, the U. S Fish and Wildlife Service (USFWS) studied the fisheries resources and flow regimes of the Beaverhead River calculating that a minimum flow of 250 cfs was required to maintain productive aquatic habitat during the winter, or nonirrigation, period of flow management in the tailwater reach (USFWS 1956). Nelson (1977) discussed a WSP (Water Surface Profile) application developed by the Bureau of Reclamation (BOR) to eight cross sections established in the upper Beaverhead River tailwater that yielded a minimum instream flow evaluation of 200 cfs to maintain aquatic habitat. Finally, Montana Fish, Wildlife, and Parks (MFWP) applied the Wetted Perimeter Method of instream flow determination to a riffle habitat in close proximity to the original eight cross sections to determine a Minimum Instream Flow Reservation of 200 cfs for the upper Beaverhead River fishery (MFWP 1989).

The Beaverhead River tailwater reach is classified as a Category 1 or “Blue Ribbon” sport fishery by MFWP based on its exceptional standing crops and densities of large fish within its wild trout populations. Exceptionally high densities of large brown and rainbow trout in excess of 18 or 20 inches in length accompany sustained periods of over-winter flow release above the 200 cfs minimum. Nelson (1977) described exceptional standing crops, growth rates, mean weights, and densities of Age IV and older fish for both rainbow and brown trout in association with consecutive years of relatively ample minimum flows. Oswald (1986 and 2000) described maximum observed standing crops, spring condition factors, and densities of Age IV and older and Age V and older brown trout after consecutive years of elevated minimum flows in the 1982 – 1985 and 1996 – 2000 periods. Conversely, Oswald and Brammer (1993) and Oswald (2003 and 2006) described substantial declines in the same set of brown trout population parameters in two Beaverhead River tailwater study sections following severe drought episodes and minimal over-winter flow regimes in the 1988 – 1992 and 2001 – 2006 periods.

Angler use of the tailwater fishery also rises and declines with minimum flow regimes and the quality of the tailwater fishery (Oswald 2003). FWP angling pressure estimates (McFarland 1982 – 2007) exhibit maximum angler participation approximating 40,000 angler days per year in 1997 and 1999 under ample flow and strong trout populations compared with minimal participation approximating 15,000 angler days per year in 1991 and 2001 under minimal flow regimes and reduced trout populations.

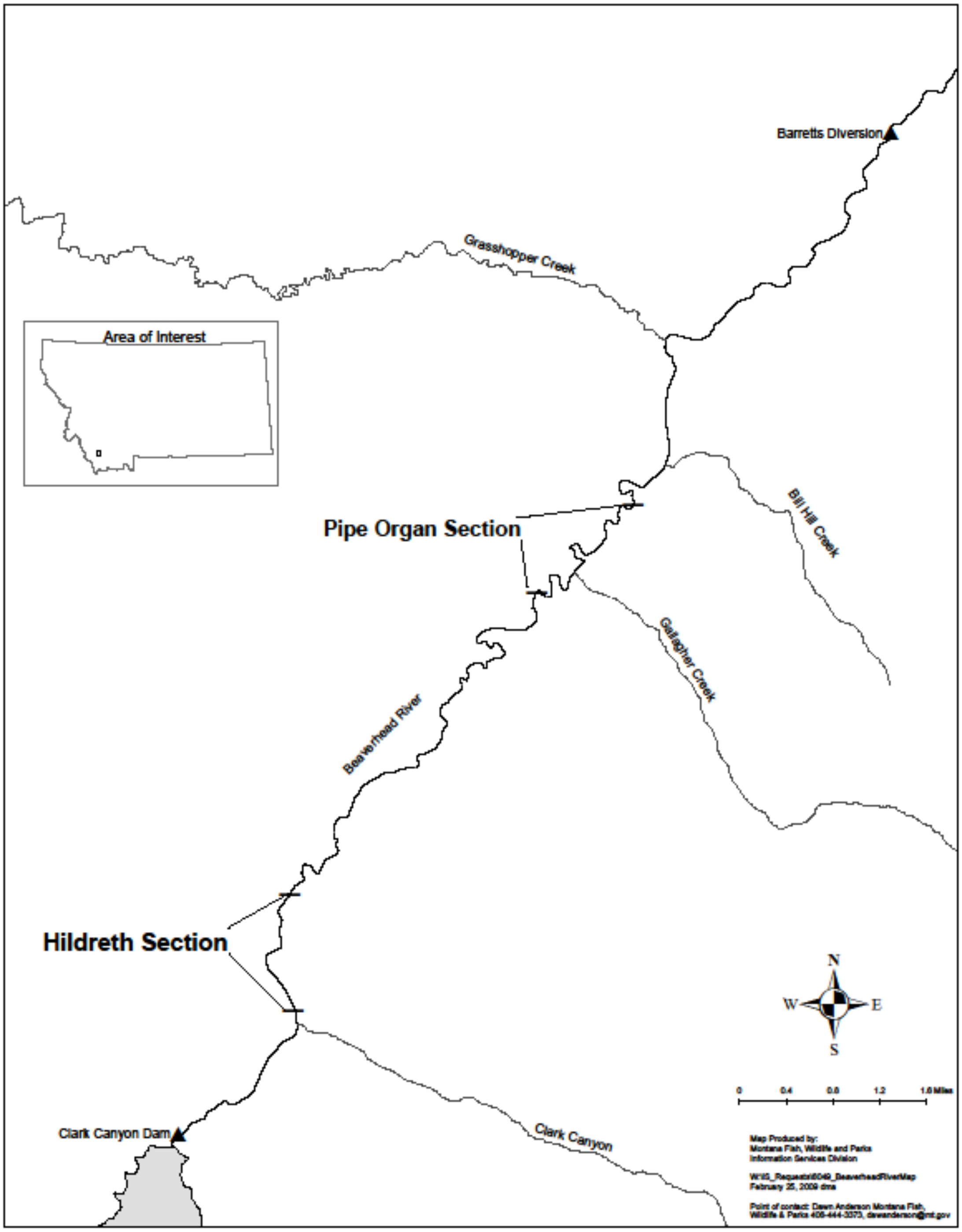
STUDY AREA

The Beaverhead River originates at the confluence of the Red Rock River and Horse Prairie Creek and flows 79.5 miles in a northerly direction, through Beaverhead and Madison Counties in southwest Montana. The Beaverhead River confluences with the Big Hole River near Twin Bridges, Montana to form the Jefferson River, one of the three headwater forks of the Missouri River named by the Lewis and Clark Expedition. Major tributary drainages to the Beaverhead River include the Ruby River, Blacktail Deer Creek and Grasshopper Creek. The modern origin of the Beaverhead River lies impounded beneath the surface of Clark Canyon Reservoir, constructed for irrigation supply, flood control, and recreation in 1964.

Studies discussed in this report were limited to the upper Beaverhead River tailwater reach defined as the 16 mile long river reach between Clark Canyon Dam and Barretts Diversion (Figure A) that exhibits characteristics of the influence of the hypolimnion discharge of the reservoir (Smith 1973). Major irrigation withdrawal at Barretts, including the East Bench Canal, significantly alters the flow regime of the river and the resultant tailwater effect. The only major tributary, Grasshopper Creek, enters the reach from the Pioneer Mountains to the west at mile 12.5 while minor tributaries, Clark Canyon Creek and Gallagher Gulch, enter the river from the Blacktail Mountains to the east at mile 1.7 and 9.1, respectively. Additional flow accretions are focused at two major springs, Gordon and McMenomey springs located within the first three miles downstream of Clark Canyon Dam.

Studies evaluated in this report were focused within two long-term fish population study sections located within the tailwater reach (Figure A). The Hildreth Section is located in the upper tailwater reach and is used to depict trout populations under the influence of good habitat quality and strong tailwater dominance. The Pipe Organ Section

Figure A. Map of the Study Area



is located at mid – tailwater and is representative of declining habitat conditions and declining tailwater productivity.

The Hildreth Section was established by MFWP in 1966 and has been sampled annually through 2008 with minor interruptions in 1981 and 1982 due to access issues. The study section originates at mile 1.8 downstream from Clark Canyon Dam (Lat. N45.01751, Long. W112.83884) and extends 6,250 feet downstream to a private ranch access bridge. Clark Canyon Creek enters the river immediately upstream from the study section and McMenomey spring enters the river in mid – study section. Nelson (1977) provided a limited physical description of the Hildreth Section that included a sinuosity of 1.32, a gradient of 0.33%, woody riparian bank cover of 77% and bank riprap alteration of 2.3% of total bank length. Minimum flow characteristics measured for the upstream boundary of the Hildreth Section exhibited flows of 42 to 45 cfs when minimum flows of 25 to 27 cfs were released at the dam.

The Pipe Organ Section, established by MFWP in 1970, was sampled annually through 1976 and from 1981 through 2008. The study section originates approximately at mile 8.3 downstream from Clark Canyon Dam (Lat. N54.07079, Long. W112.79920) and extends 10,800 feet downstream to the abandoned county road bridge cross section upstream from the Bill Hill Creek confluence. Gallagher Gulch Creek enters the river in mid study section and the reach is closely bordered by the Union Pacific Railroad track on the east. Nelson (1977) provided a limited physical description of the Pipe Organ Section that included a sinuosity of 1.62, a gradient of 0.24%, woody riparian bank cover of 50% and rock riprap alteration of 3.4% of total bank length. Active channel avulsions to the east have resulted in a significant increase in the amount of rock riprap along the toe of the railroad bed since Nelson's study. Minimum flow characteristics measured for the upstream boundary of the Pipe Organ Section exhibited flows of 60 to 65 cfs when minimum flows of 25 to 27 cfs were released at the dam.

METHODS

Brown trout populations were sampled using electrofishing techniques based on mark-recapture methodologies described by Vincent (1971a). Electrofishing was conducted via boat - mounted, mobile anode techniques that utilized a 3,500 watt Honda generator and Leach type rectifying box. A straight or continuous wave DC current was used at 1,500 to 1,800 watts. Fish captured within the field were drawn to the boat, netted, and deposited into a live car. The electrofishing boat consisted of a modified 16 foot Clackacraft drift boat. Individual fish captured were anesthetized, measured for length and weight, marked with a small identifying fin clip, and released. Scale samples for age determination were collected from a representative subsample by 0.5 inch length increment. A single Marking run was made through each study section followed by a single Recapture run approximately 12 to 14 days later.

Trout population statistics were analyzed under a log-likelihood methodology developed and described by MFWP (1994) under guidelines presented by Brittain, Lere, and McFarland (1998). Population estimates were calculated for brown trout from March and April samples to maximize resident stability and to avoid population estimate bias due to spawning movements and migrations.

Flow data presented in this report were extracted from Bureau of Reclamation reservoir operations records, USGS Gage reports (USGS 1981 – 2008), or measured directly by FWP staff. Direct measurement of instantaneous discharge was made with a Marsh McBirney Flo-Mate Model 2000 current meter.

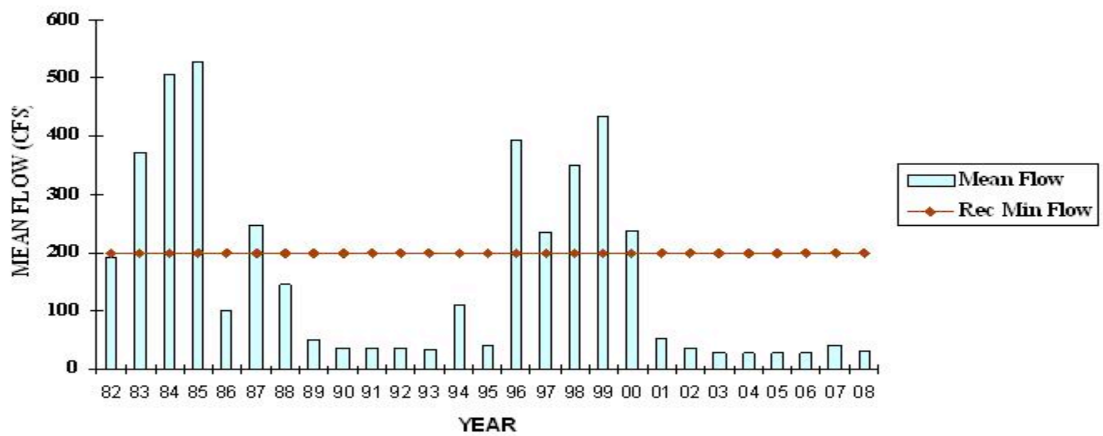
RESULTS

Over-winter Flow Regimes

The climate of southwest Montana has been dominated by drought conditions from 1985 through 2008. Mountain snowpack, critical May and June precipitation totals, Water Surface Supply and Palmer Soil indices have largely remained far below long-term averages often resulting in Extreme or Exceptional Drought Categorizations for Beaverhead and Madison Counties (NWS Montana data, Great Falls). These severe climatic conditions can result in an intensified need for crop irrigation and subsequently have also resulted in chronically sub-average inflows and storage pools in Clark Canyon Reservoir (USBOR Reservoir Operations 2009). Extreme depletions in residual storage in Clark Canyon Reservoir at irrigation season end have been accompanied by extreme reductions in dam release and Beaverhead River flow during the nonirrigation period. Thus, markedly reduced over-winter flow regimes have become a chronic condition as attempts to recover valuable storage prior to the next irrigation season are prioritized by BOR and water user boards. Figure 1 depicts patterns of mean nonirrigation season flow release from Clark Canyon Dam over the 1982 – 2008 Water Years. The nonirrigation or over-winter season is defined as the October through March period. The flow regimes reflect a minimal variation from the exhibited means as releases are generally determined shortly after irrigation ends and set for the winter period by BOR and the irrigation boards. The static line depicted at 200 cfs represents the minimum instream flow recommendation calculated for the Beaverhead River through the WETP Method (Nelson 1980) and also represents the Minimum Instream Flow Reservation held by MFWP for the Beaverhead River (MFWP 1989).

Figure 1 exhibits relatively brief periods of abundant water supply during the 1983 – 1985 and 1996 – 2000 Water Years when recommended minimum instream flows were significantly exceeded during the winter months. Both of these episodes were followed by extended periods of sub-minimum flow releases that dominated winter flow regimes through the 1986 – 1995 and 2001 – 2008 Water Years. While both periods represented extended periods of drought, chronic minimum flows in 2001 – 2008 exhibited a longer duration and more severe amplitude than those observed over the 1986 – 1995 period. Over-winter flows in 1987 actually exceeded the 200 cfs recommended minimum while mean flows in 1986, 1988, and 1994 were at or above 100 cfs. Sub-minimum over-winter flow regimes during the 1986 – 1995 period ranged between 34 and 146 cfs averaging 65.4 cfs or 32.7 % of the recommended minimum flow. Conversely, sub minimum over-winter flows during the 2001 – 2008 Water Years exhibited a much more attenuated range of 27 – 53 cfs and a mean of 34.8 cfs or 17.4% of the recommended minimum instream flow.

Figure 1. Mean over-winter (October through March) flow release into the Beaverhead River from Clark Canyon Dam over the 1982 - 2008 Water Years.



While over-winter release regimes from Clark Canyon Reservoir reflect the severity of flow depletion below the recommended minimum of 200 cfs, it is beneficial to have a relative understanding of how those releases are reflected at the trout population study reaches discussed in this report. In order to provide that insight for the period of study, a limited series of discharge measurements were obtained near the upstream end of the Hildreth and Pipe Organ Study Sections after flow releases were set to minimum values of 25 - 27 cfs and reservoir storage pools were near annual minima. Minimum flow values at the upper end of the Hildreth Section ranged between 42 and 45 cfs while minimum flows near the upstream boundary of the Pipe Organ Study Section ranged between 60 and 65 cfs. Flows ranged slightly higher as winter flow releases were increased above 27 cfs and storage pools in the reservoir increased but were not observed to exceed 81 cfs at the Hildreth Section and 118 cfs at the Pipe Organ Section under the most optimal conditions measured during the period. Nelson (1977) also attempted to relate flows recorded at the USGS Grant Gage to those observed in the Hildreth Section and used a constant of 35 cfs to account for accretions within the Hildreth section for the nonirrigation or October – March period. He also suggested that flow could never be depleted below a minimum of 50 cfs in the Hildreth Section because of the accretions. Differences between accretions observed in this study and Nelson's are probably associated with Nelson's point of measurement and the much more substantially reduced over-winter flow releases and minimum reservoir storage pools observed in the current study.

Brown Trout Population Data Quality

Data directly analyzed and providing the base source for brown trout population dynamics for this report came from spring samples collected over the 1998 – 2008 period in the Hildreth Study Section. Similarly, supporting data from the Pipe Organ Study Section in mid- tailwater were also collected over the 1998 – 2008 period in order to span the affects of ample and sub minimum over-winter flow regimes on the wild brown trout populations. Estimates of brown trout standing crop, estimated densities of older, larger fish in the populations, and calculations of condition factor were all generated from this base data set and were dependant upon the quality of the sampling efforts. Point estimates of population density (per mile) of Age II and older brown trout and accompanying Standard Deviations ($P<.05$), sample size, and sample efficiency (R/C) are presented in Table 1 for the Hildreth Section. Standard Deviations of the population estimates ranged from 2.1% of the point estimate in 2005 to 3.9% in 1998 and averaged 3.2% over the study period. Sample size ranged from a minimum of 669 fish in 2006 to a maximum of 1,601 under burgeoning recruitment of Age II and Age III fish in 2008. Mean sample size was 1,073 over the study period. Sample efficiencies (R/C) ranged from 21.3% in 1999 to a high of 45.3% at minimum sample size and population density in 2006 and exhibited a mean of 28.8% over the study period. Samples from the Pipe Organ section exhibited similar statistics although Standard Deviations were slightly wider than those observed in the Hildreth Section ranging between 3.7% and 6.0% of the estimated density, averaging 4.8% over the study period. Sample size for the longer Pipe Organ Section was also higher, averaging 1,401 over the study period.

Table 1. Estimated spring population density (PD) of Age II and older brown trout with accompanying Standard Deviation (SD) at the 95% Confidence Interval, sample size (N), and efficiency (R/C) for the Hildreth Section of the Beaverhead River, 1998 – 2008.

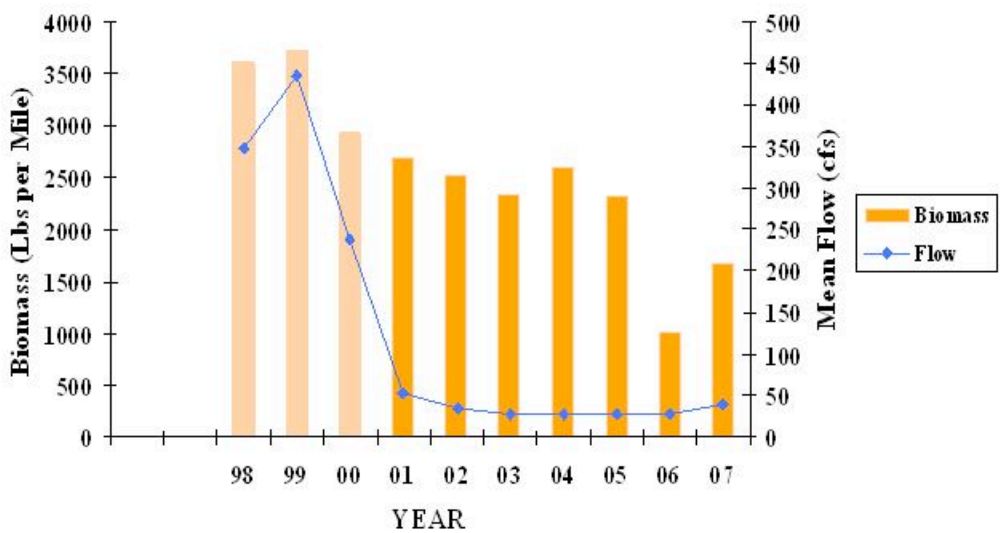
Year	PD	SD	N	R/C
1998	2,129	83.0	975	23.6
1999	2,155	77.6	1,061	21.3
2000	1,633	64.1	844	25.4
2001	1,647	52.8	1,037	24.4
2002	1,681	57.0	991	25.8
2003	1,561	50.4	957	27.3
2004	1,760	49.4	1,122	33.4
2005	1,657	35.1	1,266	36.0
2006	869	22.1	669	45.3
2007	1,723	55.2	1,288	24.6
2008	3,101	89.0	1,601	29.4

Brown Trout Standing Crop

Recent trends in brown trout standing crop are presented in association with mean over-winter flow release regimes in Figure 2 over the 1998 – 2007 period of study in the

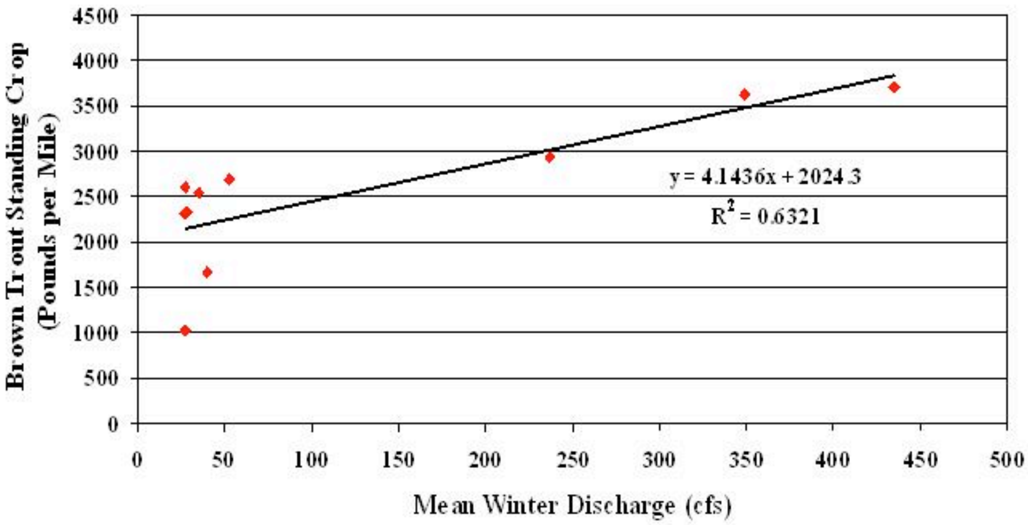
Hildreth Section. Brown trout standing crop attained historic observed maxima for the study section under relatively abundant over-winter flow regimes during the 1998 – 2000 period but declined under markedly reduced flow regimes in subsequent years. The 2006 sample revealed a brown trout population density and standing crop representative of a modern observed low for the study section. Declines in standing crop represent a relatively linear trend while declines in over-winter flow regime exhibited a more abrupt decline followed by a relatively flat trend at persistent low levels. While standing crop and over-winter flow regime both exhibited clear declines over the same period of time, the relationship between the two parameters was not necessarily linked or clearly defined in Figure 2.

Figure 2. Estimated spring standing crop of Age II and older brown trout compared with mean overwinter flow release regime from Clark Canyon Dam in the Hildreth Study Section of the Beaverhead River; 1998 - 2007.



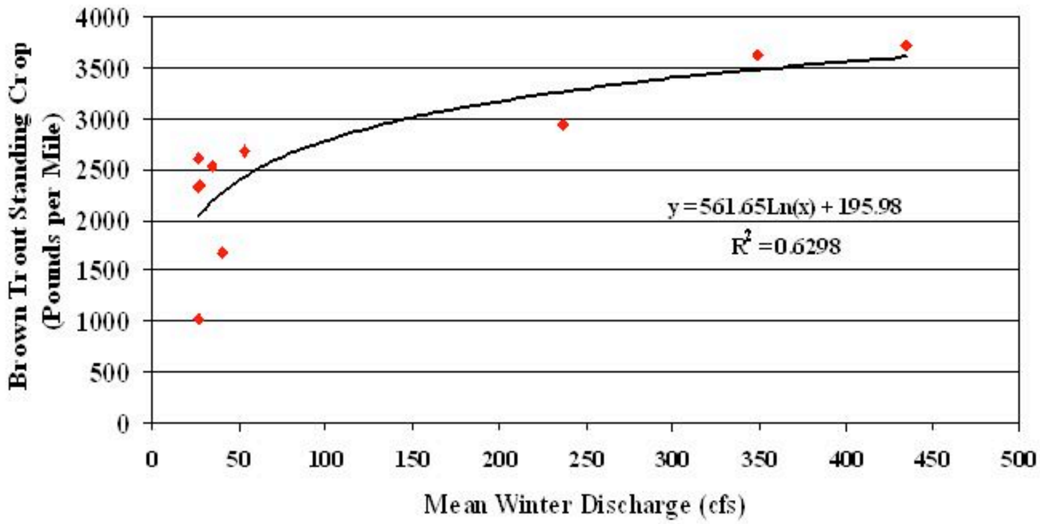
For this reason, brown trout standing crop data were tested for a functional link with minimum over-winter flow regime (Figure 3) via correlation and linear regression. The correlation between the two parameters was highly significant ($r = 0.80$, $P < .01$). Linear regression of brown trout standing crop as a function of over-winter flow regime demonstrated a relatively tight fit with a Coefficient of Determination (R^2) of 0.63 and a slope of 4.14. Linear regression provided a direct link between flow and standing crop attributing 63% of the observed variation in brown trout standing crop to variation in flow and suggesting that slightly more than 200 pounds of biomass might be gained by a 50 cfs flow increase from a minimum value of about 25 cfs.

Figure 3. Linear Regression of the estimated spring brown trout standing crop as a function of mean over-winter flow release regime from Clark Canyon Dam in the Hildreth Section of the Beaverhead River; 1998 - 2007.



While Hildreth Section brown trout standing crops appeared to exhibit a satisfactory linear trend, the scatter plot of the data also appeared to exhibit a vertical distribution at the low end of the flow range suggestive of a curvilinear trend. For this reason, brown trout standing crop was also examined as a function of mean over-winter flow regime under a logarithmic analysis (Figure 4). Similar to the linear analysis, the logarithmic analysis yielded a strong correlation (r = 0.79) that was highly significant ($P<.01$). The log distribution of brown trout standing crop also exhibited a relatively tight fit as a function of over-winter flow regime and exhibited an R^2 of 0.63 which was virtually identical to that associated with the linear analysis. The logarithmic analysis differed from the linear most markedly in its predicted response of standing crop to flow regimes at mid ranges in flow and in the variable rate of change as maximum and minimum levels of standing crops were approached under maximum and minimum flow regimes. The logarithmic analysis tends to predict a higher standing crop as flows increase from the minimum than those predicted under a linear analysis. The logarithmic analysis also exhibited its greatest rate of change as minimum standing crops were supported at minimum flow regimes and lowest rate of change as maximum standing crops, at or near carrying capacity, were approached at flow regimes in excess of the recommended minimum of 200 cfs. For these reasons, the logarithmic analysis appeared to more closely mimic an expected natural population response than that demonstrated through the linear analysis for brown trout standing crop.

Figure 4. Logarithmic analysis of the estimated spring brown trout standing crop as a function of mean over-winter flow release regime from Clark Canyon Dam in the Hildreth Section of the Beaverhead River; 1998 - 2007.



Recent trends in brown trout standing crop are presented with the same range of winter flow regimes in Figure 5 for the Pipe Organ Study Section from 1998 – 2007. Similar to the Hildreth Section, brown trout standing crops in the Pipe Organ Section exhibited a generally declining trend as mean over-winter flows declined below 200 cfs. Slight increases in standing crop in 2001 and 2007 were associated with the recruitment of strong cohorts of Age II and III fish at low densities of mature brown trout (Oswald 2006 and 2009). A somewhat different response than that observed in the Hildreth Section was a virtual stagnation of standing crop over the 2003 – 2006 study period at persistent minimal flow regimes.

As was the case for the Hildreth Section data, Pipe Organ standing crop data was subjected to linear and logarithmic analyses (Figure 6) in an attempt to discern a relationship between standing crop and over-winter flow regime. Both the linear (r= 0.80) and logarithmic analyses (r=0.82) exhibited relatively strong correlations that were highly significant (P<01) for brown trout standing crop as a function of over-winter flows. Similar to the Hildreth Section, the linear regression for Pipe Organ exhibited an R^2 of 0.64 but deviated markedly from the Hildreth Section with a much flatter slope of 1.70. As was the case in the Hildreth Section, the logarithmic analysis provided for a slightly better fit of the scatter plot, a steeper rate of loss as minimum flows were encountered, a slower rate of increase as maximum standing crops were approached, and higher predicted standing crops at mid ranges of flow. Unlike the analysis for the Hildreth Section standing crops, the logarithmic R^2 increased to 0.68 for the Pipe Organ data.

Figure 5. Estimated spring standing crop of Age II and older brown trout compared with mean over-winter flow release regime from Clark Canyon Dam in the Pipe Organ Section of the Beaverhead River; 1998 - 2007.

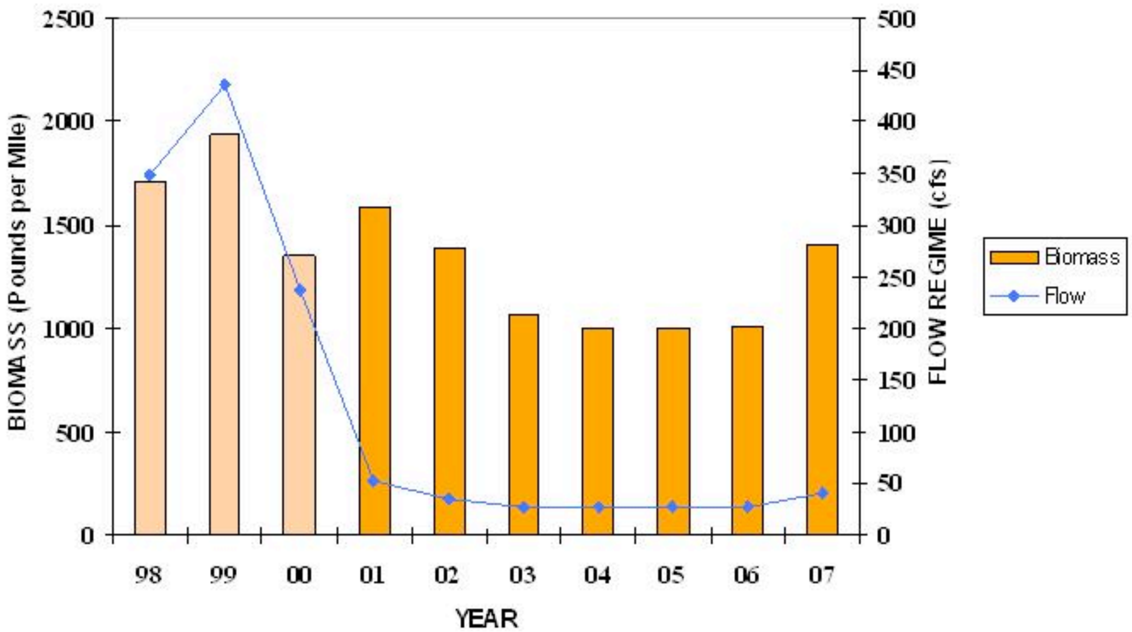
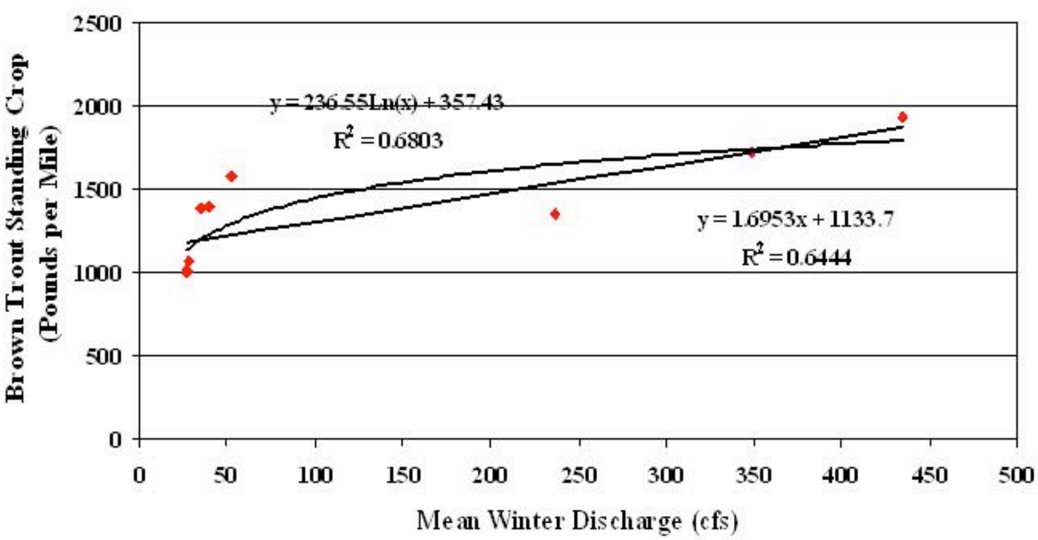


Figure 6. Linear regression and logarithmic analysis of the estimated spring brown trout standing crop as a function of mean over-winter flow regime from Clark Canyon Dam in the Pipe Organ Section of the Beaverhead River; 1998 - 2007.

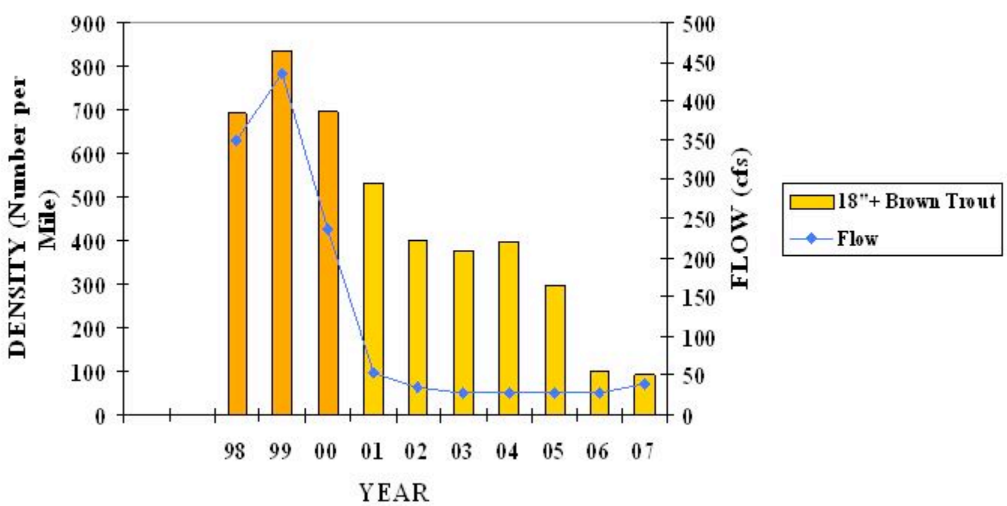


Density of Mature Brown Trout

Previous studies have demonstrated the effects of instream flow on the densities of older, larger fish within wild brown trout populations in southwest Montana rivers (Oswald 2003, 2005, 2006). Within the upper tailwater reach of the Beaverhead River, scale analysis combined with length frequency distribution demonstrate that brown trout in excess of 18 inches in length in spring samples can very conservatively be classified as Age IV and older fish under a full range of population dynamics and environmental conditions. While all Age IV and older brown trout are not included in the 18 inch and larger size group, virtually all 18 inch and larger individuals would be expected to be at least Age IV fish. Similarly, 20 inch and larger fish would be expected to conservatively include Age V and older individuals in spring samples.

Recent trends in the density of eighteen inch and larger, or, Age IV and older brown trout are shown in Figure 7 for the Hildreth Section and compared with trends in over-winter flow regime for the 1998 – 2007 period of study. As was the case with standing crop, ample flow years over the 1998 – 2000 period were accompanied by record high observed densities of 18 inch and larger fish while persistent low over-winter flow regimes were accompanied by record low densities for the study section. The 1999 – 2007 period also exhibited an apparent steep, linear decline in the density of these Age IV and older fish as over-winter flow regimes declined below the minimum flow and persisted at chronic low levels.

Figure 7. Estimated spring density of 18 inch and larger (Age IV+) brown trout compared with mean overwinter flow release regime from Clark Canyon Dam in the Hildreth Section of the Beaverhead River; 1998 - 2007.



The relationship between the densities of 18 inch and larger brown trout and flow was strongly correlated (r = 0.84) at a highly significant (P<.01) level of confidence. This relationship is also demonstrated through linear regression in Figure 8. Again, the data exhibited a strong fit under linear analysis with a relatively steep slope of 1.34 and a coefficient of determination of 0.70. Because of the apparent curvilinear distribution of the scatter plot, the data were also subjected to a logarithmic analysis (Figure 9) that exhibited traits similar to those observed with the relationships between standing crop and flow. Figure 9 demonstrated a variable rate of change that was more rapid at lower flow regimes and slower as higher flows and densities of 18 inch and larger fish appeared to approach carrying capacity. The logarithmic relationship between densities of these larger fish and flow also exhibited a slightly more robust R^2 than that observed for the linear regression suggesting that 74% of the variation in the density of 18 inch and larger brown trout was due to the observed variation in flow regime.

Figure 8. Linear Regression of the estimated spring density of 18 inch and larger (Age IV+) brown trout as a function of mean over-winter flow release regime from Clark Canyon Dam in the Hildreth Section of the Beaverhead River; 1998 - 2007.

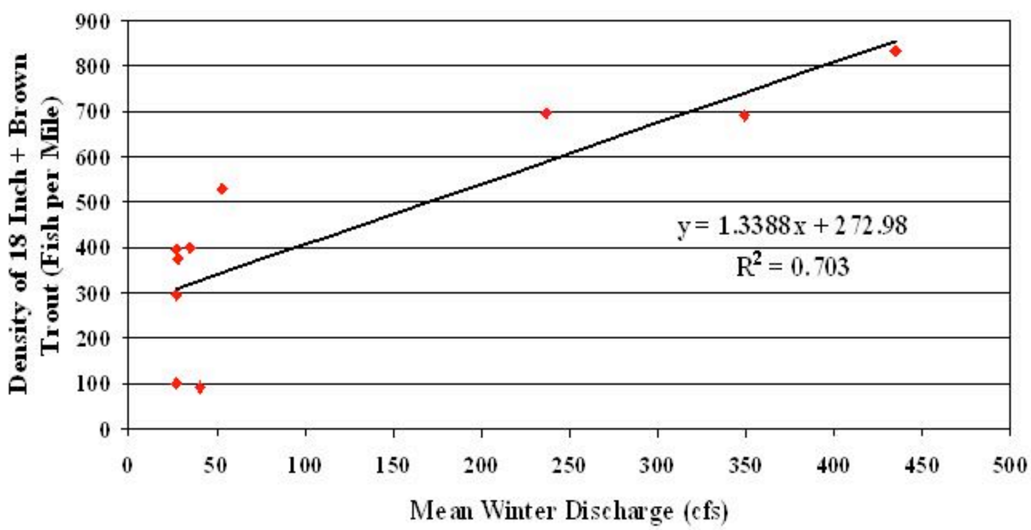
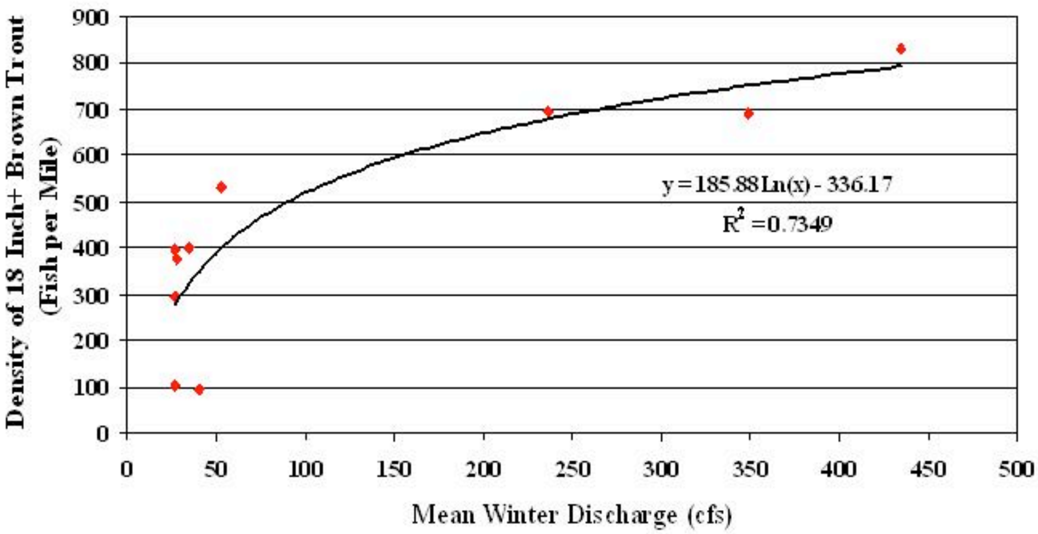


Figure 9. Logarithmic analysis of the estimated spring density of 18 inch and larger (Age IV+) brown trout as a function of mean over-winter flow release regime from Clark Canyon Dam in the Hildreth Section of the Beaverhead River; 1998 - 2007.



Because of the high productivity of the upper tailwater reach, the Hildreth Section data also afforded the opportunity to analyze densities of the twenty inch and larger, Age V and older component of the brown trout population. Recent trends in the density of these older, larger fish (Figure 10) exhibited a more rapid decline than those observed for brown trout standing crop or for densities of the18 inch and larger component and more closely mimic the pattern observed for declining flow regimes over the 1998 – 2007 period. Unlike observations for brown trout standing crop or densities of 18 inch and larger fish, the 1999 sample did not result in the observed high density of 20 inch and larger fish for the Hildreth Section, however, the 2006 and 2007 samples did yield record low densities at low flow regimes.

Linear regression and logarithmic analyses of the estimated densities of the 20 inch and larger component of the Hildreth Section brown trout population as a function of over-winter flow regime are presented in Figure 11. Both the linear (r = 0.88) and logarithmic (r = 0.87) analyses exhibited relatively strong and highly significant ($P<.01$) correlations and relatively robust R^2 values of 0.78 and 0.75, respectively. Again, the logarithmic analysis appeared to represent a better fit to a curvilinear scatter plot of the data. The slight increase in R^2 values observed over those associated with the 18 inch and larger, Age IV and older component suggests that the older, larger brown trout densities were slightly more impacted by winter flow regime.

Figure 10. Estimated spring density of 20 inch and larger (Age V+) brown trout compared with mean overwinter flow release regime from Clark Canyon Dam in the Hildreth Section of the Beaverhead River; 1998 - 2007.

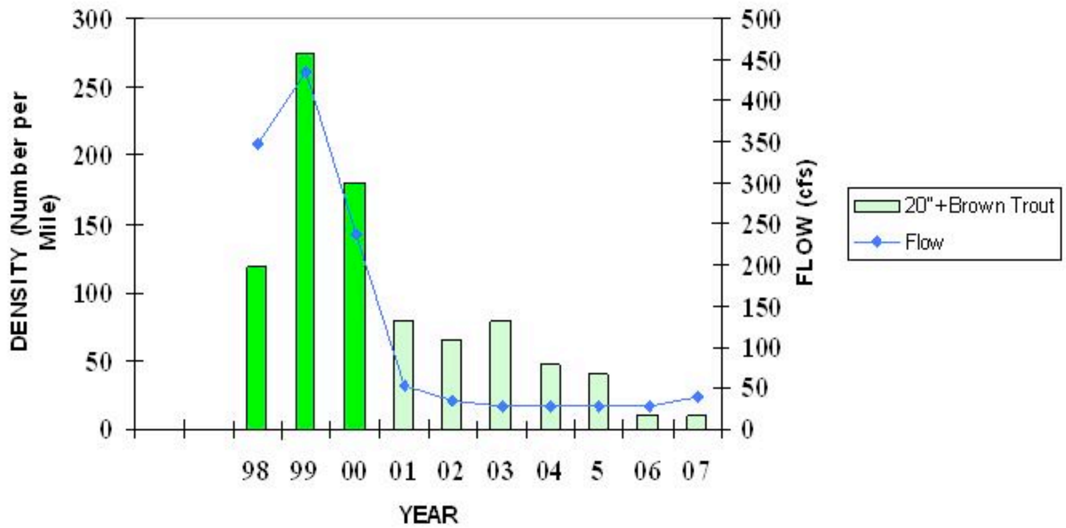
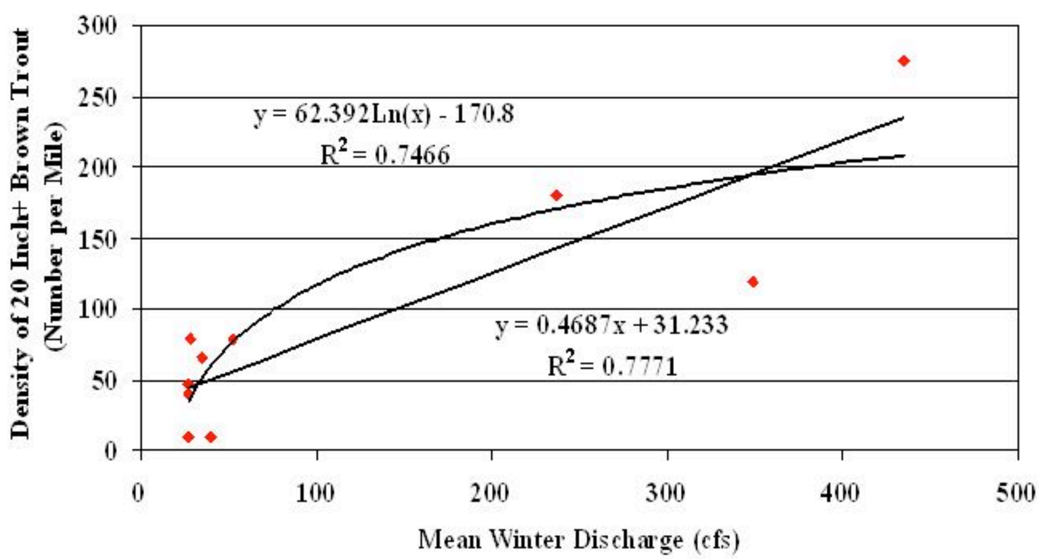
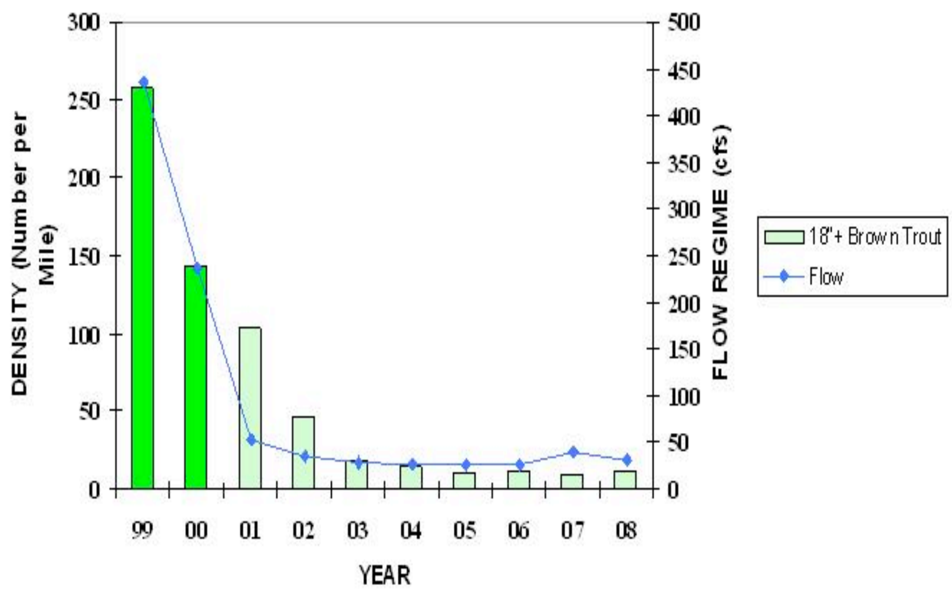


Figure 11. Linear and logarithmic analyses of the estimated spring density of 20 inch and larger (Age V+) brown trout as a function of over-winter flow release regime from Clark Canyon Dam in the Hildreth Section of the Beaverhead River; 1998 - 2007.



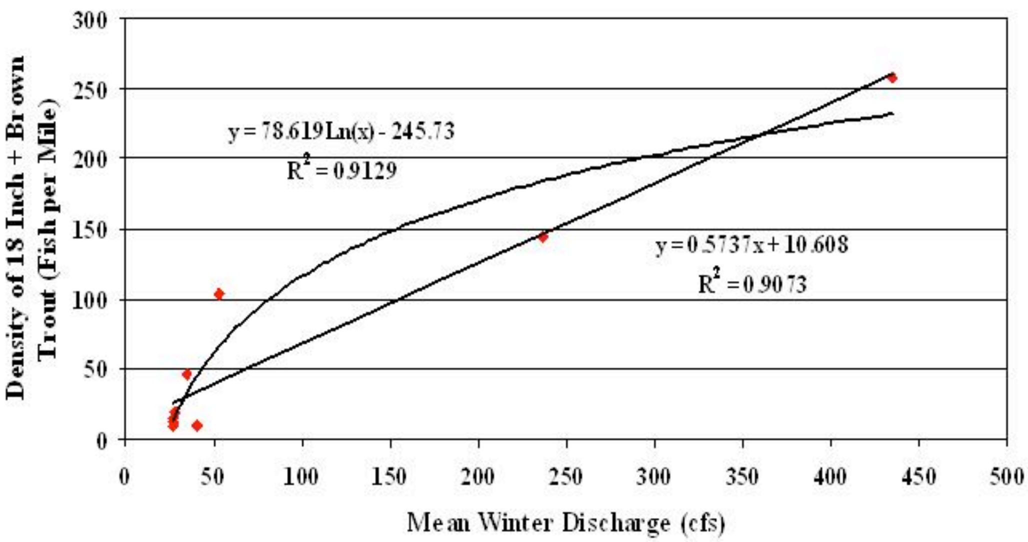
Due to its location at mid – tailwater, the brown trout populations of the Pipe Organ Section tend to support significantly lower densities of large fish than those of the Hildreth Section in much closer proximity to the dam outlet. Due to slower growth rates and a more attenuated ultimate size potential, the 18 inch and larger brown trout of the Pipe Organ Section are conservatively representative of the Age V and older segment of the population. Recent trends in the density of these older, larger fish are presented in Figure 12 in association with mean over-winter flow regimes for the 1999 – 2008 period. The trends and relationship between brown trout density and flow regime very closely mimic those observed for the 20 inch and larger, Age V and older component in the Hildreth Section (Figure 10).

Figure 12. Estimated spring density of 18 inch and larger (Age V+) brown trout compared with the mean overwinter flow release regime from Clark Canyon Dam in the Pipe organ Section of the Beaverhead River; 1999 - 2008.



Linear regression and logarithmic analyses of the estimated densities of the 18 inch and larger component of the Pipe Organ Section brown trout population as a function of over-winter flow regime are presented in Figure 13. Both forms of analysis exhibited highly significant ($P<.01$) and extremely robust ($r = 0.95$) correlations with flow regime. Again, both means of analysis provide a slightly different trend prediction. The linear analysis provided a fixed rate of change and mid flow densities that were lower than those predicted under a logarithmic equation. As was the case with analyses for brown trout standing crop, the slope of the regression for the Pipe Organ Section was lower than those observed for the Hildreth Section, indicative of lower amplitudes of decline for both parameters. Logarithmic analysis resulted in steep rates of change at low flow regimes and slower rates of change as maximum observed densities were observed as carrying capacity was approached and appeared to more closely fit a curvilinear scatter plot of data. Both the linear and logarithmic analyses exhibited very robust R^2 values of 0.91, the highest observed for any of the prior forms of analysis.

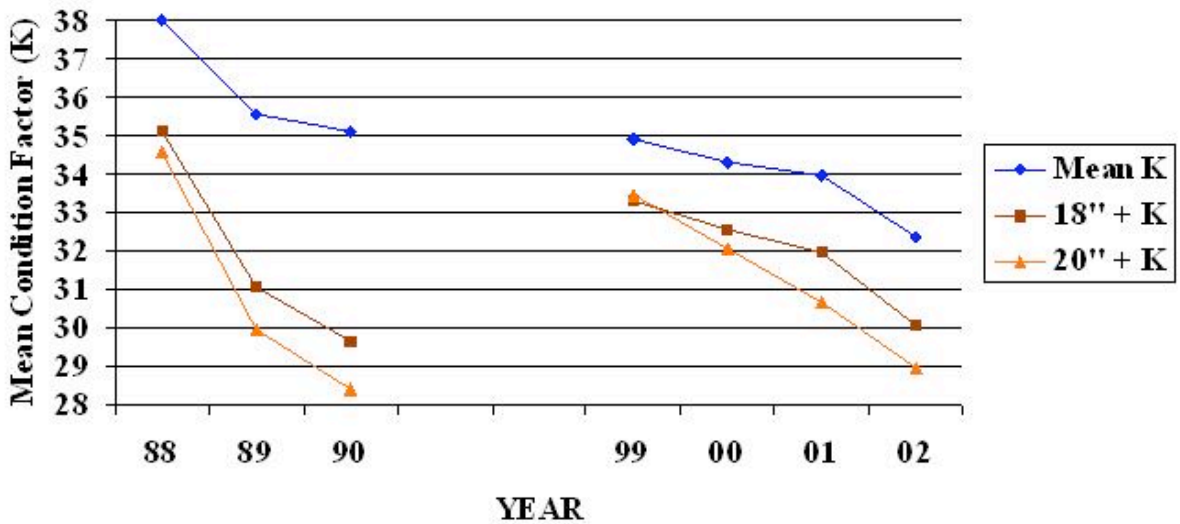
Figure 13. Linear and logarithmic analyses of the estimated spring density of 18 inch and larger (Age V+) brown trout as a function of over-winter flow release regime from Clark Canyon Dam in the Pipe Organ Section of the Beaverhead River, 1999 - 2007.



Brown Trout Condition Factor

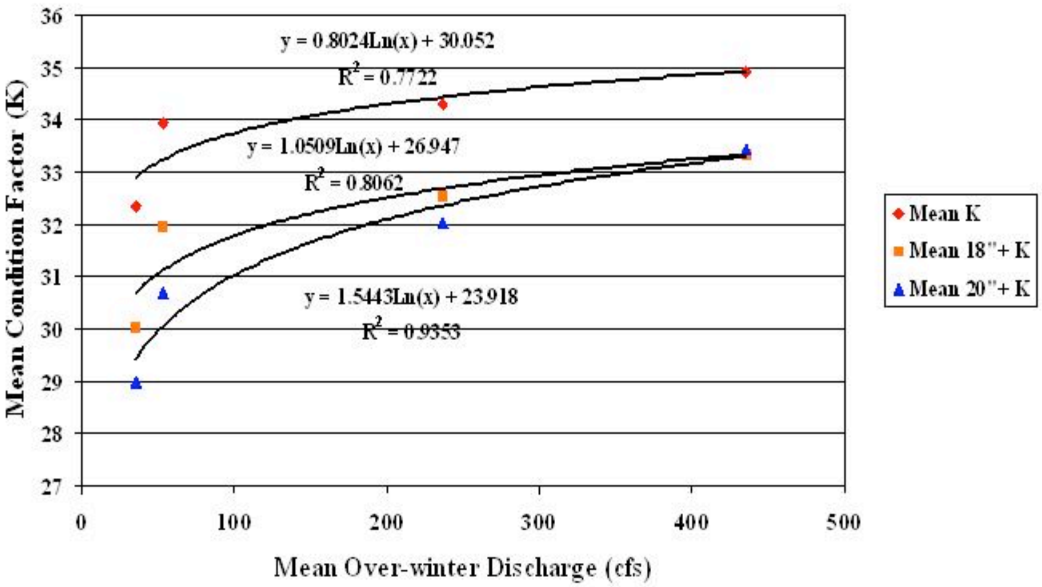
Numerous studies have demonstrated the effects of declining flow regimes on brown trout condition factors, particularly, the condition of the older, larger fish in the populations (Vincent et al 1990, Oswald 2003, 2005, and 2006). Oswald (2006) observed that brown trout condition factors exhibited steep declines with declining over-winter flow regimes in the Hildreth Section over the 1988 – 1990 and 1999 – 2002 periods of study (Figure 14). Both of these declines in condition shared similar characteristics as standing crops and densities of older, larger brown trout entered into steep declines from observed highs relative to each time period. The declines in condition were also limited to relatively short periods of time as major declines in biomass and density of older, larger fish rapidly reduced competition and biotic demand on the habitat, ultimately providing for increases in individual fish condition at lower density. While Figure 14 clearly depicts decreases in condition factor over periods of declining flow, it does not provide for a direct link between both variables.

Figure 14. Mean spring brown trout Condition Factor (K) for Age II and older brown trout and for discreet length groups of mature brown trout in the Hildreth Section of the Beaverhead River; 1988 - 1990 and 1999 - 2002.



The 1999 – 2002 Hildreth Section decline in brown trout condition was analyzed as a function of flow under a logarithmic regression (Figure 15) for the Age II and older population mean, the 18 inch and larger, and 20 inch and larger components. A logarithmic analysis was chosen as a better fit to a curvilinear scatter set of data points. All three population segments chosen for analysis exhibited obvious trends as a function of mean over-winter flow regime with the condition of the mean brown trout population exhibiting an R^2 of 0.77. The 18 inch and larger or Age IV and older component exhibited a slightly stronger R^2 of 0.81 while the 20 inch and larger or Age V and older

Figure 15. Logarithmic correlation of mean spring brown trout Condition Factor (K) as a function of mean over-winter flow release regime from Clark Canyon Dam in the Hildreth Section of the Beaverhead River; 1999 - 2002.



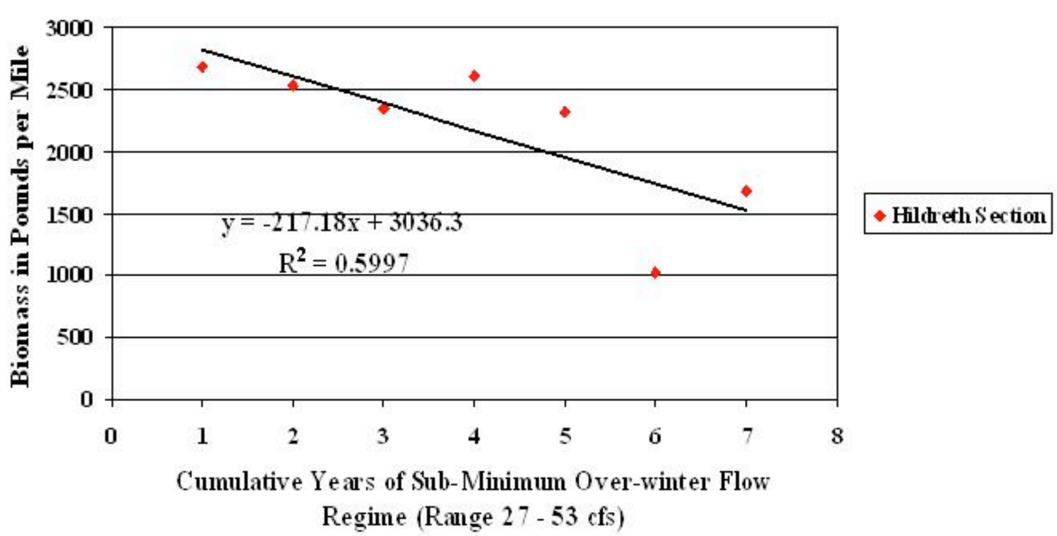
component exhibited a highly robust R^2 of 0.91. Correlation analysis, however, only attributed a significant relationship ($P<.05$, $r = 0.97$) between condition and flow regime for the 20 inch and larger component. The correlation coefficient for the 18 inch and larger component was 0.90 but fell into the P.05 – P.10 probability range. As was the case with the densities of older, larger brown trout within the population, the oldest and largest segment analyzed at 20 inches and larger proved most directly affected by the over-winter flow regime. Logarithmic analysis of declining condition factors in Age V and older, 18 inch and larger brown trout over the 1999 – 2003 period in the Pipe Organ Section exhibited an R^2 of 0.72 as a function of declining over-winter flow regime, however, the correlation, $r = 0.85$ fell between $P<.10$ and $P=.05$ and was not considered significant.

<u>Cumulative Affects of Sub- Minimum Over-winter Flows</u>

Recent over-winter flow release regimes (Figure 1) clearly depict a chronic minimal flow condition exhibiting an extremely attenuated range for eight consecutive water years. This relatively stable condition has been manifest at an annual mean of about 34 cfs, or about 17% of the FWP Minimum Flow, with a very narrow range of variation. Prior sections of this report have discussed this condition relative to the curvilinear distribution of various brown trout population dynamics as a function of minimum flow but did not discuss or analyze the influence of time on those distributions. For this reason, a second form of analysis was applied to the selected brown trout population dynamics as a function of consecutive years of over-winter flow regimes below the recommended minimum of 200 cfs. This analysis was applied to brown trout standing crop and densities of older, larger fish within the populations but did not include condition factor. Condition factor was eliminated from a cumulative temporal analysis because the response of condition would logically vary upward as standing crop and densities of large, mature fish were reduced and was limited to a declining response to flow over two years of supra- and two years of sub – minimum flows (Figure 15).

Brown trout standing crops exhibited a relatively tight linear fit and steep decline in a cumulative temporal response to sub – minimum flow regimes in the Hildreth Section (Figure 16). The correlation between standing crop and cumulative years of sub-minimum flows was significant (P<.05) and relatively strong, exhibiting a coefficient of 0.77. The relationship also exhibited an R^2 of 0.60, quite similar to those observed for the response of standing crop to declining flow regimes (Figures 3, 4, and 6). A similar analysis of cumulative affects applied to the spring standing crop of brown trout in the Pipe Organ Section yielded a much weaker R^2 of only 0.39 but exhibited a better fit to a logarithmic, rather than a linear, analysis. The correlation between cumulative affects of low flows and brown trout standing crops in the Pipe Organ Section became highly significant (P<.01) and much more powerful ($r = 0.95$, $R^2 = 0.91$), however, with elimination of the 2007 population estimate and its strong recruitment cohort of juvenile fish. These relationships indicate that the persistence of low over-winter flow regimes over an extended period of years also had a direct affect on the standing crop of brown trout in the Beaverhead River tailwater.

Figure 16. Linear regression of the estimated spring brown trout standing crop as a function of cumulative years of overwinter dam releases under the Minimum Instream Flow of 200 cfs in the Beaverhead River; 2001 - 2007.



Similarly, the densities of older, larger brown trout were analyzed for linear response to cumulative years of sub-minimum flow regimes during the over-winter period. Figure 17 depicts the response of 18 inch and larger (Age IV +) brown trout to cumulative years of sub-minimum flows over the 2001 – 2007 period while Figure 18 presents the same analysis for the 20 inch and larger (Age V +) segment of the spring brown trout populations. Both subdivisions of the older, larger portion of the brown trout population yielded highly significant (P<.01) correlations with very robust coefficients of 0.94 and 0.93, respectively. They also exhibited similar patterns of response to cumulative years of sub minimal over-winter flow regimes, i.e., steep, tight fitting, negative linear regressions with robust Coefficients of Determination. The 18 inch and larger portion of the Hildreth section brown trout exhibited an R^2 of 0.88 while the 20 inch and larger component exhibited an R^2 of 0.86 indicating that a substantial amount of large fish density variation was explained by cumulative years of sub-minimal flow regimes. Steep negative slopes exhibited by both age and size groups were indicative of relatively high and constant annual attrition rates at persistent low flow regimes. The same scrutiny of cumulative affects (Figure 19) applied to the 18 inch and larger (Age V +) brown trout in the Pipe Organ Section yielded a highly significant correlation (P<.01, r = 0.91) with a similar R^2 of 0.83 but exhibited a better fit to a logarithmic, rather than a linear, analysis. Again, these relationships demonstrated a direct cumulative affect of sustained periods of time at sub-minimal over-winter flow regimes on the observed densities of larger, mature brown trout within the populations of the tailwater.

Figure 17. Linear regression of the estimated spring density of 18 inch and larger (Age IV+) brown trout as a function of cumulative years of overwinter dam releases under the Minimum Instream Flow of 200 cfs in the Beaverhead River; 2001 - 2008.

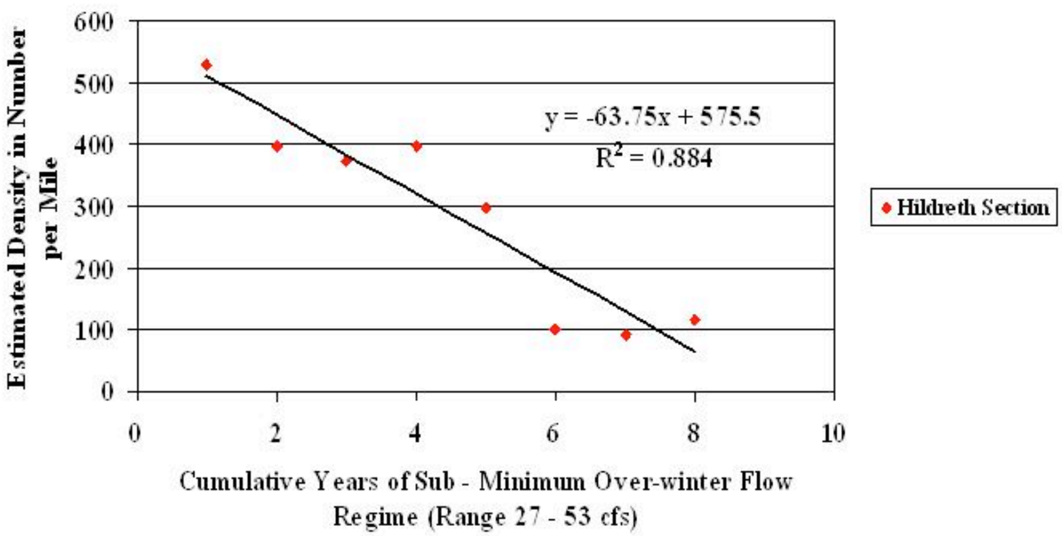


Figure 18. Linear regression of estimated spring density of 20 inch and larger (Age V+) brown trout as a function of cumulative years of over-winter dam releases under the Minimum Instream Flow of 200 cfs in the Beaverhead River; 2001 - 2008.

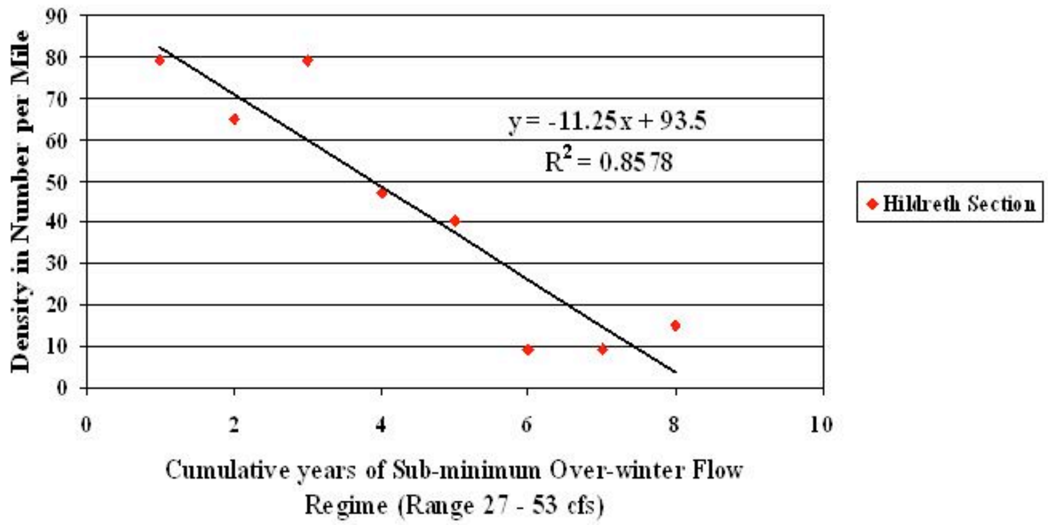
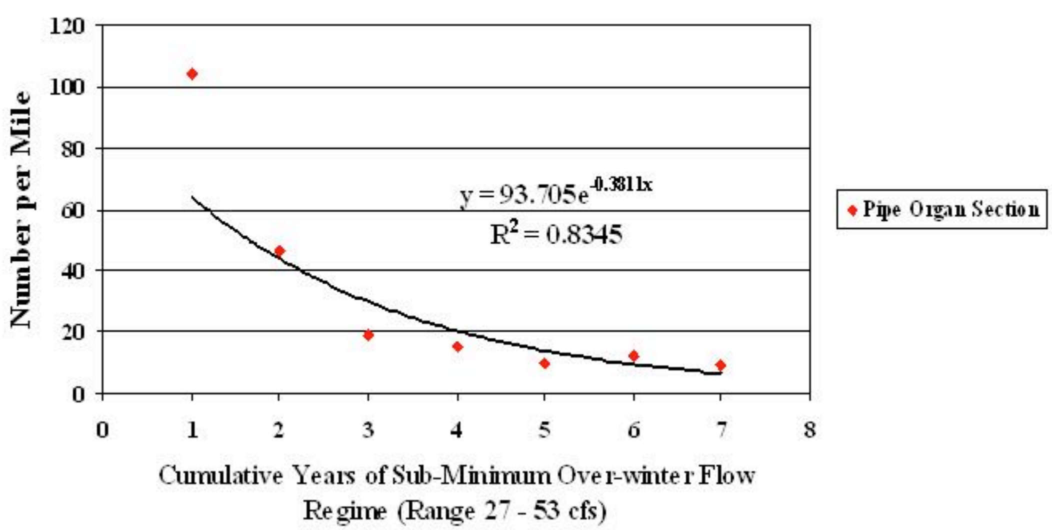


Figure 19. Logarithmic decline in the estimated spring density of 18 and larger (Age V+) brown trout as a function of cumulative years of over-winter dam releases under the Minimum Instream Flow of 200 cfs in the Beaverhead River; 2001-2007.



DISCUSSION

Numerous studies and methods have been applied to describe the affects of managed flow regimes and define minimum and optimum flow regimes to maintain fish habitat and sport fisheries in the Beaverhead River tailwater. Prior to impoundment, the US Fish and Wildlife Service studied the fishery, angler use, and habitat characteristics of the Beaverhead River and examined USGS flow records for the 1926 – 1951 period of record. Those studies resulted in recommendations that a minimum flow of 250 cfs was required to maintain productive aquatic habitat during the winter, or nonirrigation, months within the tailwater reach (USFWS 1956).

Nelson (1977) established correlations between specific fish population dynamics and summer irrigation and winter storage flow regimes. These relationships resulted in a minimum flow recommendation of 250 cfs in order to maintain all aspects of the fishery at high potential at all times of the year. He also established eight cross sections for application of the Bureau of Reclamation's WSP analysis, deriving a minimum recommended instream flow of 200 cfs within the Beaverhead River tailwater reach. Finally, Nelson's studies identified 50 cfs as a minimum flow for short-term trout survival. He further noted that the maintenance of flows at or under 50 cfs for extended periods would result in severe reductions in trout populations. While Nelson's studies established significant correlations between specific trout population parameters and minimum flow, mean over-winter flow regimes ranged between 97 and 467 cfs over the 1966 – 1977 period of study.

A comparison of four different commonly used instream flow methodologies was applied to the Beaverhead River tailwater reach as well as three other southwest Montana rivers by Nelson (1980). Recommendations from the four methods were also compared with recommended flow ranges generated through the analysis of correlations between trout population standing crops and flow records (Nelson 1977 and 1980). The standing crop and flow data analyses resulted in a minimum instream flow range recommendation of 150 –300 cfs for the Beaverhead River tailwater reach. The Single Transect wetted perimeter method resulted in a minimum flow recommendation of 225 cfs from a single defined inflection point on the wetted perimeter discharge curve. The Multiple Transect method, limited to an analysis of only four cross sections, failed to identify multiple inflection points and resulted only in the identification of a single base minimum flow of 100 cfs. The Tennant method defined severe degradation of fisheries within the 0 to 44 cfs range and optimum habitat conditions in the 265 to 441 cfs range for over-winter flow regimes. The Tennant method was also the only method under which any effort to describe the affects of a range of sub-optimal flow regimes on fish habitat was attempted. The IFG Incremental method defined optimum ranges of minimum instream flows for different life stages of brown and rainbow trout in the 225 cfs to 343 cfs and greater range.

Sando (1981) provided a detailed description of spawning and rearing habitats for brown and rainbow trout in the Beaverhead River tailwater reach. His descriptive parameters defined optimum depths and flow velocities for redd selection as well as detailed use of microhabitat features by emergent fry. Sando concluded that critical spawning and rearing features were provided in riffle and near – shore environs that were most sensitive to dewatering and subsequent loss of wetted perimeter, however, no quantification of minimum instream flow regimes accompanied his conclusions. Nelson (1977) also investigated the affects of minimum fall spawning flows on brown trout recruitment in the Beaverhead River tailwater concluding that a minimum of 150 cfs promoted strong recruitment of juveniles to Age I but also concluded that the amount of variation in flow management during the spawning period was the most important determinant in recruitment success. Frazer (2003) noted substantial declines in brown trout density as over-winter flows declined below the recommended minimum in the Big Horn River tailwater and attributed much of the observed declines to declines in recruitment of Age I fish. Frazer's analyses, however, did not investigate other population dynamics presented in the current study or prior studies in the Beaverhead River tailwater.

Finally, Montana Fish, Wildlife, and Parks, in preparation of their application for instream flow reservations in the upper Missouri River basin, selected and applied the Wetted Perimeter (WETP) method as the most desirable means of determining minimum instream flow requirements for cold water fisheries in Montana (MFWP 1989). The specific analysis for the upper Beaverhead River yielded consistent inflection points of 200 cfs for a single cross section and for a summation of eight cross sections located near the upper end of the Hildreth Study Section. The 200 cfs minimum flow standard appears to represent a realistic fit to the response of Beaverhead River trout populations in that select population dynamics increase or appear maximized when minimum flows exceed and remain above 200 cfs and go into decline to approach observed minima as flows decline and remain below 200 cfs (Oswald 2003 and 2006).

In summation, all of the attempts to quantify minimum instream flow requirements for fisheries on the Beaverhead River span a range of 100 to 343 cfs and none, other than the Tennant method, were usable in a predictive capacity at flow ranges below about 150 cfs. The absolute minimum of 150 cfs (Nelson 1980) based on trout standing crops was established using data restricted to observed minimum flow regimes in excess of 97 cfs. Bureau of Reclamation flow records for Clark Canyon Dam demonstrate that mean over-winter flow regimes declined below 200 cfs in only six years over the 1965 – 1981 period of record and Nelson (1980) determined that the absolute minimum of 150 cfs would be available during the October – March period in 9 out of 10 years. Since 1986, however, March – October flow regimes have failed to meet or exceed the 200 cfs minimum in17 of the 23 Water Years of record (Figure 1). Moreover, mean over-winter flows of that period have failed to average at least 100 cfs or near 100 cfs in 13 of those 17 years of minimal flows and have failed to attain a mean in excess of 53 cfs over the 2001 – 2008 period of study. While the 1988 – 1995 period of study also represented the affects of eight consecutive years of sub-minimum over-winter flow regimes, the mean flow release for that period was 64.4 cfs and habitat mitigation, in the form of mean flows of 146 cfs and 110 cfs, occurred in two of the eight winters of the period. For these reasons, it is believed that the current period of study represents the best and most unique opportunity to clearly define the affects of chronic low amplitude over-winter flow regimes on brown trout population dynamics since the Beaverhead River was impounded in 1964.

Estimated spring standing crops of Age II and older brown trout exhibited highly significant linear and logarithmic responses to over-winter flow regimes in the Hildreth and Pipe Organ Sections of the Beaverhead River. These relationships yielded relatively strong correlations with Coefficients of Determination that were interpreted to suggest that 63 to 68% of the observed variation in brown trout standing crops could be attributed to variations in over-winter flow regimes over the 2001 – 2007 study period. These graphic representations, with accompanying equations, can also be examined as potential means of estimating or predicting the affects of over-winter flow regimes on brown trout standing crop across a broad range of mean flow regimes above and below the 200 cfs minimum flow. Examination of the logarithmic equations for brown trout standing crop suggest that losses in biomass might be mitigated to support approximately 78 – 83% of optimal standing crops in the Hildreth and Pipe Organ Sections by maintaining over-winter flow releases at a minimum of 100 cfs. Similar examinations of the linear regressions yield lower predicted standing crops but still suggest that approximately 66 to 77% of optimum standing crop could be maintained at a 100 cfs release. The mitigative value of such improved over-winter releases would also be modified, of course, by the cumulative affects of consecutive years of sub-minimum release regimes.

Oswald and Brammer (1993) and Oswald (2000, 2005, and 2006) noted maximum observed brown trout standing crops following periods of prolonged flow regimes in excess of defined minima followed by sharp declines in standing crop associated with prolonged flow regimes below defined minima in the Big Hole, Beaverhead, Red Rock, and Ruby Rivers of southwest Montana but made no attempt to quantify the relationships. Brown trout standing crop data from the Beaverhead and Ruby Rivers included specific analyses for study sections located within productive tailwater reaches. Attempts have also been made to correlate brown trout standing crops with sub-minimum flow regimes in the free flowing Big Hole River over the same drought impacted periods. These attempts have generally focused on low, late summer flow regimes and accompanying high thermal regimes. Oswald (2009) presented linear and logarithmic analyses of brown trout standing crops as a function of mean and minimum August flows, total annual flow regime, and July – August maximum temperature regimes for the Hog Back Section of the Big Hole River. Of the three flow parameters, the total annual discharge in acre feet yielded the most powerful ($r = 0.79$, $R^2 = 0.63$) and highly significant ($P<.01$) correlation with brown trout standing crop. Total annual discharge incorporates the affects of reduced flow regimes in all seasons of the year and does not merely focus on summer base minima. Interestingly, high summer thermal regimes were not significantly correlated ($R^2 = 0.28$) with variations in brown trout standing crop over the same period of study. Nelson (1977) examined the affects of flow regimes on specific age segments of the brown and rainbow trout standing crops in the Hildreth Section of the Beaverhead River demonstrating a significant correlation ($r = 0.77$) between the standing crop of Age IV and older rainbow trout and mean over-winter flow regime but failed to detect a significant relationship for brown trout. Nelson (1980) in a continuation of studies of the affects of flow on brown and rainbow trout standing crops in the Beaverhead River tailwater observed a highly significant correlation ($r = 0.96$) between rainbow trout standing crop and the number of days of average flows at or below 100 cfs and a significant correlation ($r = 0.73$) between rainbow trout standing crop and the number of days of average flows below 150 cfs. Again, the work failed to reveal a significant correlation between flow regime and brown trout standing crop. Nelson‘s work, while establishing a link between standing crop and flow, also did not establish any linear relationships or equations that could be used to estimate or predict the affects of flow on standing crops across a broad range of variation.

Analysis of the affects of minimum flows on standing crop can often be frustrated by the sudden addition of strong recruitment cohorts into the population. It is reasonable to expect that substantial declines in standing crop and substantial declines in densities of older, larger fish in the population could be accompanied by compensatory opportunism in the form of high juvenile survival and recruitment (Ricker 1954). The concept of age structure suppressing recruitment through competitive or predatory advantage is among the major assumptions implicit in modifying the simple logistic model of population growth (Slobodkin 1961). Substantial declines or chronic low numbers of older, larger individuals in brown trout populations have often been accompanied by above average recruitment of juvenile fish into the population. Strong recruitment cohorts have been noted in Beaverhead and Ruby River tailwater study sections as densities of large fish declined with declining flow regimes (Oswald 2006 and 2009). This same response has been noted in brown trout populations in the free flowing Big Hole River (Oswald 2005) and has generally been marked by the appearance of two consecutive strong recruitment cohorts. As these cohorts attain Ages II and III their influence can be manifest as significant increases in standing crop that may or may not be maintained into the future dependant upon habitat availability and carrying capacity at any given moment in time. Oswald (2005 and 2009) presented oscillating patterns in densities of Age II and Age V and older brown trout exhibiting five peaks in Age II abundance in association with four peaks in Age V and older densities over a twenty-one year period in a Big Hole River study section. The largest decline in Age V and older fish in association with declining base streamflows was followed by two Age II recruitment cohorts strong enough to temporarily reverse a declining trend in brown trout standing crop for two years. This temporary increase in densities of Age II and Age III fish and standing crop was also accompanied by substantial decreases in brown trout condition. Similar observations were made in the brown trout population of the Pipe Organ Section over the 2001 – 2008 period as strong recruitment cohorts entered the population and affected standing crop trends in the 2001-2002 and 2007-2008 samples under declining and base minimum densities of 18 inch and larger (Age V+) fish in the population (Oswald 2006 and 2009). Successive strong recruitment cohorts in a Ruby River tailwater study section increased brown trout standing crop for three years under declining over-winter flow regimes but failed to result in any increase in the density of 18 inch and larger fish at Age V, were accompanied by severe declines in condition factor, and ultimately resulted in a downturn in standing crop as growth and ultimate size were markedly attenuated (Oswald 2009). For these reasons, use of brown trout standing crop as an indicator of the affects of low flows is probably best limited to periods of declining flow regimes immediately following average or above average habitat conditions and average or above average standing crops.

Estimated spring densities of older, larger brown trout exhibited highly significant linear and logarithmic responses to over-winter flow regimes in the Hildreth and Pipe Organ Sections of the Beaverhead River. These relationships exhibited relatively strong correlations with the logarithmic analysis yielding a slightly more powerful R^2 than that of linear regression for two of the three individual analyses performed. The Beaverhead River tailwater study sections provided a unique opportunity to examine relatively high potential densities of large fish under optimum flow conditions due to the relatively high productivity of the reach. This was manifest as highly confident estimates of the numbers of 18 inch and larger brown trout as the Age IV and older component of the Hildreth Section and the Age V and older component of the Pipe Organ Section. It also provided for a more subtle differentiation of the Hildreth Section population into an Age V and older component with ample estimable numbers of 20 inch and larger fish. These data were interpreted to indicate that 70 to 73% of the observed variation in the densities of Age IV and older brown trout and 76 – 78% of the variation in the densities of Age V and older brown trout was attributable to the variation in over-winter flow regimes in the Hildreth Section of the Beaverhead River. The data from the Pipe Organ Section exhibited an even more powerful relationship with 91% of the variation in density of the 18 inch and larger (Age V+) component of the brown trout population attributable to variations in flow over the 1999 – 2007 study period.

These graphic representations, with accompanying equations, can also be examined as a potential means of estimating or predicting the affects of over-winter flow regimes on the densities of the fully mature, or largest, fish in upper Beaverhead River brown trout populations across a broad range of mean flow regimes above and below the 200 cfs minimum. Examination of the logarithmic equations for densities of large brown trout suggest that losses in these mature fish might be mitigated to support approximately 60 – 67% of maximum densities of the 20 inch and 18 inch and larger segments of the population in the Hildreth Section by maintaining over-winter flow releases at a minimum of 100 cfs. The same analysis for the Pipe Organ Section 18 inch and larger component predicts that about 57% of the maximum18 inch and larger component might be maintained at minimum over-winter releases of 100 cfs. The logarithmic analyses exhibited a high degree of similarity between the predicted response of the Age V and older components of the Hildreth and Pipe Organ Study Sections despite the productivity driven size differences between the study sections. Similar examinations of the linear regressions yield lower predicted large fish densities but still suggest that substantially higher densities could be maintained at a 100 cfs minimum release. Again, the mitigative value of such improved over-winter releases would also be modified by the cumulative affects of consecutive years of sub-minimum release regimes.

Oswald (2009) also noted a highly significant ($P<.01$, $r = 0.84$) correlation of the density of 18 inch and larger (Age V+) brown trout as a function of over-winter flow regime in a Ruby River tailwater study section. The regression yielded a relatively strong R^2 of 0.71 for a logarithmic analysis of the relationship. Linear analyses of the affects of flow on the densities of 18 inch and larger (Age V+) brown trout in a lower Big Hole River study section yielded an R^2 of 0.58 as a function of mean August flow regimes, an R^2 of 0.68 as a function of the minimum August flow, and an R^2 of 0.76 as a function of the total annual flow regime over a nine year period spanning a range of base summer and winter flows above and below the recommended minimum of 260 cfs (Oswald 2009). A companion linear regression of densities of 18 inch and larger brown trout in the Big Hole River as a function of maximum July and August temperature regimes failed to yield a significant relationship with an R^2 of 0.34, similar to the observations on potential thermal affects on brown trout standing crop. These observations support the importance of sufficient instream flow at all seasons of the year for the support of maximum densities of older larger fish within brown trout populations. While Nelson (1977) failed to demonstrate a significant relationship between densities of Age IV and older brown trout and over-winter flow regimes in the Hildreth Section (r = 0.46), he was able to link the densities of Age IV and older rainbow trout to over-winter flows (r = 0.85) at the 95% Confidence Interval. This could have been due to the far less severe over-winter flow regimes experienced during Nelson's study or associated with much higher densities of rainbow trout relative to the brown trout population of that study period. Nelson's observations further demonstrated the importance of over-winter flows on the older, larger component of the rainbow trout population as correlation coefficients for both the density and standing crop of Age IV and older fish substantially exceeded those observed for the Age III and older component of the population.

The examination of spring brown trout condition factors strongly supports the hypothesis that older, larger fish were more severely impacted by over-winter flow regimes than were other components of the brown trout populations. These observations have represented a consistent response of brown trout populations to rapidly declining flow regimes in the tailwater of the Ruby River and downstream reaches in the Beaverhead River (Oswald 2006) as well as free flowing reaches of the Big Hole River (Oswald 2005). While only the 20 inch and larger brown trout condition analysis yielded a significant correlation ($P<.05$), the outcome of the tests were strongly affected by limited treatment sample size and resultant degrees of freedom. Condition factor analyses provide a physiological link to mechanisms under which adult brown trout densities are reduced as the carrying capacity of the habitat is reduced under low over-winter flow regimes. Other compensatory shifts in population age structure, size distribution, and standing crop can be expected to accompany alterations in carrying capacity as habitat availability or quality is reduced (Slobodkin 1961). These shifts might be associated with simple and direct factors like food availability or energy transfers or might be associated with more complex interactions such as competition among adults for security cover or mating territory. Such compensatory shifts may quickly adjust condition factor upward in response to decreased population demand on the habitat. The initial affects of rapidly diminished carrying capacity, however, usually result in substantial declines in the condition of the older, larger, reproductive component of brown trout populations that generally persist for about three to four consecutive years.

The analysis of the affects of cumulative years of sub-minimum over-winter flows on brown trout standing crop and densities of older, larger fish within the populations yielded significant or highly significant correlations as a function of time. Coefficients of determination strongly suggested that 83% to 88% of the variation in density of older, larger brown trout within the Hildreth and Pipe Organ Study Sections could be explained by the accumulation of consecutive years of sub-minimum over-winter flow regimes. In a manner consistent with the other forms of analysis presented in this report and with observations of Nelson (1977), standing crop exhibited a very consistent R^2 of 0.60 as a function of cumulative years of sub-minimal over-winter flow regimes.

The analysis of cumulative affects yielded extremely tight linear distributions for the densities of older larger brown trout and brown trout standing crops in the Hildreth Section while those same parameters better fit a curvilinear or logarithmic distribution in the Pipe Organ Section. The linear response in the Hildreth Section brown trout population is an example of a Type II survivorship curve under which mortality is constant over units of time regardless of the density of individuals left in the population

(Slobodkin 1961). Thus, factors other than compensatory mortality (Ricker 1954) or other normal brown trout population dynamics appear to be the major determinant in population variation over the selected study period. The data strongly suggest that these factors were a result of sub-minimum over-winter flow regimes and their persistence over an extended period of time. This assumption is further supported by the generation of normal fish population survivorship relationships (Ricker 1958), which conform to a Type III survivorship curve of Slobodkin (1961) and exhibit a relatively low and consistent rate of mortality among adult age classes. The observed tendency of these same parameters to exhibit a curvilinear or logarithmic distribution over time in the Pipe Organ Section was probably due to increased flow accretions over the downstream distance from the dam and more indicative of the lower end of a Ricker (1958) fish population survivorship model.

The affects of low over-winter flow regimes on the selected brown trout population dynamics were analyzed via linear and logarithmic regression. All of the analyzed scatter plots exhibited a curvilinear distribution that, in most of the analyses, yielded a slightly more robust or virtually equal R^2 for the logarithmic equation when compared with the linear equation. The logarithmic analysis also compares most favorably with the shape of the simple logistic equation as animal population growth approaches or declines below the carrying capacity of the habitat at any given point in time (Slobodkin 1961). The current analyses strongly suggest that maximum observed densities of older, larger brown trout and maximum observed brown trout standing crops over the study period are at or very near carrying capacity for the habitat under ample over-winter flow regimes. Conversely observed low standing crops and low densities of mature brown trout, coupled with declines in condition factor were indicative of substantially reduced carrying capacity of the habitat at substantially reduced flow regimes. Because the current work was predicated on these assumptions, was focused on the older, larger components of the brown trout populations and because the current work demonstrates that all individual fish in the brown trout populations were not expected to respond instantaneously to the environmental alterations under study, it is strongly suggested that a logarithmic analysis of the data most closely mimics the expected response of brown trout populations at the upper end of the sigmoidal population growth model. For these reasons, it is recommended that the logarithmic equations represent the best fit for analysis and prediction of the affects of over-winter flow regimes on the brown trout populations of the upper Beaverhead River tailwater reach. As another alternative for analysis, the area between the linear and logarithmic analyses could be assumed to bracket the potential affects of over-winter flow management and used to explain or anticipate differences in brown trout population dynamics in tailwater fisheries.

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