Characterization of Sebago Lake Lower Bay Trophic State Since 1976

A Statistical Calibration of Pre-1990 Secchi Transparency, Total Phosphorous and Chlorophyll *a* to Post-1990 Secchi Transparency, Total Phosphorous and Chlorophyll *a*.

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Abstract

Recent Portland Water District (PWD) publications have highlighted a disturbing trend in Sebago Lake water quality. Since 1990, the lake has become less clear and has more Phosphorous and algae. While this trend exists, it is important for PWD to determine how these recent measurements compare to historical measurements.

The water district has been testing Sebago Lake since the early 1900's. Over time, the tests have changed, the sample locations have changed, and these measurements are generally not comparable. For these reasons there are two distinctly different data sets, from 1976 to 1989 and from 1990 to present. Since natural systems often undergo cyclical changes, it is crucial to analyze the longest period of record possible.

Through a series of statistical tests and side by side comparisons, these two different data sets have been linked. Results of the combined data sets show that the Phosphorous, algae and clarity measurements from 1990 to present are not statistically different from those of 1989 to 1976. The overall trend of the combined data sets is neutral.

Introduction

The Portland Water District (PWD) has monitored Sebago Lake for trophic state parameters (total phosphorous, chlorophyll *a* and Secchi transparency) since the mid 1970s. During this period, the sample locations and tools used to analyzing samples have changed. These changes complicate direct comparison of the entire data set together. Such comparisons, though imperfect, are important because a lake will generally exhibit a natural cyclical variation in these parameters in any given year and from one year to the next. Thus, the longer the period of record, the more likely a trend or anomaly will be apparent.

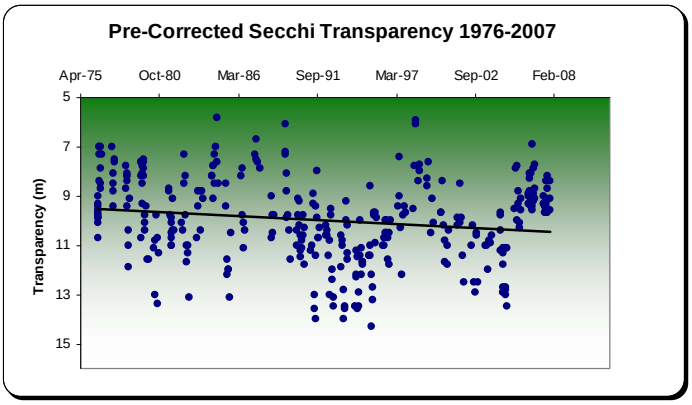
In 2007, the PWD reviewed the historical record of lake monitoring data and concluded that the methodology used to collect pre-1990 monitoring data was different enough from that used after 1990 that direct comparison of these two sets of data was not scientifically appropriate. Charts and statistical analysis were thus revised to exclude pre-1990 data. By eliminating pre-1990 data, the trophic state trends showed a decline with 95% confidence. While this decline since 1990 is real, it can be misleading.

In a lake with cyclical changes over time, the slope of the trend (improving or declining) changes depending on the time period selected for analysis. Therefore it is important to consider the largest data set possible. The larger the data set, the less influence cyclical variation has on the trend outcome and the more valid trend analysis becomes for historical context.

Because of the changes in methodology, direct comparison of pre-and post-1990 data should be done with caution. Before the data can be compared, the data should be adjusted to account for these differences in methodology. This paper describes that calibration and concludes with charts of these water quality parameters for the entire period of PWD monitoring.

Secchi Transparency

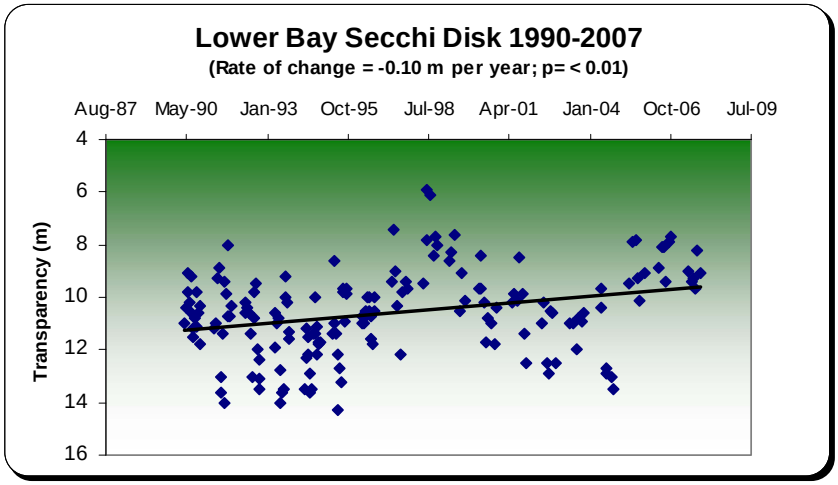
Prior to 2007, the Portland Water District (PWD) had published Secchi transparency measurements from the Lower Bay of Sebago Lake which included data dating back to 1976. See graph below.



However, a 2007 review of field sheets recorded during sample collection revealed that the Lower Bay sample location prior to 1990 was different from the sample location used after 1990. To confound the issue even more, the scope design used to measure Secchi disk had improved after 1996. It is reasonable to expect that had those measurements been taken at the post-1990 location and using the post-1996 viewing scope, the results would have been different. This was discussed in the 2007 lake report, which stated:

> *"…this improving transparency trend in Lower Bay is not considered scientifically acceptable due to the lack of a standard sampling station from 1976 to the early 1990's. The reason for including this data in this report is to address the recent discovery of the sample station discrepancy. Before the next statistical analysis and report is written, the Lower Bay sampling station should be standardized"* (Whalen 2007).

In the 2008 PWD report titled *Sebago Lake Trophic State Trends: presenting data from 1990-2007* this discrepancy was addressed by removing the pre-1990 data and evaluating just the data collected at the same sample location. (Whalen 2008). Removing the pre-1990 data resulted in a declining trend with a probability (p) value less than 0.01. A low p-value means that there is a low probability that the data analysis is due to random chance (example; if p = 0.05 then there is a 5% chance the trend is due to random chance).

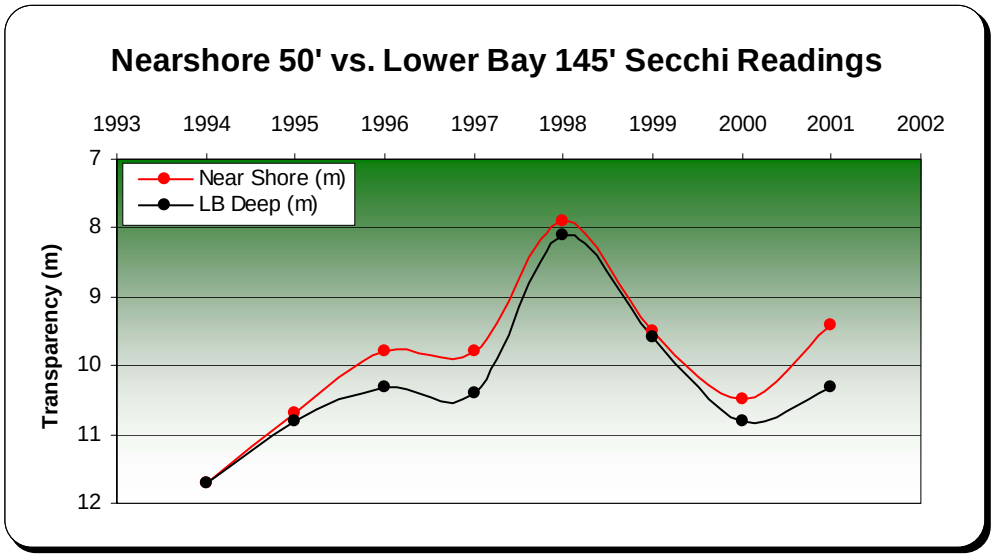


In order to use pre-1990 data to assess the degree to which this post-1990 trend represents a departure from historical transparency, the pre-1990 data must be adjusted to account for differences in collection.

Secchi Sample Location Adjustment

Prior to 1990, PWD used "Site # 7" and "Off 1952" as the primary sampling stations in Lower Bay (see attached map). The depth of "Site #7" ranged from 70-95' and "Off 1952" ranged from 60-85.' Since 1990, measurements have been made at the "Lower Bay Deep Basin" in 145± feet of water. Measurements from "Site #7" and "Off 1952" would be expected be similar but not identical to measurements taken at "Lower Bay Deep Basin." The highest readings (greatest transparency) would generally be expected at the deeper location. Deeper locations are further away from shoreland activity and provide time for storm water pollution to settle.

From 1994-2001 the PWD did nearshore Secchi transparency measurements in 34 locations around the lake. During this same period, measurements were made at the "Lower Bay Deep Basin" location. . Near-shore locations were all located in 50' of water while the "Lower Bay Deep Basin" location is in 145± feet of water. Analysis of 1000+ readings reveals that measurements at the "Lower Bay Deep Basin" were, on average, 0.34 meters greater than near-shore locations. Adding 0.34 meters to all pre-1990 Secchi readings will more than compensate for the difference the measured reading and that which would be expected if the reading was made at the same time in the "Lower Bay Deep Basin" location. See chart below.



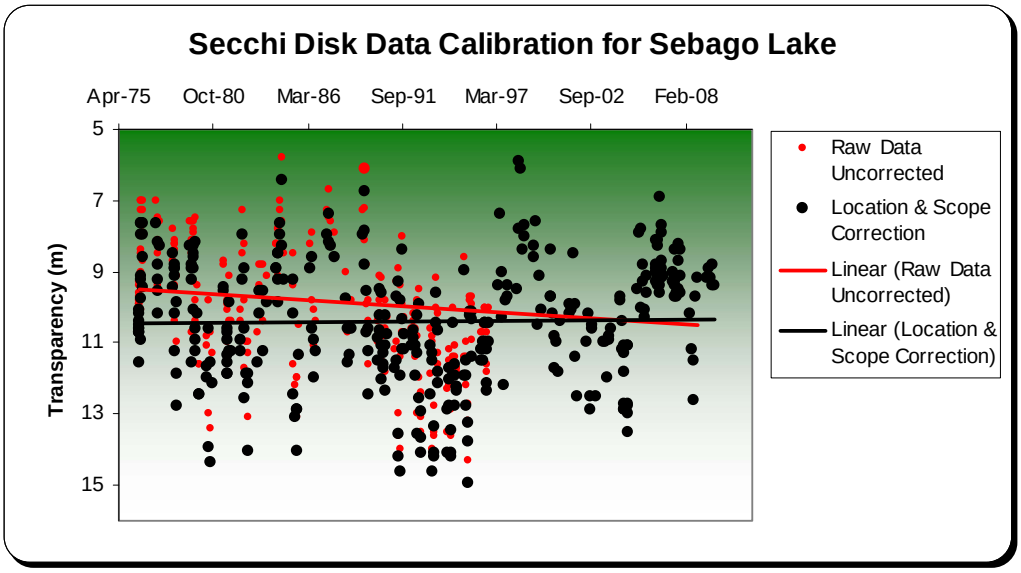
Secchi Scope Adjustment

From 1996 through 1999 the Maine DEP conducted paired Secchi readings using different scope types. Their analysis of 3600 data points included 5 scope types and considered other factors such as lake color, wind and cloud cover. Results applicable to Sebago Lake showed the slant glass with mask, which has been used by PWD since 1996, gave readings 4.5% higher than readings made with the flat glass scope with no mask, which was used by PWD prior to 1996 (Bouchard 2000). In order to compare pre-1996 data with post-1996 data, each pre-1996 measurement must be multiplied by 1.045.

Results of Calibration 1976-2009 Secchi Transparency

The graph below depicts all PWD Lower Bay Secchi data from 1976 to 2009. The red data points depict unadjusted data from the period before 1996, which shows an improving trend. The black marks show the pre-1990 Secchi data adjusted for sample location and scope type as described above.

It is notable that slope of the trend, with adjusted data, from 1976 to 2009 is flat. Throughout the analysis period, there are periods of improving transparency and periods of declining transparency as would be expected on most natural lakes.



Total Phosphorous

Total Phosphorous (Total P) measurements for Lower Bay were taken at "Site # 7" and "Off 1952" prior to 1990 and at the "Lower Bay Deep Basin" site since then. It is unclear if, as with Secchi transparency, samples from these shallower locations would be expected to be the same, higher, or lower than samples collected from the "Lower Bay Deep Basin" location. Statistical analysis is required to assess this.

The PWD has its own state-certified laboratory that does thousands of distribution system and source water sample analyses each year. The Ascorbic Acid Method for Total Phosphorous has remained constant since PWD began analyzing for Total P. However, PWD purchased a more sensitive instrument in 1998 which allows results to be reported to the 0.1 ug/l level, 10 times more sensitive than the pre-1998 instrument which could read to the 1 ug/l level.

Total Phosphorous Sample Location Calibration

From 2000 to 2005, PWD collected samples at various stations to investigate how water quality conditions were different around the lake. Sample stations included developed areas (Ward's Cove and Harmon's Beach), an erosive shoreline bank (Frye Island West), the outlet of the two major tributaries (Crooked-Songo), the most protected location from human activity (Intakes) and the three deep basin locations (Lower Bay, Jordan Bay, and Big Bay). Testing was discontinued at the Frye Island West, Harmon's Beach and Wards Cove sampling stations because water quality conditions in 50' of water at these locations were not statically different than deep basin locations.

A statistical test called the H-Test (Kruskal-Wallis) is used to compare groups of data for similarities and differences. Results show that the data can be divided in to three distinct groups. The Total P at the Crooked-Songo outlet is statistically higher, Frye Island West is statistically lower, and the other sampling locations are statistically the same.

H-Test (Kruskal-Wallis)

StationName	N (# of measurements)	Mean TP (ug/L)	p (0.03)
Big Bay	37	4.1	Similar
Crooked-Songo	47	4.6	Higher
Frye Island West	32	3.4	Lower
Harmons beach	34	4.0	Similar
Intakes	34	4.0	Similar
Jordan Bay	36	4.1	Similar
Lower Bay	37	4.0	Similar
Wards Cove	33	3.9	Similar

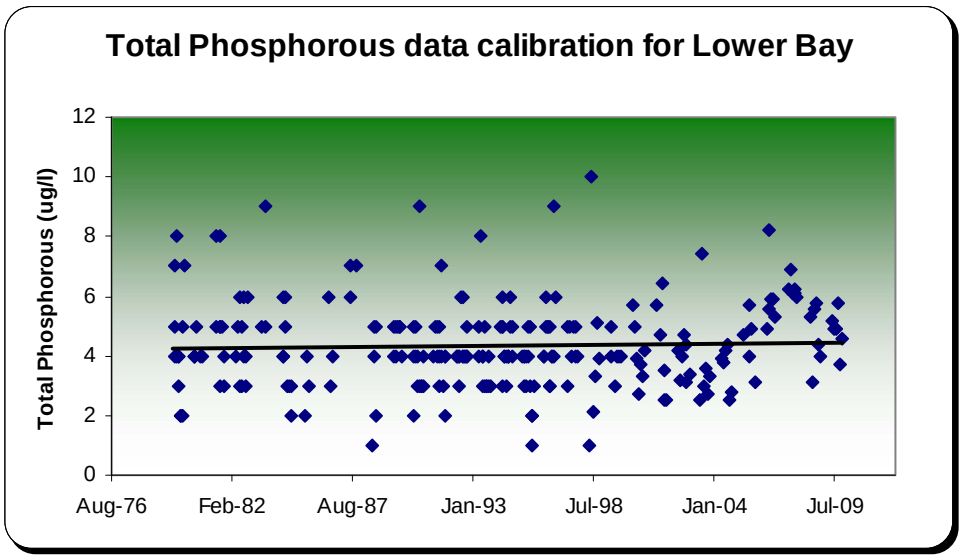
Based on the Total P data collected from 2000-2005, we can conclude that sample locations "Site # 7" and "Off 1952" (sample locations pre-1990) have statistically similar Total P values to the "Lower Bay Deep Basin" (sample location post 1990). No adjustment is needed in order to compare pre-1990 Lower Bay samples with post-1990 Lower Bay samples.

Total Phosphorous Method Detection Limit Calibration

The direction and slope of the linear regression of the data are the same regardless of the difference in method detection limit of the newer more sensitive instrument. No calibration is required for the method detection limit difference.

Calibration Results for Total Phosphorous

The Total P data for Lower Bay 1979-2009 shows periods of increasing and periods of decreasing concentration. Overall the trend is essentially flat over the past 30 years. See chart below.



Direct Statistical Comparison of Pre-1990 vs Post-1990 Lower Bay Total Phosphorous

A direct comparison of pre 1990 vs. post 1990 data sets, using the H-test shows there are not enough data points to determine if the difference in means are statistically the same or different. With a p-value of 0.29, there is a 29% probability that the differences in means are due to random chance.

The pre-1990 Total P mean of 4.5 vs. the post-1990 mean of 4.3 was neither due to the sampling location nor the point in time but was likely due to random chance. The Total P is not statistically increasing from 1979 to 2009.

H-Test (Kruskal-Wallis)

StationName	N (# of measurements)	Mean TP (ug/L)	p (0.29)
Lower Bay Deep Basin Post 1990	178	4.3	Neither Same Nor Different
Lower Bay Pre-1990	73	4.5	Neither Same Nor Different

Chlorophyll *a*

Statistical trend analysis for pre-1990 chlorophyll *a* data has never been done because of a laboratory method change in December 1992. Results after 1993 were reported as pheophyton corrected chlorophyll *a*. Pheophyton is a degradation product of chlorophyll, which represents the chlorophyll molecule that has lost the central Mg+ ion. This change makes the pre-1993 and post-1993 data sets distinctly different, therefore not suitable for trend analysis. Even though results were reported differently, the spectrometric absorbances at the same wavelengths were recorded in laboratory notebooks which are still available. Therefore post-1993 data can be recalculated to compare directly with the pre-1993 data. (The reverse is not true, however. The pre-1993 data cannot be recalibrated for direct comparison with post-1993 data because of the pheophyton correction). The data has been recalculated and standardized.

Chlorophyll *a* Sample Location Calibration

The same sampling station discrepancy between pre & post 1990 data exists with the chlorophyll *a* data as with the Secchi and Total P data. Chlorophyll a measurements for Lower Bay were taken at "Site # 7" and "Off 1952" prior to 1990 and at the "Lower Bay Deep Basin" location post 1990. Statistical analysis is required to determine if these two different sampling stations affect chlorophyll *a* results.

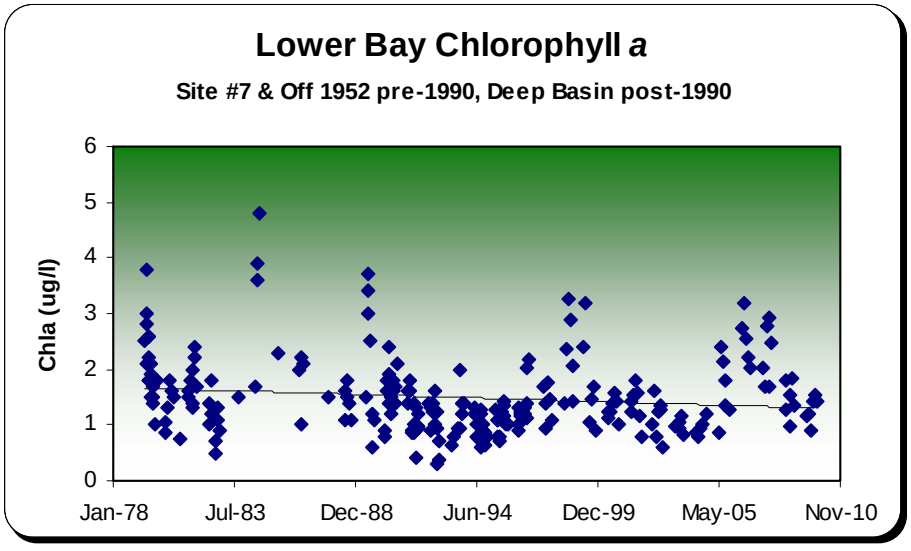
A statistical test called the H-Test (Kruskal-Wallis) is used to compare groups of data for similarities and differences. Results showed that the chlorophyll *a* data can not be divided into any groups based on location. The p-value of 0.59 indicates the differences in the means are likely due to random chance. More data are required to confirm or deny statistically significant groups based on chlorophyll *a* concentrations.

H-Test (Kruskal-Wallis)

StationName	N (# of measurements)	Mean Chl *a* (ug/L)	p (0.59)
Big Bay	38	1.26	Neither Same Nor Different
Crooked-Songo	45	1.28	Neither Same Nor Different
Frye Island West	34	1.10	Neither Same Nor Different
Harmons beach	35	1.22	Neither Same Nor Different
Intakes	32	1.22	Neither Same Nor Different
Jordan Bay	38	1.17	Neither Same Nor Different
Lower Bay	37	1.24	Neither Same Nor Different
Wards Cove	35	1.23	Neither Same Nor Different

Chlorophyll *a* Results

Due to the results of the sampling station correlation statistical test, it is not scientifically valid to quantitatively analyze the pre vs. post 1990 data together. However, it is interesting to look at the trend from a qualitative perspective. Results show periods of oscillating chlorophyll concentrations both positive and negative with an overall trend that is improving.



Direct Statistical Comparison of Pre-1990 vs. Post-1990 Lower Bay Chlorophyll *a*

A direct comparison of pre 1990 vs. post 1990 data sets, using the H-test, shows the data are statistically different. With a p value < 0.01, there is less than a 1% chance that the difference in mean rank is due to random chance.

The difference in the pre-1990 mean Chl *a* of 1.84 vs. the post-1990 mean of 1.32 is either due to the sampling location or the time period. Since the H-test of sample location was inconclusive, the difference in Chlorophyll *a* is likely due to the time period and is not statistically increasing from 1979 to 2009.

H-Test (Kruskal-Wallis)

Station Name	N (# of measurements)	Mean Chl *a* (ug/L	p (<0.01)
Lower Bay Deep Basin Post 1990	172	1.32	Lower
Lower Bay Pre-1990	69	1.84	Higher

Conclusion

Lakes have continual changing water quality conditions throughout the seasons of a year as well as cyclical changes from year to year. These water quality conditions depend on numerous factors (sunlight, rainfall, sediment inputs, water temperature, macro-nutrient levels, micro-nutrient levels, O^2/CO^2 concentrations, complex ecological interaction, and others) with varying degrees of influence at any given time. Long term monitoring data is critical to the understanding and evaluation of these changes. When evaluating statistical trends over time, the analysis can reveal positive or negative changes depending on the time series selected for analysis. The larger and longer time period of the data set, the less influence cyclical variation has on the trend outcome and the more valid trend analysis becomes for historical context.

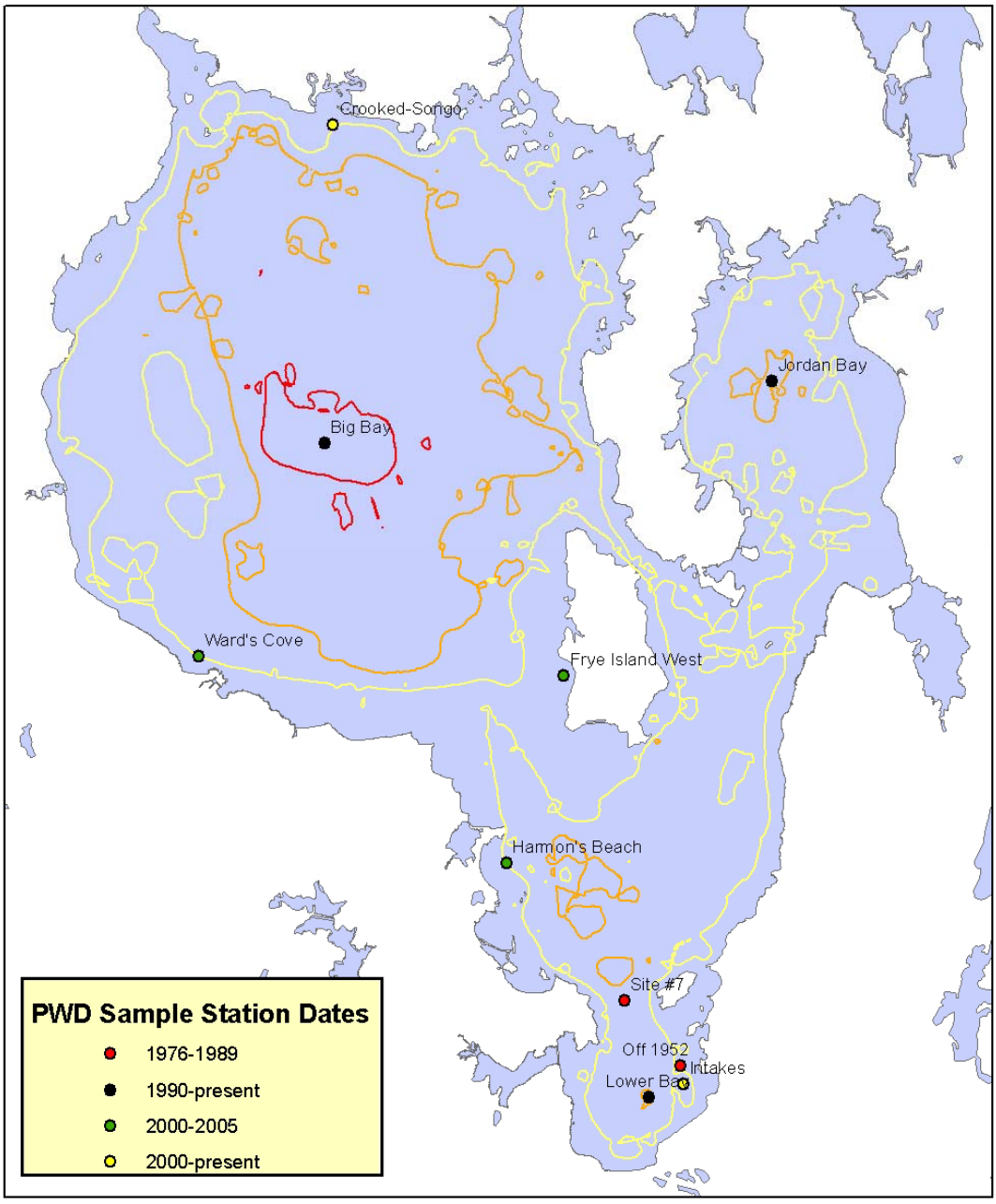
The Portland Water District has been monitoring Sebago Lake with various methods and procedures since the early 1900's. While tests, techniques and sample locations have changed throughout this time, it is critical to evaluate the longest times series possible with the highest degree of professional scientific judgment practical.

Reports published by PWD evaluating water quality trends based on strict method and site location standards utilized a data set from 1990-2008. This time series shows a decline in water quality. However, by incorporating the 1976-1989 data set, with scientifically valid statistical calibration, results show that Sebago Lake has undergone cyclical variation with an overall neutral water quality trend. The larger data set provides a historical prospective to the measurements.

The Portland Water District will continue to monitor the water quality of Sebago Lake. As monitoring methods improve and change, we must be mindful how the data fits into the long term historical context. If an extraordinary and overwhelming need should arise to change method or procedure, a link to the historical data must be vigorously maintained and documented.

The PWD has also contracted a paleolimnology sediment study by the University of Maine to evaluate the trophic status of the lake over the past 200-300 years. We are committed to understand and protect the lake for the interest of the 200,000 people that depend on the lake every day.

Current and Historical Portland Water District Sebago Lake Profile Sampling Stations



References

Whalen, Nathan. 2007. Portland Water District, Sebago Lake Watershed Monitoring Programs, Lake Monitoring, Presenting data from 1976 to 2006.

Whalen, Nathan. 2008. Sebago Lake Trophic State Trends, presenting data from 1990-2007.

Bouchard, Roy. 2000. Comparisons of Secchi Scope Types