Eagle Lake Golf Course

Introduction

The natural beauty and diversity of terrain in Minnesota has become attractive for many of the top designers to build golf courses throughout the state. The abundance of water resources in Minnesota are aesthetic natural features that are often incorporated into specific site designs. The designing of a golf course involves significant changes to the natural terrain and landscape that may potentially degrade these existing water resources. Consequently, it becomes important to incorporate practice and design standards that will ensure the preservation of environmental quality. Emphasis should be placed upon the design of irrigation, drainage, and retention systems that provide for efficient use of water and the protection of water quality. Drainage and stormwater retention systems are often incorporated into the design as features of the course to help provide for the short and long term irrigation needs that are required for maintenance. However, the actual performance of these stormwater retention systems relative to minimizing water quality impacts is unknown. There appears to be insufficient monitoring data to substantiate whether these stormwater retention systems designed for golf course irrigation purposes are effective in reducing runoff volume and nutrient loading.

The Three Rivers Park District designed a stormwater retention system that would be used for irrigation of Eagle Lake Golf Course. A major portion of the golf course watershed drains to the stormwater retention system that eventually flows to Pike Lake. A pond was constructed as part of the stormwater retention system and serving as a water reservoir for irrigation of the golf course. The irrigation pond also receives water from an adjacent augmentation well. The water volume in the pond is currently managed to ensure an adequate supply of water for turf needs. The pond also has the potential to manipulate the water volume storage to reduce potential run-off and nutrient loading. There is concern that the nutrient loading from the golf course may degrade Pike Lake water quality. The Minnesota Pollution Control Agency classified Pike Lake as an impaired water body for excessive nutrients in 2002. Consequently, Three Rivers Park District monitored the performance of the stormwater retention system to improve on the current management of Eagle Lake Golf Course. The monitoring data was further used to develop a P8 model to improve on the operation of the irrigation pond to reduce run-off volume and nutrient loading to Pike Lake.

Study Site

The Eagle Lake Golf Course is located in the City of Plymouth, Hennepin County, north of the intersection of Zachary Lane and Bass Lake Road. The golf course has a network series of five inter-connected ponds that provide water quality treatment for runoff flowing to Pike Lake (Figure 1). The water quality ponds also provide flow-rate and volume control. The entrance road into Eagle Lake Golf Course separates nutrient detention Pond 1 and Pond 2. Pond 1 receives water run-off from the golf course maintenance facility building and parking lot. The water from Pond 1 discharges through a 12-inch pipe into Pond 2 when water levels exceed the culvert outlet elevation. Pond 2 also receives surface run-off from the Eagle Lake Golf Course Club House and main parking lot area. The discharge from Pond 2 flows north through a 12-inch pipe into a pond that is used as a water reservoir for irrigating the golf course. The irrigation pond also receives water from an adjacent augmentation well. The pond water volume is managed to ensure an adequate supply of water for turf needs. Because the irrigation system has a much higher pumping capacity than the augmentation well, the pond level is typically lowered during the nighttime irrigation activities, and then raised through use of the augmentation well during the day. The normal water level of the pond can be adjusted by controlling the volume of water pumped by the augmentation well.

During high intensity rainfall events, storm water flows over the embankment of the irrigation pond. The water continues to flow through a grassed buffer swale to Pond 3 (Figure 1). The discharge from Pond 3 drains through a 12-inch pipe into Pond 4 located at the northern edge of the golf course. The outlet for Pond 4 discharges through a 12-inch culvert into a drainage channel that conveys water to Pike Lake. Although these ponds receives some runoff from the adjacent golf course greens and fairways, the primary volume of storm water and nutrients entering Ponds 3 and 4 is typically a function of the water level of the irrigation pond. Consequently, the water level elevation within the irrigation pond has the ability to influence the potential nutrient loading into Pike Lake.

Since the irrigation pond appears to be the control point for downstream nutrient loading, monitoring stations were located at the irrigation pond as well as downstream from the irrigation pond (Figure 1). The first monitoring station (EG1) was located at the irrigation pond to measure changes in water level elevation. There were three monitoring stations located down stream from the irrigation pond to measure flow volume and to collect water quality samples. The first sampling site (EG2) downstream of the irrigation pond monitored flow from the grassed buffer swale prior to draining into Pond 3. The second downstream station (EG3) monitored flow from a 12-inch culvert that drained from Pond 3 to Pond 4. The third downstream monitoring station (EG4) was located at the outlet of Pond 4 prior to draining into the channel that conveys water to Pike Lake.

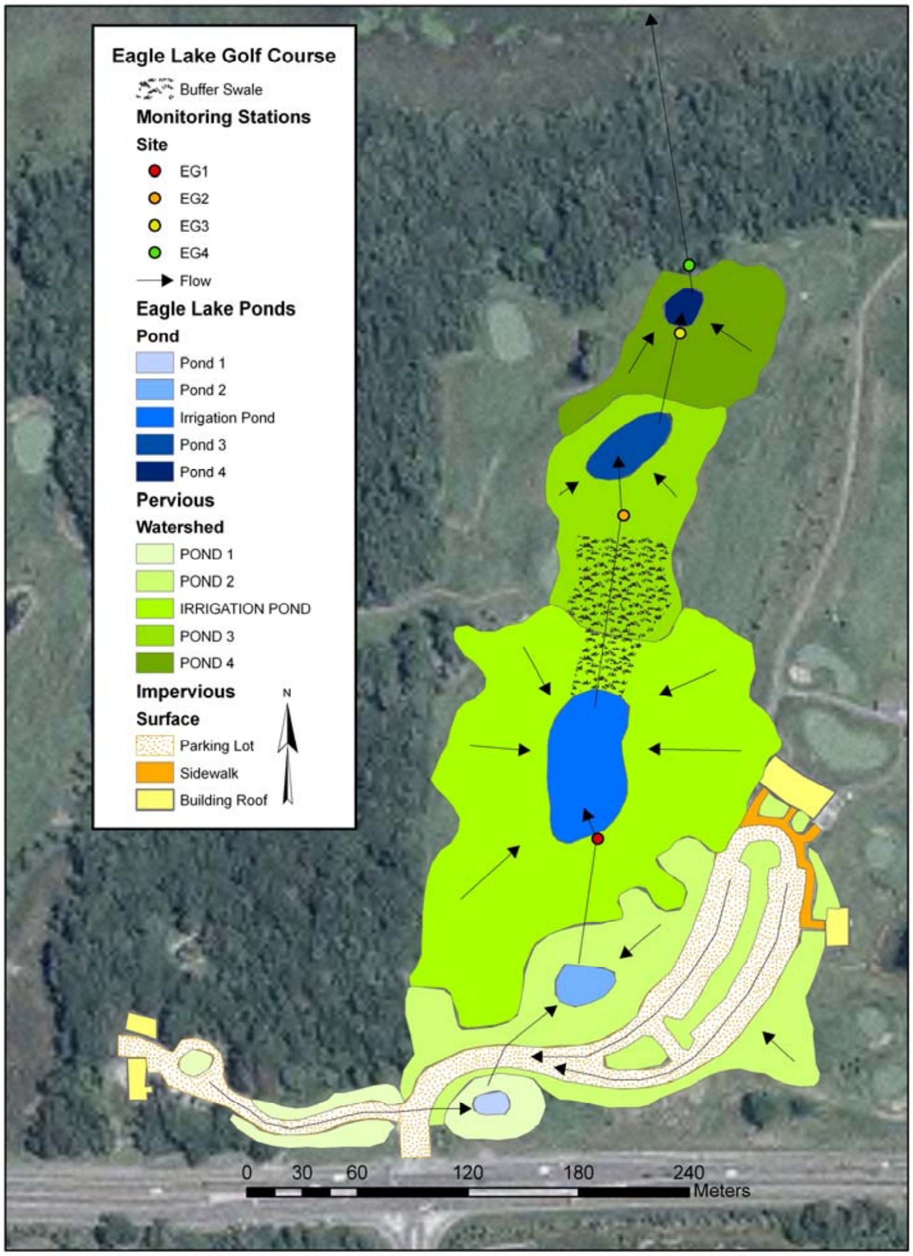

Figure 1: Eagle Lake Golf Course Watershed and Monitoring Sites.

Methods

Three Rivers Park District monitored each sampling site from May through November in 2005. At each of the monitoring stations, an automated sampler/data logger was installed. The monitoring station located at the irrigation pond (EG1) recorded the changes in water level elevation at 15 minute intervals. The monitoring stations located downstream (EG2, EG3, and EG4) of the irrigation pond measured water level, velocity, and flow at one-minute intervals. All of the data loggers were programmed to initiate sample collection after a predetermined increase in water level was obtained. After sampling was initiated, water samples were collected every 60 to 120 minutes for the EG1 sampling site; and flow weighted composite water samples were sequentially collected for the EG2, EG3, and EG4 sampling sites. Stormwater samples were collected to encompass the entire storm distribution. The anticipated storm events were based upon estimated precipitation volume. After each precipitation event, the water quality samples were collected within 24-hours. During extended periods without precipitation, grab samples were collected to determine nutrient concentrations during base flow conditions. All samples were labeled immediately after collection, stored in a cooler with ice, and delivered to the Three Rivers Park District for laboratory analysis. During each site visit, flow meter data was downloaded by a field laptop computer.

Three Rivers Park District analyzed each water quality sample for nutrient analysis. The water quality samples were analyzed for total phosphorus, soluble reactive phosphorus, total nitrogen, and total suspended solids. The Standard Methods for the Examination of Water and Wastewater (1995) was used to determine nutrient concentrations of the water samples. Sample analysis was prioritized by analyte holding time to ensure that analyses are completed within the recommended time interval. Samples were stored at 4° C in a refrigerator until all analysis was completed. A quality assurance and quality control protocol was followed to ensure the precision and accuracy of laboratory data analysis.

The flow meter data and water quality data was used to determine the nutrient loading for each monitoring site. The nutrient loading for each storm event was calculated by multiplying the flow volume and nutrient concentration. The monitoring data was used to calibrate a P8 model developed for the Eagle Lake Golf Course. The P8 model was calibrated to mimic similar flow and nutrient loading conditions that were observed during the sampling interval. The model was only calibrated with flow and nutrient concentration data that was considered reliable. The differences in nutrient loading between monitoring sites provided estimates of nutrient removal efficiencies for each treatment device. The removal efficiency for the treatment devices were calculated using a mass balance equation. The nutrient loading and % removal efficiencies were compared to values estimated by the calibrated P8 model. The details pertaining to model calibration is further described in the following section.

Eagle Lake Golf Course
Model Calibration

The P8 model was used to examine treatment efficiencies associated with golf course pond operation. The model was calibrated using monitoring data collected from the sampling sites. The parameters entered into the model included the pervious and impervious watershed characteristics (Table 1). The parameters corresponding to each treatment device included morphological characteristics of the irrigation pond, the buffer swale, and the downstream ponds (Table 2 & 3). The rainfall data collected hourly at the monitoring site was used for model application; and a daily average temperature file was also developed from data collected at Crystal Airport in 2005 (Appendix). The flow network diagram further describes how the P8 model was set-up for the Eagle Lake Golf Course (Figure 2).

The Eagle Lake Golf Course modeling efforts needed to account for the volume of well water being pumped into and out of the irrigation pond. The augmentation well was metered to determine the volume of water entering and leaving the pond for irrigation. To simulate the amount of ground water pumped into the pond, an artificial watershed was created in the P8 model to capture rainfall that directly infiltrated into an aquifer device flowing directly to the irrigation pond. The watershed was sized appropriately to simulate the volume of water that was pumped into the irrigation pond from the well. The volume of water pumped out of the pond for irrigation of the golf course was incorporated into the P8 model rainfall file. Eagle Lake Golf Course irrigation records were used to determine the volume of water used per month. The monitored study area is approximately 25% of the total acreage for the Eagle Lake Golf Course (54.5 acres). Consequently, it was assumed that 25% of the total volume of water used for irrigation of the golf course was distributed throughout the study area and was incorporated into the rainfall file. Typically, irrigation of the golf course occurred during days without measurable precipitation between 12 to 6 A.M. The adjusted volume of water each day was incorporated into the P8 rainfall file to reflect the actual time period of irrigation.

The model was initially calibrated to mimic the 2005 observed flow conditions at each of the monitoring sites. The volume of water with the corresponding flow hydrographs that were predicted by the model was compared to observed flow conditions. The time of concentration within the model was adjusted accordingly to mimic the observed peaks in the hydrograph. After the model was calibrated to the observed flow conditions, the scale factor for each water quality parameter was adjusted in the particle file (NURP50.PAR) to estimate nutrient loading. The scale factor for each parameter was adjusted until the model accurately predicted nutrient loads similar to the observed conditions.

Table 1: Eagle Lake Golf Course Sub-watershed Characteristics.

Sub-Watershed Characteristics								
	Primary	Total	Impervious		Pervious		Treatment Device	
Sub-watershed	Land-Use	Acres	Acres	%	Acres	%	Type	Acres
Pond 1	Commercial/Golf Course	0.722	0.562	78	0.16	22	Pond	0.050
Pond 2	Commercial/Golf Course	3.146	2.208	70	0.938	30	Pond	0.136
Irrigation Pond	Commercial/Golf Course	6.044	0.167	3	5.877	97	Pond	0.737
Pond 3	Golf Course	1.987	0	0	1.987	100	Swale/Pond	0.993
Pond 4	Golf Course	1.394	0	0	1.394	100	Pond	0.080

Table 2: Eagle Lake Golf Course Treatment Pond Characteristics.

Treatment Pond Characteristics										
	Drainage Flow		Bottom		Normal Water Level			Ordinary High Water Level		
Device	Receives	Discharges	Elevation	Acres	Elevation	Acres	Volume (acre-ft)	Elevation	Acres	Volume (acre-ft)
Pond 1	Sub-watershed	Pond 2	922.6	0.005	928.6	0.110	0.43	929.6	0.226	0.67
Pond 2	Pond 1 & Sub-watershed	Irrigation Pond	920.9	0.045	927.9	0.275	1.00	931.5	0.471	2.04
Irrigation Pond	Pond 2 & Sub-watershed	Swale	912.0	0.045	924.5	0.761	4.70			
Pond 3	Swale & Sub-watersehd	Pond 4	895.8	0.028	903.8	0.270	1.24	907.8	0.415	2.36
Pond 4	Pond 3 & Sub-watershed	Pike Lake	885.8	0.017	891.8	0.133	0.36	892.8	0.164	0.52

Table 3: Eagle Lake Golf Course Swale Characteristics.

Swale Characteristics									
		Drainage Flow		Bottom	Bottom	Flow Path	Maximum	Side Slope	Slope
Device	Description/Type	Receives	Discharges	Elevation (ft)	Width (ft)	Length (ft)	Depth (ft)	ft-h/ft/v	%
Swale	Wooded/Shrubs	Irrigation Pond	Pond 3	922	25	407	2	3	3

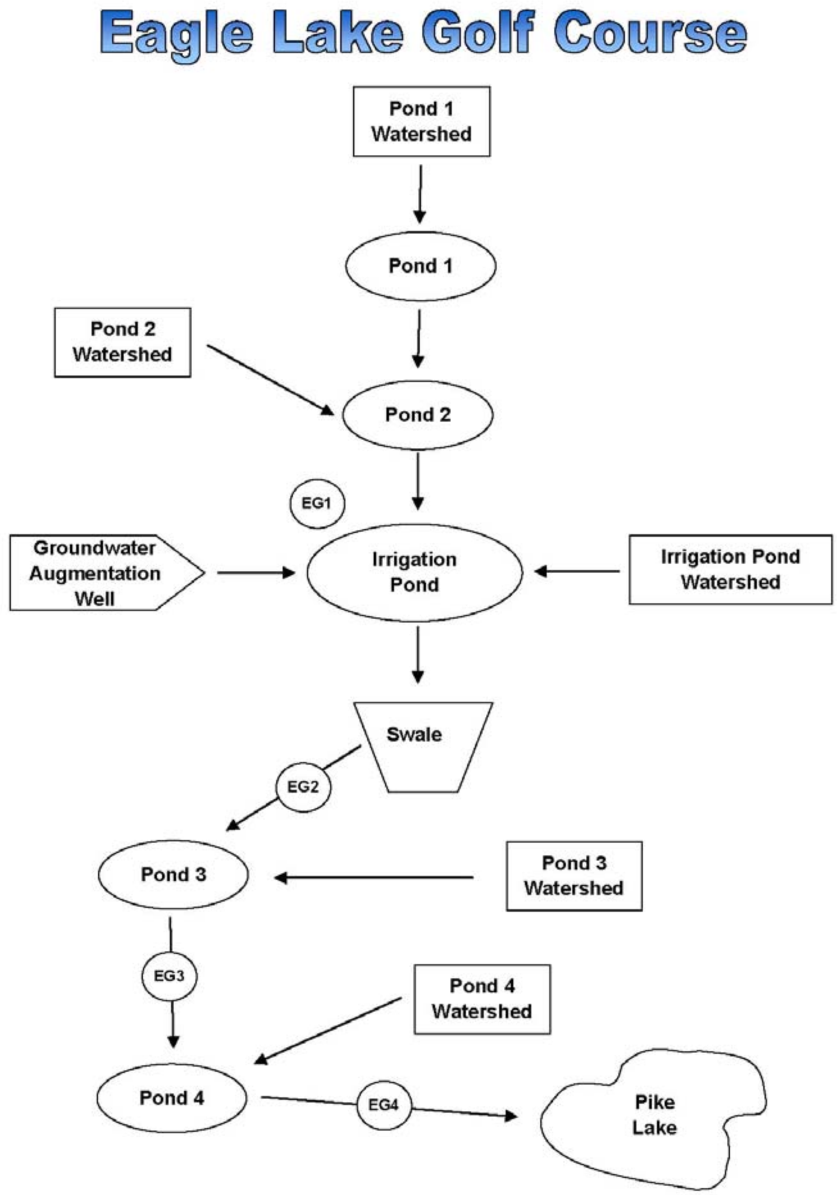

Figure 2: Eagle Lake Golf Course Flow Diagram.

After the model was calibrated to observed conditions, the model was used to determine the nutrient loading removal efficiency of the buffer swale and ponds downstream from the irrigation pond. The nutrient removal efficiency was calculated for each parameter for conditions observed in 2005. The model was re-run with a rainfall file that represents average precipitation conditions for the Minneapolis, Minnesota area. The nutrient loading and removal efficiency of the buffer swale and ponds downstream of the irrigation pond were compared to the observed conditions in 2005. To simulate nutrient loading conditions without the series of treatment devices, the model was re-run by removing the buffer swale and ponds from the model. This provided an estimate of the nutrient loading without the treatment devices downstream of the irrigation pond.

The P8 model was further used to improve the operation of the irrigation pond to reduce runoff volume and nutrient loading to Pike Lake. The water level within the irrigation pond can be adjusted to ensure that it receives the majority of the runoff without overflowing to the downstream treatment devices. The model was run with a 1-year storm event (2.5 inches in 24 hours) rainfall file to determine the volume of runoff from the irrigation pond watershed. The estimated volume of runoff (acre-ft) was the minimum storage capacity required to accommodate the runoff from a 1-year storm event so there is no overflow to the down stream treatment devices. The water level elevation on the irrigation pond was adjusted accordingly to accommodate the estimated runoff volume from the 1-year storm event. These model simulations should provide insight into the potential operation of the irrigation pond to further reduce potential downstream nutrient loading.

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Results and Discussion

Three Rivers Park District monitored the performance of the stormwater retention system that was designed for the Eagle Lake Golf Course. The sampling sites were monitored from May 3 through November 14 in 2005. During the monitoring interval, the rain gauge recorded 21.8 inches of precipitation. There were 15 precipitation events that produced sufficient runoff volume for sample collection. Water quality samples were collected throughout the flow hydrograph for each precipitation event. A total of 53 water quality samples were collected from all of the sample sites. The data collected from the monitoring sites suggests that the stormwater retention system downstream from the irrigation pond appears to reduce runoff volume and nutrient loading prior to draining to Pike Lake (Table 4). The annual runoff volume for the series of treatment devices decreased from 31 acre-ft to 8 acre-ft, and the total phosphorus concentration decreased from 288 µg/L to 177 µg/L. Consequently, the stormwater retention system provides storage capacity for runoff volume as well as nutrient removal. Although water quality samples were not collected for each precipitation event, the samples were representative of the rainfall distribution with respect to the amount and intensity of precipitation observed in 2005. The flow and nutrient concentration data collected from these monitoring sites were used for calibration of the P8 model.

Table 4: Eagle Lake Golf Course Monitoring Data Summary in 2005.

Site	Samples (n)	Observed Volume (acre-ft)	Average Concentrations TP (µg/L)	SRP (µg/L)	TN (mg/L)	TSS (mg/L)
EG1	15	-	197.4	114.9	1.3	10.7
EG2	15	31.2	288.3	237.2	1.4	14.2
EG3	12	17.9	190.4	91.4	1.2	27.1
EG4	11	8	176.7	102.9	1.3	21.5

The model was initially calibrated for flow conditions that were observed in 2005. To simulate the observed flow conditions, modeling efforts needed to account for the volume of well water pumped into and out of the irrigation pond. The augmentation well pump operation records indicated that there was 32.9 acre-ft of water used for irrigation of the Eagle Lake Golf Course in 2005 (Table 5). Based on the study area acreage, approximately 25% of the volume of water was used for irrigation of the monitored portion of the watershed study area. It was estimated that there was approximately 8 acre-ft used for irrigation of the study area (Table 5). The adjusted irrigation volume for the study area provided approximately 7.4 inches of water that was incorporated into the model rainfall file for each month (Table 5). The adjusted rainfall file was used for modeling the ground water pumped into the irrigation pond. To simulate ground water pumped into the irrigation pond, an artificial watershed was developed in the model to receive rainfall that infiltrated into an aquifer device flowing directly to the irrigation

pond. The size of the watershed was adjusted until the modeled flow volume was similar to observed conditions. Modeling with a 25-acre watershed was required to simulate the 52 acre-ft of water pumped into the irrigation pond. The volume adjustments pumped into the irrigation pond were necessary to mimic the downstream observed hydrologic flow conditions.

Table 5: Eagle Lake Golf Course irrigation volume in 2005.

Month	Total Irrigation Volume (acre-ft)	Study Area Irrigation Adjusted Volume (acre-ft)	Irrigation Depth (inches)
April	0.85	0.21	0.19
May	2.03	0.51	0.46
June	4.61	1.15	1.04
July	12.86	3.21	2.90
August	9.71	2.43	2.19
September	2.52	0.63	0.57
October	0.28	0.07	0.06
Total	32.86	8.22	7.41

The model appears to adequately simulate the observed hydrologic flow conditions. The model provided reliable estimates of total flow volumes that were similar to the observed conditions (Table 6). The only discrepancy between the modeled and observed flow conditions is that the model appears to slightly over predict the total flow volume for the sampling sites. Variations in predicted versus observed total flow volumes may be related to the time of concentration applied for the treatment devices network. The time of concentration for each treatment device was adjusted accordingly in the model so that predicted hydrographs were similar to the observed flow conditions. The adjustments pertaining to the time of concentration was difficult due to the inputs and outputs of the irrigation pond. Despite the difficulty with flow calibration efforts, the model appears to provide estimates that are reasonably similar to the observed flow conditions.

Table 6: Eagle Lake Golf Course observed and modeled flow volumes.

Site	Observed Flow Volume (Acre-ft)	Modeled Flow Volume (Acre-ft)
EG2	31.2	34.0
EG3	17.9	19.4
EG4	8.0	11.1

After the model was calibrated for flow volume, the model was further adjusted to mimic the observed nutrient loading conditions. Typically, the scale factors for each water quality parameter are adjusted accordingly until the model predicts nutrient loading and concentrations similar to observed conditions. Unfortunately, scale factors for each water quality parameter in the model can not be adjusted for each treatment device. The limitations in adjusting scale factors led to difficulties in model calibration for nutrient concentrations. The model appears to substantially over predict the concentrations for total phosphorus and total nitrogen for the EG3 and EG4 sampling sites (Table 7). Scale factors for these water quality parameters could not be adjusted appropriately to compensate for the differences in predicted and observed concentrations. Despite these differences in nutrient concentrations, the modeled estimates for nutrient loading were similar to observed conditions (Table 8). The only substantial difference in modeling estimates in comparison to observed conditions occurred for total nitrogen loading at the EG4 sampling site (Table 8). The model estimation of nutrient loading does not appear to be sensitive to the predicted increase in nutrient concentrations when flow volumes are relatively low. The predicted flow-weighted mean concentrations may have more influence on nutrient loading estimates during periods of increased flow volume. The majority of the storm events in 2005 produced low amounts of runoff volume. Consequently, the model appears to provide estimates of nutrient loading that are reasonably comparable to observed conditions.

Table 7: Eagle Lake Golf Course observed and modeled nutrient concentrations.

Site	Observed			Modeled		
	TP (µg/L)	TN (mg/L)	TSS (mg/L)	TP (µg/L)	TN (mg/L)	TSS (mg/L)
EG2	288	1.4	14.2	257	1.3	11.8
EG3	190	1.2	18.9	294	1.5	21.8
EG4	177	1.3	21.5	294	1.5	12.5

Table 8: Eagle Lake Golf Course observed and modeled nutrient loadings.

Site	Observed			Modeled		
	TP (lbs)	TN (lbs)	TSS (lbs)	TP (lbs)	TN (lbs)	TSS (lbs)
EG2	25.4	120.0	1060.4	23.8	119.6	1087.4
EG3	13.5	79.0	1170.7	15.5	76.7	1148.2
EG4	4.7	26.6	378.6	8.9	44.6	378.0

The calibrated P8 model was used to determine the removal efficiencies for the network of treatment devices. The model suggests that the series of treatment devices were efficient at reducing nutrient loading downstream of the irrigation pond (Tables 9-11). The buffer swale immediately downstream of the irrigation pond provided approximately 18% removal of total phosphorus and total nitrogen loading; and provided approximately 42% removal of total suspended solids. The buffer swale flows directly into the Pond 3 treatment device. Pond 3 reduced total phosphorus and total nitrogen loading by approximately 38%; and reduced the total suspended solid loading by approximately 56%. The furthest downstream pond provided additional treatment for water flowing out of Pond 3. The model estimated that Pond 4 had a nutrient removal efficiency of approximately 40% for total phosphorus and total nitrogen, and a nutrient removal efficiency of 69% for total suspended solids. Consequently, it appears that the series of treatment devices were extremely effective at reducing the nutrient loading.

Table 9: Total Phosphorus Nutrient Removal Efficiency.

Site	Volume (Acre-ft)		Total Phosphorus (pounds)		% Removal
	In	Out	In	Out	
Buffer-Swale	41.9	34.0	29.9	23.8	18.6
Pond 3	34.3	19.4	26.6	15.5	37.9
Pond 4	19.4	11.1	15.8	8.9	40.3

Table 10: Total Nitrogen Nutrient Removal Efficiency.

Site	Volume (Acre-ft)		Total Nitrogen (pounds)		% Removal
	In	Out	In	Out	
Buffer-Swale	41.9	34.0	149.0	119.6	17.9
Pond 3	34.3	19.4	131.1	76.7	37.7
Pond 4	19.4	11.1	78.1	44.6	39.1

Table 11: Total Suspended Solids Removal Efficiency.

Site	Volume (Acre-ft)		Total Suspended Solids (pounds)		% Removal
	In	Out	In	Out	
Buffer-Swale	41.9	34.0	1869.3	1087.4	41.8
Pond 3	34.3	19.4	2610.1	1148.2	56.0
Pond 4	19.4	11.1	1221.6	378.0	69.1

These estimates could not sufficiently be compared to the measured conditions. The nutrient loading inputs to the buffer-swale was not monitored to determine nutrient removal efficiency. In addition, the monitored conditions did not take into account nutrient loading to treatment devices that was attributed to direct run-off. The model incorporates direct watershed loading that was not captured from the monitoring sites. The model was calibrated to the observed nutrient loading conditions for each respective monitoring site so the estimates for nutrient removal efficiency should corroborate with

the measured conditions. The modeled nutrient removal efficiencies should provide a conservative estimate that is more accurate than the measured conditions because direct watershed nutrient loading is accounted for in the model.

After removal efficiencies were calculated for each treatment device, the model was re-run by removing the series of connected treatment devices to further assess the potential impact on nutrient loading. There was a significant increase in the amount of nutrient loading when the treatment devices were removed from the model (Figure 2). The model estimated that the total phosphorus loading increased from 8.9 to 35 pounds, and total nitrogen loading increased from 44.6 to 168.5 pounds. In addition, the model predicted that the total suspended solids would increase from 378 to 4460 pounds. The Eagle Lake Golf Course flows directly to Pike Lake. Consequently, the potential increases in nutrient loading without the series of treatment devices would have had a significant impact on Pike Lake water quality. The modeling scenario suggests that the development of a series of connected treatment devices significantly reduced the nutrient loading as well as potential impacts on Pike Lake water quality.

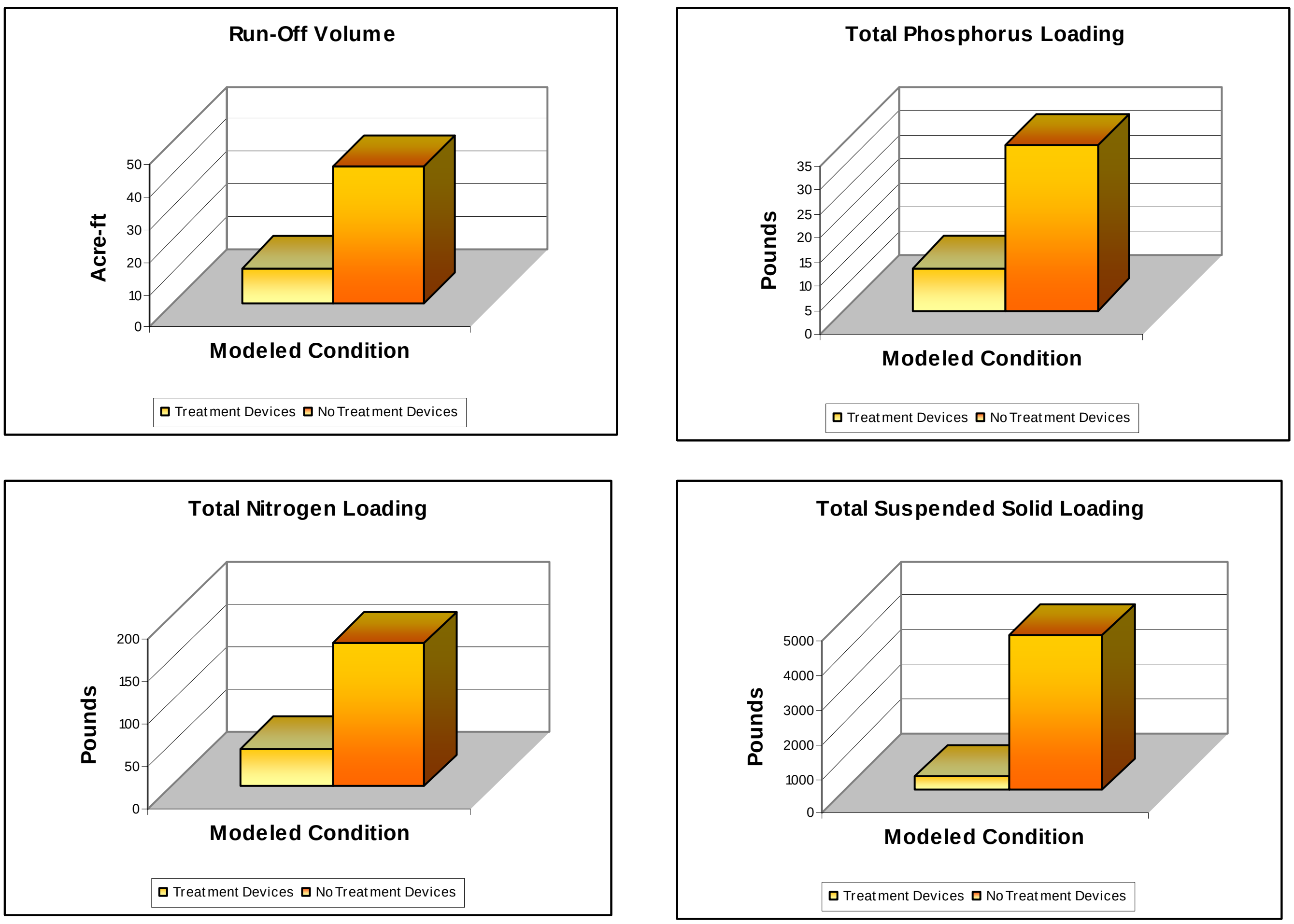

Figure 2: Modeled changes in nutrient loading after removing treatment devices.

Although the series of connected treatment devices are effective at reducing nutrient loading, there are potential opportunities to improve the treatment network by managing the water level of the irrigation pond. A significant portion of the Eagle Lake Golf Course watershed flows into the irrigation pond. The watershed primarily consists of impervious acreage that drains to the irrigation pond. Based on modeling estimates in 2005, the irrigation pond received approximately 16 pounds of phosphorus loading, 64 pounds of total nitrogen loading, and 10,021 pounds of total suspended solids. The available storage volume within the irrigation pond has the potential to contain the majority of the nutrient loading from the upper portion of the watershed. Consequently, the potential exists to contain the majority of the nutrient loading within the irrigation pond through water level management.

The model was re-run to determine the operational water level elevation of the irrigation pond that would adequately provide enough storage volume for a 2.5-inch precipitation event in a 24-hour period. Modeling for the 2.5-inch precipitation event results in approximately 1.29 acre-ft of runoff draining to the irrigation pond. The modeling scenario indicates that the 2.5-inch precipitation event potentially can provide 32 pounds of total phosphorus loading, 120 pounds of total nitrogen loading, and 26,000 pounds of total suspended solids. The spillway elevation of the pond is at 924.5, in which the pond overflows to the buffer swale. Based on the modeling scenario, the irrigation pond should be maintained at a maximum water level elevation of 923 to ensure adequate storage volume necessary to accommodate the runoff from the 2.5-inch rainfall event. Maintaining the pond at a water level elevation of 923 would allow approximately 9.44 acre-ft of water available for irrigation of the golf course. The modeling scenario suggests that adjusting the water level elevation of the irrigation pond potentially could provide adequate storage volume to capture runoff from majority of the precipitation events. Consequently, adjusting the water level within the irrigation pond could reduce nutrient loading as well as provide enough water available to accommodate the irrigation of the golf course.