Lake Okeechobee Littoral Zone

Project Leader: Jennifer Field, Battelle
Statistician: Matthew Sanders, Battelle

Project Code: OLIT

Type: Type II

Mandate or Permit:
- Lake Okeechobee Protection Act (LOPA)
- Surface Water Improvement and Management Act (SWIM) Ch 373.4595 F.S

Project Start Date: 1996

Division Manager: Lake Okeechobee: Susan Gray

Program Manager: Tom James

Points of Contact: Tom James, Bruce Sharfstein, Chuck Hanlon, Patrick Davis

Field Point of Contact: Patrick Davis

Spatial Description
Project OLIT is designed to monitor water quality in the littoral zone at 12 sampling stations on the north and west shore of Lake Okeechobee (Figure 1). The project is working under the hypothesis that the marsh area is disconnected from the lake proper, is an oligotrophic area, and is more pristine than other parts of the lake. Water enters the project area from the east by exchange with the lake proper and from the north and west through LD-4, C-38, L69, C40, and C41 and from rainfall. Water is distributed from the lake to areas adjacent to the western-most shore of the lake by the L50 and LD3. Water is taken from the southern part of the project area at the S77 to supply the Caloosahatchee River and estuary. Water flow across the eastern portion of the project area is restricted by an area with abundant cattails that are growing in response to the high phosphorous in the sediments and high water levels in the lake.

Removal of the cattails and increased access for fishermen from the main lake to the littoral area is proposed by the Fish and Wildlife Conservation Commission (FWCC). Openings through the cattails have potential to increase the supply of nutrients to the marsh area, which could further increase the extent of cattails. Restoration of the marsh area by removal of the exotic torpedo grass species through treatment is ongoing and results in substantial amount of degrading grass which can place high biological oxygen demand to the project area. Understanding the water flow from the lake to the littoral zone and gradients in the nutrients levels are considered critical to managing the incursion of cattails into the project area.

The project team believes they are beginning to have enough data from the database covering drought and wet conditions to understand the potential environmental responses to management decisions but need to understand what conditions trigger movement of water into the littoral zone. An optimization that reduced the original number of stations included in the project was previously conducted. The project team also believes additional stations in the "cuts" are needed to understand the impact of the navigation and access decisions.

Project Purpose, Goals and Objectives
The purpose of OLIT is to gather baseline data for the development of management strategies and research objectives for Lake Okeechobee, estimate long-term phosphorus loading to Lake Okeechobee; identify trends in total phosphorus and other water quality variables that are indicators of the Lake's health over time; and provide a water quality data base for:

a. complying with monitoring requirements of the Lake Okeechobee Operating Permit #50-0679349 issued by the Florida Department of Environmental Protection (FDEP)
b. determining effectiveness of the implementation of basin management plans in reducing nutrient loadings into the lake as specified in the Surface Water Improvement and Management Act of 1987
c. determining long and short term trends necessary to identify potential problem areas in terms of water quality degradation, nutrient loadings, and tracking eutrophication of the lake
d. applying eutrophication models to verify and refine the nutrient load targets for the lake and rank its trophic status.

The primary focus of the OLIT Project's design is the estimation of long-term phosphorus loading to Lake Okeechobee and the identification of trends in total phosphorus and other water quality variables that are indicators of the Lake's health over time.

Sampling Frequency and Parameters Sampled

Tables 1 and 2 present the current parameters sampled in situ and by grab, respectively. All stations for Project OLIT are sampled on a monthly basis. Parameters include: alkalinity, ammonia, nitrite, nitrite+nitrate (NOX), total Kjeldahl nitrogen (TKN), orthophosphate, total phosphorus (TPO4), silica, several forms of chlorophyll, potassium, sodium, calcium, magnesium, chloride, sulfate color, total suspended solids, turbidity, and VSS.

The OLIT staff was not sure that COLOR was a key parameter to retain in the project as it relates to drinking water mandates and its applicability in this project was uncertain. They suggested the following parameters could be dropped from the program: CARO, CHLB, CHLC, Mg, and Na. These parameters are not included in the table below. They also suggested adding Total organic carbon, dissolved organic carbon and Calcium to the project to support the modeling, enhance the comparability to the Project Y data, and for data interpretation.

Table 1. Parameters measured In Situ for Project OLIT

Station	DO	TEMP	PH	SCOND	SECCI	TDEPTH
FEBIN	m	m	m	m	m	m
FEBOUT	m	m	m	m	m	m
MBOXSOU	m	m	m	m	m	m
MH12000	m	m	m	m	m	m
MH16000	m	m	m	m	m	m
MH24000	m	m	m	m	m	m
MH32000	m	m	m	m	m	m
OISLAND	m	m	m	m	m	m
TIN13700	m	m	m	m	m	m
TIN16100	m	m	m	m	m	m
TIN8100	m	m	m	m	m	m

m = monthly; all stations are Type 2 mandate

Table 2. Parameters measured from grab samples for Project OLIT

Station	CHLA	CHLA2	PHAEO	TSS	TURBI	ALKA	CL	NH4	NO2	NOX	TKN	TDKN	TPO4	TDPO4	OPO4	VSS
FEBIN	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m
FEBOUT	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m
MBOXSOU	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m
MH12000	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m
MH16000	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m
MH24000	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m
MH32000	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m
OISLAND	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m
TIN13700	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m
TIN16100	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m
TIN8100	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m

m = monthly; all stations are Type 2 mandate; the following parameters were proposed for removal: CARO, CHLB, CHLC, Color, Mg, NA.

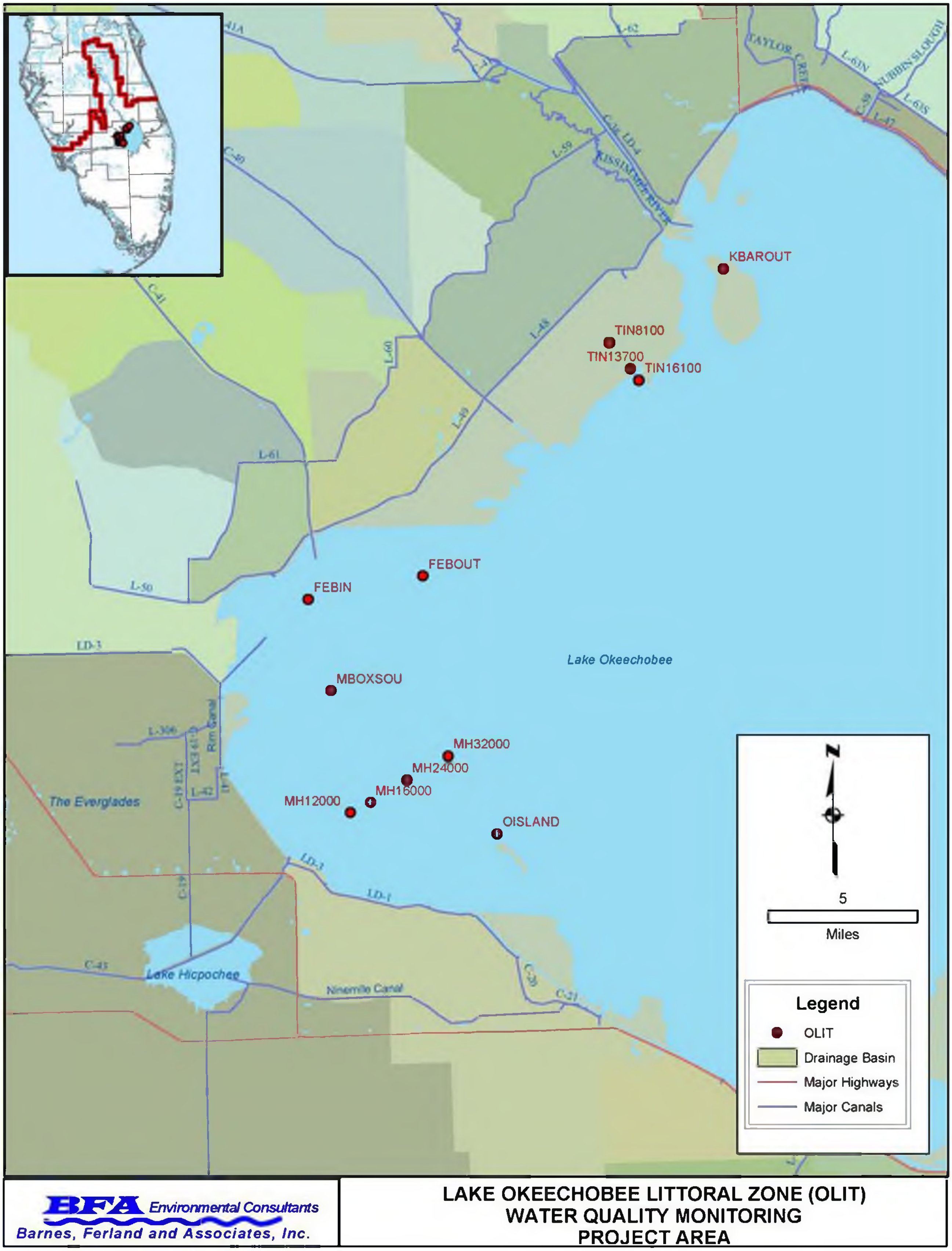

Figure 1. OLIT Sampling Locations

Current and Future Data Uses
Water quality data from OLIT are used to: assess the impact of operating permit management implementations, verify water quality models, examine differences in water quality between the limnetic and littoral zones; monitor possible algal blooms in the limnetic and littoral zones; provide water quality data in support of nutrient dynamics studies; monitor for change in water quality following basin management strategies; and establish nutrient budgets for Lake Okeechobee.. The data are incorporated into the South Florida Environmental Report, various Bioassessment projects in the lake and are used extensively in the Lake Okeechobee Environment Model. In the future, data may be used in CERP, particularly the RECOVER Monitoring and Assessment Plan.

Statistical Optimizations
Because many of the current and future uses for OLIT data involve the ability to detect a trend and then evaluate changes from the trend, the principal statistical optimization for this project focused on the minimum, true annual percent change that would be consistently detected by the statistical test for evaluating trends. These analyses were conducted for temporal trends and are summarized below. Preliminary spatial optimizations also were conducted; however, power analyses to evaluate the annual percent change that would be detected by tests evaluating trends under alternative spatial scenarios also need to be evaluated.

Spatial Optimizations Spearman rank correlations were used to assess spatial redundancy and identify stations that co-varied over time suggesting the potential for sampling redundancies in the monitoring program. For OLIT, the Spearman rank correlations were conducted for each of the geographic domains (North Littoral Zone, Fisheating Bay and South Littoral Zone) and only for the five optimization parameters (CHLA2, TKN, NOX, TPO4 and TSS; DBHydro codes: 112, 21, 18, 25, 16, respectively). No evaluations were made on the other parameters collected during project OLIT and how these may or may not be correlated between sampling stations.

Results and Recommendations
North Littoral Zone: Of the three sampling stations in the North Littoral Zone, no apparent patterns were observed with respect to correlated stations and parameters (Table 3). However, many of the stations were significantly correlated with respect to TKN, NOX and TSS. TIN8100 was not significantly correlated with the other two stations for CHLA2 and TIN8100 was not correlated to TIN16100 for TPO4. For those stations that were correlated, the Spearman rank correlation coefficients were generally low. Only for stations TIN13700 and TIN16100 for TKN and NOX were coefficients greater than 0.60. These results suggest that even though the stations may be correlated, the relationships are not particularly strong.

Because of the small number of sites in the North Littoral Zone and the weak relationship observed with significant correlations, there is no clear reason from a spatial perspective to eliminate stations within this geographic domain. Subsequent correlations using all the parameters may provide more certainty of redundancies, but this information must be weighed against the field sampling logistics to determine if there are any real savings.

Fisheating Bay: Only two stations are sampled in Fisheating Bay, and for all parameters except CHLA2, the correlations were significant (Table 4). Correlation coefficients were generally low (less than 0.5) suggesting that the relationships are not particularly strong. Based on these results only, removing one of the sampling stations in Fisheating Bay may not provide much in cost savings considering the field sampling logistics and the position of these stations relative to each other. Evaluation of additional parameters that may be highly correlated between the stations should be considered.

South Littoral Zone: Stations within the South Littoral Zone were often significantly correlated, particularly for CHLA2, TKN, NOX, and TPO4 (Table 5). For CHLA2, the relationships were generally weak (correlation coefficients generally below 0.4). For NOX, the relationships between the stations were mid-range with correlation coefficients ranging between 0.5 and 0.7. Except for two instances where stations were not significantly correlated (MH1200-MH3200 and MH1200-OISLAND), significant correlations between stations for TPO4 were not particularly strong with coefficients below 0.6. The South Littoral Zone stations were all significantly correlated with respect to TKN. Additionally, many of the correlation coefficients were high (often above 0.7) suggesting a strong relationship between these stations for this parameter. Several of the stations were not significantly related with respect to TSS.

Based on these correlation results only, some stations within the South Littoral Zone may be candidates for removal or possibly re-location, for select parameters (i.e., TKN, and possibly NOX). Prior to any re-design, however, additional correlation analyses using many of the other parameters collected during OLIT should be evaluated to determine if similar patterns are observed with specific stations and parameters. This information must also be considered with field sampling logistics to determine whether there would be any cost savings to such a re-design.

Table 3. Spearman Rank Correlation Results for Stations within the North Littoral Zone.

CHLA2		TIN13700	TIN16100	TIN8100
	TIN13700	1	0.37*	0.11
	TIN16100	0.37*	1	-0.03
	TIN8100	0.11	-0.03	1
TKN		TIN13700	TIN16100	TIN8100
	TIN13700	1	0.67**	0.51**
	TIN16100	0.67**	1	0.36*
	TIN8100	0.51**	0.36*	1
NOX		TIN13700	TIN16100	TIN8100
	TIN13700	1	0.64*	0.33*
	TIN16100	0.64*	1	0.39
	TIN8100	0.33*	0.39	1
TPO4		TIN13700	TIN16100	TIN8100
	TIN13700	1	0.35*	0.34*
	TIN16100	0.35*	1	-0.04
	TIN8100	0.34*	-0.04	1
TSS		TIN13700	TIN16100	TIN8100
	TIN13700	1	0.58**	0.29*
	TIN16100	0.58**	1	0.35*
	TIN8100	0.29*	0.35*	1

* Prob > |r| Under HC: RHO = 0 < 0.05
**Prob > |r| Under HC: RHO = 0 < 0.0001

Table 4. Spearman Rank Correlation Results for Stations within Fisheating Bay.

		FEBIN	FEBOUT
CHLA2	FEBIN	1	0.19
TKN	FEBIN	1	0.50**
NOX	FEBIN	1	0.42*
TPO4	FEBIN	1	0.51**
TSS	FEBIN	1	0.37*

* Prob > |r| Under HC: RHO = 0 < 0.05
**Prob > |r| Under HC: RHO = 0 < 0.0001

Table 5. Spearman Rank Correlation Results for Stations within the South Littoral Zone.

		MBOXSOU	MH12000	MH16000	MH24000	MH32000	OISLAND
CHLA2	MBOXSOU	1	0.30*	0.31*	0.38*	0.38*	0.34*
	MH12000	0.30*	1	0.37*	0.28*	0.34*	0.35*
	MH16000	0.31*	0.37*	1	0.40*	0.26*	0.31*
	MH24000	0.38*	0.28*	0.40*	1	0.27*	0.41*
	MH32000	0.38*	0.34*	0.26*	0.27*	1	0.32*
	OISLAND	0.34*	0.35*	0.31*	0.41*	0.32*	1
TKN		MBOXSOU	MH12000	MH16000	MH24000	MH32000	OISLAND
	MBOXSOU	1	0.76**	0.77**	0.82**	0.66**	0.73**
	MH12000	0.76**	1	0.91**	0.76**	0.51**	0.75**
	MH16000	0.77**	0.91**	1	0.82**	0.59**	0.79**
	MH24000	0.82**	0.76**	0.82**	1	0.72**	0.81**
	MH32000	0.66**	0.51**	0.59**	0.72**	1	0.73**
	OISLAND	0.73**	0.75**	0.79**	0.81**	0.73**	1
NOX		MBOXSOU	MH12000	MH16000	MH24000	MH32000	OISLAND
	MBOXSOU	1	0.59**	0.65**	0.70**	0.65**	0.71**
	MH12000	0.59**	1	0.67**	0.72**	0.49**	0.62**
	MH16000	0.65**	0.67**	1	0.61**	0.57**	0.60**
	MH24000	0.70**	0.72**	0.61**	1	0.57**	0.61**
	MH32000	0.65**	0.49**	0.57**	0.57**	1	0.67**
	OISLAND	0.71**	0.62**	0.60**	0.61**	0.67**	1
TPO4		MBOXSOU	MH12000	MH16000	MH24000	MH32000	OISLAND
	MBOXSOU	1	0.32*	0.42*	0.44*	0.59**	0.54**
	MH12000	0.32*	1	0.68**	0.64**	0.23	0.22
	MH16000	0.42*	0.68**	1	0.57**	0.49**	0.44*
	MH24000	0.44*	0.64**	0.57**	1	0.41*	0.46*
	MH32000	0.59**	0.23	0.49**	0.41*	1	0.59**
	OISLAND	0.54**	0.22	0.44*	0.46*	0.59**	1
TSS		MBOXSOU	MH12000	MH16000	MH24000	MH32000	OISLAND
	MBOXSOU	1	0.13	-0.17	0.12	0.09	-0.11
	MH12000	0.13	1	0.54**	0.51**	0.22	0.11
	MH16000	-0.17	0.54**	1	0.32*	0.23	0.21
	MH24000	0.12	0.51**	0.32*	1	0.34*	0.05
	MH32000	0.09	0.22	0.23	0.34*	1	0.28*
	OISLAND	-0.11	0.11	0.21	0.05	0.28*	1

* Prob > |r| Under HC: RHO = 0 < 0.05
**Prob > |r| Under HC: RHO = 0 < 0.0001

Temporal Optimizations Because many of the data uses for this monitoring program are aimed at detecting trends in various water quality parameters, optimizations were conducted to estimate the power to detect a trend for given water quality parameters (CHLA2, TKN, NOX, TPO4 and TSS; DBHydro codes: 112, 21, 18, 25, 16, respectively). Statistical power analyses were used to determine the smallest water quality trends that will be detectable with high probability based on water quality data collected according to current monitoring plans. The power analyses were performed by carrying out the following power analysis steps for each station-parameter and/or geographic region-parameter combination.

- Fit a statistical model to the water quality parameter data in order to have a basis for generating simulated data to support a Monte Carlo based power analysis procedure

- Generate multiple replicate simulated water quality time series data sets; for all power analyses reported here, each time series generated was for a 5-year monitoring period

- Perform a Seasonal Kendall Tau trend analysis procedure (Reckhow et al. 1993) for each simulated time series data set; in particular, obtain a point estimate of the slope vs. time for the log-transformed water quality parameter values

- Estimate the *annual proportion change* (APC) in water quality parameter values that is detectable with 80% power using a simple two-sided test based on the Seasonal Kendall Tau slope estimate performed at a 5% significance level. A target slope equivalent to a 20% APC was used throughout this effort.

Parameter values were natural log-transformed for statistical modeling because the log-transformed data was more nearly normally distributed than were the untransformed data. The fitted statistical model contains the following components:

- Fixed seasonal effects that repeat themselves in an annual cycle

- A long-term linear trend in the log-transformed parameter concentrations; this corresponds to a fixed percentage increase or decrease in the water quality parameter each year

- A random error term representing temporal variability in true water quality parameter values; these error terms are allowed to be correlated from one time point to the next in order to capture any serial autocorrelation that is present in the monitoring data

- A random error term representing sampling and chemical analysis variability; these error terms are assumed to be stochastically independent from one time point to the next

The fitted statistical model is used to perform a Monte Carlo simulation analysis in which multiple time series data sets are simulated and used to determine the anticipated statistical properties of trend detection procedures that will be used by the District. All statistical trend analyses performed on the simulated data were based on the Seasonal Kendall Tau trend analysis procedure (Reckhow et al. 1993) preferred by the District.

In the course of performing the power analyses for the District, it was determined that the basic Seasonal Kendall Tau trend detection procedures do not necessarily control the true significance level of the hypothesis test for trend when there is serial autocorrelation exhibited in the data. This was found to be true even for procedures that attempt to correct for serial autocorrelation. For this reason, all power analysis results reported here are for a simple hypothesis test procedure based on the median slope estimator that accompanies the Seasonal Kendall Tau test procedure. The median slope estimator is assumed to follow a normal distribution and power results are obtained by performing a simple z-test with this estimator.

Currently, the OLIT stations are sampled monthly. For this optimization, the statistical approach evaluated the power to detect a trend in a water quality parameter at each individual station at the current sampling frequency (i.e., monthly – 12 samples/year) as well as three alternative frequencies: quarterly (4 samples/year), bi-weekly (24 samples/ year) and weekly (52 samples/year) (Table 6).

The statistical approach was also used to evaluate the power to detect trends in the various water quality parameters for each of the geographic domains. Data for the individual stations within each of the three geographic domains were averaged and the statistical methods applied (Table 7). Again, the temporal alternatives consisted of increased sampling frequency (bi-weekly and weekly) and decreased sampling frequency (quarterly).

For each alternative, an estimate was obtained of the minimum Annual Percent Change (APC) in the parameter concentration that is detectable with 80% power using the median slope estimator z-test procedure performed at a 2-sided significance level of 0.05. Rust (2005) describes the power analysis procedure and underlying statistical model employed here in detail. Rust (2005) also documents the SAS program used to carry out the power analyses for which results are reported here.

Results and Recommendations

Individuals Stations: In general, the power analyses results suggest that with decreased sampling frequency (i.e., quarterly sampling) detection of annual percent changes of specific water quality parameters would be well above a target of 20% for many stations and parameters. Detection of a 20% annual change for the TKN parameter at 4 stations is possible with quarterly sampling, but more frequent sampling is necessary to meet this target for the other stations and parameters. If the District desires the ability to show that a slope equivalent to a 20% annual change in the parameter is sufficient for their purposes, then only a few stations for any given parameter meet or are below this target with the current design or more frequent sampling. None of the design alternatives are able to meet an annual percent change in slope of 20% for TPO4. The current monthly sampling for TPO4 supports detection of annual percent changes in the range of 25% to greater than 100%. For stations where annual percent changes are greater than 100%, increasing the sampling frequency (bi-weekly or weekly) does not substantially change the results.

Geographic Domain: Using the geographic domains to determine if any of the sampling frequency alternatives would enhance the ability to consistently detect the 20% annual change in a given parameter did not result in substantial changes from those observed using individual stations. However, in many cases, the detectable annual percent change fell between or slightly below those observed for the individual stations within a specific geographic domain. For example, for TPO4 in the Fisheating Bay geographic domain, the detection of annual percent change ranges from 27% for the weekly alternative to 34% for the quarterly alternative. The ability to detect an annual rate of change at the two stations representing Fisheating Bay, FEBIN and FEBOUT, for the weekly alternative are 28% and 36%, respectively and for the quarterly alternative are 37% and 41%, respectively.

Based on the results of the temporal optimizations, it is not recommended that the District reduce their sampling frequency for Project OLIT. Further optimizations efforts must take into account modifications to the spatial design along with the various temporal alternatives to determine if spatial and temporal changes together could enhance the ability to consistently detect an annual percent change of 20% or lower.

Table 6. Minimum true annual percent change that would be consistently detected by a statistical test for trend at individual stations for four frequency alternatives.

Parameter	Station	Quarterly	Monthly	Bi-weekly	Weekly
CHLA2	FEBIN	64%	41%	39%	38%
	FEBOUT	40%	29%	25%	23%
	MBOXSOU	70%	58%	55%	54%
	MH12000	32%	20%	16%	14%
	MH24000	38%	20%	14%	9%
	MH32000	45%	31%	27%	25%
	OISLAND	53%	40%	38%	38%
	TIN13700	155%	144%	142%	138%
	TIN16100	82%	73%	72%	70%
	TIN8100	71%	57%	54%	53%
NOX	FEBIN	84%	42%	29%	18%
	FEBOUT	196%	172%	166%	167%
	MBOXSOU	29%	21%	19%	18%
	MH12000	35%	21%	17%	16%
	MH16000	30%	19%	16%	13%
	MH24000	30%	19%	17%	16%
	MH32000	51%	35%	30%	27%
	OISLAND	23%	15%	13%	12%

Parameter	Station	Quarterly	Monthly	Bi-weekly	Weekly
	TIN13700	86%	72%	72%	70%
	TIN16100	100%	82%	80%	80%
	TIN8100	26%	15%	13%	12%
TKN	FEBIN	15%	11%	10%	10%
	FEBOUT	13%	9%	8%	8%
	MBOXSOU	27%	26%	25%	25%
	MH12000	30%	29%	29%	29%
	MH16000	34%	33%	32%	32%
	MH24000	37%	35%	35%	35%
	MH32000	31%	30%	29%	29%
	OISLAND	36%	35%	34%	34%
	TIN13700	31%	29%	28%	28%
	TIN16100	12%	7%	5%	3%
	TIN8100	17%	14%	13%	12%
TPO4	FEBIN	37%	30%	28%	28%
	FEBOUT	41%	37%	36%	36%
	MBOXSOU	153%	148%	147%	147%
	MH12000	30%	25%	24%	24%
	MH16000	32%	27%	27%	27%
	MH24000	42%	35%	35%	34%
	MH32000	139%	136%	133%	132%
	OISLAND	150%	141%	138%	141%
	TIN13700	166%	162%	158%	160%
	TIN16100	130%	127%	126%	125%
	TIN8100	49%	41%	40%	38%
TSS	FEBIN	114%	102%	100%	98%
	FEBOUT	54%	45%	43%	42%
	MBOXSOU	23%	13%	9%	6%
	MH12000	22%	18%	17%	17%
	MH16000	18%	10%	7%	5%
	MH24000	41%	32%	29%	28%
	MH32000	41%	36%	34%	34%
	OISLAND	39%	30%	29%	29%
	TIN13700	148%	132%	129%	128%
	TIN16100	211%	204%	204%	201%
	TIN8100	76%	64%	60%	58%

Table 7. Minimum true annual percent change that would be consistently detected by a statistical test for trend at the OLIT geographic domains for four frequency alternatives.

Parameter	Zone	Quarterly	Monthly	Bi-weekly	Weekly
CHLA2	Fisheating Bay	45%	27%	23%	21%
	North Littoral	128%	126%	123%	119%
	South Littoral	33%	21%	17%	14%
NOX	Fisheating Bay	109%	81%	74%	70%
	North Littoral	97%	84%	80%	80%
	South Littoral	37%	24%	19%	17%
TKN	Fisheating Bay	13%	9%	8%	8%
	North Littoral	25%	23%	22%	22%
	South Littoral	29%	29%	28%	28%
TPO4	Fisheating Bay	34%	29%	28%	27%
	North Littoral	104%	99%	98%	98%
	South Littoral	162%	157%	162%	160%
TSS	Fisheating Bay	72%	64%	62%	61%
	North Littoral	149%	143%	139%	140%
	South Littoral	27%	17%	14%	12%

Lake Okeechobee In Lake North and South

Optimization Leader: Jennifer Field, Battelle
Statistician: Matthew Sanders, Battelle

Project Code: YNRG/YSRG = Y

Type: Type II

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Project Start Date: 1972

Division Manager: Lake Okeechobee: Susan Gray

Program Manager: Tom James

Points of Contact: Tom James, Bruce Sharfstein, Patrick Davis

Field Point of Contact: Patrick Davis

Spatial Description:
Project Y combines the data from two projects YSRG and YNRG that measure water quality within the limnetic area of Lake Okeechobee. These projects have been combined for optimization since the projects were set up as two projects to serve logistical constraints; the parameter sets are identical. The project area encompasses the greater portion of Lake Okeechobee outside of the littoral area that is sampled in Project OLIT. Water generally enters Lake Okeechobee from the north and northwest. The majority of water flows into the lake through the Kissimmee River, C-41A, Fisheating Creek and Taylor Creek. A number of other sources also contribute water to the lake. Water from the project area within the lake is distributed to adjacent areas by wind driven currents. The major outlets from Lake Okeechobee within in the project area include the St. Lucie and the Caloosahatchee River, the Miami, Hillsboro, North New River, West Palm Beach, and Industrial canals. The project supports the Lake Okeechobee Protection Program (LOPP) and assessment of long-term phosphorus loading impacts to Lake Okeechobee and examines trends in total phosphorus and other water quality variables as indicators of the Lake's health over time.

Project Purpose, Goals and Objectives:
The main focus of the monitoring is to address the mandates listed above. The goal/objectives of the project are:
1. Estimation of long-term impacts of phosphorus loading to Lake Okeechobee
2. Identification of trends in total phosphorus and other water quality variables over time.
3. Provide a water quality data base to:
   a. Comply with monitoring requirements of the Lake Okeechobee Operating Permit #50-0679349 issued by the Florida Department of Environmental Protection (FDEP)
   b. Determine effectiveness of the implementation of basin management plans in improving lake water quality as specified in the Surface Water Improvement and Management Act of 1987
   c. Determine long and short term trends necessary to identify potential problem areas in terms of water quality degradation and tracking eutrophication of the lake
   d. Apply eutrophication models to verify and refine the nutrient load targets and to assist development of management alternatives
4. Measure total calcium, dissolved organic carbon, and total organic carbon to provide a baseline to determine the impacts of releases from the Aquifer Storage and Recovery wells.
5. Measure total organic carbon and dissolved organic carbon to better understand the carbon cycle
6. Data are used to:

- Assess the impact of operating permit management implementations;
- Verify water quality models;
- Examine differences in water quality between the pelagic and littoral zones(OLIT project);
- Monitor possible algal blooms in the pelagic zone;
- Define algal bloom conditions on lake Okeechobee
- Provide water quality data in support of nutrient dynamics studies
- Monitor for changes in water quality following basin management strategies.
- Establish nutrient budgets for Lake Okeechobee.

Sampling Frequency and Parameters Sampled:
All stations for Project Y are sampled monthly for chlorophyll a phaeophytin, color, total suspended solids, turbidity, volatile suspended solids, ammonia, nitrite, nitrite+nitrate (NOX), total kjeldahl nitrogen (TKN), total phosphorus (TPO4), orthophosphorus, alkalinity and chloride (Tables 1 and 2). Ions such as potassium, magnesium, sodium, as well as silicate and sulfate are sampled quarterly at all stations. The dissolved ion, calcium, is also sampled at all stations; however, it is sampled monthly at L001, L002, L003, L004, L005, L006, L007, L008, LZ42, LZ42N and CLV10A and quarterly at all other stations. Dissolved organic carbon, total organic carbon and total calcium also are sampled at this subset of stations on a monthly basis. In-situ measurements of water depth, temperature, pH, dissolved oxygen, and specific conductivity are made simultaneously with the grab samples.

Discussions with District staff suggested the following parameters could be dropped from the program: CARO, CHLB, CHLC, Mg, and Na. These parameters have been removed from the table below. They also felt that TOC, DOC, and Ca measurements should be sampled at more stations to support the modeling and data interpretation. Staff believed that more stations may be required for this project to support RECOVER and understand the changes brought about when the Taylor Slough STA (CERP Project) is brought on line. Under this scenario, it will be critical to understand the nutrient gradients in the project area.

Table 1. Parameters measured from In Situ for Project Y (YNRG and YSRG)

Station	DO	TEMP	PH	SCOND	SECCI	DEPTH
3RDPTOUT	m	m	m	m	m	m
KBAROUT	m	m	m	m	m	m
KISSR0.0	m	m	m	m	m	m
L001	m	m	m	m	m	m
L002	m	m	m	m	m	m
L003	m	m	m	m	m	m
L004	m	m	m	m	m	m
L005	m	m	m	m	m	m
L008	m	m	m	m	m	m
LZ2	m	m	m	m	m	m
LZ40	m	m	m	m	m	m
LZ42N	m	m	m	m	m	m
POLESOUT	m	m	m	m	m	m
STAKEOUT	m	m	m	m	m	m
CLV10A	m	m	m	m	m	m
L006	m	m	m	m	m	m
L007	m	m	m	m	m	m
LZ25	m	m	m	m	m	m
LZ30	m	m	m	m	m	m
LZ42	m	m	m	m	m	m
PALMOUT	m	m	m	m	m	m
PELMID	m	m	m	m	m	m
PLN2OUT	m	m	m	m	m	m
POLE3S	m	m	m	m	m	m
RITAEAST	m	m	m	m	m	m
RITAWEST	m	m	m	m	m	m
TREEOUT	m	m	m	m	m	m

m = monthly; all stations are Type 2 mandate

Table 2. Parameters measured from grab samples for Project Y (YNRG and YSRG)

Station	CHLA	CHLA2	PHAEO	COLOR	TSS	TURBI	NH4	NO2	NOX	TKN	TPO4	OPO4	ALKA	CL	VSS	CA	K	SIO2	SO4	TORGC	DORC
3RDPTOUT	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	qrt	qrt	qrt	qrt		
KBAROUT	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	qrt	qrt	qrt	qrt		
KISSR0.0	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	qrt	qrt	qrt	qrt		
L001	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	qrt	qrt	qrt	m	m
L002	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	qrt	qrt	qrt	m	m
L003	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	qrt	qrt	qrt	m	m
L004	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	qrt	qrt	qrt	m	m
L005	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	qrt	qrt	qrt	m	m
L008	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	qrt	qrt	qrt	m	m
LZ2	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	qrt	qrt	qrt	qrt		
LZ40	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	qrt	qrt	qrt	qrt		
LZ42N	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	qrt	qrt	qrt	m	m
POLESOUT	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	qrt	qrt	qrt	qrt		
STAKEOUT	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	qrt	qrt	qrt	qrt		
CLV10A	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	qrt	qrt	qrt	m	m
L006	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	qrt	qrt	qrt	m	m
L007	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	qrt	qrt	qrt	m	m
LZ25	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	qrt	qrt	qrt	qrt		
LZ30	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	qrt	qrt	qrt	qrt		
LZ42	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	qrt	qrt	qrt	m	m
PALMOUT	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	qrt	qrt	qrt	qrt		
PELMID	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	qrt	qrt	qrt	qrt		
PLN2OUT	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	qrt	qrt	qrt	qrt		
POLE3S	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	qrt	qrt	qrt	qrt		
RITAEAST	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	qrt	qrt	qrt	qrt		
RITAWEST	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	qrt	qrt	qrt	qrt		
TREEOUT	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	qrt	qrt	qrt	qrt		

m = monthly; qtr = quarterly; all stations are Type 2 mandate; the following parameters were proposed for removal: CARO, CHLB, CHLC, Mg, and NA

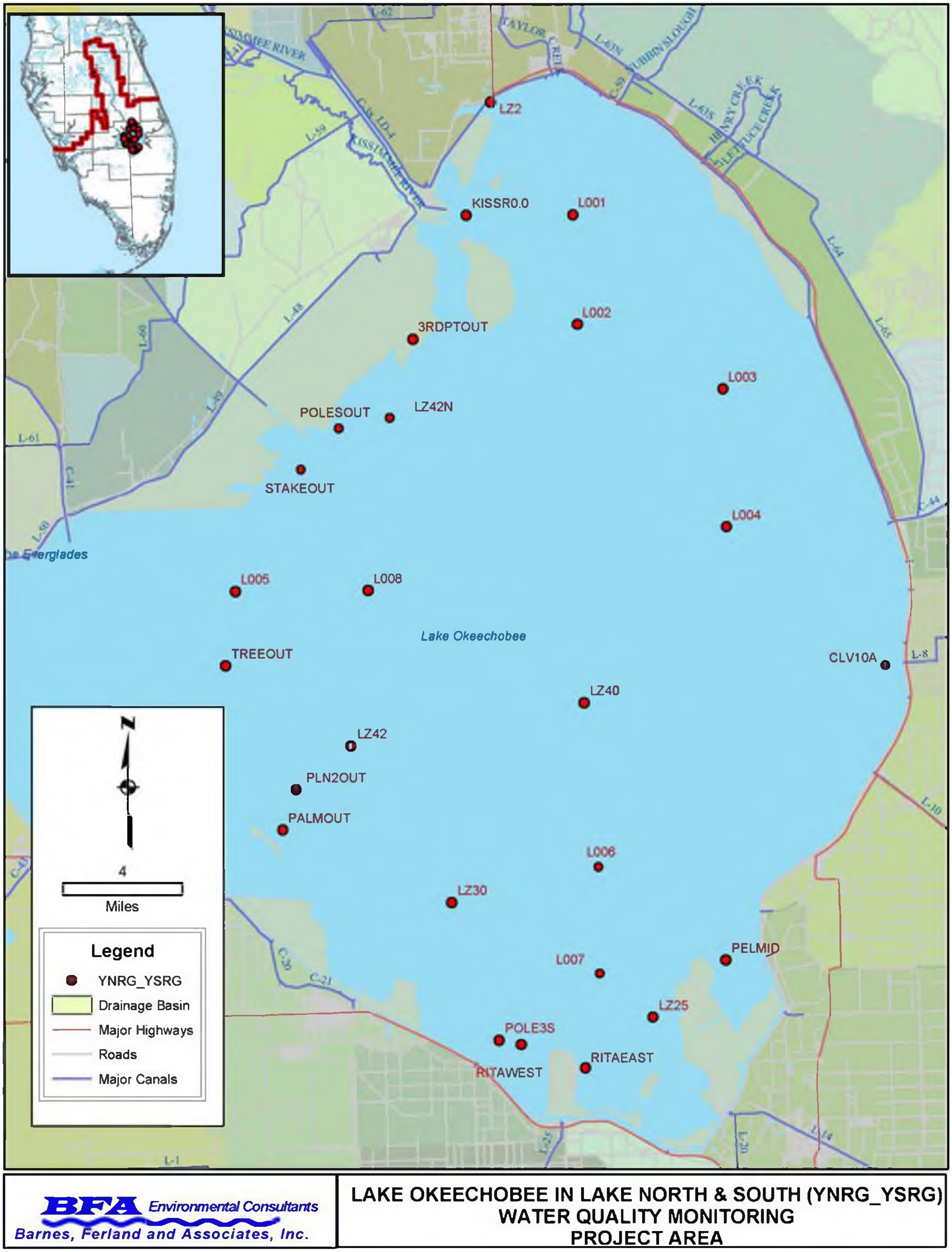

Figure 1. Project Y Sampling Locations

Current and Future Data Uses

Water quality data from Project Y are used to assess the impact of operating permit management implementations, verifying water quality models, examining differences in water quality between the limnetic and littoral zones; monitoring possible algal blooms in the limnetic and littoral zones; defining conditions that produce algal blooms; providing water quality data in support of nutrient dynamics studies; monitoring for change in water quality following basin management strategies; establishing nutrient budgets for Lake Okeechobee; and complying with Lake Okeechobee Total Maximum Daily Loads. The data are incorporated into the South Florida Environmental Report, various Bioassessment projects in the lake and are used extensively in the Lake Okeechobee Environment Model. In the future, data will be used in CERP, particularly the RECOVER Monitoring and Assessment Plan.

Statistical Analyses Conducted Using These Data

Several statistical analyses have been performed on the data and include:

1) Seasonal Kendall's Tau: Determine time trends in data (James et al. 1995b)
2) Correlation: determine relationships among water quality parameters (James et al. 1995b)
3) Logistic regression: determine water quality parameters that increase the probability of an algal bloom (James and Havens 1996)
4) Regression analysis: determine if chlorophyll *a* (algae) can be predicted from phosphorus concentration, determine the relationships between the offshore and nearshore water quality (Havens and James 1997)
5) Principal Component analysis: determine grouping of water quality data in relation to changes over time (James et al. 1995b)
6) Mixed ANOVA: determine the differences of water quality at high and low water levels between the offshore and nearshore regions (James and Havens 2005)
7) TTEST, root mean square error, correlation, regression, local model efficiency: determine the goodness of fit of the Lake Okeechobee Water Quality Model (LOWQM) to the observed data zones (James et al. 2005; James et al. 1997; James and Bierman 1995; Bierman and James 1995)
8) TTEST: determine the impact of a 1999 hurricane (Irene) on the water quality of Lake Okeechobee.(Havens et al. 2001)
9) Volume x concentration calculations to determine mass of nutrient in the lake for development of budgets and to determine the amount of nutrient retained per year in the lake.(James et al. 1995a, Havens and James 1997, Havens and James 2005)

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Statistical Optimizations

Because many of the current and future uses for Y data involve the ability to detect a trend and then evaluate changes from the trend, the principal statistical optimization for this project focused on the minimum, true annual percent change that would be consistently detected by the statistical test for evaluating trends. These analyses were conducted for temporal trends and are summarized below. Preliminary spatial optimizations were also conducted; however, power analyses to evaluate the annual percent change that would be detected by tests evaluating trends under alternative spatial scenarios also need to be evaluated.

Spatial Optimizations. Spearman rank correlations were used to assess spatial redundancy and identify stations that co-varied over time suggesting the potential for sampling redundancies in the monitoring program. For Project Y, the Spearman rank correlations were conducted for each of the geographic domains (Near Shore North, Near Shore South and Pelagic) and only for the five optimization parameters (CHLA2, TKN, NOX, TPO4 and TSS; DBHydro codes: 112, 21, 18, 25, 16, respectively). It is suggested that Chloride be evaluated as well because this may indicate whether the water masses are similar or different. No evaluations were made on the other parameters collected during project Y and how these may or may not be correlated between sampling stations.

Results and Recommendations

Near Shore North: All of the sampling stations located within the northern, near shore region of the lake are significantly correlated for all parameters (Table 3). Several patterns also appear to be developing. For the parameters considered, stations POLESOUT and STAKEOUT often exhibit strong relationships (coefficients ranging from 0.68 – 0.86) compared to other station combinations. Station LZ42N also exhibits fairly strong correlations with these two stations. Station 3RDPTOUT has moderate to strong correlations with all three stations above, as well as LZ2 and LZ2 exhibits moderate correlations with KISSR0.0 for several parameters.

Based on these results, further spatial analysis is suggested to evaluate whether some stations in the northern near shore region could be removed or re-located. Prior to moving or relocating any stations, however, the other parameters collected for Project Y should be evaluated to see if these same patterns of correlated stations exist. Additionally, any changes in station locations or numbers should be subjected to power analysis to determine spatial alterations would have on the ability to detect trends.

Near Shore South: Except for a few station combinations for the CHLA2 parameter, all other stations exhibited significant correlations with respect to the parameters examined (Table 4). Additionally, there are several stations that exhibit strong correlation (correlation coefficients > 0.80) for all parameters. These include PALMOUT and PLN2OUT, PALMOUT and TREEOUT and PLN2OUT and TREEOUT. Other stations to evaluate more closely include RITAEAST and RITAWEST. These two stations have moderately strong or high correlations for several parameters. Other stations that show moderately strong correlations for a few parameters include combinations of POLES3S with PALMOUT, PELMID, PLN2OUT, RITAEAST and RITAWEST.

Based on these results, the District may want to evaluate whether some of these stations in the southern near shore region could be removed or re-located. Like the northern near shore region, station by station correlations evaluating whether the same patterns emerge when considering the other parameters should be conducted. Likewise, conducting spatial power analyses to evaluate whether changes in the trends of parameters could be detected at sufficient power if some of these stations were removed would be beneficial.

Pelagic Zone: Except for several station combinations for the CHLA2 parameter and one station combination for TKN, all other stations exhibited significant correlations with each other with respect to the parameters evaluated (Table 5). Although no patterns as apparent as those observed in the northern and southern near shore regions emerge, there are several stations that have moderate to strong correlations for several of the parameters evaluated. Pelagic stations such as L003 and L004 often have correlation coefficients exceeding 0.8. L006 and L007 also exhibit moderate to high correlations as do LZ40 and L008. Those stations that do show tighter correlations may do so because they are geographically more similar. For example L006 and L007 are both situated more towards the southeast portion of the lake compared to any other stations. Likewise, L004 and LZ40 are located in the more central open water areas of the lake.

Due to the large size of the lake and the relative small numbers of samples representing this vast region, it is not recommended to remove any of the pelagic stations without first conducting follow-on statistical analyses. Similar to the recommendations above for the northern and southern near shore regions, using a series of power analyses or additional spatial analyses (i.e., kriging) to evaluate whether the stations that are present can adequately address the variation in the system (and the ability to detect changes in parameter trends) would be beneficial. In lieu of removing sites, the District may want to consider re-locating some of the stations that do show stronger correlations for all parameters.

Table 3. Spearman Rank Correlation Results for Stations within the Northern Near Shore Region of the Lake.

CHLA2		3RDPTOUT	KBAROUT	KISSR0_0	LZ2	LZ42N	POLESOUT	STAKEOUT
	3RDPTOUT	1	0.34*	0.43**	0.52**	0.67**	0.74**	0.66**
	KBAROUT	0.34*	1	0.46**	0.59**	0.29*	0.39*	0.37*
	KISSR0_0	0.43**	0.46**	1	0.61**	0.29*	0.45**	0.38*
	LZ2	0.52**	0.59**	0.61**	1	0.39**	0.52**	0.37*
	LZ42N	0.67**	0.29*	0.29*	0.39**	1	0.56**	0.55**
	POLESOUT	0.74**	0.39*	0.45**	0.52**	0.56**	1	0.68**
	STAKEOUT	0.66**	0.37*	0.38*	0.37*	0.55**	0.68**	1
TKN		3RDPTOUT	KBAROUT	KISSR0_0	LZ2	LZ42N	POLESOUT	STAKEOUT
	3RDPTOUT	1	0.46**	0.49**	0.58**	0.70**	0.77**	0.74**
	KBAROUT	0.46**	1	0.52**	0.59**	0.32*	0.43**	0.44**
	KISSR0_0	0.49**	0.52**	1	0.68**	0.39**	0.47**	0.50**
	LZ2	0.58**	0.59**	0.68**	1	0.42**	0.48**	0.51**
	LZ42N	0.70**	0.32*	0.39**	0.42**	1	0.73**	0.67**
	POLESOUT	0.77**	0.43**	0.47**	0.48**	0.73**	1	0.78**
	STAKEOUT	0.74**	0.44**	0.50**	0.51**	0.67**	0.78**	1
NOX		3RDPTOUT	KBAROUT	KISSR0_0	LZ2	LZ42N	POLESOUT	STAKEOUT
	3RDPTOUT	1	0.49**	0.54**	0.70**	0.76**	0.67**	0.62**
	KBAROUT	0.49**	1	0.63**	0.48**	0.52**	0.51**	0.47**
	KISSR0_0	0.54**	0.63**	1	0.70**	0.55**	0.53**	0.54**
	LZ2	0.70**	0.48**	0.70**	1	0.63**	0.65**	0.60**
	LZ42N	0.76**	0.52**	0.55**	0.63**	1	0.76**	0.72**
	POLESOUT	0.67**	0.51**	0.53**	0.65**	0.76**	1	0.68**
	STAKEOUT	0.62**	0.47**	0.54**	0.60**	0.72**	0.68**	1
TPO4		3RDPTOUT	KBAROUT	KISSR0_0	LZ2	LZ42N	POLESOUT	STAKEOUT
	3RDPTOUT	1	0.43**	0.42**	0.69**	0.89**	0.80**	0.77**
	KBAROUT	0.43**	1	0.68**	0.50**	0.33*	0.38*	0.57**
	KISSR0_0	0.42**	0.68**	1	0.51**	0.35**	0.51**	0.61**
	LZ2	0.69**	0.50**	0.51**	1	0.60**	0.62**	0.62**
	LZ42N	0.89**	0.33*	0.35**	0.60**	1	0.75**	0.69**
	POLESOUT	0.80**	0.38*	0.51**	0.62**	0.75**	1	0.77**
	STAKEOUT	0.77**	0.57**	0.61**	0.62**	0.69**	0.77**	1
TSS		3RDPTOUT	KBAROUT	KISSR0_0	LZ2	LZ42N	POLESOUT	STAKEOUT
	3RDPTOUT	1	0.63**	0.66**	0.71**	0.78**	0.78**	0.72**
	KBAROUT	0.63**	1	0.64**	0.74**	0.52**	0.67**	0.63**
	KISSR0_0	0.66**	0.64**	1	0.70**	0.59**	0.73**	0.78**

TSS		3RDPTOUT	KBAROUT	KISSR0_0	LZ2	LZ42N	POLESOUT	STAKEOUT
	LZ2	0.71**	0.74**	0.70**	1	0.66**	0.66**	0.60**
	LZ42N	0.78**	0.52**	0.59**	0.66**	1	0.72**	0.72**
	POLESOUT	0.78**	0.67**	0.73**	0.66**	0.72**	1	0.86**
	STAKEOUT	0.72**	0.63**	0.78**	0.60**	0.72**	0.86**	1

* Prob > |r| Under HC: RHO = 0 < 0.05
**Prob > |r| Under HC: RHO = 0 < 0.0001

Table 4. Spearman Rank Correlation Results for Stations within the Southern Near Shore Region of the Lake.

CHLA2		LZ25	PALMOUT	PELMID	PLN2OUT	RITAEAST	RITAWEST	TREEOUT	POLE3S
	LZ25	1	0.23*	0.58**	0.17	0.44**	0.51**	0.15	0.58**
	PALMOUT	0.23*	1	0.06	0.84**	0.37*	0.42**	0.79**	0.62**
	PELMID	0.58**	0.06	1	0.25*	0.26*	0.37**	0.13	0.43**
	PLN2OUT	0.17	0.84**	0.25*	1	0.31*	0.36*	0.81**	0.58**
	RITAEAST	0.44**	0.37*	0.26*	0.31*	1	0.73**	0.16	0.46**
	RITAWEST	0.51**	0.42**	0.37**	0.36*	0.73**	1	0.33*	0.68**
	TREEOUT	0.15	0.79**	0.13	0.81**	0.16	0.33*	1	0.54**
	POLE3S	0.58**	0.62**	0.43**	0.58**	0.46**	0.68**	0.54**	1
TKN		LZ25	PALMOUT	PELMID	PLN2OUT	RITAEAST	RITAWEST	TREEOUT	POLE3S
	LZ25	1	0.61**	0.60**	0.48**	0.50**	0.60**	0.52**	0.63**
	PALMOUT	0.61**	1	0.47**	0.83**	0.52**	0.57**	0.71**	0.75**
	PELMID	0.60**	0.47**	1	0.36*	0.37**	0.41**	0.34*	0.46**
	PLN2OUT	0.48**	0.83**	0.36*	1	0.39*	0.49**	0.73**	0.57**
	RITAEAST	0.50**	0.52**	0.37**	0.39*	1	0.68**	0.48**	0.53**
	RITAWEST	0.60**	0.57**	0.41**	0.49**	0.68**	1	0.57**	0.59**
	TREEOUT	0.52**	0.71**	0.34*	0.73**	0.48**	0.57**	1	0.58**
	POLE3S	0.63**	0.75**	0.46**	0.57**	0.53**	0.59**	0.58**	1
NOX		LZ25	PALMOUT	PELMID	PLN2OUT	RITAEAST	RITAWEST	TREEOUT	POLE3S
	LZ25	1	0.57**	0.72**	0.45**	0.56**	0.56**	0.52**	0.73**
	PALMOUT	0.57**	1	0.57**	0.76**	0.49**	0.51**	0.77**	0.72**
	PELMID	0.72**	0.57**	1	0.53**	0.45**	0.56**	0.56**	0.73**
	PLN2OUT	0.45**	0.76**	0.53**	1	0.46**	0.47**	0.75**	0.63**
	RITAEAST	0.56**	0.49**	0.45**	0.46**	1	0.67**	0.45**	0.67**
	RITAWEST	0.56**	0.51**	0.56**	0.47**	0.67**	1	0.45**	0.66**
	TREEOUT	0.52**	0.77**	0.56**	0.75**	0.45**	0.45**	1	0.69**
	POLE3S	0.73**	0.72**	0.73**	0.63**	0.67**	0.66**	0.69**	1
TPO4		LZ25	PALMOUT	PELMID	PLN2OUT	RITAEAST	RITAWEST	TREEOUT	POLE3S
	LZ25	1	0.70**	0.81**	0.66**	0.71**	0.72**	0.67**	0.78**
	PALMOUT	0.70**	1	0.56**	0.95**	0.73**	0.76**	0.91**	0.83**
	PELMID	0.81**	0.56**	1	0.56**	0.59**	0.64**	0.55**	0.70**
	PLN2OUT	0.66**	0.95**	0.56**	1	0.72**	0.74**	0.94**	0.84**
	RITAEAST	0.71**	0.73**	0.59**	0.72**	1	0.90**	0.73**	0.76**
	RITAWEST	0.72**	0.76**	0.64**	0.74**	0.90**	1	0.78**	0.84**
	TREEOUT	0.67**	0.91**	0.55**	0.94**	0.73**	0.78**	1	0.82**
	POLE3S	0.78**	0.83**	0.70**	0.84**	0.76**	0.84**	0.82**	1
TSS		LZ25	PALMOUT	PELMID	PLN2OUT	RITAEAST	RITAWEST	TREEOUT	POLE3S
	LZ25	1	0.49**	0.75**	0.35*	0.70**	0.68**	0.36*	0.69**
	PALMOUT	0.49**	1	0.41**	0.91**	0.52**	0.53**	0.90**	0.70**

TSS		LZ25	PALMOUT	PELMID	PLN2OUT	RITAEAST	RITAWEST	TREEOUT	POLE3S
	PELMID	0.75**	0.41**	1	0.36*	0.53**	0.49**	0.38*	0.62**
	PLN2OUT	0.35*	0.91**	0.36*	1	0.43**	0.42**	0.93**	0.68**
	RITAEAST	0.70**	0.52**	0.53**	0.43**	1	0.84**	0.44**	0.70**
	RITAWEST	0.68**	0.53**	0.49**	0.42**	0.84**	1	0.43**	0.72**
	TREEOUT	0.36*	0.90**	0.38*	0.93**	0.44**	0.43**	1	0.65**
	POLE3S	0.69**	0.70**	0.62**	0.68**	0.70**	0.72**	0.65**	1

* Prob > |r| Under HC: RHO = 0 < 0.05
**Prob > |r| Under HC: RHO = 0 < 0.0001

Table 5. Spearman Rank Correlation Results for Stations within the Pelagic Zone of the Lake.

CHLA2		L001	L002	L003	L004	L005	L006	L007	L008	LZ30	LZ42	LZ40	CLV10A
	L001	1	0.47**	0.52**	0.37**	0.28*	0.31*	0.24*	0.30*	0.26*	0.20*	0.45**	0.36*
	L002	0.47**	1	0.44**	0.28*	0.43**	0.36**	0.04	0.31*	0.10	0.04	0.38*	0.52**
	L003	0.52**	0.44**	1	0.64**	0.21*	0.26*	0.19*	0.41**	0.20*	0.17*	0.47**	0.60**
	L004	0.37**	0.28*	0.64**	1	0.12	0.35**	0.21*	0.34**	0.21*	0.16	0.49**	0.46**
	L005	0.28*	0.43**	0.21*	0.12	1	0.15	0.08	0.36**	0.29*	0.30*	0.16	0.21
	L006	0.31*	0.36**	0.26*	0.35**	0.15	1	0.31*	0.20*	0.37**	0.27*	0.30*	0.40*
	L007	0.24*	0.04	0.19*	0.21*	0.08	0.31*	1	0.13	0.61**	0.42**	0.16	0.34*
	L008	0.30*	0.31*	0.41**	0.34**	0.36**	0.20*	0.13	1	0.25*	0.35**	0.47**	0.29*
	LZ30	0.26*	0.10	0.20*	0.21*	0.29*	0.37**	0.61**	0.25*	1	0.68**	0.30*	0.17
	LZ42	0.20*	0.04	0.17*	0.16	0.30*	0.27*	0.42**	0.35**	0.68**	1	0.21*	0.19
	LZ40	0.45**	0.38*	0.47**	0.49**	0.16	0.30*	0.16	0.47**	0.30*	0.21*	1	0.27*
	CLV10A	0.36*	0.52**	0.60**	0.46**	0.21	0.40*	0.34*	0.29*	0.17	0.19	0.27*	1
TKN		L001	L002	L003	L004	L005	L006	L007	L008	LZ30	LZ42	LZ40	CLV10A
	L001	1	0.73**	0.60**	0.56**	0.35**	0.33**	0.39**	0.48**	0.21*	0.21*	0.39*	0.30*
	L002	0.73**	1	0.51**	0.50**	0.41**	0.40**	0.41**	0.47**	0.32**	0.27**	0.40**	0.23*
	L003	0.60**	0.51**	1	0.77**	0.22*	0.53**	0.56**	0.59**	0.51**	0.43**	0.66**	0.52**
	L004	0.56**	0.50**	0.77**	1	0.29*	0.54**	0.52**	0.71**	0.47**	0.42**	0.67**	0.49**
	L005	0.35**	0.41**	0.22*	0.29*	1	0.23*	0.25*	0.33**	0.28*	0.33**	0.26*	0.18
	L006	0.33**	0.40**	0.53**	0.54**	0.23*	1	0.63**	0.58**	0.69**	0.70**	0.64**	0.46**
	L007	0.39**	0.41**	0.56**	0.52**	0.25*	0.63**	1	0.51**	0.64**	0.64**	0.52**	0.48**
	L008	0.48**	0.47**	0.59**	0.71**	0.33**	0.58**	0.51**	1	0.59**	0.54**	0.71**	0.39*
	LZ30	0.21*	0.32*	0.51**	0.47**	0.28*	0.69**	0.64**	0.59**	1	0.70**	0.55**	0.53**
	LZ42	0.21*	0.27*	0.43**	0.42**	0.33**	0.70**	0.64**	0.54**	0.70**	1	0.53**	0.39*
	LZ40	0.39*	0.40**	0.66**	0.67**	0.26*	0.64**	0.52**	0.71**	0.55**	0.53**	1	0.58**
	CLV10A	0.30*	0.23*	0.52**	0.49**	0.18	0.46**	0.48**	0.39*	0.53**	0.39*	0.58**	1
NOX		L001	L002	L003	L004	L005	L006	L007	L008	LZ30	LZ42	LZ40	CLV10A
	L001	1	0.78**	0.82**	0.76**	0.53**	0.71**	0.54**	0.65**	0.58**	0.59**	0.77**	0.82**
	L002	0.78**	1	0.78**	0.75**	0.48**	0.73**	0.51**	0.60**	0.59**	0.57**	0.78**	0.76**
	L003	0.82**	0.78**	1	0.89**	0.51**	0.79**	0.56**	0.73**	0.62**	0.61**	0.82**	0.82**
	L004	0.76**	0.75**	0.89**	1	0.55**	0.79**	0.59**	0.76**	0.61**	0.66**	0.86**	0.79**
	L005	0.53**	0.48**	0.51**	0.55**	1	0.58**	0.58**	0.65**	0.59**	0.62**	0.55**	0.64**
	L006	0.71**	0.73**	0.79**	0.79**	0.58**	1	0.75**	0.77**	0.78**	0.76**	0.89**	0.80**
	L007	0.54**	0.51**	0.56**	0.59**	0.58**	0.75**	1	0.66**	0.78**	0.71**	0.62**	0.73**
	L008	0.65**	0.60**	0.73**	0.76**	0.65**	0.77**	0.66**	1	0.75**	0.76**	0.83**	0.67**
	LZ30	0.58**	0.59**	0.62**	0.61**	0.59**	0.78**	0.78**	0.75**	1	0.81**	0.71**	0.71**
	LZ42	0.59**	0.57**	0.61**	0.66**	0.62**	0.76**	0.71**	0.76**	0.81**	1	0.74**	0.68**
	LZ40	0.77**	0.78**	0.82**	0.86**	0.55**	0.89**	0.62**	0.83**	0.71**	0.74**	1	0.73**
	CLV10A	0.82**	0.76**	0.82**	0.79**	0.64**	0.80**	0.73**	0.67**	0.71**	0.68**	0.73**	1

TPO4		L001	L002	L003	L004	L005	L006	L007	L008	LZ30	LZ42	LZ40	CLV10A
	L001	1	0.78**	0.80**	0.71**	0.60**	0.56**	0.55**	0.73**	0.61**	0.59**	0.65**	0.45**
	L002	0.78**	1	0.70**	0.61**	0.63**	0.62**	0.56**	0.65**	0.62**	0.62**	0.55**	0.36*
	L003	0.80**	0.70**	1	0.86**	0.58**	0.63**	0.54**	0.80**	0.63**	0.66**	0.79**	0.64**
	L004	0.71**	0.61**	0.86**	1	0.57**	0.71**	0.58**	0.81**	0.62**	0.69**	0.82**	0.75**
	L005	0.60**	0.63**	0.58**	0.57**	1	0.68**	0.72**	0.71**	0.78**	0.80**	0.48**	0.34*
	L006	0.56**	0.62**	0.63**	0.71**	0.68**	1	0.86**	0.71**	0.84**	0.81**	0.70**	0.63**
	L007	0.55**	0.56**	0.54**	0.58**	0.72**	0.86**	1	0.64**	0.82**	0.73**	0.57**	0.52**
	L008	0.73**	0.65**	0.80**	0.81**	0.71**	0.71**	0.64**	1	0.72**	0.77**	0.86**	0.61**
	LZ30	0.61**	0.62**	0.63**	0.62**	0.78**	0.84**	0.82**	0.72**	1	0.86**	0.61**	0.54**
	LZ42	0.59**	0.62**	0.66**	0.69**	0.80**	0.81**	0.73**	0.77**	0.86**	1	0.65**	0.60**
	LZ40	0.65**	0.55**	0.79**	0.82**	0.48**	0.70**	0.57**	0.86**	0.61**	0.65**	1	0.69**
	CLV10A	0.45**	0.36*	0.64**	0.75**	0.34*	0.63**	0.52**	0.61**	0.54**	0.60**	0.69**	1
TSS		L001	L002	L003	L004	L005	L006	L007	L008	LZ30	LZ42	LZ40	CLV10A
	L001	1	0.76**	0.73**	0.68**	0.38**	0.41**	0.34**	0.59**	0.31*	0.28*	0.62**	0.46**
	L002	0.76**	1	0.52**	0.50**	0.43**	0.40**	0.29*	0.45**	0.23*	0.18*	0.52**	0.24*
	L003	0.73**	0.52**	1	0.87**	0.45**	0.49**	0.44**	0.72**	0.43**	0.43**	0.75**	0.61**
	L004	0.68**	0.50**	0.87**	1	0.48**	0.62**	0.56**	0.80**	0.56**	0.56**	0.87**	0.69**
	L005	0.38**	0.43**	0.45**	0.48**	1	0.49**	0.46**	0.59**	0.52**	0.56**	0.50**	0.20
	L006	0.41**	0.40**	0.49**	0.62**	0.49**	1	0.82**	0.68**	0.79**	0.72**	0.68**	0.59**
	L007	0.34**	0.29*	0.44**	0.56**	0.46**	0.82**	1	0.63**	0.83**	0.73**	0.62**	0.59**
	L008	0.59**	0.45**	0.72**	0.80**	0.59**	0.68**	0.63**	1	0.64**	0.66**	0.90**	0.58**
	LZ30	0.31*	0.23*	0.43**	0.56**	0.52**	0.79**	0.83**	0.64**	1	0.88**	0.60**	0.52**
	LZ42	0.28*	0.18*	0.43**	0.56**	0.56**	0.72**	0.73**	0.66**	0.88**	1	0.58**	0.50**
	LZ40	0.62**	0.52**	0.75**	0.87**	0.50**	0.68**	0.62**	0.90**	0.60**	0.58**	1	0.59**
	CLV10A	0.46**	0.24*	0.61**	0.69**	0.20	0.59**	0.59**	0.58**	0.52**	0.50**	0.59**	1

* Prob > |r| Under HC: RHO = 0 < 0.05
**Prob > |r| Under HC: RHO = 0 < 0.0001

Temporal Optimizations Because many of the data uses for this monitoring program are aimed at detecting trends in various water quality parameters (CHLA2, TKN, NOX, TPO4 and TSS; DBHydro codes: 112, 21, 18, 25, 16, respectively), optimizations were conducted to estimate the power to detect a trend for given water quality parameters. Statistical power analyses were used to determine the smallest water quality trends that will be detectable with high probability based on water quality data collected according to current monitoring plans. The power analyses were performed by carrying out the following power analysis steps for each station-parameter and/or geographic region-parameter combination.

- Fit a statistical model to the water quality parameter data in order to have a basis for generating simulated data to support a Monte Carlo based power analysis procedure

- Generate multiple replicate simulated water quality time series data sets; for all power analyses reported here, each time series generated was for a 5-year monitoring period

- Perform a Seasonal Kendall's Tau trend analysis procedure (Reckhow et al. 1993) for each simulated time series data set; in particular, obtain a point estimate of the slope vs. time for the log-transformed water quality parameter values

- Estimate the *annual proportion change* (APC) in water quality parameter values that is detectable with 80% power using a simple two-sided test based on the Seasonal Kendall's Tau slope estimate performed at a 5% significance level. A target slope equivalent to a 20% APC was used throughout this effort.

Parameter values were natural log-transformed for statistical modeling because the log-transformed data was more nearly normally distributed than were the untransformed data. The fitted statistical model contains the following components:

- Fixed seasonal effects that repeat themselves in an annual cycle
- A long-term linear trend in the log-transformed parameter concentrations; this corresponds to a fixed percentage increase or decrease in the water quality parameter each year
- A random error term representing temporal variability in true water quality parameter values; these error terms are allowed to be correlated from one time point to the next in order to capture any serial autocorrelation that is present in the monitoring data
- A random error term representing sampling and chemical analysis variability; these error terms are assumed to be stochastically independent from one time point to the next

The fitted statistical model is used to perform a Monte Carlo simulation analysis in which multiple time series data sets are simulated and used to determine the anticipated statistical properties of trend detection procedures that will be used by the District. All statistical trend analyses performed on the simulated data were based on the Seasonal Kendall's Tau trend analysis procedure (Reckhow et al. 1993) preferred by the District.

In the course of performing the power analyses for the District, it was determined that the basic Seasonal Kendall's Tau trend detection procedures do not necessarily control the true significance level of the hypothesis test for trend when there is serial autocorrelation exhibited in the data. This was found to be true even for procedures that attempt to correct for serial autocorrelation. For this reason, all power analysis results reported here are for a simple hypothesis test procedure based on the median slope estimator that accompanies the Seasonal Kendall's Tau test procedure. The median slope estimator is assumed to follow a normal distribution and power results are obtained by performing a simple z-test with this estimator.

Currently, the Y stations are sampled monthly. For this optimization, the statistical approach evaluated the power to detect a trend in a water quality parameter at each individual station at the current sampling frequency (i.e., monthly – 12 samples/year) as well as three alternative frequencies: quarterly (4 samples/year), bi-weekly (24 samples/ year) and weekly (52 samples/year). Table 6 presents the results of the temporal optimizations of the individual Y sampling stations for the five optimization parameters. Attachment 1 presents these results graphically.

The statistical approach was also used to evaluate the power to detect trends in the various water quality parameters for each of the geographic domains. Data for the individual stations within each of the three geographic domains were averaged and the statistical methods applied. Again, the temporal alternatives consisted of increased sampling frequency (bi-weekly and weekly) and decreased sampling frequency (quarterly).

For each alternative, an estimate was obtained of the minimum Annual Percent Change (APC) in the parameter concentration that is detectable with 80% power using the median slope estimator z-test procedure performed at a 2-sided significance level of 0.05. Rust (2005) describes the power analysis procedure and underlying statistical model employed here in detail. Rust (2005) also documents the SAS program used to carry out the power analyses for which results are reported here.

Results and Recommendations

Individuals Stations: In most instances, the power analyses suggest that with decreased sampling frequency (i.e., quarterly sampling) detection of annual percent changes of specific water quality parameters would be above a target of 20% for many stations and parameters with the exception of TKN (Table 6). Detection of a 20% annual change or less is observed for each station when sampling is quarterly. The other frequency alternatives for the

TKN parameter were well below the 20% target ranging from 6-12% for monthly sampling, 5-11% for bi-weekly sampling and 3-10% for weekly sampling.

For TPO4, the 20% target was attainable at 8 of the sampling stations (range from 15-20%). The current sampling frequency (i.e., monthly) supports consistent detection of annual percent changes in the range of 10% - 18% at 15 stations. Increasing the sampling to bi-weekly or weekly, 17 stations show annual percent changes in the range of 6% - 20%.

For the other parameters evaluated (CHLA2, TSS, and NOX), the target annual percent change of 20% was not attainable with quarterly sampling and current sampling (monthly) meets or is below the target for CHLA2 at 2 locations. Bi-weekly sampling increases the number of stations that meet or are below the minimum annual percent change that would be consistently detectable for CHLA2 (4 stations, range of 12-18%) and TSS (5 stations, range 14-20%). Likewise, weekly sampling also increases the number of stations that meet the target for CHLA2 (6 stations, range 8-20%) and TSS (8 stations, range 9-19%). None of the frequency alternatives were able to meet the 20% target for NOX.

Geographic Domain: Using the geographic domains to determine if any of the sampling frequency alternatives would enhance the ability to consistently detect the 20% annual change in a given parameter did result in detectable annual percent changes that were below or within the values observed for the individual stations within a given geographic domain (Table 7). Similar to what was observed at the individual stations, all frequency alternatives support detection of annual percent changes at or below the 20% target for each of the geographic domains for TKN.

All frequency alternatives also support detection of the annual percent change at or below the target level for TPO4 in the Pelagic zone. The current sampling (monthly), as well as increased sampling frequency, is sufficient to meet the 20% target for the southern nearshore zone for TPO4. In the northern nearshore zone, the frequency alternatives just miss the target for the current sampling frequency as well as the increased sampling frequency (annual percent change = 21% for each alternative).

For CHLA2 and NOX, the current and alternative frequency designs do not attain the 20% target in any of the geographic domains; however, the annual percent change is 21% for monthly, bi-weekly and weekly sampling for CHLA2 in the pelagic zone, just missing the 20% target. For TSS, only bi-weekly and weekly sampling would allow for consistent detection of a 20% or less annual change in the pelagic zone. Monthly sampling is close to this goal at 21%.

Based on the results of the temporal optimizations, it is not recommended that the District reduce their sampling frequency for Project Y. If data are to be evaluated based on geographic domains, the current monthly sampling for some parameters in some geographic domains does meet the target or is very close. When the target is not met (i.e., large annual percent change), the bi-weekly or weekly sampling frequencies don't necessarily make it substantially better. Additionally, given the sampling logistics of the program, increased sampling frequency may simply not be feasible. Further optimization efforts must take into account modifications to the spatial design along with the various temporal alternatives to determine if spatial and temporal changes together could enhance the ability to consistently detect an annual percent change of 20% or lower.

Table 6. Minimum true annual percent change that would be consistently detected by a statistical test for trend at individual stations for four frequency alternatives.

Parameter	Station	Quarterly	Monthly	Bi-weekly	Weekly
CHLA2	3RDPTOUT	67%	61%	60%	58%
	CLV10A	31%	17%	12%	8%
	KBAROUT	51%	42%	39%	38%
	KISSR0.0	79%	71%	69%	67%
	L001	37%	26%	23%	21%
	L002	40%	27%	24%	21%
	L003	42%	32%	29%	27%
	L005	38%	23%	21%	20%
	L006	37%	26%	22%	20%
	LZ2	50%	41%	39%	37%
	LZ25	44%	33%	30%	29%
	LZ30	37%	25%	22%	21%
	LZ40	35%	22%	18%	16%
	LZ42	41%	28%	25%	23%
	LZ42N	36%	21%	18%	15%
	PALMOUT	62%	47%	44%	41%
	PELMID	42%	27%	23%	21%
	PLN2OUT	53%	43%	41%	39%
	POLE3S	60%	48%	44%	42%
	POLESOUT	43%	35%	33%	32%
	RITAEAST	49%	37%	35%	33%
	RITAWEST	48%	36%	32%	31%
	STAKEOUT	31%	20%	16%	14%
	TREEOUT	41%	28%	25%	23%
NOX	3RDPTOUT	153%	126%	118%	117%
	CLV10A	132%	99%	89%	86%
	KBAROUT	212%	189%	183%	180%
	KISSR0.0	92%	68%	65%	62%
	L001	96%	56%	48%	45%
	L002	119%	85%	76%	74%
	L003	89%	67%	60%	57%
	L004	92%	70%	65%	62%
	L005	119%	80%	73%	67%
	L006	65%	43%	37%	34%
	L007	100%	59%	49%	43%
	L008	111%	76%	64%	59%
	LZ2	98%	71%	67%	66%
	LZ25	125%	77%	65%	60%
	LZ30	98%	60%	51%	47%
	LZ40	89%	65%	58%	53%
	LZ42	100%	50%	33%	21%
	LZ42N	103%	59%	48%	45%
	PALMOUT	272%	255%	252%	242%
	PELMID	214%	160%	147%	139%
	PLN2OUT	237%	209%	204%	199%
	POLE3S	161%	126%	115%	112%
	POLESOUT	126%	96%	89%	87%

Parameter	Station	Quarterly	Monthly	Bi-weekly	Weekly
NOX	RITAEAST	121%	90%	83%	80%
	STAKEOUT	118%	81%	75%	71%
	TREEOUT	186%	159%	154%	151%
TKN	3RDPTOUT	10%	6%	5%	4%
	CLV10A	10%	8%	7%	6%
	KBAROUT	13%	9%	8%	8%
	KISSR0.0	12%	7%	6%	6%
	L001	10%	6%	5%	4%
	L002	11%	6%	5%	3%
	L004	12%	8%	8%	7%
	L005	10%	7%	6%	5%
	L006	13%	9%	8%	7%
	LZ2	10%	6%	5%	4%
	LZ25	13%	8%	6%	5%
	LZ30	12%	8%	7%	6%
	LZ40	12%	7%	6%	6%
	LZ42	14%	9%	8%	7%
	LZ42N	13%	10%	9%	8%
	PALMOUT	11%	8%	7%	7%
	PELMID	13%	9%	7%	6%
	PLN2OUT	14%	11%	10%	10%
	POLE3S	14%	12%	11%	10%
	POLESOUT	10%	6%	4%	3%
	RITAEAST	12%	8%	7%	7%
	RITAWEST	12%	7%	6%	6%
	STAKEOUT	11%	7%	6%	6%
	TREEOUT	16%	12%	10%	9%
TPO4	3RDPTOUT	32%	28%	27%	27%
	CLV10A	17%	10%	8%	6%
	KBAROUT	46%	39%	37%	36%
	KISSR0.0	22%	16%	15%	14%
	L001	19%	13%	12%	11%
	L002	22%	17%	16%	15%
	L003	17%	11%	9%	8%
	L004	15%	11%	10%	9%
	L005	25%	18%	17%	16%
	L006	17%	12%	10%	10%
	L007	18%	13%	12%	11%
	L008	23%	17%	16%	15%
	LZ2	35%	30%	30%	29%
	LZ25	28%	18%	15%	13%
	LZ30	20%	14%	13%	12%
	LZ40	24%	20%	18%	18%
	LZ42	26%	17%	15%	13%
	LZ42N	20%	15%	13%	13%
	PALMOUT	44%	40%	39%	39%
	PELMID	21%	14%	12%	11%
	PLN2OUT	41%	36%	35%	34%

Parameter	Station	Quarterly	Monthly	Bi-weekly	Weekly
	POLE3S	27%	21%	20%	19%
	POLESOUT	31%	26%	25%	24%
	RITAEAST	32%	25%	23%	22%
	RITAWEST	29%	23%	22%	21%
	STAKEOUT	27%	23%	22%	21%
	TREEOUT	32%	25%	24%	23%
TSS	3RDPTOUT	58%	49%	46%	44%
	CLV10A	38%	21%	14%	9%
	KBAROUT	114%	100%	100%	97%
	KISSR0.0	110%	104%	99%	97%
	L001	39%	24%	20%	17%
	L002	37%	25%	21%	19%
	L003	36%	20%	14%	9%
	L004	39%	24%	18%	15%
	L005	44%	31%	28%	26%
	L006	39%	25%	20%	18%
	L007	44%	28%	24%	21%
	L008	35%	23%	21%	19%
	LZ2	72%	64%	62%	62%
	LZ25	51%	35%	31%	28%
	LZ30	41%	26%	22%	19%
	LZ40	49%	39%	37%	35%
	LZ42	50%	32%	27%	24%
	LZ42N	37%	27%	24%	23%
	PALMOUT	55%	43%	40%	39%
	PELMID	49%	30%	25%	21%
	PLN2OUT	62%	48%	44%	42%
	POLE3S	44%	33%	30%	28%
	POLESOUT	65%	57%	56%	54%
	RITAEAST	42%	30%	27%	26%
	RITAWEST	47%	37%	34%	32%
	STAKEOUT	67%	59%	57%	55%
	TREEOUT	77%	66%	64%	60%

Table 7. Minimum true annual percent change that would be consistently detected by a statistical test for trend at the Y geographic domains for four frequency alternatives.

Parameter	Zone	Quarterly	Monthly	Bi-weekly	Weekly
CHLA2	Nearshore - North	37%	31%	30%	29%
	Nearshore - South	33%	27%	26%	25%
	Pelagic	25%	22%	21%	21%
NOX	Nearshore - North	86%	65%	60%	57%
	Nearshore - South	109%	79%	71%	68%
	Pelagic	53%	44%	42%	41%
TKN	Nearshore - North	8%	5%	5%	5%
	Nearshore - South	10%	8%	7%	7%
	Pelagic	8%	6%	5%	5%
TPO4	Nearshore - North	25%	21%	21%	21%
	Nearshore - South	21%	17%	16%	16%
	Pelagic	15%	13%	12%	12%
TSS	Nearshore - North	55%	49%	48%	46%
	Nearshore - South	36%	27%	24%	24%
	Pelagic	28%	21%	19%	18%