



COLD RIVER LOCAL ADVISORY COMMITTEE
P.O. Box 68, S. ACWORTH, NH 03607

April 9, 2012

Mrs. Joyce Curll
Lake Warren Association
11 Inlet Cove Road
East Alstead, NH 03602

RE: Water Quality Review
Lake Warren Sampling Program

Dear Joyce:

The purpose of this report is to summarize the results of a comprehensive review of historical water quality data for the Lake Warren sampling program. The review was completed by Professional Geologist Michael Heidorn of the Cold River Local Advisory Committee (CRLAC), at the request of and with assistance from the Lake Warren Association (LWA).

In summary, this letter includes:

- An overview of the lake's water quality and sampling program.
- A description of the role of sub-watersheds in determining lake water quality.
- An evaluation of the trends in key water quality indicators common to both the sub-watersheds and the lake.
- A prioritization of sub-watershed phosphorous impacts.
- Conclusions/recommendations for future actions.

The NH Department of Environmental Services (NHDES) has already provided the LWA with annual in-lake trend analyses and recommendations for managing watershed water quality. While there is some overlap, our goal was to supplement those efforts by evaluating long-term trends at all locations with substantial data sets to better understand the impact of the lake's tributaries and other features on the lake and to prioritize areas for further investigation.

BACKGROUND

The LWA is currently developing a management plan for Lake Warren which describes natural and cultural resources in and around the lake and provides a reasoned framework for addressing the environmental challenges faced by the lake and its surrounding lands.

Serving the Watershed Towns of:

Acworth ♦ Alstead ♦ Charlestown ♦ Langdon ♦ Lempster ♦ Marlow ♦ Unity ♦ Walpole

The CRLAC strongly supports the LWA's management efforts and our recent collaboration grew directly out of recommendations detailed in the *Cold River Watershed Management Plan* (CRLAC, April 2009). The Lake Warren plan will ultimately complement the Cold River plan, resulting in more comprehensive protection of local resources.

Lake Warren is included within the Cold River watershed. The lake is fed by tributaries draining sub-watersheds in East Alstead. The lake discharges to Warren Brook, one of the major tributaries of the river. Portions of Warren Brook were devastated by the Flood of 2005, increasing the brook's sensitivity to water quality and habitat fluctuations. The CRLAC seeks to protect the brook from further degradation as one part of its work with the LWA.

As part of the current planning process, the LWA is focused on water quality issues in and around the lake. The LWA feels, and the CRLAC concurs, that maintenance of abundant, clean water in the lake is critical for the Town, its residents and visitors from a variety of perspectives – including not only environmental but social, financial, recreational and historical.

WATER QUALITY IN THE LAKE

The LWA recognizes that water quality monitoring is vital to understanding lake health, and has devoted a significant expenditure of resources toward monitoring since the 1990's.

As a participant in the NHDES' Volunteer Lake Assessment Program (VLAP), the LWA collects a variety of water samples from the lake and its tributaries each summer. The NHDES analyzes the samples in their laboratory and submits annual reports to the LWA describing the monitoring results, with a special emphasis on trends and observations within the lake. The NHDES also provides valuable technical advice and education to the LWA and general public.

The annual reports suggest that water quality in the lake remains generally acceptable by comparison to other lakes in the state. However, long-term trends in key indicators show that water quality is declining overall. For example, while in-lake mean total phosphorous (TP) levels in the epilimnion (upper layer of the lake) are generally satisfactory, over the last two decades those levels have increased on the order of 60%. Copies of the NHDES' long-term in-lake trend graphs for mean TP, chlorophyll-a and transparency are included in Attachment A.

The graphs show a combination of increasing chlorophyll-a (a measure of algal abundance) and TP (the key nutrient in biological lake processes) and decreasing transparency. This suggests that the lake is aging faster than would otherwise be expected.

Eutrophication is a term used to describe lake aging that is accelerated by the process of increased nutrient input. Lakes can be classified accordingly on a scale ranging from *oligotrophic* (highest lake quality; low nutrient levels and minimal algae/bacteria problems) to *eutrophic* (poor lake quality; high nutrient levels and increased algae/bacteria problems). Lakes in the middle of the continuum are termed *mesotrophic*.

In the last two decades, Lake Warren appears to have shifted from an oligotrophic-mesotrophic classification to a mesotrophic-eutrophic classification as shown in Attachment A. Extrapolation of the NHDES long-term trend lines for mean TP, chlorophyll-a and transparency

suggest that at the current rate of decline, the lake could reach an early eutrophic state in less than 35 years, depending on which parameter you evaluate and what level you consider eutrophic.

Eutrophic levels were examined using the following VLAP criteria:

- **TP:** ≥ 20 micrograms/liter (ug/l)
- **Chlorophyll-a:** ≥ 15 milligrams/cubic meter (mg/m^3)
- **Transparency:** ≤ 2 meters

It is important to note the eutrophic state predictions are only approximations, subject to the above assumptions as well as the limitations inherent in the data and the statistical analyses performed. For example, changing the target level for mean TP to 30 ug/l results in early stage eutrophication at 64 years. Using the trend for actual TP data versus mean TP data results in an early stage prediction of 108 years at a target level of 30 ug/l.

Regardless of the target levels chosen for the above extrapolations, the “bottom line” message is the same: the predictions suggest the lake could become eutrophic sometime within this century if the current trends continue.

Eutrophic water bodies may develop into what can be called “pea-soup ponds.” This development can result in adverse aesthetic, recreation and habitat impacts as well as significant reductions in property values. Remediation of these conditions can be difficult and costly, easily totaling hundreds of thousands of dollars or more.

The NHDES currently classifies the lake as “Impaired” for aquatic habitat uses based on elevated nutrient/algae levels and acidity. Federal law requires the NHDES to determine the pollutant sources causing impairments and to develop a pollution management, or Total Maximum Daily Load (TMDL), plan for the lake. However, the TMDL study is considered a low priority by the NHDES and is tentatively scheduled for initiation in 2023.

According to the NHDES (Sara Steiner, personal communication), Lake Warren will not be removed from the Impaired waters list until water quality data suggest that the lake has returned to an oligotrophic state. TP and chlorophyll-a levels must consistently fall below 8 ug/l and $3.3 \text{ mg}/\text{m}^3$, respectively. This does not appear to be a likely scenario given current trends.

The above discussion highlights the need to not only monitor the lake but to assess the causes of water quality issues and develop an action plan for protecting water quality.

WATERSHED SAMPLING PROGRAM & DATA

The first step in developing a water quality action plan is to evaluate existing data for trends, data gaps and areas of concern. A brief description of data availability and the current sampling program on and around Lake Warren is provided below.

A list and basic map of all sampling stations in the target area is provided in Attachment B. The LWA’s current sampling program includes 24 lake, tributary and outlet sites.

Complementing those sites are five additional NHDES culvert monitoring sites at the NW corner of the lake and a CRLAC monitoring site co-located at the lake's outlet (Warren Brook).

Samples have been collected at some of the above-referenced sites as far back as 1980. Up until the 1990's, samples were only collected by the NHDES, usually from the middle of the lake (the "Deep Spot"). Since that time, the sampling program expanded to include the tributary/outlet and near-shore (in-lake) sites and has largely been a volunteer effort by the LWA.

The sampling sites have been analyzed for a wide variety of parameters at varying frequencies. Ten of the LWA sites were monitored for only a year or two and have very limited data. The culverts also have very limited data. The remaining tributary/outlet sites are monitored three times per year by the LWA for pH, specific conductance (SC), TP, turbidity and chloride.

The Deep Spot is typically monitored three times per year by the LWA for those parameters plus dissolved oxygen (DO), chlorophyll-a, transparency, acid-neutralizing capacity (ANC), phytoplankton and cyanobacteria. Many near-shore (in-lake) sites are monitored once or twice per year by the LWA for e.Coli bacteria.

The CRLAC routinely monitors the lake outlet (site "12-WAB") for pH, SC, temperature, DO, turbidity and water level, and has also monitored that site on a limited basis for e.Coli bacteria, nitrite/nitrate and TP. The data from this site may be compared directly to the data from the LWA outlet site ("WARALSO").

The data available from the NHDES during the preparation of this report span the time period between 1980 and 2011. Graphical analyses of all available analytical data provided by the NHDES for those parameters that were sampled in both the tributaries/outlet and the lake are provided in Attachment C. This approach was selected since the common parameters facilitated a direct comparison of most sampling stations (allowing us to focus on the relationship between the tributaries and the lake), and the status of the lake's water quality had already been more fully evaluated by the NHDES in their annual reports as described above.

The parameters that are only monitored at near-shore sites or the Deep Spot have been discussed in detail by the NHDES and were not further evaluated here.

The pH data were not included in the graphical analysis because the lake and its tributaries are known to be slightly acidic and further evaluation of the data was not anticipated to yield significant insights at this time. As the NHDES states in their annual VLAP reports: "Due to the state's abundance of granite bedrock and acid deposition received from snowmelt, rainfall, and atmospheric particulates, there is little that can be feasibly done to effectively increase pH."

Attachment C includes (a) bar graph chart summaries of average and maximum TP, SC, turbidity and chloride concentrations for all applicable sites during the 1980-2011 period and (b) individual trend graphs of measured TP, SC and chloride concentrations for key sites during the 1980-2011 period. Key sites selected for the latter analysis were the Deep Spot, tributary and outlet sites where a significant volume of TP and SC data has been collected.

Each of the trend graphs includes descriptions of applicable NHDES water quality standards, typical NH lake water quality data and local lake/pond/stream data. Each graph with ten or more years of data also includes a best-fit regression line to clarify increasing or decreasing trends. While the regressions would benefit from additional data and are subject to (a) change based on future data and (b) a large degree of data variability in some cases, they provide the LWA with a relatively objective sense of preliminary trends.

The volume of data generated for the sampling stations, almost exclusively by LWA volunteers, is impressive. Over 900 measurements were evaluated during this study, just for the four parameters listed above. We estimate several thousand measurements have been completed in total. Collectively, these measurements represent an invaluable database for examining current water quality trends as well as monitoring future land use impacts.

IMPORTANCE OF SUB-WATERSHEDS

Water flowing into the lake is derived primarily from stream flow and groundwater discharge. The quality of water in the lake is a direct function of the quality of water flowing into it. While the exact percentage contributions of stream flow and groundwater discharge to Lake Warren are not known, both items are anticipated to be important contributors to the lake's health. Consequently, understanding water quality in the lake's tributaries and their associated sub-watersheds is one important component of any lake management strategy.

Lake Warren is fed by two major tributaries, Carmen Cove (Hale) and Smith Hill Brooks, and a number of smaller tributaries including Colburn Hill, Pickerel Cove and Dam Brooks as well as Spruce "River" and a small stream at Scotland Yard. Each tributary is monitored by the LWA. A preliminary review of topographic maps for the area suggests that there may be several unnamed small tributaries that are not monitored.

Lakefront properties often drain surface runoff directly into the lake (rather than into a stream) or indirectly via groundwater discharge. The contributions of direct runoff and groundwater discharge to water quality in the lake, while not the focus of this evaluation, are also important to consider in the development of a lake management strategy.

WATER QUALITY TRENDS

Trends in TP, SC, turbidity and chloride concentrations are described below for each monitored sub-watershed, the outlet and the Deep Spot. Where appropriate, observations at near-shore and culvert sites are also included.

Total Phosphorous:

In NH, phosphorous is the key nutrient responsible for lake eutrophication. Thus, TP monitoring and evaluation is critical for understanding the health of Lake Warren.

Many high and low intensity land uses have the potential to increase TP levels. Possible human sources of TP include sewage, septic system effluent, manure, fertilizer, pesticides, soil

erosion, air pollution, land clearing, development of impervious surfaces and certain types of logging. Natural sources such as local soils, rocks, wetlands and precipitation are also possible.

There are no numerical surface water quality standards for TP in NH. In lieu of a numerical standard, the NHDES offers the following guidance:

- **Ideal:** <10 ug/l (streams and lakes);
- **Average:** 11 – 25 ug/l (streams); 11 – 20 ug/l (lakes)
- **More than Desirable:** 26 – 49 ug/l (streams); 21 – 40 ug/l (lakes)
- **Excessive:** ≥50 ug/l (streams); >40 ug/l (lakes)

The NHDES suggests the median TP concentration in New Hampshire lakes ranges from 12 ug/l in the epilimnion (upper lake layer) to 14 ug/l in the hypolimnion (lower lake layer). In NH lakes comparable to Lake Warren in size, depth and volume (referred to as “Similar Lakes” on the graphs in Attachment C), the mean TP in the epilimnion is 15 ug/l.

The NHDES analyses show that mean TP concentrations are increasing in Lake Warren, especially in the epilimnion. TP graphs provided in Attachment C for the Deep Spot show linear regression trends consistent with that observation. TP is the limiting nutrient in the lake, meaning that small TP increases can cause big increases in algal abundance. Those changes are evident in the negative chlorophyll and transparency trends identified by the NHDES.

Sample data collected by the LWA suggest that sub-watershed and culvert sources are contributing to the negative in-lake TP trend. Sub-watershed sources with worsening TP trends (TP concentrations increasing over time) include Carmen Cove, Colburn Hill, Dam and Pickerel Cove Brooks as well as Spruce River. Maximum TP concentrations ranging from More than Desirable to Excessive as defined by the NHDES have been observed at each of those streams except for Dam Brook, in most cases on more than one occasion.

Elevated TP concentrations were observed at Smith Hill Brook up until 2005. As documented in our January 25, 2005 letter to the LWA, historical land uses in the Smith Hill Brook sub-watershed included a large logging operation and a significant wetland alteration that was the subject a NHDES enforcement action. Both land uses could have contributed to elevated TP concentrations in the brook. Currently there is a decreasing TP concentration trend, suggesting that those land uses have declined in frequency or ceased altogether.

No discernible TP trends are evident yet at Scotland Yard due to the limited data set for that location. The average and maximum TP concentrations observed at that site are considered More than Desirable as defined by the NHDES.

TP concentrations in the lake outlet appear to be on an increasing trend, with recent levels in the More than Desirable range as defined by the NHDES. While this trend does not add to the nutrient load of the lake, it is one representation of overall water quality in the lake and the concentrations have been increasing quickly. The trend is also a concern for the CRLAC due to the potential downstream impacts on Warren Brook and the Cold River.

Elevated TP levels ranging from More than Desirable to Excessive were observed in all five of the culvert outfalls sampled in the fall of 2010. The highest TP concentrations ever recorded in the Lake Warren sampling program, ranging from 350 to 650 ug/l, were measured at Culverts 3, 4 and 7. With the exception of Culvert 7, the culverts collect road runoff and discharge directly to the lake. Culvert 7 discharges to a small stream which empties into the lake.

In 2011, the NHDES issued a Letter of Deficiency (LOD) to the Town of Alstead regarding the culvert discharges based on the turbidity/TP levels measured in the discharges and the sediment plumes observed going into the lake. Elevated turbidities caused by sediment runoff are often associated with elevated TP readings. The NHDES retracted the LOD after the Town showed that the data did not prove a violation of state water quality standards had occurred.

TP levels observed in all near-shore samples fell within the Ideal to Average range as defined by the NHDES. However, near-shore sampling data are difficult to interpret due to the mixing of water within the lake and are not necessarily representative of on-shore sources. Furthermore, of the five near-shore stations sampled for TP (including Curll Cove, Lawlor Shore, Rawson Cove, Red House and Shadowlands), only one was sampled more than once. These data limitations preclude the drawing of any conclusions regarding the near-shore sites at this time.

Comparison of the TP data from all sampling stations to the NHDES guidance levels showed that 87% of the phosphorous concentrations over a 30-year period were in the Ideal to Average range as defined by the NHDES. These results suggest that water quality in the tributaries, outlet and lake is usually satisfactory and that elevated TP levels are infrequent or the product of recent trends or localized concerns (such as the culverts).

The results also showed that 65% of the TP concentrations measured in the tributaries and culverts exceeded the NH median epilimnetic lake TP level of 12 ug/l, and that 25% of those concentrations were classified as More than Desirable or Excessive. These results suggest that the tributaries and culverts are important contributing factors to the long-term increase in phosphorous levels observed in the lake.

It is important to understand that TP levels in the lake are governed not only by the TP concentrations of the incoming waters but also by the flow rates of those waters. In other words, due to mass-balance considerations, relatively small increases in TP in a high flow stream can result in relatively large contributions of TP to the lake. Likewise, relatively large TP levels in a tiny stream can result in relatively small contributions of TP to the lake.

A qualitative survey of the lake's tributaries was completed by the CRLAC in the summer of 2011. Based on that survey, Carmen Cove (Hale) and Smith Hill Brooks clearly represent the largest inflows to the lake. As noted above, an increasing TP trend was observed at Carmen Cove (Hale) Brook. Consequently, the identification and reduction of TP sources to that brook should be considered one important component of any lake management strategy.

Specific Conductance:

SC is a measure of the ability of water to carry an electrical current and a measure of the free ion content in the water. Free ions are charged particles such as chlorides, nitrates, sulfates,

phosphates, sodium, magnesium, calcium, iron and aluminum. SC readings can help locate many types of potential pollution sources (road salt, septic systems, fertilizers, stormwater runoff, fuels, etc.) because polluted water usually has a higher SC than unpolluted water. SC is also related to natural sources such as geology and groundwater quality.

There are no numerical surface water quality standards for SC in NH. In lieu of a numerical standard, the NHDES offers the following guidance:

- **Normal:** 0 – 100 micromhos/centimeter (umhos/cm)
- **Low Impact:** 101 – 200 umhos/cm
- **Moderate Impact:** 201 – 500 umhos/cm
- **High Impact:** >501 umhos/cm

The NHDES also allows for SC measurements to be used as a surrogate to predict compliance with numeric water quality criteria for chloride (a common component of road salt pollution). If SC exceeds 835 umhos/cm, the chronic chloride standard of 230 mg/l is inferred to have been exceeded based on statewide water quality studies that the NHDES has completed.

Because SC readings are impacted by naturally-occurring ions, it can be difficult to interpret low values relative to pollution potential. However, trends can sometimes be discerned that show changes potentially caused by pollutants. For example, one may find that a particular sampling site exhibits elevated SC relative to similar nearby or upstream sites. Another example is a site that demonstrates increasing SC over time.

The NHDES suggests the median and mean SC in New Hampshire lakes are 40 umhos/cm and 59 umhos/cm, respectively. The mean SC observed at the Deep Spot (epilimnion) in Lake Warren is 59 umhos/cm, and no significantly increasing trend is evident for the Deep Spot from the best-fit linear regression analysis in Attachment C. All SC readings for the Deep Spot and near-shore sampling sites fall within the Normal range as defined by the NHDES.

While the in-lake SC results are encouraging with regards to our water quality assessment, it is important to note that those results may not be particularly sensitive to small changes in ion concentrations (especially those associated with TP) that can be very important to the health of the lake. It is easier to use SC as a pollution screening tool for the tributaries and culverts.

LWA sampling data show that SC readings suggestive of human impacts (>100 umhos/cm) have occurred in the culverts and Carmen Cove, Colburn Hill and Pickerel Cove Brooks as well as Spruce River. Those tributaries were also observed to have elevated TP. The highest SC (540 umhos/cm) ever recorded for the Lake Warren sampling program was measured in a Spruce River sample. Maximum SC levels ranging from Moderate to High Impact as defined by the NHDES have been recently observed on Colburn Hill Brook and Spruce River.

The possibility of a consistent correlation between SC and TP was evaluated by comparing the graphs in Attachment C for the streams with elevated SC. Increasing SC and TP trends were observed at both Colburn Hill and Pickerel Cove Brooks. However, similar correlations were not observed at Carmen Cove (Hale) Brook and Spruce River. At the culverts,

the most elevated TP levels do appear to be broadly associated with the most elevated SC levels but a poor best-fit correlation is evident when graphed.

The lack of a consistent correlation between TP and SC is not surprising given the many variables influencing SC levels. A natural conclusion is that sources of elevated SC should be evaluated on their own terms, and not assumed to necessarily represent elevated TP sources.

Nearly all SC levels in samples collected from the outlet and Smith Hill Brook during the evaluation period were Normal as defined by the NHDES. Elevated SC levels in the Low to Moderate Impact range were observed in four of the five culverts sampled in the fall of 2010.

Turbidity:

Turbidity is a measure of the amount of suspended material in the water. This material typically includes clay, silt, algae and plant particles. Clean waters are generally associated with low turbidity, but there is a high degree of natural variability involved.

Rain events can increase turbidity in surface water by flushing sediment and organic matter into the water. Human activities such as vegetation removal and soil disruption can lead to dramatic increases in turbidity levels. High turbidities may increase water temperature, reduce DO concentrations and photosynthesis, and negatively affect the health of aquatic organisms including fish. Turbidity levels also strongly influence lake transparency.

The NHDES' water quality standard for turbidity in the Lake Warren area is "shall not exceed naturally occurring conditions by more than 10 Nephelometric Turbidity Units (NTUs)."

Because elevated turbidities can be associated with natural events as well as human activities and sampling error, it can be difficult to interpret the turbidity source(s). However, by carefully collecting data during both wet- and dry-weather events, or upstream and downstream of suspected sources, one may be able to assign changes in turbidity to natural and/or human causes.

The NHDES suggests the median turbidity in New Hampshire lakes is 1.0 NTU. The mean turbidity recorded for the Deep Spot in Lake Warren is 1.2 NTUs. No turbidities measured at the Deep Spot or near-shore (in-lake) stations exceeded 3 NTUs.

Mean turbidities measured for most of the tributaries range from 0.6 to 3.9 NTUs. These values do not exceed the applicable water quality standard. They are consistent with the range of readings observed by the CRLAC on similar streams elsewhere in the Cold River watershed.

It is important to note that the LWA's turbidity results for the most part reflect dry weather sampling conditions. Wet weather sampling is necessary to adequately assess turbidity levels and impacts. The same holds true for examining TP impacts associated with storm erosion.

Maximum turbidities ranging from 22 to 34 NTUs were recorded for Upper Warren Brook (the outlet), Spruce River and Smith Hill Brook. These streams were sampled by the

CRLAC during Tropical Storm (TS) Irene in August 2011 to better gauge the impact of wet weather on the data set. These values may not exceed the applicable water quality standard if they are considered naturally-occurring. Turbidity readings in the 30 NTU range were observed at other local forested streams during that storm including Camp Brook, Dodge Brook and the upper reach of Great Brook, suggestive of natural conditions or only minor erosion problems.

A maximum turbidity of 178 NTUs was recorded for Carmen Cove (Hale) Brook in August 2011. This value is clearly more than 10 NTUs beyond what would be considered normal for this stream. It is suggestive of an erosion issue that was exacerbated by TS Irene. Turbidities exceeding 100 NTUs have only been recently observed by the CRLAC in streams with moderate to significant erosion problems resulting primarily from the 2005 Flood, including the lower reaches of Great, Warren and Crane Brooks as well as the Cold River below South Acworth.

Turbidity readings ranging from 88 NTUs to 785 NTUs were observed at the culverts during wet weather sampling by the NHDES in the fall of 2010. According to the NHDES, “turbidity plumes were evident in the lake directly in front of each culvert.” These values appear to exceed the NHDES turbidity standard but culvert runoff is not technically considered surface water by the NHDES.

As noted earlier in this report, in 2011 the NHDES issued an LOD to the Town of Alstead for the culvert discharges based on the turbidity/TP levels measured in the discharges and the sediment plumes observed in the lake. The NHDES retracted the LOD at the Town’s request after the Town showed that the sampling data were insufficient to prove a violation of the state’s water quality standards had occurred.

The possibility of consistent correlations between turbidity and TP/SC was evaluated using the culvert data. The evaluation suggested that elevated turbidities above 500 NTUs could potentially be associated with elevated TP and SC levels. However, no clear correlation was observed using the limited data, especially at lower turbidity concentrations.

Overall, with the exception of the culverts and Carmen Cove (Hale) Brook, the turbidity data are currently encouraging with regards to our water quality assessment of the lake.

Chloride:

Low levels of the chloride ion are found naturally in fresh waters. In NH, higher-than-normal chloride concentrations are typically associated with road salt or septic system discharges. Chloride ions are conservative, which means they are not degraded in the environment and tend to remain in solution, once dissolved. According to the NHDES, research shows elevated chloride levels can be toxic to freshwater aquatic life. Among the species tested, freshwater aquatic plants and invertebrates tend to be the most sensitive to chloride.

In order to protect freshwater aquatic life, the NHDES has adopted **acute** and **chronic** surface water quality standards of 860 milligrams/liter (mg/l) and 230 mg/l, respectively, for chloride. According to the NHDES, the median chloride content in remote NH lakes is 4 mg/l.

The mean chloride concentration at the Deep Spot, where a handful of samples have been collected since 1980, is approximately 8 mg/l. While the data points are limited, no clear trend over time is evident. This suggests that chloride is not increasing due to human activities.

With the exception of the Deep Spot, chloride sampling was first initiated in 2010-11. Only one or two rounds of chloride sampling have been completed at many of the sampled sites. It is difficult to say anything conclusive based on the limited data, but the results are encouraging. None of the samples contained chloride at levels exceeding the applicable standards.

It is worth noting that relatively elevated chloride levels were observed in two of the tributaries, Spruce River and Pickerel Cove Brook. Maximum levels ranging from 29 mg/l to 41 mg/l could be suggestive of potential sewage-related pollutant impacts. Additional monitoring would be needed to more fully assess this observation.

It is important to note that wet weather sampling during winter and spring snowmelt periods is necessary to adequately assess potential impacts associated with road salt pollution. If the LWA wishes to more comprehensively address this issue, wet weather sampling should be incorporated into the monitoring program. It does not appear at this time, however, that road salt pollution is a priority concern.

PHOSPHOROUS IMPACT PRIORITIZATION

In order to develop a better understanding of which tributaries are experiencing elevated or increasing TP levels and prioritize their sub-watersheds according to the need for management or remedial actions, a set of prioritization criteria were developed using the above guidelines, graphical trends and relative stream flow contributions.

A summary table listing the sampling stations and ranking each station based on nine prioritization criteria is provided in Attachment D. A detailed description of the table follows:

- **Stream Flow:** The first two prioritization criteria relate to potential TP contributions to the lake based on flow. The tributaries have been separated into two groups. The first group is associated with high flow sub-watersheds (Carmen Cove and Smith Hill Brooks) and the second with low flow sites. Stations in the first group are weighted more in the priority ranking process due to mass-balance considerations.
- **Graphical Trends:** The next prioritization criterion is based on the best-fit linear regression trend demonstrated on the concentration-versus-time graph for each sampling site. While the regressions would benefit from the collection of additional data, the trends are one important clue as to the potential impact of the tributaries on the lake. The trends are described in the Water Quality Trends section of this letter. Streams with increasing TP trends are weighted more in the priority ranking process. Please note that of the streams with increasing TP, three (Colburn Hill and Pickerel Cove Brooks as well as the outlet) are increasing at a faster rate than the others.
- **Excessive Level:** The fourth prioritization criterion is a comparison of long-term maximum concentrations to the “Excessive” NHDES classification (>50 ug/l). The

fifth prioritization criterion identifies which sites had more than one concentration exceeding the Excessive level.

Sites that exhibited maximum concentrations exceeding 50 ug/l included Smith Hill, Colburn Hill and Pickerel Cove Brooks as well as Spruce River. At Colburn Hill Brook, maximum concentrations were Excessive on more than one occasion.

- **More-than-Desirable Level:** The sixth and seventh prioritization criteria include comparisons of recent (last five years) and long-term average concentrations to the “More than Desirable” NHDES classification (>25 ug/l).

Most stations with recent data have experienced greater-than-desirable levels in the last five years, including a high flow site (Carmen Cove Brook) and several low flow sites (Colburn Hill and Pickerel Cove Brooks as well as Spruce River). Recent levels at Colburn Hill and Pickerel Cove Brooks far exceeded 25 ug/l. Greater-than-desirable long-term average concentrations were not observed at any of the sites.

- **Median NH Lake Level:** The eighth prioritization criterion is a comparison of long-term average stream concentrations to the median concentration (12 ug/l) observed in the upper portions of New Hampshire lakes. All sites with the exception of Dam Brook had long-term average concentrations exceeding the median lake level.
- **Turbidity/SC Levels:** The ninth and last prioritization criterion is based on the maximum turbidity and SC levels documented for the streams. Sites with turbidity exceeding 100 NTUs or SC exceeding 200 umhos/cm were weighted more in the priority ranking process. The turbidity cutoff was selected based on experience in the Cold River Watershed, while the SC cutoff is representative of Moderate Impact.

After assessing the nine criteria at each of the sampling stations as discussed above, a priority ranking of High, Medium or Low was assigned to each station by comparing the assessed values and employing weighting factors.

Increasing trends and/or elevated concentrations in the high flow sub-watersheds were considered to be more heavily weighted. In the low flow sub-watersheds, similar weighting criteria were used but the trends/concentrations needed to be greater in magnitude/frequency in order to receive a rating comparable to a high flow site.

In addition, tributaries to the lake were weighted more heavily than the lake outlet since the LWA’s primary focus is maintaining the lake. It is anticipated that prioritizing the tributaries will ultimately result in reduced TP levels both in the lake and its outlet.

The resultant priority rankings (as shown in Attachment D) indicate that critical (Medium to High) priority areas include the following sub-watersheds:

- **High Flow:** Carmen Cove (Hale) Brook
- **Low Flow:** Colburn Hill Brook, Pickerel Brook, Spruce River

Lower priority areas include the following sub-watersheds:

- **High Flow:** Smith Hill Brook
- **Low Flow:** Scotland Yard, Dam Brook, Outlet

The culverts were not included in the prioritization table due to the limited data available for those sites and the inability to apply NHDES water quality standards directly to the sampling results. However, the Excessive TP levels and turbidities measured at the culverts as well as the sediment plumes observed downstream of the culverts by the NHDES suggest that the culverts warrant a High Priority ranking in the Low Flow category.

CONCLUSIONS

Based on the above evaluation, we conclude the following:

- Water quality in the lake is generally acceptable for many parameters relative to applicable NHDES standards and guidelines. There are still opportunities to maintain this level of quality and reduce the adverse trends outlined below.
- NHDES TP/chlorophyll/transparency graphs suggest water quality in the lake is declining, currently resulting in Impairments for aquatic habitat and possibly resulting in early-stage eutrophication (premature aging) in less than 35 years.
- A detailed sampling program completed primarily by LWA volunteers in and around the lake has contributed greatly to our understanding of the lake's health.
- Despite the volume of data collected, existing data gaps include the need for:
 - Flow data at the tributaries and outlet
 - Identification of other tributaries that may require sampling
 - Completion of wet weather sampling
 - Targeted sampling to address the culverts and tributaries with identified water quality concerns
- Stream flow, groundwater discharge and surface runoff are important contributors to water quality in the lake, and water quality in the lake in turn influences Warren Brook and the Cold River.
- TP is the key nutrient responsible for eutrophication. Increasing TP trends in the lake, some tributaries, the culverts and the outlet are a significant water quality concern for the LWA and all lake stakeholders.
- Flow rates in the tributaries must be considered when evaluating TP trends. Carmen Cove (Hale) and Smith Hill Brooks represent the largest inflows to the lake. Small increases in TP levels in those streams could have large impacts on the lake.
- SC can be a good general pollution indicator. Elevated SC levels were observed in several of the tributaries and culverts. Increasing SC trends are occurring in Colburn Hill and Pickerel Cove Brooks.
- Turbidities measured at the lake, tributaries, outlet and near-shore sites are generally well below the applicable NHDES standard. However, excessive turbidities have

been measured during wet weather events at Carmen Cove (Hale) Brook and the culverts. Wet weather sampling data are generally not yet available.

- No violations of the NHDES chloride standard have been observed, and road salt pollution does not appear to be a significant water quality issue. However, the data set is limited. Spruce River and Pickerel Cove Brook had relatively elevated chloride levels suggestive of the potential for sewerage pollution.
- Prioritization of TP impacts associated with the tributaries/outlet using a set of nine qualitative and numerical criteria indicated that critical priority areas for TP management include Carmen Cove (Hale), Colburn Hill and Pickerel Brooks and Spruce River. The culverts were also identified as a critical TP concern.

RECOMMENDATIONS

Based on the above evaluation, we recommend the following action items to manage water quality and reduce potential pollutant loads in Lake Warren:

- In general, continue to implement the water quality protection recommendations provided by the NHDES in their annual VLAP reports. Maintain and increase support for the ongoing VLAP sampling program to monitor water quality trends.
- Consider developing a “VLAP Subcommittee” within the LWA as one means of support. Also, promote the interest and retention of VLAP volunteers. One or two long-term trainees with a willingness to learn and ability to retain the volunteer protocols would go a long way towards a more sustainable program.
- Continue to foster strategic partnerships with local, regional and state groups that share a common interest with the LWA, including but not limited to the CRLAC, Alstead Conservation Commission, Monadnock Conservancy, etc.
- Incorporate the *Cold River Watershed Management Plan* by reference into the lake management plan to better leverage future planning and funding opportunities.
- Initiate targeted investigations of critical priority areas for TP management using the phased approach discussed below, and including windshield/stream surveys, site visits, bracket sampling and/or storm sampling to identify specific pollution sources.
- Initiate targeted investigations of sub-watersheds where adverse concentrations or trends of SC, turbidity and chloride were identified. Expand the existing sampling program to include rain events. The easiest way to do this may be to substitute one wet weather event for one of the routine summer tributary sampling rounds.
- Attempt to identify the source of sediment causing elevated turbidity in Carmen Cove (Hale) Brook. A logical first step is to walk upstream during/after a rain event.
- Request that the NHDES and the Town follow up on the outstanding culvert issue and complete a more defensible wet-weather sampling round. Assist as needed and, based on the results, encourage the Town to remedy the situation.

- If not already completed, consider adding water level, temperature and DO monitoring to the tributary sampling program. Water levels may serve as rough gauge of flow, and could be easily incorporated by establishing reference points at each site.
- Verify drainage patterns in the vicinity of the dam and also on the upper reach of Gilsum Mine Road. Modify tributary sampling approach if needed.
- Consider hiring a consultant to complete a nutrient loading study, including the collection of additional stream flow data, incorporation of historical concentration data and consideration of non-assessed sub-watersheds. A loading study identifies nutrient sources in the lake's watershed and estimates how much each source contributes to the lake over time. The consultant may also be able to assist the LWA in reviewing lake ecological processes and evaluating the likelihood of boating impacts to water quality.
- Develop targets for in-lake TP concentration, Secchi disk transparency and chlorophyll content based on desired lake uses, NHDES nutrient impairment criteria and the relation among these variables for this lake. This effort may require the use of predictive models. Model predictions of in-lake TP concentrations in response to specific management actions. Compare predictions to measured data.
- Further examine the type of algae that are dominant in the lake and seasonal algae changes. Discuss expected dominance of algae vs. rooted vegetation (achieving transparent water in shallow lakes may exacerbate rooted plant problems). Continue to monitor for the presence of the so-called toxic blue-green algae.
- Work with Alstead Planning Board and Conservation Commission to better understand the state of the Town's regulations with regards to the discouragement of impervious surfaces and encouragement of on-site storm water disposal. Request to be put on the e-mailing list for those groups to stay abreast of land use changes.
- Review chemical, storm water and wastewater management practices at sub-watershed businesses. These practices can be a potential water quality concern.
- Continue pursuing and promoting a discounted septic pump-out program to encourage regular pump-outs for waterfront and watershed homes. Encourage waterfront and stream-side owners to avoid vegetated buffer removal and storm drainage to water.
- Initiate or continue discussions with large property owners in the watershed regarding land conservation benefits/opportunities. LWA members have been instrumental in protecting land (which also protects water quality) over the last few years.
- Develop a more specific understanding of the benefits the lake provides to non-waterfront land owners, and use that understanding to reach out to those owners. Their land use practices strongly influence the quality of water in the tributaries.
- Continue providing public outreach/education about lake health, land stewardship and best management practices (BMPs) for water quality protection. Involve children and youth groups to the extent possible, as well as recreational users and the Town. Take advantage of the many excellent NHDES water quality and BMP fact sheets.

- Contact the NH Lakes Association regarding their Lake Conservation Corps program. This program is designed to actively involve youth in hands-on shoreline and watershed restoration projects. The Association may be able to work with the LWA, the Town and local students to help improve the quality of Lake Warren, or at least help the LWA to develop a comparable local program with the same objectives.
- Consider providing copies of the NHDES' NH Homeowner's Guide to Stormwater Management to each lakeshore resident and key landowners on the tributaries.

We recognize that the LWA has very limited human, material and financial resources and that implementing all of these recommendations presents a significant challenge. However, the LWA should consider implementing urgent or relatively low-cost and less labor-intensive recommendations as soon as possible. Less urgent, more expensive or more time-consuming ideas can be prioritized for long-term implementation, as resources allow. Long-term priorities will require extra LWA support and cannot reasonably be completed by one or two volunteers.

To facilitate TP management efforts, we suggest that the LWA structure or phase its future actions in the sub-watersheds to address priority areas in the following sequence:

- Critical priority areas (High Flow)
- Critical priority areas (Low Flow, including culverts)
- Sub-watershed areas not yet assessed
- Lower priority areas (High or Low Flow)

The above suggestion is offered with at least two important caveats. The first caveat is that prioritization is an ongoing process that will evolve as additional sampling data are collected and evaluated. In particular, the classification of some sub-watersheds as a lower priority should not be construed to mean that sampling should be immediately discontinued in those areas or that the priority status of those sub-watersheds cannot change over time.

The second caveat is that while a compelling case can be made to focus management efforts solely on critical high flow priority areas based on the concept that high flow tributaries contribute more TP to the lake than low flow tributaries, it remains important to consider management actions in critical low flow priority areas because:

- Localized TP impacts may be enhanced in parts of the lake near those streams.
- Impacted stream habitat may be ecologically tied to near-shore lake habitat.
- Low flow sub-watersheds tend to be relatively small and manageable, potentially with fewer and/or more evident phosphorous sources.
- Cumulative flow from several of the smaller streams could potentially be equivalent to the flow in one of the larger streams.
- Excessive TP concentrations and increasing TP trends have been measured at Colburn Hill and Pickerel Brooks and Spruce River.

This concludes our review of water quality in and around Lake Warren as evidenced by historical sampling data. The CRLAC would like to take this opportunity to commend the LWA for their proactive approach to management planning and the LWA VLAP Coordinator for her heartfelt dedication to the sampling program. These types of efforts often are largely under-appreciated but absolutely essential to the process of democratically protecting water resources.

This report was reviewed in detail by Kate Morgan, LWA VLAP Coordinator; Phil Sanford, LWA Weed Watch Coordinator; Lisa Murphy, LWA Management Plan Coordinator for the Southwest Region Planning Commission (SWRPC); and Sara Steiner, VLAP Coordinator for NHDES. The comments received from these reviewers were invaluable and much appreciated.

Thank you for allowing the CRLAC to assist you with this project. Please contact me at 603-835-2328 or heidorn1@sover.net if you have any questions.

Respectfully yours,



Michael A. Heidorn
Professional Geologist

CC: *Kate Morgan, LWA VLAP Coordinator*
Lisa Murphy, SWRPC Senior Planner
Sara Steiner, NHDES VLAP Coordinator
Ted Walsh, NHDES Rivers Program



Attachments:

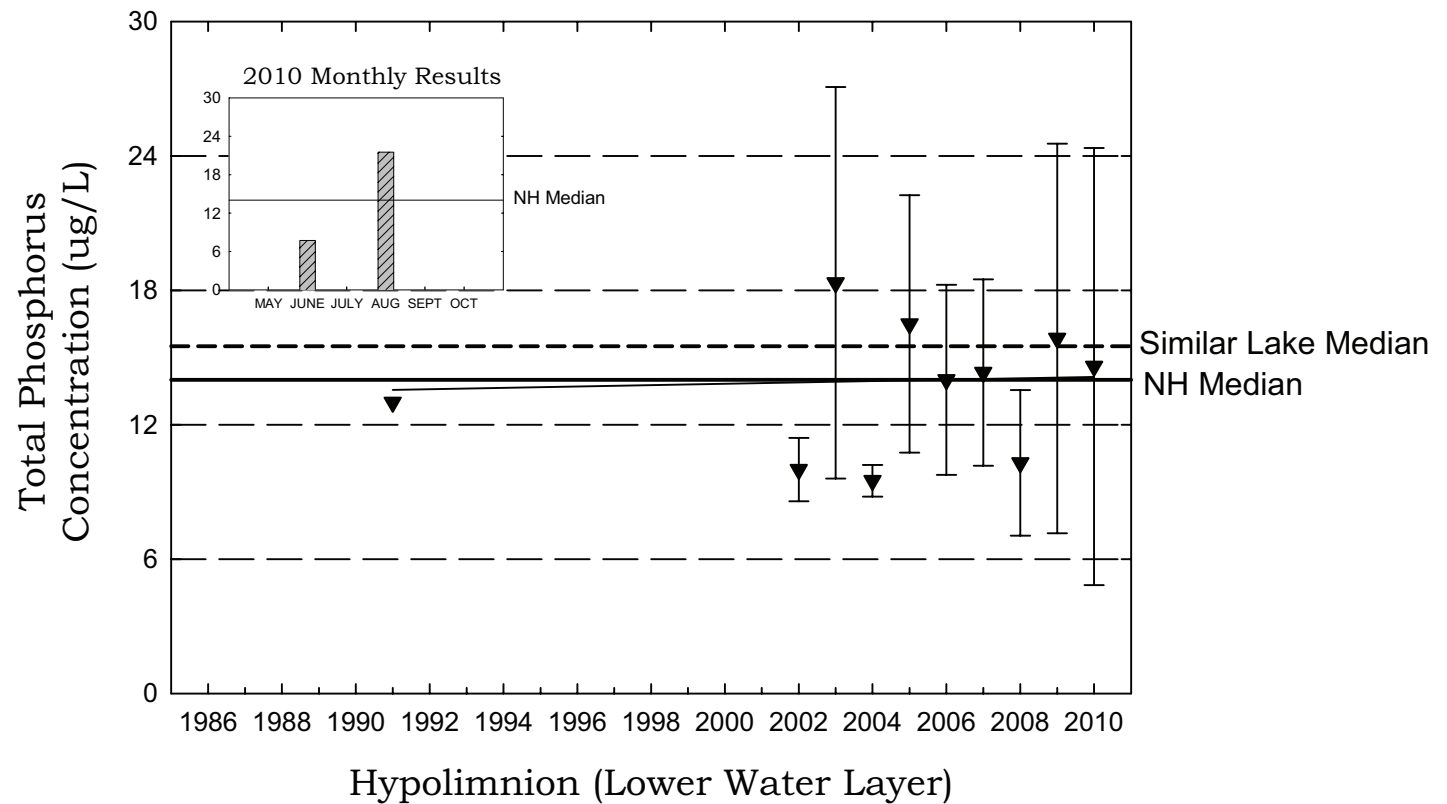
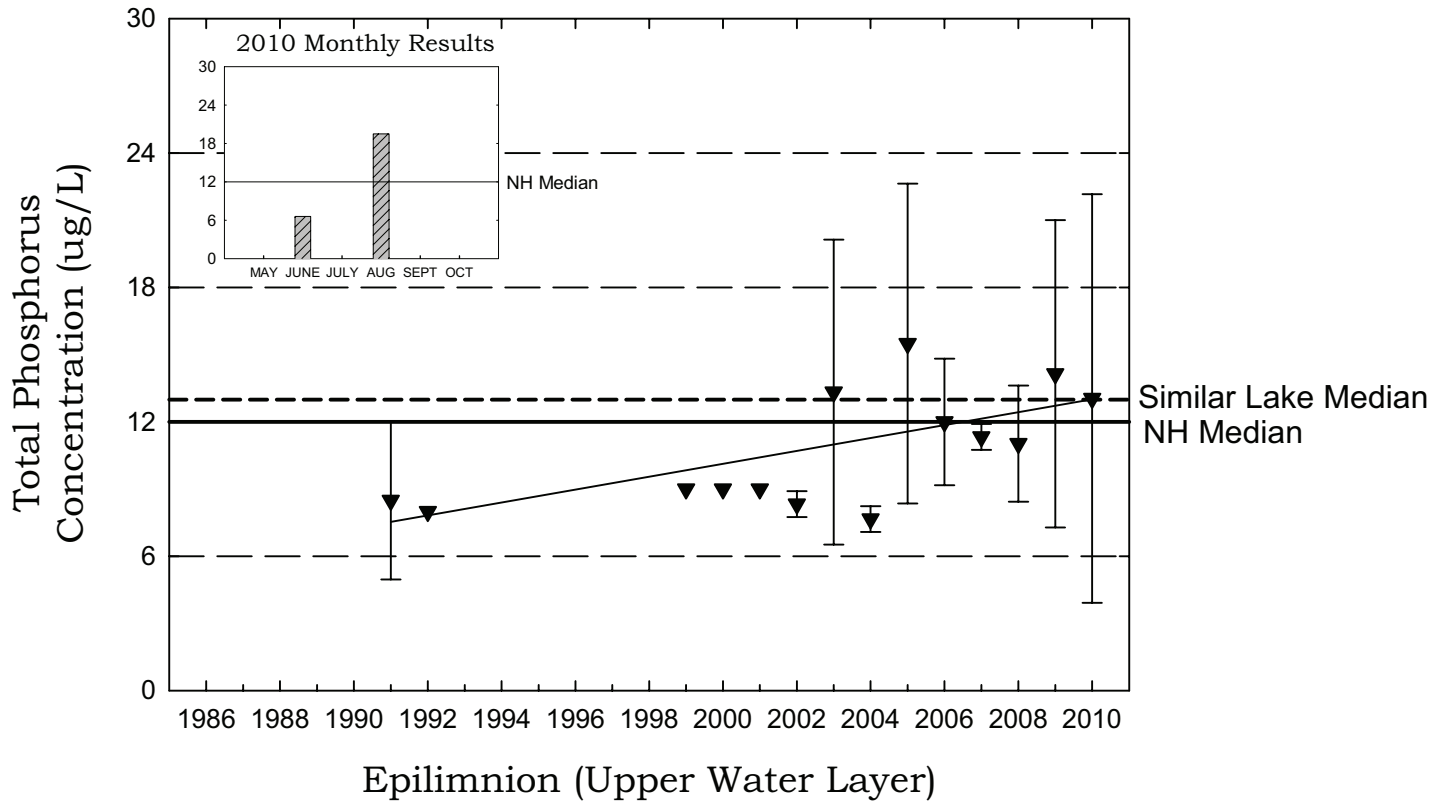
- Attachment A – Lake Water Quality Trend Graphs*
- Attachment B – Sampling Site Index & Map*
- Attachment C – Graphical Summaries of TP, SC, Turbidity & Chloride Data*
- Attachment D – Sub-Watershed TP Impact Prioritization Summary*

ATTACHMENT A

Lake Water Quality Trend Graphs

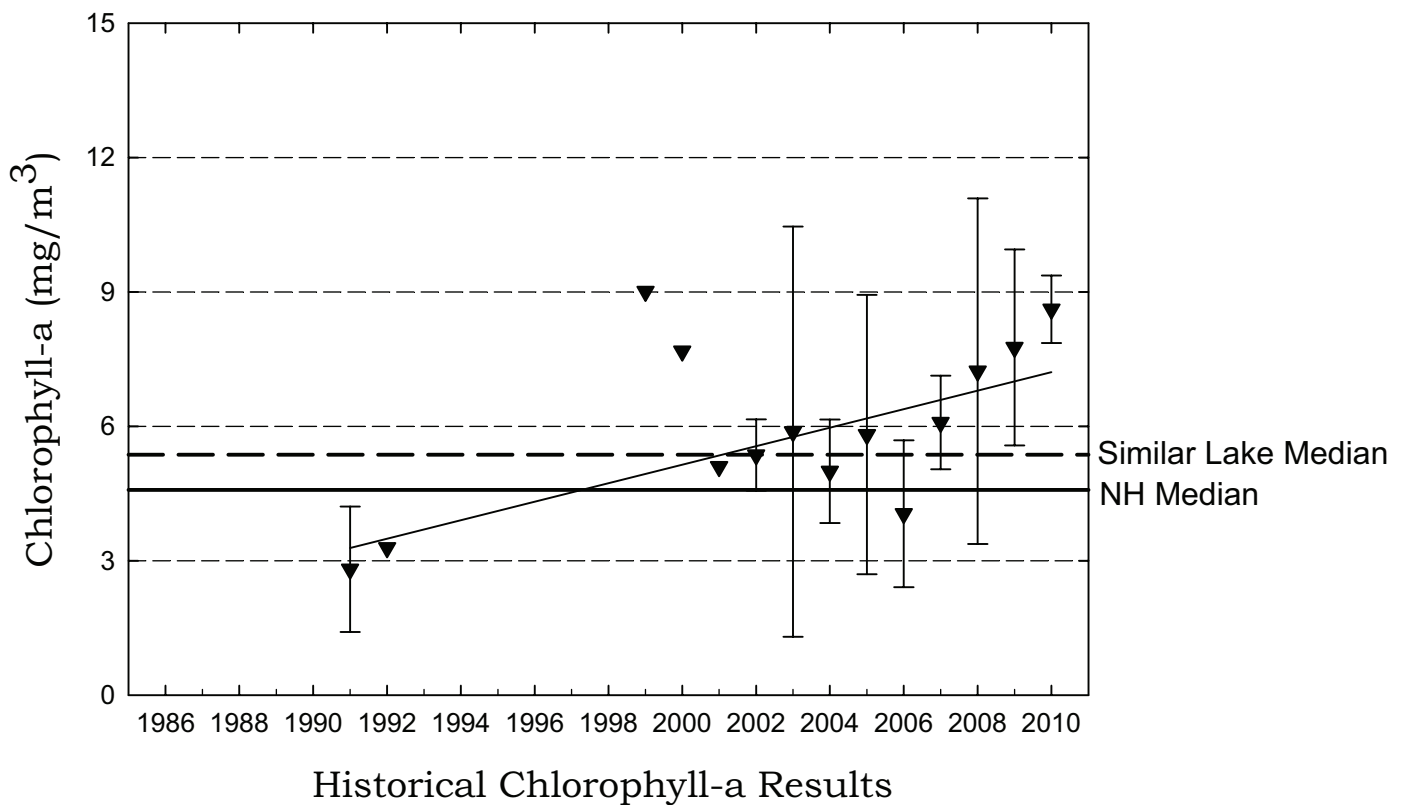
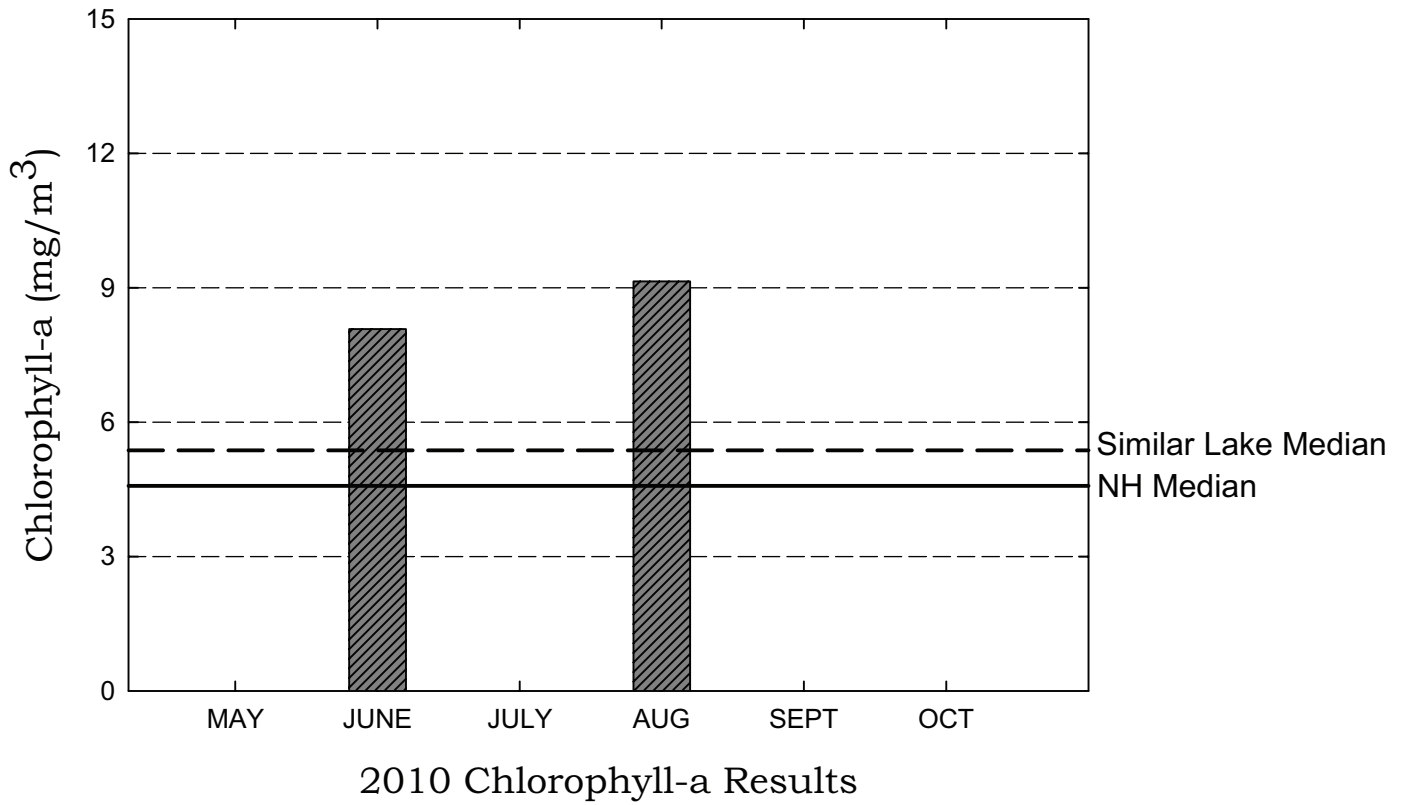
Warren Lake, Alstead

Figure 3. Monthly and Historical Total Phosphorus Data



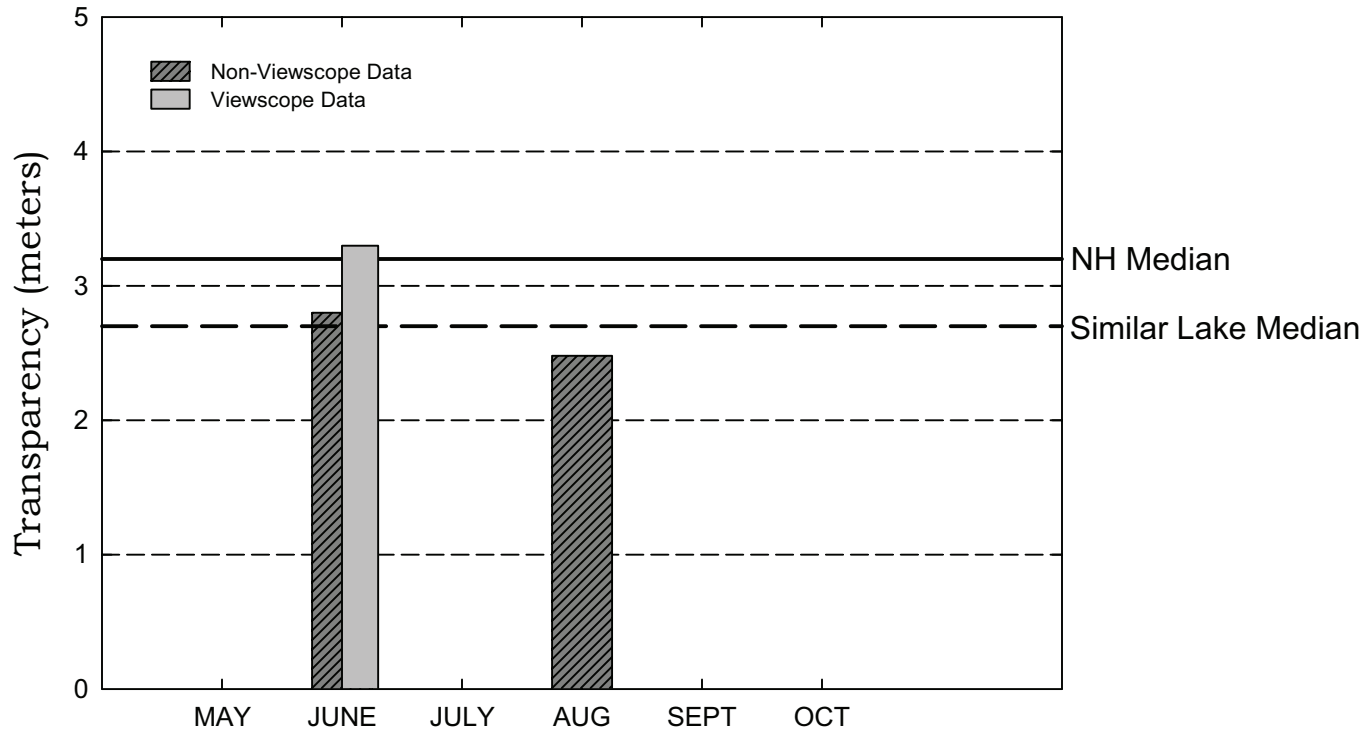
Warren Lake, Alstead

Figure 1. Monthly and Historical Chlorophyll-a Results

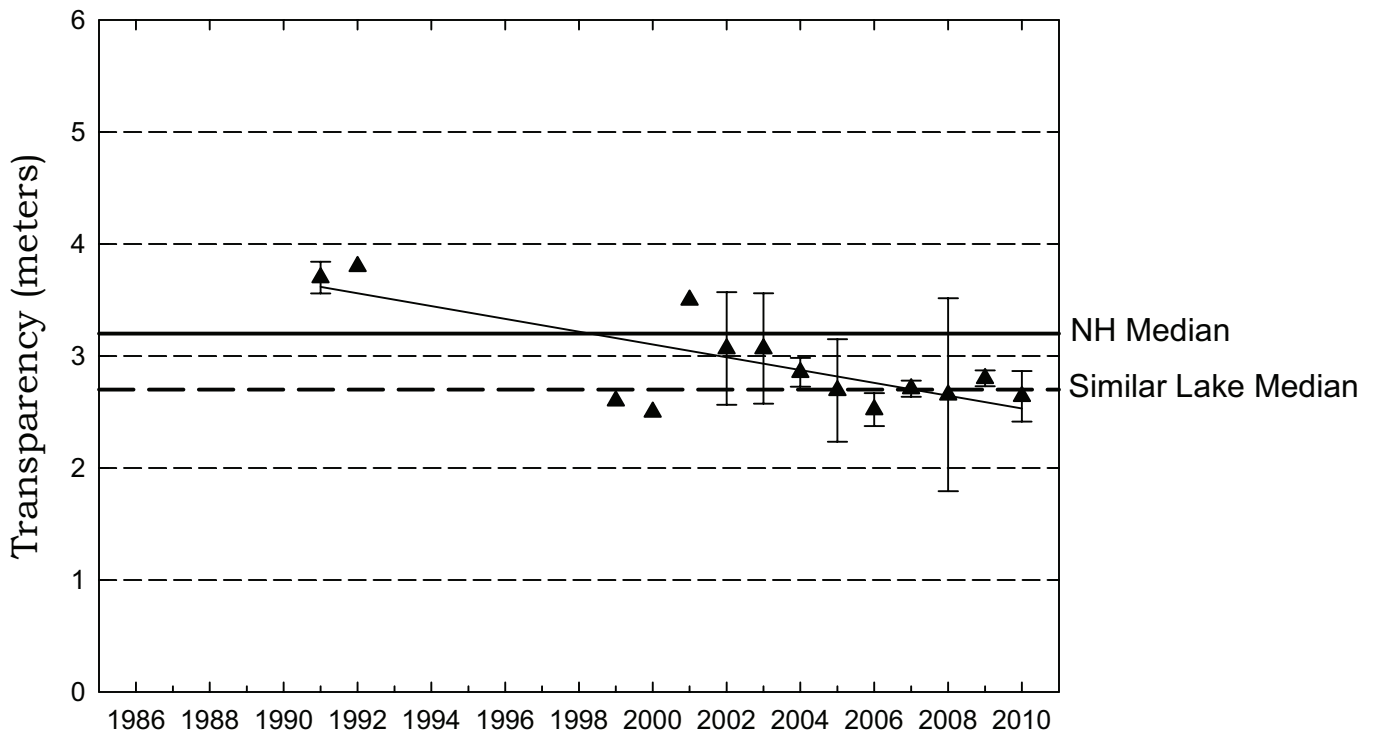


Warren Lake, Alstead

Figure 2. Monthly and Historical Transparency Results

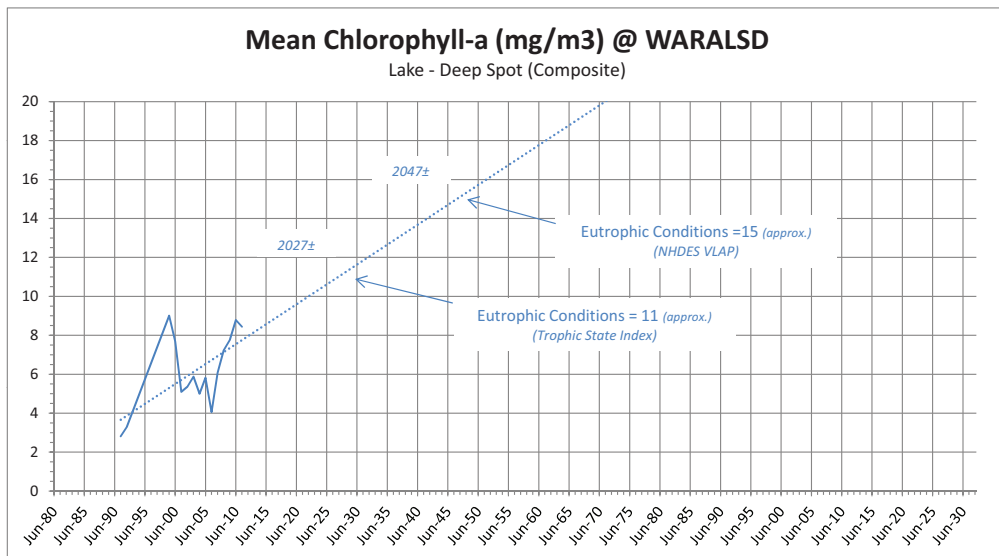
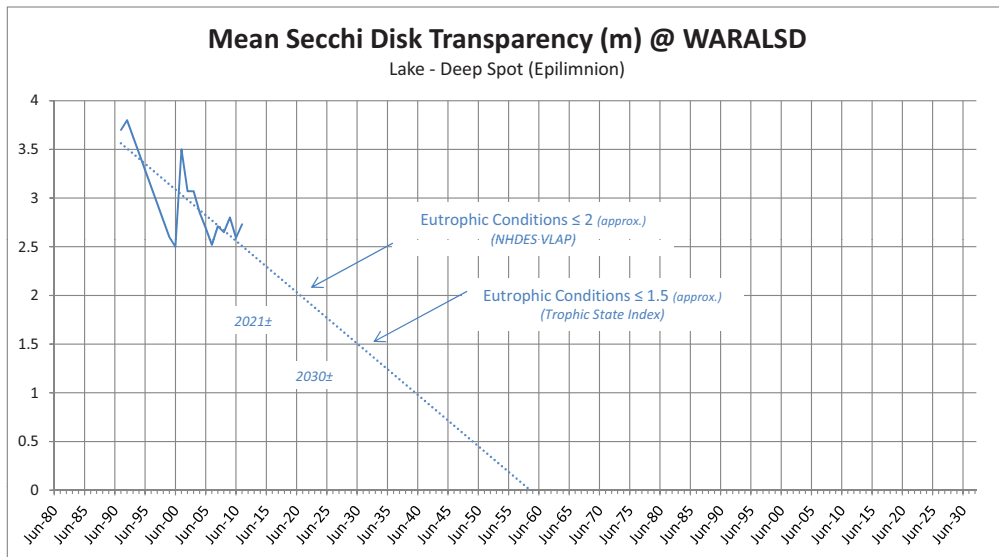
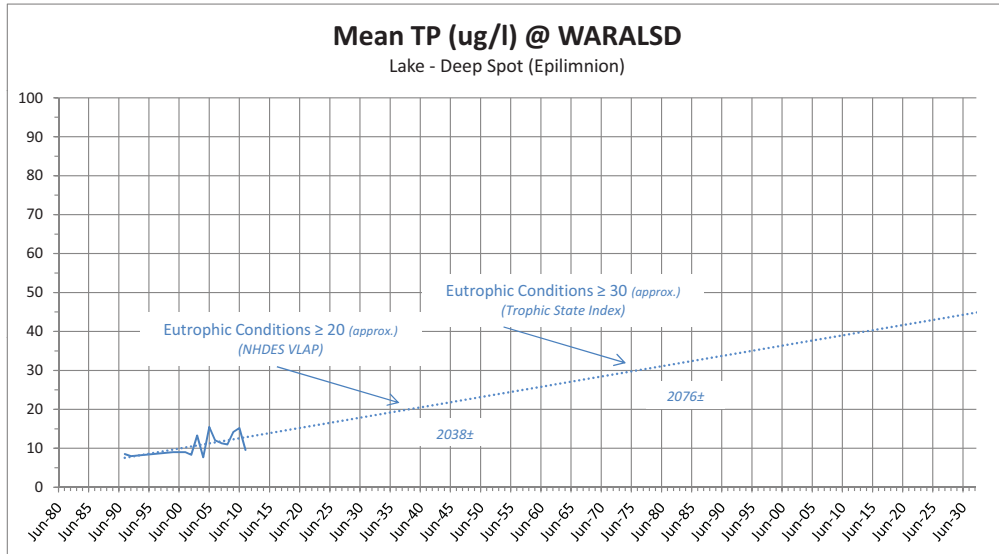


2010 Transparency Viewscope and Non-Viewscope Results



Historical Transparency Non-Viewscope Results

EUTROPHICATION ESTIMATES
Lake Warren, Alstead, NH



Eutrophication and Aquatic Plant Management in Massachusetts

PHYSICAL	"DEFINITE ALGAE"	—————→
APPEARANCE	"HIGH ALGAE"	—————→
> 10% RISK	"SEVERE SCUMS"	—————→
RECREATION	"MINOR AESTHETIC PROB"	—————→
POTENTIAL	"SWIMMING IMPAIRED"	—————→
> 10% RISK	"NO SWIMMING"	—————→

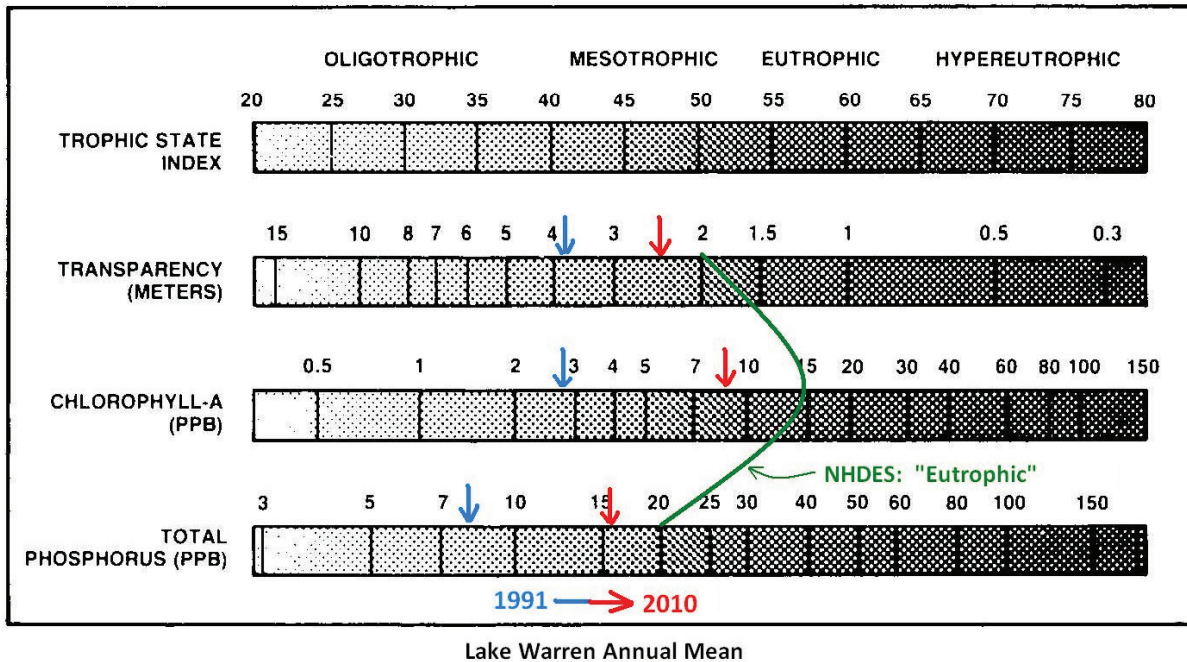


Figure 1-15 Carlson's Trophic State Index related to perceived nuisance conditions (Heiskary and Walker, 1987). Lengths of arrows indicate range over which a greater than 10 percent probability exists that users will perceive a problem.

Excerpted from: *Eutrophication and Aquatic Plant Management in Massachusetts, Final Generic Environmental Impact Report*, MA Executive Office of Environmental Affairs, 2004.

ATTACHMENT B

Sampling Site Index & Map

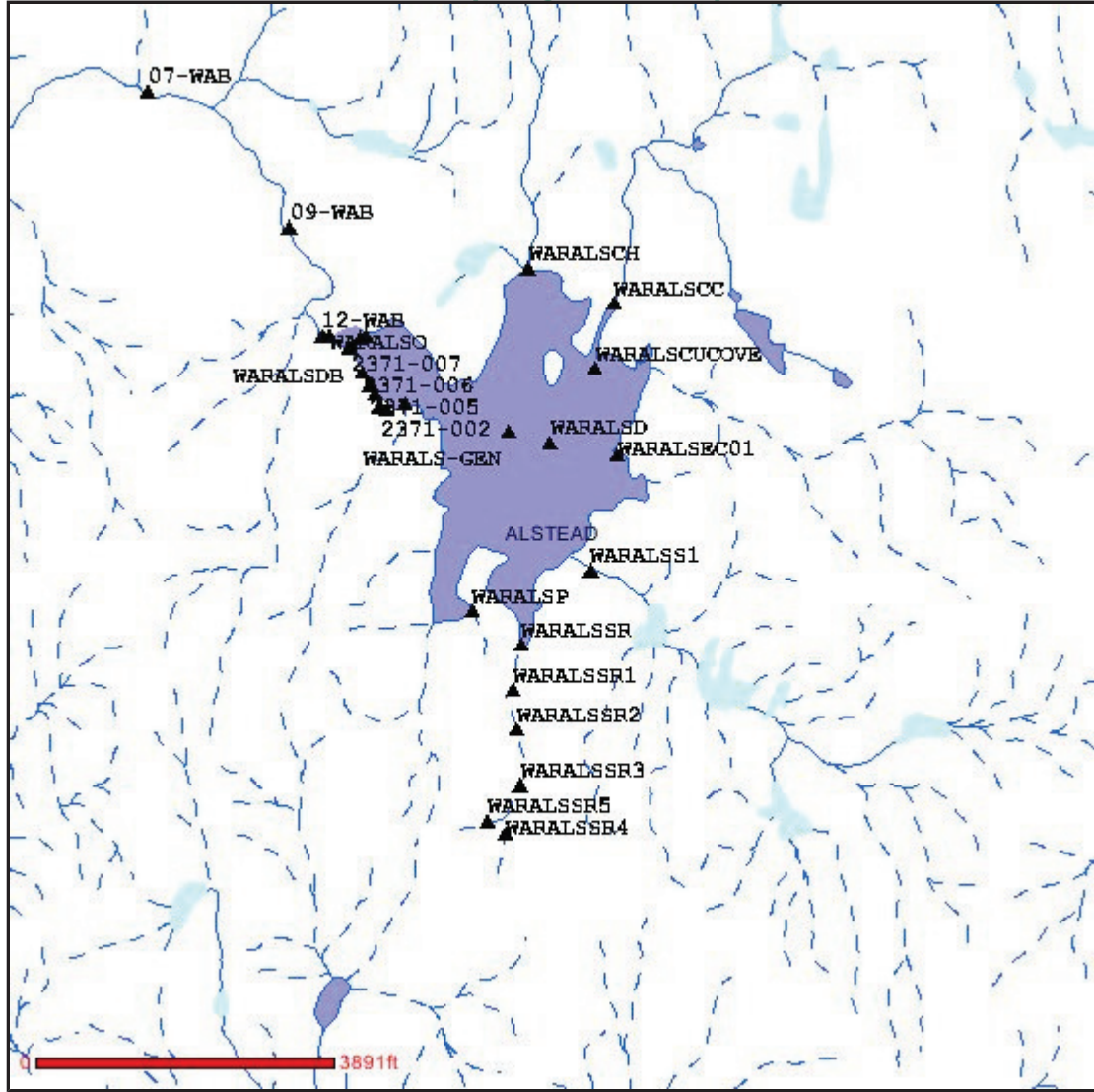
SAMPLING SITE INDEX

Lake Warren, Alstead, NH

<u>NHDES Station ID</u>	<u>NHDES Station Name</u>	<u>Location</u>
2371-001	CULVERT 1 (Wetland Culvert #9)	Culvert
2371-003	CULVERT 3 (Wetland Culvert #8)	Culvert
2371-004	CULVERT 4 (Wetland Culvert #7)	Culvert
2371-006	CULVERT 6 (Wetland Culvert #5)	Culvert
2371-007	CULVERT 7 (24-inch Plastic Pipe)	Culvert
WARALSEC01	BACTERIA SAMPLE #01	Lake
WARALSEC02	BACTERIA SAMPLE #02	Lake
WARALSBL	BOAT LANDING	Lake
WARALSCUCOVE	CURLL COVE	Lake
WARALSD	DEEP SPOT	Lake
WARALSEB	EDITHS BEACH	Lake
WARALS-GEN	GENERIC	Lake
WARALSLS	LAWLOR SHORE	Lake
WARALSRC	RAWSON COVE	Lake
WARALSRED	RED HOUSE	Lake
WARALSSL	SHADOWLANDS	Lake
WARALSSB	SPENCER BEACH	Lake
WARALSO	OUTLET	Outlet
12-WAB	PRENTICE HILL ROAD BRIDGE	Outlet
WARALSCC	CARMEN COVE (Hale) BROOK	Tributary
WARALSCH	COLBURN HILL BROOK	Tributary
WARALSDB	DAM BROOK	Tributary
WARALSP	PICKEREL COVE BROOK	Tributary
WARALSSY	SCOTLAND YARD	Tributary
WARALSS1	SMITH HILL BROOK	Tributary
WARALSSR	SPRUCE RIVER	Tributary
WARALSSR1	SPRUCE RIVER 1	Tributary
WARALSSR2	SPRUCE RIVER 2	Tributary
WARALSSR3	SPRUCE RIVER 3	Tributary
WARALSSR4	SPRUCE RIVER 4	Tributary
WARALSSR5	SPRUCE RIVER 5	Tributary



OneStop Program GIS Map



- Legend**
- ▲ Environmental Monitoring Site*
 - ~ River, stream
 - - - Intermittent stream
 - Open water
 - Wetland
 - - - Town Boundary
 - - - County Boundary
 - - - State Boundary

Map Scale = 1 : 51581 (1" = 0.8 miles or 4298 feet)

The information contained in the OneStop Program GIS is the best available according to the procedures and standards of each of the contributing programs and of the GIS. The different programs are regularly maintaining the information in their databases. As a result, the GIS may not always provide access to all existing information, and it may occasionally contain unintentional inaccuracies. The Department can not be responsible for the misuse or misinterpretation of the information presented by this system.

Map prepared 5/10/2011 4:06:29 PM



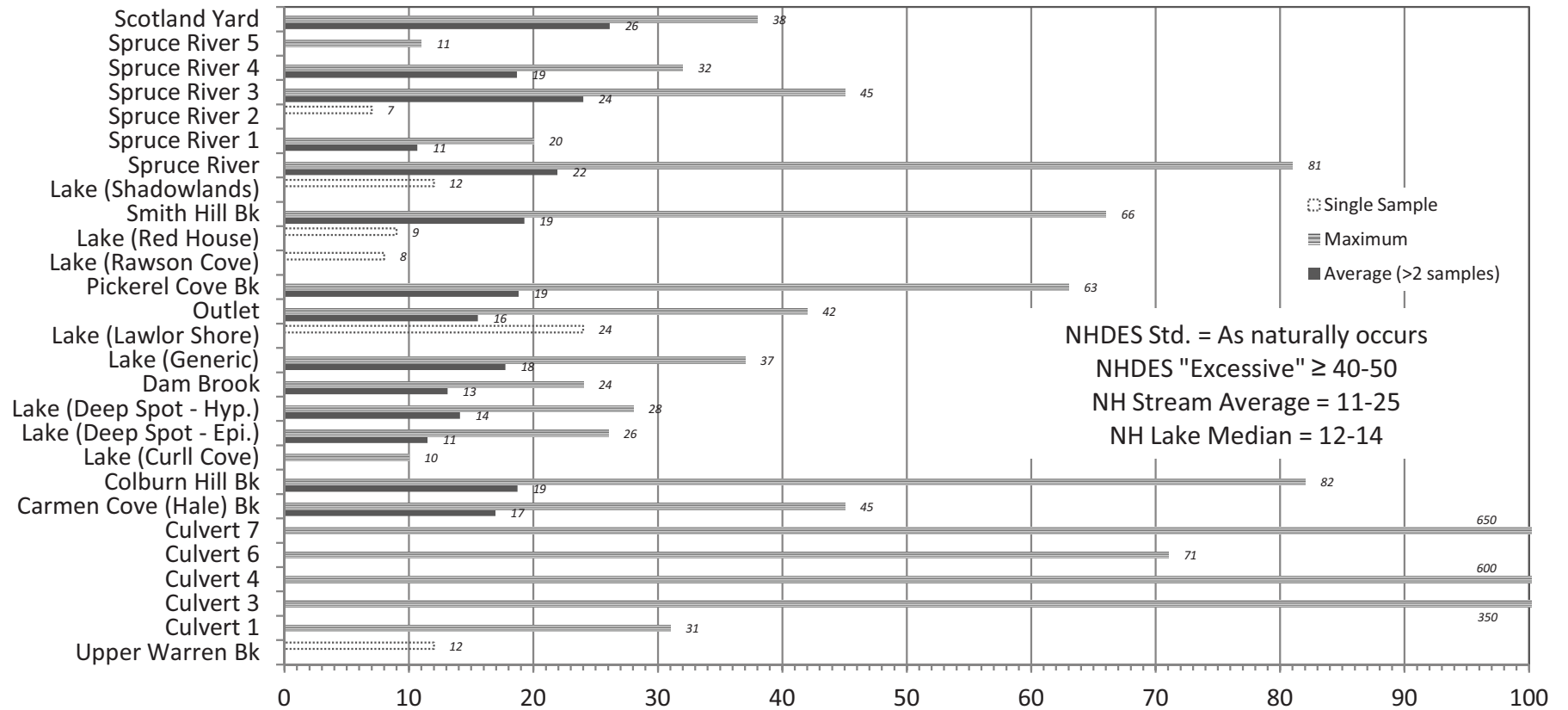
Developed in
cooperation with
NH GRANIT

ATTACHMENT C

Graphical Summaries of TP, SC, Turbidity & Chloride Data

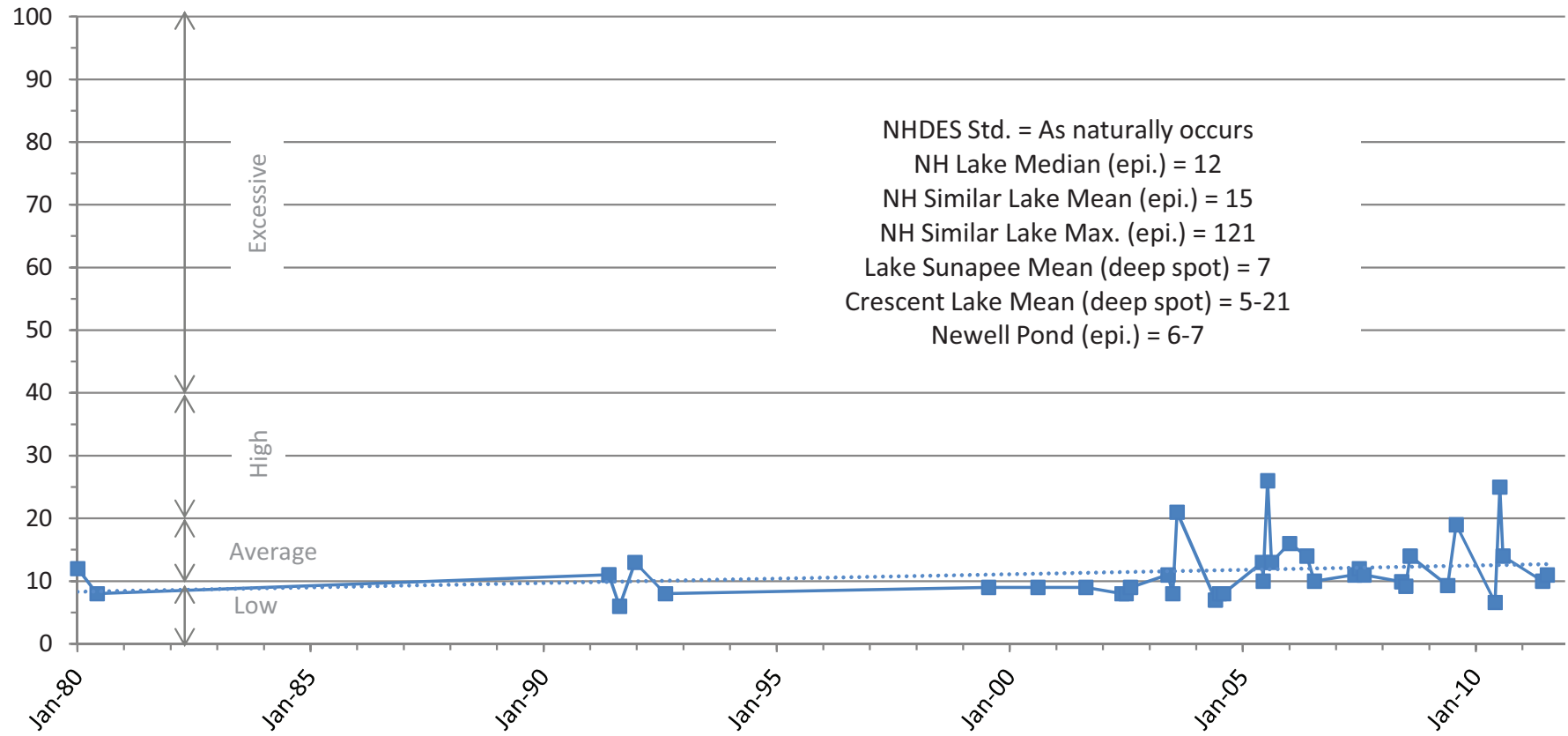
TP (ug/l) @ Lake Warren Sites

1980 - 2011



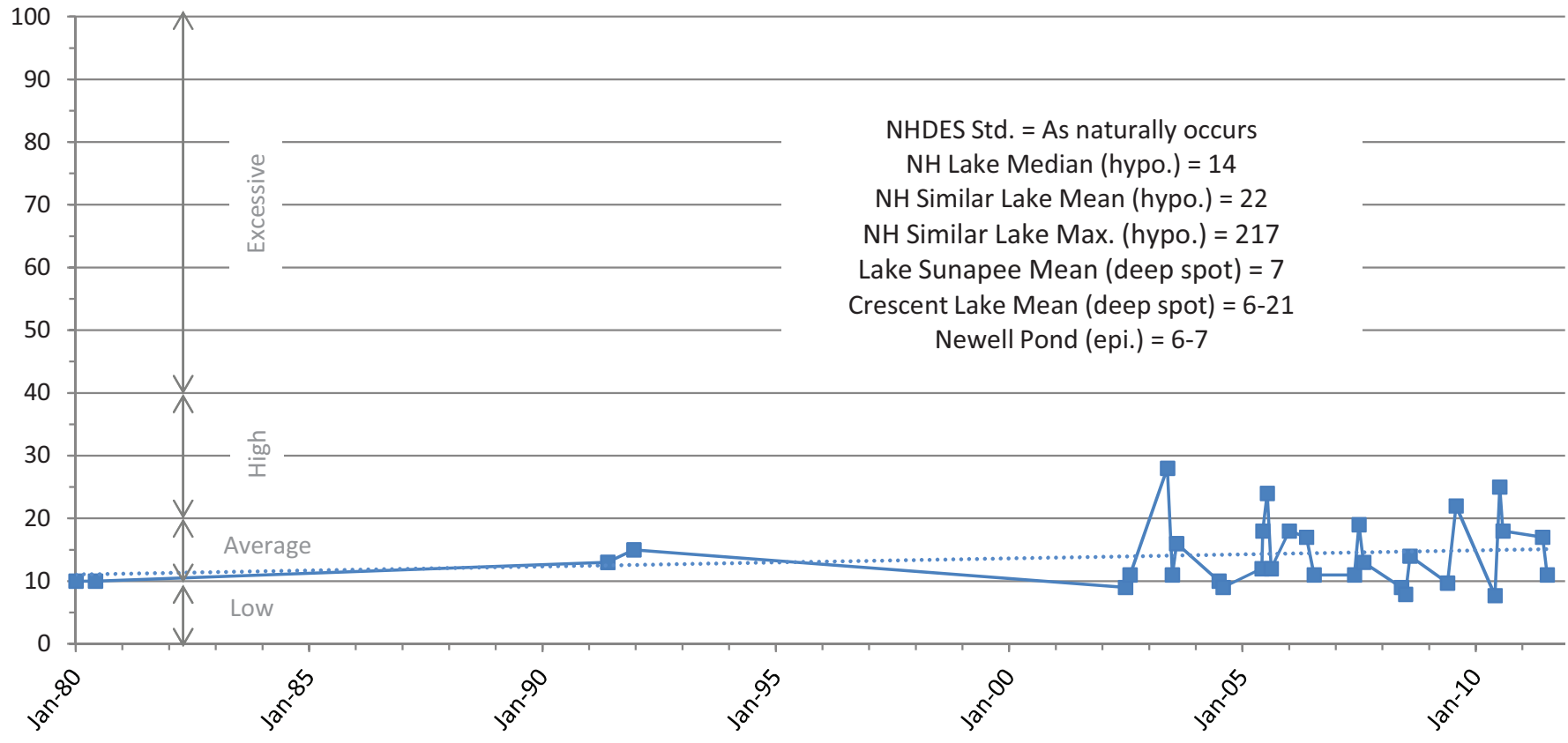
TP (ug/l) @ WARALSD

Lake - Deep Spot (Epilimnion)



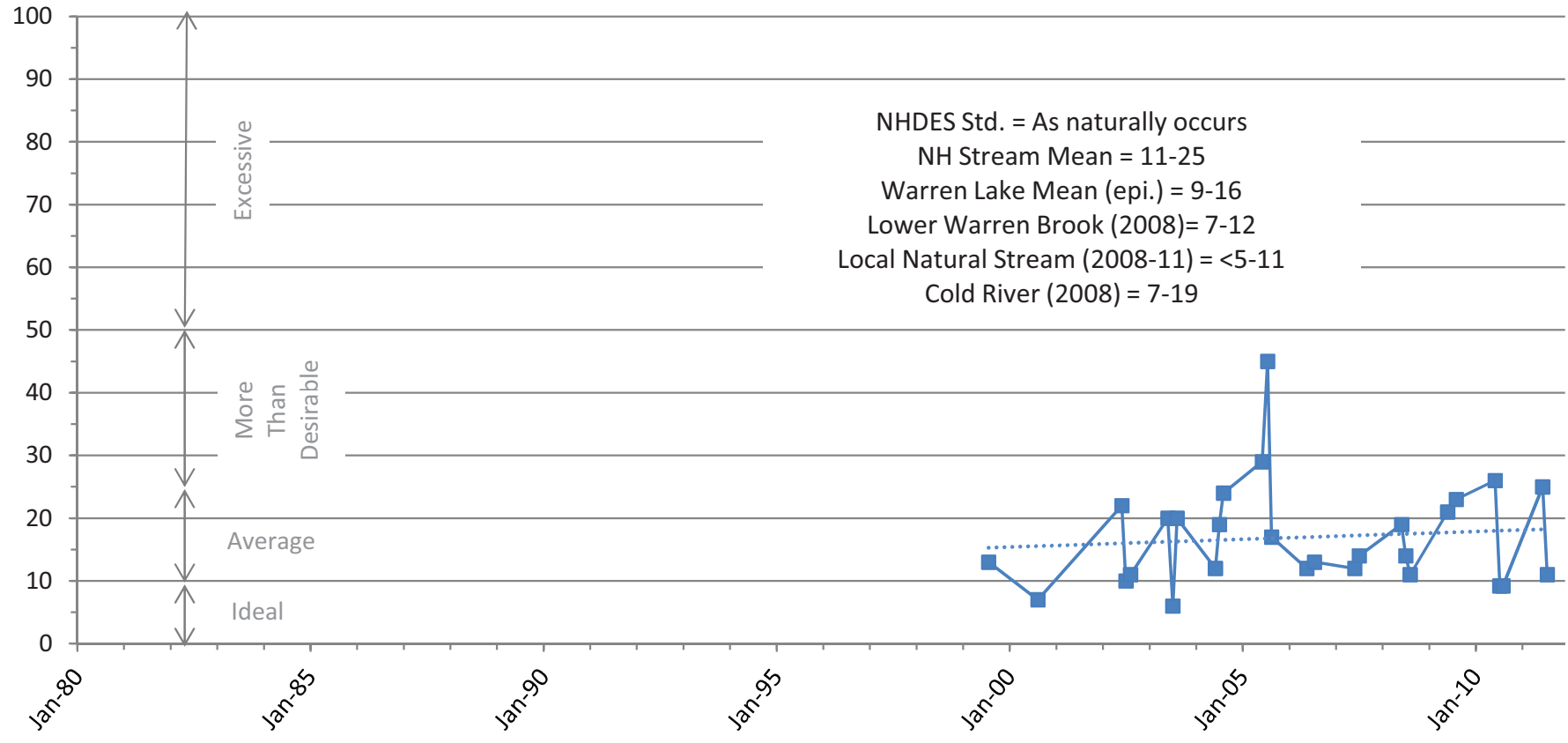
TP (ug/l) @ WARALSD

Lake - Deep Spot (Hypolimnion)



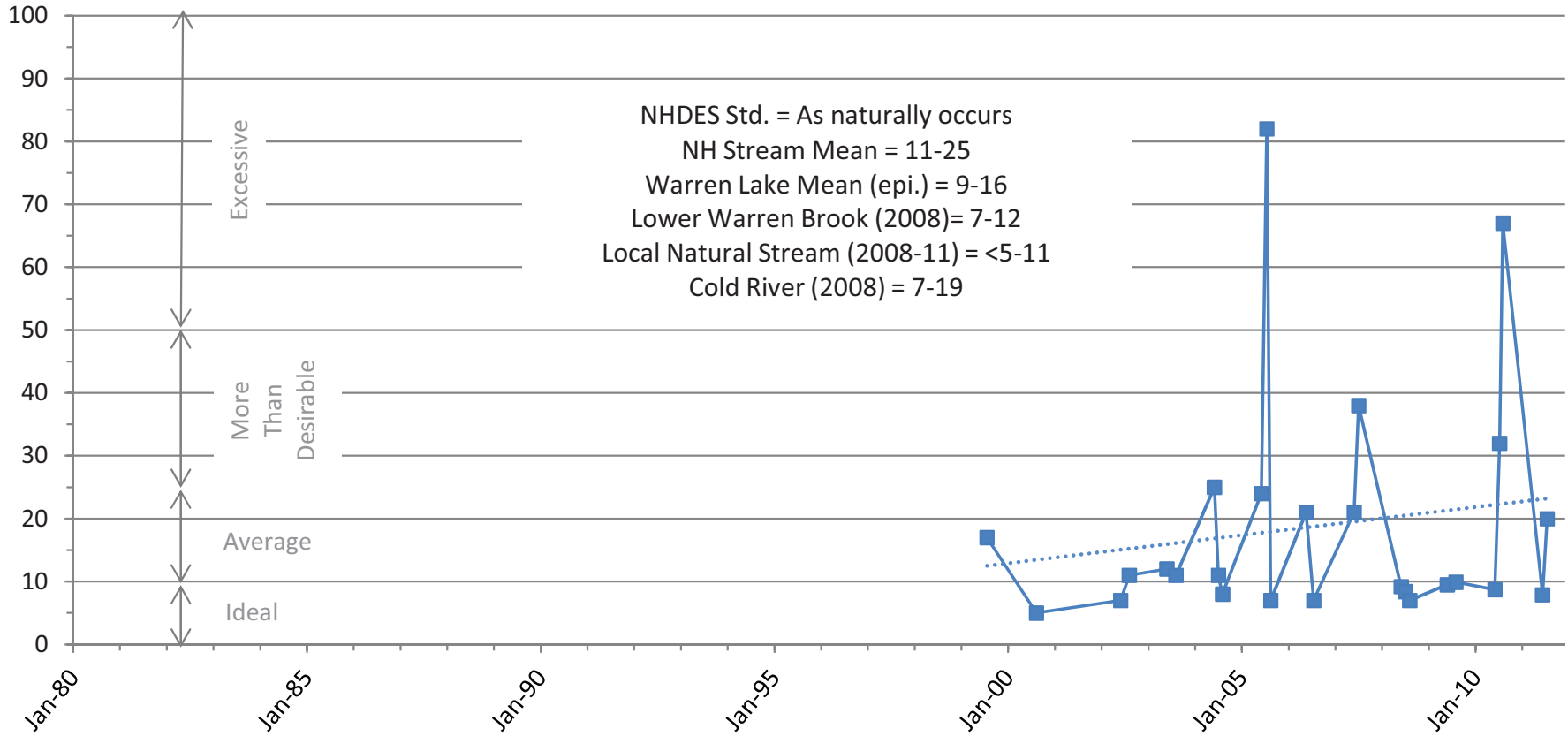
TP (ug/l) @ WARALSCC

Trib - Carmen Cove (Hale) Brook



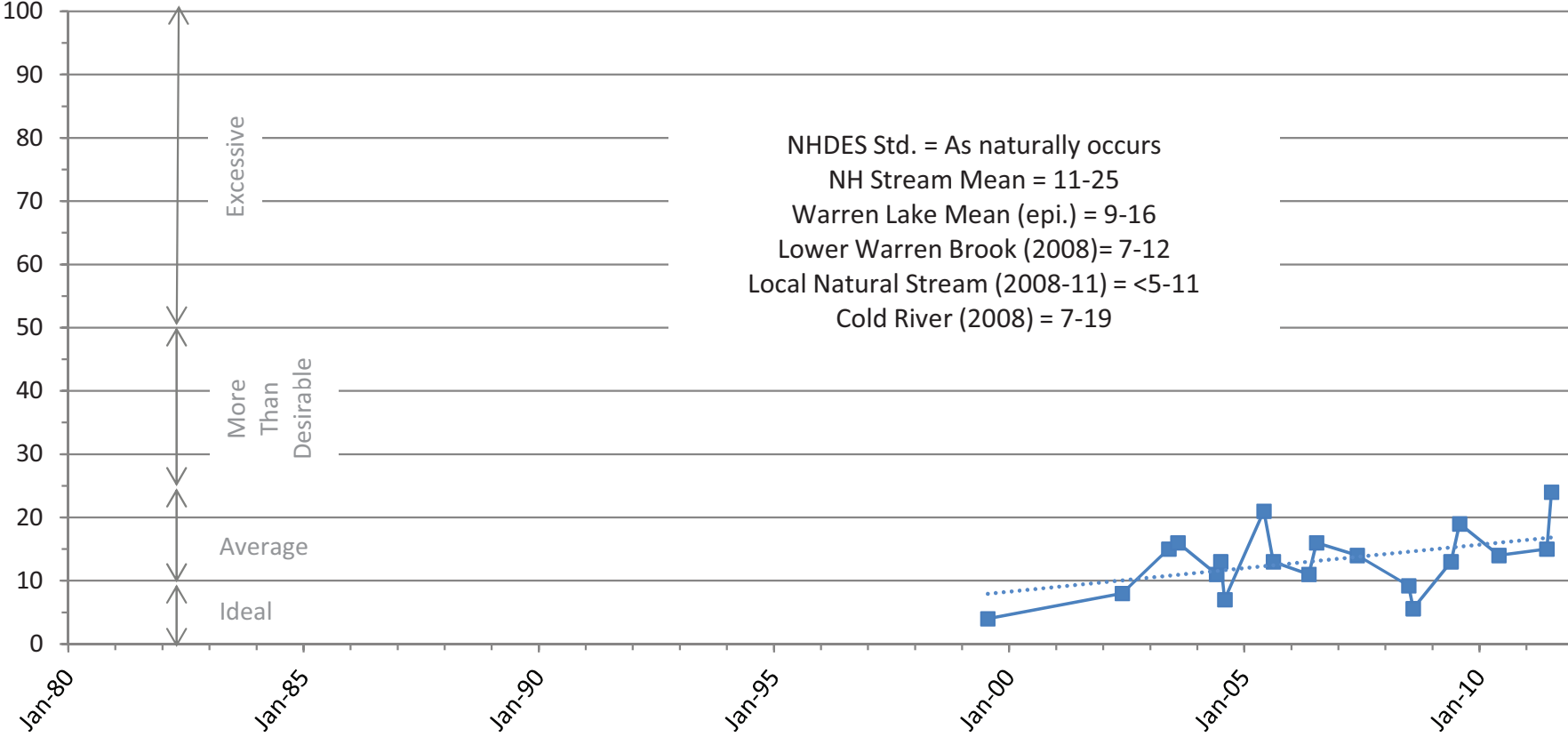
TP (ug/l) @ WARALSCH

Trib - Colburn Hill Brook



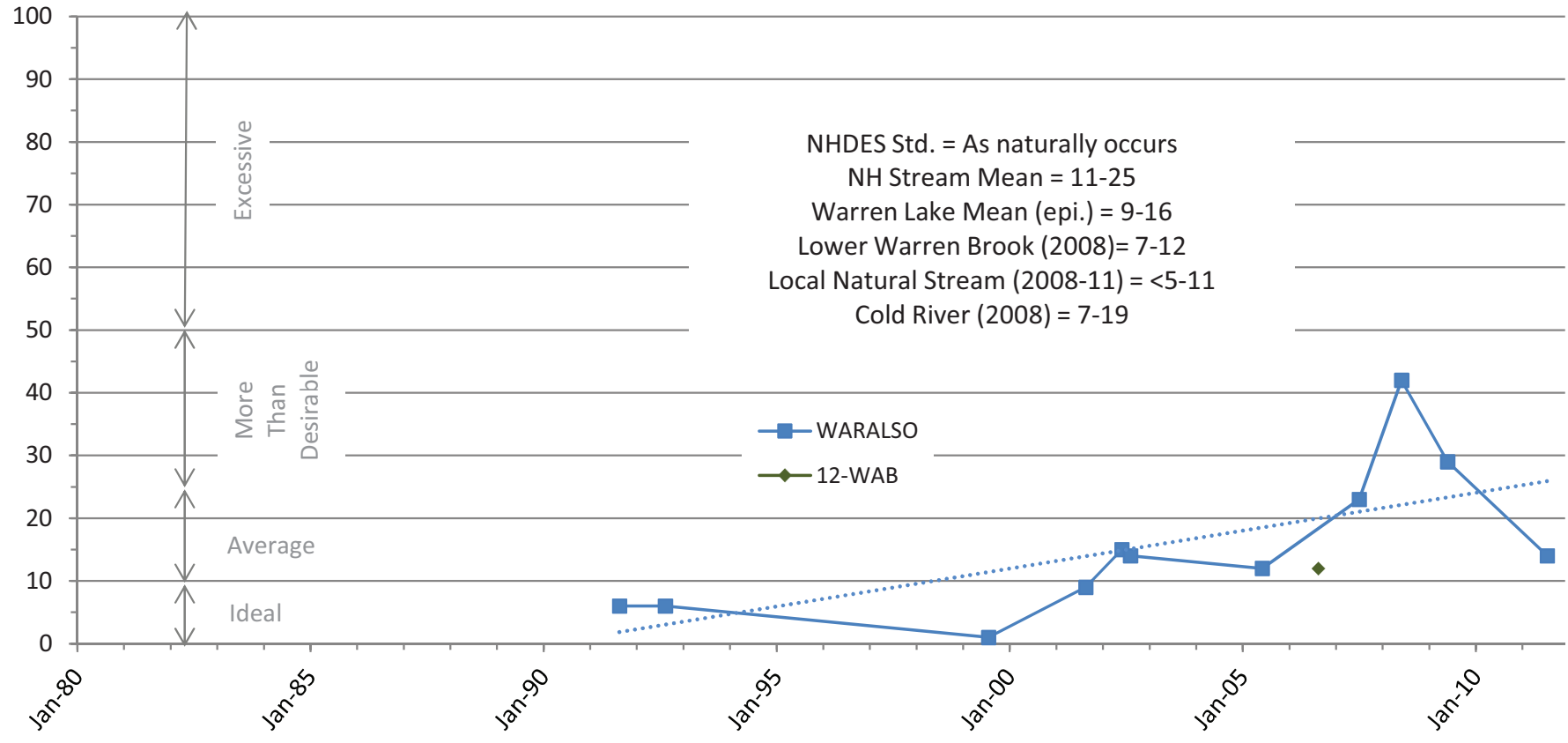
TP (ug/l) @ WARALSDB

Trib - Dam Brook



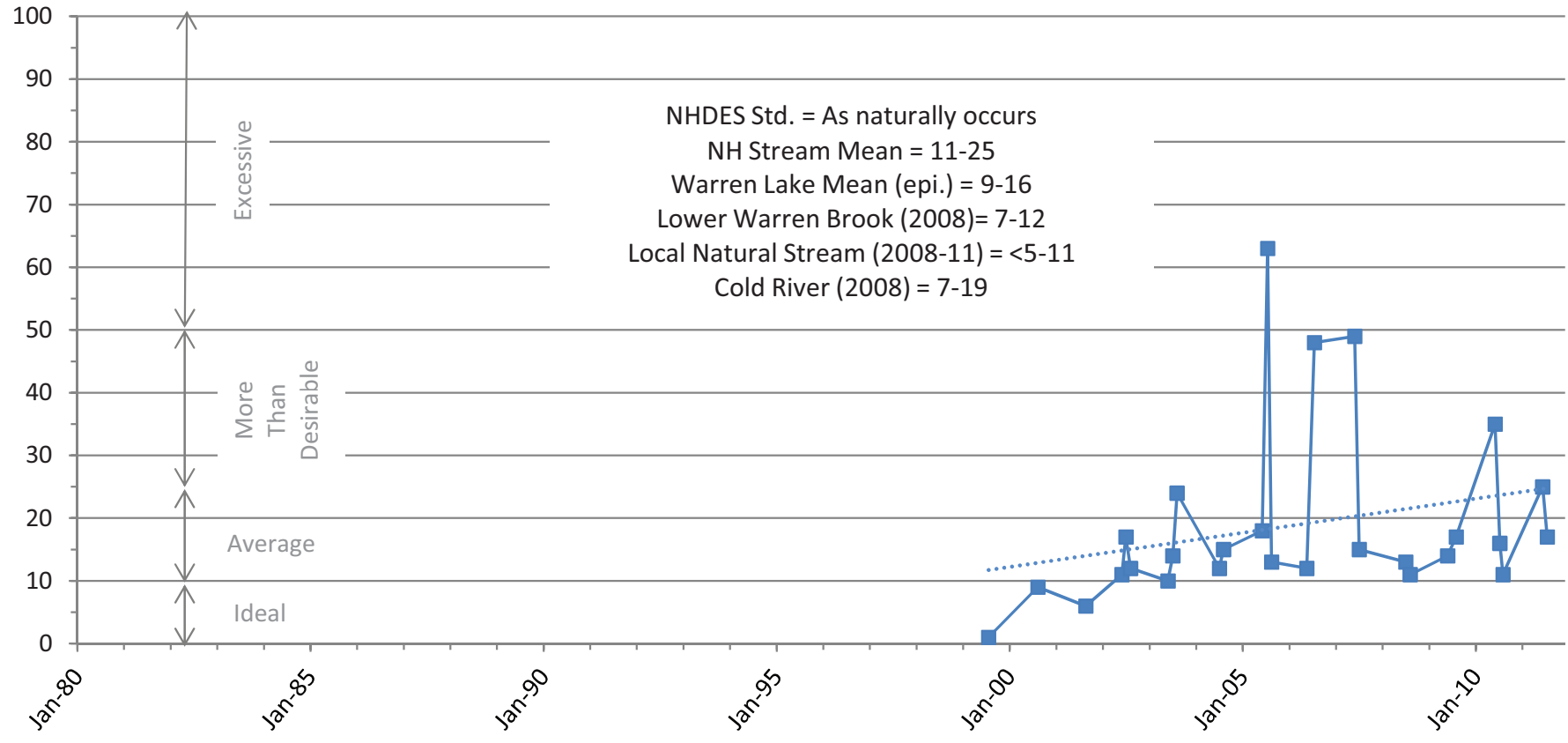
TP (ug/l) @ WARALSO/12-WAB

Trib - Outlet / Upper Warren Brook



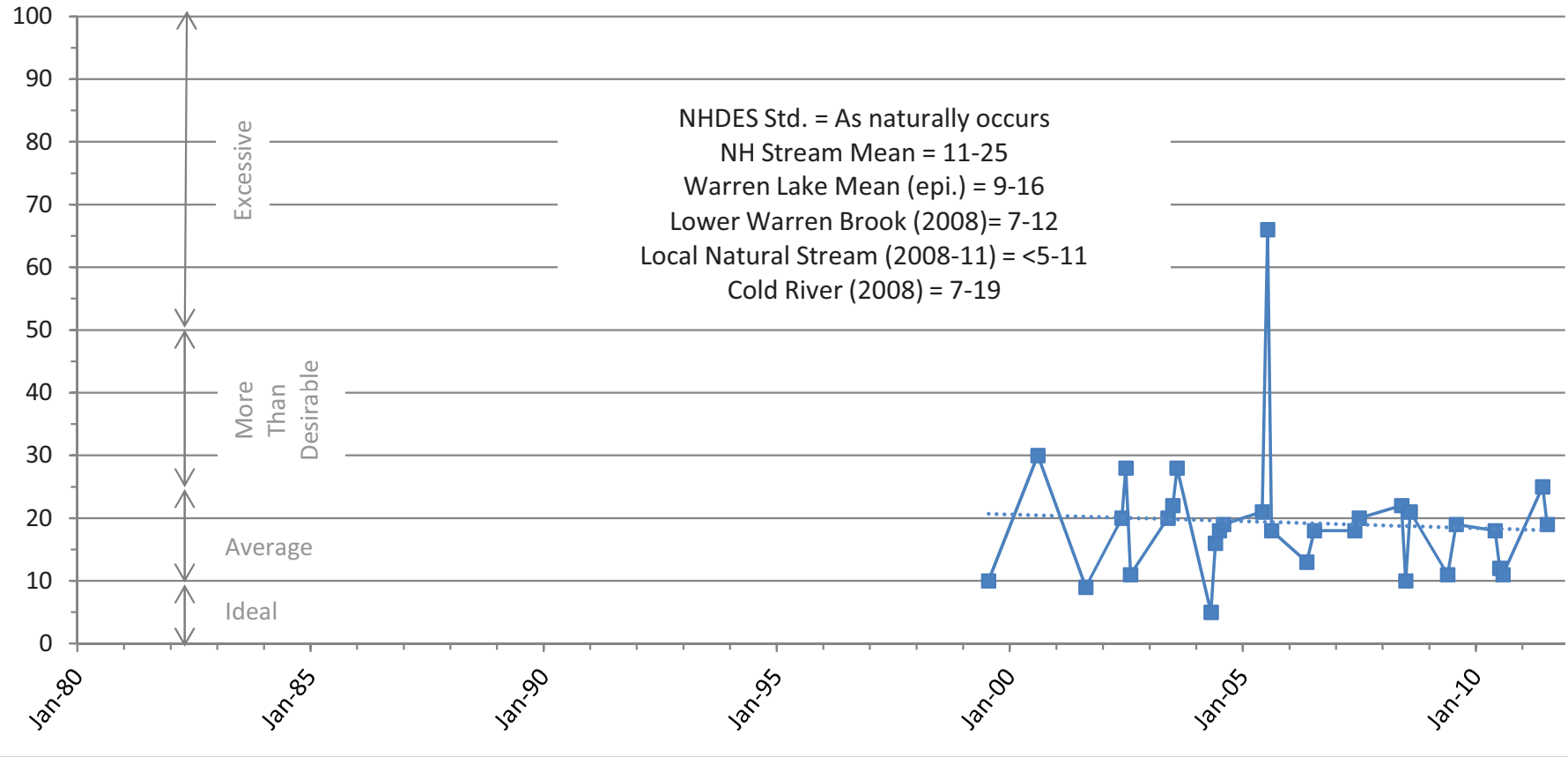
TP (ug/l) @ WARALS

Trib - Pickerel Cove Brook



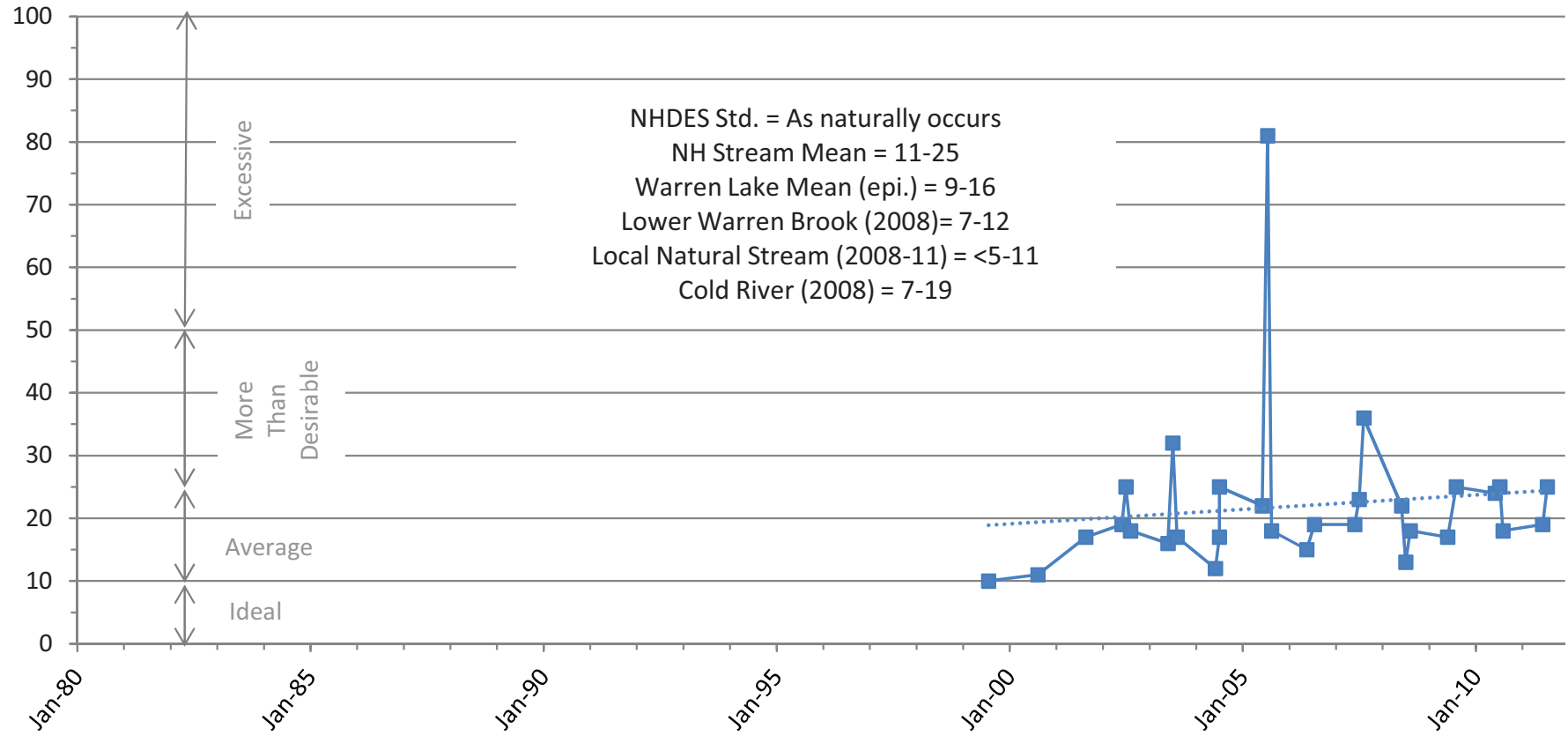
TP (ug/l) @ WARALSS1

Trib - Smith Hill Brook



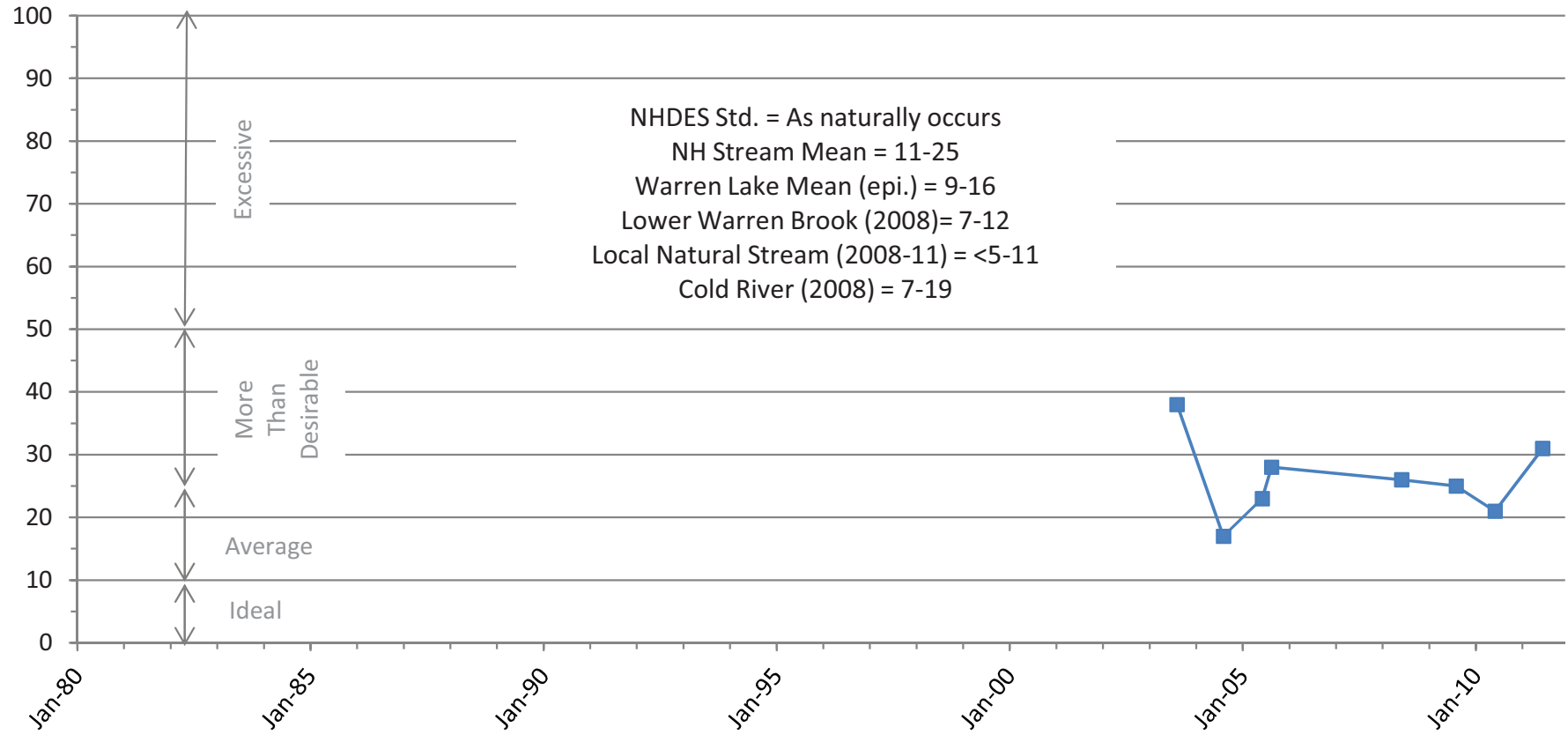
TP (ug/l) @ WARALSSR

Trib - Spruce River



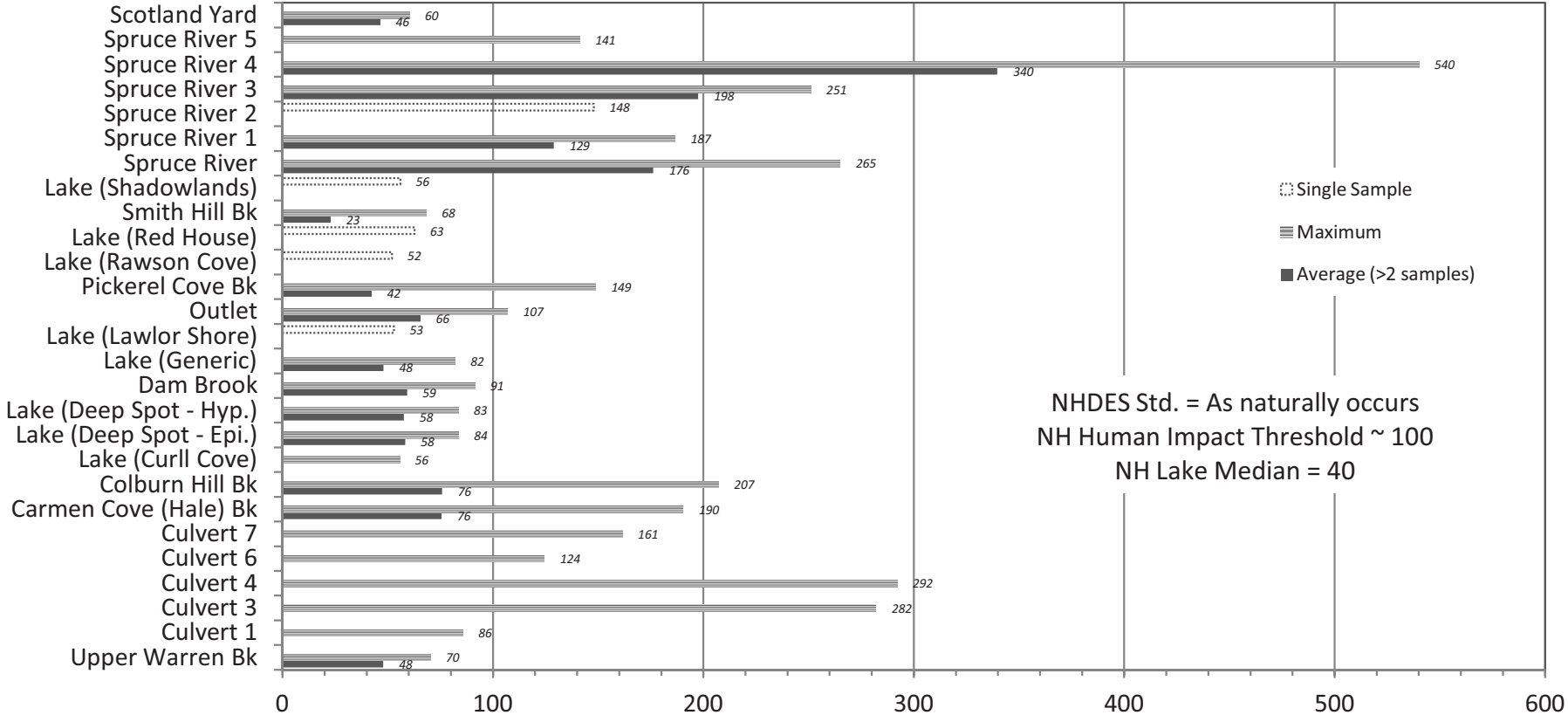
TP (ug/l) @ WARALSSY

Trib - Scotland Yard



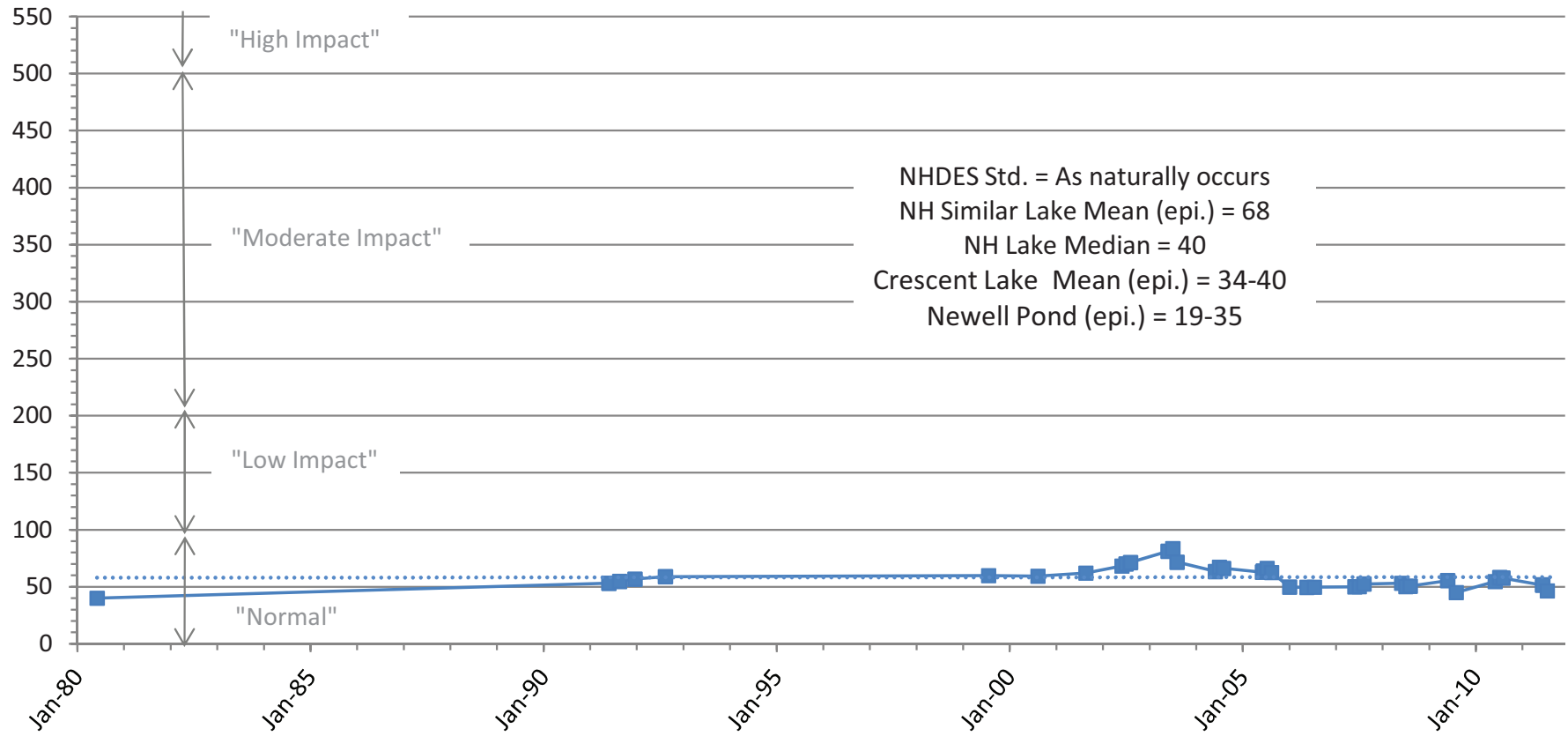
SC (umhos/cm) @ Lake Warren Sites

1980 - 2011



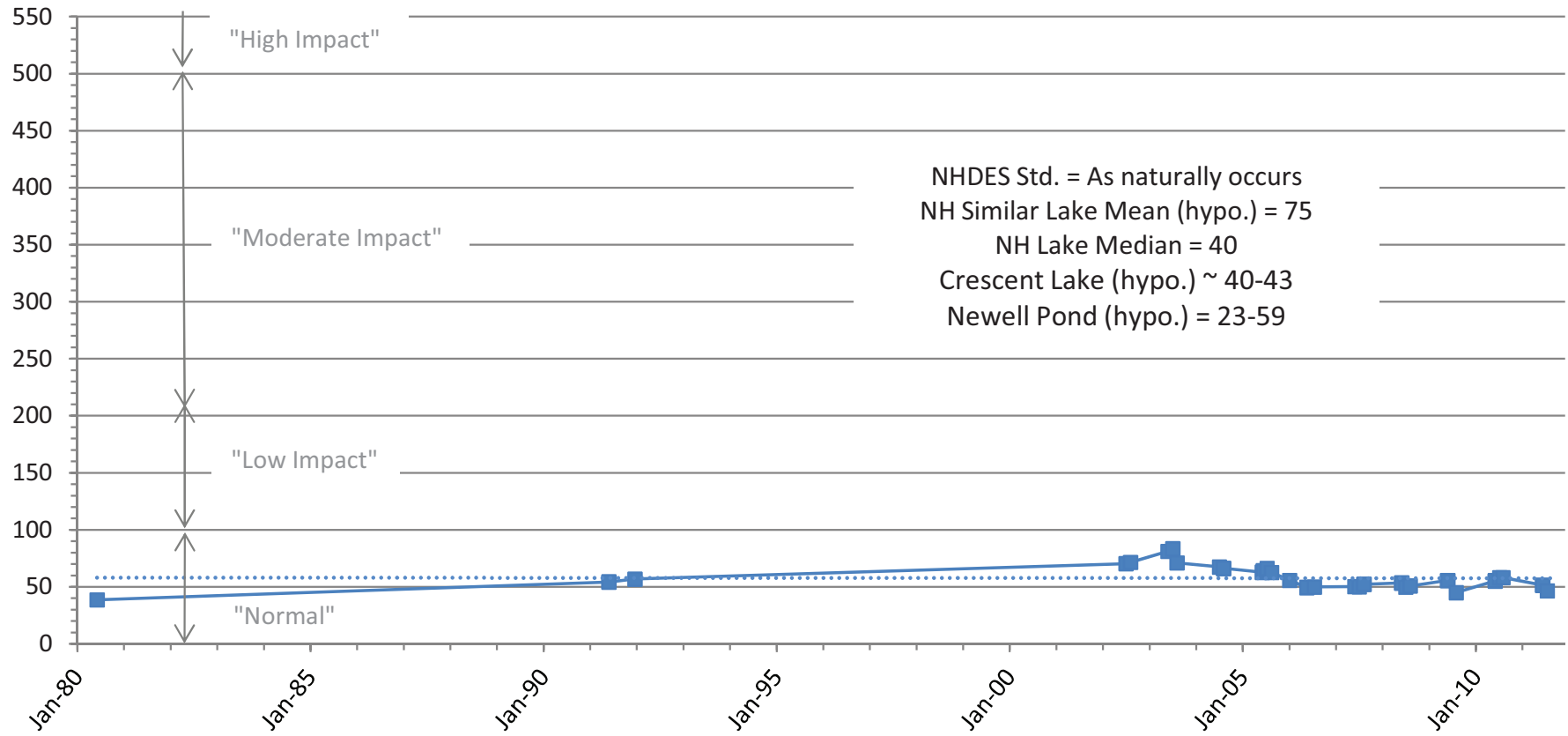
SC (umhos/cm) @ WARALSD

Lake - Deep Spot (Epilimnion)



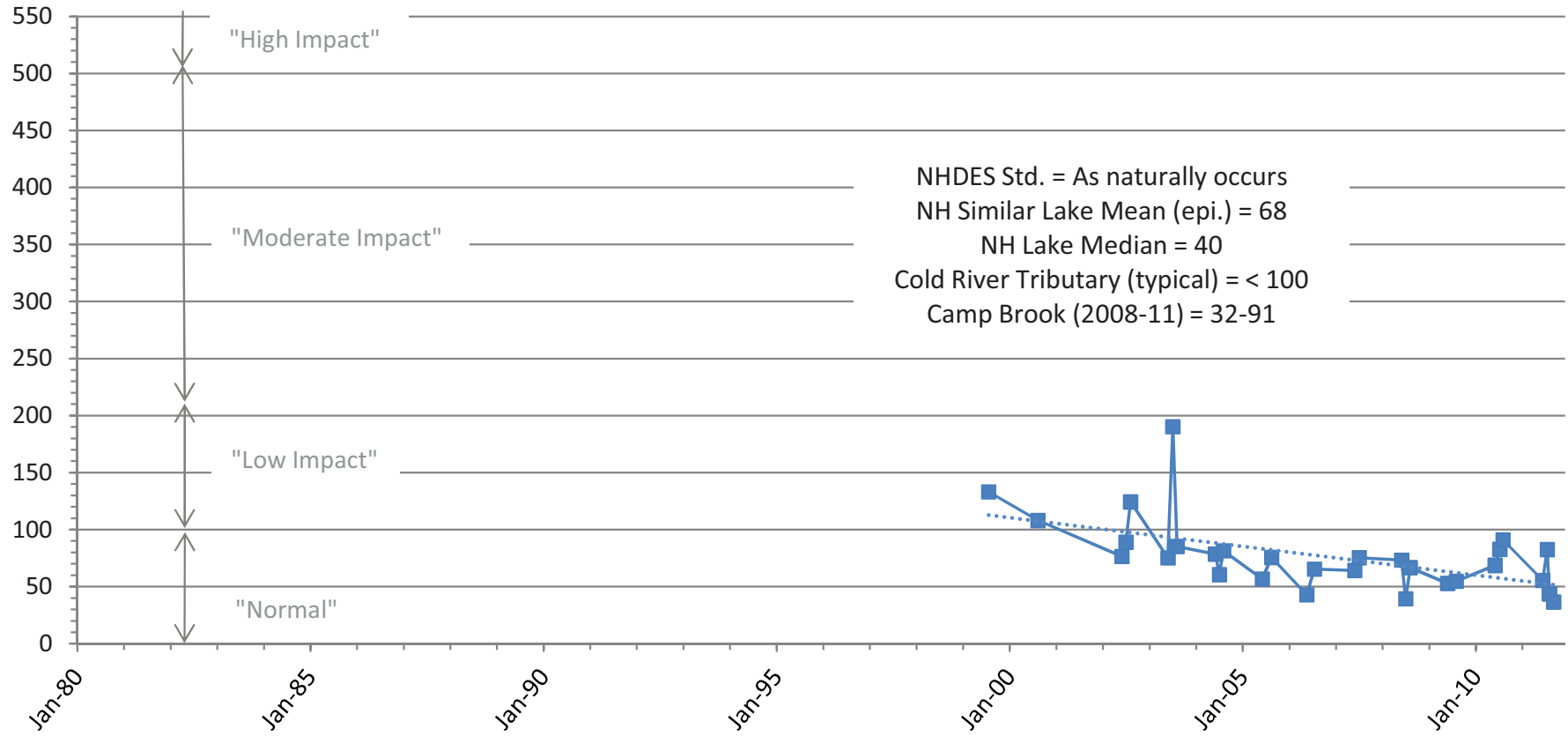
SC (umhos/cm) @ WARALSD

Lake - Deep Spot (Hypolimnion)



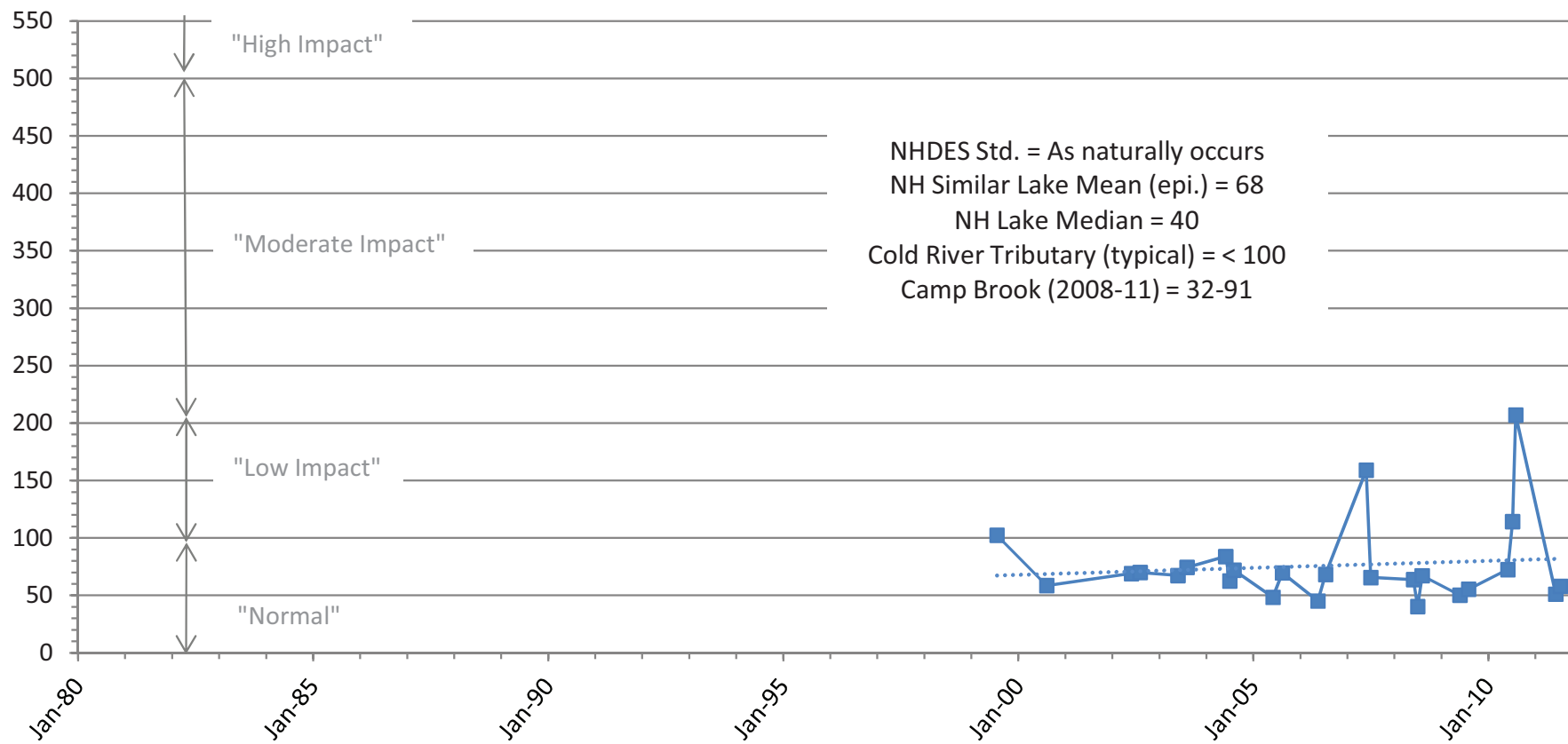
SC (umhos/cm) @ WARALSCC

Trib - Carmen Cove (Hale) Brook



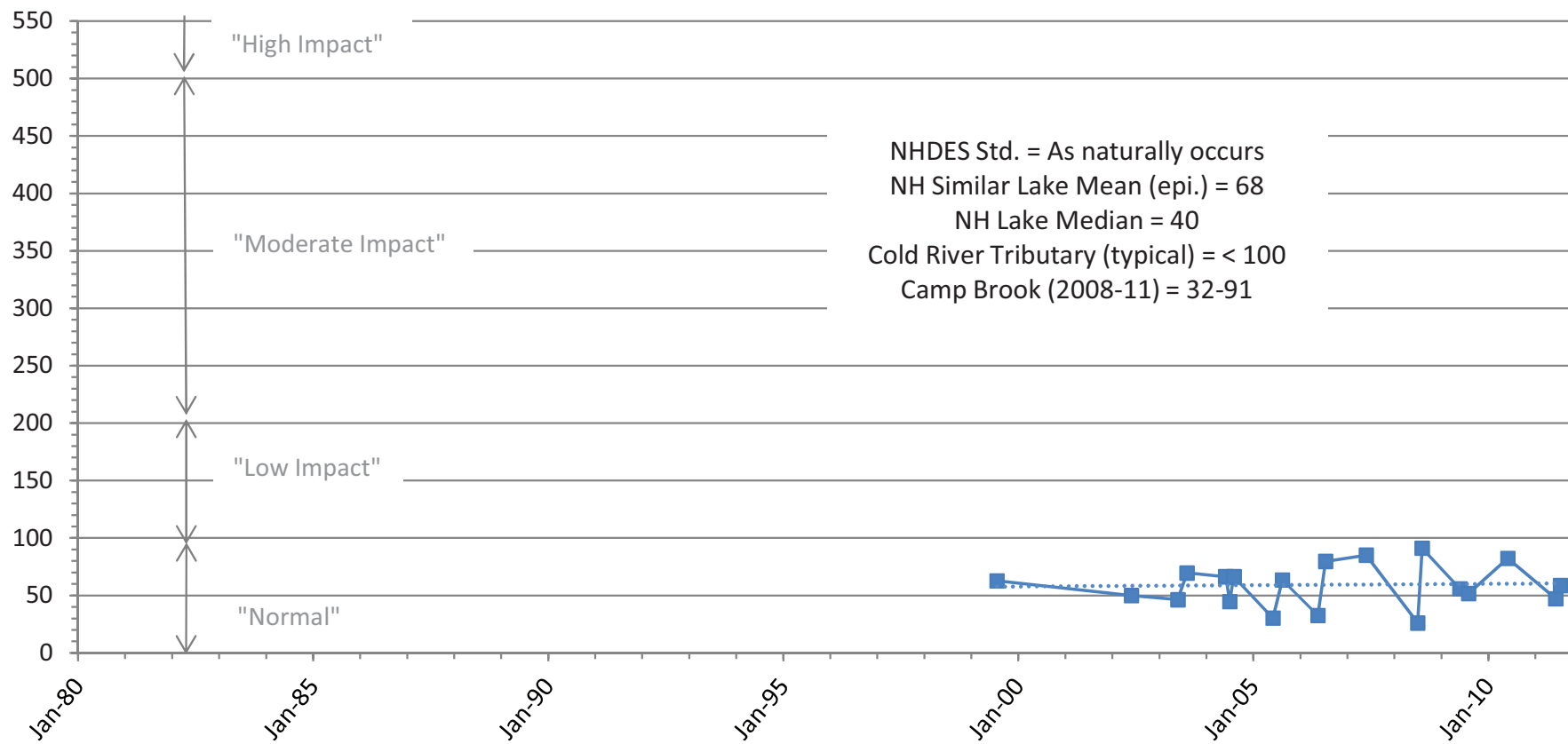
SC (umhos/cm) @ WARALSCH

Trib - Colburn Hill Brook



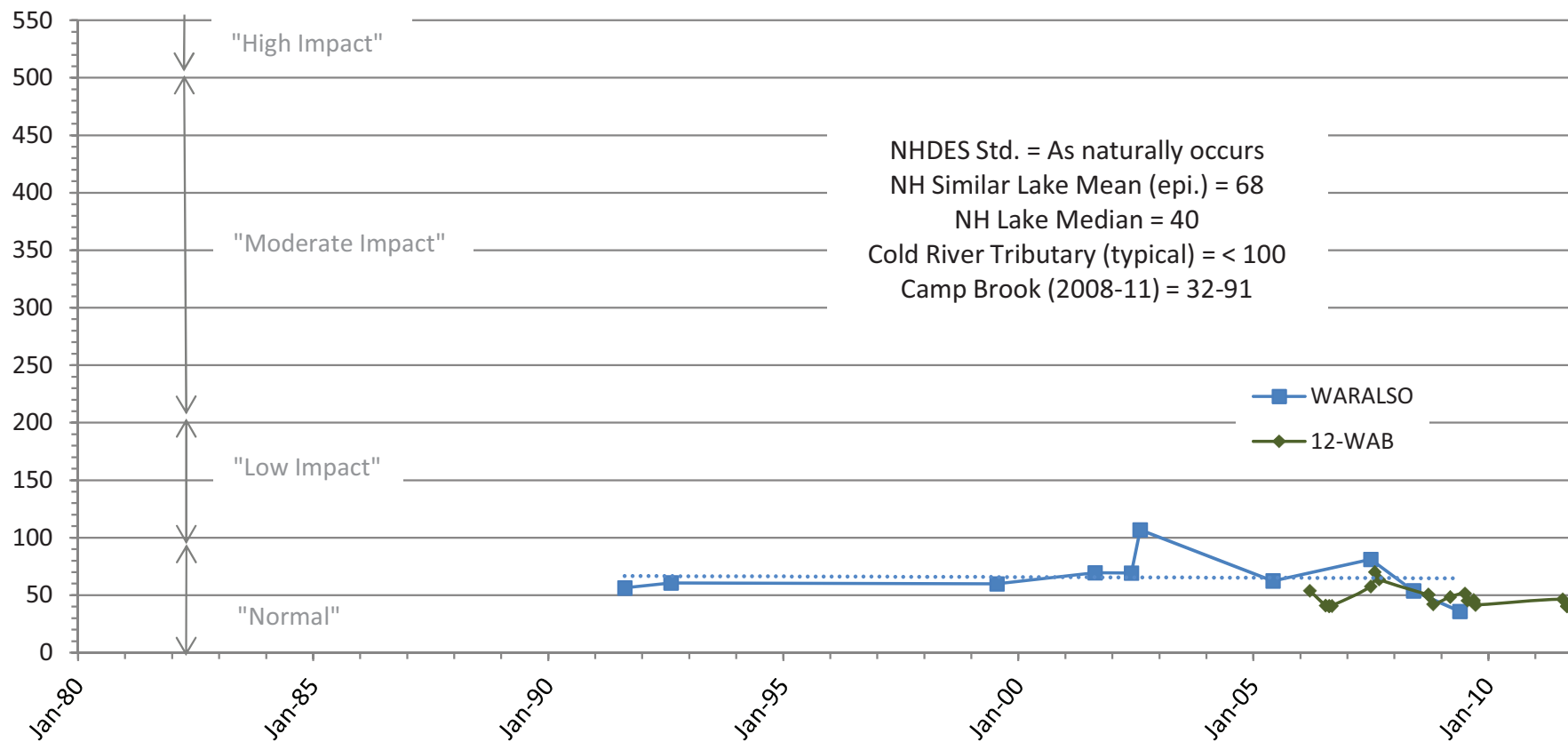
SC (umhos/cm) @ WARALSDB

Trib - Dam Brook



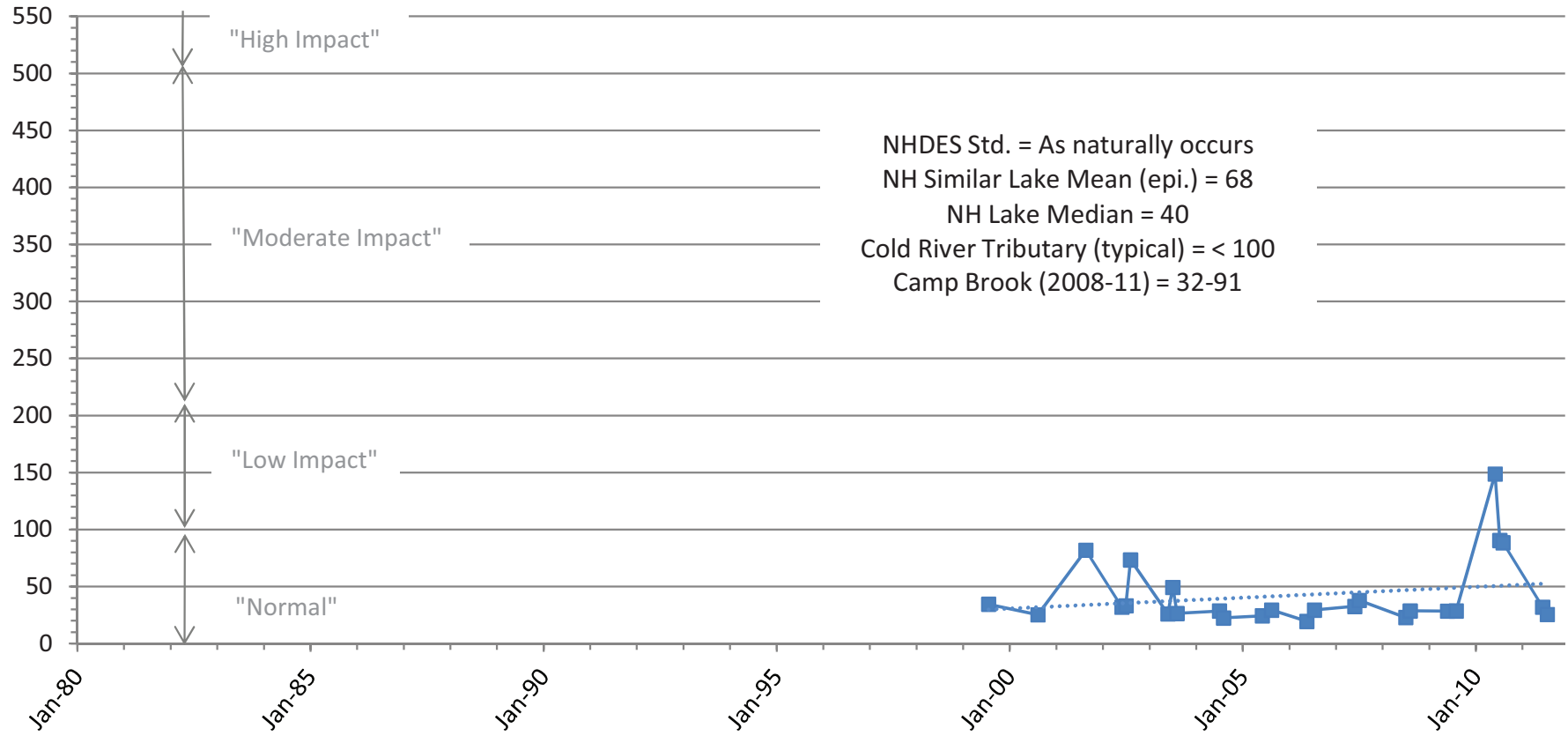
SC (umhos/cm) @ WARALSO/12-WAB

Trib - Outlet / Upper Warren Brook



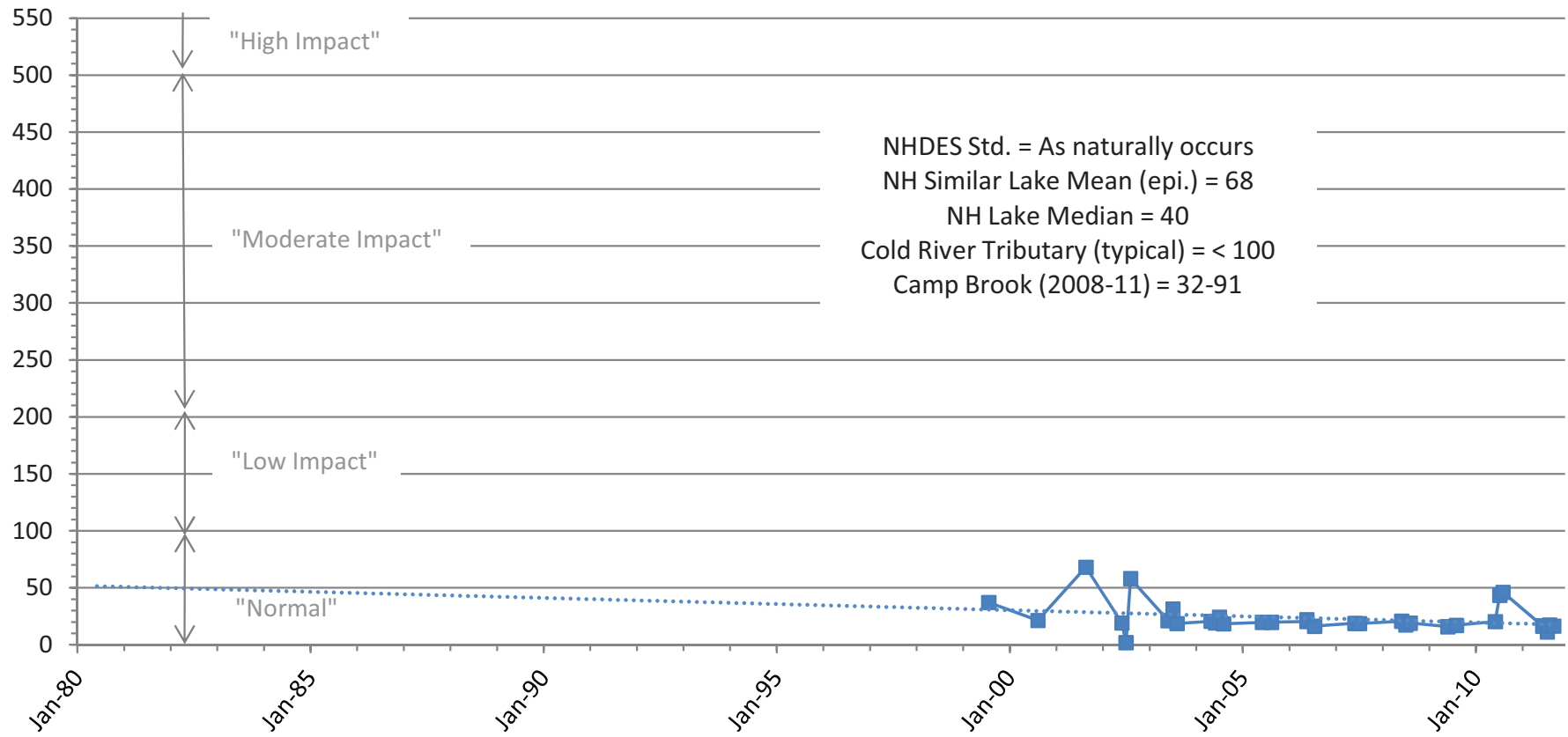
SC (umhos/cm) @ WARALSP

Trib - Pickerel Cove Brook



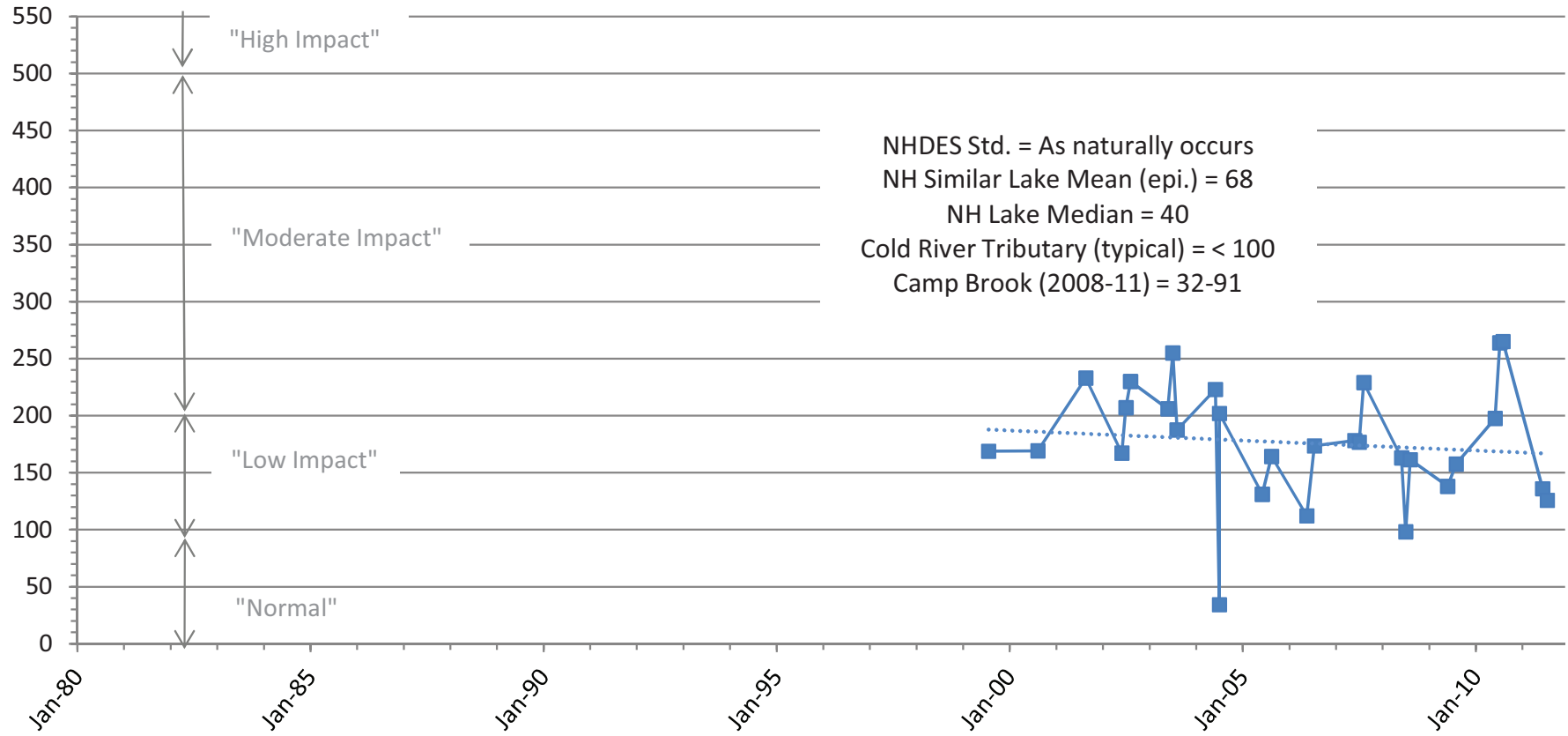
SC (umhos/cm) @ WARALSS1

Trib - Smith Hill Brook



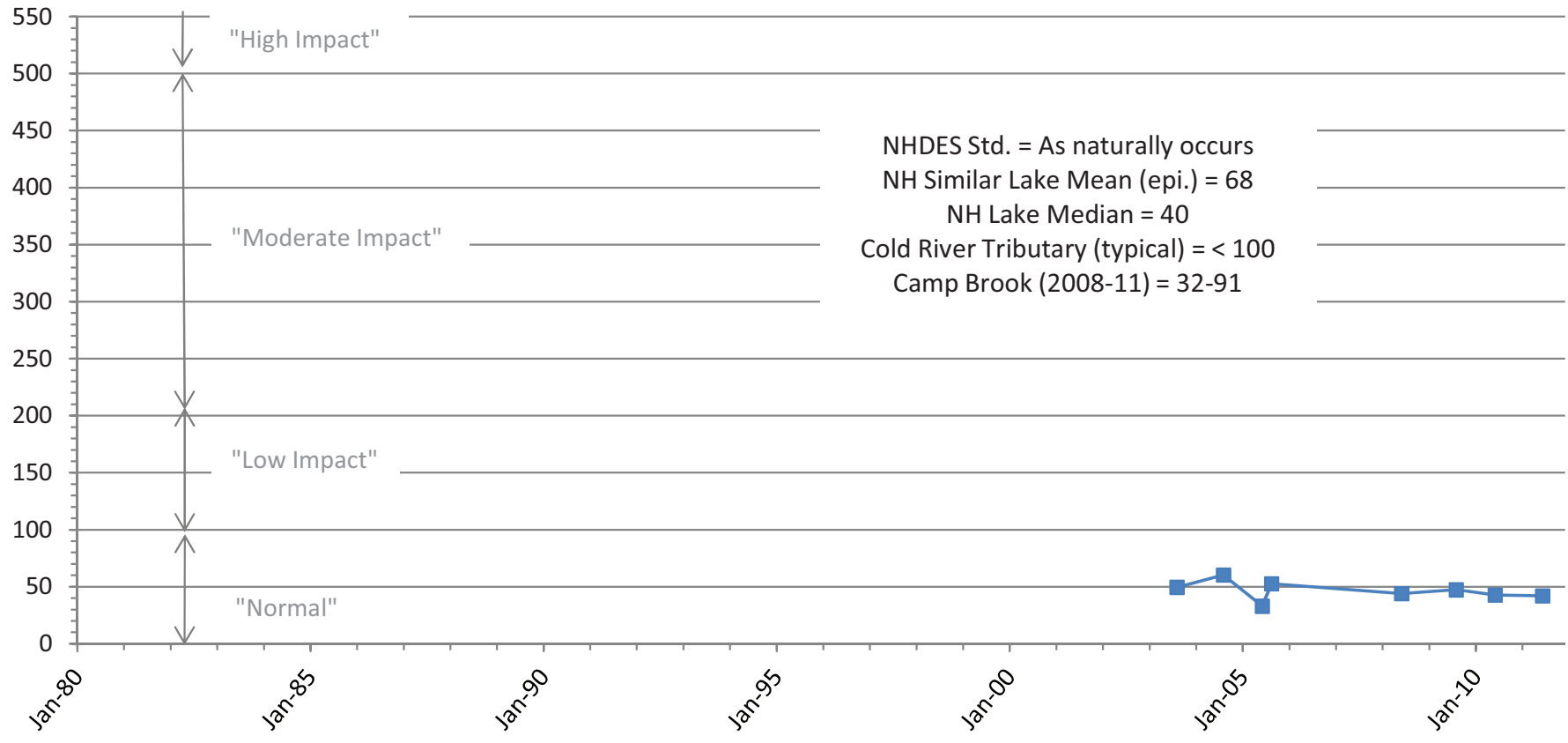
SC (umhos/cm) @ WARALSSR

Trib - Spruce River



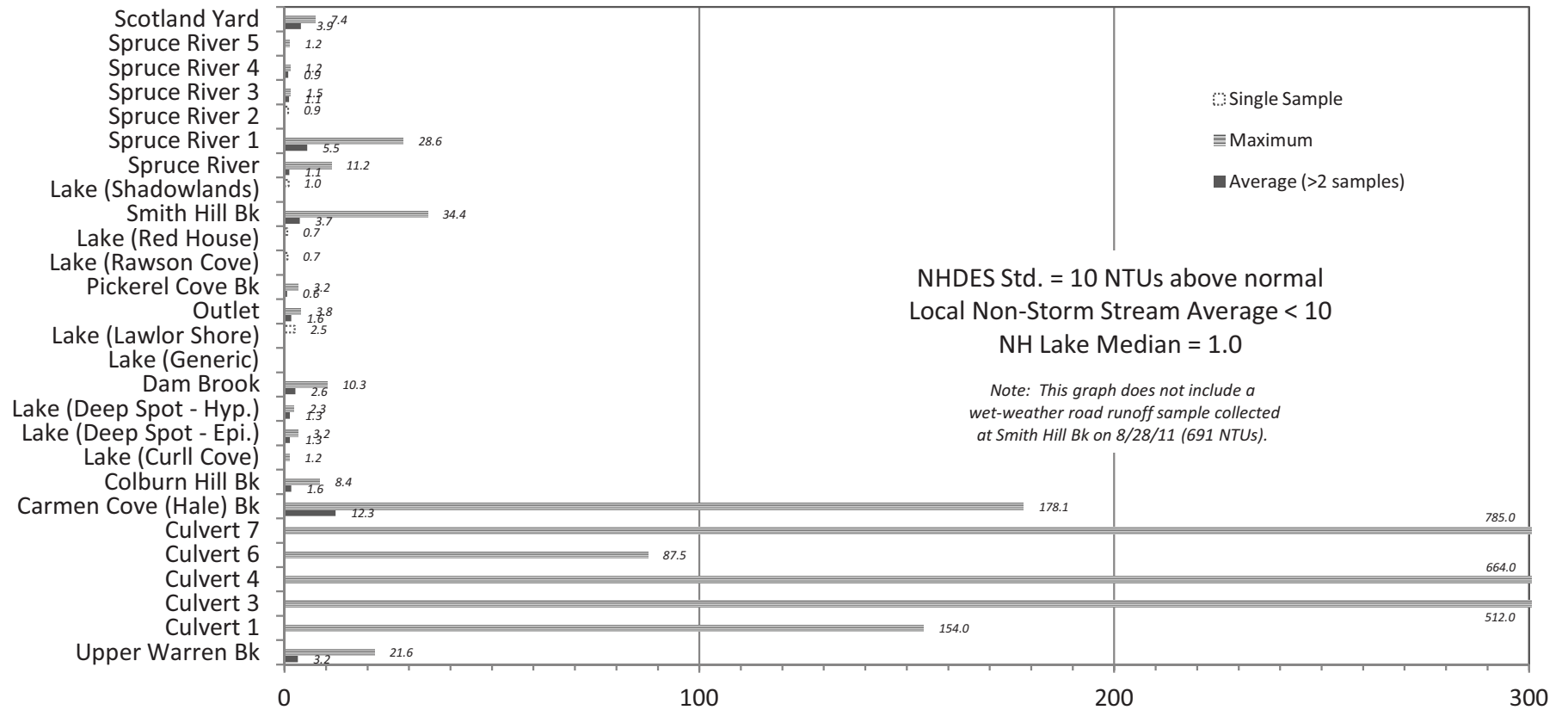
SC (umhos/cm) @ WARALSSY

Trib - Scotland Yard



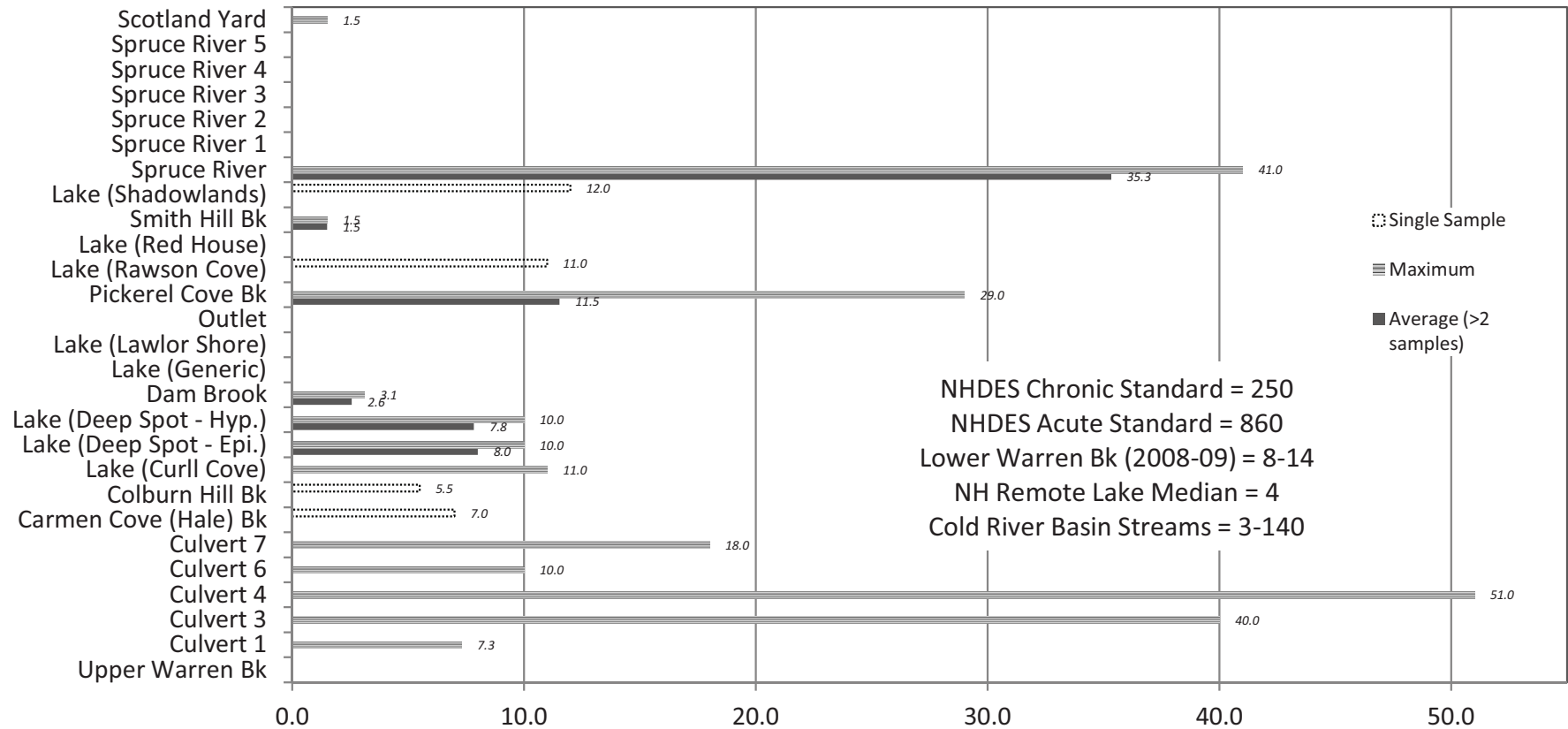
Turbidity (NTUs) @ Lake Warren Sites

1980 - 2011



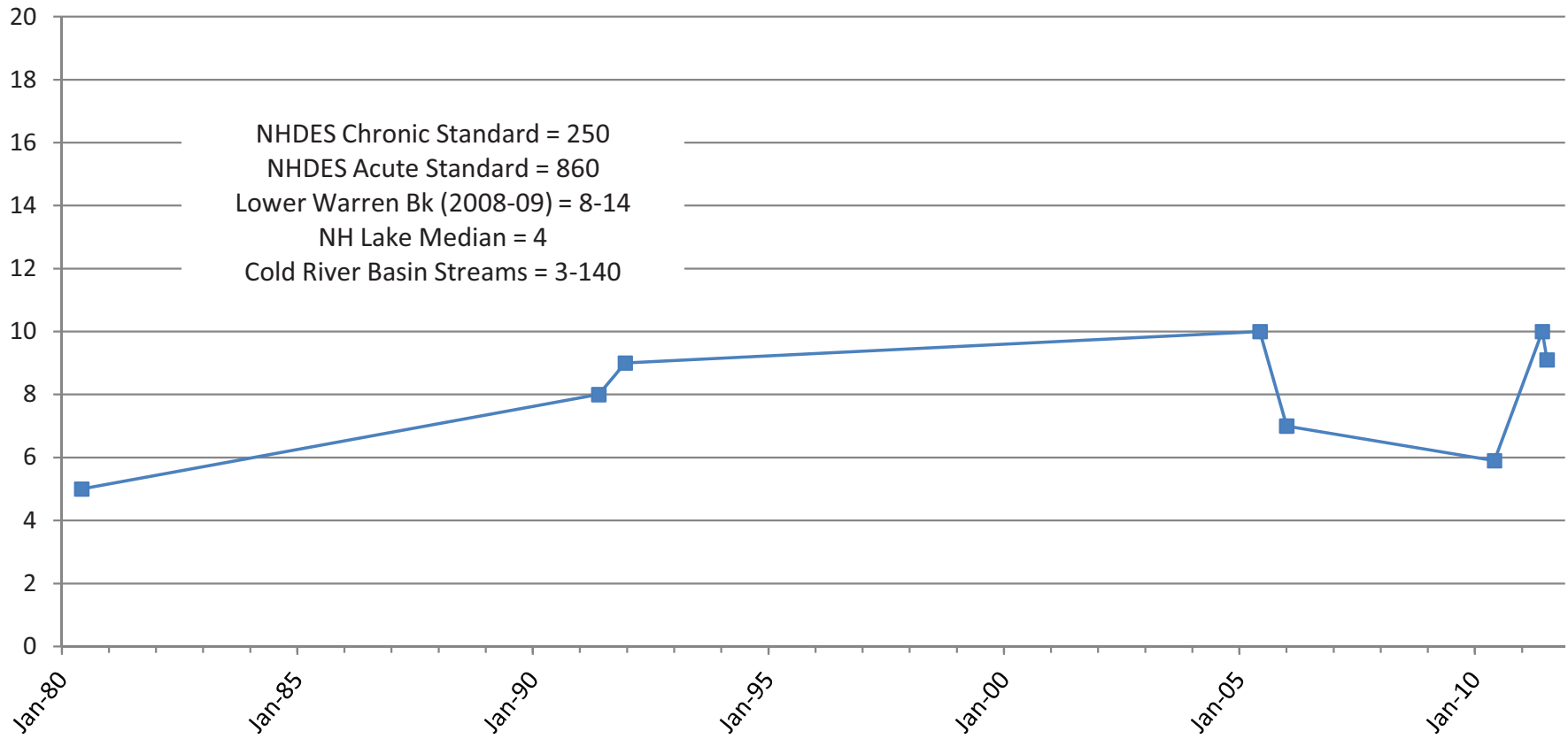
Cl (mg/l) @ Lake Warren Sites

1980 - 2011



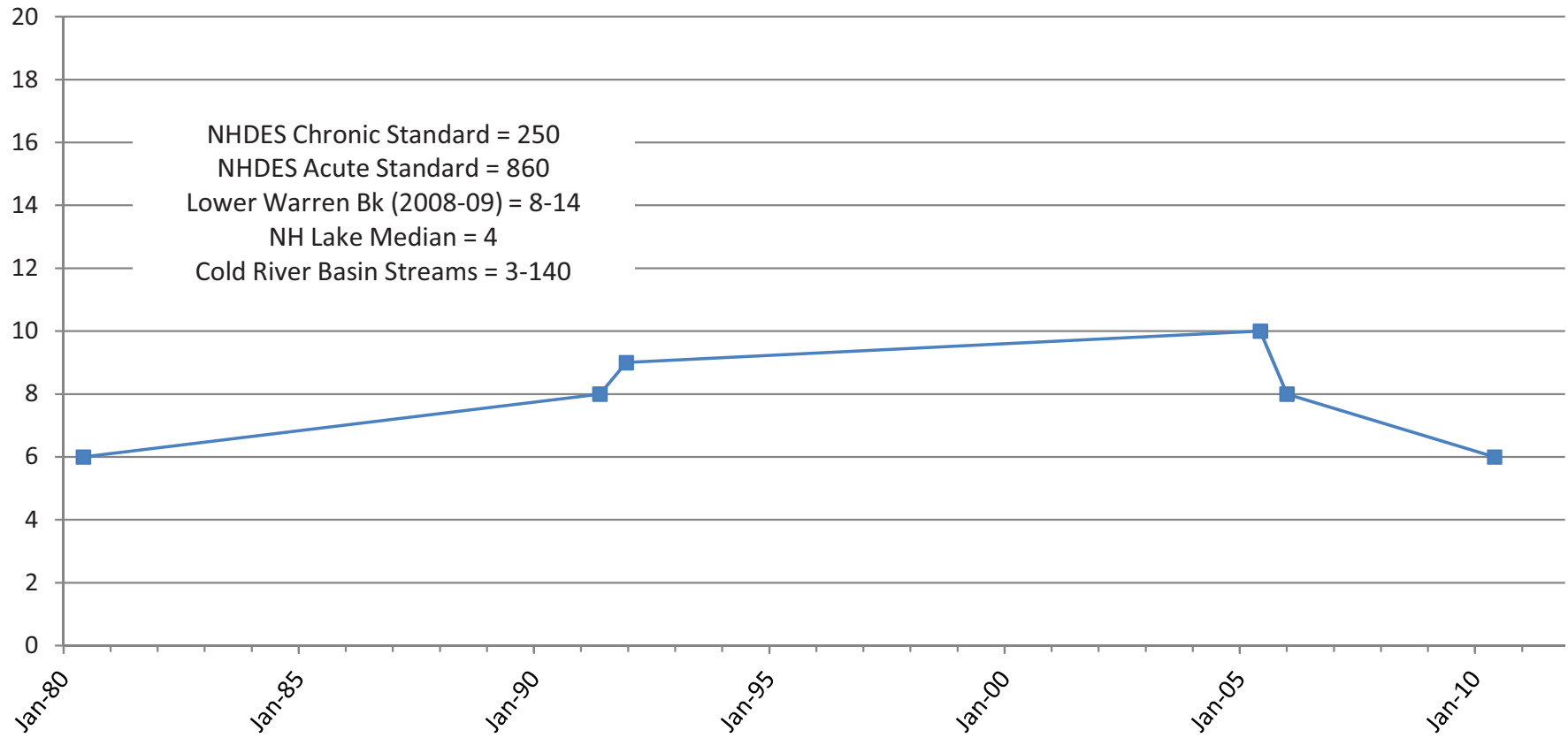
Cl (mg/l) @ WARALSD

Lake - Deep Spot (Epilimnion)



Cl (mg/l) @ WARALSD

Lake - Deep Spot (Hypolimnion)



ATTACHMENT D

Sub-Watershed TP Impact Prioritization

SUB-WATERSHED PHOSPHOROUS IMPACT PRIORITIZATION SUMMARY

Lake Warren, April 2012

		High Flow Site	Low Flow Site	Linear Reg. Trend	Max. Conc. > Level of Concern (0.05 mg/l)	Multiple Conc. > Level of Concern (0.05 mg/l)	Recent Conc. > Desirable (0.025 mg/l)	Avg. Conc. > Desirable (0.025 mg/l)	Avg. Conc. > Epilim. Median (0.012 mg/l)	Unusually High Turbidity or SC	Current Priority Level
<u>HIGH FLOW SUB-WATERSHEDS</u>											
WARALSCC	Carmen Cove (Hale) Bk	*	-	↑	-	-	*	-	*	*	H
WARALSS1	Smith Hill Bk	*	-	↓	*	-	-	-	*	-	L
<u>LOW FLOW SUB-WATERSHEDS</u>											
WARALSCH	Colburn Hill Bk	-	*	↑↑	*	*	*	-	*	*	M
WARALSDB	Dam Bk	-	*	↑	-	-	-	-	-	-	L
WARALSO	Outlet	-	*	↑↑	-	-	*	-	*	-	L
WARALSP	Pickereel Cove Bk	-	*	↑↑	*	-	*	-	*	-	M
WARALSSY	Scotland Yard	-	*	NA	-	-	*	*	*	-	L
WARALSSR	Spruce River	-	*	↑	*	-	*	-	*	*	M
<i>(Culverts are not included here because of their limited data set and the inapplicability of NHDES surface water quality standards to road runoff.</i>											
<i>However, their very elevated TP/turbidity concentrations are suggestive of High Priority, Low Flow sites.)</i>											

KEY:

-
NA
*
↑
↑↑

Does not meet prioritization criterion
Not available or applicable
Meets or exceeds prioritization criterion
Increasing trend
Steeply increasing trend

↔
↓
H
M
L

Stable or near-stable trend
Decreasing trend
High priority
Medium priority
Low priority