Effects of Flow, Reservoir Storage, and Water Temperatures on Trout in Lower Rush and Lee Vining Creeks, Mono County, California

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Executive Summary

We explored how flows and water temperatures influenced the variation in fish population parameters we estimated from 1999 through 2008 in lower Rush Creek (below Grant Reservoir) and lower Lee Vining Creek (below Highway 395). Flow data were provided by Los Angeles Department of Water Power (LADWP). Water temperature data were provided by McBain and Trush. Many of the flow and temperature variables were correlated with each other. For Rush Creek, storage levels in Grant Reservoir were also related to many of the flow and temperature variables. We used English units for measurements of flow (cubic feet per second; cfs) and temperature (degrees F) and metric units of measurement for fish length (millimeters; mm), fish weight (grams and kilograms; g and kg), and surface area (hectares; ha).

Body condition of brown trout 150 to 250 mm (about 6 to 10 inches) in lower Rush Creek was positively correlated with minimum annual flow and number of days that water temperatures were ideal for growth, and negatively correlated with mean summer flow (Table A). A positive correlation among two variables means that as the value of one variable goes up the value of the other variable also goes up, while a negative correlation means that as the value of one variable goes up the value of the second variable goes down. Total biomass of brown trout in Rush Creek was negatively correlated with minimum and maximum annual flows, and positively correlated with the number of days that water temperatures were ideal for growth and the interaction of minimum and maximum annual flows (Table A).

Densities of age-0 brown trout in lower Rush Creek were negatively correlated with minimum annual flows and the number of days flows were higher than 150 cfs, and positively correlated with the number of days that water temperatures were ideal for growth and by minimum summer storage in Grant Reservoir (Table A). Densities of age-1 and older brown trout were negatively correlated with minimum annual flows and positively with mean summer storage in Grant Reservoir. Densities of age-0 and age-1 and older brown trout in lower Rush Creek appeared to regulate growth of age-0 brown trout. The average length of age-0 brown trout increased from about 80 to over 100 mm as densities of age-0 brown trout declined lower than 6,000 trout per hectare, but average lengths remained relatively constant at about 80 mm when densities were above 6,000/ha. The average length of age-0 brown trout declined more linearly with increases in densities of age-1 and older brown trout. Other variables that were correlated with growth of age-0 brown trout were maximum annual flow (positively) and mean summer flow (negatively). Adding water temperature variables did not significantly improve flow-covariate models for explaining variation in average length of age-0 brown trout.

Based on these analyses for the range of conditions that were tested from 1999 through 2008, we concluded that brown trout populations in lower Rush Creek performed better when water temperatures were maintained in a range that was ideal for growth (52 to

Table A. Summary of significant simple Spearman rank correlations (Rho) and the regression coefficients for variables included in the “best” multiple regression model that explained variation in condition of brown trout 150 to 250 mm (K), estimated biomass of all brown trout (Biom), estimated density of age-1 and older brown trout (Dens1), estimated density of age-0 brown trout (Dens0), and average length of age-0 brown trout (AveL.0) in Rush Creek from 1999 to 2008. Only the coefficient signs (positive or negative) are shown for density of age-0 brown trout (Dens0) because a log-transformation of these densities were used in the regression analysis to normalize these data.

Fish	Simple Correlations		Multiple Regression	
variable	Variable	Rho	Variable	Coefficient
K	Days_Ideal_Temp	0.756	Days_Ideal_Temp	0.0011
	DaysGT70F	-0.769	MinAnnFlow	0.0025
	Avg_Max_Daily.Sum_Temp	-0.764	Mean6_9Flow	-0.0003
	Days.GT67F	-0.759		
	Avg_Sum_Temp	-0.546		
Biom	Dens1	0.724	Days_Ideal_Temp	1.072
	Dens0	0.693	MinAnnFlow	-3.936
	Days_Ideal_Temp	0.523	MaxAnnFlow	-0.492
	DaysGT70F	-0.488	Max*MinAnnFlow	0.010
Dens1	Biom	0.724	MinAnnFlow	-3.936
	MinAnnFlow	-0.500	GrantMin	0.026
Dens0	Biom	0.693	Days_Ideal_Temp	+
	June_Flow	-0.534	MinAnnFlow	-
	SumDays>150	-0.522	SumDays>150cfs	-
			GrantMin	+
Ave.L.0	Dens0	-0.669	Dens0	-0.001
	MaxAnnFlow	0.587		
	Days.GT67F	0.581		
	Sept_Flow	0.580		
	DaysGT70F	0.524		
	Dens1	-0.512		

67˚F; Elliott and Hurley 1999), peak flows were not too high (< 300 cfs), and the number of days that summer flows fell below 50 cfs was not too low (> 20 days). Since base summer flows during this study rarely fell below 40 cfs in lower Rush Creek; we could not assess effects of base summer flows below this flow. Minimum annual flow was positively correlated with body condition (higher minimum annual flows were associated with better body condition), but negatively with biomass and densities of both age-0 and age-1 and older brown trout. The effect of the magnitude of peak flow (maximum annual flow) was negative for biomass, but surprisingly appeared positively related to growth of age-0 brown trout. Grant Reservoir storage levels were highly correlated to many of the water temperature and flow variables, making it difficult to separate reservoir storage effects from effects that flow and temperature variables had on brown trout. Grant Reservoir storage levels were negatively correlated to water temperature (high storage provides cooler temperatures), especially during late summer.

In Lee Vining Creek the number of days summer flows exceeded 100 cfs explained about 80% of the variation in the relative abundance of age-0 brown trout (Table B). High summer flows are caused by high snow-melt flows that extend well into the summer months. The negative coefficient for the number of days summer flows exceeded 100 cfs indicated that a longer duration of high flows led to lower abundances of age-0 brown trout. Growth of age-0 brown trout in lower Lee Vining Creek was also negatively related to the number of days summer flows exceeded 100 cfs (Table B). Since we could not fully sample Lee Vining Creek in 2006 due to extremely high flows that made wading in the main channel of the stream too dangerous, we tested flow relationships with and without that sample year. Simple regressions that tested for associations between flow variables on both the relative abundance and size of age-0 brown trout indicated that higher flows were significantly associated with lower relative abundances and smaller sizes of age-0 brown trout (Table B). Similar, though slightly weaker, associations between flow variables and the relative abundances and sizes of age-0 rainbow trout in lower Lee Vining Creek were also found (Table B).

In Lee Vining Creek recruitment of age-0 brown and rainbow trout appear to control population abundances for both species. Recruitment of young trout in Lee Vining Creek appears to be stochastic (i.e. “boom or bust”) and is likely regulated by annual flow conditions. Regression and correlation results suggest that for maintaining robust trout populations in lower Lee Vining Creek high summer flows should not exceed 300 cfs and the number of days summer flows exceed 100 cfs should be limited to under 40 days to provide better conditions for age-0 brown and rainbow trout.

These analyses provide a basis for recommending a water management strategy for protecting trout populations in lower Rush and Lee Vining creeks. However, we recognize and support the adoption of a water management strategy that strives to maintain ecological processes in streams of the Mono Basin. Studies are currently being conducted to identify instream flow needs for trout and water temperature modeling will be a part of those studies. In addition, geomorphic scientists are analyzing flow data to determine flows needed to maintain channel form and riparian function. All of these studies will then be utilized to make flow recommendations in the synthesis report. These flow recommendations will balance the needs of trout along with a suite of ecological processes. The synthesis report will also evaluate the feasibility and reliability of LADWP delivering the recommended flows.

Table B. Summary of significant simple Spearman rank correlations (Rho) and regression coefficients for variables and r^2 values for significant ($P<0.05$) simple regression models that explained variation in relative abundance of age-0 brown (LL0_ha1) and rainbow trout (RB0_ha1) and average lengths of age-0 brown (LL0_L) and rainbow trout (RB0_L) in lower Lee Vining Creek from 1999 through 2008. Results for all years and without the year 2006 are shown because during 2006 not all habitats could be sampled.

	Simple Correlations			Simple Regression				
		Spearman Rho			Without 2006		All Years	
Fish variable	Variable	Without 2006	All Years	Variable	Coefficient	r^2	Coefficient	r^2
LL0_ha1	DaysGT100	-0.912	-0.924	DaysGT100	-7.535	0.795	-7.085	0.836
	LL0_L	0.867	0.891	MeanSumFlow	-4.909	0.842	-3.494	0.771
	MeanSumFlow	-0.800	-0.842	MeanAnnFlow	-10.900	0.703	-7.269	0.661
	MeanFalFlow	0.750	0.455					
	MeanAnnFlow	-0.733	-0.794					
	DaysLT40	0.717	0.782					
	MeanSprFlow	-0.617	-0.709					
	MaxAnnFlow	-0.483	-0.612					
LL0_L	DaysGT100	-0.971	-0.942	DaysGT100	-0.466	0.849	-0.353	0.697
	MeanSumFlow	-0.917	-0.903	MeanSumFlow	-0.303	0.894	-0.160	0.518
	LL0_ha1	0.867	0.891					
	DaysLT40	0.850	0.855					
	MeanAnnFlow	-0.833	-0.842					
	MeanSprFlow	-0.800	-0.818					
	MeanFalFlow	0.633	0.455					
	MaxAnnFlow	-0.633	-0.685					
	RB0_L	0.597	0.616					

	Simple Correlations			Simple Regression				
		Spearman Rho			Without 2006		All Years	
Fish variable	Variable	Without 2006	All Years	Variable	Coefficient	r^2	Coefficient	r^2
RB0_ha1	MaxAnnFlow	-0.862	-0.353	MaxAnnFlow	-1.349	0.554	N.S.	N.S.
	MeanSumFlow	-0.720	-0.249					
	DaysLT40	0.695	0.231					
	RB0_L	0.692	0.434					
	MeanWinFlow	0.686	0.772					
	MeanSprFlow	-0.611	-0.170					
RB0_L	DaysLT40	0.849	0.829	MeanSumFlow	-0.538	0.669	-0.273	0.614
	MaxAnnFlow	-0.798	-0.817					
	MeanSumFlow	-0.723	-0.726					
	MeanAnnFlow	-0.698	-0.695					
	RB0_ha1	0.692	0.434					
	LL0_L	0.597	0.616					
	DaysGT100	-0.587	-0.602					
	LL0_ha1	0.546	0.591					

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Introduction

Stream flows and water temperatures in Rush Creek below Grant Reservoir and Lee Vining Creek below Highway 395 are influenced by Los Angeles Department of Water Power's (LADWP) water management in the Mono Basin. In this report we evaluate relationships between stream flows, Grant Reservoir storage levels, water temperatures, and several trout population and growth metrics from 1999 through 2008 to investigate how flows, reservoir storage, and temperatures might be affecting trout condition and abundance. We used English units for measurements of flow (cubic feet per second; cfs) and temperature (degrees F; ˚F) and metric units of measurement for fish length (millimeters; mm), fish weight (grams and kilograms; g and kg), and surface area (hectares; ha). We followed this convention because all our fish monitoring data and reports used metric units (Hunter et al. 1999-2008), but English units for flow and temperature are more easily understood by most readers.

Brown Trout Habitat

In his comprehensive evaluation of habitat selection by resident brown trout populations native to streams in Norway and Scotland, Heggenes (2002) found that macrohabitats favored by juvenile and adult brown trout were deep and slow-flowing pool areas. More specifically, quoting Heggenes, "On a microscale, however, the niche selected was rather narrow (i.e., brown trout occupied holding positions in slow-flowing water, usually in association with the riverbed)". When defining "association with the riverbed", he reported that the holding positions of nearly all brown trout observed during snorkeling surveys were within 0-15 cm (cm = centimeters, or 0-6 inches) of the stream bottom, regardless of water column depth.

During our 2002 pool survey on Rush Creek, many larger pools with excellent depth and cover components were found to have mean water column velocities ranging from 1.0 to 1.5 fps (fps = feet per second; Hunter et al. 2004a). Heggenes found that brown trout essentially avoided areas with water velocities >1.5 fps. He further found that very few fish (only 3.9%) selected holding positions where water column velocities were greater than 30 cm/s (1.0 fps), even though habitats with water velocities >1.0 fps were abundant in the streams he studied. Finally, he observed that most brown trout (48.6%) selected holding positions where water velocities ranged from 0-10 cmps (cmps = centimeters per second, or about 0-0.3 fps). Strakosh et al. (2003) found similar results for adult brown trout in a small river of Connecticut, USA. They estimated brown trout selected total water depths of about 0.6 to 1.0 m (m = meters, or about 2 to 3.3 feet), positions 6 to 17 cm (2 to 6.7 in) off the bottom, and positions with nose velocities of 10 to 40 cmps (0.3 to 1.2 fps).

During the relocation of radio-tagged brown trout on Rush Creek from 2005-2008, nearly all of the fish were found in microhabitats with water column velocities <1.0 fps. In fact, 98% of these adult brown trout were relocated where these velocities were equal to or less than 0.7 fps. The holding positions of these fish were also associated with various types of cover, but the most consistent habitat variable that was required by these fish was low water velocity near the stream bottom. Furthermore, similar to what was found in the Heggenes (2002) study, most (52.2%) of the relocated brown trout on Rush Creek selected holding positions where water velocities ranged from 0-10 cmps (0-0.3 fps).

About 90% of the radio-tagged adult brown trout in Rush Creek were relocated where water depths were >1.0 feet, which is similar to the findings of previous research (Heggenes 2002; Strakosh et al. 2003). Almost all Rush Creek brown trout that were relocated in shallower (<1.0 feet) water were actively spawning (i.e. on or very near redds in riffle areas). Thus, water depths at nearly all (about 98%) of the sites occupied by relocated fish exceeded 1.0 feet when spawning season (Nov-Jan) relocations were omitted.

Heggenes (2002) also noted that the brown trout populations that he studied clearly exhibited "size structured habitat use"; i.e., there is a distinct pecking order wherein the largest fish occupy the most suitable habitats and progressively smaller fish are forced to occupy increasingly less suitable sites. Heggenes also stated, "…smaller fish more often held positions close to the bottom in slower, shallower water with less cover, typically along the stream banks." During nine years of electrofishing and snorkeling surveys on Rush Creek, similar hierarchical habitat use by brown trout has been noted, with juvenile fish primarily occupying the shallower areas of runs and pools, while the majority of fry were found in riffle habitats and along the margins of pools and runs.

Rainbow Trout Habitat

Unlike Rush Creek, rainbow trout have recently made up a significant component of the Lee Vining Creek trout population, comprising from 10% to 40% of the total standing crop estimates over the past ten years. However, no rainbow trout were reported being found by Carl Mesick Consultants (1994) in lower Lee Vining Creek in their 1986 to 1993 study. We suggest that stocking of rainbow trout by California Department of Fish and Game within the Lee Vining drainage, particularly in on-channel lakes and reservoirs, combined with habitat changes in lower Lee Vining Creek over the past 15 years has led to the increases in rainbow trout occurrence that we have documented.

Rainbow trout have slightly different habitat preferences than brown trout. Adams (1994) reported an average preferred focal point velocity of 0.6 ± 0.2 fps for 155-175 mm rainbow trout in the Little Weiser River in Idaho. No season was specified as to when these measurements were taken. Baltz and Moyle (1984) documented that rainbow trout ≥120 mm in three western Sierra streams preferred locations where the focal velocity was 0.5 ± 0.4 fps. During an instream flow study in the Pit River, Vondracek and Longanecker (1993) reported focal point velocities for rainbow trout ≥120 mm in length for three habitat types: pools of 0.9 fps ± 0.6 fps, runs of 0.9 fps ± 0.5 fps, and riffles of 1.1 fps ± 0.7 fps. They reported that the largest rainbow trout occurred in slow, deep areas of pools, where they moved slowly without orientation to flow and were not observed feeding, whereas small fish generally faced upstream and fed in all habitat types. The study also reported that rainbow trout apparently sought shelter in interstitial spaces in the substrate of runs and riffles during the day in early winter. Foraging forays were directed up in the water column at velocities similar to the mean water column velocities at holding positions. Rainbow trout were the most abundant species in 76% of the population survey stations. Other species that might have influenced microhabitat selection by rainbow trout were uncommon.

Muhlfeld et al. (2001a; 2001b) found that juvenile (36-125 mm) and adult (> 126 mm) redband trout (native inland rainbow trout) in tributaries of the upper Kootenai River drainage in Montana preferred deeper microhabitats (> 0.4 meters) with low to moderate velocities (< 50 cmps or 1.6 fps) adjacent to the thalweg. Conversely, age-0 (< 35mm) redband trout selected slower (< 10 cmps) and shallower (< 0.2 meter) sites located in lateral areas of the channel. Age-0, juvenile, and adult redband trout all strongly selected pools and avoided riffles; runs were used in approximately the same proportion as their availability by juveniles and adults, but more by age-0 redband trout. At the macrohabitat scale, a multiple regression model indicated that low-gradient, mid-elevation reaches with an abundance of complex pools are critical areas for the production of redband trout. Mean reach densities ranged from 0.01-0.10 fish/m^2.

Muhlfeld et al. (2001a) found that during the fall and winter period, 26 radioed adult redband trout occupied small home ranges, based on relocations made twice a week. These adults were found to spend the winter in deep main-channel pool habitats with extensive amounts of cover. As water temperatures dropped in November and December, the proportional use of primary pool habitat increased by 29%. Most documented movements of tagged redband trout into main-channel pools were made by those fish initially captured in runs, pocket water and lateral pools. Sedentary fish commonly remained in the main-channel pool where they were originally captured, tagged and released. Main-channel pools were relatively deep and contained extensive amounts of cover (mean cover = 60%; range: 30-100%). Large woody debris covered an average of 27% of the pool surface area (range 0-70%). Muhlfeld et al (2001a) suggested that maintaining deep pools with complex cover is critical for the conservation of native redband trout in the upper Kootenai River drainage.

Habitat preference criteria for brown and rainbow trout were also reported for eastern Sierra Nevada streams by Smith and Aceituno (1987). Their work involved snorkel observations of trout followed by velocity, depth and distance-to-cover measurements made at the focal points where trout were observed in an undisturbed state. Their results suggest that rainbow trout often occupy slightly faster velocities than brown trout; however, they were uncertain if rainbow preferred these higher velocity sites or if they were displaced to these higher-velocity areas by more dominant brown trout. In all of their study streams brown trout were, by far, the more abundant trout species.

Rainbow trout position themselves in lower velocity areas next to shear zones of faster moving water during the summer (Campbell and Neuner 1985). They reported, “Trout were observed immediately adjacent to fast moving water, but almost always at a station where the current velocity was reduced. Typical stations were in lee of boulders or submerged objects in flowing waters or along shear-lines in pool environments".

Flow and Temperature Effects

High spring snowmelt stream flows have been shown to reduce survival of emerging brown trout fry and were correlated to fall trout densities (Zorn and Nuhfer 2007). The reason for this relationship is due to the fact that the transition period when fry shift from yolk-sac dependence to independent foraging is critical and the availability of slow-flowing habitats along stream margins or in backwater areas during the first month of life is crucial (Armstrong and Nislow 2006). Nislow et al. (2004) found that low summer flows led to slower growth for age-0 Atlantic salmon due to a reduction in the availability of foraging habitats for this age-class.

Gonzalez et al. (2002) investigated brown trout recruitment in the Central Iberian Peninsula where they detected two strong linear relationships between young-of-year recruitment and the frequency and magnitude of flood events between spawning and emergence. These relationships suggest that when more frequent floods occur between spawning and emergence, recruitment is lower. This paper also cited several other studies that came to similar conclusions (Jensen and Johnson 1999; Spina 2001; Cattaneo et al. 2002). However, Cattaneo et al. (2002) concluded that hydrology only constrained trout dynamics during the critical emergence period, after which intra-cohort interactions regulated age-0+ densities in 30 French stream reaches.

Nuhfer et al. (1994) monitored brown trout populations in the South Branch of the Au Sable River in Michigan for 16 years and used linear regression to test empirical relationships between age-0 recruitment and stream flow and winter severity. Results indicated that variations in stream flow (higher discharges) during the 30-day period corresponding to brown trout emergence and initial foraging behavior was when flow significantly influenced recruitment. No other time period (including spawning and incubation period) showed statistical relationships between flow and age-0 recruitment. No relationship was found between age-0 recruitment and measures of winter severity.

Previous studies in Rush Creek indicated that production of age-0 brown trout was positively correlated to high flows the previous fall when spawning for that year-class occurred (Carl Mesick Consultants 1994). They also found that high stream flows recorded for the winter through early summer period in Rush Creek during 1986 (sustained flows of about 350 cfs for almost six months between February and July) did not adversely affect brown trout embryos incubating in the streambed gravels, emergence of fry, or early survival of fry, as estimates of age-0 fish later that year were high. Conversely, during periods of low flow, abundances of species with low velocity preferences (such as brown trout) may increase with lower flows as long as enough instream habitats are available (Jowett et al. 2005).

Winter flows may also be important, especially during winters when ice builds up in the stream channels (Maciolek and Needham 1951). Ice formations within stream channels during the winter may provide trout with cover (Maciolek and Needham 1951). However, ice jams may also block water flows from moving down some channels (Maciolek and Needham 1951). Carl Mesick Consultants (1994) reported that brown trout in Rush Creek experienced low survivals and growth rates during the winter of 1992-1993, which they attributed to high winter flows during that time period. They suggested that brown trout seek out low velocity water with cover during the winter to conserve energy and high winter flows reduce the amount of this type of habitat and force brown trout into higher velocity areas. They indicated that during the winter of 1992-1993 survival indices of brown trout in Rush Creek was highest in sites that provided the “most refuge from high velocity water”. They estimated that survival indices for age-3 brown trout were less than 3% during both the winters of 1991-1992 and 1992-1993, suggesting that winter conditions are very stressful. A conclusion supported by numerous other studies of trout in temperate climates (e.g. Biro et al. 2004; Johnsson and Bohlin 2006; Goodwin et al. 2008; however, for an alternative view see Lund et al. 2003).

Raleigh et al. (1986) reported that the optimum water temperature range for the survival and growth of brown trout is from 12 to 19˚C (approximately 54 to 66˚F). Elliott and his colleagues developed and refined a series of growth models for brown trout that use water temperature as an independent variable to predict growth (Elliott 1975a; Elliott 1975b; Elliott et al. 1995; Elliott and Hurley 1999; Elliott and Hurley 2000). These studies found that brown trout fed an unlimited diet of invertebrates grew (had a positive weight gain) only when water temperatures ranged from 3 to 19˚C (37 to 67˚F), and had their highest growth rate at 14˚C (57˚F). When fish (sticklebacks) made up part of the diet, larger brown trout (300 grams) experienced an increased growth rate, grew across a wider range of water temperatures (2 to > 20˚C;), and their maximum growth occurred at a higher temperature (~18˚C; Elliott and Hurley 2000). Ojanguren et al. (2001) found that the optimal temperature for growth of juvenile brown trout was 16.9˚C, the breadth of temperatures for 90% of maximum growth potential was between 13.8 and 19.6˚C, and the breadth of temperatures for positive growth was 1.2 to 24.7˚C. Wehrly et al. (2007) found that brook and brown trout had similar thermal tolerance limits. They reported high mean and maximum water temperatures tolerated by both species depended upon exposure times and declined rapidly from 25.3 to 22.5˚C and from 27.6 to 24.6˚C, respectively, for exposure times of 1 to 14 days. They reported a 7-day upper tolerance of 23.3˚C (74˚F) for mean and 25.4˚C (77.7˚F) for maximum temperatures.

Evaluating flow and temperature conditions is commonly done for trout populations that occupy rivers immediately below large dams, especially for fluctuating power-peaking flows, but is less commonly done for smaller streams under more stable flow releases (i.e. Robertson et al. 2004; Krause et al. 2005; Scruton et al. 2005; Flodmark et al. 2006). Arnekliev et al. (2006) evaluated temporal and spatial variation in growth of juvenile Atlantic salmon and found that between-year variation was higher than within year spatial variation. They found that a large part of the annual variation in growth was explained by variation in mean daily flows and spring temperatures.

Rainbow trout spawn during the spring, thus their embryos remain within the gravel through much of the high water period and they often emerge as peak flows begin declining. Extremely high stream flows can mobilize the streambed, crushing incubating embryos. Rapidly varying flows soon after emergence can either strand or flush newly emerged fry because they are relatively poor swimmers and have difficulty maintaining positions along the channel margins. Kondolf et al. (1991) documented spawning gravel distribution and bed mobility in seven high-gradient stream reaches in the eastern Sierras over two seasons, 1986 (a wet year) and 1987 (a dry year). During the wet year, all tracer rocks placed in spawning gravel pockets were swept away, and substantial scour, fill, and channel changes were noted throughout their study streams. The authors theorized that periodic mobility of gravels may explain why brown trout are more abundant than rainbow trout in many eastern Sierra streams where high flows occur in May and June due to snowmelt. Brown trout are fall spawners, and their fry emerge before high snowmelt flows; whereas rainbow trout are spring spawners whose eggs (or alevins) are in the gravel, and thus, more vulnerable to scour during snowmelt flows. Interestingly, these authors noted that most of their study streams looked more like typical rainbow trout streams, yet brown trout have been much more successful in these systems (Kondolf et al. 1991).

Study Objectives

Our objectives are to evaluate how flow and water temperatures influence:

- Densities of age-1 and older brown trout in Rush Creek,
- Densities of age-0 brown trout in Rush Creek,
- Average length of age-0 brown trout in Rush Creek,
- Total (all ages) standing crops of brown trout in Rush Creek,
- Condition of 150 to 250 mm brown trout in Rush Creek,
- Densities of age-0 brown trout and rainbow trout in Lee Vining Creek,
- Average length of age-0 brown trout and rainbow trout in Lee Vining Creek.

Study Area

Sample Sites

Fish data that we collected at our standard fish monitoring sample sites (Hunter et al.2000, 2001, 2002, 2004a, 2004b, 2005, 2006, 2007, 2008) were used for evaluating effects of flows and water temperatures on fish in Rush and Lee Vining creeks (Figure 1). LADWP monitored daily flows at several locations throughout the Mono Basin (Figure 1). Flow monitoring data for the LADWP Grant Reservoir Release to Mono Lake (Station GLRML, included Station 5007 plus spill flows from Grant Reservoir minus exports) site was used for upper Rush Creek. Summed flows for Station GLRML plus Parker Creek below the LADWP conduit (Station 5003) and Walker Creek below the LADWP conduit (Station 5002) were used to compute flows in Rush Creek below the mouth of Walker Creek at the Narrows. There were a few flows reported by LADWP as negative and these flows were converted to positive flows. We verified questionable flows with hydrographers from LADWP and followed their recommendations to correct these questionable values.

Flows

Summer flows in Rush Creek were summarized for the period June 1 through September 30 for the years 1999 through 2008. The highest summer flows for the years 1999 through 2008 occurred during 2006, the next highest in 2005, and the lowest during 2007 (Figure 2). The lowest daily flows recorded during the summer period for the years 1999 through 2008 occurred during 2008 when “test flows” were released to meet the needs of the instream flow field study. For Lee Vining Creek we used the flows below the LADWP conduit (Station 5009; Figure 3). Flow patterns for these years followed a similar trend as in Rush Creek.

Grant Reservoir Storage

Data for elevations (feet MSL) and storage (acre-feet) of Grant Reservoir were also obtained from LADWP. Daily Grant Reservoir storage data from May through September were summarized to evaluate reservoir filling during the spring snowmelt period and reservoir drawdown during the mid- to late-summer period (Figure 4). During the period 1999 through 2008 Grant Reservoir was highest during 2006 after the two high flow years of 2005 and 2006, but has subsequently dropped rapidly and in 2008 was at its lowest level in recent history.

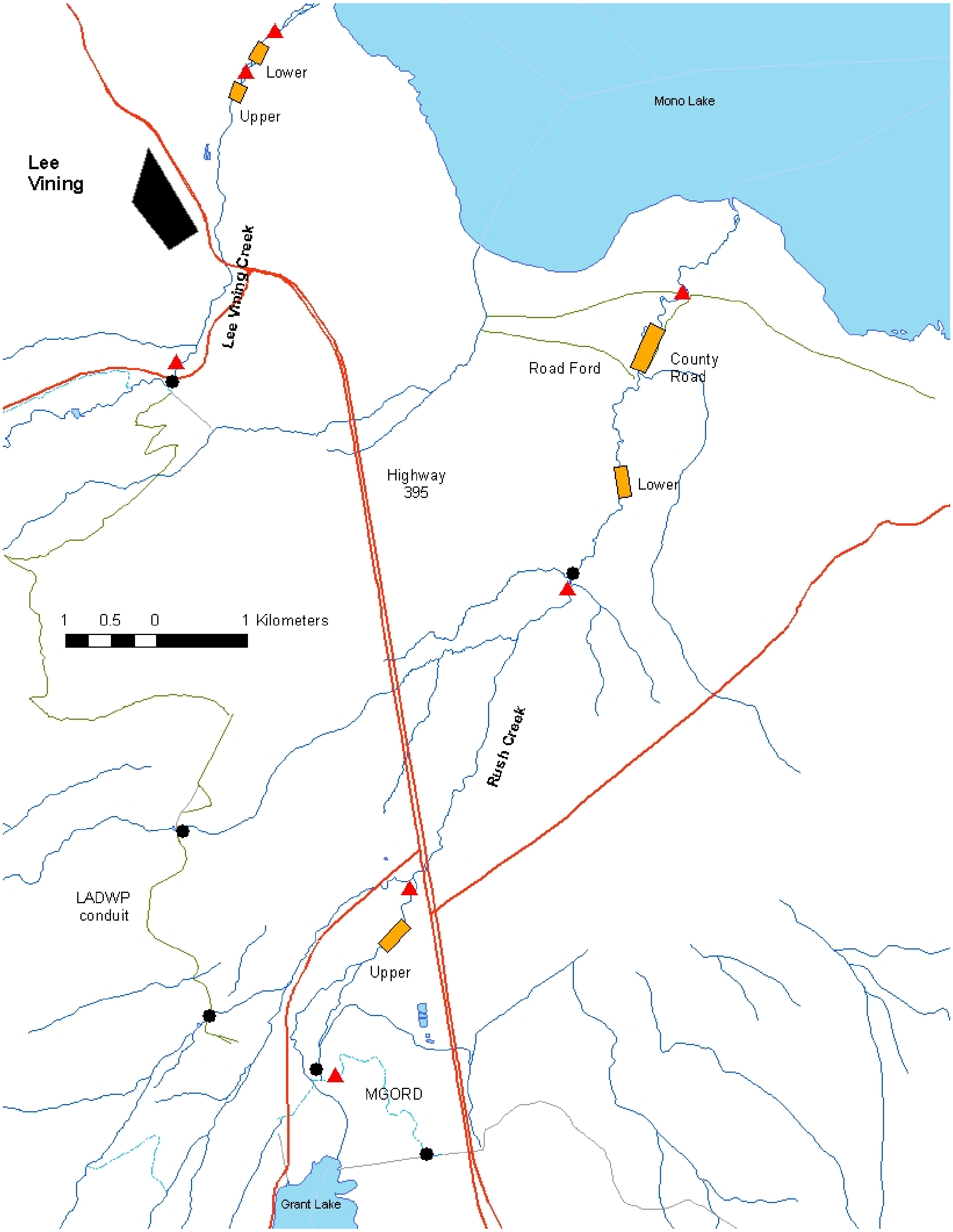
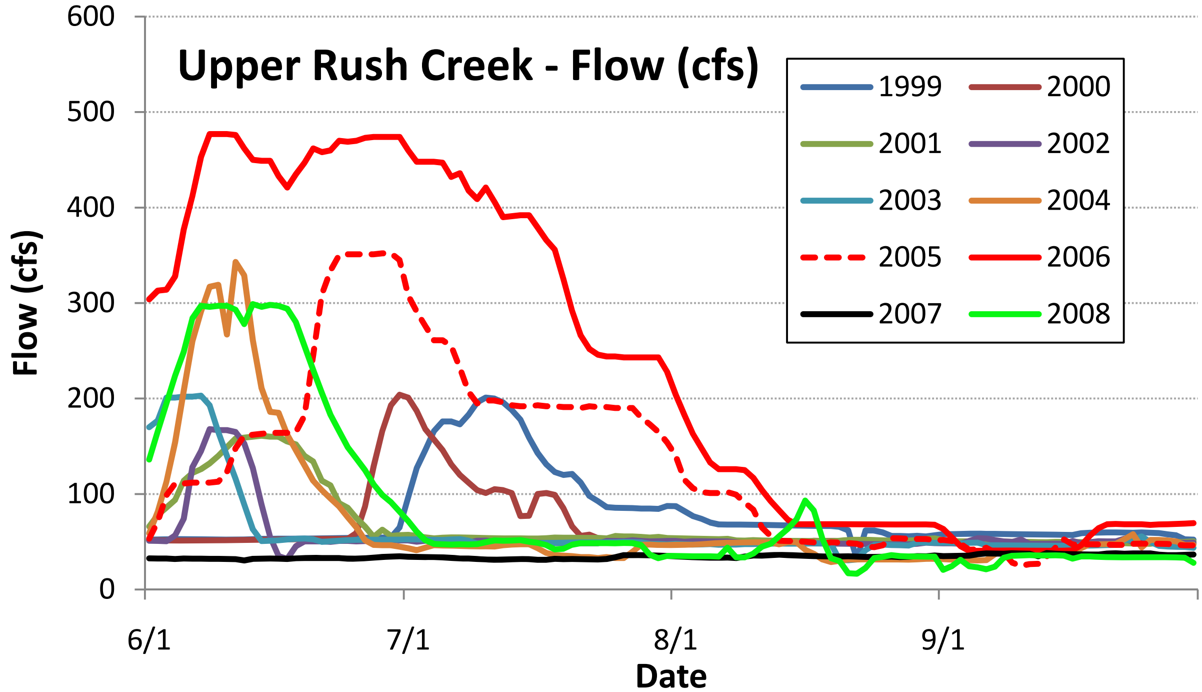


Figure 1. Study area map showing fish monitoring sections (gold rectangles with section names adjacent), flow monitoring sites (black filled circles), and water temperature sites (red triangles).



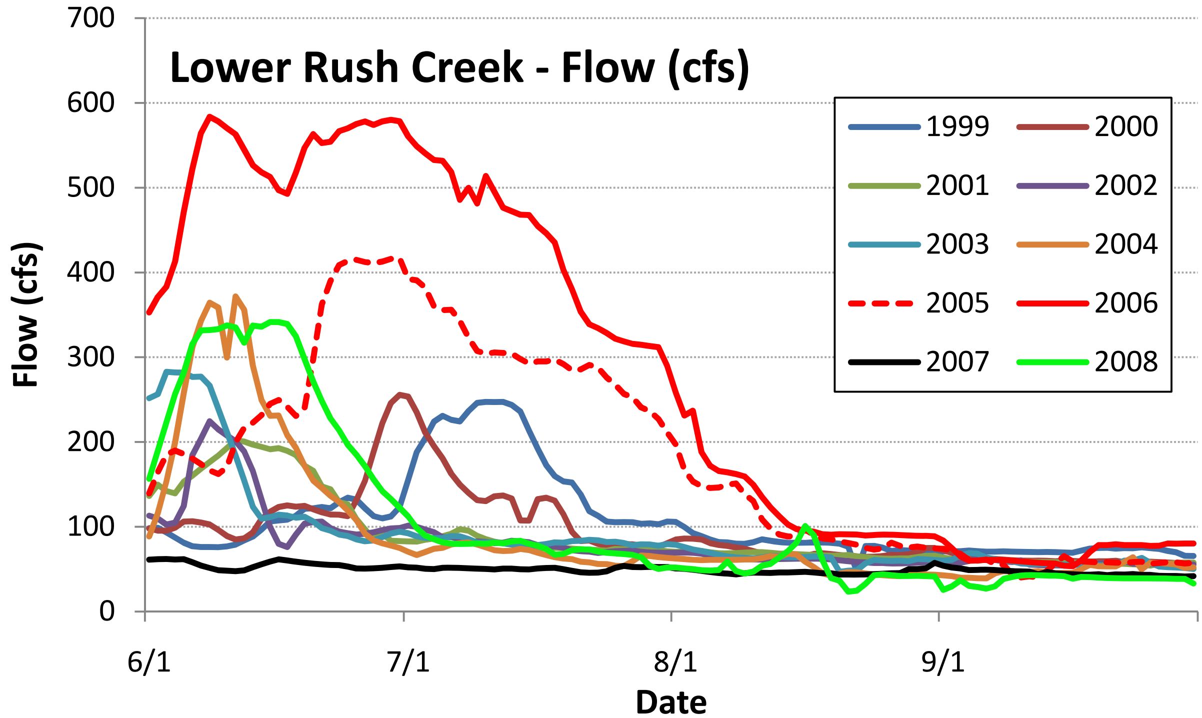


Figure 2. Flows (cubic feet per second, cfs) in Upper and Lower Rush Creek during the summer (June 1 through September 30) for the years 1999 through 2008. Flow data provide by LADWP. Upper flows are flows down the Mono Gate Return Ditch plus flows spilled over Grant Reservoir dam. Lower flows are Upper flows plus flows in Parker and Walker creeks measured below the LADWP water conduit.

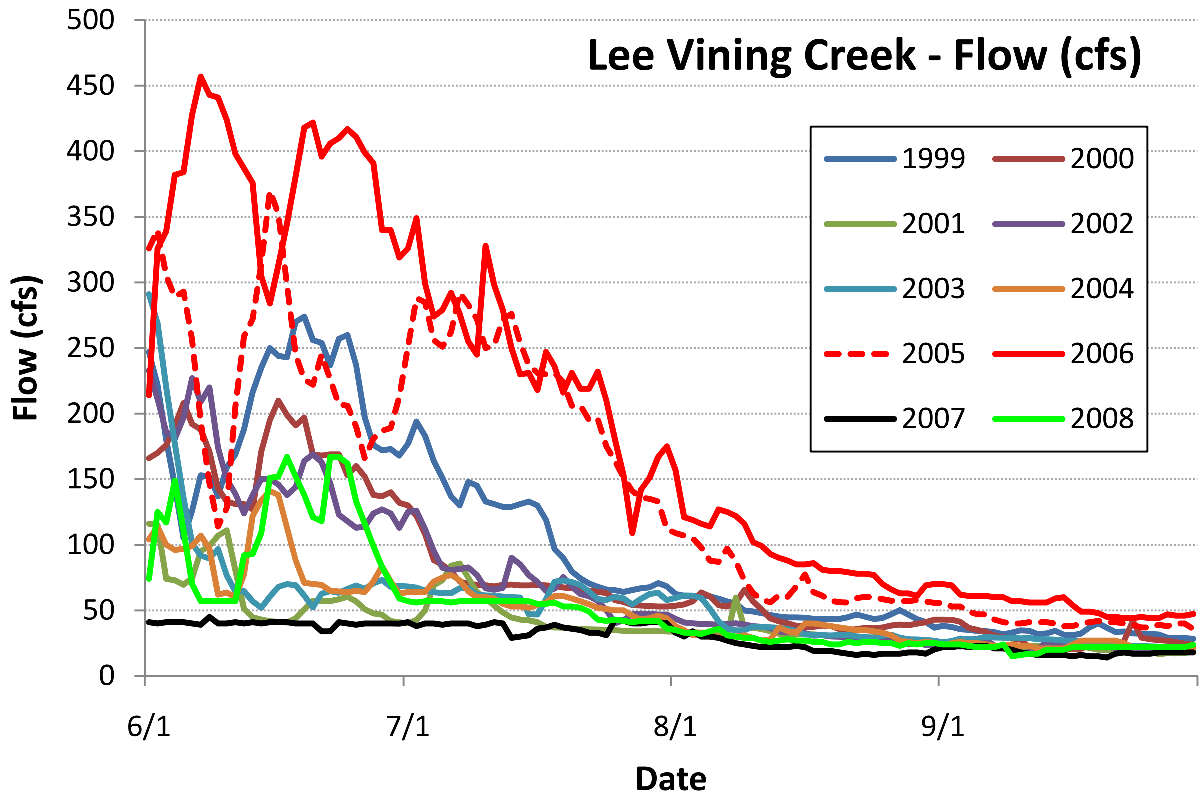


Figure 3. Flows (cubic feet per second, cfs) in Lee Vining Creek during the summer (June 1 through September 30) for the years 1999 through 2008. Flow data provide by LADWP

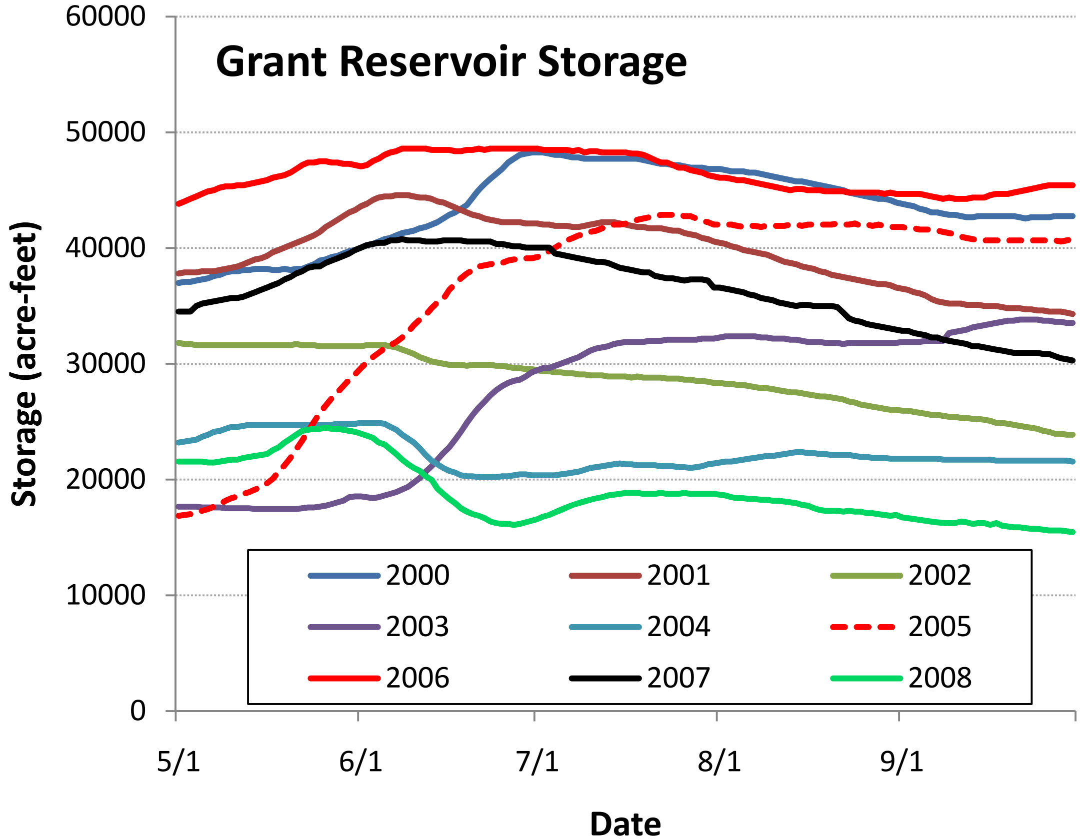


Figure 4. Storage (acre-feet) in Grant Reservoir from May 1 to September 30 for the years 1999 through 2008. Data provided by LADWP.

Climate

Climate data were summarized from stations at Lee Vining and Mono Lake (Western Regional Climate Center; http://www.wrcc.dri.edu). Data from the weather stations at Lee Vining and Mono Lake were combined to compute long-term averages because the Lee Vining station replaced the Mono weather station in 1988. Mean and maximum monthly air temperatures at the Lee Vining weather station were averaged by year for the years 1999 through 2008 (Figure 5). For the period of record (1951 to 2008) the overall summer monthly average was 63.5˚F and overall summer monthly maximum was 79.8˚F. It is apparent that the period 1999 through 2008 was warmer than average. The years 1999 and 2005 had near average summer air temperatures, but all other years during this time period had warmer than average air temperatures.

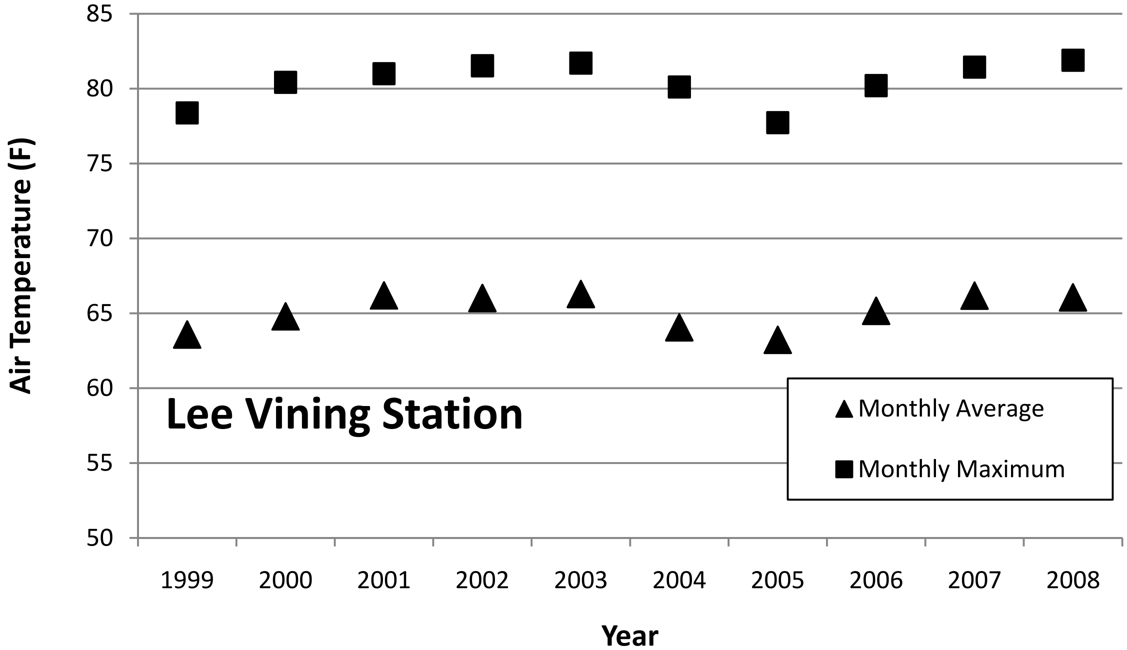


Figure 5. Mean average monthly and maximum monthly air temperatures for the summers (June through September) of 1999 through 2008 recorded at Lee Vining, California (data obtained from NOAA; Western Regional Climate Center; http://www.wrcc.dri.ed).

Water Temperature

McBain and Trush deployed recording thermographs at several locations in Rush and Lee Vining creeks (Figure 1). Mean daily summer temperatures in upper Rush Creek frequently exceeded 65˚F (Figure 6), while mean daily temperatures in lower Rush Creek did not (Figure 7). Temperatures in Lee Vining Creek were much lower than in Rush Creek (Figures 8 and 9).

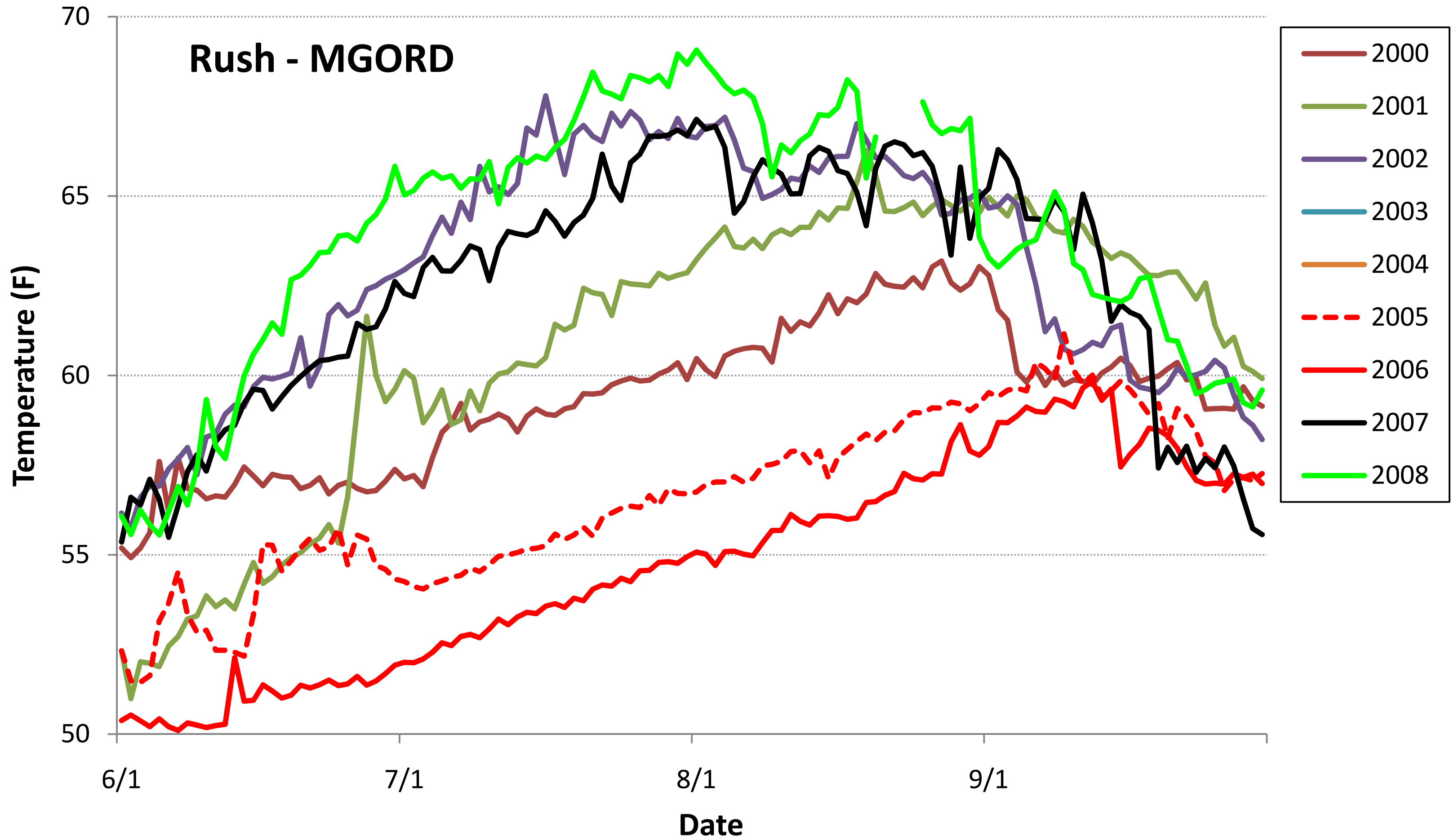


Figure 6. Mean daily water temperatures in Rush Creek at the bottom of the Mono Gate Return Ditch (MGORD) during the summer (June 1 through September 30) by year from 2000 through 2008.

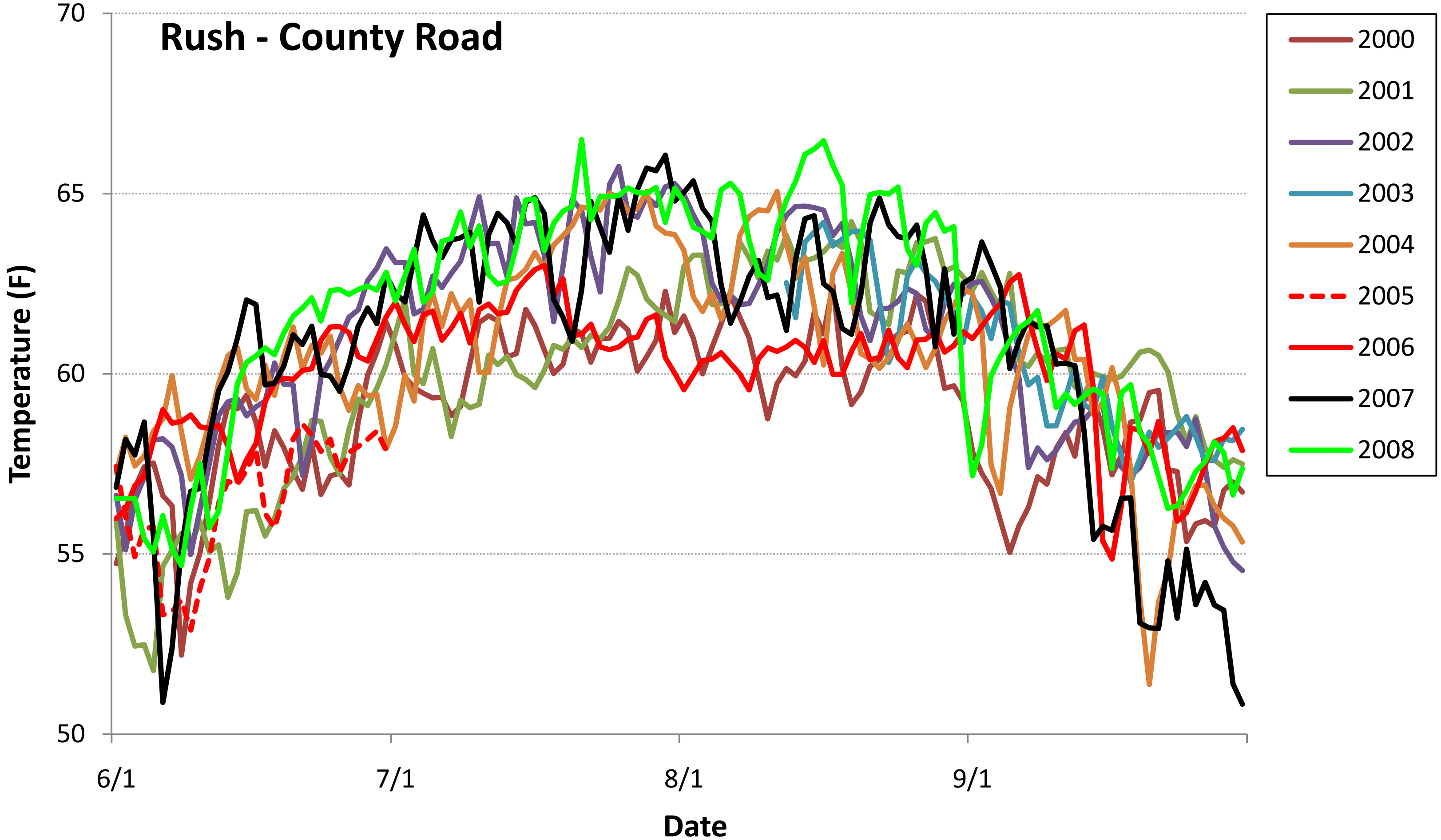
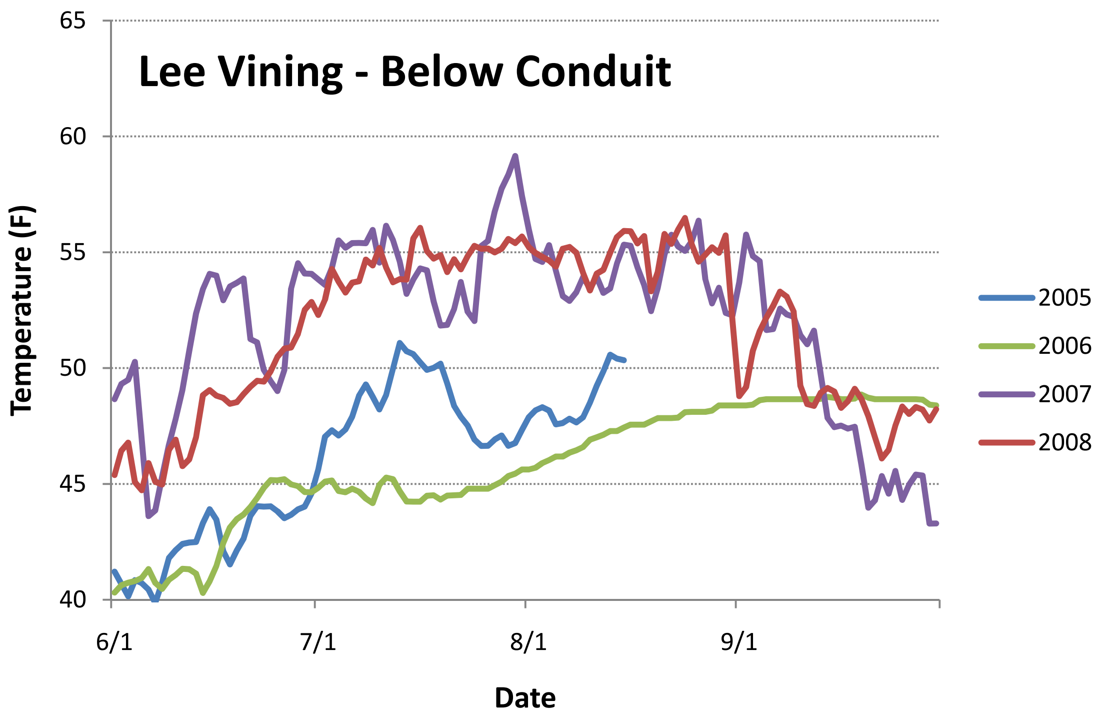


Figure 7. Mean daily water temperatures in Rush Creek at the County Road crossing during the summer (June 1 through September 30) by year from 2000 through 2008.



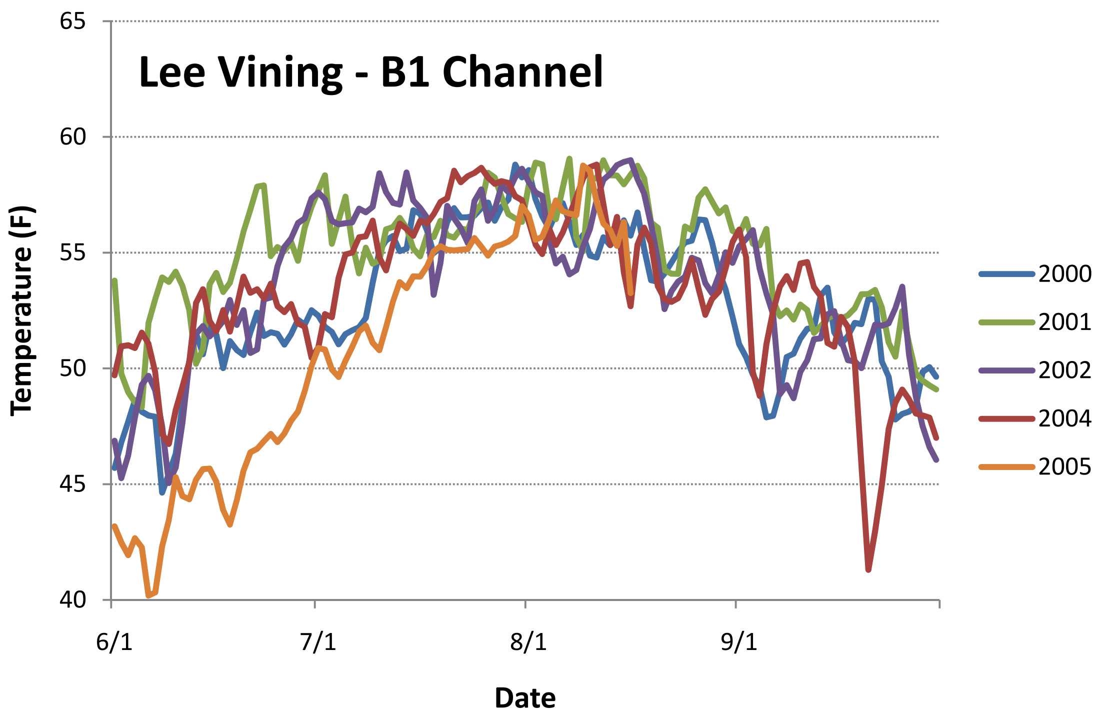


Figure 8. Mean daily water temperatures in Lee Vining Creek immediately below the LADWP conduit (top graph) and at the B1 Side Channel (lower graph) for the summer (June 1 through September 30) by year.

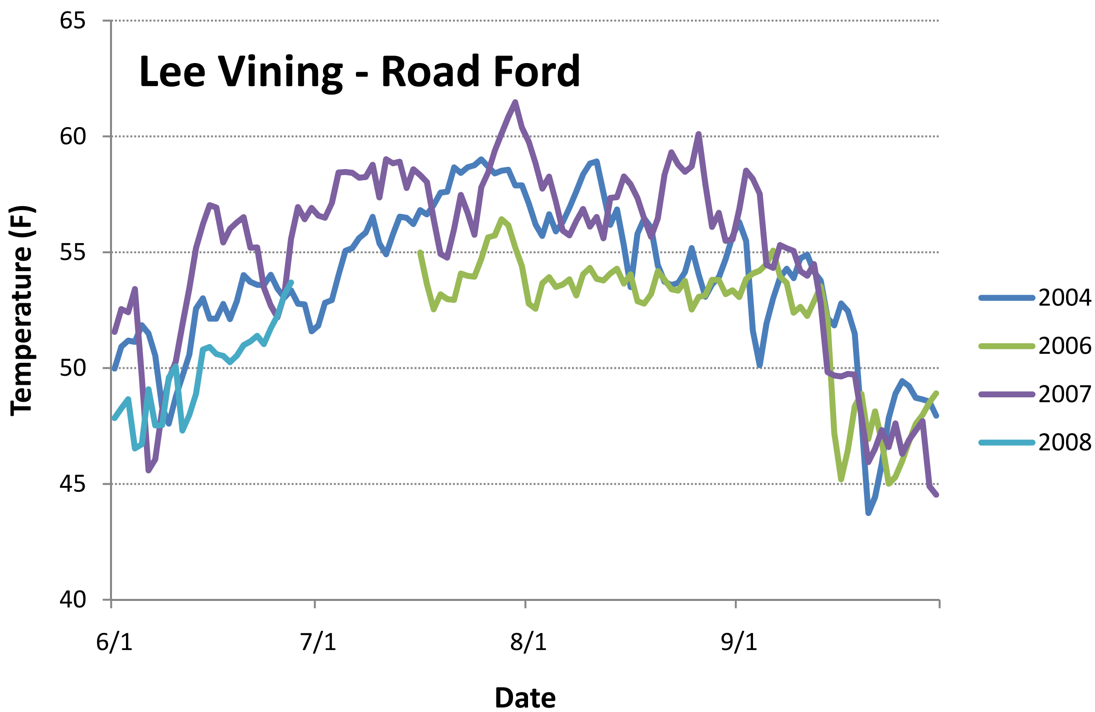
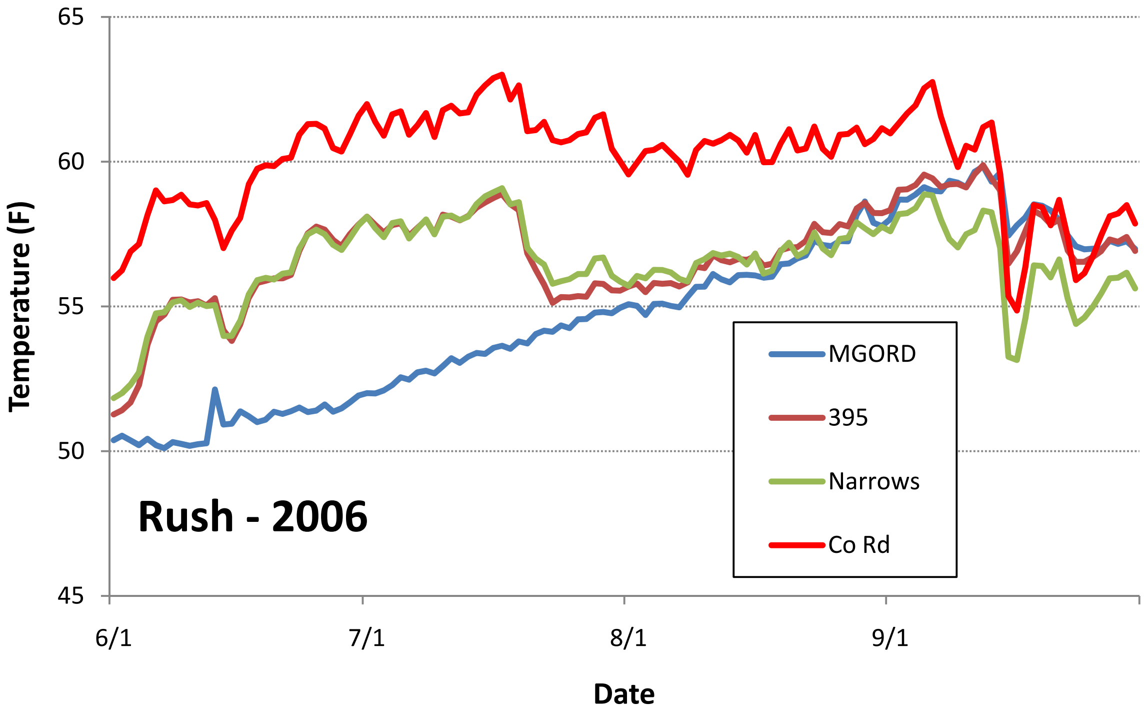


Figure 9. Mean daily water temperatures in Lee Vining Creek at the road ford for the summer (June 1 through September 30) by year.

Longitudinal differences in mean daily temperatures within Rush Creek were more pronounced during a high water year (2006) than during a low water year (2007; Figure 10). However, average daily temperatures were lower during the high water year than during the low water year. Ranges between daily maximum and minimum water temperatures (diurnal fluctuations) were much wider in a low water year (2007) than during a high water year (2006) at the upper MGORD site (Figure 11), but not as different between the high and low water years at the lower County Road site, especially later in the summer (Figure 12). Daily variations in water temperatures were relatively high at the County Road site later in the summer, frequently exceeding 20 F, but early summer high flows during 2006 reduced these daily fluctuations to 10˚F or less. Temperature data suggests that the critical time period when high temperatures will likely impact fish is from late July to September. During low flow years this critical period may begin as early as early July.



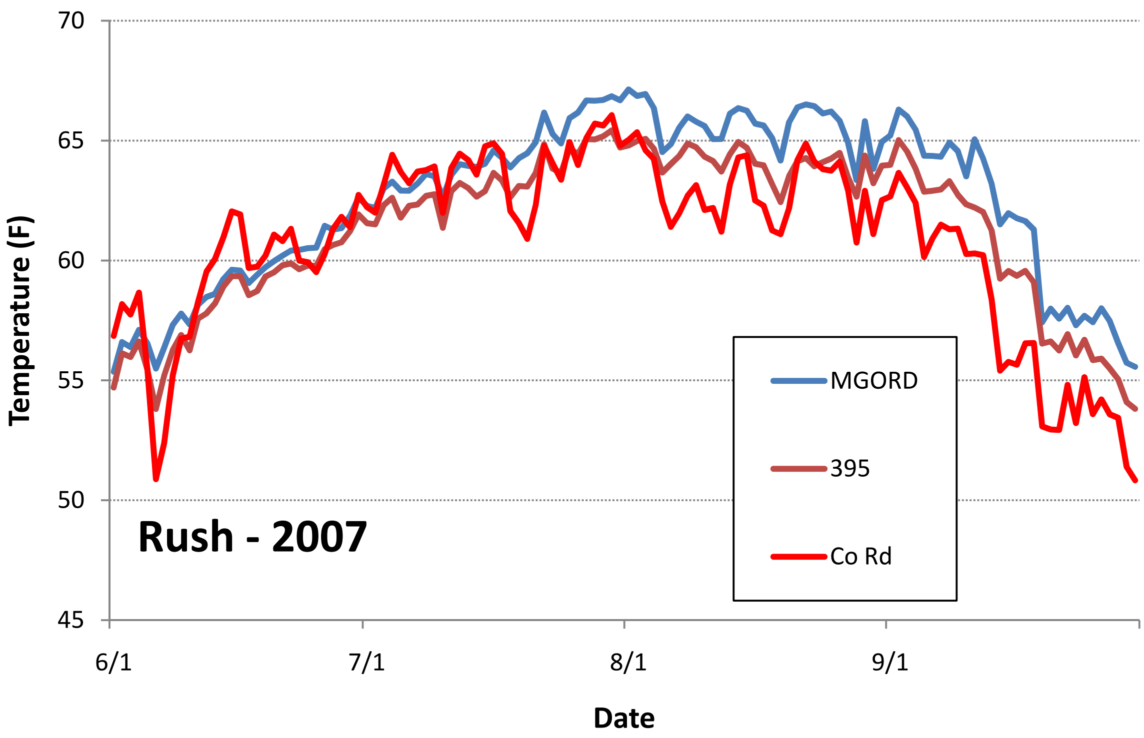


Figure 10. Average daily water temperatures during the summer in several locations in lower Rush Creek during a high water year (2006) and low water year (2007).

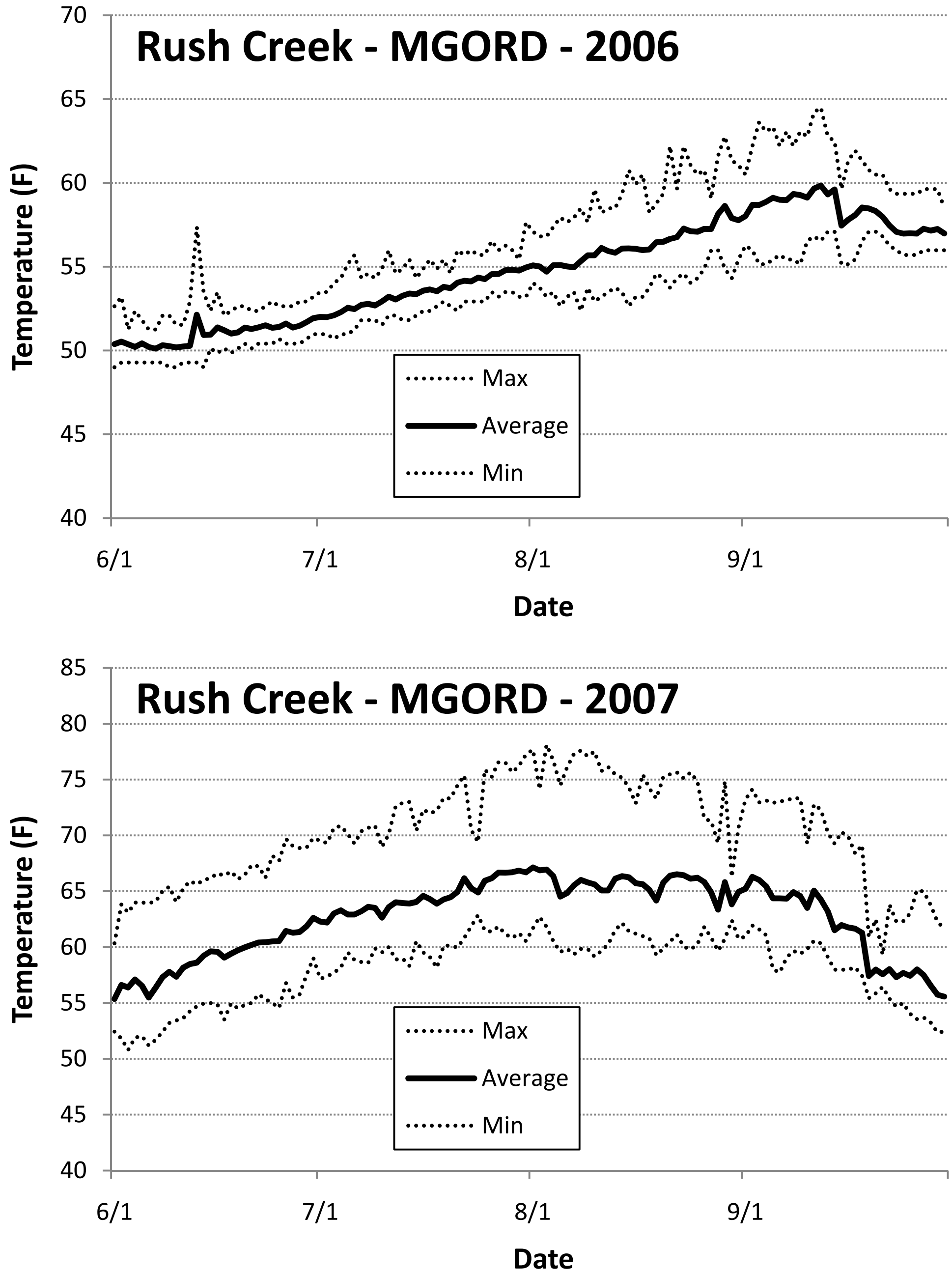


Figure 11. Maximum, average, and minimum daily water temperatures during the summer at the bottom of the Mono Gate Return Ditch (MGORD) at the head of lower Rush Creek during a high water year (2006) and low water year (2007).

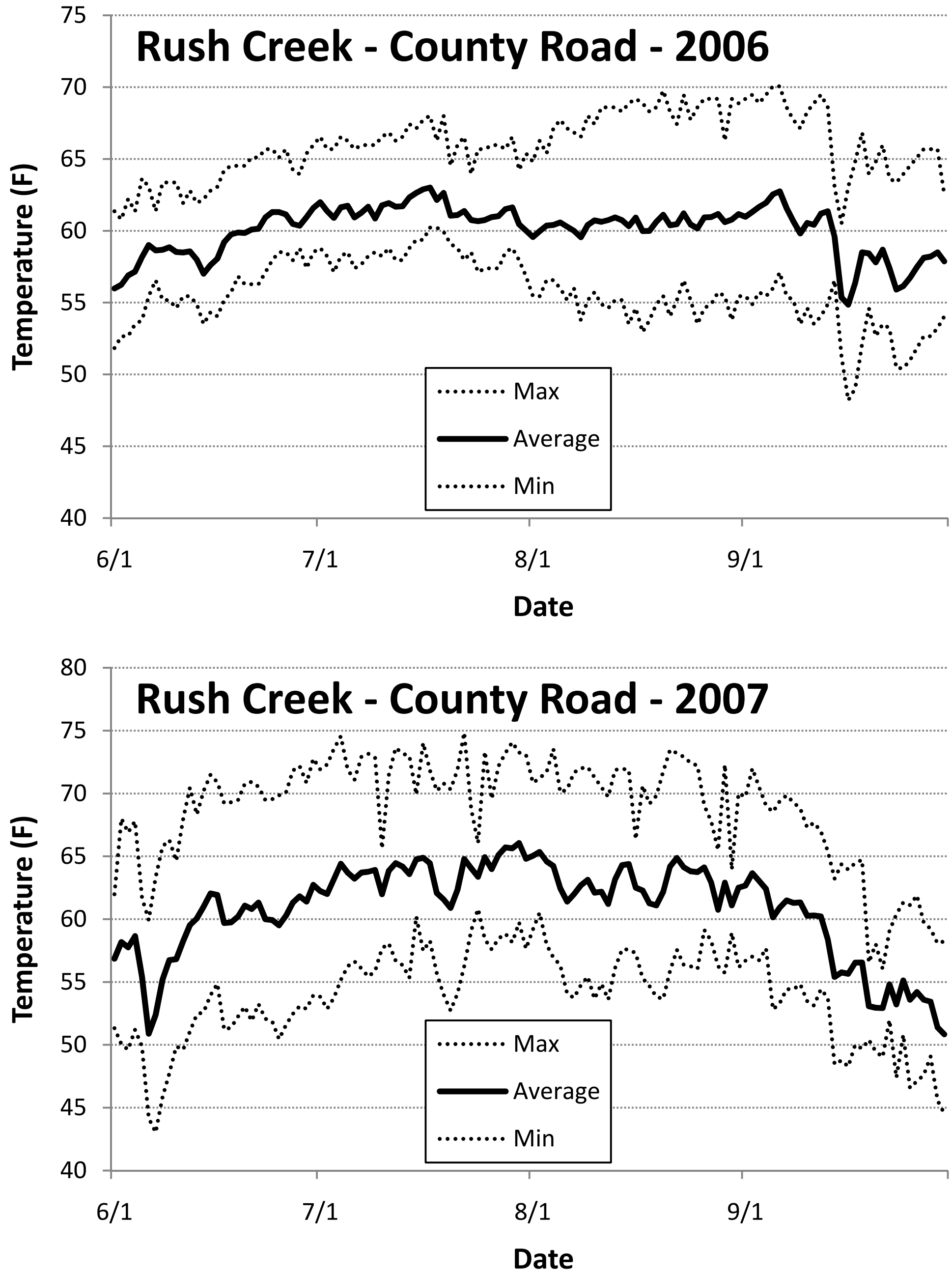


Figure 12. Maximum, average, and minimum daily water temperatures during the summer at the County Road crossing of lower Rush Creek just above Mono Lake during a high water year (2006) and low water year (2007).

Methods

Separate analyses were conducted for Rush Creek and Lee Vining Creek because measured water temperatures appeared to be high enough to affect trout in Rush Creek, but not in Lee Vining Creek. We also had much more reliable estimates of fish densities for both age-1 and older and age-0 trout in Rush Creek, than in Lee Vining Creek. We first present methodology for Rush Creek and then describe similarities and differences in our analyses for Lee Vining Creek.

Rush Creek

The following variables were initially tested to evaluate associations among water temperature, stream flow, and trout condition and abundance in Rush Creek:

- Fish variables
    - Biomass (standing crop; kg/ha) of all (age-0 and older) brown trout
    - Density (number/ha) of age-0 brown trout
    - Density (number/ha) of age-1and older brown trout
    - Fulton condition factor (K) of brown trout 150 to 250 mm
    - Average length of age-0 brown trout (< 125 mm)
- Flow variables
    - Average, minimum, and maximum annual flow (cfs)
    - Average, minimum, and maximum summer (June through September) flow
    - Number of days per year summer flows were below 50 cfs
    - Number of days per year summer flows were above 150 cfs
    - Mean June, July, August, and September flow
- Grant Reservoir variables
    - Mean summer (May through September) storage (acre-feet)
    - Minimum summer storage
    - Maximum summer storage
- Temperature variables
    - Average, minimum, and maximum annual temperature (F)
    - Average, minimum, and maximum summer (June through September) temperature
    - Number of days per year maximum temperatures were > 70 F
    - Number of days per year maximum temperatures were > 67˚F
    - Number of days temperatures were in range ideal for growth (52 to 67˚F – 11.1 to 19.4˚C; Elliott and Hurley 1999; Figure 13)

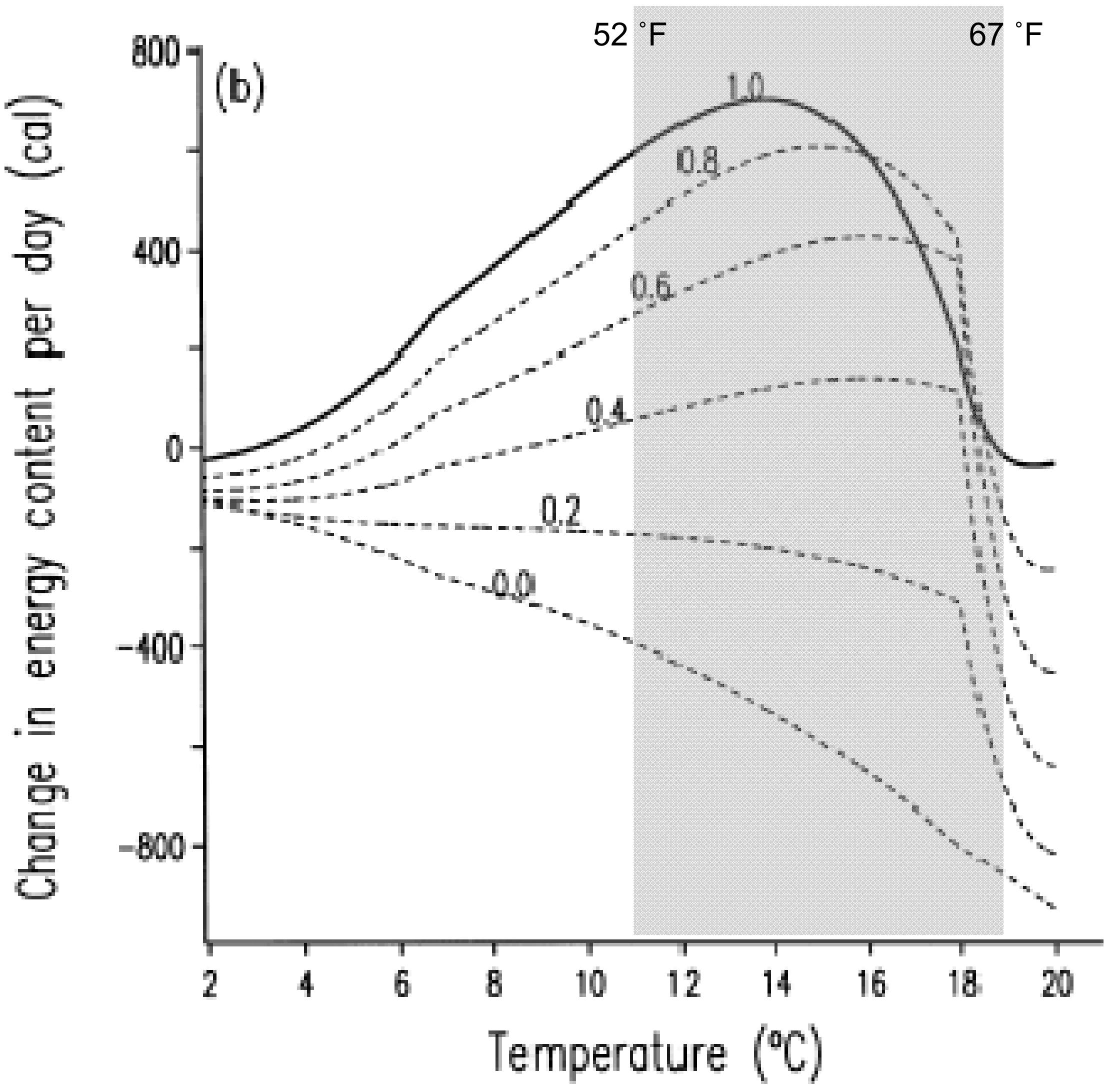


Figure 13. Relationship between water temperature (C) and growth (expressed in change in energy content per day in calories) with numbers showing proportion of full ration provided to fish (graph from Elliott and Hurley 1999). The shaded portion of the graph is the temperature range used as "ideal temperature" for growth based on several studies (Raleigh et al. 1986; Elliott 1975a; Elliott 1975b; Elliott et al. 1995; Elliott and Hurley 1999; Elliott and Hurley 2000; Ojanguren et al. 2001) and the upper and lower bounds of this temperature range are shown in degrees Fahrenheit at the top of the shaded box.

Data from flow and water temperature monitoring sites that best represented conditions at fish monitoring sites were used (Table 1). McBain and Trush provided water temperature data based on recording thermographs that generally recorded water temperatures every hour; however, these data were not available for all years or all months within some years (Table 2; Appendix A). Flow data were provided by LADWP and were available for all days from 1998 through September of 2008.

Table 1. Data sites used for fish, flow, and water temperature analyses.

Fish site	Flow site	Water temperature site
MGORD	Bottom of MGORD	Bottom of MGORD
Upper Rush	Rush below MGORD	Old 395 or MGORD when data were not available for Old 395 site (2000 through 2002)
Lower Rush	Rush below Narrows	Narrows, or County Road when Narrows data unavailable (2002)
County Road	Rush below Narrows	County Road

During fish sampling we estimated fish population numbers using mark-recapture and depletion estimators (Hunter et al. 2000, 2001, 2002, 2004a, 2004b, 2005, 2006, 2007, and 2008). Lengths of all captured fish were measured (TL; nearest mm) and nearly all captured fish were also weighed (grams to nearest g). Because slopes of $\log_{10}$(length) to $\log_{10}$(weight) regressions were near 3.0 for brown trout during all years (Hunter et al. 2000, 2001, 2002, 2004a, 2004b, 2005, 2006, 2007, 2008), we assumed isometric growth for brown trout 150 to 250 mm, and computed Fulton-type condition factors as these were easier to compare among years than regression metrics (Pope and Kruse 2007). We computed the condition factor for each individual brown trout for which both length and weight had been recorded using the equation

$$K = \frac{100{,}000 * W}{L^3}$$

where K is condition, W is weight (g), and L is length (mm; Anderson and Gutreuter 1983).

Condition factors for individual brown trout $\geq$150 mm and <250 mm were averaged by sample section and year. We averaged lengths for all brown trout <125 mm as an index of age-0 growth. Our data suggests brown trout <125 mm were almost always age-0. For the few years when a few age-1 brown trout might be less than 125 mm a slight bias was introduced.

Table 2. Numbers of days per month water temperature data were available for each site in Rush Creek. Shaded columns represent summer months.

		Month											
Stream	Year	1	2	3	4	5	6	7	8	9	10	11	12
Rush Creek - 395	2005						30	31	31	30	31	30	31
Rush Creek - 395	2006	31	28	31	30	31	30	31	31	30	31	30	31
Rush Creek – 395	2007	31	28	31	30	31	30	31	31	30	31	30	31
Rush Creek - 395	2008	31	29	31	30	31	30	31	31	30	21		
Rush Creek - At Narrows	1999										22	30	31
Rush Creek - At Narrows	2000	31	29	31	30	31	30	31	31	30	31	30	31
Rush Creek - At Narrows	2001	31	28	31	30	31	30	31	31	30	31	30	31
Rush Creek - At Narrows	2002	31	28	31	5					15	31	30	31
Rush Creek - At Narrows	2003	31	28	31	30	31	19				31	30	31
Rush Creek - At Narrows	2004	31	29	31	30	31	30	31	31	30	19		
Rush Creek - At Narrows	2005											10	31
Rush Creek - At Narrows	2006	31	28	31	30	31	30	31	31	30	18		
Rush Creek – County Rd	1999										22	30	31
Rush Creek – County Rd	2000	31	29	31	30	31	30	31	31	30	31	30	31
Rush Creek – County Rd	2001	31	28	31	30	31	30	31	31	30	31	30	31
Rush Creek – County Rd	2002	31	28	31	12	31	30	31	31	30	31	30	31
Rush Creek – County Rd	2003	31	28	21					20	30	31	30	31
Rush Creek – County Rd	2004	31	29	31	30	31	30	31	31	30	31	30	31
Rush Creek – County Rd	2005	31	28	31	30	31	30						
Rush Creek – County Rd	2006					1	30	31	31	30	31	30	31
Rush Creek – County Rd	2007	31	28	31	30	31	30	31	31	30	31	30	31
Rush Creek – County Rd	2008	31	29	31	30	31	30	31	31	30	22		
Rush Creek - MGORD	1999										22	30	31
Rush Creek - MGORD	2000	31	29	31	30	31	30	31	31	30	31	30	31
Rush Creek - MGORD	2001	31	28	31	30	31	30	31	31	30	31	30	31
Rush Creek - MGORD	2002	31	28	31	12	31	30	31	31	30	31	30	31
Rush Creek - MGORD	2003	31	28	20							31	30	31
Rush Creek - MGORD	2004	31	29	31	30	6							31
Rush Creek - MGORD	2005	31	28	31	30	31	30	31	31	30	31	30	31
Rush Creek - MGORD	2006	31	28	31	30	31	30	31	31	30	31	30	31
Rush Creek - MGORD	2007	31	28	31	30	31	30	31	31	30	31	30	31
Rush Creek - MGORD	2008	31	29	31	30	31	30	31	27	30	19		

Table 3. Parameters estimated and included in analyses of flow and temperature effects on brown trout in Rush Creek. All "summer" estimates were for the period June through September, except Grant Reservoir storage parameters where the period May through September was used.

Parameter estimated	Units	Abbreviation
All Models		
Fulton-type condition factor (K)	None	K
Biomass of all brown trout (age-0 and older)	kg/ha	Biom
Density of age-0 brown trout	#/ha	Dens0
Density of age-1 and older brown trout	#/ha	Dens1
Minimum annual flow	cfs	MinAnnFlow
Maximum annual flow	cfs	MaxAnnFlow
Mean summer flow	cfs	Mean6_9Flow
Days summer flows < 50 cfs	days	SumDays.50
Days summer flows >150 cfs	days	SumDays.150
Mean flow in June	cfs	June_Flow
Mean flow in July	cfs	July_Flow
Mean flow in August	cfs	Aug_Flow
Mean flow in September	cfs	Sept_Flow
Grant mean summer storage	acre-ft	GrantMean
Grant maximum summer storage	acre-ft	GrantMax
Grant minimum summer storage	acre-ft	GrantMin
Average summer water temperature	F	Avg_Sum_Temp
Average maximum daily summer water temperature	F	Avg_Max_Daily.Sum_Temp
Days water temperature > 70 F	days	DaysGT70F
Days water temperature > 67 F	days	Days.GT67F
Days water temperature 52 to 67 F	days	Days_Ideal_Temp
Age-0 Density Models Only		
Average length of fish < 125 mm	mm	AvgL.0

The MGORD fish sample site was removed from analysis because there were not enough brown trout in the 150-250 mm size class to obtain reliable estimates of condition and this section was not sampled annually. We eliminated annual water temperature variables because there were many years for which data for all days of the year were unavailable (Table 2; Appendix A1). Conversely, summer temperature data were available for most years, so we used these data to test for potential effects of temperature on fish metrics (Tables 2 and 3; Appendix A2). Water temperatures measured at the MGORD site may have been slightly different than water temperatures in Rush Creek immediately below Grant Reservoir when water was spilled from Grant Reservoir through the dam. Annual data for each variable listed above was summarized for each fish-monitoring site (Table 1 and Appendix B).

To meet our primary objective of evaluating how flows, water temperatures, and Grant Reservoir storage were associated with trout populations in lower Rush and Lee Vining creeks we chose linear regression modeling. Linear regression modeling is relatively straightforward and regression model results are relatively easy to interpret. Flow, temperature, and reservoir storage were entered into regression models as independent variables (covariates). Estimates of condition factors of brown trout 150 to 250 mm, total brown trout biomass, density of age-0 brown trout, and density of age-1+ brown trout were entered into models as dependent (response) variables in separate runs for each independent variable (covariate) or groups of independent variables.

Since regression analysis assumes that dependent variables are normally distributed, frequency distributions of all potential dependent variables were plotted to determine whether data were normally distributed, or deviated significantly from normality (Appendix C). Due to the relatively low sample sizes (10 years or less) statistical tests to evaluate whether these data distributions were normally distributed could not be reliably done. Plots of frequency distributions indicated condition factor (K) and density of age-1 and older brown trout appeared normally distributed (Appendix C). Estimated biomass and density of age-0 brown trout deviated from normality and while a natural-log transformation appeared to normalize the age-0 density data, it did not normalize the biomass data. Data for covariates were also plotted over time to observe how they changed through time and in bivariate plots to see how they might be associated with each other (Appendix D). While many of the flow and temperature variables also appeared to deviate from normality (Appendix C), an assumption of normality for covariates in regression analyses is not required. Instead, the residuals should be normally distributed for valid inference using regression analyses. We plotted normal probabilities for residuals for all regression models.

We expected that many of the flow, temperature, and Grant Reservoir storage variables would be correlated with each other (i.e. as values for one variable go up values for another variable go either up or down in a relatively predictable fashion). However, when selecting independent variables to use in a linear regression model an important assumption is that each independent variable included within the model has minimal correlation with other independent variables in the model. A general goal of regression model building is to find independent variables that explain as much of the variation in the dependent variable as possible, while minimizing correlation among the independent variables used in the model. All potential flow, temperature and reservoir storage variables were screened using the following process to select the best variables to use in regression analyses.

1. Pair-wise Spearman rank correlations were computed between each flow, temperature, and Grant Reservoir storage variable and each of the fish variables to find those physical variables that had the highest correlations with each fish variable. Rank correlation analysis was used because several of the variables were not normally distributed.
2. Pair-wise Spearman rank correlations were computed among all of the flow, temperature, and Grant Reservoir storage variables to find out which variables were least correlated with each other.
3. Principal components analysis (PCA) was used to further assess how flow, temperature, and reservoir storage variables were associated with each other. PCA constructs "components" that are made up of all tested variables (in this case all flow, storage, and temperature variables). Each component is constructed to maximize the amount of variation in the data explained by individual components, while minimizing the correlation among the components. PCA was also used to determine which individual variable explained most of the variation in each constructed component using the full flow, temperature, and reservoir storage dataset.
4. Based on the above three steps, a candidate set, or sets, of independent flow, temperature, and reservoir storage variables were selected to use in regression models.

The candidate sets of flow, temperature, and reservoir storage variables selected for further analysis could be different for different dependent fish variables. These differences were primarily related to the strength of correlations between the independent variables and the fish variable. After selecting these candidate sets of independent variables, actual regression model building started. Regression models were constructed for each fish variable using the following process.

1. "Best subsets" regression analysis was used to further screen the flow, temperature, and reservoir storage variables. Mallow's C_p was the metric used to evaluate "best" candidate models (Netter et al. 1996). Lower values of Mallow's C_p indicate better models for predicting the dependent variable based on model fit criteria with a penalty for the number of independent variables used. Models that have Mallow's C_p values within about 3 units of each other are usually considered as reasonably similar to each other, so all models that were within three Mallow's C_p units of the model with the lowest Mallow's C_p were considered during initial screening.
2. Linear regression models were run for all candidate set combinations of selected flow, temperature, and reservoir storage variables.
3. The best linear regression model was selected based on the highest adjusted-R^2 value combined with significant independent variable regression coefficients.

4. After finding a regression model that explained the highest proportion of variation in each fish variable, models that included all possible interactions among those independent variables were evaluated to determine if interactions were significant.

Since temperature variables were not available for all years, best subsets regression was first done for all observations using just flow variables (n=28 observations) to evaluate flow effects. We then included observations for which temperature data were also available (n=20 observations) to test for effects of both temperature and flow. Since density of age-0 brown trout was unavailable for one year in the County Road section, this variable was excluded as an independent variable for testing other fish metrics (condition factor, biomass, and density of age-1+). However, for tests of age-0 densities as the response variable that year's estimate for County Road was excluded from the analyses. Models that excluded fish variables as covariates (independent variables) were compared to models that included them. Occam's razor, related to the principle of parsimony, was applied so that models were reduced to as few independent variables as possible. Various potential models were compared using analysis of variance to test for the best models.

None of the independent variables used in these regression analyses were transformed, but we observed whether errors were normally distributed by plotting the residuals on a normal probability plot (regression diagnostic plots are provided in Appendix F). Non-normality in independent variables is not a problem in regression analyses as long as the residual errors are normally distributed (Netter et al. 1996). We examined these final models and recommended a "best" final model based on our opinion that included biological, as well as statistical, significance.

The program R (R Development Core Team 2008) was used for all data plotting and statistical analyses. We used the least squares linear regression ("lm", R Development Core Team 2008) and best subset regression ("leaps", Lumley 2004), packages to develop and test regression models.

Lee Vining Creek

Only the influence of flows on abundance and growth of age-0 trout was evaluated in Lee Vining Creek. Water temperatures in Lee Vining Creek consistently ranged from 45 to 60˚F during the summer months (Figure 7), never rising high enough to limit growth or survival. Thus, temperature was not evaluated.

Age-0 trout metrics were used as response variables because our observations during the past ten years indicated that age-0 trout responded more dramatically to changes in flows than other age classes. Estimates of relative abundance of age-0 trout by species were computed for the Lower fish population estimate section. Analyses were only done for the Lower Section because this section will continue to be monitored in the future and the side channel associated with the Upper Section had little or no flow in it during the last several years this section was monitored (2005 through 2007). Catch per effort information was used to derive indices of relative abundance because reliable population estimates could not be made consistently in Lee Vining Creek. Catch per effort indices for age-0 trout were computed by 1) summing all trout < 125 mm by species captured in the first electrofishing pass in both the side channel and main channel, 2) summing the total area sampled (length times average width; m^2) in both the main and side channels, 3) dividing total numbers of captured age-0 trout by the total area sampled, and then 4) multiplying that estimated number per square meter by 10,000 to standardize estimates to number of age-0 trout per hectare. The effort in this case is a single electrofishing pass through the entire sample section. We believe analyses for brown trout better represent flow effects on trout populations in lower Lee Vining Creek than using rainbow trout because of the contribution that hatchery rainbow trout make to the rainbow trout population. However, we present results for both species.

Relationships between catch per effort indices that used catches of the first pass versus catches of all passes (total catch) were evaluated to determine if trends were consistent using both methods (Figure 14). These relationships were relatively consistent for both brown and rainbow trout, so catch of the first pass was used. We felt that using the catch during the first pass represented a more consistent effort (a single electrofishing pass) than catches of all passes as the number of electrofishing passes was variable, especially in the side channel (LL0_ha1 and RB0_ha1; Table 4). In 2006 the main channel was not sampled because high flows that year made sampling too dangerous. This year was included and excluded to investigate effects that sampling only the side channel during this year might have had on flow relationships and our conclusions.

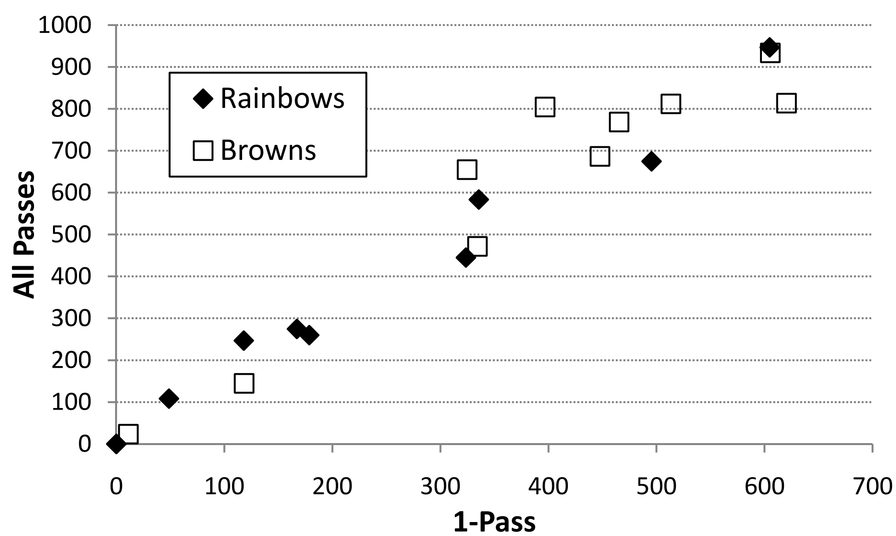


Figure 14. Relationship between catch per hectare of age-0 rainbow trout (solid diamonds) and brown trout (open squares) in one electrofishing pass versus all electrofishing passes in the Lower Lee Creek sample section from 1999 through 2008.

The distribution of the relative abundance of age-0 rainbow trout did not appear to be normal, but log-transformation did not help to normalize these data (Appendix B). Consequently, we used the untransformed data in regression analyses for age-0 rainbow trout. In contrast, the distribution of the relative abundance of age-0 brown trout appeared normally distributed so regression analyses using these data better meet the assumptions inherent in regression analyses. Because rainbow trout populations appear reliant on stocking of hatchery rainbow trout in the system and the apparent lack of normality in the distribution of estimates of relative abundance of age-0 rainbow trout and apparent normal distribution for brown trout age-0 relative abundance, we have emphasized the use of age-0 brown trout abundance for evaluating the effects of flow in Lee Vining Creek.

Minimum, mean, and maximum annual, mean summer (June through September), mean spring (May and June), mean winter (December through April), and mean fall (October and November) flows were compared to age-0 trout metrics (Table 4). The number of days summer flows exceeded 100 cfs and were less than 40 cfs were also computed along with the difference of mean winter flows from mean fall flows. Winter and fall flows the year prior to the estimates were used.

Table 4. Parameters estimated and included in analyses of flow and temperature effects on age-0 brown and rainbow trout in Lee Vining Creek. All “summer” estimates were for the period June through September and spring period was May and June.

Parameter estimated	**Units**	**Abbreviation**
Catch/ha of age-0 rainbows all passes	#/ha	RB0_haAll
Catch/ha of age-0 browns all passes	#/ha	LL0_haAll
Catch/ha of age-0 rainbows pass 1	#/ha	RB0_ha1
Catch/ha of age-0 browns pass 1	#/ha	LL0_ha1
Average length of rainbows <125 mm	mm	RB0_L
Average length of browns <125 mm	mm	LL0_L
Minimum annual flow	cfs	MinAnnFlow
Mean annual flow	cfs	MeanAnnFlow
Maximum annual flow	cfs	MaxAnnFlow
Mean summer flow	cfs	MeanSumFlow
Mean spring flow	cfs	MeanSprFlow
Days summer flows < 40 cfs	days	DaysLT40
Days summer flows >100 cfs	days	DaysGT100
Mean winter flow	cfs	MeanWinFlow
Mean fall flow	cfs	MeanFalFlow
Mean fall minus mean winter flow	cfs	Fall.Win

Results

Rush Creek

Condition factors of brown trout 150 to 250 mm ranged from 0.89 to 1.12 and averaged 1.00 (Appendix E). The number of fish used to compute condition factors for each year ranged from 73 to 573 and standard errors ranged from 0.0001 to 0.0011 (average SE = 0.0004). Condition factors for 150-250 mm brown trout were highest in Upper Rush sample section from 1999 through 2003 and in 2007 and 2008 (Figure 15). Condition factors for brown trout in the County Road sample section were generally lower than the other two sections, except for 2005.

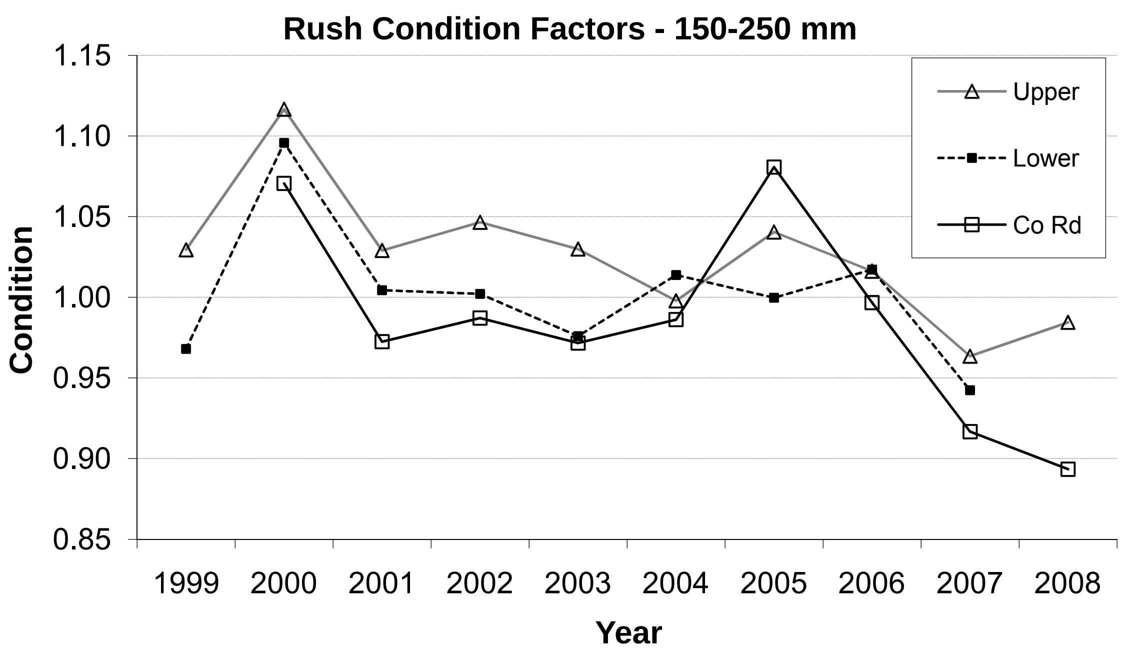


Figure 15. Condition factors of brown trout 150 to 250 mm (95% confidence intervals are narrower than the symbols) in four sections of Rush Creek by year.

Estimates of biomass among the different sections tracked similarly through time; however, after 2006 estimated biomass in the Lower Rush site declined faster than the other sections, probably related to physical changes in this site due to a higher proportion of the stream's flow shifting to the 10-channel and out of the channel where estimates were made. Estimated total biomass (kg/ha) of brown trout (all brown trout including age-0) was also highest in the Upper Rush Creek section during all years (Figure 16). Densities (#/ha) of age-0 brown trout were highest (except for 2003) and most variable in the Upper Rush Creek section (Figure 17, top).

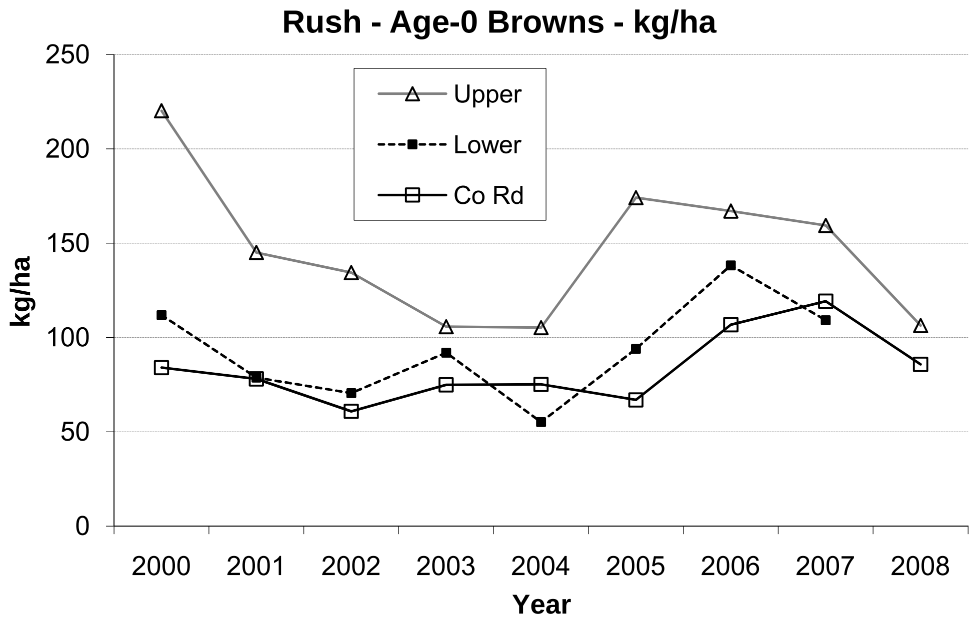


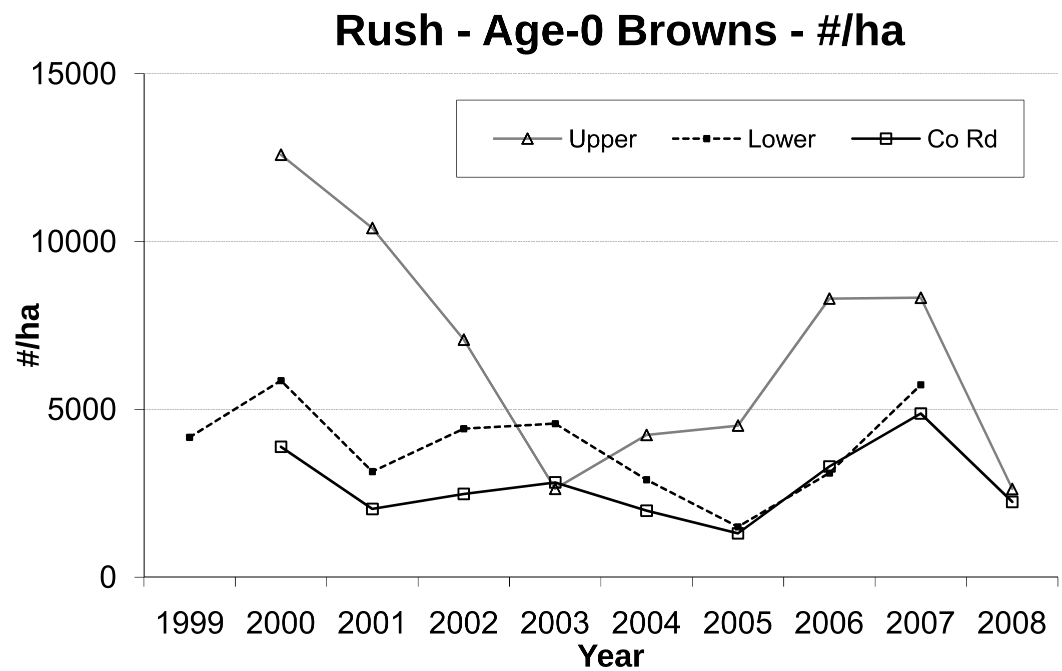
Figure 16. Estimated biomass (kg/ha) of all brown trout (age-0 and older) in four sections of Rush Creek by year.

Densities of age-0 brown trout in the Lower Rush and County Road sections tracked each other closely through time. Densities of age-1 and older brown trout in the four sample sections generally tracked each other relatively closely through time (Figure 17, bottom).

Associations among Flow, Temperature and Grant Reservoir Variables

Correlation Analyses

Flow variables were generally highly correlated to each other, except for variables related to minima versus maxima flows (Table 5). Several flow variables were also highly correlated to water temperature variables and Grant Reservoir storage variables. All water temperature variables were highly correlated with each other and most were correlated to Grant Reservoir storage variables (Table 6). These correlations among flow, temperature, and Grant Reservoir storage variables required that screening of these variables as potential covariates to explain variation in fish condition, biomass, and density be done prior to model development and testing.



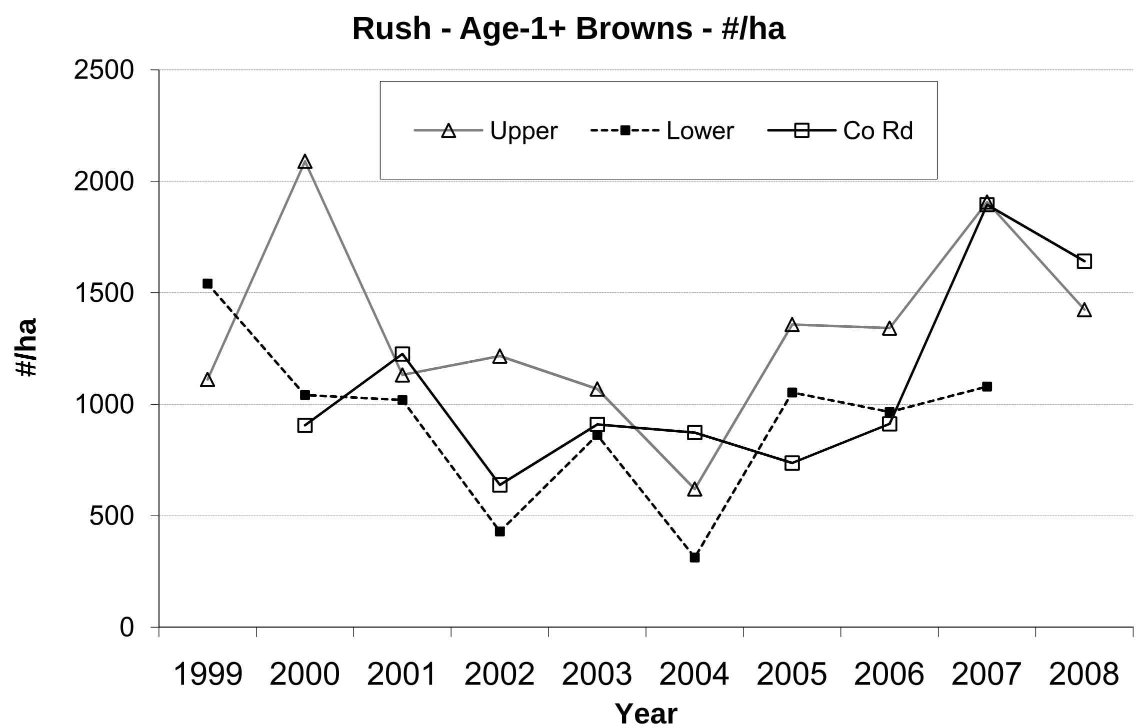


Figure 17. Densities (#/ha) of age-0 (top) and age-1 and older (bottom) brown trout estimated in three sections of Rush Creek by year.

Table 5. Spearman rank correlation results (significant correlations, $P < 0.05$, are shown in bold type) for flow variables (columns and bold variables) in Rush Creek from 1999 through 2008. Negative sign indicates a negative correlation and no negative sign indicates a positive correlation. Variable abbreviations are explained in Table 2.

Variables	Min Ann Flow	Max Ann Flow	Mean Summer Flow	Days Flows < 50	Days Flows > 150	June Flow	July Flow	Aug Flow	Sept Flow
K	0.2812	0.1871	0.1830	-0.2059	0.0752	0.0341	0.3668	0.3112	0.2322
Biom	-0.3066	-0.1696	-0.1175	0.3510	-0.1024	-0.2332	0.0397	-0.0984	-0.1729
Dens0	-0.0816	-0.4355	-0.3854	0.1953	**-0.5221**	**-0.5339**	-0.1177	-0.2521	-0.1079
Dens1	**-0.5003**	-0.4115	-0.2625	0.4054	-0.1685	-0.3501	-0.1567	-0.2674	-0.3310
MinAnnFlow	**-**	0.1350	0.3314	**-0.9021**	0.0489	0.0971	**0.5146**	**0.5942**	**0.8441**
MaxAnnFlow	0.1350	**-**	**0.8640**	-0.2005	**0.8698**	**0.9221**	**0.5842**	**0.5732**	0.1618
Mean6_9Flow	0.3314	**0.8640**	**-**	**-0.5012**	**0.8929**	**0.8217**	**0.8069**	**0.8546**	**0.4745**
SumDays.50	**-0.9021**	-0.2005	**-0.5012**	**-**	-0.2587	-0.2108	**-0.6815**	**-0.7705**	**-0.9117**
SumDays.150	0.0489	**0.8698**	**0.8929**	-0.2587	**-**	**0.8918**	**0.6115**	**0.6648**	0.2440
June_Flow	0.0971	**0.9221**	**0.8217**	-0.2108	**0.8918**	**-**	**0.4794**	**0.5326**	0.1048
July_Flow	**0.5146**	**0.5842**	**0.8069**	**-0.6815**	**0.6115**	**0.4794**	**-**	**0.9347**	**0.6786**
Aug_Flow	**0.5942**	**0.5732**	**0.8546**	**-0.7705**	**0.6648**	**0.5326**	**0.9347**	**-**	**0.7800**
Sept_Flow	**0.8441**	0.1618	**0.4745**	**-0.9117**	0.2440	0.1048	**0.6786**	**0.7800**	**-**
Avg_Sum_Temp	-0.3283	**-0.4958**	**-0.6106**	**0.4734**	**-0.4629**	-0.3327	**-0.7300**	**-0.7239**	**-0.4513**
Avg_Max_Daily.Sum_Temp	-0.2399	-0.4095	**-0.4578**	0.3602	-0.3983	-0.2873	**-0.5875**	**-0.5814**	-0.3959
DaysGT70F	-0.2881	-0.3739	**-0.4575**	0.4218	-0.3991	-0.2827	**-0.6201**	**-0.5882**	**-0.4423**
Days.GT67F	-0.1850	**-0.4938**	**-0.5165**	0.3358	**-0.5009**	-0.3869	**-0.5991**	**-0.5491**	-0.3331
Days_Ideal_Temp	0.1612	0.3740	0.3491	-0.2628	0.3733	0.3068	**0.4947**	0.4072	0.2789
GrantMean	0.3822	0.1470	0.4382	**-0.5019**	0.2796	0.0394	**0.7699**	**0.7217**	**0.6262**
GrantMin	0.4112	-0.0281	0.2598	**-0.4969**	0.1141	-0.1027	**0.5783**	**0.5665**	**0.5882**
GrantMax	**0.4544**	0.0743	0.3738	**-0.5414**	0.1991	-0.0014	**0.6972**	**0.6722**	**0.6460**

Table 6. Spearman rank correlation results (significant correlations, *P* < 0.05, are shown in bold type) for temperature and Grant Reservoir summer storage variables (columns and bold variables) in Rush Creek from 1999 through 2008. Negative sign indicates a negative correlation and no negative sign indicates a positive correlation. Variable abbreviations are explained in Table 2.

Variables	Mean Summer Temp	Max Daily Summer Temp	Days > 70F	Days > 67F	Days Ideal Temp	Grant Mean	Grant Min	Grant Max
K	**-0.5461**	**-0.7643**	**-0.7686**	**-0.7594**	**0.7558**	0.4176	0.3232	0.4248
Biom	-0.1967	-0.4387	**-0.4875**	-0.4371	**0.5233**	0.4394	0.4113	0.4322
Dens0	-0.0708	-0.3612	-0.3776	-0.2722	0.3893	0.2795	0.4084	0.3237
Dens1	0.2374	0.0730	0.0053	-0.0053	0.1062	0.1889	0.2153	0.1911
MinAnnFlow	-0.3283	-0.2399	-0.2881	-0.1850	0.1612	0.3822	0.4112	**0.4544**
MaxAnnFlow	**-0.4958**	-0.4095	-0.3739	**-0.4938**	0.3740	0.1470	-0.0281	0.0743
Mean6_9Flow	**-0.6106**	**-0.4578**	**-0.4575**	**-0.5165**	0.3491	0.4382	0.2598	0.3738
SumDays.50	**0.4734**	0.3602	0.4218	0.3358	-0.2628	**-0.5019**	**-0.4969**	**-0.5414**
SumDays.150	**-0.4629**	-0.3983	-0.3991	**-0.5009**	0.3733	0.2796	0.1141	0.1991
June_Flow	-0.3327	-0.2873	-0.2827	-0.3869	0.3068	0.0394	-0.1027	-0.0014
July_Flow	**-0.7300**	**-0.5875**	**-0.6201**	**-0.5991**	**0.4947**	**0.7699**	**0.5783**	**0.6972**
Aug_Flow	**-0.7239**	**-0.5814**	**-0.5882**	**-0.5491**	0.4072	**0.7217**	**0.5665**	**0.6722**
Sept_Flow	**-0.4513**	-0.3959	**-0.4423**	-0.3331	0.2789	**0.6262**	**0.5882**	**0.6460**
Avg_Sum_Temp	**-**	**0.7541**	**0.6847**	**0.7147**	**-0.4581**	**-0.7052**	**-0.6079**	**-0.6664**
Avg_Max_Daily.Sum_Temp	**0.7541**	**-**	**0.9651**	**0.9542**	**-0.8742**	**-0.6700**	**-0.5698**	**-0.6366**
DaysGT70F	**0.6847**	**0.9651**	**-**	**0.9539**	**-0.9036**	**-0.7225**	**-0.6338**	**-0.6995**
Days.GT67F	**0.7147**	**0.9542**	**0.9539**	**-**	**-0.9201**	**-0.6325**	**-0.5250**	**-0.5989**
Days_Ideal_Temp	**-0.4581**	**-0.8742**	**-0.9036**	**-0.9201**	**-**	**0.5346**	0.4336	**0.5034**
GrantMean	**-0.7052**	**-0.6700**	**-0.7225**	**-0.6325**	**0.5346**	**-**	**0.9105**	**0.9768**
GrantMin	**-0.6079**	**-0.5698**	**-0.6338**	**-0.5250**	0.4336	**0.9105**	**-**	**0.9320**
GrantMax	**-0.6664**	**-0.6366**	**-0.6995**	**-0.5989**	**0.5034**	**0.9768**	**0.9320**	**-**

Principal component analyses indicated that the first component appeared to contrast flow and temperature variables, while the next four components were weighted more heavily to high flow, low flow, ideal temperature, or Grant Reservoir storage variables, respectively (Appendix F). In general, we tried to include a low flow, high flow, and Grant storage variable for the full 28-observation dataset because these types of variables were not too highly correlated with each other. We then added one temperature variable to this suite of flow-storage variables for the 20 observations where temperature data were available. Adding a temperature variable usually required the elimination of a Grant Reservoir storage variable because water temperature and storage were correlated.

Effects of Temperature and Flow on Condition of 150-250 mm Brown Trout

Scatter-plots of condition factors of 150 to 250 mm brown trout versus other factors indicated some factors had relatively strong relationships and most of these relationships appeared linear (Appendix D). Spearman rank correlations indicated that condition of 150 to 250 mm brown trout (K) were significantly correlated to water temperatures, weakly and insignificantly correlated to some flow variables, and moderately, though insignificantly, correlated to Grant Reservoir storage levels (Table 7). Directions of correlations (signs) indicated that higher temperatures and number of days with higher temperatures were negatively correlated to fish condition. Thus, high water temperatures contribute to poorer fish condition. Storage in Grant Reservoir was inversely, and significantly, correlated to high temperature variables (Table 6), indicating that during years when Grant Reservoir was lower, water temperature were higher in Rush Creek below the reservoir. Conversely, the positive correlation between days of ideal temperature and condition indicated that brown trout were in better condition during years when there were more days that water temperatures were ideal for growth. Average flows during July, August, and September were positively correlated to fish condition as were the three Grant Reservoir storage variables. These findings are congruent with the biology of the fish.

For just flow and reservoir storage independent variables, the candidate set included one low flow variable (minimum annual flow), one of two high flow variables (maximum annual flow or mean summer flow), and one Grant storage variable (mean summer storage) to account for variation in condition of brown trout (Appendix G). Comparisons of all possible combinations of these candidate variables (Appendix H) showed that the best model included only the mean storage of Grant Reservoir (adjusted-R^2 = 0.1645; $P < 0.05$; Appendix I).

When temperature variables were added to the above flow variables the best candidate set included those flow variables (minimum annual flow, maximum annual flow, mean summer flow, and mean summer storage in Grant Reservoir) and one temperature variable (days of ideal temperature) for the 20 observations where all these data were available. After this screening process the model that best explained variation in fish condition included minimum annual flow, mean summer flow, and days of ideal temperature (adjusted-R^2 = 0.638; P < 0.01). Coefficients for all three of these covariates were significantly different than zero (P < 0.05), indicating they all explained some variation in fish condition. These three covariates were not too highly correlated with each other (Table 5). This model did a reasonable job of predicting the condition of 150 to 250 mm brown trout and there was no obvious clustering of the data points by site (Figure 18; Appendix I). Models that included all three-way and two-way interactions were also tested and none of these interactions were significant, so all interactions were removed from the model. The effects of biomass and density of age-1 and older brown trout for this best flow-temperature model were also evaluated by including them in the model as independent covariates and neither biomass nor density added significantly to the model.

Table 7. Spearman rank correlation results (significant correlations, P < 0.05, are shown in bold type) for variables related to brown trout, flow, and water temperatures in Rush Creek from 1999 through 2008. Variable abbreviations are explained in Table 2.

Variable	K	Biom	Dens0	AvgL.0	Dens1
K	**-**	0.1872	0.2078	-	-0.1740
Biom	0.1872	**-**	**0.6929**	0.2091	**0.7236**
Dens0	0.2078	**0.6929**	**-**	**-0.6689**	0.4084
Dens1	-0.1740	**0.7236**	0.4084	**-0.5121**	**-**
MinAnnFlow	0.2812	-0.3066	-0.0816	0.1261	**-0.5003**
MaxAnnFlow	0.1871	-0.1696	-0.4355	**0.5867**	-0.4115
Mean6_9Flow	0.1830	-0.1175	-0.3854	-0.3346	-0.2625
SumDays.50	-0.2059	0.3510	0.1953	0.1647	0.4054
SumDays.150	0.0752	-0.1024	**-0.5221**	0.0041	-0.1685
June_Flow	0.0341	-0.2332	**-0.5339**	0.2283	-0.3501
July_Flow	0.3668	0.0397	-0.1177	-0.2518	-0.1567
Aug_Flow	0.3112	-0.0984	-0.2521	-0.0984	-0.2674
Sept_Flow	0.2322	-0.1729	-0.1079	**0.5801**	-0.3310
Avg_Sum_Temp	**-0.5461**	-0.1967	-0.0708	0.3776	0.2374
Avg_Max_Daily.Sum_Temp	**-0.7643**	-0.4387	-0.3612	-0.0205	0.0730
DaysGT70F	**-0.7686**	**-0.4875**	-0.3776	**0.5239**	0.0053
Days.GT67F	**-0.7594**	-0.4371	-0.2722	**0.5812**	-0.0053
Days_Ideal_Temp	**0.7558**	**0.5233**	0.3893	0.0644	0.1062
GrantMean	0.4176	0.4394	0.2795	0.1543	0.1889
GrantMin	0.3232	0.4113	0.4084	0.0549	0.2153
GrantMax	0.4248	0.4322	0.3237	-0.0550	0.1911

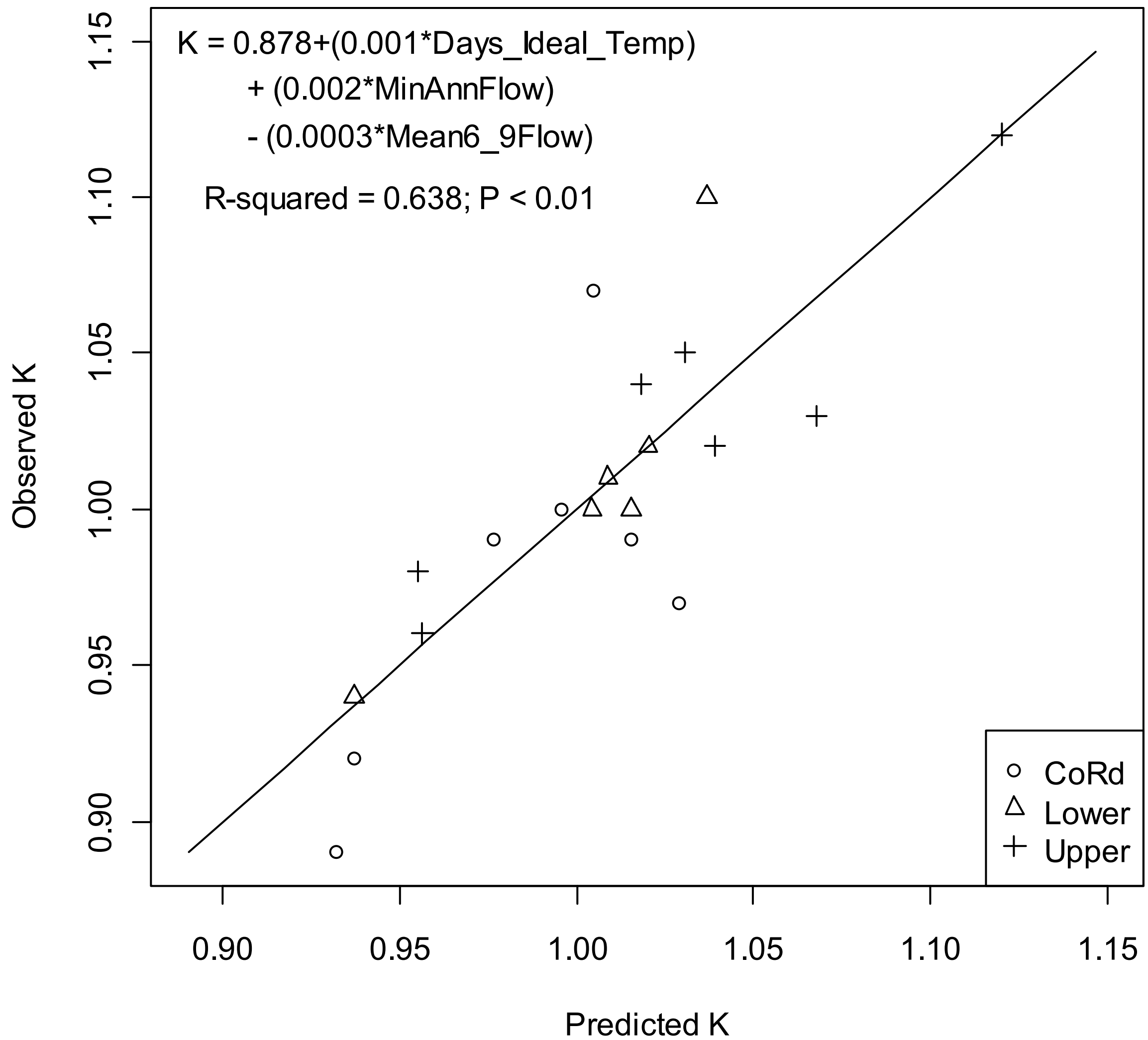


Figure 18. Observed versus predicted condition factor for brown trout 150 to 250 mm in Rush Creek by fish sample site location (CoRd = County Road; Upper = Upper Rush; Lower = Lower Rush) based on flow and temperature covariates minimum annual flow (MinAnnFlow), mean summer flow (Mean6_9Flow) and days of ideal water temperature (Days_Ideal_Temp). Final model is shown in upper left corner of graph.

Effects of Temperature and Flow on Total Biomass of Brown Trout

As expected, biomass ("Biom") was positively and significantly correlated to densities of age-0 and age-1+ brown trout. Biomass was also positively and significantly correlated to the number of days of ideal water temperatures and positively, though insignificantly, to Grant Reservoir storage levels, and negatively correlated to days maximum temperatures exceeded 70˚F (Table 7). The best regression model (adjusted-R^2 = 0.475 ; P < 0.01) that evaluated biomass as the response and flow variables as covariates (n=28) included as significant positive covariates the number of days that summer flows were less than 50 cfs and the mean summer storage of Grant Reservoir (Figure 19; Appendix I). Additional variables that were tested did not add significantly to this model and interactions between the two included variables were not significant. When the number of days of ideal temperatures was added to the model for the 20 observations where water temperature data were available the best model included days of ideal temperatures (positive) and flow variables minimum annual flow (negative), maximum annual flow (negative), and the interaction between minimum and maximum annual flows (positive) as significant covariates (Figure 20; Appendix I).

Effects of Temperature and Flow on Densities of Brown Trout

Densities of age-0 brown trout (Dens0) were negatively and significantly correlated to flows, especially June flows, number of days that flows were higher than 150 cfs, and minimum annual flows suggesting that high peak flows and low base flows led to lower densities of age-0 brown trout (Table 7). Densities of age-0 and age-1 and older brown trout were also negatively correlated to the average length of age-0 brown trout (Spearman's rho of -0.67 and -0.51, respectively; P < 0.01). The relationship for age-0 brown trout appeared curvilinear and suggested that when densities of age-0 brown trout were less than about 6,000/ha, growth of brown trout increased in a nearly linear fashion as densities declined further, but at densities over 6,000/ha average length of age-0 brown trout averaged less than 85 mm (Figure 21). While the relationship for densities of age-1 and older brown trout appeared more linear (Figure 21).

Since the distribution of estimated densities of age-0 brown trout was not normally distributed, but log-transformed estimated densities were more normally distributed (Appendix C), regression analyses were done on log-transformed densities. Multiple regression analyses indicated that minimum annual flow, days flows were >150 cfs during the summer, and minimum Grant Reservoir storage from May through September explained almost 50% of the variation in log(density) of age-0 brown trout (R^2 = 0.495, P < 0.001). Since flow variables were moderately correlated with each other, we did not test many more combinations of flow variables. There appeared to be an effect of sample site on densities of age-0 brown trout, as evidenced by the grouping of sites in the graph of observed densities versus densities predicted by the regression (especially for Upper Rush, Figure 22; Appendix I). This site effect is not too surprising for age-0 densities as most of the largest brown trout are located in the MGORD and they spawn primarily in the upper portion of Rush Creek.

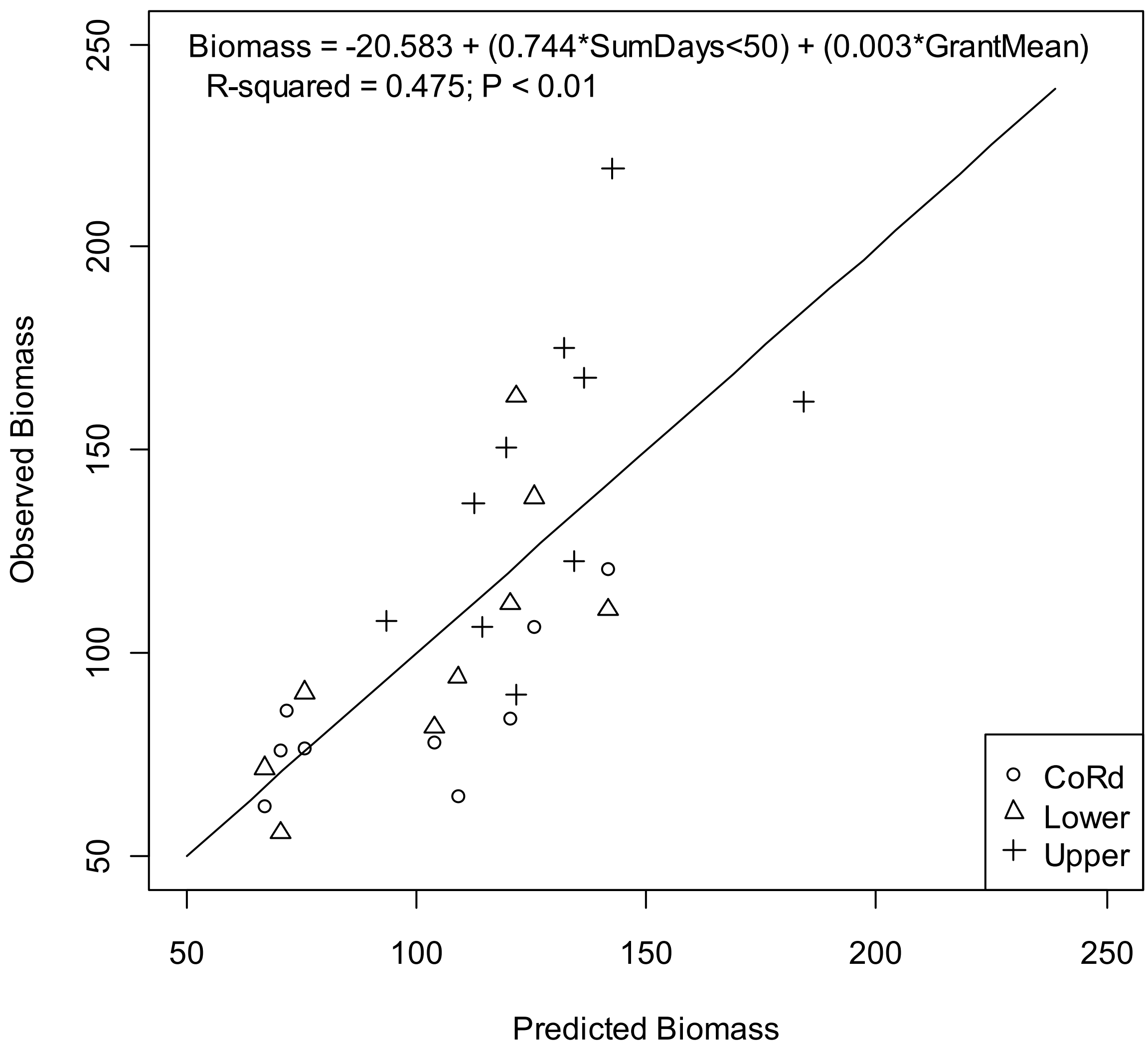


Figure 19. Observed versus predicted biomass (kg/ha) of all brown trout in Rush Creek by fish sample site location (CoRd = County Road; Upper = Upper Rush; Lower = Lower Rush) based on covariates of the number of days when summer flows were below 50 cfs and mean summer storage in Grant Reservoir. Final model is shown in upper left corner of graph.

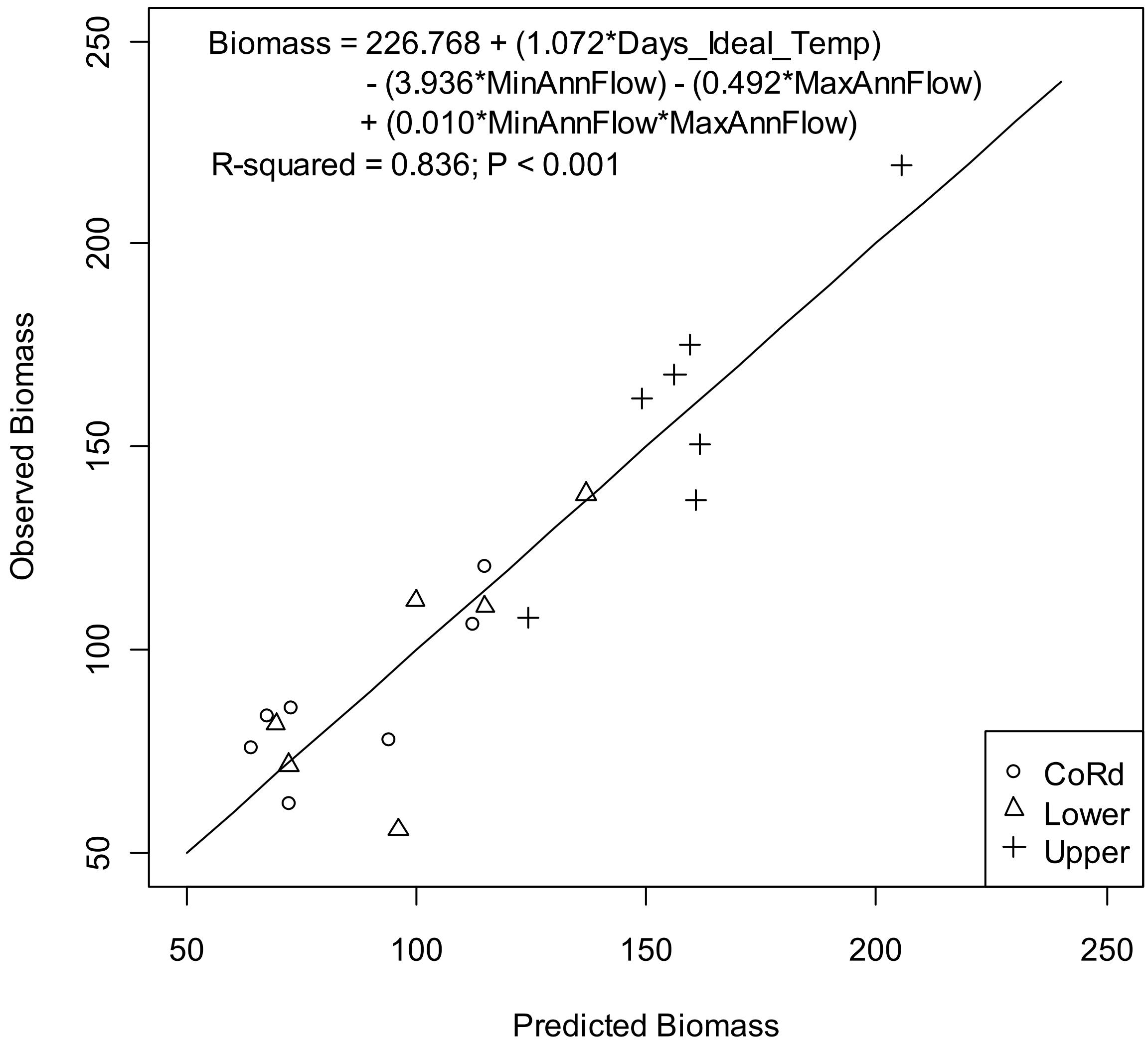


Figure 20. Observed versus predicted biomass (kg/ha) of all brown trout in Rush Creek by fish sample site location (CoRd = County Road; Upper = Upper Rush; Lower = Lower Rush) based on the temperature covariate of days water temperatures were ideal and flow covariates minimum and maximum annual flows. Final model is shown in upper left corner of graph.

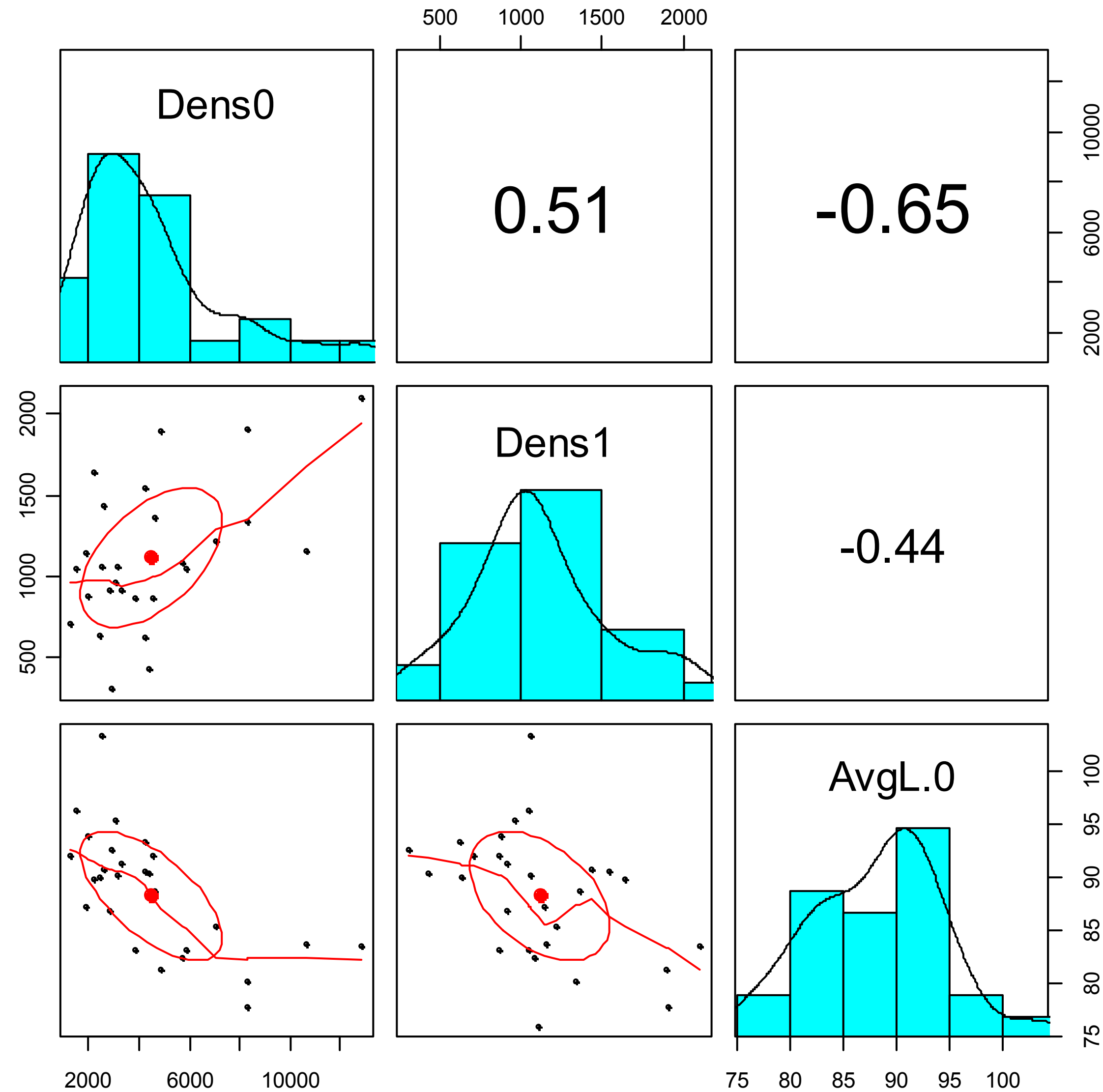


Figure 21. Relationship between density of age-0 brown trout (Dens0; number/ha), density of age-1 and older brown trout (Dens1; number/ha), and average length of age-0 brown trout (AvgL.0; mm). Histograms are shown on diagonals. Pearson correlations are shown above the diagonals. Scatter plots and loess fit lines are shown below the diagonals.

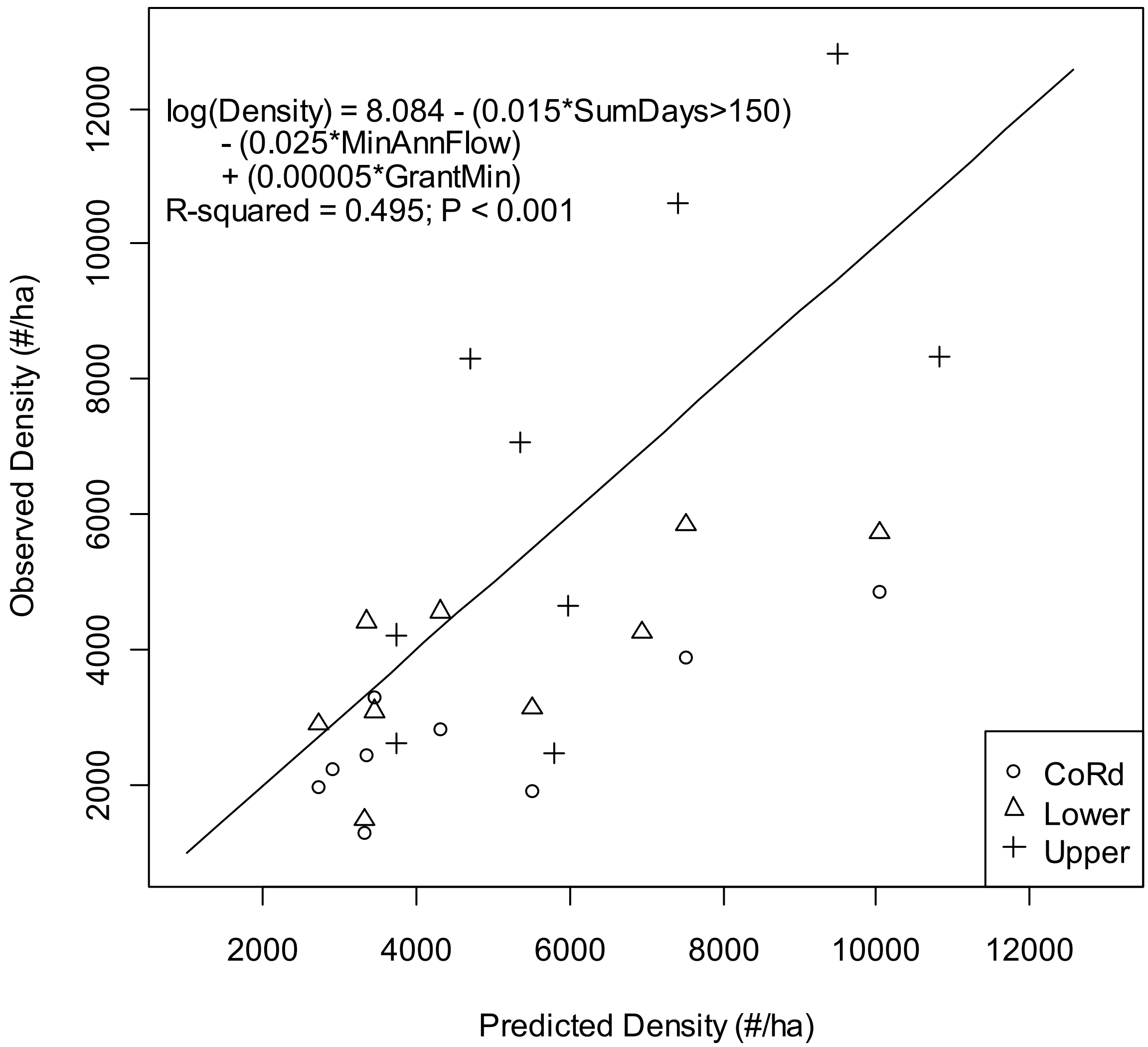


Figure 22. Observed versus predicted density (#/ha) of age-0 brown trout in Rush Creek by fish sample site location (CoRd = County Road; Upper = Upper Rush; Lower = Lower Rush) based on the number of days flows were > 150 cfs, minimum annual flows, and minimum summer storage in Grant Reservoir. Final model is shown in upper left corner of graph.

When the variable "number of days of ideal water temperatures" was included with the above three flow and reservoir variables (for the 20 observations for which these data were available) we found that the adjusted-R^2 increased from 0.495 to 0.710 and the coefficients for all four variables were significant ($P < 0.05$). If minimum annual flow was replaced with number of days the flows fell below 50 cfs the adjusted-R^2 increased slightly from 0.710 to 0.729. Since this increase was very slight, we elected to use the model that included minimum annual flow because this variable was in most other models (Figure 23; Appendix I). We did not find any significant interactions among covariates included in this model. Minimum Grant Reservoir storage and number of days of ideal water temperatures were correlated, though not significantly (Table 5).

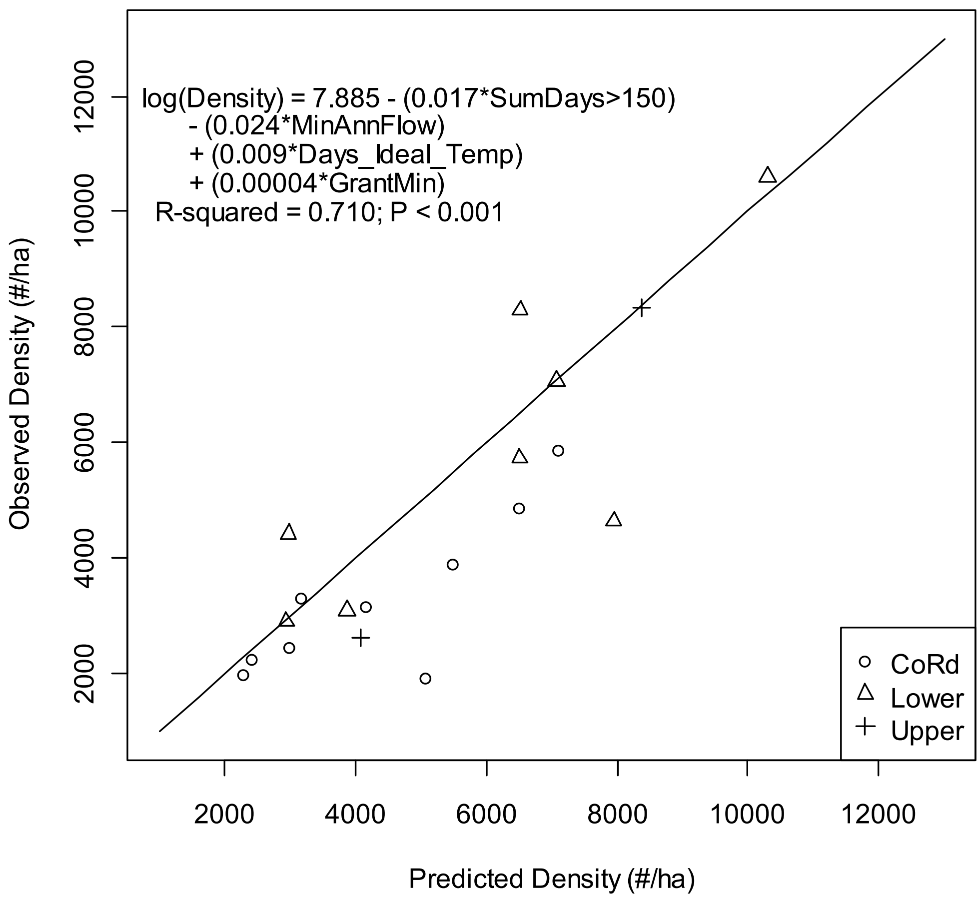


Figure 23. Observed versus predicted density (#/ha) of age-0 brown trout in Rush Creek by fish sample site location (CoRd = County Road; Upper = Upper Rush; Lower = Lower Rush) based on the number of days flows were > 150 cfs, minimum annual flows, minimum summer storage in Grant Reservoir, and days of ideal water temperatures. Final model is shown in upper left corner of graph.

Density of age-1 and older brown trout appeared significantly associated only with minimum annual flows and Grant Reservoir storage when we tested for associations using regression with flow variables as covariates ($R^2 = 0.400$; $P < 0.001$). We did not find significant effects for any water temperature variable when water temperature variables were included for the 20 observations where temperature data were available. The model that best explained variation in density of age-1 and older brown trout included only minimum annual flow and mean summer storage of Grant Reservoir and the interaction term was not significant (Figure 24).

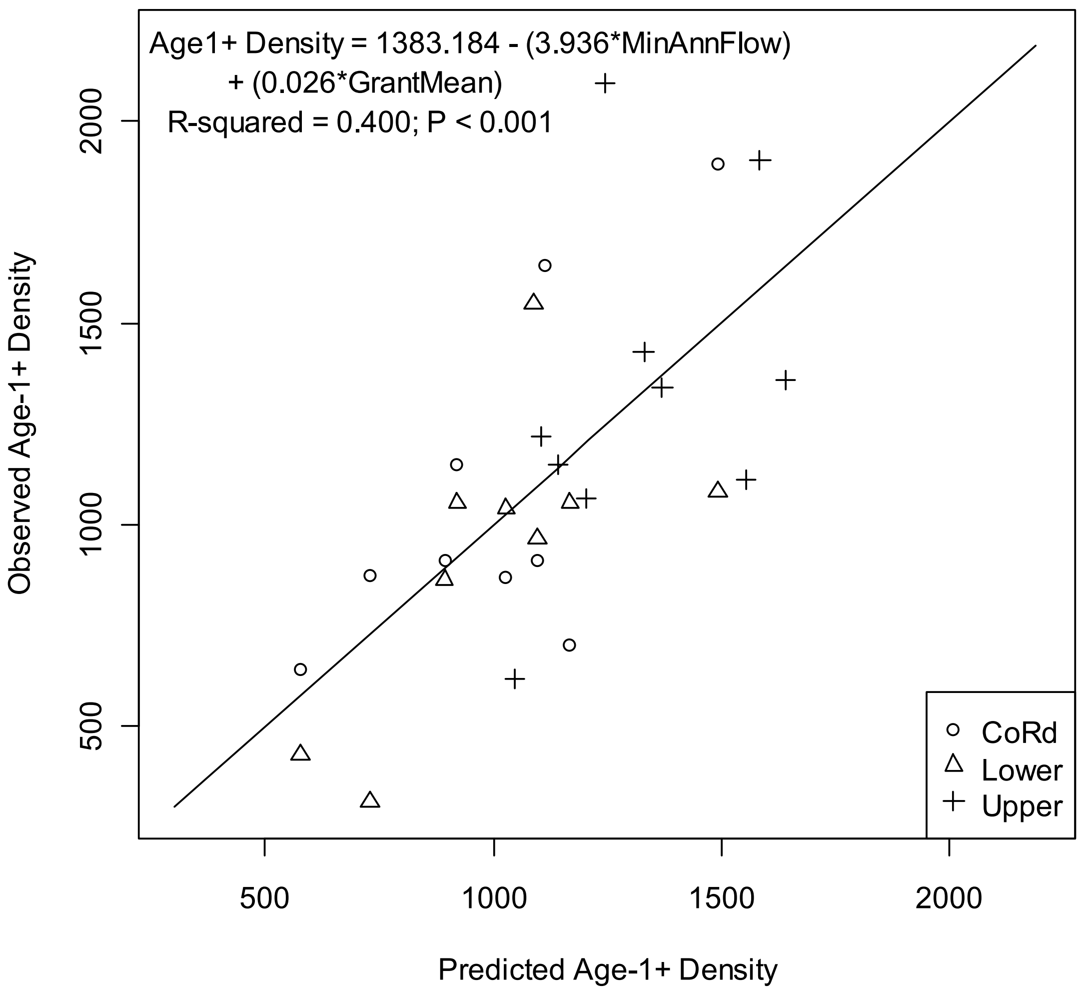


Figure 24. Observed versus predicted density (#/ha) of age-1 and older brown trout in Rush Creek by fish sample site location (CoRd = County Road; Upper = Upper Rush; Lower = Lower Rush) based on the flow covariates minimum annual flow and mean summer storage in Grant Reservoir. Final model is shown in upper left corner of graph.

Effects of Temperature and Flow on Average Length of Age-0 Brown Trout

Average length of age-0 brown trout was negatively correlated to density of age-0 and age-1+ brown trout, and positively to several other flow and water temperature variables (Table 7). The simple regression model that only included density of age-0 brown trout was highly significant ($P < 0.001$) and explained about 40% of the variation in average length of age-0 brown trout. When flow variables were added they did not improve the model fit very much (best adjusted-R^2 of 0.49) and either flow variables that were included were highly correlated with each other or their coefficients were not significantly different than zero. Temperature variables also did not add significantly to regressions that included density.

Lee Vining Creek

The effects of flow on variation in relative abundance (catch per area) and average length of age-0 brown trout and rainbow trout was explored in Lee Vining Creek. As suggested in the “Methods” section we believe brown trout analyses better indicate effects of flow on trout in Lee Vining Creek than rainbow trout due to the influence of hatchery rainbow trout and because the distribution of estimated age-0 brown trout relative abundances was normally distributed, while rainbow trout was not. Spearman rank correlation analyses indicated that catches in one pass and catches over all passes were high and positive (>0.9; Table 8) and that relationships were consistent whether total catches over all passes (RB0_haAll and LL0_haAll for rainbow and brown trout catches per hectare, respectively; Table 10) or over just the first pass (RB0_ha1 and LL0_ha1 for rainbow and brown trout catches per hectare, respectively) were evaluated. Average lengths of age-0 browns and rainbow trout were also tested as response variables. The number of days between June and September that flows exceeded 100 cfs (DaysGT100) was highly and negatively correlated to both the abundance and average length of age-0 brown trout (LL0_ha1 and LL0_L; Table 8). Mean summer flows were significantly and negatively correlated with all fish variables (Table 8).

Correlation Among Flow Variables

All flow variables were highly correlated with each other, except for minimum annual flow (Table 8). Due to this high degree of correlation among mean and high flow variables simple regressions with one high or one average flow covariate were regressed against each of the fish response variables. Multiple regressions that incorporated one high or average flow variable covariate plus a minimum annual flow covariate were also regressed against relative abundance fish response variables. The best regression model for each fish response variable was selected.

Table 8. Spearman rank correlations among fish response variables and flow variables for the Lower Lee Vining Creek fish monitoring section from 1999 through 2008. Data from 2006 were excluded because all habitats were not sampled that year. Bold values indicate significance at $P < 0.05$.

	Min Ann Flow	Mean Ann Flow	Max Ann Flow	Mean Sum Flow	Mean Spr Flow	Days <40 cfs	Days >100 cfs	Mean Win Flow	Mean Fall Flow	Fall Minus Winter
RB0_haAll	0.2008	-0.4770	**-0.8787**	**-0.7364**	**-0.6276**	**0.7280**	-0.5630	**0.6527**	0.3598	-0.1925
LL0_haAll	-0.3500	**-0.8667**	-0.5333	**-0.8167**	**-0.7000**	**0.7667**	**-0.9121**	-0.0167	**0.6000**	0.5500
RB0_ha1	0.2343	-0.4603	**-0.8619**	**-0.7197**	**-0.6109**	**0.6946**	-0.5630	**0.6862**	0.4100	-0.1757
LL0_ha1	-0.0500	**-0.7333**	-0.4833	**-0.8000**	**-0.6167**	**0.7167**	**-0.9121**	0.2333	**0.7500**	0.3333
RB0_L	-0.2521	**-0.6975**	**-0.7983**	**-0.7227**	-0.5210	**0.8488**	-0.5865	0.2185	0.3614	0.1933
LL0_L	-0.1500	**-0.8333**	**-0.6333**	**-0.9167**	**-0.8000**	**0.8500**	**-0.9707**	0.2333	**0.6333**	0.2833
MinAnnFlow	**-**	0.3500	0.1000	0.1167	0.1500	-0.2000	0.1674	**0.6500**	-0.0667	**-0.8833**
MeanAnnFlow	0.3500	**-**	**0.7500**	**0.9167**	**0.8833**	**-0.9333**	**0.8954**	0.0000	-0.3333	-0.3333
MaxAnnFlow	0.1000	**0.7500**	**-**	**0.8500**	**0.8333**	**-0.8833**	**0.6611**	-0.4000	-0.2167	0.0000
MeanSumFlow	0.1167	**0.9167**	**0.8500**	**-**	**0.9000**	**-0.9667**	**0.9456**	-0.2500	-0.4167	-0.1833
MeanSprFlow	0.1500	**0.8833**	**0.8333**	**0.9000**	**-**	**-0.8500**	**0.8452**	-0.2833	-0.3167	-0.1000
Days <40 cfs	-0.2000	**-0.9333**	**-0.8833**	**-0.9667**	**-0.8500**	**-**	**-0.8703**	0.1833	0.3333	0.1833
Days >100 cfs	0.1674	**0.8954**	**0.6611**	**0.9456**	**0.8452**	**-0.8703**	**-**	-0.1841	**-0.5941**	-0.3264
MeanWinFlow	**0.6500**	0.0000	-0.4000	-0.2500	-0.2833	0.1833	-0.1841	**-**	0.4667	**-0.6000**
MeanFalFlow	-0.0667	-0.3333	-0.2167	-0.4167	-0.3167	0.3333	**-0.5941**	0.4667	**-**	0.3167
Fall – Winter	**-0.8833**	-0.3333	0.0000	-0.1833	-0.1000	0.1833	-0.3264	**-0.6000**	0.3167	**-**

Effects of Flow on Abundance of Age-0 Brown Trout

Spearman rank correlations indicated that abundances of age-0 brown trout were negatively and significantly correlated to all flow variables, except fall flows during spawning (Table 8). However, when only the side-channel information was used and the year 2006 was included correlations between the abundance of age-0 brown trout and flow variables were not significant (Table 9). Data used in regression analyses only included flow variables because temperatures were well within ranges that were suitable for trout (Appendix B, Table B2). The best simple regression model that evaluated each flow variable as a covariate to explain the variation in abundance of age-0 brown trout used the number of days summer flows exceeded 100 cfs (Figure 25). The number of days summer flows exceeded 100 cfs explained 83% of the variation in abundance of age-0 brown trout and when data from 2006 was removed from the dataset, because the main channel was not sampled that year, results were similar (84% of the variation in age-0 brown trout abundance was explained). When minimum annual flow was added to models that included one maximum or average flow covariate it did not add significantly to any of the models. It appeared that maximum annual flows over 300 cfs were related to lower abundances of age-0 brown trout (Figure 26).

Table 9. Spearman rank correlations between abundance of age-0 rainbow (SC_RB_ha) and brown trout (SC_LL_ha) in the Lower Lee Vining Creek side channel and flow variables that include the year 2006. Bold values indicate significance at *P* < 0.05.

	SC_RB_ha	SC_LL_ha
RB0_haAll	**0.8537**	0.1581
LL0_haAll	-0.0243	0.3333
RB0_ha1	**0.8659**	0.2067
LL0_ha1	0.1459	**0.6000**
SC_RB_ha	-	0.3891
SC_LL_ha	0.3891	-
RB0_L	0.3364	0.1646
LL0_L	0.1824	0.3939
MinAnnFlow	0.4742	0.3697
MeanAnnFlow	0.0486	-0.0909
MaxAnnFlow	-0.2796	-0.1758
MeanSumFlow	-0.1520	-0.2848
MeanSprFlow	-0.0608	-0.1515
DaysLT40	0.1459	0.1879
DaysGT100	-0.0122	-0.3708
MeanWinFlow	**0.6626**	0.2121
MeanFalFlow	0.2432	0.3576
Fall minus Winter	-0.4195	-0.0788

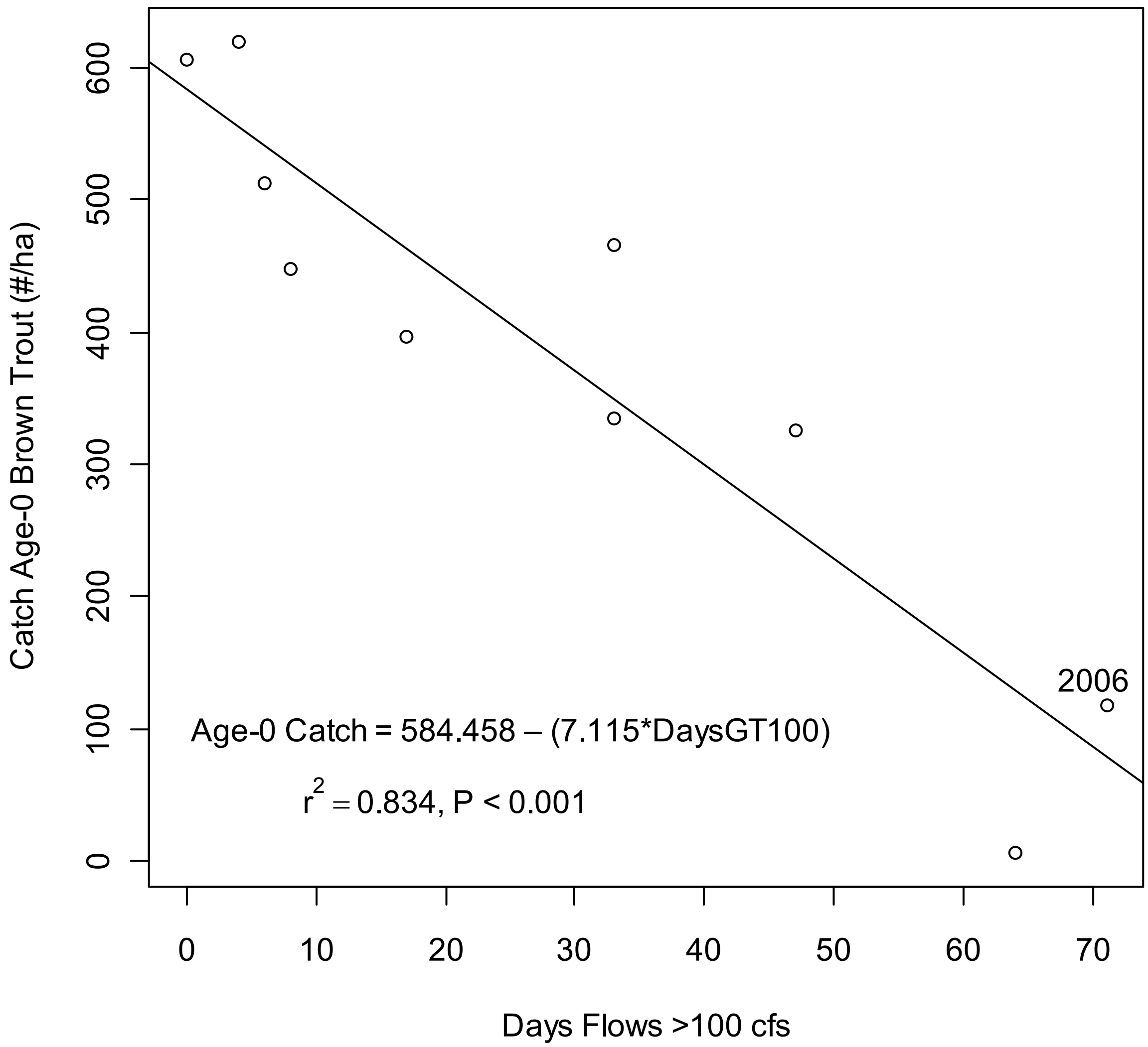


Figure 25. Results of simple linear regression of catch of age-0 brown trout in one electrofishing pass (number/ha) versus the number of days summer flows (June through September) exceeded 100 cfs. The regression equation for all years is shown at the bottom-left and the data for the year 2006 is shown with a label.

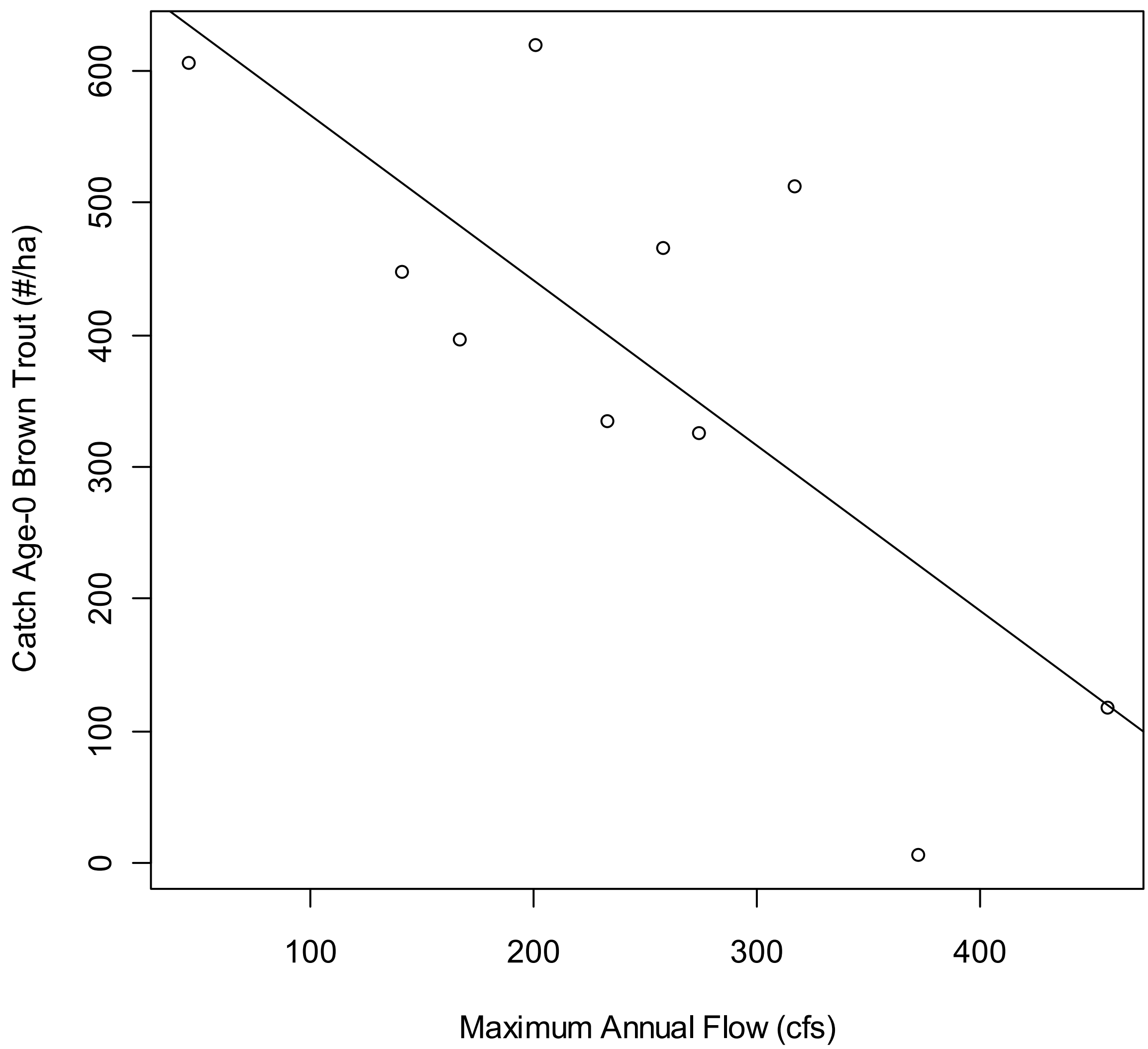


Figure 26. Results of simple linear regression of catch of age-0 brown trout in one electrofishing pass (number/ha) versus the maximum annual flow for all years.

Effects of Flow on Average Length of Age-0 Brown Trout

The average length of age-0 brown trout (LL0_L) was positively and significantly related to the relative abundance of age-0 brown trout and average length of rainbow trout and negatively to all of the flow variables (Table 8). Simple regression analyses indicated that the number of days summer flows exceeded 100 cfs also did a moderately good job of explaining the variation in average length of age-0 brown trout (r^2 = 0.697; Figure 27); however, when the observation from 2006 was removed the regression improved dramatically with the r^2 increasing from 0.70 to 0.85 and the significance of the regression increasing from P = 0.0011 to P = 0.00025. The slope of the regression line became more steeply negative when the 2006 observation was removed.

Effect of Flow on Abundance of Age-0 Rainbow Trout

There were no significant correlations between the abundance of age-0 rainbow trout (RB0_ha1) and any of the flow variables when all years were included (Table 8); however, both the highest catch per hectare and highest flows were in 2006 when only the side channel was sampled. When 2006 was removed from the dataset there were significant negative correlations for all of the high flow variables (maximum annual flow, mean spring flow, and mean summer flow). Regression analyses that included observations for all years did not find any significant models, but when 2006 data were removed the model that included maximum annual flow was the best model and this model explained 55% of the variation in abundance of age-0 rainbow trout (Figure 28).

Effect of Flow on Mean Length of Age-0 Rainbow Trout

Years when no rainbow trout were captured during the first electrofishing pass (2003 and 2005) were removed prior to the analysis. The average length of age-0 rainbow trout was negatively and significantly correlated with all flow variables, except minimum annual flow was not significant and days flows were less than 40 cfs was positively and significantly correlated (Table 8). There was no strong correlation between average length of rainbow trout and relative abundance of age-0 rainbow trout. Simple linear regression indicated that the number of days that flows were less than 40 cfs explained much (78%) of the variation in mean length of age-0 rainbow trout (Figure 29). Removing the observation for the year 2006 did not improve the regression fit (r^2 = 0.74 for regression without 2006).

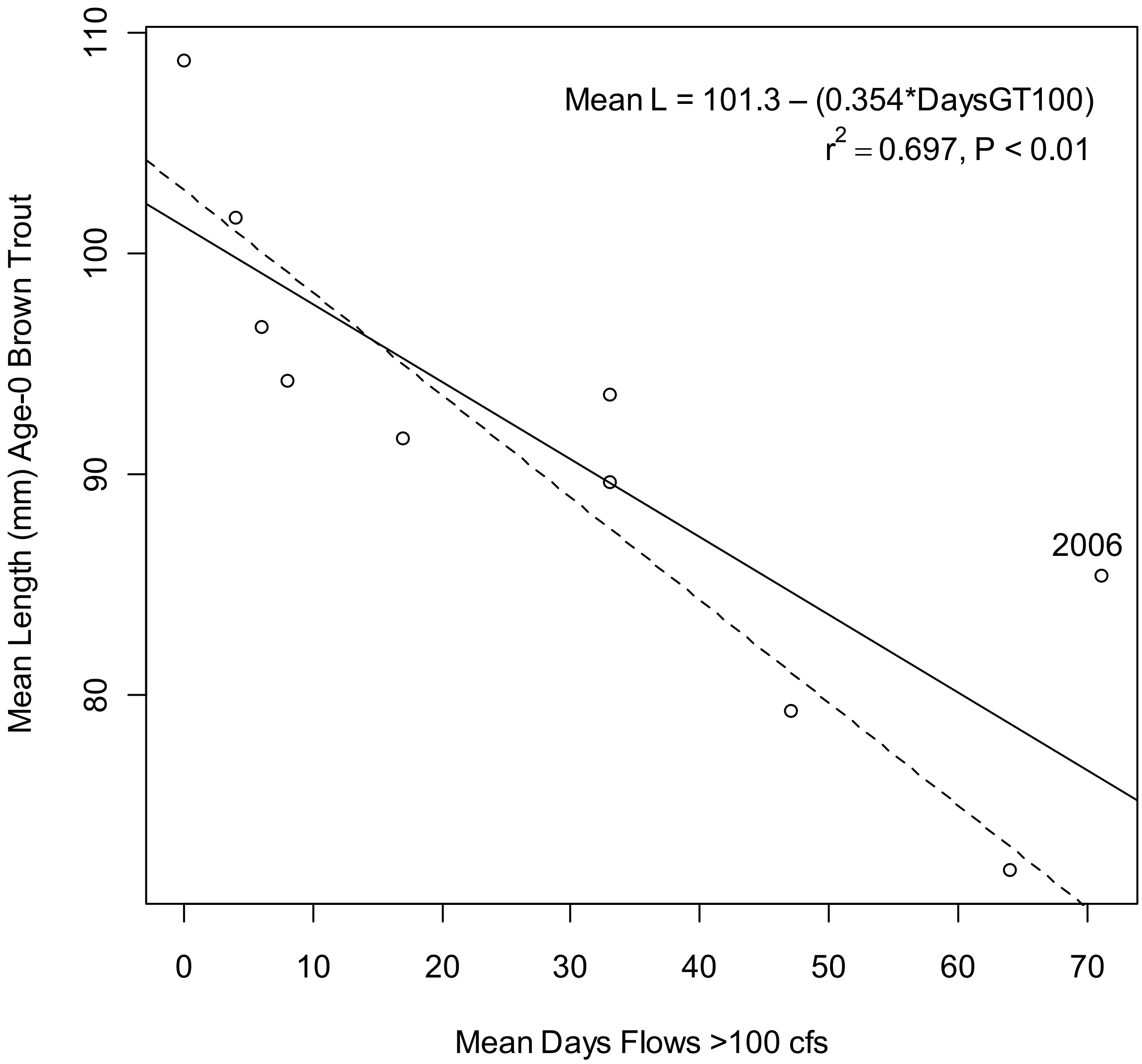


Figure 27. Results of simple linear regression of average length (mm) of age-0 brown trout in the late summer versus the number of days summer (June through September) flows exceeded 100 cfs in Lower Lee Vining Creek. Solid line is regression for all years and dashed line is regression that excludes 2006. The observation for year 2006 is labeled with the year. The regression equation for all years is shown at the top-left.

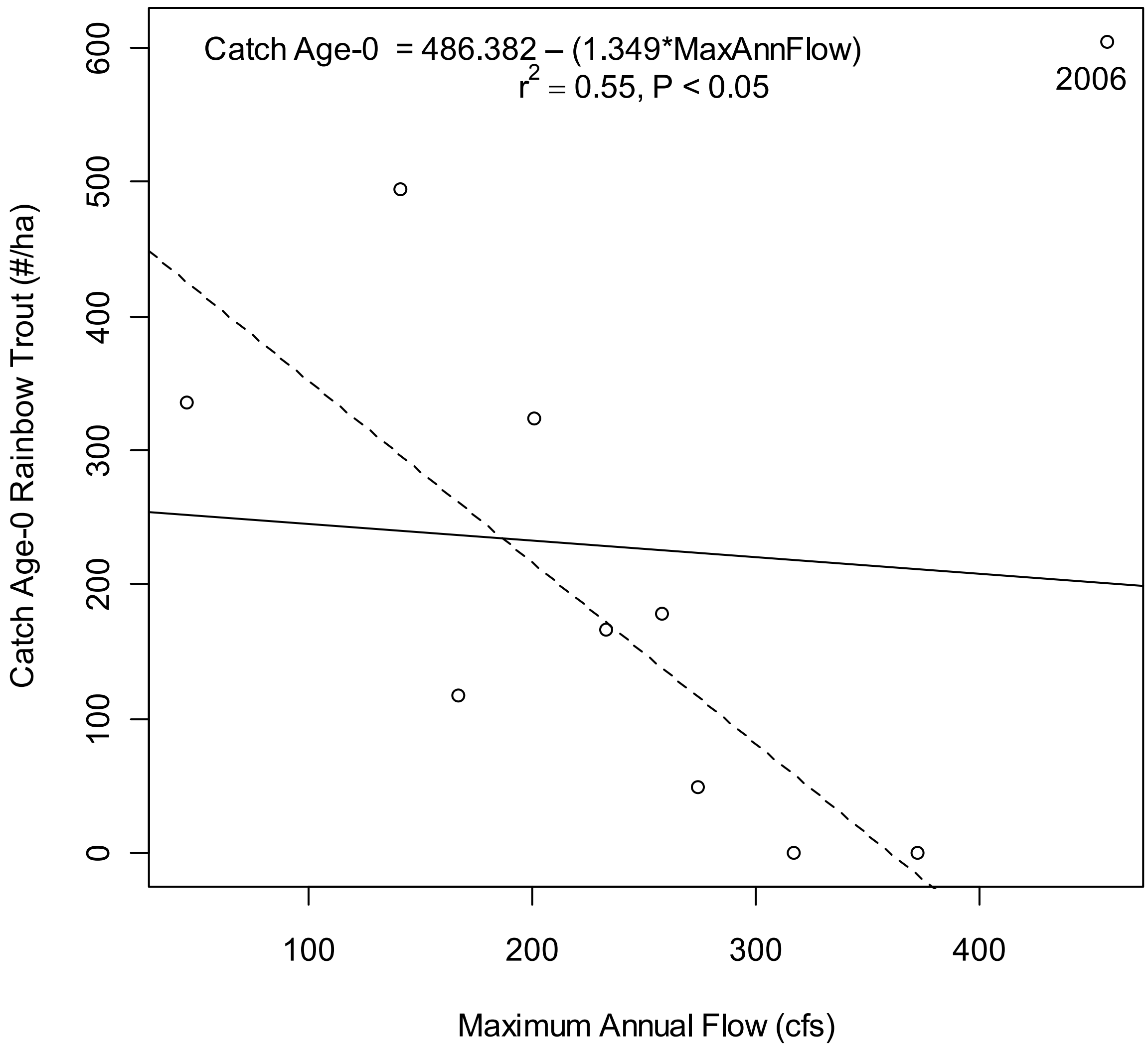


Figure 28. Results of simple linear regression of catch of age-0 rainbow trout (#/ha) in the late summer versus mean maximum annual flow (expressed as cubic feet per second – cfs) in Lower Lee Vining Creek with and without the observation from 2006. Solid line is regression model for all years (including 2006) and the dashed line is the regression model without 2006. The regression equation for data that excluded 206 is shown at the top-left. The data point for 2006 is labeled (top-right).

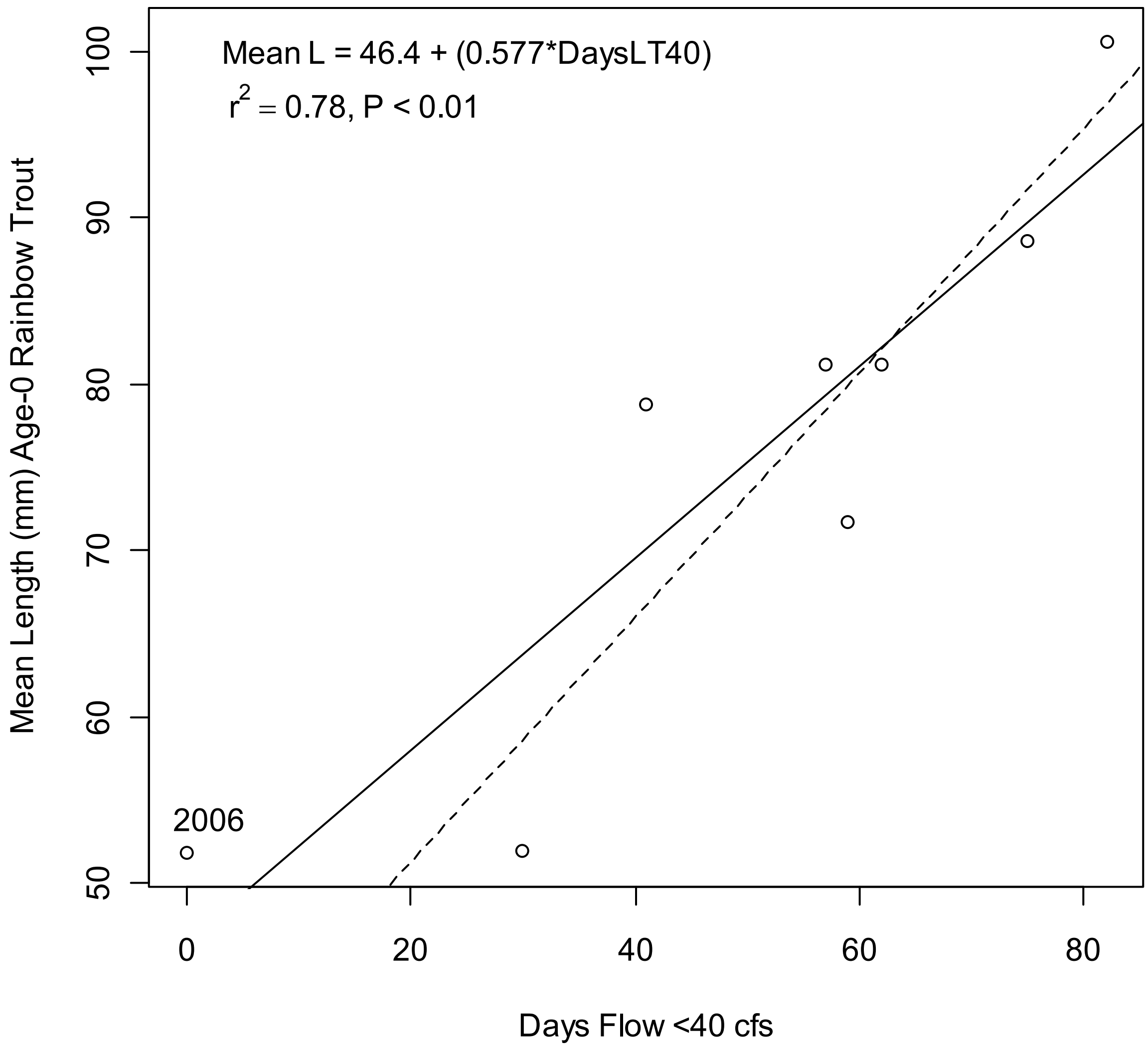


Figure 29. Results of simple linear regression of average length (mm) of age-0 rainbow trout in the late summer versus number of days flows were less than 40 cfs in lower Lee Vining Creek. Solid line is regression for all years and dashed line is regression that excludes 2006. The observation for year 2006 is labeled with the year. The regression equation for all years is shown at the top-left.

Discussion

These results clearly demonstrate that flow and temperature affect both the abundance and growth of trout in lower Rush and Lee Vining creeks. In general, high peak, high average summer, and higher minimum flows were associated with lower abundances of trout (Table 9). These relationships held up whether the number of days of low flows and high flows were used (number of days of low flows were positively associated with abundance, while number of days of high flows were negatively associated with abundance) or annual or summer minimums, maximums, or averages were used. Conversely, condition factors for brown trout 150 to 250 mm in length were positively associated with minimum annual flows (Table 9 and Figure 18). This positive association indicates that condition factors for brown trout were higher at higher minimum annual flows and lower at lower minimum annual flows. This finding suggests that low flows can negatively impact condition of older brown trout.

We found that densities of age-0 brown trout in lower Rush Creek were negatively correlated to high flow variables (Table 9). Several studies have shown that high flows, especially during the period immediately prior to and after emergence of fry from the spawning sites, negatively impact recruitment of brown trout (Nuhfer et al. 1994; Jensen and Johnson 1999; Spina 2001; Cattaneo et al. 2002; Gonzalez et al. 2002; Armstrong and Nislow 2006; Zorn and Nuhfer 2007). The high correlation among almost all flow variables and the fact that fish response variables were estimated on an annual basis (during the late summer season) made it extremely difficult to separate effects of different flow events, so we cannot confidently attribute variation in fish responses to particular flow events. Since low flows during this study did not reach extremely low levels, we could not evaluate impacts of extremely low flows.

Carl Mesick Consultants (1994) conducted similar regression analyses for the years 1985 through 1992 in lower Rush Creek, but they evaluated high flow variables for the year preceding their estimates of age-0 abundance, rather than during the same year as we did. They found a positive correlation between high flows the preceding year and abundances of age-0 brown trout. Carl Mesick Consultants (1994) suggested that this positive relationship was related to increased availability of suitable spawning gravel; however, they had limited empirical data to support this suggestion. Another potential explanation for this positive correlation was that increased flows the preceding year resulted in higher densities of adult spawners. We observed that high flow levels during their study were relatively low (range: 20 – 350 cfs, with only one year above 160 cfs), compared to high flows during our study (range: 60 – 584 cfs, mean = 281 cfs). We also evaluated flow effects at a slightly finer scale by separating Rush Creek flows into separate estimates above Parker and Walker creeks and below Parker and Walker creeks and comparing those flows to fish parameter estimates in these two reaches of lower Rush Creek (below Walker Creek and above Highway 395). Our finding that densities of age-1 and older and biomass of all brown trout were negatively associated with both high flows and summer flows in lower Rush Creek was similar to findings of Carl Mesick Consultants (1994).

Table 9. Summary of significant simple Spearman rank correlations (Rho) and the regression coefficients for variables included in the "best" multiple regression model that explained variation in condition of brown trout 150 to 250 mm (K), estimated biomass of all brown trout (Biom), estimated density of age-1 and older brown trout (Dens1), estimated density of age-0 brown trout (Dens0), and average length of age-0 brown trout (AveL.0) in Rush Creek from 1999 to 2008. Only the coefficient sign (positive or negative) are shown for density of age-0 brown trout (Dens0) because a log-transformation of these densities were used in the regression analysis to normalize these data.

Fish	Simple Correlations		Multiple Regression	
variable	Variable	Rho	Variable	Coefficient
K	Days_Ideal_Temp	0.756	Days_Ideal_Temp	0.0011
	DaysGT70F	-0.769	MinAnnFlow	0.0025
	Avg_Max_Daily.Sum_Temp	-0.764	Mean6_9Flow	-0.0003
	Days.GT67F	-0.759		
	Avg_Sum_Temp	-0.546		
Biom	Dens1	0.724	Days_Ideal_Temp	1.072
	Dens0	0.693	MinAnnFlow	-3.936
	Days_Ideal_Temp	0.523	MaxAnnFlow	-0.492
	DaysGT70F	-0.488	Max*MinAnnFlow	0.010
Dens1	Biom	0.724	MinAnnFlow	-3.936
	MinAnnFlow	-0.500	GrantMin	0.026
Dens0	Biom	0.693	Days_Ideal_Temp	+
	June_Flow	-0.534	MinAnnFlow	-
	SumDays>150	-0.522	SumDays>150cfs	-
			GrantMin	+
Ave.L.0	Dens0	-0.669	Dens0	-0.001
	MaxAnnFlow	0.587		
	Days.GT67F	0.581		
	Sept_Flow	0.580		
	DaysGT70F	0.524		
	Dens1	-0.512		

Past reports suggest that low summer base flows of about 19 cfs only slightly reduced brown trout abundance and growth in lower Rush Creek compared to a high flow summer flow of about 350 cfs (Carl Mesick Consultants 1994). However, Carl Mesick Consultants (1994; Figure 4-123) data suggests that total estimated biomass of brown trout declined as base summer flows were increased from 1989 through 1993 to provide additional flows to raise the level of Mono Lake. It appears that moderate base summer flows between 20 to 40 cfs may be close to ideal for production of brown trout in lower Rush Creek. However, the influence of lower flows on water temperatures must be considered as high water temperatures were found to significantly limit growth and biomass of brown trout in lower Rush Creek. California Department of Fish and Game (1991) recommended monthly flows between 30 and 60 cfs for dry years, 40 and 60 cfs for normal years, and 54 and 60 cfs for wet years. We will be conducting more detailed analyses to recommend seasonal flows in lower Rush Creek.

The number of days that water temperatures were ideal for growth was positively associated with all brown trout metrics in Rush Creek and these associations were significant using both Spearman correlations and regression analyses for condition factors and total biomass (Table 9). Days where peak water temperatures rose above 70˚F were negatively correlated with all brown trout metrics except for average length of age-0 brown trout. It appears that higher temperatures may increase growth of age-0 brown trout. We are unsure what mechanism, if any, is related to this association between high water temperatures and growth of age-0 brown trout. It may be that growth of age-0 brown trout increases during years of higher temperature because total biomass of brown trout is reduced by high temperatures and fewer age-1 and older brown trout reduces competition for food and space used by age-0 brown trout.

Many studies have demonstrated that water temperature is a major driver of brown trout growth (Elliott 1975a; Elliott 1975b; Raleigh et al. 1986; Elliott et al. 1995; Elliott and Hurley 1999; Elliott and Hurley 2000; Ojanguren et al. 2001; Wehrly et al. 2007). Increased growth and body condition allow fish to survive at higher rates by increasing their energy reserves. Higher survival rates and faster growth translate to either higher population abundance, more large fish in the population, or both. Lower Rush Creek is no exception and our findings are consistent with those of Carl Mesick Consultants (1994) that show that extremely high temperatures reduce growth and biomass of brown trout.

Carl Mesick Consultants (1994) actually had to use storage levels in Grant Reservoir as a surrogate measure for stream water temperatures because they did not have data for water temperatures during all years they sampled. They found high correlations among stream water temperatures and Grant Reservoir storage levels, as did we and another study by Cullen and Railsback (1993). Cullen and Railsback (1993) developed a thermal model for Grant Reservoir that could predict outflow temperatures into lower Rush Creek within 3˚C. They evaluated whether some type of selective withdrawal system that delivered cooler water to Rush Creek could reduce maximum summer water temperatures in Rush Creek. They concluded that because Grant Reservoir was seldom stratified (due to windy conditions and its uniformly shallow depth) a selective withdrawal system would have limited benefits. They recommended that the best way to provide cooler water to lower Rush Creek was to ensure that Grant Reservoir reached full pool by May of each year (7110 feet) and that this full pool level be maintained through August. They estimated that implementing this recommendation would allow the reservoir to deliver water that would be 2˚C (3.6˚F) cooler than for the typical operation of Grant Reservoir.

In Lee Vining Creek flow variables were negatively correlated to abundances and average lengths of age-0 brown and rainbow trout (Table 10). Higher flows led to lower abundances and smaller age-0 brown and rainbow trout. The number of days summer flows exceeded 100 cfs explained over 80% of the variation in estimated abundance of age-0 brown trout and over 69% of the variation in estimated average length of age-0 brown trout. Removing the year when no sampling was possible in the main channel portion of the sample section improved the model fit for average length of age-0 brown trout, but not for abundance of age-0 brown trout. Estimated abundances and average lengths of age-0 brown trout were positively and significantly correlated, a finding that was the opposite of what was observed in lower Rush Creek. We suspect that densities of age-0 brown trout in lower Lee Vining Creek do not reach levels high enough to impact their growth in a density-dependent fashion. Relative abundance estimates of age-0 brown trout in lower Rush Creek sections were often two to three times as high as those estimated for Lower Lee Vining Creek. These data show that flow conditions that promote faster growth of age-0 brown trout also promote higher abundances.

Years of higher peak flows dramatically reduced abundances of age-0 rainbow trout in Lee Vining Creek, when data from both the side channel and main channel habitats were combined. However, the relative abundance of age-0 rainbow trout in the side channel of Lee Vining Creek was very high in 2006, when flows were also extremely high. This finding indicates that age-0 rainbow trout in some side channels may be less impacted by high flows under certain flow regimes. There was some evidence for this type of side channel response in age-0 brown trout, though it was not nearly as strong as for rainbow trout.

Conclusions and Recommendations

In both Rush Creek downstream of Grant Reservoir and Lee Vining Creek downstream of Highway 395 there was evidence that peak flow magnitudes and durations were both negatively correlated with density of brown trout. However, very low summer flows were negatively related to condition of adult brown trout. These findings indicate that to maximize fish density, growth, and condition, the best flow regime would be stable and moderate; however, there is a vital need for high flows that emulate the natural snowmelt hydrograph to form fish habitats, flush fine sediments from the streambed, transport streambed material, fill Mono Lake, create diverse riparian habitats (including a diverse riparian vegetation community), and to maintain a whole host of other riparian and geomorphic ecosystem functions.

Table 10. Summary of significant simple Spearman rank correlations (Rho) and regression coefficients for variables and r^2 values for significant (P<0.05) simple regression models that explained variation in relative abundance of age-0 brown (LL0_ha1) and rainbow trout (RB0_ha1) and average lengths of age-0 brown (LL0_L) and rainbow trout (RB0_L) in lower Lee Vining Creek from 1999 through 2008. Results for all years and without the year 2006 are shown because during 2006 not all habitats could be sampled.

	Simple Correlations			Simple Regression				
		Spearman Rho			Without 2006		All Years	
Fish variable	Variable	Without 2006	All Years	Variable	Coefficient	r^2	Coefficient	r^2
LL0_ha1	DaysGT100	-0.912	-0.924	DaysGT100	-7.535	0.795	-7.085	0.836
	LL0_L	0.867	0.891	MeanSumFlow	-4.909	0.842	-3.494	0.771
	MeanSumFlow	-0.800	-0.842	MeanAnnFlow	-10.900	0.703	-7.269	0.661
	MeanFalFlow	0.750	0.455					
	MeanAnnFlow	-0.733	-0.794					
	DaysLT40	0.717	0.782					
	MeanSprFlow	-0.617	-0.709					
	MaxAnnFlow	-0.483	-0.612					
LL0_L	DaysGT100	-0.971	-0.942	DaysGT100	-0.466	0.849	-0.353	0.697
	MeanSumFlow	-0.917	-0.903	MeanSumFlow	-0.303	0.894	-0.160	0.518
	LL0_ha1	0.867	0.891					
	DaysLT40	0.850	0.855					
	MeanAnnFlow	-0.833	-0.842					
	MeanSprFlow	-0.800	-0.818					
	MeanFalFlow	0.633	0.455					
	MaxAnnFlow	-0.633	-0.685					
	RB0_L	0.597	0.616					

	Simple Correlations			Simple Regression				
		Spearman Rho			Without 2006		All Years	
Fish variable	Variable	Without 2006	All Years	Variable	Coefficient	r^2	Coefficient	r^2
RB0_ha1	MaxAnnFlow	-0.862	-0.353	MaxAnnFlow	-1.349	0.554	N.S.	N.S.
	MeanSumFlow	-0.720	-0.249					
	DaysLT40	0.695	0.231					
	RB0_L	0.692	0.434					
	MeanWinFlow	0.686	0.772					
	MeanSprFlow	-0.611	-0.170					
RB0_L	DaysLT40	0.849	0.829	MeanSumFlow	-0.538	0.669	-0.273	0.614
	MaxAnnFlow	-0.798	-0.817					
	MeanSumFlow	-0.723	-0.726					
	MeanAnnFlow	-0.698	-0.695					
	RB0_ha1	0.692	0.434					
	LL0_L	0.597	0.616					
	DaysGT100	-0.587	-0.602					
	LL0_ha1	0.546	0.591					

In Rush Creek, where Grant Reservoir allows for more control of flows, decisions will need to be made regarding the magnitude of peak flows, duration of peak flows, the timing of peak flows, the speed at which peak flows are ramped down to base summer flows, the lower limit for summer base flows, timing of reduction to even lower winter flows, level of low winter flows, and duration of low winter flows. A synthesis report that will be collaboratively developed by a diverse group of scientists (i.e. geomorphologists, riparian ecologists, and fisheries biologists) will address these aspects of the Rush Creek hydrograph in making flow recommendations. The synthesis report will also evaluate the ability of LADWP to feasibly and reliably deliver these flows.

From these analyses it appears that providing relatively high channel forming flows for a relatively short time period from mid- to late June might be a reasonable strategy to maintain and enhance the brown trout fish population in Rush Creek. Flows could be ramped up relatively fast and then ramped down at a slower rate through early July to ensure fish were not stranded during declining flows. We suspect that very low summer flows (< 20 cfs) would negatively impact abundances of brown trout and documented a slight negative association between low flows and condition of brown trout. Thus, we believe a minimum summer flow above 20 cfs would probably be needed.

Maintaining water temperatures that are ideal for growth of brown trout in Rush Creek appears more critical than flow levels within the range of flows we analyzed. We strongly recommend managing flows and riparian vegetation within Rush Creek below Grant Reservoir to limit the number of days that peak water temperatures exceed 70˚F. Ideally, peak water temperatures should not exceed 67˚F. Grant Reservoir storage is negatively correlated to water temperature (high storage provides cooler temperatures), especially during late summer. We strongly recommend that Grant Reservoir be maintained as near to full pool as possible throughout the hottest part of the summer to provide cooler waters to lower Rush Creek. The synthesis report due later in 2009 will address minimum storage pool requirements in Grant Reservoir, as well as additional management strategies to maintain or augment storage during the critical summer months. We also believe that additional solar shading of the MGORD and Rush Creek stream channel, especially between Highway 395 and the Narrows, could help mediate temperatures. When completed later in 2009, the SNTEMP model will provide better information regarding the effects of additional shading along these two reaches of Rush Creek.

Water temperatures currently do not rise high enough in lower Lee Vining Creek to limit trout populations. High flows in lower Lee Vining Creek were negatively associated with abundances and growth of age-0 brown and rainbow trout. We recommend exploring options for transferring additional water from Lee Vining Creek to Grant Reservoir during wet and average years. It appears that if maximum flows could be held below 250 cfs and mean summer flows held below 100 cfs, age-0 trout would survive and grow better than at higher flows; however geomorphic and riparian needs may require higher peak flows. As previously mentioned, the synthesis report must weigh the needs of the entire stream ecosystem and make recommendations that benefit the whole ecosystem.

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Appendix A – Days Water Temperature Data Were Available for Year and Summer

Table A1. Number of days per year water temperature information was available in Rush Creek by site and year.

Code	Stream	Location	Year	Days
DITCH	Rush Creek - MGORD	Approximately 100 ft downstream of footbridge at lower end of MGORD	1999	83
DITCH	Rush Creek - MGORD	Approximately 100 ft downstream of footbridge at lower end of MGORD	2000	366
DITCH	Rush Creek - MGORD	Approximately 100 ft downstream of footbridge at lower end of MGORD	2001	365
DITCH	Rush Creek - MGORD	Approximately 100 ft downstream of footbridge at lower end of MGORD	2002	347
DITCH	Rush Creek - MGORD	Approximately 100 ft downstream of footbridge at lower end of MGORD	2003	171
DITCH	Rush Creek - MGORD	Approximately 100 ft downstream of footbridge at lower end of MGORD	2004	158
DITCH	Rush Creek - MGORD	Approximately 100 ft downstream of footbridge at lower end of MGORD	2005	365
DITCH	Rush Creek - MGORD	Approximately 100 ft downstream of footbridge at lower end of MGORD	2006	365
DITCH	Rush Creek - MGORD	Approximately 100 ft downstream of footbridge at lower end of MGORD	2007	365
DITCH	Rush Creek - MGORD	Approximately 100 ft downstream of footbridge at lower end of MGORD	2008	293
RUSH395	Rush Creek - 395	At old Highway 395 bridge	2005	214
RUSH395	Rush Creek - 395	At old Highway 395 bridge	2006	365
RUSH395	Rush Creek - 395	At old Highway 395 bridge	2007	365
RUSH395	Rush Creek - 395	At old Highway 395 bridge	2008	295
RUSHCORD	Rush Creek - County Road	Main channel of Rush Creek just above the washed out dirt road ford above the County Road	1999	83
RUSHCORD	Rush Creek - County Road	Main channel of Rush Creek just above the washed out dirt road ford above the County Road	2000	366
RUSHCORD	Rush Creek	Main channel of Rush Creek just above the	2001	365

Code	Stream	Location	Year	Days
	- County Road	washed out dirt road ford above the County Road		
RUSHCORD	Rush Creek - County Road	Main channel of Rush Creek just above the washed out dirt road ford above the County Road	2002	347
RUSHCORD	Rush Creek - County Road	Main channel of Rush Creek just above the washed out dirt road ford above the County Road	2003	222
RUSHCORD	Rush Creek - County Road	Main channel of Rush Creek just above the washed out dirt road ford above the County Road	2004	366
RUSHCORD	Rush Creek - County Road	Main channel of Rush Creek just above the washed out dirt road ford above the County Road	2005	181
RUSHCORD	Rush Creek - County Road	Main channel of Rush Creek just above the washed out dirt road ford above the County Road	2006	215
RUSHCORD	Rush Creek - County Road	Main channel of Rush Creek just above the washed out dirt road ford above the County Road	2007	365
RUSHCORD	Rush Creek - County Road	Main channel of Rush Creek just above the washed out dirt road ford above the County Road	2008	296
RUSHNAR	Rush Creek - At Narrows	Main channel of Rush Creek below the Narrows	1999	83
RUSHNAR	Rush Creek - At Narrows	Main channel of Rush Creek below the Narrows	2000	366
RUSHNAR	Rush Creek - At Narrows	Main channel of Rush Creek below the Narrows	2001	365
RUSHNAR	Rush Creek - At Narrows	Main channel of Rush Creek below the Narrows	2002	202
RUSHNAR	Rush Creek - At Narrows	Main channel of Rush Creek below the Narrows	2003	262
RUSHNAR	Rush Creek - At Narrows	Main channel of Rush Creek below the Narrows	2004	293
RUSHNAR	Rush Creek - At Narrows	Main channel of Rush Creek below the Narrows	2005	41
RUSHNAR	Rush Creek - At Narrows	Main channel of Rush Creek below the Narrows	2006	291

Table A2. Number of days per summer (June through September) water temperature information was available in Rush Creek by site and year (122 days indicates all days were available).

Code	Stream	Location	Year	Summer Days
DITCH	Rush Creek - MGORD	Approximately 100 ft downstream of footbridge at lower end of MGORD	2000	122
DITCH	Rush Creek - MGORD	Approximately 100 ft downstream of footbridge at lower end of MGORD	2001	122
DITCH	Rush Creek - MGORD	Approximately 100 ft downstream of footbridge at lower end of MGORD	2002	122
DITCH	Rush Creek - MGORD	Approximately 100 ft downstream of footbridge at lower end of MGORD	2005	122
DITCH	Rush Creek - MGORD	Approximately 100 ft downstream of footbridge at lower end of MGORD	2006	122
DITCH	Rush Creek - MGORD	Approximately 100 ft downstream of footbridge at lower end of MGORD	2007	122
DITCH	Rush Creek - MGORD	Approximately 100 ft downstream of footbridge at lower end of MGORD	2008	122
RUSH395	Rush Creek - 395	At old Highway 395 bridge	2005	122
RUSH395	Rush Creek - 395	At old Highway 395 bridge	2006	122
RUSH395	Rush Creek - 395	At old Highway 395 bridge	2007	122
RUSH395	Rush Creek - 395	At old Highway 395 bridge	2008	122
RUSHCORD	Rush Creek - County Road	Main channel of Rush Creek just above the washed out dirt road ford above the County Road	2000	122
RUSHCORD	Rush Creek - County Road	Main channel of Rush Creek just above the washed out dirt road ford above the County Road	2001	122
RUSHCORD	Rush Creek - County Road	Main channel of Rush Creek just above the washed out dirt road ford above the County Road	2002	122
RUSHCORD	Rush Creek - County Road	Main channel of Rush Creek just above the washed out dirt road ford above the County Road	2003	50
RUSHCORD	Rush Creek - County Road	Main channel of Rush Creek just above the washed out dirt road ford above the County Road	2004	122

Code	Stream	Location	Year	Summer Days
RUSHCORD	Rush Creek - County Road	Main channel of Rush Creek just above the washed out dirt road ford above the County Road	2005	30
RUSHCORD	Rush Creek - County Road	Main channel of Rush Creek just above the washed out dirt road ford above the County Road	2006	122
RUSHCORD	Rush Creek - County Road	Main channel of Rush Creek just above the washed out dirt road ford above the County Road	2007	122
RUSHCORD	Rush Creek - County Road	Main channel of Rush Creek just above the washed out dirt road ford above the County Road	2008	122
RUSHNAR	Rush Creek - At Narrows	Main channel of Rush Creek below the Narrows	2000	122
RUSHNAR	Rush Creek - At Narrows	Main channel of Rush Creek below the Narrows	2001	122
RUSHNAR	Rush Creek - At Narrows	Main channel of Rush Creek below the Narrows	2002	15
RUSHNAR	Rush Creek - At Narrows	Main channel of Rush Creek below the Narrows	2003	19
RUSHNAR	Rush Creek - At Narrows	Main channel of Rush Creek below the Narrows	2004	122
RUSHNAR	Rush Creek - At Narrows	Main channel of Rush Creek below the Narrows	2006	122

Appendix B – Data used in Regression Analyses

Table B1 – Rush Creek regression data.

Code	Year	K	Biom Tot	Dens 0	Age-0 Mean Length	Dens 1+	Min Ann Flow	Max Ann Flow	Mean Sum Flow	Sum Days <50cfs	Sum Days >150cfs	Mean June Flow	Mean July low	Mean Aug Flow	Mean Sept Flow
CoRd	2000	1.07	84.0	3883.8	83.2	871.8	48.6	255.6	95.8	0	11	125.3	125.4	71.4	60.7
CoRd	2001	0.97	78.2	1934.2	87.1	1150.1	47.8	202.1	89.2	0	16	153.0	79.3	67.1	58.4
CoRd	2002	0.99	62.4	2451.2	89.9	641.4	49.2	224.5	81.0	0	8	126.5	79.5	61.7	57.1
CoRd	2003	0.97	76.8	2823.2	86.8	913.7	40.6	282.7	90.3	3	12	158.8	82.6	63.1	57.8
CoRd	2004	0.99	75.9	1980.8	93.9	873.1	39.1	371.7	92.1	31	18	199.9	67.6	53.8	49.2
CoRd	2005	1.08	65.0	1304.7	91.9	702.9	40.1	416.9	184.1	5	64	271.7	300.5	106.0	57.1
CoRd	2006	1.00	106.7	3298.7	91.3	912.1	47.8	583.7	287.1	0	70	526.7	427.6	126.2	68.7
CoRd	2007	0.92	120.9	4876.8	81.2	1894.9	26.5	66.6	49.5	65	0	55.2	50.5	46.6	45.6
CoRd	2008	0.89	85.7	2243.5	89.7	1641.5	23.5	341.4	105.2	49	27	259.9	75.6	50.7	37.5
Lower	1999	0.97	163.3	4266.6	90.5	1548.6	46.8	247.4	107.5	1	20	102.9	174.5	79.8	71.5
Lower	2000	1.10	112.2	5856.4	83.1	1041.5	48.6	255.6	95.8	0	11	125.3	125.4	71.4	60.7
Lower	2001	1.00	81.7	3146.1	90.1	1054.6	47.8	202.1	89.2	0	16	153.0	79.3	67.1	58.4
Lower	2002	1.00	71.7	4423.0	90.3	429.4	49.2	224.5	81.0	0	8	126.5	79.5	61.7	57.1
Lower	2003	0.98	90.5	4573.4	91.9	862.4	40.6	282.7	90.3	3	12	158.8	82.6	63.1	57.8
Lower	2004	1.01	55.8	2903.2	92.5	312.9	39.1	371.7	92.1	31	18	199.9	67.6	53.8	49.2
Lower	2005	1.00	94.0	1499.6	96.2	1053.0	40.1	416.9	184.1	5	64	271.7	300.5	106.0	57.1
Lower	2006	1.02	138.4	3101.4	95.3	965.2	47.8	583.7	287.1	0	70	526.7	427.6	126.2	68.7
Lower	2007	0.94	110.9	5730.8	82.4	1083.2	26.5	66.6	49.5	65	0	55.2	50.5	46.6	45.6
Upper	1999	1.03	89.8	NA	76.0	1111.2	31.7	201.0	78.2	1	12	53.5	135.0	64.9	58.0
Upper	2000	1.12	219.4	12819.0	83.4	2096.2	41.6	204.0	66.0	30	7	69.6	94.0	50.4	49.4
Upper	2001	1.03	150.5	10606.5	83.7	1150.2	40.6	161.0	67.2	21	8	113.9	54.4	51.9	49.6
Upper	2002	1.05	136.8	7077.3	85.4	1219.4	32.1	168.0	56.8	61	5	79.0	50.0	48.6	49.9
Upper	2003	1.03	122.6	2482.7	103.2	1065.4	30.6	203.0	60.4	82	9	100.1	49.6	45.8	47.1
Upper	2004	1.00	106.4	4229.1	93.3	620.0	28.8	343.0	70.5	90	14	160.0	41.8	40.1	42.1
Upper	2005	1.04	175.2	4645.8	88.6	1357.5	24.8	352.0	131.2	36	50	206.0	207.1	68.1	43.3
Upper	2006	1.02	167.7	8298.4	80.1	1341.5	38.9	477.0	233.1	15	64	437.1	346.8	95.6	53.8
Upper	2007	0.96	162.1	8325.6	77.8	1904.2	23.5	59.7	34.2	122	0	32.6	33.0	34.6	36.9
Upper	2008	0.98	108.0	2628.7	90.7	1429.3	16.5	299.0	84.6	78	22	220.3	48.1	40.9	31.7

Table B1 (continued). Rush Creek regression data.

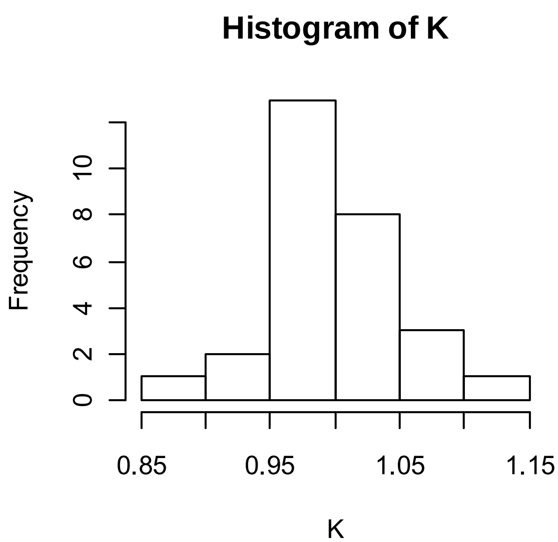
Code	Year	Avg Sum Temp	Avg Max Daily Sum Temp	Days >70F	Days >67F	Days Ideal Temp	Avg Max Daily Sum Temp	Grant Mean	Grant Min	Grant Max	Avg Spawn Flow	Avg Win Flow	Min Win Flow	Max Win Flow	Min Fall Flow	Max Spr Flow
CoRd	2000	59.0	66.8	16	58	31	66.8	44906	40047	48267	59.0	56.0	53.3	60.6	54.1	255.6
CoRd	2001	60.0	66.2	6	54	54	66.2	39682	34315	44575	53.9	52.6	47.8	62.5	48.6	202.1
CoRd	2002	61.0	67.7	39	82	36	67.7	27902	23876	31613	55.2	54.5	49.2	66.2	51.4	224.5
CoRd	2003	NA	NA	NA	NA	NA	NA	29934	18403	33827	57.5	54.4	42.0	65.9	52.6	282.7
CoRd	2004	60.6	68.4	47	82	26	68.4	21655	20217	24903	49.4	53.0	43.4	63.5	46.5	371.7
CoRd	2005	NA	NA	NA	NA	NA	NA	40061	29643	42870	51.2	53.7	44.9	70.8	46.6	416.9
CoRd	2006	60.1	66.0	2	43	75	66.0	46527	44253	48597	52.8	57.8	47.8	94.7	47.5	583.7
CoRd	2007	60.8	68.8	63	95	7	68.8	36299	30294	40772	68.3	50.2	33.4	68.0	58.3	63.7
CoRd	2008	61.6	69.2	59	87	24	69.2	17850	15465	23961	41.9	31.9	25.7	53.4	30.8	341.4
Lower	1999	NA	NA	NA	NA	NA	NA	45064	41712	48157	70.8	64.3	57.6	68.9	65.7	134.3
Lower	2000	58.8	65.7	3	44	61	65.7	44906	40047	48267	59.0	56.0	53.3	60.6	54.1	255.6
Lower	2001	59.8	67.1	35	79	31	67.1	39682	34315	44575	53.9	52.6	47.8	62.5	48.6	202.1
Lower	2002	61.0	67.7	39	82	36	67.7	27902	23876	31613	55.2	54.5	49.2	66.2	51.4	224.5
Lower	2003	NA	NA	NA	NA	NA	NA	29934	18403	33827	57.5	54.4	42.0	65.9	52.6	282.7
Lower	2004	57.0	62.3	5	28	56	62.3	21655	20217	24903	49.4	53.0	43.4	63.5	46.5	371.7
Lower	2005	NA	NA	NA	NA	NA	NA	40061	29643	42870	51.2	53.7	44.9	70.8	46.6	416.9
Lower	2006	56.5	61.2	0	1	98	61.2	46527	44253	48597	52.8	57.8	47.8	94.7	47.5	583.7
Lower	2007	60.8	68.8	63	95	7	68.8	36299	30294	40772	68.3	50.2	33.4	68.0	58.3	63.7
Upper	1999	NA	NA	NA	NA	NA	NA	45064	41712	48157	57.5	55.7	49.4	60.5	55.2	65.0
Upper	2000	59.4	62.7	0	0	147	62.7	44906	40047	48267	48.8	48.1	44.2	49.3	45.3	204.0
Upper	2001	60.8	64.0	0	35	101	64.0	39682	34315	44575	44.9	45.3	40.6	49.4	41.6	161.0
Upper	2002	63.1	66.1	11	65	83	66.1	27902	23876	31613	47.8	47.2	43.5	52.2	45.5	168.0
Upper	2003	NA	NA	NA	NA	NA	NA	29934	18403	33827	49.7	47.7	33.0	58.3	47.7	203.0
Upper	2004	NA	NA	NA	NA	NA	NA	21655	20217	24903	43.8	45.7	36.9	52.7	40.0	343.0
Upper	2005	56.5	60.6	0	0	108	60.6	40061	29643	42870	44.6	44.8	37.6	51.1	39.5	352.0
Upper	2006	56.9	60.4	0	0	122	60.4	46527	44253	48597	44.5	46.6	38.9	70.4	40.7	477.0
Upper	2007	61.3	67.6	38	82	28	67.6	36299	30294	40772	59.6	42.8	26.3	60.2	47.4	35.6
Upper	2008	63.4	68.5	58	76	56	68.5	17850	15465	23961	36.9	26.1	21.1	44.4	27.0	299.0

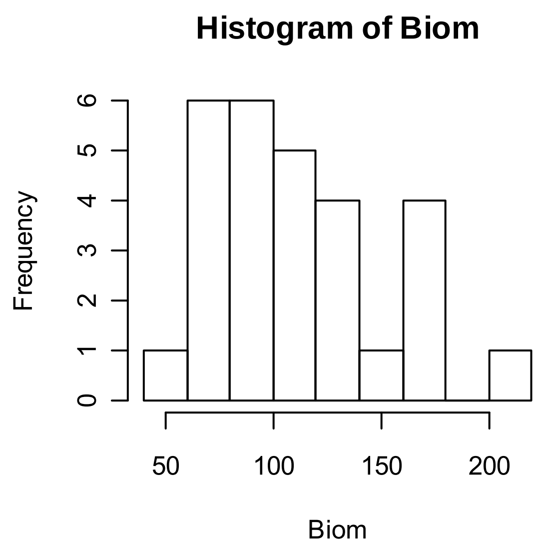
Table B2 – Lee Vining regression data

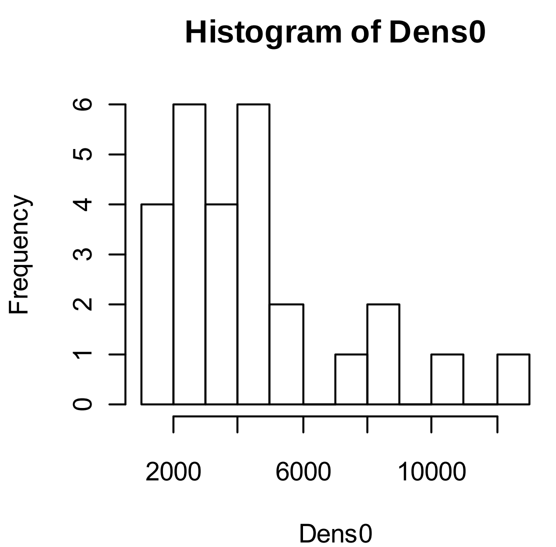
Year	RB0 ha1	LL0 ha1	RB0 L	LL0 L	Min Ann Flow	Mean Ann Flow	Max Ann Flow	Mean Sum Flow	Mean Spr Flow	Days < 40	Days > 100	Mean Winter Flow	Mean Fall Flow	Fall Minus Winter
1999	49	325	52.0	79.2	4.2	56.0	274.0	99.1	165.2	30	47	14.3	27.8	13.5
2000	179	465	78.8	89.6	19.0	55.2	258.0	77.3	143.5	41	33	34.3	32.2	-2.0
2001	324	620	88.6	101.6	16.5	42.7	201.0	41.1	103.7	75	4	29.3	30.0	0.7
2002	167	334	81.2	93.6	14.0	50.2	233.0	70.7	129.0	57	33	32.2	29.8	-2.4
2003	0	513	0.0	96.7	13.3	43.0	317.0	54.7	96.1	55	6	26.4	30.1	3.7
2004	495	448	71.7	94.2	19.4	43.7	141.0	50.1	83.3	59	8	37.9	28.6	-9.4
2005	0	6	0.0	72.0	19.3	78.9	372.0	143.0	184.3	8	64	31.1	27.7	-3.4
2006	605	118	51.8	85.4	16.0	105.2	457.0	189.1	297.2	0	71	39.6	38.7	-0.9
2007	336	605	100.6	108.8	9.0	28.1	45.0	29.5	40.1	82	0	32.6	39.0	6.5
2008	118	397	81.2	91.6	11.0	36.3	167.0	52.3	88.1	62	17	20.7	21.3	0.5

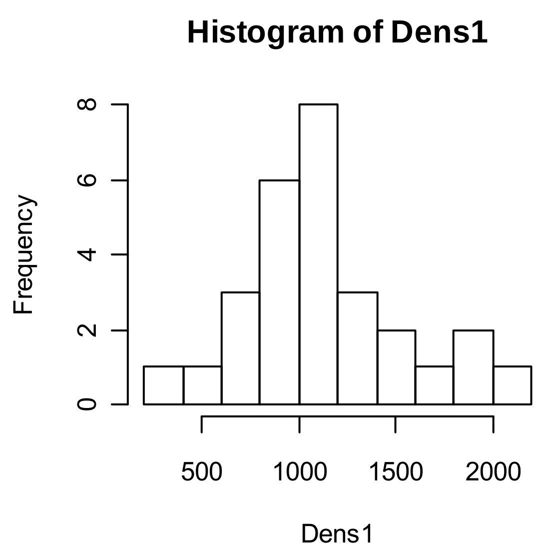
Appendix C - Histograms of untransformed and transformed data

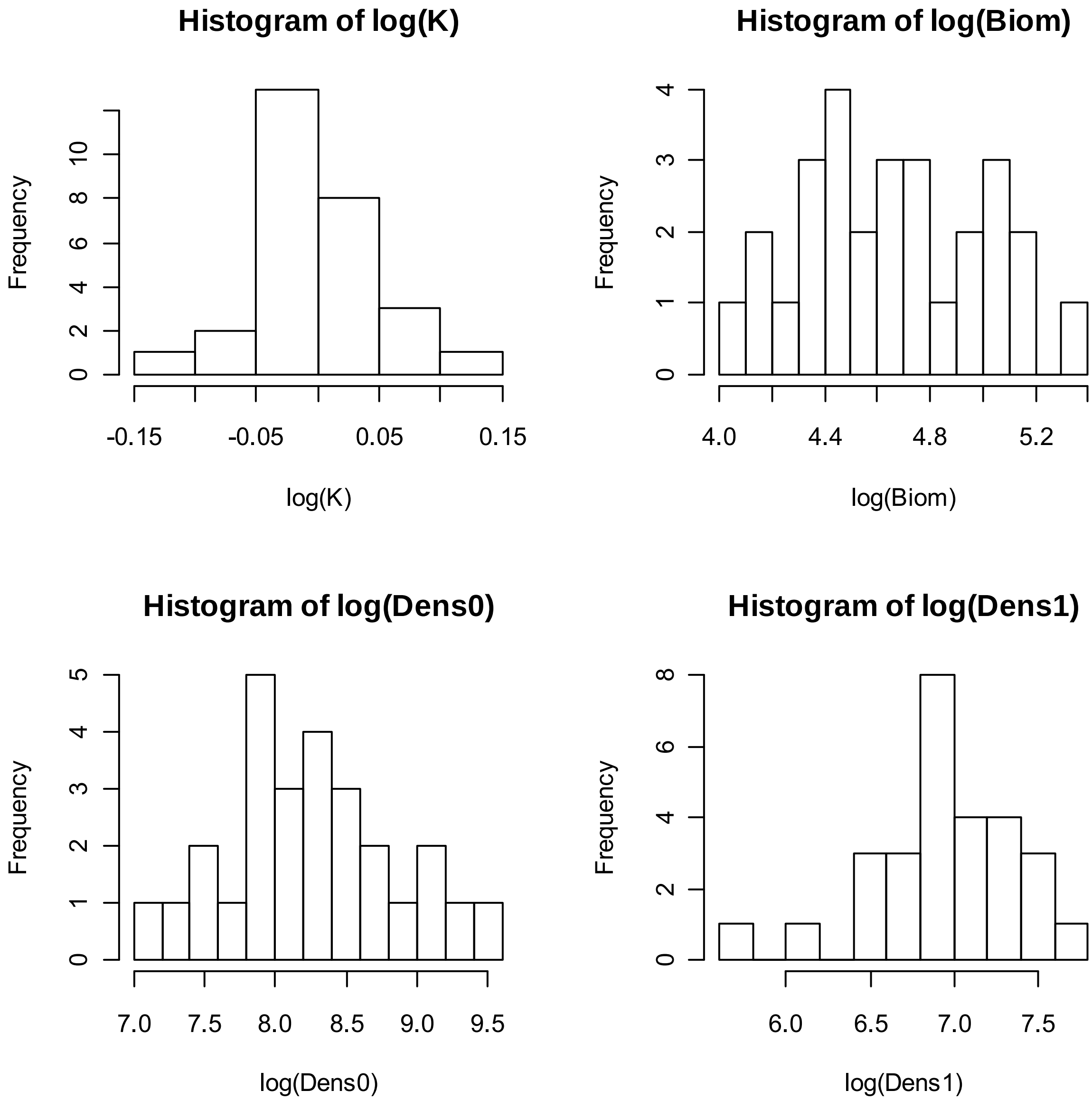
Rush Creek

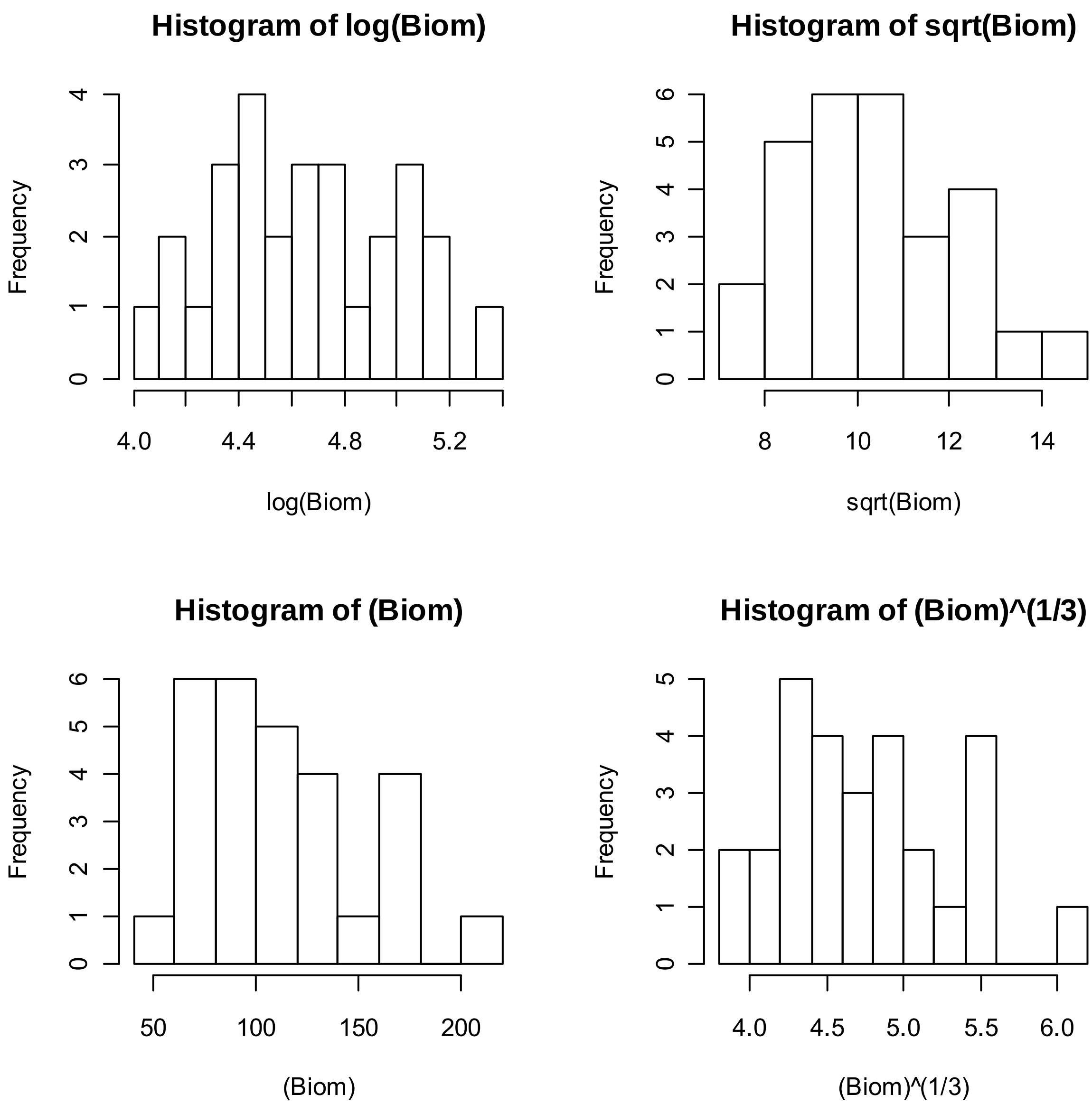


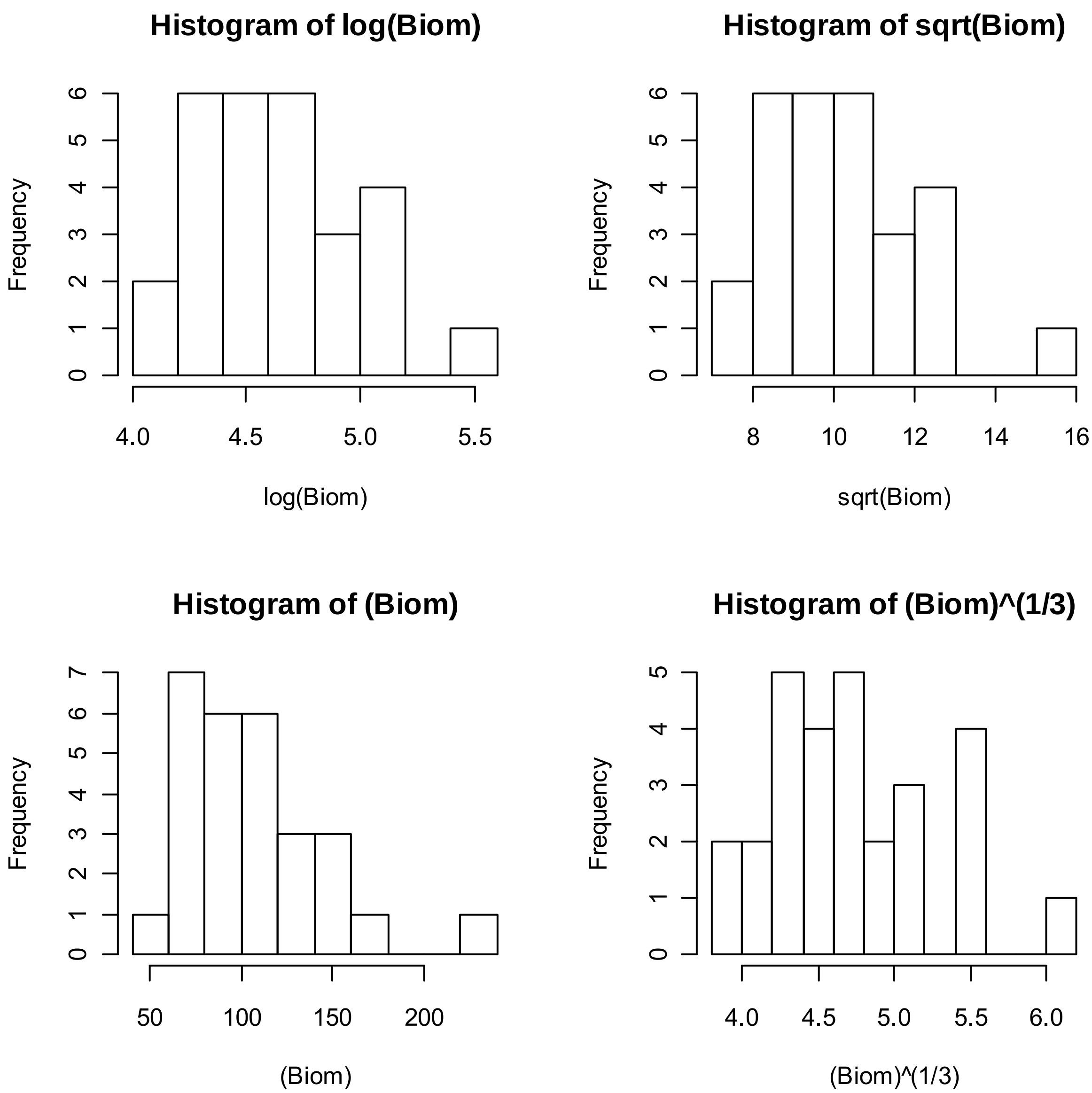


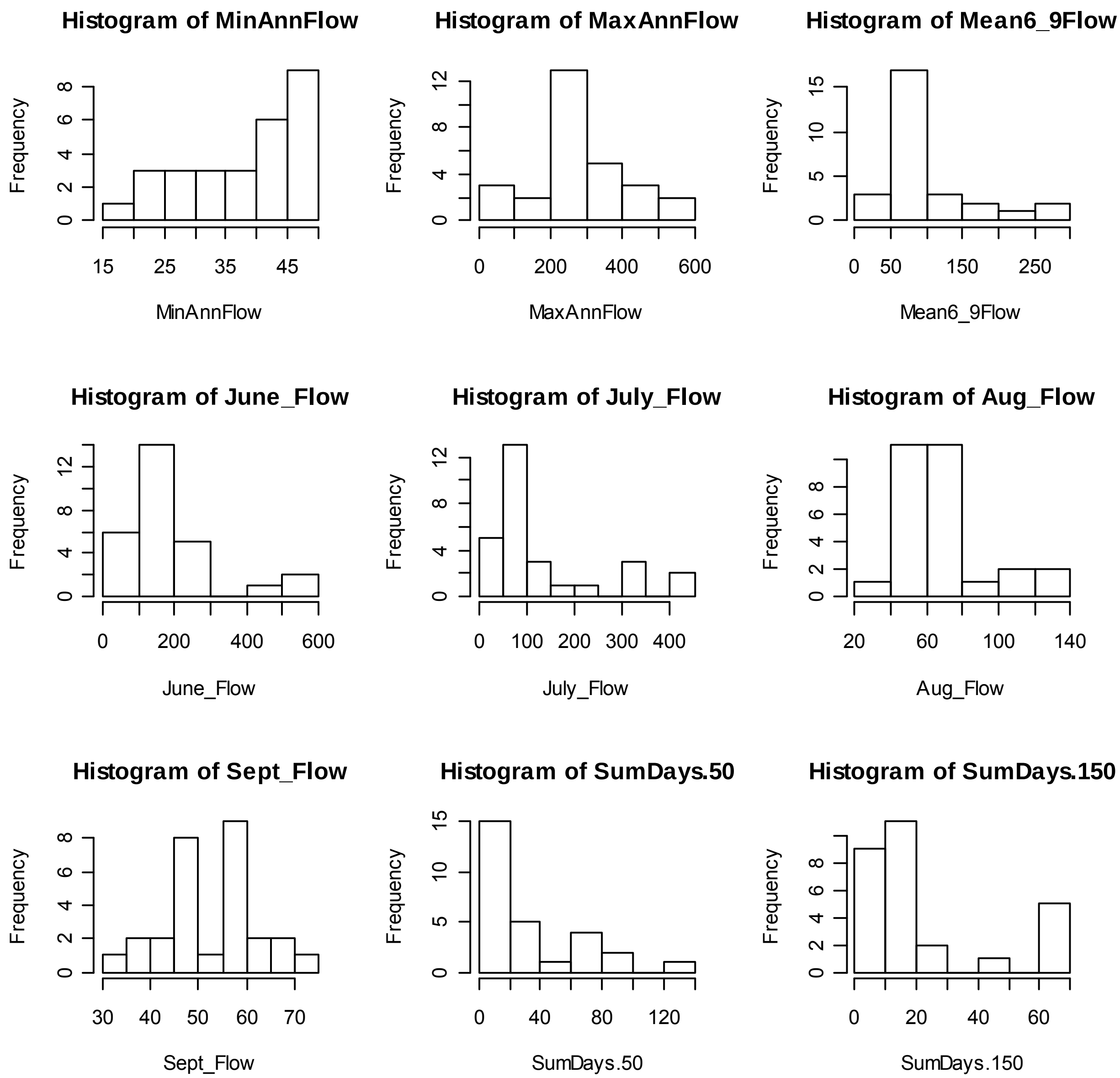


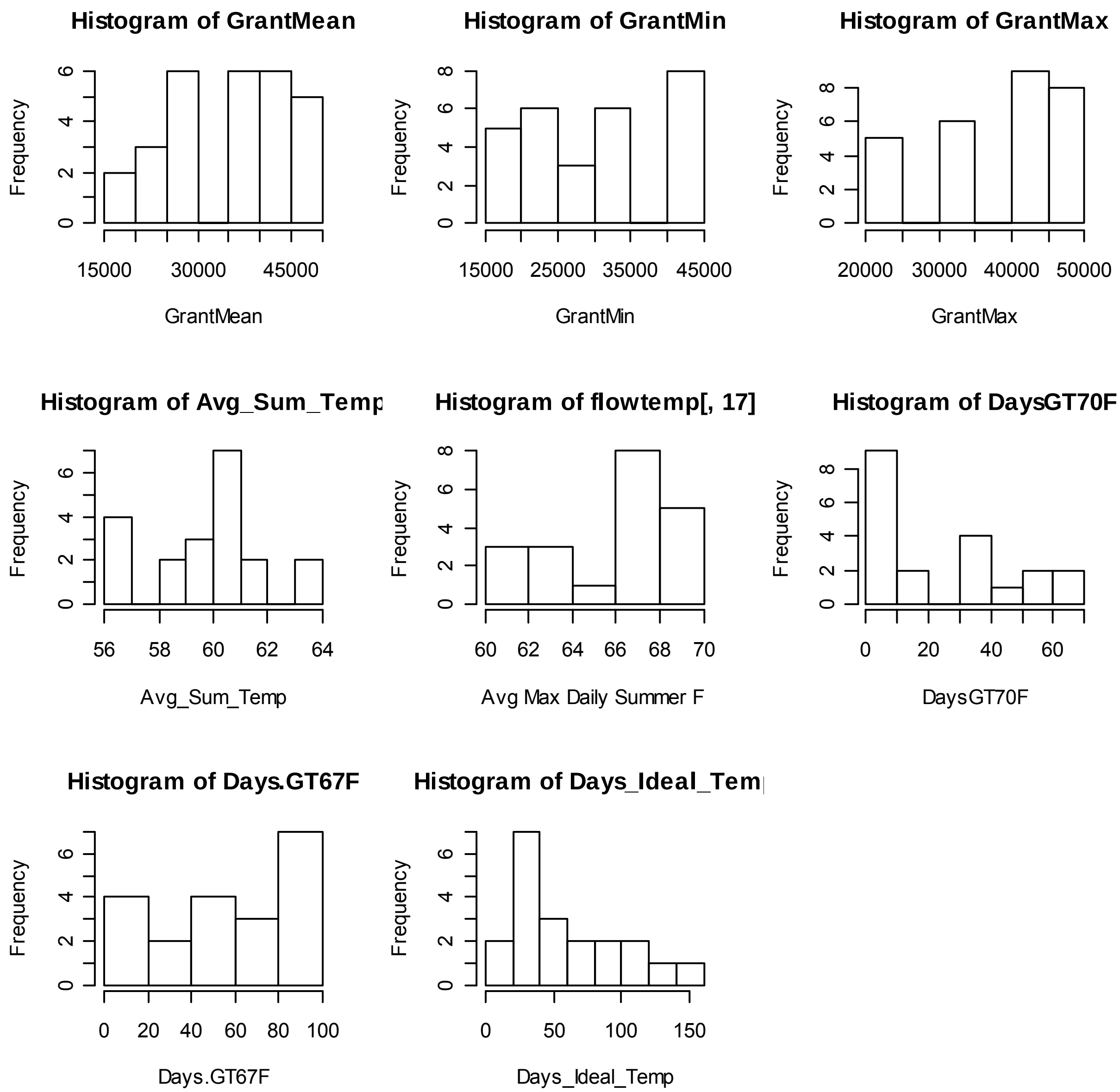


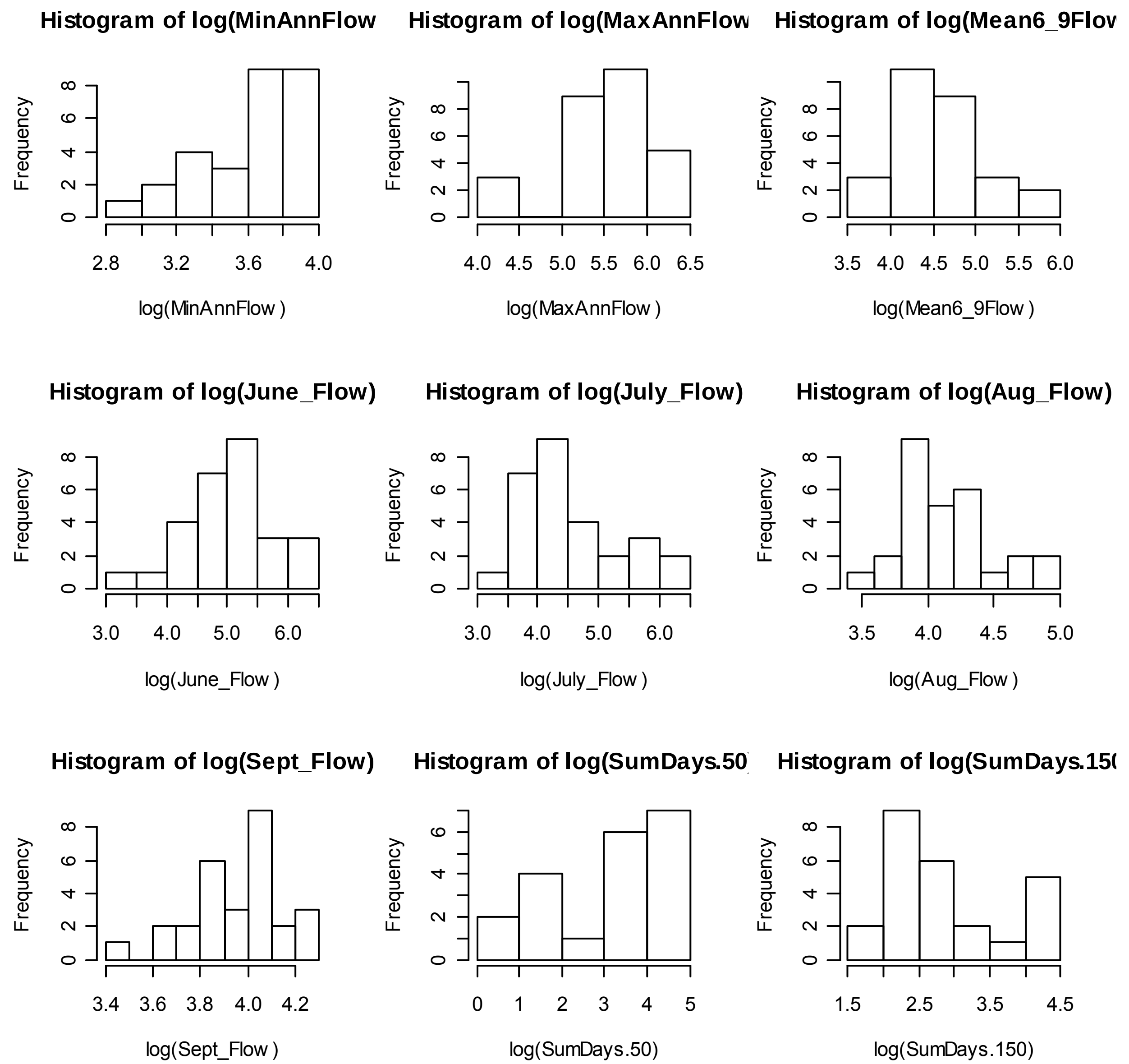

Histogram of log(K)
Frequency
log(K)
Histogram of log(Biom)
Frequency
log(Biom)
Histogram of log(Dens0)
Frequency
log(Dens0)
Histogram of log(Dens1)
Frequency
log(Dens1)

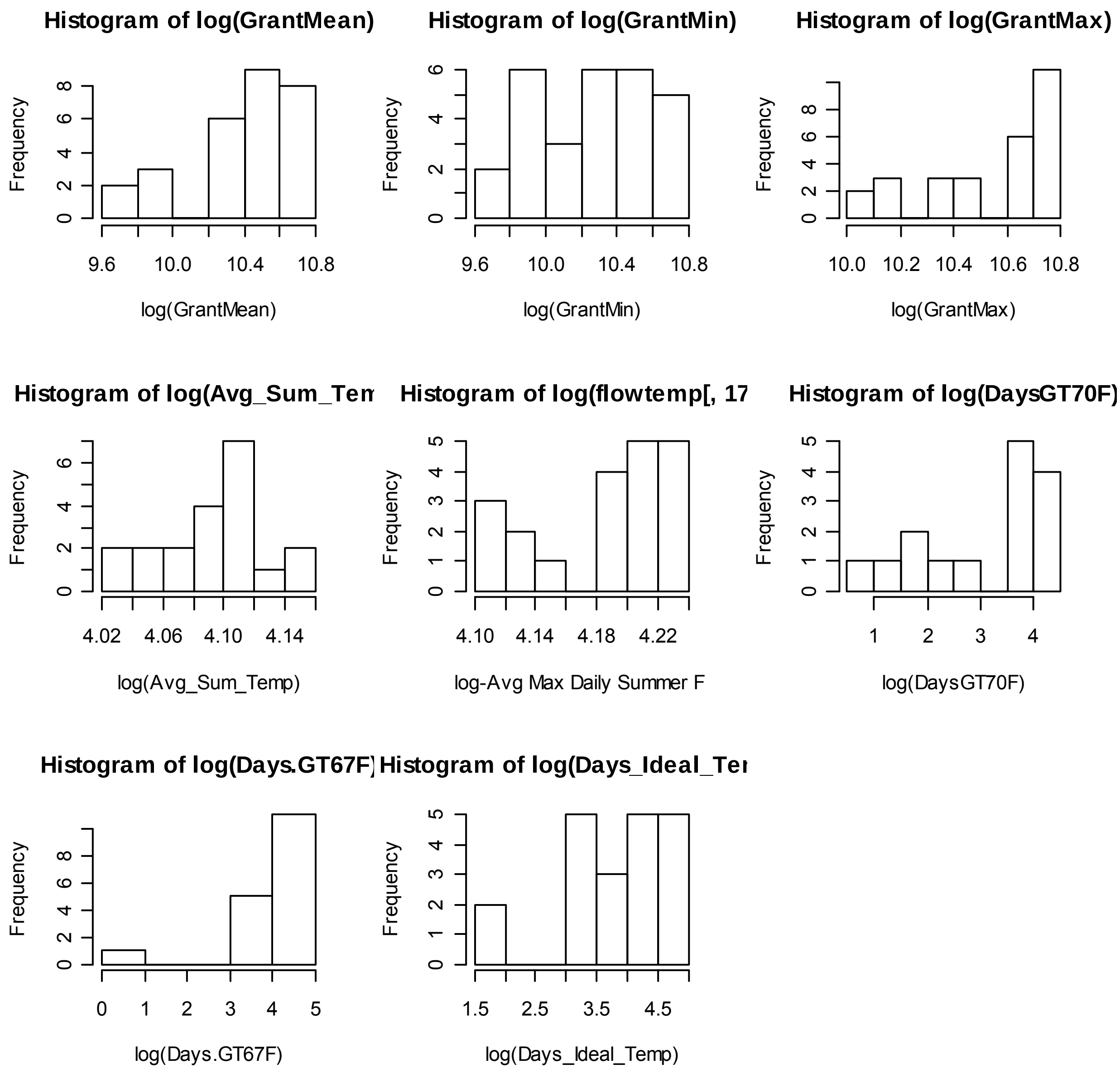

Histogram of log(Biom)
Frequency
0
1
2
3
4
4.0
4.4
4.8
5.2
log(Biom)
Histogram of sqrt(Biom)
Frequency
0
1
2
3
4
5
6
8
10
12
14
sqrt(Biom)
Histogram of (Biom)
Frequency
0
1
2
3
4
5
6
50
100
150
200
(Biom)
Histogram of (Biom)^(1/3)
Frequency
0
1
2
3
4
5
4.0
4.5
5.0
5.5
6.0
(Biom)^(1/3)


Histogram of log(Biom)
Frequency
0 1 2 3 4 5 6
4.0 4.5 5.0 5.5
log(Biom)
Histogram of sqrt(Biom)
Frequency
0 1 2 3 4 5 6
8 10 12 14 16
sqrt(Biom)
Histogram of (Biom)
Frequency
0 1 2 3 4 5 6 7
50 100 150 200
(Biom)
Histogram of (Biom)^(1/3)
Frequency
0 1 2 3 4 5
4.0 4.5 5.0 5.5 6.0
(Biom)^(1/3)

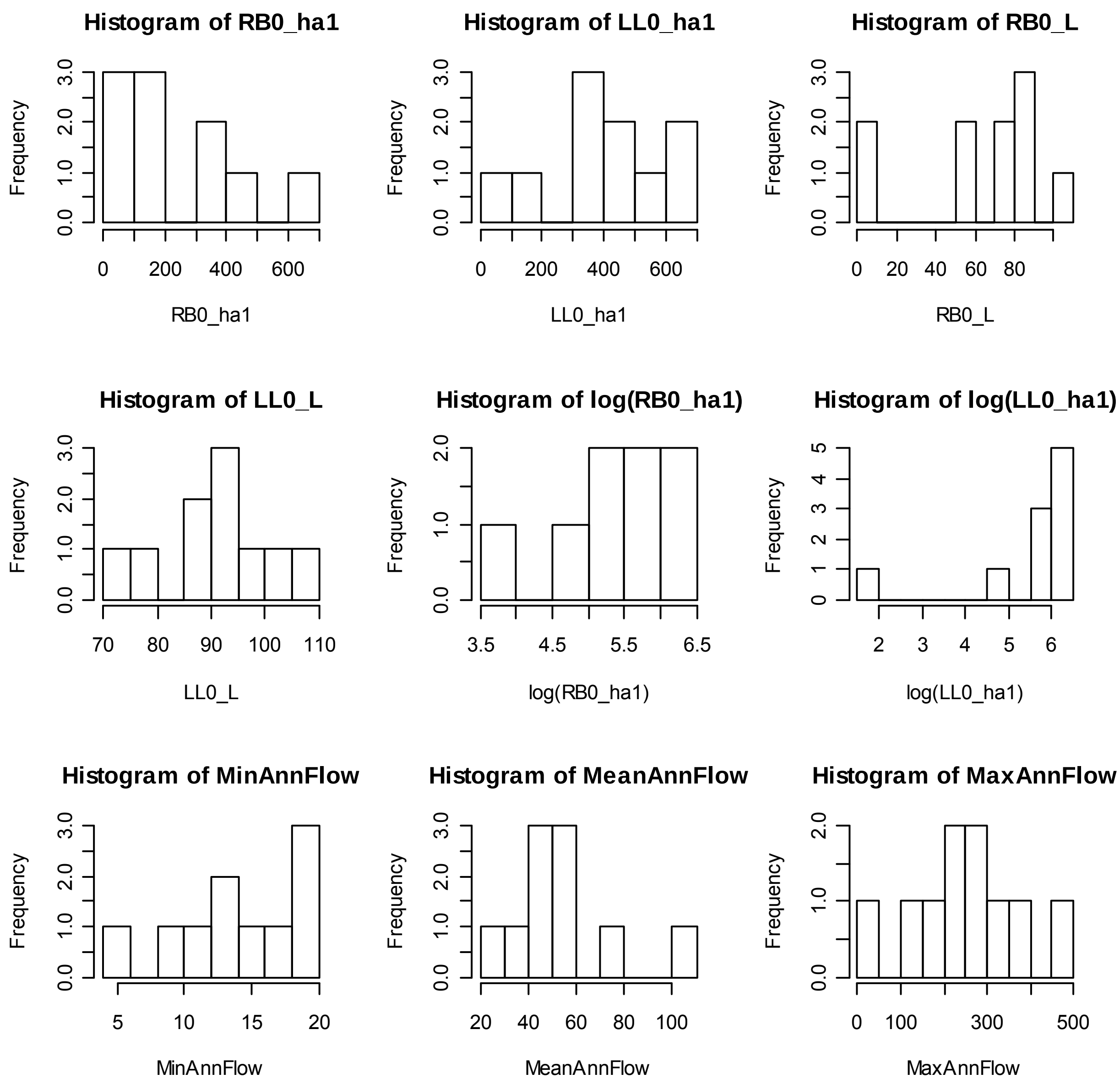

Histogram of MinAnnFlow
Frequency
0 2 4 6 8
15 25 35 45
MinAnnFlow
Histogram of MaxAnnFlow
Frequency
0 4 8 12
0 200 400 600
MaxAnnFlow
Histogram of Mean6_9Flow
Frequency
0 5 10 15
0 50 150 250
Mean6_9Flow
Histogram of June_Flow
Frequency
0 4 8 12
0 200 400 600
June_Flow
Histogram of July_Flow
Frequency
0 4 8 12
0 100 200 300 400
July_Flow
Histogram of Aug_Flow
Frequency
0 2 4 6 8
20 60 100 140
Aug_Flow
Histogram of Sept_Flow
Frequency
0 2 4 6 8
30 40 50 60 70
Sept_Flow
Histogram of SumDays.50
Frequency
0 5 10 15
0 40 80 120
SumDays.50
Histogram of SumDays.150
Frequency
0 2 4 6 8
0 20 40 60
SumDays.150

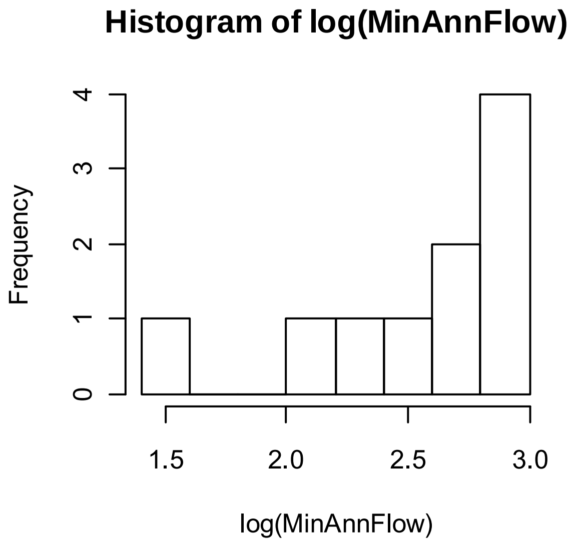

Histogram of GrantMean
Frequency
GrantMean
Histogram of GrantMin
GrantMin
Histogram of GrantMax
GrantMax
Histogram of Avg_Sum_Temp
Avg_Sum_Temp
Histogram of flowtemp[, 17]
Avg Max Daily Summer F
Histogram of DaysGT70F
DaysGT70F
Histogram of Days.GT67F
Days.GT67F
Histogram of Days_Ideal_Tem
Days_Ideal_Temp

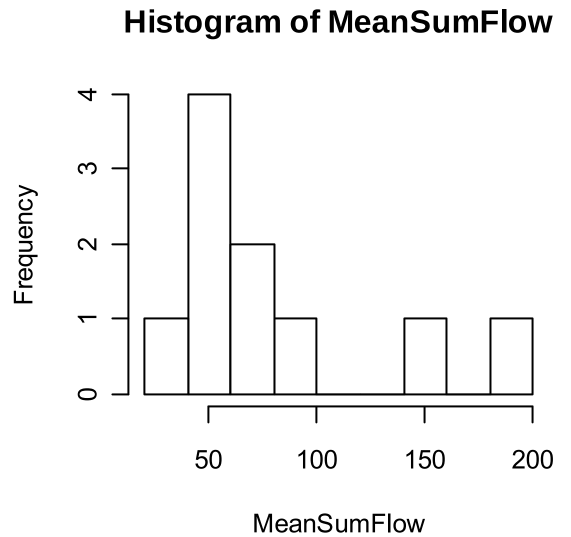

Histogram of log(MinAnnFlow
Frequency
log(MinAnnFlow)
Histogram of log(MaxAnnFlow
Frequency
log(MaxAnnFlow)
Histogram of log(Mean6_9Flov
Frequency
log(Mean6_9Flow)
Histogram of log(June_Flow)
Frequency
log(June_Flow)
Histogram of log(July_Flow)
Frequency
log(July_Flow)
Histogram of log(Aug_Flow)
Frequency
log(Aug_Flow)
Histogram of log(Sept_Flow)
Frequency
log(Sept_Flow)
Histogram of log(SumDays.50)
Frequency
log(SumDays.50)
Histogram of log(SumDays.15(
Frequency
log(SumDays.150)

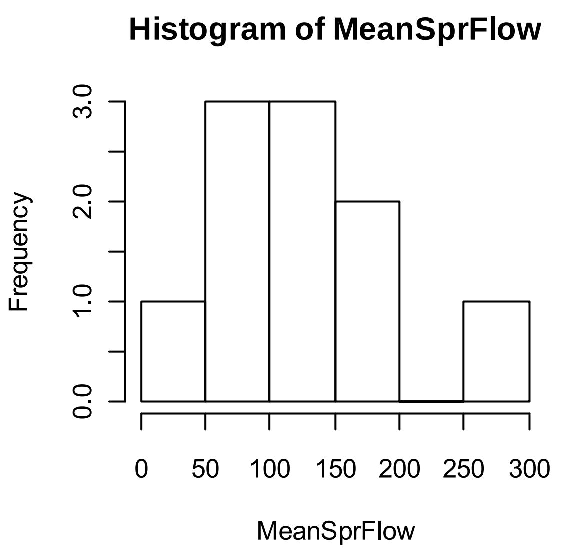

Histogram of log(GrantMean)
log(GrantMean)
Histogram of log(GrantMin)
log(GrantMin)
Histogram of log(GrantMax)
log(GrantMax)
Histogram of log(Avg_Sum_Ten
log(Avg_Sum_Temp)
Histogram of log(flowtemp[, 17
log-Avg Max Daily Summer F
Histogram of log(DaysGT70F)
log(DaysGT70F)
Histogram of log(Days.GT67F)
log(Days.GT67F)
Histogram of log(Days_Ideal_Ter
log(Days_Ideal_Temp)
Frequency

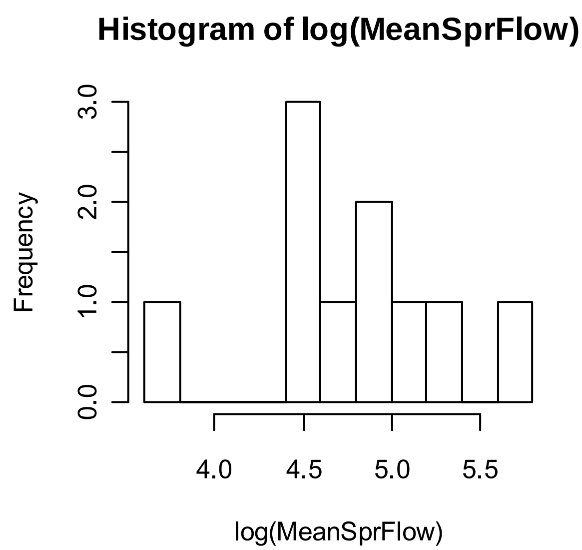
Lee Vining Creek




Histogram of log(MinAnnFlow)
Frequency
0
1
2
3
4
1.5
2.0
2.5
3.0
log(MinAnnFlow)


Histogram of MeanSumFlow
Frequency
0
1
2
3
4
50
100
150
200
MeanSumFlow

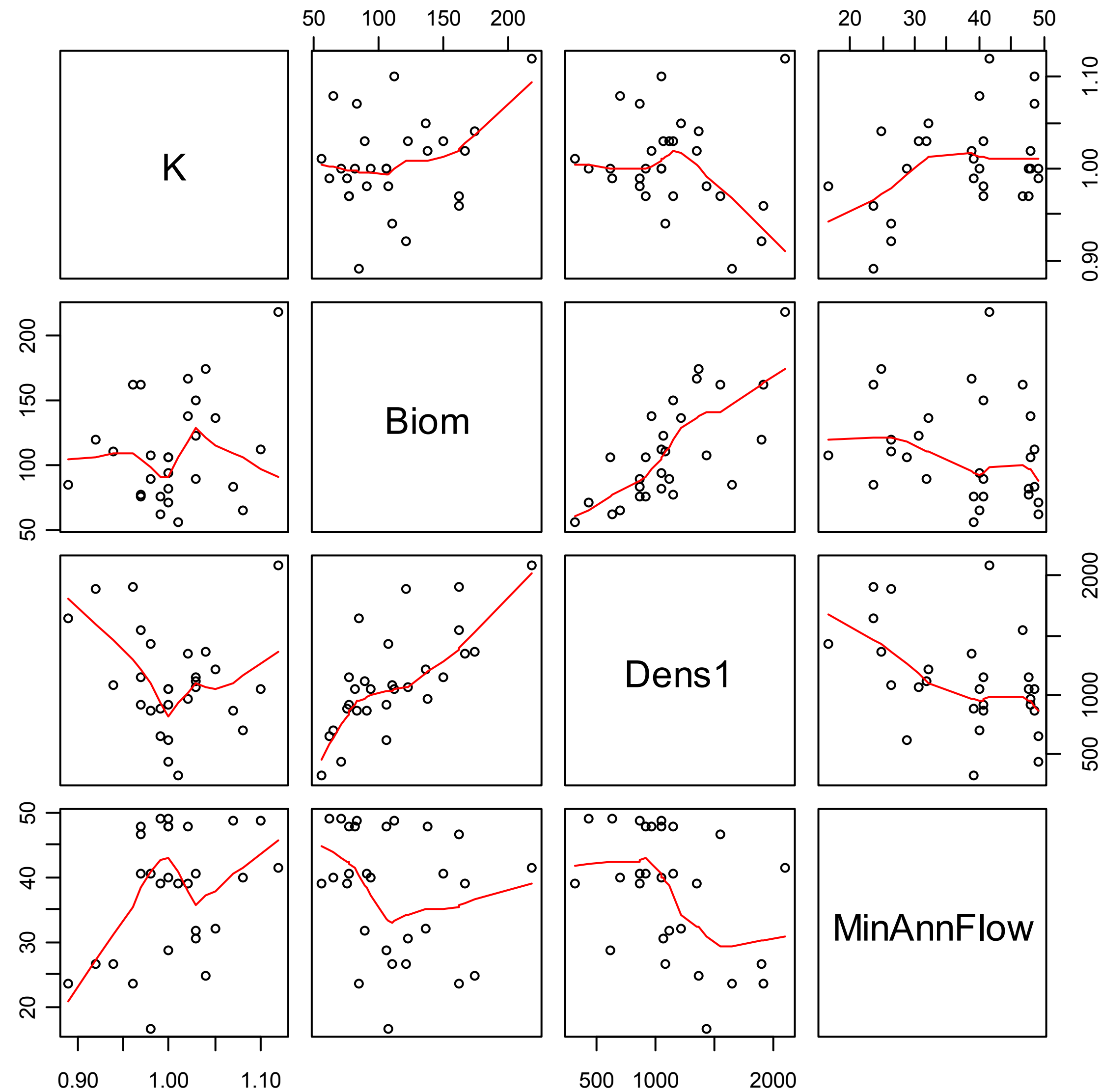

Histogram of MeanSprFlow
Frequency
0.0
1.0
2.0
3.0
0
50
100
150
200
250
300
MeanSprFlow

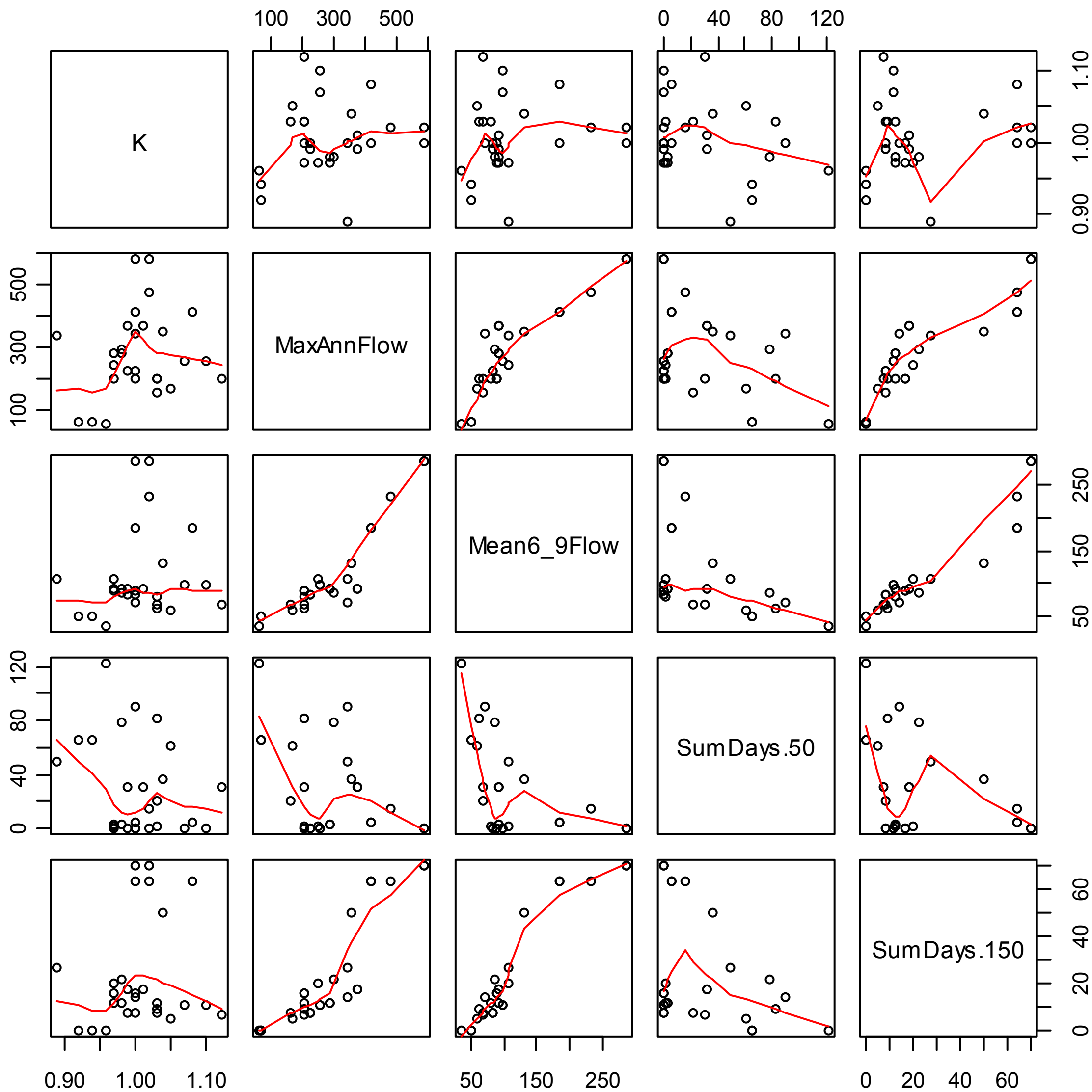

Histogram of log(MeanSprFlow)
Frequency
0.0
1.0
2.0
3.0
4.0
4.5
5.0
5.5
log(MeanSprFlow)

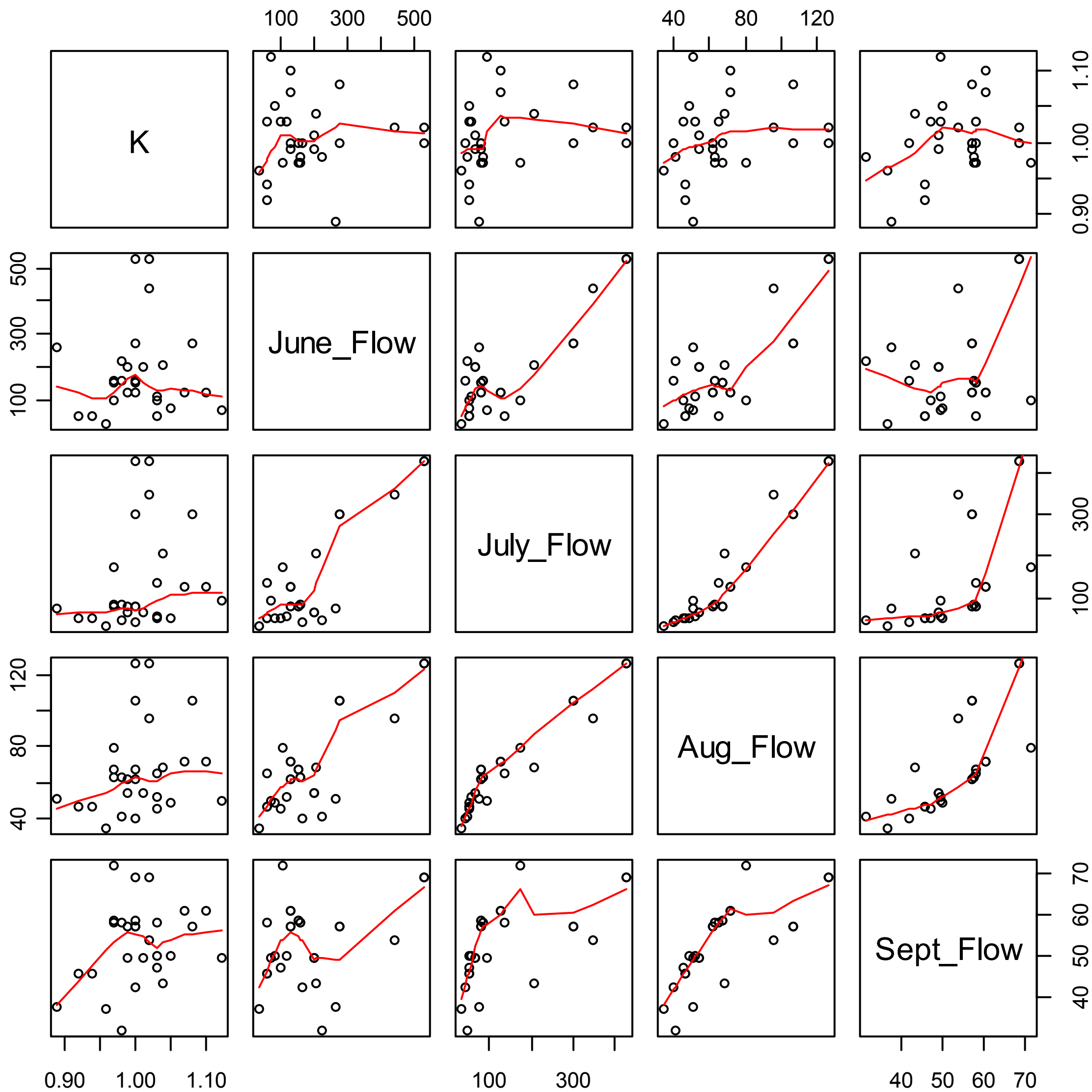
Appendix D – Bivariate Scatter Plots

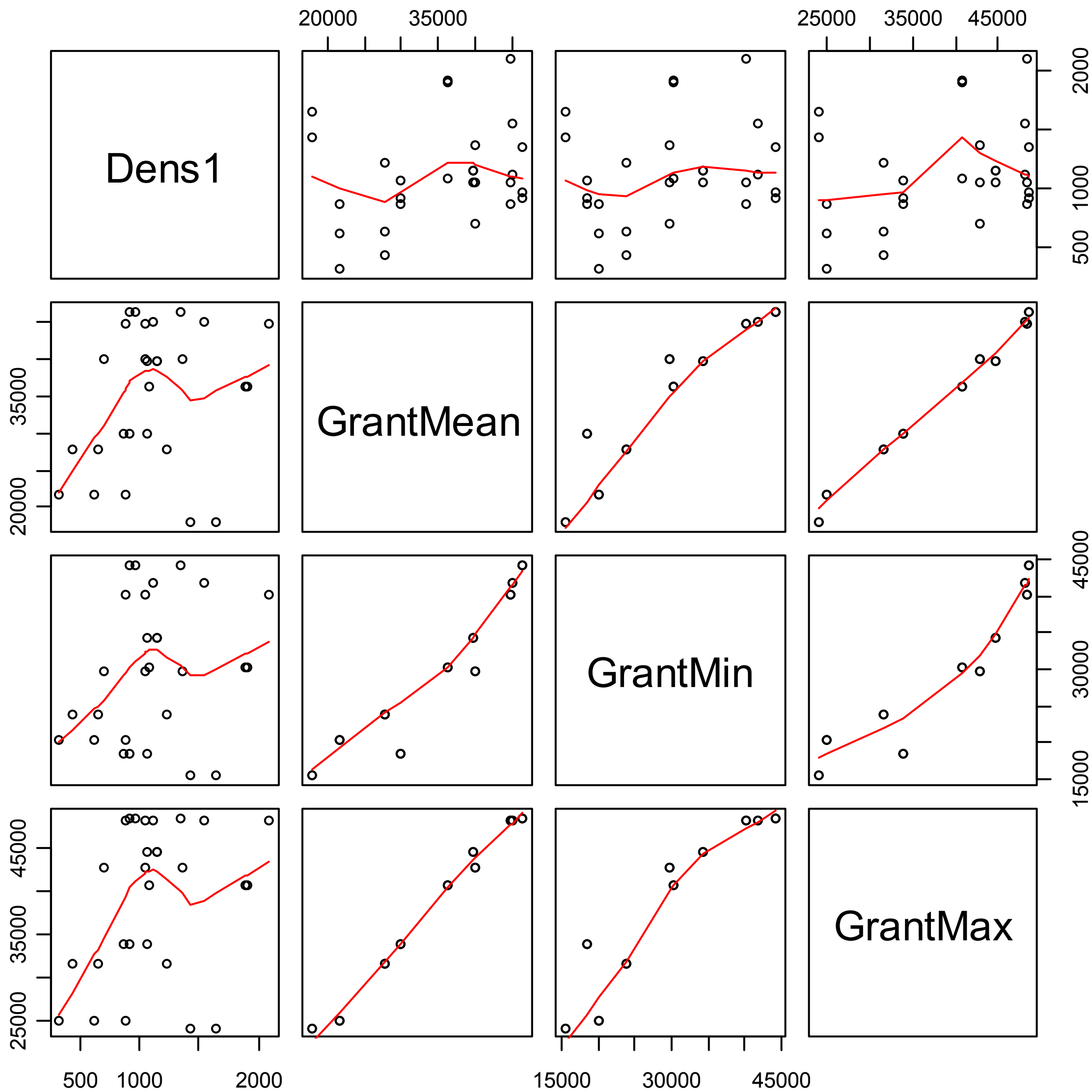
Rush Creek

JUST FLOW VARIABLES with n=28 observations

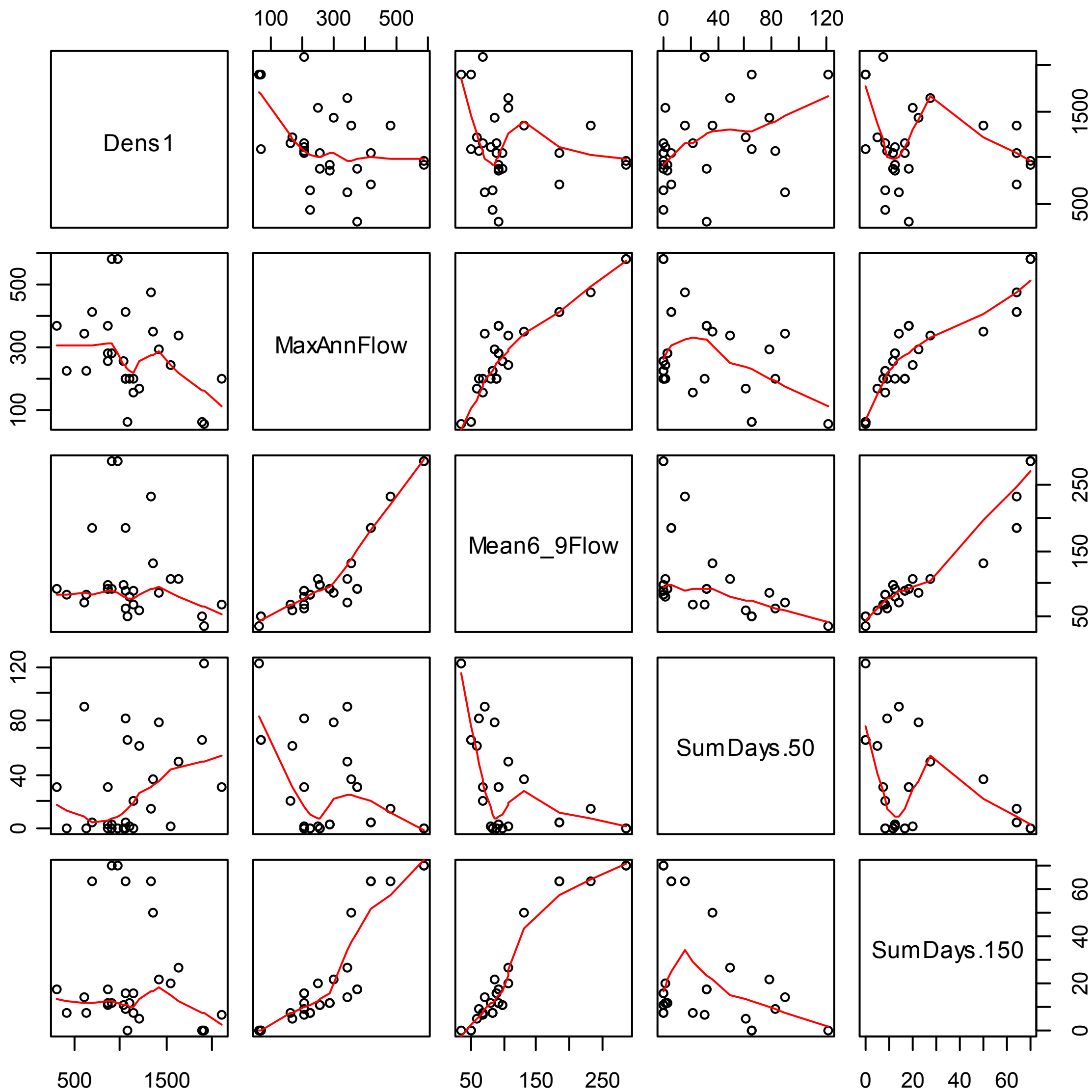



K
MaxAnnFlow
Mean6_9Flow
SumDays.50
SumDays.150
100
300
500
0
40
80
120
1.10
1.00
0.90
500
300
100
250
150
50
120
80
40
0
60
40
20
0
0.90
1.00
1.10
50
150
250
0
20
40
60

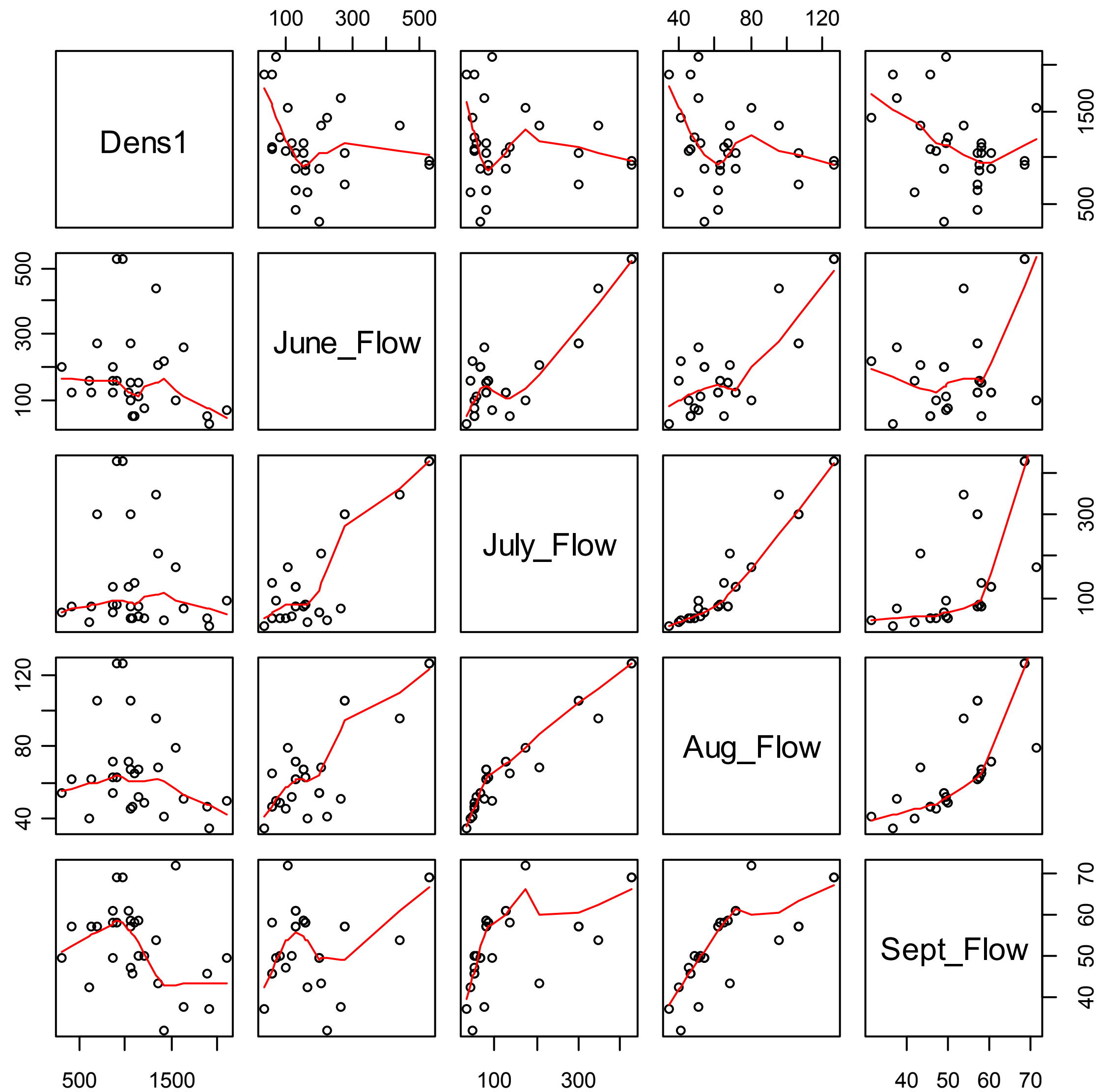

K
June_Flow
July_Flow
Aug_Flow
Sept_Flow
100 300 500
40 80 120
0.90 1.00 1.10
100 300
40 50 60 70



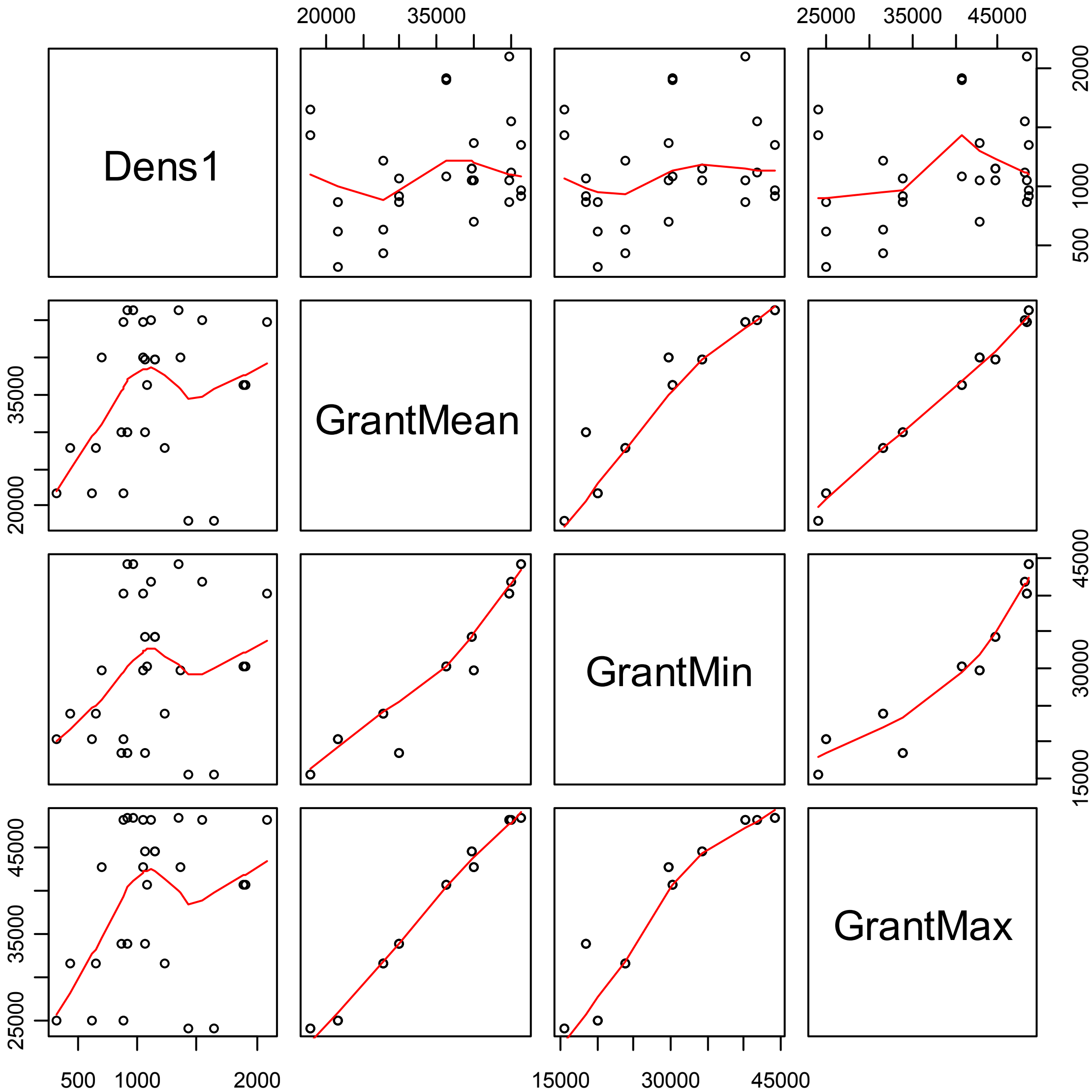
Dens1
GrantMean
GrantMin
GrantMax
20000
35000
25000
35000
45000
2000
1000
500
35000
20000
45000
30000
15000
45000
35000
25000
500
1000
2000
15000
30000
45000



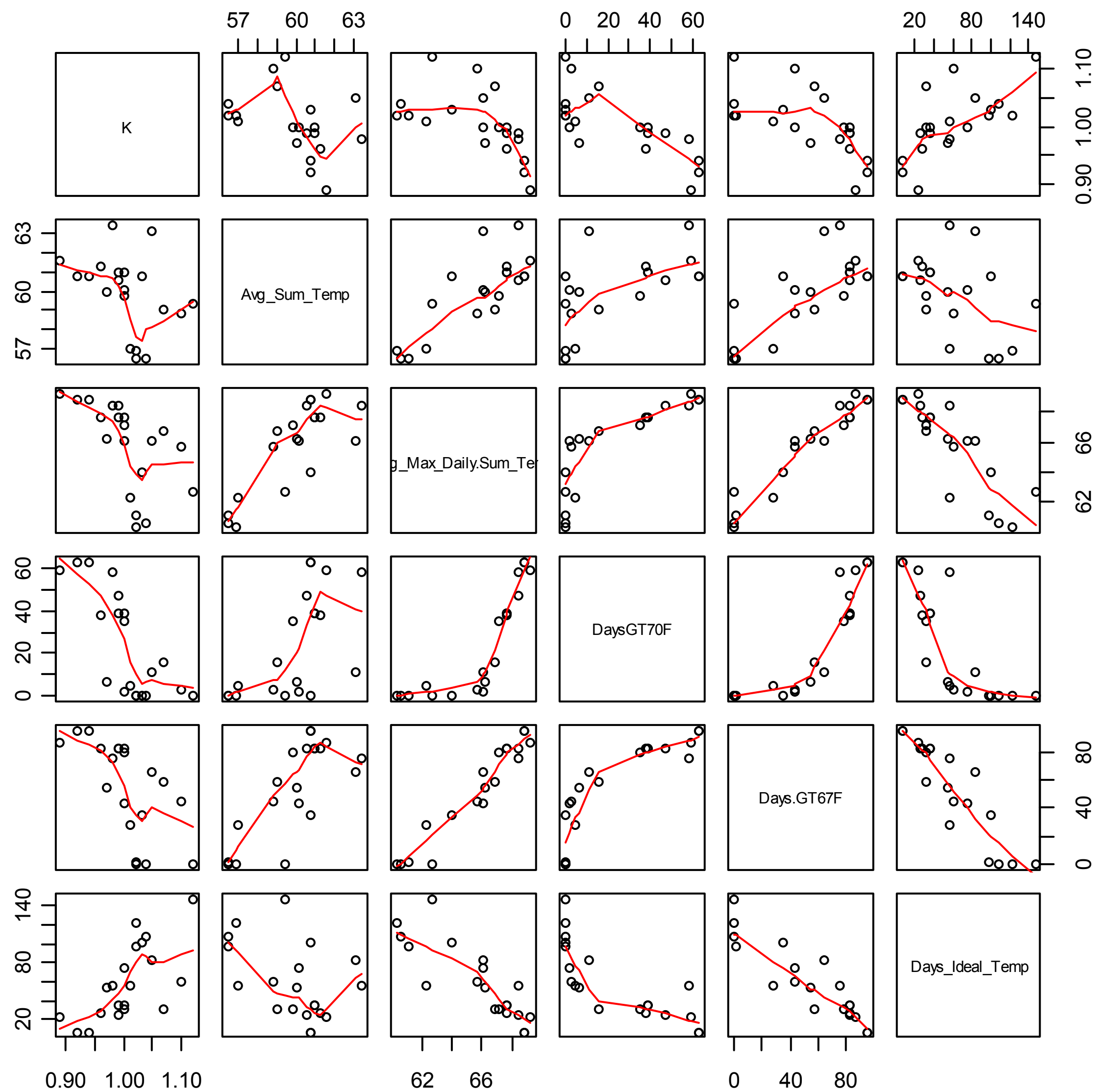
Dens1
MaxAnnFlow
Mean6_9Flow
SumDays.50
SumDays.150
100
300
500
0
40
80
120
1500
500
300
100
250
150
50
0
20
40
60
1500
500
50
150
250
0
20
40
60

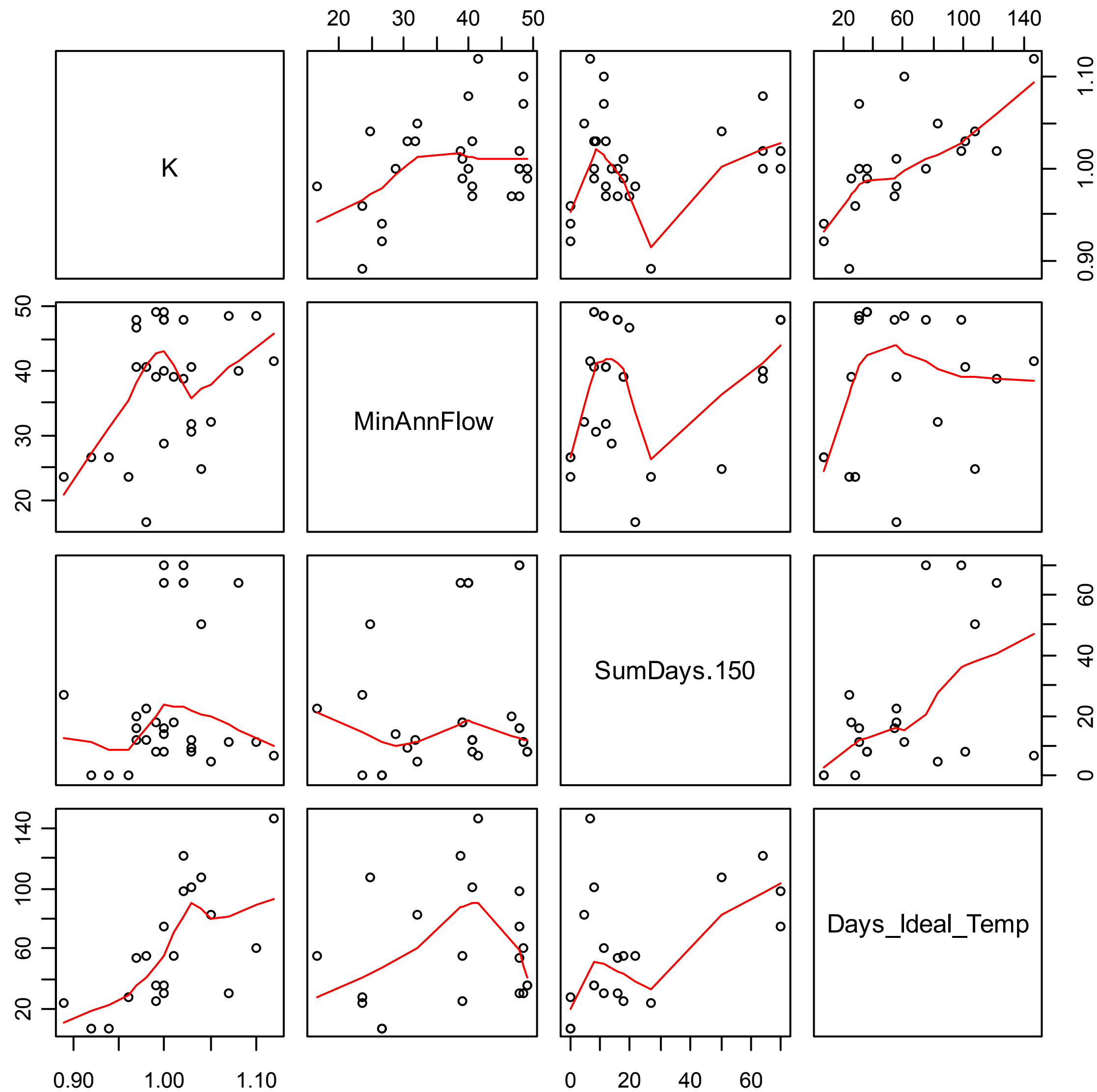


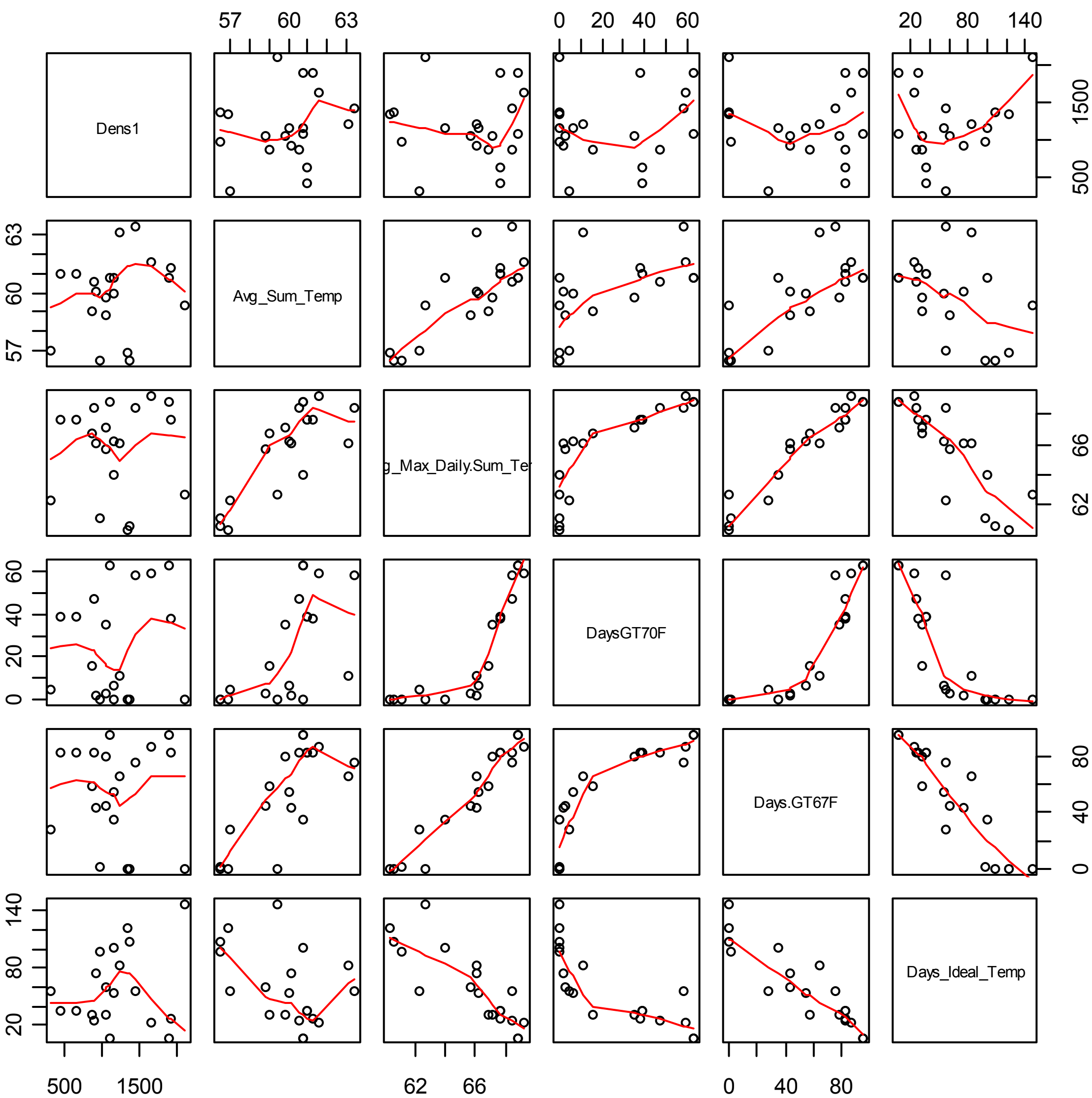
Dens1
June_Flow
July_Flow
Aug_Flow
Sept_Flow
100
300
500
40
80
120
500
1500
500
300
100
300
100
120
80
40
70
60
50
40
500
1500
100
300
40 50 60 70


Dens1
GrantMean
GrantMin
GrantMax
20000
35000
25000
35000
45000
2000
1000
500
35000
20000
45000
30000
15000
45000
35000
25000
500
1000
2000
15000
30000
45000

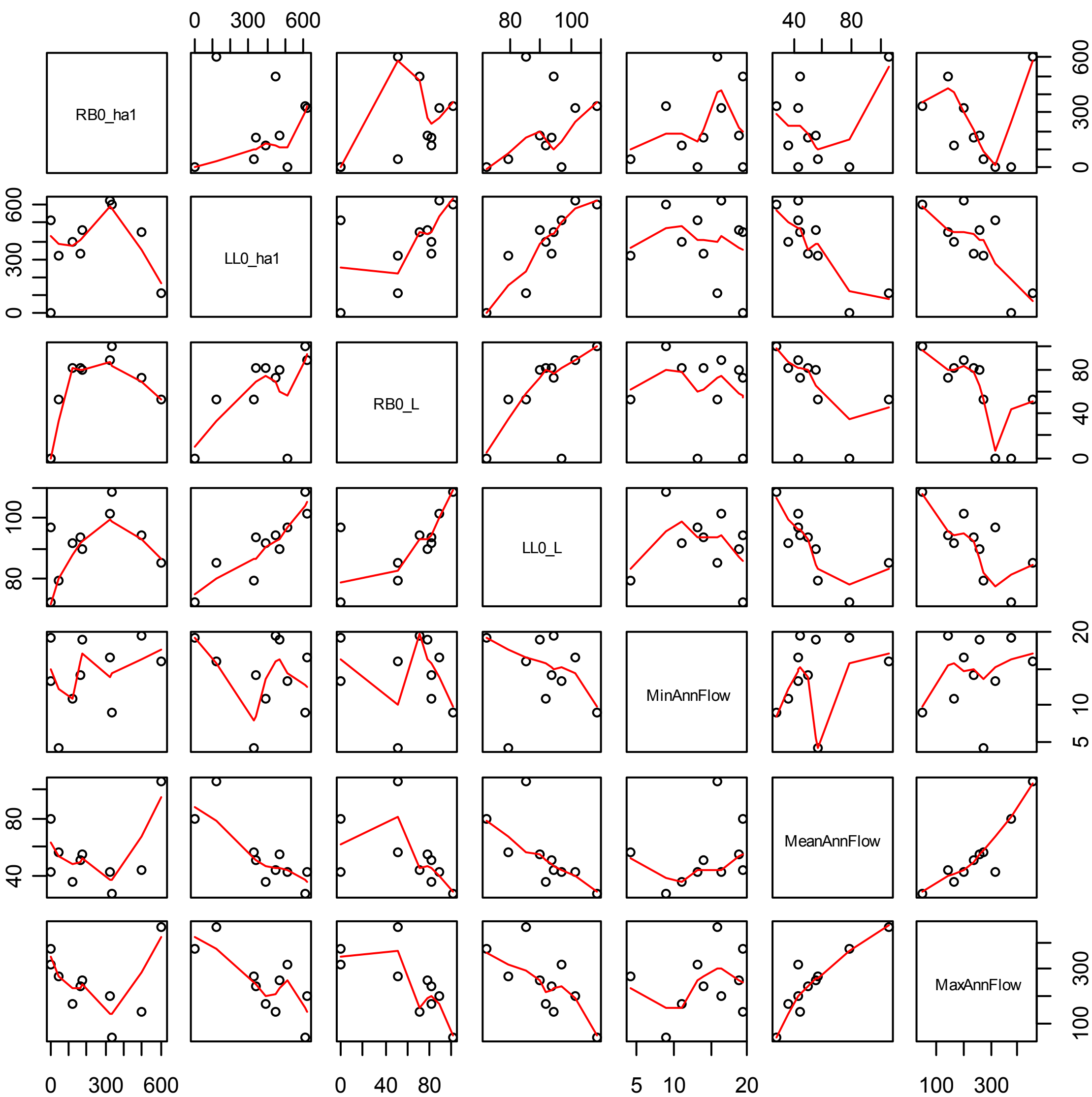
Flow and Temperature Variables with n=20 observations

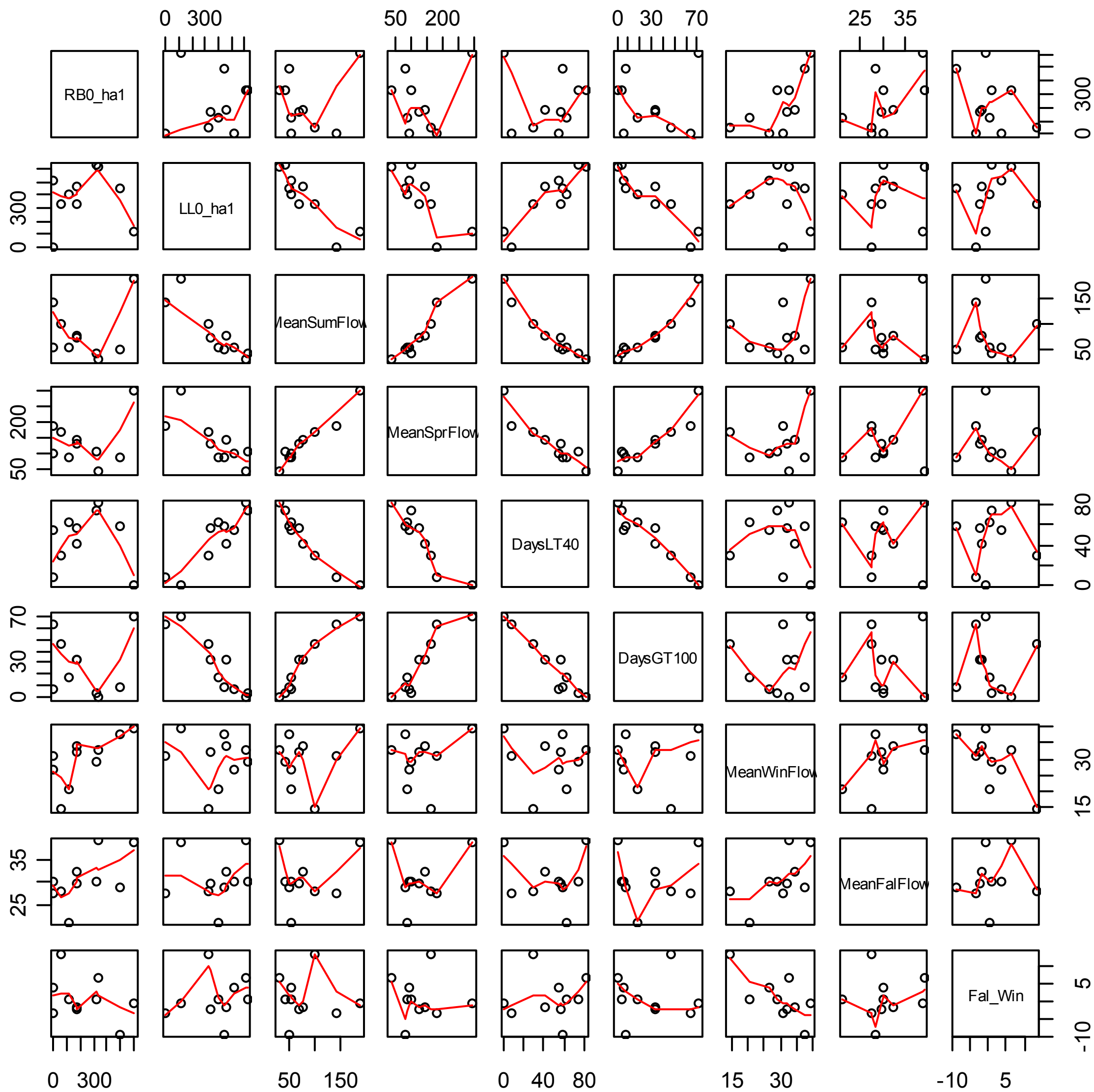



K
MinAnnFlow
SumDays.150
Days_Ideal_Temp
0.90
1.00
1.10
20
30
40
50
0
20
40
60
60
100
140


Dens1
Avg_Sum_Temp
g_Max_Daily.Sum_Te
DaysGT70F
Days.GT67F
Days_Ideal_Temp
57
60
63
0
20
40
60
20
80
140
1500
500
66
62
80
40
0
500
1500
62
66
0
40
80
140
80
20

Lee Vining Creek





RB0_ha1
LL0_ha1
MeanSumFlow
MeanSprFlow
DaysLT40
DaysGT100
MeanWinFlow
MeanFalFlow
Fal_Win

Appendix E – Condition Factor Metrics by Site and Year

Appendix E1. Mean, standard deviation (SD), minimum (Min), maximum (Max), and sample size (n) for individual condition factors of brown trout 150 to 250 mm in length by site (RUC = County Road; RUL = Lower; RUU = Upper) and year for Rush Creek.

CONDITION Mean SD n min-max 150 to 250 by Site and Year							
Site	Year	Mean	SD	Min	Max	n	SE
RUC	2000	1.07	0.08	0.7	1.27	309	0.0002597
RUC	2001	0.97	0.08	0.65	1.29	407	0.000197
RUC	2002	0.99	0.07	0.83	1.24	292	0.0002405
RUC	2003	0.97	0.1	0.76	2.01	427	0.0002347
RUC	2004	0.99	0.06	0.82	1.18	390	0.0001542
RUC	2005	1.08	0.1	0.82	1.42	199	0.0005051
RUC	2006	1	0.08	0.76	1.28	233	0.0003448
RUC	2007	0.92	0.08	0.58	1.24	573	0.0001399
RUC	2008	0.89	0.06	0.78	1.03	94	0.0006452
RUL	1999	0.97	0.07	0.77	1.22	244	0.0002881
RUL	2000	1.1	0.1	0.87	1.32	160	0.0006289
RUL	2001	1	0.09	0.79	1.43	193	0.0004688
RUL	2002	1	0.07	0.84	1.19	103	0.0006863
RUL	2003	0.98	0.07	0.78	1.21	199	0.0003535
RUL	2004	1.01	0.08	0.82	1.19	73	0.0011111
RUL	2005	1	0.08	0.84	1.21	129	0.000625
RUL	2006	1.02	0.06	0.88	1.17	119	0.0005085
RUL	2007	0.94	0.06	0.8	1.13	184	0.0003279
RUU	2000	1.12	0.09	0.74	1.37	170	0.0005325
RUU	2001	1.03	0.08	0.78	1.27	209	0.0003846
RUU	2002	1.05	0.09	0.8	1.7	207	0.0004369
RUU	2003	1.03	0.08	0.83	1.6	241	0.0003333
RUU	2004	1	0.08	0.79	1.24	153	0.0005263
RUU	2005	1.04	0.07	0.87	1.26	159	0.000443
RUU	2006	1.02	0.11	0.84	2.29	184	0.0006011
RUU	2007	0.96	0.07	0.75	1.2	241	0.0002917
RUU	2008	0.98	0.07	0.83	1.19	155	0.0004545
Average		1.004815	0.078889	0.78963	1.338889	223.963	0.0004342

Appendix F – Principal Component Analyses

Principal component analyses (PCA) of flow and temperature variables indicated that many of these variables were related to each other. This result was to be expected since many of these variables were just different ways of computing flow or temperature conditions. Three of the principal components explained almost 87% and five components explained over 97% of the variation in these data. Unfortunately, the first component had moderately high loadings for many variables, including both flow and temperature variables (PC1 in Table 6). The second principal component loaded most heavily and positively on high flow variables and negatively on minimum annual flow and Grant Reservoir storage variables. The third component loaded most heavily on number of days water temperatures were ideal and on number of summer days flows were less than 50 cfs. The fourth component also was heavily loaded by number of summer days flows were less than 50 cfs, but negatively rather than positively as for third component. Based on this analysis it appeared that at least one high flow variable, one low flow variable, one temperature variable, and one Grant Reservoir storage variable could be included in the model.

Table F1. Results from principal components analyses (PC and number indicate the principal component derived from the data) of flow and temperature variables for Rush Creek. Bold values are less than - 0.25 or greater than 0.25.

Variable	PC1	PC2	PC3	PC4	PC5
MinAnnFlow	-0.1787	**-0.2553**	**-0.3758**	**0.3680**	-0.0726
MaxAnnFlow	-0.2410	**0.3724**	-0.0573	0.1254	-0.0077
Mean6_9Flow	**-0.2768**	**0.2657**	-0.1011	-0.1428	-0.0548
SumDays.50	0.2047	0.1208	**0.3331**	**-0.4143**	-0.0256
SumDays.150	**-0.2599**	**0.3283**	0.0290	-0.1274	0.0174
June_Flow	-0.2440	**0.3691**	-0.0934	-0.0912	-0.0738
July_Flow	**-0.2887**	0.1861	-0.0557	-0.2167	-0.0315
Aug_Flow	**-0.2905**	0.1192	-0.2128	-0.1093	-0.0363
Sept_Flow	-0.2314	-0.1736	**-0.3876**	0.1341	-0.0512
Avg_Sum_Temp	0.2383	0.0469	-0.1532	-0.1269	**-0.8061**
Avg_Max_Daily.Sum_Temp	0.2411	0.0347	**-0.3887**	-0.1987	-0.1687
DaysGT70F	0.2490	0.1809	-0.2127	**-0.2610**	0.2249
Days.GT67F	**0.2557**	0.0397	**-0.3695**	-0.1684	-0.0007
Days_Ideal_Temp	-0.2073	-0.0518	**0.4102**	0.1590	**-0.4991**
GrantMean	-0.2269	**-0.3505**	0.0136	**-0.3548**	0.0254
GrantMin	-0.2495	**-0.2958**	-0.0349	**-0.3223**	-0.0414
GrantMax	-0.2100	**-0.3704**	0.0136	**-0.3850**	0.0038

Appendix G – Best Subset Regression Results

Table G1. Best subsets regression results for condition as the dependent variable and independent flow and Grant Reservoir storage variables for samples where flow data were available (n=28). An “X” under the independent variable name indicates that variable is included in the model. Models are shown in order from lowest to highest number of variables tested. Lower Mallow’s C_p values indicate models are more reasonable candidate models.

Vars In	Vars tested	Mallow's C_p	Min Ann Flow	Max Ann Flow	Mean 6_9 Flow	Sum Days <50	Sum Days >150	June Flow	July Flow	Aug Flow	Sept flow	Grant Mean	Grant Min	Grant Max
1	2	23.2223										X		
1	2	24.9342												X
1	2	25.2115											X	
1	2	26.6503	X											
1	2	29.8457				X								
1	2	30.1524									X			
1	2	31.3394							X					
1	2	31.3970								X				
1	2	32.9700		X										
1	2	33.3080					X							
2	3	19.2409										X		X
2	3	23.1293	X									X		
2	3	24.2103	X											X
2	3	24.3323		X								X		
2	3	24.7292				X						X		
2	3	24.7432	X										X	
2	3	24.9242						X				X		
2	3	25.0642			X							X		
2	3	25.1384										X	X	
2	3	25.1470								X		X		
3	4	9.5321		X	X							X		

Vars In	Vars tested	Mallow's C_p	Min Ann Flow	Max Ann Flow	Mean 6_9 Flow	Sum Days <50	Sum Days >150	June Flow	July Flow	Aug Flow	Sept flow	Grant Mean	Grant Min	Grant Max
3	4	11.2857		X				X				X		
3	4	11.4724		X	X									X
3	4	11.6417		X				X						X
3	4	12.8698		X				X					X	
3	4	16.9488							X			X		X
3	4	17.3128			X							X		X
3	4	17.4207		X					X			X		
3	4	17.8060								X		X		X
3	4	17.9781						X				X		X
4	5	9.9650		X	X							X		X
4	5	10.6689		X	X				X			X		
4	5	11.0644		X	X			X				X		
4	5	11.1749	X	X	X							X		
4	5	11.2681		X	X						X	X		
4	5	11.2685		X				X		X		X		
4	5	11.2831		X	X							X	X	
4	5	11.4202		X	X		X					X		
4	5	11.4444		X	X	X						X		
4	5	11.4589		X	X					X		X		
5	6	6.0983	X	X				X			X	X		
5	6	7.0426	X	X				X			X			X
5	6	9.7843	X	X	X						X	X		
5	6	10.3486	X	X	X			X	X					
5	6	10.7995	X	X				X			X		X	
5	6	10.8358	X	X	X				X		X			
5	6	11.2859		X	X						X	X		X
5	6	11.5544	X	X	X				X			X		
5	6	11.6624		X			X	X			X	X		
5	6	11.7063	X	X				X		X		X		
6	7	7.2159	X	X				X			X	X		X
6	7	7.5233	X	X		X		X			X	X		

Vars In	Vars tested	Mallow's C_p	Min Ann Flow	Max Ann Flow	Mean 6_9 Flow	Sum Days <50	Sum Days >150	June Flow	July Flow	Aug Flow	Sept flow	Grant Mean	Grant Min	Grant Max
6	7	7.7462	X	X			X	X			X	X		
6	7	7.8254	X	X	X				X		X	X		
6	7	8.0380	X	X				X	X		X	X		
6	7	8.0630	X	X	X			X			X	X		
6	7	8.0676	X	X				X			X	X	X	
6	7	8.0891	X	X				X		X	X	X		
6	7	8.1316	X	X		X		X			X			X
6	7	8.3112	X	X	X				X		X			X
7	8	8.5818	X	X	X		X	X			X	X		
7	8	8.6782	X	X			X	X	X		X	X		
7	8	8.8414	X	X	X		X	X			X			X
7	8	8.8942	X	X			X	X	X		X			X
7	8	8.9130	X	X			X	X			X	X		X
7	8	8.9660	X	X	X		X		X		X	X		
7	8	9.0500	X	X			X	X		X	X	X		
7	8	9.0992	X	X		X		X			X	X		X
7	8	9.1207	X	X	X		X		X		X			X
7	8	9.1617	X	X				X			X	X	X	X
8	9	7.8918	X	X	X			X	X	X	X	X		
8	9	8.4470	X	X	X			X	X	X	X			X
8	9	9.2983		X	X			X	X	X	X	X		X
8	9	10.0841	X	X	X		X	X			X	X	X	
8	9	10.1392	X	X			X	X	X		X	X	X	
8	9	10.1795	X	X			X	X		X	X	X		X
8	9	10.3289	X	X	X		X		X		X	X	X	
8	9	10.4507	X	X	X		X	X			X	X		X
8	9	10.4561	X	X			X	X	X		X		X	X
8	9	10.4681	X	X	X	X	X	X			X	X		
9	10	8.5218	X	X	X			X	X	X	X	X		X
9	10	8.9053	X	X	X	X		X	X	X	X	X		
9	10	8.9114	X	X	X			X	X	X	X	X	X	

Vars In	Vars tested	Mallow's C_p	Min Ann Flow	Max Ann Flow	Mean 6_9 Flow	Sum Days <50	Sum Days >150	June Flow	July Flow	Aug Flow	Sept flow	Grant Mean	Grant Min	Grant Max
9	10	9.3763	X	X	X	X		X	X	X	X			X
9	10	9.4261	X	X	X		X	X	X	X	X	X		
9	10	9.7284	X	X	X			X	X	X	X		X	X
9	10	9.9272	X	X	X		X	X	X	X	X			X
9	10	11.0913		X	X		X	X	X	X	X	X		X
9	10	11.1214		X	X			X	X	X	X	X	X	X
9	10	11.2964		X	X	X		X	X	X	X	X		X
10	11	9.8237	X	X	X	X		X	X	X	X	X	X	
10	11	9.8661	X	X	X			X	X	X	X	X	X	X
10	11	10.1025	X	X	X	X		X	X	X	X	X		X
10	11	10.1144	X	X	X		X	X	X	X	X	X	X	
10	11	10.3106	X	X	X		X	X	X	X	X	X		X
10	11	10.4710	X	X	X	X		X	X	X	X		X	X
10	11	10.6822	X	X	X	X	X	X	X	X	X	X		
10	11	10.8522	X	X	X		X	X	X	X	X		X	X
10	11	11.1198	X	X	X	X	X	X	X	X	X			X
10	11	12.8008		X	X		X	X	X	X	X	X	X	X
11	12	11.3175	X	X	X	X		X	X	X	X	X	X	X
11	12	11.3595	X	X	X	X	X	X	X	X	X	X	X	
11	12	11.4187	X	X	X		X	X	X	X	X	X	X	X
11	12	11.9485	X	X	X	X	X	X	X	X	X		X	X
11	12	11.9774	X	X	X	X	X	X	X	X	X	X		X
11	12	14.7994		X	X	X	X	X	X	X	X	X	X	X
11	12	15.7686	X	X	X	X	X	X	X		X	X	X	X
11	12	15.8303	X	X	X	X	X	X		X	X	X	X	X
11	12	15.8368	X	X		X	X	X	X	X	X	X	X	X
11	12	15.8652	X	X	X	X	X		X	X	X	X	X	X
12	13	13.0000	X	X	X	X	X	X	X	X	X	X	X	X

Table G2. Best subsets regression results for condition as the dependent variable and independent flow, Grant Reservoir storage, and water temperature variables for samples where both flow and water temperature data were available (n=20). An “X” under the independent variable name indicates that variable is included in the model. Models are shown in order from lowest to highest number of variables tested. Lower Mallow’s C_p values indicate models are more reasonable candidate models.

Vars In	Vars tested	Mallow's C_p	Min Ann Flow	Max Ann Flow	Mean 6_9 Flow	Sum Days <50	Sum Days >150	June Flow	July Flow	Aug Flow	Mean Summer Temp	Avg Max Summer Temp	Days >70F	Days >67F	Days Ideal Temp	Grant Mean	Grant Min	Grant Max
1	2	282.2949											X					
1	2	347.2553													X			
1	2	369.818												X				
1	2	429.8969										X						
1	2	485.141															X	
1	2	487.589														X		
1	2	497.2751	X															
1	2	509.8942																X
1	2	536.2394				X												
1	2	553.9737									X							
2	3	223.3675						X					X					
2	3	224.809					X						X					
2	3	237.2864			X								X					
2	3	251.4279							X				X					
2	3	254.9625								X			X					
2	3	256.2402	X												X			
2	3	257.7429					X							X				
2	3	260.6452		X									X					
2	3	272.1045											X		X			
2	3	276.1275	X										X					
3	4	147.9802		X				X									X	
3	4	166.3624		X				X								X		
3	4	168.664		X				X										X
3	4	174.1117	X					X							X			
3	4	174.6405		X				X					X					
3	4	181.4266			X					X					X			
3	4	187.4461	X					X						X				
3	4	188.3553	X				X								X			

Vars In	Vars tested	Mallow's C_p	Min Ann Flow	Max Ann Flow	Mean 6_9 Flow	Sum Days <50	Sum Days >150	June Flow	July Flow	Aug Flow	Mean Summer Temp	Avg Max Summer Temp	Days >70F	Days >67F	Days Ideal Temp	Grant Mean	Grant Min	Grant Max
3	4	190.3287	X		X										X			
3	4	190.9717						X		X					X			
4	5	76.08445		X				X							X		X	
4	5	84.30931		X				X		X					X			
4	5	94.71686		X				X							X	X		
4	5	96.75519		X				X							X			X
4	5	105.8453		X	X			X							X			
4	5	111.0629		X			X								X	X		
4	5	113.0234		X				X					X				X	
4	5	119.8942		X			X								X			X
4	5	121.7938		X				X						X			X	
4	5	123.6927		X	X					X					X			
5	6	39.15796		X				X			X	X					X	
5	6	54.81556		X				X			X	X				X		
5	6	55.98472		X				X			X				X		X	
5	6	58.59814		X				X			X	X						X
5	6	59.11136		X				X						X	X		X	
5	6	59.97773		X				X			X			X			X	
5	6	66.58893		X			X	X							X	X		
5	6	66.80673		X			X	X							X		X	
5	6	69.71885		X			X	X							X			X
5	6	69.84659		X				X							X	X	X	
6	7	35.80028		X				X			X	X		X			X	
6	7	37.86664		X				X		X	X	X					X	
6	7	38.40793		X				X			X	X			X		X	
6	7	38.73182		X		X		X			X	X					X	
6	7	39.05831		X				X			X	X	X				X	
6	7	39.54292		X			X	X			X	X				X		
6	7	39.57964	X	X				X			X	X					X	
6	7	39.91292		X			X	X			X	X					X	
6	7	40.57166		X	X			X			X	X					X	
6	7	40.71273		X				X			X	X				X	X	
7	8	33.78337		X			X	X			X	X		X				X

Vars In	Vars tested	Mallow's C_p	Min Ann Flow	Max Ann Flow	Mean 6_9 Flow	Sum Days <50	Sum Days >150	June Flow	July Flow	Aug Flow	Mean Summer Temp	Avg Max Summer Temp	Days >70F	Days >67F	Days Ideal Temp	Grant Mean	Grant Min	Grant Max
7	8	33.93378		X				X		X	X	X	X				X	
7	8	33.94436		X				X			X	X	X	X			X	
7	8	34.00515		X				X			X	X	X		X		X	
7	8	35.93378		X		X		X			X	X	X				X	
7	8	36.03731	X	X				X			X	X	X				X	
7	8	36.25469		X			X	X			X	X		X		X		
7	8	36.3365		X			X	X			X	X	X			X		
7	8	36.56325		X		X		X			X	X		X			X	
7	8	37.15081		X				X		X	X	X		X			X	
8	9	22.83469		X			X	X			X	X	X	X				X
8	9	26.33399		X		X		X			X	X	X		X		X	
8	9	27.25945		X	X				X	X	X	X	X				X	
8	9	28.72818		X	X			X		X	X	X	X				X	
8	9	28.96248		X			X	X			X	X	X		X			X
8	9	29.45527		X				X	X	X	X	X	X				X	
8	9	29.84861		X			X	X			X	X	X	X		X		
8	9	31.09488	X	X				X			X	X	X		X		X	
8	9	31.30078		X				X		X	X	X	X		X		X	
8	9	31.38839		X			X	X			X	X	X		X	X		
9	10	22.00737		X	X				X	X	X	X	X		X		X	
9	10	23.88391		X			X	X			X	X	X	X		X		X
9	10	23.99196		X			X	X			X	X	X	X	X			X
9	10	24.12716		X				X	X		X	X		X		X	X	X
9	10	24.12958		X			X	X		X	X	X	X	X				X
9	10	24.39187		X			X	X			X	X	X	X			X	X
9	10	24.66842		X	X			X		X	X	X	X		X		X	
9	10	24.72105		X	X				X	X	X	X	X	X			X	
9	10	24.74289		X		X	X	X			X	X	X	X				X
9	10	24.75366		X	X		X	X			X	X	X	X				X
10	11	11.6892		X	X			X	X	X		X		X	X		X	X
10	11	12.16746		X	X			X	X	X		X		X	X	X	X	
10	11	18.85174		X	X			X			X	X	X	X		X	X	X
10	11	18.93282		X	X			X	X	X	X	X	X				X	X

Vars In	Vars tested	Mallow's C_p	Min Ann Flow	Max Ann Flow	Mean 6_9 Flow	Sum Days <50	Sum Days >150	June Flow	July Flow	Aug Flow	Mean Summer Temp	Avg Max Summer Temp	Days >70F	Days >67F	Days Ideal Temp	Grant Mean	Grant Min	Grant Max
10	11	20.86024		X				X		X	X	X	X		X	X	X	X
10	11	21.18095		X	X		X	X	X	X		X		X	X		X	
10	11	21.27485		X				X	X		X	X	X	X		X	X	X
10	11	21.45295		X	X			X	X	X	X	X	X			X	X	
10	11	21.56935		X				X		X	X	X	X	X		X	X	X
10	11	22.27492		X	X			X	X	X	X	X	X		X		X	
11	12	9.925867		X	X	X		X	X	X		X		X	X		X	X
11	12	10.79599		X	X			X	X	X		X	X	X	X		X	X
11	12	12.84346		X	X		X	X	X	X		X		X	X		X	X
11	12	13.00115		X	X			X	X	X		X		X	X	X	X	X
11	12	13.30858		X	X			X	X	X		X	X	X	X	X	X	
11	12	13.37503		X	X			X	X	X	X	X		X	X		X	X
11	12	13.47395		X	X			X	X	X	X	X	X	X		X	X	
11	12	13.48716	X	X	X			X	X	X		X		X	X		X	X
11	12	13.61324		X	X	X		X	X	X		X		X	X	X	X	
11	12	13.93521		X	X		X	X	X	X		X		X	X	X	X	
12	13	11.21928		X	X	X		X	X	X		X	X	X	X		X	X
12	13	11.5091		X	X			X	X	X	X	X	X	X	X		X	X
12	13	11.60495		X	X	X	X	X	X	X		X		X	X		X	X
12	13	11.66352		X	X	X		X	X	X	X	X		X	X		X	X
12	13	11.81707	X	X	X	X		X	X	X		X		X	X		X	X
12	13	11.90927		X	X			X	X	X	X	X	X	X	X	X	X	
12	13	11.92182		X	X	X		X	X	X		X		X	X	X	X	X
12	13	12.49438		X	X		X	X	X	X		X	X	X	X		X	X
12	13	12.49878		X	X	X		X	X	X	X	X	X	X		X	X	
12	13	12.6872	X	X	X			X	X	X		X	X	X	X		X	X
13	14	11.04657		X	X	X		X	X	X	X	X	X	X	X		X	X
13	14	12.82447		X	X	X		X	X	X	X	X	X	X	X	X	X	
13	14	13.02471		X	X	X	X	X	X	X		X	X	X	X		X	X
13	14	13.0278	X	X	X			X	X	X	X	X	X	X	X		X	X
13	14	13.17315		X	X	X		X	X	X		X	X	X	X	X	X	X
13	14	13.17874	X	X	X	X		X	X	X		X	X	X	X		X	X
13	14	13.24512		X	X			X	X	X	X	X	X	X	X	X	X	X
13	14	13.35264		X	X	X	X	X	X	X	X	X		X	X		X	X

Vars In	Vars tested	Mallow's C_p	Min Ann Flow	Max Ann Flow	Mean 6_9 Flow	Sum Days <50	Sum Days >150	June Flow	July Flow	Aug Flow	Mean Summer Temp	Avg Max Summer Temp	Days >70F	Days >67F	Days Ideal Temp	Grant Mean	Grant Min	Grant Max
13	14	13.35674		X	X		X	X	X	X	X	X	X	X	X		X	X
13	14	13.3861	X	X	X	X	X	X	X	X		X		X	X		X	X
14	15	13.00907		X	X	X	X	X	X	X	X	X	X	X	X		X	X
14	15	13.02987	X	X	X	X		X	X	X	X	X	X	X	X		X	X
14	15	13.04451		X	X	X		X	X	X	X	X	X	X	X	X	X	X
14	15	14.81486		X	X	X	X	X	X	X		X	X	X	X	X	X	X
14	15	14.81947	X	X	X	X		X	X	X	X	X	X	X	X	X	X	
14	15	14.81976		X	X	X	X	X	X	X	X	X	X	X	X	X	X	
14	15	14.91477	X	X	X			X	X	X	X	X	X	X	X	X	X	X
14	15	14.92003	X	X	X	X	X	X	X	X		X	X	X	X		X	X
14	15	14.99758	X	X	X		X	X	X	X	X	X	X	X	X		X	X
14	15	15.14806	X	X	X	X		X	X	X		X	X	X	X	X	X	X
15	16	15.00358	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X
15	16	15.00589		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
15	16	15.0294	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X
15	16	16.74196	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X
15	16	16.81681	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
15	16	16.91416	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X
15	16	17.12261	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X
15	16	17.8423	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X
15	16	22.03676	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X
15	16	24.66134	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X
16	17	17	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Table G3. Best subsets regression results for estimated density of age-1 and older brown trout as the dependent variable and independent flow and Grant Reservoir storage variables for samples where flow data were available (n=28). An “X” under the independent variable name indicates that variable is included in the model. Models are shown in order from lowest to highest number of variables tested. Lower Mallow’s C_p values indicate models are more reasonable candidate models.

Vars In	Vars tested	Mallow's C_p	Min Ann Flow	Max Ann Flow	Mean 6_9 Flow	Sum Days <50	Sum Days >150	June Flow	July Flow	Aug Flow	Sept Flow	Grant Mean	Grant Min	Grant Max
1	2	29.959	X											
1	2	32.466				X								
1	2	34.356		X										
1	2	34.947									X			
1	2	37.147												X
1	2	38.955										X		
1	2	39.013								X				
1	2	39.320											X	
1	2	39.730						X						
1	2	40.597			X									
2	3	11.540									X			X
2	3	12.732	X											X
2	3	13.780									X	X		
2	3	15.198	X									X		
2	3	15.356	X										X	
2	3	15.984				X								X
2	3	16.212									X		X	
2	3	18.785				X						X		
2	3	20.705				X							X	
2	3	23.284								X				X
3	4	8.603	X									X		X
3	4	9.877				X						X		X
3	4	10.608	X							X				X
3	4	10.613									X	X		X
3	4	11.614	X						X					X
3	4	11.776	X				X							X

Vars In	Vars tested	Mallow's C_p	Min Ann Flow	Max Ann Flow	Mean 6_9 Flow	Sum Days <50	Sum Days >150	June Flow	July Flow	Aug Flow	Sept Flow	Grant Mean	Grant Min	Grant Max
3	4	11.791	X								X			X
3	4	12.004	X	X										X
3	4	12.311				X					X			X
3	4	12.314	X		X									X
4	5	4.470							X	X		X		X
4	5	9.068	X			X						X		X
4	5	9.724	X									X	X	X
4	5	9.844	X							X		X		X
4	5	9.960	X								X	X		X
4	5	10.357				X					X	X		X
4	5	10.370	X				X					X		X
4	5	10.517	X		X							X		X
4	5	10.524	X						X			X		X
4	5	10.558	X	X								X		X
5	6	3.680			X			X		X		X		X
5	6	4.934						X	X	X		X		X
5	6	5.159			X				X	X		X		X
5	6	5.634							X	X	X	X		X
5	6	6.116		X					X	X		X		X
5	6	6.206					X		X	X		X		X
5	6	6.331				X			X	X		X		X
5	6	6.346							X	X		X	X	X
5	6	6.436	X						X	X		X		X
5	6	8.653			X			X	X			X		X
6	7	5.243	X		X			X		X		X		X
6	7	5.253			X			X	X	X		X		X
6	7	5.294			X			X		X	X	X		X
6	7	5.352						X	X	X	X	X		X
6	7	5.361			X				X	X	X	X		X
6	7	5.538		X	X			X		X		X		X
6	7	5.595			X		X	X		X		X		X
6	7	5.598			X			X	X		X	X		X
6	7	5.637			X	X		X		X		X		X

Vars In	Vars tested	Mallow's C_p	Min Ann Flow	Max Ann Flow	Mean 6_9 Flow	Sum Days <50	Sum Days >150	June Flow	July Flow	Aug Flow	Sept Flow	Grant Mean	Grant Min	Grant Max
6	7	5.678			X			X		X		X	X	X
7	8	5.299			X			X	X	X	X	X		X
7	8	6.923	X		X	X		X		X		X		X
7	8	7.026			X	X		X	X	X		X		X
7	8	7.065		X	X			X	X	X		X		X
7	8	7.082			X	X		X		X	X	X		X
7	8	7.088	X	X	X			X		X		X		X
7	8	7.106		X	X			X		X	X	X		X
7	8	7.114	X		X			X	X	X		X		X
7	8	7.127	X		X			X		X		X	X	X
7	8	7.139	X		X			X		X	X	X		X
8	9	6.681			X	X		X	X	X	X	X		X
8	9	6.762			X			X	X	X	X	X	X	X
8	9	7.127			X		X	X	X	X	X	X		X
8	9	7.248		X	X			X	X	X	X	X		X
8	9	7.249	X		X			X	X	X	X	X		X
8	9	8.437	X	X	X	X		X		X		X		X
8	9	8.530		X	X	X		X	X	X		X		X
8	9	8.597		X	X	X		X		X	X	X		X
8	9	8.655		X		X		X	X	X	X	X		X
8	9	8.667		X	X	X			X	X	X	X		X
9	10	8.110			X	X		X	X	X	X	X	X	X
9	10	8.117			X	X	X	X	X	X	X	X		X
9	10	8.320		X	X	X		X	X	X	X	X		X
9	10	8.436	X		X	X		X	X	X	X	X		X
9	10	8.605	X		X			X	X	X	X	X	X	X
9	10	8.683			X		X	X	X	X	X	X	X	X
9	10	8.714		X	X			X	X	X	X	X	X	X
9	10	9.079	X		X		X	X	X	X	X	X		X
9	10	9.127		X	X		X	X	X	X	X	X		X
9	10	9.199	X	X	X			X	X	X	X	X		X
10	11	9.622	X		X	X		X	X	X	X	X	X	X
10	11	9.731			X	X	X	X	X	X	X	X	X	X

Vars In	Vars tested	Mallow's C_p	Min Ann Flow	Max Ann Flow	Mean 6_9 Flow	Sum Days <50	Sum Days >150	June Flow	July Flow	Aug Flow	Sept Flow	Grant Mean	Grant Min	Grant Max
10	11	9.750		X	X	X		X	X	X	X	X	X	X
10	11	9.769	X		X	X	X	X	X	X	X	X		X
10	11	9.980	X	X	X	X		X	X	X	X	X		X
10	11	10.059		X	X	X	X	X	X	X	X	X		X
10	11	10.537	X		X		X	X	X	X	X	X	X	X
10	11	10.559	X	X	X			X	X	X	X	X	X	X
10	11	10.679		X	X		X	X	X	X	X	X	X	X
10	11	11.078	X	X	X		X	X	X	X	X	X		X
11	12	11.122	X	X	X	X		X	X	X	X	X	X	X
11	12	11.170	X		X	X	X	X	X	X	X	X	X	X
11	12	11.628		X	X	X	X	X	X	X	X	X	X	X
11	12	11.682	X	X	X	X	X	X	X	X	X	X		X
11	12	12.532	X	X	X		X	X	X	X	X	X	X	X
11	12	13.827	X	X	X	X	X	X	X	X		X	X	X
11	12	13.885	X	X	X	X	X	X		X	X	X	X	X
11	12	13.961	X	X		X	X	X	X	X	X	X	X	X
11	12	13.978	X	X	X	X	X		X	X	X	X	X	X
11	12	14.270	X	X	X	X	X	X	X		X	X	X	X
12	13	13.000	X	X	X	X	X	X	X	X	X	X	X	X

Table G4. Best subsets regression results for estimated density of age-1 and older brown trout as the dependent variable and independent flow, Grant Reservoir storage, and temperature variables for samples where both flow and water temperature data were available (n=20). An “X” under the independent variable name indicates that variable is included in the model. Models are shown in order from lowest to highest number of variables tested. Lower Mallow’s C_p values indicate models are more reasonable candidate models.

Vars In	Vars tested	Mallow's C_p	Min Ann Flow	Max Ann Flow	Mean 6_9 Flow	Sum Days <50	Sum Days >150	June Flow	July Flow	Aug Flow	Mean Summer Temp	Avg Max Summer Temp	Days >70F	Days >67F	Days Ideal Temp	Grant Mean	Grant Min	Grant Max
1	2	5.048				X												
1	2	5.620	X															
1	2	12.841		X														
1	2	13.174								X								
1	2	14.760																X
1	2	14.794						X										
1	2	14.871									X							
1	2	14.933			X													
1	2	15.074													X			
1	2	15.399														X		
2	3	-0.962	X															X
2	3	-0.122	X													X		
2	3	-0.006	X														X	
2	3	0.096				X												X
2	3	0.919				X										X		
2	3	1.471				X											X	
2	3	3.092				X									X			
2	3	4.771				X								X				
2	3	4.835	X												X			
2	3	5.208							X	X								
3	4	-1.024	X							X							X	
3	4	-0.720			X					X								X
3	4	-0.660	X								X							X
3	4	-0.634	X						X								X	
3	4	-0.403	X		X												X	
3	4	-0.391	X							X								X
3	4	-0.314	X													X		X
3	4	-0.240	X								X					X		
3	4	-0.160	X				X										X	

Vars In	Vars tested	Mallow's C_p	Min Ann Flow	Max Ann Flow	Mean 6_9 Flow	Sum Days <50	Sum Days >150	June Flow	July Flow	Aug Flow	Mean Summer Temp	Avg Max Summer Temp	Days >70F	Days >67F	Days Ideal Temp	Grant Mean	Grant Min	Grant Max
3	4	-0.096	X								X						X	
4	5	-1.489	X									X			X			X
4	5	-1.407							X	X						X		X
4	5	-1.141				X							X		X			X
4	5	-1.135				X					X	X			X			
4	5	-1.114	X									X			X	X		
4	5	-1.087			X					X	X							X
4	5	-0.914			X					X		X						X
4	5	-0.689	X									X			X		X	
4	5	-0.594			X					X	X					X		
4	5	-0.448				X									X	X		X
5	6	-0.977				X					X	X			X			X
5	6	-0.803				X							X		X	X		X
5	6	-0.587		X		X	X					X		X				
5	6	-0.539				X					X	X			X	X		
5	6	-0.515		X		X					X	X			X			
5	6	-0.453	X							X		X			X		X	
5	6	-0.292	X						X			X			X		X	
5	6	-0.283	X								X	X			X			X
5	6	-0.243			X					X		X			X			X
5	6	-0.206		X	X					X		X		X				
6	7	-1.252				X					X	X			X	X		X
6	7	-0.792		X		X		X			X	X			X			
6	7	-0.623		X		X	X				X	X			X			
6	7	0.033				X					X	X			X		X	X
6	7	0.094	X	X				X			X	X			X			
6	7	0.187	X			X					X	X			X			X
6	7	0.277		X	X	X					X	X			X			
6	7	0.290	X	X							X	X			X		X	
6	7	0.375	X							X	X	X			X		X	
6	7	0.399				X					X	X	X		X			X
7	8	0.223				X					X	X		X	X	X		X
7	8	0.508				X					X	X	X		X	X		X
7	8	0.671	X			X					X	X			X	X		X
7	8	0.715				X	X				X	X			X	X		X

Vars In	Vars tested	Mallow's C_p	Min Ann Flow	Max Ann Flow	Mean 6_9 Flow	Sum Days <50	Sum Days >150	June Flow	July Flow	Aug Flow	Mean Summer Temp	Avg Max Summer Temp	Days >70F	Days >67F	Days Ideal Temp	Grant Mean	Grant Min	Grant Max
7	8	0.721		X		X		X	X		X	X			X			
7	8	0.722	X	X		X		X			X	X			X			
7	8	0.724		X	X	X		X			X	X			X			
7	8	0.724				X			X		X	X			X	X		X
7	8	0.733			X	X					X	X			X	X		X
7	8	0.738				X				X	X	X			X	X		X
8	9	2.078				X				X	X	X		X	X	X		X
8	9	2.093				X			X		X	X		X	X	X		X
8	9	2.100			X	X					X	X		X	X	X		X
8	9	2.103				X	X				X	X		X	X	X		X
8	9	2.114				X		X			X	X		X	X	X		X
8	9	2.146		X		X					X	X		X	X	X		X
8	9	2.158	X			X					X	X		X	X	X		X
8	9	2.165		X	X	X	X		X		X	X			X			
8	9	2.191		X	X	X					X	X			X	X		X
8	9	2.194				X					X	X		X	X	X	X	X
9	10	3.898		X		X	X				X	X			X	X	X	X
9	10	3.999		X		X				X	X	X		X	X	X		X
9	10	4.016		X	X	X					X	X		X	X	X		X
9	10	4.041		X		X			X		X	X		X	X	X		X
9	10	4.049				X		X		X	X	X		X	X	X		X
9	10	4.053		X		X		X			X	X		X	X	X		X
9	10	4.055			X	X				X	X	X		X	X	X		X
9	10	4.056		X		X	X				X	X		X	X	X		X
9	10	4.058			X	X		X			X	X		X	X	X		X
9	10	4.061		X		X	X	X			X	X			X	X		X
10	11	5.825		X		X	X	X			X	X			X	X	X	X
10	11	5.840		X		X	X				X	X	X		X	X	X	X
10	11	5.877		X		X	X			X	X	X			X	X	X	X
10	11	5.890		X		X	X				X	X		X	X	X	X	X
10	11	5.892		X	X	X	X				X	X			X	X	X	X
10	11	5.895		X		X	X		X		X	X			X	X	X	X
10	11	5.897	X	X		X	X				X	X			X	X	X	X
10	11	5.939		X	X	X					X	X	X	X	X	X		X
10	11	5.969		X		X				X	X	X	X	X	X	X		X

Vars In	Vars tested	Mallow's C_p	Min Ann Flow	Max Ann Flow	Mean 6_9 Flow	Sum Days <50	Sum Days >150	June Flow	July Flow	Aug Flow	Mean Summer Temp	Avg Max Summer Temp	Days >70F	Days >67F	Days Ideal Temp	Grant Mean	Grant Min	Grant Max
10	11	5.973		X		X			X		X	X	X	X	X	X		X
11	12	7.183			X	X	X	X	X	X	X	X			X	X		X
11	12	7.482			X	X	X	X	X	X	X	X		X		X		X
11	12	7.545		X		X	X	X		X	X	X			X	X	X	X
11	12	7.640		X	X	X	X			X	X	X			X	X	X	X
11	12	7.661		X	X	X	X	X			X	X			X	X	X	X
11	12	7.751			X	X		X	X	X	X	X			X	X	X	X
11	12	7.759		X		X	X	X	X		X	X			X	X	X	X
11	12	7.785		X		X	X		X	X	X	X			X	X	X	X
11	12	7.798		X		X	X	X			X	X	X		X	X	X	X
11	12	7.803			X	X	X	X			X	X		X	X	X	X	X
12	13	9.012	X		X	X	X	X	X	X	X	X			X	X		X
12	13	9.172			X	X	X	X	X	X	X	X			X	X	X	X
12	13	9.173			X	X	X	X	X	X	X	X		X	X	X		X
12	13	9.181			X	X	X	X	X	X	X	X	X		X	X		X
12	13	9.183		X	X	X	X	X	X	X	X	X			X	X		X
12	13	9.315			X	X	X	X	X	X	X	X	X	X		X		X
12	13	9.353	X		X	X	X	X	X	X	X	X		X		X		X
12	13	9.482		X	X	X	X	X	X	X	X	X		X		X		X
12	13	9.482			X	X	X	X	X	X	X	X		X		X	X	X
12	13	9.495		X	X	X	X	X	X		X	X			X	X	X	X
13	14	11.003	X		X	X	X	X	X	X	X	X			X	X	X	X
13	14	11.005	X		X	X	X	X	X	X	X	X		X	X	X		X
13	14	11.006	X	X	X	X	X	X	X	X	X	X			X	X		X
13	14	11.008	X		X	X	X	X	X	X	X	X	X		X	X		X
13	14	11.150			X	X	X	X	X	X	X	X	X	X	X	X		X
13	14	11.165			X	X	X	X	X	X	X	X	X		X	X	X	X
13	14	11.167			X	X	X	X	X	X	X	X		X	X	X	X	X
13	14	11.167		X	X	X	X	X	X	X	X	X			X	X	X	X
13	14	11.171		X	X	X	X	X	X	X	X	X		X	X	X		X
13	14	11.179		X	X	X	X	X	X	X	X	X	X		X	X		X
14	15	13.000	X		X	X	X	X	X	X	X	X		X	X	X	X	X
14	15	13.002	X		X	X	X	X	X	X	X	X	X		X	X	X	X
14	15	13.002	X	X	X	X	X	X	X	X	X	X			X	X	X	X
14	15	13.004	X	X	X	X	X	X	X	X	X	X		X	X	X		X

Vars In	Vars tested	Mallow's C_p	Min Ann Flow	Max Ann Flow	Mean 6_9 Flow	Sum Days <50	Sum Days >150	June Flow	July Flow	Aug Flow	Mean Summer Temp	Avg Max Summer Temp	Days >70F	Days >67F	Days Ideal Temp	Grant Mean	Grant Min	Grant Max
14	15	13.005	X		X	X	X	X	X	X	X	X	X	X	X	X		X
14	15	13.006	X	X	X	X	X	X	X	X	X	X	X		X	X		X
14	15	13.143			X	X	X	X	X	X	X	X	X	X	X	X	X	X
14	15	13.150		X	X	X	X	X	X	X	X	X	X	X	X	X		X
14	15	13.155		X	X	X	X	X	X	X	X	X		X	X	X	X	X
14	15	13.164		X	X	X	X	X	X	X	X	X	X		X	X	X	X
15	16	15.000	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X
15	16	15.000	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X
15	16	15.001	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X
15	16	15.004	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X
15	16	15.139		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
15	16	15.228	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X
15	16	15.387	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X
15	16	15.415	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X
15	16	15.467	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X
15	16	15.469	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X
16	17	17.000	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Appendix H – Details of Brown Trout Condition Regression Analyses for Rush Creek

Models that included five to nine flow and storage variables were all equally plausible models to explain variation in condition factor based on “best subsets” regression analyses that used all observations (n=28; Appendix G1). The single “best” model included minimum annual flow, maximum annual flow, June flow, September flow, and mean summer Grant Reservoir storage. While this model did the best job of accounting for the variation in condition of brown trout (adjusted-R^2 = 0.538; P < 0.001), the high correlation among many of the independent covariates indicated that several of the covariates were likely explaining the same effect (i.e., June flow and maximum annual flow). Minimum annual flow was a better low flow variable than September flow and maximum annual flow was a better high flow variable than June flow in accounting for variation in condition factor. Mean summer storage of Grant Reservoir had the highest adjusted-R^2 (0.1645) of the three Grant storage variables tested and the model was significant (P < 0.05). The best three-variable model based on best subset regression analysis included maximum annual flow, mean summer flow, and mean summer storage in Grant Reservoir (Appendix G1); however, maximum annual flow and mean summer flow were highly correlated. For just flow and reservoir storage independent variables, the candidate set included one low flow variable (minimum annual flow), one of two high flow variables (maximum annual flow or mean summer flow), and one Grant storage variable (mean summer storage) to account for variation in condition of brown trout. Comparisons of all possible combinations of these candidate independent variables showed that the best model included only the mean storage of Grant Reservoir (adjusted-R^2 = 0.1645; P < 0.05).

Next the influence of both flow and temperature on condition of brown trout was evaluated for the 20 sampling observations for which water temperature data were also available. Best subsets regression analyses indicated that many of the tested covariates (10 to 14) were included in all the best models; however, due to the inter-correlated nature of these covariates, variables were screened prior to their inclusion into multiple regression models to reduce effects of correlation among independent covariates.

When temperature variables were added to the above flow variables the best candidate set included those flow variables (minimum annual flow, maximum annual flow, mean summer flow, and mean summer storage in Grant Reservoir) and one temperature variable (days of ideal temperature) for the 20 observations where all these data were available. After this screening process the model that best explained variation in fish condition included minimum annual flow, mean summer flow, and days of ideal temperature (adjusted-R^2 = 0.638; P < 0.01). Coefficients for all three of these covariates were significantly different than zero (P < 0.05), indicating they all explained some variation in fish condition. These three covariates were not too highly correlated with each other. This model did a reasonable job of predicting the condition of 150 to

250 mm brown trout and there was no obvious clustering of the data points by site (Figure H1). Models that included all three-way and two-way interactions were also tested and none of these interactions were significant, so all interactions were removed from the model. Model diagnostics graphs illustrated that residual errors were uniformly and normally distributed, and no single point had too much influence on the model (Appendix I1). It appeared that the first and eighth observations had the most deviation. These observations were for the County Road and Lower Rush sites during the year 2000. The effects of biomass and density of age-1 and older brown trout for this best flow-temperature model were also evaluated by including them in the model as independent covariates and neither biomass nor density added significantly to the model.

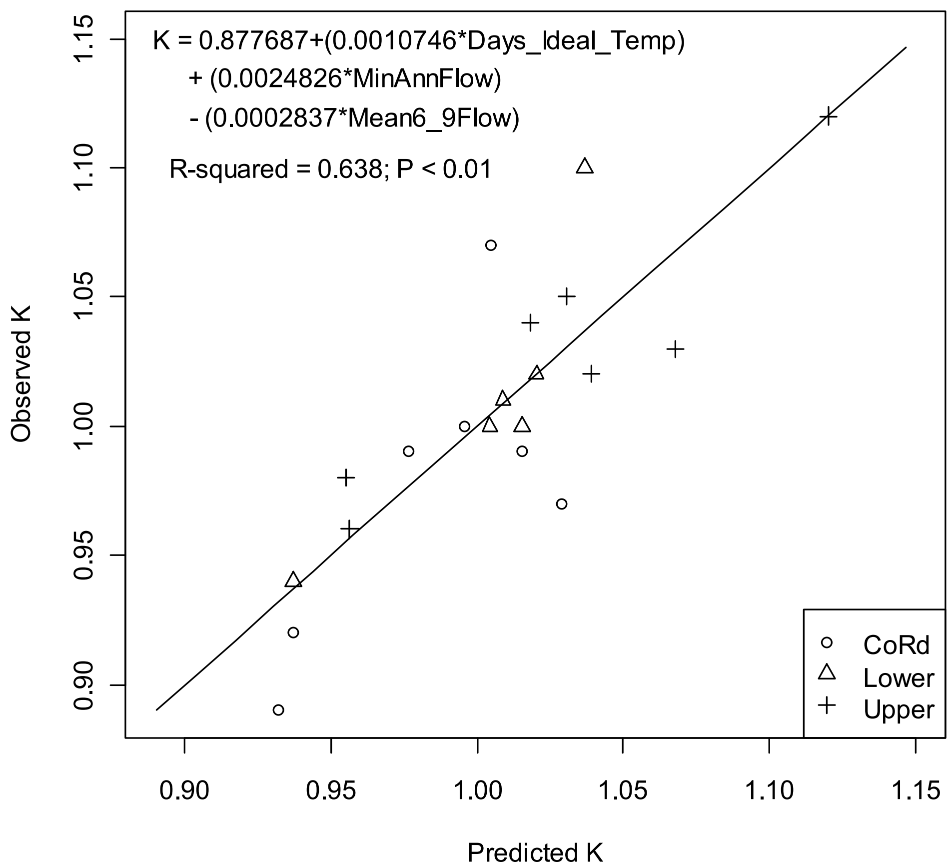


Figure H1. Observed versus predicted condition factor for brown trout 150 to 250 mm in Rush Creek by fish sample site location (CoRd = County Road; Upper = Upper Rush; Lower = Lower Rush) based on flow and temperature covariates minimum annual flow (MinAnnFlow), mean summer flow (Mean6_9Flow) and days of ideal water temperature (Days_Ideal_Temp). Final model is shown in upper left corner of graph.

Appendix I – Regression Diagnostics

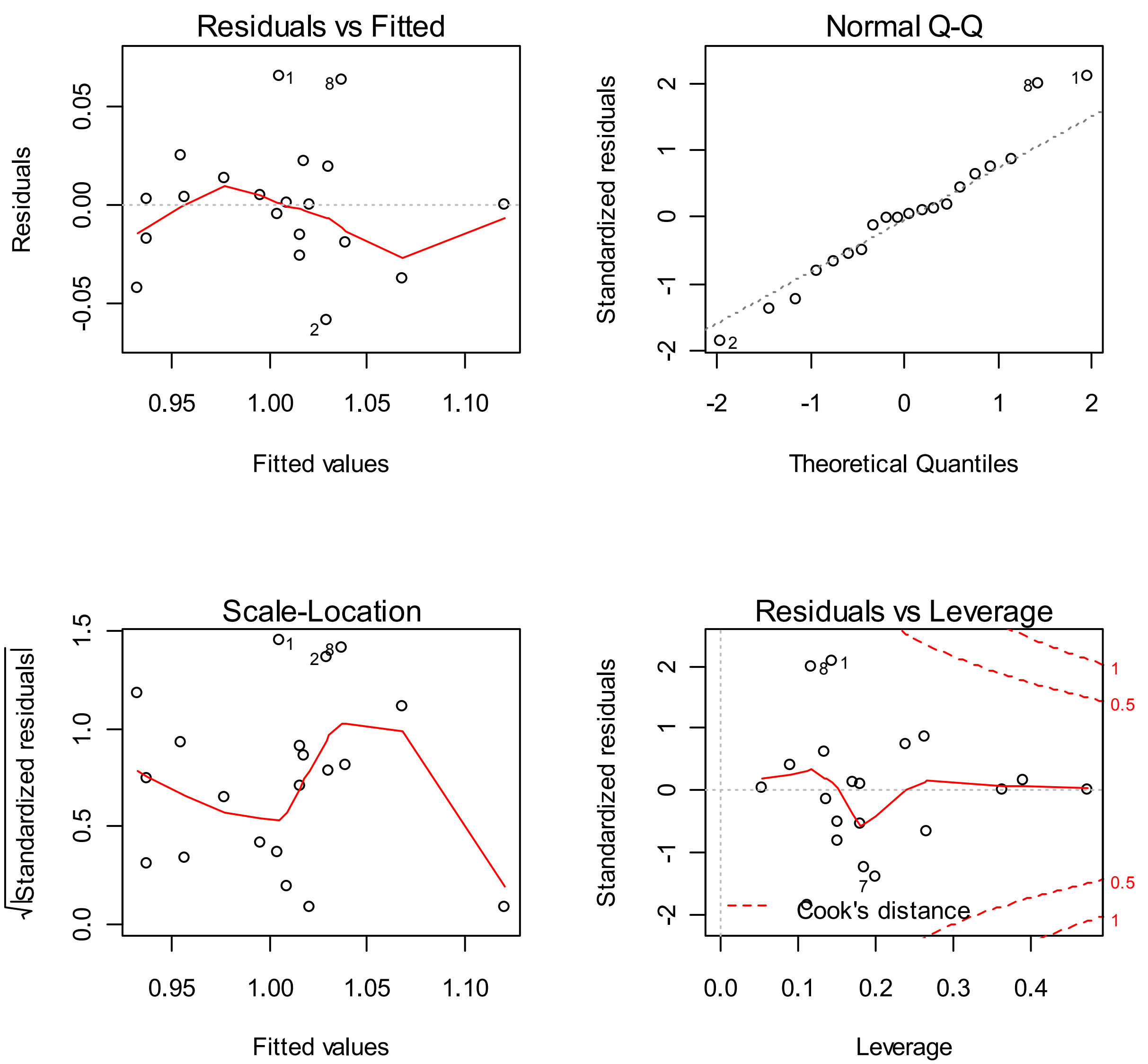


Figure I1. Regression diagnostics for best multiple regression model evaluating associations of flow and temperature to condition of brown trout 150 to 250 mm.

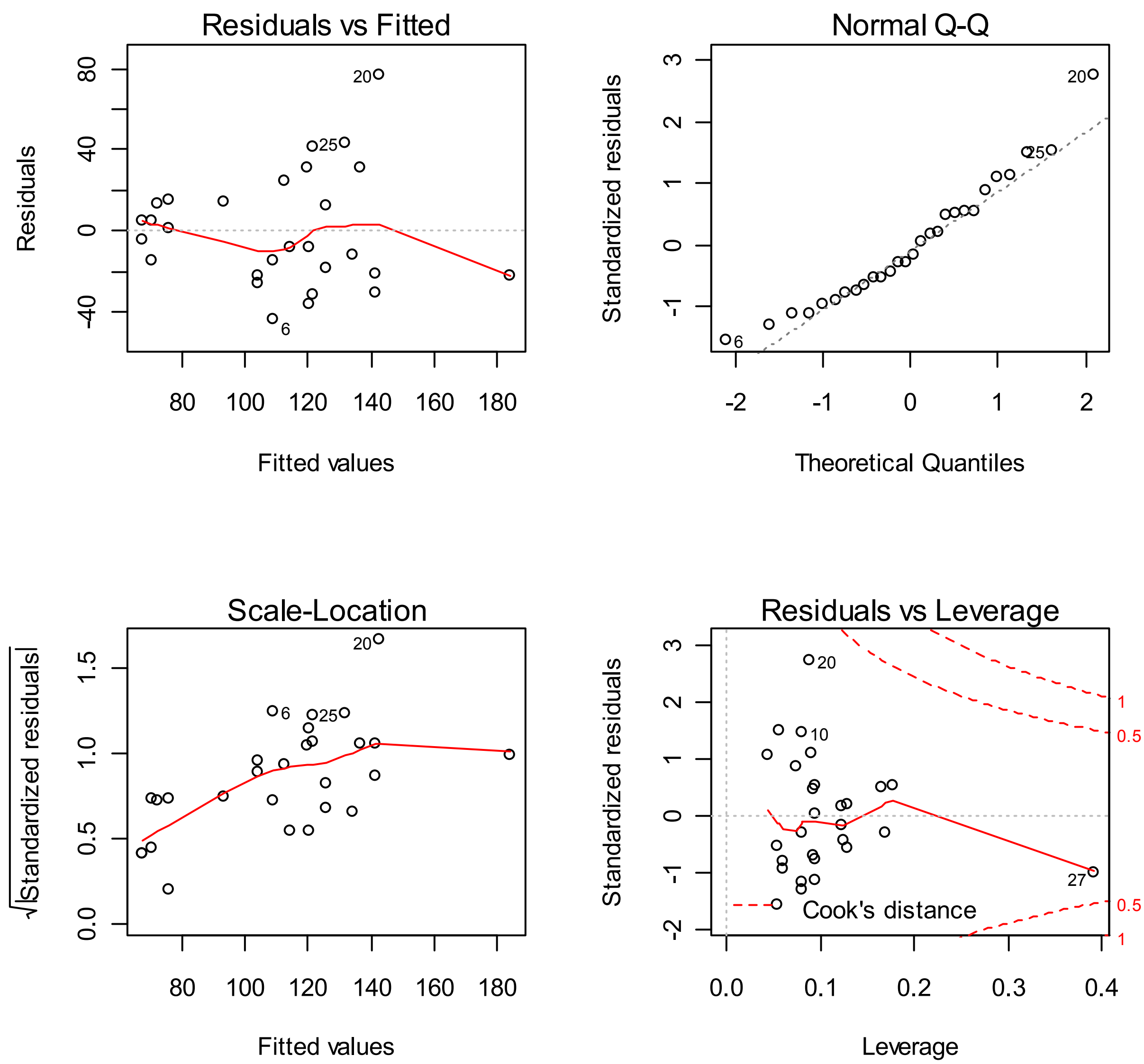


Figure I2. Regression diagnostics for best multiple regression model evaluating associations of flow to total biomass of brown trout.

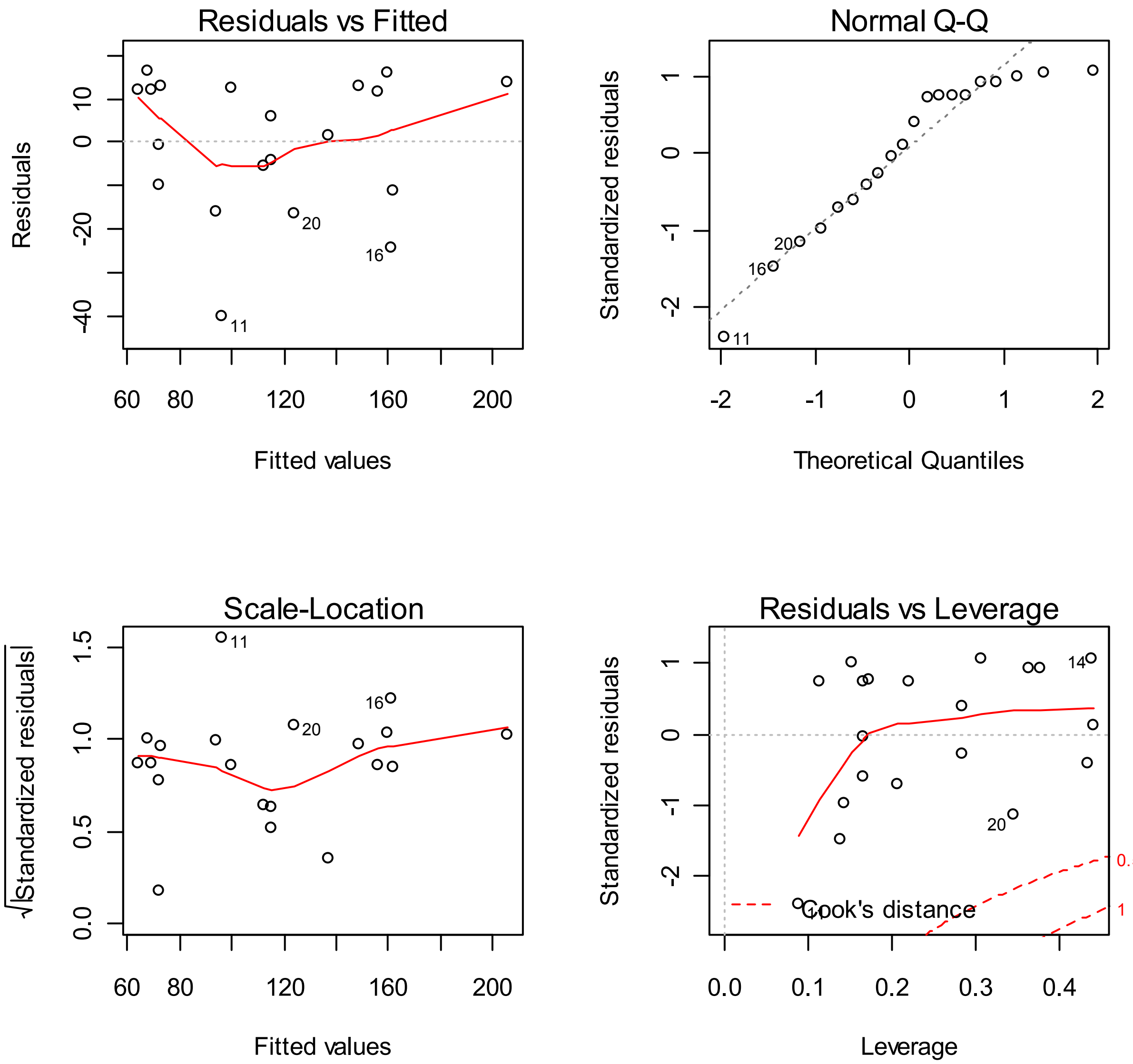


Figure I3. Regression diagnostics for best multiple regression model evaluating associations of flow and temperature to total biomass of brown trout.

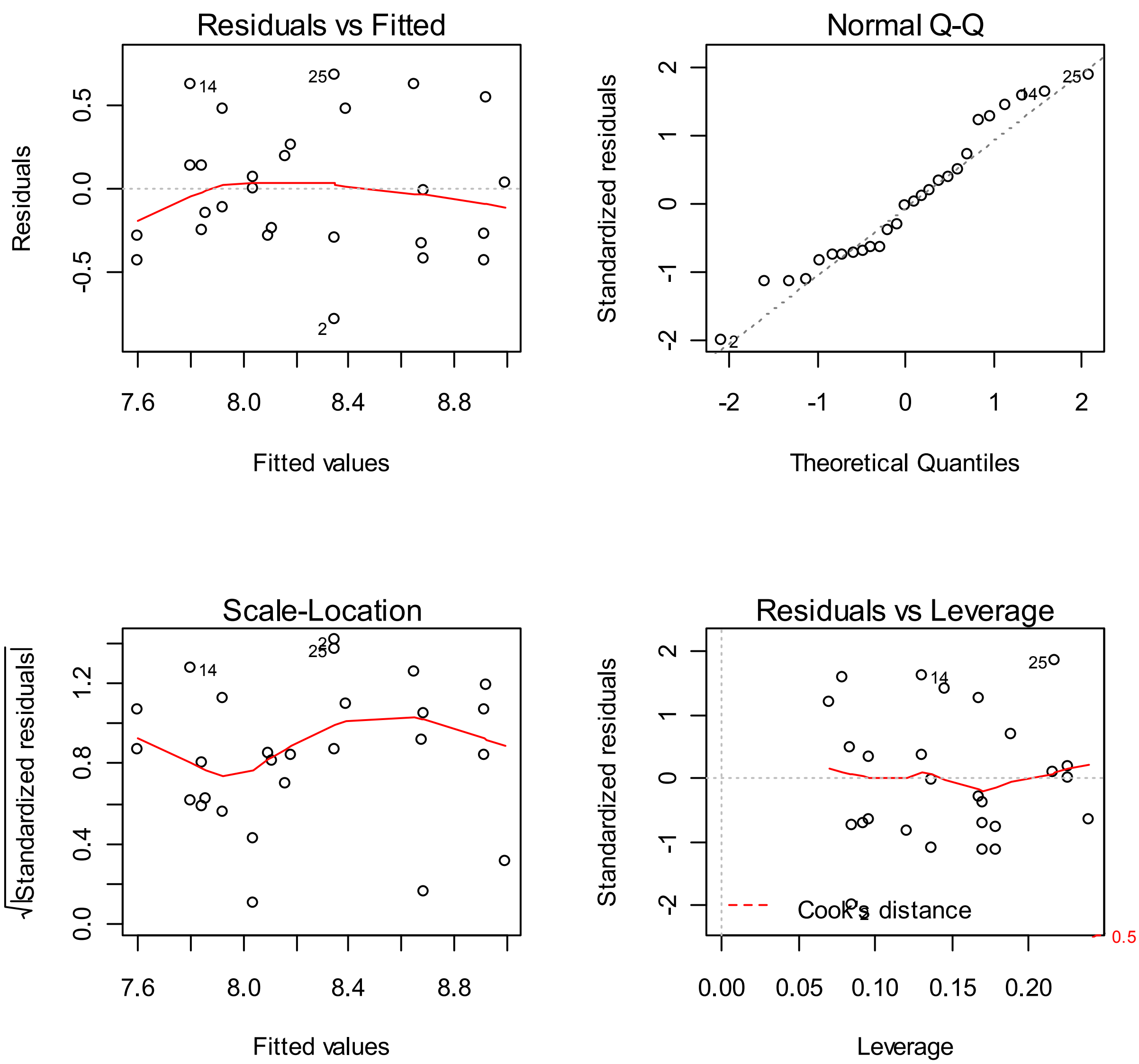


Figure I4. Regression diagnostics for best multiple regression model evaluating associations of flow and storage in Grant Reservoir to density of age-0 brown trout.

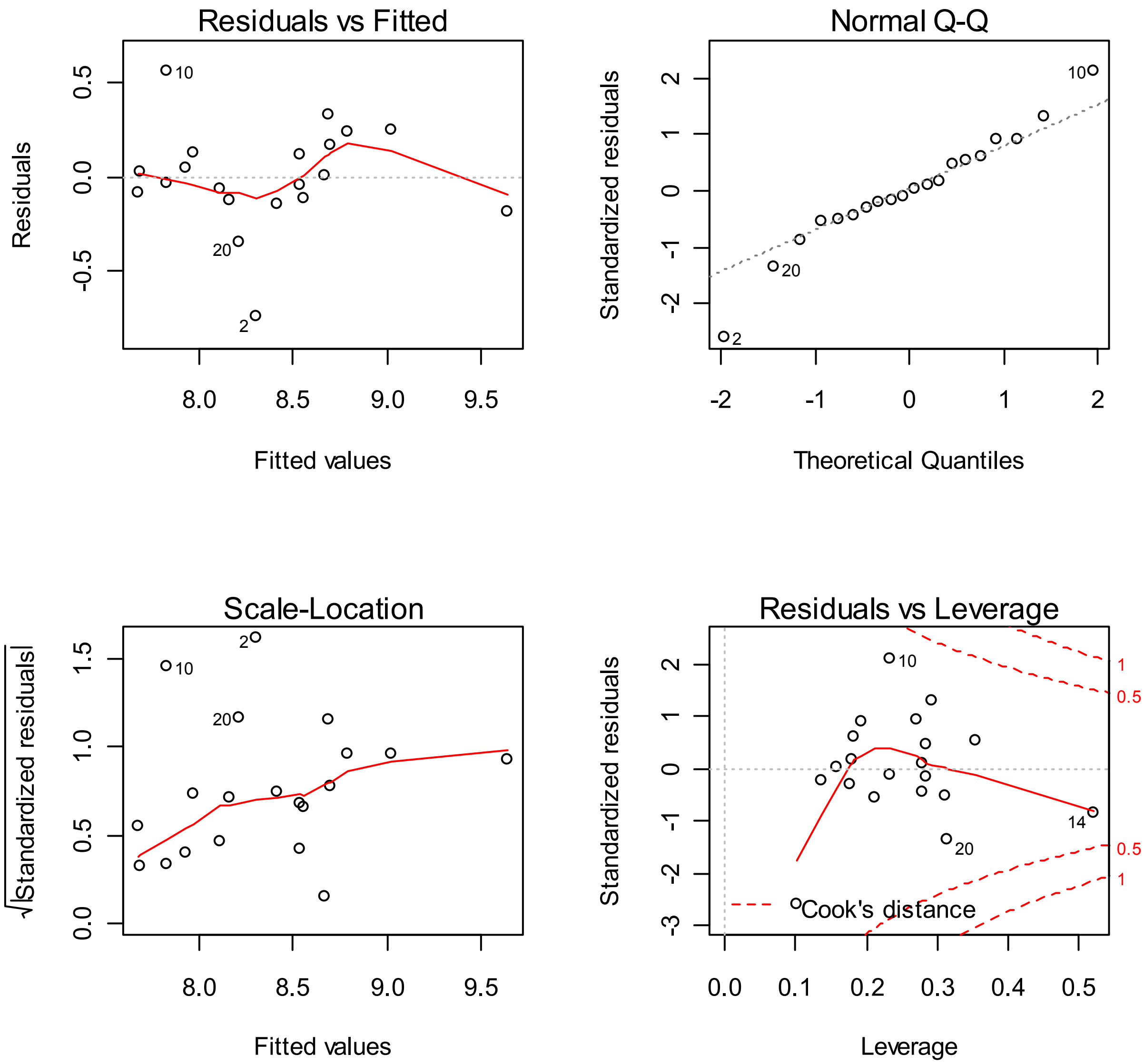


Figure I5. Regression diagnostics for best multiple regression model evaluating associations of temperature, flow and storage in Grant Reservoir to density of age-0 brown trout.

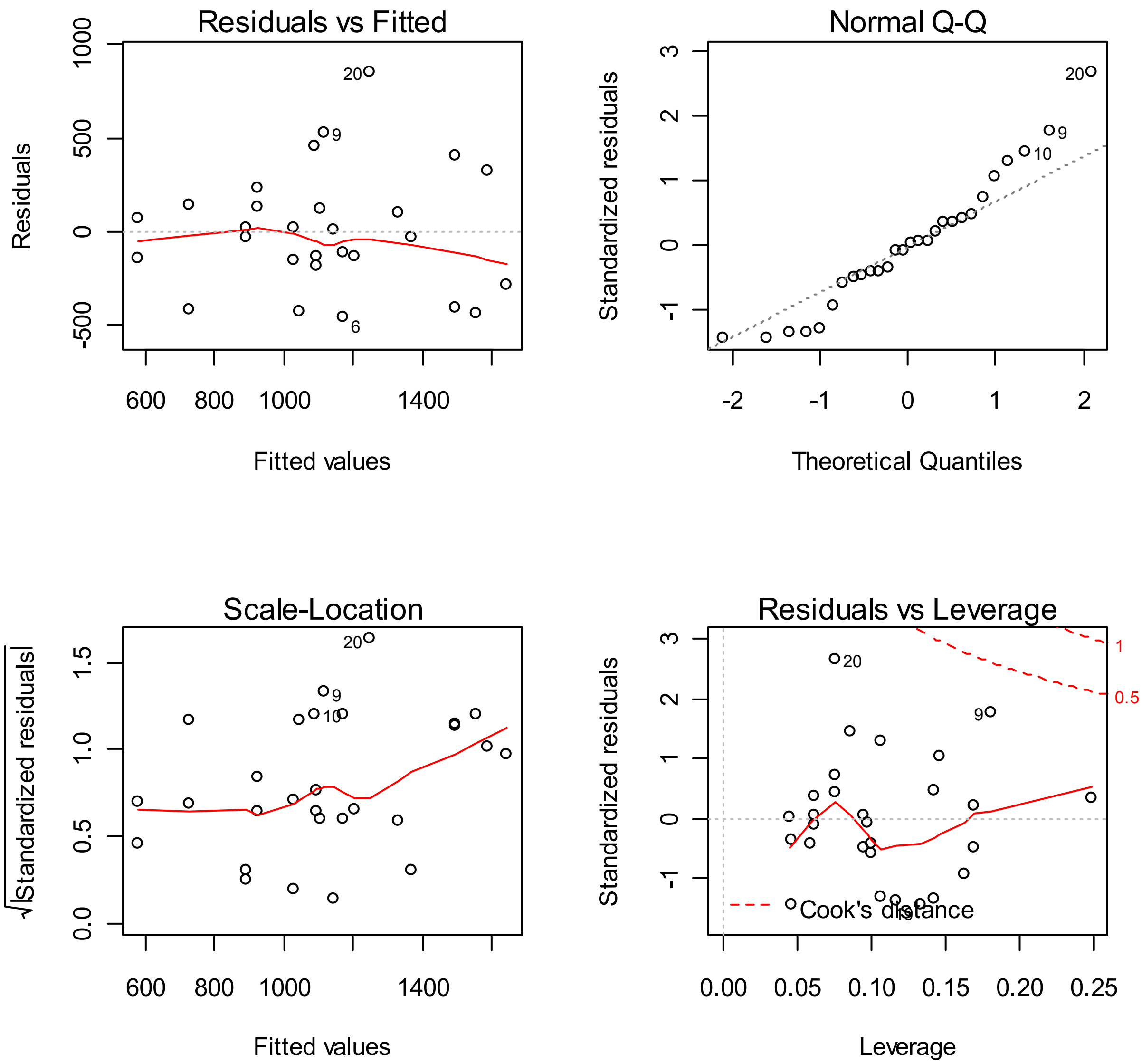


Figure I6. Regression diagnostics for best multiple regression model evaluating associations of flow to density of age-1+ brown trout.

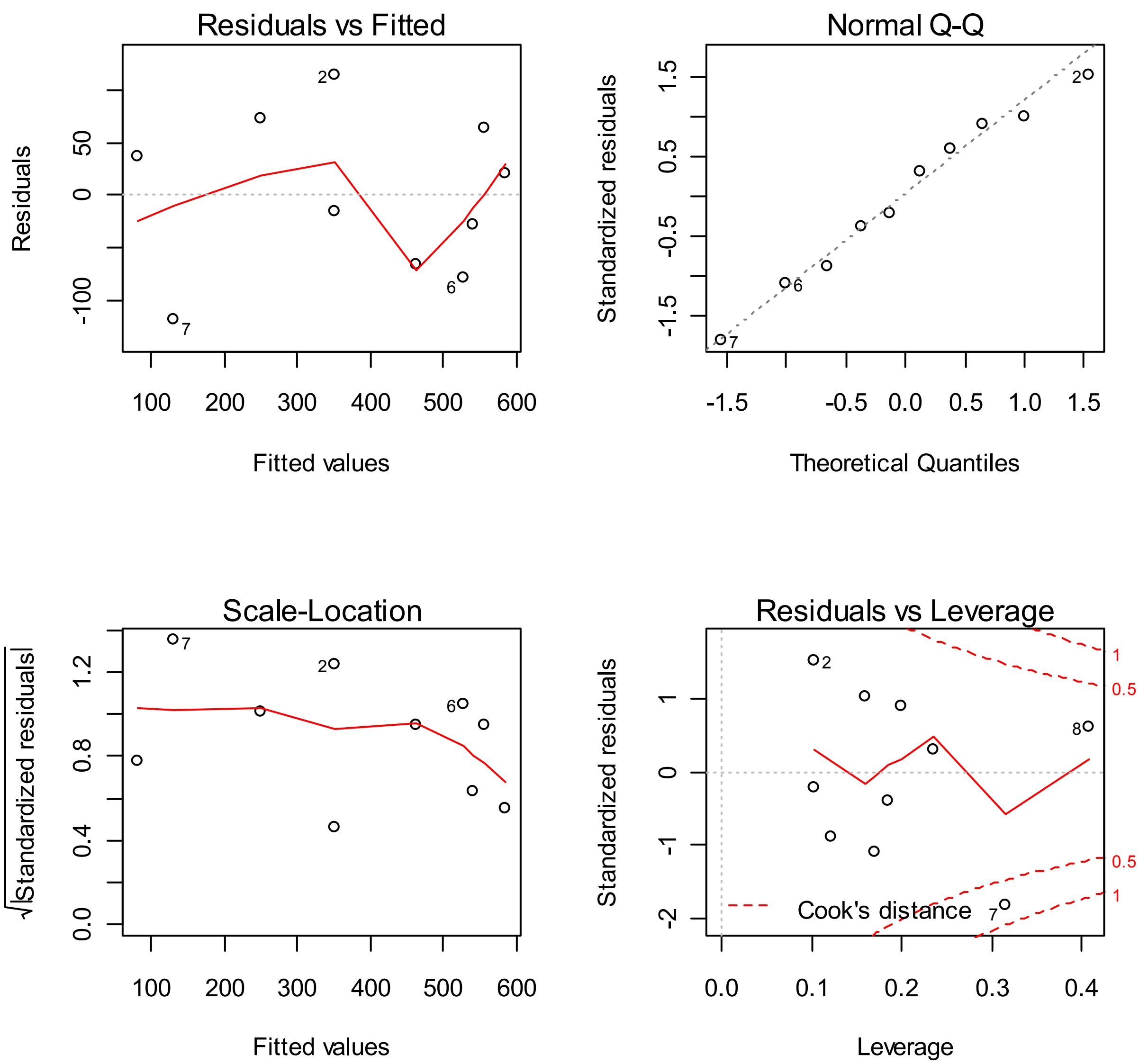


Figure I7. Regression diagnostics for best simple regression model evaluating the number of days summer flows exceeded 100 cfs to relative abundance of age-0 brown trout in Lee Vining Creek.

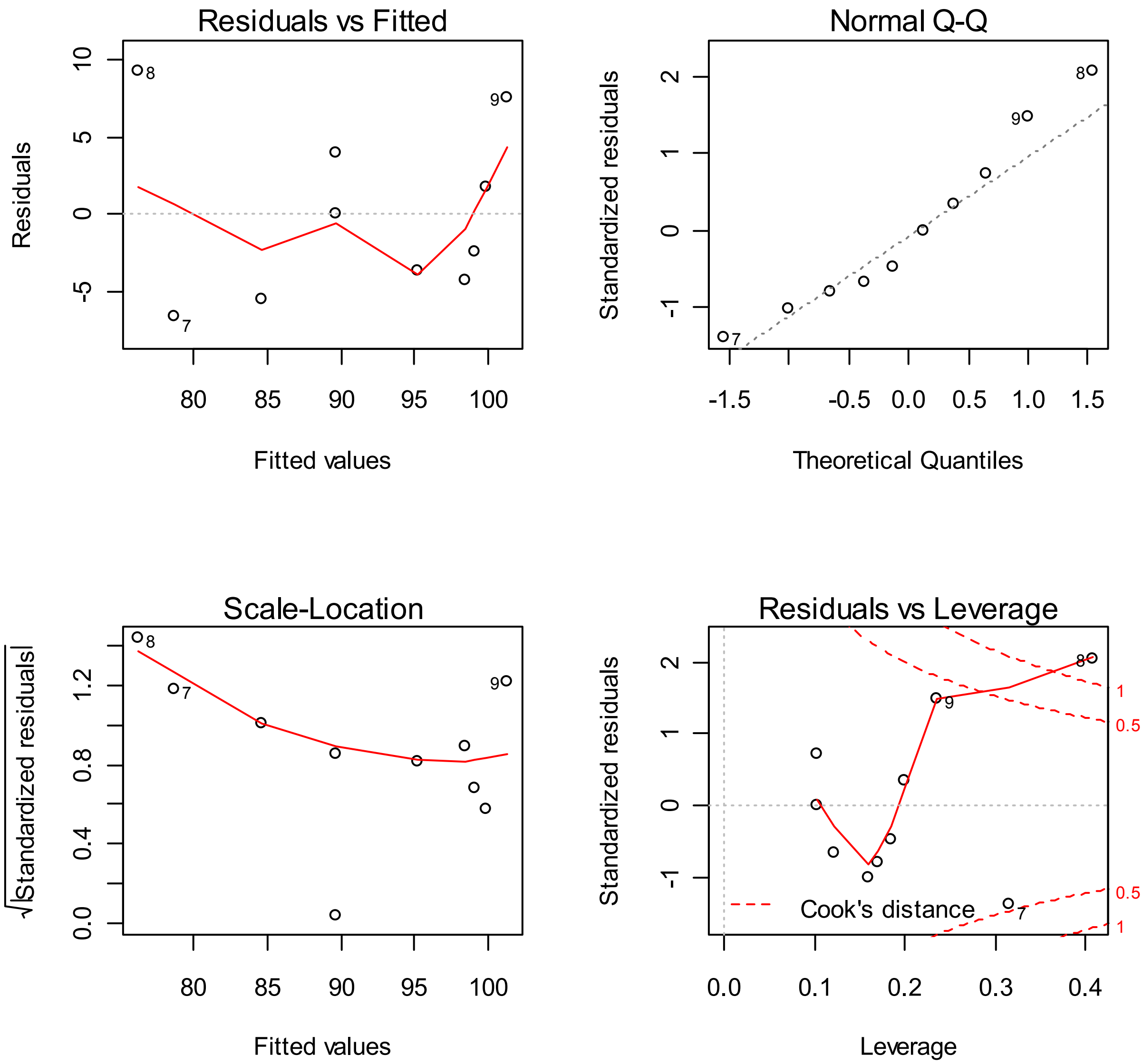


Figure I9. Regression diagnostics for best simple regression model evaluating the number of days summer flows exceeded 100 cfs to average length of age-0 brown trout in Lee Vining Creek.