THE EFFECT OF BEAVER (*Castor canadensis*) DAM REMOVAL ON TOTAL

PHOSPHORUS CONCENTRATION IN TAYLOR CREEK AND WETLAND,

SOUTH LAKE TAHOE, CALIFORNIA

by

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ABSTRACT

The effect of beaver (*Castor canadensis*) dam removal
on total phosphorus concentration in Taylor Creek and Wetland,
South Lake Tahoe, California

Sarah A. Muskopf

Taylor Creek is located in the Lake Tahoe basin and drains into Lake Tahoe. A beaver colony in Taylor Wetland has built 14 dams along Taylor Creek and in the wetland, creating nine beaver ponds upstream. All of the dams in the main channel of Taylor Creek are destroyed annually in early fall by United States Department of Agriculture Forest Service to allow kokanee salmon (*Onchorynchus nerka*) to spawn. In addition, flows from Fallen Leaf Dam, located upstream of Taylor Wetland, are increased to supply ample flows for spawning (United States Department of Agriculture 1981). To determine whether beaver activity, specifically the creation of beaver dams and ponds, improve water clarity by reducing the amount of total phosphorus entering Lake Tahoe, water samples were taken before and after beaver dam removal at sites upstream from beaver influence (control sites) and downstream from beaver pond sites (impacted sites). Results were analyzed using multiple linear regression models and mixed-effect models with site random effects for intercept and covariate coefficients. The mean total phosphorus concentration for control sites before and after dam removal was 51.0μg/l and 64.5μg/l, respectively. The impacted sites increased from 70.4 μg/l to 170.5μg/l (p = 0.1517). This study implies that the presence of beaver ponds in Taylor Creek could

improve water quality by reducing the phosphorus load entering Lake Tahoe when flows are increased from Fallen Leaf Dam.

ACKNOWLEDGMENTS

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INTRODUCTION

Historically, wetlands were home to an estimated beaver (*Castor canadensis*) population of 60 to 100 million whose range covered over two-thirds of North America (Butler 1995). Beavers built dams in riparian areas, trapping flowing waters and creating wetlands. Before Europeans colonized North America, wetlands spanned more than 89 million hectares (200 million acres) (Dahl 1990). When the fur trade nearly drove beavers to extinction in the early 1900s, beaver dams were removed and wetlands drained for other uses, such as grazing and agriculture. By the 1980s, wetland area was reduced to 42 million hectares (104 million acres) (Johnston 1994).

In the Lake Tahoe basin, 75 percent of wetland habitat has been significantly altered and 25 percent has been developed (Elliot-Fisk, et al. 1996). Some of the causes for the reduction in wetland habitat range from watershed impacts, such as logging, modification to the lake level and grazing, to localized impacts, such as development of recreation and boating facilities. Each of these land use changes had impacts on the ecology of wetland systems by altering the hydrology and reducing habitat complexity and productivity. Taylor Wetland is one of the few natural wetlands remaining in the basin (Figure 1). Taylor Creek and Taylor Wetland are heavily influenced by the presence of beaver. Natural lagoons formed by high lake levels and ponds formed by beavers combine with the natural topography of the landscape to provide natural buffers, reducing pollutants and sediment loads entering Lake Tahoe.
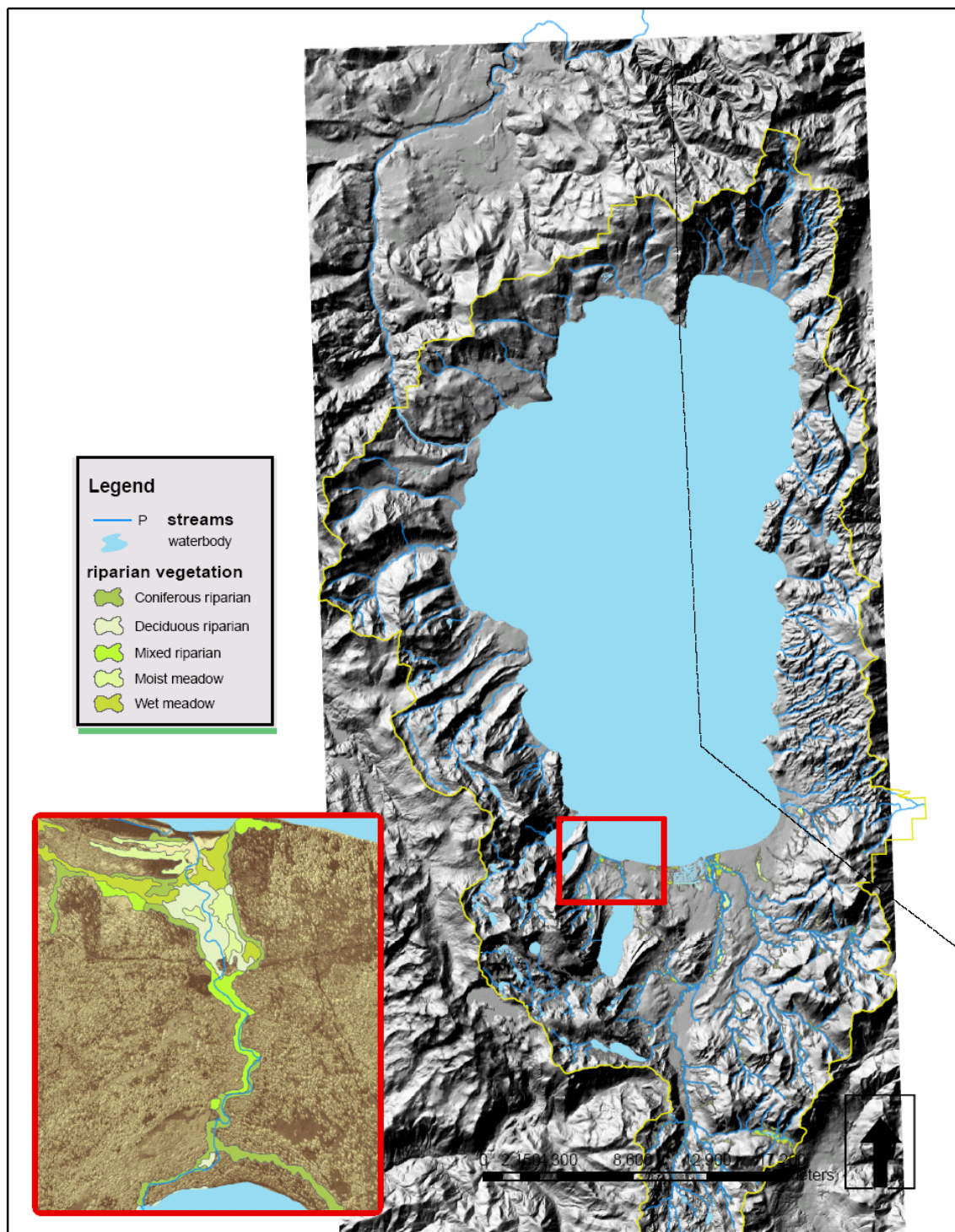
Figure 1.   Vicinity map of Taylor Creek and Taylor Wetland, located on the South shore of Lake Tahoe, California.

Watershed management in the Lake Tahoe basin focuses on preserving the water clarity of Lake Tahoe. Studies by the Tahoe Research Group (Goldman 1988) showed a decline in water clarity by 0.3 m (1.2 feet) per year and an increase in algal production of 5 percent per year. The reduction in water clarity was attributed to increased phosphorus concentrations. Increased loading rates of nutrients and sediments into Lake Tahoe were associated with alterations within the surrounding landscape. Alterations included modifying natural ecosystems, such as wetland removal, that aid in filtering nutrient and sediment-laden runoff before it reaches the lake (United States Department of Agriculture 2000). During an average water year, major sources of total phosphorus entering Lake Tahoe are considered to be stream loading (29 percent) and direct runoff (34 percent) (United States Department of Agriculture 2000). Because surface inflow is usually a major source of phosphorus from sediment adsorption (Mitsch and Gosselink 2000), deposition of sediments in beaver ponds could reduce the amount of phosphorus carried downstream.

The role of beaver in riparian habitats has been extensively studied (Naiman et al. 1986, Naiman 1988, Hammerson 1994, Hey 2001) but data is limited in the Lake Tahoe basin. Beaver dams alter structure and dynamics of stream ecosystems by increasing the wetted surface area, modifying nutrient cycling and deposition, altering the hydraulic regime, decreasing water velocity, and increasing water depth creating anaerobic zones (Naiman et al. 1986, Hammerson 1994). Similarly, beaver impoundments, like constructed wetlands, have been known to act as buffers for suspended solids, nitrate-nitrogen, and total phosphorus entering lacustrine systems (Hey and Phillippi 1999). In

addition, because wetlands are transitional areas between lacustrine and riverine environments where essential ecological interactions occur, the wetland reach is typically the most diverse area of the watershed in terms of number of species.

Beavers were introduced in the 1930s to establish a fur trade in the Sierras and as a means to "improve" wetlands and watershed wildlife habitats (Tappe 1942). Today beaver colonies in Tahoe basin streams demonstrate successful adaptation to a wide range of stream conditions. Tahoe Resource Conservation District (2003) found evidence that beaver activity in the Upper Truckee River watershed, located in South Lake Tahoe, stimulated wetland creation and diversification, including the development of breeding habitat for the willow fly catcher, a special status species. There were also, however, instances where beaver activity caused channel avulsion, meadow destruction, and loss of highly valued aspen stands. Beaver activity also has a significant effect on the hydrology and ecosystem function in Meeks Creek meadow located on the west shore of Lake Tahoe. There are over 6 hectares (10%) of meadow area affected by beaver in the lower Meeks Meadow (United States Department of Agriculture 2004). Some beaver dams in Meeks Creek are 1.2 m (5 feet) high and block the low flow channel of Meeks Creek, which likely affects fish passage during low flow conditions. However, water impoundments on the meadow surface formed by beaver dams have converted large areas of seasonally wet meadow to perennially wet meadow, forming large areas of standing water. These areas provide diverse wetland habitat and, as in the case of the Upper Truckee River, quality habitat for willow fly catcher breeding. It is not known, however, how the beaver activity in these areas affects water quality.

A beaver colony built 14 dams along Taylor Creek and in the wetland creating nine beaver ponds (Figure 2). Currently, no data are available on the effects of beaver activity on water quality, specifically total phosphorous concentration, which is a leading cause of eutrophication. Because beaver dams increase wetland area and reduce flows (Naiman et al. 1986), their presence in Taylor Creek and Taylor Wetland could influence nutrient retention. The focus of this study was to determine whether beaver dams would influence concentration of phosphorus in the wetland or phosphorus entering Lake Tahoe.

To determine the effects of beaver dam removal on phosphorus loading, the following hypothesis was tested:

- H_o; control/impact[*]before/after effect is not significant.

Total phosphorus concentration differences between the inlet (control) and outlet (impact) of Taylor Creek did not change before and after the impact was imposed (i.e. beaver dams were removed).
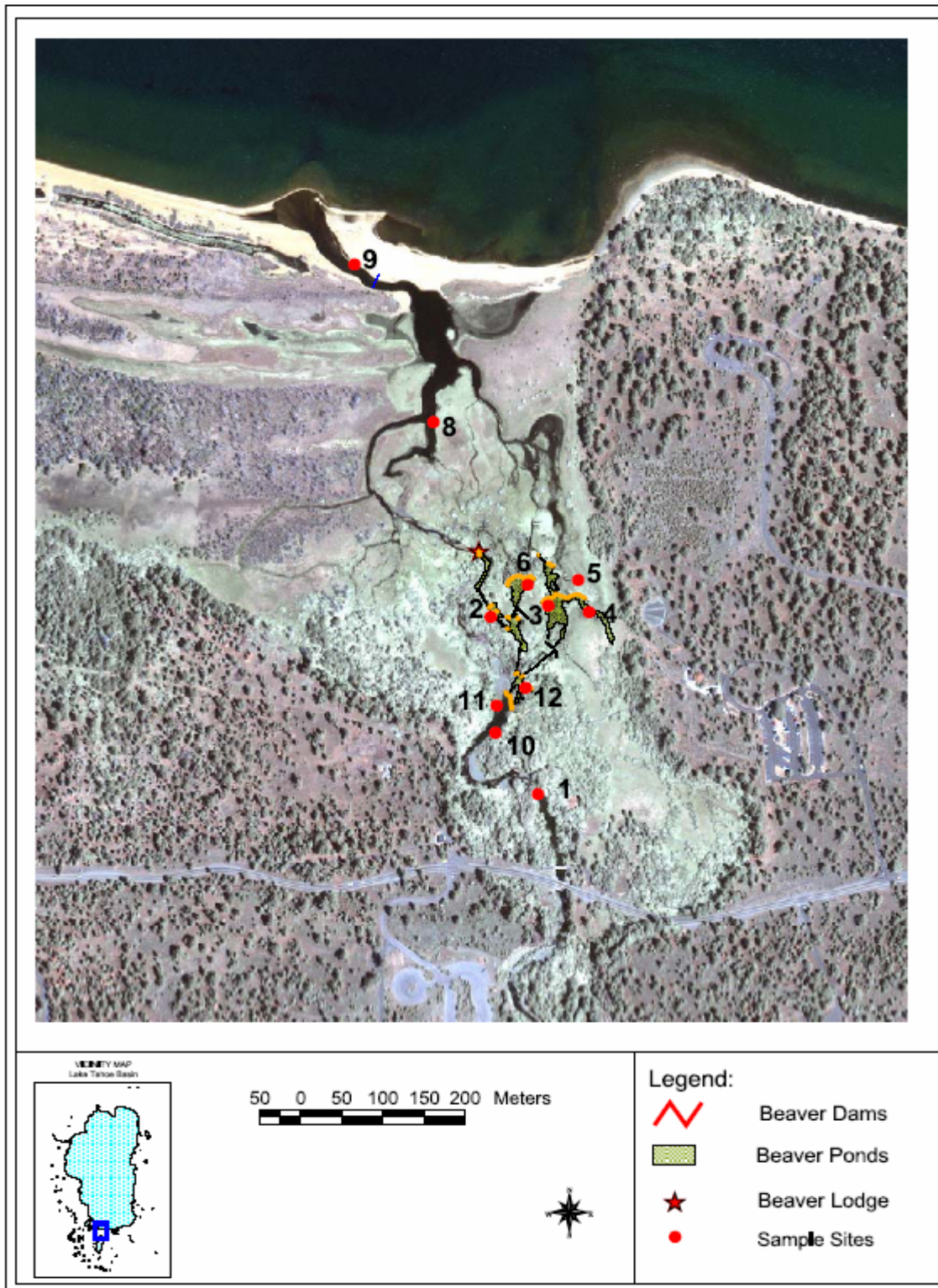
Figure 2.   Water sample sites in Taylor Creek and Wetland, South Lake Tahoe, California.

MATERIALS AND METHODS

Taylor Wetland (Figure 1) is on the south shore of Lake Tahoe, California. It is considered to be the last natural wetland in the Lake Tahoe basin and is managed by the United States Department of Agriculture Forest Service. Taylor Creek flows into Taylor Wetland, then directly into Lake Tahoe (Figure 2). Water samples were collected along Taylor Creek and in Taylor Wetland. Three control sites (sites 1, 10, and 11) were established in the main creek channel before it enters the wetland and above any beaver activity. Eight impact sites were sampled in the creek and wetland. Site 8 was in the lagoon where all channels of Taylor Creek merge after passing through the wetland. Site 9 was the last collection site before Taylor Creek enters Lake Tahoe. The remaining six impact sites were in beaver ponds in the main channel of Taylor Creek or wetland.

Water samples were collected weekly from June 2001 to December 2001 and monthly from February 2002 to May 2002. Sample collection started at approximately 1100 at inlet (control) sites and ended at outlet sites. Grab samples were collected in 100mL Whirl-Pak bags collecting water 6cm below the water surface in accordance with Standard Methods for the Examination of Water and Wastewater (American Public Health Association 1998). Three replicates were collected at each sample site on each sample day. All samples were frozen within six hours of collection. Frozen water samples were placed on dry ice and sent twice per month to Humboldt State University Wastewater Utilization laboratory for analysis. All water samples were analyzed within 28 days of collection (American Public Health Association 1998). Total phosphorus

concentrations from unfiltered water samples were calculated by using the persulfate

digestion and ascorbic acid methods (American Public Health Association 1998).

Samples from control and impacted sites were analyzed. A Bausch and Lomb Spectronic

21 measured absorbance of each sample. A standard curve was run for each sampling

period (American Public Health Association 1998). Dissolved oxygen (DO), water

temperature (°C), and pH were taken at each sample site on each sample day. Three

readings of each measurement were taken at all sample sites and averaged. A Yellow

Spring Instrument (YSI) model 55 was used to measure DO (mg/L) and water

temperature (°C). A Hanna microcomputer pH meter model 9025 was used to measure

pH. Quality control analysis was conducted by North Coast Laboratories, Arcata,

California.

The locations of beaver dams, ponds and collection sites were determined with a

Trimble Navigation Limited Geographical Positioning System (GPS) unit model TSC1

(Figure 3). Beaver pond area was recorded before and after dam removal to determine

the effect of dam removal on the amount of wetland habitat. Beaver ponds were

considered wetland habitat based on the presence of standing water, hydric soil, and

hydrophytes (Cowardian et al. 1979).

Discharge (outflow), measured in cubic feet per second (cfs), was recorded

monthly at the outlet of Taylor Creek from July 2001 through May 2002 (excluding

January 2002). Discharge was measured at 0.18m (0.6 ft) from the surface of the water

by using a top setting rod and a Marsh McBirney Flow Meter. Distance from the transect

endpoints (ft), width between each measurement (ft), and velocity were recorded in the

field. The inlet discharge (inflow), also measured in cfs, was recorded using USGS two-valve corrugated metal stilling well. A float and pulley system recorded changes in stream level (stage) over time. The discharge curve (stage vs. discharge) was adjusted in 1992. Data were collected by using a digital data collector and cellular communication system or by reading stage plate gauges at the stilling well and Fallen Leaf Dam.

Statistical Analysis

Results were statistically analyzed using multiple linear regression models and mixed-effect models with site random effects for intercept and covariate coefficients (Pinheiro and Bates 2000). Nine models were analyzed using a multiple linear regression, while sixteen were analyzed using mixed-effect models with site random effects for intercept and covariate coefficients. An increasing complexity of models was analyzed to determine interaction between covariates. The study design was based on the Before, After, Control, Impact (BACI) principle (Underwood 1994) where samples were taken before and after a disturbance to measure changes due to impact as well as temporal changes. Sample sites included control sites, which did not experience the disturbance, and impact sites, which were influenced by the disturbance. The control and impact sites were used to measure spatial changes. The BACI design was used in order to examine the interaction effect, changes in mean abundance of total phosphorus from time to time and difference from place to place. An eighty percent confidence (20% significance level) was used to determine the statistical significance of beaver dam removal on total
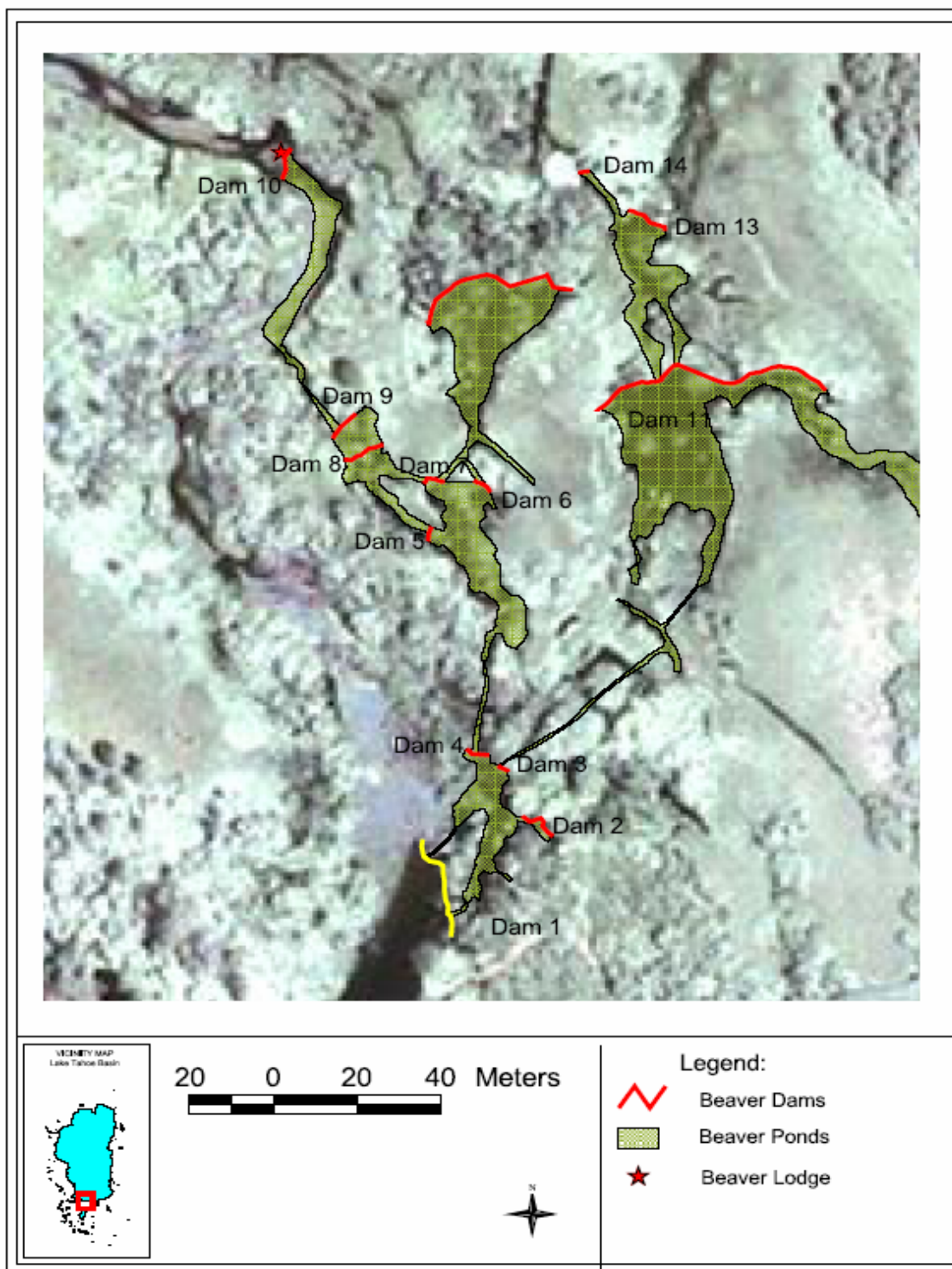
Figure 3.   Beaver dam and pond location in Taylor Creek and Wetland, South Lake Tahoe, California

phosphorous levels. I compared the collection of models using Akaike's Information Criteria (AIC), the information-theoretic criteria that evaluates the relative competitiveness of statistical models. The model with the lowest AIC was the best fitting model. Models within two AIC units of each other are relatively competitive (Burnham and Anderson 1998).

A total of 162 water samples over 19 weeks were collected for total phosphorus (tp) concentration (µg/L). Nine sample days were surveyed before and ten after the beaver dams were removed from Taylor Creek. Seven covariate coefficients including dissolved oxygen, pH, water temperature, inflow, outflow, control sites versus impacted sites, and before versus after disturbance were incorporated into the comparative analysis for their influence on changes in total phosphorus loads.

The data set was created in Microsoft Excel and imported into SPLUS 2000 as a grouped data frame for the mixed-effects analysis. A collection of models with various combinations of fixed effects, and random effects with respect to site were used to determine the best-fitting model for the data set. The fixed effects covariates included before and after (beforeafter), control and impact (ci), week nested inside before and after (beforeafter1week and beforeafter2week), dissolved oxygen (DO), pH, water temperature (h_2O temp), inflow, and outflow. The intercept and the covariate coefficients with respect to site were modeled as random effects. This was done to account for the variability in the response between sites. Model 16.1, for example, incorporated random effects $\acute{\epsilon}_0$ for intercept and $\acute{\epsilon}_1$ for the before and after covariate with respect to site in the linear model.

Equation (1):

$$tp = (\beta_0 + \acute{\varepsilon}_0) + (\beta_1 + \acute{\varepsilon}_1)*beforeafter + \beta_2*ci + \beta_3*DO$$
$$+ \beta_4*pH + \beta_5*h2otemp. + \beta_6*inflow + \beta_7*outflow$$
$$+ \beta_8*week \subset before + \beta_9*week \subset after + \beta_{10}*beforeafter*ci$$
$$+ \beta_{11}*week \subset before*ci + \beta_{12}*weeks \subset after*ci + \varepsilon$$

where:

$\varepsilon_0 \sim N(0, \sigma_0)$ are normally distributed random effects for the intercept with

respect to site

$\varepsilon_1 \sim N(0, \sigma_1)$ are normally distributed random effects for the beforeafter

coefficient with respect to site

$\varepsilon \sim N(0, \sigma)$ are normally distributed random effects for the remaining noise

Therefore, the mixed-effects analysis for this model provided estimates for the sixteen

parameters: $\beta_0, \beta_1, \beta_2, \ldots, \beta_{12}, \sigma_0, \sigma_1,$ and σ.

RESULTS

The comparative analysis examined a collection of multiple linear and mixed-effect models. The outcome of the comparative analysis suggested that the best fitting model was Model 16.1 with an AIC of 1953.33 and Akaike weight of 0.7572 (Table 1). Model 16.1 was the full model with site random effects for intercept and covariate coefficient beforeafter (Table 2). Equation (2):

$$tp = (-88.8870 + \varepsilon_0) + (-215.4731 + \varepsilon_1)*beforeafter + 38.8751*ci$$
$$- 5.1432*DO + 12.2719*pH + 1.0086*h2otemp. - 16.7242*inflow$$
$$- 0.8069*outflow + -17.9140*week \subset before + 35.7589*week \subset after$$
$$+ 92.9693*beforeafter*ci + 8.8995*week \subset before*ci$$
$$- 7.0853*weeks \subset after*ci + \varepsilon$$

where: $\varepsilon_0 \sim N\ (0,\ 59.91069)$

$\varepsilon_1 \sim N\ (0,\ 67.61746)$

$\varepsilon \sim N\ (0,\ 125.63039)$

Using AIC and Akaike weight, the only other competing model was Model 16.3 with an AIC of 1955.605 and Akaike weight of 0.2428. Model 16.3, seen in Table 1, was the full model with site random effects for intercept and covariate coefficients beforeafter and ci. The cumulative Akaike weight for Model 16.1 and 16.3 was 0.999. The cumulative Akaike weight for all twenty-two models was 1.0. Model 16.1 was determined the best-fitting model based on AIC and Akaike weight and was used for the subsequent estimation of the effect of beaver dam removal on total phosphorus.

Table 1. AIC and Akaike table testing models to determine the best fitting.

Model	Covariates	Site Random Effects	Residual Standard Error $s|_x$	AIC	Likelihoods	Akaike Weights
1	beforeafter (ba)		164.008	2076.9830	0.000000000000	0.000000000000
2	controlimpact (ci)		170.468	2089.2690	0.000000000000	0.000000000000
3	ba+ci		163.008	2076.0230	0.000000000000	0.000000000000
4	ba*ci		162.198	2075.4160	0.000000000000	0.000000000000
5	ba*ci+week*ci		164.541	2108.6010	0.000000000000	0.000000000000
6	full model (ba, ci, week, pH, DO, water temp.inflow, outflow)		152.093	2074.6200	0.000000000000	0.000000000000
7	ba,ci,week, DO inflow, outflow)		155.851	2080.7550	0.000000000000	0.000000000000
8	ba,ci,week, DO, pH, inflow, outflow)		154.668	2079.1500	0.000000000000	0.000000000000
9	ba, ci, week, DO, water temp., inflow, outflow		152.264	2074.1680	0.000000000000	0.000000000000
11	beforeafter (ba)	intercept	154.956	2056.8670	0.000000000000	0.000000000000
12	controlimpact (ci)	intercept	161.690	2068.9120	0.000000000000	0.000000000000
13	ba+ci	intercept	154.884	2049.2020	0.000000000000	0.000000000000
14	ba*ci	intercept	154.153	2041.1000	0.000000000000	0.000000000000
15	ba*ci+week*ci	intercept	155.497	2024.1130	0.000000000000	0.000000000000
16	full model (ba, ci, week, pH, DO, water temp.inflow, outflow)	intercept	144.876	1981.7240	0.000000682844	0.000000517063
17	ba,ci,week, DO inflow, outflow)	intercept	144.906	1993.7890	0.000000001638	0.000000001241
18	ba,ci,week, DO, pH, inflow, outflow)	intercept	144.793	1986.1260	0.000000075586	0.000000057235
19	ba, ci, week, DO, water temp., inflow, outflow	intercept	144.881	1989.0740	0.000000017310	0.000000013107

Table 1. AIC and Akaike table testing models to determine the best fitting, (continued).

Model	Covariates	Site Random Effects	Residual Standard Error $s|_x$	AIC	Likelihoods	Akaike Weights
16.1	full model (ba, ci, week, pH, DO, water temp.inflow, outflow)	intercept, beforeafter	125.630	1953.3300	1.000000000000	0.757219803601
16.2	full model (ba, ci, week, pH, DO, water temp.inflow, outflow)	intercept, ci	144.367	1984.6420	0.000000158740	0.000000120201
16.3	full model (ba, ci, week, pH, DO, water temp.inflow, outflow)	intercept, beforeafter, ci	124.919	1955.6050	0.320619569639	0.242779487552
						1.000000000000

Table 2. Model 16.1 Mixed-effects model: full model with site random effects for
   intercept and before/after (ba).

	Value	Standard Error	Degree of Freedom	T-value	P-value
Intercept	-88.8870	167.0197	137	-0.532195	0.5955
beforeafter	-215.4731	85.3239	137	-2.525356	0.0127
ci	38.8751	62.8244	9	0.618790	0.5514
do	-5.1432	5.3499	137	-0.961368	0.3381
pH	12.2719	20.7770	137	0.590649	0.5557
water temp.	1.0086	4.9220	137	0.204914	0.8379
inflow	-16.7242	5.3945	137	-3.100227	0.0023
outflow	-0.8069	2.5819	137	-0.312550	0.7551
beforeafter1week	-17.9140	9.6586	137	-1.854719	0.0658
beforeafter2week	35.7589	12.2393	137	2.921641	0.0041
beforeafter:ci	92.9693	64.4879	137	1.441656	0.1517
beforeafter1weekci	8.8995	8.6637	137	1.027227	0.3061
beforeafter2weekci	-7.0853	6.8369	137	-1.036330	0.3019

The estimated effects in the best fitting model (Table 2) were intercept (p = 0.5955), beforeafter (p = 0.0127), ci (p = 0.5514), do (p = 0.3381), ph (p = 0.5557), h20temp (p = 0.8379), inflow (p = 0.0023), outflow (p = 0.7551), beforeafter1week (p = 0.0658), beforeafter2week (p = 0.0041), beforeafter:ci ((p = 0.1517), beforeafter1weekci (p = 0.3061), and beforeafter2weekci (p = 0.3019). The following effects were statistically significant at the five percent significance level: inflow, beforeafter2week, and beforeafter. These additional effects were statistically significant at the twenty percent significance level: beforeafter1week and beforeafter:ci. The remainder of the effects, ci, do, ph, $h_2 0$ temp, outflow, beforeafter1weekci, beforeafter2weekci and random effects, were not statistically significant. The estimated standard deviations for the site random effects were σ_0 = 59.91096 for the intercept, σ_1 = 67.61746 for the beforeafter coefficient, and σ = 59.91096 for the noise.

Mean total phosphorus for all sites before dam removal was 52.83μg/L while concentrations after dams were removed had a mean total of 151.35μg/L (Figure 4). Average flow varied from 2.2cfs to 11.2cfs after dam removal with the low and peak flows ranging from 1.1cfs before to 22.1cfs.

Mean total phosphorus concentration in control and impact sites was 67.30μg/L and 113.9μg/L, respectively (Figure 5). Mean total phosphorus concentration at control site before and after beaver dam removal was 51.03μg/L to 64.52μg/L. Impacted sites had a mean total phosphorus concentration of 70.40μg/L pre-dam removal and 170.49μg/L after dam removal (Figure 6). Additionally, total wetland area was reduced from 3758 to 2264 square meters when beaver dams were removed.
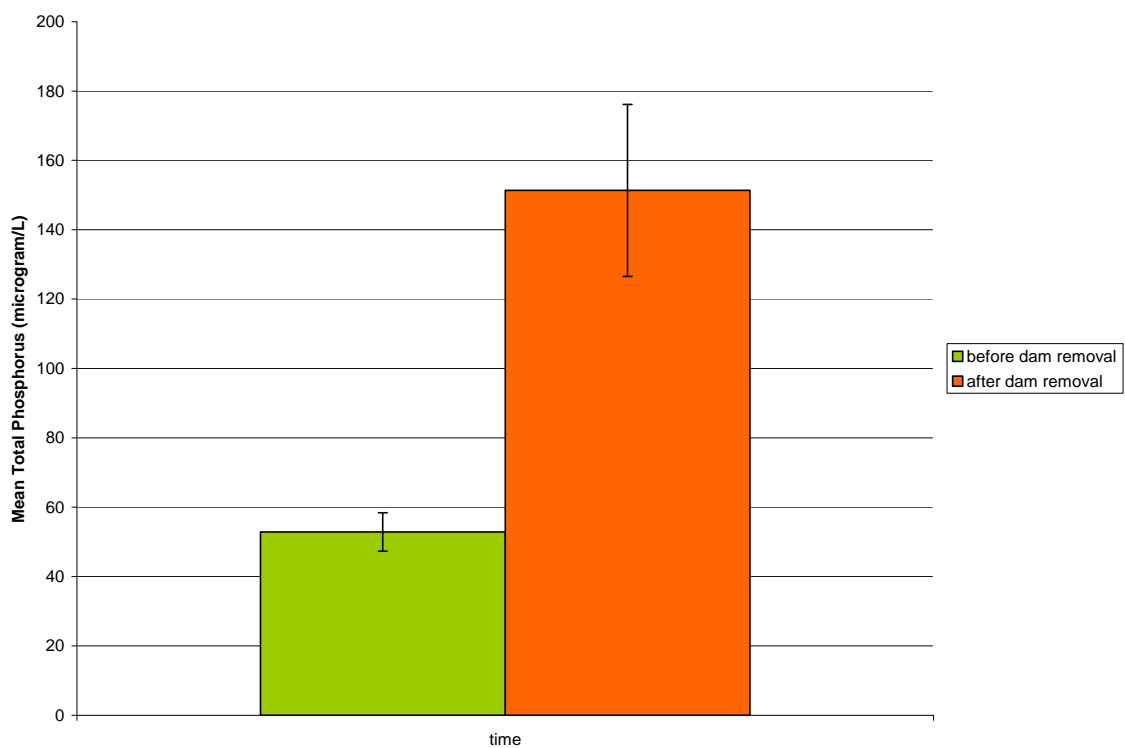
Figure 4.   Mean Total phosphorous in Taylor Creek and Wetland Before and After
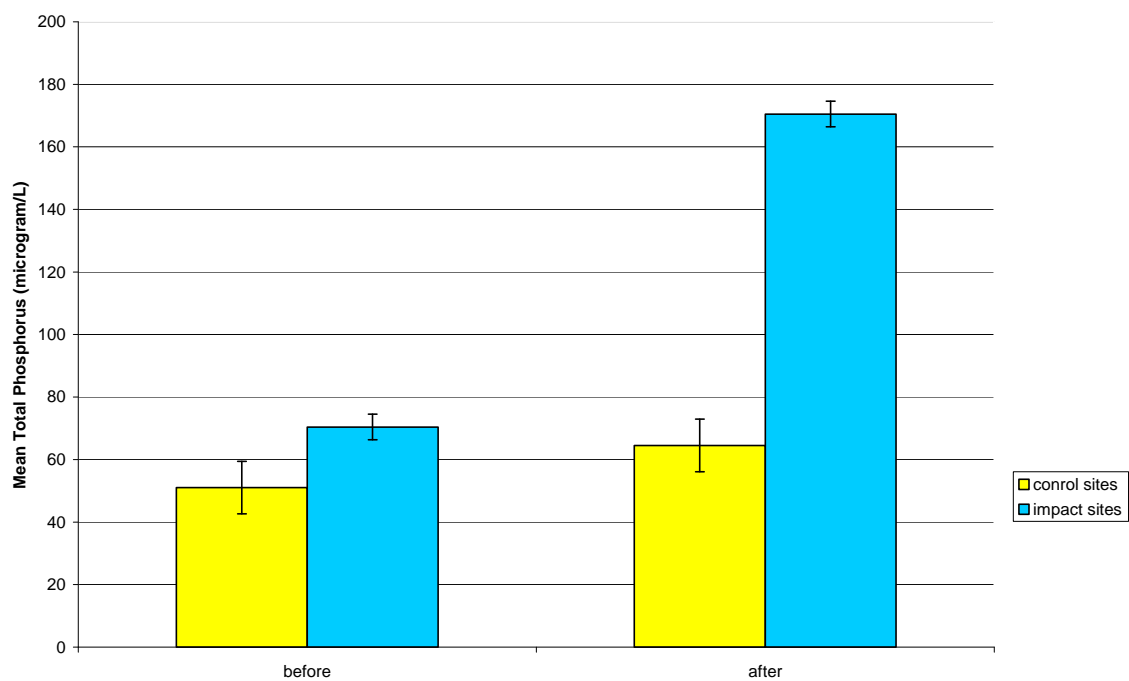   Beaver Dam Removal in Taylor Creek and Wetland.

Figure 5.   Mean Total Phosphorous in Control and Impacted Sites in Taylor Creek and
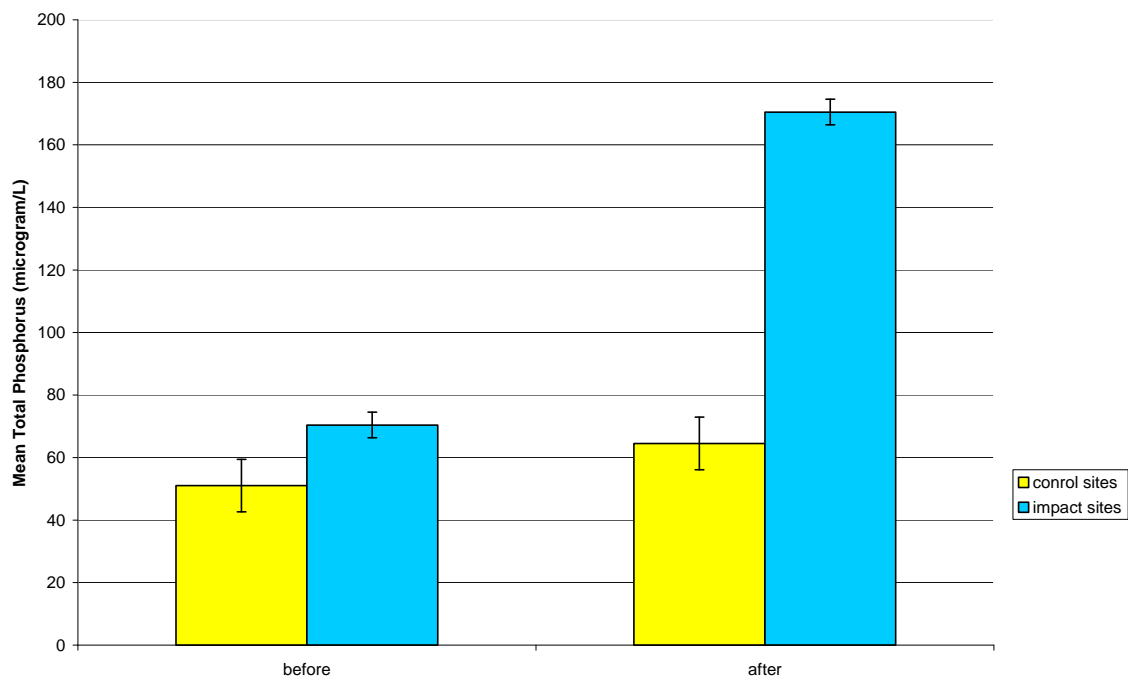Wetland.

Figure 6.   Mean Total Phosphorus in Control and Impacted Sites Before and After
Beaver Dam Removal in Taylor Creek and Wetland.

DISCUSSION

The removal of beaver dams from Taylor Creek decreased wetland habitat, increased stream flow, and increased total phosphorus entering Lake Tahoe. Hey and Philippi (1999) propose that beaver were historically present in all areas of North America except the arctic north, western deserts, and Florida peninsula while other documentation (Tappe 1942) suggest beaver were introduced in the Sierras. Regardless of their origin, the presence of beaver in the Lake Tahoe basin is controversial. Wetlands created by beaver dams serve as valuable areas for sediment and nutrient storage. Development within the Lake Tahoe basin is growing and urbanization is impacting water quality by increasing sediments flowing into Lake Tahoe (United States Department of Agriculture 2000, United States Geologic Survey 2002, United States Department of Agriculture 2004). Nelson and Booth (2002) agree that urbanization increases annual sediment loads in streams. Likewise, a study by Newman, et al. (2006) found that construction was the primary activity that significantly contributed to soil erosion resulting in increased sediment loading into an urban lake. Destruction of large wetland complexes in the Tahoe basin in the 1960's included 304 hectares (750 acres) of functioning wetland now known as the Tahoe Keys housing development (USDA 2000). Another 8 hectares (20 acres) in Tallac Wetland was converted to roads and parking lots and 15 hectares (38 acres) in Meeks Creek Lagoon was dredged and converted into a marina and campground (USDA 2004). The results of wetland destruction are reflected in water quality degradation of Lake Tahoe.

A study conducted on 14 streams in the Lake Tahoe basin concluded that increased nutrient and suspended sediment concentrations were related to increased stream flow (United States Geologic Survey 2002). Above-normal total phosphorus concentrations are associated with high flow events. During my study, average flow before beaver dam removal was 2.2cfs. After beaver dam removal, average flow increased to 11.2cfs, with a peak flow of 22.1cfs. Phosphorus binds with soil particles so it can become suspended into the water column and travel downstream. Morris et al. (1981) determined that the majority of phosphorus entering Lake Tahoe is attached to sediment, especially during increased flows. In my study, inflow had a significant effect on total phosphorus concentrations ($p = 0.0023$). When the gates were opened at the Fallen Leaf Lake Dam, flows increased from 1.6cfs to 22.1cfs within one sampling period. Additionally, the interaction (beforeafter:ci) was statistically significant at the 20 percent significance level ($p = 0.15$). The impacted sites had a significant increase in total phosphorous concentration after the dams were removed and flow was increased. Most importantly, because of the BACI design, my data suggests that the increase in total phosphorus concentration at impacted sites in response to beaver dam removal was greater than the total phosphorus concentration increase at control sites. This interaction allowed us to examine changes in mean abundance of total phosphorus concentration from time to time and difference from place to place. This is crucial since temporal variance of many responses, like total phosphorus, are very "noisy" (Underwood 1994), as was the response in my experiment ($\sigma = 67.62$). The interaction between these covariate coefficients becomes fundamental to understanding the relationship between

the independent variables (beforeafter and ci) and the response variable (total

phosphorus).

Beaver dams located in Ward Creek, located on the west shore of Lake Tahoe,

contributed to a reduction in nutrients and sediments traveling downstream (United States

Geologic Survey 2002). Several studies support the concept that beaver ponds store

nutrients and sediments during high flow events (Naiman and Melillo 1984, Francis et al.

1985, Maret et al. 1987, Correll et al. 2000). When beaver activity modifies stream

dynamics, the function of that ecosystem is altered (Mitsch and Gosselink 1993, Boothe

and Jackson 1997). Other contributing sources of phosphorus include stream loading,

direct runoff, groundwater, and atmospheric input (United States Department of

Agriculture 2000). Stream loading contributes approximately 29 percent of the

phosphorus entering Lake Tahoe while direct runoff contributes about 34 percent (United

States Department of Agriculture 2000). Algal blooms associated with increased

phosphorus levels have reduced lake water clarity from 30.5m in 1960 to 22.0m in 2005

(University of California Davis 2006). In my study, the mean level of phosphorus from

site nine, the last sample collection site before entering Lake Tahoe, increased from

42μg/L before and to 196μg/L after dam removal. Guidelines to help control

eutrophication by the United States Environmental Protection Agency (1986) recommend

that total phosphorus should not exceed 50μg/L in any portion of stream that enters a

lake. In our study, 40 percent of samples before dam removal and 58 percent of samples

after dam removal exceeded the Environmental Protection Agency standard.

Physical and chemical transformations are substantial processes considered desirable functions of wetlands (Smith et al. 2002). Typically, most of the phosphorus that enters a wetland goes through a relatively quick uptake and release processes via microbial and plant metabolic activities (Correll et al. 2000). Phosphorus that is released eventually settles and becomes buried in a peat layer of a wetland. By removing beaver dams and destroying wetlands, storage capacity is lost and the trapped phosphorus re-enters the water column (Correll et al. 2000). When phosphorous is released from sediment back into the water column, the majority is in the form of ortho-phosphate, which is completely available for algae. Total phosphorus concentrations increased by 21 percent (13.48µg/L) in control sites after the dams were removed while the impacted sites increased by 59 percent (100.10µg/L) ($p=0.15$). In areas such as Lake Tahoe where policy and regulations govern water quality and native species, adapted to cold water oligotrophic conditions, depend on pristine conditions; protecting wetland habitat, even that habitat created by beaver activity, is vital in reducing eutrophication.

In conclusion, the ability of beaver ponds in Taylor Creek to store sediment and nutrients was reduced because of the dam removal in conjunction with the unnatural flows released from Fallen Leaf Dam. Reducing impacts from upstream disturbances or discharges from Fallen Leaf Dam would be the most critical step in stabilizing conditions. Until then, beaver dams provide in-stream sediment storage structures.

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