Lake Lillinonah: A Study in Water Quality through the Years

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Photo Credit: Tod Osier (2007)

Executive Summary:

The goal of this project was to reconstruct the water quality history at one site, near the Route 133 Bridge, in Lake Lillinonah. This lake is an impoundment on the Housatonic River that was created in 1955 for the purpose of electric power generation. Since early in its existence as a lake, Lillinonah has had frequent algal blooms during the summer months. Algal blooms are the result of excess nutrients, particularly phosphorus. They have a negative impact on lake ecosystems because as they start to die, bacteria associated with decaying organic matter that once was the unsightly algae consumes dissolved oxygen in the water and can result in hypoxic conditions near the bottom. In addition, cyanobacteria, common bloom-forming species, have been known to produce toxins which can be

harmful to humans or to pets and livestock who may come into contact with them (Yoo, 1995). Thus, this is not just an aesthetic problem, but one affecting the general health of the lake.

Although water quality data has been collected in Lake Lillinonah intermittently since the early 1970's, to our knowledge, there has been no comprehensive analysis of the entire time-series. We compiled data from a variety of sources to assess if water quality has changed over time and if any patterns in water quality could be explained by hydrologic events or nutrient management programs throughout Lillinonah's history. For example, phosphorus removal was instituted in wastewater treatment plants (WWTP) upstream of Lillinonah in the 1970's and 80's, and we expected that these would have lead to improvements in water clarity. The water quality variables we used were total nitrogen (TN) and total phosphorus (TP) concentration (mg/L), secchi disk depth (m) – a measure of water clarity, and water temperature (C). We also collected anecdotal evidence which suggests that water quality on the lake was poor for many of the years we did not have any data for (including the 50's and 60's).

Our analyses show that total phosphorus concentration at the Route 133 Bridge site has declined over the course of time and this overall trend did seem to map with some of the major nutrient management changes and hydrologic events within the watershed. We also show a negative correlation between TP and secchi depth. However, despite TP declining over time and being correlated with secchi depth, we did not detect improvements in water clarity (measured as secchi depth) since the early 1970's. There are a number of factors which may be contributing to this pattern.

We have greater power to capture TP trends, relative to secchi depth, because the secchi depth data is not as complete as the nutrient data we were able to compile; and we have no secchi data for the lowest TP years. In addition, TN was correlated with both TP and secchi depth, so it is possible that TN also plays a role. And while we know that TN is significantly related to secchi depth, TN did not decline over time. Whatever the reasons are for the in-lake TP concentrations trending downward, the bottom line is that concentrations are still relatively high and appear to be leveling off, which is of concern for the future of the lake.

Introduction:

Lake Lillinonah is an impoundment on the Housatonic River. It was formed for hydroelectric power generation by Connecticut Light and Power in 1955. It is Connecticut's second largest lake and one of its best bass fishing areas; further, the lake is the winter home to as many as 40 Bald Eagles annually (LLA). The lake extends roughly 12 miles from New Milford to the Shepaug Dam. It covers 1900 acres, has a maximum water depth of 110 feet near the dam, and has approximately 45 miles of shoreline, of which about 43 are wooded (LLA). The Housatonic River watershed begins up in Western Massachusetts and extends all the way to the Long Island Sound at Milford Point in Connecticut (see Supplemental Figures 1 and 2).

Lake Lillinonah is a eutrophic system with a history of frequent and extensive algal blooms in the summer months. Eutrophication is a process which leads to a reduction in water quality. Excess nutrient input promotes algal growth (blooms). Common bloom-forming species include the photosynthetic cyanobacteria (i.e., "blue-green" algae). As blooms die and decompose, bacteria associated with the decaying organic matter consume dissolved oxygen in the water causing hypoxic conditions in the bottom waters. Certain cyanobacteria produce toxins which can be harmful to humans or to pets and livestock who may come into contact with them (Yoo, 1995). Thus, algal blooms pose more than just a threat to the lake's aesthetics; they are harmful to the health and biodiversity of the ecosystem as a whole (Schindler, 1977). Historical accounts – whether they were from local residents or scientists – document early algal blooms on the lake, dating back to 1956 (Supplemental Figures 3 and 4). Unfortunately, blooms persist despite efforts to both study and limit the nutrient load into the lake. A 2007 Brookfield Journal article noted that Lake Lillinonah "has become known as the 'emerald lake' because it is covered with algae," (FOTL).

As in many lakes (Schindler 1977), nutrient bioassays suggest phosphorus is the primary growth limiting nutrient in Lillinonah (Frink, 1975), but co-limitation by nitrogen has been observed (J. Klug, unpublished data). Nutrient input comes from both point and non-point sources. Point-sources are those from traceable origins of discharge; examples for Lake Lillinonah include the Pittsfield, MA and Danbury, CT waste-water treatment plants (WWTPs). 20-30% of the phosphorus load into Lillinonah comes from the Danbury WWTP alone (Jones and Lee, 1981; USGS, unpublished analyses). Non-point sources are harder to quantify because they are more diffuse, but mainly involve run-off from storm events which can bring eroded soil and fertilizers into the system.

Water quality data have been collected on Lake Lillinonah intermittently since the early 1970's, but to our knowledge, no comprehensive analysis of the entire time-series had been completed until now. We were interested in learning if water quality in Lake Lillinonah has changed across time and asked if there is a relationship between nutrient concentration and water clarity over the history of the lake. In addition, we asked whether any patterns in water quality could be explained by hydrologic events or changes in nutrient management within the watershed.

Materials and Methods:

To begin, we compiled all data available on Lake Lillinonah's water quality (Supplemental Table 1). We started with a spreadsheet that had been previously compiled by the Department of Energy and Environmental Protection (DEEP). We then went through DEEP paper files for more data and anecdotal evidence about lake conditions. Further, data was obtained from the EPA, USGS, J. Klug, G. Knoecklein, and C. Read. We also obtained USGS discharge data from the Gaylordsville, CT station on the Housatonic River. Some of this information was used to create a timeline highlighting some major historical events and changes affecting Lillinonah (Figure 1).

Analysis of all the data available was beyond the scope of this project. We chose one site, Route 133 Bridge, because of its central location within the lake, and because it has been a common site in both historical and current studies. We then chose focal water quality and potential explanatory variables: surface total nitrogen (TN) and surface total phosphorus (TP) concentrations (mg/L), secchi disk depth (m) – a measure of water clarity, discharge (cfs) – a measure of water flow into the system (affected by rainfall or other weather events), and surface water temperature (C).

We focused on the summer season for a number of reasons. The summer season, which was defined as the period between July and September, was chosen in part because summers are when the algal blooms occur. There is also a seasonal component to many of the water quality parameters we were considering, especially secchi depth, which should not be ignored. Lastly, our designated "summer season" had the most data available.

We used Kendall trend analyses to test for significant changes over the entire time series and post nutrient removal period. A Kendall trend test is a nonparametric test that compares the relationship between points at separate time periods or seasons and determines if there is a trend; it is highly robust and relatively powerful, and is commonly used for water quality trend monitoring (Aroner, 2001). In addition, we used correlation (Pearson) analysis to explore relationships between water quality variables.

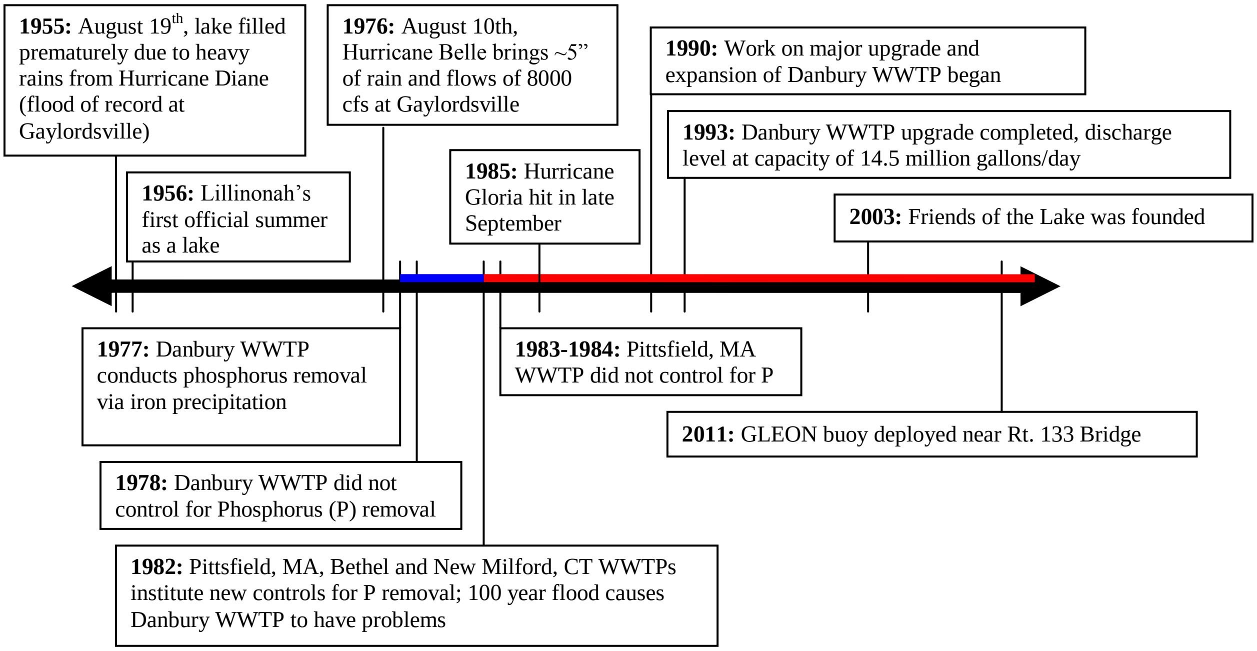


Figure 1. Timeline of some important events in Lillinonah's history. Blue marks the start of phosphorus removal at the Danbury CT WWTP, red marks the start of phosphorus removal at other upstream WWTPs.

Results:

Summer total phosphorus (TP) concentration at the Rt 133 Bridge declined over time (Figure 2). Kendall trend tests yielded a significant decline in TP over the entire time-series ($r = -0.38$, $p = <0.0001$) as well as for the post-removal period (1977-2009) ($r = -0.29$, $p = <0.0001$). Summer secchi depth and summer total nitrogen were also analyzed, however Kendall trend analyses found no significant trends for either parameter (Supplemental Figures 5 a & b) for the full time period: secchi depth ($r = -0.03$, $p = 0.71$) and total nitrogen concentration ($r = -0.047$, $p = 0.55$).

TP (Figure 3a) was negatively correlated with secchi depth in both the spring ($r = -0.45$, $p = 0.004$) and summer ($r = -0.33$, $p = 0.007$) as well as across all seasons ($r = -0.37$, $p = <0.0001$). TN (Figure 3b) was negatively correlated with secchi depth for summer ($r = -0.44$, $p = 0.002$) and across all seasons ($r = -0.27$, $p = 0.011$) but not for spring. TP and TN were also strongly positively correlated ($r = 0.65$, $p = <0.0001$ for the summer season (July-Sept) and $r = 0.46$, $p = <0.0001$ for all data). None of the water quality variables were significantly correlated with water temperature.

Since we were interested in assessing if any patterns were present between hydrologic events and our study variables, we compared discharge data to our nutrient concentrations. The discharge data used were the average monthly discharge calculations available from USGS. We found that, for July-Sept, TP and average monthly discharge were significantly positively correlated ($r = 0.18$, $p = 0.05$) although the correlation was fairly weak. This pattern suggests that loading of phosphorus during high-flow events may play a role in determining in-lake TP concentrations.

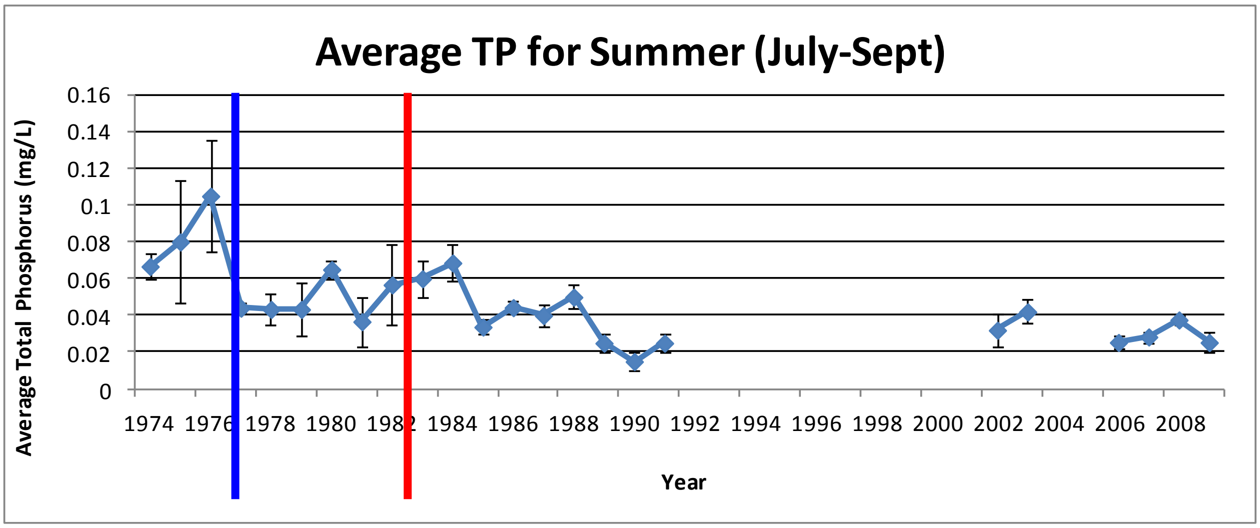
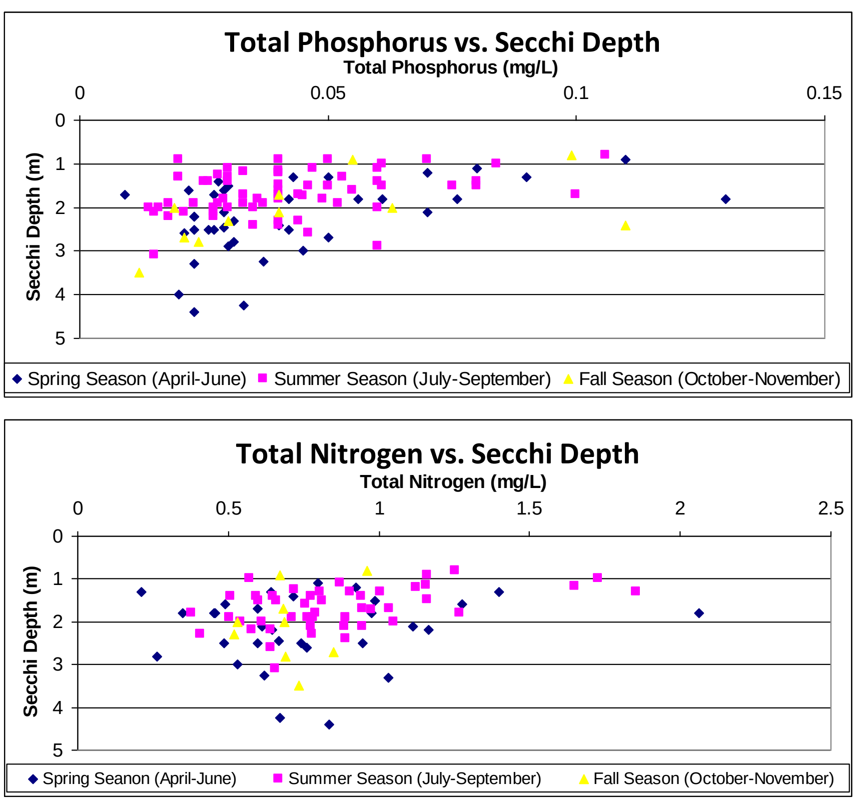


Figure 2. Average total phosphorus (TP) for the summer season graphed over time. The blue line marks the year the Danbury, CT WWTP began to control for P removal, while the red line indicates the year Pittsfield, MA, Bethel & New Milford, CT WWTPs all instituted controls for P removal.



Figures 3 a & b. TP (a) and TN (b) vs.secchi depth. TP is correlated with secchi depth in both the spring ($r = -0.45$, $p = 0.004$) and summer ($r = -0.33$, $p = 0.007$) as well as across all seasons ($r = -0.37$, $p = <0.0001$). TN was correlated with secchi depth for summer ($r = -0.44$, $p = 0.002$) and across seasons ($r = -0.27$, $p = 0.011$).

Discussion:

Summer total phosphorus concentration has declined over time, yet we did not detect improvements in summer water clarity (measured as secchi depth) since the 1970's. There are a number of factors which may be contributing to this pattern. First of all, we have greater power to capture TP trends because the secchi depth data is more sparse than TP and we have no secchi data for the lowest TP years. We also know that TN is significantly related to secchi depth, but that TN did not to decline over time. And even though in-lake TP concentrations trended downward, the concentrations are still relatively high and appear to be leveling off (Figure 2).

The apparent leveling off in TP concentration could be related to contributions from phosphorus normally stored in sediments being re-suspended and recycled around in the water column during major hydrologic events, or phosphorus simply not being removed at a high enough concentration from the waters entering Lillinonah to make any further and noticeable improvements on the lake. WWTPs in the watershed have recently implemented nitrogen removal processes, so it is likely that TN concentrations will decline in the near future; it will be interesting if this will have any impact on the water quality conditions moving forward.

Correlation analyses suggest that secchi depth is partially driven by both TP and TN, yet there is a considerable amount of variability in secchi depth that is not explained by these relationships. Water temperature was not correlated with secchi depth, but is known to play a role in timing of algal blooms. Secchi depth is driven by particles in the water – during storms those particles are sediment, whereas during blooms the particles are algae – thus the correlations between nutrients (TN or TP) and secchi depth do not always explain the whole picture.

River flow, even on a coarse scale of average monthly discharge, was correlated with TP during the summer season. This suggests that some of the variability in TP over time is be related to hydrologic events. For example, the day following Hurricane Belle in 1976, TP and turbidity (a measure of particles in the water column) spiked and remained elevated for the next several months.

While this project did reinforce some previously documented relationships (i.e. those between TP and secchi depth, or between TP and TN), it also provided a new general-picture historical perspective on the water quality of the lake. There is still plenty more that could be done moving forward using more of the data that was compiled – and it is also likely that there is still more data out there that we have been unable to find or access yet. Among some of the future considerations in terms of this project would be to analyze data from other sites on the lake to look at spatial variability, analyze the data using multiple regression analyses, and to analyze discharge data on a finer scale (rather than monthly average) to look more closely at extreme hydrologic events.

This retrospective study is complementary to ongoing water quality monitoring. For instance, the Lake Lillinonah Volunteer Water Quality Monitoring program (http://faculty.fairfield.edu/dockmonitoring/) collects secchi depth and other water quality variables at sites around the lake. In addition, a monitoring buoy moored near the Route 133 Brigde collects high-frequency data which can be viewed in near real-time at http://www.friendsofthelake.org/resources/data/). Other ongoing initiatives involving Lillinonah could lead to future reductions in nutrient loading. A watershed management plan is in the early stages of planning, aimed at reducing nutrient loading into the upper Housatonic watershed which should reduce loads to Lillinonah. This is a collaborative effort started by FOTL and HVA, also involving the DEEP, USGS, and Fairfield University. The current study can serve as a baseline from which to measure future water quality improvements.

Acknowledgements:

Part of this work was funded through a Friends of the Lake internship to KW. Many thanks go to the FOTL (particularly Greg Bollard) and the Fairfield University Department of Biology for all of their help and support. Several other people and organizations also need to be thanked for their contributions to this project. They include: Dr. Laura McSweeney, Dr. George Knocklein, DEEP (particularly Chuck Lee and Bill Foreman), HVA, LLA, EPA, and USGS (particularly Jon Morrison and Mike Columbo).

Works Cited:

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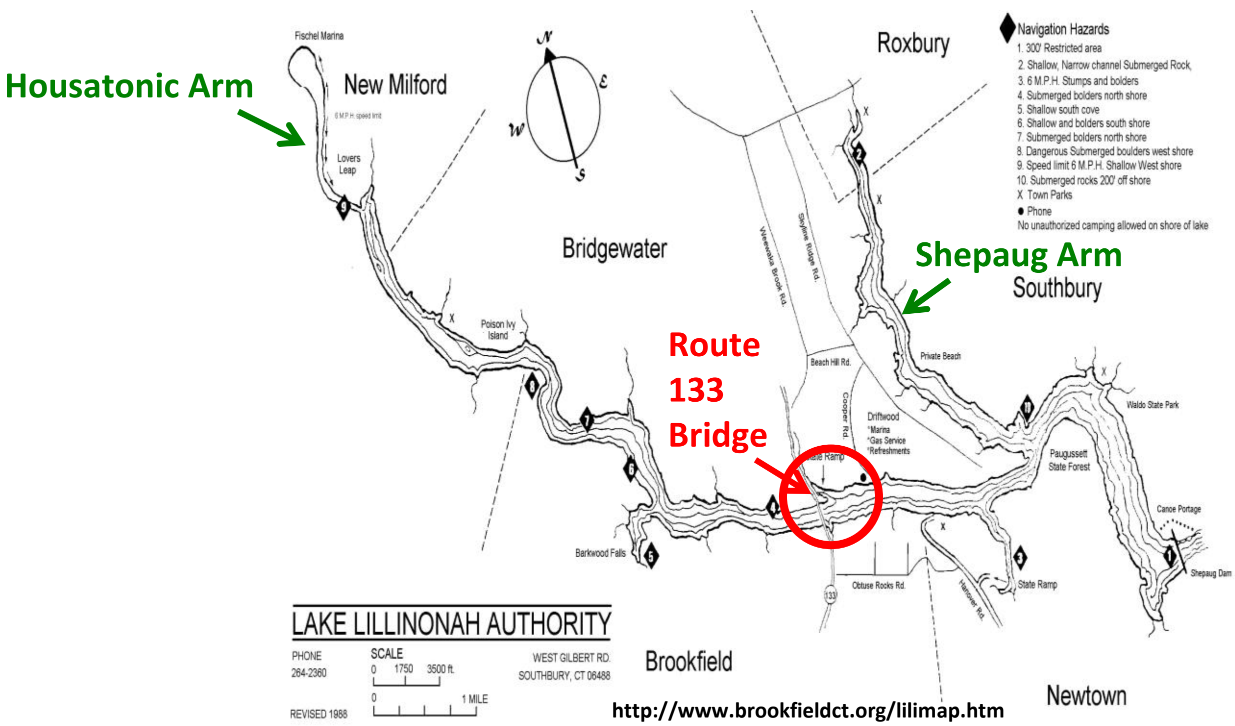
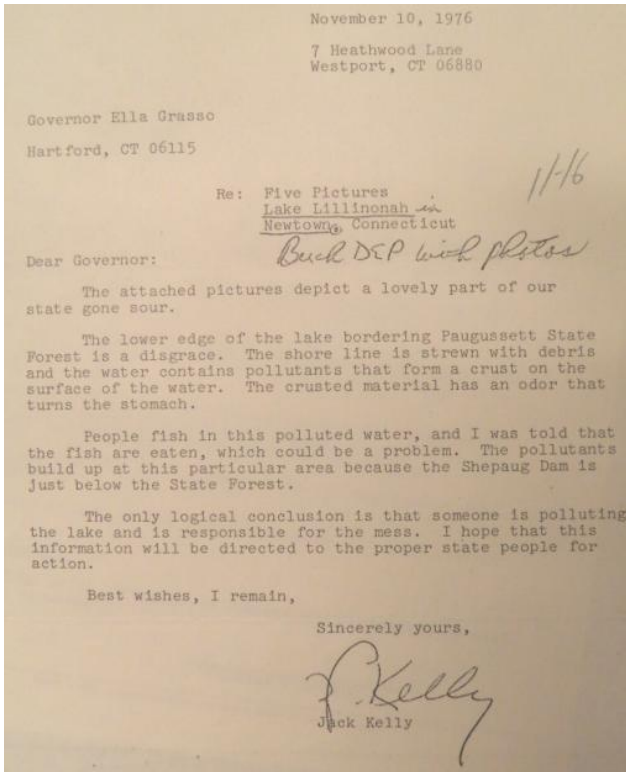
Supplemental Materials:

Supplemental Figure 1. Map of the Housatonic River Watershed. The red dot marks Lake Lillinonah.



Supplemental Figure 2. Map of Lillinonah identifying major landmarks; including site used in this study, Route 133 Bridge.



November 10, 1976

7 Heathwood Lane
Westport, CT 06880

Governor Ella Grasso
Hartford, CT 06115

1/16

Re: Five Pictures
Lake Lillinonah
Newtown, Connecticut

Buck DEP with photos

Dear Governor:

The attached pictures depict a lovely part of our state gone sour.

The lower edge of the lake bordering Paugussett State Forest is a disgrace. The shore line is strewn with debris and the water contains pollutants that form a crust on the surface of the water. The crusted material has an odor that turns the stomach.

People fish in this polluted water, and I was told that the fish are eaten, which could be a problem. The pollutants build up at this particular area because the Shepaug Dam is just below the State Forest.

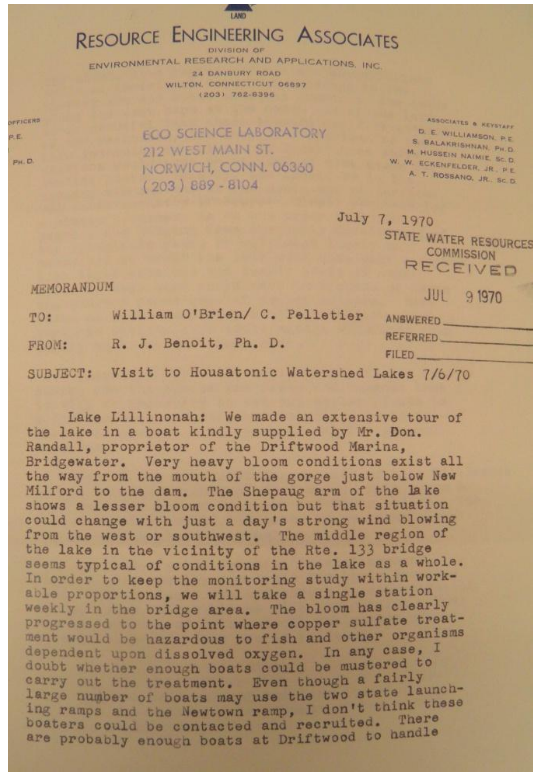
The only logical conclusion is that someone is polluting the lake and is responsible for the mess. I hope that this information will be directed to the proper state people for action.

Best wishes, I remain,

Sincerely yours,

J. Kelly

Jack Kelly



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July 7, 1970

STATE WATER RESOURCES COMMISSION
RECEIVED
JUL 9 1970
ANSWERED
REFERRED
FILED

MEMORANDUM

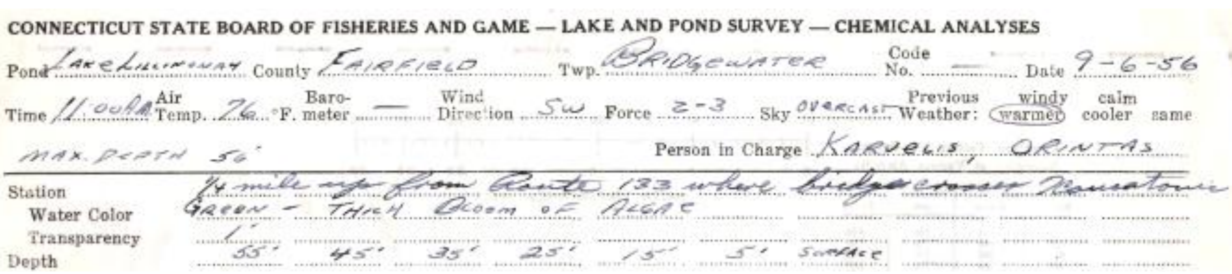
TO: William O'Brien/ C. Pelletier

FROM: R. J. Benoit, Ph. D.

SUBJECT: Visit to Housatonic Watershed Lakes 7/6/70

Lake Lillinonah: We made an extensive tour of the lake in a boat kindly supplied by Mr. Don. Randall, proprietor of the Driftwood Marina, Bridgewater. Very heavy bloom conditions exist all the way from the mouth of the gorge just below New Milford to the dam. The Shepaug arm of the lake shows a lesser bloom condition but that situation could change with just a day's strong wind blowing from the west or southwest. The middle region of the lake in the vicinity of the Rte. 133 bridge seems typical of conditions in the lake as a whole. In order to keep the monitoring study within workable proportions, we will take a single station weekly in the bridge area. The bloom has clearly progressed to the point where copper sulfate treatment would be hazardous to fish and other organisms dependent upon dissolved oxygen. In any case, I doubt whether enough boats could be mustered to carry out the treatment. Even though a fairly large number of boats may use the two state launching ramps and the Newtown ramp, I don't think these boaters could be contacted and recruited. There are probably enough boats at Driftwood to handle

Supplemental Figures 3 a & b. Letters on file at the DEEP summarizing the observations of local residents (a; Left, 1976) and professional surveyors (b; Right, 1970) regarding the extensive bloom conditions on the lake.



CONNECTICUT STATE BOARD OF FISHERIES AND GAME — LAKE AND POND SURVEY — CHEMICAL ANALYSES

Pond Lake Lillinonah County Fairfield Twp. Bridgewater Code No. — Date 9-6-56

Time 11:00AM Air Temp. 76 °F. Barometer — Wind Direction SW Force 2-3 Sky Overcast Previous Weather: windy calm (warmer) cooler same

MAX. DEPTH 56'

Person in Charge Karvelis, Orintas

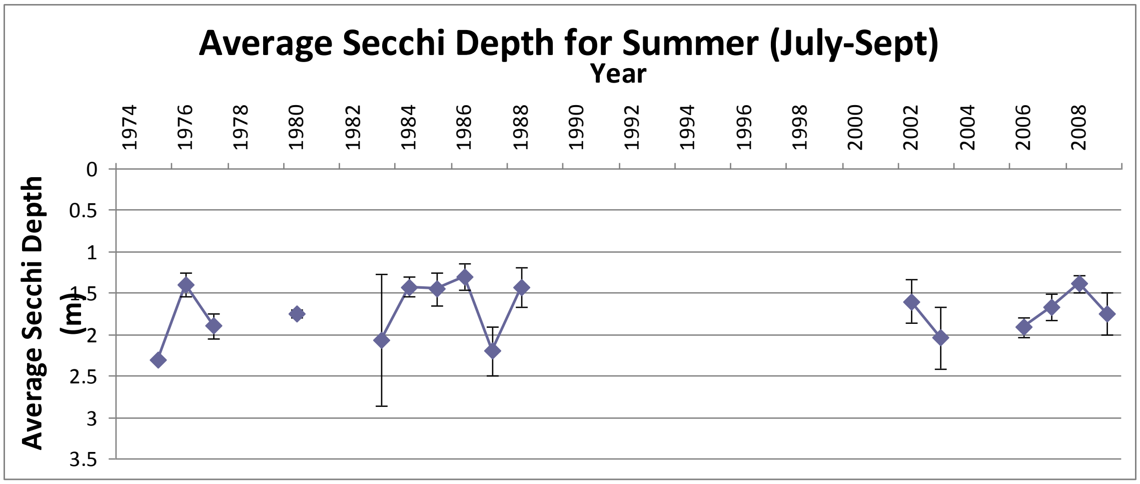
Station: 1/4 mile up from Route 133 where bridge crosses Housatonic

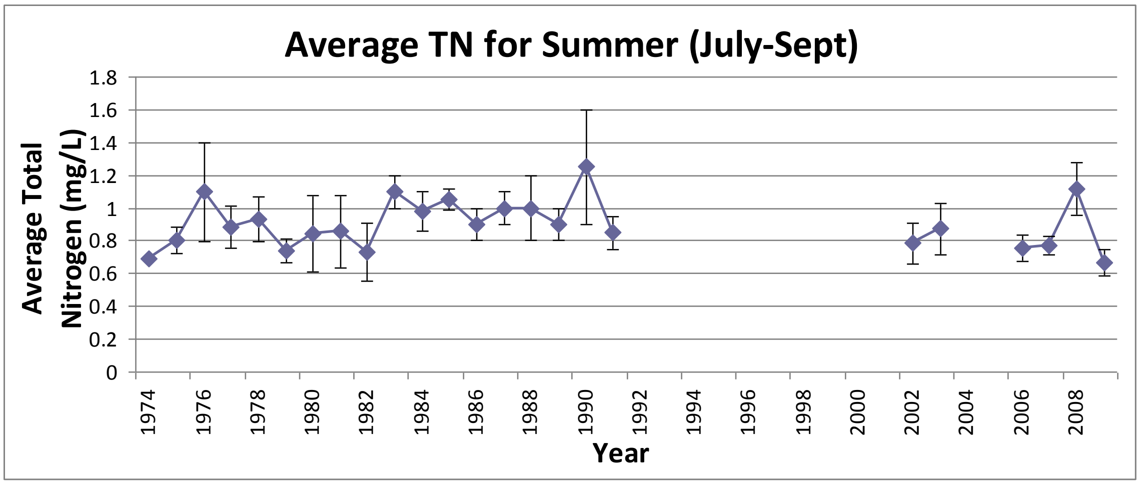
Water Color: Green - Thick Bloom of Algae

Transparency: 1'

Depth: 55' 45' 35' 25' 15' 5' Surface

Supplemental Figure 4. Survey sheet from 1956 indicating algal blooms present at Route 133 Bridge site.





Supplemental Figures 5 a & b. Average secchi depth (a) and average total nitrogen (b) during the summer season. Kendall trend analysis found no significant trends; secchi depth ($r = -0.03$, $p = 0.71$), total nitrogen ($r = -0.047$, $p = 0.55$).

Supplemental Table 1. Complete list of all the data sources used for the analyses on the Route 133 Bridge site.

REPORT TITLE	REPORT AUTHOR	REPORT DATE	SAMPLING DATES	TN (mg/L)	TP (mg/L)	SECCHI DEPTH (m)	TEMP (C)	DO (mg/L)
CT State Board of Fisheries & Game - Lake and Pond Survey	Orintas Karuelis	6-Sep-56	September 6, 1956			X	X	
Water Chemistries, Lake Lillinonah - Fish Division, District #1	Stephen H. Taub	31-Aug-63	August 28, 1963				X	X
Results of a Bio-Engineering Survey of Lake Lillinonah	Allied Biological Control Corporation		October 24, 1973		X	X	X	X
USGS Data	USGS Data		7/1974-11/1982, then every other month through 9/1991	X	X		X	X
Nutrient-Algal Relationships in Lake Lillinonah	National Enforcement Investigations Center and US Environmental Protection Agency (EPA) Region 1	November, 1975	6/1975-8/1975		X	X	X	X
The Effect of Chemical Treatment for Phosphorus Removal at the Danbury, Connecticut Sewage Treatment Plant on Lake Lillinonah Water Quality	William W. Smith and Jane W. Brown, FMC Corporation	May 2, 1978	4/1976-10/1976 & 4/1977-10/1977	X	X	X	X	X
Connecticut Biological Monitoring, Physical Survey Data Sheet	Alan Carey - transcribed; Nestico, Hays, Hoffman & Pizzuto	7/29/1980	7/1980 & 8/1980			X	X	X
Connecticut Lakes Monitoring Program - Survey Data Sheet	Guy Hoffman, Hick, Burcroff, (Haze)	6/30/1983	6/1983-9/1983		X	X	X	X
Lake Lillinonah and Lake Zoar 1984-1985 Water Quality Study	CT DEP and NU	May, 1988	8/1984-10/1984 & 4/1985-10/1985	X	X	X	X	X
Pittsfield NPDES Permit Stipulated Agreement - Annual Monitoring Report	Charles Fredette, CT Department of Environmental Protection (DEP)	December, 1985 - D	1985, 1986, 1987 & 1988		X	X		
Aquatic Vegetation Survey for Lake Lillinonah	IEP	12/5/1989	September 1, 1989			X		
Diagnostic Feasibility Study of Lake Lillinonah, 2002 & 2003	Northeast Aquatic Research; George Knoecklein		4/2002-10/2002 & 4/2003-10/2003	X	X	X	X	X
Unpublished	Jennifer Klug	2003	5/2003-9/2003	X	X	X		
2006 Profile Summary	George Knoecklein	2006	7/2006-10/2006	X	X	X	X	
Unpublished	Curtis Read		7/2006, 9/2006 & 5/2008-9/2008		X	X	X	
2007 Profile Summary	George Knoecklein	2007	4/2007-10/2007	X	X	X	X	X
2008 Profile Summary	George Knoecklein	2008	5/2008-9/2008	X	X	X	X	X
2009 Profile Summary	George Knoecklein	2009	6/2009-10/2009	X	X	X	X	X
2010 Profile Summary	George Knoecklein	2010	5/2010-9/2010			X	X	X