The Dams Are Alright?

A Comparison of the Effects of Mountain and Valley Reservoirs in Western Montana

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Abstract

In the United States, most major waterways have been dammed at some point along their course, often for irrigation, domestic water use, hydroelectricity, or flood control. However, reservoirs can have major impacts on the modified aquatic ecosystems. In this study, I investigated how dams influenced physical properties, chemical properties, and invertebrate communities of mountain reservoirs and valley reservoirs in the Mission Mountains and Mission Valley in western Montana. Sample sites were located upstream of the reservoir, 100m downstream of the dam, and 300m downstream of the dam. Chemical and physical data, including temperature, pH, dissolved oxygen, conductivity, nitrate levels, phosphate levels, and flow, as well as invertebrate diversity and abundance showed few differences between upstream and downstream sites. However, strong differences in temperature, conductivity, periphyton density, flow, and phosphate were observed between mountains and valleys. Using relative abundance of invertebrate genera greater than 10% abundant and percent composition of functional feeding groups, cluster trees tended to group by upstream or downstream and by mountain or valley. Additionally, Jaquard's Similarity Index indicates that mountain reservoirs affect the aquatic systems differently than valley reservoirs do. In the mountains, streams tended to be more similar upstream of the dam while in the valleys, the streams were more similar downstream of the reservoirs. Low similarity was seen between mountain sites, while higher similarity was seen between downstream sites in the valleys.

Introduction

Throughout much of the United States, damming rivers and streams has become a common practice. Impounding rivers is an increasingly important and necessary means of supporting and sustaining agriculture and cattle ranching as one moves west into more arid climates. Many of these dams also provide hydroelectric power to the surrounding area in addition to supplying a constant supply of drinking water and, in some cases, act to control flooding. However, dams may also have negative, though often unintended, effects on the hydrologic system and the biota. In the western states, many of the dams are large and can have a significant impact on the aquatic ecosystem upstream and downstream of the reservoir. Dams near coasts may block migration routes for fish species (Lundqvist 2008). Poff et al (2007) showed that widespread impoundment across the country has reduced the natural heterogeneity of rivers and streams, thus homogenizing habitat and decreasing the complexity and diversity of aquatic systems and reducing biodiversity (Muotka 2007).

Baron et al (2002) described in broad terms how dams impact the ecological web of aquatic systems by altering the flow regime and water quality, thereby affecting sediment flux, chemical and nutrient fluxes, and thermal and light inputs. The extent and the type of these effects can depend on the size of the dam, its management, and its placement. Deeper reservoirs often contain water that is thermally stratified and the deep water may be anoxic due to decomposition. Larger detritus that would have normally been carried downstream can be trapped in the reservoir or behind the dam wall, depriving downstream fauna of allochthonous nutrients (Baxter 1977). The timing of water release is also typically different from the natural flood regime that can be important for spawning in some species. Changed abiotic factors in turn determine what type of biological community will be able to survive in that habitat. Often, the macroinvertebrate community of a stream can help to characterize the stream in a more abstract, though arguably more complete, manner.

Many insects have aquatic stages in their life cycles and they are frequently used as bio-indicators of stream health (Levy 1998). Because some taxa spend much of their lives in the water and feed on a wide variety of resources, they are often sensitive to transient or periodic changes in the chemical and physical characteristics of the water and can therefore be used to characterize and assess a stream. Insects can be classified into functional feeding groups and the relative abundance of these groups can also help characterize the stream. In addition to playing an important role in food webs as prey species for various fishes and birds, different taxa have different sensitivities to chemical pollutants, sediment alterations, or temperature changes and thus, their presence or absence can lend valuable and easily-gathered information about the stream habitat. In this study, benthic invertebrates were used to help classify and characterize the streams upstream and downstream of six different reservoirs. Three of the reservoirs were in the mountains and three were in the valley. Along with the composition of the invertebrate community, chemical and physical properties were compared above and below the reservoirs.

Materials and Methods

I studied three impoundments in Mission Valley – Kicking Horse Reservoir (KH), Ninepipe Reservoir (NP), and Pablo Reservoir (PB) – and three impoundments in the Mission Mountains – McDonald Lake (MD), Mission Reservoir (MS), and Swartz Lake (SZ). Two sampling sessions were performed. The first was between July 13 and 22, 2008. The second session was between July 27 and August 3, 2008. At each reservoir, there were three sample sites. The first (U) was upstream of the reservoir in the main inflow. The second (D1) and third (D3) sites were, respectively, 100m and 300m downstream of the last dam structure in the main outflow.

At each site, three samples of benthic macroinvertebrates were collected using a $0.1m^2$ Surber sampler with 363um Nitex mesh. Rocks were rubbed and substrate disturbed in order to dislodge invertebrates into the net. Invertebrates were identified to the lowest possible taxonomic level, typically genus, using a standard 10x Zeiss dissecting microscope and Merritt and Cummins (1996). Invertebrates were placed into Functional Feeding Groups using Merritt and Cummins (1996) and

Smith (2001). Also, temperature, conductivity, percent dissolved oxygen, mg/L dissolved oxygen, pH, nitrate, and phosphate levels were recorded at each site. Periphyton growth at each site was determined by scraping periphyton off of four rocks, filtering the periphyton, drying it, and weighing it. The density of periphyton of each site was calculated by averaging the densities of the four rocks. Finally, flow was recorded using the Orange Method.

All statistics were done on SYSTAT v.10 or v.11. Diversity was calculated using a Shannon Index for each site by summing invertebrate counts for the three samples taken at each site. General Linear Models (GLMs) were run with all chemical and physical measures to determine differences between sites (U, D1, D3) and also reservoir type (mountain or valley). ANOVAs were used to search for relationships between the chemophysical measurements and diversity as well as abundance. Both site and type were used as categorical factors.

To determine clusters in functional feeding groups and invertebrate genera, two separate cluster analyses were performed. The first used functional feeding group percent abundances for each site. A principle component analysis was performed on arcsin-transformed data, followed by a hierarchical cluster analysis using Pearson distances. The second principle component analysis was performed using arcsin-transformed percent abundances of invertebrate taxa that composed at least 10% of at least one site. Pearson distances were used in the hierarchical clustering.

Similarities between sites were calculated using Jaquard's Similarity Index. To determine similarity differences between mountains and valleys, average within-reservoir similarities were calculated for mountain reservoirs as well as valley reservoirs (U vs. D1, U vs. D3, D1 vs. D3). These compared average similarities along the stream gradient of each reservoir. Average between-reservoir similarities were also calculated for mountain reservoirs and valley reservoirs separately (U vs. U, D1 vs. D1, D3 vs. D3). These compared the similarities of corresponding sites across different reservoirs.

Results

Temperature varied significantly between sites ($p=0.0387$), reservoir type ($p<0.001$), and sampling period ($p=0.001$) (Table 1). Upstream sites were colder than the downstream sites. Temperatures were warmer in the valley reservoirs. Also, the second sampling period was warmer than the first (Fig. 1). No other chemical or physical measurements were significantly different between upstream and downstream sites (Table 1, Table 2). Dissolved oxygen (mg/L) was significantly higher in the mountain reservoirs ($p=0.018$). Phosphate (mg/L) and flow (m/s) were also higher in the mountain reservoirs ($p=0.009$, $p=0.029$, respectively). Conductivity (uS) and periphyton density (mg/cm^2) were both higher in the valley reservoirs ($p=0.0001$, $p=0.057$, respectively). Diversity was also higher in the mountain reservoirs than in the valleys ($p=0.008$) (Table 3).

When using macroinvertebrate functional feeding groups, six distinct clusters were identified (Fig. 2). Cluster A was characterized by a high percentage of leeches and detritivores (Fig. 3) and included only two of the valley sites. Cluster B included only downstream mountain sites and was characterized by more predators and detritus shredders. Cluster C was mostly mountain sites or upstream valley sites and was characterized by roughly 45% scrapers and 45% collector-gatherers. Cluster D was all downstream sites and showed very high percentages of collector-gatherers. Cluster E was determined by very high numbers of collector-filterers and included mainly downstream sites. Cluster F was dominated by detritivores.

For the genera cluster, four or five clusters formed (Fig. 4). Cluster A was composed of nearly all valley sites and/or downstream sites. Cluster B_1 consisted of mostly mountain upstream sites and was characterized mostly by abundant *Epeorus* spp., Heptageniid mayflies. Cluster B_2 was entirely downstream mountain sites and contained abundant *Epeorus* and Baetid mayflies. Cluster C was nearly all downstream valley sites and was generally characterized by *Trichorythodes* spp., Trichorythid mayflies. Cluster D consisted only of two mountain sites.

Analyses using the Similarity Indices showed differing trends between mountain and valley sites (Fig. 5). Comparing average similarities between sites within mountain reservoirs showed almost no differences. However, in the valley reservoirs, though not significant, a trend seemed to have developed in which downstream sites were more similar to each other than the upstream site. Also, a small recovery gradient may be present since average U vs. D3 similarity was higher than average U vs. D1 similarity.

Comparison of similarities between corresponding sites among reservoirs, showed that in the mountains, the streams were less similar downstream of the dam than they were upstream. Average U vs. U similarity was higher than average D1 vs. D1 similarity or D3 vs. D3 similarity. This trend appears to be significant. In the valleys, the opposite trend emerged. Downstream sites were more similar than upstream sites were. In terms of similarity, the reservoirs in the mountains seem to have varying effects on the stream biota while the reservoirs in the valleys seem to increase homogeneity downstream. However, the trends in the valley were not significant, though the trend appears to be fairly strong.

Discussion

Few significant differences were seen in the chemical and physical properties of the streams between the upstream and the downstream sites (Table 1, 2, & 3). Temperature was higher in the downstream sites because the water warmed in the reservoirs. Temperature was higher in the valleys than in the mountains because the mountain streams consist of relatively fresh snow-melt while the valley streams have warmed on their way down the mountains and into the valleys. The second sampling period showed higher temperatures because it was later in the summer. The higher dissolved oxygen (DO) in the mountains was likely a byproduct of the fact that cold water can hold more oxygen, but the water may also have more oxygenation because of the higher flow and rockier substrate. Percent DO was not significantly different between reservoir types (p=0.689). As expected, flow was higher in the mountains because of the higher stream gradient. Higher flow leads to more erosion, the main source of phosphorous in stream systems. Thus, phosphorous concentrations were also higher in the mountains. Conductivity and periphyton density, which may be positively related since conductivity correlates with higher nutrient levels (Klco, unpublished), were both higher in the valleys than in the mountains. Many of the valley sites had more sediment in the stream bed than was found in the mountain sites. This is likely a result of both the lower flow, which allows smaller particles to settle, and potentially run-off from nearby agriculture. Higher sediment load increases conductivity and, thus, allows for more primary productivity. In addition, the mountain sites were forested, allowing less light to penetrate to the streambed and therefore inhibiting periphyton growth, while the valley sites tended to be more open.

Although no differences in abundance or diversity of invertebrates were found between upstream and downstream sites, the functional feeding group composition did differ (Fig. 2, 3). Notably, cluster C consisted of nearly all upstream sites (and mostly upstream mountain sites) and was characterized by roughly even numbers of collector-gatherers and scrapers. The presence of collector-gatherers as a dominant species was expected since most of these sites were forested, so much of the allochthonous input was coarse organic matter. The similarly high abundance of scrapers, however, was not expected and it seems to contradict the fact that periphyton was less dense in the mountain streams than in the valley streams.

Another important cluster to note is cluster E, which includes only downstream sites if the upstream site from Ninepipe is instead seen as an outflow of Kicking Horse (Fig. 2). These sites were all dominated by collector-filterers, generally Simuliid larvae (Fig. 3). Collector-filterers likely thrive in these sites because of the presence of both a rocky substrate and finer organic matter that was released from the dam or stirred up by the release of water.

In the genera cluster trees, cluster B is composed almost entirely of mountain sites (Fig. 4). Heptageniids of the genus *Epeorus*, which were absent from all valley sites, were found in all of these sites. In addition, cluster B_1 includes nearly all of the upstream mountain sites and was characterized by, among other genera, *Rhithrogena* spp., Heptageniid mayflies. *Rhithrogena* mayflies have abdominal gills that form a suction cup, making them especially well-adapted to the fast mountain streams (Merritt and Cummins 1996). Cluster B includes many of the same sites as the functional feeding group C, suggesting that these Heptageniids make up a large and important portion of the invertebrate communities at these sites.

According to the genera cluster, all of the upstream mountain sites were similar to each other (Fig. 4). The downstream sites did not all cluster, suggesting that the impoundments impacted the streams differently. That is, in terms of invertebrate community composition, the mountain streams were more similar to each other upstream of the reservoir than they were downstream of the reservoir.

This is supported by the trends seen in the similarity index analyses. Among mountain reservoirs, the upstream sites were more similar to each other than the downstream sites were (Fig. 5). This could be expected since the streams were all low order, fast streams originating from snowmelt. They were all fairly near each other in the same mountain range, descending on the western side of the mountain range. The outflows of the mountain reservoirs were structurally different as well. The outflow of Mission Reservoir is channelized and deep along the entire stretch that was sampled. The outflow of McDonald Reservoir is channelized for approximately the first 75m after the dam, but progressively becomes more spread-out with increasing distance from the dam. The outflow of Swartz

Lake, which was not channelized at all, seemed to be the least altered.

The valley reservoirs, on the other hand, showed the opposite effect (Fig. 5). Among reservoirs, the outflows were more similar than the inflows. All of the outflows were channelized, deep, and slow-moving. Thus, the outflows had less habitat and substrate variability downstream of the reservoir than upstream. This is reflected in the relatively high similarity index among the downstream valley sites.

Thus, though there was no significant decline in diversity and no significant change in abundance, there was a likely shift in the major species composition between upstream and downstream sites. Aside from a temperature increase in the downstream sites, no significant chemical or physical differences were seen among sites. Rader and Ward (1988) also found few differences in water chemistry between the upstream and downstream sites of three reservoirs. The same study found declines in diversity coupled with large increases in the abundance of a few taxa. These changes were not observed in my study, but there seemed to be a change in the structure of the invertebrate community, both in functional feeding group composition and genera found.

In addition, Rader and Belish (1999) found that periods of high flow allowed formerly reduced invertebrate communities downstream of a dam to replenish through drift. In fact, Nelson and Lieberman (2002) found that flow was the most important factor in the determination of the insect community. If periodic drift is important in these reservoirs, it would not have been seen due to the relatively consistent high flow downstream of the reservoirs. However, in considering the low similarity between upstream and downstream sites, it seems unlikely that the downstream communities are sustained through drift. Water level was often lower in the upstream sites during the second period, but not across all reservoirs. Because this has been a particularly wet year, the effects of the reservoirs may not be as apparent or as extreme as they are in other years. Therefore, depending on the timing of the study and the current releases from the reservoir, different results may be found for the studied reservoirs.

There was a trend of downstream recovery in the similarity indices of the valley reservoirs. Camargo and Voelz (1996) observed a recovery gradient downstream of the Granby Dam on the Colorado River in which the invertebrate community became more like the upstream site with increasing distance from the dam. In this study, at least in the valleys, the D3 sites were more similar to the U sites than the D1 sites were. In the mountains, there was not much evidence of such a trend, which may be because of the elevation change between the upstream and downstream sites in the mountains. Even in the absence of a reservoir, the streams would naturally change and similarity would be expected to decrease with increasing distance downstream from the upstream site. Unfortunately, control streams with no reservoirs are anything but plentiful in this area. Therefore, it is difficult to separate the effects of the reservoir from the natural changing of the mountain streams.

Although no declines in diversity were seen, the invertebrate communities downstream seemed to be different than the upstream communities based on the cluster analyses. Especially in the valleys, the downstream sites tended to form clusters both by genera and by functional feeding groups. This supports the trend seen in the similarity indices that valley downstream sites were fairly similar to each other. Therefore, it seems that the reservoirs are altering the invertebrate communities, but not depleting populations or diversity. The diversity and abundances stayed fairly similar, but the actual invertebrate taxa changed.

Conclusion

This study did not find evidence that the reservoirs in the area are having major negative effects on the stream or the stream biota. Differences in the chemical and physical properties were present between mountain and valley reservoirs, but, with the exception of temperature, no significant differences were seen between upstream and downstream sites. Cluster analyses and similarity index comparison showed that the invertebrate communities were being affected by the reservoirs, but those effects are not negative in terms of diversity or abundance, as no decline in either was seen downstream of the reservoirs.

Potential problems with this study include a lack of control stream system. No unaltered streams were sampled at similar distances to test for natural changes that would occur across distance and elevation. This may have been especially important for the mountain streams because of the steep elevation gradient between upstream and downstream sites. Also, the sampling time was relatively short. Most other similar studies involved sampling throughout a year or over the course of several years. This would incorporate more potential impacts of the reservoir as the amount and timing of water released changed. In this study, flow was not significantly different between sampling periods and impoundment management practices seemed relatively unaltered over the course of the study. Finally, this study did not consider channelization as a possible factor affecting the benthic community. Many of the streams were channelized either above or below the reservoir. This seemed to have a major impact on the stream bed and, of course, the diversity of habitats available to invertebrates.

Future studies regarding mountain reservoir inflows and outflows should attempt to find control streams that have not been dammed. This would help separate the effects of natural topographically-induced changes from the effects of the reservoirs. In addition, many of the sample sites were channelized. This channelization seemed to have had major effects on physical characteristics of the streams, including flow and substrate type. It seems likely that channelization could impact other stream characteristics and the invertebrate communities. Channelization may also account for some of the variability seen in this study. Sampling over an extended time period to incorporate different levels of flow released from the reservoirs would also be important in future studies.

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References

Armitage PD. 2006. Long-term faunal changes in a regulated and an unregulated stream – Cow Green thirty years on. *River Research and Applications.* 22: 947-966.

Baxter RM. 1977. Environmental effects of dams and impoundments. *Annual Reviews of Ecological Systems.* 8: 255-283.

Camargo JA, Voelz NJ. 1996. Biotic and abiotic changes along the recovery gradient of two impounded rivers with different impoundment use. *Environmental Monitoring and Assessment*. 50: 143-158.

Cortes RMV, Ferreira MT, Oliveira SV, Godinho F. 1998. Contrasting impact of small dams on the macroinvertebrates of two Iberian mountain rivers. *Hydrobiologia*. 389: 51-61.

Finn DS, Poff NL. 2005. Variability and convergence in benthic communities along the longitudinal gradients of four physically similar Rocky Mountain streams. *Freshwater Biology*. 50: 243-261.

Fleituch T. 2003. Structure and functional organization of benthic invertebrates in a regulated stream. *International Reviews of Hydrobiology*. 88: 332-344.

Greenwood MT, Bickerton MA, Gurnell AM, Petts GE. 1999. Channel changes and invertebrate faunas below Nant-Y-Moch Dam, River Rheidol, Wales, UK: 35 years on. *Regulated Rivers: Research and Management*. 15:99-112.

Heino J, Mykra H, Hamalainen H, Aroviita J, Muotka T. 2007. Responses of taxonomic distinctness and species diversity indices to anthropogenic impacts and natural environmental gradients in stream macroinvertebrates. *Freshwater Biology*. 52: 1846-1861.

Levy S. 1998. Using bugs to bust polluters. *BioScience*. 48(5):342-346.

Lundqvist H. 2008. Upstream passage problems for wild Atlantic salmon (*Salmo salar L.*) in a regulated river and its effect on the population. *Hydrobiologia*. 602:111-127.

Maiolini B, Lencioni V, Boggero A, Thaler B, Lotter AF, Rossaro B. 2006. Zoobenthic communities of inlets and outlets of high altitude Alpine lakes. *Hydrobiologia*. 562: 217-229.

Marchant R. 2007. The use of taxonomic distinctness to assess environmental disturbance of insect communities from running water. *Freshwater Biology*. 52:1634-1645.

Merritt, R. W., K. W. Cummins. 1996. *An Introduction to the Aquatic Insects of North America*. Third Edition. Dubuque, Iowa: Kendall/Hunt Publishing Company.

Muotka T and Syrjänen J. 2007. Changes in habitat structure, benthic invertebrate diversity, trout populations and ecosystem processes in restored forest streams: a boreal perspective. *Freshwater Biology*, 52: 724-737.

Nelson SM, Lieberman DM. 2002. The influence of flow and other environmental factors on benthic invertebrates in the Sacramento River, USA. *Hydrobiologia*. 489:117-129.

Pimentel, D., U. Stachow, D. A. Takacs, H. W. Brubaker, A. R. Dumas, J. J. Meaney, J. A. S. O'Neil, D. E. Onsi, D. B. Corsillus. 1992. Conserving Biological Diversity in Agricultural/Forestry Systems. *BioScience* 42(5): 354-362.

Poff NL, Oldgen JD, Merritt DM, Pepin DM. 2007. Homogenization of regional river dynamics by dams and global biodiversity implications. *PNAS*, 104 (14): 5732-5737.

Rader RB, JV Ward. 1988. Influence of regulation on environmental conditions and the macroinvertebrate community in the Upper Colorado River. *Regulated Rivers: Research and Management*. 2: 597-618.

Rader RB, Belish TA. 1999. Influence of mild to severe flow alterations on invertebrates in three mountain streams. *Regulated Rivers: Research and Management*. 15:353-363.

Smith, D. G. 2001. *Pennak's Freshwater Invertebrates of the United States: Porifera to Crustacea*. Fourth Edition. New York: John Wiley & Sons, Inc.

Vinson MR. 2001. Long-term dynamics of an invertebrate assemblage downstream from a large dam. *Ecological Applications*. 11(3): 711-730.

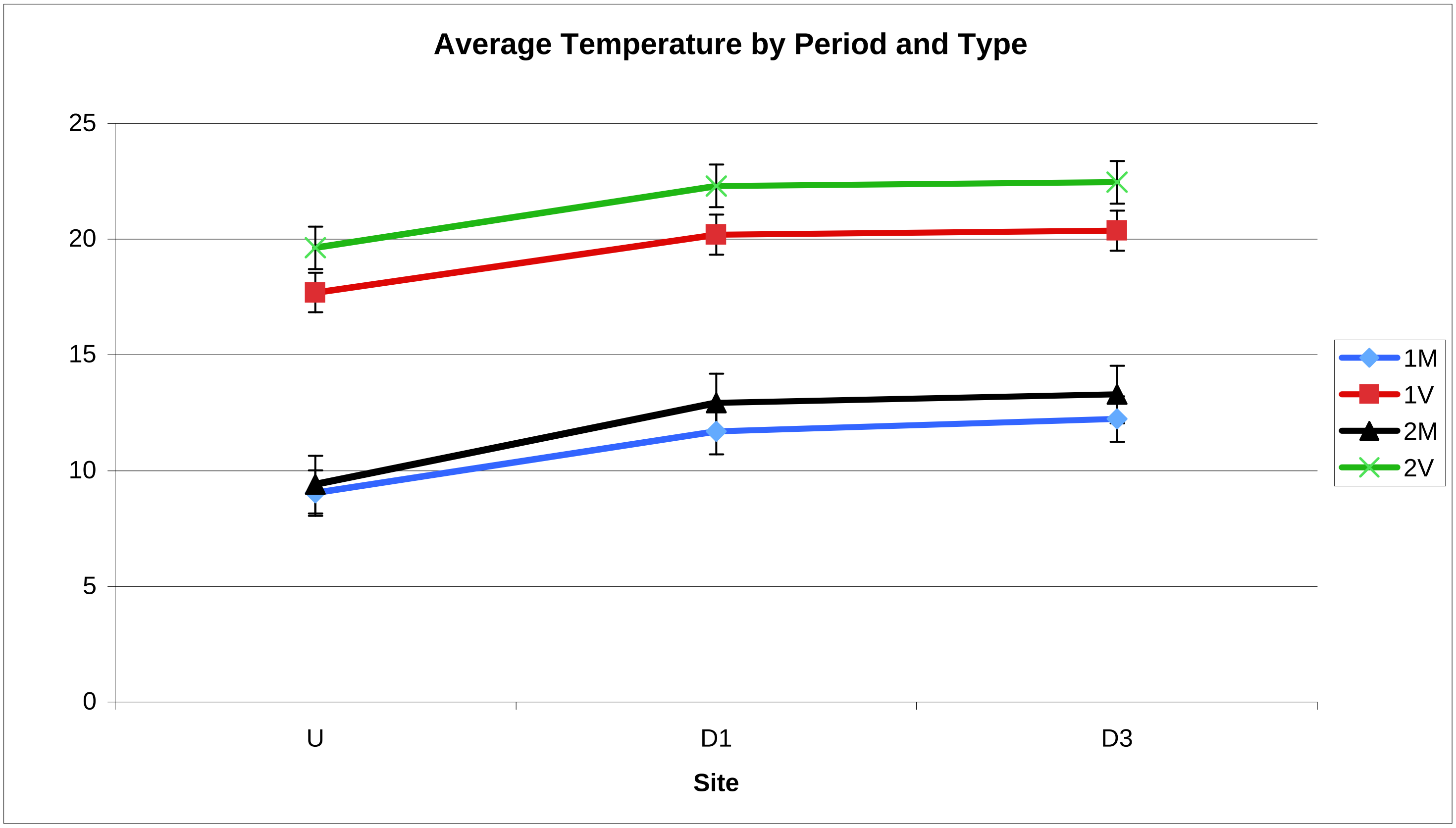


Figure 1. Average temperature by period and type. Temperature was significantly higher in the valleys than in the mountains ($p<0.001$), significantly higher during the second sampling period ($p=0.0387$), and significantly higher in the downstream sites ($p=0.001$).

Functional Feeding Group Cluster Tree

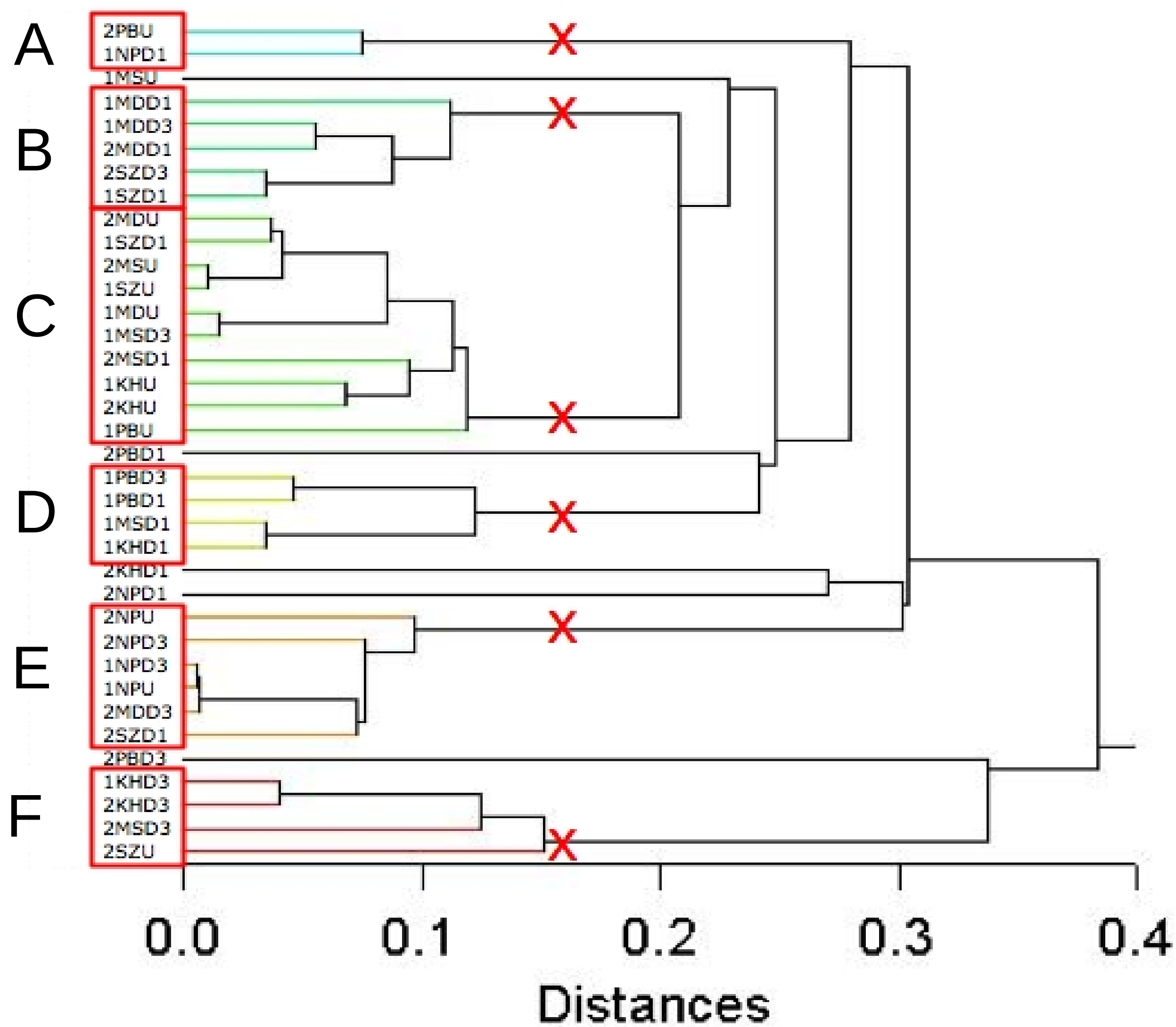


Figure 2. Functional Feeding Group cluster tree. This cluster tree was formed using arcsin-transformed percent abundances of the functional feeding groups at each site. Pearson distances were used. Clusters correspond roughly with mountain or valley sites and upstream or downstream sites. Mountain sites are MD,MS, and SZ. Valley sites are PB, NP, and KH.

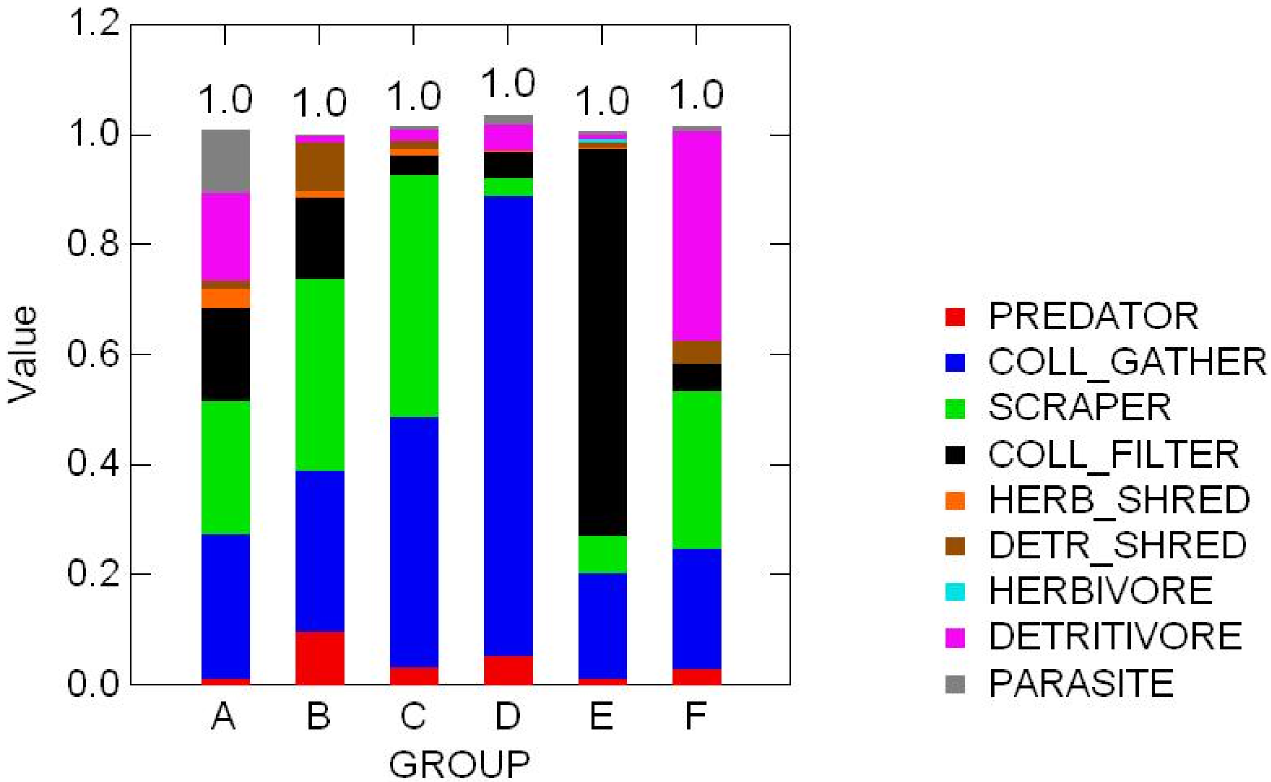


Figure 3. Percent abundance of each Functional Feeding Group by clusters. Cluster groups are from Fig. 2. Several clusters are well-defined by large percentages of specific functional feeding groups.

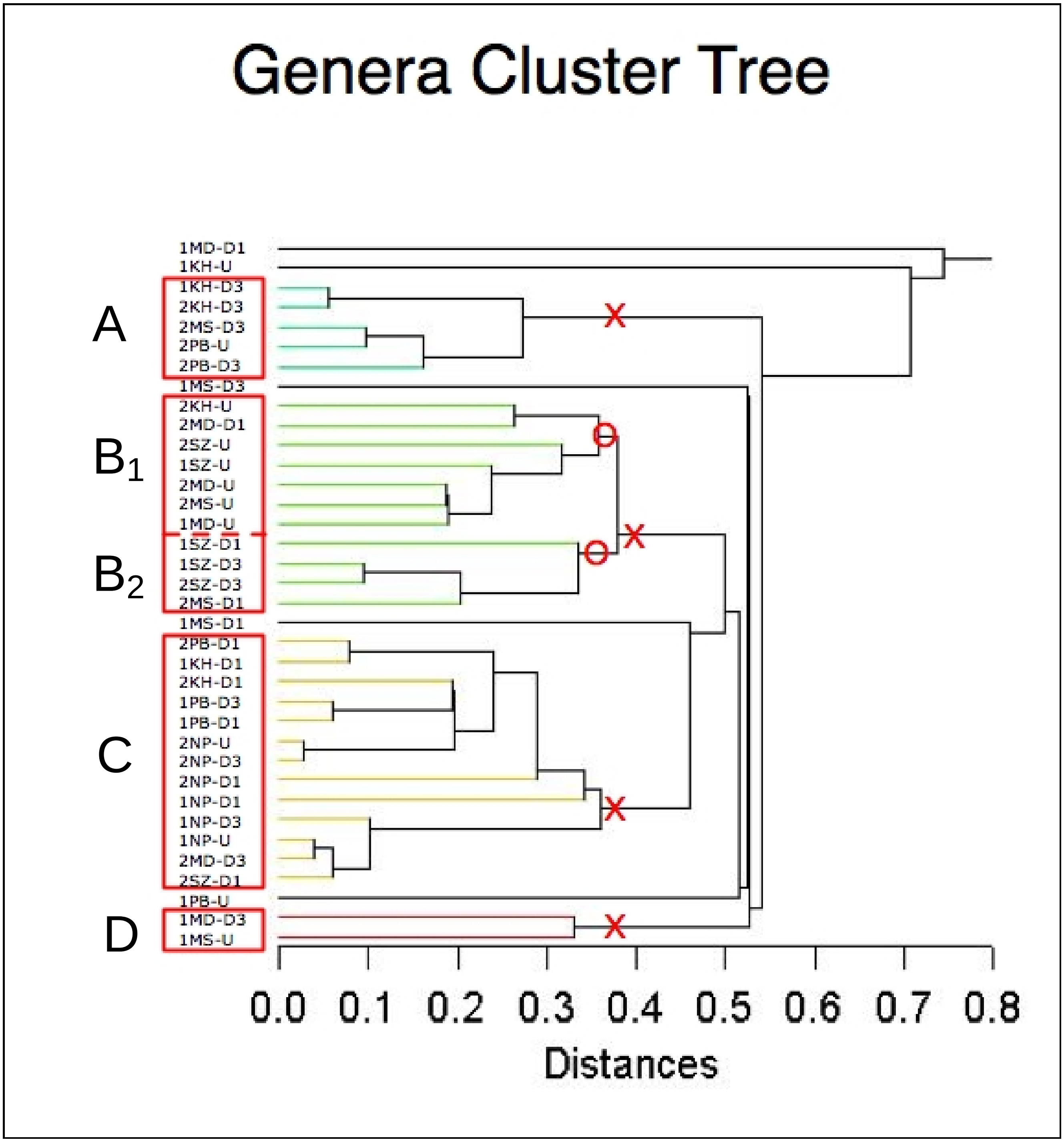
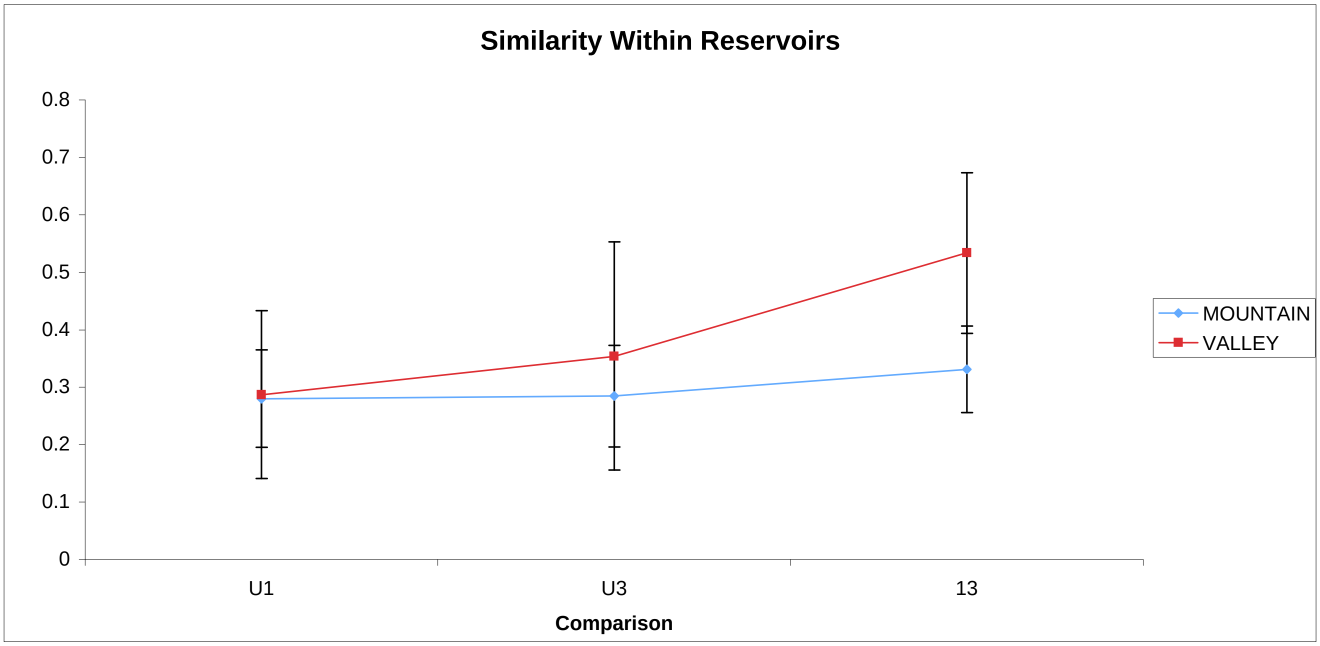


Figure 4. Cluster tree by genera. Genera appearing in at least one site at 10% abundance or greater were used to create this tree. The clusters that formed are strongly grouped by upstream and downstream sites as well as by mountain and valley. Mountain sites are MD,MS, and SZ. Valley sites are PB, NP, and KH. This indicates that the reservoirs are impacting the invertebrate taxa that can survive downstream of the reservoir, though no significant decline in diversity was found.



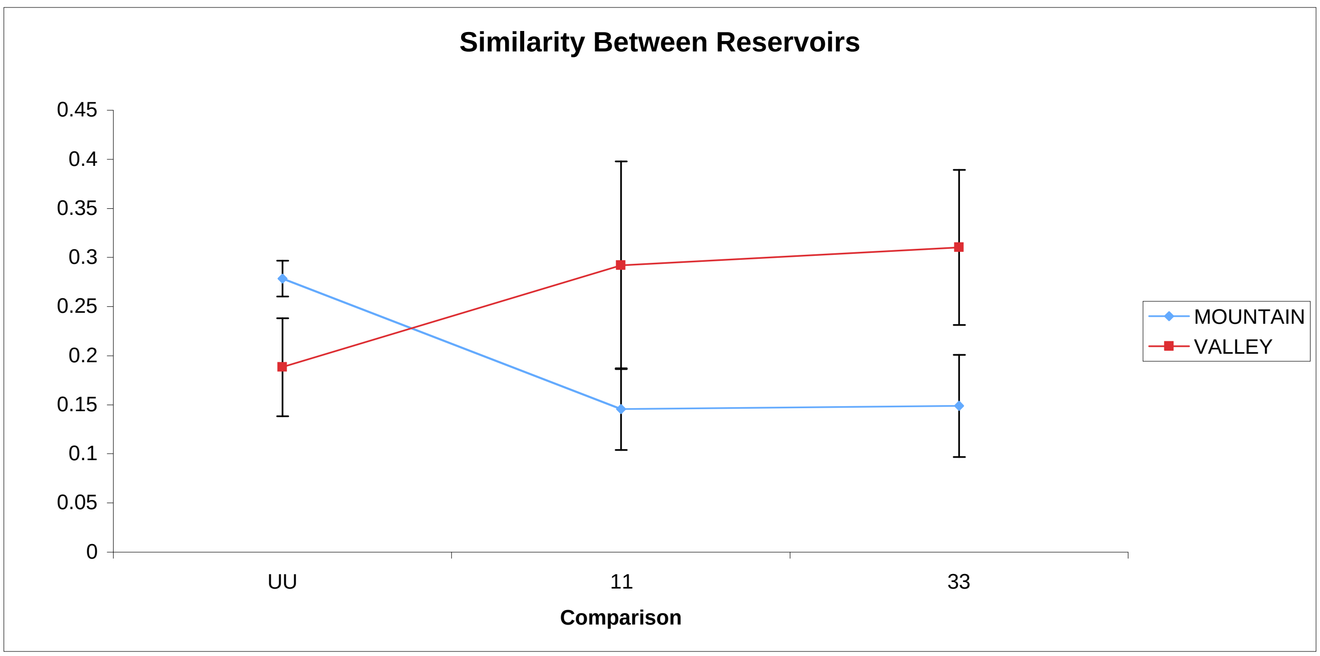


Figure 5. Graphs of similarity indices within and between reservoirs. Within mountain reservoirs, there was low similarity between all sites. Within valley reservoirs, higher similarity was found between the two downstream sites than between the upstream sites with either of the downstream sites. Among mountain reservoirs, the upstream sites were more similar to each other than downstream sites were. In the valleys, the opposite trend appeared. Downstream sites were more similar than upstream sites were. However, most of these relationships are not significant, though it seems that there is a trend.

	Temperature (ºC)			DO (mg/L)			pH		
	df	F	p	df	F	p	df	F	p
Period	1	9.231	**0.005**	1	1.563	0.224	1	124.562	**<0.001**
Type	1	83.929	**<0.001**	1	6.483	**0.018**	1	0.236	0.631
Site	2	17.254	**0.001**	2	1.598	0.224	2	0.71	0.501
Type x Site	2	0.095	0.909	2	0.085	0.919	2	0.036	0.917

	Conductivity (uS)			Flow (m/s)		
	df	F	p	df	F	p
Period	1	1.317	0.261	1	0.01	0.921
Type	1	24.489	**<0.001**	1	5.352	**0.029**
Site	2	0.014	0.986	2	0.002	0.998
Type x Site	2	0.007	0.993	2	0.839	0.444

Table 1. ANOVA Table of physical characteristics of the streams. Only temperature was significantly different between sites. Other characteristics were different between reservoir types, but did not show effects from the reservoir. Significant p-values are shown in bold.

	Nitrate (mg/L)			Phosphate (mg/L)		
	df	F	p	df	F	p
Period	1	2.644	0.117	1	5.337	**0.030**
Type	1	1.162	0.292	1	8.182	**0.009**
Site	2	0.401	0.674	2	0.207	0.815
Type x Site	2	0.110	0.896	2	1.530	0.237

Table 2. ANOVA Table for chemical characteristics. No significant differences were seen between sites, though significant differences were found between mountain and valley reservoirs.

	Periphyton (mg/cm^2)			Diversity (H)			log(Abundance)		
	df	F	p	df	F	p	df	F	p
Period	1	9.231	**0.005**	1	2.822	0.106	1	1.402	0.248
Type	1	3.92	**0.057**	1	8.301	**0.008**	1	0.002	0.966
Site	2	0.503	0.609	2	1.189	0.322	2	1.299	0.291
Type x Site	2	1.747	0.191	2	0.329	0.723	2	1.314	0.288

Table 3. ANOVA Table for biological characteristics. Only periphyton density showed significant differences. Periphyton densities were higher during the second period and it was also higher in the valleys. This is likely due to more sediment and more sunlight.