Modeling the Relationship Between McPhee Dam Selective Level Outlet Operations, Downstream Algal Biomass, Dissolved Oxygen and Temperature:
Phase 1,
Background Data and Model Development.

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Executive Summary

The Dolores River has changed considerably since McPhee Dam was constructed. The Selective Level Outlet Works (SLOWs), a million dollar structure built with McPhee Dam, were designed to help Stakeholders meet downstream water quality goals but have never been used as they were designed. Water has only been released from the 3^{rd} SLOW and the bottom of the reservoir. Releases from the bottom of the reservoir discharge highly reactive forms of nutrients downstream, increasing algal biomass and its negative impacts on dissolved oxygen. Limiting releases to the 3rd SLOW and the bottom of the reservoir also restricts opportunities to manage for downstream water temperature goals.

This report illustrates water quality changes to the Dolores River since construction of McPhee Dam and outlines a couple of models developed to predict downstream changes in water temperature and other water quality parameters given full use of the SLOW's. The models predict the effect of various release levels through the outlet works on temperature, algal biomass and dissolved oxygen of receiving waters below McPhee. One model, developed by the U.S. Army Corps of Engineers, has been applied to McPhee reservoir data to predict water temperature discharge from McPhee given various discharge scenarios through the outlet works, reservoir elevation and time of year. The other model, developed by B.U.G.S. Consulting, was constructed to predict daily maximum water temperature in the Dolores River between the dam and the confluence with the San Miguel given various release scenarios and time of year,

Preliminary testing of the models indicates that a discharge of 75 cfs exclusively from the 3^{rd} selective level outlet (no releases from the bottom of the reservoir) under normal reservoir elevations (i.e. the 3^{rd} SLOW being at or near the bottom of the thermocline) will result in downstream temperatures that do not exceed Colorado temperature standards for cold-water fisheries. This strategy may facilitate the Colorado Division of Wildlife's goal of a gold medal fishery. Other release scenarios may help improve non-native fish populations.

The models will be refined with data collected summer 2010 and operational and experimental recommendations will be developed for full use of the SLOWs to meet downstream water quality goals. Further use of the SLOWs and their impacts could then be experimentally completed utilizing baseline data collected on fish biomass, algal biomass, dissolved oxygen and temperature as response variables.

It is recommended that the thermometers that were originally installed at each SLOW inlet be repaired prior to expanding use of the SLOWs to SLOW 1 and SLOW 2. This will ensure up-to-date and accurate temperature data for model input. Also, it would be prudent to take the Biology Committees recommendation and complete a thorough investigation of fish entrainment through the outlet works to determine the probability of non-native fish (primarily white suckers and small mouth bass) making it to and into the SLOWs, surviving a trip through the SLOWs and the turbines and surviving and reproducing in the reaches below the reservoir given various temperature regimes.

Background data and information

McPhee Dam Outlet Works

Selective Level Outlet Works (SLOWs) were constructed with McPhee Dam in 1984 to minimize releases of highly reactive forms of nitrogen and phosphorus from the bottom of the reservoir and to facilitate downstream water temperature objectives. The SLOWs have never been fully utilized for either of these purposes.

The U.S. Army Corps of Engineers and the Bureau of Reclamation have been using selective withdrawal from reservoirs to manage downstream water quality since the 1970s (Vermelyen *et. al.* 2003). Selective withdrawal is a method of withdrawing water from a particular level within a reservoir that has ambient stratification. Typically, decisions regarding selective withdrawal operations are tied to established downstream water quality goals (in most cases temperature). Meeting a daily release-quality target involves selecting an outlet or outlets for which the predicted, flow-weighted release approaches the release objective.

A problem faced by reservoir managers is the daily or short-term operational decisions required for a selective withdrawal structure to meet specific water quality management objectives. An operational decision model should identify which outlets to open when and how much to open the outlets to meet downstream water quality and discharge goals of the project.

The SLOWs for McPhee Dam consist of 3 inlets with sills at elevations 6,892 (SLOW 1), 6,896 (SLOW 2) and 6,840 feet (SLOW 3) opening into a tower sitting on a shelf near the dam (Figure 1, full reservoir elevation is 6,924 ft). Each inlet empties into a shaft that takes water through the bedrock and the dam (Figure 2). The original design of the SLOWs allowed for a maximum discharge of 205 cfs. Temperature recorders were placed at each SLOW inlet to facilitate downstream temperature goals. Since construction of McPhee Dam, little if any water has ever been released through SLOW 1 or SLOW 2 and the temperature recorders are no longer operable.

A power plant was added to the selective level outlet works in 1993. This altered the flow outlet equation so that only a maximum of 144cfs can now be discharged through the SLOW tower. To discharge more than 75 cfs through the SLOW tower the power plant would have to be taken offline. Power can only be generated at discharge increments of 25, 50 and 75 cfs. If demands for downstream water are other than 25, 50 or 75 cfs, the additional water is run through a bypass gate located at the bottom of the reservoir. Maximum discharge through the bypass gate at the bottom of the reservoir is 55 cfs. Power has been generated since 1993, except from September 1994 to January 1997 due to a turbine problem and from May 2002 to January 2003 due to low reservoir elevations and during short periods of maintenance. In addition to the SLOWs and the bypass gate, two 4 by 4ft gates located at the bottom of the reservoir allow for discharges up to 4,500 cfs.

Algal biomass

Algal biomass data indicates that nutrient releases from the bottom of McPhee reservoir through the bypass gate at the bottom of McPhee Dam creates high levels of algae in the Dolores River below McPhee Dam (Figure 3). A consequence to the fisheries is that, as the algae accumulates, and decays, the dissolved oxygen in the river falls below critical thresholds for trout and possibly for native fish. The over enrichment of the river associated with releases from the bottom of McPhee Dam may also cause toxicity issues associated with de-nitrification from the benthos (Cheslak and Carpenter, 1990).

Reactive forms of nitrogen and phosphorus form during the summer/fall stratification of reservoirs and within the deeper, denser, anaerobic layers of the reservoir (Correl, 1998). When water is released from near the bottom of the reservoir, the reactive forms of nitrogen and phosphorus essentially act as fertilizer, resulting in high concentrations of algae in downstream reaches (Figure 3). During the oxygen consuming phases of algal respiration and decomposition and when large amounts of oxygen producing photosynthesis is not occurring, the negative balance of oxygen can result in low concentrations of dissolved oxygen in the reaches downstream of the dam. These periods of low concentrations of oxygen occur at night, during cloudy periods, when the water is turbid and in the winter. This negative balance can overwhelm the positive effects of cold water and the rate of atmospheric exchange on dissolved oxygen concentrations.

I hypothesize that by eliminating releases from the bottom of McPhee reservoir (*e.g.* through the bypass gate) and utilizing only water from the Selective Level Outlet Works (SLOWs) during the base-flow period, water quality, primarily dissolved oxygen, can be improved in both the cold-water and warm water reaches below McPhee Dam.

Discharge from McPhee Reservoir

Diversions out of the Dolores basin began in the late 1880s when the majority of the river was diverted during late summer months at the Great Cut Diversion that took water out of the Dolores River and discharged it into the Montezuma Valley which lies in the watershed of the San Juan River. Flows prior to the Great Cut Diversion were most likely similar to flows at the Town of Dolores, just upstream of the Diversion (Figure 4).

After diversions began in the late 1880s, a USGS gage at the old town site of McPhee, CO (now buried by McPhee Reservoir) shows that flows were most likely intermittent (surface water limited to pools and no surface flows connecting the pools) during late summer months (flows < 10 cfs, Figure 5) from McPhee Dam to Bedrock (DRD Reaches 1 through 5). The Great Cut Diversion could take almost 1,400 cfs from the river at a site just below the town of Dolores, CO. Since McPhee dam was completed in 1985, median April flows decreased from 850 cfs to 50 cfs and median June flows decreased from 900 to 85 cfs and median base-flows for July, August and September *increased* from less than 10 cfs to 70, 60 and 50 cfs respectively (Figure 7).

Discharge data from the USGS Bedrock Gage shows that median flows prior to the construction of McPhee Dam were less than after the construction of McPhee Dam July through November (Figure 6). Discharge data from the USGS Ciscoe, Utah gage show that median flows were less prior to the construction of McPhee dam for the months of August through March. Median flows were much greater in the Dolores prior to the construction of McPhee Dam for the months of May and June (Figure 8).

Post dam discharge changed as projects came on line and affected the amount of water available to discharge downstream (Figure 9). During the period from 1985 to 1996, when the downstream release from McPhee were determined on an “indexed” basis ((i.e., 78cfs in “wet” years, 50cfs in “average” years, 20cfs in “dry” years, (Appendix 1), base flows below McPhee Dam ranged from 30 cfs during the winter months to 78 cfs during the summer months (Figure 9). When flows changed from being an ‘indexed’ flow regime to a ‘managed pool’ flow regime with the 1996 Environmental Assessment. Pre 1996 McPhee Dam discharge resulted in a baseflow of at least 50 cfs, and more, often well over 78 cfs. The change to the managed pool in 1996 reduced baseflows significantly. There was a brief period in 1990 where the index went to 20 cfs but was quickly changed to 50 cfs due to the recognition that 20 cfs would not sustain the fishery.

In the summer of 2002, under the “managed pool,” established releases from McPhee Dam were as low as 15 cfs due to drought and shared shortage among project allocations. Releases from the dam were less than 20 cfs from April 28, 2002 to May 4, 2003. Peak flow in 2003 was 41 cfs and hovered around 40 cfs for a few weeks and then below 20 cfs until May 4th, when slight improvements in base-flow occurred. Peak flow in 2004 was 92 cfs and lasted for only 1 day.

Water Temperature in the Dolores

Temperature, pH, conductivity and dissolved oxygen data in the Dolores was obtained from the USGS. Other temperature data in the river was compiled from data collected by the Colorado Division of Wildlife and the Dolores Water Conservancy District (Appendix 2). Means and standard deviations of maximum daily temperatures were calculated and graphed to determine the effect McPhee Dam had on downstream water temperatures. The data set is incomplete and below is a summary of the data available.

Mean daily water temperature in the Dolores River prior to the construction of McPhee Dam was significantly less than post McPhee water temperature for the months of April, June and September at the USGS Bedrock gage (Figure 10). At the Cisco USGS gage near the confluence with the Colorado River, mean daily temperatures were less prior to the construction of McPhee Dam for each month of the year except August through December compared to post construction mean daily temperatures (Figure 11).

Summer ambient daily maximum water temperature is reached near Disappointment Creek (Figure 12). Winter daily maximum water temperatures are greater upstream of Bradfield Bridge than are winter daily maximum temperatures recorded downstream of Bradfield Bridge (Figure 13) due to the influence of deep releases from the reservoir.

The acute temperature threshold for trout (74.9° F) was not exceeded in 1986, 1987 or 1988 (Appendix 2, Colorado Department of Public Health and Environment. 2007). The chronic temperature threshold for trout (64.9° F) was exceeded twice for periods greater than 24 hours and the acute temperature threshold was exceeded on 5 dates in 1990 at Bradfield Bridge (Figure 14). The chronic temperature threshold for trout was exceeded several times for periods greater than 24 hours and the acute temperature threshold was exceeded on numerous occasions in 2002 at Bradfield Bridge (Figure 15). The chronic temperature threshold for trout was never exceeded for a period of 24 hours and the acute temperature threshold was never exceeded on any date in

2005, 2006, 2007, and 2009 at Bradfield Bridge (only late summer and fall data collected in 2008, Figure 16).

In 2009, daily maximum water temperature exceeded the chronic threshold of 64.9° F but never for more than 24 hours. Daily minimum water temperature was always below the chronic threshold in part because air temperatures for 2009 were less than the overall average (Figure 17). When flows were ramped up from 40 cfs on 9/30/09 to 196 cfs on 10/1/09, minimum water temperature at Bradfield Bridge went from 54° to 40° F and maximum water temperature went from 60° to 50° F, a decline of 20° F in less than 36 hours.

Reservoir Dynamics Water Quality and Fish Distribution

Reservoir discharge data and elevation data was obtained from the Dolores Water Conservancy District and reservoir water quality data and fish data was obtained from the Bureau of Reclamation and the Colorado Division of Wildlife (Appendix 3).

Since first reaching its maximum elevation of 6,924 ft in June of 1987, reservoir elevation has varied with a low of 6,806 ft occurring in October 2002 (Figure 18). Data collected each month (April – November) in 1987 by the Colorado Division of Wildlife shows that McPhee Reservoir began stratifying in April and the stratification lasted into October (Figure 19, Appendix 3). Dissolved oxygen in 1987 began stratifying in July, peaking in September with stratification continuing to be present into November (Figure 20). Data collected fall 2004 and summer 2005 by the Bureau of Reclamation shows similar stratification patterns.

Data collected by the CDOW in 2003 and 2004 near the outlet works show that fish are distributed from near the surface, through the thermocline down to 10 meters above the bottom gates (sonar data). Gill net data from near the outlet works captured 1 small mouth bass 4 meters below the level of the SLOW, several Kokanee salmon and rainbow trout. No white suckers were captured in the gill nets which is expected given that white suckers are benthic foragers and avoid predators in open waters (Figure 21).

Dissolved Oxygen in the Dolores

Mean concentration of dissolved oxygen (grab samples) at the USGS Bedrock Gage (data obtained from the USGS) was greater prior to the construction (1965-1984) of McPhee Dam for the months of March, May, June and August when compared to the post dam dissolved oxygen data (1984-2007, Figure 22).

Temperature and dissolved oxygen data was also collected with a YSI sonde at three sample stations: below McPhee Dam, Ferris Creek Campground and Bradfield Bridge, September 17-19th, 2008. The data show low dissolved oxygen concentrations (5.99mg/l @ Bradfield Bridge and 6.06mg/l @ Ferris Creek Campground and 6.55mg/l @ the Dam) measured in the early morning due to biological respiration and decomposition of organic matter (discharge from McPhee was 40 cfs). The Colorado State dissolved oxygen standard for cold water trout fisheries is 6mg/l. The chronic temperature threshold for trout (64.9° F) was not exceeded during the sample period (Figure 23). Dissolved oxygen was also less than the 6mg/l at several locations in DRD Reach 1 (McPhee Dam to Bradfield Bridge) measured June 25, 1990.

Conductivity and pH in the Dolores

Mean conductivity (grab samples) at the USGS Bedrock Gage prior to the construction of McPhee Dam 1965-1984 data) was greater for the months of July through November and less for the month of June compared to post McPhee data (1984 – 2007, Figure 24). Mean daily conductivity at the USGS Ciscoe, Utah gage prior to the construction of the McPhee Dam (1951-1984) was greater for each month of the year except June compared to post McPhee data (1984 – 2004, Figure 25). Mean pH at the USGS Bedrock Gage prior to the construction of McPhee Dam was less for each month of the year with greater variability (Figure 26).

Limiting Nutrient Analysis in the Dolores

Quantitative limiting nutrient analysis for algae using artificial nutrient diffusing substrates (NDS) took place in September of 2007 along the Dolores River at three sites: Dolores below McPhee dam, Dolores at Ferris Canyon Campground and Dolores at Bradfield Bridge.

Twenty clay saucers containing a 2% agar solution with four different treatments were deployed on the Dolores River at each station to determine whether nitrogen or phosphorus were limiting. The four treatments were: Control (i.e., ambient nutrient chemistry) (C); nitrogen-supplemented (N); phosphorus-supplemented (P); and nitrogen and phosphorus-supplemented (NP).

Nutrient concentrations for the phosphorus treatments were 0.1 M $K_2H_2PO_4$; for the nitrogen treatment was 0.5 M $NaNO_3$ and for the NP treatment was a combination of the two. Control saucers (C) were placed upstream of NDS saucers, and all saucers were deployed at the same depth. Five replicates of each treatment at each site were deployed. Saucers were deployed on September 18th, 2008 and retrieved after 2 weeks of incubation time.

The periphyton was scrubbed off with a brush and rinsed with de-ionized water to capture the periphyton grown on the tiles. The periphyton was transferred to label Whirl-Pak bags. Samples were processed at the B.U.G.S. lab according to state and EPA approved Standard Operating Procedures to measure quantity of periphyton growing on the tiles.

The addition of nitrogen and phosphorus to tiles at Bradfield Bridge resulted in significantly greater amounts of algal growth measured as concentration of chlorophyll-a (Figure 29). It does not appear there is a specific limiting nutrient discharged from McPhee Reservoir but rather both highly reactive forms of nitrogen and phosphorus are being discharged from the bottom of the reservoir resulting in the high amounts of periphyton biomass found below the dam.

Periphyton biomass data was also collected from cobble substrate in riffles at the same sample sites and during the same sample period as the NDS study and biomass was measured using chlorophyll-a and ash-free dry mass (AFDM) analyses. Data was incorporated into the periphyton biomass database (Figure 3).

Discussion

Clearly McPhee Dam has altered downstream hydrology, temperature, pH, conductivity and dissolved oxygen. The Selective Level Outlet Works were designed to minimize the deleterious effects of many of the water quality impacts and to meet downstream water quality goals.

Existing goals and constraints are many and varied (Appendix 4) and, although there exists the Selective Level Outlet Works at McPhee (unlike most dams), the opportunities to meet a large number of goals are still limited.

Utilizing the SLOWs fully may benefit either or both the trout and the native fish. Further refinement of the models and better understanding of life history needs of native fish may identify such opportunities to benefit the native fisheries – i.e. through better cueing and timing of reproduction by manipulating water temperatures with the SLOWs. Also, ther may be an opportunity to expand native fisheries habitat upstream with warmer baseflows.

Because white suckers are benthic, utilizing the upper SLOWs with the powerplant on line will not increase the probability of white suckers being entrained and surviving a journey into and through the turbines. Utilizing the upper SLOWs, however, may increase the probability of small mouth bass being entrained into the SLOWs *and* with warmer water temperatures downstream the probability of survival of white suckers and small mouth bass may increase if they do make it through the SLOWs and the turbines. Warmer downstream temperatures due to use of the upper SLOWs may also increase habitat of small mouth bass upstream of Dove Creek Pumps. There may, however, be opportunity to reduce populations of small mouth bass by mis-cueing them to reproduce at the wrong time of year. Further understanding of the impacts that the SLOWs could have on downstream water temperatures and of the life-history characteristics of both native and non-native fish is important.

Water temperature models

A model has been employed to predict discharge temperature from McPhee Reservoir given various release scenarios through the SLOWs at various reservoir elevations, discharge rates and dates. Another model has been developed to predict the effects of water temperature released from McPhee Reservoir on downstream water temperatures. In addition to these models, baseline data has been collected to determine the effect of different release scenarios on downstream algal biomass and consequent impacts to dissolved oxygen.

Purpose of models and baseline:

1. Evaluate the degree that periphyton biomass can be reduced in downstream reaches;
2. Understanding the response of the concentrations of dissolved oxygen to decreasing levels of algal biomass;
3. Predict changes in water temperature in the Dolores River below McPhee Dam if the SLOWs were to be fully utilized;
4. Create operational recommendations for the SLOWs for McPhee Dam Managers and Operators to meet particular downstream goals.

SELECT Reservoir model

SELECT is a numerical, one-dimensional model of selective withdrawal developed at the U.S. Army Engineer Research and Development Center to compute withdrawal characteristics and release water quality for various operational alternatives. The spreadsheet implementation of the SELECT model provides an interactive environment for the application of the model. Input parameters include release elevation (s) and discharge at each release point; output is water quality parameters – temperatures, dissolved oxygen, pH and specific conductivity. The Bureau of Reclamation has provided the DRD with guidance regarding the SELECT model and will be collecting input data for the model May, July and September 2010. Data collected by the CDOW will also be input into the SELECT model further refine discharge values through the SLOWs.

River Water Quality Model

B.U.G.S. Consulting created a multiple regression equation to predict maximum water temperature at Bradfield Bridge for the purpose of determining the degree that eliminating releases from the bottom of the reservoir during summer/fall months and utilizing SLOW 1 and SLOW 2 would affect maximum temperature in downstream reaches. To develop the regression, input parameters were: daily maximum temperature of water discharged from McPhee (from the SELECT Model), discharge (Q) from McPhee, average air temperature at Bradfield Bridge, angle of sun, and maximum water temperature at Bradfield Bridge.

If the River Model developed for predicting water temperature downstream of McPhee Reservoir suggests that full operation of the SLOW (including SLOW 1 and SLOW 2) would be effective at improving water quality, operational changes of McPhee Dam to further refine a water quality operations model and improve water quality below McPhee Dam would be worth considering. If serious consideration is given to use of SLOW 1 and SLOW 2, in addition to SLOW 3 which is currently used on a regular basis, then it would be important to further evaluate whether the probability of live escapement of non –native fish increases and the potential that warming of the downstream environment results in an expansion of the area currently occupied by small mouth bass (Dolores Project Biology Committee 2010).

Methods

The predictive model was developed using 2008 and 2009 discharge and temperature data collected by the Dolores Water Conservancy District.

Input parameters for the model development (See Appendix 2):

- Maximum water temperature at Bradfield Bridge;
- Flow from McPhee Dam;
- Maximum water temperature in the stilling basin below McPhee Dam;
- Average air temperature collected at Bradfield Bridge; and,
- Angle of the sun.

Utilizing an Excel based multiple regression equation generator and analysis tool, the resulting model equation (linear multiple regression equation) is:

Predicted maximum water temperature @ Bradfield Bridge = 0.27 *X* Angle of Sun + 0.51 *X* Average Air Temp - 0.03 *X* Flow Below McPhee Dam + 0.43 *X* Water Temp. Below McPhee Dam + 1.3

This equation was applied to the existing data set and graphically analyzed showing that the model slightly over-predicts water temperature at the upper end of actual water temperature ranges (Figure 27). Because the model is linear and input flow data was limited (i.e. low flow data was incremental and not continuous) the model only works well at flows between 30 and 100 cfs, tending to over-predict water temperature at flows greater than 100 cfs.

Using the 75th percentile of the water temperature data found at the level of the 3rd SLOW in the reservoir, the 75th percentile of average air temperature at Bradfield Bridge and a flow of 75 cfs below McPhee Dam, the model predicts a maximum daily water temperature of 72.24^{O} F in June, 74.97^{O} F in July and 72.57 ^{O} F in August at Bradfield Bridge (Figure 28). These values are just above or below the acute maximum daily temperature for trout (74.9 ^{O} F). Daily maximum water temperatures between Bradfield and McPhee Dam would be less.

Conclusions

Given reservoir temperature and a release of 75 cfs in June and July the river model predicts that by eliminating releases from the bottom of the reservoir and only using SLOW 3 the probability of exceeding the acute temperature threshold for trout in DRD Reach 1 (McPhee Dam to Bradfield Bridge) is low.

Because the water quality model tends to over predict maximum water temperatures at Bradfield Bridge during the critical time frames (June – September) and a conservative use of the 75th percentile of water temperature at the 3rd SLOW and 75th percentile of average air temperature were used as input parameters and the acute temperature for cold water fisheries was just reached at Bradfield Bridge by model predictions, I conclude that the use of the SLOWs should be further studied to determine the degree that they can be utilized to improve downstream water quality conditions (primarily algal biomass, dissolved oxygen, temperature and other parameters associated with over-enrichment of rivers – i.e. ammonia toxicity). Further use of the SLOWs and their impacts can be experimentally completed utilizing baseline data collected on fish biomass, algal biomass, dissolved oxygen and temperature as response variables. It would be prudent to take the Biology Committees recommendation (Spring 2010) and complete a thorough investigation of fish entrainment through the outlet works as well and to repair the thermometers that were originally installed at each SLOW outlet.

Next Steps

The following next steps will be completed 2010:

1. Collecting data on temperature, pH, dissolved oxygen and nutrients at various levels in the reservoir near the SLOWs
2. Collecting diurnal data monthly, at 6 sample sites (Bradfield Bridge to Bedrock) on temperature, pH, and dissolved oxygen; and,
3. Creating a predictive, more accurate, *non-linear* multiple regression model that includes the interaction between date and reservoir elevation to be utilized by dam managers for management of the SLOWs through the summer months year.

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APPENDICES

Appendix 1. History of Dolores River Diversions and the Dolores Project (from the DRD Hydrology Report)

The first diversions from the Dolores River, except for domestic purposes, were in 1875. These diversions were for agricultural purposes stretching from Rico and Dunton at the high end of the basin to Paradox Valley at the lower end of the basin. The amount of water diverted was negligible – less than 10,000 acre-feet per year. In 1883 the Cortez Canal Companies No1 & No2 were privately incorporated and funded. The purpose of those two companies was to develop the infrastructure to trans-basin divert up to 1,400 cubic feet per second from the Dolores Basin to irrigable lands in the upper areas of McElmo Creek, tributary to the San Juan River. Two physical diversions were constructed. One was a 1 ½ mile long tunnel and the other was 6 mile long canal. Diversion of water first began in 1886. From that day forward, until McPhee Dam was constructed, Montezuma Valley Irrigation Company, successor to the original two Canal Companies, diverted the entire Dolores River from the conclusion of the spring runoff until the end of the irrigation season, in late October.

During the 1970s planning for the needs of the multi-purpose Dolores Project, the BOR, not only planned for the traditional uses of a project, but planned for two unique / non-traditional needs. First, the Dolores Project would be the means for satisfying Ute Mountain Ute Indian Tribe's ("UMUT") Winters Doctrine claims to the Mancos River; and second, a year-round by-pass flow for a trout fishery below McPhee Dam.

To get the water for what was considered up until then, non-traditional needs, the BOR converted the design of non-Indian Full Service irrigation features of Project from an open ditch surface delivery system to an "underground pipeline / pressurized" system. Doing so saves enough water to meet the needs of the two purposes described above. One, it provided 23,200 AF of water for the UMUT to irrigate 7,500 acres of land. It also provided 25,400 AF of water for a trout fishery below McPhee Dam.

The BOR realized that without being able to develop all of the flow of the Dolores River (to do so meant flooding the town of Dolores) the downstream fishery would have to share water supply shortage commensurate with other users, specifically irrigators. The method the BOR chose to administer such a shortage was to incorporate into the Final Environmental Impact Statement ("EIS") a mechanism whereby the release below McPhee would be 20, 50, or 78 cfs, depending on whether it was a dry, normal or wet year. The type of year was to be determined on March 1st of each year based on the content of the reservoir and the relative amount of snow pack. If those two criteria established a "dry" year then 20 cfs would be released for the next 365 days. If the formula determined a "normal" year then 50 cfs would be the next years release and if it was a "wet" year, then 78 cfs was the annual release.

Construction of McPhee Dam was completed in the fall of 1983. Filling began in the spring of 1984. The Division of Wildlife ("DOW") began a fish-stocking program below the dam in the fall 1983 and continued throughout the filling of the reservoir and beyond. A quality fishery was established. Filling of the reservoir was completed in 1987. Very few irrigators were on line, so there was plenty of water for the downstream fishery during filling. The release was set at 150 cfs until the drought of 1988 through 1992.

In accordance with the Project's EIS, the March 1st 1990 content of the reservoir and the snow pack dictated a "dry" year, meaning a 20 cfs downstream release. Contrary to the Environmental Impact Statement ("EIS") guidelines, the District & the BOR agreed to re-evaluate the criteria on May 1st. As a result of April precipitation, the calculation was much nearer being a "normal" year, which would have designated a 50 cfs release, but the absolute criteria still indicated "dry", so the District and the BOR abided by the EIS guidelines and set the release at 20 cfs. Had the calculation been redone on May 5th it would have clearly been a normal year.

In May, the Five Rivers Chapter of Trout Unlimited ("TU") wrote "arbitrary selection of water use and management by DWCD is offensive and wrong". Naturally, the District responded with a defensive retort as follows: "More water for the fishery hurts all the other users". By June 10th the 20 cfs was clearly having a negative effect on the fishery. The word on the street and in the State's newspapers was, "Dolores means river of sorrow" - "The River will die" – "lawsuit in works". On June 12th the BOR in Washington - ordered the gates below McPhee be opened - that the flow be increased back to 78 cfs. The District's response was, "the EIS is being abided by", and "By what authority do you make such a request". I gather, somewhat uniquely, the DWCD owns the projects water rights, rather than the Federal Government.

The stage was set for a confrontation. In many cases the better way to manage water is obvious. In this case it was clear that if a way could be found to manage the fishery release in such a manner that water could be saved during the winter season for higher flows during the summer (a pool concept) the fishery would benefit. However, the irrigators would suffer greater shortages during consecutive drought years.

Changing from a "flow release" to a "managed pool" was a process which took 6 years. In 1996 an Environmental Assessment was issued, with a FONSI (Finding of No Significant Impact) which officially changed the release below McPhee Dam from an "annual flow" to a "managed pool". In addition the parties agreed to work together to create a pool of 36,500 AF of water for the fishery. As of 2010, the pool of water available for downstream uses includes 29,300 AF of Project water allocated to fisheries, 1274 AF of non-project downstream senior water (although this quantity is subject to river administration and downstream 'beneficial uses'), and 700AF of Project water to meet augmentation needs at the Paradox Salinity Unit (this amount does not share shortages). Therefore, on a year when all Project allocations can be met, the water available for downstream uses is 31,274AF. In years when all project allocations cannot be met (e.g., 2002) all except the Paradox Augmentation shares the shortage with other project allocations. Trout Unlimited and DWCD cooperatively provided the leadership in forming an ad hoc group, in 1997, called the Dolores River In-stream-flow Partnership (DRIP). The purpose of the group was to "work together to create a pool of 36,500 AF" for the downstream fishery. The focus of the DRIP effort was for more water. Many options were explored. A consensus could not be reached and because of the 2000 - 2004 drought the DRIP process was suspended.

In the fall of 2003, San Juan Citizen's Alliance, guided by Chuck Wanner (SJCA staff) and DWCD, guided by Steve Arveshough, (DWCD Gen. Manager) resurrected talks. That collaborative effort resulted in the formation of the Dolores River Dialogue.

Appendix 2. Dolores River temperature data compiled from data provided by the Colorado Division of Wildlife and the Dolores Water Conservancy District (see separate document).

Appendix 3. Reservoir data compiled from data provided by the Colorado Division of Wildlife and the Bureau of Reclamation (see separate document).

Appendix 4. Existing McPhee Dam Operational Constraints

There are 2 distinct operational discharges from McPhee Dam – 1) spill-discharge and base-discharge. Spill-discharge usually occurs in the spring when predicted inflow from snowmelt exceeds the available storage capacity in the reservoir and the excess water is discharged through the 2 large gates at the bottom of the reservoir. To the degree possible this water is managed for recreational and commercial boating. Spill discharge occurred once in the fall 1999 due to low demand for irrigation water that left a relatively full reservoir and high inflow from a large rainfall event.

Base-discharge begins when demand for water from the reservoir exceeds inflow and water for downstream purposes is discharged through the 3rd SLOW, the turbines and the bottom by-pass gate. Beginning April 1rst, 31,978 acre feet of water known as the fish pool water and managed by the Biology Committee begins to be used. The clock for the fish pool ends October 1rst.

The amount of water that can be stored each year in the reservoir depends on reservoir elevation at the beginning of the spring-runoff period which in turn depends on the level that the reservoir was filled the previous spring, the amount of inflow and demand for water since the reservoir was filled. Spill water cannot be used to enhance base-flows.

Dam operations since the construction of the power-plant in 1993 for spill-discharge has consisted of discharges up to 4,500 cfs through the large gates at the bottom of the reservoir plus 75 cfs through the turbines to generate power. Dam operation to date for base-discharge has been through the 3rd Selective Level Outlet Work (SLOW) and the turbines plus additional flows through the bypass gate at the bottom of the reservoir to meet downstream priority water rights and base-flow recommendations from the Biology Committee.

Other constraints include:

- If at all possible, no water is to ever be released over the spillway to avoid introduction of non-native fish and damage to the spillway;
- To satisfy water supply contracts the reservoir must be filled to capacity each year and carry-over to the next year must be maximized;
- If the reservoir cannot be filled to capacity, then shared shortage is required by law for all water supply contracts including non-priority water for downstream uses such as the fisheries.
- Spill-discharges are required to be managed for rafting, meaning flows near 1000 cfs for as long as possible.
- The Bureau of Reclamation desires to continue use of and maximize use of the turbines to generate power.

Figures

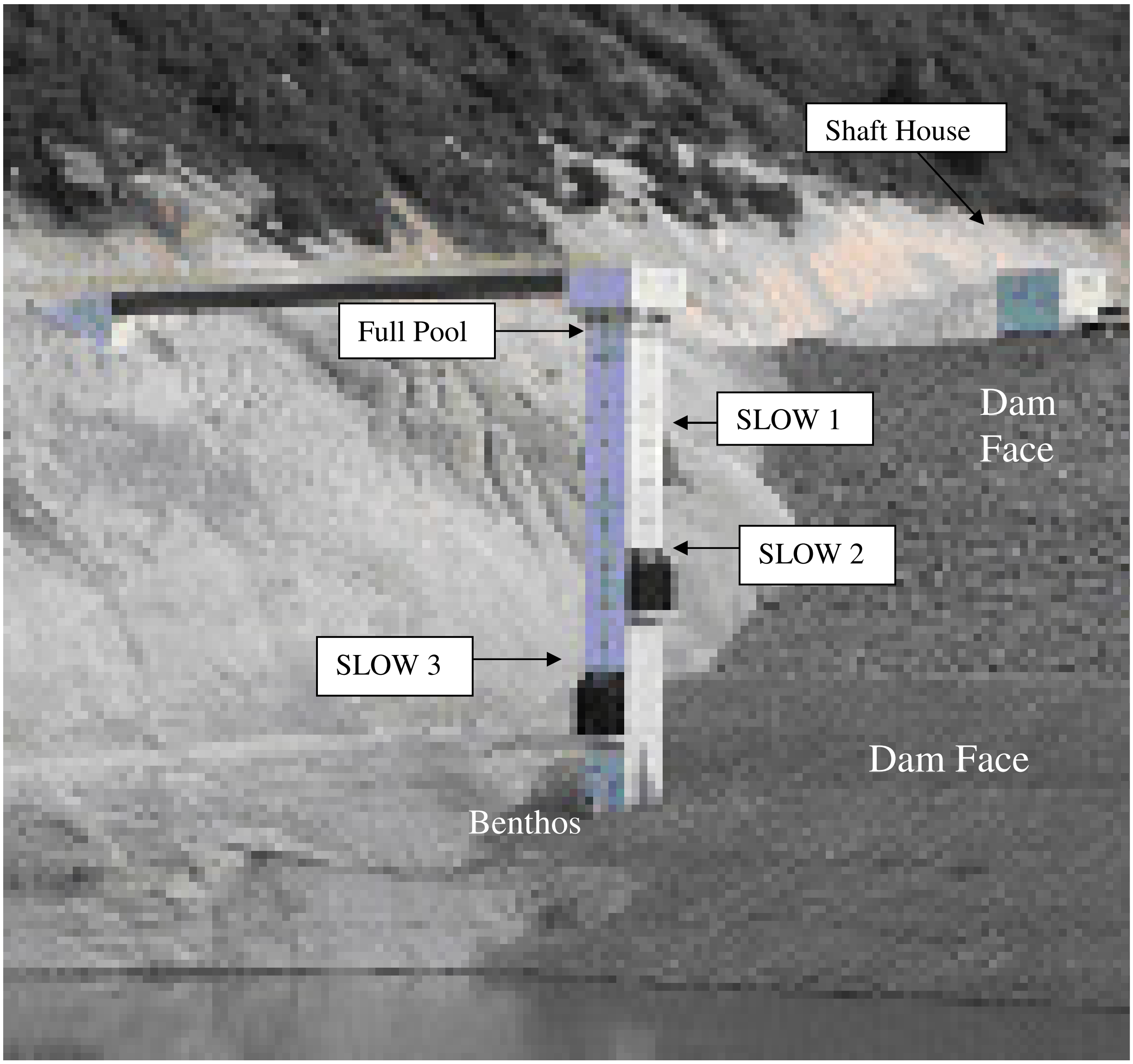

Figure 1. Selective Level Outlet Works showing the 2nd and 3rd inlets. The 1rst inlet faces the dam. The sills of the inlets are located at elevations 6,892 (SLOW 1), 6,896 (SLOW 2) and 6,840 feet (SLOW 3). Full reservoir elevation is 6,924 ft. Note the proximity of the 3rd SLOW to the benthos, habitat for white suckers.

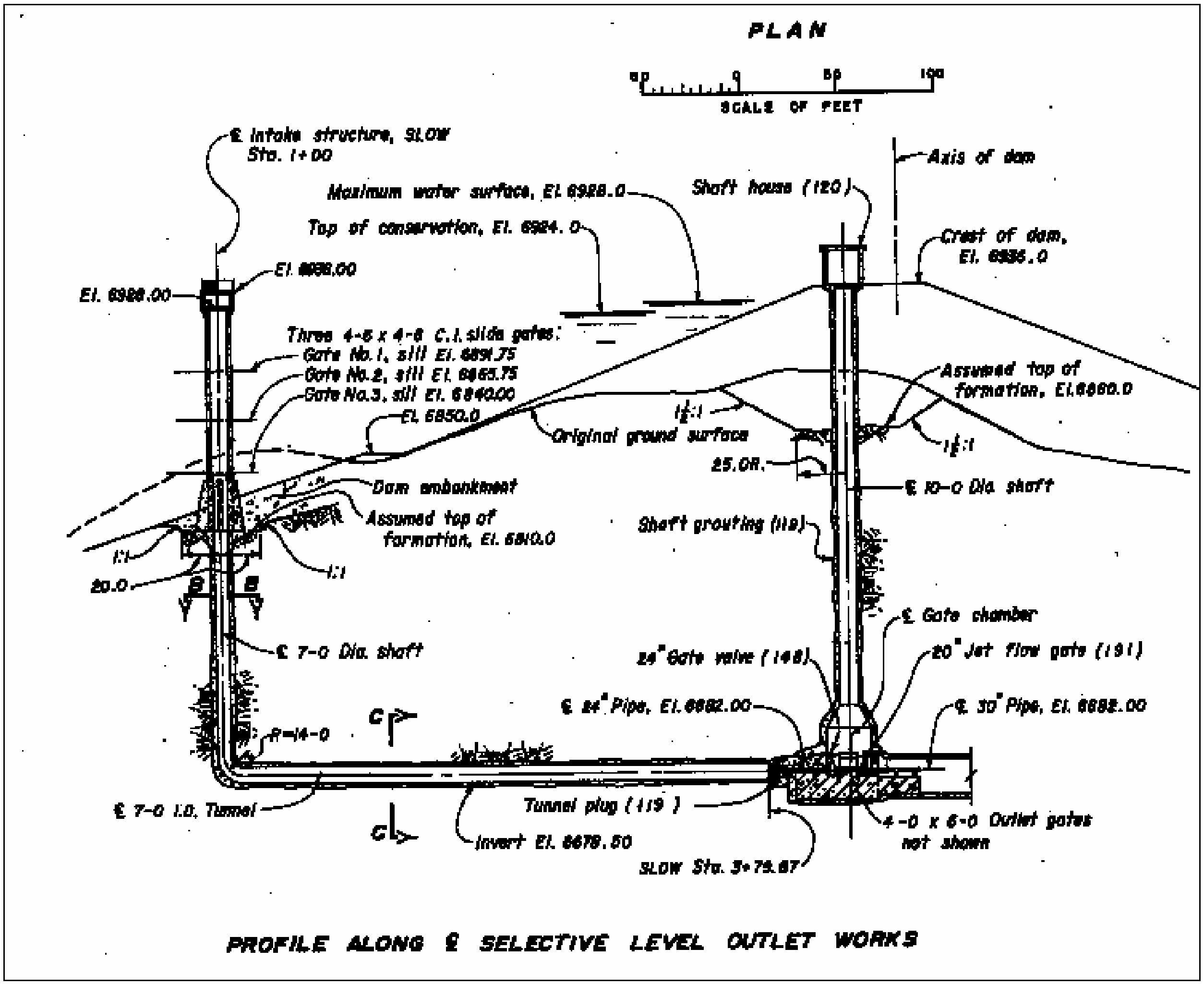

Figure 2. Copy of blue prints cross section of Selective Level Outlet Works (SLOWs)

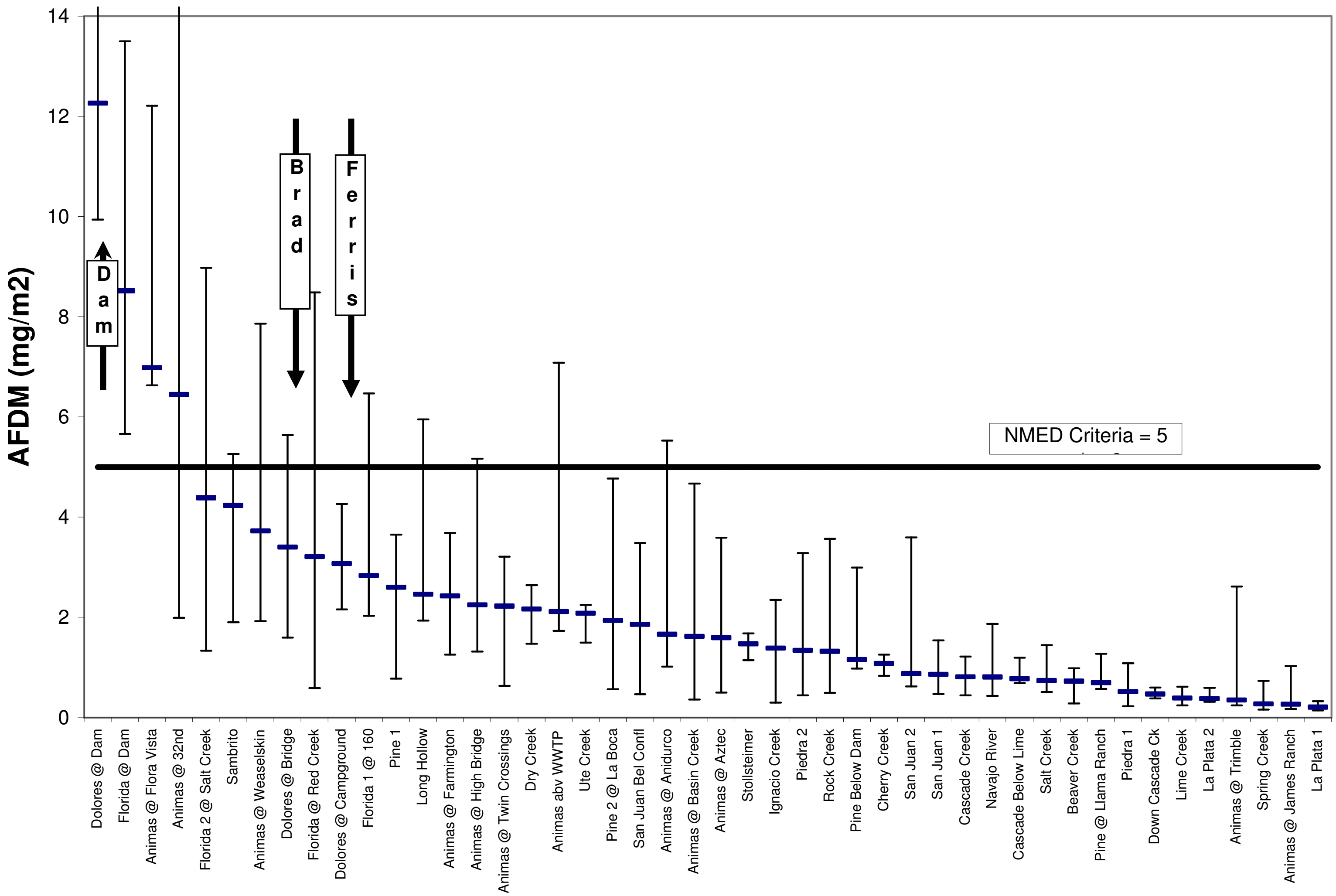

Figure 3. Quantity of organic matter (median ± 75th and 25th percentile) measured as ash-free dry mass in relation to other streams in the region. Note, the Dolores sites (@ dam, Ferris Creek Campground and Bradfield Bridge) are at the high end of concentrations. The Colorado Department of Public Health and Environment is in the process of setting nutrient criteria. The New Mexico Environment Department has established a regional criterion of 5mg/m2.

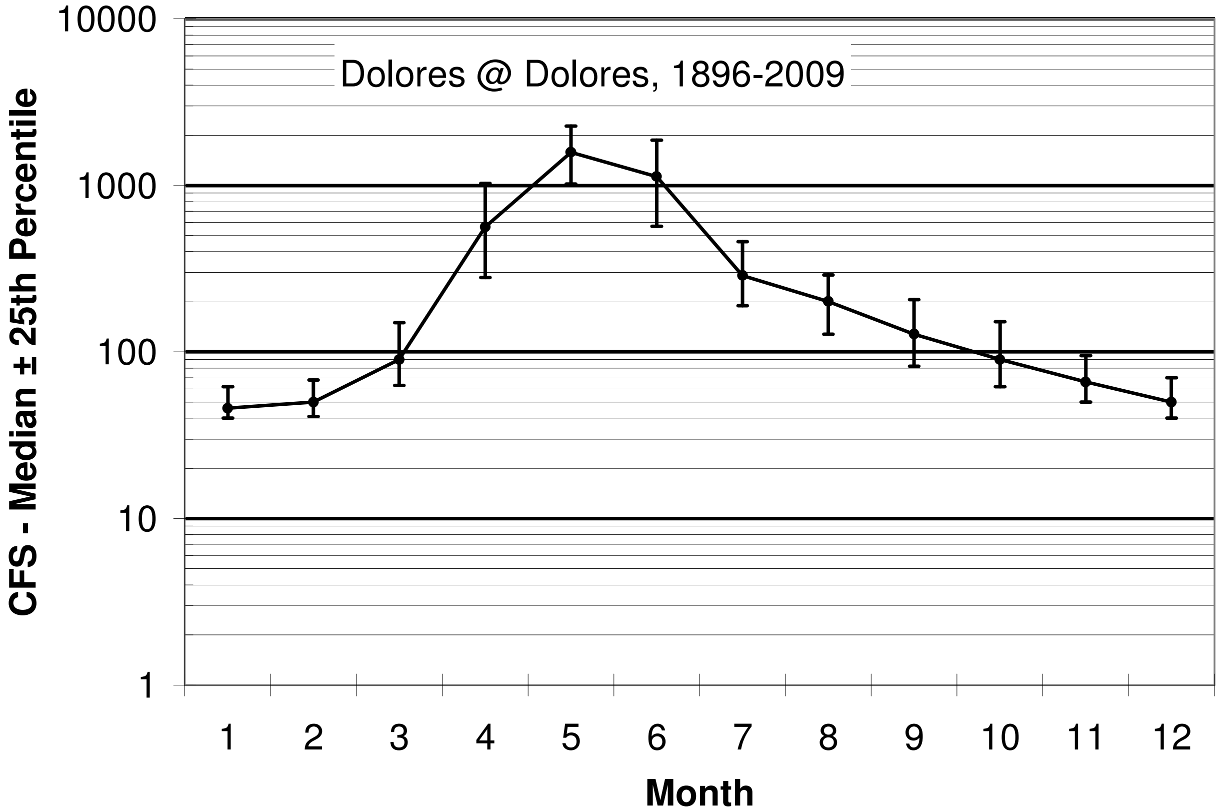

Figure 4. Median (±25th percentiles) discharge at the USGS Gage located above the MVIC diversion. Because there are few diversions above this site this graph is a close illustration of the native hydrograph.

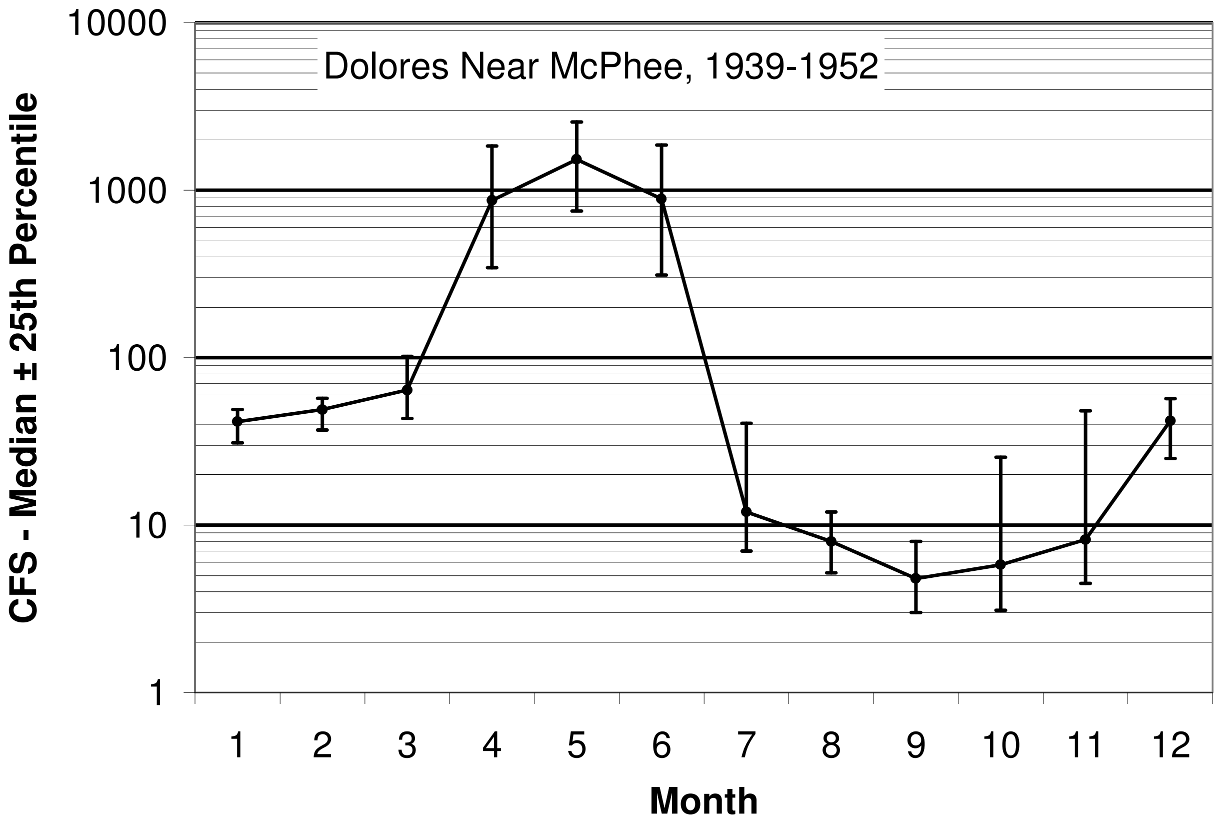

Figure 5. Median (±25th percentiles) discharges at the old town site of McPhee, CO (now buried by McPhee Reservoir) below the MVIC diversion during dates prior to the construction of McPhee Dam and after construction of the Great Cut Diversion. During the months of August through November, flows were less than 10 cfs 50% of the time.

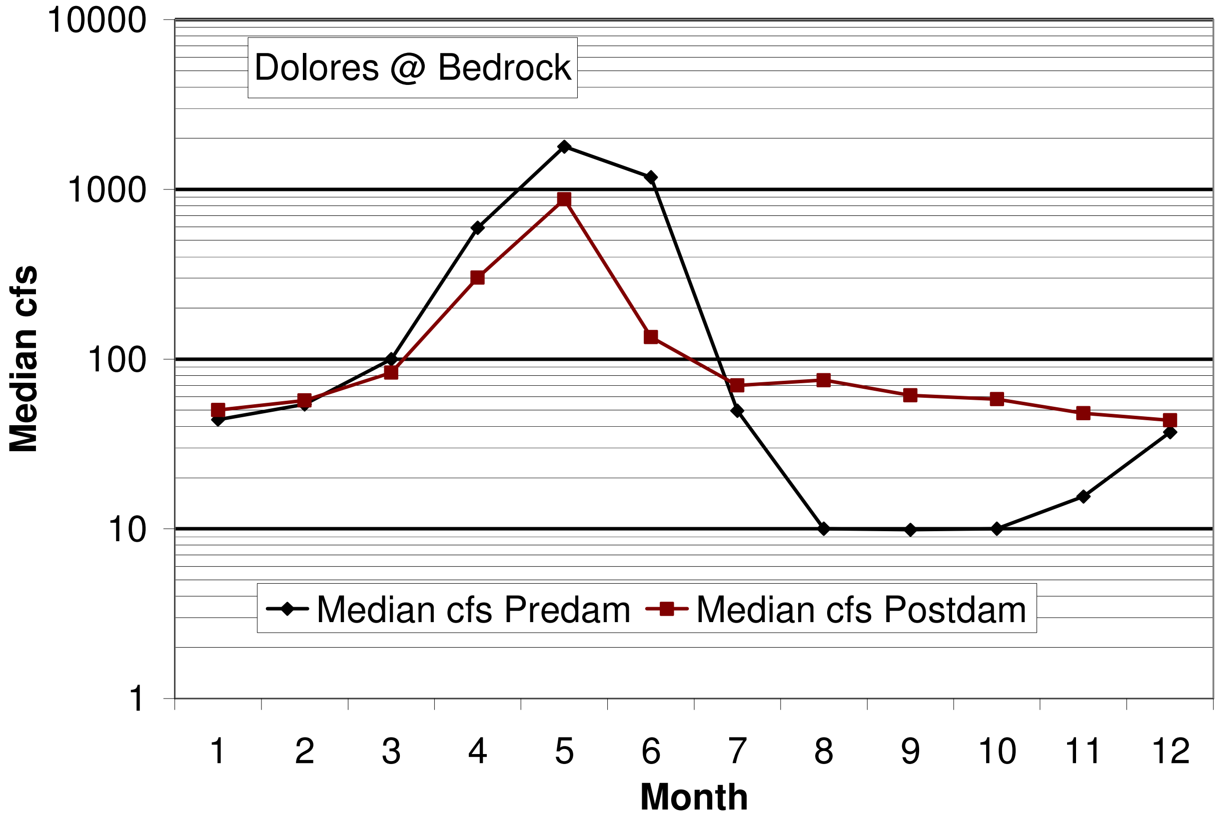

Figure 6. Median discharge at the USGS Bedrock Gage. Median flows prior to the construction of McPhee Dam were less than after the construction of McPhee Dam July through November and greater April through June.

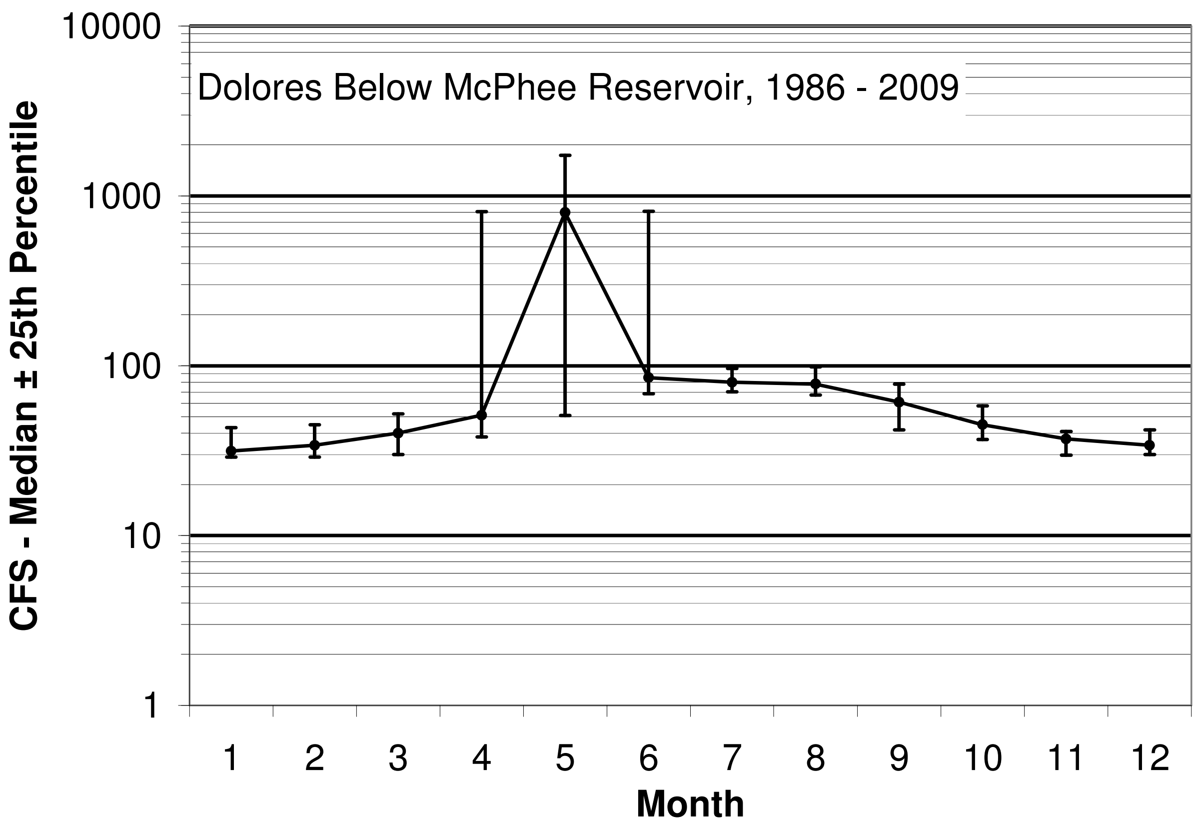

Figure 7. Median discharge (±25th percentiles) from McPhee Dam. Median flows were 30 cfs or greater for each month of the year. Note the 10 fold decrease in post-dam median flows for the months of April and June (see Figure 5).

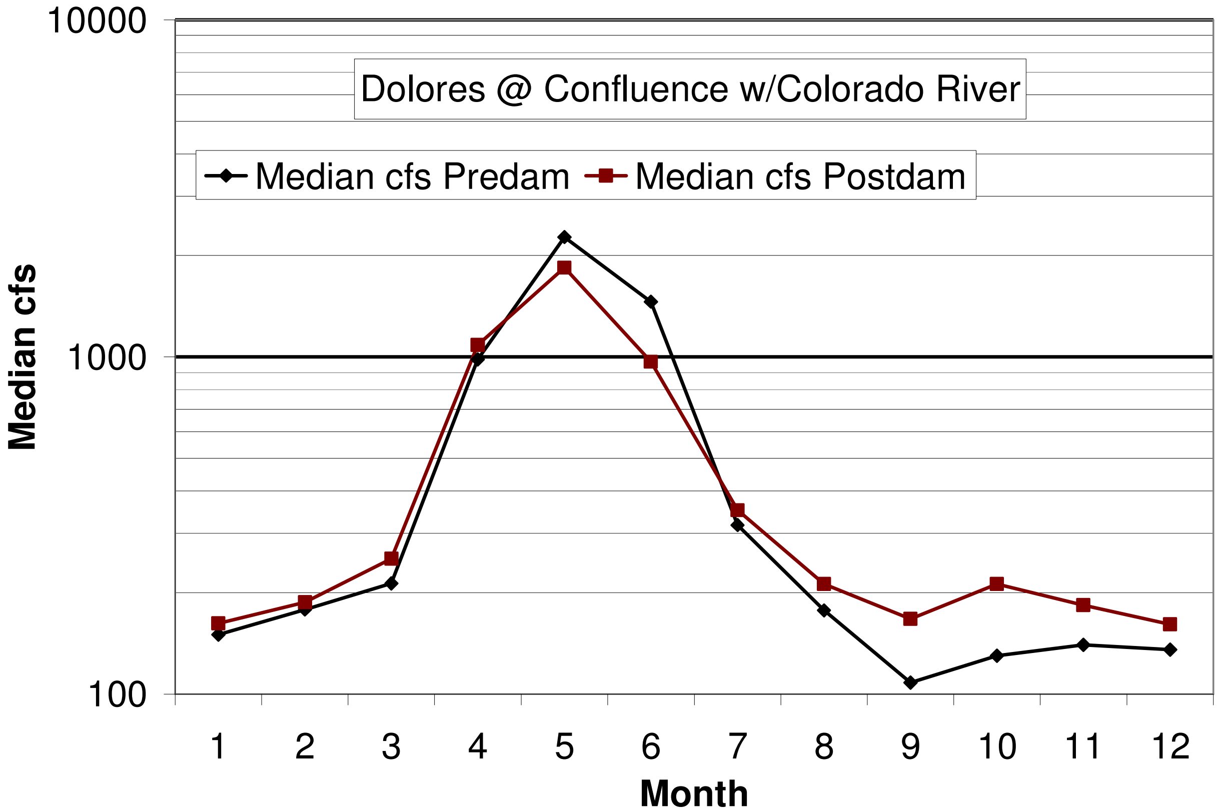

Figure 8. Discharge at the Ciscoe, Utah USGS gage. Median flows were less prior to the construction of McPhee dam for the months of August through March. Median flows were greater in the Dolores prior to the construction of McPhee Dam for the months of May and June.

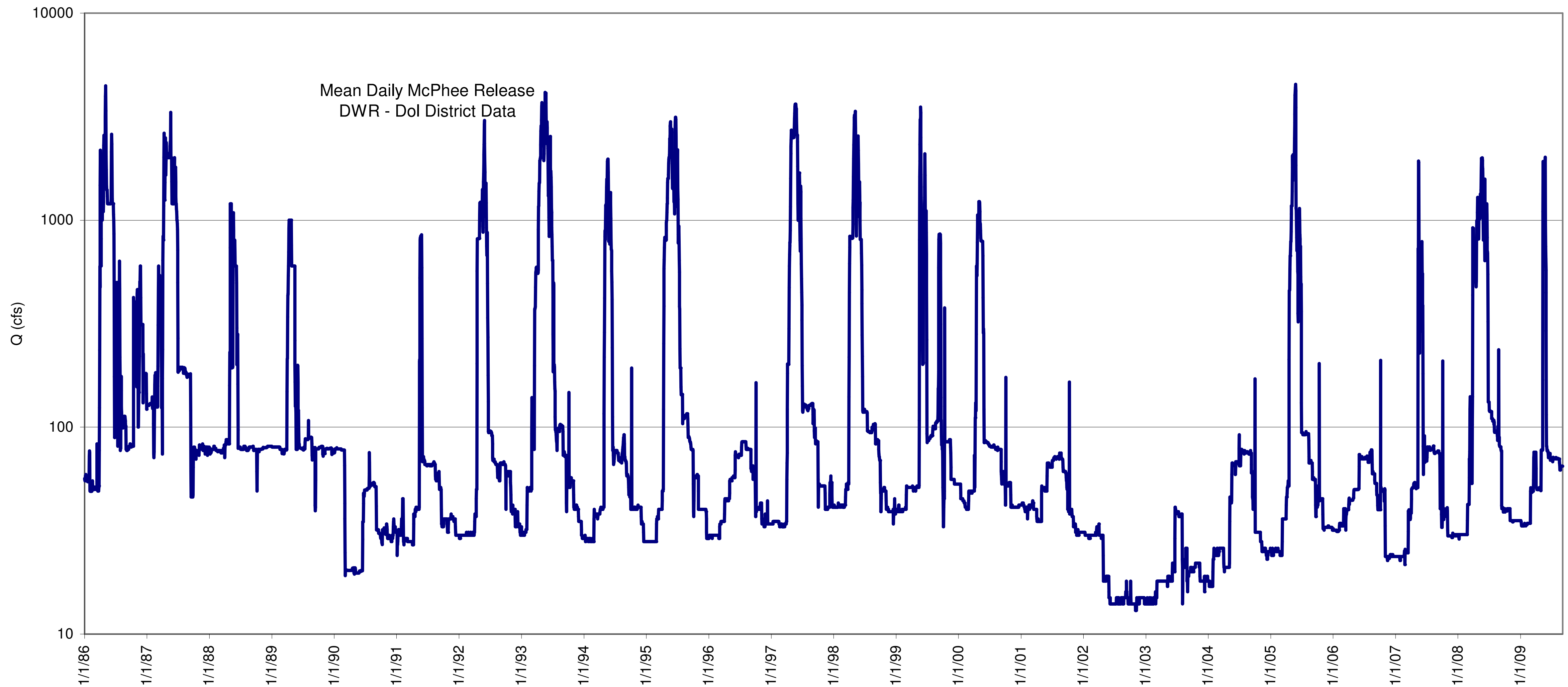

Figure 9. Discharge data from McPhee Reservoir illustrating the low summer/fall flows in 1990, 2002, and 2003.

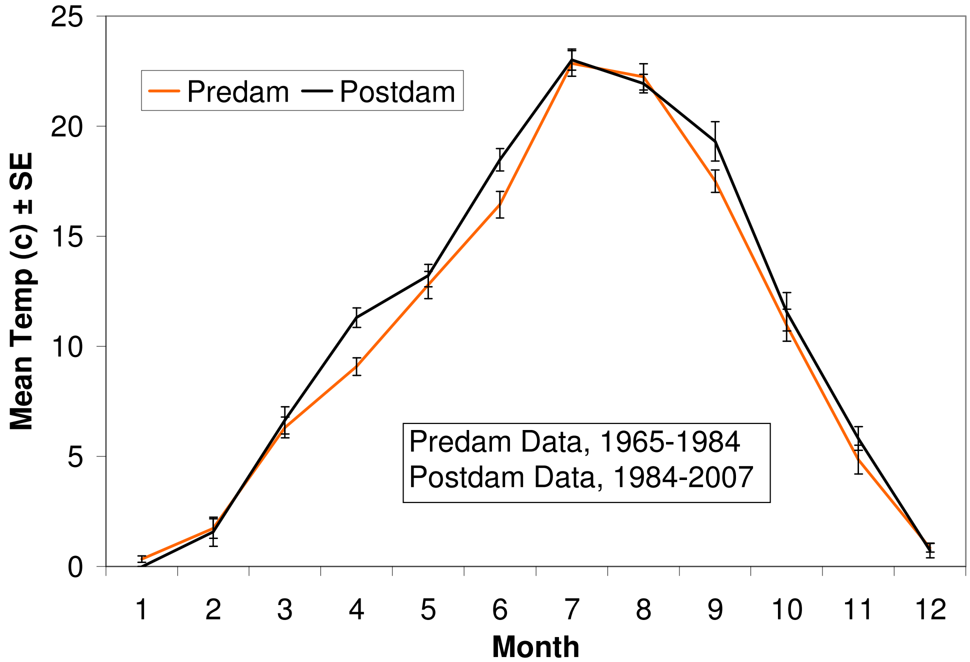

Figure 10. Pre and post dam differences in mean (± SE) daily water temperature (^{o}C) collected at the USGS Gage at Bedrock, CO (grab samples). Note differences in April and June during the spawning period for native fish.

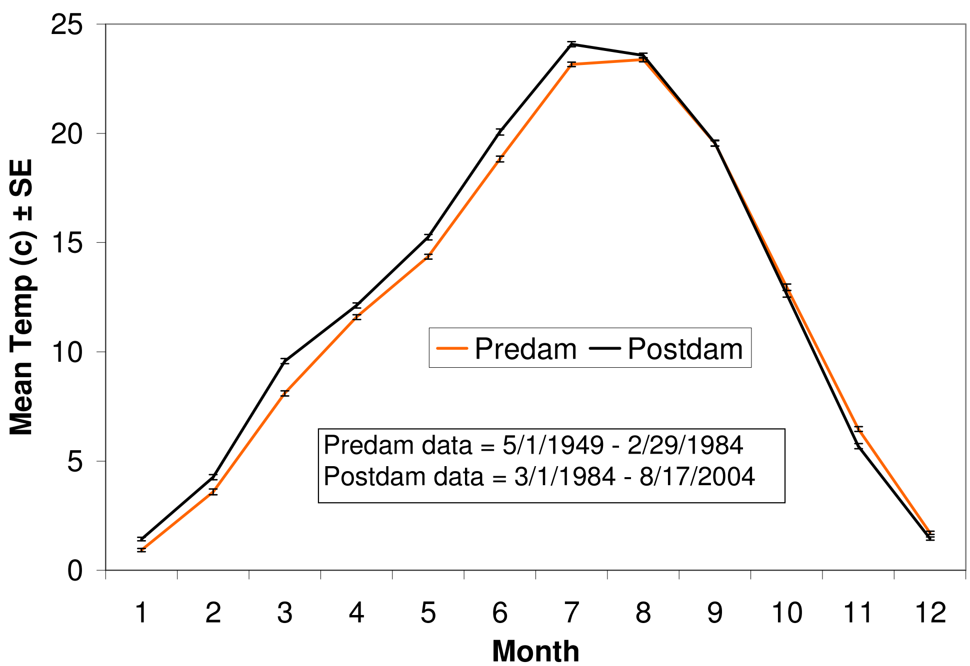

Figure 11. Mean (± SE) daily temperatures at the Ciscoe USGS Gage. Mean temperatures were less prior to the construction of McPhee Dam January through July. Data set includes data from 1986, 87, 88, 90, 02 and 05 through 09.

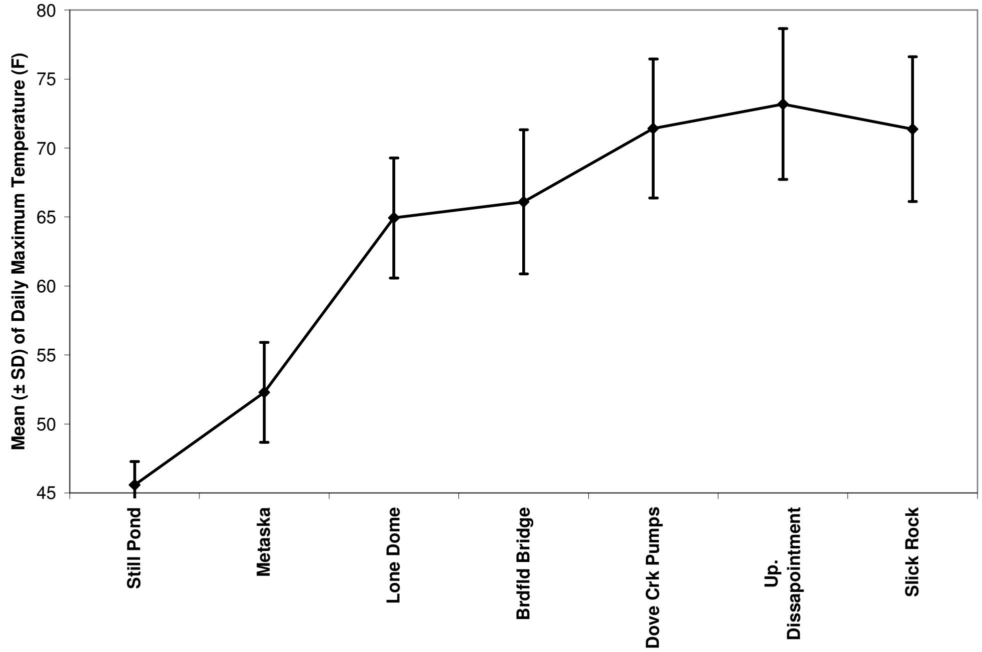

Figure 12. Mean ± standard deviation of daily maximum temperature at 7 sites, McPhee dam downstream to Slick Rock. Ambient temperature is reached near Disappointment Creek where temperature of the water discharged from the dam has little influence on temperatures found in the river.

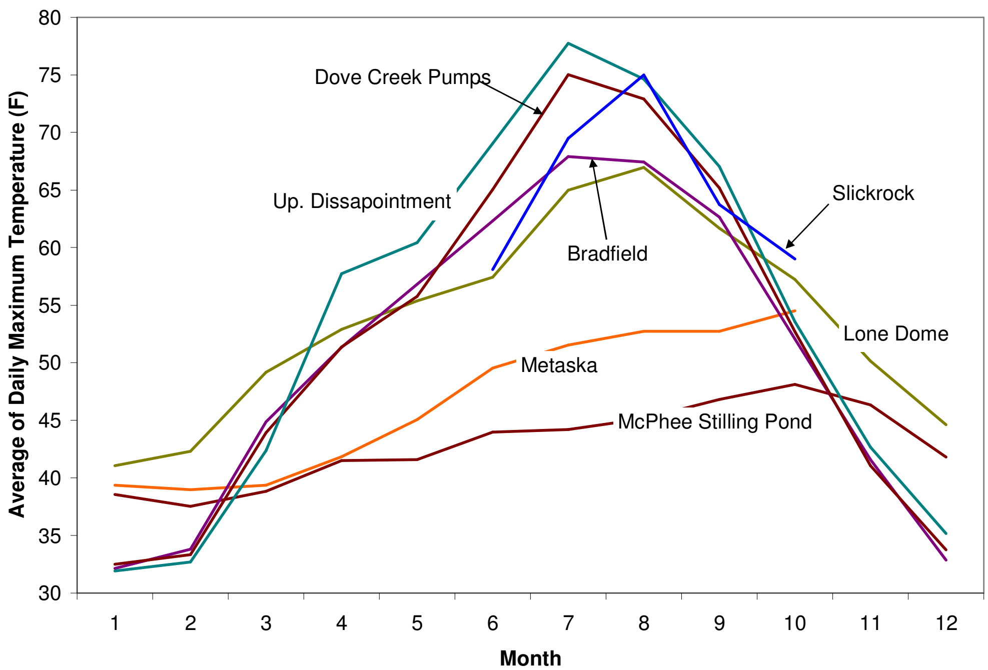

Figure 13. Average of daily maximum temperature at 7 sites, McPhee Dam downstream to Slickrock. Winter temperature upstream of Bradfield Bridge is greater than winter water temperature Bradfield Bridge downstream showing the influence of the dam in DRD Reach 1 (McPhee to Bradfield Bridge).

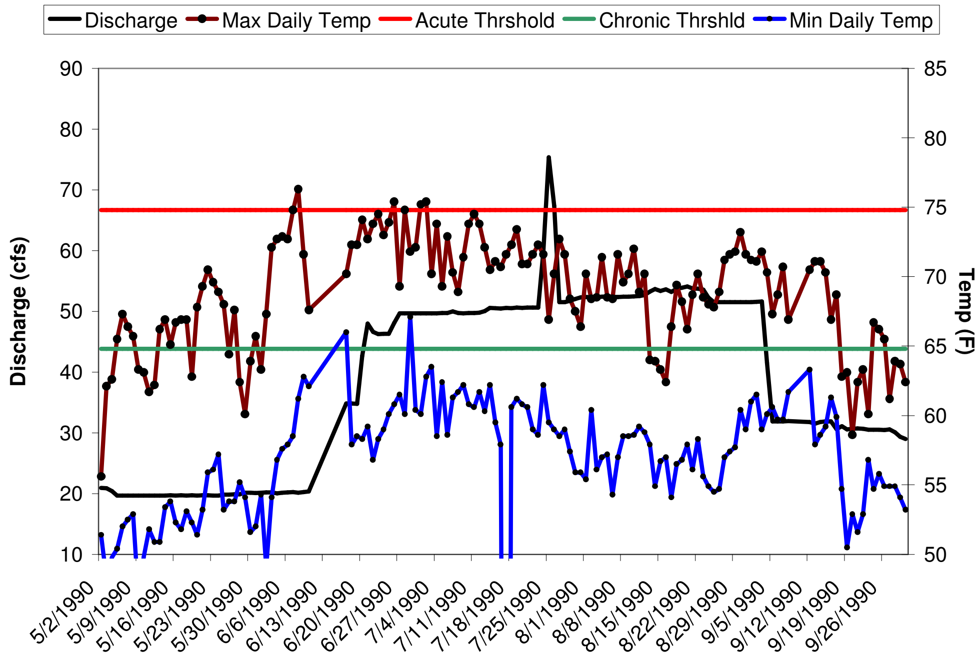

Figure 14. May 1rst through September 30th daily maximum and minimum temperature and discharge data during the 1990 drought, measured at Bradfield Bridge. Note that the chronic temperature threshold for trout was exceeded twice for periods greater than 24 hours and the acute temperature threshold was exceeded on 5 dates at discharges of both 20 and 50 cfs.

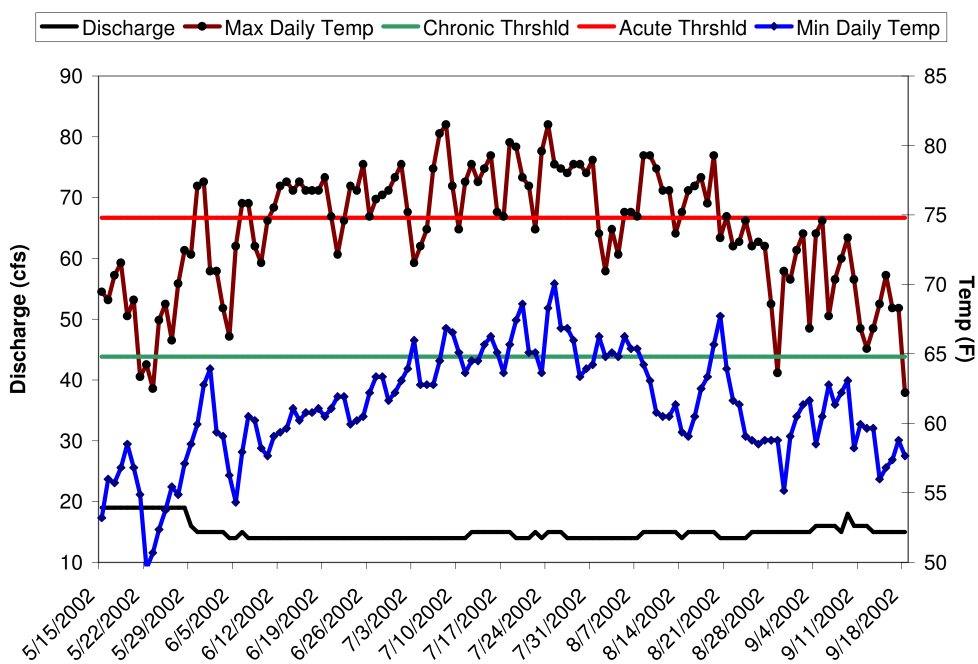

Figure 15. May through September daily maximum and minimum temperature and discharge data during the 2002 drought, measured at Bradfield Bridge. Note that the chronic temperature threshold for trout was exceeded several times for periods greater than 24 hours and the acute temperature threshold was exceeded

on numerous occasions. Discharge from McPhee less than 20cfs. No temperature data available for 2003 also a period of very low discharge from McPhee.

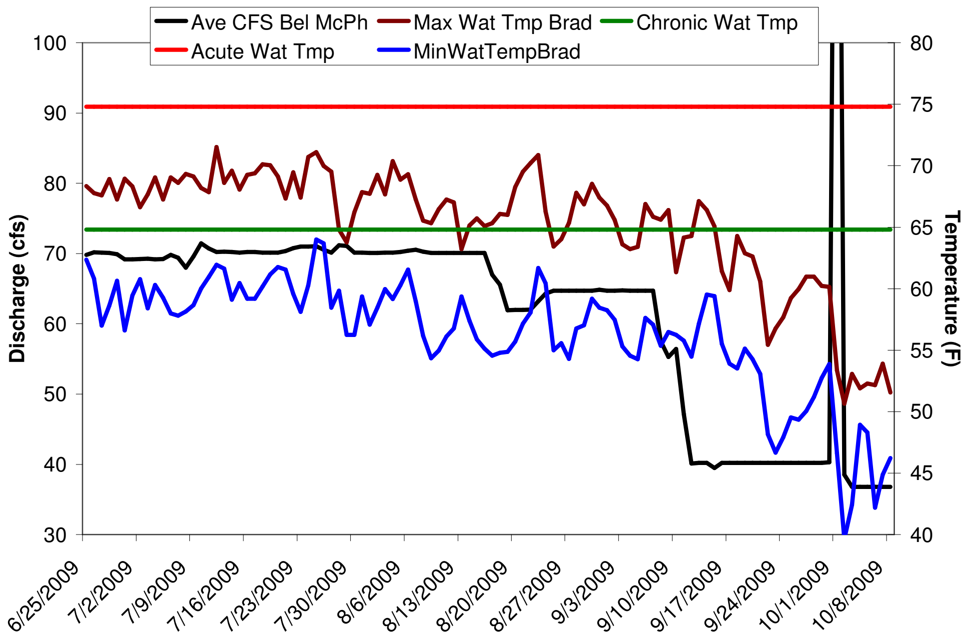

Figure 16. Discharge from McPhee and daily maximum and minimum temperature at Bradfield Bridge in 2009. The chronic temperature threshold for trout (64.9° F) was never exceeded for more than 24 hours and the acute temperature threshold for trout (74.9° F) was never exceeded at flows of 70 cfs during the summer months.

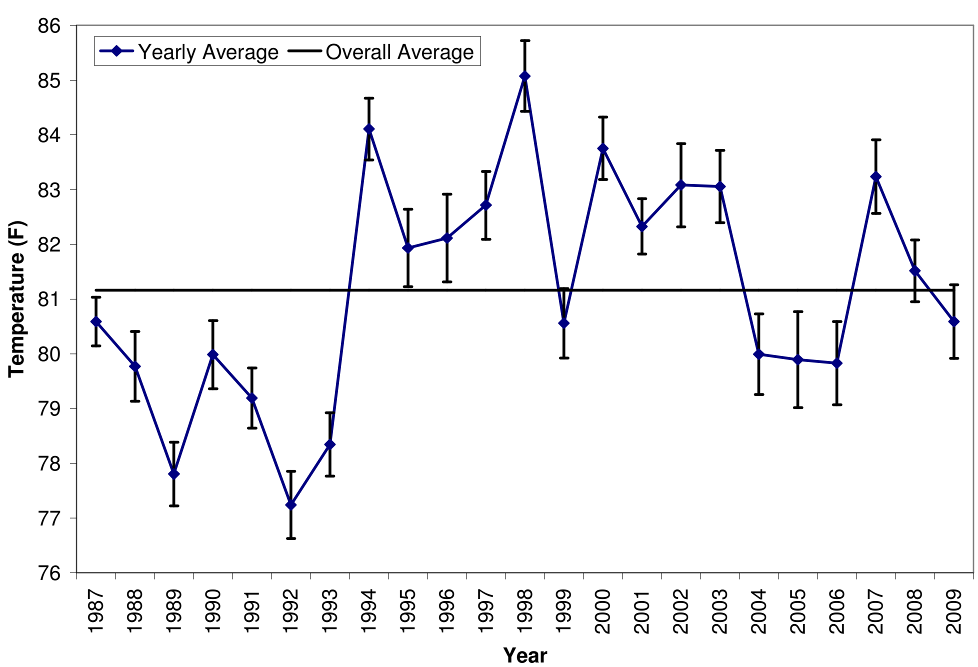

Figure 17. Overall (1987-2009) and summer (July through September) average of maximum daily air temperature. Data collected at Great Cut operations center.

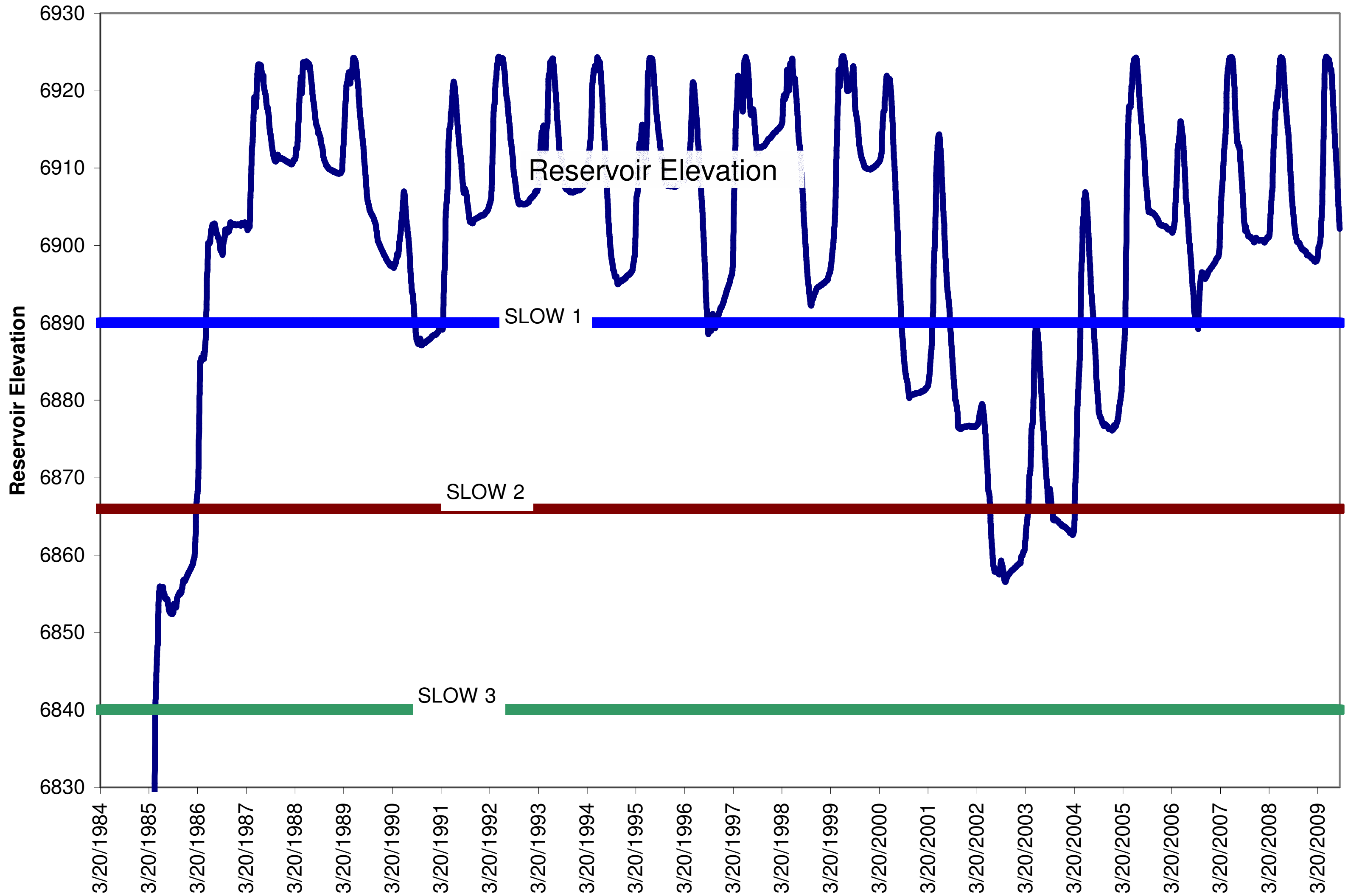

Figure 18. Reservoir Elevation in relationship to the SLOWs. The 3rd SLOW was less than 20 feet below the water surface from July 15th 2002 to February 24th 2003.

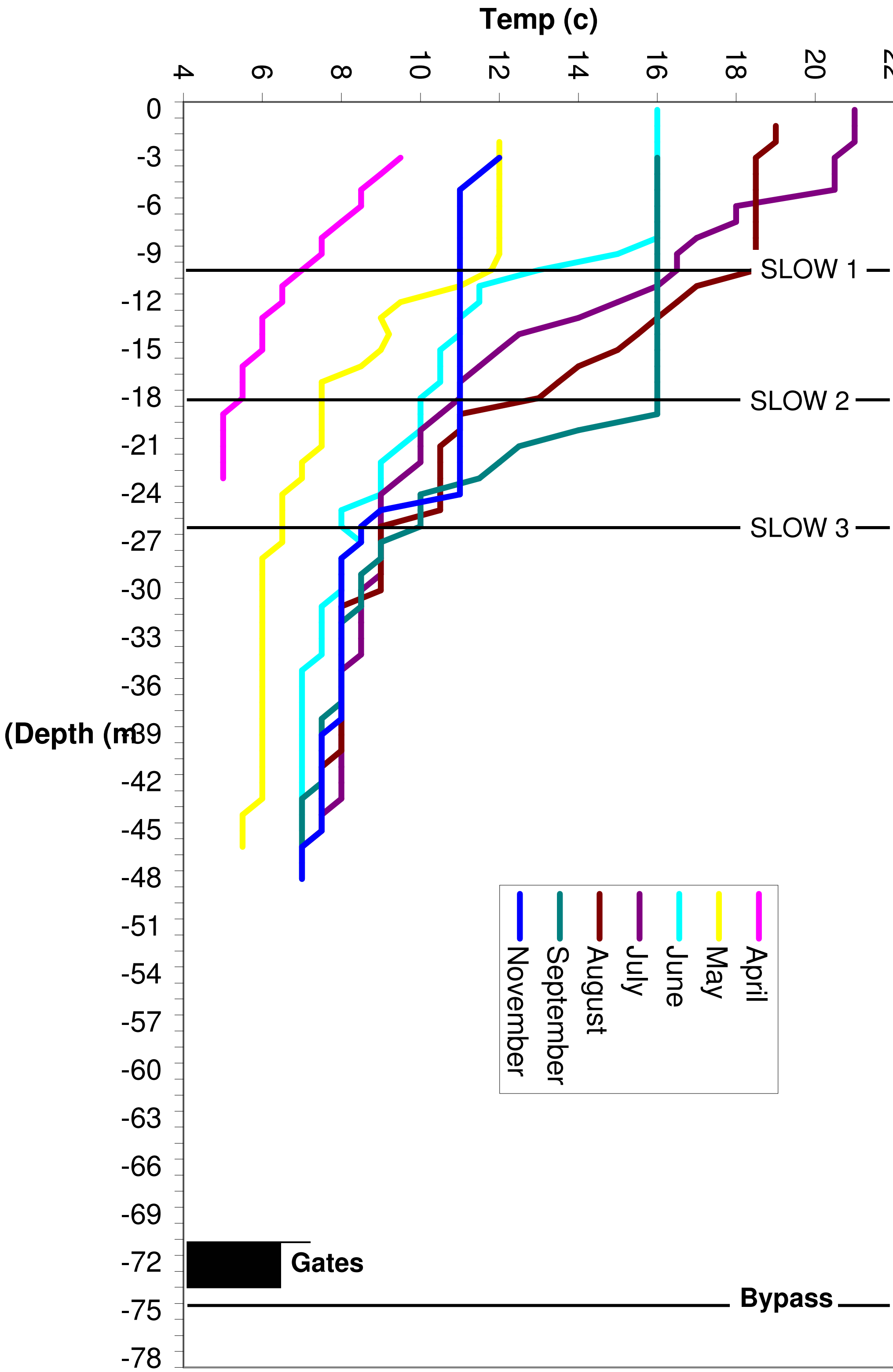

Figure 19. Thermoclines for McPhee Reservoir measured at the dam in 1987 in relation to the SLOWs. Note that the top of the thermocline was between SLOW 1 & 2 for the September and November sample dates and at or above the SLOW 1 for May, June, July and August sample dates and non-existent for April.

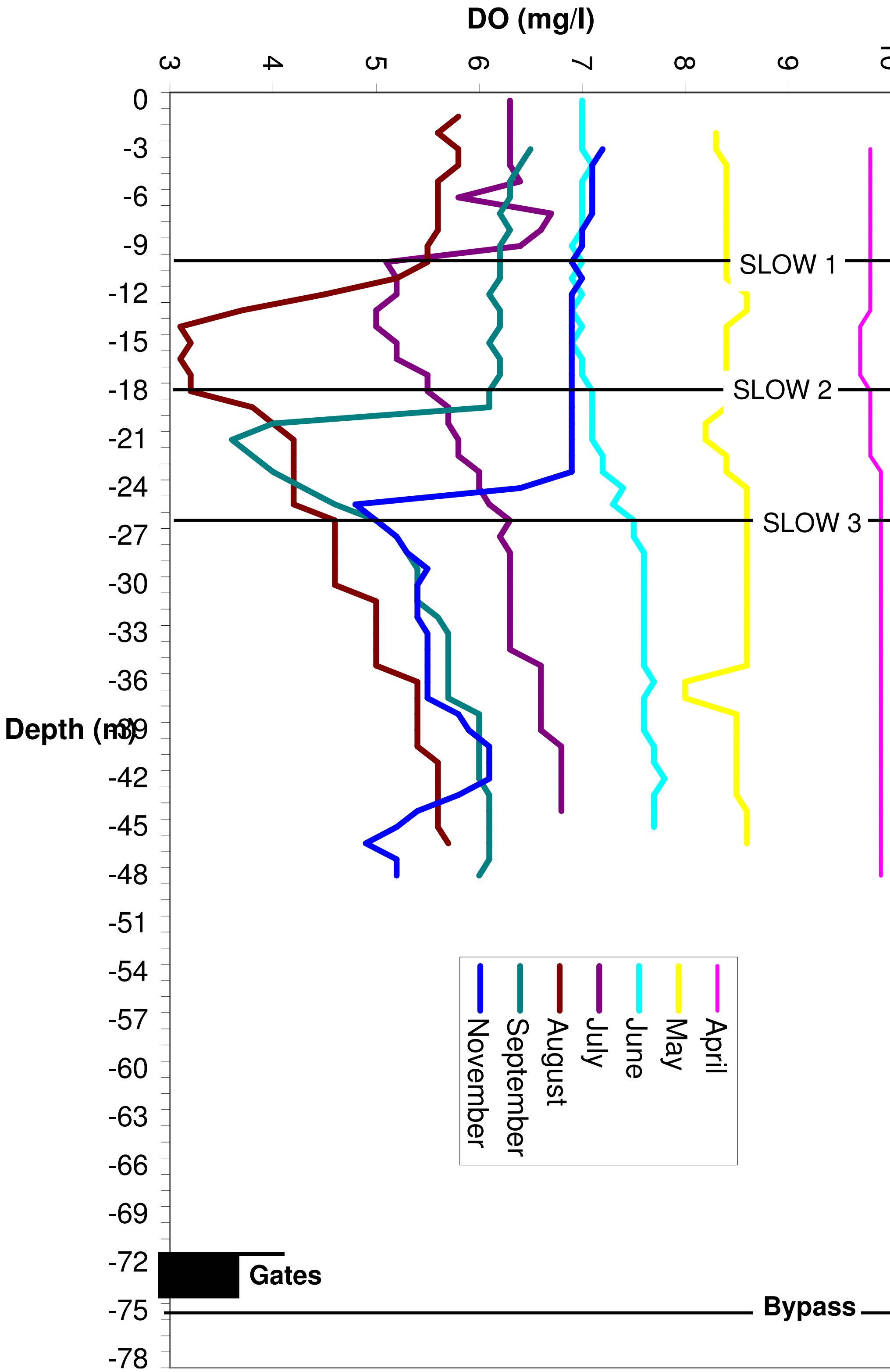

Figure 20. Dissolved oxygen-clines for McPhee Reservoir measured at the Dam in 1987 in relation to the SLOWs. Note that the top of the oxygen-cline was between SLOW 2 & 3 for September and November and between SLOW 1 and 2 for August and at or above the SLOW 1 for July and non-existent for April and May.

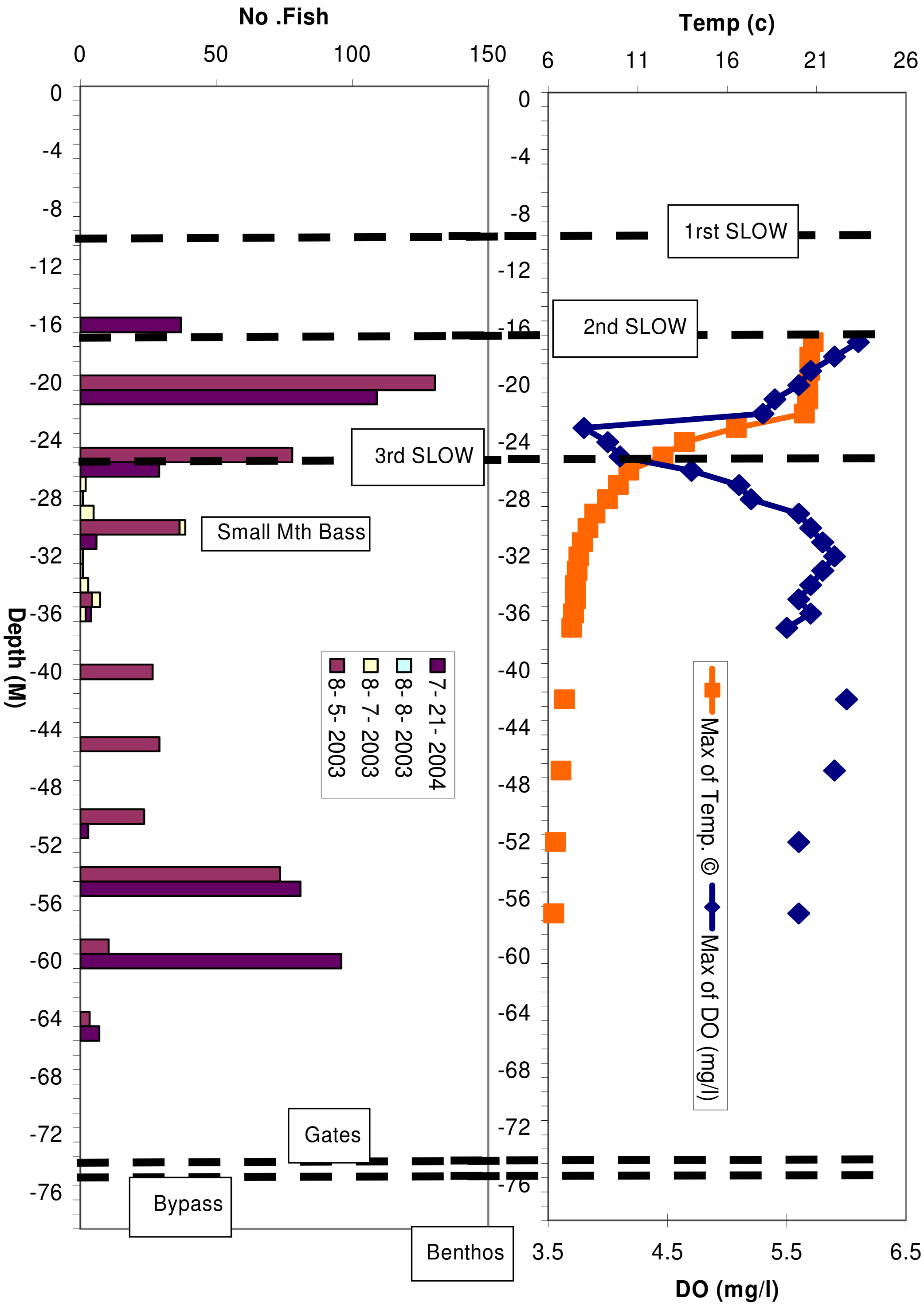

Figure 21. Fish, thermocline and oxygen-cline data collected August 2003. The 3rd Selective Outlet Work was just below the clines 8-5-03. Sonar data indicates fish living below the clines. Vertical gill nets set for 24 hours caught 20 fish of which 1 was a small mouth bass. The others were Kokanee Salmon, Rainbow and Brown Trout. Reservoir elevation August 5-8, 2003 averaged 15-17.5 meters below full. July 21rst, 2004 it was 9m below full and 8-24-1994 it was 6m below full. All catch depths are in relationship to elevation of the SLOWs.

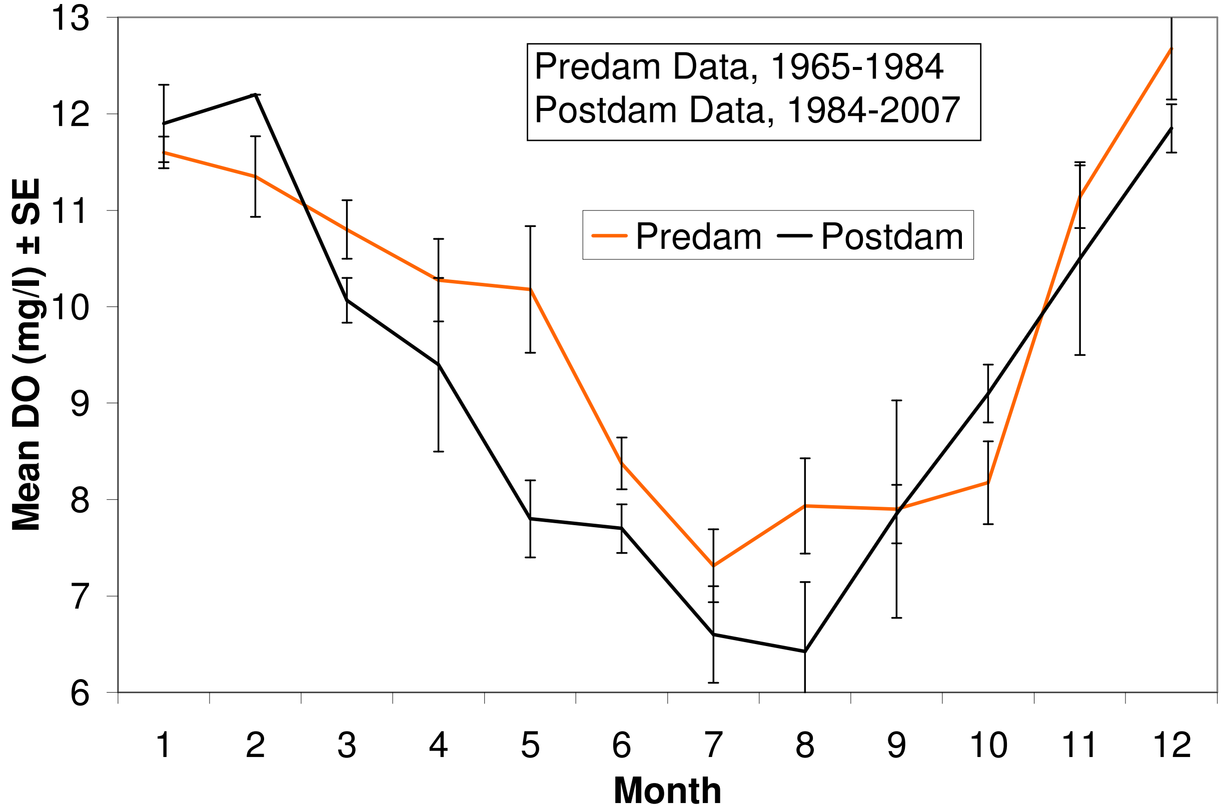

Figure 22. Mean concentration of dissolved oxygen at the Bedrock USGS Gage (grab samples). Dissolved oxygen was less in the Dolores after the construction of McPhee Dam for the months of March, May, June and August despite lower, post-dam temperatures (see Figure 10) indicating the possible effects of respiration of organic matter on dissolved oxygen.

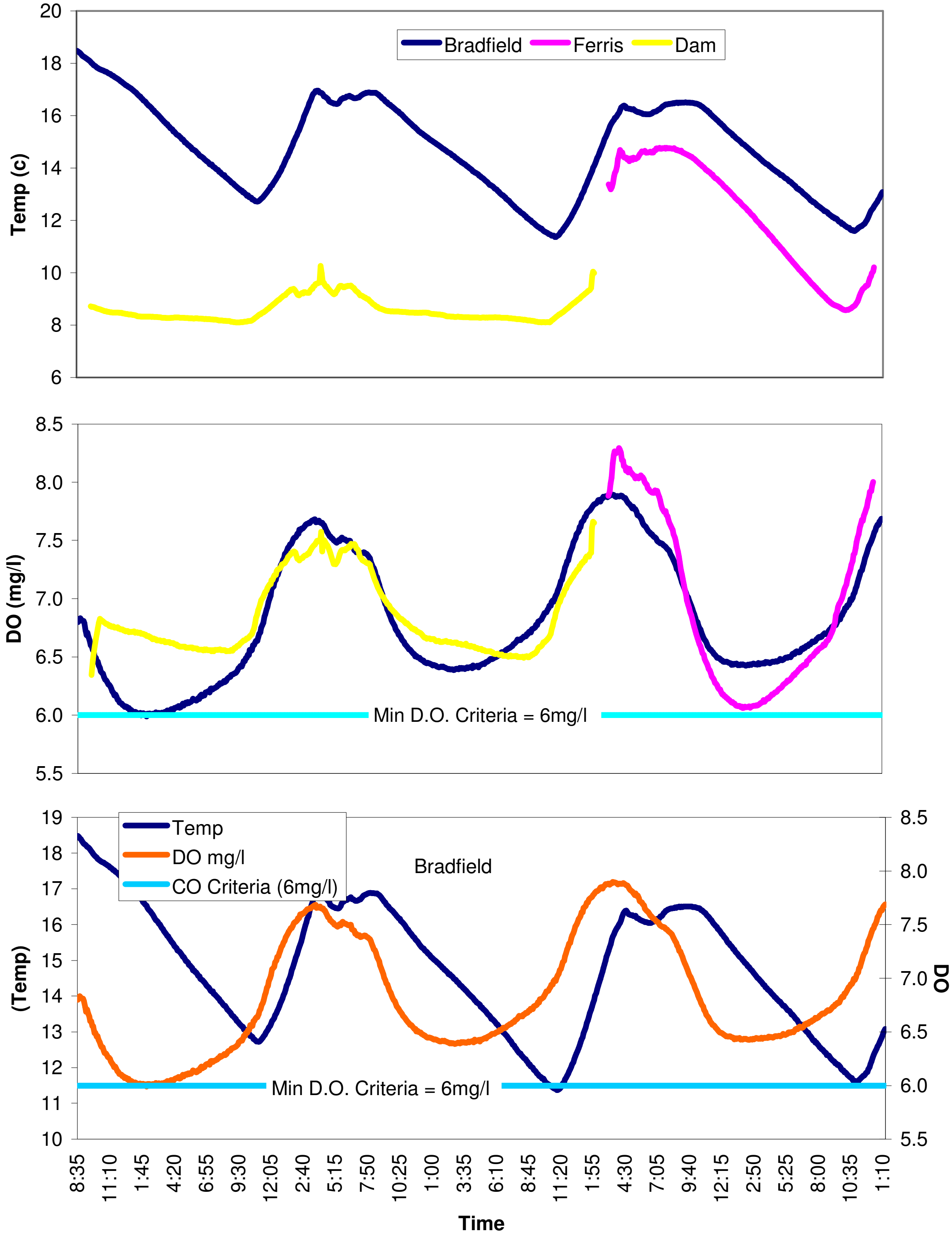

Figure 23. Temperature and dissolved oxygen data obtained with a YSI sonde at 3 sample stations: Below McPhee Dam, Ferris Creek Campground and Bradfield Bridge, September 17-19th 2008. Note the low DO concentrations (5.99mg/l @ Bradfield Bridge and 6.06mg/l @ Ferris Creek Campground and 6.55mg/l @ the Dam measured in the early morning due to decomposition of organic matter. The State standard for Trout Fisheries is 6mg/l. The chronic temperature threshold for trout (18.22C) was not exceeded during the time period. Discharge from McPhee Reservoir was 40cfs.

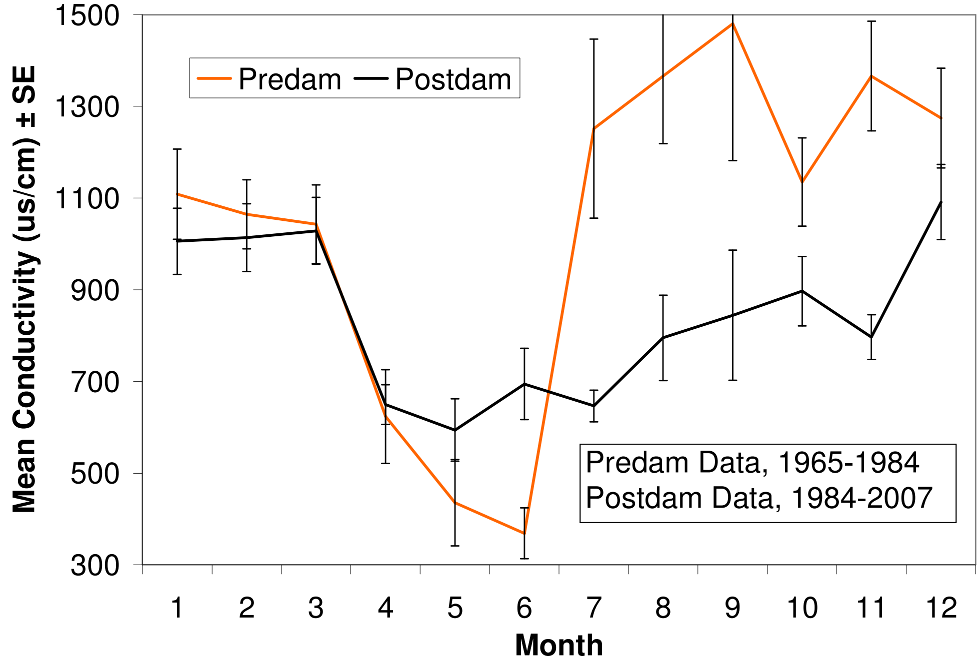

Figure 24. Mean conductivity at the Bedrock USGS Gage (grab samples) prior to the construction of McPhee Dam. The conductivity was greater for the months of July through November and less for the month of June.

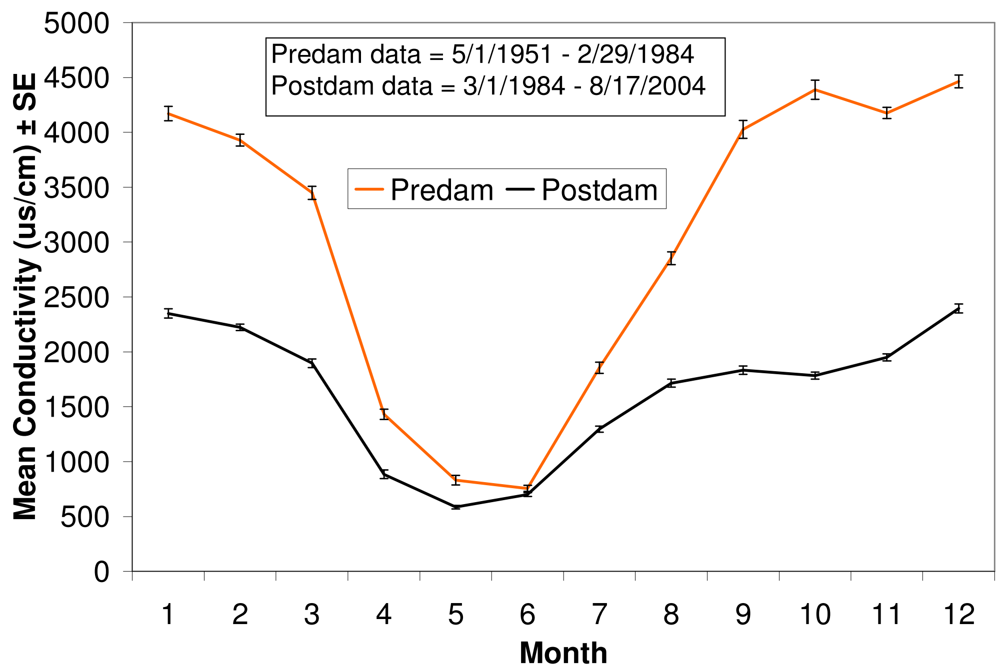

Figure 25. Mean daily conductivity at the Ciscoe, Utah USGS Gage prior to the construction of the McPhee Dam. Conductivity was greater for each month of the year except June prior to the construction of McPhee Dam.

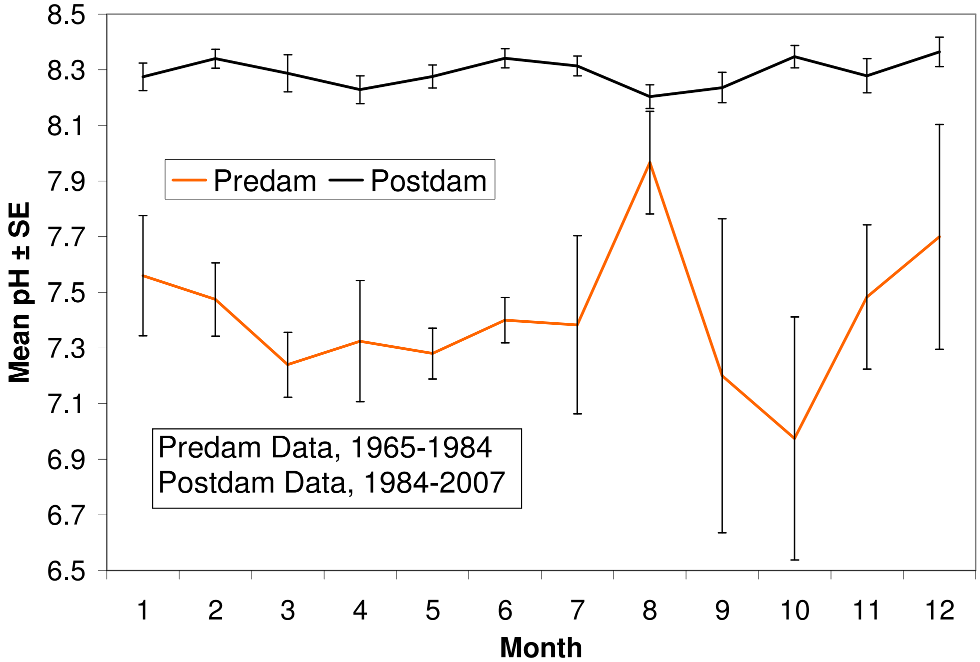

Figure 26. Mean pH at the USGS Bedrock Gage (grab samples) prior to the construction of McPhee Dam. The pH was less for each month of the year and had much greater variability prior to the construction of McPhee Dam.

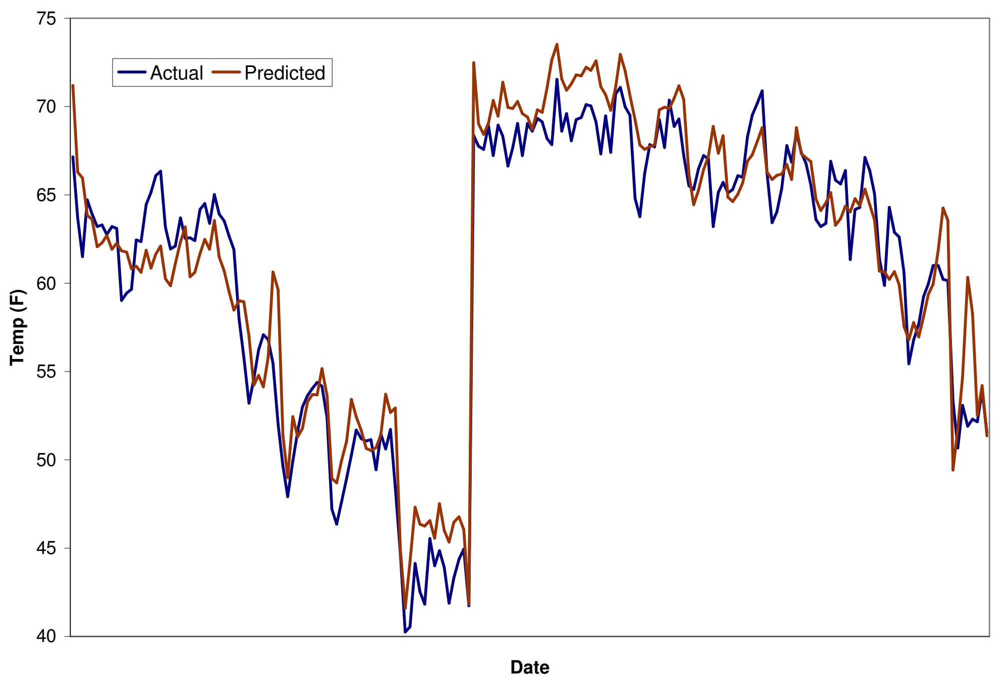

Figure 27. Actual compared to predicted maximum water temperature @ Bradfield Bridge based on a multiple regression equation using maximum air temperature at Bradfield Bridge, average air temperature at Bradfield Bridge, discharge (Q) from McPhee Reservoir, maximum temperature of water discharged from McPhee Reservoir, and angle of the sun . The model tends to over predict water temperatures at actual temperatures greater than 65 °F. Data collected at Bradfield Bridge in 2008 and 2009.

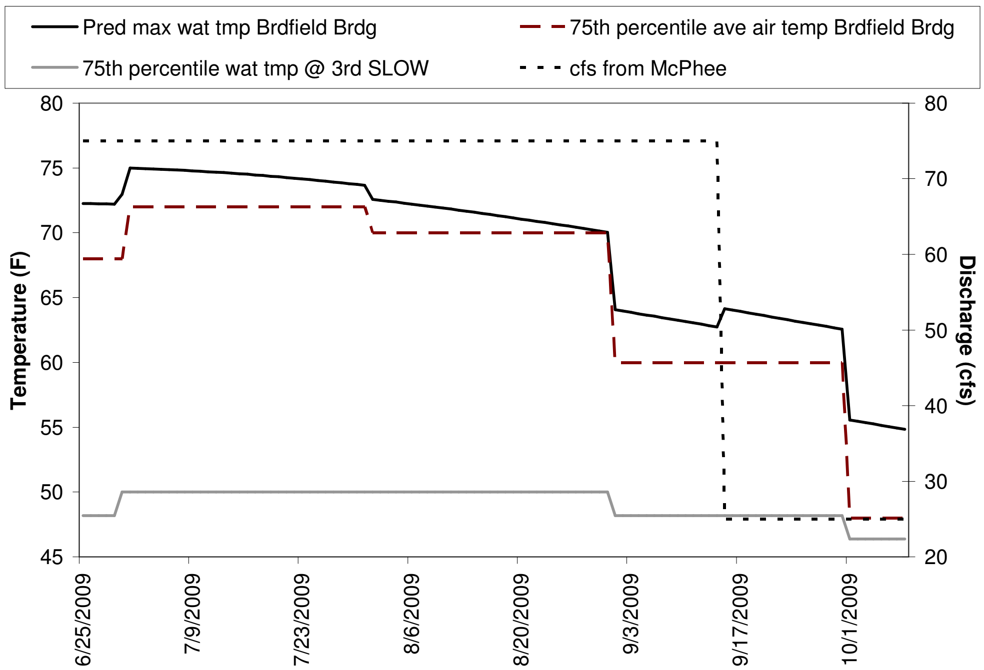

Figure 28. Predicted maximum water temperature at Bradfield Bridge given the 75th percentile of average air temperature at Bradfield Bridge, the 75th percentile of water temperature discharged from McPhee Dam from the 3rd SLOW, and 75 cfs, June to September 15th and 35 cfs after September 15th from McPhee Reservoir.

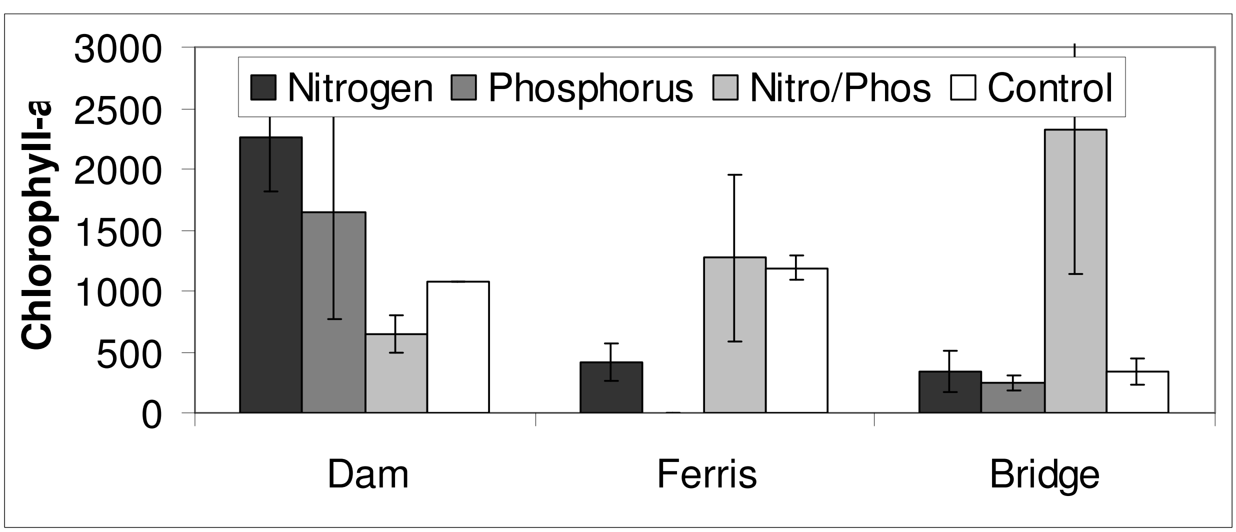

Figure 29. Algal bioassay data. Mean ± S.E. at 3 Dolores River sites: below McPhee Dam, at Ferris Creek Campground and at Bradfield Bridge. The addition of nitrogen and phosphorus to tiles at Bradfield Bridge resulted in significantly greater amounts of algal growth measured as concentration of chlorophyll-a. No significant differences at the upstream sites.